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TITLE
ITERATIVE-STRUCTURE DIGITAL SIGNAL RECEPTION DEVICE, AND MODULE AND
METHOD THEREFOR

U.S. DEPT. of COMMERCE • Patent and Trademark Office-PCT-436L (rev. 7-94)

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N 10 Formal Drawings (shs) set
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Exhibit 1002
U.S. Patent No. 6,108,388

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PATENT APPLICATION SERIAL NO. **08/894207**

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PATENT AND TRADEMARK OFFICE
FEE RECORD SHEET

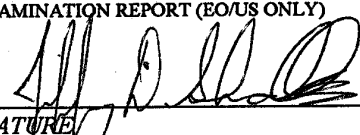
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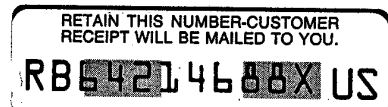
Form PTO 1390 (REV 10-96)		U.S. Department of Commerce Patent and Trademark Office		ATTORNEY'S DOCKEY NUMBER F264.312-16	
TRANSMITTAL LETTER TO THE UNITED STATES DESIGNATED/ELECTED OFFICE (DO/EO/US) CONCERNING A FILING UNDER 35 USC § 371				08/894207	
INTERNATIONAL APPLICATION NO. PCT/FR96/00197		INT'L FILING DATE February 6, 1996		PRIORITY DATE CLAIMED February 7, 1995	
TITLE OF INVENTION DEVICE FOR THE RECEPTION OF DIGITAL SIGNALS WITH ITERATIVE STRUCTURE, AND CORRESPONDING MODULE AND METHOD					
APPLICANT(S) FOR DO/EO/US Catherine Douillard, Alain Glavieux, Michel Jezequel and Claude Berrou					
Applicant herewith submits to the United States Designated/Elected Office (DO/EO/US) the following items and other information.					
1. ☒ This is a FIRST submission of items concerning a filing under 35 USC § 371.					
2. ☐ This is a SECOND or SUBSEQUENT submission of items concerning a filing under 35 USC § 371.					
3. ☐ This express request to begin national examination procedures (35 USC § 371(f)) at any time rather than delay examination until the expiration of the applicable time limit set in 35 USC § 371(b) and PCT Articles 22 and 39(1).					
4. ☒ A proper Demand for International Preliminary Examination was made by the 19th month from the earliest claimed priority date.					
5. ☒ A copy of the International Application as filed (35 USC § 371(c)(2)) a. ☐ is transmitted herewith (required only if not transmitted by the International Bureau). b. ☒ has been transmitted by the International Bureau. c. ☐ is not required, as the application was filed in the United States Receiving Office (RO/US).					
6. ☒ A translation of the International Application into English (35 USC 371 § 371(c)(2).					
7. ☐ Amendments to the claims of the International Application under PCT Article 19 (35 USC § 371(c)(3)) a. ☐ are transmitted herewith (required only if not transmitted by the International Bureau). b. ☐ have been transmitted by the International Bureau. c. ☐ have not been made; however, the time limit for making such amendments has NOT expired. d. ☐ have not been made and will not be made.					
8. ☐ A translation of the amendments to the claims under PCT Article 19 (35 USC 371(c)(3)).					
9. ☒ An oath or declaration of the inventor(s) (35 USC § 371(c)(4)).					
10. ☐ A translation of the annexes to the International Preliminary Examination Report under PCT Article 36 (35 USC § 371(c)(5)).					
Items 11 to 16 below concern other document(s) or information included:					
11. ☒ An Information Disclosure Statement under 37 CFR §§ 1.97 and 1.98.					
12. ☐ An assignment document for recording. A separate cover sheet in compliance with 37 CFR §§ 3.28 and 3.31 is included.					
13. ☒ A FIRST preliminary amendment. ☐ A SECOND or SUBSEQUENT preliminary amendment.					
14. ☐ A substitute specification.					
15. ☐ A change of power of attorney and/or address letter.					
16. ☐ Other items or information: a. ☐ CERTIFICATE UNDER 37 CFR § 3.73(b) b. ☐ POWER OF ATTORNEY c. ☒ INTERNATIONAL PUBLICATION NO. WO 96/24999 (COVER PAGE ONLY) d. ☒ COPY OF INTERNATIONAL SEARCH REPORT e. ☒ COPY OF INTERNATIONAL PRELIMINARY EXAMINATION REPORT (EO/US ONLY)					
SEND ALL CORRESPONDENCE TO: Jeffrey D. Shewchuk KINNEY & LANGE, P.A. Suite 1500 625 Fourth Avenue South Minneapolis, Minnesota 55415-1659 Telephone: 612/339-1863 Telefacsimile: 612/339-6580					
SIGNATURE  Jeffrey D. Shewchuk 37,235 REGISTRATION NUMBER July 29, 1997 DATE					

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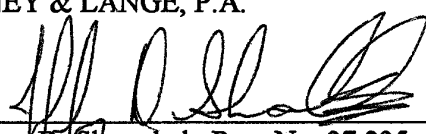
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I certify that the following paper(s) and/or fee(s) are being deposited with the United States Postal Service "Express Mail Post Office to Addressee" service under 37 CFR § 1.10 on July 29, 1997, addressed to the Assistant Commissioner for Patents, Washington, D.C. 20231:

1. Check in the amount of \$910.00
2. Transmittal Letter to PTO (in duplicate)
3. Translation of International Application as filed
4. Unexecuted Declaration
5. Information Disclosure Statement with Form PTO-1449 and 8 references
6. Preliminary Amendment
7. International Publication WO 96/24999(cover page only)
8. Copy of International Search Report
9. Copy of International Preliminary Examination Report

Respectfully submitted,

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DEVICE FOR THE RECEPTION OF DIGITAL SIGNALS WITH
ITERATIVE STRUCTURE, AND CORRESPONDING MODULE AND

METHOD

Background of the Invention

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The field of the invention is that of the
5 transmission and broadcasting of digital signals,
especially in the presence of transmission noises.
More specifically, the invention relates to the
reception of digital signals encoded by means of a
convolutive type error correction code.

10 The invention can be applied in all cases where
digital signals are transmitted or broadcast on noise-
infested channels. For example, the present invention
can be implemented in receivers of systems for digital
radiocommunications with mobile units such as the GSM
15 system.

Other possible applications are, for example, the
reception of signals transmitted by RF channels,
satellites, etc. More generally, the invention can be
applied advantageously in all cases where a convolutive
20 type code is implemented at transmission.

In the known type of receivers, the symbols
retrieved at output of the demodulator take the form of
analog samples which, after quantification, are
generally processed by an equalizer (a transversal
25 filter) given the task of eliminating the inter-symbol
interference introduced by the channel. The equalized
samples are then de-interleaved if necessary and
decoded before being given to the addressee.

The principle of equalization consists in
30 estimating the response of the transmission channel for
the application, to the received signal, of a filtering
operation symmetrical to this response so as to obtain
a corrected signal. In particular, the equalization is
aimed at eliminating or, at least, at limiting the
35 inter-symbol interference introduced by the channel.

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The response of the channel is generally estimated by the analysis of a reference signal known to the receivers. Of course, the transmission of these reference signals leads to a reduction of the useful
 5 bit rate.

The equalized items of data are then de-interleaved (in an operation symmetrical to the interleaving done at the time of encoding, if such an interleaving is planned) and then decoded.

10 In certain situations, it happens that the equalization of this type is not sufficient to ensure high quality source decoding.

The article by P. Jung and P.W. Baier, "VLSI implementation of soft output Viterbi equalizers for
 15 mobile radio applications" (Proc. of IEEE 42nd Vehicular Technology Society Conference, Denver, Colorado, pp. 577-585, May 1992) proposes the use, instead of a transversal filter, of a symbol detector working according to the principle of maximum
 20 likelihood.

This technique is more efficient if the coefficients representing the channel are properly estimated. However, once again, the equalized items of data may prove to be of insufficient quality.
 25 Furthermore, it is more complicated to make and requires more space than with the transverse filter technique.

Convolutional codes are codes that associate at least one encoded item of data with each item of source data
 30 to be encoded. This encoded item of data is obtained by the modulo 2 summation of this item of source data with at least one of the previous items of source data. Thus, each encoded signal is a linear combination of the item of source data to be encoded and previous
 35 items of source data taken into account.

In the decoder, the original items of data are most usually reconstructed by means of a maximum likelihood algorithm, for example the Viterbi algorithm, whose decisions may be weighted if necessary. The Viterbi
 5 algorithm, in taking account of a sequence of received encoded symbols, provides an estimation of each item of data encoded at transmission, in defining the source sequence most probably corresponding to the received sequence.

10 The Viterbi algorithm may also be used to detect sequences affected by inter-symbol interference. The invention can be also applied in this case.

Clearly, the greater the number of symbols taken into account, the more reliable is the decision. By
 15 contrast, the greater this number, the more complicated is the decoder or the detector (hereinafter, the term «decoder» is used to describe decoders themselves as well as detectors. This observation is applicable also
 20 to the term «decoding», which must be understood to mean «decoding» or «detection» as the case may be. The memory space needed soon becomes very great, as do
 21, 22 the corresponding computation times.

The integrated circuits that implement such algorithms therefore most usually rely on a compromise
 25 between cost and performance. These industrial-level choices do not always enable the construction of decoders that correspond in an optimum way to a given application. For example, it is not possible to make low-cost decoders for applications where the reception
 30 quality is not of crucial importance, as integrated circuits cost too much. Conversely, these integrated circuits too are not suited to the making of receivers with very high decoding quality for which the cost price is of little importance.

35 An advantageous example of convolutive encoding, to which the invention can be applied, is described in the

French patent application FR 91 05280 filed on behalf of the same Applicants as well as in the article by C. Berrou, A. Glavieux and P. Thitimajshima, "Near Shannon limit error-correcting coding and decoding: turbo-codes" (Proc. ICC'93, pp. 1064-1070, Geneva, Switzerland, May 1993). This class of codes is known in particular as "turbo-codes".

The elementary codes (recursive systematic or pseudo-systematic codes) described in the French patent application FR 91 05278 filed on behalf of the present Applicants may also be used.

The invention is aimed especially at overcoming the drawbacks of the prior art reception device and more specifically at improving the corresponding performance characteristics.

More specifically, a goal of the invention is to provide a device of this kind with very high corrective capacity as compared with known methods presently used in digital communications systems.

The invention is aimed in particular at providing methods of this kind that are particularly efficient, again with respect to known methods, for transmission in highly noise-infested channels.

It is also an aim of the invention to provide a device of this kind that is highly efficient but nevertheless easy to manufacture on an industrial scale at acceptable costs.

Thus, a particular aim of the invention is to provide a decoding method enabling implantation on a silicon surface that is small enough for its industrial-scale manufacture to be possible, for example, on a surface area smaller than 50 mm².

It is also an aim of the invention to provide a method of reception used for the making of numerous types of receivers with performance characteristics and cost price that vary as a function of the needs

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fulfilled, implementing one or more integrated circuits of a single type.

In other words, an essential aim of the invention is to provide methods of this kind enabling firstly
 5 profitable industrial-scale manufacture based on the development of a single and relatively simple integrated circuit and, secondly, the making of receivers that can be used for a very wide variety of applications.

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10 *Brief Summary of the Invention*
 These goals as well as others that shall appear hereinafter are achieved according to the invention by means of a device for the reception of signals formed by a series of digital symbols corresponding to the convolutive encoding of items of source digital data
 15 comprising p cascade-connected detection and decoding modules M_1 to M_p , p being greater than or equal to 2, each of said modules M_i including:

inter-symbol interference correction means supplied by a symbol input R_i and delivering estimated symbols
 20 $A_{i,1}$ with weighted values,

means for the decoding of said estimated symbols $A_{i,1}$, performing operations symmetrical to said convolutive encoding and delivering decoded symbols $A_{i,2}$ with weighted values, and

25 means for the computation of an item of correction information Z_{i+1} from said estimated symbol $A_{i,1}$ and said decoded symbol $A_{i,2}$,

said means for the correction of each of said modules M_i , except for the first module M_1 , taking
 30 account of at least one item of correction information Z_i determined by the previous module M_{i-1} .

Thus, according to the invention, the standard function of equalization (filtering) is replaced by a symbol detector that takes account of the memory effect
 35 introduced by the channel.

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In other words, the invention proposes a completely novel and optimized approach to the correction of inter-symbol interference. Indeed, conventionally, the equalization does not take account of the items of data transmitted but only of the channel estimation. By contrast, the invention is based on a dynamic approach, in taking account of the last symbols received to improve the equalization.

In other words again, the invention, in its general principle, likens the effect of inter-symbol interference to a particular convolutive encoding (except that there is no redundancy in the case of interference: to a symbol emitted on the channel, there corresponds one and only received symbol), and carries out its decoding. More specifically, the phenomenon of inter-symbol interference introduced by the channel may be represented by a lattice. This lattice differs from a convolutive encoding lattice by the presence of multiplier coefficients that vary in time. Thus, each module of the invention includes correction means and decoding means having similar structures based on convolutive decoding techniques.

The technique of the invention therefore consists in computing an item of correction information that represents the received symbol and in taking account of one or more of these items of information to correct the interference.

It will be understood that the taking into account of this information element dictates an iterative reception structure because of the latency introduced by the processing operations. Thus, during the first iteration, a first item of correction information is computed. This information element is used and, as the case may be, it is recomputed during the following iterations. According to the invention, the iterative approach takes the form of a structuring of the

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receiver (detector of symbols and decoder) in the form of cascade-connected modules with each module corresponding to an iteration. This is a completely novel approach to the correction of inter-symbol interference.

Advantageously, these modules are all identical. In particular, they may take the form of integrated circuits.

The greater the number of modules, the greater is the increase in the efficiency of reception (correction of inter-symbol interference and decoding). The modular approach of the invention can be used to easily obtain several types of receivers corresponding to different levels of reception quality, as a function of the modules implemented. Similarly, it is possible to provide for decoders with an open-ended structure to which modules may be added as needed.

According to a preferred embodiment of the invention, each of said modules M_i has two inputs, one symbol input R_i and one correction input Z_i and three outputs, one symbol output R_{i+1} , one correction output Z_{i+1} and one decoded symbol output D_{i+1} , the symbol input R_i of the module M_i being connected to the symbol output R_i of the module M_{i-1} for i greater than 1 and being supplied with the symbols received for i equal to 1,

the correction input Z_i of the module M_i being connected to the correction output Z_i of the module M_{i-1} for i greater than 1 and being supplied with a neutral value that does not affect the correction for i equal to 1,

the symbol output R_{i+1} of the module M_i being equal to the symbol input R_i of said module M_i delayed by the latency time dictated by the module M_i ,

the correction output Z_{i+1} delivering said correction information, and

the decoded symbol output D_{i+1} being unused for the modules M_1 to M_{p-1} and being supplied with the decoded symbol $A_{p,2}$ of the module M_p if the code implemented is a systematic code and, if not, with a corresponding reconstituted value.

This structure, as indicated further above, makes it possible to design identical modules. Of course, depending on whether it is the first module, the last module or an intermediate module, the inputs and outputs used may be different.

Advantageously, said means for the correction of the inter-symbol interference are supplied with an item of correction information Z_i representing a difference between each decoded symbol $A_{i,2}$ and the corresponding estimated symbol $A_{i,1}$.

In this case, preferably, said means to compute the item of correction information comprise means for the multiplication of said estimation symbols $A_{i,1}$ by a positive weighting coefficient γ_2 delivering weighted symbols, and subtraction means computing the difference between each decoded symbol $A_{i,2}$ and the corresponding weighted symbol and delivering said item of correction information Z_i .

In particular, the value of this coefficient is set in such a way that the information borne by Z_i no longer contains any information relating to $A_{i,1}$ so that the noise affecting Z_i and the received samples R_i are decorrelated. Thus the information element reinjected into the input of the equalizer is "new" as compared with the received samples (it comes from the decoding process). It shall be called "extrinsic information".

According to an advantageous embodiment, said means for the correction of inter-symbol interference perform the following operations:

- the computation of a correction value $V_i = \gamma_i |Z_i|$, where γ_i is a positive coefficient and where $||$ represents the absolute value operator;

- for each arm of the lattice corresponding to said
5 convolutive code, the determining of a detected symbol $A_{i,0}$, comprising the following steps:

- if the symbol assigned to said branch has the same sign as said item of correction information Z_i , the subtraction, from the metric associated with
10 said arm, of said correction value V_i ;

- if the symbol assigned to said arm has a sign opposite that of said item of correction information Z_i , the addition, to the metric associated with said arm, of said correction value V_i ;

15 - the subtraction, from said detected symbol $A_{i,0}$, of the value $\gamma_i Z_i$.

An object of the latter subtraction is to "rid" the output of the symbol detector and hence, all the more so, the input of the convolutive decoder, of the
20 information element carried by Z_i .

The weighting of the symbols transmitted on the channel is aimed, conventionally, at representing the inter-symbol interference. The weighting coefficients may be fixed or, preferably, estimated, for example by
25 means of a learning sequence.

Preferably, said coefficient γ_i depends on at least one of the items of information belonging to the group comprising:

- the signal-to-noise ratio;
- 30 - the number i of the module considered.

Indeed it can be seen that the greater the value of γ_i , the more reliable is the output of the decoder.

When the symbols are subjected to interleaving at transmission, the decoder preferably comprises:

- 35 - de-interleaving means providing for the symmetrical operation of said interleaving, inserted

between said correction means and said decoding means;
and

- interleaving means providing for an interleaving of said items of correction information that is identical to said interleaving at transmission.

The interleaving and de-interleaving may be done by means of matrices.

- The reading and writing increments may be fixed or, more advantageously, may depend on the read or write address.

- The invention also relates to a detection and decoding module designed to be implemented in a device for the reception of signals formed by a series of digital symbols corresponding to the convolutive encoding of items of source digital data, said device comprising at least two cascade-connected modules, the module having two inputs, one symbol input R_i and one correction input Z_i , and three outputs, one symbol output R_{i+1} , one correction output Z_{i+1} and one decoded symbol output D_{i+1} , and comprising:

- means for the correction of inter-symbol interference supplied by said symbol input R_i and taking account of said correction input Z_i and delivering estimated symbols $A_{i,1}$,

means for the decoding of said estimated symbols $A_{i,1}$, performing operations symmetrical to said convolutive encoding and delivering decoded symbols $A_{i,2}$, and

- means for the computation of an item of correction information Z_{i+1} from said estimated symbol $A_{i,1}$ and said decoded symbol $A_{i,2}$, the symbol output R_{i+1} being equal to the symbol input R_i delayed by a predefined latency time, the correction output Z_{i+1} delivering said correction information, and

the decoded symbol output D_{i+1} being supplied with said decoded symbol $A_{i,2}$ or with a value reconstituted as a function of the code implemented.

As indicated here above, a module of this kind in particular may take the form of an integrated circuit.

The invention further relates to a method for the reception of signals formed by a series of digital symbols corresponding to the convolutive encoding of items of source digital data comprising the following steps:

- supplying with received symbols R_i ;
- the correction of inter-symbol interference affecting each of said received symbols, by means of an item of correction information Z_i , and the delivery of estimated symbols $A_{i,1}$;
- the decoding of said estimated symbols $A_{i,1}$, entailing operations symmetrical to said convolutive encoding, and the delivery of decoded symbols $A_{i,2}$;
- the computation of said items of correction information Z_i from at least one of said estimated symbols $A_{i,1}$ and at least one of said decoded symbols $A_{i,2}$.

~~Other features and advantages of the invention shall appear from the following description of a preferred embodiment of the invention given by way of a non-restricted example and from the appended drawings, of which:~~

- ~~Figure 1 is a block diagram illustrating a standard transmission line that can be incorporated into a reception device according to the invention;~~
- ~~Figure 2 gives a simplified view of a discrete model, equivalent in terms of baseband to a transmission channel affected by an inter-symbol interference, illustrating the approach of the invention;~~

~~- Figure 3 shows the corresponding lattice of the channel of Figure 2, illustrating possible developments of the state of the channel as a function of time;~~

~~- Figure 4 is a block diagram showing the principle of the receiver of the invention;~~

~~- Figure 5 is a simplified flow chart illustrating the method of the invention implemented in the receiver of Figure 4;~~

~~- Figure 6 illustrates the modular structure of the receiver of the invention in the case of four cascade-connected modules;~~

~~- Figure 7 shows a block diagram of a module of Figure 6;~~

~~- Figure 8 shows a series of curves illustrating the performance characteristics of the invention in the case of a Gaussian channel.~~

The invention can be applied, as indicated here above, to all systems of digital transmission implementing a convolutive error correction encoding operation as shown in Figure 1.

This system has a digital source 11 that must be transmitted to an addressee 12.

The term «digital source» is understood to mean any useful digital signal (sound, image, data) and more generally any set of useful signals, for example time-division multiplexed and/or frequency-division multiplexed signals. The addressee 12 may be a single addressee (in the case of transmission) or a multiple addressee (in the case of broadcasting). Similarly, the transmission line may of course be one-way (as in radio broadcasting) or two-way (as in radio communications for example).

The source of signal is first of all subjected to a convolutive encoding 13 of a type known per se. It may consist, in particular, of a standard systematic convolutive encoding associating, with each item of

source data, at least one determined value by the combination of this item of data with at least one of the previous items of source data.

It may also be a code such as one of those described in the patent application FR 91 05278. These codes, known as "pseudo-systematic" codes, are characterized by the fact that the source data is transmitted systematically, in conjunction with at least one encoded item of data or redundancy symbol.

Any other convolutive code may also be used.

The items of data delivered by the encoder 13 are then advantageously (although this is not an obligatory characteristic) subjected to an interleaving operation 14.

This interleaving operation may be obtained conventionally by means of an interleaving matrix in which the items of source data are introduced line by line and restored column by column.

The module 14 provides for matrix interleaving. The items of data are written, in successive lines, in a memory with a size $n_E \times n_E$, and restored in successive columns. This technique is described for example in the article by E. Dunscombe and F.C. Piper, "Optimal interleaving scheme for convolutional coding", in "Electronics Letters", Vol. 25, No. 22, October 1989.

As can be seen in this article, the efficiency of the interleaving for small values of n_E (some tens) is improved if the succession of rows and columns occurs according to an increment greater than 1, this increment being, by necessity, relatively prime with n_E .

An additional improvement to this technique of interleaving may be implemented. For it appears to be advantageous that the row-skip increment, which is always relatively prime with n_E , should be a function of the position of the column considered. This makes

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it possible to break the rectangular-positioned error packets.

In this case, the interleaving matrix read increments are chosen in such a way that the minimum distance at output between two symbols that are neighboring at input is as great as possible. These increments may, for example, be determined empirically.

Other interleaving techniques may of course be used, especially the usual method of write and read increments equal to 1, without departing from the framework of the invention. It is also clear that the rows and columns may be inverted.

Then, the interleaved signal is transmitted through the transmission channel 15. It therefore undergoes a modulation and a filtering operation 16, according to any appropriate technique, and is then transmitted through the transmission medium 17.

This transmission medium 17 is generally noise-infested and shows interference between the symbols transmitted in it.

It must be noted that, according to the invention, the two sources of disturbance namely noise and inter-symbol interference (IES) are considered in a dissociated manner. In other words, the symbols affected by IES are in addition noise-infested. The IES is chiefly due to distortion introduced by the filtering elements of the transmission system and the presence of multiple paths induced by the physical medium of transmission (due to reflections and obstacles, etc.). These phenomena lead to disturbances between symbols. The noise induced by the physical medium gets added to this IES phenomenon and is likely in addition to modify the items of information borne by the symbols.

15

Figure 2 illustrates this approach in the simplified case of interference relating to two symbols.

The reference A_n is given to the symbol transmitted at the instant nT , where $1/T$ is the speed of modulation (T being the duration of the symbol). The received signal S_n can be written, after passage in the transmission channel:

$$S_n = \sum_k h_k A_{n-k}$$

This signal comprises a term dependent on the symbol A_n , namely $h_0 A_n$, but also a term dependent on the symbols transmitted prior to and subsequently to A_n . This second term is the inter-symbol interference term. It can be written in the form $\sum_{k \neq 0} h_k A_{n-k}$. It is due to the filtering introduced by the channel and may be modelled by a lattice with $N = 2^v$ states, for an IES modelled by a discrete equivalent channel with a memory v (two in the case of Figures 2 and 3).

In the case of Figure 2, interference relating to two symbols (A_{n-1} and A_{n+1}) is considered. The effect of the channel may then be represented by two delay cells 21_1 and 21_2 , each with a duration T .

When the symbol A_{n+1} is presented at input of the cell 21_1 , the output of this cell 21_1 is A_n and the output of the second cell 21_2 is A_{n-1} . The filtering of the channel amounts to the multiplying (22_1 to 22_3) of each of these symbols by the corresponding filtering coefficient h_i . The corresponding terms are then added up (23) to form the signal S_n .

The architecture of Figure 2 corresponds to a convolutive encoding with $v = 2$, the decoding lattice of which is illustrated in Figure 3. Conventionally, this lattice illustrates the possible transitions as a function of the two preceding values depending on whether the value of A_{n+1} is 1 (solid lines) or 0 (dashes).

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Returning to Figure 1, the noise-infested signal S_n is subjected to a filtering and a demodulation 18, which are symmetrical to the operations performed by the module 16.

5 Then, conventionally, the signal is equalized (19) by the application of a filtering operation designed to compensate for the effects of the transmission medium 17. The equalized signal is then de-interleaved (110) symmetrically to the interleaving operation 14.

10 Finally, the signal is transmitted to a convolutive decoder 111 which, for example, implements an operation of maximum likelihood decoding such as the Viterbi algorithm to deliver decoded items of data to the addressee 12.

15 The essential characteristic of the invention is the iterative association of a symbol detection module with weighted outputs and a decoding module, also with weighted outputs. If we consider the effect of the channel according to the approach presented, the
20 standard equalization (the filtering of the received signal by means of a transversal filter, for example) is replaced by an operation of symbol detection that takes account of the memory effect introduced by the channel.

25 Thus, the proposed device includes a detector with weighted input and output that estimates the symbols A_n from the noise-infested output of the channel. For example, this detector may be made by using the algorithm described in the patent document FR 91 05279.
30 It requires knowledge of the coefficient h_k which should therefore be estimated externally to the proposed device, for example by means of learning sequences.

Figure 4 illustrates the general principle of the
35 invention.

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Each received sample R_n , which corresponds to the noise-infested output of the transmission channel, is processed as follows:

- a detector 41 of symbols with weighted outputs produces an estimation $A_{n,1}$ of the corresponding transmitted symbol;
- the symbols $A_{n,1}$ at output of the detector 41 are de-interleaved (42) to give the symbols $A_{k,1}$;
- the de-interleaved symbols $A_{k,1}$ are presented to the input of a convolutive decoder 43 which gives a new estimation $A_{k,2}$ of symbols A_k ;
- at output of the decoder 43, there is defined (44) a correction data element Z_k called an extrinsic data element obtained from the estimations $A_{k,1}$ and $A_{k,2}$;
- the correction data element Z_k is then used, after a re-interleaving operation 45, in the detector 41.

More specifically, in the embodiment described, the item of data Z_k is obtained by difference between $A_{k,2}$ and $\gamma_2 A_{k,1}$ delivered by the multiplier 46, where γ_2 is a positive coefficient, Z_n is still an estimation of the symbol A_n , but this time affected by a noise that is not correlated with the noise that affects $A_{n,1}$ and is slightly correlated with the noise affecting R_n by means of the interleaving function 45.

The extrinsic information Z_n is then used by the detector 41 by the addition or deduction, to or from each arm metric of the lattice associated with the channel (cf. Figure 3), of the term $\gamma_1 |Z_n|$, where γ_1 is a positive coefficient. The term $\gamma_1 |Z_n|$ is deducted (or added respectively) when the symbol assigned to the arm considered has the same sign as Z_n (or respectively the opposite sign). The value of the coefficient γ_1 depends on both the signal-to-noise ratio and the reliability of the extrinsic information element Z_n .

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The extrinsic information element, assigned the coefficient γ_1 for the multiplier 48, is furthermore deducted (47) from the output of the detector 41 before being presented to the input of the decoder 43.

5 Indeed, since the extrinsic information element Z_n has been produced by the decoder 43, it cannot be reused by this decoder 43.

The symbol detector 41 takes its decisions according to a Viterbi type algorithm. All the
10 operations performed by this detector correspond to those described in the patent FR 91 05279. The difference, as compared with a convolutive decoding algorithm, lies in the computation of the transition metrics or branch metrics, which is done differently.

15 Each node of the lattice is represented by a possible state of the channel at a given instant nT . For an IES value relating to K_1 symbols subsequent to the symbol considered and K_2 symbols prior to the symbols considered, namely for:

$$20 \quad S_n = \sum_{k=K_1 \text{ to } K_2} h_k A_{n-k}$$

the state of the channel at $t = nT$ is given by the (K_1+K_2) -uplet $(A_{n+K_1-1} \dots A_{n+1} A_n A_{n-1} \dots A_{n-K_2})$. The
knowledge of the state of the channel at $t = nT$ as well as the value of A_{n+K_1} (symbol « entering » the channel)
25 then provides knowledge of its state at $t = (n+1)T$.

Thus, for each node j of the lattice taken at the instant $t = nT$, two transition metrics L_{j0} and L_{j1} are computed. They correspond to the two possible transitions ($A_{n+K_1}=0$ and $A_{n+K_1}=1$). They have the form:

$$30 \quad L_{j0} = (R_n - R_{j0})^2 \text{ and } L_{j1} = (R_n - R_{j1})^2$$

where R_n represents the sample actually received at input of the detector and R_{j0} (or R_{j1} respectively) is the theoretical value of the sample that is not noise-infested when the state of the channel corresponds to
35 the node j of the lattice and when $A_{n+K_1}=0$ (or $A_{n+K_1}=1$ respectively). R_{j0} (or R_{j1} respectively) therefore has

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the form: $\sum_{k=K1 \text{ to } K2} h_k A_{n-k}$. If $A_{n+K1}=0$, then the value is R_{j0} and if $A_{n+K1}=1$ then the value is R_{j1} .

In practice, the following simplified expression is used to compute the metrics:

$$L_{j0} = |R_n - R_{j0}| \text{ and } L_{j1} = |R_n - R_{j1}|$$

The performance characteristics of the detection are then very close to those obtained with the previous expression and the implantation of the computation on silicon is greatly simplified.

Apart from this computation of the metrics, the computation algorithm is similar in principle as well as in its implementation to a convolutive decoding algorithm.

In practice, the receiver shown in Figure 4 induces a computation latency (processing time of the detector 41, the decoder 43, the interleaving operation 45 and the de-interleaving operation 42). It is therefore not possible to obtain instantaneous knowledge of Z_n when R_n is received in the detector 41. Consequently, according to an essential characteristic of the invention, the process implemented is iterative.

This process is illustrated schematically by Figure 5. For each symbol received R_n (reception step 51), at least two iterations 52 are performed.

Each iteration 52 includes a step 521 for the correction of inter-symbol interference. As indicated here above, this correction implements a convolutive decoding technique and takes account of an item of extrinsic correction information Z_n and items of data h_i representing the transmission channel.

The items of information Z_n are computed during the step 524. Naturally, at the first iteration, no particular value of Z_n is known. Consequently, this value is set at a neutral value, namely at a value having no effect on the computations.

After the correction 521, the estimated symbols are de-interleaved during the de-interleaving step 522 (if an interleaving operation has been implemented at transmission) and then decoded according to a standard
 5 technique of convolutive decoding 523 and for example according to the technique described in the French patent application FR 91 02579.

Then, the item of extrinsic information Z_k is computed (524) from the item of data 525 detected by
 10 the correction step 521 and the item of data 526 decoded by the decoding step 523. Then, the items of information Z_k are re-interleaved (527) symmetrically with the de-interleaving 522 to give the item of information Z_n . The item of information Z_n is taken
 15 into account in the correction step 521 of the next iteration.

At the last iteration, the step 524 for the computation of Z_k is not implemented. The decoded symbol D_k is delivered by the decoding step 523.

20 The corresponding reception device may advantageously be made in a modular fashion, by associating one module with each iteration. Figure 6 illustrates a device of this kind comprising four modules.

25 The first module 61 of the system receives $(R)_n$, the symbol received by the device and delivers firstly $(R)_{n,2}$, which is equal to $(R)_n$ assigned a delay corresponding to the latency of the module and, secondly, $(Z)_{n,2}$ the extrinsic information computed by
 30 the module 61. Each of the following modules 62 to 64 receives the delayed symbol $(R)_{n,i}$ and the item of extrinsic information $(Z)_{n,i}$. The last module 64 delivers the decoded symbol $(D)_n$.

It will easily be understood that the performance
 35 characteristics of the device in terms of error rate

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are a function of the number of cascade-connected modules.

Advantageously, all the modules are identical. Figure 7 illustrates an exemplary embodiment of a module of this kind. More specifically, it is the module corresponding to the p^{th} iteration. It includes:

- two inputs: $(R)_p$ and $(Z)_p$,
- three outputs: $(R)_{p+1}$, $(Z)_{p+1}$ and $(D)_{p+1}$.

The input $(R)_p$ is equal to the output of the channel delayed by the latency of $p-1$ modules.

The input $(Z)_p$ comes from the previous module and is set, for $p = 1$, at a neutral value, namely a value that has no influence on the output of the detector.

The output $(R)_{p+1}$, equal to the input $(R)_p$ delayed by the latency of a module, is unused if the iteration is the last one of the process ($p=P$, P being the total number of modules).

The output $(Z)_{p+1}$ is the extrinsic information element prepared at the p^{th} iteration. This output is also unused if $p=P$.

The output $(D)_{p+1}$ which is the decoded item of data is unused by the $P - 1$ first modules, and only the items of data coming from $(D)_{p+1}$ are given to the addressee.

The elements of this module that have already been described with reference to Figure 4 are not described again, and bear the same references. It will be noted that, as compared with the schematic diagram of Figure 4, different delays are added to take account of the latencies of the different elements.

Thus, the extrinsic information $(Z)_p$ used for the difference 47 must be delayed (71) by a duration equal to the latency L_1 of the detector 41. This is also the case with $(A)_{p,1}$ which must be delayed by the latency L_2 of the decoder 43. Finally, $(R)_p$ must be delayed

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(73) by the total latency introduced by a module L_T in order that $(R)_{p+1}$ and $(Z)_{p+1}$ may be presented at the same instant to the input of the following module. This latency L_T is equal to the sum of the latency of the detector 41, L_1 , the latency of the decoder L_2 and the latency introduced by the interleaving operations 45 and de-interleaving operations 42 L_{ED} .

The performance characteristics of the device of the invention have been simulated and are illustrated in Figure 8. The item of source data is encoded by a recursive systematic convolutive code (CSR code) with a constraint length $K = 5$ and efficiency $R = 1/2$. The encoded items of data are sent on the transmission channel after a non-uniform interleaving in a matrix of 64 rows and 64 columns. The modulation used is a binary phase-shift keying (BPSK) modulation.

The multiplier coefficients h_i are real and constant and known to the symbol detector but the principle is applicable when they are complex and variable. For the results presented hereinafter, the coefficients h_i have been fixed at:

$$h_0 = \sqrt{0.45}, h_1 = \sqrt{0.25}, h_2 = \sqrt{0.15}, h_3 = \sqrt{0.10}, h_4 = \sqrt{0.05}$$

They verify $\sum_{i=0}^4 h_i^2 = 1$. The transmission channel is also disturbed by a Gaussian white additional noise.

At output of the channel, the received samples R_n are quantified on 8 bits. The symbol detector and the channel decoder use the algorithm presented in the patent FR 91 05279. The working of the decoder is also represented by a 16-state lattice. The values of coefficients γ_1 and γ_2 have been determined empirically.

The results shown use four modules. The curves C_1 and C_2 represent the error rate at output of the transmission system, respectively without and with

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channel encoding, when there is no inter-symbol interference: C_3 gives the error rate in the classic case where the symbol detector gives a binary decision (firm decision) and the curves C_{4i} show the results
 5 obtained with the proposed device after the i -order iteration.

These curves therefore show that, at an error rate of 10^{-5} , the use of a symbol detector with weighted output makes it possible to gain 1.6 dB as compared
 10 with a firm decision detector and the three additional iterations provide an additional gain of about 3 dB. When the number of iterations increases, the performance characteristics approach those obtained on an encoded Gaussian channel.

CONFIDENTIAL

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CLAIMS

- Sub
a1
1. Device for the reception of signals formed by a series of digital symbols corresponding to the convolutive encoding of items of source digital data characterized in that it comprises p cascade-connected detection and decoding modules (61 to 64) M_1 to M_p , p being greater than or equal to 2, each of said modules M_i including:
 - inter-symbol interference correction means (41, 47, 48) supplied by a symbol input R_i and delivering estimated symbols $A_{i,1}$ with weighted values,
 - means (43) for the decoding of said estimated symbols $A_{i,1}$ performing operations symmetrical to said convolutive encoding and delivering decoded symbols $A_{i,2}$ with weighted values, and
 - means (44, 46) for the computation of an item of correction information Z_{i+1} from said estimated symbol $A_{i,1}$ and said decoded symbol $A_{i,2}$,
 - said means (41) for the correction of each of said modules M_i , except for the first module M_1 , taking account of at least one item of correction information Z_i determined by the previous module M_{i-1} .
 2. Device according to claim 1, characterized in that each of said modules M_i has two inputs, one symbol input R_i and one correction input Z_i and three outputs, one symbol output R_{i+1} , one correction output Z_{i+1} and one decoded symbol output D_{i+1} , the symbol input R_i of the module M_i being connected to the symbol output R_i of the module M_{i-1} for i greater than 1 and being supplied with the symbols received for i equal to 1,
 - the correction input Z_i of the module M_i being connected to the correction output Z_i of the module M_{i-1} for i greater than 1 and being supplied with a neutral value that does not affect the correction for i equal to 1,

the symbol output R_{i+1} of the module M_i being equal to the symbol input R_i of said module M_i delayed by the latency time dictated by the module M_i ,
 the correction output Z_{i+1} delivering said correction information, and
 the decoded symbol output D_{i+1} being unused for the modules M_1 to M_{p-1} and being supplied with the decoded symbol $A_{p,2}$ of the module M_p if the code implemented is a systematic code and, if not, with a corresponding reconstituted value.

3. Device according to any of the claims 1 and 2, characterized in that said means (41) for the correction of the inter-symbol interference are supplied with an item of correction information Z_i representing a difference (44) between each decoded symbol $A_{i,2}$ and the corresponding estimated symbol $A_{i,1}$.

4. Device according to claim 3, characterized in that said means to compute the item of correction information comprise means (46) for the multiplication of said estimation symbols $A_{i,1}$ by a positive weighting coefficient γ_2 delivering weighted symbols, and subtraction means (44) computing the difference between each decoded symbol $A_{i,2}$ and the corresponding weighted symbol and delivering said item of correction information Z_i .

5. Device according to any of the claims 1 to 4, characterized in that said means (41, 47, 48) for the correction of inter-symbol interference perform the following operations:

- the computation (41) of a correction value $V_i = \gamma_1 |Z_i|$, where γ_1 is a positive coefficient and where $||$ represents the absolute value operator;

- for each arm of the lattice corresponding to said convolutive code, the determining (41) of a detected symbol $A_{i,0}$, comprising the following steps:

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- if the symbol assigned to said branch has the same sign as said item of correction information Z_i , the subtraction, from the metric associated with said arm, of said correction value V_i ;

5 - if the symbol assigned to said arm has a sign opposite that of said item of correction information Z_i , the addition, to the metric associated with said arm, of said correction value V_i ;

10 - the subtraction (47), from said detected symbol $A_{i,0}$, of the value $\gamma_i Z_i$.

6. Device according to claim 5, characterized in that said coefficient γ_1 depends on at least one of the items of information belonging to the group comprising:

- the signal-to-noise ratio;
- 15 - the number i of the module considered.

7. Device according to any of the claims 1 to 6, applied to the reception of symbols subjected to an interleaving operation at transmission, characterized in that it comprises:

- 20 - de-interleaving means (42) providing for the symmetrical operation of said interleaving, inserted between said correction means and said decoding means; and
- interleaving means (45) providing for an interleaving of said items of correction information that is identical to said interleaving at transmission.

8. Detection and decoding module designed to be implemented in a device for the reception of signals formed by a series of digital symbols corresponding to
30 the convolutive encoding of items of source digital data, said device comprising at least two cascade-connected modules,
characterized in that it has two inputs, one symbol input R_i and one correction input Z_i , and three
35 outputs, one symbol output R_{i+1} , one correction output Z_{i+1} and one decoded symbol output D_{i+1} ,

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and in that it comprises:

means (41, 47, 48) for the correction of inter-symbol interference, supplied by said symbol input R_i and taking account of said correction input Z_i and
 5 delivering estimated symbols $A_{i,1}$,

means (43) for the decoding of said estimated symbols $A_{i,1}$, performing operations symmetrical to said convolutive encoding and delivering decoded symbols $A_{i,2}$, and

10 means (44, 46) for the computation of an item of correction information Z_{i+1} from said estimated symbol $A_{i,1}$ and said decoded symbol $A_{i,2}$, the symbol output R_{i+1} being equal to the symbol input R_i delayed by a predefined latency time,
 15 the correction output Z_{i+1} delivering said correction information, and the decoded symbol output D_{i+1} being supplied with said decoded symbol $A_{i,2}$ or with a value reconstituted as a function of the code implemented.

20 ~~Sub 29~~. Method for the reception of signals formed by a series of digital symbols corresponding to the convolutive encoding of items of source digital data comprising the following steps:

- supplying (51) with received symbols R_i ;
- 25 - the correction (521) of inter-symbol interference affecting each of said received symbols, by means of an item of correction information Z_i , and the delivery of estimated symbols $A_{i,1}$;
- the decoding (523) of said estimated symbols $A_{i,1}$
- 30 entailing operations symmetrical to said convolutive encoding, and the delivery of decoded symbols $A_{i,2}$;
- the computation (524) of said items of correction information Z_i from at least one of said estimated symbols $A_{i,1}$ and at least one of said decoded symbols
- 35 $A_{i,2}$.

ABSTRACT

DEVICE FOR THE RECEPTION OF DIGITAL SIGNALS WITH
ITERATIVE STRUCTURE, AND CORRESPONDING MODULE AND
METHOD

5 The invention relates to a device for the reception
of signals formed by a series of digital symbols
corresponding to the convolutive encoding of items of
source digital data comprising p cascade-connected
detection and decoding modules M_1 to M_p , p being
10 greater than or equal to 2,
each of said modules M_i including:
inter-symbol interference correction means (41, 47,
48) supplied by a symbol input R_i and delivering
estimated symbols $A_{i,1}$ with weighted values,
15 means (43) for the decoding of said estimated
symbols $A_{i,1}$, performing operations symmetrical to said
convolutive encoding and delivering decoded symbols
 $A_{i,2}$ with weighted values, and
means (44, 46) for the computation of an item of
20 correction information Z_{i+1} from said estimated symbol
 $A_{i,1}$ and said decoded symbol $A_{i,2}$,
said means for the correction of each of said modules
 M_i , except for the first module M_1 , taking account of
at least one item of correction information Z_i
25 determined by the previous module M_{i-1} .

Figure 4.

462027-10216600

DECLARATION

IN ☐ ORIGINAL ☒ NATIONAL STAGE OF PCT APPLICATION
☐ DIVISIONAL ☐ CONTINUATION
☐ CONTINUATION-IN-PART

Attorney Docket No.
F264.312-16

SPECIFICATION AND INVENTORSHIP IDENTIFICATION

As a below named inventor, I declare that:

My residence, post office address and citizenship are as stated below next to my name.

I believe I am the original, first and ☐ sole ☒ joint inventor of the subject matter which is claimed, and for which a patent is sought, on the invention entitled DEVICE FOR THE RECEPTION OF DIGITAL SIGNALS WITH ITERATIVE STRUCTURE, AND CORRESPONDING MODULE AND METHOD, the specification of which;

- ☒ is attached hereto.
- ☐ was filed on _____ as Appln. Serial No. _____
☐ and was amended on _____.
- ☒ was described and claimed in PCT International Application No. PCT/FR96/00197, filed on February 6, 1996,
☐ and was amended under PCT Article 19 on _____.

ACKNOWLEDGEMENT OF REVIEW OF PAPERS AND DUTY OF CANDOR

I have reviewed and understand the contents of the above identified specification, including the claims, as amended by any amendment referred to above. I acknowledge the duty to disclose information which is known to me to be material to the patentability of this application in accordance with Title 37, Code of Federal Regulations, § 1.56.

PRIORITY CLAIM (35 USC § 119)

I claim foreign priority benefits under Title 35, United States Code, § 119 of any foreign application(s) for patent or inventor's certificate listed below and have also identified below any foreign application for patent or inventor's certificate having a filing date before that of the application on which priority is claimed:

Prior Foreign Application(s)

Number	Country	Day/Month/Year Filed	Priority Claimed
<u>95 01603</u>	<u>France</u>	<u>7 February 1995</u>	☒ Yes ☐ No
_____	_____	_____	☐ Yes ☐ No
_____	_____	_____	☐ Yes ☐ No

PRIORITY CLAIM (35 USC § 120)

I claim the benefit under Title 35, United States Code, § 120 of any United States application(s) listed below. Insofar as the subject matter of each of the claims of this application is not disclosed in the prior United States application in the manner provided by the first paragraph of Title 35 United States Code § 112, I acknowledge the duty to disclose to the Patent Office all information known to me to be material to patentability as defined in Title 37 Code of Federal Regulations § 1.56 which became available between the filing date of the prior application and the national or PCT international filing date of this application:

U.S. Serial No.	International Appln. No. (under PCT)	Filing Date	Status (patented, pending, abandoned)
_____	_____	_____	_____
_____	_____	_____	_____

DECLARATION

I declare that all statements made herein that are of my own knowledge are true and that all statements that are made on information and belief are believed to be true; and further that these statements were made with the knowledge that willful false statements and the like so made are punishable by fine or imprisonment, or both, under Section 1001 of Title 18 of the United States Code and that such willful false statements may jeopardize the validity of the application or any patent issued thereon.

DESIGNATION OF CORRESPONDENCE ADDRESS

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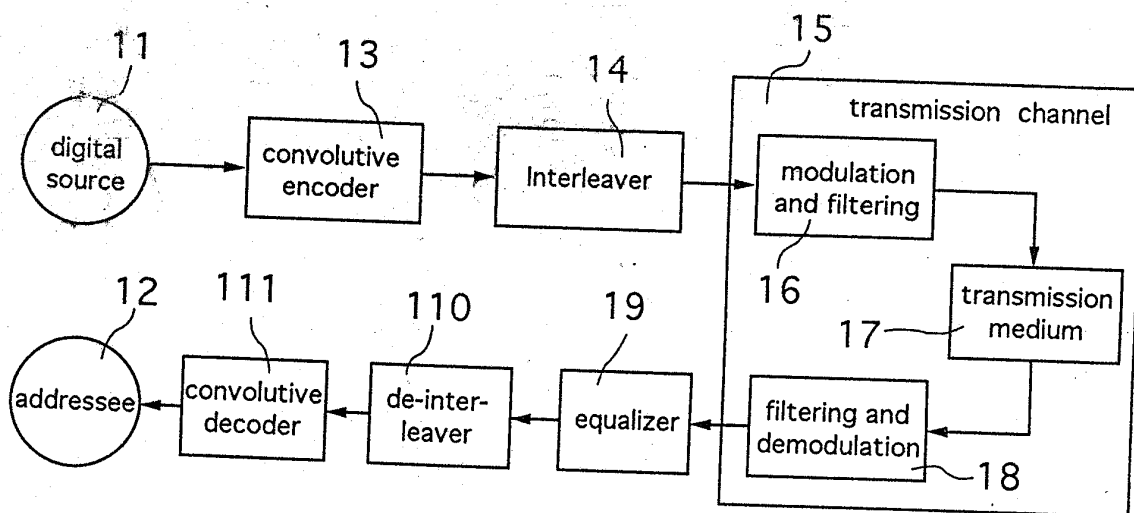


Fig. 1

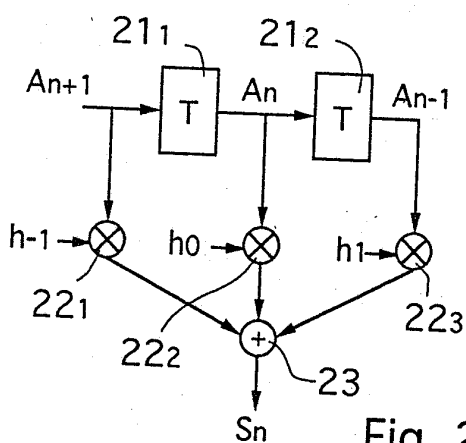


Fig. 2

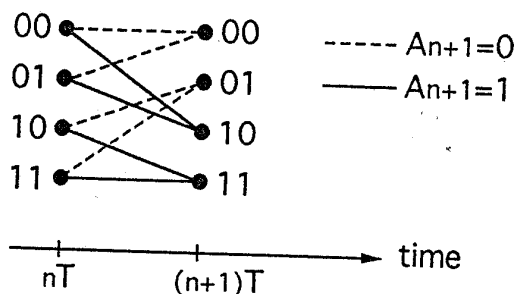


Fig. 3

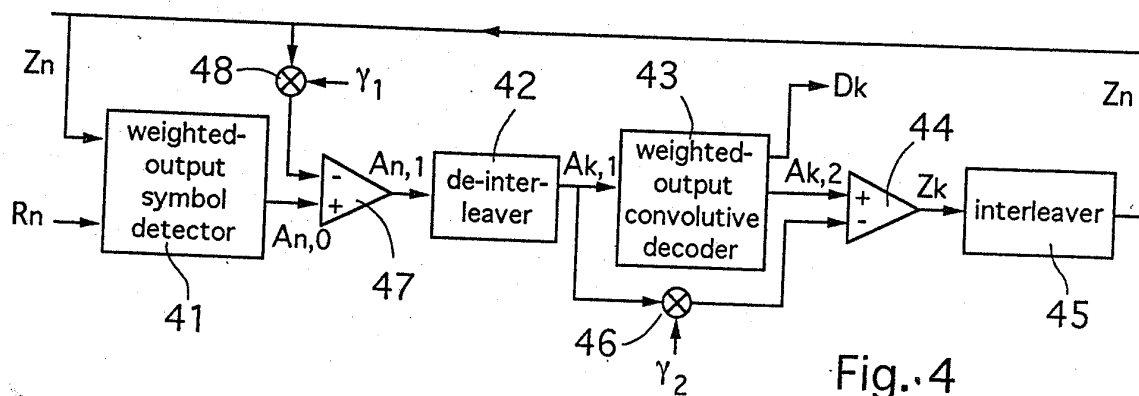


Fig. 4

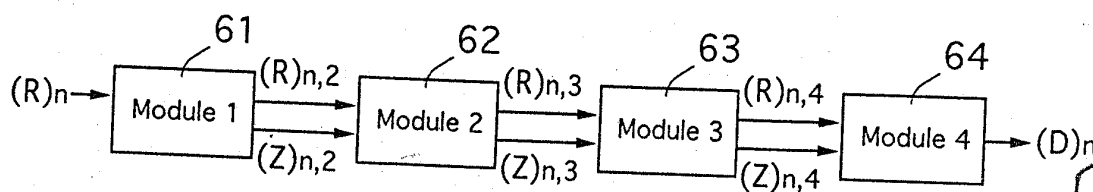


Fig. 6

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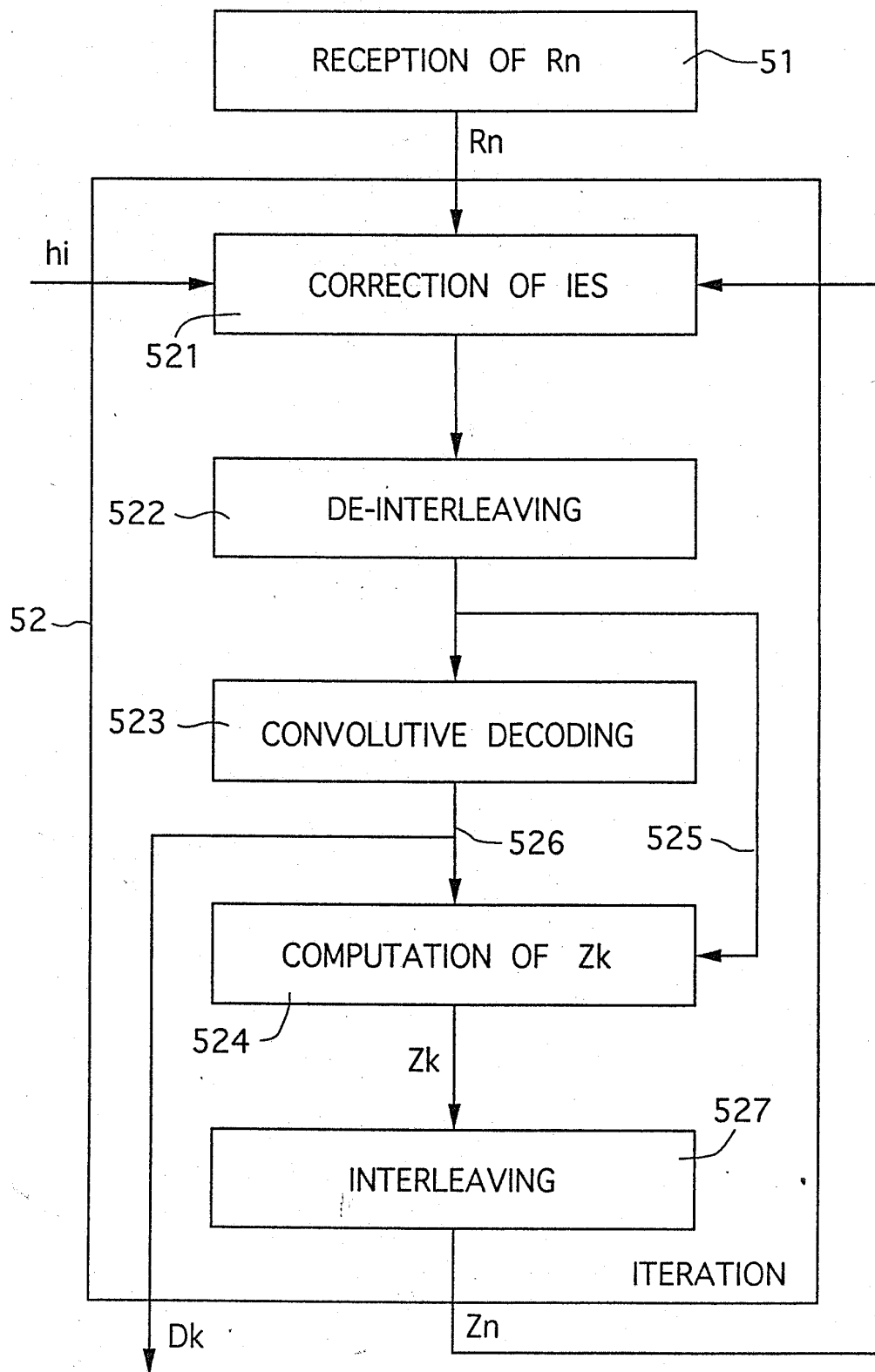


Fig. 5

APPROVED	O.G. FIG. 4
BY	CLASS
DRAFTSMAN	SUBCLASS
	375 348

08/894207

3/3

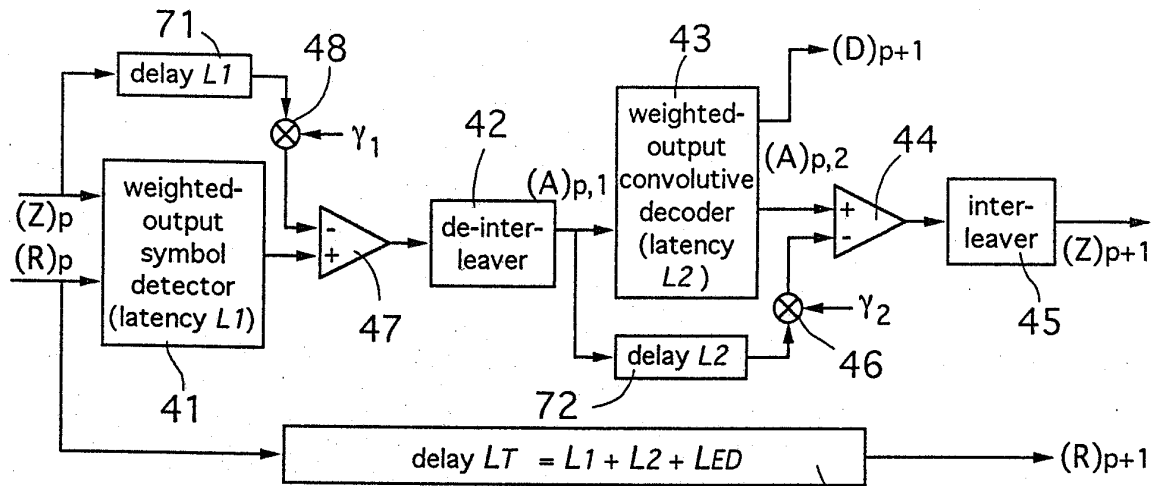


Fig. 7

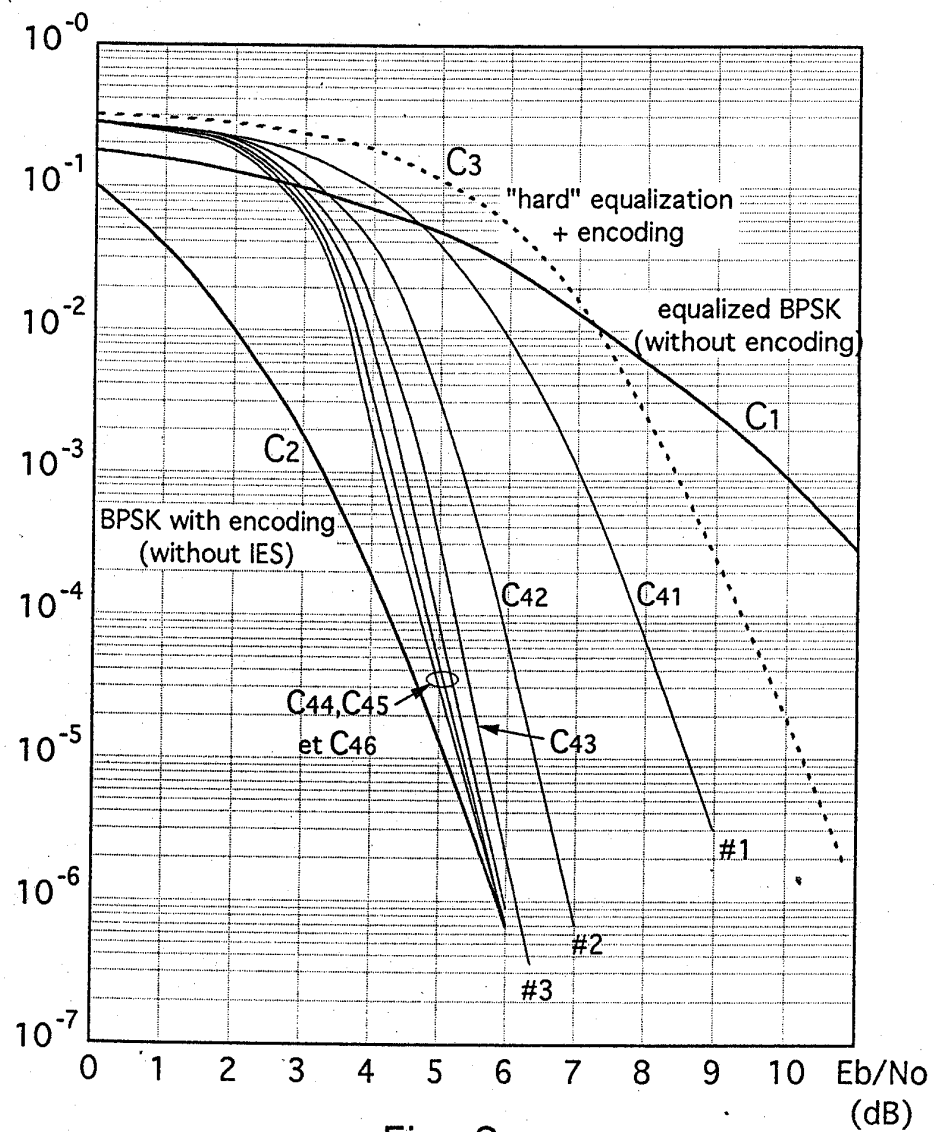


Fig. 8

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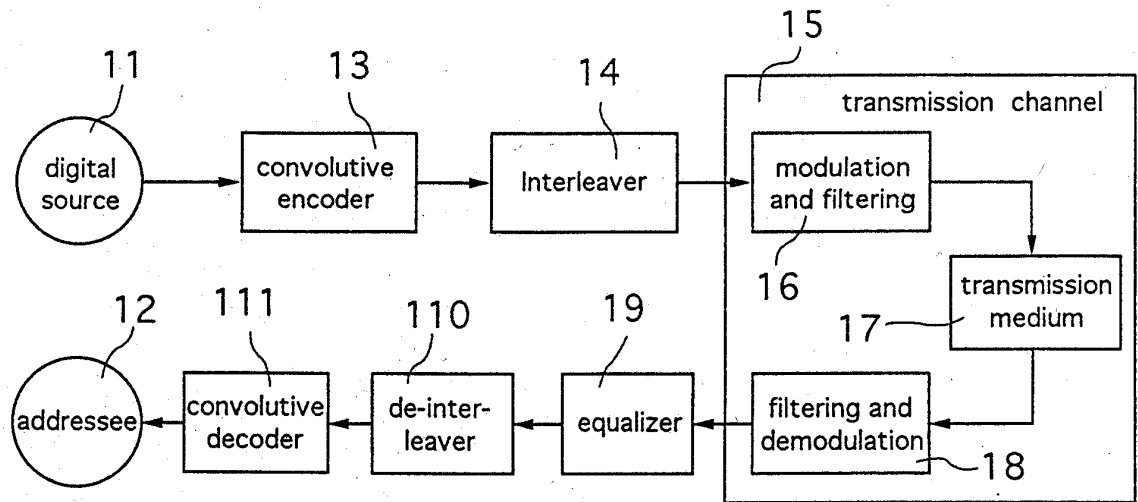


Fig. 1

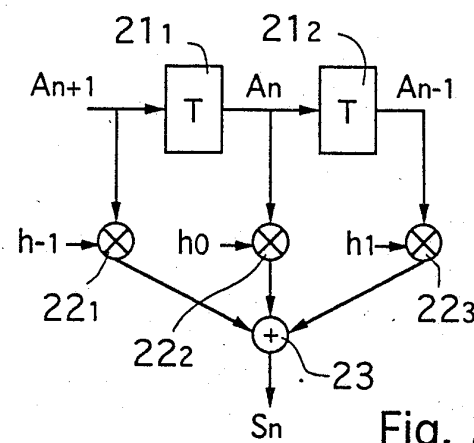


Fig. 2

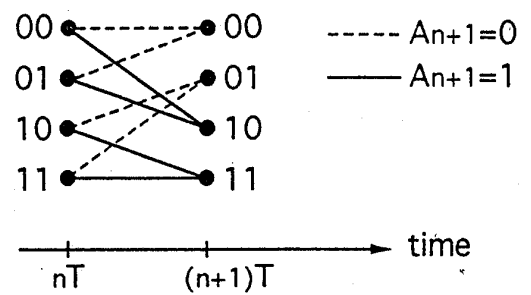


Fig. 3

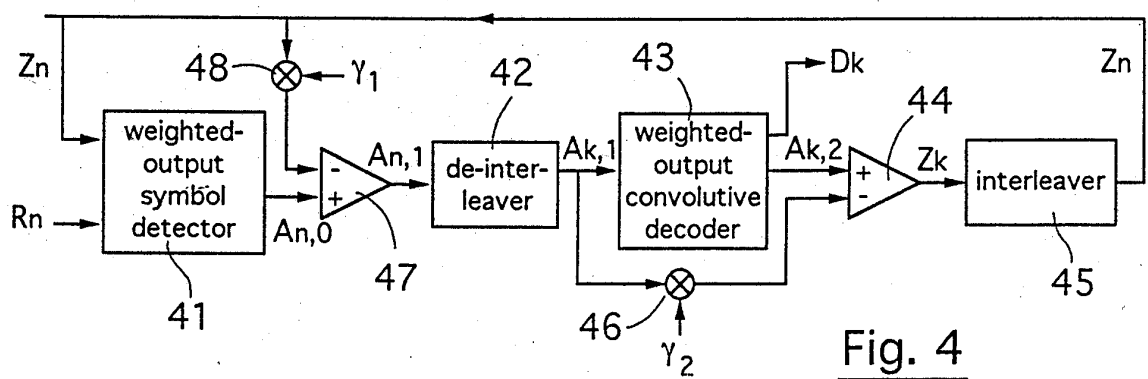


Fig. 4

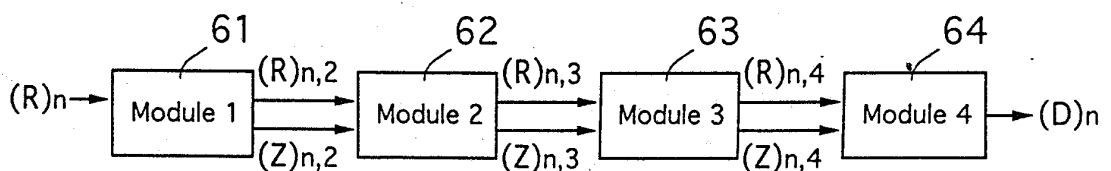


Fig. 6

2/3

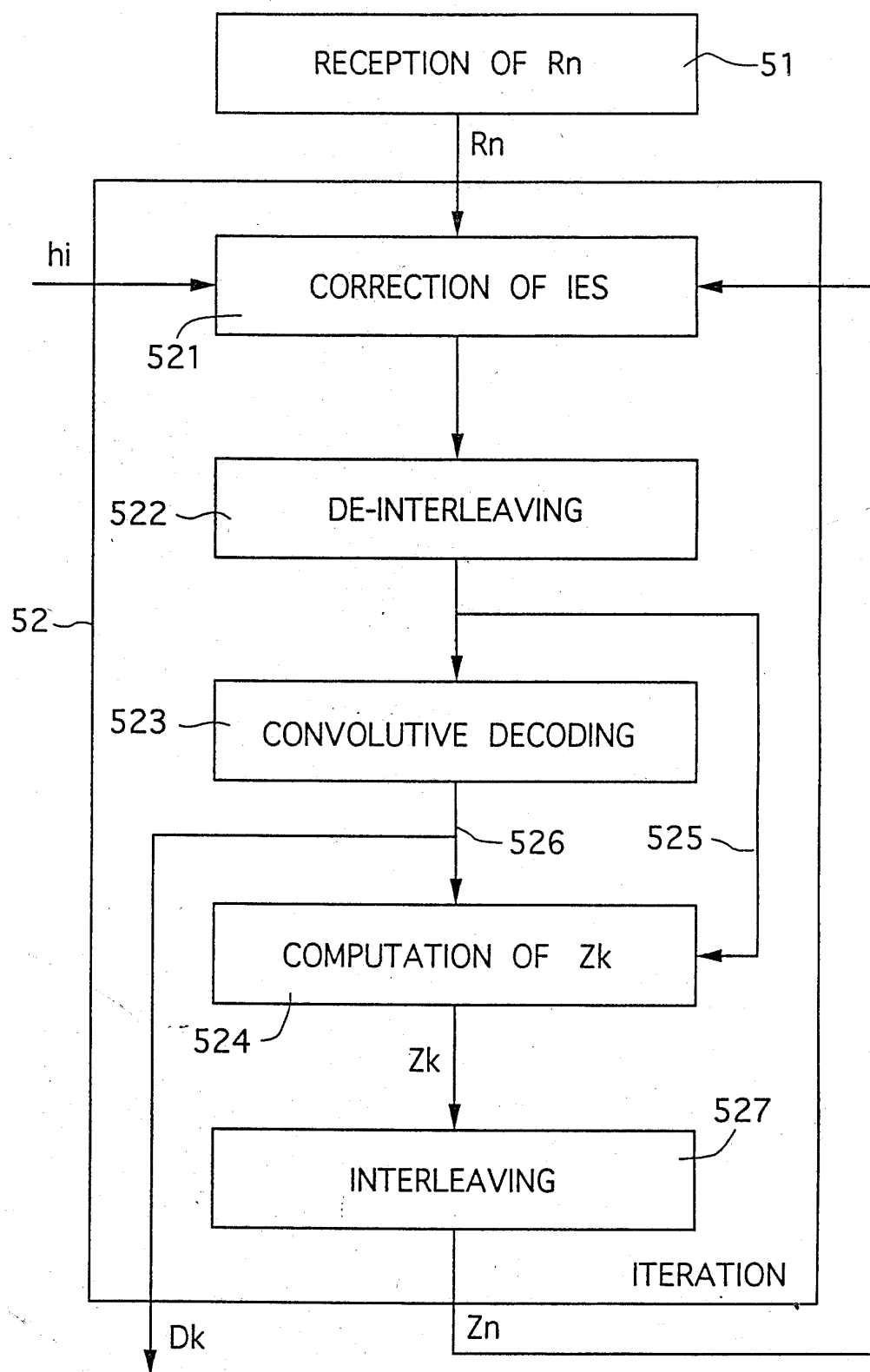
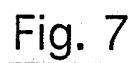


Fig. 5



me 08/894, 207

PCT/FR96/00197

TRAITE DE COOPERATION EN MATIERE DE brevets

PCT

NOTIFICATION CONCERNANT LA
TRANSMISSION DE DOCUMENTS

Expéditeur: le BUREAU INTERNATIONAL

Destinataire:
United States Patent and Trademark Office (Box PCT) Crystal Plaza 2 Washington, DC 20231 ETATS-UNIS D'AMERIQUE
en sa qualité d'office élu

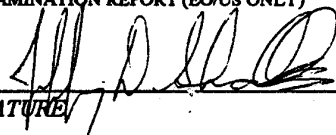
Date d'expédition (jour/mois/année) 15 décembre 1997 (15.12.97)	
Demande internationale no PCT/FR96/00197	Date du dépôt international 06 février 1996 (06.02.96)
Déposant FRANCE TELECOM etc	

Le Bureau international transmet ci-joint le nombre de copies indiqué ci-après des documents suivants:

_____ copie de la traduction en langue anglaise du rapport d'examen préliminaire international (article 36.3a))

Bureau international de l'OMPI 34, chemin des Colombettes 1211 Genève 20, Suisse no de télécopieur: (41-22) 740.14.35	Fonctionnaire autorisé F. Zotomayor no de téléphone: (41-22) 338.83.38
--	--

08/894207

Form PTO 1390 (REV 10-96)	U.S. Department of Commerce Patent and Trademark Office	ATTORNEY'S DOCKEY NUMBER F264.312-16
TRANSMITTAL LETTER TO THE UNITED STATES DESIGNATED/ELECTED OFFICE (DO/EO/US) CONCERNING A FILING UNDER 35 USC § 371		U.S. Application No. (If known, see 37 CFR § 1.57)
INTERNATIONAL APPLICATION NO. PCT/FR96/00197	INT'L FILING DATE February 6, 1996	PRIORITY DATE CLAIMED February 7, 1995
TITLE OF INVENTION DEVICE FOR THE RECEPTION OF DIGITAL SIGNALS WITH ITERATIVE STRUCTURE, AND CORRESPONDING MODULE AND METHOD		
APPLICANT(S) FOR DO/EO/US Catherine Douillard, Alain Glavieux, Michel Jezequel and Claude Berrou		
Applicant herewith submits to the United States Designated/Elected Office (DO/EO/US) the following items and other information.		
1.	☒	This is a FIRST submission of items concerning a filing under 35 USC § 371.
2.	☐	This is a SECOND or SUBSEQUENT submission of items concerning a filing under 35 USC § 371.
3.	☐	This express request to begin national examination procedures (35 USC § 371(f)) at any time rather than delay examination until the expiration of the applicable time limit set in 35 USC § 371(b) and PCT Articles 22 and 39(1).
4.	☒	A proper Demand for International Preliminary Examination was made by the 19th month from the earliest claimed priority date.
5.	☒	A copy of the International Application as filed (35 USC § 371(c)(2))
	a.	☐ is transmitted herewith (required only if not transmitted by the International Bureau).
	b.	☒ has been transmitted by the International Bureau.
	c.	☐ is not required, as the application was filed in the United States Receiving Office (RO/US).
6.	☒	A translation of the International Application into English (35 USC 371 § 371(c)(2)).
7.	☐	Amendments to the claims of the International Application under PCT Article 19 (35 USC § 371(c)(3))
	a.	☐ are transmitted herewith (required only if not transmitted by the International Bureau).
	b.	☐ have been transmitted by the International Bureau.
	c.	☐ have not been made; however, the time limit for making such amendments has NOT expired.
	d.	☐ have not been made and will not be made.
8.	☐	A translation of the amendments to the claims under PCT Article 19 (35 USC 371(c)(3)).
9.	☒	An oath or declaration of the inventor(s) (35 USC § 371(c)(4)).
10.	☐	A translation of the annexes to the International Preliminary Examination Report under PCT Article 36 (35 USC § 371(c)(5)).
Items 11 to 16 below concern other document(s) or information included:		
11.	☒	An Information Disclosure Statement under 37 CFR §§ 1.97 and 1.98.
12.	☐	An assignment document for recording. A separate cover sheet in compliance with 37 CFR §§ 3.28 and 3.31 is included.
13.	☒	A FIRST preliminary amendment.
	☐	A SECOND or SUBSEQUENT preliminary amendment.
14.	☐	A substitute specification.
15.	☐	A change of power of attorney and/or address letter.
16.	☐	Other items or information:
	a.	☐ CERTIFICATE UNDER 37 CFR § 3.73(b)
	b.	☐ POWER OF ATTORNEY
	c.	☒ INTERNATIONAL PUBLICATION NO. WO 96/24992 (COVER PAGE ONLY)
	d.	☒ COPY OF INTERNATIONAL SEARCH REPORT
	e.	☒ COPY OF INTERNATIONAL PRELIMINARY EXAMINATION REPORT (EO/US ONLY)
SEND ALL CORRESPONDENCE TO: Jeffrey D. Shewchuk KINNEY & LANGE, P.A. Suite 1500 625 Fourth Avenue South Minneapolis, Minnesota 55415-1659 Telephone: 612/339-1863 Telefacsimile: 612/339-6580		
SIGNATURE 		Jeffrey D. Shewchuk
REGISTRATION NUMBER 37,235		July 29, 1997
DATE		

U.S. APPLICATION NO. (If known, see 37 CFR § 1.57)		INTERNATIONAL APPLICATION NO. PCT/FR96/00197		ATTORNEY'S DOCKET NUMBER F264.312-16	
17. ☒ The following fees are submitted: Search Report has been prepared by the EPO or JPO \$910.00 International Preliminary examination fee paid to USPTO (37 CFR § 1.482) \$700.00 No international preliminary examination fee paid to USPTO (37 CFR § 1.482) but international search fee paid to USPTO (37 CFR § 1.445(a)(2)) \$770.00 Neither international preliminary examination fee (37 CFR § 1.482) nor international search fee (37 CFR § 1.445(a)(2)) paid to USPTO \$1040.00 International preliminary examination fee paid to USPTO (37 CFR § 1.482) and all claims satisfied provisions of PCT Article 33(2)-(4) \$96.00 ENTER APPROPRIATE BASIC FEE AMOUNT -				CALCULATIONS PTO USE ONLY 910.00 \$ 910.00	
Surcharge of \$130.00 for furnishing the oath or declaration later than <u> 20 </u> 30 months from the earliest claimed priority date (37 CFR § 1.492(e)).				\$	
Claims	Number Filed	Number Extra	Rate		
Total claims	8 - 20 =	0	X \$22.00	\$0	
Ind. Claims	3 - 3 =	0	X \$80.00	\$0	
Multiple dependent claim(s) (if applicable)			+ \$260.00	\$0	
TOTAL OF ABOVE CALCULATIONS -				\$0	
Reduction by 1/2 for filing by small entity, if applicable. Verified Small Entity statement must also be filed. (Note 37 CFR §§ 1.9, 1.27, 1.28).				\$0	
SUBTOTAL -				\$910.00	
Processing fee of \$130.00 for furnishing the English translation later the <u> 20 </u> 30 months from the earliest claimed priority date (37 CFR § 1.492(f)).				+	
TOTAL NATIONAL FEE -				\$910.00	
Fee for recording the enclosed assignment (37 CFR § 1.21(h)). The assignment must be accompanied by an appropriate cover sheet (37 CFR §§ 3.28, 3.31). \$40.00 per property				+	
TOTAL FEES ENCLOSED -				\$910.00	
				Amount to be refunded:	\$
				Charged:	\$
a. ☒ A check in the amount of <u>\$910.00</u> to cover the above fees is enclosed. b. ☐ Please charge my Deposit Account No. 11-0982 in the amount of <u> </u> to cover the above fees. A duplicate copy of this sheet is enclosed. c. ☒ The Commissioner is hereby authorized to charge any additional fees which may be required, or credit any overpayment to Deposit Account No. 11-0982. A duplicate copy of this sheet is enclosed.					
NOTE: Where an appropriate time limit under 37 CFR § 1.494 or § 1.495 has not been met, a petition to revive (37 CFR § 1.137(a) or (b)) must be filed and granted to restore the application to pending status.					

