AUTONOMOUS VEHICLE COLLISION/
CROSSING WARNING SYSTEM

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FIELD OF THE INVENTION

The present invention relates generally to the field of vehicle collision/crossing warning systems. More particularly, the present invention relates to a relatively inexpensive, low-power

10 vehicle collision/crossing warning system that enables simple and decentralized installation, operation, and maintenance of a reliable vehicle collision/crossing warning system.

BACKGROUND OF THE INVENTION

Railroad crossing warning systems are perhaps the most familiar of a variety of vehicle

15 collision/crossing warning systems. The purpose of such warning systems is to notify vehicles and/or stationery warning indicators of the approach and/or proximity of a vehicle. Other examples of such warning systems include emergency vehicle traffic light override systems, automobile navigation systems, airport and construction zone vehicle tracking systems and other navigational control and warning systems.

20 Because of the safety importance of vehicle collision/crossing warning systems, reliability and failure free operation are critical requirements in the design of such a system. In order to meet these design requirements, most existing vehicle collision/crossing warning systems are relatively expensive and require some form of centralized or coordinated communication scheme among the vehicles and other components that are part of the warning

25 system. In the case of stationery warning components, such as railroad crossing warning systems or traffic light intersections systems, installation of such warning systems can require significant effort and usually involves providing power and communication wiring as part of the installation.

Traditional railroad crossing warning systems, for example, have relied on the railroad tracks themselves to detect an approaching train and activate a warning signal apparatus. As the

30 wheels of an approaching train pass by a detector positioned at a predetermined location along the tracks relative to the crossing, the detector senses an electrical short across the tracks and sends a signal to a controller that activates flashing lights and/or descending gates at the crossing.

The expense of installing such a traditional railroad crossing warning system, coupled with the requirement for AC electrical power to operate the warning system, have limited the use of such warning systems to urban areas and other high volume traffic crossings.

One alternative to such hardwired collision/crossing warning systems involves the use of wireless transmitters and receivers. U.S. Patent Nos. 4,723,737, 4,942,395, 5,098,044, 5,739,768 and 6,179,252 are examples of such systems. Another alternative involves the use of global positioning satellite (GPS) technology to identify the location and movement of vehicles within the system. Examples of warning systems that utilize GPS technology are described in U.S. Patent Nos. 5,325,302, 5,450,329, 5,539,398, 5,554,982, 5,574,469, 5,620,155, 5,699,986, 5,757,291, 5,872,526, 5,900,825, 5,983,161, 6,160,493, 6,185,504 and 6,218,961, as well as PCT Publication Nos. WO9909429 and WO101587 and Japanese Abst. No. JP11059419. Generally, these alternatives rely on some type of centralized or coordinated communication scheme to keep track of multiple vehicles and components or to confirm transmission of messages between vehicles and components within the warning system.

Despite these developments, there continues to be a need for a relatively inexpensive, low-power vehicle collision/crossing warning system that enables simple and decentralized installation, operation, and maintenance of a reliable vehicle collision/crossing warning system.

SUMMARY OF THE INVENTION

The present invention is an autonomous vehicle collision/crossing warning system that provides for simple, inexpensive and decentralized installation, operation, and maintenance of a reliable vehicle collision/crossing warning system. The autonomous warning system preferably utilizes a single frequency TDM radio communication network with GPS clock synchronization, time slot arbitration and connectionless UDP protocol to broadcast messages to all vehicles and components in the warning system without an expectation of any acknowledgement. Adaptive localized mapping of components of interest within the warning system eliminates the need for centralized databases or coordination and control systems and enables new vehicles and warning systems to be easily added to the system in a decentralized manner. Preferably, stationary warning systems are deployed as multiple self-powered units each equipped to receive broadcast

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messages and to communicate with the other units by a low power RF channel in a redundant master-slave configuration. The communication schemes are preferably arranged for low duty cycle operation to decrease power consumption.

5   A preferred embodiment of the present invention is directed to a railroad crossing warning system that is low-cost and well-suited for use with low volume highway-rail intersections. The autonomous railroad crossing warning system in accordance with this embodiment includes a tracking device, such as a GPS receiver to calculate the position, velocity, and heading of a train. A GPS receiver is also provided at each railroad crossing to provide the location of the crossing to both passing trains and other crossings. The present

10   invention also includes at least one communication device on each train and at each crossing that provides an autonomous single-frequency radio network utilizing time division multiplexed communication and synchronizes the radios with the GPS time clock. Synchronization between transmitting and receiving of the radios on the network allows reduced power consumption by the receivers. A communication protocol is used to ensure proper channel hopping and eliminate

15   data collisions, which allows multiple devices to use one radio frequency. Software is provided at each railroad crossing to calculate train arrival time at the crossing based on GPS data received through the radio network from the train and activate the motorist warning devices at appropriate times. The software supports multiple trains in the vicinity of the crossing and screens out trains that are on different courses and will not intersect the crossing. The two-way communication

20   between trains and crossings will allow system status data from each crossing to be collected by passing trains and, if a crossing warning system is completely inoperable, automatically issuing a mayday broadcast to be received by passing vehicles and, optionally, having the passing train telephone a centralized computer system with the location of the failure through a cellular phone on the train. Preferably, data collection on the status and condition of the warning system is

25   distributively collected by each train. A handheld display/keyboard preferably is used to alert train operators to upcoming crossings and also is used to enter train length for purposes of broadcasting this information.

The present invention preferably includes an autonomous train detection system that does not impinge on the railroad right of way. In one embodiment of the present invention, low

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frequency seismic sensors are used to awaken the control system at each railroad crossing when a train approaches within a certain distance of the crossing. Additional dual ultrasonic sensors may be used to monitor for the presence of components in the crossing, as well as when the train has left the crossing. Another element of the present invention is the design allows for the use of

5   solar power to provide all system power needs at railroad crossings. Preferably, all of the hardware required for the crossing warning system is mounted on the existing cross buck posts or railroad ahead warning signs so that additional site construction is minimized.

One feature of a preferred embodiment of the present invention is a self-adaptive mapping algorithm that generates micro maps for each subsystem. The subsystems

10   communicate with devices passing through their immediate environment and learn of other components in their environment and teach the passing devices information it does not know. This self-propagating algorithm eliminates the need for a master map at each subsystem. Passing devices generate master maps that automatically update when passing through subsystems and teach subsystems of new components in their environment, thereby allowing passing vehicles to

15   learn of upcoming components in the immediate environment.

A feature of the communication scheme of the present invention provides for a dual RF arrangement having broadcast cells surrounding each component in the warning system having a radius of at least about 0.25 miles preferably using 2W transmitters and local zones surrounding each units in a stationary warning system having a radius of less than about 0.25 miles preferably

20   using 100 mW transmitters. The local zone network preferably is synchronized by the master unit with periodic GPS time stamps such that fewer GPS operations are required by the slave units. The dual RF cellular arrangement with the arbitrated UDP (user datedgram protocol) communication scheme allows for vehicles to seamlessly join and leave cells as the move across stationary warning systems. In an alternate embodiment, vehicles can be equipped with collision

25   avoidance software and systems to inform moving vehicles of impending collisions with other vehicles. In one embodiment, software in stationary devices makes decisions based upon analysis of the broadcast information to determine potential relevance and estimated arrival times of vehicles within a corresponding cell. In a preferred embodiment, the local zone network

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utilizes phase and amplitude analysis of