SEND ALL CORRESPONDENCE TO:

Jeffrey D. Shewchuk
KINNEY & LANGE, P.A.
Suite 1500
625 Fourth Avenue South
Minneapolis, Minnesota 55415-1659
Telephone: 612/339-1863
Telefacsimile: 612/339-6580

SIGNATURE

Jeffrey D. Shewchuk

37,235

REGISTRATION NUMBER

DATE

PCT

ORGANISATION MONDIALE DE LA PROPRIETE INTELLECTUELLE
Bureau international



DEMANDE INTERNATIONALE PUBLIEE EN VERTU DU TRAITE DE COOPERATION EN MATIERE DE BREVETS (PCT)

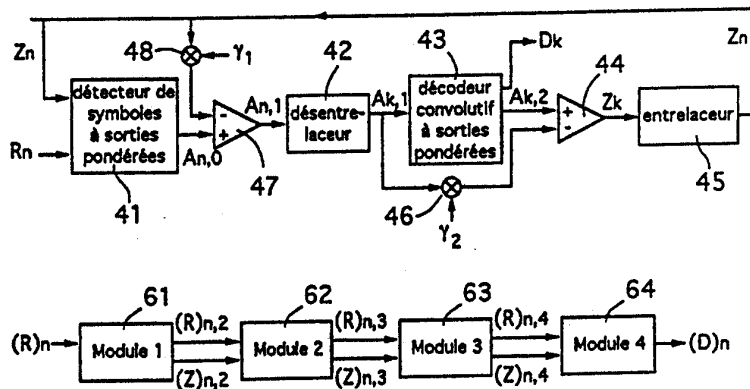
(51) Classification internationale des brevets ⁶ : H04L 25/03	A1	(11) Numéro de publication internationale: WO 96/24999 (43) Date de publication internationale: 15 août 1996 (15.08.96)
(21) Numéro de la demande internationale: PCT/FR96/00197 (22) Date de dépôt international: 6 février 1996 (06.02.96) (30) Données relatives à la priorité: 95/01603 7 février 1995 (07.02.95) FR (71) Déposants (pour tous les Etats désignés sauf US): FRANCE TELECOM [FR/FR]; 6, place d'Alleray, F-75015 Paris (FR). TELEDIFFUSION DE FRANCE S.A. [FR/FR]; 10, rue d'Oradour-sur-Glane, F-75732 Paris Cédex 15 (FR). (72) Inventeurs; et (75) Inventeurs/Déposants (US seulement): DOUILLARD, Catherine [FR/FR]; 3, rue de Lannion, F-29200 Brest (FR). GLAVIEUX, Alain [FR/FR]; ENST Bretagne, Boîte postale 832, F-29285 Brest Cédex (FR). JEZEQUEL, Michel [FR/FR]; Keresseis, F-29200 Brest (FR). BERROU, Claude [FR/FR]; 3, impasse de Gorrequaer, F-29280 Locmaria-Plouzane (FR). (74) Mandataire: VIDON, Patrice; Cabinet Patrice Vidon, Immeuble Germanium, 80, avenue des Buttes-de-Coësmes, F-35700 Rennes (FR).		(81) Etats désignés: US, brevet européen (AT, BE, CH, DE, DK, ES, FR, GB, GR, IE, IT, LU, MC, NL, PT, SE). Publiée Avec rapport de recherche internationale.

(54) Title: ITERATIVE-STRUCTURE DIGITAL SIGNAL RECEPTION DEVICE, AND MODULE AND METHOD THEREFOR

(54) Titre: DISPOSITIF DE RECEPTION DE SIGNAUX NUMERIQUES A STRUCTURE ITERATIVE, MODULE ET PROCEDE CORRESPONDANTS

(57) Abstract

A device for receiving signals consisting of a series of digital symbols corresponding to the convolutional coding of source digital data, including p cascaded sensing and decoding modules M_1-M_p , where p is at least 2. Each of said modules M_i includes: intersymbol interference correction means (41, 47, 48) supplied via a symbol input R_i and outputting weighted-value estimated symbols $A_{i,1}$; means (43) for decoding the estimated symbols $A_{i,1}$ by performing operations symmetrical to said convolutional coding and outputting weighted-value decoded signals $A_{i,2}$; and means (44, 46) for calculating correction information Z_{i+1} from said estimated symbol $A_{i,1}$ and said decoded signal $A_{i,2}$. Said means for correcting each of said modules M_i , except for the first module M_1 , takes into account at least one item of correction information Z_i determined by the preceding module M_{i-1} .



41 _WEIGHTED-OUTPUT SYMBOL SENSOR
42 _DEINTERLEAVER
43 _WEIGHTED-OUTPUT CONVOLUTIONAL DECODER
44 _INTERLEAVER
61-4 _MODULE 1/2/3/4

RAPPORT DE RECHERCHE INTERNATIONALE

Demande Internationale No
PCT/FR 96/00197

A. CLASSEMENT DE L'OBJET DE LA DEMANDE
CIB 6 H04L25/03

Selon la classification internationale des brevets (CIB) ou à la fois selon la classification nationale et la CIB

B. DOMAINES SUR LESQUELS LA RECHERCHE A PORTE

Documentation minimale consultée (système de classification suivi des symboles de classement)
CIB 6 H04L H03M

Documentation consultée autre que la documentation minimale dans la mesure où ces documents relèvent des domaines sur lesquels a porté la recherche

Base de données électronique consultée au cours de la recherche internationale (nom de la base de données, et si cela est réalisable, termes de recherche utilisés)

C. DOCUMENTS CONSIDERES COMME PERTINENTS

Catégorie *	Identification des documents cités, avec, le cas échéant, l'indication des passages pertinents	no. des revendications visées
-------------	--	-------------------------------

A	EP,A,0 511 141 (FRANCE TELECOM / TELEDIFFUSION DE FRANCE) 28 Octobre 1992 cité dans la demande voir abrégé voir page 4, ligne 21 - page 5, ligne 41; revendications; figures 3,4 ----- -/--	1-9
---	--	-----

☒ Voir la suite du cadre C pour la fin de la liste des documents

☒ Les documents de familles de brevets sont indiqués en annexe

* Catégories spéciales de documents cités:

- "A" document définissant l'état général de la technique, non considéré comme particulièrement pertinent
- "E" document antérieur, mais publié à la date de dépôt international ou après cette date
- "L" document pouvant jeter un doute sur une revendication de priorité ou cité pour déterminer la date de publication d'une autre citation ou pour une raison spéciale (telle qu'indiquée)
- "O" document se référant à une divulgation orale, à un usage, à une exposition ou tous autres moyens
- "P" document publié avant la date de dépôt international, mais postérieurement à la date de priorité revendiquée

- "T" document ultérieur publié après la date de dépôt international ou la date de priorité et n'appartenant pas à l'état de la technique pertinent, mais cité pour comprendre le principe ou la théorie constituant la base de l'invention
- "X" document particulièrement pertinent; l'invention revendiquée ne peut être considérée comme nouvelle ou comme impliquant une activité inventive par rapport au document considéré isolément
- "Y" document particulièrement pertinent; l'invention revendiquée ne peut être considérée comme impliquant une activité inventive lorsque le document est associé à un ou plusieurs autres documents de même nature, cette combinaison étant évidente pour une personne du métier
- "&" document qui fait partie de la même famille de brevets

Date à laquelle la recherche internationale a été effectivement achevée

24 Avril 1996

Date d'expédition du présent rapport de recherche internationale

29. 05. 96

Nom et adresse postale de l'administration chargée de la recherche internationale
Office Européen des Brevets, P.B. 5818 Patentlaan 2
NL - 2280 HV Rijswijk
Tel. (+31-70) 340-2040, Tx. 31 651 epo nl,
Fax (+31-70) 340-3016

Fonctionnaire autorisé

Gries, T

RAPPORT DE RECHERCHE INTERNATIONALE

Demande internationale No
PCT/FR 96/00197

C.(suite) DOCUMENTS CONSIDERES COMME PERTINENTS		
Catégorie	Identification des documents cités, avec, le cas échéant, l'indication des passages pertinents	no. des revendications visées
A	ICC '93 GENEVA. IEEE INTERNATIONAL CONFERENCE ON COMMUNICATIONS '93. TECHNICAL PROGRAM, CONFERENCE RECORD (CAT. NO.93CH3261-5), PROCEEDINGS OF ICC '93 - IEEE INTERNATIONAL CONFERENCE ON COMMUNICATIONS, GENEVA, SWITZERLAND, 23-26 MAY 1993, ISBN 0-7803-0950-2, 1993, NEW YORK, NY, USA, IEEE, USA, pages 1064-1070 vol.237, XP000371240 BERROU C ET AL: "Near Shannon limit error-correcting coding and decoding: Turbo-codes. 1" cité dans la demande voir figures 3B,4A,4B ---	1-9
A	ELECTRONICS AND COMMUNICATIONS IN JAPAN, PART 1 (COMMUNICATIONS), APRIL 1994, USA, vol. 77, no. 4, ISSN 8756-6621, pages 103-110, XP000445333 MURATA H ET AL: "Performance of adaptive equalizer using iterative application of Viterbi algorithm" voir page 103, colonne de droite, alinéa 5 - page 105, colonne de gauche, alinéa 2; figure 1 ---	1-9
A	PHILIPS JOURNAL OF RESEARCH, 1987, NETHERLANDS, vol. 42, no. 4, ISSN 0165-5817, pages 399-428, XP000565157 BERGMANS J W M ET AL: "On the use of decision feedback for simplifying the Viterbi detector" voir page 401, alinéa 2 voir page 406, alinéa 1 - page 409, alinéa 2; figures 3,4 voir page 411, alinéa 3 voir page 426, alinéa 5 - page 427, alinéa 2 --- -/--	1-9

RAPPORT DE RECHERCHE INTERNATIONALE E

Demande Internationale No
PCT/FR 96/00197

C.(suite) DOCUMENTS CONSIDERES COMME PERTINENTS		
Catégorie *	Identification des documents cités, avec, le cas échéant, l'indication des passages pertinents	no. des revendications visées
A	IEEE IN HOUSTON. GLOBECOM '93. IEEE GLOBAL TELECOMMUNICATIONS CONFERENCE, INCLUDING A COMMUNICATIONS THEORY MINI-CONFERENCE. TECHNICAL PROGRAM CONFERENCE RECORD (CAT. NO.93CH3250-8), PROCEEDINGS OF GLOBECOM '93. IEEE GLOBAL TELECOMMUNICATIONS CONFERENCE, ISBN 0-7803-0917-0, 1993, NEW YORK, NY, USA, IEEE, USA, pages 98-102 vol.1, XP000428037 JIANJUN WU ET AL: "A channel model and a novel adaptive equalizer for mobile radio communications" voir abrégé voir page 98, colonne de gauche, alinéa 3 - colonne de droite, alinéa 1 voir page 100, colonne de droite, ligne 1 - page 101, colonne de gauche, ligne 18; figure 2	1-9
A	--- WO,A,91 06165 (MOTOROLA INC.) 2 Mai 1991 voir abrégé voir page 3, ligne 18 - ligne 28; revendications; figure	1-9
A	--- VEHICULAR TECHNOLOGY SOCIETY 42ND VTS CONFERENCE. FRONTIERS OF TECHNOLOGY. FROM PIONEERS TO THE 21ST CENTURY (CAT. NO.92CH3159-1), DENVER, CO, USA, 10-13 MAY 1992, ISBN 0-7803-0673-2, 1992, NEW YORK, NY, USA, IEEE, USA, pages 577-585 vol.2, XP000339855 JUNG P ET AL: "VLSI implementation of soft output Viterbi equalizers for mobile radio applications" cité dans la demande voir page 578, colonne de gauche, alinéa 3 voir page 577, colonne de droite, alinéa 2	1-9
A	--- EP,A,0 524 597 (ALCATEL RADIOTELEPHONE) 27 Janvier 1993 voir abrégé voir page 6, ligne 8 - page 7, ligne 19 -----	1-9

5

Formulaire PCT,ISA/210 (suite de la deuxième feuille) (juillet 1992)

page 3 de 3

RAPPORT DE RECHERCHE INTERNATIONALE

Renseignements relatifs aux membres de familles de brevets

Demande Internationale No

PCT/FR 96/00197

Document brevet cité au rapport de recherche	Date de publication	Membre(s) de la famille de brevet(s)	Date de publication
EP-A-511141	28-10-92	FR-A- 2675971 US-A- 5446747	30-10-92 29-08-95
WO-A-9106165	02-05-91	US-A- 5271042 AU-B- 637166 AU-B- 6729490 CA-A, C 2066270 CN-A- 1050958 EP-A- 0495006 JP-T- 5504872 TR-A- 26468 US-A- 5144644	14-12-93 20-05-93 16-05-91 14-04-91 24-04-91 22-07-92 22-07-93 15-03-95 01-09-92
EP-A-524597	27-01-93	FR-A- 2679721 AU-B- 651472 AU-B- 1952392 CA-A- 2074277 JP-A- 5199143 NZ-A- 243590 US-A- 5331662	29-01-93 21-07-94 28-01-93 23-01-93 06-08-93 28-08-95 19-07-94

Formulaire PCT/ISA/210 (annexe familles de brevets) (juillet 1992)

TRANSLATION PATENT COOPERATION TREATY

PCT

INTERNATIONAL PRELIMINARY EXAMINATION REPORT

(PCT Article 36 and Rule 70)

2.

Applicant's or agent's file reference 3324.WO	FOR FURTHER ACTION See Notification of Transmittal of International Preliminary Examination Report (Form PCT/IPEA/416)	
International application No. PCT/FR 96/00197	International filing date (day/month/year) 06/02/1996	Priority date (day/month/year) 07/02/1995
International Patent Classification (IPC) or national classification and IPC H04L25/03		
Applicant FRANCE TELECOM et al.		

1.	This international preliminary examination report has been prepared by this International Preliminary Examining Authority and is transmitted to the applicant according to Article 36.
2.	This REPORT consists of a total of <u>6</u> sheets, including this cover sheet. ☐ This report is also accompanied by ANNEXES, i.e., sheets of the description, claims and/or drawings which have been amended and are the basis for this report and/or sheets containing rectifications made before this Authority (see Rule 70.16 and Section 607 of the Administrative Instructions under the PCT). These annexes consist of a total of _____ sheets.
3.	This report contains indications relating to the following items: - I ☒ Basis of the report - II ☐ Priority - III ☐ Non-establishment of opinion with regard to novelty, inventive step and industrial applicability - IV ☐ Lack of unity of the invention - V ☒ Reasoned statement under Article 35(2) with regard to novelty, inventive step or industrial applicability: citations and explanations supporting such statement - VI ☐ Certain documents cited - VII ☒ Certain defects in the international application - VIII ☐ Certain observations on the international application

Date of submission of the demand 09/08/1996	Date of completion of this report 13/11/1996
Name and mailing address of the IPEA/EP	Authorized officer
Facsimile No.	Telephone No.

Form PCT/IPEA/409 (cover sheet) (January 1994)

INTERNATIONAL PRELIMINARY EXAMINATION REPORT

International application No
PCT/FR96/00197

1. Basis of the report

This report has been drawn on the basis of *Replacement sheets which have been furnished to the receiving Office in response to an invitation under Article 14 are referred to in this report as "originally filed" and are not annexed to the report since they do not contain amendments.*

☒ the international application as originally filed.

☐ the description, pages _____, as originally filed.

pages _____, filed with the demand.

pages _____, filed with the letter of _____

pages _____, filed with the letter of _____

☐ the claims, Nos. _____, as originally filed.

Nos. _____, as amended under Article 19.

Nos. _____, filed with the demand.

Nos. _____, filed with the letter of _____

Nos. _____, filed with the letter of _____

☐ the drawings, sheets/fig _____, as originally filed.

sheets/fig _____, filed with the demand.

sheets/fig _____, filed with the letter of _____

sheets/fig _____, filed with the letter of _____

2. The amendments have resulted in the cancellation of:

☐ the description, pages _____

☐ the claims, Nos. _____

☐ the drawings, sheets/fig _____

3. ☐ This report has been established as if (some of) the amendments had not been made, since they have been considered to go beyond the disclosure as filed, as indicated in the Supplemental Box (Rule 70.2(c)).

4. Additional observations, if necessary:

INTERNATIONAL PRELIMINARY EXAMINATION REPORT

International application No.
PCT/FR 96/00197

V. Reasoned statement under Article 35(2) with regard to novelty, inventive step or industrial applicability; citations and explanations supporting such statement

1. Statement

Novelty (N)	Claims	1-9	YES
	Claims		NO
Inventive step (IS)	Claims	1-9	YES
	Claims		NO
Industrial applicability (IA)	Claims	1-9	YES
	Claims		NO

2. Citations and explanations

- 1). The subject matter of claim 1 concerns a device for receiving signals consisting of a series of digital symbols corresponding to the convolutional coding of source digital data.

The invention is characterised in that it proposes a new approach to intersymbol interference correction. The prior art in this field is based on an equalisation taking into account only the channel estimation and not that of the transmitted data.

The invention is characterised in that the effect of the interferences is assimilated to a particular convolutional coding, and uses corresponding decoding techniques. The corresponding state of the art is correctly cited in EP-A-511 141.

The features of claim 1 are neither known nor derivable from the cited documents. The claim meets the requirements of PCT Article 33(2) and (3).

- 2). Claim 8 corresponds to a subdevice of claim 1 and also meets the requirements of PCT Article 33(2) and (3).

INTERNATIONAL PRELIMINARY EXAMINATION REPORT

International application No.
PCT/FR 96/00197

- 3). Claim 9 is the process claim corresponding to claim 1 and meets the requirements of PCT Article 33(2) and (3).
- 4). Claims 2 to 7 correspond to embodiments of the device of the claim and also meet the requirements of PCT Article 33(2) and (3).

INTERNATIONAL PRELIMINARY EXAMINATION REPORT

International application No.
PCT/FR 96/00197

VII. Certain defects in the international application

The following defects in the form or contents of the international application have been noted:

The patent documents cited in the description should have been cited according to their publication number and not according to their application number.

TRAITE DE COOPERATION EN MATIERE DE BREVETS

PCT

NOTIFICATION D'ELECTION

(règle 61.2 du PCT)

Expéditeur: le BUREAU INTERNATIONAL

Destinataire:

United States Patent and Trademark
Office
(Box PCT)
Crystal Plaza 2
Washington, DC 20231
ETATS-UNIS D'AMERIQUE

en sa qualité d'office élu

Date d'expédition (jour/mois/année) 23 août 1996 (23.08.96)	
Demande internationale no PCT/FR96/00197	Référence du dossier du déposant ou du mandataire 3324.WO
Date du dépôt international (jour/mois/année) 06 février 1996 (06.02.96)	Date de priorité (jour/mois/année) 07 février 1996 (07.02.95)
Déposant DOUILLARD, Catherine etc	

1. L'office désigné est avisé de son election qui a été faite:

☒ dans la demande d'examen préliminaire international présentée à l'administration chargée de l'examen préliminaire international le: 09 août 1996 (09.08.96)

☐ dans une déclaration visant une election ultérieure déposée auprès du Bureau international le:

2. L'élection ☒ a été faite
☐ n'a pas été faite

avant l'expiration d'un délai de 19 mois à compter de la date de priorité ou, lorsque la règle 32 s'applique, dans le délai visé à la règle 32.2b).

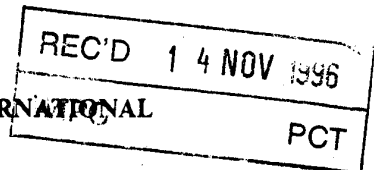
Bureau international de l'OMPI 34, chemin des Colombettes 1211 Genève 20, Suisse	Fonctionnaire autorisé Céline Faust
no de télécopieur: (41-22) 740.14.35	no de téléphone: (41-22) 730.91.11

TRAITE DE COOPERATION EN MATIERE DE BREVETS

PCT

RAPPORT D'EXAMEN PRELIMINAIRE INTERNATIONAL

(article 36 et règle 70 du PCT)



Référence du dossier du déposant ou du mandataire 3324.WO	POUR SUITE A DONNER Voir la notification de transmission du rapport d'examen préliminaire international (formulaire PCT/IPEA/416)	
Demande internationale n° PCT/FR 96/ 00197	Date du dépôt international (jour/mois/année) 06/02/1996	Date de priorité (jour/mois/année) 07/02/1995
Classification internationale des brevets (CIB) ou classification nationale et CIB H04L25/03		
Déposant FRANCE TELECOM et al.		

1. Le présent rapport d'examen préliminaire international, établi par l'administration chargée de l'examen préliminaire international, est transmis au déposant conformément à l'article 36.

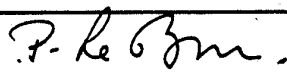
2. Ce RAPPORT comprend 6 feuilles, y comprise la présente feuille de couverture.

☐ Il est accompagné d'ANNEXES, c'est-à-dire de feuilles de la description, des revendications ou des dessins qui ont été modifiées et qui servent de base au présent rapport ou de feuilles contenant des rectifications faites auprès de l'administration chargée de l'examen préliminaire international (voir la règle 70.16 et l'instruction 607 des Instructions administratives du PCT).

Ces annexes comprennent _____ feuilles.

3. Le présent rapport contient des indications et les pages correspondantes relatives aux points suivants:

- I ☒ Base du rapport
- II ☐ Priorité
- III ☐ Absence de formulation d'opinion quant à la nouveauté, l'activité inventive et la possibilité d'application industrielle
- IV ☐ Absence d'unité de l'invention
- V ☒ Déclaration motivée selon l'article 35(2) quant à la nouveauté, l'activité inventive et la possibilité d'application industrielle; citations et explications à l'appui de cette déclaration
- VI ☐ Certains documents cités
- VII ☒ Irrégularités dans la demande internationale
- VIII ☐ Observations relatives à la demande internationale

Date de présentation de la demande d'examen préliminaire international 09/08/1996	Date d'achèvement du présent rapport 13. 11. 96
Nom et adresse postale de l'administration chargée de l'examen préliminaire international  Office Européen des Brevets D-80298 Munich Tel. (+49-89) 2399-0, Tx: 523656 epmu d Fax: (+49-89) 2399-4465	Fonctionnaire autorisé P. Le Bras  N° de Téléphone

Formulaire PCT/IPEA/409 (feuille de couverture) (janvier 1994) (22/08/1996)

RAPPORT D'EXAMEN PRELIMINAIRE INTERNATIONAL

Demande internationale n°
PCT/FR96/00197

I. Base du rapport

1. Le présent rapport a été rédigé sur la base des éléments ci-après (Les feuilles de remplacement qui ont été remises à l'office récepteur en réponse à une invitation faite conformément à l'article 14 sont considérées dans le présent rapport comme "initialement déposées" et ne sont pas jointes en annexe au rapport puisqu'elles ne contiennent pas de modifications.):

☒ de la demande internationale telle qu'initialement déposée.

☐ de la description, pages _____, telles qu'initialement déposées,
pages _____, déposées avec la demande d'examen
préliminaire international,
pages _____, déposées sous couvert d'une lettre
du _____,
pages _____, déposées sous couvert d'une lettre
du _____,

☐ des revendications, nos. _____, telles qu'initialement déposées,
nos. _____, telles que modifiées en vertu de
l'article 19,
nos. _____, déposées avec la demande d'examen
préliminaire international,
nos. _____, déposées sous couvert d'une lettre
du _____,
nos. _____, déposées sous couvert d'une lettre
du _____,

☐ des dessins, feuilles/fig _____, telles qu'initialement déposées,
feuilles/fig _____, déposées avec la demande d'examen
préliminaire international,
feuilles/fig _____, déposées sous couvert d'une lettre
du _____,
feuilles/fig _____, déposées sous couvert d'une lettre
du _____,

2. Les modifications ont entraîné l'annulation

☐ de la description, pages _____.

RAPPORT D'EXAMEN PRELIMINAIRE INTERNATIONAL

Demande internationale n°
PCT/FR96/00197

☐ des revendications, nos. _____.

☐ des dessins, feuilles/fig. _____.

3. ☐ Le présent rapport a été formulé abstraction faite (de certaines) des modifications, qui ont été considérées comme allant au-delà de l'exposé de l'invention tel qu'il a été déposé (règle 70.2.c)).

4. Observations complémentaires, le cas échéant:

RAPPORT D'EXAMEN PRELIMINAIRE INTERNATIONAL

Demande internationale n°

PCT/FR96/00197

V. Déclaration motivée selon l'article 35.2) quant à la nouveauté, l'activité inventive et la possibilité d'application industrielle; citations et explications à l'appui de cette déclaration

1. DECLARATION

Nouveauté	Revendications 1-9 _____	OUI
	Revendications _____	NON
Activité inventive	Revendications 1-9 _____	OUI
	Revendications _____	NON
Possibilité d'application industrielle	Revendications 1-9 _____	OUI
	Revendications _____	NON

2. CITATIONS ET EXPLICATIONS

1). L'objet de la revendication 1 concerne un dispositif de réception de signaux formés d'une série de symboles numériques correspondant au codage convolutif de données numériques source.

L'invention est remarquable en ce qu'elle propose un approche nouvelle de la correction de l'interférence intersymbole. L'état de la technique en la matière est basé sur une égalisation tenant compte seulement de l'estimation du canal et non pas des données transmises.

L'invention est remarquable en ce l'effet des interférences est assimilé à un codage convolutif particulier, et utilise des techniques de décodage correspondantes. L'état de la technique correspondant est correctement cité dans la description:

EP-A-0 511 141.

Les caractéristiques de la revendication 1 ne sont ni connues ni dérivables des documents cités. La revendication répond aux exigences de l'article 33 (2)

et (3) PCT.

- 2). La revendication 8 correspond à un sous dispositif de la revendication 1 et répond aussi aux exigences de l'Article 33 (2) et (3) PCT.
- 3). La revendication 9 est la revendication de procédé correspondante à la revendication 1 et répond aux exigences de l'Article 33 (2) et (3) PCT.
- 4). Les revendications 2 à 7 correspondent à des modes de réalisation du dispositif de la revendication et répondent aussi aux exigences de l'Article 33 (2) et (3) PCT.

RAPPORT D'EXAMEN PRELIMINAIRE INTERNATIONAL

Demande internationale n°
PCT/FR96/00197

VII. Irrégularités dans la demande internationale

Les irrégularités suivantes, concernant la forme ou le contenu de la demande internationale, ont été constatées:

Les documents de brevet cités dans la description auraient dû l'être par leur numéro de publication et non par leur numéro de demande.

TRAITE DE COOPERATION EN MATIERE DE BREVETS

15 NOV. 1996

Expéditeur : l'ADMINISTRATION CHARGÉE DE
L'EXAMEN PRELIMINAIRE INTERNATIONAL

PCT

NOTIFICATION DE TRANSMISSION DU RAPPORT D'EXAMEN PRELIMINAIRE INTERNATIONAL

(règle 61.1 DU PCT)

Destinataire VIDON, Patrice Cabinet PATRICE VIDON 80 Av. des Buttes de Coesmes Immeuble Germanium 35700 RENNES FRANCE		Date d'expédition <i>(Jour/mois/année)</i> 1 3. 11. 96
Référence du dossier du déposant ou du mandataire 3324.WO		NOTIFICATION IMPORTANTE
Demande internationale n° PCT/FR 96/ 00197	Date du dépôt international <i>(Jour/mois/année)</i> 06/02/1996	Date de Priorité <i>(Jour/mois/année)</i> 07/02/1995
Déposant FRANCE TELECOM et al.		

- Il est notifié au déposant que l'administration chargée de l'examen préliminaire internationale a établi le rapport d'examen préliminaire international pour la demande internationale et le lui transmet ci-joint, accompagné, le cas échéant, de ces annexes.
- Une copie du présent rapport et, le cas échéant, de ses annexes, est transmise au Bureau international pour communication à tous les offices élus.
- Si tel ou tel office élu l'exige, le Bureau international établira une traduction en langue anglaise du rapport (à l'exclusion des annexes de celui-ci) et la transmettra aux offices intéressés.
- RAPPEL**
 Pour aborder la phase national auprès de chaque office élu, le déposant doit accomplir certains actes (dépôt de traduction et paiement des taxes nationales) dans le délai de 30 mois à compter de la date de priorité (ou plus tard pour ce qui concerne certains offices) (article 39.1) (voir aussi le rappel envoyé par le Bureau international dans le formulaire PCT/IB/301).

Lorsqu'une traduction de la demande internationale doit être remise à un office élu, elle doit comporter la traduction de toute annexe du rapport d'examen préliminaire international. Il appartient au déposant d'établir la traduction en question et de la remettre directement à chaque office élu intéressé.

Pour plus de précisions en ce qui concerne les délais applicables et les exigences des offices élus, voir le Volume II du Guide du déposant du PCT.

Nom et adresse postale de l'administration chargée de l'examen préliminaire international  Office Européen des Brevets D-80298 Munich Tel. (+49-89) 2399-0, Tx: 523656 epmu d Fax: (+49-89) 2399-4465	Fonctionnaire autorisé Pietro Cremona N° de Téléphone POSTE 8244
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Formulaire PCT/IP/EA/416 (juillet 1992) P20474 (14/08/1996)

TRAITE DE COOPERATION EN MATIERE DE BREVETS
PCT

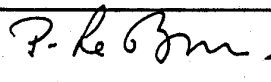
RAPPORT D'EXAMEN PRELIMINAIRE INTERNATIONAL

(article 36 et règle 70 du PCT)

Référence du dossier du déposant ou du mandataire 3324.WO	POUR SUITE A DONNER Voir la notification de transmission du rapport d'examen préliminaire international (formulaire PCT/IPEA/416)	
Demande internationale n° PCT/FR 96/ 00197	Date du dépôt international (jour;mois;année) 06/02/1996	Date de priorité (jour;mois;année) 07/02/1995
Classification internationale des brevets (CIB) ou classification nationale et CIB H04L25/03		
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- ☐ Il est accompagné d'ANNEXES, c'est-à-dire de feuilles de la description, des revendications ou des dessins qui ont été modifiées et qui servent de base au présent rapport ou de feuilles contenant des rectifications faites auprès de l'administration chargée de l'examen préliminaire international (voir la règle 70.16 et l'instruction 607 des Instructions administratives du PCT).
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- II ☐ Priorité
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- VIII ☐ Observations relatives à la demande internationale

Date de présentation de la demande d'examen préliminaire international 09/08/1996	Date d'achèvement du présent rapport 13. 11. 96
Nom et adresse postale de l'administration chargée de l'examen préliminaire international  Office Européen des Brevets. D-80298 Munich Tel. (+49-89) 2399-0, Tx: 523656 epmu d Fax: (+49-89) 2399-4465	Fonctionnaire autorisé P. Le Bras  N° de Téléphone

Formulaire PCT/IPEA/409 (feuille de couverture) (janvier 1994) (22/08/1996)

RAPPORT D'EXAMEN PRELIMINAIRE INTERNATIONAL

Demande internationale n°
PCT/FR96/00197

I. Base du rapport

1. Le présent rapport a été rédigé sur la base des éléments ci-après (Les feuilles de remplacement qui ont été remises à l'office récepteur en réponse à une invitation faite conformément à l'article 14 sont considérées dans le présent rapport comme "initialement déposées" et ne sont pas jointes en annexe au rapport puisqu'elles ne contiennent pas de modifications.):

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☐ de la description, pages _____, telles qu'initialement déposées,
pages _____, déposées avec la demande d'examen
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du _____,
pages _____, déposées sous couvert d'une lettre
du _____,

☐ des revendications, nos. _____, telles qu'initialement déposées,
nos. _____, telles que modifiées en vertu de
l'article 19,
nos. _____, déposées avec la demande d'examen
préliminaire international,
nos. _____, déposées sous couvert d'une lettre
du _____,
nos. _____, déposées sous couvert d'une lettre
du _____,

☐ des dessins, feuilles/fig _____, telles qu'initialement déposées,
feuilles/fig _____, déposées avec la demande d'examen
préliminaire international,
feuilles/fig _____, déposées sous couvert d'une lettre
du _____,
feuilles/fig _____, déposées sous couvert d'une lettre
du _____,

2. Les modifications ont entraîné l'annulation

☐ de la description, pages _____.

RAPPORT D'EXAMEN PRELIMINAIRE INTERNATIONAL

Demande internationale n°
PCT/FR96/00197

☐ des revendications, nos. _____.

☐ des dessins, feuilles/fig. _____.

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4. Observations complémentaires, le cas échéant:

RAPPORT D'EXAMEN PRELIMINAIRE INTERNATIONAL

Demande internationale n°

PCT/FR96/00197

V. Déclaration motivée selon l'article 35.2) quant à la nouveauté, l'activité inventive et la possibilité d'application industrielle; citations et explications à l'appui de cette déclaration

1. DECLARATION

Nouveauté	Revendications 1-9 _____	OUI
	Revendications _____	NON
Activité inventive	Revendications 1-9 _____	OUI
	Revendications _____	NON
Possibilité d'application industrielle	Revendications 1-9 _____	OUI
	Revendications _____	NON

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L'invention est remarquable en ce qu'elle propose un approche nouvelle de la correction de l'interférence intersymbole. L'état de la technique en la matière est basé sur une égalisation tenant compte seulement de l'estimation du canal et non pas des données transmises.

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et (3) PCT.

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RAPPORT D'EXAMEN PRELIMINAIRE INTERNATIONAL

Demande internationale n°
PCT/FR96/00197

VII. Irrégularités dans la demande internationale

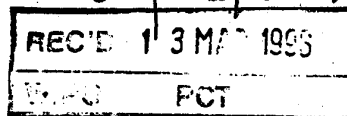
Les irrégularités suivantes, concernant la forme ou le contenu de la demande internationale, ont été constatées:

Les documents de brevet cités dans la description auraient du l'être par leur numéro de publication et non par leur numéro de demande.



PCT/FR96/00197

08/894207



BREVET D'INVENTION

CERTIFICAT D'UTILITÉ - CERTIFICAT D'ADDITION

PRIORITY DOCUMENT

COPIE OFFICIELLE

Le Directeur général de l'Institut national de la propriété industrielle certifie que le document ci-annexé est la copie certifiée conforme d'une demande de titre de propriété industrielle déposée à l'Institut.

Fait à Paris, le 11 mai 1996

Pour le Directeur général de l'Institut
national de la propriété industrielle
Le Chef de Division

Yves CAMPENON

INSTITUT
NATIONAL DE
LA PROPRIÉTÉ
INDUSTRIELLE

SIEGE
26 bis, rue de Saint Petersburg
75800 PARIS Cédex 08
Téléphone : (1) 42 94 52 52
Télécopie : (1) 42 93 59 30

64 267 03 790

ETABLISSEMENT PUBLIC NATIONAL

CRÉÉ PAR LA LOI N° 51-444 DU 19 AVRIL 1951



REQUÊTE

EN DÉLIVRANCE D'UN
TITRE DE PROPRIÉTÉ
INDUSTRIELLE *

DATE DE REMISE DES PIÈCES
07 FEV. 1995
N° D'ENREGISTREMENT NATIONAL
95 01603
CODE POSTAL DU LIEU DE DÉPÔT
35000 RENNES

a	☒	BREVET D'INVENTION
b	☐	CERTIFICAT D'UTILITÉ
c	☐	DEMANDE DIVISIONNAIRE
d	☐	TRANSFORMATION D'UNE DEMANDE DE BREVET EUROPÉEN

Pour c et d, précisez : Nature, N° et date de la
demande initiale

2 OPTIONS OBLIGATOIRES au moment du dépôt (sauf pour le certificat d'utilité)

LE DEMANDEUR REQUIERT
L'ÉTABLISSEMENT DIFFÈRE
DU RAPPORT DE RECHERCHE

OUI

☒ NONSI L'OPTION CHOISIE EST NON ET
SI LE DEMANDEUR EST UNE
PERSONNE PHYSIQUE, IL
REQUIERT LE PAIEMENT
ÉCHELONNÉ DE LA REDEVANCE
DE RAPPORT DE RECHERCHE

OUI

☐ NON

NATURE

NUMÉRO

DATE DE LA DEMANDE INITIALE

3 NOM ET ADRESSE DU DEMANDEUR OU DU MANDATAIRE À QUI TOUTE LA CORRESPONDANCE DOIT ÊTRE ADRESSÉE

Cabinet Patrice VIDON
Patrice VIDON
Immeuble Germanium
80 avenue des Buttes de Coësmes
35700 RENNES

5 RÉFÉRENCE DU CORRESPONDANT

3324

6 TÉLÉPHONE DU CORRESPONDANT

99 38 23 00

7 TITRE DE L'INVENTION

"Dispositif de réception de signaux numériques à structure itérative, module
et procédé correspondants"

8 DEMANDEUR(S) : Nom et Prénoms (souligner le nom patronymique) ou dénomination et forme juridique

N° SIREN.

- 1 - France Télécom (Etablissement Autonome de Droit Public)
2 - Télédiffusion de France (Société Anonyme)

9 ADRESSE(S) COMPLÈTE(S)

- 1 - 38-40 rue du Général Leclerc - 92131 ISSY LES MOULINEAUX
2 - 21-27 rue Barbès BP 518 - 92542 MONTROUGE CEDEX

PAYS

FRANCE
FRANCE

10 NATIONALITÉ(S)

Française

☒ DE DÉPÔT

REDEVANCES VERSÉES

☒ DE RAPPORT DE RECHERCHE☐ DE REVENDICATION DE PRIORITÉ☐ DE REVENDICATION (à partir de la 11e)

11 INVENTEUR(S)

LE DEMANDEUR EST L'UNIQUE
INVENTEUR

OUI

Si la réponse est non voir notice explicative

☒ NON

12

SI LE DEMANDEUR EST UNE PERSONNE
PHYSIQUE NON IMPOSABLE, IL
REQUIERT OU A REQUIS LA RÉDUCTION
DES REDEVANCES

OUI

☐ NON

13 DÉCLARATION DE PRIORITÉ

OU REQUÊTE DU BÉNÉFICE DE
LA DATE DE DÉPÔT D'UNE
DEMANDE ANTÉRIEURE

PAYS D'ORIGINE

DATE DE DÉPÔT

NUMÉRO

14

DIVISIONS

ANTÉRIEURES À LA
PRÉSENTE DEMANDE

N°

N°

N°

N°

15

SIGNATURE DU DEMANDEUR OU DU MANDATAIRE
NOM ET QUALITÉ DU SIGNATAIRE

P. VIDON Mandataire
(n° 92-1250)

SIGNATURE DU PRÉPOSÉ À LA RÉCEPTION

SIGNATURE APRÈS ENREGISTREMENT DE LA DEMANDE À L'INPI

* Cocher la case choisie

LES ENCADRÉS GRAS SONT RÉSERVÉS À L'ADMINISTRATION

INSTITUT NATIONAL DE LA PROPRIÉTÉ INDUSTRIELLE

DIVISION ADMINISTRATIVE DES BREVETS

DÉSIGNATION DE L'INVENTEUR

(si le demandeur n'est pas l'inventeur ou l'unique inventeur)

N° d'enregistrement national

9501603

Titre de l'invention :

"Dispositif de réception de signaux numériques à structure itérative, module et procédé correspondants"

Le (s) soussigné (s) Cabinet Patrice VIDON
Patrice VIDON
Immeuble Germanium
80 avenue des Buttes de Coësmes
35700 RENNES

désigne (nt) en tant qu'inventeur (s) (nom, prénoms, adresse)

Madame DOUILLARD Catherine
3 rue de Lannion - 29200 BREST

Monsieur GLAVIEUX Alain
ENST Bretagne
BP 832 - 29285 BREST CEDEX

Monsieur JEZEQUEL Michel
Keresseis - 29200 BREST

Monsieur BERROU Claude
3 impasse de Gorrequaer
29280 LOCMARIA PLOUZANE

Date et 07.02.95

signature (s) du (des) demandeur (s) ou du mandataire

P. VIDON (92-1250)

BA/113

Dispositif de réception de signaux numériques à structure itérative, module et procédé correspondants.

Le domaine de l'invention est celui de la transmission et de la diffusion de signaux numériques, en particulier en présence de bruits de transmission. Plus
5 précisément, l'invention concerne la réception de signaux numériques codés à l'aide d'un code correcteur d'erreurs de type convolutif.

L'invention trouve des applications dans tous les cas où un signal numérique est transmis ou diffusé sur des canaux bruités. A titre d'exemple, la présente invention peut être mise en oeuvre dans les récepteurs de systèmes de radio-communications numériques
10 avec les mobiles, tels que le GSM (Groupe Spécial Mobile).

D'autres applications possibles sont, par exemple, la réception de signaux transmis sur des canaux sous-marins, par faisceaux hertziens, par satellites... Plus généralement, l'invention s'applique avantageusement dans tous les cas où un code de type convolutif est mis en oeuvre à l'émission.

15 Dans les récepteurs de type connu, les symboles récupérés en sortie du démodulateur se présentent sous forme d'échantillons analogiques qui, après quantification, sont généralement traités par un égaliseur (filtre transversal) chargé d'éliminer l'interférence entre symboles introduite par le canal. Les échantillons égalisés sont ensuite désentrelacés, si nécessaire, et décodés avant d'être fournis au destinataire.

20 Le principe de l'égalisation consiste à estimer la réponse du canal de transmission pour appliquer au signal reçu un filtrage symétrique à cette réponse, de façon à obtenir un signal corrigé. Notamment, l'égalisation a pour but de supprimer, ou tout au moins de limiter l'interférence entre symboles introduite par le canal.

L'estimation de la réponse du canal se fait généralement par l'analyse d'un signal
25 de référence connu des récepteurs. Bien sûr, la transmission de ces signaux de référence entraîne une réduction du débit utile.

Les éléments de données égalisés sont ensuite désentrelacés (opération symétrique à l'entrelacement effectué au codage, si un tel entrelacement est prévu), puis décodés.

30 Dans certaines situations, l'égalisation de ce type s'avère insuffisante pour assurer un décodage source de bonne qualité.

L'article "VLSI implementation of soft output Viterbi equalizers for mobile radio applications" (Proc. of IEEE 42nd Vehicular Technology Society Conference, Denver, Colorado, pp. 577-585, May 1992) de P. Jung et P. W. Baier propose d'utiliser, à la place d'un filtre transverse, un détecteur de symboles fonctionnant suivant le principe du maximum de vraisemblance.

Cette technique est plus performante, si les coefficients représentatifs du canal sont correctement estimés. Toutefois, à nouveau, les données égalisées peuvent s'avérer de qualité insuffisante. Par ailleurs, elle est de réalisation plus complexe et d'un encombrement plus important que la technique à filtre transverse.

Les codes convolutifs sont des codes associant à chaque donnée source à coder au moins une donnée codée, obtenue par sommation modulo 2 de cette donnée source avec au moins une des données source précédentes. Ainsi, chaque symbole codé est une combinaison linéaire de la donnée source à coder et des données sources précédentes prises en compte.

Dans le décodeur, les données d'origine sont le plus souvent reconstruites à l'aide d'un algorithme à maximum de vraisemblance, et par exemple l'algorithme de Viterbi, dont les décisions peuvent éventuellement être pondérées. L'algorithme de Viterbi, en prenant en compte une séquence de symboles codés reçus, fournit une estimation de chaque donnée codée à l'émission, en déterminant la séquence source correspondant le plus probablement à la séquence reçue.

L'algorithme de Viterbi peut également être utilisé pour la détection de séquences affectées d'interférences entre symboles. L'invention s'applique également dans ce cas.

Clairement, la décision est d'autant plus fiable que le nombre de symboles pris en compte est élevé. En revanche, plus ce nombre est élevé, plus le décodeur, ou le détecteur (dans la suite, on utilise le terme "décodeur" pour décrire aussi bien les décodeurs au sens propre que les détecteurs. Il en est de même pour le terme "décodage", qui doit être compris comme "décodage" ou "détection", selon le cas), est complexe. La place mémoire nécessaire devient rapidement très importante, de même que les temps de calcul correspondants.

Les circuits intégrés mettant en oeuvre de tels algorithmes reposent donc le plus

souvent sur un compromis entre le coût et les performances. Ces choix industriels ne permettent pas toujours de construire des décodeurs correspondant de façon optimum à une application donnée. Il n'est par exemple pas possible de réaliser de décodeurs à faible prix de revient, pour des applications où la qualité de réception n'est pas cruciale, les circuits intégrés ayant un coût trop élevé. Inversement, ces circuits intégrés ne sont pas non plus adaptés à la réalisation de récepteurs à très haute qualité de décodage, pour lesquels le prix de revient n'a que peu d'importance.

Un exemple de codage convolutif avantageux, auquel peut s'appliquer l'invention, est décrit dans la demande de brevet française FR 91 05280 au nom des mêmes déposants, ainsi que dans l'article "de C. Berrou, A. Glavieux et P. Thitimajshima, "Near Shannon limit error-correcting coding and decoding : turbo-codes" (codage et décodage et décodage correcteurs d'erreurs à proximité de la limite de Shannon) (Proc. ICC'93, pp. 1064-1070, Genève, Suisse, Mai 1993). Cette classe de codes est notamment connue sous le nom de "turbo-codes".

Les codes élémentaires (codes systématiques récurrents ou pseudo-systématiques) décrits dans la demande de brevet française FR 91 05278 au nom des mêmes déposants peuvent également être utilisés.

L'invention a notamment pour but de pallier les inconvénients des dispositifs de réception de l'art antérieur, et plus précisément d'améliorer les performances correspondantes.

Plus précisément, un objectif de l'invention est de fournir un tel dispositif présentant un très bon pouvoir de correction, en comparaison avec les procédés connus utilisés actuellement dans les systèmes de communications numériques.

L'invention a notamment pour objectif de fournir de tels procédés, particulièrement efficaces, toujours par rapport aux procédés connus, pour la transmission dans des canaux très bruités.

L'invention a également pour objectif de fournir un tel dispositif, qui soit très performant, mais malgré tout aisément réalisable industriellement à des coûts acceptables.

Ainsi, un objectif particulier de l'invention est de fournir un procédé de décodage permettant une implantation sur une surface de silicium suffisamment restreinte pour que

son industrialisation soit possible, et par exemple sur une surface inférieure à 50 mm².

L'invention a également pour objectif de fournir un procédé de réception permettant la réalisation de nombreux types de récepteurs, à performances et prix de revient variables en fonction des besoins auxquels ils répondent, et mettant en oeuvre un ou plusieurs circuits intégrés d'un type unique.

En d'autres termes, un objectif essentiel de l'invention est de fournir de tels procédés permettant d'une part une industrialisation rentable, basée sur le développement d'un circuit intégré unique et relativement simple, et d'autre part la réalisation de récepteurs utilisables pour une très grande diversité d'applications.

Ces objectifs, ainsi que d'autres qui apparaîtront par la suite, sont atteints selon l'invention à l'aide d'un dispositif de réception de signaux formés d'une série de symboles numériques correspondant au codage convolutif de données numériques source, comprenant p modules de détection et de décodage M_1 à M_p en cascade, p étant supérieur ou égal à 2,

chacun desdits modules M_i comprenant :

- des moyens de correction de l'interférence entre symboles, alimentés par une entrée de symbole R_i et délivrant des symboles estimés $A_{i,1}$ à valeurs pondérées,
- des moyens de décodage desdits symboles estimés $A_{i,1}$, effectuant des opérations symétriques audit codage convolutif et délivrant des symboles décodés $A_{i,2}$ à valeurs pondérées, et
- des moyens de calcul d'une information de correction Z_{i+1} à partir dudit symbole estimé $A_{i,1}$ et dudit symbole décodé $A_{i,2}$,

lesdits moyens de correction de chacun desdits modules M_i , à l'exception du premier module M_1 , tenant compte d'au moins une information de correction Z_i déterminée par le module précédent M_{i-1} .

Ainsi, selon l'invention, la fonction classique d'égaleisation (filtrage) est remplacée par un détecteur de symboles, qui tient compte de l'effet de mémoire introduit par le canal.

En d'autres termes, l'invention propose une approche tout à fait nouvelle et optimisée de la correction de l'interférence entre symboles. En effet, classiquement,

l'égalisation ne tient pas compte des données émises, mais seulement de l'estimation du canal. En revanche, l'invention s'appuie sur une approche dynamique, en tenant compte des derniers symboles reçus pour améliorer l'égalisation.

En d'autres termes encore, l'invention assimile, dans son principe général, l'effet des interférences entre symboles à un codage convolutif particulier (à l'exception de l'absence de redondance, dans le cas de l'interférence : à un symbole émis sur le canal correspond un symbole reçu et un seul), et en assure le décodage. Plus précisément, le phénomène d'interférence entre symboles introduit par le canal peut être représenté par un treillis. Ce treillis diffère d'un treillis de codage convolutif par la présence de coefficients multiplicatifs variant dans le temps. Ainsi, chaque module de l'invention comprend des moyens de correction et des moyens de décodage présentant des structures similaires à base de techniques de décodage convolutif.

La technique de l'invention consiste donc à calculer une information de correction représentative du symbole reçu, et à prendre en compte une ou plusieurs de ces informations, pour corriger l'interférence.

On comprend que la prise en compte de cette information impose une structure itérative de réception du fait de la latence introduite par les traitements. Ainsi, lors de la première itération, on calcule une première information de correction, qui est utilisée et éventuellement recalculée lors des itérations suivantes. Selon l'invention, cette approche itérative se traduit par une structuration en modules cascades du récepteur (détecteur de symboles et décodeur), chaque module correspondant à une itération. Il s'agit d'une approche tout à fait nouvelle, en ce qui concerne la correction de l'interférence entre symboles.

Avantageusement, ces modules sont tous identiques. Ils peuvent notamment se présenter sous la forme de circuits intégrés.

Plus le nombre de modules est grand, plus l'efficacité de la réception (correction de l'interférence entre symboles et décodage) augmente. L'approche modulaire de l'invention permet de réaliser aisément plusieurs types de récepteurs, correspondant à différents niveaux de qualité de réception, en fonction du nombre de modules mis en oeuvre. De même, il est possible de prévoir des décodeurs évolutifs, auxquels on peut

ajouter des modules en cas de besoin.

Selon un mode de réalisation préférentiel de l'invention, chacun desdits modules M_i présente deux entrées, une entrée de symbole R_i et une entrée de correction Z_i , et trois sorties, une sortie de symbole R_{i+1} , une sortie de correction Z_{i+1} et une sortie de symbole décodé D_{i+1} .

l'entrée de symbole R_i du module M_i étant connectée à la sortie de symbole R_i du module M_{i-1} , pour i supérieur à 1, et étant alimenté par les symboles reçus pour i égal à 1,

l'entrée de correction Z_i du module M_i étant connectée à la sortie de correction Z_i du module M_{i-1} , pour i supérieur à 1, et étant alimenté par une valeur neutre, n'influant par sur la correction, pour i égal à 1,

la sortie de symbole R_{i+1} du module M_i étant égale à l'entrée de symbole R_i dudit module M_i retardée du temps de latence imposé par le module M_i ,

la sortie de correction Z_{i+1} délivrant ladite information de correction, et

la sortie de symbole décodé D_{i+1} étant inutilisée pour les modules M_1 à M_{p-1} , et étant alimentée par le symbole décodé $A_{p,2}$ du module M_p , si le code mis en oeuvre est un code systématique, et par une valeur reconstituée correspondante sinon.

Cette structure permet de concevoir, comme indiqué plus haut, des modules identiques. Bien sûr, suivant qu'il s'agit du premier module, du dernier module ou d'un module intermédiaire, les entrées et sorties utilisées peuvent être différentes.

Avantageusement, lesdits moyens de correction de l'interférence entre symboles sont alimentés par une information de correction Z_i représentative d'une différence entre chaque symbole décodé $A_{i,2}$ et le symbole estimé $A_{i,1}$ correspondant.

Dans ce cas, préférentiellement, lesdits moyens de calcul de l'information de correction comprennent des moyens de multiplication desdits symboles estimés $A_{i,1}$ par un coefficient pondérateur positif γ_2 , délivrant des symboles pondérés, et des moyens de soustraction calculant la différence entre chaque symbole décodé $A_{i,2}$ et le symbole pondéré correspondant, et délivrant ladite information de correction Z_i .

Notamment, la valeur de ce coefficient est fixée de telle façon que l'information portée par Z_i ne contienne plus d'information concernant $A_{i,1}$, afin que les bruits affectant Z_i et les échantillons reçus R_i soient décorrélés. Ainsi, l'information réinjectée en entrée

de l'égaliseur est "nouvelle" par rapport aux échantillons reçus (elle est issue du processus de décodage). Elle sera dite "information extrinsèque".

Selon un mode de réalisation avantageux, lesdits moyens de correction de l'interférence entre symboles effectuent les opérations suivantes :

- 5 - calcul d'une valeur de correction $V_i = \gamma_i |Z_i|$, où γ_i est un coefficient positif et où $| |$ représente l'opérateur valeur absolue ;
- pour chaque branche du treillis correspondant audit code convolutif, détermination d'un symbole détecté $A_{i,0}$, comprenant les étapes suivantes :
- 10 - si le symbole affecté à ladite branche est de même signe que ladite information de correction Z_i , soustraction à la métrique associée à ladite branche de ladite valeur de correction V_i ;
- si le symbole affecté à ladite branche est de signe opposé à celui de ladite information de correction Z_i , addition à la métrique associée
- 15 à ladite branche de ladite valeur de correction V_i ;
- soustraction audit symbole détecté $A_{i,0}$ de la valeur $\gamma_i Z_i$.

Cette dernière soustraction a pour objet de "débarrasser" la sortie du détecteur de symboles, et donc a fortiori l'entrée du décodeur convolutif, de l'information portée par Z_i .

- 20 La pondération des symboles émis sur le canal a pour but, classiquement, de représenter l'interférence entre symboles. Les coefficients de pondération peuvent être fixes ou, préférentiellement, estimés, par exemple à l'aide d'une séquence d'apprentissage.

- 25 De façon préférentielle, ledit coefficient γ_i dépend d'au moins une des informations appartenant au groupe comprenant :

- le rapport signal à bruit ;
- le numéro i du module considéré.

On comprend en effet que, plus γ_i est grand, plus la sortie du décodeur est fiable.

- 30 Lorsque les symboles sont soumis à un entrelacement à l'émission, le décodeur comprend préférentiellement :

- des moyens de désentrelacement assurant l'opération symétrique dudit entrelacement, insérés entre lesdits moyens de correction et lesdits moyens de décodage ; et
- des moyens d'entrelacement assurant un entrelacement desdites informations de correction identique audit entrelacement à l'émission.

L'entrelacement et le désentrelacement peuvent être réalisés à l'aide de matrices.

Les incréments de lecture ou d'écriture peuvent être fixes ou, plus avantageusement, peuvent dépendre de l'adresse de lecture ou d'écriture.

L'invention concerne également un module de détection et de décodage destiné à être mis en oeuvre dans un dispositif de réception de signaux formés d'une série de symboles numériques correspondant au codage convolutif de données numériques source, ledit dispositif comprenant au moins deux modules en cascade, module présentant deux entrées, une entrée de symbole R_i et une entrée de correction Z_i , et trois sorties, une sortie de symbole R_{i+1} , une sortie de correction Z_{i+1} et une sortie de symbole décodé D_{i+1} , et comprenant :

des moyens de correction de l'interférence entre symboles, alimentés par ladite entrée de symbole R_i et tenant compte de ladite entrée de correction Z_i , et délivrant des symboles estimés $A_{i,1}$,

des moyens de décodage desdits symboles estimés $A_{i,1}$, effectuant des opérations symétriques audit codage convolutif et délivrant des symboles décodés $A_{i,2}$, et des moyens de calcul d'une information de correction Z_{i+1} à partir dudit symbole estimé $A_{i,1}$ et dudit symbole décodé $A_{i,2}$,

la sortie de symbole R_{i+1} étant égale à l'entrée de symbole R_i retardée d'un temps de latence prédéfini,

la sortie de correction Z_{i+1} délivrant ladite information de correction, et

la sortie de symbole décodé D_{i+1} étant alimentée par ledit symbole décodé $A_{i,2}$, ou par une valeur reconstituée en fonction du code mis en oeuvre.

Comme indiqué précédemment, un tel module peut notamment se présenter sous la forme d'un circuit intégré.

L'invention concerne encore un procédé de réception de signaux formés d'une série de symboles numériques correspondant au codage convolutif de données numériques source, comprenant les étapes suivantes :

- alimentation par des symboles reçus R_i ;
- 5 - correction de l'interférence entre symboles affectant chacun desdits symboles reçus à partir d'une information de correction Z_i , et délivrant des symboles estimés $A_{i,1}$;
- décodage desdits symboles estimés $A_{i,1}$, effectuant des opérations symétriques audit codage convolutif et délivrant des symboles décodés
- 10 $A_{i,2}$;
- calcul de ladite information de correction Z_i , à partir et d'au moins un desdits symboles estimés $A_{i,1}$ et d'au moins un desdits symboles décodés $A_{i,2}$.

D'autres caractéristiques et avantages de l'invention apparaîtront à la lecture de la description suivante d'un mode de réalisation préférentiel de l'invention donné à titre

- 15 illustratif et non limitatif, et des dessins annexés, dans lesquels :
- la figure 1 est un schéma synoptique illustrant une chaîne de transmission classique, pouvant incorporer un dispositif de réception selon l'invention ;
 - la figure 2 représente de façon simplifiée un modèle discret équivalent en
 - 20 bande de base d'un canal de transmission affectée d'une interférence entre symboles, illustrant l'approche de l'invention ;
 - la figure 3 représente le treillis correspondant au canal de la figure 2 et illustrant les évolutions possibles de l'état du canal en fonction du temps ;
 - la figure 4 est un schéma synoptique de principe du récepteur de
 - 25 l'invention ;
 - la figure 5 est un organigramme simplifié illustrant le procédé de l'invention, mis en oeuvre dans le récepteur de la figure 4 ;
 - la figure 6 illustre la structure modulaire du récepteur de l'invention, dans le cas de quatre modules cascades ;
 - 30 - la figure 7 présente un schéma synoptique d'un module de la figure 6 ;

- la figure 8 présente une série de courbes illustrant les performances de l'invention, dans le cas d'un canal gaussien.

L'invention s'applique, comme indiqué précédemment, à tous les systèmes de transmission numérique mettant en oeuvre un codage correcteur d'erreur convolutif, tels qu'illustrés en figure 1.

Ce système comprend une source numérique 11 qui doit être transmise à un destinataire 12.

Par source numérique, on entend tout signal numérique utile (son, image, données) et, plus généralement tout ensemble de signaux utiles, par exemple multiplexés en temps et/ou en fréquence. Le destinataire 12 peut être unique (cas de la transmission) ou multiple (cas de la diffusion). De même, la chaîne de transmission peut bien sûr être unidirectionnelle (radiodiffusion par exemple) ou bidirectionnelle (radiocommunication par exemple).

Le signal source est tout d'abord soumis à un codage convolutif 13 de type connu en soi. Il peut notamment d'agir d'un codage convolutif systématique classique, associant à chaque donnée source au moins une valeur déterminée par combinaison de cette donnée et d'au moins une des données source précédentes.

Il peut également s'agir d'un code tels que ceux décrits dans la demande de brevet FR 91 05278. Ces codes, dits "pseudo-systématiques", sont caractérisés par le fait que la donnée source est systématiquement transmise, conjointement à au moins une donnée codée, ou symbole de redondance.

Tout autre code convolutif peut également être utilisé.

Les données délivrées par le codeur 13 sont ensuite avantageusement (bien qu'il ne s'agisse pas d'une caractéristique obligatoire) soumis à un entrelacement 14.

Cet entrelacement peut être obtenu, de façon classique, à l'aide d'une matrice d'entrelacement, dans laquelle les données source sont introduites ligne par ligne, et restituées colonne par colonne.

Le module 14 assure un entrelacement matriciel. Les données sont écrites, par lignes successives, dans une mémoire de taille $n_{\text{ex}} \times n_{\text{e}}$, et restituées par colonnes successives. Cette technique est par exemple décrite dans l'article "Optimal interleaving

scheme for convolutional coding (Méthode d'entrelacement optimal pour le codage convolutif), de Dunscombe E. et Piper F.C., paru dans l'"Electronic Letters", Vol.25, n°22, Octobre 1989.

5 Ainsi que le montre cet article, l'efficacité de l'entrelacement, pour de petites valeurs de n_E (quelques dizaines) est améliorée si la succession de lignes et de colonnes s'effectue selon un incrément supérieur à 1 et, par nécessité, premier avec n_E .

10 Une amélioration complémentaire à cette technique d'entrelacement peut être mise en oeuvre. Il apparaît en effet avantageux que l'incrément du saut de ligne, toujours premier avec n_E , soit fonction de la place de la colonne considérée. Cela permet de casser les paquets d'erreurs à disposition rectangulaire.

Dans ce cas, les incréments de lecture de la matrice d'entrelacement sont choisis de telle sorte que la distance minimale, en sortie, entre deux symboles voisins à l'entrée soit la plus grande possible. Ces incréments peuvent par exemple être déterminés de façon empirique.

15 D'autres techniques d'entrelacement peuvent bien sûr être utilisées, et notamment l'habituel procédé à incréments d'écriture et de lecture égaux à 1, sans sortir du cadre de l'invention. Il est clair par ailleurs que les rôles des lignes et des colonnes peuvent être inversés.

20 Ensuite, le signal entrelacé est transmis au travers du canal de transmission 15. il subit donc une modulation et un filtrage 16, selon toute technique adéquate, puis est émis au travers du milieu de transmission 17.

Ce milieu de transmission 17 est généralement bruité et présente de l'interférence entre les symboles émis dans celui-ci.

25 Il est à noter que, selon l'invention, les deux sources de perturbations que sont le bruit et l'interférence entre symboles (IES) sont considérées de façons dissociées. En d'autres termes, les symboles affectés d'IES sont de plus bruités. L'IES est principalement due à des distorsions introduites par les éléments de filtrage de la chaîne de transmission et la présence de trajets multiples induits par le milieu physique de transmission (due à des réflexions sur des obstacles, etc...). Ces phénomènes entraînent
30 des perturbations entre les symboles. Le bruit induit par le milieu physique vient s'ajouter

à ce phénomène d'IES et est susceptible de modifier de surcroît les informations portées par les symboles.

La figure 2 illustre cette approche dans le cas simplifié d'une interférence portant sur deux symboles.

5 On note A_n le symbole émis à l'instant nT , où $1/T$ est la rapidité de modulation (T étant la durée d'un symbole). le signal reçu S_n peut s'écrire, après passage dans le canal de transmission :

$$S_n = \sum_k h_k A_{n-k}$$

10 Ce signal comporte un terme dépendant du symbole A_n , à savoir $h_0 A_n$, mais également un terme dépendant des symboles émis antérieurement et postérieurement à A_n . Ce second terme est le terme d'interférence entre symboles. Il peut s'écrire sous la forme $\sum_{k \neq 0} h_k A_{n-k}$. Il est dû au filtrage introduit par le canal, et peut être modélisé par un treillis à $N = 2^v$ états, pour une IES modélisée par un canal discret équivalent de mémoire v (2 dans le cas des figures 2 et 3).

15 Dans le cas de la figure 2, on considère une interférence portant sur deux symboles (A_{n-1} et A_{n+1}). L'effet du canal peut alors être représenté par deux cellules à retard 21_1 et 21_2 , chacune d'une durée T .

Lorsqu'en entrée de la cellule 21_1 , est présenté le symbole A_{n+1} , la sortie de celle-ci est A_n , et la sortie de la seconde cellule 21_2 est A_{n-1} . Le filtrage du canal revient à multiplier (22_1 à 22_3) chacun de ces symboles par le coefficient de filtrage correspondant h_i . Les termes correspondants sont ensuite additionnés (23) pour former le signal S_n .

20 L'architecture de la figure 2 correspond à un codage convolutif avec $v = 2$, dont le treillis de décodage est illustré en figure 3. Classiquement, ce treillis illustre les transitions possibles en fonction des deux valeurs précédentes, selon que la valeur de A_{n+1} est 1 (traits pleins) ou 0 (traits pointillés).

25 En revenant à la figure 1, le signal S_n bruité est soumis à un filtrage et une démodulation 18, symétriques des opérations assurées par le module 16.

30 Ensuite, classiquement, le signal est égalisé (19), par application d'un filtrage visant à compenser les effets du milieu de transmission 17. Le signal égalisé est alors désentrelacé (110), symétriquement à l'entrelacement 14.

Enfin, le signal est transmis à un décodeur convolutif 111, qui met par exemple en oeuvre un décodage à maximum de vraisemblance, tel que l'algorithme de Viterbi, pour délivrer des données décodées au destinataire 12.

La caractéristique essentielle de l'invention est l'association itérative d'un module de détection de symboles à sorties pondérées et d'un module de décodage, également à sorties pondérées. En considérant l'effet du canal selon l'approche présentée, l'égalisation classique (filtrage du signal reçu, à l'aide d'un filtre transversal, par exemple) est remplacée par une détection de symbole tenant compte de l'effet de mémoire introduit par le canal.

Ainsi, le dispositif proposé inclut un détecteur à entrée et à sortie pondérées qui estime les symboles A_n à partir de la sortie bruitée du canal. Ce détecteur peut, à titre d'exemple, être réalisé en utilisant l'algorithme décrit dans le document de brevet FR 91 05279. Il nécessite la connaissance des coefficients h_k , qui devront donc être estimés de manière externe au dispositif proposé, par exemple à l'aide de séquences d'apprentissage.

La figure 4 illustre le principe général de l'invention.

Chaque échantillon R_n reçu, qui correspond à la sortie bruitée du canal de transmission est traitée comme suit :

- un détecteur 41 de symboles à sorties pondérées produit une estimation $A_{n,1}$ du symbole émis correspondant ;
- les symboles $A_{n,1}$ en sortie du détecteur 41 sont désentrelacés (42) pour fournir les symboles $A_{k,1}$;
- les symboles désentrelacés $A_{k,1}$ sont présentés à l'entrée d'un décodeur convolutif 43 qui fournit une nouvelle estimation $A_{k,2}$ de symboles A_k ;
- en sortie du décodeur 43, on détermine (44) une donnée de correction Z_k , dite information extrinsèque obtenue à partir des estimations $A_{k,1}$ et $A_{k,2}$;
- la donnée de correction Z_k est ensuite utilisée, après un réentrelacement 45, dans le détecteur 41.

Plus précisément, dans le mode de réalisation décrit, la donnée Z_k est obtenue par différence entre $A_{k,2}$ et $\gamma_2 A_{k,1}$, délivré par le multiplicateur 46, ou γ_2 est un coefficient

positif. Z_n est encore une estimation du symbole A_n , mais cette fois affectée d'un bruit non corrélé avec celui qui affecte A_{n-1} et faiblement corrélé avec celui affectant R_n , grâce à la fonction d'entrelacement 45.

5 L'information extrinsèque Z_n est ensuite utilisée par le détecteur 41 en ajoutant ou en retranchant à chaque métrique de branche du treillis associé au canal (cf figure 3) le terme $\gamma_1 |Z_n|$, où γ_1 est un coefficient positif. Le terme $\gamma_1 |Z_n|$ est retranché (respectivement ajouté) lorsque le symbole affecté à la branche considérée est de même signe que Z_n (respectivement de signe contraire). La valeur du coefficient γ_1 dépend à la fois du rapport signal à bruit et de la fiabilité de l'information extrinsèque Z_n .

10 L'information extrinsèque, affectée du coefficient γ_1 pour le multiplieur 48 est par ailleurs retranchée (47) à la sortie du détecteur 41 avant d'être présentée à l'entrée du décodeur 43. En effet, l'information extrinsèque Z_n ayant été produite par le décodeur 43, elle ne doit pas être réutilisée par celui-ci.

15 Le détecteur de symboles 41 prend ses décisions suivant un algorithme de type Viterbi. Toutes les opérations effectuées par ce détecteur correspondent à celles décrites dans le brevet FR 91 05279. La différence, par rapport à un algorithme de décodage convolutif, réside dans le calcul des métriques de transition, ou métriques de branche, qui est mené différemment.

20 Chaque noeud du treillis est représentatif d'un état possible du canal à un instant nT donné. Pour une IES portant sur K_1 symboles postérieurs et K_2 symboles antérieurs au symbole considéré, c'est-à-dire pour :

$$S_n = \sum_{k=-K_1}^{K_2} h_k A_{n-k}$$

l'état du canal à $t = nT$ est donné par le (K_1+K_2) -uplet $(A_{n+K_1-1} \dots A_{n+1} A_n A_{n-1} \dots A_{n-K_2})$. La connaissance de l'état du canal à $t = nT$ ainsi que de la valeur de A_{n+K_1} (symbole "entrant" dans le canal) permet alors de connaître son état à $t = (n+1)T$.

25 Ainsi, pour chaque noeud j du treillis pris à l'instant $t = nT$, deux métriques de transition L_{j^0} et L_{j^1} sont calculées. Elles correspondent aux deux transitions possibles ($A_{n+K_1} = 0$ et $A_{n+K_1} = 1$). Elles sont de la forme :

$$L_{j^0} = (R_n - R_{j^0})^2 \text{ et } L_{j^1} = (R_n - R_{j^1})^2$$

30 où R_n représente l'échantillon effectivement reçu en entrée du détecteur et R_{j^0}

(respectivement R_j^1) est la valeur théorique de l'échantillon non bruité lorsque l'état du canal correspond au noeud j du treillis et que $A_{n+K1}=0$ (respectivement $A_{n+K1}=1$). R_j^0 (respectivement R_j^1) est donc de la forme : $\sum_{k=-K1}^{K2} h_k A_{n-k}$. Si $A_{n+K1}=0$, il s'agit de R_j^0 , et si $A_{n+K1}=1$, il s'agit de R_j^1 .

5 En pratique, on utilise l'expression simplifiée suivante pour le calcul des métriques :

$$L_j^0 = |R_n - R_j^0| \text{ et } L_j^1 = |R_n - R_j^1|$$

Les performances de la détection sont alors très proches de celles obtenues avec l'expression précédente, et l'implantation sur silicium du calcul est très simplifiée.

10 En dehors de ce calcul des métriques, l'algorithme de calcul est similaire, dans son principe comme dans sa mise en oeuvre, à un algorithme de décodage convolutif.

Dans la pratique, le récepteur illustré en figure 4 induit une latence de calcul (temps de traitement du détecteur 41, du décodeur 43, de l'entrelacement 45 et du désentrelacement 42). Il n'est donc pas possible de connaître instantanément Z_n lorsqu'on reçoit R_n dans le détecteur 41. En conséquence, selon une caractéristique essentielle de l'invention, le processus mis en oeuvre est itératif.

15 Ce processus est schématiquement illustré par la figure 5. Pour chaque symbole reçu R_n (étape de réception 51), au moins deux itérations 52 sont effectuées.

20 Chaque itération 52 comprend une étape 521 de correction de l'interférence entre symboles. Comme indiqué précédemment, cette correction met en oeuvre une technique de décodage convolutif, et tient compte d'une information extrinsèque de correction Z_n et de données h_i représentatives du canal de transmission.

25 Les informations Z_n sont calculées lors de l'étape 524. Bien sûr, lors de la première itération, aucune valeur particulière de Z_n n'est connue. En conséquence, celle-ci est alors fixée à une valeur neutre, c'est-à-dire n'influant pas sur les calculs.

Après la correction 521, les symboles estimés sont désentrelacés lors de l'étape 522 de désentrelacement (si un entrelacement a été mis en oeuvre à l'émission), puis décodés, selon une technique classique de décodage convolutif 523, et par exemple selon la technique décrite dans la demande française FR 91 05279.

30 Ensuite on calcule (524) l'information extrinsèque Z_k , à partir de la donnée 525

détectée par l'étape 521 de correction et de la donnée 526 décodée par l'étape 523 de décodage. Puis les informations Z_k sont ré-entrelacées (527), symétriquement au désentrelacement 522, pour fournir les informations Z_n . L'information Z_n est prise en compte dans l'étape de correction 521 de l'itération suivante.

5 Lors de la dernière itération, l'étape 524 de calcul de Z_k n'est pas mise en oeuvre. Le symbole décodé D_k est délivré par l'étape de décodage 523.

Le dispositif de réception correspondant peut avantageusement être réalisé de façon modulaire, en associant un module à chaque itération. La figure 6 illustre un tel dispositif, comprenant quatre modules.

10 Le premier module 61 de la chaîne reçoit $R_{n,1}$, le symbole reçu par le dispositif, et délivre d'une part $R_{n,2}$, qui est égal à $R_{n,1}$ affecté d'un retard correspondant à la latence du module, et d'autre part $Z_{n,2}$ l'information extrinsèque calculé par le module 61. Chacun des modules suivants 62 à 64 reçoit le symbole retardé $R_{n,i}$ et l'information extrinsèque $Z_{n,i}$. Le dernier module 64 délivre le symbole décodé D_n .

15 On comprend aisément que les performances du dispositif, en terme de taux d'erreur sont fonction du nombre de modules mis en cascade.

De façon avantageuse, tous les modules sont identiques. La figure 7 illustre un exemple de réalisation d'un tel module. Plus précisément, il s'agit du module correspondant à la $p^{\text{ème}}$ itération. Il comprend :

- 20
- 2 entrées : $(R)_p$ et $(Z)_p$,
 - 3 sorties : $(R)_{p+1}$, $(Z)_{p+1}$ et $(D)_p$.

L'entrée $(R)_p$ est égale à la sortie du canal retardée de la latence de $p-1$ modules.

L'entrée $(Z)_p$ provient du module précédent et est fixée, pour $p = 1$, à une valeur neutre, c'est-à-dire n'influant pas sur la sortie du détecteur.

25 La sortie $(R)_{p+1}$, égale à l'entrée $(R)_p$ retardée de la latence d'un module, est inutilisée si l'itération est la dernière du processus ($p=P$, P étant le nombre total de modules).

La sortie $(Z)_{p+1}$ est l'information extrinsèque élaborée à la $p^{\text{ème}}$ itération. Cette sortie est également inutilisée dans le cas où $p = P$.

30 La sortie $(D)_p$, qui est la donnée décodée, est inutilisée par les $P - 1$ premiers

modules, seules les données issues de $(D)_p$ sont fournies au destinataire.

Les éléments de ce module déjà décrits en relation avec la figure 4 ne sont pas décrits à nouveau, et portent les mêmes références. On notera que, par rapport au schéma de principe de la figure 4, différents retards sont ajoutés, pour prendre en compte les latences des différents éléments.

Ainsi, l'information extrinsèque $(Z)_p$ utilisée pour la différence 47 doit être retardée (71) d'une durée égale à la latence L_1 du détecteur 41. C'est également le cas de $(A)_{p,1}$ qui doit être retardée de la latence L_2 du décodeur 43. Enfin, $(R)_p$ doit être retardée (73) de la latence totale introduite par un module, L_T , afin que $(R)_{p+1}$ et $(Z)_{p+1}$ soient présentées au même instant à l'entrée du module suivant. Cette latence L_T est égale à la somme des latences du détecteur 41, L_1 , du décodeur, L_2 , et de la latence introduite par les opérations d'entrelacement 45 et de désentrelacement 42 L_{ED} .

Les performances du dispositif de l'invention ont été simulées, et sont illustrées en figure 8. La donnée source est codée par un code convolutif systématique récursif (code CSR) de longueur de contrainte $K = 5$ et de rendement $R = 1/2$. Les données codées sont envoyées sur le canal de transmission après un entrelacement non uniforme dans une matrice de 64 lignes et 64 colonnes. La modulation utilisée est une modulation de phase à 2 états (MDP2).

Les coefficients multiplicatifs h_i sont réels et constants et connus du détecteur de symboles, mais le principe est applicable aux cas où ils sont complexes et variables. Pour les résultats présentés ci-après, les coefficients h_i ont été fixés à :

$$h_0 = \sqrt{0,45}, h_1 = \sqrt{0,25}, h_2 = \sqrt{0,15}, h_3 = \sqrt{0,10}, h_4 = \sqrt{0,05}$$

et vérifient $\sum_{i=0}^4 h_i^2 = 1$. Le canal de transmission est également perturbé par un bruit additif blanc gaussien.

En sortie du canal, les échantillons reçus R_n sont quantifiés sur 8 bits. Le détecteur de symboles et le décodeur de canal utilisent l'algorithme présenté dans le brevet FR 91 05279. Le fonctionnement du codeur est également représenté par un treillis à 16 états. Les valeurs de coefficients γ_1 et γ_2 ont été déterminées de façon empirique.

Les résultats présentés utilisent 4 modules. Les courbes C_1 et C_2 représentent le taux d'erreur en sortie de la chaîne de transmission, respectivement sans et avec codage

de canal, en l'absence d'interférence entre symboles : C_3 donne le taux d'erreur dans le cas classique où le détecteur de symboles fournit une décision binaire (décision ferme) et les courbes C_{4i} montrent les résultats obtenus avec le dispositif proposé, après l'itération de rang i .

- 5 Ces courbes montrent donc que à un taux d'erreur de 10^{-5} , l'utilisation d'un détecteur de symboles à sortie pondérée permet de gagner 1,6dB par rapport à un détecteur à décision ferme et les trois itérations supplémentaires apportent un gain supplémentaire de 3 dB environ. Lorsque le nombre d'itérations augmente, les performances se rapprochent de celles obtenues sur un canal gaussien codé.

10

REVENDICATIONS

1. Dispositif de réception de signaux formés d'une série de symboles numériques correspondant au codage convolutif de données numériques source, caractérisé en ce qu'il comprend p modules (61 à 64) de détection et de décodage M_1 à M_p en cascade, p étant supérieur ou égal à 2,
 - 5 chacun desdits modules M_i comprenant :
 - des moyens (41, 47, 48) de correction de l'interférence entre symboles, alimentés par une entrée de symbole R_i et délivrant des symboles estimés $A_{i,1}$ à valeurs pondérées,
 - 10 des moyens (43) de décodage desdits symboles estimés $A_{i,1}$, effectuant des opérations symétriques audit codage convolutif et délivrant des symboles décodés $A_{i,2}$ à valeurs pondérées, et
 - des moyens (44, 46) de calcul d'une information de correction Z_{i+1} à partir dudit symbole estimé $A_{i,1}$ et dudit symbole décodé $A_{i,2}$,
 - 15 lesdits moyens (41) de correction de chacun desdits modules M_i , à l'exception du premier module M_1 , tenant compte d'au moins une information de correction Z_i déterminée par le module précédent M_{i-1} .
2. Dispositif selon la revendication 1, caractérisé en ce que chacun desdits modules M_i présente deux entrées, une entrée de symbole R_i et une entrée de correction Z_i , et trois
 - 20 sorties, une sortie de symbole R_{i+1} , une sortie de correction Z_{i+1} et une sortie de symbole décodé D_{i+1} ,
 - l'entrée de symbole R_i du module M_i étant connectée à la sortie de symbole R_i du module M_{i-1} , pour i supérieur à 1, et étant alimenté par les symboles reçus pour i égal à 1,
 - l'entrée de correction Z_i du module M_i étant connectée à la sortie de correction Z_i du module M_{i-1} , pour i supérieur à 1, et étant alimenté par une valeur neutre, n'influant pas
 - 25 sur la correction, pour i égal à 1,
 - la sortie de symbole R_{i+1} du module M_i étant égale à l'entrée de symbole R_i dudit module M_i retardée du temps de latence imposé par le module M_i ,
 - la sortie de correction Z_{i+1} délivrant ladite information de correction, et
 - 30 la sortie de symbole décodé D_{i+1} étant inutilisée pour les modules M_1 à M_{p-1} , et étant

alimentée par le symbole décodé $A_{p,2}$ du module M_p si le code mis en oeuvre est un code systématique, et par une valeur reconstituée en fonction du code mis en oeuvre sinon.

3. Dispositif selon l'une quelconque des revendications 1 et 2, caractérisé en ce que lesdits moyens (41) de correction de l'interférence entre symboles sont alimentés par une information de correction Z_i représentative d'une différence (44) entre chaque symbole décodé $A_{i,2}$ et le symbole estimé $A_{i,1}$ correspondant.

4. Dispositif selon la revendication 3, caractérisé en ce que lesdits moyens de calcul de l'information de correction comprennent des moyens (46) de multiplication desdits symboles estimés $A_{i,1}$ par un coefficient pondérateur positif γ_2 , délivrant des symboles pondérés, et des moyens (44) de soustraction calculant la différence entre chaque symbole décodé $A_{i,2}$ et le symbole pondéré correspondant, et délivrant ladite information de correction Z_i .

5. Dispositif selon l'une quelconque des revendications 1 à 4, caractérisé en ce que lesdits moyens (41, 47, 48) de correction de l'interférence entre symboles effectuent les opérations suivantes :

- calcul (48) d'une valeur de correction $V_i = \gamma_1 |Z_i|$, où γ_1 est un coefficient positif et où $| \cdot |$ représente l'opérateur valeur absolue ;
- pour chaque branche du treillis correspondant audit code convolutif, détermination (41) d'un symbole détecté $A_{i,0}$, comprenant les étapes suivantes :
 - si le symbole affecté à ladite branche est de même signe que ladite information de correction Z_i , soustraction à la métrique associée à ladite branche de ladite valeur de correction V_i ;
 - si le symbole affecté à ladite branche est de signe opposé à celui de ladite information de correction Z_i , addition à la métrique associée à ladite branche de ladite valeur de correction V_i ;
- soustraction (47) audit symbole détecté $A_{i,0}$ de la valeur $\gamma_1 Z_i$.

6. Dispositif selon la revendication 5, caractérisé en ce que ledit coefficient γ_1 dépend d'au moins une des informations appartenant au groupe comprenant :

- le rapport signal à bruit ;

- le numéro i du module considéré.

7. Dispositif selon l'une quelconque des revendications 1 à 6, appliqué à la réception de symboles soumis à un entrelacement à l'émission, caractérisé en ce qu'il comprend :

- des moyens (42) de désentrelacement assurant l'opération symétrique dudit entrelacement, insérés entre lesdits moyens de correction et lesdits moyens de décodage ; et
- des moyens (45) d'entrelacement assurant un entrelacement desdites informations de correction identique audit entrelacement à l'émission.

8. Module de détection et de décodage destiné à être mis en oeuvre dans un dispositif de réception de signaux formés d'une série de symboles numériques correspondant au codage convolutif de données numériques source, ledit dispositif comprenant au moins deux modules en cascade, caractérisé en ce qu'il présente deux entrées, une entrée de symbole R_i et une entrée de correction Z_i , et trois sorties, une sortie de symbole R_{i+1} , une sortie de correction Z_{i+1} et une sortie de symbole décodé D_{i+1} ,

et en ce qu'il comprend :

- des moyens (41, 47, 48) de correction de l'interférence entre symboles, alimentés par ladite entrée de symbole R_i et tenant compte de ladite entrée de correction Z_i , et délivrant des symboles estimés $A_{i,1}$,
- des moyens (43) de décodage desdits symboles estimés $A_{i,1}$, effectuant des opérations symétriques audit codage convolutif et délivrant des symboles décodés $A_{i,2}$, et
- des moyens (44, 46) de calcul d'une information de correction Z_{i+1} à partir dudit symbole estimé $A_{i,1}$ et dudit symbole décodé $A_{i,2}$,
- la sortie de symbole R_{i+1} étant égale à l'entrée de symbole R_i retardée d'un temps de latence prédéfini,
- la sortie de correction Z_{i+1} délivrant ladite information de correction, et
- la sortie de symbole décodé D_{i+1} étant alimentée par ledit symbole décodé $A_{i,2}$, ou par une valeur reconstituée en fonction du code mis en oeuvre.

9. Procédé de réception de signaux formés d'une série de symboles numériques

correspondant au codage convolutif de données numériques source, caractérisé en ce qu'il comprend les étapes suivantes :

- alimentation (51) par les symboles reçus R_i ;
- correction (521) de l'interférence entre symboles affectant chacun desdits symboles reçus à partir d'une information de correction Z_i , et délivrant des symboles estimés $A_{i,1}$;
- décodage (523) desdits symboles estimés $A_{i,1}$, effectuant des opérations symétriques audit codage convolutif et délivrant des symboles décodés $A_{i,2}$;
- calcul (524) de ladite information de correction Z_i , à partir et d'au moins un desdits symboles estimés $A_{i,1}$ et d'au moins un desdits symboles décodés $A_{i,2}$.

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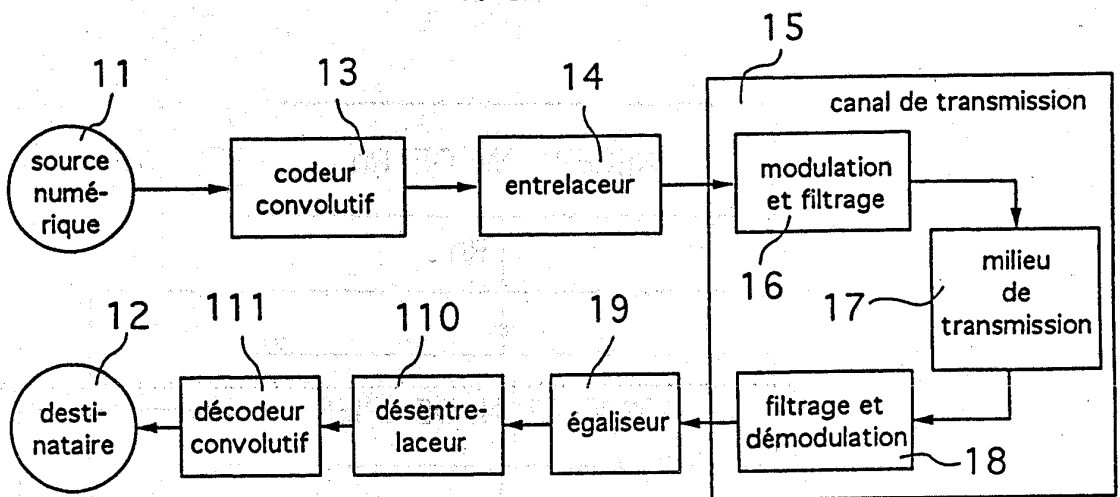


Fig. 1

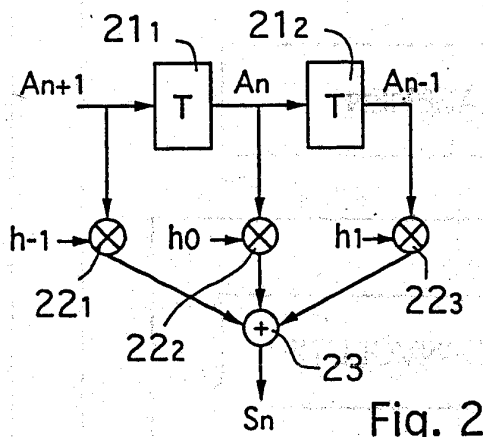


Fig. 2

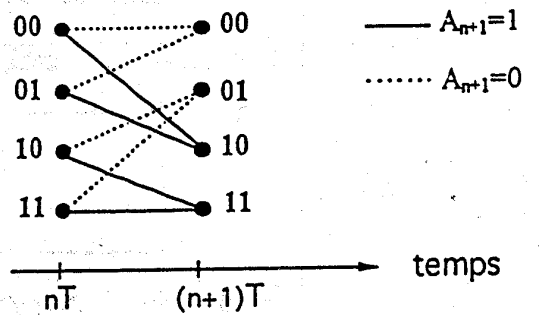


Fig. 3

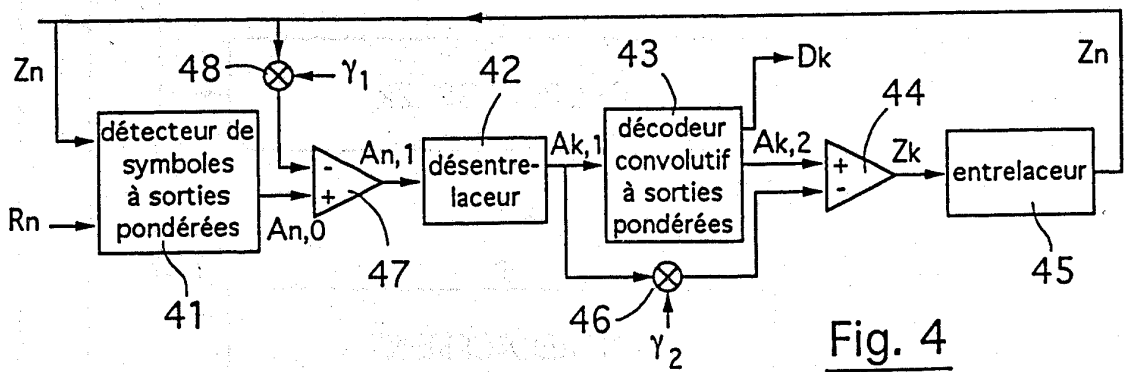


Fig. 4

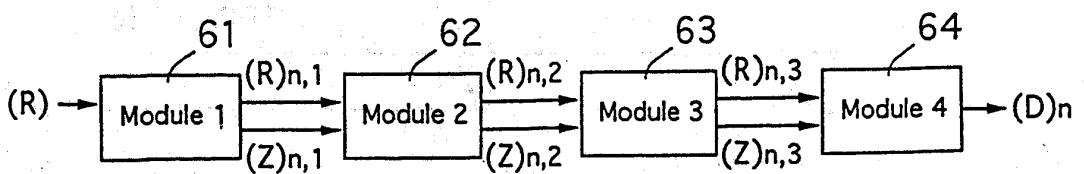


Fig. 6

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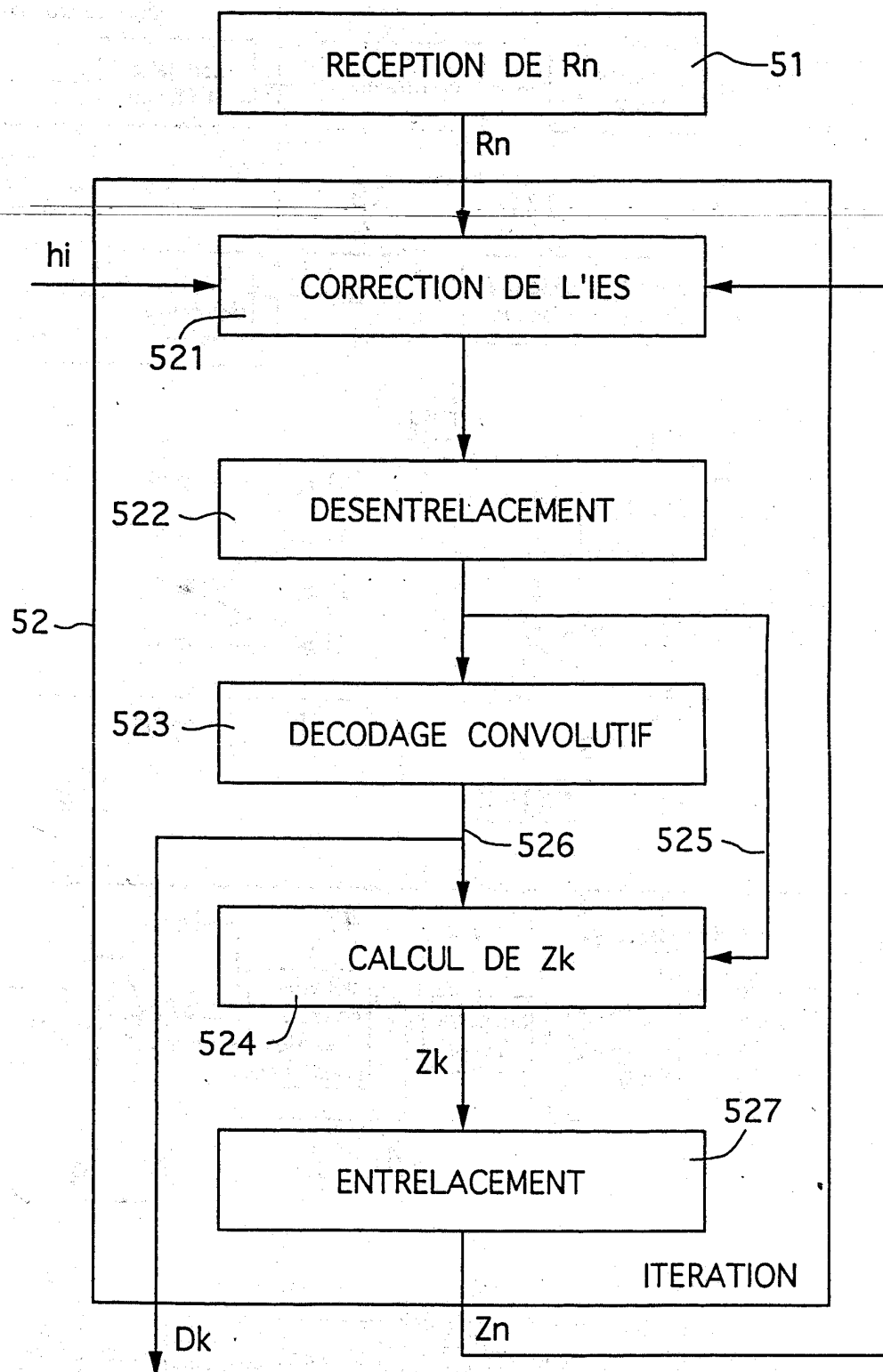


Fig. 5

3/3

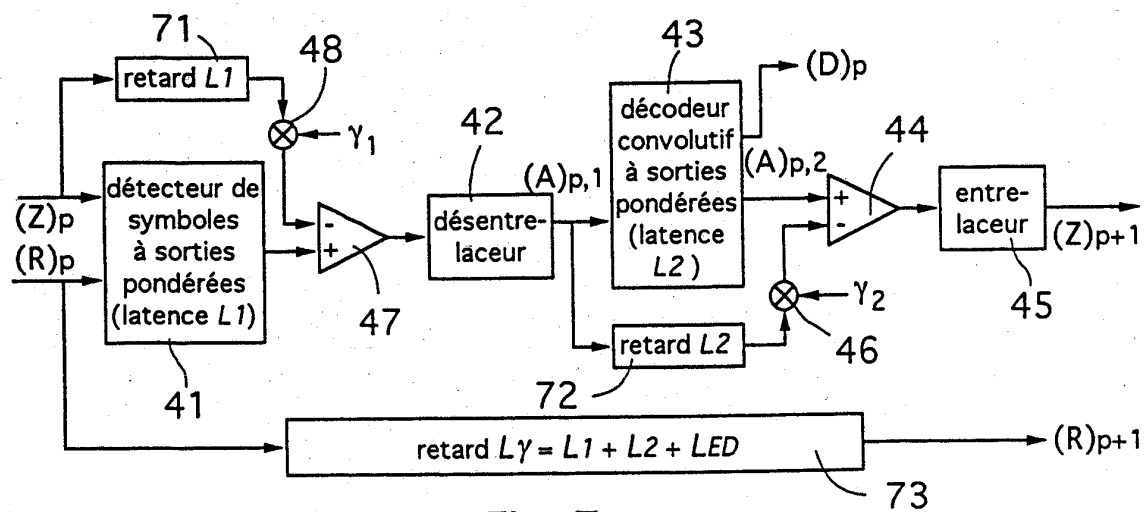


Fig. 7

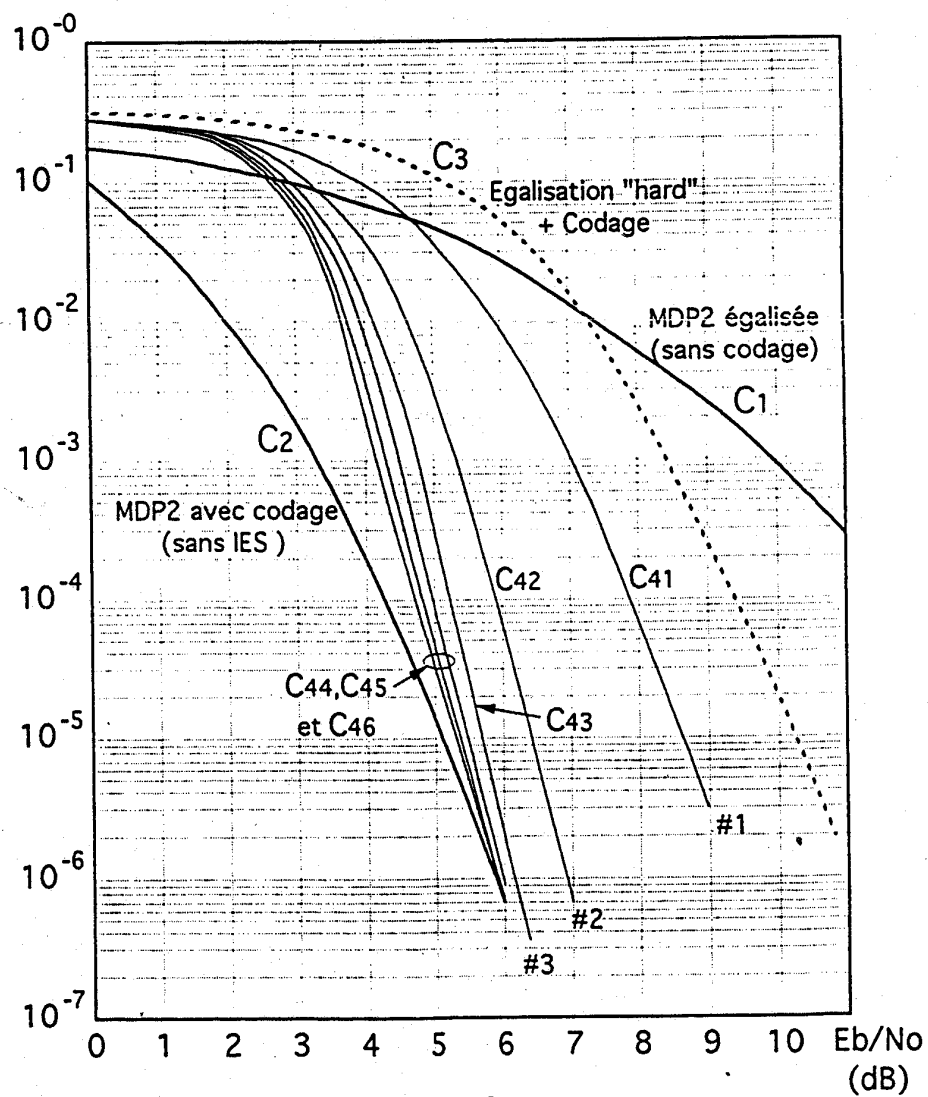


Fig. 8

TRAITE DE COOPERATION EN MATIERE DE BREVETS

PCT

08/09/2007

RAPPORT DE RECHERCHE INTERNATIONALE

(article 18 et règles 43 et 44 du PCT)

Référence du dossier du déposant ou du mandataire 3324.WO	POUR SUITE voir la notification de transmission du rapport de recherche internationale (formulaire PCT/ISA/220) et, le cas échéant, le point 5 ci-après A DONNER	
Demande internationale n° PCT/FR96/00197	Date du dépôt international(jour/mois/année) 06/02/96	(Date de priorité (la plus ancienne) (jour/mois/année) 07/02/95
Déposant FRANCE TELECOM et al.		

Le présent rapport de recherche internationale, établi par l'administration chargée de la recherche internationale, est transmis au déposant conformément à l'article 18. Une copie en est transmise au Bureau international.

Ce rapport de recherche internationale comprend 4 feuilles.

☒ Il est aussi accompagné d'une copie de chaque document relatif à l'état de la technique qui y est cité.

- ☐ Il a été estimé que certaines revendications ne pouvaient pas faire l'objet d'une recherche (voir le cadre I).
- ☐ Il y a absence d'unité de l'invention (voir le cadre II).
- ☐ La demande internationale contient la divulgation d'un listage de séquence de nucléotides ou d'acides aminés et la recherche internationale a été effectuée sur la base du listage de séquence.
 - ☐ déposé avec la demande internationale
 - ☐ fourni par le déposant séparément de la demande internationale
 - ☐ sans être accompagnée d'une déclaration selon laquelle il n'inclut pas d'éléments allant au-delà de la divulgation faite dans la demande internationale telle qu'elle a été déposée.
 - ☐ transcrit par l'administration
- En ce qui concerne le titre, ☒ le texte est approuvé tel qu'il a été remis par le déposant.
 - ☐ Le texte a été établi par l'administration et a la teneur suivante:
- En ce qui concerne l'abrégé,
 - ☒ le texte est approuvé tel qu'il a été remis par le déposant
 - ☐ le texte (reproduit dans le cadre III) a été établi par l'administration conformément à la règle 38.2b). Le déposant peut présenter des observations à l'administration dans un délai d'un mois à compter de la date d'expédition du présent rapport de recherche internationale.
- La figure des dessins à publier avec l'abrégé est la suivante:
 Figure n° 4&6
 - ☐ suggérée par le déposant.
 - ☐ parce que le déposant n'a pas suggéré de figure.
 - ☒ parce que cette figure caractérise mieux l'invention.

☐ Aucune des figures n'est à publier.

RAPPORT DE RECHERCHE INTERNATIONALE

Demande nationale No
PCT/FR 96/00197

A. CLASSEMENT DE L'OBJET DE LA DEMANDE
CIB 6 H04L25/03

Selon la classification internationale des brevets (CIB) ou à la fois selon la classification nationale et la CIB

B. DOMAINES SUR LESQUELS LA RECHERCHE A PORTE

Documentation minimale consultée (système de classification suivi des symboles de classement)
CIB 6 H04L H03M

Documentation consultée autre que la documentation minimale dans la mesure où ces documents relèvent des domaines sur lesquels a porté la recherche

Base de données électronique consultée au cours de la recherche internationale (nom de la base de données, et si cela est réalisable, termes de recherche utilisés)

C. DOCUMENTS CONSIDERES COMME PERTINENTS

Catégorie *	Identification des documents cités, avec, le cas échéant, l'indication des passages pertinents	no. des revendications visées
A	EP,A,0 511 141 (FRANCE TELECOM / TELEDIFFUSION DE FRANCE) 28 Octobre 1992 cité dans la demande voir abrégé voir page 4, ligne 21 - page 5, ligne 41; revendications; figures 3,4 --- -/--	1-9

☒ Voir la suite du cadre C pour la fin de la liste des documents

☒ Les documents de familles de brevets sont indiqués en annexe

* Catégories spéciales de documents cités:

- "A" document définissant l'état général de la technique, non considéré comme particulièrement pertinent
- "E" document antérieur, mais publié à la date de dépôt international ou après cette date
- "L" document pouvant jeter un doute sur une revendication de priorité ou cité pour déterminer la date de publication d'une autre citation ou pour une raison spéciale (telle qu'indiquée)
- "O" document se référant à une divulgation orale, à un usage, à une exposition ou tous autres moyens
- "P" document publié avant la date de dépôt international, mais postérieurement à la date de priorité revendiquée

"T" document ultérieur publié après la date de dépôt international ou la date de priorité et n'appartenant pas à l'état de la technique pertinent, mais cité pour comprendre le principe ou la théorie constituant la base de l'invention

"X" document particulièrement pertinent; l'invention revendiquée ne peut être considérée comme nouvelle ou comme impliquant une activité inventive par rapport au document considéré isolément

"Y" document particulièrement pertinent; l'invention revendiquée ne peut être considérée comme impliquant une activité inventive lorsque le document est associé à un ou plusieurs autres documents de même nature, cette combinaison étant évidente pour une personne du métier

"&" document qui fait partie de la même famille de brevets

Date à laquelle la recherche internationale a été effectivement achevée

24 Avril 1996

Date d'expédition du présent rapport de recherche internationale

29.05.96

Nom et adresse postale de l'administration chargée de la recherche internationale

Office Européen des Brevets, P.B. 5818 Patentlaan 2
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Fonctionnaire autorisé

Gries, T

RAPPORT DE RECHERCHE INTERNATIONALE

Demande internationale No
PCT/FR 96/00197

C.(suite) DOCUMENTS CONSIDERES COMME PERTINENTS		
Catégorie	Identification des documents cités, avec, le cas échéant, l'indication des passages pertinents	no. des revendications visées
A	ICC '93 GENEVA. IEEE INTERNATIONAL CONFERENCE ON COMMUNICATIONS '93. TECHNICAL PROGRAM, CONFERENCE RECORD (CAT. NO.93CH3261-5), PROCEEDINGS OF ICC '93 - IEEE INTERNATIONAL CONFERENCE ON COMMUNICATIONS, GENEVA, SWITZERLAND, 23-26 MAY 1993, ISBN 0-7803-0950-2, 1993, NEW YORK, NY, USA, IEEE, USA, pages 1064-1070 vol.237, XP000371240 BERROU C ET AL: "Near Shannon limit error-correcting coding and decoding: Turbo-codes. 1" cité dans la demande voir figures 3B,4A,4B ---	1-9
A	ELECTRONICS AND COMMUNICATIONS IN JAPAN, PART 1 (COMMUNICATIONS), APRIL 1994, USA, vol. 77, no. 4, ISSN 8756-6621, pages 103-110, XP000445333 MURATA H ET AL: "Performance of adaptive equalizer using iterative application of Viterbi algorithm" voir page 103, colonne de droite, alinéa 5 - page 105, colonne de gauche, alinéa 2; figure 1 ---	1-9
A	PHILIPS JOURNAL OF RESEARCH, 1987, NETHERLANDS, vol. 42, no. 4, ISSN 0165-5817, pages 399-428, XP000565157 BERGMANS J W M ET AL: "On the use of decision feedback for simplifying the Viterbi detector" voir page 401, alinéa 2 voir page 406, alinéa 1 - page 409, alinéa 2; figures 3,4 voir page 411, alinéa 3 voir page 426, alinéa 5 - page 427, alinéa 2 --- -/--	1-9

Formulaire PCT/ISA/210 (suite de la deuxième feuille) (juillet 1992)

RAPPORT DE RECHERCHE INTERNATIONALE

Demande	ationale No
PCT/FR 96/00197	

C.(suite) DOCUMENTS CONSIDERES COMME PERTINENTS		
Catégorie *	Identification des documents cités, avec, le cas échéant, l'indication des passages pertinents	no. des revendications visées
A	IEEE IN HOUSTON. GLOBECOM '93. IEEE GLOBAL TELECOMMUNICATIONS CONFERENCE, INCLUDING A COMMUNICATIONS THEORY MINI-CONFERENCE. TECHNICAL PROGRAM CONFERENCE RECORD (CAT. NO.93CH3250-8), PROCEEDINGS OF GLOBECOM '93. IEEE GLOBAL TELECOMMUNICATIONS CONFERE, ISBN 0-7803-0917-0, 1993, NEW YORK, NY, USA, IEEE, USA, pages 98-102 vol.1, XP000428037 JIANJUN WU ET AL: "A channel model and a novel adaptive equalizer for mobile radio communications" voir abrégé voir page 98, colonne de gauche, alinéa 3 - colonne de droite, alinéa 1 voir page 100, colonne de droite, ligne 1 - page 101, colonne de gauche, ligne 18; figure 2 ---	1-9
A	WO,A,91 06165 (MOTOROLA INC.) 2 Mai 1991 voir abrégé voir page 3, ligne 18 - ligne 28; revendications; figure ---	1-9
A	VEHICULAR TECHNOLOGY SOCIETY 42ND VTS CONFERENCE. FRONTIERS OF TECHNOLOGY. FROM PIONEERS TO THE 21ST CENTURY (CAT. NO.92CH3159-1), DENVER, CO, USA, 10-13 MAY 1992, ISBN 0-7803-0673-2, 1992, NEW YORK, NY, USA, IEEE, USA, pages 577-585 vol.2, XP000339855 JUNG P ET AL: "VLSI implementation of soft output Viterbi equalizers for mobile radio applications" cité dans la demande voir page 578, colonne de gauche, alinéa 3 voir page 577, colonne de droite, alinéa 2 ---	1-9
A	EP,A,0 524 597 (ALCATEL RADIOTELEPHONE) 27 Janvier 1993 voir abrégé voir page 6, ligne 8 - page 7, ligne 19 -----	1-9

INTERNATIONAL SEARCH REPORT

Information on patent family members

International Application No
PCT/FR 96/00197

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
EP-A-511141	28-10-92	FR-A- 2675971 US-A- 5446747	30-10-92 29-08-95
WO-A-9106165	02-05-91	US-A- 5271042 AU-B- 637166 AU-B- 6729490 CA-A,C 2066270 CN-A- 1050958 EP-A- 0495006 JP-T- 5504872 TR-A- 26468 US-A- 5144644	14-12-93 20-05-93 16-05-91 14-04-91 24-04-91 22-07-92 22-07-93 15-03-95 01-09-92
EP-A-524597	27-01-93	FR-A- 2679721 AU-B- 651472 AU-B- 1952392 CA-A- 2074277 JP-A- 5199143 NZ-A- 243590 US-A- 5331662	29-01-93 21-07-94 28-01-93 23-01-93 06-08-93 28-08-95 19-07-94

Form PCT/ISA/210 (patent family annex) (July 1992)

PTO/PST Rec'd 29 JUL

08/894207

IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

Applicant	: Catherine Douillard et al.	Group Art Unit: Examiner:
Serial No.	:	
Filed	: Herewith	
For	: DEVICE FOR THE RECEPTION OF DIGITAL SIGNALS WITH ITERATIVE STRUCTURE, AND CORRESPONDING MODULE AND METHOD	
Docket No.	: F264.312-16	

PRELIMINARY AMENDMENT

Box Non-Fee Amendment
Assistant Commissioner for Patents
Washington, D.C. 20231

I CERTIFY THAT THIS PAPER IS BEING SENT BY U.S. MAIL,
FIRST CLASS, TO THE ASSISTANT COMMISSIONER FOR
PATENTS, WASHINGTON, D.C. 20231, THIS _____ DAY OF
_____, 19____.

PATENT ATTORNEY

Sir:

Please amend the above-identified application as follows:

IN THE CLAIMS

Please amend claims 1, 3-5 and 7-9 as follows:

1. (Amended) Device for the reception of signals formed by a series of digital symbols corresponding to the convolutive encoding of items of source digital data

characterized in that it comprises p cascade-connected detection and decoding modules [(61 to 64)] M_1 to M_p , p being greater than or equal to 2,

each of said modules M_i including:

inter-symbol interference correction means [(41, 47, 48)] supplied by a symbol input R_i and delivering estimated symbols $A_{i, 1}$ with weighted values,

means [(43)] for the decoding of said estimated symbols $A_{i, 1}$ performing operations symmetrical to said convolutive encoding and delivering decoded symbols $A_{i, 2}$ with weighted values, and

Inventor: Douillard et al.

Serial No.:

-2-

means [(44, 46)] for the computation of an item of correction information Z_{i+1} from said estimated symbol $A_{i,1}$ and said decoded symbol $A_{i,2}$,

said means [(41)] for the correction of each of said modules M_i , except for the first module M_1 , taking account of at least one item of correction information Z_i determined by the previous module M_{i-1} .

2. Device according to claim 1, characterized in that each of said modules M_i has two inputs, one symbol input R_i and one correction input Z_i and three outputs, one symbol output R_{i+1} , one correction output Z_{i+1} and one decoded symbol output D_{i+1} ,
the symbol input R_i of the module M_i being connected to the symbol output R_i of the module M_{i-1} for i greater than 1 and being supplied with the symbols received for i equal to 1,
the correction input Z_i of the module M_i being connected to the correction output Z_i of the module M_{i-1} for i greater than 1 and being supplied with a neutral value that does not affect the correction for i equal to 1,
the symbol output R_{i+1} of the module M_i being equal to the symbol input R_i of said module M_i delayed by the latency time dictated by the module M_i ,
the correction output Z_{i+1} delivering said correction information, and
the decoded symbol output D_{i+1} being unused for the modules M_1 to M_{p-1} and being supplied with the decoded symbol $A_{p,2}$ of the module M_p if the code implemented is a systematic code and, if not, with a corresponding reconstituted value.

3. (Amended) Device according to [any of the claims 1 and 2] claim 1, characterized in that said means [(41)] for the correction of the inter-symbol interference are supplied with an item of correction information Z_i representing a difference [(44)] between each decoded symbol $A_{i,2}$ and the corresponding estimate symbol $A_{i,1}$.

4. (Amended) Device according to claim 3, characterized in that said means to compute the item of correction information comprise means [(46)] for the multiplication of said estimation symbols $A_{i,1}$ by a positive weighting coefficient γ_2 delivering weighted symbols, and subtraction means [(44)] computing the difference between each decoded symbol $A_{i,2}$ and the corresponding weighted symbol and delivering said item of correction information Z_i .

5. (Amended) Device according to [any of the claims 1 to 4] claim 1, characterized in that said means [(41, 47, 48)] for the correction of inter-symbol interference perform the following operations:

- the computation [(41)] of a correction value $V_i = \gamma_1 |Z_i|$, where γ_1 is a positive coefficient and where $| |$ represents the absolute value operator;
- for each arm of the lattice corresponding to said convolutive code, the determining [(41)] of a detected symbol $A_{i,0}$, comprising the following steps:
 - if the symbol assigned to said branch has the same sign as said item of correction information Z_i , the subtraction, from the metric associated with said arm, of said correction value V_i ;
 - if the symbol assigned to said arm has a sign opposite that of said item of correction information Z_i , the addition, to the metric associated with said arm, of said correction value V_i ;
 - the subtraction [(47)], from said detected symbol $A_{i,0}$, of the value $\gamma_i Z_i$.

6. Device according to claim 5, characterized in that said coefficient γ_1 depends on at least one of the items of information belonging to the group comprising:

- the signal-to-noise ratio;
- the number i of the module considered.

7. (Amended) Device according to [any of the claims 1 to 6] claim 1, applied to the reception of symbols subjected to an interleaving operation at transmission, characterized in that it comprises:

- de-interleaving means [(42)] providing for the symmetrical operation of said interleaving, inserted between said correction means and said decoding means; and

Inventor: Douillard et al.

Serial No.:

-4-

- interleaving means [(45)] providing for an interleaving of said items of correction information that is identical to said interleaving at transmission.

8. (Amended) Detection and decoding module designed to be implemented in a device for the reception of signals formed by a series of digital symbols corresponding to the convolutive encoding of items of source digital data, said device comprising at least two cascade-connected modules, characterized in that it has two inputs, one symbol input R_i and one correction input Z_i , and three outputs, one symbol output R_{i+1} , one correction output Z_{i+1} and one decoded symbol output D_{i+1} , and in that it comprises:

means [(41, 47, 48)] for the correction of inter-symbol interference, supplied by said symbol input R_i and taking account of said correction input Z_i and delivering estimated symbols $A_{i, 1}$,

1°

means [(43)] for the decoding of said estimated symbols $A_{i, 1}$, performing operations symmetrical to said convolutive encoding and delivering decoded symbols $A_{i, 2}$, and

means [(44, 46)] for the computation of an item of correction information Z_{i+1} from said estimated symbol $A_{i, 1}$ and said decoded symbol $A_{i, 2}$,

the symbol output R_{i+1} being equal to the symbol input R_i delayed by a predefined latency time,

the correction output Z_{i+1} delivering said correction information, and

the decoded symbol output D_{i+1} being supplied with said decoded symbol $A_{i, 2}$ or with a value reconstituted as a function of the code implemented.

9. (Amended) Method for the reception of signals formed by a series of digital symbols corresponding to the convolutive encoding of items of source digital data comprising the following steps:

- supplying [(51)] with received symbols R_i ;

Inventor: Douillard et al.

Serial No.:

-5-

- the correction [(521)] of inter-symbol interference affecting each of said received symbols, by means of an item of correction information Z_i , and the delivery of estimated symbols $A_{i,1}$;

- the decoding [(523)] of said estimated symbols $A_{i,1}$ entailing operations symmetrical to said convolutive encoding, and the delivery of decoded symbols $A_{i,2}$;

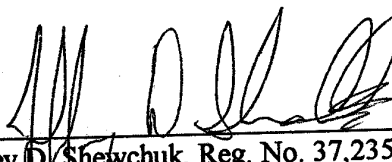
- the computation [(524)] of said items of correction information Z_i from at least one of said estimated symbols $A_{i,1}$ and at least one of said decoded symbols $A_{i,2}$.

REMARKS

In this Preliminary Amendment the claims are amended to remove multiple dependencies and reference numerals. The application is now in condition for examination. The Examiner is invited to contact the undersigned attorney at the number listed below if it would any way facilitate allowance of the claims.

Respectfully submitted,

KINNEY & LANGE, P.A.

By: 

Jeffrey D. Shewchuk, Reg. No. 37,235
Suite 1500

625 Fourth Avenue South

Minneapolis, MN 55415-1659

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JDS:cnj



UNITED STATES DEPARTMENT OF COMMERCE
Patent and Trademark Office

Address: ASSISTANT COMMISSIONER FOR PATENTS
Box PCT
Washington, D.C. 20231

08/894,207

U.S. APPLICATION NO.	FIRST NAMED APPLICANT	ATTY. DOCKET NO.
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08/894,207

DOUILLARD

C

F264.312-16

INTERNATIONAL APPLICATION NO.

5611

PCT/FR96/00197

I.A. FILING DATE

PRIORITY DATE

02/06/96

02/07/95

DATE MAILED:

10/31/97

JEFFREY D. SHEWCHUK
KINNEY & LANGE PA
SUITE 1500
625 FOURTH AVENUE SOUTH
MINNEAPOLIS MN 55415-1659

NOTIFICATION OF MISSING REQUIREMENTS UNDER 35 U.S.C. 371 IN THE UNITED STATES DESIGNATED/ELECTED OFFICE (DO/EO/US)

1. The following items have been submitted by the applicant or the IB to the United States Patent and Trademark Office as

☐ a Designated Office (37 CFR 1.494),

☐ an Elected Office (37 CFR 1.495):

☒ U.S. Basic National Fee.

☒ Copy of the international application in:

☐ a non-English language.

☐ English.

☐ Translation of the international application into English.

☐ Oath or Declaration of inventors(s) for DO/EO/US.

☐ Copy of Article 19 amendments.

☐ Translation of Article 19 amendments into English.

☐ The International Preliminary Examination Report in English and its Annexes, if any.

☐ Translation of Annexes to the International Preliminary Examination Report into English.

☒ Preliminary amendment(s) filed 29 Jul 97 and _____.

☒ Information Disclosure Statement(s) filed 29 Jul 97 and _____.

☐ Assignment document.

☐ Power of Attorney and/or Change of Address.

☐ Substitute specification filed _____.

☐ Verified Statement Claiming Small Entity Status.

☐ Priority Document.

☒ Copy of the International Search Report ☒ and copies of the references cited therein.

☐ Other:

2. The following items **MUST** be furnished within the period set forth below in order to complete the requirements for acceptance under 35 U.S.C. 371:

☐ a. Translation of the application into English. Note a processing fee will be required if submitted later than the appropriate 20 or 30 months from the priority date.

☐ The current translation is defective for the reasons indicated on the attached Notice of Defective Translation.

☐ b. Processing fee for providing the translation of the application and/or the Annexes later than the appropriate 20 or 30 months from the priority date (37 CFR 1.492(f)).

☒ c. Oath or declaration of the inventors, in compliance with 37 CFR 1.497(a) and (b), identifying the application by the International application number and international filing date.

☐ The current oath or declaration does not comply with 37 CFR 1.497(a) and (b) for the reasons indicated on the attached PCT/DO/EO/917.

☒ d. Surcharge for providing the oath or declaration later than the appropriate 20 or 30 months from the priority date (37 CFR 1.492(e)).

3. Additional claim fees of \$ _____ as a ☐ large entity ☐ small entity, including any required multiple dependent claim fee, are required. Applicant must submit the additional claim fees or cancel the additional claims for which fees are due. See attached PTO-875.

ALL OF THE ITEMS SET FORTH IN 2(a)-2(d) AND 3 ABOVE MUST BE SUBMITTED WITHIN ONE MONTH FROM THE DATE OF THIS NOTICE OR BY ☐ 21 OR ☒ 31 MONTHS FROM THE PRIORITY DATE FOR THE APPLICATION, WHICHEVER IS LATER. FAILURE TO PROPERLY RESPOND WILL RESULT IN ABANDONMENT.

The time period set above may be extended by filing a petition and fee for extension of time under the provisions of 37 CFR 1.136(a).

4. Translation of the Annexes **MUST** be submitted no later than the time period set above or the annexes will be cancelled. Note processing fee will be required if submitted later than 30 months from the priority date.

5. ☐ The Article 19 amendments are cancelled since a translation was not provided by the appropriate 20 (37 CFR 1.494(d)) or 30 (37 CFR 1.495(d)) months from the priority date.

Applicant is reminded that any communication to the United States Patent and Trademark Office must be mailed to the address given in the heading and include the U.S. application no. shown above. (37 CFR 1.5)

A copy of this notice *MUST* be returned with this response.

Enclosed: ☐ PCT/DO/EO/917 ☐ Notice of Defective Translation
☐ PTO-875

FORM PCT/DO/EO/905 (September 1996)

Telephone: (703)

Shelby Vigil
PCT International Division

305-3653



PTO/PCT Rec'd 3 DEC 1997
IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

SECTOR
130.00-154\$
#3

Applicant : Catherine Douillard et al.
Serial No. : 08/894,207
Filed : July 29, 1997
For : DEVICE FOR THE RECEPTION OF
DIGITAL SIGNALS WITH ITERATIVE
STRUCTURE AND CORRESPONDING
MODULE AND METHOD
Docket No. : F264.312-16

SV

**RESPONSE TO NOTIFICATION OF MISSING REQUIREMENTS
UNDER 35 USC 371 IN THE UNITED STATES
DESIGNATED/ELECTED OFFICE (DO/EO/US)**

Box Missing Parts
Assistant Commissioner for Patents
Washington, D.C. 20231

I CERTIFY THAT THIS PAPER IS BEING SENT BY U.S. MAIL,
FIRST CLASS, TO THE ASSISTANT COMMISSIONER FOR
PATENTS, WASHINGTON, D.C. 20231, THIS 26th DAY OF
November, 1997.
PATENT ATTORNEY

Sir:

In response to the Notification of Missing Requirements Under 35 U.S.C. 371 in the United States Designated/Elected Office (DO/EO/US) dated October 31, 1997, Applicant encloses the following documents to complete the above-identified patent application filed July 29, 1997:

1. Our checks in the amount of \$40.00 to cover the Assignment recording fee; and \$130.00 for Missing Requirements surcharge.
2. Declaration executed by the inventor(s).
3. Power of Attorney.

01/21/1998 KDUNCANI 00000036 08894207 Executed Assignment of the invention to France Telecom and Telediffusion de France, and Recordation Form Cover Sheet.

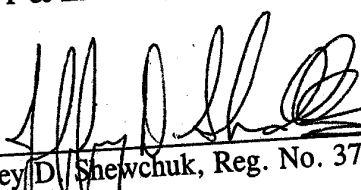
5. Certificate Under 37 CFR § 3.73(b) and attached copy of Assignment.

6. Notification of Missing Requirements Under 35 U.S.C. 371 in the United States Designated/Elected Office (DO/EO/US)

The Commissioner is authorized to charge payment of any additional fees associated with this paper or credit any overpayment to Deposit Account No. 11-0982. A duplicate copy of this sheet is enclosed.

Respectfully submitted,

KINNEY & LANGE, P.A.

By: 

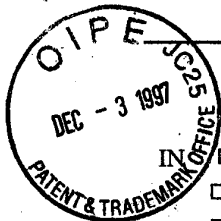
Jeffrey D. Shewchuk, Reg. No. 37,235
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JDS:atp



DECLARATION

IN ☐ ORIGINAL ☒ NATIONAL STAGE OF PCT APPLICATION
☐ DIVISIONAL ☐ CONTINUATION
☐ CONTINUATION-IN-PART

Attorney Docket No.

F264.312-16

SPECIFICATION AND INVENTORSHIP IDENTIFICATION

As a below named inventor, I declare that:

My residence, post office address and citizenship are as stated below next to my name.

I believe I am the original, first and ☐ sole ☒ joint inventor of the subject matter which is claimed, and for which a patent is sought, on the invention entitled DEVICE FOR THE RECEPTION OF DIGITAL SIGNALS WITH ITERATIVE STRUCTURE, AND CORRESPONDING MODULE AND METHOD, the specification of which;

- ☒ is attached hereto.
- ☐ was filed on _____ as Appln. Serial No. _____
☐ and was amended on _____.
- ☒ was described and claimed in PCT International Application No. PCT/FR96/00197, filed on February 6, 1996,
☐ and was amended under PCT Article 19 on _____.

ACKNOWLEDGEMENT OF REVIEW OF PAPERS AND DUTY OF CANDOR

I have reviewed and understand the contents of the above identified specification, including the claims, as amended by any amendment referred to above. I acknowledge the duty to disclose information which is known to me to be material to the patentability of this application in accordance with Title 37, Code of Federal Regulations, § 1.56.

PRIORITY CLAIM (35 USC § 119)

I claim foreign priority benefits under Title 35, United States Code, § 119 of any foreign application(s) for patent or inventor's certificate listed below and have also identified below any foreign application for patent or inventor's certificate having a filing date before that of the application on which priority is claimed:

Prior Foreign Application(s)

Number	Country	Day/Month/Year Filed	Priority Claimed
<u>95 01603</u>	<u>France</u>	<u>7 February 1995</u>	☒ Yes ☐ No
_____	_____	_____	☐ Yes ☐ No
_____	_____	_____	☐ Yes ☐ No

PRIORITY CLAIM (35 USC § 120)

I claim the benefit under Title 35, United States Code, § 120 of any United States application(s) listed below. Insofar as the subject matter of each of the claims of this application is not disclosed in the prior United States application in the manner provided by the first paragraph of Title 35 United States Code § 112, I acknowledge the duty to disclose to the Patent Office all information known to me to be material to patentability as defined in Title 37 Code of Federal Regulations § 1.56 which became available between the filing date of the prior application and the national or PCT international filing date of this application:

U.S. Serial No.	International Appln. No. (under PCT)	Filing Date	Status (patented, pending, abandoned)
_____	_____	_____	_____
_____	_____	_____	_____

DECLARATION

I declare that all statements made herein that are of my own knowledge are true and that all statements that are made on information and belief are believed to be true; and further that these statements were made with the knowledge that willful false statements and the like so made are punishable by fine or imprisonment, or both, under Section 1001 of Title 18 of the United States Code and that such willful false statements may jeopardize the validity of the application or any patent issued thereon.

DESIGNATION OF CORRESPONDENCE ADDRESS

Please address all correspondence and telephone calls to Jeffrey D. Shewchuk in care of:

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Minneapolis, Minnesota 55415-1659
Phone: (612) 339-1863 Fax: (612) 339-6580

Full name of sole or first joint inventor: Catherine Douillard

Signature: *C. Douillard*

Date: 01/09/97 (September 1st)

Residence: Brest, France

Citizenship: France

P.O. Address: 3, rue de Lannion, F-29200 Brest, France

Full name of second joint inventor: Alain Glavieux

Signature: *A. Glavieux*

Date: 01/09/97 (September 1st)

Residence: Brest Cédex, France

Citizenship: France

P.O. Address: ENST Bretagne, Boîte postale 832, F-29285 Brest Cédex, France

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MINNEAPOLIS, MINNESOTA 55415-1659
(612) 339-1863

DECLARATION

Full name of third joint inventor: Michel Jezequel

Signature: [Signature]

Date: 1/9/97 (September 1st)

Residence: Brest, France

Citizenship: France

P.O. Address: Keresseis, F-29200 Brest, France

Full name of fourth joint inventor: Claude Berrou

Signature: [Signature]

Date: 1/9/97 (September 1st)

Residence: Locamaria-Plouzane, France

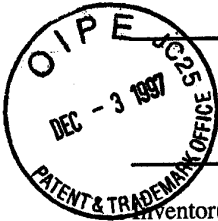
Citizenship: France

P.O. Address: 3, impasse de Gorrequaer, F-29280 Locamaria-Plouzane, France

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337405
POWER OF ATTORNEY



POWER OF ATTORNEY

Attorney Docket No.

F264.312-16

Inventor(s): Catherine Douillard, Alain Glavieux, Michel Jezequel and Claude Berrou

Title: DEVICE FOR THE RECEPTION OF DIGITAL SIGNALS WITH ITERATIVE STRUCTURE, AND CORRESPONDING MODULE AND METHOD

In the patent application:

- ☒ identified above.
☒ filed on July 29, 1997 as application Serial No. _____

I appoint the attorneys and agents associated with Customer Number 00164 to prosecute the patent application identified above and to transact all business in the Patent and Trademark Office connected therewith, including full power of association, substitution and revocation.

I ratify all prior actions taken by Kinney & Lange, P.A. or the attorneys and agents mentioned above in connection with the prosecution of the above-mentioned patent application.

I authorize Kinney & Lange, P.A. to mark the appropriate space above and to insert the filing date and Serial No. of the application, as appropriate.

I authorize the attorneys and agents named herein to accept and follow instructions from Cabinet Patrice Vidon as to any action to be taken in the Patent and Trademark Office regarding this application without direct communication between the attorneys and agents and the undersigned. In the event of a change in the persons from whom instructions may be taken, the attorneys and agents named herein will be so notified by the undersigned.

Please address all correspondence and telephone calls to Jeffrey D. Shewchuk in care of:

KINNEY & LANGE, P.A.
Suite 1500
625 Fourth Avenue South
Minneapolis, Minnesota 55415-1659
Phone: (612) 339-1863 Fax: (612) 339-6580

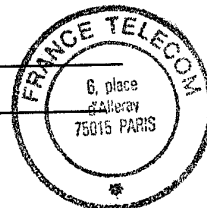
Assignee or Owner: France Telecom

Signature: Le Directeur du CCETT

Printed Name: J. GUESNIER

Title: J. GUESNIER

Date: _____



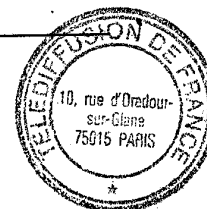
Assignee or Owner: Telediffusion De France

Signature: Le Directeur du CCETT

Printed Name: J. GUESNIER

Title: J. GUESNIER

Date: _____



**KINNEY
& LANGE**
A PROFESSIONAL ASSOCIATION

SU. 500
625 FOURTH AVENUE SOUTH
MINNEAPOLIS, MINNESOTA 55415-1600
(612) 339-1863



332445

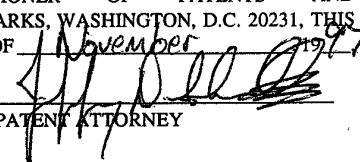
CERTIFICATE UNDER
37 CFR 3.73(b)

Applicant : Catherine Douillardet al.
Serial No. :
Filed : July 29, 1997
For : DEVICE FOR THE RECEPTION OF DIGITAL
SIGNALS WITH ITERATIVE STRUCTURE, AND
CORRESPONDING MODULE AND METHOD
Docket No. : F264.312-16

Group Art Unit:
Examiner:

CERTIFICATE UNDER 37 CFR § 3.73(b)

Commissioner of Patents and Trademarks
Washington, D.C. 20231

I HEREBY CERTIFY THAT THIS PAPER IS BEING
SENT BY U.S. MAIL, FIRST CLASS, TO THE
COMMISSIONER OF PATENTS AND
TRADEMARKS, WASHINGTON, D.C. 20231, THIS
26th DAY OF November 1997

PATENT ATTORNEY

Sir:

France Telecom, a/an company, of France and Telediffusion De France S.A., a/an company, of France,
are the owners of the entire right, title and interest in the patent application identified above by virtue of either:

A. ☒ An assignment from the inventor(s) of the patent application identified above. A copy of the
assignment is attached or was recorded in the Patent and Trademark Office at Reel _____, Frame
_____.

OR

B. ☐ A chain of title from the inventor(s), of the patent application identified above, to the current assignee
as shown below:

1. From: _____ To: _____
A copy of the document is attached or was recorded in the Patent and Trademark
Office at Reel _____, Frame _____.
2. From: _____ To: _____
A copy of the document is attached or was recorded in the Patent and Trademark
Office at Reel _____, Frame _____.
3. From: _____ To: _____
A copy of the document is attached or was recorded in the Patent and Trademark
Office at Reel _____, Frame _____.

**KINNEY
& LANGE**
A PROFESSIONAL ASSOCIATION

SU. 500
625 FOURTH AVENUE SOUTH
MINNEAPOLIS, MINNESOTA 55415-1659
(612) 339-1863

**CERTIFICATE UNDER
37 CFR 3.73(b)**

The undersigned has reviewed all the documents in the chain of title of the patent application identified above and certifies, to the best of undersigned's knowledge and belief, title is in the assignee identified above.

The undersigned (whose title is supplied below) is empowered to act on behalf of the assignee.

I hereby declare that all certified statements made herein of my own knowledge are true, and that all statements made on information and belief are believed to be true; and further, that these statements are made with the knowledge that willful false statements, and the like so made, are punishable by fine or imprisonment, or both, under Section 1001, Title 18 of the United States Code, and that such willful false statements may jeopardize the validity of the application or any patent issuing thereon.

FRANCE TELECOM

Signature: _____

J. Guesnier
Le Directeur du CCETT



Date: _____

Printed Name: _____

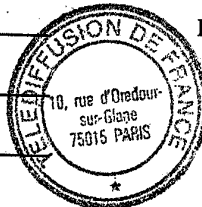
Title: _____

J. GUESNIER

TELEDIFFUSION DE FRANCE

Signature: _____

J. Guesnier
Le Directeur du CCETT



Date: _____

Printed Name: _____

Title: _____

J. GUESNIER

ASSIGNMENT

Attorney Docket No.

F264.312-16

Inventor(s): Catherine Douillard, Alain Glavieux, Michel Jezequel and Claude Berrou
Title: DEVICE FOR THE RECEPTION OF DIGITAL SIGNAL WITH ITERATIVE STRUCTURE, AND CORRESPONDING MODULE AND METHOD

WHEREAS, I, Catherine Douillard, of 3, rue de Lannion, F-29200 Brest, France, Alain Glavieux, of ENST Bretagne, Boîte postal 832, F-29285 Brest Cédex, France, Michel Jezequel of Keresseis, F-29200 Brest, France, and Claude Berrou, of 3, impasse de Gorrequaer, F-35700 Locmaria-Plouzane, France, have invented certain new and useful improvements as described in an application entitled DEVICE FOR THE RECEPTION OF DIGITAL SIGNAL WITH ITERATIVE STRUCTURE, AND CORRESPONDING MODULE AND METHOD for Letters Patent of the United States, the application having been executed on even date herewith, and/or being identifiable in the United States Patent and Trademark Office by Serial No. _____, filed _____; and

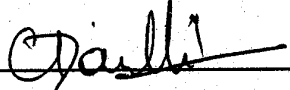
WHEREAS, France Telecom, a company organized and existing under the laws of France, and having offices at 6, place d'Alleray, F-75015 Paris, France and Telediffusion De France S.A., a company organized and existing under the laws of France, and having offices at 10, rue d'Oradour-sur-Glane, F-75732 Paris Cédex 15, France, ("Assignee") is desirous of acquiring the entire right, title and interest in and to the invention, the application, and any and all Letters Patent or similar legal protection, foreign or domestic, to be obtained therefor;

NOW, THEREFORE, for good and valuable consideration, the receipt and adequacy of which is hereby acknowledged, I transfer to Assignee, its successors and assigns, my entire right, title and interest in and to the invention, the above-identified application, corresponding domestic and foreign applications, all Letters Patent or similar legal protection issuing thereon, and all rights and benefits under any applicable treaty or convention; and I authorize the Commissioner of Patents and Trademarks of the United States or foreign equivalent thereof to issue the Letters Patent or similar legal protection to the Assignee.

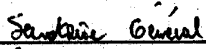
I authorize the Assignee, its successors and assigns, to insert in this instrument the filing date and serial number of the application when ascertained.

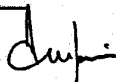
I authorize the Assignee, its successors and assigns, or anyone it may properly designate, to apply for Letters Patent or similar legal protection, in its own name if desired, in any and all foreign countries.

I represent to the Assignee, its successors and assigns, that I have not and shall not execute any writing or do any act whatsoever conflicting with this Assignment. I, my executors or administrators, will at any time upon request, without additional consideration, but at the expense of the Assignee, its successors and assigns, execute such additional writings and do such additional acts as the Assignee, its successors and assigns, may deem desirable to perfect its enjoyment of this grant, and render all assistance in making application for and obtaining, maintaining, and enforcing the Letters Patent or similar legal protection on the invention in any and all countries.

Signature: 
Printed Name: Catherine Douillard

Date: 01/09/97 (September 1st)

Witnessed By: 
Printed Name: René TURPIN
Address: Technopole de Brest Imbra
BP 832 BREST



**KINNEY
& LANGE**
A PROFESSIONAL ASSOCIATION

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625 FOURTH AVENUE SOUTH
MINNEAPOLIS, MINNESOTA 55415-1659
(612) 339-1863

ASSIGNMENT

Signature: [Signature]

Date: 01/09/97 (Sept. 1st)

Printed Name: Alain Glavieux

Witnessed By: Suzanne Ginnel

Printed Name: Rene TULLIN

Address Technopole de Brest - Iroise
B.P. 832 BREST

[Signature]

Signature: [Signature]

Date: 1/9/97 (Sept 1st)

Printed Name: Michel Jezequel

Witnessed By: Suzanne Ginnel

Printed Name: Rene TULLIN

Address Technopole de Brest - Iroise
B.P. 832 BREST

[Signature]

Signature: [Signature]

Date: 1/9/97 (Sept 1st)

Printed Name: Claude Berrou

Witnessed By: Suzanne Ginnel

Printed Name: Rene TULLIN

Address Technopole de Brest - Iroise
B.P. 832 BREST

[Signature]



UNITED STATES DEPARTMENT OF COMMERCE
Patent and Trademark Office
Address: ASSISTANT COMMISSIONER FOR PATENTS
Box PCT
Washington, D.C. 20231

08/894,207

U.S. APPLICATION NO. 08/894,207 FIRST NAMED APPLICANT DOUILLARD ATTY. DOCKET NO. C F264.312-16

JEFFREY D. SHEWCHUK
KINNEY & LANGE PA
SUITE 1500
625 FOURTH AVENUE SOUTH
MINNEAPOLIS MN 55415-1659

5611

INTERNATIONAL APPLICATION NO.

PCT/FR96/00197

I.A. FILING DATE

PRIORITY DATE

02/06/96

02/07/95

DATE MAILED:

10/31/97

NOTIFICATION OF MISSING REQUIREMENTS UNDER 35 U.S.C. 371 IN THE UNITED STATES DESIGNATED/ELECTED OFFICE (DO/EO/US)

1. The following items have been submitted by the applicant or the IB to the United States Patent and Trademark Office as ☐ a Designated Office (37 CFR 1.494), ☒ an Elected Office (37 CFR 1.495):

☒ U.S. Basic National Fee.

☒ Copy of the international application in:

☒ a non-English language.

☐ English.

☐ Translation of the international application into English.

☐ Oath or Declaration of inventors(s) for DO/EO/US.

☐ Copy of Article 19 amendments.

☐ Translation of Article 19 amendments into English.

☐ The International Preliminary Examination Report in English and its Annexes, if any.

☐ Translation of Annexes to the International Preliminary Examination Report into English.

☒ Preliminary amendment(s) filed 29/1/97 and

☒ Information Disclosure Statement(s) filed 29/1/97 and

☐ Assignment document.

☐ Power of Attorney and/or Change of Address.

☐ Substitute specification filed

☐ Verified Statement Claiming Small Entity Status.

☐ Priority Document.

☒ Copy of the International Search Report ☒ and copies of the references cited therein.

☐ Other:

2. The following items **MUST** be furnished within the period set forth below in order to complete the requirements for acceptance under 35 U.S.C. 371:

☐ a. Translation of the application into English. Note a processing fee will be required if submitted later than the appropriate 20 or 30 months from the priority date.

☐ The current translation is defective for the reasons indicated on the attached Notice of Defective Translation.

☐ b. Processing fee for providing the translation of the application and/or the Annexes later than the appropriate 20 or 30 months from the priority date (37 CFR 1.492(f)).

☒ c. Oath or declaration of the inventors, in compliance with 37 CFR 1.497(a) and (b), identifying the application by the International application number and international filing date.

☐ The current oath or declaration does not comply with 37 CFR 1.497(a) and (b) for the reasons indicated on the attached PCT/DO/EO/917.

☒ d. Surcharge for providing the oath or declaration later than the appropriate 20 or 30 months from the priority date (37 CFR 1.492(e)).

3. Additional claim fees of \$ _____ as a ☐ large entity ☐ small entity, including any required multiple dependent claim fee, are required. Applicant must submit the additional claim fees or cancel the additional claims for which fees are due. See attached PTO-875.

ALL OF THE ITEMS SET FORTH IN 2(a)-2(d) AND 3 ABOVE MUST BE SUBMITTED WITHIN ONE MONTH FROM THE DATE OF THIS NOTICE OR BY ☐ 21 OR ☒ 31 MONTHS FROM THE PRIORITY DATE FOR THE APPLICATION, WHICHEVER IS LATER. FAILURE TO PROPERLY RESPOND WILL RESULT IN ABANDONMENT.

The time period set above may be extended by filing a petition and fee for extension of time under the provisions of 37 CFR 1.136(a).

4. Translation of the Annexes **MUST** be submitted no later than the time period set above or the annexes will be cancelled. Note processing fee will be required if submitted later than 30 months from the priority date.

5. ☐ The Article 19 amendments are cancelled since a translation was not provided by the appropriate 20 (37 CFR 1.494(d)) or 30 (37 CFR 1.495(d)) months from the priority date.

Applicant is reminded that any communication to the United States Patent and Trademark Office must be mailed to the address given in the heading and include the U.S. application no. shown above. (37 CFR 1.5)

A copy of this notice MUST be returned with this response.

Enclosed: ☐ PCT/DO/EO/917
☐ PTO-875

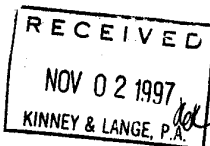
☐ Notice of Defective Translation

FORM PCT/DO/EO/905 (September 1996)

Telephone: (703)

Shelby Vigil
PCT International Division

3053653





UNITED STATES DEPARTMENT OF COMMERCE
Patent and Trademark Office
Address: ASSISTANT COMMISSIONER FOR PATENTS
Washington, D.C. 20231

08/894/207

U.S. APPLICATION NO.	FIRST NAMED APPLICANT	ATTY. DOCKET NO.
08/894,207	DOUILLARD	C F264.312-16
INTERNATIONAL APPLICATION NO.		
PCT/FR96/00197		
I.A. FILING DATE	PRIORITY DATE	
02/06/96	02/07/95	
DATE MAILED: 02/02/98		

NOTIFICATION OF ACCEPTANCE OF APPLICATION UNDER 35 U.S.C. 371
AND 37 CFR 1.494 OR 1.495

1. The applicant is hereby advised that the United States Patent and Trademark Office in its capacity as ☐ a Designated Office (37 CFR 1.494), ☒ an Elected Office (37 CFR 1.495), has determined that the above identified international application has met the requirements of 35 U.S.C. 371, and is ACCEPTED for national patentability examination in the United States Patent and Trademark Office.

2. The United States Application Number assigned to the application is shown above and the relevant dates are:

3 Dec 97
35 U.S.C. 102(e) DATE

3 Dec 97
DATE OF RECEIPT OF
35 U.S.C. 371 REQUIREMENTS

A Filing Receipt (PTO-103X) will be issued for the present application in due course. THE DATE APPEARING ON THE FILING RECEIPT AS THE "FILING DATE" IS THE DATE ON WHICH THE LAST OF THE 35 U.S.C. 371(C) REQUIREMENTS HAS BEEN RECEIVED IN THE OFFICE. THIS DATE IS SHOWN ABOVE. The filing date of the above identified application is the international filing date of the international application (Article 11(3) and 35 U.S.C. 363). Once the Filing Receipt has been received, send all correspondence to the Group Art Unit designated thereon.

3. ☐ A request for immediate examination under 35 U.S.C. 371(f) was received on _____ and the application will be examined in turn.

4. The following items have been received:

- ☒ U.S. Basic National Fee.
- ☒ Copy of the international application in:
 - ☒ a non-English language.
 - ☐ English.
- ☒ Translation of the international application into English.
- ☒ Oath or Declaration of inventor(s) for DO/EO/US.
- ☒ Copy of Article 19 amendments. ☐ Translation of Article 19 amendments into English.
The Article 19 amendments ☐ have ☐ have not been entered.
- ☐ The International Preliminary Examination Report in English and its Annexes, if any.
- ☐ Translation of Annexes to the International Preliminary Examination Report into English.
The Annexes ☐ have ☐ have not been entered.
- ☐ Preliminary amendment(s) filed _____ and _____.
- ☒ Information Disclosure Statement(s) filed 29 Jul 97 and _____.
- ☒ Assignment document.
- ☒ Power of Attorney and/or Change of Address.
- ☐ Substitute specification filed _____.
- ☐ Verified Statement Claiming Small Entity Status.
- ☒ Priority Document.
- ☒ Copy of the International Search Report ☒ and copies of the references cited therein.
- ☐ Other:

Applicant is reminded that any communication to the United States Patent and Trademark Office must be mailed to the address given in the heading and include the U.S. application no. shown above. (37 CFR 1.5)

Shelby I. Vigil
Patent Counsel
Telephone: (703) 305-3653

FORM PCT/DO/EO/903 (September 1996)

U.S. Appl. No. 08/894207

International Appl No. FR 96/1197

Application filed by: ☐ 20 months ☒ 30 months

7 Aug 97

INTERNATIONAL APPLICATION PAPERS IN THE APPLICATION FILE:

- | | |
|---|---|
| ☒ International application (RECORD COPY) | ☐ Request form PCT/RO/101 |
| ☐ Article 19 amendments | ☐ PCT/IB/302 |
| ☒ PCT/IB/331 | ☒ PCT/ISA/210-Search Report |
| ☒ PCT/IPEA/409 IPER (PCT/IPEA/416 on front) | ☒ Search Report references |
| ☐ Annexes to 409 | ☐ Other _____ |
| ☒ Priority document(s) No. <u>1</u> | |

☐ INTERNATIONAL APPLICATION-ON DOUBLE SIDED PAPER (COPIES MADE)

RECEIPTS FROM THE APPLICANT: (other than checked above)

- | | |
|--|--|
| ☐ Basic National Fee (paid or authorized to charge) | ☐ Preliminary amendment(s) filed |
| Translation of international application as filed: | |
| ☒ Description | ☒ Information Disclosure Statement |
| ☒ Claims | ☒ Assignment document |
| ☐ Words in the drawing figure(s) | ☐ Power of attorney/Change of address |
| ☐ Article 19 amendments | ☐ Substitute specification |
| ☐ Annexes to 409 | ☐ Verified small status claim |
| ☒ Oath / Declaration | ☐ Other _____ |
| ☐ DNA diskette | |

Notes:

35 U.S.C. 371 - Receipt of Request (PTO-1390)

Date acceptable oath / declaration received

Date complete 35 U.S.C 371 requirements met

102(e) Date

Date of completion of DO/EO 906 - Notification of Missing 102(e) Requirements

Date of completion of DO/EO 907 - Notification of Acceptance for 102(e) date

Date of completion of DO/EO 911 - Application accepted under 35 U.S.C. 111

Date of completion of DO/EO 905 - Notification of Missing Requirements

Date of completion of DO/EO 916 - Notification of Defective Response

Date of completion of DO/EO 903 - Notification of Acceptance

Date of completion of DO/EO 909 - Notification of Abandonment

WIPO Publication

Publication No.

WO 96/24999

Publication Date

15 Aug 96

Publication Language

French

Not Published

☐ U.S. only

Designated

☐ EP request

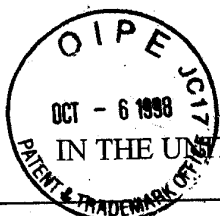
Screening done by:

Phyllis M. Lowton
Legal Instr. Examin

DO/EO BIBLIOGRAPHIC DATA ENTRY

SERIAL NUMBER:	08 / 894207	RECEIPT DATE:	07 / 23 / 97
IA NUMBER:	PCT/ FR96 / 00197	IA FILING DATE:	02 / 06 / 96
FAMILY NAME:	DOUILLARD	DELAY WAIVED (Y/N):	I
GIVEN NAME:	CATHERINE	DEMAND RECEIVED (Y/N):	Y
PRIORITY CLAIMED (Y/N):	Y	PRIORITY DATE:	02 / 07 / 95
NO BASIC FEE (Y/N):	N	US DESIGNATED ONLY (Y/N):	I
ATTORNEY DOCKET NUMBER:	F264.312-16	COUNTRY:	FRX
CORRESPONDENCE NAME/ADDRESS:	CUSTOMER NUMBER:	000000	TELEPHONE 6123391863
NAME:	JEFFREY D. SHEWCHUK		
	KINNEY & LANGE PA		
STREET:	SUITE 1500		
	625 FOURTH AVENUE SOUTH		
CITY:	MINNEAPOLIS		
STATE/COUNTRY:	MN	ZIP:	554151659
APPLICATION TITLES:			
	DEVICE FOR THE RECEPTION OF DIGITAL SIGNALS WITH ITERATIVE STRUCTURE		
	AND CORRESPONDING MODULE AND METHOD		

TAB TO LAST POSITION,PUSH SEND



IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

452731
G. Harris
10-20-98

First Named
Inventor : DOUILLARD CATHERINE
Appln. No. : 08/894207
Filed : 06FE1996
Title : DEVICE FOR THE RECEPTION OF DIGITAL SIGNALS W
Docket No. : F264.312-0016

Received

OCT 06 1998

Group 2700

CHANGE OF ATTORNEY'S ADDRESS IN APPLICATION

Assistant Commissioner for Patents
Washington, D.C. 20231

Please send all correspondence for this application to the previously designated attorney at the following address:

Kinney & Lange, P.A.
The Kinney & Lange Building
312 South Third Street
Minneapolis, MN 55415-1002

The telephone number remains unchanged.

Respectfully submitted,

KINNEY & LANGE, P.A.

Dated: September 10, 1998

By:

Jeffrey D. Shewchuk, Registration No. 37,235
Kinney & Lange, P.A.
The Kinney & Lange Building
312 South Third Street
Minneapolis, MN 55415-1002

Tel. No. (612) 339-1863
Customer No.: 00164

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98 OCT 16 PM 1:10
GROUP 2700

08/894207

Rec'd PCT/PTO 29 JUL 1997
#6

IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

Applicant	: Catherine Douillard et al.	Group Art Unit: Examiner:
Serial No.	:	
Filed	: Herewith	
For	: DEVICE FOR THE RECEPTION OF DIGITAL SIGNALS WITH ITERATIVE STRUCTURE, AND CORRESPONDING MODULE AND METHOD	
Docket No.	: F264.312-16	

INFORMATION DISCLOSURE STATEMENT

Assistant Commissioner for Patents
Washington, D.C. 20231

Sir:

The patents or publications listed on the enclosed PTO Form-1449 are submitted pursuant to 37 CFR § 1.97. Copies of the patents or publications are enclosed as necessary.

Submitted herewith is a copy (with English translation as appropriate) of an Official Search Report of the European Patent Office in counterpart foreign application No. PCT/FR96/00197 filed February 6, 1996.

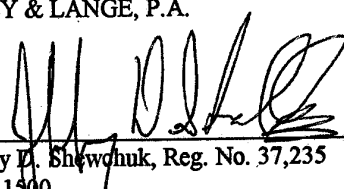
METHOD OF PAYMENT

☒ No fee is required.☐ Attached is a check in the amount of \$0.

The Commissioner is authorized to charge any fee deficiency required by this paper or credit any overpayment to Deposit Account No. 11-0982. A duplicate copy of this communication is enclosed.

Respectfully submitted,

KINNEY & LANGE, P.A.

By: Jeffrey D. Shewchuk, Reg. No. 37,235
Suite 1500

625 Fourth Avenue South

Minneapolis, MN 55415-1659

Phone: (612) 339-1863 Fax: (612) 339-6580

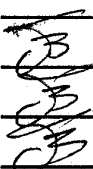
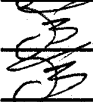
JDS:cnj

FORM PTO-1449	Atty. Docket No.: F264.312-16	Serial No.: 08/894,207
LIST OF PATENTS AND PUBLICATIONS FOR APPLICANT'S INFORMATION DISCLOSURE STATEMENT	Applicant: Catherine Douillard et al.	
	Filing Date: Herewith	Group Art: 2701

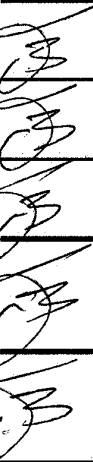
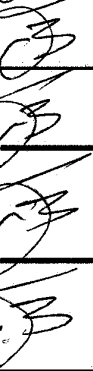
U.S. PATENT DOCUMENTS

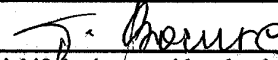
Examiner Initial	Document No.	Date	Name	Class	Sub Class	Filing Date If Appropriate
AA						
AB						
AC						
AD						
AE						
AF						

FOREIGN PATENT DOCUMENTS

		Document No.	Date	Country	Class	Sub Class	Translation Yes No
	AI	0 511 141 A1	10/28/92	European	—	—	X
	AJ	WO 91/06165	5/2/91	PCT	—	—	
	AK	0 524 597 A1	1/27/93	European	—	—	X

OTHER ART (Including Author, Title, Date, Pertinent Pages, Etc.)

	AL	Claude Berrou, et al., <u>ICC'93 Geneva</u> , IEEE International Conference on Communications '93, Technical Program Conference Record, Vol. 2/3, May 23-26, 1993, Geneva, Switzerland, pp.1065-1070.
	AM	Hidekazu Murata et al., <u>Performance of Adaptive Equalizer Using Iterative Application of Viterbi Algorithm</u> , Electronics and Communications in Japan, Part 1, Vol. 77, No. 4, April 1994, pp. 103-110.
	AN	J.W.M. Bergmans et al., <u>On the Use of Decision Feedback for Simplifying the Viterbi Detector</u> , Philips Journal of Research, Vol. 42, No. 4, 1987, pp. 428-399.
	AO	Jianjun Wu, et al., <u>A Channel Model and A Novel Adaptive Equalizer for Mobile Radio Communications</u> , IEEE in Houston, Globecom '93, IEE Global Telecommunications Conference, November 29 - December 2, 1993, Vol. 1 of 4, pp. 98-102.
	AP	Peter Jung, et al., <u>VLSI Implementation of Soft Output Viterbi Equalizers For Mobile Radio Applications</u> , Vehicular Technology Society 42 nd VTS Conference Frontiers of Technology, Vol. 2 of 2, May 10-13, 1992, Denver Colorado, pp. 577-585.

EXAMINER: 	DATE CONSIDERED: 3/12/99
EXAMINER: Initial if citation considered, whether or not citation is in conformance with MPEP 609; draw line through citation if not in conformance and not considered. Include copy of this form with next communication to applicant.	

INTERNATIONAL SEARCH REPORT

International Application No
PCT/FR 96/00197

A. CLASSIFICATION OF SUBJECT MATTER
IPC 6 H04L25/03

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

IPC 6 H04L H03M

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category *	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	EP,A,0 511 141 (FRANCE TELECOM / TELEDIFFUSION DE FRANCE) 28 October 1992 cited in the application see abstract see page 4, line 21 - page 5, line 41; claims; figures 3,4 --- -/--	1-9

☒ Further documents are listed in the continuation of box C.

☒ Patent family members are listed in annex.

* Special categories of cited documents :

- "A" document defining the general state of the art which is not considered to be of particular relevance
- "E" earlier document but published on or after the international filing date
- "L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)
- "O" document referring to an oral disclosure, use, exhibition or other means
- "P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art.

"&" document member of the same patent family

Date of the actual completion of the international search

24 April 1996

Date of mailing of the international search report

29.05.96

Name and mailing address of the ISA

European Patent Office, P.B. 5818 Patentlaan 2
NL - 2280 HV Rijswijk
Tel. (+31-70) 340-2040, Tx. 31 651 epo nl,
Fax (+31-70) 340-3016

Authorized officer

Gries, T

INTERNATIONAL SEARCH REPORT

Intern al Application No
PCT/FR 96/00197

C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT		
Category *	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	ICC '93 GENEVA. IEEE INTERNATIONAL CONFERENCE ON COMMUNICATIONS '93. TECHNICAL PROGRAM, CONFERENCE RECORD (CAT. NO.93CH3261-5), PROCEEDINGS OF ICC '93 - IEEE INTERNATIONAL CONFERENCE ON COMMUNICATIONS, GENEVA, SWITZERLAND, 23-26 MAY 1993, ISBN 0-7803-0950-2, 1993, NEW YORK, NY, USA, IEEE, USA, pages 1064-1070 vol.237, XP000371240 BERROU C ET AL: "Near Shannon limit error-correcting coding and decoding: Turbo-codes. 1" cited in the application see figures 3B,4A,4B ---	1-9
A	ELECTRONICS AND COMMUNICATIONS IN JAPAN, PART 1 (COMMUNICATIONS), APRIL 1994, USA, vol. 77, no. 4, ISSN 8756-6621, pages 103-110, XP000445333 MURATA H ET AL: "Performance of adaptive equalizer using iterative application of Viterbi algorithm" see page 103, right-hand column, paragraph 5 - page 105, left-hand column, paragraph 2; figure 1 ---	1-9
A	PHILIPS JOURNAL OF RESEARCH, 1987, NETHERLANDS, vol. 42, no. 4, ISSN 0165-5817, pages 399-428, XP000565157 BERGMANS J W M ET AL: "On the use of decision feedback for simplifying the Viterbi detector" see page 401, paragraph 2 see page 406, paragraph 1 - page 409, paragraph 2; figures 3,4 see page 411, paragraph 3 see page 426, paragraph 5 - page 427, paragraph 2 --- -/--	1-9

Form PCT/ISA/210 (continuation of second sheet) (July 1992)

RAPPORT DE RECHERCHE INTERNATIONALE

Dema	internationale No
PCT/FR 96/00197	

A. CLASSEMENT DE L'OBJET DE LA DEMANDE CIB 6 H04L25/03		
Selon la classification internationale des brevets (CIB) ou à la fois selon la classification nationale et la CIB		
B. DOMAINES SUR LESQUELS LA RECHERCHE A PORTE Documentation minimale consultée (système de classification suivi des symboles de classement) CIB 6 H04L H03M		
Documentation consultée autre que la documentation minimale dans la mesure où ces documents relèvent des domaines sur lesquels a porté la recherche		
Base de données électronique consultée au cours de la recherche internationale (nom de la base de données, et si cela est réalisable, termes de recherche utilisés)		
C. DOCUMENTS CONSIDERES COMME PERTINENTS		
Catégorie *	Identification des documents cités, avec, le cas échéant, l'indication des passages pertinents	no. des revendications visées
A	EP,A,0 511 141 (FRANCE TELECOM / TELEDIFFUSION DE FRANCE) 28 Octobre 1992 cité dans la demande voir abrégé voir page 4, ligne 21 - page 5, ligne 41; revendications; figures 3,4 --- -/--	1-9
☒ Voir la suite du cadre C pour la fin de la liste des documents ☒ Les documents de familles de brevets sont indiqués en annexe		
* Catégories spéciales de documents cités:		
"A" document définissant l'état général de la technique, non considéré comme particulièrement pertinent "E" document antérieur, mais publié à la date de dépôt international ou après cette date "L" document pouvant jeter un doute sur une revendication de priorité ou cité pour déterminer la date de publication d'une autre citation ou pour une raison spéciale (telle qu'indiquée) "O" document se référant à une divulgation orale, à un usage, à une exposition ou tous autres moyens "P" document publié avant la date de dépôt international, mais postérieurement à la date de priorité revendiquée "T" document ultérieur publié après la date de dépôt international ou la date de priorité et n'appartenant pas à l'état de la technique pertinent, mais cité pour comprendre le principe ou la théorie constituant la base de l'invention "X" document particulièrement pertinent; l'invention revendiquée ne peut être considérée comme nouvelle ou comme impliquant une activité inventive par rapport au document considéré isolément "Y" document particulièrement pertinent; l'invention revendiquée ne peut être considérée comme impliquant une activité inventive lorsque le document est associé à un ou plusieurs autres documents de même nature, cette combinaison étant évidente pour une personne du métier "&" document qui fait partie de la même famille de brevets		
Date à laquelle la recherche internationale a été effectivement achevée 24 Avril 1996		Date d'expédition du présent rapport de recherche internationale 29.05.96
Nom et adresse postale de l'administration chargée de la recherche internationale Office Européen des Brevets, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+ 31-70) 340-2040, Tx. 31 651 epo nl, Fax (+ 31-70) 340-3016		Fonctionnaire autorisé Gries, T

Formulaire PCT/ISA/210 (deuxième feuille) (juillet 1992)

RAPPORT DE RECHERCHE INTERNATIONALE

Demande internationale No
PCT/FR 96/00197

C.(suite) DOCUMENTS CONSIDERES COMME PERTINENTS		
Catégorie *	Identification des documents cités, avec, le cas échéant, l'indication des passages pertinents	no. des revendications visées
A	ICC '93 GENEVA. IEEE INTERNATIONAL CONFERENCE ON COMMUNICATIONS '93. TECHNICAL PROGRAM, CONFERENCE RECORD (CAT. NO.93CH3261-5), PROCEEDINGS OF ICC '93 - IEEE INTERNATIONAL CONFERENCE ON COMMUNICATIONS, GENEVA, SWITZERLAND, 23-26 MAY 1993, ISBN 0-7803-0950-2, 1993, NEW YORK, NY, USA, IEEE, USA, pages 1064-1070 vol.237, XP000371240 BERROU C ET AL: "Near Shannon limit error-correcting coding and decoding: Turbo-codes. 1" cité dans la demande voir figures 3B,4A,4B	1-9
A	--- ELECTRONICS AND COMMUNICATIONS IN JAPAN, PART 1 (COMMUNICATIONS), APRIL 1994, USA, vol. 77, no. 4, ISSN 8756-6621, pages 103-110, XP000445333 MURATA H ET AL: "Performance of adaptive equalizer using iterative application of Viterbi algorithm" voir page 103, colonne de droite, alinéa 5 - page 105, colonne de gauche, alinéa 2; figure 1	1-9
A	--- PHILIPS JOURNAL OF RESEARCH, 1987, NETHERLANDS, vol. 42, no. 4, ISSN 0165-5817, pages 399-428, XP000565157 BERGMANS J W M ET AL: "On the use of decision feedback for simplifying the Viterbi detector" voir page 401, alinéa 2 voir page 406, alinéa 1 - page 409, alinéa 2; figures 3,4 voir page 411, alinéa 3 voir page 426, alinéa 5 - page 427, alinéa 2 --- -/--	1-9

Formulaire PCT/ISA/210 (suite de la deuxième feuille) (juillet 1992)

INTERNATIONAL SEARCH REPORT

Information on patent family members

International Application No
PCT/FR 96/00197

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
EP-A-511141	28-10-92	FR-A- 2675971 US-A- 5446747	30-10-92 29-08-95
WO-A-9106165	02-05-91	US-A- 5271042 AU-B- 637166 AU-B- 6729490 CA-A, C 2066270 CN-A- 1050958 EP-A- 0495006 JP-T- 5504872 TR-A- 26468 US-A- 5144644	14-12-93 20-05-93 16-05-91 14-04-91 24-04-91 22-07-92 22-07-93 15-03-95 01-09-92
EP-A-524597	27-01-93	FR-A- 2679721 AU-B- 651472 AU-B- 1952392 CA-A- 2074277 JP-A- 5199143 NZ-A- 243590 US-A- 5331662	29-01-93 21-07-94 28-01-93 23-01-93 06-08-93 28-08-95 19-07-94

INTERNATIONAL SEARCH REPORT

Intern al Application No
PCT/FR 96/00197

C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT		
Category *	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	IEEE IN HOUSTON. GLOBECOM '93. IEEE GLOBAL TELECOMMUNICATIONS CONFERENCE, INCLUDING A COMMUNICATIONS THEORY MINI-CONFERENCE. TECHNICAL PROGRAM CONFERENCE RECORD (CAT. NO.93CH3250-8), PROCEEDINGS OF GLOBECOM '93. IEEE GLOBAL TELECOMMUNICATIONS CONFERENCE, ISBN 0-7803-0917-0, 1993, NEW YORK, NY, USA, IEEE, USA, pages 98-102 vol.1, XP000428037 JIANJUN WU ET AL: "A channel model and a novel adaptive equalizer for mobile radio communications" see abstract see page 98, left-hand column, paragraph 3 - right-hand column, paragraph 1 see page 100, right-hand column, line 1 - page 101, left-hand column, line 18; figure 2	1-9
A	--- WO,A,91 06165 (MOTOROLA INC.) 2 May 1991 see abstract see page 3, line 18 - line 28; claims; figure	1-9
A	--- VEHICULAR TECHNOLOGY SOCIETY 42ND VTS CONFERENCE. FRONTIERS OF TECHNOLOGY. FROM PIONEERS TO THE 21ST CENTURY (CAT. NO.92CH3159-1), DENVER, CO, USA, 10-13 MAY 1992, ISBN 0-7803-0673-2, 1992, NEW YORK, NY, USA, IEEE, USA, pages 577-585 vol.2, XP000339855 JUNG P ET AL: "VLSI implementation of soft output Viterbi equalizers for mobile radio applications" cited in the application see page 578, left-hand column, paragraph 3 see page 577, right-hand column, paragraph 2	1-9
A	--- EP,A,0 524 597 (ALCATEL RADIOTELEPHONE) 27 January 1993 see abstract see page 6, line 8 - page 7, line 19 -----	1-9

RAPPORT DE RECHERCHE INTERNATIONALE

Dema internationale No
PCT/FR 96/00197

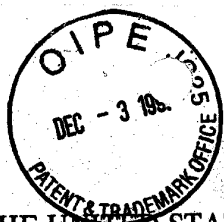
C.(suite) DOCUMENTS CONSIDERES COMME PERTINENTS		
Catégorie *	Identification des documents cités, avec, le cas échéant, l'indication des passages pertinents	no. des revendications visées
A	IEEE IN HOUSTON. GLOBECOM '93. IEEE GLOBAL TELECOMMUNICATIONS CONFERENCE, INCLUDING A COMMUNICATIONS THEORY MINI-CONFERENCE. TECHNICAL PROGRAM CONFERENCE RECORD (CAT. NO.93CH3250-8), PROCEEDINGS OF GLOBECOM '93. IEEE GLOBAL TELECOMMUNICATIONS CONFERENCE, ISBN 0-7803-0917-0, 1993, NEW YORK, NY, USA, IEEE, USA, pages 98-102 vol.1, XP000428037 JIANJUN WU ET AL: "A channel model and a novel adaptive equalizer for mobile radio communications" voir abrégé voir page 98, colonne de gauche, alinéa 3 - colonne de droite, alinéa 1 voir page 100, colonne de droite, ligne 1 - page 101, colonne de gauche, ligne 18; figure 2 ---	1-9
A	WO,A,91 06165 (MOTOROLA INC.) 2 Mai 1991 voir abrégé voir page 3, ligne 18 - ligne 28; revendications; figure ---	1-9
A	VEHICULAR TECHNOLOGY SOCIETY 42ND VTS CONFERENCE. FRONTIERS OF TECHNOLOGY. FROM PIONEERS TO THE 21ST CENTURY (CAT. NO.92CH3159-1), DENVER, CO, USA, 10-13 MAY 1992, ISBN 0-7803-0673-2, 1992, NEW YORK, NY, USA, IEEE, USA, pages 577-585 vol.2, XP000339855 JUNG P ET AL: "VLSI implementation of soft output Viterbi equalizers for mobile radio applications" cité dans la demande voir page 578, colonne de gauche, alinéa 3 voir page 577, colonne de droite, alinéa 2 ---	1-9
A	EP,A,0 524 597 (ALCATEL RADIOTELEPHONE) 27 Janvier 1993 voir abrégé voir page 6, ligne 8 - page 7, ligne 19 -----	1-9

RAPPORT RECHERCHE INTERNATIONALE

Renseignements relatifs aux membres de familles de brevets

Demar internationale No
PCT/FR 96/00197

Document brevet cité au rapport de recherche	Date de publication	Membre(s) de la famille de brevet(s)	Date de publication
EP-A-511141	28-10-92	FR-A- 2675971	30-10-92
		US-A- 5446747	29-08-95
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		AU-B- 637166	20-05-93
		AU-B- 6729490	16-05-91
		CA-A,C 2066270	14-04-91
		CN-A- 1050958	24-04-91
		EP-A- 0495006	22-07-92
		JP-T- 5504872	22-07-93
		TR-A- 26468	15-03-95
		US-A- 5144644	01-09-92
EP-A-524597	27-01-93	FR-A- 2679721	29-01-93
		AU-B- 651472	21-07-94
		AU-B- 1952392	28-01-93
		CA-A- 2074277	23-01-93
		JP-A- 5199143	06-08-93
		NZ-A- 243590	28-08-95
		US-A- 5331662	19-07-94



PTO/PCT Rec'd 3 DEC 1997

IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

Applicant	: Catherine Douillard et al.
Serial No.	: 08/894,207
Filed	: July 29, 1997
For	: DEVICE FOR THE RECEPTION OF DIGITAL SIGNALS WITH ITERATIVE STRUCTURE AND CORRESPONDING MODULE AND METHOD
Docket No.	: F264.312-16

**RESPONSE TO NOTIFICATION OF MISSING REQUIREMENTS
UNDER 35 USC 371 IN THE UNITED STATES
DESIGNATED/ELECTED OFFICE (DO/EO/US)**

Box Missing Parts
Assistant Commissioner for Patents
Washington, D.C. 20231

I CERTIFY THAT THIS PAPER IS BEING SENT BY U.S. MAIL,
FIRST CLASS, TO THE ASSISTANT COMMISSIONER FOR
PATENTS, WASHINGTON, D.C. 20231, THIS 26th DAY OF
November, 1997.
PATENT ATTORNEY

Sir:

In response to the Notification of Missing Requirements Under 35 U.S.C. 371 in the United States Designated/Elected Office (DO/EO/US) dated October 31, 1997, Applicant encloses the following documents to complete the above-identified patent application filed July 29, 1997:

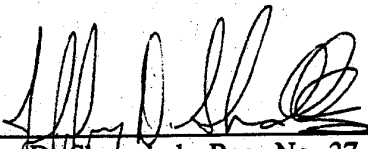
1. Our checks in the amount of \$40.00 to cover the Assignment recording fee; and \$130.00 for Missing Requirements surcharge.
2. Declaration executed by the inventor(s).
3. Power of Attorney.
4. Executed Assignment of the invention to France Telecom and Telediffusion de France, and Recordation Form Cover Sheet.
5. Certificate Under 37 CFR § 3.73(b) and attached copy of Assignment.

6. Notification of Missing Requirements Under 35 U.S.C. 371 in the United States Designated/Elected Office (DO/EO/US)

The Commissioner is authorized to charge payment of any additional fees associated with this paper or credit any overpayment to Deposit Account No. 11-0982. A duplicate copy of this sheet is enclosed.

Respectfully submitted,

KINNEY & LANGE, P.A.

By: 

Jeffrey D. Shewchuk, Reg. No. 37,235
Suite 1500
625 Fourth Avenue South
Minneapolis, MN 55415-1659
Phone: (612) 339-1863 Fax: (612) 339-6580

JDS:atp

FORM PTO-1449	Atty. Docket No.: F264.312-16	Serial No.: 08/894,207
LIST OF PATENTS AND PUBLICATIONS FOR APPLICANT'S INFORMATION DISCLOSURE STATEMENT	Applicant: Catherine Douillard et al.	
	Filing Date: Herewith	Group Art:

U.S. PATENT DOCUMENTS

Examiner Initial	Document No.	Date	Name	Class	Sub Class	Filing Date If Appropriate
AA						
AB						
AC						
AD						
AE						
AF						

FOREIGN PATENT DOCUMENTS

	Document No.	Date	Country	Class	Sub Class	Translation Yes No
AI	0 511 141 A1	10/28/92	European	—	—	X
AJ	WO 91/06165	5/2/91	PCT	—	—	
AK	0 524 597 A1	1/27/93	European	—	—	X

OTHER ART (Including Author, Title, Date, Pertinent Pages, Etc.)

AL	Claude Berrou, et al., ICC'93 Geneva, IEEE International Conference on Communications '93, Technical Program Conference Record, Vol. 2/3, May 23-26, 1993, Geneva, Switzerland, pp.1065-1070.
AM	Hidekazu Murata et al., Performance of Adaptive Equalizer Using Iterative Application of Viterbi Algorithm, Electronics and Communications in Japan, Part 1, Vol. 77, No. 4, April 1994, pp. 103-110.
AN	J.W.M. Bergmans et al., On the Use of Decision Feedback for Simplifying the Viterbi Detector, Philips Journal of Research, Vol. 42, No. 4, 1987, pp. 428-399.
AO	Jianjun Wu, et al., A Channel Model and A Novel Adaptive Equalizer for Mobile Radio Communications, IEEE in Houston, Globecom '93, IEE Global Telecommunications Conference, November 29 - December 2, 1993, Vol. 1 of 4, pp. 98-102.
AP	Peter Jung, et al., VLSI Implementation of Soft Output Viterbi Equalizers For Mobile Radio Applications, Vehicular Technology Society 42 nd VTS Conference Frontiers of Technology, Vol. 2 of 2, May 10-13, 1992, Denver Colorado, pp. 577-585.

EXAMINER: *J. Bourne*

DATE CONSIDERED: 3/12/99

EXAMINER: Initial if citation considered, whether or not citation is in conformance with MPEP 609; draw line through citation if not in conformance and not considered. Include copy of this form with next communication to applicant.



**UNITED STATES DEPARTMENT OF COMMERCE
Patent and Trademark Office**

Address: COMMISSIONER OF PATENTS AND TRADEMARKS
Washington, D.C. 20231

APPLICATION NO.	FILING DATE	FIRST NAMED INVENTOR	ATTORNEY DOCKET NO.
08/894,207	12/03/97	DOUILLARD	F264.312-16

KINNEY & LANGE, P.A.
THE KINNEY & LANGE BUILDING
312 SOUTH THIRD STREET
MINNEAPOLIS MN 55415-1002

LM02/0323

EXAMINER

BOCURE, T

ART UNIT

PAPER NUMBER

2731

7

DATE MAILED: 03/23/99

Please find below and/or attached an Office communication concerning this application or proceeding.

Commissioner of Patents and Trademarks

Office Action Summary	Application No. 08/894,207	Applicant(s) Catherine Douillard et al.	
	Examiner Tesfaldet Bocure	Group Art Unit 2731	

☒ Responsive to communication(s) filed on Dec 3, 1997

☐ This action is **FINAL**.

☐ Since this application is in condition for allowance except for formal matters, prosecution as to the merits is closed in accordance with the practice under *Ex parte Quayle*, 1935 C.D. 11; 453 O.G. 213.

A shortened statutory period for response to this action is set to expire three month(s), or thirty days, whichever is longer, from the mailing date of this communication. Failure to respond within the period for response will cause the application to become abandoned. (35 U.S.C. § 133). Extensions of time may be obtained under the provisions of 37 CFR 1.136(a).

Disposition of Claims

☒ Claim(s) 1-9 is/are pending in the application.

Of the above, claim(s) _____ is/are withdrawn from consideration.

☒ Claim(s) 8 is/are allowed.

☒ Claim(s) 1, 2, and 9 is/are rejected.

☒ Claim(s) 3-7 is/are objected to.

☐ Claims _____ are subject to restriction or election requirement.

Application Papers

☒ See the attached Notice of Draftsperson's Patent Drawing Review, PTO-948.

☐ The drawing(s) filed on _____ is/are objected to by the Examiner.

☐ The proposed drawing correction, filed on _____ is ☐ approved ☐ disapproved.

☐ The specification is objected to by the Examiner.

☐ The oath or declaration is objected to by the Examiner.

Priority under 35 U.S.C. § 119

☒ Acknowledgement is made of a claim for foreign priority under 35 U.S.C. § 119(a)-(d).

☒ All ☐ Some* ☐ None of the CERTIFIED copies of the priority documents have been

☒ received.

☐ received in Application No. (Series Code/Serial Number) _____

☐ received in this national stage application from the International Bureau (PCT Rule 17.2(a)).

*Certified copies not received: _____

☐ Acknowledgement is made of a claim for domestic priority under 35 U.S.C. § 119(e).

Attachment(s)

☒ Notice of References Cited, PTO-892

☐ Information Disclosure Statement(s), PTO-1449, Paper No(s). _____

☐ Interview Summary, PTO-413

☒ Notice of Draftsperson's Patent Drawing Review, PTO-948

☐ Notice of Informal Patent Application, PTO-152

--- SEE OFFICE ACTION ON THE FOLLOWING PAGES ---

Serial Number: 087/894,207

Page 2

Art Unit: 2731

DETAILED ACTION

Priority

1. Receipt is acknowledged of papers submitted under 35 U.S.C. 119(a)-(d), which papers have been placed of record in the file.

Drawings

2. Figure 1 should be designated by a legend such as --Prior Art-- because only that which is old is illustrated. See MPEP § 608.02(g).

Note that, figure 1 has been disclosed in page 11, lines 28-30 as "illustrating a standard transmission line that can be incorporated into the reception device according to the invention."

Specification

3. The abstract of the disclosure is objected to because the abstract of the disclosure should be one paragraph, and the title to the abstract should be deleted. Correction is required. See MPEP § 608.01(b).
4. This application is informal in the arrangement of the specification. The following guidelines illustrate the preferred layout and content for patent applications. These guidelines are suggested for the applicant's use.

Arrangement of the Specification

Art Unit: 2731

The following order or arrangement is preferred in framing the specification and, except for the reference to "Microfiche Appendix" and the drawings, each of the lettered items should appear in upper case, without underlining or bold type, as section headings. If no text follows the section heading, the phrase "Not Applicable" should follow the section heading:

- (a) Title of the Invention.
- (b) Cross-References to Related Applications.
- © Statement Regarding Federally Sponsored Research or Development.
- (d) Reference to a "Microfiche Appendix" (see 37 CFR 1.96).
- (e) Background of the Invention:
 - 1. Field of the Invention.
 - 2. Description of the Related Art including information disclosed under 37 CFR 1.97 and 1.98.
- (f) Brief Summary of the Invention.
- (g) Brief Description of the Several Views of the Drawing(s).
- (h) Detailed Description of the Invention.
- (i) Claim or Claims (commencing on a separate sheet).
- (j) Abstract of the Disclosure (commencing on a separate sheet).
- (k) Drawings.
- (l) Sequence Listing (see 37 CFR 1.821-1.825).

Claim Rejections - 35 USC § 112

5. The following is a quotation of the second paragraph of 35 U.S.C. 112:

The specification shall conclude with one or more claims particularly pointing out and distinctly claiming the subject matter which the applicant regards as his invention.

6. Claims 1 and 2 are rejected under 35 U.S.C. 112, second paragraph, as being indefinite for failing to particularly point out and distinctly claim the subject matter which applicant regards as the invention.

Claims 1 and 2: It has been claimed in claim 1 that the "the means for correction of each modules M_i , except for the first module M_1 , taking account of at least one item of correction information Z_i determined by the previous module M_{i-1} ," reads as if the correction information is

Art Unit: 2731

supplied to the rest of the modules except to the first one. While in claim 2 which depends on claim 1, it has been claimed as if all the modules are receiving a correction information Z_i , which is confusing. See the claimed "each module M_i has two inputs, one symbol input R_i and one correction input Z_i ." Applicant should refer to figures 6 and 7 and the disclosure in page 7.

Claim Rejections - 35 USC § 102

7. The following is a quotation of the appropriate paragraphs of 35 U.S.C. 102 that form the basis for the rejections under this section made in this Office action:

A person shall be entitled to a patent unless --

(e) the invention was described in a patent granted on an application for patent by another filed in the United States before the invention thereof by the applicant for patent, or on an international application by another who has fulfilled the requirements of paragraphs (1), (2), and (4) of section 371© of this title before the invention thereof by the applicant for patent.

8. Claim 8 is rejected under 35 U.S.C. 102(e) as being anticipated by **Bremer et al.** (US patent No. 5,537,441).

Bremer et al. (**Bremer** hereinafter) teaches a receiver (see figs.11-13) for receiving a digitally modulated signals comprising: an adaptive filter (280) for receiving the received demodulated signal and minimizing the Intersymbol Interference (ISI) associated with the received symbols and generating an estimate of the received signals; slicer for detecting symbols from the estimated signal by the adaptive filter; and control signal generator (260,250 and 295) for generating a control signal to control the adaptive filter (280) in response to both outputs from the slicer (220) the adaptive equalizer (280) as in claim 8.

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9. Claim 8 is rejected under 35 U.S.C. 102(e) as being anticipated by **Lester et al** (US patent No. 5,353,307).

Lester et al (**Lester** hereinafter) teaches a receiver (see fig 5b) for receiving a digitally modulated signals comprising: an adaptive filter (54) for receiving the received demodulated signal and minimizing the Intersymbol Interference (ISI) associated with the received symbols and generating an estimate of the received signals; slicer for detecting symbols from the estimated signal by the adaptive filter; and control signal generator (60,56 and 56) for generating a control signal to control the adaptive filter (54) in response to both outputs from the Viterbi decoder (58) the adaptive equalizer (54) as in claim 8.

Allowable Subject Matter

10. Claims 3-7 are objected to as being dependent upon a rejected base claim, but would be allowable if rewritten in independent form including all of the limitations of the base claim and any intervening claims.
11. Claim 2 would be allowable if rewritten to overcome the rejection(s) under 35 U.S.C. 112, 2nd paragraph, set forth in this Office action and to include all of the limitations of the base claim and any intervening claims.
12. Claim 1 would be allowable if rewritten or amended to overcome the rejection(s) under 35 U.S.C. 112, 2nd paragraph, set forth in this Office action.

Serial Number: 087/894,207

Page 6

Art Unit: 2731

13. Claim 8 allowed.

Conclusion

14. The prior art made of record and not relied upon is considered pertinent to applicant's disclosure.

US patent numbers 5,513,216; 5,537,436; 5,684,834 and 5,719,923 issued to Gadot et al., Bottoms et al., Betts et al. and Bremer et al., respectively disclose a receiver having means for removing Intersymbol Interference and decoder.

US patent number 5,446,747 issued to Berrou disclose a receiver having a cascaded decoders.

Any inquiry concerning this communication should be directed to T.Bocure at telephone number (703) 305-4735.

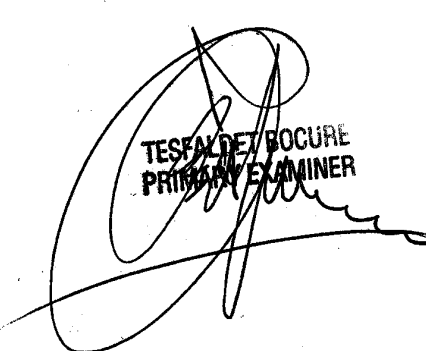
Serial Number: 087/894,207

Page 7

Art Unit: 2731

March 16, 1999

TESFA DEBOCURE
PRIMARY EXAMINER

A large, stylized handwritten signature in black ink, written over the printed name and title.

NOTICE OF DRAFTPERSON'S PATENT DRAWING REVIEW

The drawing filed (insert date) 03/29/97 are:

- A. ☒ not objected to by the Draftperson under 37 CFR 1.84 or 1.152.
- B. ☐ objected to by the Draftperson under 37 CFR 1.84 or 1.152 as indicated below. The Examiner will require submission of new, corrected drawings where necessary. Corrected drawings must be submitted according to the instructions on the back of this notice.

1. DRAWINGS. 37 CFR 1.84(a): Acceptable categories of drawings:

Black ink. Color.

☐ Color drawing are not acceptable until petition is granted.

Fig.(s) _____

☐ Pencil and non black ink is not permitted. Fig(s) _____

2. PHOTOGRAPHS. 37 CFR 1.84(b)

☐ Photographs are not acceptable until petition is granted,

☐ 3 full-tone sets are required. Fig(s) _____

☐ Photographs not properly mounted (must bristol board or photographic double-weight paper). Fig(s) _____

☐ Poor quality (half-tone). Fig(s) _____

3. TYPE OF PAPER. 37 CFR 1.84(e)

☐ Paper not flexible, strong, white and durable.

Fig.(s) _____

☐ Erasures, alterations, overwritings, interlineations, folds, copy machine marks not acceptable. (too thin)

☐ Mylar, vellum paper is not acceptable (too thin).

Fig(s) _____

4. SIZE OF PAPER. 37 CFR 1.84(f): Acceptable sizes:

☐ 21.0 cm by 29.7 cm (DIN size A4)

☐ 21.6 cm by 27.9 cm (8 1/2 x 11 inches)

☐ All drawings sheets not the same size.

Sheet(s) _____

5. MARGINS. 37 CFR 1.84(g): Acceptable margins:

Top 2.5 cm Left 2.5 cm Right 1.5 cm Bottom 1.0 cm

SIZE: A4 Size

Top 2.5 cm Left 2.5 cm Right 1.5 cm Bottom 1.0 cm

SIZE: 8 1/2 x 11

☐ Margins not acceptable. Fig(s) _____

Top (T) _____ Left (L) _____

Right (R) _____ Bottom (B) _____

6. VIEWS. 37 CFR 1.84(h)

REMINDER: Specification may require revision to correspond to drawing changes.

☐ Views connected by projection lines or lead lines.

Fig.(s) _____

Partial views. 37 CFR 1.84(h)(2)

☐ Brackets needed to show figure as one entity.

Fig.(s) _____

☐ Views not labeled separately or properly.

Fig.(s) _____

☐ Enlarged view not labeled separately or properly.

Fig.(s) _____

7. SECTIONAL VIEWS. 37 CFR 1.84(h)(3)

☐ Hatching not indicated for sectional portions of an object.

Fig.(s) _____

☐ Sectional designation should be noted with Arabic or

Roman numbers. Fig.(s) _____

8. ARRANGEMENT OF VIEWS. 37 CFR 1.84(i)

☐ Words do not appear on a horizontal, left-to-right fashion when page is either upright or turned, so that the top becomes the right side, except for graphs. Fig.(s) _____

☐ Views not on the same plane on drawing sheet. Fig.(s) _____

9. SCALE. 37 CFR 1.84(k)

☐ Scale not large enough to show mechanism with crowding when drawing is reduced in size to two-thirds in reproduction.

Fig.(s) _____

10. CHARACTER OF LINES, NUMBERS, & LETTERS. 37 CFR 1.84(l)

☐ Lines, numbers & letters not uniformly thick and well defined, clean, durable and black (poor line quality).

Fig.(s) _____

11. SHADING. 37 CFR 1.84(m)

☐ Solid black areas pale. Fig.(s) _____

☐ Solid black shading not permitted. Fig.(s) _____

☐ Shade lines, pale, rough and blurred. Fig.(s) _____

12. NUMBERS, LETTERS, & REFERENCE CHARACTERS.

37 CFR 1.48(p)

☐ Numbers and reference characters not plain and legible.

Fig.(s) _____

☐ Figure legends are poor. Fig.(s) _____

☐ Numbers and reference characters not oriented in the same

direction as the view. 37 CFR 1.84(p)(3) Fig.(s) _____

☐ English alphabet not used. 37 CFR 1.84(p)(3) Fig.(s) _____

☐ Numbers, letters and reference characters must be at least

.32 cm (1/8 inch) in height. 37 CFR 1.84(p)(3) Fig.(s) _____

13. LEAD LINES. 37 CFR 1.84(q)

☐ Lead lines cross each other. Fig.(s) _____

☐ Lead lines missing. Fig.(s) _____

14. NUMBERING OF SHEETS OF DRAWINGS. 37 CFR 1.48(t)

☐ Sheets not numbered consecutively, and in Arabic numerals beginning with number 1. Fig.(s) _____

15. NUMBERING OF VIEWS. 37 CFR 1.84(u)

☐ Views not numbered consecutively, and in Arabic numerals, beginning with number 1. Fig.(s) _____

16. CORRECTIONS. 37 CFR 1.84(w)

☐ Corrections not made from PTO-948 dated _____

17. DESIGN DRAWINGS. 37 CFR 1.152

☐ Surface shading shown not appropriate. Fig.(s) _____

☐ Solid black shading not used for color contrast.

Fig.(s) _____

COMMENTS

REVIEWER EASTER

DATE 03/27/98 TELEPHONE NO. 703-305-8404

ATTACHMENT TO PAPER NO. 7

PTO COPY

REMINDER

Drawing changes may also require changes in the specification, e.g., if Fig. I is changed to Fig. IA, Fig. IB, Fig. IC, etc., the specification, at the Brief Description of the Drawings, must likewise be changed. Please make such changes by 37 CFR 1.312 Amendment at the time of submitting drawing changes.

INFORMATION ON HOW TO EFFECT DRAWING CHANGES

1. Correction of Informalities-37 CFR 1.85

File new drawings with the changes incorporated therein. The application number or the title of the invention, inventor's name, docket number (if any), and the name and telephone number of a person to call if the Office is unable to match the drawings to the proper application, should be placed on the back of each sheet of drawings in accordance with 37 CFR 1.84(c). Applicant may delay filing of the new drawings until receipt of the Notice of Allowability (PTOL-37). Extensions of time may be obtained under the provisions of 37 CFR 1.136. The drawing should be filed as a separate paper with a transmittal letter addressed to the Drawing Review Branch.

2. Timing of Corrections

Applicant is required to submit acceptable corrected drawings within the three-month shortened statutory period set in the Notice of Allowability (PTOL-37). If a correction is determined to be unacceptable by the Office, applicant must arrange to have acceptable correction resubmitted within the original three-month period to avoid the necessity of obtaining as extension of time and paying the extension fee. Therefore, applicant should file corrected drawings as soon as possible.

Failure to take corrective action within set (or extended) period will result in ABANDONMENT of the Application.

3. Corrections other than Informalities Noted by the Drawing Review Branch on the Form PTO 948

All changes to the drawings, other than informalities noted by the Drawing Review Branch, **MUST** be approved by the examiner before the application will be allowed. No changes will be permitted to be made, other than correction of informalities, unless the examiner has approved the proposed changes.

Notice of References Cited

Application No. 08/894,207	Applicant Catherine Douillard et al.
Examiner Tesfaldet Bocure	Group Art Unit 2731
Page 1 of 1	

U.S. PATENT DOCUMENTS

	DOCUMENT NO.	DATE	NAME	CLASS	SUBCLASS
A	5,353,307	Oct. 1994	Lestee et al.	375	232
B	5,446,747	Aug. 1995	Berrou	371	43
C	5,513,216	Apr. 1996	Gadot et al.	375	233
D	5,537,436	July 1996	Bottoms et al.	375	261
E	5,537,441	July 1996	Bremer et al.	375	261
F	5,684,834	Nov. 1997	Betts et al.	375	261
G	5,719,923	Feb. 1998	Bremer et al.	379	93
H					
I					
J					
K					
L					
M					

FOREIGN PATENT DOCUMENTS

	DOCUMENT NO.	DATE	COUNTRY	NAME	CLASS	SUBCLASS
N						
O						
P						
Q						
R						
S						
T						

NON-PATENT DOCUMENTS

	DOCUMENT (Including Author, Title, Source, and Pertinent Pages)	DATE
U		
V		
W		
X		



**UNITED STATES DEPARTMENT OF COMMERCE
Patent and Trademark Office**

Address: COMMISSIONER OF PATENTS AND TRADEMARKS
Washington, D.C. 20231

APPLICATION NO.	FILING DATE	FIRST NAMED INVENTOR	ATTORNEY DOCKET NO.
-----------------	-------------	----------------------	---------------------

08/894,207 12/03/97 DOUILLARD

C F264.312-16

EXAMINER

LM02/0409

KINNEY & LANGE, P.A.
THE KINNEY & LANGE BUILDING
312 SOUTH THIRD STREET
MINNEAPOLIS MN 55415-1002

BOCURE, T

ART UNIT

PAPER NUMBER

2731

DATE MAILED:

04/09/99

Please find below and/or attached an Office communication concerning this application or proceeding.

Commissioner of Patents and Trademarks



UNITED STATES DEPARTMENT OF COMMERCE
Patent and Trademark Office

Address: COMMISSIONER OF PATENTS AND TRADEMARKS
Washington, D.C. 20231

SERIAL NUMBER 007894,287	FILING DATE 12/03/99	FIRST NAMED APPLICANT BOUILLARD	ATTORNEY DOCKET NO. F264,312-16
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LM02/0409

KINNEY & LANGE, P.A.
THE KINNEY & LANGE BUILDING
312 SOUTH THIRD STREET
MINNEAPOLIS MN 55415-1002

BOCURE, T	
EXAMINER	
2731	
ART UNIT	PAPER NUMBER
	04/09/99
	#8

DATE MAILED:

Please find below a communication from the EXAMINER in charge of this application.

Commissioner of Patents

1. In response to applicant's telephone inquiry regarding "the last office action mailed on March 23", the following action has been taken:

THE PERIOD FOR RESPONSE OF 3(THREE) MONTHS SET IN SAID OFFICE ACTION CONTINUE TO RUN FROM THE DATE OF THE LAST OFFICE ACTION WAS MAILED.

2. A corrected copy of the last office action (art rejection to claim 8 to read as --claim 9--
-) is enclosed with this correspondence.
4. Any inquiry concerning this communication or earlier communications from the examiner should be directed to T.Bocure whose telephone number is (703) 305-4735.

TESFADET BOCURE
PRIMARY EXAMINER

Serial Number: 087/894,207

Page 2

Art Unit: 2731

DETAILED ACTION

Priority

1. Receipt is acknowledged of papers submitted under 35 U.S.C. 119(a)-(d), which papers have been placed of record in the file. ✓

Drawings

2. Figure 1 should be designated by a legend such as --Prior Art-- because only that which is old is illustrated. See MPEP § 608.02(g).

Note that, figure 1 has been disclosed in page 11, lines 28-30 as "illustrating a standard transmission line that can be incorporated into the reception device according to the invention." ✓

Specification

3. The abstract of the disclosure is objected to because the abstract of the disclosure should be one paragraph, and the title to the abstract should be deleted. Correction is required. See MPEP § 608.01(b). PH
4. This application is informal in the arrangement of the specification. The following guidelines illustrate the preferred layout and content for patent applications. These guidelines are suggested for the applicant's use.

Arrangement of the Specification

Art Unit: 2731

The following order or arrangement is preferred in framing the specification and, except for the reference to "Microfiche Appendix" and the drawings, each of the lettered items should appear in upper case, without underlining or bold type, as section headings. If no text follows the section heading, the phrase "Not Applicable" should follow the section heading:

- (a) Title of the Invention.
- (b) Cross-References to Related Applications.
- © Statement Regarding Federally Sponsored Research or Development.
- (d) Reference to a "Microfiche Appendix" (see 37 CFR 1.96).
- (e) Background of the Invention.
 - 1. Field of the Invention.
 - 2. Description of the Related Art including information disclosed under 37 CFR 1.97 and 1.98.
- (f) Brief Summary of the Invention.
- (g) Brief Description of the Several Views of the Drawing(s). ✓
- (h) Detailed Description of the Invention.
- (I) Claim or Claims (commencing on a separate sheet).
- (j) Abstract of the Disclosure (commencing on a separate sheet).
- (k) Drawings.
- (l) Sequence Listing (see 37 CFR 1.821-1.825).

Claim Rejections - 35 USC § 112

5. The following is a quotation of the second paragraph of 35 U.S.C. 112:

The specification shall conclude with one or more claims particularly pointing out and distinctly claiming the subject matter which the applicant regards as his invention.

6. Claims 1 and 2 are rejected under 35 U.S.C. 112, second paragraph, as being indefinite for failing to particularly point out and distinctly claim the subject matter which applicant regards as the invention. OK

Claims 1 and 2: It has been claimed in claim 1 that the "the means for correction of each modules M_i , except for the first module M_1 , taking account of at least one item of correction information Z_i determined by the previous module M_{i-1} ," reads as if the correction information is

Art Unit: 2731

supplied to the rest of the modules except to the first one. While in claim 2 which depends on claim 1, it has been claimed as if all the modules are receiving a correction information Z_i , which is confusing. See the claimed "each module M_i has two inputs, one symbol input R_i and one correction input Z_i ." Applicant should refer to figures 6 and 7 and the disclosure in page 7.

Claim Rejections - 35 USC § 102

7. The following is a quotation of the appropriate paragraphs of 35 U.S.C. 102 that form the basis for the rejections under this section made in this Office action:

A person shall be entitled to a patent unless --

(e) the invention was described in a patent granted on an application for patent by another filed in the United States before the invention thereof by the applicant for patent, or on an international application by another who has fulfilled the requirements of paragraphs (1), (2), and (4) of section 371© of this title before the invention thereof by the applicant for patent.

8. Claim 9 is rejected under 35 U.S.C. 102(e) as being anticipated by **Bremer et al.** (US patent No. 5,537,441).

Bremer et al. (**Bremer** hereinafter) teaches a receiver (see figs. 11-13) for receiving a digitally modulated signals comprising: an adaptive filter (280) for receiving the received demodulated signal and minimizing the Intersymbol Interference (ISI) associated with the received symbols and generating an estimate of the received signals; slicer for detecting symbols from the estimated signal by the adaptive filter; and control signal generator (260, 250 and 295) for generating a control signal to control the adaptive filter (280) in response to both outputs from the slicer (220) the adaptive equalizer (280) as in claim ⁹~~8~~.

9. Claim 9 is rejected under 35 U.S.C. 102(e) as being anticipated by **Lester et al** (US patent No. 5,353,307).

Lester et al (**Lester** hereinafter) teaches a receiver (see fig 5b) for receiving a digitally modulated signals comprising: an adaptive filter (54) for receiving the received demodulated signal and minimizing the Intersymbol Interference (ISI) associated with the received symbols and generating an estimate of the received signals; slicer for detecting symbols from the estimated signal by the adaptive filter; and control signal generator (60,56 and 56) for generating a control signal to control the adaptive filter (54) in response to both outputs from the Viterbi decoder (58) the adaptive equalizer (54) as in claim 8.

Allowable Subject Matter

10. Claims 3-7 are objected to as being dependent upon a rejected base claim, but would be allowable if rewritten in independent form including all of the limitations of the base claim and any intervening claims.
11. Claim 2 would be allowable if rewritten to overcome the rejection(s) under 35 U.S.C. 112, 2nd paragraph, set forth in this Office action and to include all of the limitations of the base claim and any intervening claims.
12. Claim 1 would be allowable if rewritten or amended to overcome the rejection(s) under 35 U.S.C. 112, 2nd paragraph, set forth in this Office action.

Serial Number: 087/894,207

Page 6

Art Unit: 2731

13. Claim 8 allowed.

Conclusion

14. The prior art made of record and not relied upon is considered pertinent to applicant's disclosure.

US patent numbers 5,513,216; 5,537,436; 5,684,834 and 5,719,923 issued to Gadot et al., Bottoms et al., Betts et al. and Bremer et al., respectively disclose a receiver having means for removing Intersymbol Interference and decoder.

US patent number 5,446,747 issued to Berrou disclose a receiver having a cascaded decoders.

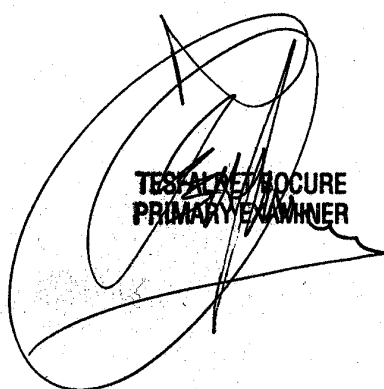
Any inquiry concerning this communication should be directed to T.Bocure at telephone number (703) 305-4735.

Serial Number: 087/894,207

Page 7

Art Unit: 2731

March 16, 1999

A large, stylized handwritten signature in black ink, consisting of several overlapping loops and a long horizontal stroke extending to the right.

**TESTALNET/OCURE
PRIMARY EXAMINER**



#9
7/6/99

IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

First Named
Inventor : Catherine Douillard
Appln. No. : 08/894,207
Filed : December 3, 1997
Title : ITERATIVE-STRUCTURE DIGITAL
SIGNAL RECEPTION DEVICE, AND
MODULE AND METHOD THEREFOR
Docket No. : F264.312-0016

Group Art Unit: 2732
Examiner: Bocure, T.

RECEIVED

JUL 06 1999

Group 2700

LETTER TO OFFICIAL DRAFTSMAN
(PROPOSED CORRECTIONS)

I CERTIFY THAT THIS PAPER IS BEING SENT BY U.S. MAIL,
FIRST CLASS, TO THE ASSISTANT COMMISSIONER FOR
PATENTS, WASHINGTON, D.C. 20231, THIS 23rd DAY OF

Assistant Commissioner for Patents
Washington, D.C. 20231

June 19 99
PATENT ATTORNEY

Sir:

Pursuant to M.P.E.P. 608.02(r), enclosed is one (1) sheet of a drawing with
corrections marked in red for filing in the above-identified application.

Respectfully submitted,

KINNEY & LANGE, P.A.

By:

Jeffrey D. Shewchuk, Reg. No. 37,235
THE KINNEY & LANGE BUILDING
312 South Third Street
Minneapolis, MN 55415-1002
Telephone: (612) 339-1863
Fax: (612) 339-6580

JDS:kmm

08/894,207

1/3 RECEIVED

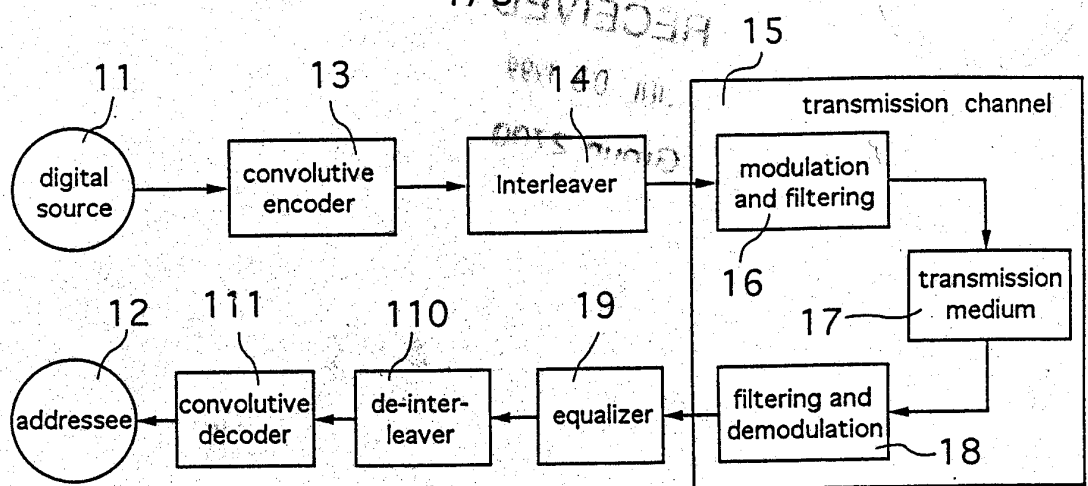


Fig. 1
(Prior Art)

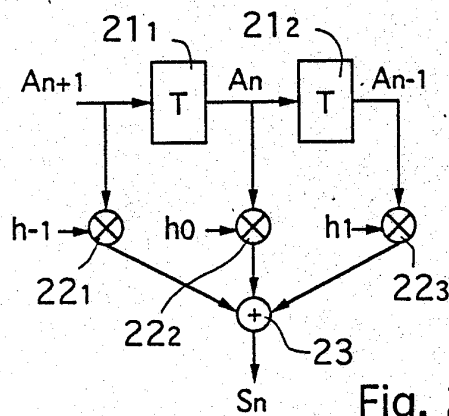


Fig. 2

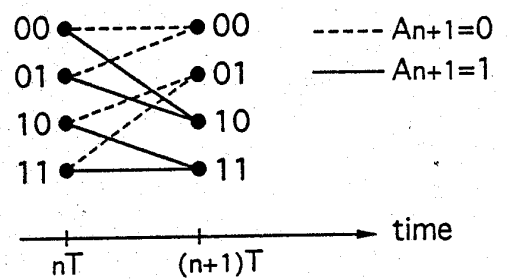


Fig. 3

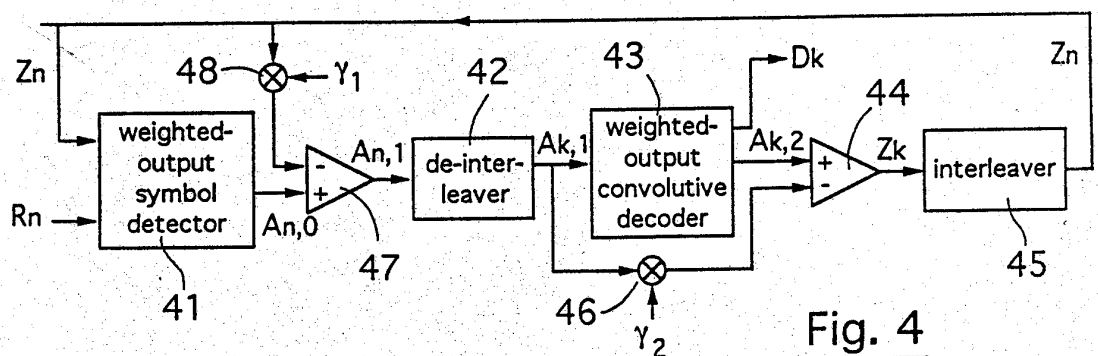


Fig. 4

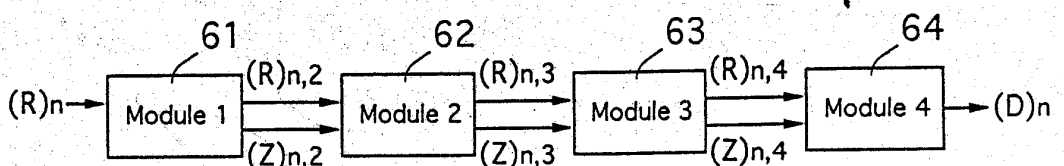


Fig. 6

JUN 28 1999
PATENT & TRADEMARK OFFICE

1m 2732
10/9
7/14/99
DS

IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

First Named Inventor : Catherine Douillard	Group Art Unit: 2732 Examiner: Bocure, T.
Appln. No. : 08/894,207	
Filed : December 3, 1997	
Title : ITERATIVE-STRUCTURE DIGITAL SIGNAL RECEPTION DEVICE, AND MODULE AND METHOD THEREFOR	
Docket No. : F264.312-0016	

RECEIVED
JUL 06 1999

AMENDMENT

Group 2700

Box Non-Fee Amendment
Assistant Commissioner for Patents
Washington, D.C. 20231

I CERTIFY THAT THIS PAPER IS BEING SENT BY U.S. MAIL, FIRST CLASS, TO THE ASSISTANT COMMISSIONER FOR PATENTS, WASHINGTON, D.C. 20231, THIS 23rd DAY OF June 1999
PATENT ATTORNEY

Sir:

This is in response to the Office Action mailed on April 9, 1999, which was a correction to the Office Action mailed on March 23, 1999. Please amend the above-identified application as follows:

IN THE SPECIFICATION

Page 1, between the title and line 1, insert --
BACKGROUND OF THE INVENTION--.

Page 5 between line 9 and line 10, insert --
BRIEF SUMMARY OF THE INVENTION--.

Page 7, between line 17 and line 18, insert --

BRIEF DESCRIPTION OF THE DRAWINGS

a 1/2

29

First Named Inventor: Catherine Douillard

Application No.: 08/894,207

-2-

Other features and advantages of the invention shall appear from the following description of a preferred embodiment of the invention giving by way of a non-restricted example and from the appended drawings, of which:

FIG. 1 is a block diagram illustrating a standard transmission line that can incorporate the reception device according to the present invention.

FIG. 2 shows a simplified view of a discrete model, equivalent in terms of baseband to a transmission channel affected by an inter-symbol interference, illustrating the approach of the present invention.

FIG. 3 shows the corresponding lattice of the channel of FIG. 2, illustrating possible developments of the state of the channel as a function of time.

FIG. 4 is a block diagram showing the principle of the receiver of the present invention.

FIG. 5 is a simplified flow chart illustrating the method of the present invention implemented in the receiver of FIG. 4.

FIG. 6 illustrates the modular structure of the receiver of the present invention in the case of four cascade-connected modules.

FIG. 7 shows a block diagram of the module of FIG. 6.

FIG. 8 shows a series of curves illustrating the performance characteristics of the present invention in the case of a Gaussian channel.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS--

✓
Delete page 11, line 23 through page 12, line 16.

IN THE ABSTRACT

Please replace the abstract with the abstract provided on the following separate page:

30

First Named Inventor: Catherine Douillard

Application No.: 08/894,207

-3-

--ABSTRACT

The invention relates to a device for the reception of signals formed by a series of digital symbols corresponding to the convolutive encoding of items of source digital data comprising p cascade-connected detection and decoding modules M_1 to M_p , p being greater than or equal to 2, each of said modules M_i including: (a) inter-symbol interference correction means supplied by a symbol input R_i and delivering estimated symbols $A_{i,1}$ with weighted values, (b) means for the decoding of said estimated symbols $A_{i,1}$, performing operations symmetrical to said convolutive encoding and delivering decoded symbols $A_{i,2}$ with weighted values, and (c) means for the computation of an item of correction information Z_{i+1} from said estimated symbol $A_{i,1}$ and said decoded symbol $A_{i,2}$, (d) said means for the correction of each of said modules M_i , except for the first module M_1 , taking account of at least one item of correction information Z_i determined by the previous module M_{i-1} .--

First Named Inventor: Catherine Douillard

Application No.: 08/894,207

-4-

IN THE CLAIMS

Please amend claims 1, 2, and 9 as follows:

1. (Amended) Device for the reception of signals formed by a series of digital symbols corresponding to the convolutive encoding of items of source digital data characterized in that it comprises:

p cascade-connected detection and decoding modules M_1 to M_p , p being greater than or equal to 2,

each of said modules M_i including:

inter-symbol interference correction means supplied by a symbol input R_i

and delivering estimated symbols $A_{i,1}$ with weighted values $[\cdot]$;

means for the decoding of said estimated symbols $A_{i,1}$ performing

operations symmetrical to said convolutive encoding and

delivering decoded symbols $A_{i,2}$ with weighted values $[\cdot]$; and

means for the computation of an item of correction information Z_{i+1} from

said estimated symbol $A_{i,1}$ and said decoded symbol $A_{i,2}$,

said means for the correction of each of said modules M_i , except for the

first module M_1 , taking account of at least one item of correction

information Z_i determined by the previous module M_{i-1} .

2. (Amended) Device according to claim 1, characterized in that:

each of said modules M_i has two inputs, one symbol input R_i and one correction input $[Z_i]$ on which correction information Z_i may be received, and three outputs, one symbol output R_{i+1} , one correction output $[Z_{i+1}]$ and one decoded symbol output $D_{i+1}[\cdot]$;

the symbol input R_i of the module M_i being connected to the symbol output R_i of the module M_{i-1} for i greater than 1 and being supplied with the symbols received for i equal to 1[.];

the correction input $[Z_i]$ of the module M_i being connected to the correction output $[Z_i]$ of the module M_{i-1} for i greater than 1 and being supplied with a neutral value that does not affect the correction for i equal to 1[.];

the symbol output R_{i+1} of the module M_i being equal to the symbol input R_i of said module M_i delayed by the latency time dictated by the module M_i ;

the correction output $[Z_{i+1}]$ delivering said correction information[.]; and

the decoded symbol output D_{i+1} being unused for the modules M_1 to M_{p-1} and being supplied with the decoded symbol $A_{p,2}$ of the module M_p if the code implemented is a systematic code and, if not, with a corresponding reconstituted value.

9.(Amended) Method for the reception of signals formed by a series of digital symbols corresponding to the convolutive encoding of items of source digital data comprising the following steps:

[-] supplying with received symbols R_i ; and

performing at least two iterations of the following steps:

[-] [the correction of] correcting inter-symbol interference affecting each of said received symbols, by means of an item of correction information Z_i , and the delivery of estimated symbols $A_{i,1}$;

[-] [the] decoding [of] said estimated symbols $A_{i,1}$ entailing operations symmetrical to said convolutive encoding, and the delivery of decoded symbols $A_{i,2}$; and

First Named Inventor: Catherine Douillard

Application No.: 08/894,207

-6-

a2
Cont.

[-] [the computation of] computing said items of correction information Z_i
from at least one of said estimated symbols A_{i-1} and at least one of
said decoded symbols A_{i-2} .

REMARKS

This Amendment is in response to the office action mailed on March 23, 1999 (and the corrected office action mailed on April 9, 1999) in which claims 1-9 were pending. Claims 1 and 2 were rejected under 35 U.S.C. § 112 as indefinite. Claims 3-7 were objected to as being dependent upon a rejected base claim and were noted as being otherwise allowable. The office action allowed claim 8. Claim 9 was rejected under 35 U.S.C. § 102(e).

With this amendment, claims 1, 2, and 9 are amended. All claims are in condition for allowance, and reconsideration and notice to that effect is respectfully requested.

Applicant respectfully thanks the examiner for the telephone interview conducted on or about April 14, 1999. In response to applicant's questions, the examiner indicated that both the rejections of paragraphs 8 and 9 of the office action mailed March 23, 1999 were intended to be directed to claim 9. This change was embodied in the office action mailed April 9, 1999.

The examiner objected to figure 1 as not being designated --prior art--. A proposed correction to figure 1 incorporating this change is submitted herewith.

The office action objected to the format of the abstract and the arrangement of the specification. Appropriate changes have been made to overcome these objections.

The office action rejected claims 1 and 2 under 35 U.S.C. § 112 as being indefinite for failing to particularly point out and distinctly claim the subject matter which applicant regards as the invention. The applicant respectfully traverses this rejection. The Examiner correctly noted that claim 1 sets forth a means for correction of each module M_i , **except** the for the first module M_1 . This means for correction takes into account at least one item of correction information Z_i determined by the previous module M_{i-1} . In other words, the

33

First Named Inventor: Catherine Douillard

Application No.: 08/894,207

-7-

correction information Z_i is supplied to all of the modules except for the first one. According to the present invention, there are at least two cascade-connected modules each having a correction input provided by the previous module. Clearly, there is no previous module when considering the first module and, consequently, the first module does not receive a correction information Z_i determined by the previous module.

Claim 2, as the Examiner correctly noted, describes each module M_i as having two inputs, one symbol input R_i and one correction input. As used in claim 2 by the Applicant, the term correction input refers to the actual physical input on which correction data **may** be received. The first module has a correction input, as all the modules are identical, but does not receive corrective information on it. The first module of the device of claim 2 is not supplied with correction information but rather with a neutral value that does not affect the correction for i equals one. Claim 2 has been amended to more clearly highlight the distinction between correction input and correction information. The symbol Z_i in claim 2 has been deleted where referring to correction input and is used solely to refer to correction information, to avoid the interpretation that correction input and correction information are in all instances the same.

Claims 1 and 2 were not rejected based upon prior art. Claims 1 and 2 remain patentable over the art of record.

Claims 3-7 were objected to as depending from a rejected independent claim. As the objection to claim 1 has been traversed by the Applicant, claims 3-7 now stand in allowable form. Claim 8 was not addressed by the office action and the Applicant assumes it to be in allowable form.

Claim 9 was rejected under 35 U.S.C. § 102(e) as anticipated by U.S. Patent No. 5,537,441 ("Bremer '441") and U.S. Patent No. 5,353,307 ("Lester '307"). Claim 9, as amended, is limited to a device that includes at least two iterations of correction steps. The references cited by the Examiner do not teach a device that includes multiple iterations. Absent the disclosure of every claimed feature in a single prior art reference, a rejection under § 102(e) is improper. Claim 9 therefore stands in allowable form.



First Named Inventor: Catherine Douillard

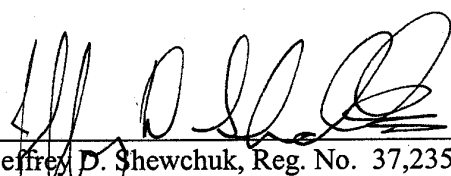
Application No.: 08/894,207

-8-

All of the currently pending claims (1-9) are patentable over the art of record and in condition for allowance. Reconsideration and notice to that affect is respectfully requested. The Examiner is invited to contact the undersigned at the telephone number listed below if such a call would facilitate allowance of the application.

Respectfully submitted,

KINNEY & LANGE, P.A.

By: 

Jeffrey D. Shewchuk, Reg. No. 37,235
THE KINNEY & LANGE BUILDING
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JDS:JRK:kmm



**UNITED STATES DEPARTMENT OF COMMERCE
Patent and Trademark Office**

Address: COMMISSIONER OF PATENTS AND TRADEMARKS
Washington, D.C. 20231

APPLICATION NO.	FILING DATE	FIRST NAMED INVENTOR	ATTORNEY DOCKET NO.
08/894,207	12/03/97	DOUILLARD	C F264.312-16

KINNEY & LANGE, P.A.
THE KINNEY & LANGE BUILDING
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LM02/0913

EXAMINER

BOCURE, T

ART UNIT

PAPER NUMBER

2721

DATE MAILED:

09/13/99

Please find below and/or attached an Office communication concerning this application or proceeding.

Commissioner of Patents and Trademarks

Office Action SummaryApplication No.
08/894,207Applicant(s)
Catherine Douillard et al.Examiner
Tesfaldet BocureGroup Art Unit
2731☒ Responsive to communication(s) filed on Jun 28, 1999☒ This action is **FINAL**.☐ Since this application is in condition for allowance except for formal matters, prosecution as to the merits is closed in accordance with the practice under *Ex parte Quayle*, 1935 C.D. 11; 453 O.G. 213.

A shortened statutory period for response to this action is set to expire three month(s), or thirty days, whichever is longer, from the mailing date of this communication. Failure to respond within the period for response will cause the application to become abandoned. (35 U.S.C. § 133). Extensions of time may be obtained under the provisions of 37 CFR 1.136(a).

Disposition of Claims☒ Claim(s) 1-9 is/are pending in the application.

Of the above, claim(s) _____ is/are withdrawn from consideration.

☒ Claim(s) 1-8 is/are allowed.☒ Claim(s) 9 is/are rejected.☐ Claim(s) _____ is/are objected to.☐ Claims _____ are subject to restriction or election requirement.**Application Papers**☐ See the attached Notice of Draftsperson's Patent Drawing Review, PTO-948.☒ The drawing(s) filed on June 18, 1999 is/are objected to by the Examiner.☐ The proposed drawing correction, filed on _____ is ☐ approved ☐ disapproved.☐ The specification is objected to by the Examiner.☐ The oath or declaration is objected to by the Examiner.**Priority under 35 U.S.C. § 119**☐ Acknowledgement is made of a claim for foreign priority under 35 U.S.C. § 119(a)-(d).☐ All ☐ Some* ☐ None of the CERTIFIED copies of the priority documents have been☐ received.☐ received in Application No. (Series Code/Serial Number) _____.☐ received in this national stage application from the International Bureau (PCT Rule 17.2(a)).

*Certified copies not received: _____

☐ Acknowledgement is made of a claim for domestic priority under 35 U.S.C. § 119(e).**Attachment(s)**☐ Notice of References Cited, PTO-892☐ Information Disclosure Statement(s), PTO-1449, Paper No(s). _____☐ Interview Summary, PTO-413☐ Notice of Draftsperson's Patent Drawing Review, PTO-948☐ Notice of Informal Patent Application, PTO-102

--- SEE OFFICE ACTION ON THE FOLLOWING PAGES ---

Serial Number: 087/894,207

Page 2

Art Unit: 2731

DETAILED ACTION

Claim Rejections - 35 USC § 103

1. The following is a quotation of 35 U.S.C. 103(a) which forms the basis for all obviousness rejections set forth in this Office action:

(a) A patent may not be obtained though the invention is not identically disclosed or described as set forth in section 102 of this title, if the differences between the subject matter sought to be patented and the prior art are such that the subject matter as a whole would have been obvious at the time the invention was made to a person having ordinary skill in the art to which said subject matter pertains. Patentability shall not be negated by the manner in which the invention was made.

2. Claim 9 is rejected under 35 U.S.C. 103(a) as being unpatentable over **Lester et al.** (US patent number 5,353,307).

Lester et al (**Lester** hereinafter) teaches a receiver (see fig 5b) for receiving a digitally modulated signals comprising: an adaptive filter (54) for receiving the received demodulated signal and minimizing the Intersymbol Interference (ISI) associated with the received symbols and generating an estimate of the received signals; decoder (58) for detecting symbols from the estimated signal by the adaptive filter; and control signal generator (60,56 and 56) for generating a control signal to control the adaptive filter (54) in response to both outputs from the Viterbi decoder (58) the adaptive equalizer (54) as in claim 9.

Even though **Lester** does not teach that each of the correction step and decoding step having at least two iterations, he shows that the channel adaption circuit (56), claimed computing, performs the Mean Square Error calculation by using the loop for performing an iterations (see

Serial Number: 087/894,207

Page 3

Art Unit: 2731

figure 6). The use a loop as shown in figure 6 would enable the receiver of **Lester** to minimize the error (phase, frequency and/or amplitude) factor which contributes the Intersymbol Interference (ISI) in the received.

Therefore, it would have been obvious to one of an ordinary skill in the art to use the iteration loop shown in figure 6 to diverge or converge the error for eliminating the ISI in the received signal at the time the invention was made.

Allowable Subject Matter

3. Claims 3-7 are objected to as being dependent upon a rejected base claim, but would be allowable if rewritten in independent form including all of the limitations of the base claim and any intervening claims.
4. Claim 2 would be allowable if rewritten to overcome the rejection(s) under 35 U.S.C. 112, 2nd paragraph, set forth in this Office action and to include all of the limitations of the base claim and any intervening claims.
5. Claim 1 would be allowable if rewritten or amended to overcome the rejection(s) under 35 U.S.C. 112, 2nd paragraph, set forth in this Office action.
6. Claim 8 allowed.

Serial Number: 087/894,207

Page 4

Art Unit: 2731

Conclusion

7. **THIS ACTION IS MADE FINAL.** Applicant is reminded of the extension of time policy as set forth in 37 CFR 1.136(a).

A shortened statutory period for reply to this final action is set to expire **THREE MONTHS** from the mailing date of this action. In the event a first reply is filed within **TWO MONTHS** of the mailing date of this final action and the advisory action is not mailed until after the end of the **THREE-MONTH** shortened statutory period, then the shortened statutory period will expire on the date the advisory action is mailed, and any extension fee pursuant to 37 CFR 1.136(a) will be calculated from the mailing date of the advisory action. In no event, however, will the statutory period for reply expire later than **SIX MONTHS** from the mailing date of this final action.

8. Any inquiry concerning this communication or earlier communications from the examiner should be directed to T.Bocure whose telephone number is (703) 305-4735. The examiner can normally be reached on Monday through Thursday the first week of a bi-week and Monday through Friday the second week of a bi-week from 7:00am to 4:30pm.

If attempts to reach the examiner by telephone are unsuccessful, the examiner's supervisor, Chi Pham, can be reached on (703) 305- 4378. The fax phone number for the organization where this application or proceeding is assigned is (703) 308-4743 or (703) 305-3988 .

Serial Number: 087/894,207

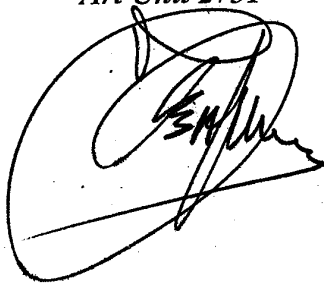
Page 5

Art Unit: 2731

Any inquiry of a general nature or relating to the status of this application or proceeding should be directed to the receptionist whose telephone number is (703) 305-3900.

Tesfaldet Bocure
Primary Examiner
Art Unit 2731

T. Bocure

A handwritten signature in black ink, appearing to be 'T. Bocure', enclosed within a large, loopy oval shape.

~~Sep. 11~~
~~March 16, 1999~~



**UNITED STATES DEPARTMENT OF COMMERCE
Patent and Trademark Office**

Address: COMMISSIONER OF PATENTS AND TRADEMARKS
Washington, D.C. 20231

APPLICATION NO.	FILING DATE	FIRST NAMED INVENTOR	ATTORNEY DOCKET NO.
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08/894,207 12/03/97 DOUILLARD C F264.312-16

LM02/1025

KINNEY & LANGE, P.A.
THE KINNEY & LANGE BUILDING
312 SOUTH THIRD STREET
MINNEAPOLIS MN 55415-1002

EXAMINER

BOCURE, T.

ART UNIT

PAPER NUMBER

2731

DATE MAILED:

10/25/99

Please find below and/or attached an Office communication concerning this application or proceeding.

Commissioner of Patents and Trademarks

Office Action SummaryApplication No.
08/894,207Applicant(s)
Catherine Douillard et al.Examiner
Tesfaldet BocureGroup Art Unit
2731☒ Responsive to communication(s) filed on Jun 28, 1999☒ This action is **FINAL**.☐ Since this application is in condition for allowance except for formal matters, prosecution as to the merits is closed in accordance with the practice under *Ex parte Quayle*, 1935 C.D. 11; 453 O.G. 213.

A shortened statutory period for response to this action is set to expire three month(s), or thirty days, whichever is longer, from the mailing date of this communication. Failure to respond within the period for response will cause the application to become abandoned. (35 U.S.C. § 133). Extensions of time may be obtained under the provisions of 37 CFR 1.136(a).

Disposition of Claims☒ Claim(s) 1-9 is/are pending in the application.

Of the above, claim(s) _____ is/are withdrawn from consideration.

☒ Claim(s) 1-8 is/are allowed.☒ Claim(s) 9 is/are rejected.☐ Claim(s) _____ is/are objected to.☐ Claims _____ are subject to restriction or election requirement.**Application Papers**☐ See the attached Notice of Draftsperson's Patent Drawing Review, PTO-948.☐ The drawing(s) filed on _____ is/are objected to by the Examiner.☒ The proposed drawing correction, filed on Jun 28, 1999 is ☒ approved ☐ disapproved.☐ The specification is objected to by the Examiner.☐ The oath or declaration is objected to by the Examiner.**Priority under 35 U.S.C. § 119**☐ Acknowledgement is made of a claim for foreign priority under 35 U.S.C. § 119(a)-(d).☐ All ☐ Some* ☐ None of the CERTIFIED copies of the priority documents have been
☐ received.☐ received in Application No. (Series Code/Serial Number) _____.☐ received in this national stage application from the International Bureau (PCT Rule 17.2(a)).

*Certified copies not received: _____

☐ Acknowledgement is made of a claim for domestic priority under 35 U.S.C. § 119(e).**Attachment(s)**☐ Notice of References Cited, PTO-892☐ Information Disclosure Statement(s), PTO-1449, Paper No(s). _____☐ Interview Summary, PTO-413☐ Notice of Draftsperson's Patent Drawing Review, PTO-948☐ Notice of Informal Patent Application, PTO-152**--- SEE OFFICE ACTION ON THE FOLLOWING PAGES ---**

Serial Number: 087/894,207

Page 2

Art Unit: 2731

DETAILED ACTION

Drawings

1. The corrected or substitute drawings were received on June 28, 1999. These drawings are approved by the Examiner.

Claim Rejections - 35 USC § 103

2. The following is a quotation of 35 U.S.C. 103(a) which forms the basis for all obviousness rejections set forth in this Office action:

(a) A patent may not be obtained though the invention is not identically disclosed or described as set forth in section 102 of this title, if the differences between the subject matter sought to be patented and the prior art are such that the subject matter as a whole would have been obvious at the time the invention was made to a person having ordinary skill in the art to which said subject matter pertains. Patentability shall not be negated by the manner in which the invention was made.

3. Claim 9 is rejected under 35 U.S.C. 103(a) as being unpatentable over Lester et al. (US patent number 5,353,307).

Lester et al (Lester hereinafter) teaches a receiver (see fig 5b) for receiving a digitally modulated signals comprising: an adaptive filter (54) for receiving the received demodulated signal and minimizing the Intersymbol Interference (ISI) associated with the received symbols and generating an estimate of the received signals; decoder (58) for detecting symbols from the estimated signal by the adaptive filter; and control signal generator (60,56 and 56) for generating

a control signal to control the adaptive filter (54) in response to both outputs from the Viterbi decoder (58) the adaptive equalizer (54) as in claim 9.

Even though **Lester** does not show that each of the correction step and decoding step having at least two iterations, he shows that the channel adaption circuit (56), claimed computing, performs the Mean Square Error calculation by using the loop for performing an iterations (see figure 6). The use of a loop as shown in figure 6 would enable the receiver of **Lester** to minimize the error (phase, frequency and/or amplitude) factor which contributes the Intersymbol Interference (ISI) in the received signal.

Therefore, it would have been obvious to one of an ordinary skill in the art to use the iteration loop shown in figure 6 to diverge or converge the error for eliminating the ISI in the received signal at the time the invention was made.

Allowable Subject Matter

4. Claims 1- 8 allowed.

Serial Number: 087/894,207

Page 4

Art Unit: 2731

Conclusion

5. **THIS ACTION IS MADE FINAL.** Applicant is reminded of the extension of time policy as set forth in 37 CFR 1.136(a).

A shortened statutory period for reply to this final action is set to expire **THREE MONTHS** from the mailing date of this action. In the event a first reply is filed within **TWO MONTHS** of the mailing date of this final action and the advisory action is not mailed until after the end of the **THREE-MONTH** shortened statutory period, then the shortened statutory period will expire on the date the advisory action is mailed, and any extension fee pursuant to 37 CFR 1.136(a) will be calculated from the mailing date of the advisory action. In no event, however, will the statutory period for reply expire later than **SIX MONTHS** from the mailing date of this final action.

6. Any inquiry concerning this communication or earlier communications from the examiner should be directed to T.Bocure whose telephone number is (703) 305-4735. The examiner can normally be reached on Monday through Thursday the first week of a bi-week and Monday through Friday the second week of a bi-week from 7:00am to 4:30pm.

If attempts to reach the examiner by telephone are unsuccessful, the examiner's supervisor, Chi Pham, can be reached on (703) 305- 4378. The fax phone number for the organization where this application or proceeding is assigned is (703) 308-4743 or (703) 305-3988.

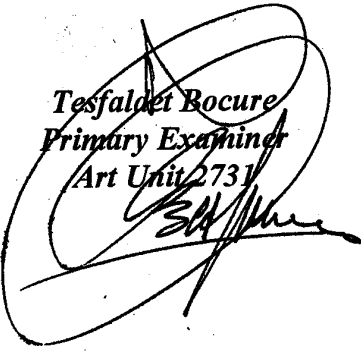
Serial Number: 087/894,207

Page 5

Art Unit: 2731

Any inquiry of a general nature or relating to the status of this application or proceeding should be directed to the receptionist whose telephone number is (703) 305-3900.

Tesfaldet Bocure
Primary Examiner
Art Unit 2731



T. Bocure

March 16, 1999

Feb. 29, 2000 1:33PM KINNEY & LANGE, P. A.

No. 1671 P. 1

URGENT

7/13

IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

First Named

Inventor : Catherine Douillard et al

Appln. No. : 08/894,207

Filed : December 3, 1997

Title : ITERATIVE-STRUCTURE DIGITAL
SIGNAL RECEPTION DEVICE AND
MODULE AND METHOD THEREFOR

Docket No. : F264.312-16

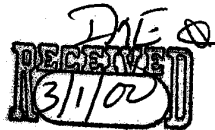
OFFICIAL

Group Art Unit: 2731

Examiner: T. Bocure

CERTIFICATION OF TELEFACSIMILE TRANSMISSION

Assistant Commissioner for Patents
Washington, D.C. 20231



(703) 308-4743

Sir:

I certify that the following papers are being telefacsimile transmitted to the U.S. *305 3712*
308 6743
305 3998

Patent and Trademark Office on the date shown below:

1. AMENDMENT AFTER FINAL
2. FEE TRANSMITTAL FORM
3. 3 MONTH EXTENSION OF TIME

KINNEY & LANGE, P.A.

Date:

February 29, 2000

By:

Jeffrey D. Shewchuk, Reg. No. 37,235
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JDS:alg

6 PAGES - INCLUDING COVER PAGE



UNITED STATES DEPARTMENT OF COMMERCE
Patent and Trademark Office

Address: COMMISSIONER OF PATENTS AND TRADEMARKS
Washington, D.C. 20231

SERIAL NUMBER	207	FILING DATE	10/13/97	FIRST NAMED APPLICANT	DOUGLEND	ATTORNEY DOCKET NO.	F264.312-16
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LM02/1025

BUCURE, T	
EXAMINER	
2731	
ART UNIT	PAPER NUMBER
	10/25/99 #12

DATE MAILED:

Please find below a communication from the EXAMINER in charge of this application.

Commissioner of Patents

1. In response to applicant's telephone inquiry regarding "the last office action mailed on September 13, 1999", the following action has been taken:

THE PERIOD FOR RESPONSE OF 3(THREE) MONTHS SET IN SAID OFFICE ACTION CONTINUE TO RUN FROM THE DATE OF THE LAST OFFICE ACTION WAS MAILED.

2. A corrected copy of the last office action indicating the withdrawal to the: objection of claims 3-7; rejection of claims 1 and 2; and objection to the proposed drawing correction filed on June 28, 1999 is enclosed with this correspondence.
4. Any inquiry concerning this communication or earlier communications from the examiner should be directed to T.Bocure whose telephone number is (703) 305-4735.

13/B (w/e)
3/1/00
DS

IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

Applicant : Catherine Douillard et al.	Group Art Unit: 2731 Examiner: T. Bocure
Serial No. : 08/894,207	
Filed : December 3, 1997	
For : ITERATIVE-STRUCTURE DIGITAL SIGNAL RECEPTION DEVICE AND MODULE AND METHOD THEREFOR	
Docket No. : F264.312-16	

do to enter
3/2/2000

AMENDMENT AFTER FINAL

Box AF
Assistant Commissioner for Patents
Washington, D.C. 20231

I CERTIFY THAT THIS PAPER IS BEING SENT BY ~~U.S. MAIL~~
FIRST CLASS, TO THE ASSISTANT COMMISSIONER FOR
PATENTS, WASHINGTON, D.C. 20231, THIS 29th DAY OF
FEBRUARY 2000
PATENT ATTORNEY

FACSIMILE

Sir:

OFFICIAL

This is in response to the Office Action mailed September 13, 1999, as corrected by the Office Action mailed October 25, 1999. Please amend the above-identified application as follows:

IN THE CLAIMS

Please amend claim 9 as follows:

9. (Amended) Method for the reception of signals formed by a series of digital symbols corresponding to the convolutive encoding of items of source digital data comprising the following steps:

supplying with received symbols R_i ; and
performing for each received symbol R_i at least two iterations of the following steps:
correcting inter-symbol interference affecting [each of said] received
symbols R_i by means of an item of correction information Z_i , said
correction information Z_i , except Z_i (first iteration), being computed

Inventor: Douillard et al.

Serial No.:

-2-

by a computing step of the previous iteration, and the delivery of
corresponding estimated symbols $A_{i,1}$ with weighted value;
decoding said estimated symbols $A_{i,1}$ with weighted value entailing
operations symmetrical to said convolutive encoding, and the delivery
of decoded symbols $A_{i,2}$ with weighted value; [and]
computing said [items of] correction information Z_i from at least one of said
estimated symbols $A_{i,1}$ and at least one of said decoded symbols $A_{i,2}$;
and
delivering said correction information Z_i to the step of correcting inter-
symbol interference of the following iteration.

REMARKS

This is in response to the Office Action mailed September 13, 1999, as corrected by the Office Action mailed October 25, 1999. Claims 1-9 were pending. In the Office Action, claim 9 was rejected under 35 U.S.C. §103(a) as being unpatentable over Lester et al. (U.S. Patent No. 5,353,307). Applicant respectfully acknowledges the Examiner's allowance of claims 1-8. Claim 9 is amended. Entry of this amendment and reconsideration is respectfully requested to place the application in condition for allowance.

Applicant respectfully thanks the Examiner for the telephone interview between the undersigned and the Examiner on or about October 22, 1999. Applicant pointed out inconsistencies in the September 13, 1999 Office Action, resulting in the corrected Office Action mailed October 25, 1999.

With this Amendment, claim 9 is amended to clarify the claimed invention. As amended, claim 9 requires at least two iterations to be performed for each received symbol R_i . The changes to claim 9 further clarify the computing and delivery of the correction information Z_i between iterations, and the use of weighted value of the corresponding estimated symbols A . Claim

Feb. 29. 2000 1:33PM KINNEY & LANGE, P. A.

No. 1671 P. 4

Inventor: Douillard et al.

Serial No.:

-3-

9 as amended has a scope similar to allowed claim 1, and Applicant submits that claim 9 as amended is clearly new and non-obvious over Lester et al.

With this Amendment, all of claims 1-9 are in condition for allowance. Entry of the amendment, reconsideration and notice to that effect is respectfully requested. The Examiner is invited to contact the undersigned attorney at the number listed below if it would any way facilitate allowance of the claims.

Respectfully submitted,

KINNEY & LANGE, P.A.

By: 

Jeffrey D. Shewchuk, Reg. No. 37,235
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312 South Third Street
Minneapolis, MN 55415-1002
Telephone: (612) 339-1863
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JDS/RMR:beh

IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

First Named Inventor	: Catherine Douillard et al.	
Appln. No.	: 08/894,207	
Filed	: December 3, 1997	Group Art Unit: 2731
Title	: ITERATIVE-STRUCTURE DIGITAL SIGNAL RECEPTION DEVICE AND MODULE AND METHOD THEREFOR	Examiner: T. Bocure
Docket No.	: F264.312-16	

PETITION FOR THREE-MONTH EXTENSION OF TIME

Assistant Commissioner for Patents
Washington, D.C. 20231

I CERTIFY THAT THIS PAPER IS BEING SENT BY ^{FAKSIMILE} ~~U.S. MAIL, FIRST CLASS~~, TO THE ASSISTANT COMMISSIONER OF PATENTS, WASHINGTON, D.C. 20231, THIS 29th DAY OF

February 2000
PATENT ATTORNEY

Sir:

Pursuant to 37 C.F.R. 1.136(a), Applicant petitions for a Three-month extension of time to respond to the Office Action dated October 25, 1999.

Respectfully submitted,

KINNEY & LANGE, P.A.

By:

Jeffrey D. Shewchuk
Jeffrey D. Shewchuk, Reg. No. 37,235
THE KINNEY & LANGE BUILDING
312 South Third Street
Minneapolis, MN 55415-1002
Telephone: (612) 339-1863
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JDS:alg

FEE TRANSMITTAL		Complete if Known																																																																																																																																											
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1. ☒ The Commissioner is hereby authorized to charge any additional fee required under 37 C.F.R. 1.16 and 1.17 and credit any over payments to Deposit Account No. 11-0982. Deposit Account Name: Kinney & Lange, P.A.		3. ADDITIONAL FEES																																																																																																																																											
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Signature

Jeffrey D. Shewchuk

Reg. No.

37,235

Date

February 29, 2000

Deposit Account No.

11-0982

Notice of Allowability

Application No.
08/894,207

Applicant(s)

Catherine Douillard et al.

Examiner

Tesfaldet Bocure

Group Art Unit

2731



All claims being allowable, PROSECUTION ON THE MERITS IS (OR REMAINS) CLOSED in this application. If not included herewith (or previously mailed), a Notice of Allowance and Issue Fee Due or other appropriate communication will be mailed in due course.

☒ This communication is responsive to 2/29/2000

☒ The allowed claim(s) is/are 1-9

☐ The drawings filed on _____ are acceptable.

☒ Acknowledgement is made of a claim for foreign priority under 35 U.S.C. § 119(a)-(d).

☒ All ☐ Some* ☐ None of the CERTIFIED copies of the priority documents have been

☒ received.

☐ received in Application No. (Series Code/Serial Number) _____

☐ received in this national stage application from the International Bureau (PCT Rule 17.2(a)).

*Certified copies not received: _____

☐ Acknowledgement is made of a claim for domestic priority under 35 U.S.C. § 119(e).

A SHORTENED STATUTORY PERIOD FOR RESPONSE to comply with the requirements noted below is set to EXPIRE **THREE MONTHS** FROM THE "DATE MAILED" of this Office action. Failure to timely comply will result in ABANDONMENT of this application. Extensions of time may be obtained under the provisions of 37 CFR 1.136(a).

☐ Note the attached EXAMINER'S AMENDMENT or NOTICE OF INFORMAL APPLICATION, PTO-152, which discloses that the oath or declaration is deficient. A SUBSTITUTE OATH OR DECLARATION IS REQUIRED.

☒ Applicant MUST submit NEW FORMAL DRAWINGS

☐ because the originally filed drawings were declared by applicant to be informal.

☒ including changes required by the Notice of Draftsperson's Patent Drawing Review, PTO-948, attached hereto or to Paper No. 7.

☒ including changes required by the proposed drawing correction filed on Jun 28, 1999, which has been approved by the examiner.

☐ including changes required by the attached Examiner's Amendment/Comment.

Identifying indicia such as the application number (see 37 CFR 1.84(c)) should be written on the reverse side of the drawings. The drawings should be filed as a separate paper with a transmittal letter addressed to the Official Draftsperson.

☐ Note the attached Examiner's comment regarding REQUIREMENT FOR THE DEPOSIT OF BIOLOGICAL MATERIAL.

Any response to this letter should include, in the upper right hand corner, the APPLICATION NUMBER (SERIES CODE/SERIAL NUMBER). If applicant has received a Notice of Allowance and Issue Fee Due, the ISSUE BATCH NUMBER and DATE of the NOTICE OF ALLOWANCE should also be included.

Attachment(s)

☐ Notice of References Cited, PTO-892

☐ Information Disclosure Statement(s), PTO-1449, Paper No(s). _____

☐ Notice of Draftsperson's Patent Drawing Review, PTO-948

☐ Notice of Informal Patent Application, PTO-152

☐ Interview Summary, PTO-413

☐ Examiner's Amendment/Comment

☐ Examiner's Comment Regarding Requirement for Deposit of Biological Material

☐ Examiner's Statement of Reasons for Allowance

TESFALDET BOCURE
PRIMARY EXAMINER
ART UNIT 2731



UNITED STATES DEPARTMENT OF COMMERCE
Patent and Trademark Office

NOTICE OF ALLOWANCE AND ISSUE FEE DUE

LM12/0306

KINNEY & LANGE, P.A.
THE KINNEY & LANGE BUILDING
312 SOUTH THIRD STREET
MINNEAPOLIS MN 55415-1002

APPLICATION NO.	FILING DATE	TOTAL CLAIMS	EXAMINER AND GROUP ART UNIT	DATE MAILED
08/894,207	12/03/97	009	BOCURE, T	03/06/00
First Named Applicant	DOUILLARD, 35 USC 154(b) term ext. = 1/2 Days.			

TITLE OF INVENTION ITERATIVE-STRUCTURE DIGITAL SIGNAL RECEPTION DEVICE, AND MODULE AND METHOD THEREFOR

ATTY'S DOCKET NO.	CLASS-SUBCLASS	BATCH NO.	APPLN. TYPE	SMALL ENTITY	FEE DUE	DATE DUE
2	F264.312-16	375-348.000	J11 UTILITY	NO	\$1210.00	06/06/00

THE APPLICATION IDENTIFIED ABOVE HAS BEEN EXAMINED AND IS ALLOWED FOR ISSUANCE AS A PATENT. PROSECUTION ON THE MERITS IS CLOSED.

THE ISSUE FEE MUST BE PAID WITHIN THREE MONTHS FROM THE MAILING DATE OF THIS NOTICE OR THIS APPLICATION SHALL BE REGARDED AS ABANDONED. THIS STATUTORY PERIOD CANNOT BE EXTENDED.

HOW TO RESPOND TO THIS NOTICE:

I. Review the SMALL ENTITY status shown above.

If the SMALL ENTITY is shown as YES, verify your current SMALL ENTITY status:

- A. If the status is changed, pay twice the amount of the FEE DUE shown above and notify the Patent and Trademark Office of the change in status, or
- B. If the status is the same, pay the FEE DUE shown above.

If the SMALL ENTITY is shown as NO:

- A. Pay FEE DUE shown above, or
- B. File verified statement of Small Entity Status before, or with, payment of 1/2 the FEE DUE shown above.

II. Part B-Issue Fee Transmittal should be completed and returned to the Patent and Trademark Office (PTO) with your ISSUE FEE. Even if the ISSUE FEE has already been paid by charge to deposit account, Part B Issue Fee Transmittal should be completed and returned. If you are charging the ISSUE FEE to your deposit account, section "4b" of Part B-Issue Fee Transmittal should be completed and an extra copy of the form should be submitted.

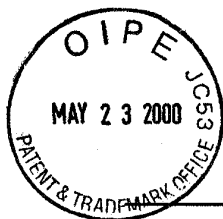
III. All communications regarding this application must give application number and batch number. Please direct all communications prior to issuance to Box ISSUE FEE unless advised to the contrary.

IMPORTANT REMINDER: Utility patents issuing on applications filed on or after Dec. 12, 1980 may require payment of maintenance fees. It is patentee's responsibility to ensure timely payment of maintenance fees when due.

PATENT AND TRADEMARK OFFICE COPY

PTOL-85 (REV. 10-96) Approved for use through 06/30/99. (0651-0033)

*U.S. GPO: 1999-454-457/24601



IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

15
JL

First Named Inventor : Catherine Douillard et al.	Batch No: J11
Appln. No. : 08/894,207	Allowed: 03/06/00
Filed : December 3, 1997	Group Art Unit: 2731
Title : ITERATIVE-STRUCTURE DIGITAL SIGNAL RECEPTION DEVICE, AND MODULE AND METHOD THEREFOR	Examiner: Bocure, T.
Docket No. : F264.312-0016	

CERTIFICATE OF MAILING - ISSUE FEE

Box Issue Fee
Assistant Commissioner for Patents
Washington, D.C. 20231

I CERTIFY THAT THIS PAPER IS BEING SENT BY U.S. MAIL, FIRST CLASS, TO THE ASSISTANT COMMISSIONER FOR PATENTS, WASHINGTON, D.C. 20231, THIS 19th DAY OF

May 2000.
PATENT ATTORNEY

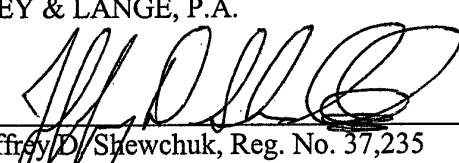
Sir:

Submitted herewith is our check in the amount of \$1,240.00 as payment of the issue fee in the above-identified application and Advanced Order for ten soft copies of the issued patent, along with the Issue Fee Transmittal.

The Examiner is authorized to charge any payment of any issue fee or document supply fees under 37 C.F.R. 1.18 or 1.19 or credit any overpayment to Deposit Account No. 11-0982. A duplicate of this paper is enclosed.

Respectfully submitted,

KINNEY & LANGE, P.A.

By: 
Jeffrey D. Shewchuk, Reg. No. 37,235
THE KINNEY & LANGE BUILDING
312 South Third Street
Minneapolis, MN 55415
Phone: (612) 339-1863
Fax: (612) 339-6580

JDS/RMR:beh



IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

First Named Inventor : Catherine Douillard et al.	Batch No: J11
Appln. No. : 08/894,207	Allowed: 03/06/00
Filed : December 3, 1997	Group Art Unit: 2731
Title : ITERATIVE-STRUCTURE DIGITAL SIGNAL RECEPTION DEVICE, AND MODULE AND METHOD THEREFOR	Examiner: Bocure, T.
Docket No. : F264.312-0016	

LETTER TO OFFICIAL DRAFTSMAN

Box Issue Fee
Assistant Commissioner for Patents
Washington, D.C. 20231

I CERTIFY THAT THIS PAPER IS BEING SENT BY U.S. MAIL,
FIRST CLASS, TO THE ASSISTANT COMMISSIONER FOR
PATENTS, WASHINGTON, D.C. 20231, THIS 19th DAY OF

May
PATENT ATTORNEY

Sir:

Enclosed are three (3) sheets of formal drawings for filing in the above-identified application.

Respectfully submitted,

KINNEY & LANGE, P.A.

By: [Signature]
Jeffrey D. Shewchuk, Reg. No. 37,235
THE KINNEY & LANGE BUILDING
312 South Third Street
Minneapolis, MN 55415-1002
Telephone: (612) 339-1863
Fax: (612) 339-6580

JDS/RMR:beh

6108388

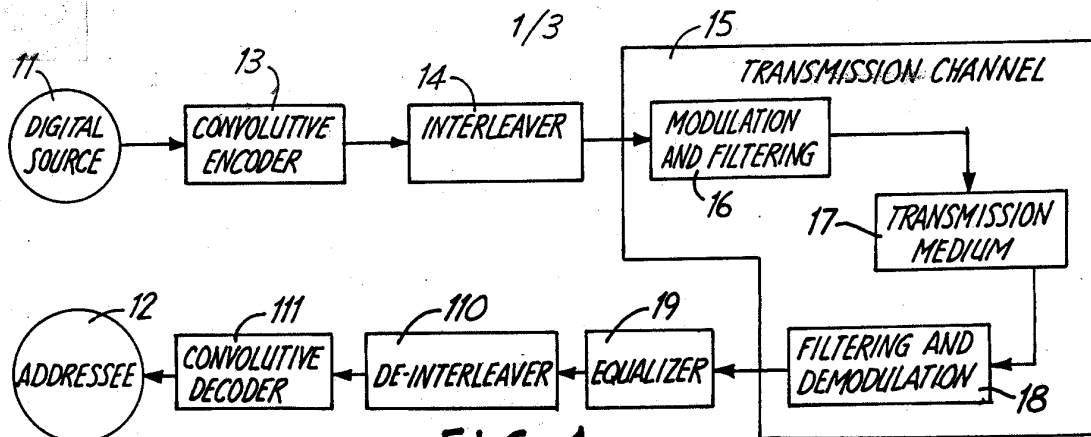


FIG. 1
PRIOR ART

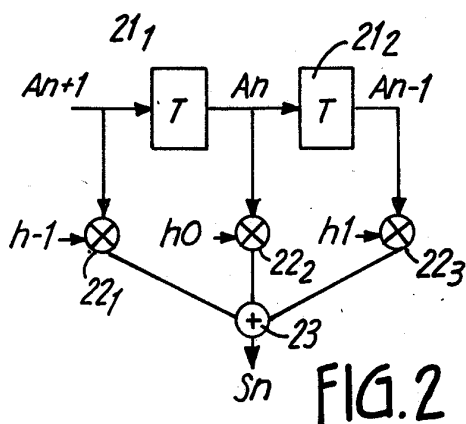


FIG. 2

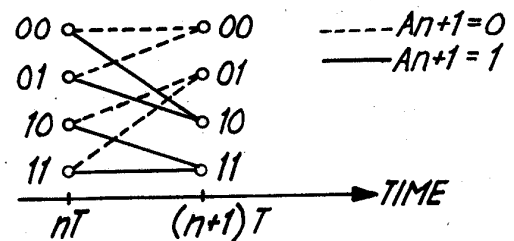


FIG. 3

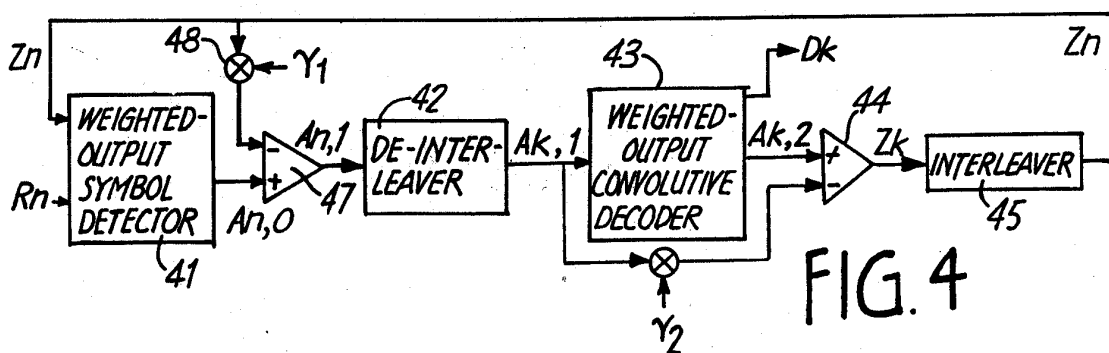


FIG. 4

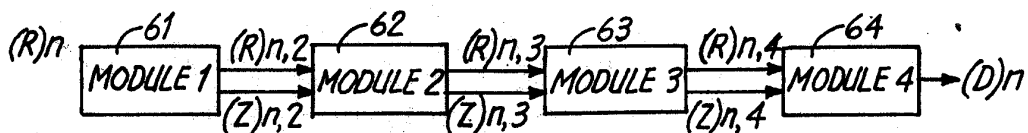


FIG. 6

2/3

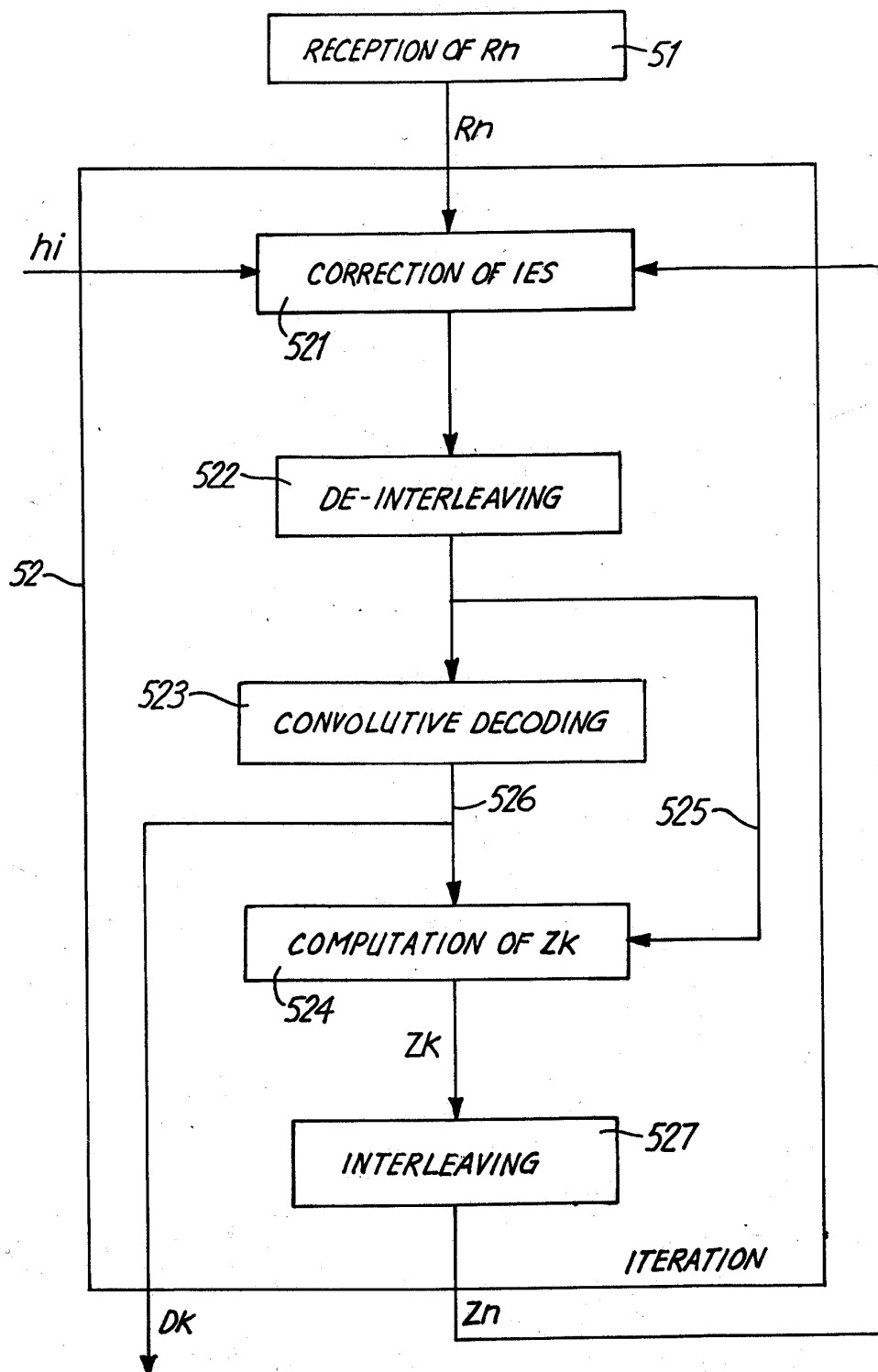


FIG. 5

3/3

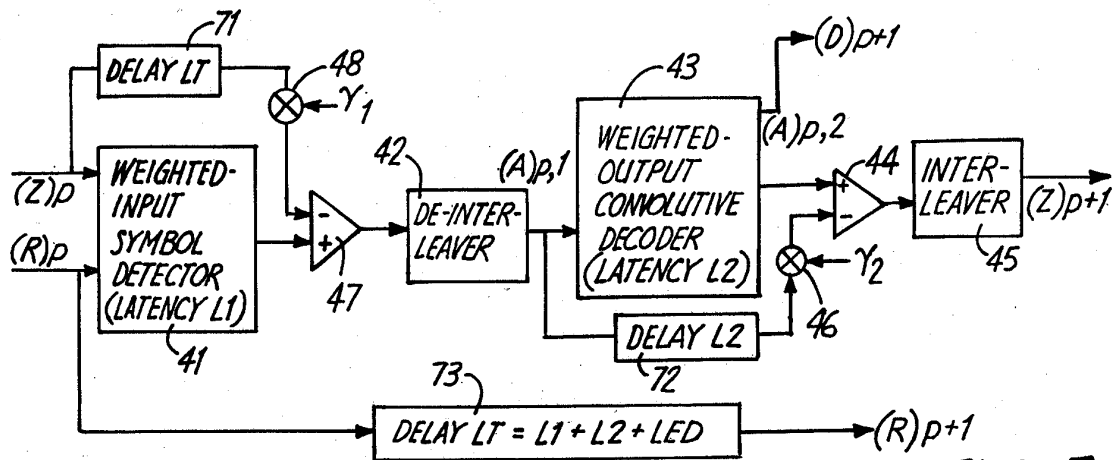


FIG. 7

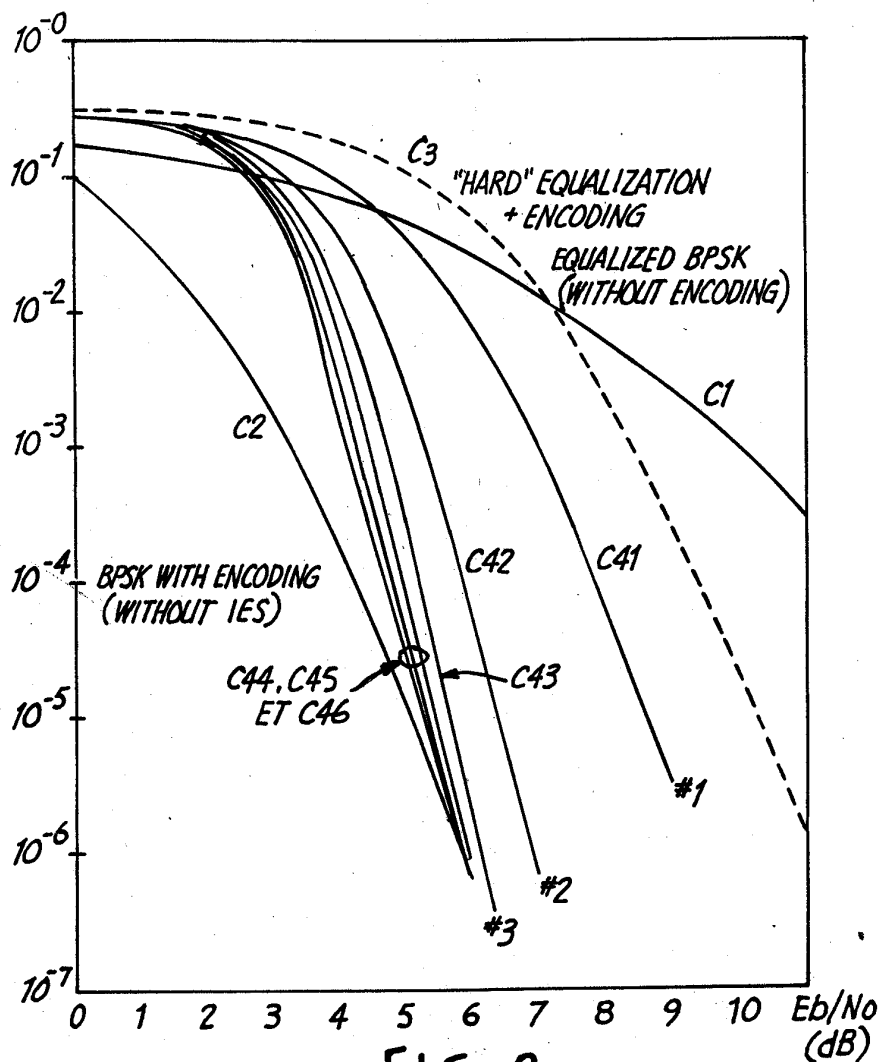


FIG. 8

FEE TRANSMITTAL



Total Amount of Payment: \$ 1,240.00

Complete if Known

Application No. 08/894,207
 Filing Date December 3, 1997
 First Named Catherine Douillard et al.
 Group Art Unit 2731
 Examiner Name Bocure, T.
 Atty. Docket F264.312-0016

METHOD OF PAYMENT (Check One)

1. ☒ The Commissioner is hereby authorized to charge any additional fee required under 37 C.F.R. 1.16 and 1.17 and credit any over payments to Deposit Account No. 11-0982.
 Deposit Account Name: Kinney & Lange, P.A.

2. ☒ Check Enclosed

FEE CALCULATION

1. BASIC FILING FEE

Large Entity Fee Code	Large Entity Fee (\$)	Small Entity Fee Code	Small Entity Fee (\$)	Fee Description
101	690	201	345	☐ Utility Filing Fee
106	310	206	155	☐ Design Filing Fee
108	690	208	345	☐ Reissue Filing Fee
114	150	214	75	☐ Prov. Filing Fee

Subtotal (1) \$

2. EXTRA CLAIM FEES

	Number Claims	Prior**	Extra	Fee from Below	Fee Paid
Total	*	*	*	*	*
Indep.	*	*	*	*	*
Multiple Dependent Claims			*	*	*

**Insert 3 and 20, or number previously paid if greater; Reissue see below

Large Entity Fee Code	Large Entity Fee (\$)	Small Entity Fee Code	Small Entity Fee (\$)	Description
103	18	203	9	Claims in excess of 20
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110	18	210	9	Reissue claims in excess of 20 and over original patent

Subtotal (2) \$

FEE CALCULATION (Continued)

3. ADDITIONAL FEES

Large Entity Fee Code	Large Entity Fee (\$)	Small Entity Fee Code	Small Entity Fee (\$)	Fee Description	Fee paid
105	130	205	65	Surcharge - Late filing fee or oath	*
127	50	227	25	Surcharge - late provisional filing fee or cover sheet	*
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118	1,360	218	690	Extension for reply within fourth month	*
128	1,850	280	925	Extension for reply within fifth month	*
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08/894,207	12/03/97	009	BOCURE, T	2731 03/06/00
First Named Applicant	DOUILLARD, 35 USC 154(b) term ext. = 0 Days.			

TITLE OF INVENTION ITERATIVE-STRUCTURE DIGITAL SIGNAL RECEPTION DEVICE, AND MODULE AND METHOD THEREFOR

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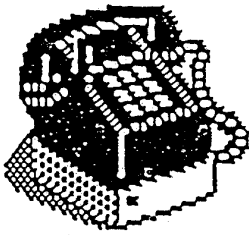
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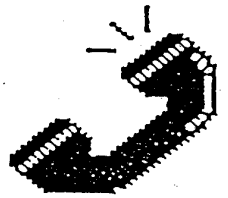


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US006108388A

United States Patent [19]
Douillard et al.

[11] **Patent Number:** **6,108,388**
[45] **Date of Patent:** **Aug. 22, 2000**

[54] **ITERATIVE-STRUCTURE DIGITAL SIGNAL RECEPTION DEVICE, AND MODULE AND METHOD THEREFOR**

[75] Inventors: **Catherine Douillard**, Brest; **Alain Glavieux**, Brest Cédex; **Michel Jezequel**, Brest; **Claude Berrou**, Locmaria-Plouzane, all of France

[73] Assignees: **France Telecom; Telediffusion de France**, both of Paris, France

[21] Appl. No.: **08/894,207**

[22] PCT Filed: **Feb. 6, 1996**

[86] PCT No.: **PCT/FR96/00197**

§ 371 Date: **Dec. 3, 1997**

§ 102(e) Date: **Dec. 3, 1997**

[87] PCT Pub. No.: **WO96/24999**

PCT Pub. Date: **Aug. 15, 1996**

[30] **Foreign Application Priority Data**

Feb. 7, 1995 [FR] France 95 01603

[51] **Int. Cl.⁷** **H03D 1/06; H04L 27/06**

[52] **U.S. Cl.** **375/348; 375/341**

[58] **Field of Search** **375/262, 341, 375/232, 233, 340, 346, 348; 371/43**

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Primary Examiner—Tessfaldet Bocure

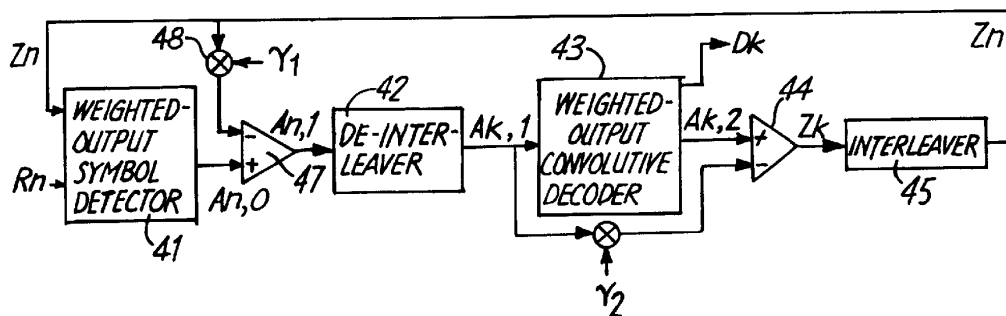
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[57]

ABSTRACT

The invention relates to a device for the reception of signals formed by a series of digital symbols corresponding to the convolutive encoding of items of source digital data comprising p cascade-connected detection and decoding modules M_1 to M_p , p being greater than or equal to 2, each of said modules M_i including: (a) inter-symbol interference correction means supplied by a symbol input R_i and delivering estimated symbols $A_{i,1}$ with weighted values, (b) means for the decoding of said estimated symbols $A_{i,1}$, performing operations symmetrical to said convolutive encoding and delivering decoded symbols $A_{i,2}$ with weighted values, and (c) means for the computation of an item of correction information Z_{i+1} from said estimated symbol $A_{i,1}$ and said decoded symbol $A_{i,2}$, (d) said means for the correction of each of said modules M_i , except for the first module M_1 , taking account of at least one item of correction information Z_i determined by the previous module M_{i-1} .

9 Claims, 3 Drawing Sheets



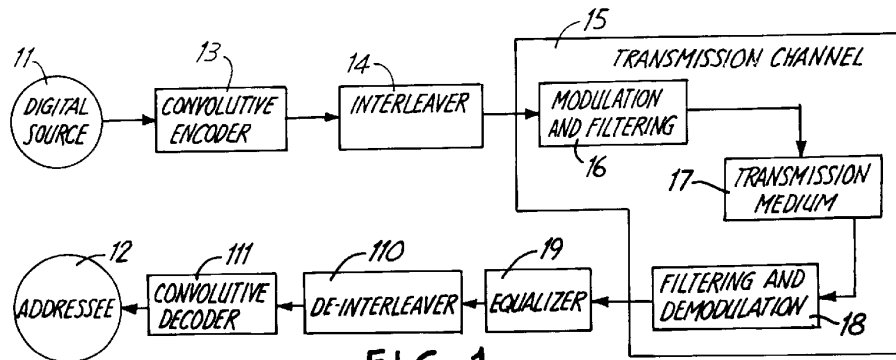


FIG. 1

PRIOR ART

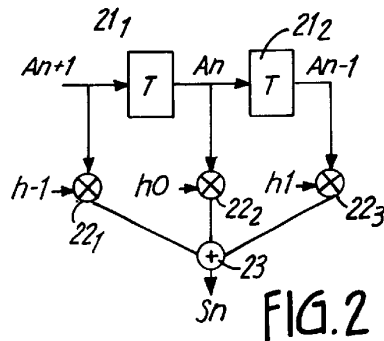


FIG. 2

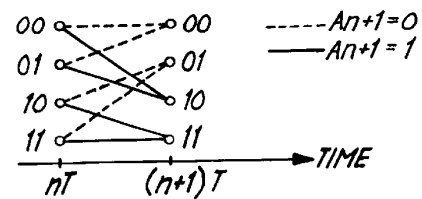


FIG. 3

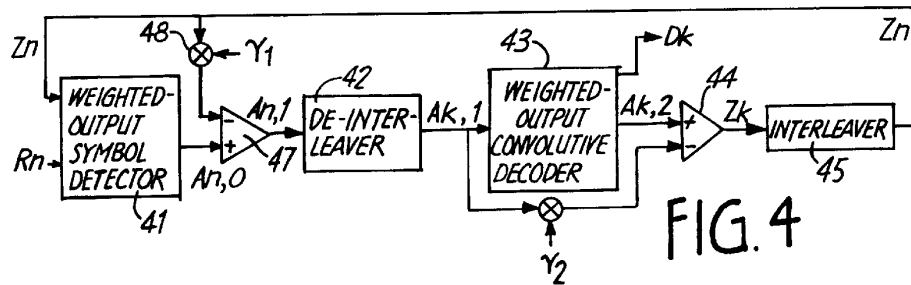


FIG. 4

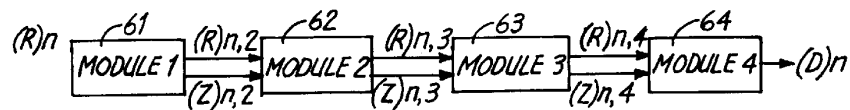


FIG. 6

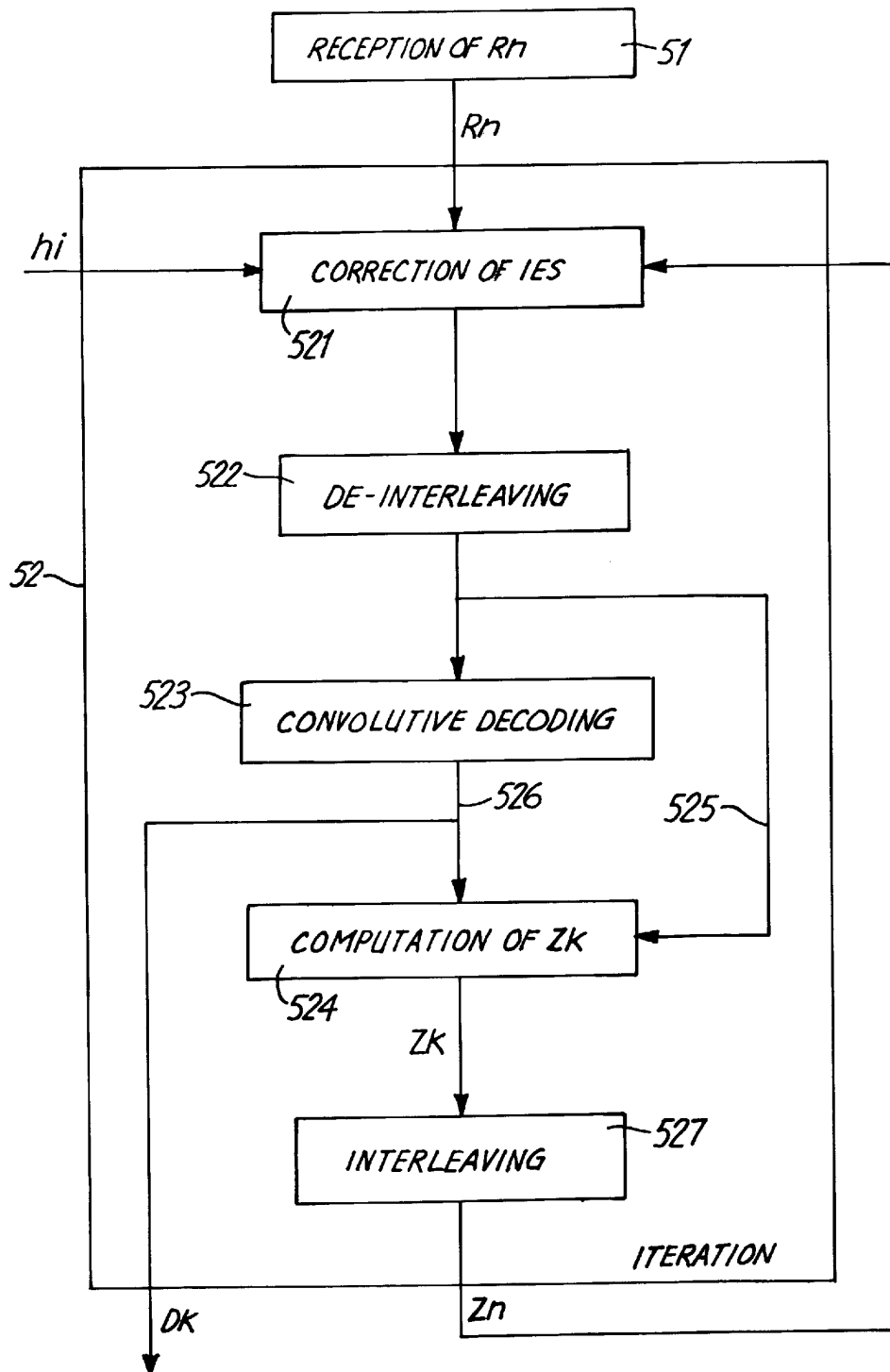


FIG. 5

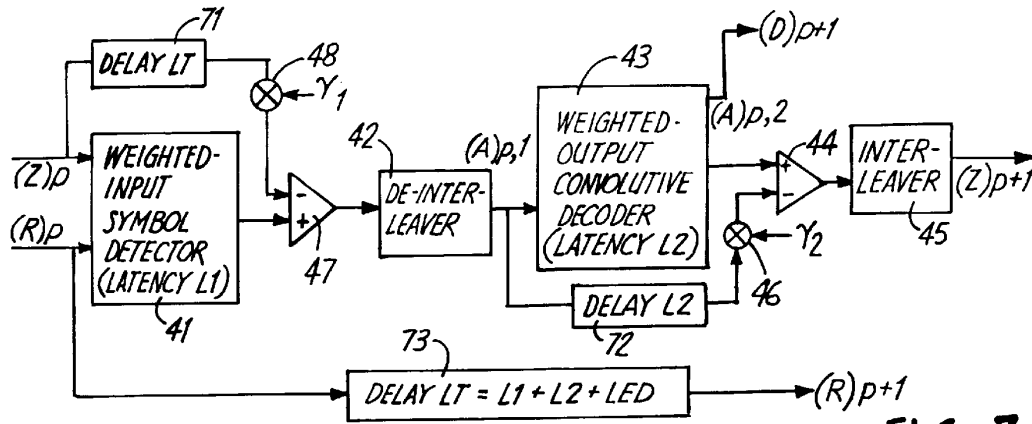


FIG. 7

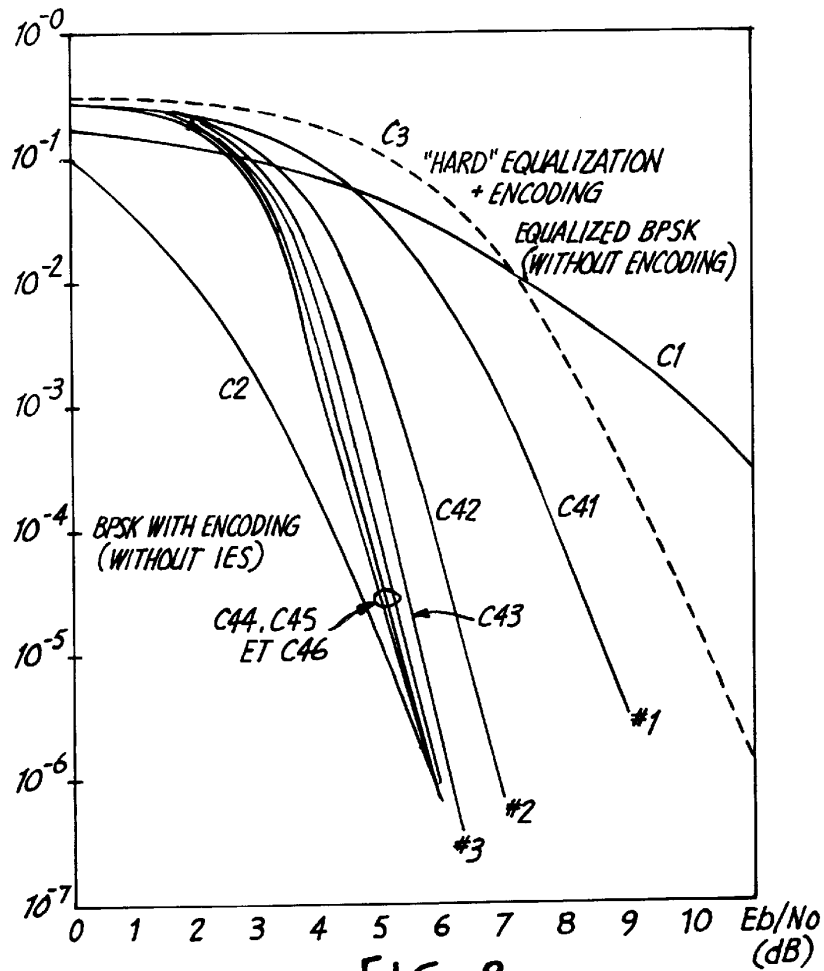


FIG. 8

ITERATIVE-STRUCTURE DIGITAL SIGNAL RECEPTION DEVICE, AND MODULE AND METHOD THEREFOR

BACKGROUND OF INVENTION

The field of the invention is that of the transmission and broadcasting of digital signals, especially in the presence of transmission noises. More specifically, the invention relates to the reception of digital signals encoded by means of a convolutive type error correction code.

The invention can be applied in all cases where digital signals are transmitted or broadcast on noise-infested channels. For example, the present invention can be implemented in receivers of systems for digital radiocommunications with mobile units such as the GSM system.

Other possible applications are, for example, the reception of signals transmitted by RF channels, satellites, etc. More generally, the invention can be applied advantageously in all cases where a convolutive type code is implemented at transmission.

In the known type of receivers, the symbols retrieved at output of the demodulator take the form of analog samples which, after quantification, are generally processed by an equalizer (a transversal filter) given the task of eliminating the inter-symbol interference introduced by the channel. The equalized samples are then de-interleaved if necessary and decoded before being given to the addressee.

The principle of equalization consists in estimating the response of the transmission channel for the application, to the received signal, of a filtering operation symmetrical to this response so as to: obtain a corrected signal. In particular, the equalization is aimed at eliminating or, at least, at limiting the inter-symbol interference introduced by the channel.

The response of the channel is generally estimated by the analysis of a reference signal known to the receivers. Of course, the transmission of these reference signals leads to a reduction of the useful bit rate.

The equalized items of data are then de-interleaved (in an operation symmetrical to the interleaving done at the time of encoding, if such an interleaving is planned) and then decoded.

In certain situations, it happens that the equalization of this type is not sufficient to ensure high quality source decoding.

The article by P. Jung and P. W. Baier, "VLSI implementation of soft output Viterbi equalizers for mobile radio applications" (Proc. of IEEE 42nd Vehicular Technology Society Conference, Denver, Colo., pp. 577-585, May 1992) proposes the use, instead of a transversal filter, of a symbol detector working according to the principle of maximum likelihood.

This technique is more efficient if the coefficients representing the channel are properly estimated. However, once again, the equalized items of data may prove to be of insufficient quality. Furthermore, it is more complicated to make and requires more space than with the transverse filter technique.

Convolutive codes are codes that associate at least one encoded item of data with each item of source data to be encoded. This encoded item of data is obtained by the modulo 2 summation of this item of source data with at least one of the previous items of source data. Thus, each encoded signal is a linear combination of the item of source data to be encoded and previous items of source data taken into account.

In the decoder, the original items of data are most usually reconstructed by means of a maximum likelihood algorithm, for example the Viterbi algorithm, whose decisions may be weighted if necessary. The Viterbi algorithm, in taking account of a sequence of received encoded symbols, provides an estimation of each item of data encoded at transmission, in defining the source sequence most probably corresponding to the received sequence.

The Viterbi algorithm may also be used to detect sequences affected by inter-symbol interference. The invention can be also applied in this case.

Clearly, the greater the number of symbols taken into account, the more reliable is the decision. By contrast, the greater this number, the more complicated is the decoder or the detector (hereinafter, the term « decoder » is used to describe decoders themselves as well as detectors. This observation is applicable also to the term « decoding » which must be understood to mean « decoding » or « detection » as the case may be. The memory space needed soon becomes very great, as do the corresponding computation times.

The integrated circuits that implement such algorithms therefore most usually rely on a compromise between cost and performance. These industrial-level choices do not always enable the construction of decoders that correspond in an optimum way to a given application. For example, it is not possible to make low-cost decoders for applications where the reception quality is not of crucial importance, as integrated circuits cost too much. Conversely, these integrated circuits too are not suited to the making of receivers with very high decoding quality for which the cost price is of little importance.

An advantageous example of convolutive encoding, to which the invention can be applied, is described in the French patent application FR 91 05280 filed on behalf of the same Applicants as well as in the article by C. Berrou, A. Glavieux and P. Thitimajshima, "Near Shannon limit error-correcting coding and decoding: turbo-codes" (Proc. ICC'93, pp. 1064-1070, Geneva, Switzerland, May 1993). This class of codes is known in particular as "turbo-codes".

The elementary codes (recursive systematic or pseudo-systematic codes) described in the French patent application FR 91 05278 filed on behalf of the present Applicants may also be used.

The invention is aimed especially at overcoming the drawbacks of the prior art reception device and more specifically at improving the corresponding performance characteristics.

More specifically, a goal of the invention is to provide a device of this kind with very high corrective capacity as compared with known methods presently used in digital communications systems.

The invention is aimed in particular at providing methods of this kind that are particularly efficient, again with respect to known methods, for transmission in highly noise-infested channels.

It is also an aim of the invention to provide a device of this kind that is highly efficient but nevertheless easy to manufacture on an industrial scale at acceptable costs.

Thus, a particular aim of the invention is to provide a decoding method enabling implantation on a silicon surface that is small enough for its industrial-scale manufacture to be possible, for example, on a surface area smaller than 50 mm².

It is also an aim of the invention to provide a method of reception used for the making of numerous types of receiv-

ers with performance characteristics and cost price that vary as a function of the needs fulfilled, implementing one or more integrated circuits of a single type.

In other words, an essential aim of the invention is to provide methods of this kind enabling firstly profitable industrial-scale manufacture based on the development of a single and relatively simple integrated circuit and, secondly, the making of receivers that can be used for a very wide variety of applications.

BRIEF SUMMARY OF THE INVENTION

These goals as well as others that shall appear hereinafter are achieved according to the invention by means of a device for the reception of signals formed by a series of digital symbols corresponding to the convolutive encoding of items of source digital data comprising p cascade-connected detection and decoding modules M_1 to M_p , p being greater than or equal to 2, each of said modules M_i including:

inter-symbol interference correction means supplied by a symbol input R_i and delivering estimated symbols $A_{i,1}$ with weighted values,

means for the decoding of said estimated symbols $A_{i,1}$, performing operations symmetrical to said convolutive encoding and delivering decoded symbols $A_{i,2}$ with weighted values, and

means for the computation of an item of correction information Z_{i+1} from said estimated symbol $A_{i,1}$ and said decoded symbol $A_{i,2}$,

said means for the correction of each of said modules M_i , except for the first module M_1 , taking account of at least one item of correction information Z_i determined by the previous module M_{i-1} .

Thus, according to the invention, the standard function of equalization (filtering) is replaced by a symbol detector that takes account of the memory effect introduced by the channel.

In other words, the invention proposes a completely novel and optimized approach to the correction of inter-symbol interference. Indeed, conventionally, the equalization does not take account of the items of data transmitted but only of the channel estimation. By contrast, the invention is based on a dynamic approach, in taking account of the last symbols received to improve the equalization.

In other words again, the invention, in its general principle, likens the effect of inter-symbol interference to a particular convolutive encoding (except that there is no redundancy in the case of interference: to a symbol emitted on the channel, there corresponds one and only received symbol), and carries out its decoding. More specifically, the phenomenon of inter-symbol interference introduced by the channel may be represented by a lattice. This lattice differs from a convolutive encoding lattice by the presence of multiplier coefficients that vary in time. Thus, each module of the invention includes correction means and decoding means having similar structures based on convolutive decoding techniques.

The technique of the invention therefore consists in computing an item of correction information that represents the received symbol and in taking account of one or more of these items of information to correct the interference.

It will be understood that the taking into account of this information element dictates an iterative reception structure because of the latency introduced by the processing operations. Thus, during the first iteration, a first item of correction information is computed. This information element is used and, as the case may be, it is recomputed during the

following iterations. According to the invention, the iterative approach takes the form of a structuring of the receiver (detector of symbols and decoder) in the form of cascade-connected modules with each module corresponding to an iteration. This is a completely novel approach to the correction of inter-symbol interference.

Advantageously, these modules are all identical. In particular, they may take the form of integrated circuits.

The greater the number of modules, the greater is the increase in the efficiency of reception (correction of inter-symbol interference and decoding). The modular approach of the invention can be used to easily obtain several types of receivers corresponding to different levels of reception quality, as a function of the modules implemented. Similarly, it is possible to provide for decoders with an open-ended structure to which modules may be added as needed.

DESCRIPTION OF THE DRAWINGS

Other features and advantages of the invention shall appear from the following description of a preferred embodiment of the invention giving by way of a non-restricted example and from the appended drawings, of which:

FIG. 1 is a block diagram illustrating a standard transmission line that can incorporate the reception device according to the present invention.

FIG. 2 shows a simplified view of a discrete model, equivalent in terms of baseband to a transmission channel affected by an inter-symbol interference, illustrating the approach of the present invention.

FIG. 3 shows the corresponding lattice of the channel of FIG. 2, illustrating possible developments of the state of the channel as a function of time.

FIG. 4 is a block diagram showing the principle of the receiver of the present invention.

FIG. 5 is a simplified flow chart illustrating the method of the present invention implemented in the receiver of FIG. 4.

FIG. 6 illustrates the modular structure of the receiver of the present invention in the case of four cascade-connected modules.

FIG. 7 shows a block diagram of the module of FIG. 6.

FIG. 8 shows a series of curves illustrating the performance characteristics of the present invention in the case of a Gaussian channel.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

According to a preferred embodiment of the invention, each of said modules M_i has two inputs, one symbol input R_i and one correction input Z_i and three outputs, one symbol output R_{i+1} , one correction output Z_{i+1} and one decoded symbol output D_{i+1} ,

the symbol input R_i of the module M_i being connected to the symbol output R_i of the module M_{i-1} for i greater than 1 and being supplied with the symbols received for i equal to 1,

the correction input Z_i of the module M_i being connected to the correction output Z_i of the module M_{i-1} for i greater than 1 and being supplied with a neutral value that does not affect the correction for i equal to 1,

the symbol output R_{i+1} of the module M_i being equal to the symbol input R_i of said module M_i delayed by the latency time dictated by the module M_i ,

the correction output Z_{i+1} delivering said correction information, and the decoded symbol output D_{i+1} being

5

unused for the modules M_1 to M_{p-1} and being supplied with the decoded symbol $A_{p,2}$ of the module M_p if the code implemented is a systematic code and, if not, with a corresponding reconstituted value.

This structure, as indicated further above, makes it possible to design identical modules. Of course, depending on whether it is the first module, the last module or an intermediate module, the inputs and outputs used may be different.

Advantageously, said means for the correction of the inter-symbol interference are supplied with an item of correction information Z_i representing a difference between each decoded symbol $A_{i,2}$ and the corresponding estimated symbol $A_{i,1}$.

In this case, preferably, said means to compute the item of correction information comprise means for the multiplication of said estimation symbols $A_{i,1}$ by a positive weighting coefficient γ_2 delivering weighted symbols, and subtraction means computing the difference between each decoded symbol $A_{i,2}$ and the corresponding weighted symbol and delivering said item of correction information Z_i .

In particular, the value of this coefficient is set in such a way that the information borne by Z_i no longer contains any information relating to $A_{i,1}$ so that the noise affecting Z_i and the received samples R_i are decorrelated. Thus the information element reinjected into the input of the equalizer is "new" as compared with the received samples (it comes from the decoding process). It shall be called "extrinsic information".

According to an advantageous embodiment, said means for the correction of inter-symbol interference perform the following operations:

the computation of a correction value $V_i = \gamma_1 |Z_i|$, where γ_1 is a positive coefficient and where $| \cdot |$ represents the absolute value operator;

for each arm of the lattice corresponding to said convolutive code, the determining of a detected symbol $A_{i,o}$, comprising the following steps:

if the symbol assigned to said branch has the same sign as said item of correction information Z_i , the subtraction, from the metric associated with said arm, of said correction value V_i ;

if the symbol assigned to said arm has a sign opposite that of said item of correction information Z_i , the addition, to the metric associated with said arm, of said correction value V_i ;

the subtraction, from said detected symbol $A_{i,o}$, of the value $\gamma_2 Z_i$.

An object of the latter subtraction is to "rid" the output of the symbol detector and hence, all the more so, the input of the convolutive decoder, of the information element carried by Z_i .

The weighting of the symbols transmitted on the channel is aimed, conventionally, at representing the inter-symbol interference. The weighting coefficients may be fixed or, preferably, estimated, for example by means of a learning sequence.

Preferably, said coefficient γ_1 depends on at least one of the items of information belonging to the group comprising:

the signal-to-noise ratio;

the number i of the module considered.

Indeed it can be seen that the greater the value of γ_1 , the more reliable is the output of the decoder.

When the symbols are subjected to interleaving at transmission, the decoder preferably comprises:

de-interleaving means providing for the symmetrical operation of said interleaving, inserted between said correction means and said decoding means; and

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interleaving means providing for an interleaving of said items of correction information that is identical to said interleaving at transmission.

The interleaving and de-interleaving may be done by means of matrices.

The reading and writing increments may be fixed or, more advantageously, may depend on the read or write address.

The invention also relates to a detection and decoding module designed to be implemented in a device for the reception of signals formed by a series of digital symbols corresponding to the convolutive encoding of items of source digital data, said device comprising at least two cascade-connected modules, the module having two inputs, one symbol input R_i and one correction input Z_i , and three outputs, one symbol output R_{i+1} , one correction output Z_{i+1} and one decoded symbol output D_{i+1} , and comprising:

means for the correction of inter-symbol interference supplied by said symbol input R_i and taking account of said correction input Z_i and delivering estimated symbols $A_{i,1}$,

means for the decoding of said estimated symbols $A_{i,1}$, performing operations symmetrical to said convolutive encoding and delivering decoded symbols $A_{i,2}$, and

means for the computation of an item of correction information Z_{i+1} from said estimated symbol $A_{i,1}$ and said decoded symbol $A_{i,2}$,

the symbol output R_{i+1} being equal to the symbol input R_i delayed by a predefined latency time,

the correction output Z_{i+1} delivering said correction information, and

the decoded symbol output D_{i+1} , being supplied with said decoded symbol $A_{i,2}$ or with a value reconstituted as a function of the code implemented.

As indicated here above, a module of this kind in particular may take the form of an integrated circuit.

The invention further relates to a method for the reception of signals formed by a series of digital symbols corresponding to the convolutive encoding of items of source digital data comprising the following steps:

supplying with received symbols R_i ;

the correction of inter-symbol interference affecting each of said received symbols, by means of an item of correction information Z_i , and the delivery of estimated symbols $A_{i,1}$;

the decoding of said estimated symbols $A_{i,1}$, entailing operations symmetrical to said convolutive encoding, and the delivery of decoded symbols $A_{i,2}$;

the computation of said items of correction information Z_i from at least one of said estimated symbols $A_{i,1}$ and at least one of said decoded symbols $A_{i,2}$.

The invention can be applied, as indicated here above, to all systems of digital transmission implementing a convolutive error correction encoding operation as shown in FIG. 1.

This system has a digital source **11** that must be transmitted to an addressee **12**.

The term « digital source » is understood to mean any useful digital signal (sound, image, data) and more generally any set of useful signals, for example time-division multiplexed and/or frequency-division multiplexed signals. The addressee **12** may be a single addressee (in the case of transmission) or a multiple addressee (in the case of broadcasting). Similarly, the transmission line may of course be one-way (as in radio broadcasting) or two-way (as in radio communications for example).

The source of all signal is first of all subjected to a convolutive encoding **13** of a type known per se. It may consist,

in particular, of a standard systematic convolutive encoding associating, with each item of source data, at least one determined value by the combination of this item of data with at least one of the previous items of source data.

It may also be a code such as one of those described in the patent application FR 91 05278. These codes, known as "pseudo-systematic" codes, are characterized by the fact that the source data is transmitted systematically, in conjunction with at least one encoded item of data or redundancy symbol.

Any other convolutive code may also be used.

The items of data delivered by the encoder **13** are then advantageously (although this is not an obligatory characteristic) subjected to an interleaving operation **14**.

This interleaving operation may be obtained conventionally by means of an interleaving matrix in which the items of source data are introduced line by line and restored column by column.

The module **14** provides for matrix interleaving. The items of data are written, in successive lines, in a memory with a size $n_E \times n_E$, and restored in successive columns. This technique is described for example in the article by E. Dunscombe and F. C. Piper, "Optimal interleaving scheme for convolutional coding", in "Electronics Letters", Vol. 25, No. 22, October 1989.

As can be seen in this article, the efficiency of the interleaving for small values of n_E (some tens) is improved if the succession of rows and columns occurs according to an increment greater than 1, this increment being, by necessity, relatively prime with n_E .

An additional improvement to this technique of interleaving may be implemented. For it appears to be advantageous that the row-skip increment, which is always relatively prime with n_E , should be a function of the position of the column considered. This makes it possible to break the rectangular-positioned error packets.

In this case, the interleaving matrix read increments are chosen in such a way that the minimum distance at output between two symbols that are neighboring at input is as great as possible. These increments may, for example, be determined empirically.

Other interleaving techniques may of course be used, especially the usual method of write and read increments equal to 1, without departing from the framework of the invention. It is also clear that the rows and columns may be inverted.

Then, the interleaved signal is transmitted through the transmission channel **15**. It therefore undergoes a modulation and a filtering operation **16**, according to any appropriate technique, and is then transmitted through the transmission medium **17**.

This transmission medium **17** is generally noise-infested and shows interference between the symbols transmitted in it.

It must be noted that, according to the invention, the two sources of disturbance namely noise and inter-symbol interference (IES) are considered in a dissociated manner. In other words, the symbols affected by IES are in addition noise-infested. The IES is chiefly due to distortion introduced by the filtering elements of the transmission system and the presence of multiple paths induced by the physical medium of transmission (due to reflections and obstacles, etc.). These phenomena lead to disturbances between symbols. The noise induced by the physical medium gets added to this IES phenomenon and is likely in addition to modify the items of information borne by the symbols.

FIG. 2 illustrates this approach in the simplified case of interference relating to two symbols.

The reference A_n is given to the symbol transmitted at the instant nT , where $1/T$ is the speed of modulation (T being the duration of the symbol). The received signal S_n can be written, after passage in the transmission channel:

$$S_n = \sum_k h_k A_{n-k}$$

This signal comprises a term dependent on the symbol A_n , namely $h_0 A_n$, but also a term dependent on the symbols transmitted prior to and subsequently to A_n . This second term is the inter-symbol interference term. It can be written in the form $\sum_{k \neq 0} h_k A_{n-k}$. It is due to the filtering introduced by the channel and may be modelled by a lattice with $N=2^v$ states, for an IES modelled by a discrete equivalent channel with a memory v (two in the case of FIGS. 2 and 3).

In the case of FIG. 2, interference relating to two symbols (A_{n-1} and A_{n+1}) is considered. The effect of the channel may then be represented by two delay cells **21**₁ and **21**₂, each with a duration T .

When the symbol A_{n+1} is presented at input of the cell **21**₁, the output of this cell **21**₁ is A_n and the output of the second cell **21**₂ is A_{n-1} . The filtering of the channel amounts to the multiplying (**22**₁ to **22**₃) of each of these symbols by the corresponding filtering coefficient h_i . The corresponding terms are then added up (**23**) to form the signal S_n .

The architecture of FIG. 2 corresponds to a convolutive encoding with $v=2$, the decoding lattice of which is illustrated in FIG. 3, conventionally, this lattice illustrates the possible transitions as a function of the two preceding values depending on whether the value of A_{n+1} is 1 (solid lines) or 0 (dashes).

Returning to FIG. 1, the noise-infested signal S_n is subjected to a filtering and a demodulation **18**, which are symmetrical to the operations performed by the module **16**.

Then, conventionally, the signal is equalized (**19**) by the application of a filtering operation designed to compensate for the effects of the transmission medium **17**. The equalized signal is then de-interleaved (**110**) symmetrically to the interleaving operation **14**.

Finally, the signal is transmitted to a convolutive decoder **111** which, for example, implements an operation of maximum likelihood decoding such as the Viterbi algorithm to deliver decoded items of data to the addressee **12**.

The essential characteristic of the invention is the iterative association of a symbol detection module with weighted outputs and a decoding module, also with weighted outputs. If we consider the effect of the channel according to the approach presented, the standard equalization (the filtering of the received signal by means of a transversal filter, for example) is replaced by an operation of symbol detection that takes account of the memory effect introduced by the channel.

Thus, the proposed device includes a detector with weighted input and output that estimates the symbols A_n from the noise-infested output of the channel. For example, this detector may be made by using the algorithm described in the patent document FR 91 05279. It requires knowledge of the coefficient h_k which should therefore be estimated externally to the proposed device, for example by means of learning sequences.

FIG. 4 illustrates the general principle of the invention. Each received sample R_n , which corresponds to the noise-infested output of the transmission channel, is processed as follows:

a detector **41** of symbols with weighted outputs produces an estimation A_{n+1} of the corresponding transmitted symbol;

the symbols $A_{n,1}$ at output of the detector 41 are de-interleaved (42) to give the symbols $A_{k,1}$;

the de-interleaved symbols $A_{k,1}$ are presented to the input of a convolutive decoder 43 which gives a new estimation $A_{k,2}$ of symbols A_k ;

at output of the decoder 43, there is defined (44) a correction data element Z_k called an extrinsic data element obtained from the estimations $A_{k,1}$ and $A_{k,2}$;

the correction data element Z_k is then used, after a re-interleaving operation 45, in the detector 41.

More specifically, in the embodiment described, the item of data Z_k is obtained by difference between $A_{k,2}$ and $\gamma_2 A_{k,1}$ delivered by the multiplier 46, where γ_2 is a positive coefficient, Z_n is still an estimation of the symbol A_n , but this time affected by a noise that is not correlated with the noise that affects $A_{n,1}$ and is slightly correlated with the noise affecting R_n by means of the interleaving function 45.

The extrinsic information Z_n is then used by the detector 41 by the addition or deduction, to or from each arm metric of the lattice associated with the channel (cf. FIG. 3), of the term $\gamma_1 |Z_n|$, where γ_1 is a positive coefficient. The term $\gamma_1 |Z_n|$ is deducted (or added respectively) when the symbol assigned to the arm considered has the same sign as Z_n (or respectively the opposite sign). The value of the coefficient γ_1 depends on both the signal-to-noise ratio and the reliability of the extrinsic information element Z_n .

The extrinsic information element, assigned the coefficient γ_1 for the multiplier 48, is furthermore deducted (47) from the output of the detector 41 before being presented to the input of the decoder 43. Indeed, since the extrinsic information element Z_n has been produced by the decoder 43, it cannot be reused by this decoder 43.

The symbol detector 41 takes its decisions according to a Viterbi type algorithm. All the operations performed by this detector correspond to those described in the patent FR 91 05279. The difference, as compared with a convolutive decoding algorithm, lies in the computation of the transition metrics or branch metrics, which is done differently.

Each node of the lattice is represented by a possible state of the channel at a given instant nT . For an IES value relating to $K1$ symbols subsequent to the symbol considered and $K2$ symbols prior to the symbols considered, namely for:

$$S_n = \sum_{k=K1 \text{ to } K2} h_k A_{n-k}$$

the state of the channel at $t=nT$ is given by the $(K1+K2)$ -uplet $(A_{n+K1-1} \dots A_{n+1} A_n A_{n-1} \dots A_{n-K2})$. The knowledge of the state of the channel at $t=nT$ as well as the value of A_{n+K1} (symbol $\leftarrow$ entering $\rightarrow$ the channel) then provides knowledge of its state at $t=(n+1)T$.

Thus, for each node j of the lattice taken at the instant $t=nT$, two transition metrics L_j0 and L_j1 are computed. They correspond to the two possible transitions ($A_{n+K1}=0$ and $A_{n+K1}=1$). They have the form:

$$L_j0 = (R_n - R_j0)^2 \text{ and } L_j1 = (R_n - R_j1)^2$$

where R_n represents the sample actually received at input of the detector and R_j0 (or R_j1 respectively) is the theoretical value of the sample that is not noise-infested when the state of the channel corresponds to the node j of the lattice and when $A_{n+K1}=0$ (or $A_{n+K1}=1$ respectively). R_j0 (or R_j1 respectively) therefore has the form: $\sum_{k=K1 \text{ to } K2} h_k A_{n-k}$. If $A_{n+K1}=0$, then the value is R_j0 and if $A_{n+K1}=1$ then the value is R_j1 .

In practice, the following simplified expression is used to compute the metrics:

$$L_j0 = |R_n - R_j0| \text{ and } L_j1 = |R_n - R_j1|$$

The performance characteristics of the detection are then very close to those obtained with the previous expression and the implantation of the computation on silicon is greatly simplified.

Apart from this computation of the metrics, the computation algorithm is similar in principle as well as in its implementation to a convolutive decoding algorithm.

In practice, the receiver shown in FIG. 4 induces a computation latency (processing time of the detector 41, the decoder 43, the interleaving operation 45 and the de-interleaving operation 42). It is therefore not possible to obtain instantaneous knowledge of Z_n when R_n is received in the detector 41. Consequently, according to an essential characteristic of the invention, the process implemented is iterative.

This process is illustrated schematically by FIG. 5. For each symbol received R_n (reception step 51), at least two iterations 52 are performed.

Each iteration 52 includes a step 521 for the correction of inter-symbol interference. As indicated here above, this correction implements a convolutive decoding technique and takes account of an item of extrinsic correction information Z_n and items of data h_i representing the transmission channel.

The items of information Z_n are computed during the step 524. Naturally, at the first iteration, no particular value of Z_n is known. Consequently, this value is set at a neutral value, namely at a value having no effect on the computations.

After the correction 521, the estimated symbols are de-interleaved during the de-interleaving step 522 (if an interleaving operation has been implemented at transmission) and then decoded according to a standard technique of convolutive decoding 523 and for example according to the technique described in the French patent application FR 91 02579.

Then, the item of extrinsic information Z_k is computed (524) from the item of data 525 detected by the correction step 521 and the item of data 526 decoded by the decoding step 523. Then, the items of information Z_k are re-interleaved (527) symmetrically with the de-interleaving 522 to give the item of information Z_n . The item of information Z_n is taken into account in the correction step 521 of the next iteration.

At the last iteration, the step 524 for the computation of Z_k is not implemented. The decoded symbol D_k is delivered by the decoding step 523.

The corresponding reception device may advantageously be made in a modular fashion, by associating one module with each iteration. FIG. 6 illustrates a device of this kind comprising four modules.

The first module 61 of the system receives $(R)_n$, the symbol received by the device and delivers firstly $(R)_{n,2}$, which is equal to $(R)_n$, assigned a delay corresponding to the latency of the module and, secondly, $(Z)_{n,2}$ the extrinsic information computed by the module 61. Each of the following modules 62 to 64 receives the delayed symbol $(R)_{n,i}$ and the item of extrinsic information $(Z)_{n,i}$. The last module 64 delivers the decoded symbol $(D)_n$.

It will easily be understood that the performance characteristics of the device in terms of error rate are a function of the number of cascade-connected modules.

Advantageously, all the modules are identical. FIG. 7 illustrates an exemplary embodiment of a module of this

kind. More specifically, it is the module corresponding to the p^{th} iteration. It includes:

two inputs: $(R)_p$ and $(Z)_p$,

three outputs: $(R)_{p+1}$, $(Z)_{p+1}$ and $(D)_{p+1}$.

The input $(R)_p$ is equal to the output of the channel 5 delayed by the latency of $p-1$ modules.

The input $(Z)_p$ comes from the previous module and is set, for $p=1$, at a neutral value, namely a value that has no influence on the output of the detector.

The output $(R)_{p+1}$, equal to the input $(R)_p$ delayed by the latency of a module, is unused if the iteration is the last one of the process ($p=P$, P being the total number of modules).

The output $(Z)_{p+1}$ is the extrinsic information element prepared at the p^{th} iteration. This output is also unused if $p=P$.

The output $(D)_{p+1}$ which is the decoded item of data is unused by the $P-1$ first modules, and only the items of data coming from $(D)_{p+1}$ are given to the addressee.

The elements of this module that have already been described with reference to FIG. 4 are not described again, and bear the same references. It will be noted that, as compared with the schematic diagram of FIG. 4, different delays are added to take account of the latencies of the different elements.

Thus, the extrinsic information $(Z)_p$ used for the difference 47 must be delayed (71) by a duration equal to the latency L_1 of the detector 41. This is also the case with $(A)_{p-1}$ which must be delayed by the latency L_2 of the decoder 43. Finally, $(R)_p$ must be delayed (73) by the total latency introduced by a module L_T in order that $(R)_{p+1}$ and $(Z)_{p+1}$ 30 may be presented at the same instant to the input of the following module. This latency L_T is equal to the sum of the latency of the detector 41, L_1 , the latency of the decoder L_2 and the latency introduced by the interleaving operations 45 and de-interleaving operations 42 L_{ED} .

The performance characteristics of the device of the invention have been simulated and are illustrated in FIG. 8. The item of source data is encoded by a recursive systematic convolutional code (CSR code) with a constraint length $K=5$ and efficiency $R=1/2$. The encoded items of data are sent on the transmission channel after a non-uniform interleaving in a matrix of 64 rows and 64 columns. The modulation used is a binary phase-shift keying (BPSK) modulation.

The multiplier coefficients h_i are real and constant and known to the symbol detector but the principle is applicable 45 when they are complex and variable. For the results presented hereinafter, the coefficients h_i have been fixed at: $h_0=\sqrt{0.45}$, $h_1=\sqrt{0.25}$, $h_2=\sqrt{0.15}$, $h_3=\sqrt{0.10}$, $h_4=\sqrt{0.05}$

They verify $\sum_{i=0}^{i=4} h_i^2=1$. The transmission channel is also disturbed by a Gaussian white additional noise.

At output of the channel, the received samples R_n are quantified on 8 bits. The symbol detector and the channel decoder use the algorithm presented in the patent FR 91 05279. The working of the decoder is also represented by a 16-state lattice. The values of coefficients γ_1 and γ_2 have been determined empirically.

The results shown use four modules. The curves C_1 and C_2 represent the error rate at output of the transmission system, respectively without and with channel encoding, when there is no inter-symbol interference: C_3 gives the error rate in the classic case where the symbol detector gives a binary decision (firm decision) and the curves C_{4i} show the results obtained with the proposed device after the i -order iteration.

These curves therefore show that, at an error rate of 10^{-5} , the use of a symbol detector with weighted output makes it possible to gain 1.6 dB as compared with a firm decision

detector and the three additional iterations provide an additional gain of about 3 dB. When the number of iterations increases, the performance characteristics approach those obtained on an encoded Gaussian channel.

What is claimed is:

1. Device for the reception of signals formed by a series of digital symbols corresponding to the convolutive encoding of items of source digital data characterized in that it comprises:

p cascade-connected detection and decoding modules M_1 to M_p , p being greater than or equal to 2,

each of said modules M_i including:

inter-symbol interference correction means supplied by a symbol input R_i and delivering estimated symbols $A_{i,1}$ with weighted values;

means for the decoding of said estimated symbols $A_{i,1}$ performing operations symmetrical to said convolutive encoding and delivering decoded symbols $A_{i,2}$ with weighted values; and

means for the computation of an item of correction information Z_{i+1} from said estimated symbol $A_{i,1}$ and said decoded symbol $A_{i,2}$,

said means for the correction of each of said modules M_i , except for the first module M_1 , taking account of at least one item of correction information Z_i determined by the previous module M_{i-1} .

2. Device according to claim 1, characterized in that:

each of said modules M_i has two inputs, one symbol input R_i and one correction input on which correction information Z_i may be received, and three outputs, one symbol output R_{i+1} , one correction output and one decoded symbol output D_{i+1} ;

the symbol input R_i of the module M_i being connected to the symbol output R_i of the module M_{i-1} or i greater than 1 and being supplied with the symbols received for i equal to 1;

the correction input of the module M_i being connected to the correction output of the module M_{i-1} for i greater than 1 and being supplied with a neutral value that does not affect the correction for i equal to 1;

the symbol output R_{i+1} of the module M_i being equal to the symbol input R_i of said module M_i delayed by the latency time dictated by the module M_i ;

the correction output delivering said correction information; and

the decoded symbol output D_{i+1} being unused for the modules M_1 to M_{p-1} and being supplied with the decoded symbol $A_{p,2}$ of the module M_p if the code implemented is a systematic code and, if not, with a corresponding reconstituted value.

3. Device according to any of the claims 1 and 2, characterized in that said means (41) for the correction of the inter-symbol interference are supplied with an item of correction information Z_i representing a difference (44) between each decoded symbol $A_{i,2}$ and the corresponding estimated symbol $A_{i,1}$.

4. Device according to claim 3, characterized in that said means to compute the item of correction information comprise means (46) for the multiplication of said estimation symbols $A_{i,1}$ by a positive weighting coefficient γ_2 delivering weighted symbols, and subtraction means (44) computing the difference between each decoded symbol $A_{i,2}$ and the corresponding weighted symbol and delivering said item of correction information Z_i .

5. Device according to any of the claims 1 to 4, characterized in that said means (41, 47, 48) for the correction of inter-symbol interference perform the following operations:

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the computation (41) of a correction value $V_i = \gamma_1 |Z_i|$, where γ_1 is a positive coefficient and where $||$ represents the absolute value operator;

for each arm of the lattice corresponding to said convolutive code, the determining (41) of a detected symbol $A_{i,0}$, comprising the following steps:

if the symbol assigned to said branch has the same sign as said item of correction information Z_i , the subtraction, from the metric associated with said arm, of said correction value V_i ;

if the symbol assigned to said arm has a sign opposite that of said item of correction information Z_i , the addition, to the metric associated with said arm, of said correction value V_i ;

the subtraction (47), from said detected symbol $A_{i,0}$, of the value $\gamma_i Z_i$.

6. Device according to claim 5, characterized in that said coefficient γ_1 depends on at least one of the items of information belonging to the group comprising:

the signal-to-noise ratio;

the number i of the module considered.

7. Device according to any of the claims 1 to 6, applied to the reception of symbols subjected to an interleaving operation at transmission, characterized in that it comprises:

de-interleaving means (42) providing for the symmetrical operation of said interleaving, inserted between said correction means and said decoding means; and

interleaving means (45) providing for an interleaving of said items of correction information that is identical to said interleaving at transmission.

8. Detection and decoding module designed to be implemented in a device for the reception of signals formed by a series of digital symbols corresponding to the convolutive encoding of items of source digital data, said device comprising at least two cascade-connected modules, characterized in that it has two inputs, one symbol input R_i and one correction input Z_i , and three outputs, one symbol output

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R_{i+1} , one correction output Z_{i+1} and one decoded symbol output D_{i+1} , and in that it comprises:

means (41, 47, 48) for the correction of inter-symbol interference, supplied by said symbol input R_i and taking account of said correction input Z_i and delivering estimated symbols $A_{i,1}$,

means (43) for the decoding of said estimated symbols $A_{i,1}$, performing operations symmetrical to said convolutive encoding and delivering decoded symbols $A_{i,2}$, and

means (44, 46) for the computation of an item of correction information Z_{i+1} from said estimated symbol $A_{i,1}$ and said decoded symbol $A_{i,2}$, the symbol output R_{i+1} being equal to the symbol input R_i delayed by a predefined latency time, the correction output Z_{i+1} delivering said correction information, and the decoded symbol output D_{i+1} being supplied with said decoded symbol $A_{i,2}$ or with a value reconstituted as a function of the code implemented.

9. Method for the reception of signals formed by a series of digital symbols corresponding to the convolutive encoding of items of source digital data comprising the following steps:

supplying with received symbols R_i ; and

performing at least two iterations of the following steps: correcting inter-symbol interference affecting each of said received symbols, by means of an item of correction information Z_i , and the delivery of estimated symbols $A_{i,1}$;

decoding said estimated symbols $A_{i,1}$ entailing operations symmetrical to said convolutive encoding, and the delivery of decoded symbols $A_{i,2}$; and

computing said items of correction information Z_i from at least one of said estimated symbols $A_{i,1}$ and at least one of said decoded symbols $A_{i,2}$.

* * * * *

UNITED STATES PATENT AND TRADEMARK OFFICE
CERTIFICATE OF CORRECTION

PATENT NO. : 6,108,388
APPLICATION NO. : 08/894207
DATED : August 22, 2000
INVENTOR(S) : Catherine Douillard et al.

Page 1 of 2

It is certified that error appears in the above-identified patent and that said Letters Patent is hereby corrected as shown below:

In the Claims

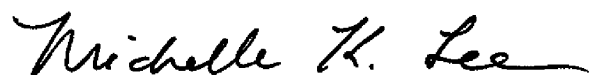
In column 14, lines 21 through 36:
For Claim 9, please delete:

“Method for the reception of signals formed by a series of digital symbols corresponding to the convolutive encoding of items of source digital data comprising the following steps:
supplying with received symbols R_i ; and
performing at least two iterations of the following steps:
correcting inter-symbol interference affecting each of said received symbols, by means of an item of correction information Z_i , and the delivery of estimated symbols $A_{i,1}$;
decoding said estimated symbols $A_{i,1}$ entailing operations symmetrical to said convolutive encoding, and the delivery of decoded symbols $A_{i,2}$; and
computing said items of correction information Z_i from at least one of said estimated symbols $A_{i,1}$ and at least one of said decoded symbols $A_{i,2}$.”

and insert:

--Method for the reception of signals formed by a series of digital symbols corresponding to the convolutive encoding of items of source digital data comprising the following steps:
supplying with received symbols R_i ; and
performing for each received symbol R_i at least two iterations of the following steps:
correcting inter-symbol interference affecting received symbols R_i , by means of an item of correction information Z_i , said correction information Z_i except Z_1 (first iteration), being computed by a computing step of the previous iteration, and the delivery of corresponding estimated symbols $A_{i,1}$ with weighted value;

Signed and Sealed this
Twenty-eighth Day of July, 2015



Michelle K. Lee
Director of the United States Patent and Trademark Office

decoding said estimated symbols $A_{i,1}$ with weighted value entailing operations symmetrical to said convolutive encoding, and the delivery of decoded symbols $A_{i,2}$ with weighted value;
computing said correction information Z_i from at least one of said estimated symbols $A_{i,1}$ and at least one of said decoded symbols $A_{i,2}$; and
delivering said correction information Z_i to the step of correcting inter-symbol interference of the following iteration.--



XP 000371240

NEAR SHANNON LIMIT ERROR - CORRECTING CODING AND DECODING : TURBO-CODES (1)

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p1064-1070

Abstract - This paper deals with a new class of convolutional codes called *Turbo-codes*, whose performances in terms of Bit Error Rate (BER) are close to the SHANNON limit. The *Turbo-Code* encoder is built using a parallel concatenation of two Recursive Systematic Convolutional codes and the associated decoder, using a feedback decoding rule, is implemented as *P* pipelined identical elementary decoders.

I - INTRODUCTION

Consider a binary rate $R=1/2$ convolutional encoder with constraint length K and memory $M=K-1$. The input to the encoder at time k is a bit d_k and the corresponding codeword C_k is the binary couple (X_k, Y_k) with

$$X_k = \sum_{i=0}^{K-1} g_{1i} d_{k-i} \mod 2 \quad g_{1i} = 0,1 \quad (1a)$$

$$Y_k = \sum_{i=0}^{K-1} g_{2i} d_{k-i} \mod 2 \quad g_{2i} = 0,1 \quad (1b)$$

where $G_1: \{g_{1i}\}$, $G_2: \{g_{2i}\}$ are the two encoder generators, generally expressed in octal form.

It is well known, that the BER of a classical Non Systematic Convolutional (NSC) code is lower than that of a classical Systematic code with the same memory M at large SNR. At low SNR, it is in general the other way round. The new class of Recursive Systematic Convolutional (RSC) codes, proposed in this paper, can be better than the best NSC code at any SNR for high code rates.

A binary rate $R=1/2$ RSC code is obtained from a NSC code by using a feedback loop and setting one of the two outputs X_k or Y_k equal to the input bit d_k . For an RSC code, the shift register (memory) input is no longer the bit d_k but is a new binary variable a_k . If $X_k=d_k$ (respectively $Y_k=d_k$), the output Y_k (resp. X_k) is equal to equation (1b) (resp. 1a) by substituting a_k for d_k and the variable a_k is recursively calculated as

$$a_k = d_k + \sum_{i=1}^{K-1} \gamma_i a_{k-i} \mod 2 \quad (2)$$

where γ_i is respectively equal to g_{1i} if $X_k=d_k$ and to g_{2i} if $Y_k=d_k$. Equation (2) can be rewritten as

$$d_k = \sum_{i=0}^{K-1} \gamma_i a_{k-i} \mod 2. \quad (3)$$

One RSC encoder with memory $M=4$ obtained from an NSC encoder defined by generators $G_1=37$, $G_2=21$ is depicted in Fig.1.

Generally, we assume that the input bit d_k takes values 0 or 1 with the same probability. From equation (2), we can show that variable a_k exhibits the same statistical property

$$P_r\{a_k = 0 / a_1 = \epsilon_1, \dots, a_{k-1} = \epsilon_{k-1}\} = P_r\{d_k = \epsilon\} = 1/2 \quad (4)$$

with ϵ is equal to

$$\epsilon = \sum_{i=1}^{K-1} \gamma_i \epsilon_i \mod 2 \quad \epsilon = 0,1. \quad (5)$$

Thus the trellis structure is identical for the RSC code and the NSC code and these two codes have the same free distance d_f . However, the two output sequences $\{X_k\}$ and $\{Y_k\}$ do not correspond to the same input sequence $\{d_k\}$ for RSC and NSC codes. This is the main difference between the two codes.

When punctured code is considered, some output bits X_k or Y_k are deleted according to a chosen puncturing pattern defined by a matrix P . For instance, starting from a rate $R=1/2$ code, the matrix P of rate $2/3$ punctured code is

$$P = \begin{bmatrix} 1 & 1 \\ 1 & 0 \end{bmatrix}$$

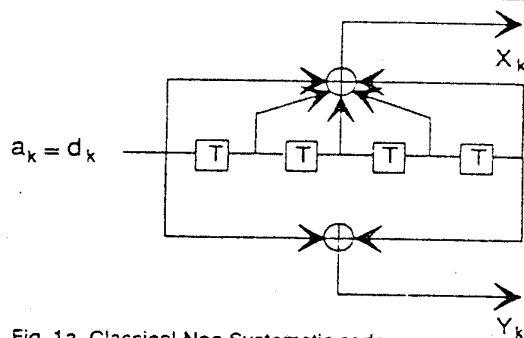


Fig. 1a Classical Non Systematic code.

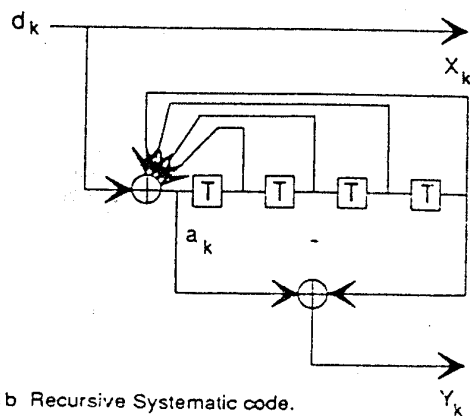


Fig. 1b Recursive Systematic code.



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II - PARALLEL CONCATENATION OF RSC CODES

With RSC codes, a new concatenation scheme, called parallel concatenation can be used. In Fig. 2, an example of two identical RSC codes with parallel concatenation is shown. Both elementary encoder (C_1 and C_2) inputs use the same bit d_k but according to a different sequence due to the presence of an interleaver. For an input bit sequence $\{d_k\}$, encoder outputs X_k and Y_k at time k are respectively equal to d_k (systematic encoder) and to encoder C_1 output Y_{1k} , or to encoder C_2 output Y_{2k} . If the coded outputs (Y_{1k}, Y_{2k}) of encoders C_1 and C_2 are used respectively n_1 times and n_2 times and so on, the encoder C_1 rate R_1 and encoder C_2 rate R_2 are equal to

$$R_1 = \frac{n_1 + n_2}{2n_1 + n_2} \quad R_2 = \frac{n_1 + n_2}{2n_2 + n_1} \quad (6)$$

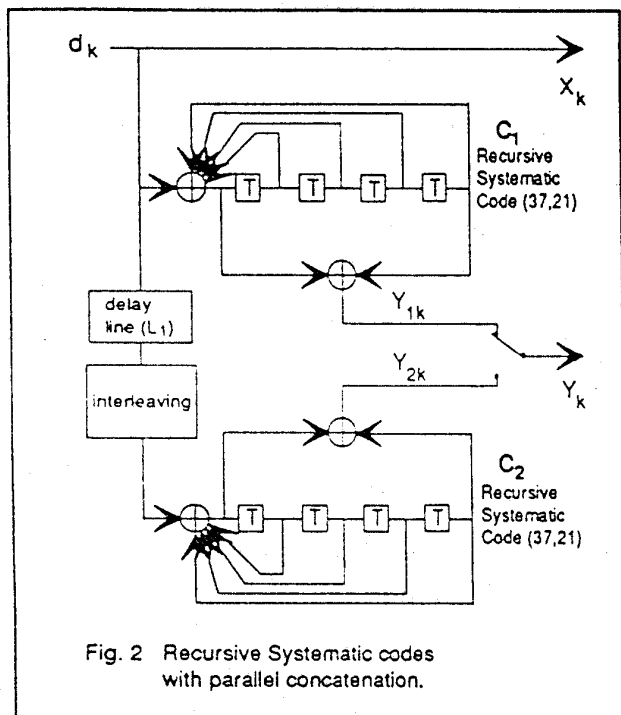


Fig. 2 Recursive Systematic codes with parallel concatenation.

The decoder DEC depicted in Fig. 3a, is made up of two elementary decoders (DEC_1 and DEC_2) in a serial concatenation scheme. The first elementary decoder DEC_1 is associated with the lower rate R_1 encoder C_1 and yields a soft (weighted) decision. The error bursts at the decoder DEC_1 output are scattered by the interleaver and the encoder delay L_1 is inserted to take the decoder DEC_1 delay into account. Parallel concatenation is a very attractive scheme because both elementary encoder and decoder use a single frequency clock.

For a discrete memoryless gaussian channel and a binary modulation, the decoder DEC input is made up of a couple R_k of two random variables x_k and y_k , at time k

$$x_k = (2d_k - 1) + i_k \quad (7a)$$

$$y_k = (2Y_k - 1) + q_k \quad (7b)$$

where i_k and q_k are two independent noises with the same variance σ^2 . The redundant information y_k is demultiplexed and sent to decoder DEC_1 when $Y_k = Y_{1k}$ and toward decoder DEC_2 when $Y_k = Y_{2k}$. When the redundant information of a

given encoder (C_1 or C_2) is not emitted, the corresponding decoder input is set to zero. This is performed by the DEMUX/INSERTION block.

It is well known that soft decoding is better than hard decoding, therefore the first decoder DEC_1 must deliver to the second decoder DEC_2 a weighted (soft) decision. The Logarithm of Likelihood Ratio (LLR), $\Lambda_1(d_k)$ associated with each decoded bit d_k by the first decoder DEC_1 is a relevant piece of information for the second decoder DEC_2

$$\Lambda_1(d_k) = \log \frac{P_r\{d_k = 1/\text{observation}\}}{P_r\{d_k = 0/\text{observation}\}} \quad (8)$$

where $P_r\{d_k = i/\text{observation}\}$, $i = 0, 1$ is the a posteriori probability (APP) of the data bit d_k .

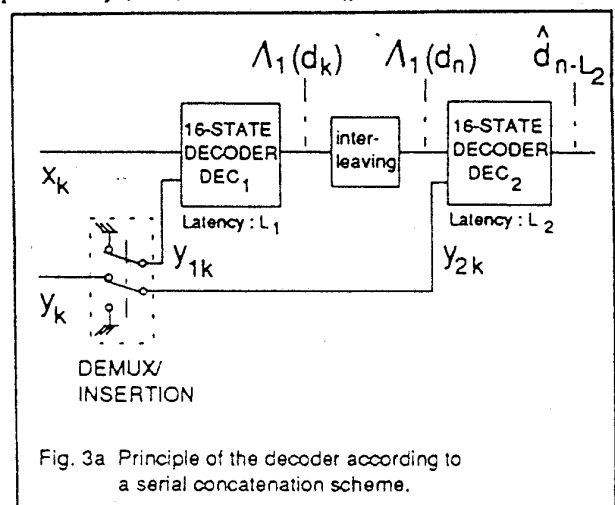


Fig. 3a Principle of the decoder according to a serial concatenation scheme.

III - OPTIMAL DECODING OF RSC CODES WITH WEIGHTED DECISION

The VITERBI algorithm is an optimal decoding method which minimizes the probability of sequence error for convolutional codes. Unfortunately this algorithm is not able to yield the APP for each decoded bit. A relevant algorithm for this purpose has been proposed by BAHLE *et al.* [1]. This algorithm minimizes the bit error probability in decoding linear block and convolutional codes and yields the APP for each decoded bit. For RSC codes, the BAHLE *et al.* algorithm must be modified in order to take into account their recursive character.

III - 1 Modified BAHLE *et al.* algorithm for RSC codes

Consider a RSC code with constraint length K ; at time k the encoder state S_k is represented by a K -uple

$$S_k = (a_k, a_{k-1}, \dots, a_{k-K+1}) \quad (9)$$

Also suppose that the information bit sequence $\{d_k\}$ is made up of N independent bits d_k , taking values 0 and 1 with equal probability and that the encoder initial state S_0 and final state S_N are both equal to zero, i.e.

$$S_0 = S_N = (0, 0, \dots, 0) = 0 \quad (10)$$

The encoder output codeword sequence, noted $C_1^N = \{C_1, \dots, C_k, \dots, C_N\}$ is the input to a discrete gaussian memoryless channel whose output is the sequence $R_1^N = \{R_1, \dots, R_k, \dots, R_N\}$ where $R_k = (x_k, y_k)$ is defined by relations (7a) and (7b).

The APP of a decoded data bit d_k can be derived from the joint probability $\lambda_k^i(m)$ defined by

$$\lambda_k^i(m) = P_r\{d_k = i, S_k = m / R_1^N\} \quad (11)$$

and thus, the APP of a decoded data bit d_k is equal to

$$P_r\{d_k = i / R_1^N\} = \sum_m \lambda_k^i(m), \quad i = 0, 1 \quad (12)$$

From relations (8) and (12), the LLR $\Lambda(d_k)$ associated with a decoded bit d_k can be written as

$$\Lambda(d_k) = \text{Log} \frac{\sum_m \lambda_k^1(m)}{\sum_m \lambda_k^0(m)}. \quad (13)$$

Finally the decoder can make a decision by comparing $\Lambda(d_k)$ to a threshold equal to zero

$$\begin{aligned} \hat{d}_k &= 1 & \text{if } \Lambda(d_k) > 0 \\ \hat{d}_k &= 0 & \text{if } \Lambda(d_k) < 0. \end{aligned} \quad (14)$$

In order to compute the probability $\lambda_k^i(m)$, let us introduce the probability functions $\alpha_k^i(m)$, $\beta_k(m)$ and $\gamma_i(R_k, m', m)$

$$\alpha_k^i(m) = \frac{P_r\{d_k = i, S_k = m, R_1^k\}}{P_r\{R_1^k\}} P_r\{d_k = i, S_k = m / R_1^k\} \quad (15)$$

$$\beta_k(m) = \frac{P_r\{R_{k+1}^N / S_k = m\}}{P_r\{R_{k+1}^N / R_1^k\}} \quad (16)$$

$$\gamma_i(R_k, m', m) = P_r\{d_k = i, R_k, S_k = m / S_{k-1} = m'\}. \quad (17)$$

The joint probability $\lambda_k^i(m)$ can be rewritten using BAYES rule

$$\lambda_k^i(m) = \frac{P_r\{d_k = i, S_k = m, R_1^k, R_{k+1}^N\}}{P_r\{R_1^k, R_{k+1}^N\}}. \quad (18)$$

Thus we obtain

$$\lambda_k^i(m) = \frac{P_r\{d_k = i, S_k = m, R_1^k\}}{P_r\{R_1^k\}} \frac{P_r\{R_{k+1}^N / d_k = i, S_k = m, R_1^k\}}{P_r\{R_{k+1}^N / R_1^k\}}. \quad (19)$$

Taking into account that events after time k are not influenced by observation R_1^k and bit d_k if state S_k is known, the probability $\lambda_k^i(m)$ is equal

$$\lambda_k^i(m) = \alpha_k^i(m) \beta_k(m). \quad (20)$$

The probabilities $\alpha_k^i(m)$ and $\beta_k(m)$ can be recursively calculated from probability $\gamma_i(R_k, m', m)$. From annex I, we obtain

$$\alpha_k^i(m) = \frac{\sum_{m'} \sum_{j=0}^1 \gamma_i(R_k, m', m) \alpha_{k-1}^j(m')}{\sum_{m'} \sum_{j=0}^1 \sum_{i=0}^1 \gamma_i(R_k, m', m) \alpha_{k-1}^j(m')} \quad (21)$$

and

$$\beta_k(m) = \frac{\sum_{m'} \sum_{i=0}^1 \gamma_i(R_{k+1}, m, m') \beta_{k+1}(m')}{\sum_{m'} \sum_{i=0}^1 \sum_{j=0}^1 \gamma_i(R_{k+1}, m', m) \alpha_{k+1}^j(m')}. \quad (22)$$

The probability $\gamma_i(R_k, m', m)$ can be determined from transition probabilities of the discrete gaussian memoryless

channel and transition probabilities of the encoder trellis. From relation (17), $\gamma_i(R_k, m', m)$ is given by

$$\gamma_i(R_k, m', m) = p(R_k / d_k = i, S_k = m, S_{k-1} = m')$$

where $p(\cdot)$ is the transition probability of the discrete gaussian memoryless channel. Conditionally to $(d_k = i, S_k = m, S_{k-1} = m')$, x_k and y_k are two uncorrelated gaussian variables and thus we obtain

$$\begin{aligned} p(R_k / d_k = i, S_k = m, S_{k-1} = m') &= \\ p(x_k / d_k = i, S_k = m, S_{k-1} = m') &= \end{aligned}$$

$$p(y_k / d_k = i, S_k = m, S_{k-1} = m'). \quad (24)$$

Since the convolutional encoder is a deterministic machine, $q(d_k = i / S_k = m, S_{k-1} = m')$ is equal to 0 or 1. The transition state probabilities $\pi(S_k = m / S_{k-1} = m')$ of the trellis are defined by the encoder input statistic. Generally, $P_r\{d_k = 1\} = P_r\{d_k = 0\} = 1/2$ and since there are two possible transitions from each state, $\pi(S_k = m / S_{k-1} = m') = 1/2$ for each of these transitions.

Different steps of modified Bahl *et al.* algorithm

-Step 0 : Probabilities $\alpha_0^i(m)$ and $\beta_N(m)$ are initialized according to relation (12)

$$\alpha_0^i(0) = 1 \quad \alpha_0^i(m) = 0 \quad \forall m \neq 0, \quad i = 0, 1 \quad (25a)$$

$$\beta_N(0) = 1 \quad \beta_N(m) = 0 \quad \forall m \neq 0. \quad (25b)$$

-Step 1 : For each observation R_k , the probabilities $\alpha_k^i(m)$ and $\gamma_i(R_k, m', m)$ are computed using relations (21) and (23) respectively.

-Step 2 : When the sequence R_1^N has been completely received, probabilities $\beta_k(m)$ are computed using relation (22), and probabilities $\alpha_k^i(m)$ and $\beta_k(m)$ are multiplied in order to obtain $\lambda_k^i(m)$. Finally the LLR associated with each decoded bit d_k is computed from relation (13).

IV- THE EXTRINSIC INFORMATION OF THE RSC DECODER

In this chapter, we will show that the LLR $\Lambda(d_k)$ associated with each decoded bit d_k , is the sum of the LLR of d_k at the decoder input and of another information called extrinsic information, generated by the decoder. Using the LLR $\Lambda(d_k)$ definition (13) and relations (20) and (21), we obtain

$$\Lambda(d_k) = \text{Log} \frac{\sum_{m'} \sum_{j=0}^1 \gamma_i(R_k, m', m) \alpha_{k-1}^j(m') \beta_k(m)}{\sum_{m'} \sum_{j=0}^1 \gamma_0(R_k, m', m) \alpha_{k-1}^j(m') \beta_k(m)}. \quad (26)$$

Since the encoder is systematic ($X_k = d_k$), the transition probability $p(x_k / d_k = i, S_k = m, S_{k-1} = m')$ in expression $\gamma_i(R_k, m', m)$ is independent of state values S_k and S_{k-1} . Therefore we can factorize this transition probability in the numerator and in the denominator of relation (26)

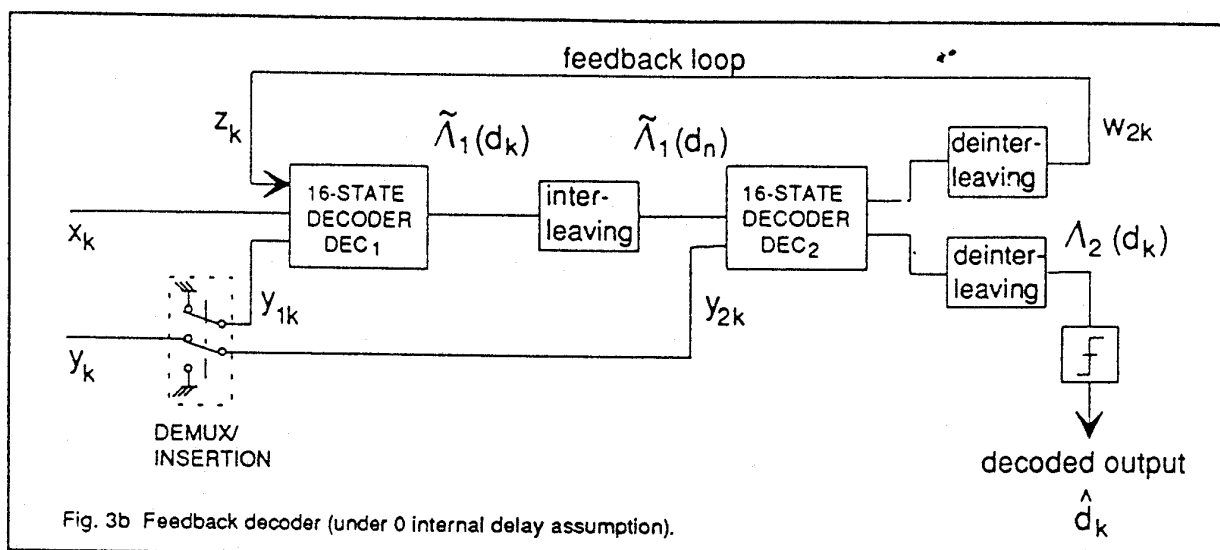


Fig. 3b Feedback decoder (under 0 internal delay assumption).

$$\Lambda(d_k) = \text{Log} \frac{p(x_k/d_k=1)}{p(x_k/d_k=0)} + \frac{\sum_m \sum_{m'=0}^1 \gamma_1(y_k, m', m) \alpha_{k-1}^j(m') \beta_k(m)}{\sum_m \sum_{m'=0}^1 \gamma_0(y_k, m', m) \alpha_{k-1}^j(m') \beta_k(m)} \quad (27)$$

Conditionally to $d_k=1$ (resp. $d_k=0$), variables x_k are gaussian with mean 1 (resp. -1) and variance σ^2 , thus the LLR $\Lambda(d_k)$ is still equal to

$$\Lambda(d_k) = \frac{2}{\sigma^2} x_k + W_k \quad (28)$$

where

$$W_k = \Lambda(d_k) |_{x_k=0} = \frac{\sum_m \sum_{m'=0}^1 \gamma_1(y_k, m', m) \alpha_{k-1}^j(m') \beta_k(m)}{\sum_m \sum_{m'=0}^1 \gamma_0(y_k, m', m) \alpha_{k-1}^j(m') \beta_k(m)} \quad (29)$$

W_k is a function of the redundant information introduced by the encoder. In general W_k has the same sign as d_k ; therefore W_k may improve the LLR associated with each decoded data bit d_k . This quantity represents the extrinsic information supplied by the decoder and does not depend on decoder input x_k . This property will be used for decoding the two parallel concatenated encoders.

V - DECODING SCHEME OF PARALLEL CONCATENATION CODES

In the decoding scheme represented in Fig. 3a, decoder DEC₁ computes LLR $\Lambda_1(d_k)$ for each transmitted bit d_k from sequences $\{x_k\}$ and $\{y_k\}$, then the decoder DEC₂ performs the decoding of sequence $\{d_k\}$ from sequences $\{\Lambda_1(d_k)\}$ and $\{y_k\}$. Decoder DEC₁ uses the modified Bahl *et al.* algorithm and decoder DEC₂ may use the VITERBI algorithm. The global decoding rule is not optimal because the first decoder uses only a fraction of the available redundant information. Therefore it is possible to improve the performance of this serial decoder by using a feedback loop.

V-1 Decoding with a feedback loop

We consider now that both decoders DEC₁ and DEC₂ use the modified Bahl *et al.* algorithm. We have seen in section IV that the LLR at the decoder output can be expressed as a sum of two terms if the decoder inputs were independent. Hence if the decoder DEC₂ inputs $\Lambda_1(d_k)$ and y_{2k} are independent, the LLR $\Lambda_2(d_k)$ at the decoder DEC₂ output can be written as

$$\Lambda_2(d_k) = f(\Lambda_1(d_k)) + W_{2k} \quad (30)$$

with

$$\Lambda_1(d_k) = \frac{2}{\sigma^2} x_k + W_{1k} \quad (31)$$

From relation (29), we can see that the decoder DEC₂ extrinsic information W_{2k} is a function of the sequence $\{\Lambda_1(d_n)\}_{n \neq k}$. Since $\Lambda_1(d_n)$ depends on observation R_1^N , extrinsic information W_{2k} is correlated with observations x_k and y_{1k} . Nevertheless from relation (29), the greater $|n-k|$ is, the less correlated are $\Lambda_1(d_n)$ and observations x_k, y_k . Thus, due to the presence of interleaving between decoders DEC₁ and DEC₂, extrinsic information W_{2k} and observations x_k, y_{1k} are weakly correlated. Therefore extrinsic information W_{2k} and observations x_k, y_{1k} can be jointly used for carrying out a new decoding of bit d_k , the extrinsic information $z_k = W_{2k}$ acting as a diversity effect in an iterative process.

In Fig. 3b, we have depicted a new decoding scheme using the extrinsic information W_{2k} generated by decoder DEC₂ in a feedback loop. This decoder does not take into account the different delays introduced by decoder DEC₁ and DEC₂ and a more realistic decoding structure will be presented later.

The first decoder DEC₁ now has three data inputs, (x_k, y_{1k}, z_k) and probabilities $\alpha_{1k}^j(m)$ and $\beta_{1k}(m)$ are computed in substituting $R_k = \{x_k, y_{1k}\}$ by $R_k = \{x_k, y_{1k}, z_k\}$ in relations (21) and (22). Taking into account that z_k is weakly correlated with x_k and y_{1k} and supposing that z_k can be approximated by a gaussian variable with variance $\sigma_z^2 \neq \sigma^2$, the transition probability of the discrete gaussian memoryless channel can be now factored in three terms

$$p(R_k/d_k=i, S_k=m, S_{k-1}=m') = p(x_k/.)p(y_k/.)p(z_k/.) \quad (32)$$

The encoder C_1 with initial rate R_1 , through the feedback loop, is now equivalent to a rate R'_1 encoder with

$$R'_1 = \frac{R_1}{1 + R_1} \quad (33)$$

The first decoder obtains an additional redundant information with z_k that may significantly improve its performances; the term *Turbo-codes* is given for this iterative decoder scheme with reference to the turbo engine principle.

With the feedback decoder, the LLR $\Lambda_1(d_k)$ generated by decoder DEC_1 is now equal to

$$\Lambda_1(d_k) = \frac{2}{\sigma_x^2} x_k + \frac{2}{\sigma_z^2} z_k + W_{1k} \quad (34)$$

where W_{1k} depends on sequence $\{z_n\}_{n \neq k}$. As indicated above, information z_k has been built by decoder DEC_2 at the previous decoding step. Therefore z_k must not be used as input information for decoder DEC_2 . Thus decoder DEC_2 input sequences at step p ($p \geq 2$) will be sequences $\{\tilde{\Lambda}_1(d_n)\}$ and $\{y_{2k}\}$ with

$$\tilde{\Lambda}_1(d_n) = \Lambda_1(d_n)_{z_n=0} \quad (35)$$

Finally from relation (30), decoder DEC_2 extrinsic information $z_k = W_{2k}$, after deinterleaving, can be written as

$$z_k = W_{2k} = \Lambda_2(d_k)_{\tilde{\Lambda}_1(d_k)=0} \quad (36)$$

and the decision at the decoder DEC output is

$$\hat{d}_k = \text{sign}[\Lambda_2(d_k)]. \quad (37)$$

The decoding delays introduced by decoder DEC ($DEC=DEC_1+DEC_2$), the interleaver and the deinterleaver imply that the feedback information z_k must be used through an iterative process as represented in Fig. 4a, 4b. In fact, the global decoder circuit is composed of P pipelined identical elementary decoders (Fig. 4a). The p th decoder DEC (Fig. 4b) input, is made up of demodulator output sequences $(x)_p$ and $(y)_p$ through a delay line and of extrinsic information $(z)_p$ generated by the $(p-1)$ th decoder DEC . Note that the variance σ_z^2 of the extrinsic information and the variance of $\tilde{\Lambda}_1(d_k)$ must be estimated at each decoding step p .

V-2 Interleaving

The interleaver uses a square matrix and bits $\{d_k\}$ are written row by row and read pseudo-randomly. This non-uniform reading rule is able to spread the residual error blocks of rectangular form, that may set up in the interleaver located behind the first decoder DEC_1 , and to give the greater free distance as possible to the concatenated (parallel) code.

VI - RESULTS

For a rate $R=1/2$ encoder with constraint length $K=5$, generators $G_1=37$, $G_2=21$ and parallel concatenation ($R_1=R_2=2/3$), we have computed the Bit Error Rate (BER) after each decoding step using the Monte Carlo method, as a function of signal to noise ratio E_b/N_0 where E_b is the energy received per information bit d_k and N_0 is the noise monolateral power spectral density. The interleaver consists of a 256×256 matrix and the modified BAH *et al.* algorithm has been used with length data block of $N=65536$ bits. In

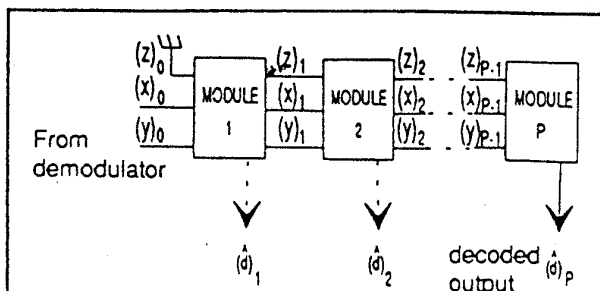


Fig. 4a Modular pipelined decoder, corresponding to an iterative process of the feedback decoding.

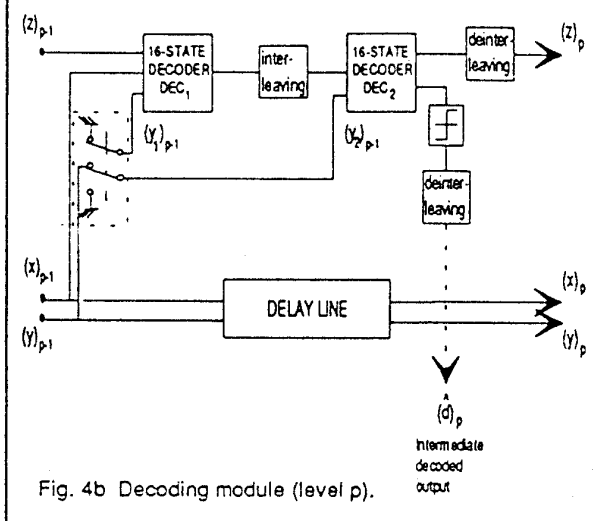
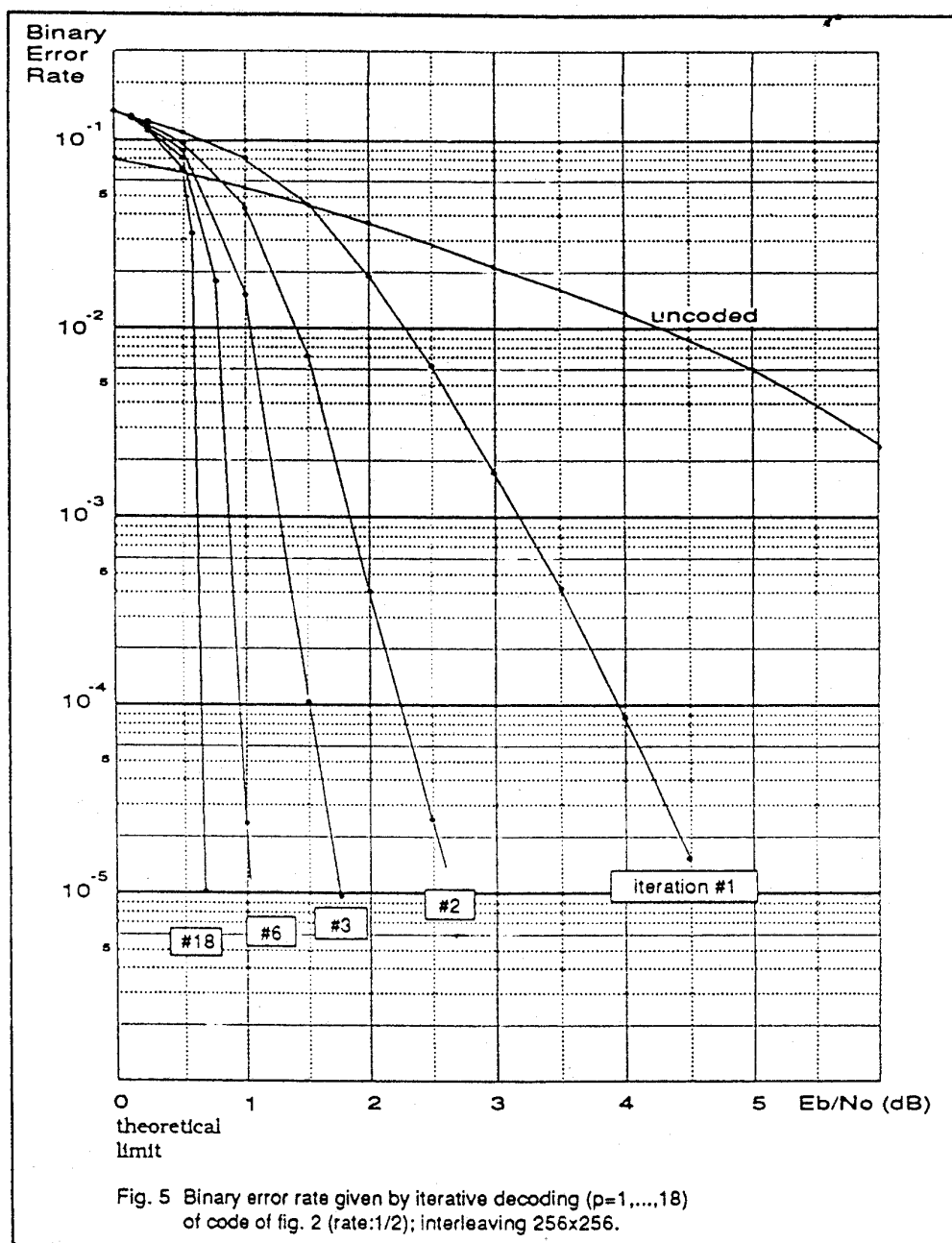


Fig. 4b Decoding module (level p).

order to evaluate a BER equal to 10^{-5} , we have considered 128 data blocks i.e. approximately 8×10^6 bits d_k . The BER versus E_b/N_0 , for different values of p is plotted in Fig. 5. For any given signal to noise ratio greater than 0 dB, the BER decreases as a function of the decoding step p . The coding gain is fairly high for the first values of p ($p=1,2,3$) and carries on increasing for the subsequent values of p . For $p=18$ for instance, the BER is lower than 10^{-5} at $E_b/N_0=0,7$ dB. Remember that the Shannon limit for a binary modulation with $R=1/2$, is $P_e=0$ (several authors take $P_e=10^{-5}$ as a reference) for $E_b/N_0=0$ dB. With parallel concatenation of RSC convolutional codes and feedback decoding, the performances are at 0,7 dB from Shannon's limit.

The influence of the constraint length on the BER has also been examined. For K greater than 5, at $E_b/N_0=0,7$ dB, the BER is slightly worst at the first ($p=1$) decoding step and the feedback decoding is inefficient to improve the final BER. For K smaller than 5, at $E_b/N_0=0,7$ dB, the BER is slightly better at the first decoding step than for K equal to 5, but the correction capacity of encoders C_1 and C_2 is too weak to improve the BER with feedback decoding. For $K=4$ (i.e. 8-state elementary decoders) and after iteration 18, a BER of 10^{-5} is achieved at $E_b/N_0=0,9$ dB. For K equal to 5, we have tested several generators (G_1, G_2) and the best results were achieved with $G_1=37, G_2=21$.



For low signal to noise ratios, we have sometimes noticed that BER could increase during the iterative decoding process. In order to overcome this effect, we have divided the extrinsic information z_k by $[1 + \theta |\hat{\Lambda}_1(d_k)|]$ with $\theta = 0,15$.

In Fig. 6, the histogram of extrinsic information $(z)_p$ has been drawn for several values of iteration p , with all data bits equal to 1 and for a low signal to noise ratio ($E_b/N_0 = 0,8$ dB). For $p=1$ (first iteration), extrinsic information $(z)_p$ is very poor about bit d_k , furthermore the gaussian hypothesis made above for extrinsic information $(z)_p$, is not satisfied! Nevertheless when iteration p increases, the histogram merges towards a gaussian law with a mean equal to 1. For instance, for $p=13$, extrinsic information $(z)_p$ becomes relevant information concerning data bits.

VII CONCLUSION

In this paper, we have presented a new class of convolutional codes called *Turbo-codes* whose performances in terms of BER are very close to SHANNON's limit. The decoder is made up of P pipelined identical elementary modules and rank p elementary module uses the data information coming from the demodulator and the extrinsic information generated by the rank $(p-1)$ module. Each elementary module uses a modified BAML *et al.* algorithm which is rather complex. A much simpler algorithm yielding weighted (soft) decisions has also been investigated for *Turbo-codes* decoding [2], whose complexity is only twice the complexity of the VITERBI algorithm, and with performances which are very close to those of the BAML *et al.* algorithm. This new algorithm will enable encoders and

decoders to be integrated in silicon with error correcting performances unmatched at the present time.

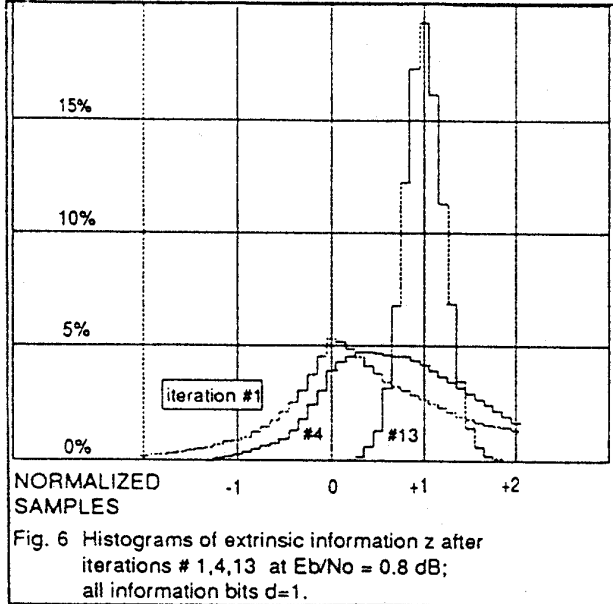


Fig. 6 Histograms of extrinsic information z after iterations # 1,4,13 at $E_b/N_0 = 0.8$ dB; all information bits $d=1$.

ANNEX I: EVALUATION OF PROBABILITIES $\alpha_k^i(m)$ AND $\beta_k(m)$.

From relation (15) probability $\alpha_k^i(m)$ is equal to

$$\alpha_k^i(m) = \frac{Pr\{d_k = i, S_k = m, R_1^{k-1}, R_k\}}{Pr\{R_1^{k-1}, R_k\}} = \frac{Pr\{d_k = i, S_k = m, R_k / R_1^{k-1}\}}{Pr\{R_k / R_1^{k-1}\}} \quad (A1)$$

The numerator of $\alpha_k^i(m)$ can be expressed from state S_{k-1} and bit d_{k-1} .

$$Pr\{d_k = i, S_k = m, R_k / R_1^{k-1}\} = \sum_{m', j=0}^1 Pr\{d_k = i, d_{k-1} = j, S_k = m, S_{k-1} = m', R_k / R_1^{k-1}\} \quad (A2)$$

By using BAYES rule, we can write

$$Pr\{d_k = i, S_k = m, R_k / R_1^{k-1}\} = \sum_{m', j=0}^1 \frac{Pr\{d_{k-1} = j, S_{k-1} = m', R_1^{k-1}\}}{Pr\{R_1^{k-1}\}} Pr\{d_k = i, S_k = m, R_k / d_{k-1} = j, S_{k-1} = m', R_1^{k-1}\} \quad (A3)$$

By taking into account that events after time $(k-1)$ are not influenced by observation R_1^{k-1} and bit d_{k-1} if state S_{k-1} is known and from relation (17) we obtain

$$Pr\{d_k = i, S_k = m, R_k / R_1^{k-1}\} = \sum_{m', j=0}^1 \gamma_i(R_k, m', m) \alpha_{k-1}^j(m'). \quad (A4)$$

The denominator can be also expressed from bit d_k and state S_k

$$Pr\{R_k / R_1^{k-1}\} = \sum_{m, i=0}^1 Pr\{d_k = i, S_k = m, R_k / R_1^{k-1}\} \quad (A5)$$

and from relation (A4), we can write :

$$Pr\{R_k / R_1^{k-1}\} = \sum_m \sum_{m'} \sum_{i=0}^1 \sum_{j=0}^1 \gamma_i(R_k, m', m) \alpha_{k-1}^j(m'). \quad (A6)$$

Finally probability $\alpha_k^i(m)$ can be expressed from probability $\alpha_{k-1}^j(m')$ by the following relation

$$\alpha_k^i(m) = \frac{\sum_{m', j=0}^1 \gamma_i(R_k, m', m) \alpha_{k-1}^j(m')}{\sum_m \sum_{m'} \sum_{i=0}^1 \sum_{j=0}^1 \gamma_i(R_k, m', m) \alpha_{k-1}^j(m')}. \quad (A7)$$

In the same way, probability $\beta_k(m)$ can be recursively calculated from probability $\beta_{k+1}(m)$. From relation (16), we have

$$\beta_k(m) = \frac{Pr\{R_{k+1}^N / S_k = m\}}{Pr\{R_{k+1}^N / R_1^k\}} = \frac{\sum_{m', i=0}^1 Pr\{d_{k+1} = i, S_{k+1} = m', R_{k+2}^N, R_{k+1} / S_k = m\}}{Pr\{R_{k+1}^N / R_1^k\}} \quad (A8)$$

By using BAYES rule, the numerator is equal to

$$Pr\{R_{k+1}^N / S_k = m\} = \sum_{m', i=0}^1 Pr\{R_{k+2}^N / S_{k+1} = m'\} Pr\{d_{k+1} = i, S_{k+1} = m', R_{k+1} / S_k = m\}. \quad (A9)$$

By taking into account expressions of $\gamma_i(R_{k+1}, m, m')$ and $\beta_{k+1}(m')$, we can write

$$\beta_k(m) = \frac{\sum_{m', i=0}^1 \gamma_i(R_{k+1}, m, m') \beta_{k+1}(m')}{Pr\{R_{k+1} / R_1^k\}} \quad (A10)$$

In substituting k by $(k+1)$ in relation (A6), the denominator of (A10) is equal to

$$Pr\{R_{k+1} / R_1^k\} = \sum_m \sum_{m'} \sum_{i=0}^1 \sum_{j=0}^1 \gamma_i(R_{k+1}, m', m) \alpha_k^j(m'). \quad (A11)$$

Finally probability $\beta_k(m)$ can be expressed from probability $\beta_{k+1}(m')$, by the following relation

$$\beta_k(m) = \frac{\sum_{m', i=0}^1 \gamma_i(R_{k+1}, m, m') \beta_{k+1}(m')}{\sum_m \sum_{m'} \sum_{i=0}^1 \sum_{j=0}^1 \gamma_i(R_{k+1}, m', m) \alpha_k^j(m')}. \quad (A12)$$

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Performance of Adaptive Equalizer Using Iterative Application of Viterbi Algorithm

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SUMMARY

The Viterbi equalizer is effective for frequency selective fading in digital mobile communication, but as the multipath component propagation delay time difference increases, the number of states increases exponentially and the computation amount increases drastically. Combining the Viterbi equalizer and interference reduction operation based on the equalization result, this paper proposes a new type of Viterbi equalizer with iterative equalization. It can expand the equalizable range without increasing the number of states. Computer simulation result shows that its performance is better than that of a conventional one.

Key words: Adaptive equalizer; Viterbi equalizer; iterative equalization; frequency-selective fading; digital mobile communication.

1. Introduction

Digital mobile communication is very close to being realized. To meet the requirement for communication varieties and advanced services, higher-speed digital mobile communication must be realized in the future.

Radio propagation in the urban area becomes multipath due to reflection and diffraction by surrounding buildings. If transmission speed is increased under this propagation environment, delay time difference of multi-

path component becomes nonnegligible compared to the transmission signal symbol interval, and communication quality degradation due to frequency selective fading becomes remarkable.

To realize high-speed digital mobile communication, this frequency selective fading must be overcome and hence the anti-multipath modulation system [1], adaptive equalizer [2], and so on, are being studied. However, the anti-multipath modulation system is effective only when the delay time difference is 0.5 or within 1 symbol length.

On the one hand, in the area where a receiver point can observe mountains or hills there can be delayed components with a delay time difference of 20 μ s or more. If high-speed digital mobile communication with around 512 kbit/s is applied in such an area, delayed components of 10-bit length must be overcome.

For this reason attention is being paid to the adaptive equalizer, which is effective for long-delayed components. Decision Feedback Equalizer (DFE) and Viterbi Equalizer (VE) are typical adaptive equalizers [3, 4]. VE with maximum likelihood sequence estimation is expected to give a performance superior to that of DFE, but as the delay time difference increases, the number of states for Viterbi algorithm increases exponentially and its realization becomes difficult.

To suppress this increase in the number of states, various proposals have been made. However, the method of using linear equalizers [5, 6] tends to increase the

noise. The method of using DFE [7] can suppress this noise, but the performance tends to deteriorate due to error propagation. For this reason, DDFSE (Delayed Decision Feedback Sequence Estimation) [8], RSSE (Reduced-State Sequence Estimation) [9], etc., have been proposed. By referring to the path history of Viterbi algorithm, DDFSE and RSSE can reduce the effect of delayed components which exceed the equalizable range of the Viterbi equalizer. The application of DDFSE to mobile communication is mentioned in [10].

In this paper a simple and practical method modifying the Viterbi equalizer to deal with a longer multipath delay time without increasing the number of states is proposed [11]. It equalizes the channel by applying the Viterbi algorithm iteratively after canceling the effect of longer delayed multipath components based on an estimated sequence in the previous step. Although its computational amount is large compared with conventional methods, the equalization performance can be improved for longer delayed components.

2. Principle

The proposed method extends the equalizable range without increasing the number of states by reducing the effect of longer delayed components with delay time difference exceeding the equalizable range of VE. A received signal is a convolution of transmitted signals, transmitter/receiver filter, and impulse response of propagation path (hereafter they are referred to as "delay profile"). Therefore, if a correct transmission sequence and delay profile are obtained, the effect of longer delayed multipath components exceeding the equalizable range of VE can be eliminated. However, since the received sequence and delay profile estimated at the receiver side are not accurate, their effect cannot completely be eliminated. By iteratively applying the equalization, the proposed method improves the accuracy in eliminating the effect of longer delayed components and attempts to improve the performance.

Specifically, after the effect of longer delayed components is reduced by using the information symbol sequence $\{a_i^1\}$ estimated with the maximum likelihood by VE, the maximum likelihood estimation again is applied by VE.

Let $\{a_i^2\}$ be this estimated sequence. Then, it is expected that the symbol error rate of $\{a_i^2\}$ is better than that of $\{a_i^1\}$. Furthermore, by using $\{a_i^2\}$, the interference is reduced and $\{a_i^3\}$ is obtained. As mentioned later, the location of errors tends to vary at each iteration, and

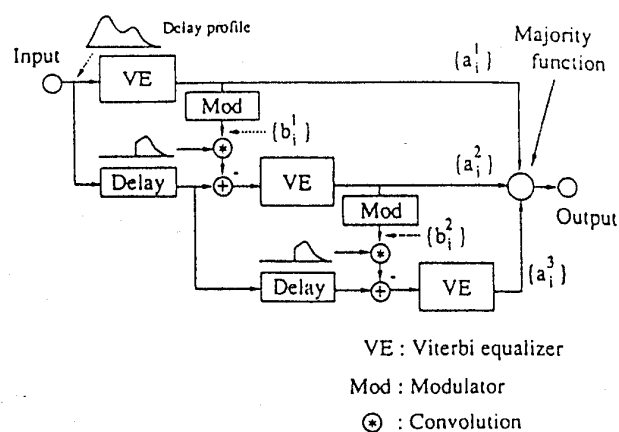


Fig. 1. Flow of signal processing of the proposed method ($n = 3$).

hence there is a possibility that based on these sequences a sequence with fewer error rates can be generated. For this purpose the majority function is applied in this paper.

Hereafter, let n be the number of VE applications. As for the Bit Error Rate, the BER when a symbol is Gray-encoded is calculated. Figure 1 shows the flow of signal processing of the proposed method for $n = 3$. The case of $n = 1$ corresponds to the ordinary VE. As shown in this figure, the processing for reducing the effect of longer delayed components is applied only by using the part exceeding the equalizable range of estimated profile.

In this study, VE is operated by using delayed components within m -symbol delay, and the effect of delayed components within L -symbol delay ($m < L$) is reduced by using the preceding equalization result. Similar operation is applied also to DDFSE, which is to be compared with, by referring to path history.

The operation of reducing the effect of longer delayed components is as follows:

$$y_k(t) = y(t) - \sum_i b_i^k h'(t - iT_s) \quad (k=1, 2, 3, \dots, n-1) \quad (1)$$

$$h'(t) = \begin{cases} h(t) & mT_s < t \leq LT_s \\ 0 & \text{otherwise} \end{cases} \quad (2)$$

Here, $y(t)$ is the received signal and $y_k(t)$ is the signal with the effect of longer delayed components being reduced; $h(t)$ is the delay profile estimated at the receiver; $\{b_i^k\}$ is

Table 1. Simulation parameters

Items	Features
Modulation system	$\pi/4$ -shift QPSK
Demodulation system	Quasi-coherent detection
Transmitter/receiver filter	Gaussian Filter ($BT_s = 1.0$)
Training sequence	00100 1011100001000100 10111
Data length	58 symbol $\times$ 2
Propagation path	Static 2-component multipath model
m and L	$m = 2$ and $L = 5$

the complex baseband signal sequence obtained by modulating $\{a_i^k\}$; and T_s is the symbol width. With $\pi/4$ -shift QPSK modulation system, which is used in later computer simulation, four symbols of a_i^k are Gray-encoded as 00, 01, 11, and 10, and associated b_i^k is assumed to be $(1 + j)/\sqrt{2}$, $(-1 + j)/\sqrt{2}$, $(1 - j)/\sqrt{2}$, and $(-1 - j)/\sqrt{2}$ when i is odd, and 1, j , -1 , and $-j$ when i is even.

As understood from Eq. (1), $y_k(t)$ is obtained directly from the received signal $y(t)$, not from $y_{k-1}(t)$. Therefore, there is no noise addition. The decoding by VE is applied to $y_k(t)$ calculated in this way and $\{a_i^{k+1}\}$ is obtained. Final decoding result is obtained by applying majority function to $\{a_i^{n-2}\}$, $\{a_i^{n-1}\}$ and $\{a_i^n\}$ for $n \geq 3$, and is $\{a_i^2\}$ for $n = 2$. This majority function is applied on bit-by-bit basis to Gray-encoded symbols, just as in the calculation of the error rate.

3. Computer Simulation

Table 1 shows the parameters used in the computer simulation. As shown in Fig. 2, one TDMA timeslot consists of a pair of information symbol sequences, a training sequence in between, head symbols, and tail symbols. There are five symbols in the head, and as many symbols as required for state convergence are added in the tail. The estimation of delay profile is done for each timeslot by the correlated reception of the training sequence [12]. The delay profile obtained by this correlated reception is used directly as $h(t)$.

The simulation is carried out at an equivalent baseband system and thermal noise is assumed. Gaussian

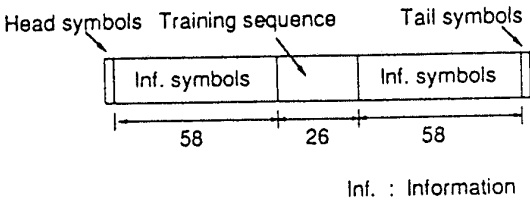


Fig. 2. TDMA timeslot structure.

filters with $BT_s = 1.0$ (BT_s is the 3-dB bandwidth normalized by the transmission symbol rate) are used for both transmitter and receiver filters. It is assumed that there is no frequency shift between receiving frequency and transmitting frequency.

The $\pi/4$ -shift QPSK is used as a modulation system and quasi-coherent detection is applied. The quasi-coherent detection is applied because we can get to know the phase of the received signal from delay profile estimation and the phase can be corrected. Static 2-component multipath propagation model is used as a propagation path. Its impulse response is given by

$$h_p(t) = A_D\delta(t) + A_U\delta(t - \tau)e^{j\phi} \tag{3}$$

Here, $\delta(t)$ is the delta function, A_D is the amplitude of leading component D signal, A_U is the amplitude of delayed component U signal, τ is the delay time difference between D and U signals, and ϕ is the carrier phase difference between D and U signals. The number of states in the used VE is $16(m = 2)$ and $L = 5$. As a

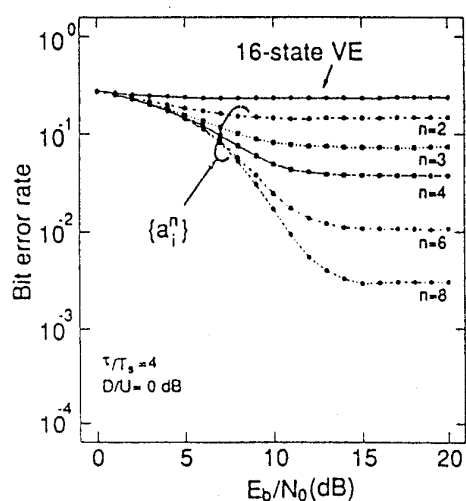


Fig. 3. Comparison of BER vs. E_b/N_0 curves. ($D/U = 0$ dB)

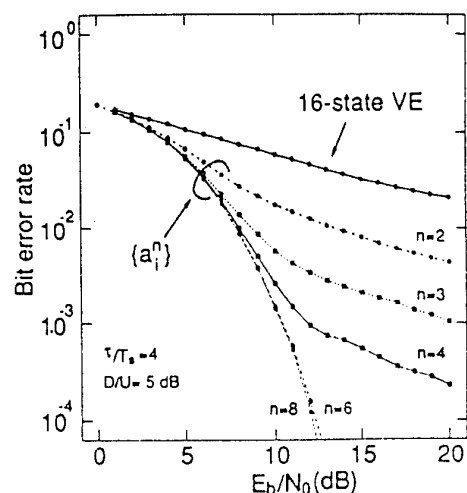


Fig. 4. Comparison of BER vs. E_b/N_0 curves. ($D/U = 5$ dB)

result, the equalization effect is obtained in the range $\tau/T_s \leq 5$. The sample position is located at the peak position of the D signal in the delay profile, and one sample is sampled for one symbol. Values averaged over carrier phase difference ϕ are shown.

4. Results of Computer Simulation

4.1. Basic characteristic

First, BER of symbol sequence $\{a_i^n\}$ before application of the majority function is discussed. Figures 3 and 4 show the BER vs. E_b/N_0 characteristics for $D/U = 0$ dB and 5 dB. Since it is assumed that $\tau/T_s = 4$, sufficient equalization is not obtained by 16-state VE ($n = 1$). As n is increased, BER characteristics improve. In case of $D/U = 0$ dB shown in Fig. 3, a floor of BER, or a flat area of BER, is observed at a high range of E_b/N_0 . By contrast, no floor is observed in case of $D/U = 5$ dB shown in Fig. 4, and an excellent characteristic is obtained.

4.2. Performance of proposed method

In the preceding section the characteristic with no majority function is shown. In succeeding sections the characteristics with majority function are studied.

Figure 5 shows the characteristic of BER vs. D/U of the proposed method, where the condition of $\tau/T_s = 4$ and $E_b/N_0 = 10$, a propagation environment which cannot be equalized by a 16-state VE is considered. Better performances are obtained both for $n = 4$ and $n = 8$ compared with those by 16-state VE. As D/U becomes large, or delayed components become weak, differences in the characteristics for $n = 4$ and for $n = 8$ become small. The characteristic for DDFSE is located between those for $n = 4$ and $n = 8$.

From Fig. 5 it is observed that D/U of about 5 dB or more is required for the proposed method and DDFSE to obtain BER of around 10^{-3} under this condition. Thus, the proposed method is effective in case delayed components are somewhat weak compared to leading components. For this reason, D/U is set to be 5 dB in the computer simulation thereafter.

Figure 6 is the BER vs. E_b/N_0 characteristic for $\tau/T_s = 4$. For $n \geq 4$, the performances for the proposed method are better than those for DDFSE. Compared with Fig. 4, the performances for $n = 3$ and $n = 4$ are improved by the majority function. This is because the error locations due to longer delayed components, in principle, tend to be different for $\{a_i^{n-2}\}$, $\{a_i^{n-1}\}$, and $\{a_i^n\}$. For example, on the basis of the i -th symbol of the preceding equalization result, the interference is reduced at the locations from the $i + m + 1$ -th to $i + L$ -th symbols according to Eq. (2). Thus, the effect of the

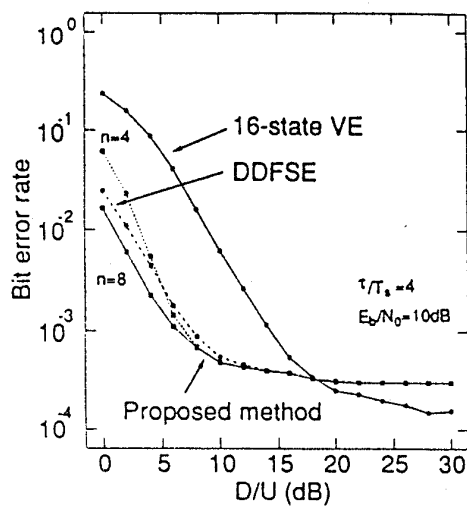


Fig. 5. Comparison of BER vs. D/U curves.

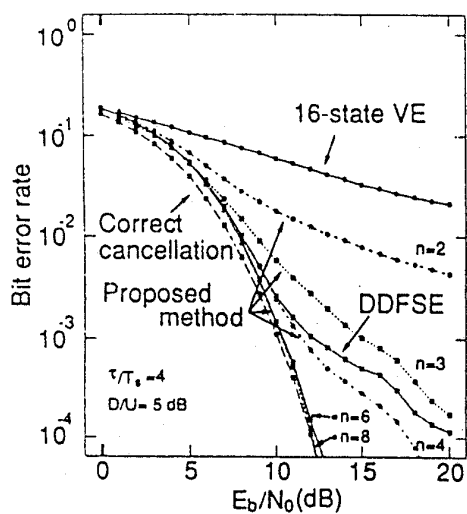


Fig. 6. Comparison of BER vs. E_b/N_0 curves.
($\tau/T_s = 4$)

error of a symbol becomes effective at locations a few symbols later. Therefore, the effect of majority function appears in the propagation environment where longer delayed components ($m < \tau/T_s \leq L$) exist.

Figure 7 shows an example of majority function. This is a part of the simulation result for $\tau/T_s = 4$, $E_b/N_0 = 10$ dB, $D/U = 5$ dB, and an error

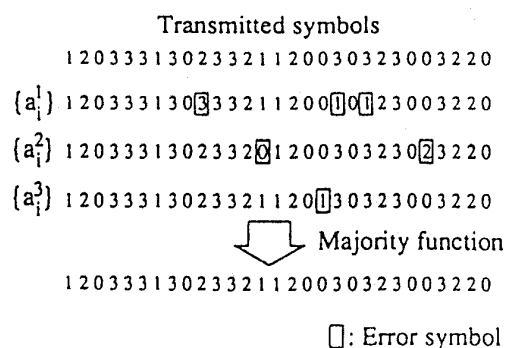


Fig. 7. Effect of majority function.

symbol is marked by a square. It is observed that the number of error symbols decreases while changing their locations. The movement width of error locations is four symbols, which coincides with the delay time difference. Thus, the reason for error location movement and the effectiveness of majority function are confirmed.

By contrast, any performance improvement due to majority function is not observed for $n = 6$ and $n = 8$. At this stage, most errors are caused by the noise and the error locations are identical. As a result, no improvement is expected by the majority function. For the case of $D/U = 5$ dB, the performance improvement with n tends to be saturated at around $n = 6$. The characteristic indicated by "correct cancellation" in Fig. 6 is the BER characteristic of $\{a_1^2\}$ for the case where transmitted symbol sequence is used as $\{a_1^1\}$. This characteristic and the characteristic for $n \geq 6$ agree well. By applying iterative equalization, the proposed method is almost not affected by the effect of error propagation.

Figure 8 shows BER vs. τ/T_s characteristic, where D/U is 5 dB and $n = 4$ for the proposed method. Characteristics for DDFSE, 16-state VE, 64-state VE, and 1024-state VE also are shown. The proposed method and DDFSE can equalize a wider range than 16-state and 64-state VEs. Since E_b/N_0 is low, i.e., 10 dB and n is small, i.e., 4, the proposed method is only slightly better than DDFSE. This difference increases if n and E_b/N_0 are taken large, considering Fig. 6. On the one hand, in the range of $\tau/T_s \leq 2$, where no interference reduction is required, the performance of the proposed method is worse than those of 16-state and 64-state VEs. Figure 9 shows BER vs. E_b/N_0 characteristics for such shorter delayed components, where $\tau/T_s = 1$. In the range of small delay time difference, the performance deterioration in E_b/N_0 is shown to be about 1 dB. This is because

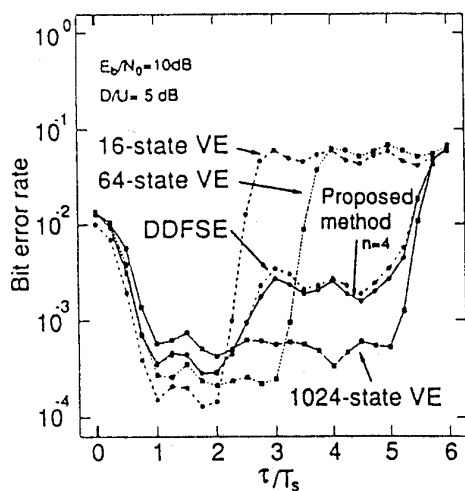


Fig. 8. Comparison of BER vs. τ/T_s curves.

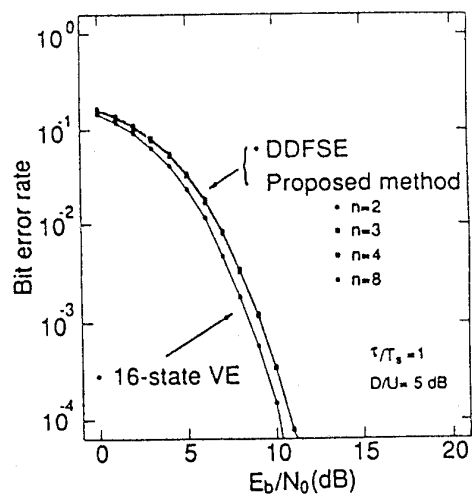


Fig. 9. Comparison of BER vs. E_b/N_0 curves. ($\tau/T_s = 1$).

unnecessary interference reduction operation increases the effect of delay profile estimation error.

5. Computational Complexity

Generally, the computation amount depends on how much memory size is used. In this paper, it is assumed that sufficient memory is available. With the static 2-component model used in this computer simulation, $h(t)$ is constant within a timeslot. In this case the computation amount required for branchmetric calculation can be reduced significantly. In an actual propagation environment, however, $h(t)$ is not constant, and hence we assume only for evaluating the computation amount that $h(t)$ varies within a timeslot. Therefore, the increase in branchmetric computation amount is taken into account, but the computation amount for updating $h(t)$ itself is not taken into account.

Path history operation and related procedures, and integer operation, which depend greatly on implementation, are not evaluated. In calculating the branchmetric of Viterbi equalization for the third time and thereafter, reduction amount $\sum_i b_i^k h'(t - iT_s)$ at time t for reducing interference is recalculated only when the amount is different from the preceding amount, and preceding branchmetric remaining in the memory is again used when the amount is the same.

Now, consider the j -th equalization. As understood from Eq. (1), if one symbol of $\{b_i^{j-1}\}$ is different from $\{b_i^{j-2}\}$, the branchmetric of $L - m$ symbols must be recalculated. The maximum probability that $\{b_i^{j-1}\}$ is varied is $2(P_{BER, j-2} + P_{BER, j-1})$, where $P_{BER, j}$ is the BER at the j -th equation. Since two bits constitute one symbol, a coefficient 2 is multiplied. Therefore, the probability of branchmetric recalculation does not exceed P_j given by

$$P_j = 2(L - m)(P_{BER, j-2} + P_{BER, j-1}) \quad (j \geq 3) \quad (4)$$

The maximum computation amount is evaluated by using this equation, where the BER for $E_b/N_0 = 15$ dB and $D/U = 5$ dB is used as $P_{BER, j}$. Table 2 shows the comparison of computation amount per symbol. In this paper parameters are set so that both the proposed method and DDFSE can equalize delay component of $5T_s$ at the maximum. An ordinary Viterbi equalizer requires 1024 states to equalize delayed components of up to $5T_s$. Table 2 shows that the computation amount of both the proposed method and DFSE can be reduced significantly compared with this 1024-state VE.

6. Conclusions

A new method of expanding the equalization range of Viterbi equalizer without increasing its number of states is proposed. It equalizes the channel by applying

Table 2. Comparison of computational amount per symbol

System	Product	Sum
16-state VE	368	424
64-state VE	1344	1760
1024-state VE	20576	31792
DDFSE ($m = 2, L = 5$)	560	616
Proposed method ($m = 2, L = 5, n = 4$)	799	915
Proposed method ($m = 2, L = 5, n = 6$)	832	953

a Viterbi algorithm iteratively and it is shown that the equalization performance for longer-delayed multipath components can be improved compared with conventional method.

DDFSE where equalization is applied by referring to path history is considered as a soft-decision method. Then the proposed method can be considered as a hard decision method. By iteratively applying equalization, which is characteristic of the proposed method, a superior equalization performance than that by DDFSE can be obtained.

However, the computation amount of the proposed method is larger than that of DDFSE. Therefore, the proposed method is considered as being located between VE and DDFSE, and the trade-off between computation amount and equalization performance can be controlled by selecting the number of equalization iterations.

Considering the time until final equalization result is obtained and necessary memory size, the proposed method is not necessarily an effective method. As discussed in section 5, however, its computation amount of real numbers is not proportional to the number of iterations, but is comparatively small as shown in Table 2. Through advancement of circuit technology and algorithm improvement, this method may lead to a new equalizer in the future.

Studies on decision functions superior to the majority function used in this paper, and performance evaluation of multipath model and that under fading environment are future problems. If n is set adaptively depending on propagation environment, both computation amount and equalization performance can be improved for

short-delayed components. Therefore, adaptive selection of n also must be studied.

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ON THE USE OF DECISION FEEDBACK FOR SIMPLIFYING THE VITERBI DETECTOR

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Abstract

This paper explores and compares two methods of simplifying the Viterbi detector (VD) by means of feedback from preliminary decisions present in the VD. Both methods use these decisions to cancel trailing intersymbol interference (ISI) in order to reduce the effective memory length of the channel and thereby the number of states retained in the detector. They differ in that in the first method a single cancellation takes place on the basis of the most likely survivor residing in the VD, while in the second one a local cancellation is carried out for each state in the VD on the basis of the associated survivor. The paper shows that the somewhat larger complexity of the local method of feedback results in a better error propagation behaviour. In addition, it derives simple estimates for the quality of the preliminary and final decisions produced by the VD in the absence of error propagation, and these expressions are used to show that the optimum prefilter for the VD is the canonical form of Forney's Whitened Matched Filter, irrespective of the precise span of ISI exploited by the VD. The analytical performance predictions are verified numerically by means of a hardware realization of both detectors.

Keywords: decision feedback equalizer, intersymbol interference, Viterbi detector, whitened matched filter.

1. Introduction

Among the methods available for combating intersymbol interference (ISI) and noise, the Viterbi detector (VD) distinguishes itself by its ability to achieve an essentially unsurpassable transmission quality¹⁾. Even though it represents the simplest known manner of achieving this ideal, the VD is still highly complicated for channels with a large memory length. For this reason, numerous methods have been proposed to lower its complexity at an intentionally small expense to performance.

In one category of methods, referred to as reduced-state detection²⁻⁴⁾, the VD is simplified by retaining only the most likely fraction of the candidate data sequences of which the full-fledged VD keeps track. In a second category, the memory length of the channel is reduced by means of a linear equalizer, which curtails the impulse response of the channel into a substan-

For VD's simplified by means of linear equalization, the subject of optimum prefiltering has been studied in great detail⁶⁻¹⁰). In contrast, optimum prefiltering for VD's simplified by means of decision feedback has received scant attention to date. In several instances, a DIR has been used to transform the received signal into one with prescribed ISI within the span of the VD^{11,15,28}). Besides causing colouration and enhancement of noise and a consequential performance degradation of the VD, this approach has the problem that only heuristic procedures are available for selecting a suitable DIR. In other instances, the canonical form of Forney's Whitenened Matched Filter (WMF)¹) has been applied^{13,14,20,21,28}). This prefilter does not entail noise enhancement or noise colouration, and yields a system impulse response with minimum-phase. It is known to be the optimum prefilter for the zero-forcing decision-feedback equalizer (ZF DFE)²⁴), and it is also opti-

After analysing the results, it is found that the bit error rate of a hardware realization of the algorithm is the performance difference of the phase of the final decisions and of increasing the span of the span of the things, it is found that with decision feedback in performance.

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*) In our research, the λ with global feedback, we have noticed that it is described in ref. 20. Also, herein were forwarded

achieve the smallest must be chosen ap- depressions of the is largest category of ive an effective re- essence, these meth- all attempt to elim- synthesizing a replica relatively large de- use of preliminary st be relatively reli- error propagation will ns of a separate de- most likely candidate a separate feedback iding in the VD, the or the recursive ex-

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the subject of opti- contrast, optimum dback has received een used to trans- the span of the nt of noise and a approach has the electing a suitable Whittened Matched filter does not entail system impulse re- m filter for the also opti-

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imum for the VD since any WMF is optimum for this detector¹). Because it can be regarded as an intermediate form of the ZF DFE and the VD, one may expect that this choice is also optimum for the VD employing decision feedback. Among other things, the present paper shows that this is indeed the case.

The paper focuses on two of the most powerful VD's employing decision feedback, viz. one that uses global feedback from the most likely data sequence^{11,17}) and one that uses the local and distributed form of feedback just mentioned^{15,18,20,22}). After giving a unified description of their operation, we show that the local method can be interpreted as a special form of reduced-state detection, and that its error propagation behaviour makes it preferable over the global method^{*}). The quality of the final and preliminary decisions produced by the detector with local feedback is then analysed subject to the assumption that error propagation can be neglected. On the basis of these results, it is shown that the optimum prefilter for the detector should indeed be a canonical WMF, irrespective of the precise span of the trailing ISI used in the feedback process. Furthermore, it is shown that this ideal can be easily reached adaptively.

After analysing five example channels, a final section of the paper presents bit error characteristics that were measured for these channels by means of a hardware realization of both detectors. These characteristics illustrate the performance differences between both methods of feedback, the influence of the phase characteristics of the equalized channel on the preliminary and final decisions generated by the VD, and the performance consequences of increasing the span of ISI exploited by the VD in exchange for a reduction of the span of trailing ISI used in the feedback process. Among other things, it is found that at a much smaller hardware cost, the Viterbi detector with decision feedback often comes close to the fully fledged Viterbi detector in performance, particularly when local feedback is used.

2. A discrete-time channel model

The intersymbol interference and noise which arise in digital transmission and recording can be represented in the canonic discrete-time form

$$r_k = (a * f)_k + n_k, \quad (1)$$

^{*}) In our research, the VD with local feedback originated as a natural development of the VD with global feedback, much in the way described later. After its analysis and construction, we have noticed that it is similar to previous detectors^{15,18}), and in fact equivalent to the one described in ref. 20. Also, while preparing this manuscript some of the ideas and results contained herein were forwarded independently in ref. 22 for an essentially equivalent detector.

where r_k is the received discrete-time data sequence, a_k is the data sequence to be conveyed, f_k is the sampled impulse response of the channel, '*' denotes linear convolution, and n_k is a zero-mean white Gaussian noise sequence with variance N_0 ²⁵). Denoting the channel memory length (expressed in symbol intervals) as L we have, apart from a pure delay without further relevance, that

$$f_k = 0 \quad \text{for } k \notin \{0, \dots, L\}. \quad (2)$$

For mathematical convenience, we shall take a_k to be an uncorrelated sequence of binary digits drawn from the alphabet $\{-1, +1\}$ with equal probability. Both N_0 and f_k can be determined from the parameters of the actual continuous-time channel by successively applying a matched filter, a symbol-rate sampler and a discrete-time noise whitening filter, together referred to as a Whitened Matched Filter (WMF)¹⁾. Because noise whitening can be achieved with arbitrary phase-frequency characteristics, there are in general many WMF's for a given continuous-time channel. To express this fact, f_k may be factored as

$$f_k = (g * h)_k \quad (3)$$

into a causal minimum-phase impulse response g_k which captures the prescribed amplitude-frequency characteristics of f_k and an impulse response h_k which describes a causal and stable phase shifting operation. If we define the $\mathcal{D}$ -transform of g_k as

$$g(\mathcal{D}) \triangleq \sum_{k=-\infty}^{\infty} g_k \mathcal{D}^k, \quad (4)$$

then $g(\mathcal{D})$ must have its L zeros β_i , $i \in \{0, \dots, L-1\}$, all outside the unit circle^{*}, i.e.

$$g(\beta_i) = 0 \quad \text{for } |\beta_i| > 1, i \in \{0, \dots, L-1\}. \quad (5)$$

To ensure that the convolution of g_k and h_k satisfies eq. (2), the $\mathcal{D}$ -transform $h(\mathcal{D})$ of h_k must be of the form

^{*}) By performing an appropriate limiting operation, zeros on the unit circle can also be included in these considerations.

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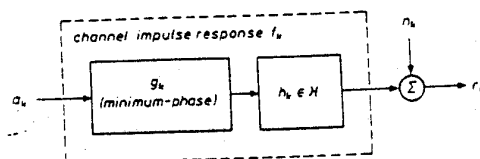


Fig. 1. Factorized discrete-time model of a data transmission system.

$$h(\mathcal{D}) \triangleq \prod_{i \in S} \frac{\beta_i^* \mathcal{D} - 1}{\mathcal{D} - \beta_i} \quad (6)$$

where S is an arbitrary subset of $\{0, \dots, L-1\}$ and the superscript $**$ indicates complex conjugation $*$). Because $|h(\mathcal{D})| = 1$ for all $\mathcal{D}$ with $|\mathcal{D}| = 1$, $h(\mathcal{D})$ describes a pure phase shifting operation. Furthermore, because its poles are all outside the unit circle, h_k will indeed be stable and causal (though possibly infinite in length). The model described by eqs (1) and (3) is depicted in fig. 1. In this figure, $\mathcal{H}$ represents the set of all impulse responses h_k whose $\mathcal{D}$ -transform satisfies eq. (6). The choice $h_k = \delta_k$, with δ_k the Kronecker delta-function, causes f_k to have minimum-phase, and corresponds to the use of a canonical WMF¹⁾.

3. Viterbi detection

The received signal r_k is applied to a maximum-likelihood sequence detector (MLSD), which produces a maximum-likelihood estimate $\hat{a}_{k-D}$ of a_k , with $D \gg L$ representing the delay inherent in the detection process. The MLSD essentially regards ISI as an implicit form of coding which causes the incoming data sequence a_k to be transformed into an 'encoded' sequence $(a * f)_k$ with a well defined correlation structure, and it attempts to find the data sequence $\hat{a}_k$ whose 'encoded' version matches the received signal r_k as closely as possible (in the Euclidean sense). The Viterbi detector (VD) is the simplest known (and recursive) version of the MLSD¹⁾. For each of the 2^L possible combinations of L most recent bits

$$s_k^i \triangleq \{a_{k-L}^i, \dots, a_{k-1}^i\}, \quad i \in \{0, \dots, 2^L - 1\}. \quad (7)$$

hereafter referred to as states, the VD contains a Basic Viterbi Algorithm

^{*)} The composition of S is subjected to restrictions of symmetry if h_k is to be real-valued²⁹⁾. Such restrictions do not affect the results of this paper.

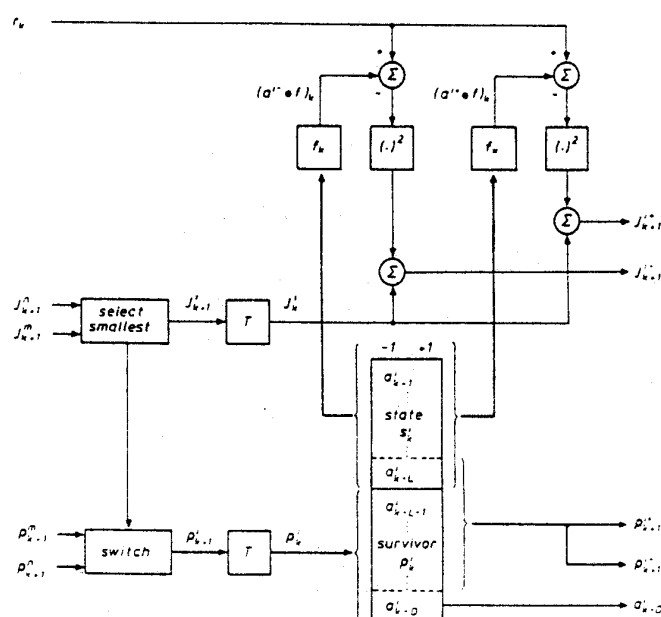


Fig. 2. Basic Viterbi algorithm unit (BVAU) for the standard Viterbi algorithm.

Unit (BVAU; fig. 2), which keeps track of the associated survivor, i.e. the most likely path of previous bits

$$p_k^i \triangleq \{a_{k-D}^i, \dots, a_{k-L-1}^i\} \quad (8)$$

leading to s_k^i , and also of an accumulated Euclidean distance

$$J_k^i \triangleq \sum_{l=0}^{k-1} (r - (a^i * f))_l^2 = \sum_{l=0}^{k-1} (((a - a^i) * f) + n)_l^2, \quad (9)$$

which is a direct measure of the momentary likelihood of the data path

$$a_k^i \triangleq \{a_{k-D}^i, \dots, a_{k-1}^i\} = p_k^i \cup s_k^i. \quad (10)$$

Out of all 2^L data paths a_k^i contained in the VD, the one with the smallest metric value J_k^i , referred to as $\hat{a}_k (= \hat{p}_k \cup \hat{s}_k)$, has the greatest likelihood¹⁾. The 'oldest' digit $\hat{a}_{k-D}$ of $\hat{a}_k$ serves as the final estimate of the VD about a_{k-D} . To achieve near-MLSD performance, the detection delay D should be much

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larger than the memory length L of the channel, e.g. $D \approx 5L^{26}$).

Because Viterbi detection is a recursive process, each BVAU contains provisions for the transition of k to $k+1$, i.e. for the recursive update of s_k^i , p_k^i and J_k^i . This update involves appending both new possible bits $a_k = +1$ and $a_k = -1$ to every data path a_k^i . For each old data path a_k^i this determines two new data paths $a_{k+1}^{\pm}$ and henceforth two new states $s_{k+1}^{\pm} = \{a_{k-L+1}^i, \dots, a_k^i, \pm 1\}$ with associated (and identical) candidate survivors $p_{k+1}^{\pm} = \{a_{k-D+1}^i, \dots, a_k^i\}$, as well as two new accumulated Euclidean distance values

$$J_{k+1}^{\pm} = J_k^i + (r_k - (a^{\pm} * f)_k)^2. \quad (11)$$

Because of the finite memory length of the channel, the contribution $(a^{\pm} * f)_k$ in this expression is completely determined by the state s_k^i and the newly appended digit $a_k = \pm 1$ according to

$$(a^{\pm} * f)_k = \pm f_0 + \sum_{l=1}^L a_{k-l}^i f_l. \quad (12)$$

It is apparent that two old states s_k^m and s_k^n which differ only in their oldest bit a_{k-L}^m and a_{k-L}^n , respectively, will both lead to an identical new state, say s_{k+1}^i , when extended with identical digits. Of these two possibilities, only the one with the smallest accumulated distance value can possibly correspond to the most likely data sequence, and the other one can hence be ignored. Because after extension a_{k-L}^m and a_{k-L}^n form the most recent bits of the competing candidate survivors p_{k+1}^m and p_{k+1}^n , it follows that these candidate survivors differ at least in their most recent bit. This means that selection of an erroneous survivor will inevitably lead to an erroneous value of a_{k-L}^i .

After selecting the new survivors p_{k+1}^i for all distinct states s_{k+1}^i there are again 2^L distinct data paths a_{k+1}^i and accumulated Euclidean distance values J_{k+1}^i . This process of appending, comparison and selection is also shown in fig. 2. For channels with a modest or large memory length L , the large number (2^L) of BVAU's comprised in the VD often renders full-fledged Viterbi detection too complicated to be practical. The following section discusses two methods of simplifying the VD by applying feedback from previously detected digits in order to establish an effective reduction of the channel memory length.

4. Global versus local feedback

To lower the complexity of the VD, the data path $\hat{a}_k = \hat{s}_k \cup \hat{p}_k$ with the largest instantaneous likelihood may be used to generate a compensation signal for trailing ISI^{11,17,19}). In fig. 3, trailing ISI outside a predefined span of length $M < L$ is dealt with in this way.

The digits $\hat{a}_{k-L}, \dots, \hat{a}_{k-M-1}$ of $\hat{a}_k$ are applied to a linear combiner with weights $f_{M+1}, \dots, f_L$, whose output signal is subtracted from the received signal r_k . This yields a signal

$$z_k = (a * f)_k + n_k - (\hat{a} * f^r)_k \quad (13)$$

which is applied to the Viterbi detector (see fig. 3). Here f_k^r denotes the residual impulse response of the channel, given by

$$f_k^r \triangleq \begin{cases} 0, & k \in \{M+1, \dots, L\}, \\ f_k, & k \in \{0, \dots, M\}. \end{cases} \quad (14)$$

Whenever the decisions $\hat{a}_{k-M-1}, \dots, \hat{a}_{k-L}$ are all correct, eq. (13) simplifies to

$$z_k = (a * f^r)_k + n_k, \quad (15)$$

where

$$f_k^r \triangleq f_k - f_k^r = \begin{cases} f_k, & k \in \{0, \dots, M\}, \\ 0, & k \in \{M+1, \dots, L\}. \end{cases} \quad (16)$$

is the truncated impulse response of the channel. According to eq. (15), the VD operates upon an input signal with a reduced ISI span of only M symbol intervals. For this reason, it now needs to maintain only 2^M states

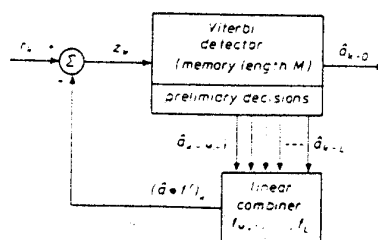


Fig. 3. Viterbi detector simplified by means of global feedback from the most likely survivor.

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$$s_k^i \triangleq \{a_{k-M}^i, \dots, a_{k-1}^i\}. \quad (17)$$

and survivors

$$p_k^i \triangleq \{a_{k-D}^i, \dots, a_{k-M-1}^i\} \text{ for all } i \in \{0, \dots, 2^M - 1\}. \quad (18)$$

This means a complexity reduction by a factor 2^{L-M} . In return for this reduction, signal energy outside the span of the VD is cancelled and hence not exploited in the detection process, while imperfect cancellation may furthermore cause error propagation.

Because z_k , cf. eq. (13), rather than r_k is the input signal of the VD and because the VD is dimensioned to operate upon the truncated rather than upon the original channel, the metric values J_k^i as given by eq. (9) for the full-fledged VD are now given by

$$J_k^i = \sum_{l=0}^{k-1} (r - a^i * f^l - \hat{a} * f^l)_l^2 \text{ for all } i \in \{0, \dots, 2^M - 1\}. \quad (19)$$

It is seen from this expression that the compensation signal $(\hat{a} * f^l)_k$ affects all 2^M metric values and their increments. For this reason we refer to this type of decision feedback as global. Making use of eqs (1) and (16), eq. (19) can alternatively be written as

$$J_k^i = \sum_{l=0}^{k-1} ((a - a^i) * f^l + (a - \hat{a}) * f^l + n)_l^2. \quad (20)$$

When the preliminary decisions $\hat{a}_0, \dots, \hat{a}_{k-M-2}$ are correct, this expression simplifies to

$$J_k^i = \sum_{l=0}^{k-1} ((a - a^i) * f^l + n)_l^2. \quad (21)$$

In this case the only penalty for the simplification by means of global feedback is a performance decrement due to the fact that the filtered error sequences $((a - a^i) * f^l)_k$ generally have a smaller amplitude than their untruncated versions $((a - a^i) * f)_k$, cf. eq. (9), which causes their discrimination against the noise signal n_k to be more difficult. However, in case not all of the symbols $\hat{a}_{k-L}, \dots, \hat{a}_{k-M-1}$ are correct, it is according to eq. (20) inevitable

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that erroneous cancellation occurs at moment k for all maintained data paths a_k^i . The false information thus incorporated in the metric values may cause the correct data path to be completely lost in favour of an incorrect data path in one of the following selections. This problem can be circumvented by using the local survivor p_k^i rather than the most likely one to generate individual estimates $(a^i * f^r)_k$ of the trailing ISI^{15,18,20,22}. By using these estimates in the update of the i^{th} data path a_k^i only, trailing ISI will be correctly cancelled whenever the local survivor p_k^i is correct. Thus even at instants when the correct data path does not have the greatest likelihood, the new metric values of many data paths a_k^i (viz. those with a correct survivor p_k^i) will still be calculated correctly. As a consequence, error propagation will be reduced.

Substituting a_k^i for $\hat{a}_k$ in eqs (19) and (20), we see that this local method of feedback gives rise to metric values

$$\begin{aligned} J_k^i &= \sum_{l=0}^{k-1} (r - (a^i * f^r)_l - (a^i * f^r)_l^2) \\ &= \sum_{l=0}^{k-1} (r - (a^i * f)_l^2) = \sum_{l=0}^{k-1} (((a - a^i) * f) + n)_l^2. \end{aligned} \quad (22)$$

Because this expression is identical to the one for the full-fledged VD, eq. (9), the calculations performed in the respective BVAU's are also identical. This can be seen more clearly by comparing fig. 2 with fig. 4, which shows the BVAU for local feedback.

In fig. 2 the states s_k^i contain all the information required for calculating the noiseless estimates $(a^{i*} * f)_k$ of r_k involved in the metric update process. Since s_k^i characterizes the BVAU and hence does not change in time, the values of $(a^{i*} * f)_k$ need to be calculated only once and can be used ever after. In contrast, in fig. 4 the bits $a_{k-M-1}^i, \dots, a_{k-L}^i$ form part of the survivor p_k^i , and can hence change dynamically. To account for their influence in the metric update process, a feedback operation is now needed to calculate their contribution $(a^{i*} * f^r)_k$ to $(a^{i*} * f)_k$ at any instant k . The remainder $(a^{i*} * f^r)_k$ of $(a^{i*} * f)_k$ depends entirely upon s_k^i , and is thus again a fixed value that can be calculated beforehand.

According to figs 2 and 4, the detector with local feedback uses fewer states than the full-fledged VD (2^M vs. 2^L), and it performs identical metric calculations. For this reason it can be regarded as a somewhat special reduced-state detector, in which a highly structured subset of the original states is retained. This opposes the conventional reduced-state VD, where at any in-

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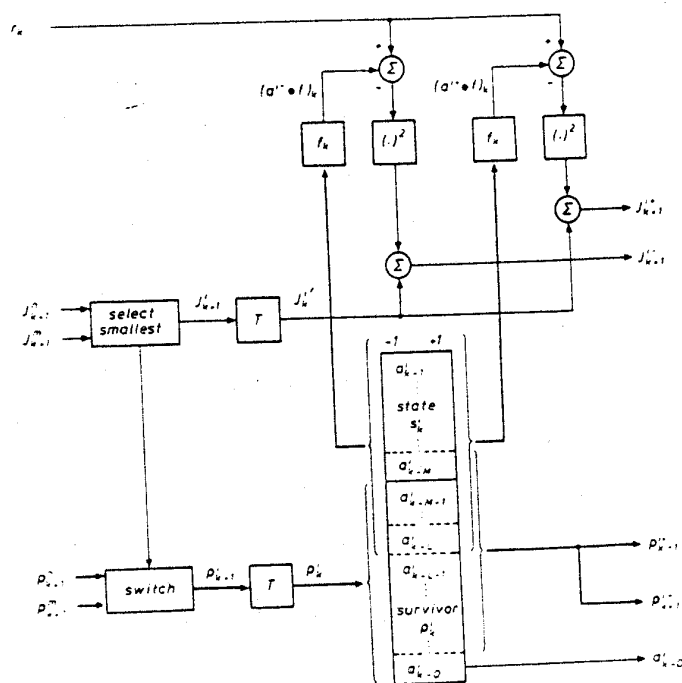


Fig. 4. Basic Viterbi algorithm unit (BVAU) for Viterbi detector simplified by means of local feedback.

stant k a new subset of states is formed by the topmost part of a stack that is ordered according to the metric values of the contained states²⁻⁴). The unpredictable composition of this subset, the dynamically varying size of the stack and the need to order states according to their metric values all cause the conventional reduced-state VD to be more complicated than the VD with local feedback. In spite of these simplifications, we shall see soon that even performances close to that of the full-fledged VD are often within reach.

For both local and global feedback, the receiver under study degenerates into a conventional decision feedback equalizer (DFE) in the extreme case $M = 0$, because it then has only one survivor $\hat{p}_k = \hat{a}_k$ left and attempts to cancel all trailing ISI. By varying M between 0 and L performance can be traded against complexity and vice versa. We shall now explore this trade-off in more detail for the situation that single bit errors prevail.

5. Prefiltering for the Viterbi detector with decision feedback

For channels in which only a modest amount of ISI arises, the full-fledged Viterbi detector often produces predominantly single-bit errors¹⁾. Its bit error probability $\text{Pr}[E]$ then approaches the matched filter bound (MFB)

$$\text{Pr}[E] = Q\left(\sqrt{\frac{E_b}{N_0}}\right), \quad (23)$$

where

$$Q(x) \triangleq \frac{1}{\sqrt{2\pi}} \int_x^\infty e^{-\frac{y^2}{2}} dy, \quad (24)$$

while

$$E_b = \sum_{k=0}^L f_k^2 \quad (25)$$

is the received data energy per transmitted bit. Because of the quadratic nature of eq. (25), only samples f_k whose magnitude is comparable with the magnitude of the largest sample can contribute significantly to E_b . It is thus of little use to exploit the energy that stems from the remaining samples in the detection process. As reflected in eqs (15) and (16), the VD with feedback ideally cancels all energy of f_k in the span $\{M+1, \dots, L\}$. For optimum performance, f_k should thus have the largest possible fraction of its energy concentrated inside the remaining span of length $M+1$ which is exploited by the VD. As we saw in sec. 2 (eq. (3)), f_k is determined within a factor h_k that depends upon the precise characteristics of the prefilter in the actual continuous-time system. Because the Viterbi algorithm considered here relies upon the presence of uncorrelated noise, h_k can be chosen freely only within the set $\mathcal{H}$ defined in eq. (6).

Now for any minimum-phase function g_k and any $h_k \in \mathcal{H}$, we have that

$$\sum_{k=0}^M (e * g)_k^2 \geq \sum_{k=0}^M (e * g * h)_k^2. \quad (26)$$

This inequality applies for any non-negative integer M and any signal e_k (ref. 29, p. 200). Taking $e_k = \delta_k$ in this expression and using eq. (3) to recognize

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$(g * h)_k$ as f_k , it follows that f_k has the largest possible fraction of its energy concentrated in the span $\{0, \dots, M\}$ when $h_k = \delta_k$. Hence for any $M \in \{0, \dots, L\}$ the optimum prefilter of the continuous-time system should be a canonical WMF, for which $f_k = g_k^{-1}$. This result should not come as a surprise, since it is well known that minimum-phase responses have their energy optimally concentrated near the time origin²⁹, and also because it has long been known that for the DFE (i.e. for the degenerate case $M = 0$) the optimum sampled impulse response of the system should indeed have minimum-phase³⁰⁻³².

In the sequel we shall see that this same conclusion can be reached subject to less restrictive assumptions.

6. Performance of the VD with local feedback

In optimizing the DFE, one normally overcomes the mathematical intractability of error propagation by neglecting it, i.e. by assuming that previous decisions which affect the current decision variable are all correct. This approach is justified a posteriori by the fact that the resulting solution indeed causes little error propagation on typical channels^{28,30}. For $M = 0$, the receiver under study is just a DFE, and by increasing M the compensation signal generated by the feedback filter(s) becomes smaller in magnitude, causing error propagation to be less severe. In analysing and optimizing the VD with feedback, it is thus reasonable to assume a similar absence of error propagation, particularly for the VD with local feedback, which suffers least from error propagation. Apart from the final decisions with delay D , our analysis for this VD will also cover the poorest preliminary decisions applied in the feedback process (viz. those with delay M), because their quality determines the severeness of error propagation most strongly.

For the full-fledged VD, an error event is said to occur between the instants k_1 and k_2 if $\hat{s}_{k_1} = s_{k_1}$ and $\hat{s}_{k_2} = s_{k_2}$ but $\hat{s}_k \neq s_k$ for all $k \in \{k_1 + 1, \dots, k_2 - 1\}$. Unlike the full-fledged VD, the metric increments $(r_k - (a^i * f)_k)^2$ determined by the VD with local feedback depend not only upon the newly appended digit $a_k = \pm 1$ and the state s_k^i , but also upon the $L - M$ most recent digits $a_{k-L}^i, \dots, a_{k-M-1}^i$ of the survivor p_k^i associated to s_k^i . To ensure that no error propagation was in progress at the instant k_1 , it is thus necessary to assume that $\hat{s}_k$ was correct both at k_1 and at the $L - M$ instants immediately preceding k_1 . With eq. (17) this means that

$$\hat{a}_k = a_k \quad \text{for } k \in \{k_1 - L, \dots, k_1 - 1\}. \quad (27)$$

Also, the condition $\hat{s}_{k_2} = s_{k_2}$ does not necessarily demarcate the end of a cluster of errors now, because incorrect preliminary decisions

$\hat{a}_{k_2-L}, \dots, \hat{a}_{k_2-M-1}$ will cause erroneous contributions in the metric calculations during the moments $k_2, \dots, k_2 + L - M - 1$. As motivated above, we shall neglect this error propagation problem in our analysis. We do this by splitting a cluster of errors up into an error event which is defined to occur between the instants k_1 and k_2 , and a subsequent propagation-induced part which is not accounted for in the analysis.

Because $\hat{s}_{k_2} = s_{k_2}$, we have with eq. (17) that

$$\hat{a}_k = a_k \quad \text{for } k \in \{k_2 - M, \dots, k_2 - 1\}. \quad (28)$$

However,

$$\hat{a}_{k_1} \neq a_{k_1} \quad (29)$$

and

$$\hat{a}_{k_2-M-1} \neq a_{k_2-M-1}, \quad (30)$$

because $\hat{s}_{k_1+1} \neq s_{k_1+1}$ and $\hat{s}_{k_2-1} \neq s_{k_2-1}$, respectively. We define the error sequence e_k corresponding to this error event as

$$e_k \triangleq \begin{cases} 0, & k \notin \{0, \dots, k_2 - k_1 - M - 1\}, \\ a_{k+k_1} - \hat{a}_{k+k_1}, & k \in \{0, \dots, k_2 - k_1 - M - 1\}. \end{cases} \quad (31)$$

Hence every error sequence of length $N = k_2 - k_1 - M$ characterizes a corresponding error event of length $N + M - 1$. For this error event to occur, it is necessary that a bad span of noise n_k causes an erroneous state $\hat{s}_k$ to be more likely than the true state s_k for $k \in \{k_1, \dots, k_2\}$. This will be so if

$$\begin{aligned} \hat{J}_{k_2} - J_{k_2} &= \sum_{k=k_1}^{k_2-1} [(r_k - (\hat{a} * f)_k)^2 - (r_k - (a * f)_k)^2] \\ &= \sum_{k=0}^{N+M-1} [(e * f)_k^2 + 2n_{k+k_1}(e * f)_k] \end{aligned} \quad (32)$$

is smaller than zero. Here $\hat{J}_k$ and J_k denote the accumulated metric values of the most likely and the actually transmitted data sequence, respectively. Due to its linear dependence on the noise signal n_k , the right hand side of eq. (32) is a Gaussian stochastic variable with mean

$$\sum_{k=0}^{N+M-1} (e * f)_k^2 \triangleq d_M^2 \quad (33)$$

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and variance

$$\sigma^2 \triangleq 4N_0 \sum_{k=0}^{N+M-1} (e * f)_k^2 = 4N_0 d_M^2. \quad (34)$$

Hence the probability that J_{k_2} exceeds $\hat{J}_{k_2}$ equals

$$\Pr[\hat{J}_{k_2} - J_{k_2} < 0] = Q\left(\frac{\hat{d}_M^2}{\sigma}\right) = Q\left(\frac{\hat{d}_M}{2\sqrt{N_0}}\right), \quad (35)$$

where $Q(\cdot)$ was defined in eq. (24).

At high signal-to-noise ratio's and in the absence of error propagation, the error probability $\Pr[E]$ achieved by the VD with local feedback will be linearly proportional to $\Pr[\hat{J}_{k_2} - J_{k_2} < 0]$ for the error sequence e_k which leads to the smallest possible value d_M^2 of $\hat{d}_M^2$. From eqs (31) and (33), it follows that

$$d_M^2 = \min_{e_k \in S} \sum_{k=0}^{N+M-1} (e * f)_k^2. \quad (36)$$

where S is the set of all error sequences $e_k \in \{-2, 0, +2\}$ of arbitrary length N , starting at moment 0^{*}). Because the channel has a memory length of L symbol intervals, the effect of a filtered error sequence $(e * f)_k$ extends in principle over an interval of length $N + L$. Hence for $M < L$ the summation in eq. (36) covers only a part of the energy of filtered error sequences, reflecting the fact that insufficient states are available to be able to take full advantage of the Euclidean distance properties of the received signal. Conversely, the full-fledged VD has the smallest value $M = L$ for which all energy of $(e * f)_k$ is exploited, and from this point of view it can be regarded as the canonical implementation of an MLSD in the sense that it has the smallest number of states needed to achieve MLSD performance. Finally, for the zero-forcing DFE (i.e. for $M = 0$) it is easily verified that $d_0 = 4f_0^2$, in accordance with refs 24 and 31. These results indicate that the VD with local feedback is a natural and canonical intermediate between the DFE and the full-fledged VD.

On the basis of eq. (36) it is easy to optimize the prefilter of the VD with feedback. To this end, we first notice that for $M = L$, d_M^2 just describes the

^{*}) This result was obtained independently by Eyubogiu and Qureshi²²⁾.

minimum distance $d_{\min}^2$ introduced by Forney¹⁾. Because it is determined by the total energy of filtered error sequences, this distance depends by Parseval's equality²⁹⁾ exclusively upon the amplitude characteristics of f_k ¹⁾. Hence the all-pass response h_k comprised in f_k according to eq. (3) may take any value in $\mathcal{H}$ ¹⁾. Interestingly, the quality of the preliminary decisions generated by the full-fledged VD may still depend quite heavily upon h_k , as will become apparent soon.

For $M < L$, d_M^2 also depends upon the phase characteristics of f_k (and hence upon h_k) because it no longer reflects all energy of the filtered error sequences. Writing f_k as $(g * h)_k$, with g_k and h_k as defined in sec. 2, we can again use eq. (26) to show that for any error sequence $e_k \in S$ and any $h_k \in \mathcal{H}$

$$\sum_{k=0}^{N+M-1} (e * g)_k^2 \geq \sum_{k=0}^{N+M-1} (e * g * h)_k^2 = \sum_{k=0}^{N+M-1} (e * f)_k^2. \quad (37)$$

Hence d_M^2 is maximized by choosing $h_k = \delta_k$, which is equivalent to applying a canonical WMF.

Apart from optimizing the performance of the VD with feedback in the absence of error propagation, the use of this WMF also leads to a favourable error propagation behaviour in the sense that it optimizes the quality of the poorest preliminary decisions applied in the feedback process (viz. those with delay M). To show this^{*)}, we note that $k_1 + M + 1$ is the first moment at which the survivors p_k^i contain preliminary decisions about a_{k_1} . If we again assume that no error event or error propagation was in progress at the instant k_1 , i.e. that eq. (27) applies, then we may restrict attention to the 2^{M+1} data paths $a_{k_1+M+1}^i$ that emanate from the correct path $\hat{a}_{k_1} = a_{k_1}$ ¹⁾. Because there are 2^M distinct states, these paths do not merge before the moment $k_1 + M + 1$. At this moment, the path with greatest likelihood has accumulated metric

$$\hat{J}_{k_1+M+1} = J_{k_1} + \sum_{k=k_1}^{k_1+M} ((\hat{a} - a) * f)_k, \quad (38)$$

where J_{k_1} is the (correct) accumulated metric at moment k_1 . Denoting the accumulated metric value at moment $k_1 + M + 1$ of the actually transmitted data sequence a_k as J_{k_1+M+1} and making use of eq. (27), we have with eq. (38) that

^{*)} The following argument is partly due to F.M.J. Willems, University of Technology, Eindhoven.

$$\hat{J}_{k_1+M+1} - J_{k_1+M+1} = \sum_{k=0}^M [(e * f)_k^2 + 2n_k(e * f)_k], \quad (39)$$

where

$$e_k \triangleq \begin{cases} 0, & k < 0, \\ a_{k+k_1} - \hat{a}_{k+k_1}, & k \geq 0. \end{cases} \quad (40)$$

Out of all possible error sequences e_k of this form, only those with $e_0 \neq 0$ correspond to an erroneous estimate $\hat{a}_{k_1-1}$ of a_{k_1-1} . Proceeding as before, it follows that at high signal-to-noise ratio's the probability that such an erroneous preliminary decision is made is linearly proportional to $Q(d'_M/\sqrt{4N_0})$, where

$$(d'_M)^2 = \min_{e_k \in S'} \sum_{k=0}^M (e * f)_k^2. \quad (41)$$

and where S' is the set of all error sequences $e_k \in \{-2, 0, 2\}$ of arbitrary length and with $e_0 \neq 0$. Because the summation range in this expression is smaller than the one in eq. (36) and because $S' \supseteq S$, we have for all M that $d'_M \leq d_M$. For $M=0$ it is easily verified that the single bit error $e_k = \pm 2\delta_k$ minimizes eq. (41). Hence $d'_0 = d_0 = 2|f_0|$. For larger values of M , d'_M is usually strictly smaller than d_M , as we will see later. A large difference between d'_M and d_M indicates that preliminary decisions are of considerably poorer quality than the final ones, so that error propagation is likely to be serious. By a similar reasoning as used before it is straightforward to show that d'_M is maximized by choosing f_k to have minimum-phase, i.e. by applying a canonical WMF.

Whenever multiple bit errors determine d'_M , the sequence $(e * f)_k$ will have one or more non-zero values for $k \geq L+1$. Because their magnitude may depend quite heavily on h_k , we see with eq. (41) that even for the full-fledged VD the phase characteristics of f_k can have a significant influence upon the quality of its preliminary decisions, and hence upon the minimum detection delay D needed to virtually achieve MLSD performance. Because eq. (41) coincides with a lower bound on the performance of any detector with a restricted decoding delay³³, we may conclude that the preliminary decisions with delay M , present in the VD with local feedback, have a quality that can effectively not be improved upon by any type of receiver, provided that error propagation is indeed insignificant.

7. Adaptive implementation

To dimension the prefilter appropriately when incomplete prior knowledge about the channel characteristics is available, its output signal r_k may be applied to a separate adaptive decision-feedback equalizer^{14,21,28}). Both the feedback filter (with impulse response $p_k, k \geq 1$) and the prefilter can then be adapted on the basis of the error signal $\varepsilon_k = r_k - (\hat{a} * p)_k - \hat{a}_k$ formed by the DFE (see fig. 5).

Provided that the decisions $\hat{a}_k$ are mostly correct, this leads after convergence to a minimum-phase impulse response $f_k \approx g_k$ scaled according to $f_0 = 1$, and to a feedback filter impulse response $p_k = f_k, k \geq 1$ ²⁸). Thus the prefilter will closely approximate a canonical WMF. Furthermore, together with the a priori known value $p_0 = f_0 = 1$ the feedback filter coefficients $p_k, k \geq 1$ completely determine the values of f_k needed in the linear weighers of the VD.

Interestingly, an error signal essentially equivalent to ε_k is in fact available within the VD. To see this, we write the impulse responses of the linear weighers of figs 2 and 4 as p_k so as to account for their adaptive nature. From the two extensions $a_k = \pm 1$ of the most likely data path $\hat{a}_k$, the one with the smallest error power $(r_k - (\hat{a} * p)_k)^2$ is a preliminary decision about a_k , with a quality at least as good as that of the symbol-wise decision $\hat{a}_k$ produced by the DFE because erroneous preliminary decisions $\hat{a}_{k-L}, \dots, \hat{a}_{k-1}$ are rarer for the VD than for the DFE. Consequently, the error signal $r_k - (\hat{a} * p)_k$ corresponding to this preliminary decision can be used instead of ε_k when p_0 is assigned the fixed value 1. Thus, it is apparently possible to adapt the prefilter and the coefficients $p_k, k \geq 1$ of the linear weighers of the VD without the aid of a separate DFE by making use of this error signal.

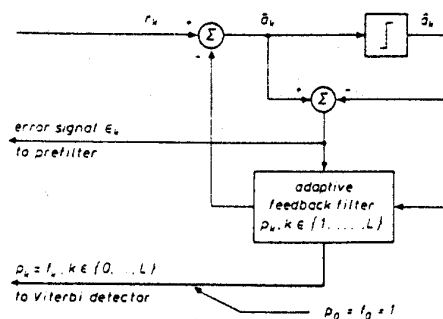


Fig. 5. Adaptive decision feedback equalizer controlling the VD with feedback.

8. Hardware realization

To enable a detailed comparison of the detectors with local and global feedback, they were both implemented using two NEC μ PD7720 digital signal processors and some external hardware. The first DSP contains a pseudo-random data generator with a polynomial of length 32, a channel filter and a noise source in which, at any instant k , 17 independent and uniform deviates, generated according to the linear congruential method described in ref. 34, pp. 9-25 are added in order to obtain a nearly Gaussian noise distribution. After a signal-to-noise ratio dependent weighing, the noise signal n_k is added to the filtered data signal $(a * f)_k$. The resulting channel output signal r_k has a data rate of about 10 kbit/s, and is transferred serially to the second DSP. This DSP contains a VD equipped with both types of feedback and with up to 8 states ($M = 3$). The latter restriction is imposed to be able to store all candidate survivors and their associated data in the 16 memory rows available in the DSP. Because the channels used in the measurements have a priori known impulse responses with appropriate phase characteristics, the receiver does not contain a prefilter and it is not adaptive. Instead, the coefficients f_k are transferred serially to the VD upon initialization.

In each BVAU (see fig. 4), the weighing functions f_k have a fixed length of 16 bit intervals. The weights $f_M, \dots, f_{15}$ which account for the feedback operation of the detector are split into three parts. The corresponding three partial feedback sums are determined by table look-up operations and then added. In return for a modest occupation of nominally $3 \times 2^4 = 48$ internal ROM locations, this method of weighing is computationally more efficient than the straightforward transversal approach. Because one 16-bit word is reserved for each survivor p_k^i , the detection delay D has a maximum value of $3 + 16 = 19$ bit intervals. Scaling and saturation arithmetic within the BVAU are designed to make optimum use of the 16-bit accuracy of the processor while minimizing errors due to overflow. After the selection of the minimum metric value, all metric values are renormalized by subtracting this minimum value.

The entire program for the receiver with local feedback comprises about 400 instructions. This quantity is reduced by less than 20 percent for the receiver with global feedback. In terms of their internal memory consumption (both ROM and RAM), the net difference between both receivers is even smaller.

It is worth noting that the use of local feedback yields a more homogeneous receiver structure and goes without the need of first making a decision as to which survivor is most likely before the precise feedback signal can be determined. This facilitates the incorporation of parallelism and potentially

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reduces latency. Consequently, for dedicated high-speed implementations the use of local feedback may be favourable.

9. Five channels and their distance properties

To illustrate the effect of the phase characteristics of the channel on the performance of the VD with feedback, fig. 6 depicts three channel impulse responses with $\mathcal{D}$ -transforms $f(\mathcal{D})$ equal to $(2 + \mathcal{D})^2$, $(2 + \mathcal{D})(1 + 2\mathcal{D})$ and $(1 + 2\mathcal{D})^2$, respectively.

The channels have a memory length $L = 2$ and identical amplitude-frequency characteristics

$$|F(\omega)| = 5 + 4\cos\omega, \quad (42)$$

as depicted in fig. 7. Here $F(\omega)$ is defined as

$$F(\omega) \triangleq \sum_{k=-\infty}^{\infty} f_k e^{-j\omega k}. \quad (43)$$

Because its $\mathcal{D}$ -transform has both zeros outside the unit circle, the $(2 + \mathcal{D})^2$ -channel has minimum-phase. Conversely, apart from an insignificant delay the $(2 + \mathcal{D})(1 + 2\mathcal{D})$ and $(1 + 2\mathcal{D})^2$ -channels can be said to have linear and maximum-phase, respectively. The following table clearly reveals that these phase characteristics are less desirable.

TABLE I
Distance profile of the channels of fig. 6.

channel	$M=0$	$M=1$		$M=2$	
	$d'_0 = d_0$ (dB)	d'_1 (dB)	d_1 (dB)	d'_2 (dB)	$d_2 = d_{\min}$ (dB)
$f(\mathcal{D}) = (2 + \mathcal{D})^2$	-3.1	-3.1	-1.2	-2.9	-1.0
$f(\mathcal{D}) = (2 + \mathcal{D})(1 + 2\mathcal{D})$	-9.2	-4.0	-1.8	-3.7	-1.0
$f(\mathcal{D}) = (1 + 2\mathcal{D})^2$	-15.2	-5.2	-5.2	-5.2	-1.0

The table uses a 0 dB level equal to $E_b = \sum_{k=0}^L f_k^2 = 33$. The comprised values of d_M and d'_M (as defined in eqs (36) and (41), respectively) can therefore be interpreted as losses relative to the Matched Filter Bound (MFB).

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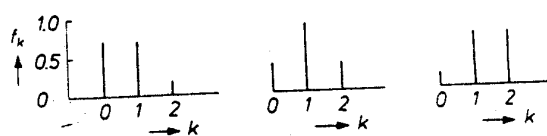


Fig. 6. Power-normalized versions of three channel impulse responses f_k with $L = 2$ and identical amplitude-frequency characteristics.

It is seen that the performance of the full-fledged VD (which has $M = L = 2$) is indeed independent of the phase characteristics of the channel. Conversely, its preliminary decisions are (judged by d'_2) clearly best for the minimum-phase channel. Consequently, for the other two channels a larger detection delay D will be needed to reach the performance level specified by $d_{\min}$ than for the minimum-phase channel. The performance of the DFE (which has $d'_0 = d_0$ because preliminary and final decisions are identical) is apparently a strong function of the phase characteristics of the channel. Finally, for the $M = 1$ VD with feedback, performance levels are somewhat closer to the VD than to the DFE. Here, serious error propagation is to be expected for the $(2 + \mathcal{D})^2$ and $(2 + \mathcal{D})(1 + 2\mathcal{D})$ channels because d'_1 and d_1 differ considerably.

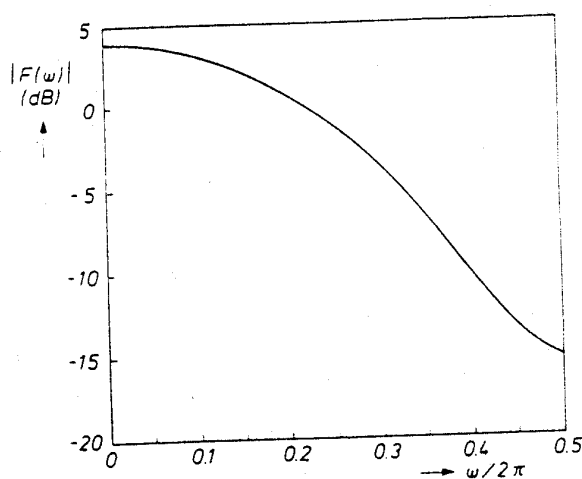


Fig. 7. Amplitude frequency-characteristic of the channels of fig. 6. The 0 dB level corresponds to a transfer magnitude of $\sqrt{E_s} = \sqrt{33}$.

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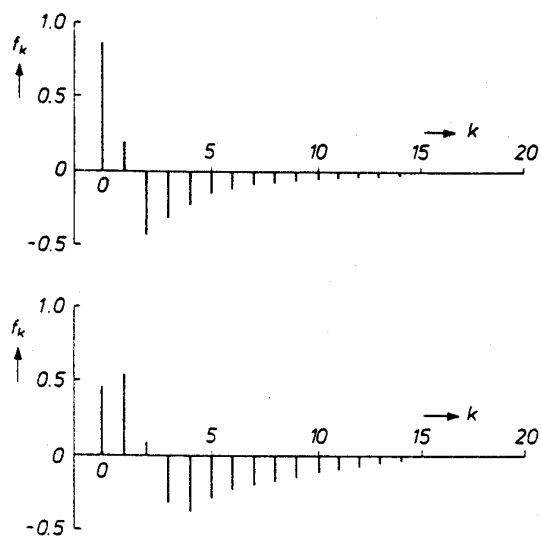


Fig. 8. Power normalized minimum-phase responses f_k for digital magnetic recording systems having $D = 2.0$ (above) and $D = 3.3$ (below).

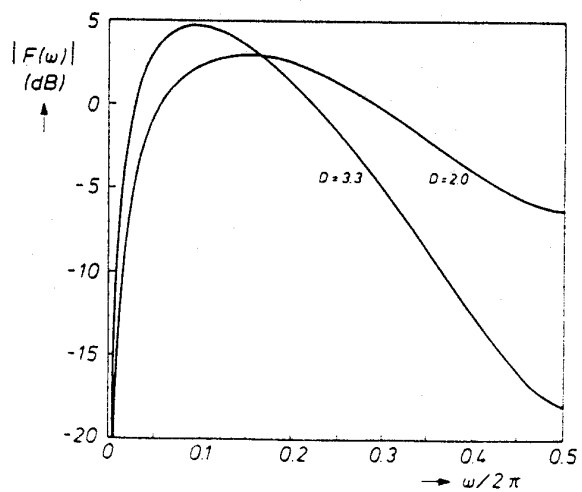


Fig. 9. Amplitude-frequency characteristics $|F(\omega)|$ of the channels of fig. 8. The 0dB level corresponds to a transfer magnitude of $\sqrt{E_b} = \sqrt{\frac{\sinh \pi D}{2\pi D(D^2 - 1)}}$.

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Although they enable a clear illustration of the importance of minimum-phase, the impulse responses of fig. 6 are not the most logical candidates for the application of a VD with feedback because of their very small memory length. Two more appropriate responses are shown in fig. 8.

These responses, used earlier in refs 35 and 36, have a minimum-phase and pertain to digital magnetic recording systems which use an NRZ-like transmission code and a differentiating playback head. Their channel transfer function $F(\omega)$ satisfies

$$|F(\omega)| = |\sin(\omega/2)| \sqrt{\cosh D(\pi - |\omega|)} \text{ for } |\omega| \leq \pi. \quad (44)$$

Here D characterizes the spatial information density on the magnetic storage medium, and ranges between roughly 0.2 and 3 in present systems³⁷. Apart from a zero at the lower band edge ($\omega = 0$), transfer functions in this class have an attenuation near the upper band edge ($\omega \approx \pi$) which increases rapidly with the information density D (fig. 9).

The distance properties of both channels are summarized in table II.

TABLE II
Distance profile of $D = 2.0$ and $D = 3.3$ recording channels. The 0 dB-level corresponds to $\sqrt{E_b} = \sqrt{\frac{\sinh \pi D}{2\pi D(D^2 + 1)}}$.

channel	$M = 0$	$M = 1$		$M = 2$		$M = 3$		...	$M = \infty$
	$d'_0 = d_0$ (dB)	d'_1 (dB)	d_1 (dB)	d'_2 (dB)	d_2 (dB)	d'_3 (dB)	d_3 (dB)		$d_\infty = d_{\min}$ (dB)
$D = 2.0$	-1.4	-1.2	-1.2	-0.5	-0.5	-0.15	-0.15	...	0.0
$D = 3.3$	-4.4	-4.4	-3.3	-4.4	-3.3	-3.6	-3.0	...	-2.1

From table II, it is seen that the VD promises advantages up to 1.4 and 2.3 dB over the DFE ($M = 0$), of which a major fraction should already be attainable with values of M no larger than 1 or 2, thanks to the optimum energy concentration provided by the minimum-phase nature of f_k . Because single-bit errors prevail for the $D = 2.0$ channel, the corresponding values of d'_M and d_M coincide for all M . This indicates that error propagation is insignificant, and that the preliminary decisions used in the feedback process are effectively as good as the final ones. Conversely, for $D = 3.3$ even the full-fledged VD incurs a loss (of 2.1 dB) relative to the MFB, because for this channel multiple bit errors prevail. Here d'_M and d_M differ considerably, sug-



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A CHANNEL MODEL AND A NOVEL ADAPTIVE EQUALIZER FOR
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ABSTRACT This paper presents a multi-ray channel model and a novel reduced-state soft decision feedback Viterbi equalizer (RSSDFVE). The channel model can implement any channel impulse response which is required in mobile communications and the distribution functions of channel parameters can be chosen according to the environment. We use a 5 ray channel model for the simulation in this paper. For mobile radio channels with severe ISI, a Viterbi equalizer needs to handle both postcursors and precursors, like a decision feedback equalizer (DFE) having both linear and feedback filters. We propose an equalizer using maximum likelihood sequence estimation (MLSE) to handle precursors and truncates overall postcursors with the soft decision feedback of MLSE to reduce the implementation complexity of Viterbi equalizers. According to the simulation results, the proposed equalizer gives nearly the same performance as MLSE in the presence of severe selective multipath fading with much less implementation complexity than MLSE.

INTRODUCTION

In this paper, we are concerned with QPSK and $\pi/4$ -QPSK transmission systems in mobile radio communications subject to severe intersymbol interference (ISI). Firstly, we modify our indoor channel model for mobile radio communications because the two ray model used in most papers is not quite realistic in mobile radio communications [1]. One of the main differences of our channel is that path delay τ_k can be any time instead intervals of T .

It is well known that MLSE, implemented by Viterbi algorithm (VA) [2], can provide a significant improvement compared to the DFE. However, because the implementation complexity of MLSE is exponentially increased with M^L where L is the length of overall channel impulse response and M is the levels of modulations, it is difficult to implement MLSE for QPSK or $\pi/4$ -QPSK which is corrupted by severe selective multipath fading.

A lot of research has been undertaken to achieve the performance of the MLSE at reduced complexity [3-9]. Most of earlier work concentrated on preprocessing techniques to reduce the channel impulse response to a short length [3]-[6]. In [3], a linear equaliser was used to reduced the overall impulse response. Falconer [4] and Beare [5] investigated the optimization of the desired impulse response for fixed given length. Lee [6] used a separated DFE with hard decision to

truncate part of postcursors. Cheung [7] also used a separate DFE with soft decision feedback to reduce the channel impulse response but his MLSE is used for ISI introduced by continuous phase modulation. Eyuboglu [8] proposed reduced-state sequence estimation (RSSE) with set partitioning which is more applicable to high level modulations and Duell-hallen [9] proposed a delayed decision feedback sequence estimator (DFSE), but both RSSE and DFSE only can handle postcursors.

MATHEMATICAL CHANNEL MODEL

The mathematical model used for the complex low-pass impulse response of the mobile radio channel is given by

$$c(t) = \sum_{k=0}^N a_k(t) e^{j\theta_k(t)} \delta[t - \tau_k(t)] \quad (1)$$

where $\delta(t)$ is a delta function, $a_k(t)$ is the real positive gain of the k th path, propagation delay $\tau_k(t)$ is the arrival time of the k th path and the associated phase shift $\theta_k(t)$ is the phase of k th path; k is the path index; in principle, k extends from 0 to infinite.

Because of the motion of mobiles, the parameters $a_k(t)$, $\tau_k(t)$ and $\theta_k(t)$ are randomly time-varying functions. We treat them as slowly varying random variables in low bit rate and big Doppler frequency (f_d) systems and put special low-pass filters in the generators of these variables. For high bit rate and small f_d mobile communication systems, the rate of their variations during bursts is very slow compared to the transmitted symbol rate. Then we can treat these parameters as time-invariant random variables. Equation (1) can then be rewritten as follow:

$$c(t) = \sum_{k=0}^N a_k e^{j\theta_k} \delta(t - \tau_k) \quad (2)$$

1. The Distribution Functions of a_k , τ_k and θ_k A. The Probability Distribution of the Path Gains, $\{a_k\}$

Path gains, a_k , are represented by Rayleigh or Rician distribution depending on the topography of the site. We use two probability density functions (pdfs) for our channel model.

(a) Rayleigh Distribution [when a line-of-sight (LOS)

component is absent]

$$f(x) = \frac{x}{\sigma^2} e^{-x^2/\sigma^2} \quad (3)$$

where σ^2 is the variance of the faded component.

(b) Rician Distribution (when a LOS component is present)

$$f(x) = \frac{x}{\sigma^2} e^{-(x^2 + A^2)/2\sigma^2} I_0\left(\frac{xA}{\sigma^2}\right) \quad (4)$$

where, A is the mean, σ^2 is the variance of the faded component, $I_0(xA/\sigma^2)$ is the zeroth order Bessel function.

For a Rician-distributed envelope with a uniformly distributed phase component, the theoretical spectral density of the complex envelope of the a_k is given by

$$S(f) = 1/(\pi\sqrt{1-(ff_d)^2}) \quad -f_d \leq f \leq f_d \quad (5)$$

$$S(f) = 0 \quad \text{otherwise} \quad (6)$$

where f_d is the maximum Doppler frequency shift. The Rice factor, that is the severity of the fading, is determined by the direct to multipath signal power ratio and given by:

$$C/M = \frac{A^2}{2\sigma^2} \quad (7)$$

By selecting $C/M=0$ a severe Rayleigh fading channel is obtained.

B. Arrival Time $\{\tau_k\}$

According to [1], τ_k can be described by the independent inter-arrival exponential probability density function where LOS is present.

$$f(x) = \frac{1}{a} e^{-x/a} \quad (8)$$

where $x \geq 0$, a is the mean ($a > 0$), a^2 is the variance. This distribution is suitable for a small cell size. Where LOS is absent, the arrival times $\tau_k = t_k - t_{k-1}$ were modeled by the Weibull distribution:

$$f(x) = \frac{\beta x^{\beta-1}}{\alpha^\beta} e^{-(x/\alpha)^\beta} \quad (9)$$

where $x \geq 0$, α is a scale parameter ($\alpha > 0$), and β is a shape parameter ($\beta > 0$).

C. Phase $\{\theta_k\}$

Like others, we assume that the phase of each ray has a

uniform distribution from 0 to 2π .

SYSTEM MODEL

We consider the use of uncoded quadrature phase modulation (QPSK or $\pi/4$ -QPSK) systems corrupted by additive Gaussian noise (AWGN), as shown in Fig. 1.

The complex finite baseband signal sampled at symbol rate ($1/T$) can be represented as a function of sampling time and given by:

$$r_i(t_0) = \sum_{k=-N1}^{N2} d_{i-k} h_{\alpha k}(t_0) + n_i \quad (10)$$

where $r_i(t_0)$ and n_i are i th received signal and additive noise samples, respectively, d_i is the corresponding transmitted data symbol, which is complex-valued, and $h_{\alpha k}(t_0) = h_{\alpha k}(kT + t_0)$ is k th sample of the finite overall channel impulse $h(t)$ including the response of the transmitter and receiver filters. For the quadrature phase modulations,

$$d_i = \sqrt{2} e^{j(\Phi_i + \frac{\pi}{4})} \quad (11)$$

where

$$\Phi_i - \Phi_{i-1} = m_i \frac{\pi}{2} + \Phi \quad m_i = 0, 1, 2, 3 \quad (12)$$

m is the value transmitted by k th symbol, Φ is the offset phase shift, if Φ is $\pi/4$, we got $\pi/4$ -QPSK; if Φ is zero, we got normal QPSK.

We assume the composite of the transmit filter and receive matched filter response are satisfied Nyquist's first criterion in order to guarantee zero ISI. The ISI is only resulted from multipath fading. According our channel model, we can use two methods to represent the overall channel impulse response for equaliser with sampling rate at $1/T$ and be shown in equation (13) and (14). We can implement different channel impulse response by these methods. When the overall impulse response is known, equation (13) is used, otherwise, equation (14) is used. The received signal sampled once per symbol at $iT + t_0$, where t_0 is the sample time yielding the signal sample sequence, can be rewritten by our method as follows:

$$r_i(t_0) = r(iT + t_0) = \sum_{k=-K1}^{K2} d_{i-k} h_{\alpha k}(t_0) e^{j\theta_k} + n_i \quad (13)$$

$$r_i(t_0) = \sum_{k=0}^K a_k e^{j\theta_k} d_{i-k} h_{\alpha k}(t_0 - \tau_k) + n_i \quad (14)$$

where h_{α} is the overall channel impulse response, h_T is the transmit filter impulse response, h_c is the multipath fading

channel impulse response, h_r is the match filter impulse response, h_n is the overall channel impulse response without multipath fading, K is the number of multipath, $K1-1$ is the number of precursors and $K2$ is the number of postcursors.

For the sake of easily understanding, two static channel models are used in this paper, channel one is the channel model used by Proakis as channel A[10], channel two is one which only has delayed rays with an exponential profile compared with the main ray and shows that there are precursors for overall channel impulse response. For channel one, overall channel impulse response $h_n = \{-0.2, -0.5, 0.7, 0.36, 0.2\}$; Using equation (13), our equivalent channel parameters are $[h_{nk}] = \{0.2, 0.5, 0.7, 0.36, 0.2\}$; $\theta_{nk} = \{\pi, \pi, 0, 0, 0\}$; $kT = \{2T, T, 0, -T, -2T\}$. For channel two, Our channel parameters are $a_k = \{1, 0.8, 0.6, 0.4, 0.2\}$; $\theta_k = \{0, 0.1\pi, 0.2\pi, 0.3\pi, 0.4\pi\}$; $\tau_k = \{0, 0.1T, 0.2T, 0.3T, 0.4T\}$ according equation (14) and the estimated overall channel impulse response is $h_n = \{(0.007, 0.037), (-0.072, -0.148), (1.646, 1.049), (-0.028, 0.760), (-0.005, -0.129)\}$. You can see that the first precursor is bigger than first postcursor in inphase channel.

PROPOSED REDUCED STATE SOFT DECISION FEEDBACK VITERBI EQUALISER AND SIMULATION RESULTS

The structure of our proposed Viterbi equaliser is given in Fig. 1.

Before RSSDFVE is discussed, let us recall how the DFE works and why a DFE has much a better performance than a transversal equaliser(TE). The equations of the DFE are given by:

$$y(n) = \sum_{i=1}^{N1} a_i * r(n-i-N1) + \sum_{i=1}^{N2} b_i * d(n+i) \quad (15)$$

$$e = d(n) - y(n) \quad (16)$$

where $r(n)$ is the input of the DFE, $y(n)$ is the output of the DFE and $d(n)$ is the decision signal, a_i are the forward taps and b_i are the feedback taps of the DFE, $e(n)$ is the error of the DFE.

For a LMS algorithm, the equations are given by:

$$c(n+1) = c(n) + \lambda u(n) e^*(n) \quad (17)$$

$$e(n) = d(n) - c^H u(n) \quad (18)$$

where $c(n) = \{a_{N1-1}, \dots, a_1, a_0, b_0, \dots, b_{N2-1}\}^T$, $u(n) = \{r_{n-N1+1}, \dots, r_n, d_{n+1}, \dots, d_{n+N2+1}\}^T$, $*$ is the conjugate, H indicates the transposed conjugate, λ is step factor.

When error propagation is not serious, DFE has a much better performance than TE because of its decision feedback,

therefore we introduce the more reliable soft decision rather than hard decision to improve the RSSDFVE performance. For our RSSDFVE, we use channel estimation to get channel impulse response[11] and update the RSSDFVE metrics by a method proposed by us. Our RSSDFVE computes the cost function according to equation (19).

$$\text{cost}(r_p, d_i(k), r(p_p, h_p)) = |r_i - \sum_{k=1}^{N2} d_i(k) * h_{-k} - r(p_p, h_p)|^2 \quad (19)$$

The formed metrics are added to the previous accumulative metric of the corresponding states to determine a new set of survivors. The survivor with the smallest metric is used to determine the tentative soft decisions. The final decision of MLSE is further delayed according to the decision depth of the Viterbi algorithm which is usually longer than the feedback part of the RSSDFVE. It is mean that the feedback part of the RSSDFVE can be used as long as the decision depth of the Viterbi algorithm.

The simulation results for channel one and two are given in Fig.3. The results show that there is 9DB improvement compared to the LMS DFE with correct decision feedback and only 1DB worse than MLSE at $\text{SER} = 10^{-2}$ for channel one, and RSSDFVE has nearly the same performance as MLSE for channel two.

CONCLUSIONS

Our proposed RSSDFVE has following characteristics:
<1> Good performance

1) This RSSDFVE retains the MLSE structure to obtain good performance and only uses soft decisions to subtract the postcursor interference before VA metric computations. The RSSDFVE could equal the MLSE performance if earlier soft decisions are the same as final soft decisions. However, although the earlier soft decisions are not as good as the final soft decisions, they are quickly improved as the delay is increased.

2) Using MLSE to handle precursors, RSSDFVE does not suffer from the poor performance of linear equalisers on severely distorted channels or low SNR because linear equalisers will introduce noise during the sum, On the other hand, the taps of linear equalisers will affect each other, therefore, linear equalisers need more taps than precursors. It means that RSSDFVE does not have a linear filter and there will be no noise enhancement for the RSSDFVE.

3) The RSSDFVE can be used for any modulations and severe distorted channels if we use the method of reduced-state sequence estimation with set partitioning for high modulations and time reverse method for long precursors channel where the delayed path is predominant[12]. This is because the equivalent channel impulse response as seen by equaliser becomes a time-reverse of the actual channel impulse response by reversing the sequential order of the received signal samples in time prior to equalization.

4) In our implementation, the RSSDFVE is different from the DFSE and does not become a zero-forcing equaliser although

RSSDFVE uses soft decision feedback to cancel postcursors. Our RSSDFVE can handle infinite ISI channels with rational response by using recursion in path metric computations as the DFSE does.

<2> Less complexity

For QPSK with the 5 ray channel, the complexity of RSSDFVE is 16 times less than MLSE because the possible transitions become from 4^5 to 4^3 . It is apparent that the complexity is much less if the channel impulse response has long postcursors.

<3> Flexibility

For fewer precursors channels, we can let MLSE handle not only precursors but also some postcursors so that more delayed soft decisions are used and make the error propagation become negligible. In this case, our proposed RSSDFVE will reduce to DFSE if the precursors are zero. If we introduce set partitioning in the RSSDFVE, it would reduce to RSSE with this condition.

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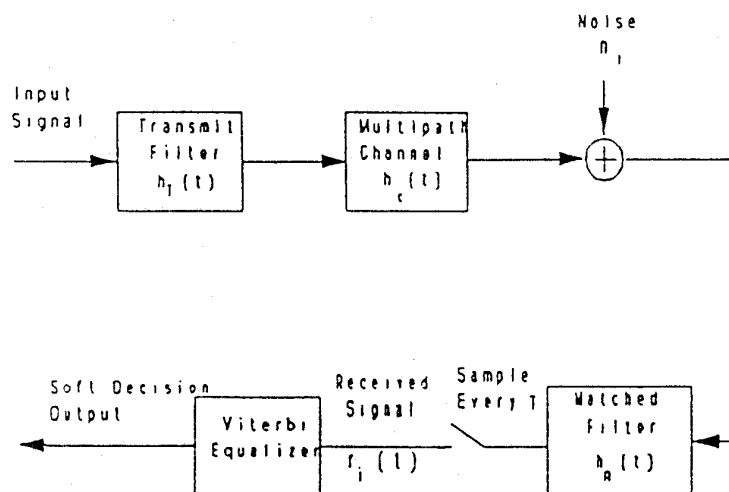


Fig. 1. A digital transmission system operating over a multipath channel

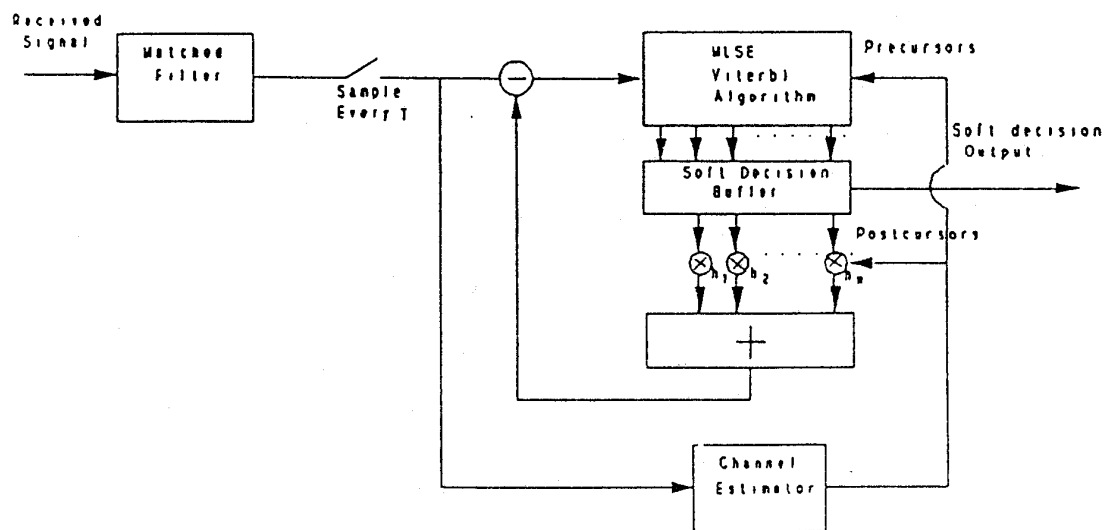
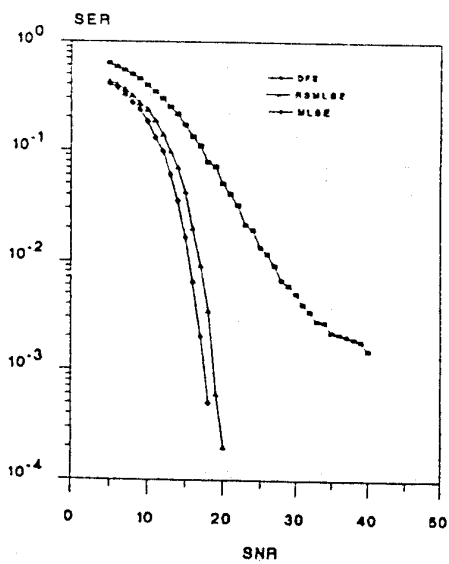
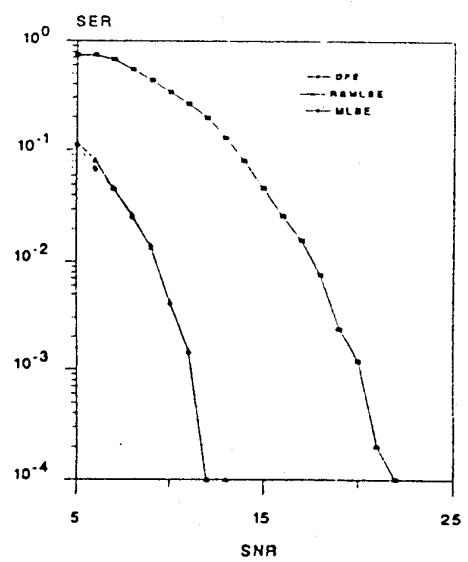


Fig. 2. Structure of the RSSDFVE



(a)



(b)

Fig 3. The performances of the DFE, MLSE and RSSDFVE
(a) for channel one . (b) for channel two.

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gesting that the preliminary decisions used in the feedback process are of considerably poorer quality than the final ones. Hence error propagation is bound to be serious, and particularly for small values of M the predictions of table II are bound to be somewhat too optimistic.

10. Simulation results

To validate the predictions of tables I and II, we have performed a set of bit error rate measurements for signal-to-noise ratio's

$$SNR \triangleq \frac{E_b}{N_0} = \frac{\sum_{k=0}^L f_k^2}{N_0} \quad (45)$$

ranging from 0 to 15 dB. Figs 10 to 12 depict the results for the channels with $f(\mathcal{D}) = (2 + \mathcal{D})^2$, $f(\mathcal{D}) = (2 + \mathcal{D})(1 + 2\mathcal{D})$ and $f(\mathcal{D}) = (1 + 2\mathcal{D})^2$, respectively. The significance of minimum-phase is evident from these figures. For the

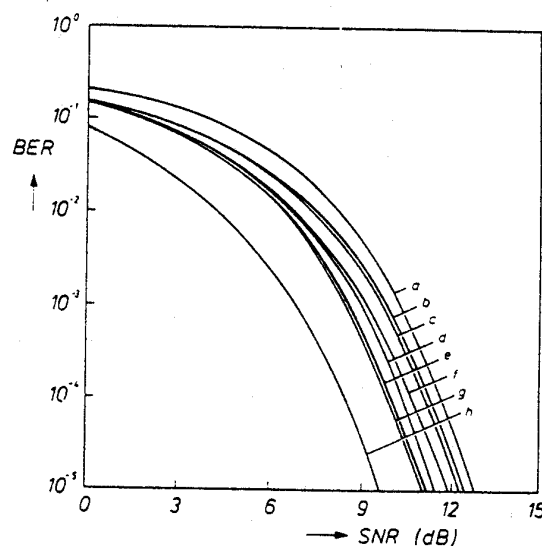


Fig. 10. Bit error characteristics (BER) for various receivers operating on a channel with $f(\mathcal{D}) = (2 + \mathcal{D})^2$. a) DFE ($M = 0$); b) Preliminary decisions with delay $D = M$ of $M = 1$ VD with global feedback; c) Preliminary decisions with delay $D = M$ of $M = 1$ VD with local feedback; d) Final decisions of $M = 1$ VD with global feedback; e) Final decisions of $M = 1$ VD with local feedback; f) Preliminary decisions with delay $D = M$ of full-fledged VD ($M = 2$); g) Final decisions of full-fledged VD ($M = 2$). The Matched Filter Bound (MFB) is also depicted (curve h).

On the use of decision feedback for simplifying the Viterbi detector

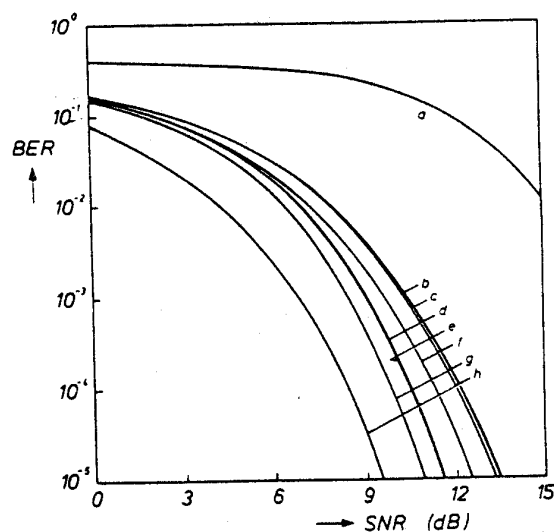


Fig. 11. As fig. 10, but for a channel with $f(\omega) = (2 + \omega)(1 + 2\omega)$.

DFE ($M = 0$) and the $M = 1$ VD the other two phase characteristics invariably result in serious performance degradations. Somewhat less strongly, a similar remark applies for the preliminary decisions of the full-fledged VD

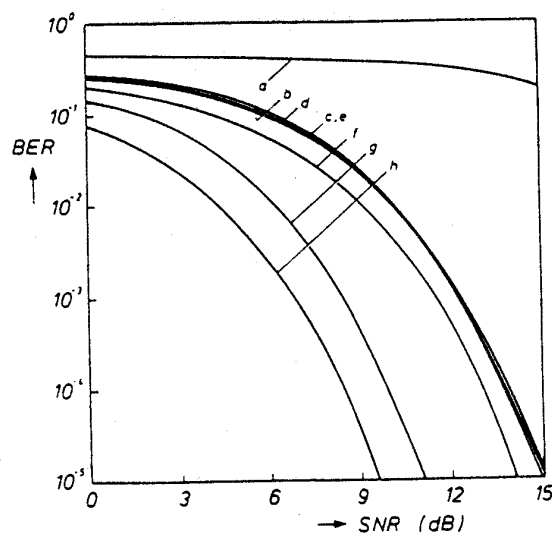


Fig. 12. As fig. 10, but for a channel with $f(\omega) = (1 + 2\omega)^2$.

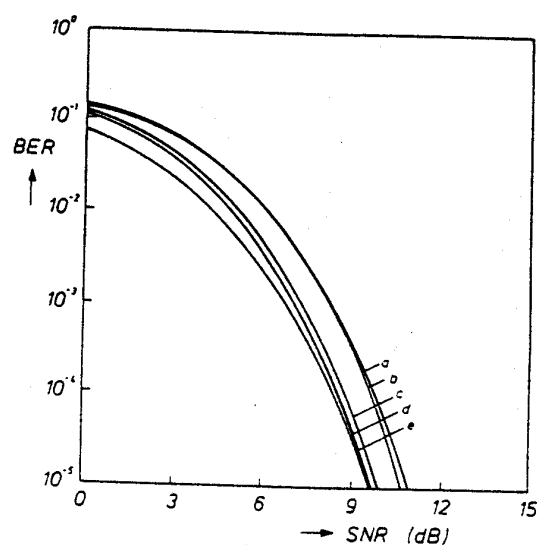


Fig. 13. Bit error characteristics (BER) for various receivers operating on the $D = 2.0$ channel. a) DFE ($M = 0$); b) VD with $M = 1$; c) VD with $M = 2$; d) VD with $M = 3$. The Matched Filter Bound (MFB) is also depicted (curve e.).

($M = 2$). The consequential increment of the detection delay D needed to virtually achieve MLSD performance is elaborated in more detail in ref. 33.

In this paper, it is also shown that the Q -function which governs the probability of erroneous preliminary decisions is preceded by a constant of proportionality whose value normally decreases rapidly with the detection delay D . This explains the somewhat better quality of the preliminary decisions than anticipated on the basis of table I, especially for $D = M = 2$.

Particularly for the final decisions and minimum-phase channels, global feedback indeed leads to inferior performance figures as compared to local feedback. Judged by the predictions of table I, figs 10 to 12 suggest that the severeness of error propagation decreases with M , and that it is smallest in the minimum-phase situation.

Because of its modest amplitude distortion, the $D = 2.0$ channel causes little error propagation for any of the receivers studied. Thus performances are observed which validate the predictions of table I, and which are essentially identical for both types of feedback (fig. 13). Also, even the poorest preliminary decisions (viz. those with delay $D = M$) are invariably effectively as good as the final ones. For this reason, fig. 13 contains only one performance curve for each value of M . Here, the $M = 3$ VD virtually achieves matched filter

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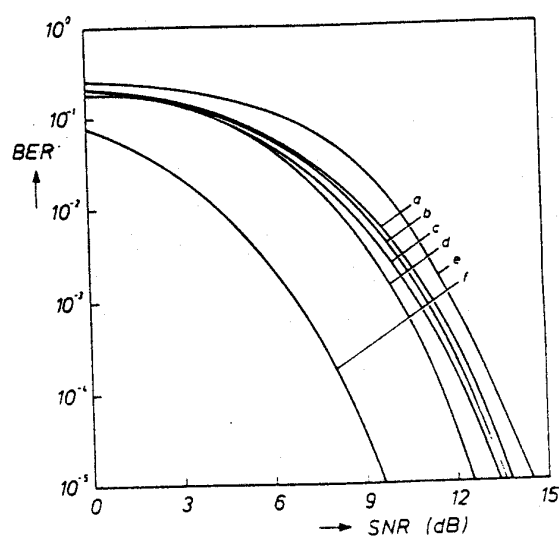


Fig. 14. Bit error characteristics (BER) for various $M=1$ receivers operating on the $D=3.3$ channel. a) Preliminary decisions with delay $D=M$, global feedback; b) Preliminary decisions with delay $D=M$, local feedback; c) Final decisions, global feedback; d) Final decisions, local feedback. The DFE performance ($M=0$, curve e) and the Matched Filter Bound (MFB, curve f) are also shown.

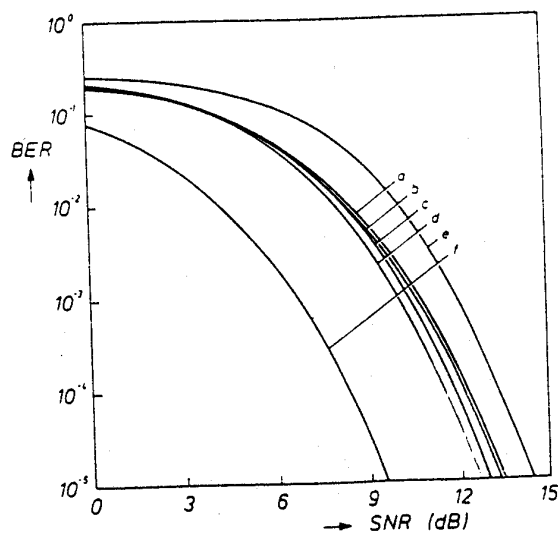


Fig. 15. As fig. 14, but for $M=2$.

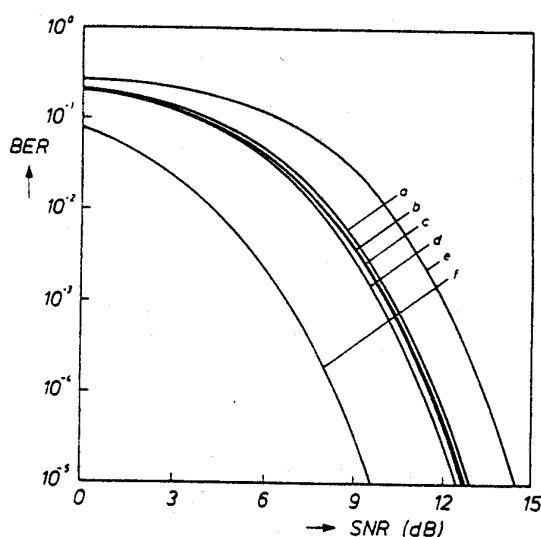


Fig. 16. As fig. 14, but for $M = 3$.

bound performance. It is hence effectively as powerful as the full-fledged VD detector.

For the $D = 3.3$ channel, the performances actually achieved by the DFE ($M = 0$) and the $M = 1$ VD with global feedback are slightly poorer than expected on the basis of table I (see fig. 14). This means that error propagation is significant. To a smaller extent, this is also true for the $M = 2$ receiver with global feedback (fig. 15).

In both figures (14 and 15) the preliminary decisions with delay $D = M$ are seen to be considerably poorer in quality than the final ones, in accordance with table II. Finally, for $M = 3$ the measured performances accurately reflect the predictions of table I (fig. 16).

Figs 14 to 16 confirm that error propagation decreases as M increases, and that the performance estimates derived before are indeed quite accurate, particularly if local feedback is used. The results reconfirm the expected superiority of local over global feedback. The advantage is largest for $M = 1$, and then amounts to about 0.8 dB. The $M = 1$ receiver with local feedback is seen to be effectively as good as the more complicated $M = 2$ and $M = 3$ receivers. This remarkable phenomenon was indeed predicted in table II.

11. Concluding remarks

In this paper we have explored and compared two methods of simplifying

On the use of decision feedback for simplifying the Viterbi detector

the Viterbi detector (VD) by using feedback from preliminary decisions present in the VD. The first one uses the most likely data path to perform a global cancellation of trailing intersymbol interference outside the span of the VD. The second one forms a separate compensation signal for each path, which is used for the recursive extension of that data path only. In this way erroneous cancellation may be avoided at instants when the VD fails to regard the actually transmitted data sequence as the most likely one. This yields an improved error propagation behaviour, particularly for channels with severe amplitude distortion and when the VD exploits only a small intersymbol interference span. We have shown that the VD with local feedback is in fact a simplified reduced-state detector, which differs from the conventional one in that a highly structured subset of the original states is retained, thus e.g. omitting the need to use a stack and to order it according to the likelihood of the contained states. Although it involves a somewhat larger computational effort, the local method of feedback yields a fully homogeneous receiver structure with less latency. This facilitates the use of parallelism and the realization of dedicated high-speed implementations. We have shown that both types of receiver can be easily implemented adaptively, without requiring a separate adaptation mechanism to determine an optimum Desired Impulse Response (DIR), as needed for simplifying the VD by means of linear equalization only.

Simple estimates were derived for the performance of the detector in the absence of error propagation. These estimates were used to show that its optimum prefilter should transform the impulse response of the channel into an overall system impulse response with minimum-phase. Because it should also perform a noise whitening operation, this prefilter should be the canonical form of Forney's whitened matched filter, irrespective of the precise span of ISI exploited by the detector. Simulations for several channels have confirmed the validity of the performance estimates, and have shown that even substantial reductions of the span of the VD (and thus substantial simplifications) do not seriously degrade its performance.

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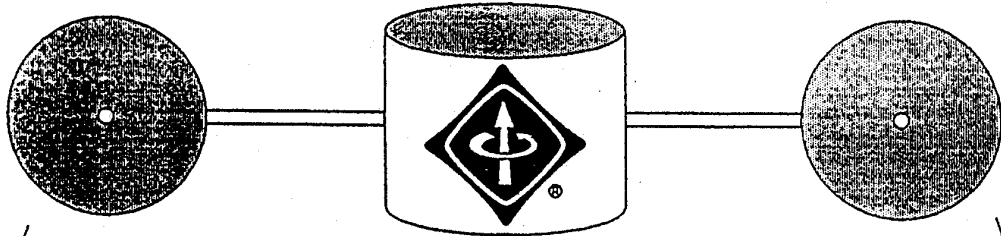
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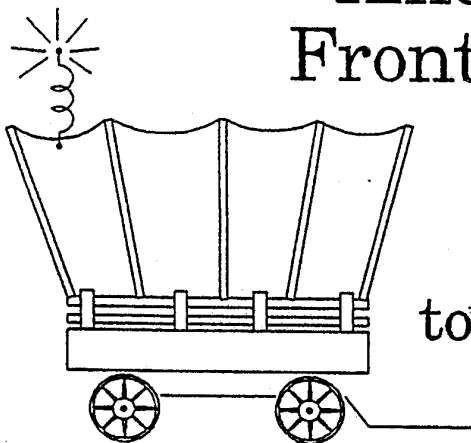
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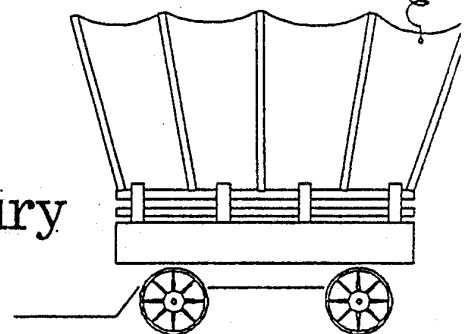


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VLSI IMPLEMENTATION OF SOFT OUTPUT VITERBI
EQUALIZERS FOR MOBILE RADIO APPLICATIONS

Peter Jung* and Paul Walter Baier**

H03M13/00 E1

Introduction

In the course of this paper, advantageous optimum and suboptimum receiver structures operating in the IF domain, therefore, enabling real signal processing and reducing the hardware expense are presented. Petri net representations of the soft output Viterbi Equalizer (SOVE) and the transition metric calculation combined with the so-called "add-soft-output-select" recursion are given. Hence, an efficient design flow as well as an easy to accomplish validation of the functionality of the design is achieved. Further, the impact of the quantization and the duration of the channel impulse response on both the performance and the complexity of SOVE VLSIs are considered.

Communication system

In digital mobile radio systems, spectrum efficiency is the most important goal. Hence, bandwidth efficient modulation schemes such as GMSK (Gaussian minimum shift keying) and GFSK (Gaussian frequency shift keying) are often applied. It is a well-known fact that binary digital continuous phase modulations (BDCPM) with modulation index 1/2 can be approximated by linear modulation schemes [1]. Recently, a simple modulator structure for the direct generation of BDCPM signals in the IF domain has been presented [2, 3]. Accordingly, assuming the transmission of finite bursts consisting of binary data sequences $\{a_k\}$ with K elements, with the real impulse $D_0(t)$ of a finite duration, the IF domain output signal $s(t)$ of the BDCPM modulator with

respect to a carrier frequency

$$f_c = \frac{4i-1}{4T}, \quad i \in \mathbb{N}, \quad (1)$$

is approximately given by

$$s(t) \approx \sum_{k=0}^{K-1} a_k D_0(t - kT). \quad (2)$$

Due to the time-variant and frequency-selective multipath reception caused by the mobile radio channel, the intersymbol interference (ISI) must be removed in the receiver by an adaptive equalizer. It has been shown that the optimum receiver structure consists of a whitened matched filter (WMF) at the receiver input sampled at the bit rate $1/T$, followed by an ISI cancellation device based on the maximum-likelihood sequence estimation (MLSE) principle [4]. The latter can be efficiently implemented using the Viterbi algorithm operating over additive white Gaussian noise (AWGN) channels. According to (2), the signal processing in the receiver can be carried out in the IF domain choosing a frequency given by (1). This leads to a significant complexity reduction of the digital signal processing because no complex calculus has to be applied any more.

A further simplification of the signal processing can be achieved by the omission of the WMF, cf. Fig. 1. After the received and distorted signal has been converted into the IF domain it is oversampled at the rate σ/T , $\sigma > 1$. The sample sequence $\{\tilde{r}_n\}$ is re-ordered in sets containing samples which are separated in time by one bit duration T . For each one of these sets, the channel estimation is carried out, and on the basis of an appropriate criterion one of these sets named $\{r_k\}$ is selected. The sequence $\{r_k\}$ and the corresponding estimated channel impulse response $\{g_i\}$ are then put into the Viterbi equalizer which estimates the output sequence $\{S_k\}$. By appropriately choosing the bandpass filter at the receiver input, the noise samples separated

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in time by one bit duration T can still be regarded as uncorrelated. Hence, the same Viterbi equalizer which is used in the WMF receiver can be applied. Simulations have shown a degradation below 1dB compared with the optimum WFM receiver.

Channel as a finite state machine

From the viewpoint of the Viterbi equalizer, the approximately linear modulator, the physical mobile radio channel, and the receiver bandpass filter form a FIR filter with a tap spacing of one bit duration T . As shown in Fig. 2, this FIR filter can be modelled as a finite state Mealy machine [4]. Assuming a time-variant sequence g_l of $(L+1)$ samples, each sample representing the signal attenuation introduced over each one of the $(L+1)$ paths of the multipath channel, the next state function δ' contains L registers storing the elements of the state vector $Z_k = \{z_k^{L-1}, z_k^{L-2}, \dots, z_k^0\}$ at the time instant kT . The output function ω' outputs the distorted sample $r_{u,k} = \sum_{l=0}^L a_k - l g_l$ which is then disturbed by AWGN.

Soft output Viterbi algorithm

Due to the correspondence of the FIR model shown in Fig. 2 to a convolutional encoder, the Viterbi algorithm is known to be an optimum equalizer structure [4]. Unfortunately, hard decision equalizers discard valuable information which could be used in a following decoding unit. Hence, efficient implementations of the Viterbi algorithm for ISI cancellation must provide a soft decision output.

Since it is rather costly to calculate the optimum soft output value suggested in [5], a simplification represented by the product of the decided output bit and the absolute value of the difference of the possible path metrics leading to the same trellis state is used. In Fig. 3 the recursion step of a SOVE operating over a 3-path channel ($L = 2$) with binary data input is illustrated. In every state of the trellis, the actions to be carried out are shown. After determining the possible undisturbed samples $y_b^{(m)} = -g_L + \sum_{l=1}^{L-1} z_k^{l-1} g_l + (2b-1)g_0$ and $y_b^{(m+2^{L-1})} = +g_L + \sum_{l=1}^{L-1} z_k^{l-1} g_l + (2b-1)g_0$, with b being the possible binary input to the channel of Fig. 2, the metric increments $[d_b^{(m)}]^2 = [r_k - y_b^{(m)}]^2$ and $[d_b^{(m+2^{L-1})}]^2 = [r_k - y_b^{(m+2^{L-1})}]^2$ are calculated. Based on the path metrics $F_k^{(m)}$ and $F_k^{(m+2^{L-1})}$ the two possible path metrics $P_b^{(m)} = F_k^{(m)} + [d_b^{(m)}]^2$

and $P_b^{(m+2^{L-1})} = F_k^{(m+2^{L-1})} + [d_b^{(m+2^{L-1})}]^2$ for the next time instant $(k+1)T$ are calculated. The above-mentioned soft decision output is directly represented by the difference

$$S_{k+1}^{(2m+b)} = P_b^{(m)} - P_b^{(m+2^{L-1})}. \quad (3)$$

This is explained by the following example examining state 0 of the trellis depicted in Fig. 3. In the case of $P_0^{(0)}$ being lower than $P_0^{(2)}$, the transition starting at the preceding state 0 would be chosen. Thus, the soft output would be negative. In the vice versa case, the soft output would be positive. Hence, the soft output is correctly represented by (3). The calculation of the soft output replaces the "compare" action of the add-compare-select (ACS) unit. The new action sequence is called "add-soft-output-select" (ASOS). On the basis of the soft output, the new path metric $F_{k+1}^{(2m+b)}$ is selected. As it is shown in Fig. 3, the signal processing can be carried out using identical basic components, calculating the transitions from two start states to two final states [6]. In the case of 2^L trellis states there is a maximum of 2^{L-1} such components, which are called transition-metric/add-soft-output-select (TM/ASOS) units, needed to calculate the trellis step.

In the case of a transmission of bursts which was already assumed in (2), the calculation of the trellis step and the trace-back can be carried out in separate concurrent steps. This is shown in the Petri net [7, 8] of Fig. 4. After proper initialization, the TM/ASOS processing is carried out until the sufficient set of statistics of the transmitted sequence $\{a_k\}$ has been entirely used for the calculations. In the case of transmitting L known tail bits following the K data bits, the final state of the trellis is exactly known, and the comparisons of final path metrics in order to decide the initial state for the trace back are not necessary. Thus, the hardware complexity is reduced. The trace-back is carried out using the first calculated and stored data while the next burst is already calculated by the TM/ASOS processor. Both the TM/ASOS and the trace-back processing are carried out until the final burst has been calculated.

TM/ASOS and trace-back processors

In this section, the hardware expense of the operational parts of the TM/ASOS and trace-back processors is discussed. The most hardware expensive part of the SOVE is formed by the TM/ASOS processor consisting of $1, 2, 4, \dots, 2^{L-1}$ single TM/ASOS units, depending on the data rates that are to be

achieved. Assuming q_g bits for the quantization of the channel impulse response $\{g_i\}$, q_r bits for the quantization of the input sequence $\{r_k\}$, q_{mi} bits for the quantization of the metric increments,

$$q_F = \lceil \log_2[(K + L)(2^{q_{mi}} - 1)] \rceil, \quad (4)$$

bits for the quantization of the path metrics, $\lceil \cdot \rceil$ denoting the rounding of $\cdot$ to the nearest integer towards $+\infty$, and q_s bits for the quantization of the soft output, the complexity $k_{TM/ASOS}$ of the TM/ASOS unit hardware is given as follows:

$$\begin{aligned} k_{TM/ASOS} = & 2[L + 1]k_{b-add}(q_g) \\ & + 4k_{b-add}(q_r) \\ & + 6k_{b-add}(q_F) \\ & + 4k_{b-sqr}(q_r) \\ & + 2[L - 1]k_{cntr-neg}(q_g) \quad (5) \\ & + 4k_{cntr-neg}(q_r) \\ & + 2[q_g + 2q_r + q_F]k_{inv} \\ & + 2[L + 2]k_{exor2} \\ & + 2q_F k_{mux21} \\ & + \underbrace{k_{pipo}(q_r)}_{\text{store } r_k} \\ & + \underbrace{[L + 1]k_{pipo}(q_g)}_{\text{store } \{g_i\}} \end{aligned}$$

In (5), $k_{b-add}(q)$, $k_{b-sqr}(q)$, $k_{cntr-neg}(q)$, k_{inv} , k_{exor2} , k_{mux21} , and $k_{pipo}(q)$ correspond to the complexity of a binary adder for q -bit quantized words, a binary squarer for q -bit quantized words, a controllable two's complement negate operator for q -bit quantized words, an inverter, an exclusive-or gate with two inputs, a 2 to 1 bit multiplexer, and a parallel-in-parallel-out register of width q , respectively.

The block diagram of one half of such a TM/ASOS unit is depicted in Fig. 5. In the case of the parameter b equal to one it is the upper half and in the case of b equal to zero it represents the lower half, cf. Fig. 3. The actions to be carried out by each half of the TM/ASOS unit are shown in the Petri net of Fig. 6. Using modern semi-custom CMOS technologies, and assuming $L \leq 16$, each TM/ASOS unit will operate in a time interval of a duration well below 100ns. Therefore, for 5-path and 6-path channels typical for digital mobile radio systems, the implementation of just one TM/ASOS unit within the TM/ASOS processor is sufficient for transmission systems operating at data rates below 500kbit/s.

In order to enable the presetting of the path metric registers at the beginning of the TM/ASOS calculation, with k_{and2} being the hardware expense of

an and gate with two inputs and $k_{decoderLto2L}$ being the hardware expense of a L to 2^L decoder, the following hardware adds to $k_{TM/ASOS}$:

$$\begin{aligned} k_{reset} = & 2^L q_F [k_{mux21} + k_{and2}] \quad (6) \\ & + k_{pipo}(L) + k_{decoderLto2L} \end{aligned}$$

When using only one TM/ASOS unit, the newly calculated path metrics cannot all be stored directly in the 2^L registers. It can easily be seen that there are 2^{L-2} more registers needed to guarantee a proper processing. Hence, the expense of the trellis registers is given by

$$k_{trellis} = 5 \cdot 2^{L-2} k_{pipo}(q_F). \quad (7)$$

In order to correctly store the calculated path metrics and the soft decision outputs in the trellis registers and a RAM, respectively, a demultiplexer logic is necessary increasing the hardware expense as follows:

$$\begin{aligned} k_{demux} = & 2^{L-2} q_F k_{demux12} \\ & + 2q_F k_{demux1(2^{L-1}-2^{L-3})} \\ & + \underbrace{k_{counter}(L-1)}_{\text{row}} \quad (8) \\ & + \underbrace{k_{counter}(\lceil \log_2(K+L) \rceil)}_{\text{column}} \end{aligned}$$

with $k_{demux12}$, $k_{demux1(2^{L-1}-2^{L-3})}$, and $k_{counter}(q)$ being the hardware expenses of a 1 to 2 demultiplexer, a 1 to $(2^{L-1}-2^{L-3})$ demultiplexer, and a q -bit counter, respectively. The two counters are used for the determination of both the row and the column address of a RAM cell.

The operational part of the trace-back processor is comparably small, consisting only of the addressing logic for the RAM which contains the calculated soft decision output data

$$k_{tb} = \underbrace{k_{sipo}(L)}_{\text{row}} + \underbrace{k_{counter}(\lceil \log_2(K) \rceil)}_{\text{column}} \quad (9)$$

with $k_{sipo}(q)$ indicating the hardware expense of a q bit wide serial-in-parallel-out register.

Since the RAM for the SOVE following the presented principle is large, it is not recommended to integrate it on the VLSI itself but to use an external RAM.

Results

In order to estimate the impact of the finite resolution due to quantization on the performance of the

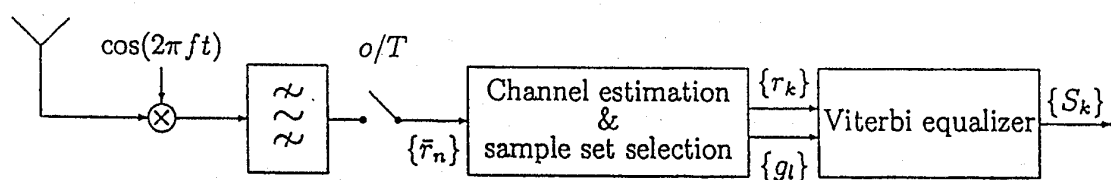


Fig. 1: Simple suboptimum receiver structure using IF domain signal processing

q_r / bits	q_g / bits	q_{ml} / bits	q_F / bits	gate counts $L = 4$	gate counts $L = 5$
5	8	6	13	$\approx 8.0k$	$\approx 13.0k$
5	8	7	14	$\approx 8.5k$	$\approx 13.5k$
5	8	8	15	$\approx 9.0k$	$\approx 14.5k$
6	7	7	14	$\approx 9.0k$	$\approx 14.0k$
6	7	8	15	$\approx 9.0k$	$\approx 14.5k$
6	8	6	13	$\approx 8.5k$	$\approx 13.5k$
6	8	7	14	$\approx 9.0k$	$\approx 14.0k$
6	8	8	15	$\approx 9.5k$	$\approx 15.0k$
7	7	7	14	$\approx 9.0k$	$\approx 14.0k$
7	7	8	15	$\approx 9.5k$	$\approx 15.0k$
7	8	6	13	$\approx 9.0k$	$\approx 13.5k$
7	8	7	14	$\approx 9.0k$	$\approx 14.5k$
7	8	8	15	$\approx 9.5k$	$\approx 15.0k$
8	7	7	14	$\approx 9.5k$	$\approx 14.5k$
8	7	8	15	$\approx 10.0k$	$\approx 15.0k$
8	8	6	13	$\approx 9.0k$	$\approx 14.0k$
8	8	7	14	$\approx 9.5k$	$\approx 14.5k$
8	8	8	15	$\approx 10.0k$	$\approx 15.5k$

Tab. 1: Complexity of the operational TM/ASOS and trace-back processor parts of the SOVE with external RAM

SOVE, the degradations resulting from the suboptimum receiver filter and the channel estimation as well as the sample set selection had to be suppressed. Therefore, the channel impulse response $\{g_l\}$ was preset and the undisturbed samples $r_{u,k}$ were calculated accordingly and then superimposed by an AWGN sequence. The quantization of $\{g_l\}$ and $\{r_k\}$ was then carried out and the quantized data were processed by the SOVE. Typical simulation results of the bit error rate as a function of the SNR per bit using different sets of (q_r, q_g, q_{mi}) are presented in Fig. 7 for the case of a 6-path channel with an impulse response typical for hilly terrain. It has been found that for $q_r \geq 5$, $q_g \geq 7$ and $q_{mi} \geq 6$ there exist sets of (q_r, q_g, q_{mi}) which lead to degradations below 0.5dB compared with the optimum performance in the case of no quantization.

In Tab. 1, these sets are compared with respect to their hardware expense of the operational TM/ASOS and trace-back processor parts of the SOVE for 5-path and 6-path channels assuming an upper bound of 128 for the sum of K and L . It can be seen that the most important parameter for the complexity of the SOVE is the duration $(L+1)$ of the channel impulse response $\{g_l\}$ followed by the quantization q_{mi} of the metric increments, whereas the effect of changing q_r and q_g is almost negligible.

It must be noted that the bit error rate depends on the type of gain control at the input of the SOVE. In the case of a non-ideal AGC, a significant increase of the BER must be expected. Hence, it should be recommended to choose rather large values of $q_r \geq 7$, $q_g \geq 7$ and $q_{mi} \geq 7$ for the design.

Conclusions

In the course of this paper, a SOVE operating in both the optimum and suboptimum receiver structures has been presented. The soft decision output can be calculated in a simple fashion by replacing the "compare" action of the TM/ACS unit by an appropriately chosen subtractor forming the TM/ASOS unit. The Petri net representation of the SOVE and the TM/ASOS recursion have been introduced as a simple means of describing concurrent hardware, thus enabling an easy to accomplish validation of the VLSI design. The hardware expense of the operational parts of both the TM/ASOS processor and the trace-back processor have been estimated for a typical implementation of the SOVE as it could be used in mobile radio systems with moderate data rates operating over channels with impulse responses of up to 5 five symbol durations. The estimations can be easily extended based on

the introduced equations. The impact of the quantization of $\{r_k\}$, $\{g_l\}$ and the metric increments on the performance have been studied by simulations. Based on these data, an efficient design of the SOVE can be reached.

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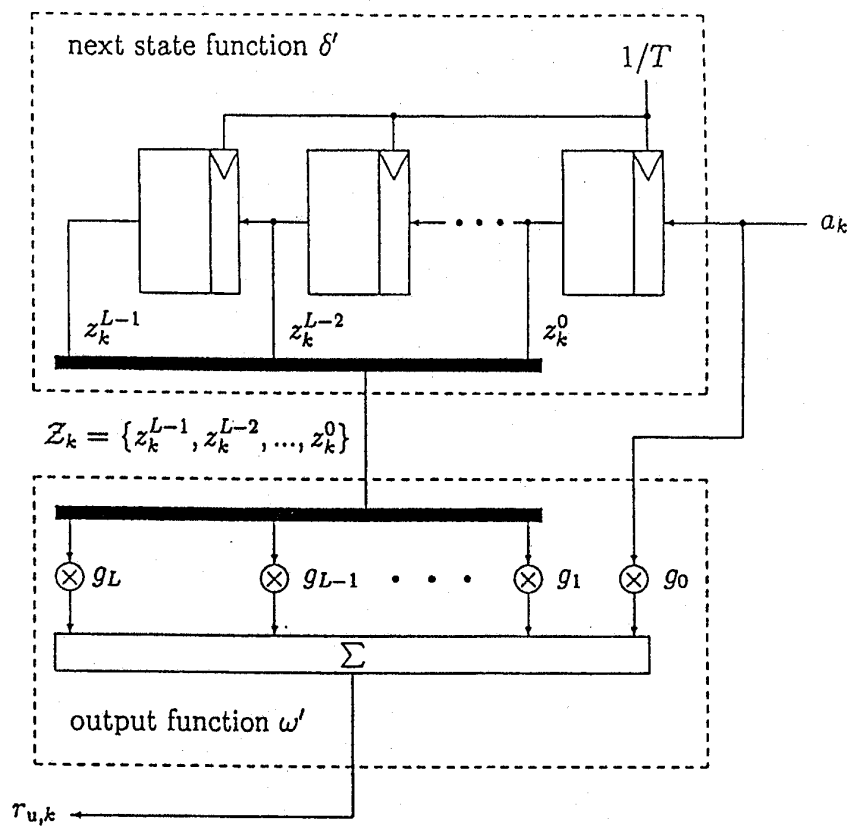


Fig. 2: FIR transmission channel as finite state machine (Mealy modelling)

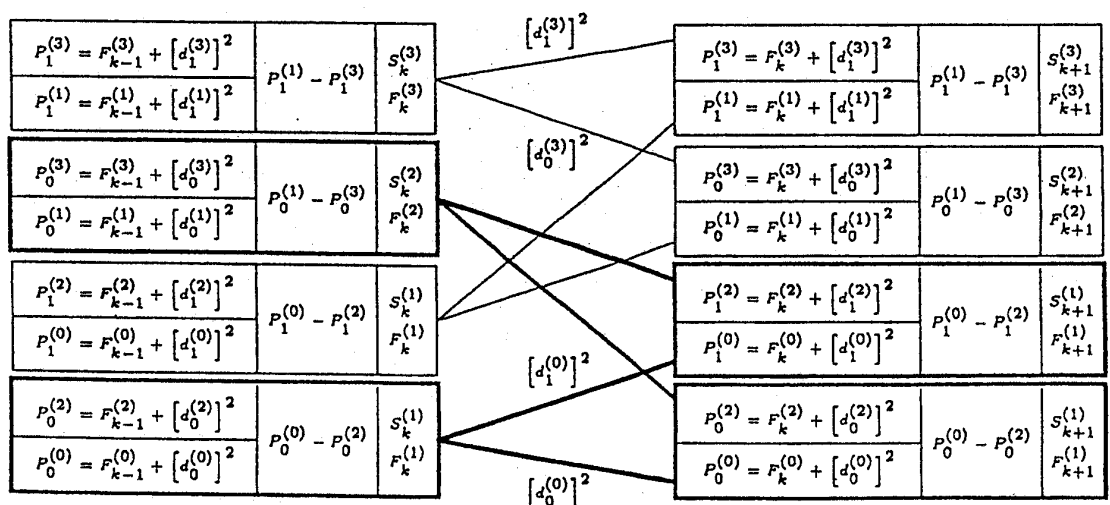


Fig. 3: Recursion step of the Viterbi-equalizer (Mealy modelling) for binary data sequences \$\{a_k\}\$ and 3-path channels (\$L=2\$) --

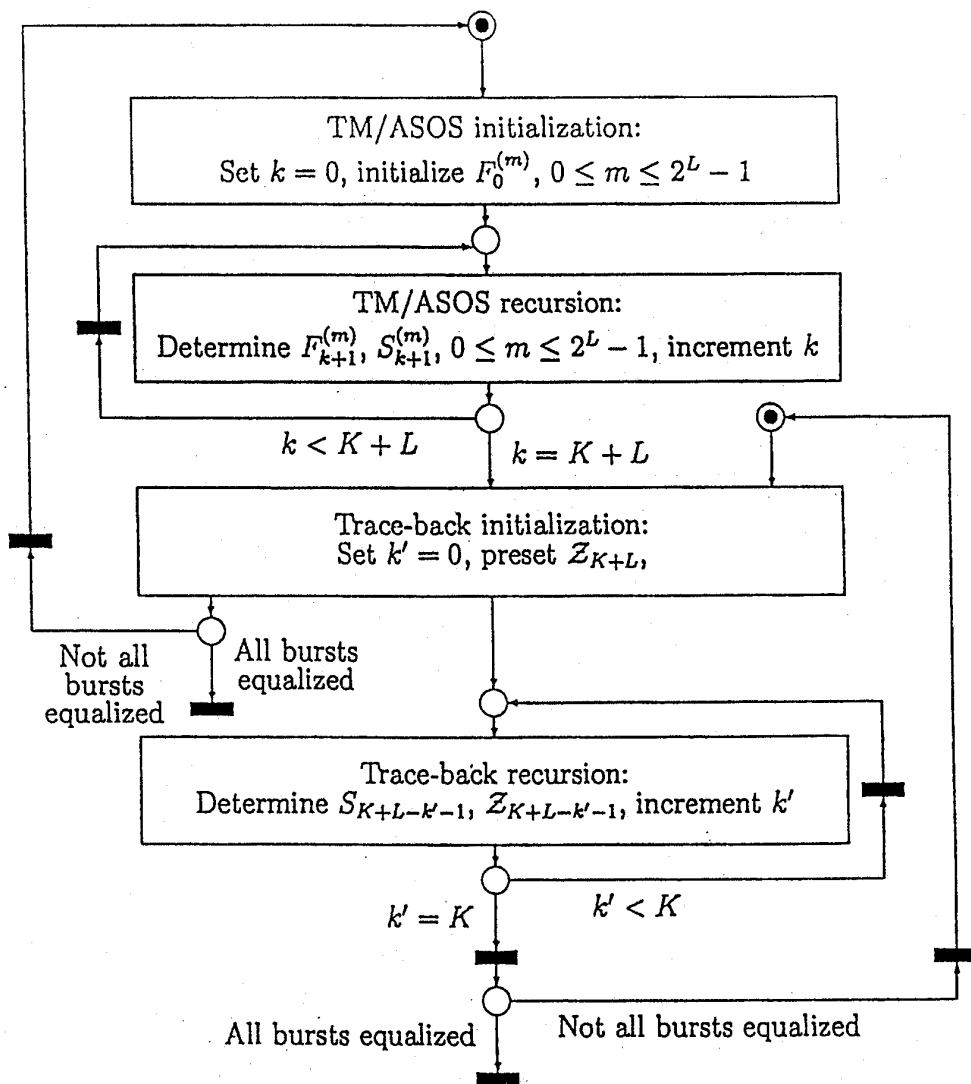


Fig. 4: Petri net of the Viterbi-equalizer (Mealy modelling)

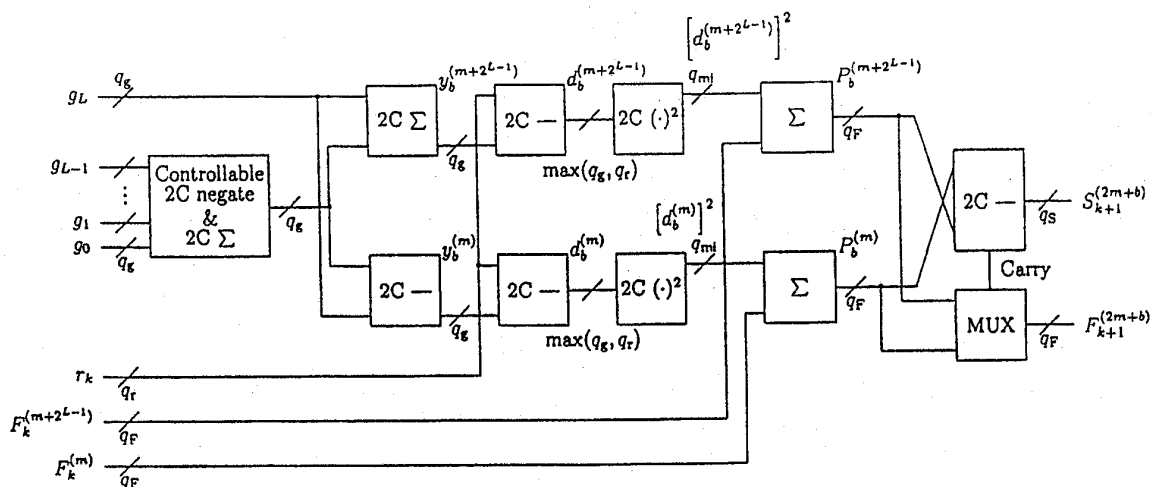


Fig. 5: Block structure of one half of the TM/ASOS unit, with $2C\Sigma$, $2C-$, $2C(\cdot)^2$, Σ , and MUX denoting the two's complement addition, the two's complement subtraction, the two's complement square operation, the binary addition, and the multiplexing operation. In the case of b equal to one, the shown block structure represents the upper half and vice versa the lower half of the TM/ASOS unit

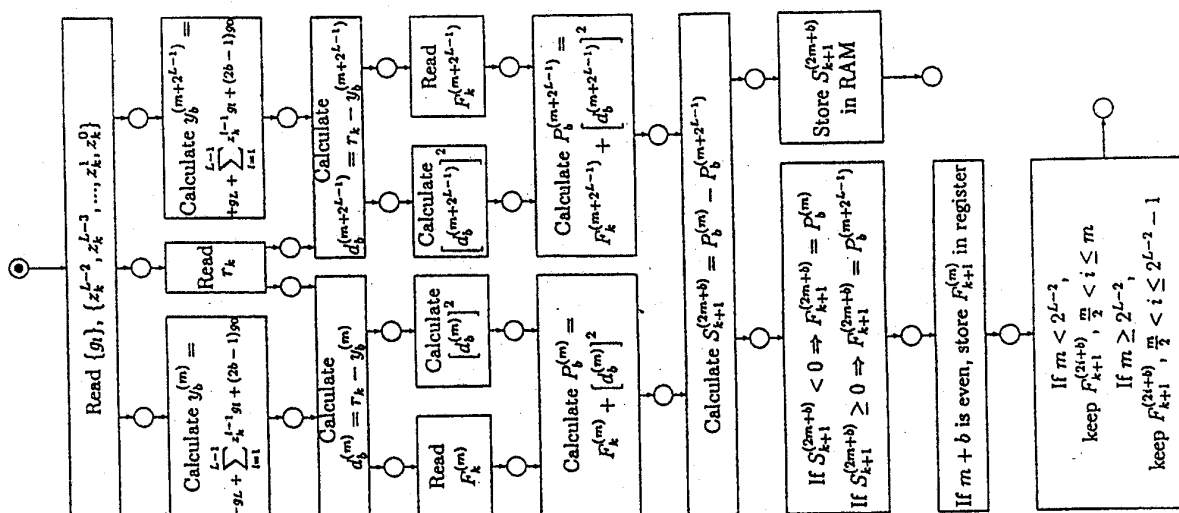


Fig. 6: Petri net of one half of the TM/ASOS recursion

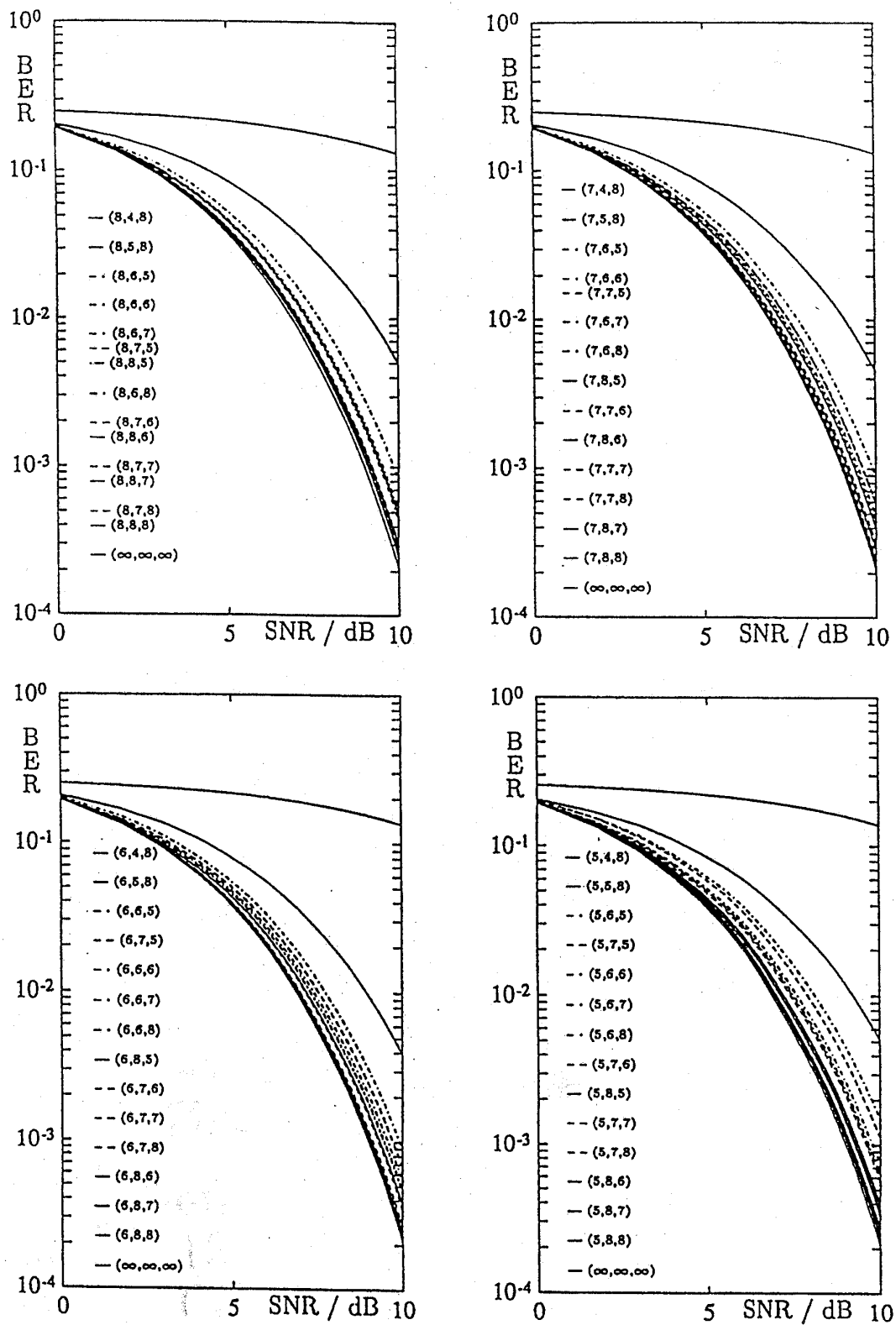


Fig. 7: Comparison of simulated bit error rates dependent on the quantization. The numbers in brackets refer to the resolution (q_r, q_g, q_{mi}) , respectively. The order of the legends correspond to the order of the BER curves. Legends not being separated by a line skip indicate identical BER curves

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(FILE 'USPAT' ENTERED AT 07:58:03 ON 15 MAR 1999)
L1 340 S CASCAD?(3A)DECODER# OR PIPELINE#(3A)DECODER#
L2 2440 S INTERSYMBOL# INTERFERENCE# OR ISI
L3 149 S SERIES##(2A)CONNECT?(2A)DECODER# OR SERIAL?(2A)CONNECT?(
2A)
L4 12 S L1 AND L2
L5 0 S L2 AND L3
L6 317 S SERIES##(4A)CONNECT?(4A)DECODER# OR SERIAL?(4A)CONNECT?(
4A)
L7 899 S (INTERSYMBOL# INTERFERENCE# OR ISI) AND DECODER#
L8 44822 S CORRECT?(3A)SIGNAL# OR CORRECT?(3A)SYMBOL# OR CORRECT?(3
A)B
L9 376 S L7 AND L8
L10 2629 S RECEIV?(2A)SYMBOL#
L11 131 S L9 AND L10

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22. 5,799,047, Aug. 25, 1998, Carrier synchronization unit and synchronization method; Vasic Dobrica, 375/350, 354; 708/320 [IMAGE AVAILABLE]
23. 5,793,759, Aug. 11, 1998, Apparatus and method for digital data transmission over video cable using orthogonal cyclic codes; Selim Shlomo Rakib, et al., 370/342; 348/6; 370/441; 455/3.1 [IMAGE AVAILABLE]
24. 5,768,323, Jun. 16, 1998, Symbol synchronizer using modified early/punctual/late gate technique; Brian W. Kroeger, et al., 375/355, 344, 345 [IMAGE AVAILABLE]
25. 5,764,646, Jun. 9, 1998, Packet data transmission with clash subtraction; Paul W. Dent, 370/479, 342 [IMAGE AVAILABLE]
26. 5,757,789, May 26, 1998, Dual mode satellite/cellular terminal; Paul W. Dent, 370/337, 347, 501; 375/202; 455/524 [IMAGE AVAILABLE]
27. 5,757,787, May 26, 1998, Dual mode satellite/cellular terminal; Paul W. Dent, 370/330, 337, 436, 468, 478; 455/450 [IMAGE AVAILABLE]
28. 5,754,538, May 19, 1998, System for transmitting learning information via a time-varying transmission channel and corresponding transmission and receiving equipment; Vinod Kumar, et al., 370/347, 498, 503, 535; 375/230, 231, 232; 709/224 [IMAGE AVAILABLE]
29. 5,751,774, May 12, 1998, Transmission system for digital audio broadcasting; Jin-Der Wang, 375/367; 370/509, 515, 522; 375/261, 298, 364

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[IMAGE AVAILABLE]

30. 5,751,766, May 12, 1998, Non-invasive digital communications test system; Jeffrey Marc Kletsky, et al., 375/224; 348/184, 192, 193; 375/225, 228, 285, 326, 344, 346 [IMAGE AVAILABLE]
31. 5,751,730, May 12, 1998, Encoding/interleaving method and corresponding deinterleaving/decoding method; Christophe Mourrot, 714/780 [IMAGE AVAILABLE]
32. 5,748,686, May 5, 1998, System and method producing improved frame synchronization in a digital communication system; Ehud Langberg, et al., 375/367; 370/515; 375/368 [IMAGE AVAILABLE]
33. 5,742,642, Apr. 21, 1998, Signal processing method and apparatus for reducing equalizer error; Antoni Fertner, 375/233, 348, 350; 708/323 [IMAGE AVAILABLE]
34. 5,742,622, Apr. 21, 1998, Error detection and correction system for a stream of encoded data; Anthony Peter John Claydon, et al., 714/790 [IMAGE AVAILABLE]
35. 5,732,113, Mar. 24, 1998, Timing and frequency synchronization of OFDM signals; Timothy M. Schmidl, et al., 375/355, 354 [IMAGE AVAILABLE]
36. 5,729,558, Mar. 17, 1998, Method of compensating for Doppler error in a wireless communications system, such as for GSM and IS54; Mohammad Shafiul Mobin, 375/232, 341, 346 [IMAGE AVAILABLE]
37. 5,729,538, Mar. 17, 1998, Dual mode satellite/cellular terminal; Paul W. Dent, 370/347, 349; 714/746 [IMAGE AVAILABLE]
38. 5,719,923, Feb. 17, 1998, Sketching unit for transmission of sketches and notes over normal telephone lines; Gordon Bremer, et al., 379/100.01; 370/493; 379/93.17 [IMAGE AVAILABLE]
39. 5,715,280, Feb. 3, 1998, Method for partially modulating and demodulating data in a multi-carrier transmission system; Stuart D. Sandberg, et al., 375/260, 261 [IMAGE AVAILABLE]
40. 5,712,873, Jan. 27, 1998, Multi-mode equalizer in a digital video signal processing system; Dong-Chang Shiue, et al., 375/233, 230, 231, 232 [IMAGE AVAILABLE]
41. 5,703,904, Dec. 30, 1997, Impulse noise effect reduction; Ehud Langberg, 375/232; 708/322 [IMAGE AVAILABLE]
42. 5,694,423, Dec. 2, 1997, Method and apparatus for detecting and correcting misconvergence of a blind equalizer; Patrik Larsson, et al., 375/231, 232 [IMAGE AVAILABLE]
43. 5,692,011, Nov. 25, 1997, Dual decision equalization apparatus; Ramin Nobakht, et al., 375/233; 333/18; 375/341, 348; 708/323 [IMAGE AVAILABLE]
44. 5,684,834, Nov. 4, 1997, Simultaneous analog and digital communication using fractional rate encoding; William Lewis Betts, et al., 375/298, 261 [IMAGE AVAILABLE]
45. 5,677,934, Oct. 14, 1997, Multipath propagation compensation in a TDMA system; Kjell I. Ostman, 375/349, 231, 232; 708/313, 323 [IMAGE AVAILABLE]

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46. 5,675,697, Oct. 7, 1997, Signal restoring apparatus with DVCR using two threshold values; Dong Wha Lee, 386/124, 40 [IMAGE AVAILABLE]
47. 5,663,957, Sep. 2, 1997, Dual mode satellite/cellular terminal; Paul W. Dent, 370/347, 350, 468; 375/267; 714/821 [IMAGE AVAILABLE]
48. 5,661,718, Aug. 26, 1997, Simultaneous analog and digital communication; Gordon Bremer, et al., 370/207, 286; 375/222 [IMAGE AVAILABLE]
49. 5,659,578, Aug. 19, 1997, High rate Reed-Solomon concatenated trellis coded 16 star QAM system for transmission of data over cellular mobile radio; Siavash M. Alamouti, et al., 375/261, 265, 322, 341; 714/792 [IMAGE AVAILABLE]
50. 5,636,246, Jun. 3, 1997, Multicarrier transmission system; Michael A. Tzannes, et al., 375/260; 370/480; 375/221 [IMAGE AVAILABLE]
51. 5,625,652, Apr. 29, 1997, Timing recovery controller and method for adjusting the timing of synchronizing windows in a PSK demodulator; James E. Petranovich, 375/355, 329, 365 [IMAGE AVAILABLE]
52. 5,610,949, Mar. 11, 1997, Phase detector and a method determining the phase of received PSK symbols; James E. Petranovich, 375/330; 329/304 [IMAGE AVAILABLE]
53. 5,604,769, Feb. 18, 1997, Hybrid equalizer arrangement for use in data communications equipment; Jin-Der Wang, 375/229, 231, 233 [IMAGE AVAILABLE]
54. 5,594,758, Jan. 14, 1997, Frequency controller and method of correcting phase estimates in a PSK demodulator using frequency control; James E. Petranovich, 375/344; 329/304; 375/329 [IMAGE AVAILABLE]
55. 5,594,496, Jan. 14, 1997, Detection of co-channel interference in digital television signals; Larry E. Nielsen, et al., 348/21, 470, 607 [IMAGE AVAILABLE]
56. 5,590,160, Dec. 31, 1996, Symbol and frame synchronization in both a TDMA system and a CDMA; Kjell Ostman, 375/367; 370/342, 515; 375/209, 210 [IMAGE AVAILABLE]
57. 5,581,579, Dec. 3, 1996, Method and apparatus to adaptively control the frequency of reception in a digital wireless communication system; Nan-Sheng Lin, et al., 375/331; 329/304; 375/283 [IMAGE AVAILABLE]
58. 5,579,345, Nov. 26, 1996, Carrier tracking loop for QPSK demodulator; Brian W. Kroeger, et al., 375/344, 261, 330; 455/192.2 [IMAGE AVAILABLE]
59. 5,568,330, Oct. 22, 1996, Recording/reproducing apparatus with maximum likelihood sequence estimation; Hideki Sawaguchi, et al., 360/46, 51 [IMAGE AVAILABLE]
60. 5,550,596, Aug. 27, 1996, Digital television signal processing system including a co-channel rejection filter; Christopher H. Strolle, et al., 348/607, 471, 726; 375/233 [IMAGE AVAILABLE]
61. 5,546,429, Aug. 13, 1996, Frequency hopping code division multiple access radio communication unit; Gregory M. Chiasson, et al., 375/341, 343, 347; 455/137 [IMAGE AVAILABLE]
62. 5,541,955, Jul. 30, 1996, Adaptive data rate modem; Jay M.

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Jacobsmeier, 375/222, 265 376, 377 [IMAGE AVAILABLE]

63. 5,539,774, Jul. 23, 1996, Dual decision equalization method and device; Ramin Nobakht, et al., 375/232; 333/18; 375/233; 708/322, 323 [IMAGE AVAILABLE]

64. 5,537,441, Jul. 16, 1996, Controlled simultaneous analog and digital communication; Gordon Bremer, et al., 375/261; 370/206; 375/222; 379/93.08 [IMAGE AVAILABLE]

65. 5,537,436, Jul. 16, 1996, Simultaneous analog and digital communication applications; Stanley Bottoms, et al., 375/222, 261; 455/553, 557 [IMAGE AVAILABLE]

66. 5,524,127, Jun. 4, 1996, Unique word detector and method for detecting a unique word within one of several windows offset in time; James E. Petranovich, 375/368, 363 [IMAGE AVAILABLE]

67. 5,517,535, May 14, 1996, Numerically controlled oscillator with complex exponential outputs using recursion technique; Brian W. Kroeger, et al., 375/373; 327/146; 331/1A [IMAGE AVAILABLE]

68. 5,513,216, Apr. 30, 1996, Hybrid equalizer arrangement for use in data communications equipment; Shlomo Gadot, et al., 375/233, 231; 708/323 [IMAGE AVAILABLE]

69. 5,506,861, Apr. 9, 1996, System and method for joint demodulation of CDMA signals; Gregory E. Bottomley, 370/441; 375/334, 347; 380/34; 455/65 [IMAGE AVAILABLE]

70. 5,491,726, Feb. 13, 1996, Method and apparatus to determine the frequency and time slot position in a digital wireless communication session; Jong-Keung Cheng, et al., 375/343, 349; 455/182.3 [IMAGE AVAILABLE]

71. 5,483,557, Jan. 9, 1996, Channel equalisation in particular for fading channels; William T. Webb, 375/349, 229, 233 [IMAGE AVAILABLE]

72. 5,471,504, Nov. 28, 1995, Bilinear decision feedback equalizer; Jungshi Lee, et al., 375/233, 229, 230, 232 [IMAGE AVAILABLE]

73. 5,461,644, Oct. 24, 1995, Adaptive viterbi detector; Johannes W. M. Bergmans, et al., 375/341; 714/794 [IMAGE AVAILABLE]

74. 5,461,426, Oct. 24, 1995, Apparatus for processing modified NTSC television signals, with digital signals buried therewithin; Allen L. Limberg, et al., 348/475, 473 [IMAGE AVAILABLE]

75. 5,448,555, Sep. 5, 1995, Simultaneous analog and digital communication; Gordon Bremer, et al., 370/206; 329/304; 332/103; 370/286; 375/222, 261 [IMAGE AVAILABLE]

76. 5,440,585, Aug. 8, 1995, Applications of simultaneous analog and digital communication; B. Waring Partridge, III, 375/261, 222 [IMAGE AVAILABLE]

77. 5,438,595, Aug. 1, 1995, Method of estimating the speed of a mobile unit in a digital wireless communication system; Jong-Keung Cheng, et al., 375/340; 340/466; 455/238.1 [IMAGE AVAILABLE]

78. 5,436,942, Jul. 25, 1995, Method of equalizing digitally encoded signals transmitted in a plurality of non-contiguous time slots; Jong-Keung Cheng, et al., 375/229; 370/458; 375/340, 342 [IMAGE AVAILABLE]

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AVAILABLE]

79. 5,425,050, Jun. 13, 1995, Television transmission system using spread spectrum and orthogonal frequency-division multiplex; William F. Schreiber, et al., 375/200; 380/10, 13 [IMAGE AVAILABLE]
80. 5,408,504, Apr. 18, 1995, Symbol and frame synchronization in a TDMA system; Kjell I. Ostman, 375/354; 370/350; 375/343; 708/422 [IMAGE AVAILABLE]
81. 5,408,503, Apr. 18, 1995, Adaptive viterbi detector; Josephus A. H. M. Kahlman, 375/340, 348; 714/795 [IMAGE AVAILABLE]
82. 5,406,593, Apr. 11, 1995, Adaptive phase-locked loop employing channel state information estimation from received signal phase angles; Sandeep Chennakeshu, et al., 375/376; 331/1R; 375/327, 351 [IMAGE AVAILABLE]
83. 5,400,368, Mar. 21, 1995, Method and apparatus for adjusting the sampling phase of a digitally encoded signal in a wireless communication system; Jong-Keung Cheng, et al., 375/354, 365 [IMAGE AVAILABLE]
84. 5,394,439, Feb. 28, 1995, Bisdn compatible modem codec for digital information communication system; Farhad Hemmati, 375/242; 332/103; 375/260, 262, 280, 308 [IMAGE AVAILABLE]
85. 5,394,410, Feb. 28, 1995, Differentially coded and guard pulse position modulation for communication networks; Kwang-Cheng Chen, 371/47.1 [IMAGE AVAILABLE]
86. 5,392,316, Feb. 21, 1995, Decoding method and apparatus with maximum likelihood sequence estimation; Hideki Sawaguchi, et al., 375/290; 360/46; 375/286 [IMAGE AVAILABLE]
87. 5,392,300, Feb. 21, 1995, Dual mode radio communication unit; David E. Borth, et al., 714/761, 786 [IMAGE AVAILABLE]
88. 5,376,894, Dec. 27, 1994, Phase estimation and synchronization using a PSK demodulator; James E. Petranovich, 329/306, 310; 375/324, 329 [IMAGE AVAILABLE]
89. 5,375,146, Dec. 20, 1994, Digital frequency conversion and tuning scheme for microwave radio receivers and transmitters; Harvey Chalmers, 375/350, 344; 708/313 [IMAGE AVAILABLE]
90. 5,365,229, Nov. 15, 1994, Adaptive telemetry system for hostile environment well logging; Wallace R. Gardner, et al., 340/855.4, 855.5; 367/76 [IMAGE AVAILABLE]
91. 5,363,408, Nov. 8, 1994, Mode selective quadrature amplitude modulation communication system; Woo H. Paik, et al., 375/261; 329/304; 332/103; 375/341, 354; 714/789 [IMAGE AVAILABLE]
92. 5,353,307, Oct. 4, 1994, Automatic simulcast alignment; Howard L. Lester, et al., 375/233, 341, 348; 455/503; 708/323 [IMAGE AVAILABLE]
93. 5,351,274, Sep. 27, 1994, Post detection selection combining diversity receivers for mobile and indoor radio channels; Sandeep Chennakeshu, et al., 375/347, 341; 455/135, 137 [IMAGE AVAILABLE]
94. 5,343,498, Aug. 30, 1994, Sample timing selection and frequency offset correction for U.S. digital cellular mobile receivers; Raymond L. Toy, et al., 375/259; 370/337, 350; 375/355, 365, 376 [IMAGE AVAILABLE]

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95. 5,335,250, Aug. 2, 1994, Method and apparatus for blind sectional demodulation of digitally modulated signals; Paul W. Dent, et al., 375/224, 340 [IMAGE AVAILABLE]
96. 5,317,595, May 31, 1994, Rapidly adaptable channel equalizer; Kjell Ostman, 375/232, 230 [IMAGE AVAILABLE]
97. 5,311,558, May 10, 1994, Data receiver comprising a control loop with reduced sampling frequency; Johannes W. M. Bergmans, 375/346; 370/290; 375/232, 348 [IMAGE AVAILABLE]
98. 5,311,546, May 10, 1994, Carrier phase recovery for an adaptive equalizer; Woo H. Paik, et al., 375/232, 344; 708/323 [IMAGE AVAILABLE]
99. 5,311,545, May 10, 1994, Modem for fading digital channels affected by multipath; David N. Critchlow, 375/232; 329/304; 375/324, 332, 343, 344 [IMAGE AVAILABLE]
100. 5,305,349, Apr. 19, 1994, Quantized coherent rake receiver; Paul W. Dent, 370/209, 342 [IMAGE AVAILABLE]
101. 5,303,263, Apr. 12, 1994, Transmission channel characteristic equalizer; Yasuo Shoji, et al., 375/229, 341; 714/795 [IMAGE AVAILABLE]
102. 5,301,167, Apr. 5, 1994, Apparatus for improved underwater acoustic telemetry utilizing phase coherent communications; John G. Proakis, et al., 367/134 [IMAGE AVAILABLE]
103. 5,283,815, Feb. 1, 1994, Tangential type differential detector for pulse shaped PI/4 shifted differentially encoded quadrature phase shift keying; Sandeep Chennakeshu, et al., 375/330; 329/304; 455/60 [IMAGE AVAILABLE]
104. 5,283,811, Feb. 1, 1994, Decision feedback equalization for digital cellular radio; Sandeep Chennakeshu, et al., 375/233, 234; 708/323 [IMAGE AVAILABLE]
105. 5,249,200, Sep. 28, 1993, Device and method for combining precoding with symbol-rate spectral shaping; Michael Chen, et al., 375/285; 329/349; 332/159; 375/296 [IMAGE AVAILABLE]
106. 5,220,568, Jun. 15, 1993, Shift correcting code for channel encoded data; Dennis G. Howe, et al., 341/59, 94; 714/775 [IMAGE AVAILABLE]
107. 5,202,901, Apr. 13, 1993, Digital discriminator for pulse shaped .pi./4 shifted differentially encoded quadrature phase shift keying; Sandeep Chennakeshu, et al., 375/331; 329/304; 455/60 [IMAGE AVAILABLE]
108. RE 34,206, Mar. 30, 1993, Method and apparatus for timing recovery; Babak Sayar, 375/293, 344, 371 [IMAGE AVAILABLE]
109. 5,195,108, Mar. 16, 1993, System and method for determining absolute phase of a differentially-encoded, phase-modulated signal; Kevin L. Baum, et al., 375/330; 323/304; 375/331, 332, 343 [IMAGE AVAILABLE]
110. 5,159,609, Oct. 27, 1992, Data receiving device with delayed equalization and retroactive time-pulse recovery; Jacques Palicot, 375/232; 333/18; 708/323 [IMAGE AVAILABLE]
111. 5,151,926, Sep. 29, 1992, Sample timing and carrier frequency estimation circuit for sine-cosine detectors; Sandeep Chennakeshu, et al., 375/333; 329/304 [IMAGE AVAILABLE]

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112. 5,131,011, Jul. 14, 1992, Receiver for data transmission system with nonlinearities; Johannes W. M. Bergmans, et al., 375/348; 341/106; 375/341; 702/191; 714/759 [IMAGE AVAILABLE]
113. 5,052,000, Sep. 24, 1991, Technique for improving the operation of decision feedback equalizers in communications systems utilizing error correction; Jin-Der Wang, et al., 375/233, 265; 714/784, 792 [IMAGE AVAILABLE]
114. 5,022,053, Jun. 4, 1991, Data communications with alternation of signaling constellations; Hong Y. Chung, et al., 375/265; 370/522; 375/262 [IMAGE AVAILABLE]
115. 4,995,031, Feb. 19, 1991, Equalizer for ISDN-U interface; Sami A. H. Aly, et al., 370/286; 375/230, 232 [IMAGE AVAILABLE]
116. 4,964,118, Oct. 16, 1990, Apparatus and method for echo cancellation; Sami A. H. Aly, et al., 370/291; 379/411 [IMAGE AVAILABLE]
117. 4,959,845, Sep. 25, 1990, Receiver of a system for transmitting data symbols at a given baud-rate; Simon J. M. Tol, et al., 375/354, 357 [IMAGE AVAILABLE]
118. 4,918,685, Apr. 17, 1990, Transceiver arrangement for full-duplex data transmission comprising an echo canceller and provisions for testing the arrangement; Simon J. M. Tol, et al., 370/249, 286 [IMAGE AVAILABLE]
119. 4,914,699, Apr. 3, 1990, High frequency anti-jam communication system terminal; James G. Dunn, et al., 380/34; 375/202, 207, 209, 343; 380/46 [IMAGE AVAILABLE]
120. 4,896,334, Jan. 23, 1990, Method and apparatus for timing recovery; Babak Sayar, 375/293; 370/276; 375/344, 371 [IMAGE AVAILABLE]
121. 4,866,736, Sep. 12, 1989, Data transmission system comprising a decision feedback equalizer and using partial-response techniques; Johannes W. M. Bergmans, 375/291, 233, 350 [IMAGE AVAILABLE]
122. 4,833,693, May 23, 1989, Coded modulation system using interleaving for decision-feedback equalization; Vedat M. Eyuboglu, 375/254, 233, 346; 714/792, 795 [IMAGE AVAILABLE]
123. 4,651,320, Mar. 17, 1987, Inband coding of secondary data; Hemant K. Thapar, 370/207, 522; 375/261 [IMAGE AVAILABLE]
124. 4,644,537, Feb. 17, 1987, Inband coding of secondary data; Richard D. Gitlin, et al., 370/207, 522; 375/261 [IMAGE AVAILABLE]
125. 4,608,703, Aug. 26, 1986, Synchronization detection system for data transmission; Mitsuru Kaga, et al., 375/365, 231, 261 [IMAGE AVAILABLE]
126. 4,597,089, Jun. 24, 1986, Single pulse fast learn modem; David M. Motley, et al., 375/231, 222 [IMAGE AVAILABLE]
127. 4,466,108, Aug. 14, 1984, TDMA/PSK Carrier synchronization without preamble; Smith A. Rhodes, 375/329; 329/308; 375/344, 371 [IMAGE AVAILABLE]
128. 4,370,749, Jan. 25, 1983, Phase noise correction circuit for a data transmission system; Michel Levy, et al., 375/346; 327/146; 375/373 [IMAGE AVAILABLE]

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129. 3,962,637, Jun. 8, 1976, Ultrafast adaptive digital modem; David M. Motley, et al., 375/232; 3/18; 375/235, 355 [IMAGE AVAILABLE]

130. 3,935,535, Jan. 27, 1976, Fast equalization acquisition for automatic adaptive digital modem; David M. Motley, et al., 375/231; 333/18; 375/235, 290; 708/323 [IMAGE AVAILABLE]

131. 3,747,065, Jul. 17, 1973, SYSTEM FOR CORRECTING DETECTED ERRORS IN A HIGH SPEED DIGITAL DATA TRANSMISSION SYSTEM; Earl D. Gibson, 375/346 [IMAGE AVAILABLE]

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08/894207

OFFICE OF FINANCE
CRYSTAL PLAZA 2 LOBBY

SERIAL NUMBER

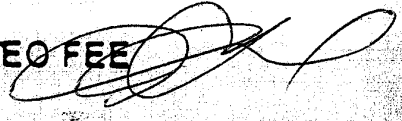
FROM PGT INTERNATIONAL DIVISION-DO/EO

PLEASE PROCESS THE FOLLOWING COLLECTIONS

FEE CODE	AMOUNT	FEE CODE	AMOUNT
BASIC FEE		CLAIMS/MULTIPLE DEPENDENT	
960		964	
961		965	
970	910 ⁰⁰	966	
971		967	
958		968	
959		969	
956		LATE FEE/SURCHARGE	
957		154	
962		254	
963		156	
OTHER:		581	

THE ORIGINAL METHOD OF PAYMENT

- ☒ BY A CHECK
- ☐ BY A CHARGE TO DEPOSIT ACCOUNT NO _____

DO/EO FEE 

MULTIPLE DEPENDENT CLAIM FEE CALCULATION SHEET (FOR USE WITH FORM PTO-875)	SERIAL NO. 08/894207	FILING DATE
APPLICANT(S)		

CLAIMS													
	AS FILED		AFTER 1st AMENDMENT		AFTER 2nd AMENDMENT								
	IND.	DEP.	IND.	DEP.	IND.	DEP.		IND.	DEP.	IND.	DEP.	IND.	DEP.
1	1		1				51						
2		1					52						
3		2					53						
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48							98						
49							99						
50							100						
TOTAL IND.	3		3				TOTAL IND.						
TOTAL DEP.	8		6				TOTAL DEP.						
TOTAL CLAIMS	11		9				TOTAL CLAIMS						

U.S. DEPARTMENT of COMMERCE
Trademark Office

STAPLE

AREA

☆ U.S. GOVERNMENT PRINTING OFFICE: 1998-446-168

PATENT NUMBER

APPLICATION SERIAL NUMBER

APPLICANT'S NAME (PLEASE PRINT)

IF REISSUE, ORIGINAL PATENT NUMBER

INTERNATIONAL CLASSIFICATION

H 0 3 D
H 0 4 L

1/06
27/06

GROUP
ART UNIT

ASSISTANT EXAMINER (PLEASE STAMP OR PRINT FULL NAME)

PRIMARY EXAMINER (PLEASE STAMP OR PRINT FULL NAME)

ISSUE CLASSIFICATION SLIP

U.S. DEPARTMENT OF COMMERCE
PATENT AND TRADEMARK OFFICE

PATENT APPLICATION FEE DETERMINATION RECORD

Effective October 1, 1996

Application or Docket Number

08/894207

CLAIMS AS FILED - PART I

(Column 1)

(Column 2)

FOR	NUMBER FILED	NUMBER EXTRA
BASIC FEE		
TOTAL CLAIMS	11 minus 20 = *	
INDEPENDENT CLAIMS	3 minus 3 = *	
MULTIPLE DEPENDENT CLAIM PRESENT		

* If the difference in column 1 is less than zero, enter "0" in column 2

SMALL ENTITY

OR

OTHER THAN SMALL ENTITY

RATE	FEE	RATE	FEE
	385.00		910
x\$11=		x\$22=	770.00
x40=		x80=	
+130=		+260=	
TOTAL		TOTAL	

CLAIMS AS AMENDED - PART II

(Column 1)

(Column 2)

(Column 3)

AMENDMENT A	CLAIMS REMAINING AFTER AMENDMENT	HIGHEST NUMBER PREVIOUSLY PAID FOR	PRESENT EXTRA
Total	* 9 Minus ** 20 =		
Independent	* 3 Minus *** 3 =		
FIRST PRESENTATION OF MULTIPLE DEPENDENT CLAIM			

SMALL ENTITY

OR

OTHER THAN SMALL ENTITY

RATE	ADDITIONAL FEE	RATE	ADDITIONAL FEE
x\$11=		x\$22=	
x40=		x80=	
+130=		+260=	
TOTAL ADDIT. FEE		TOTAL ADDIT. FEE	

(Column 1)

(Column 2)

(Column 3)

AMENDMENT B	CLAIMS REMAINING AFTER AMENDMENT	HIGHEST NUMBER PREVIOUSLY PAID FOR	PRESENT EXTRA
Total	* 9 Minus ** 20 =		
Independent	* 3 Minus *** 3 =		
FIRST PRESENTATION OF MULTIPLE DEPENDENT CLAIM			

SMALL ENTITY

OR

OTHER THAN SMALL ENTITY

RATE	ADDITIONAL FEE	RATE	ADDITIONAL FEE
x\$11=		x\$22=	
x40=		x80=	
+130=		+260=	
TOTAL ADDIT. FEE		TOTAL ADDIT. FEE	

(Column 1)

(Column 2)

(Column 3)

AMENDMENT C	CLAIMS REMAINING AFTER AMENDMENT	HIGHEST NUMBER PREVIOUSLY PAID FOR	PRESENT EXTRA
Total	* Minus ** =		
Independent	* Minus *** =		
FIRST PRESENTATION OF MULTIPLE DEPENDENT CLAIM			

SMALL ENTITY

OR

OTHER THAN SMALL ENTITY

RATE	ADDITIONAL FEE	RATE	ADDITIONAL FEE
x\$11=		x\$22=	
x40=		x80=	
+130=		+260=	
TOTAL ADDIT. FEE		TOTAL ADDIT. FEE	

* If the entry in column 1 is less than the entry in column 2, write "0" in column 3.

** If the "Highest Number Previously Paid For" IN THIS SPACE is less than 20, enter "20."

*** If the "Highest Number Previously Paid For" IN THIS SPACE is less than 3, enter "3."

The "Highest Number Previously Paid For" (Total or Independent) is the highest number found in the appropriate box in column 1.

Staple Issue Slip Here

POSITION	ID NO.	DATE
CLASSIFIER		9-4-97
EXAMINER		5/10/97
TYPIST		3-17-98
VERIFIER		
CORPS CORR.		
SPEC. HAND		
FILE MAINT.		
DRAFTING		

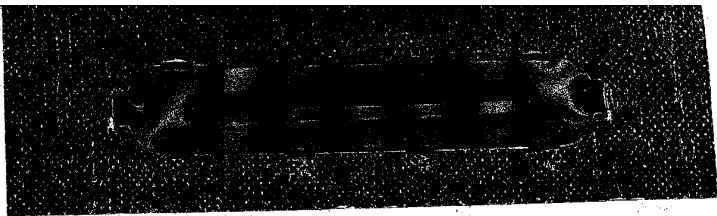
INDEX OF CLAIMS

Claim		Date			
Final	Original	4/10/99	9/13/99	3/1/2000	
1	1	✓	2	2	
2	2	✓		2	
3	3	0		2	
4	4			2	
5	5			2	
6	6			2	
7	7	0		2	
8	8	2	2	2	
9	9	✓	✓	2	
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Claim		Date			
Final	Original				
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SYMBOLS
✓ Rejected
= Allowed
- (Through numeral) Canceled
+ Restricted
N Non-elected
I Interference
A Appeal
O Objected

(LEFT INSIDE)



SEARCHED			
Class	Sub.	Date	Exmr.
375	262, 341	3/14/99	JB
	232, 233	↑	
	340, 346	↑	
371	43	-	
Updated above 9/10/99 JB			
375 348			
Updated above 3/1/2000 JB			

INTERFERENCE SEARCHED			
Class	Sub.	Date	Exmr.
375	262, 341	3/2/2000	JB
	232, 233	↑	
	340, 346	↑	
	348	✓	

SEARCH NOTES		
A/S	Date	Exmr.
	3/15/99	JB

(RIGHT OUTSIDE)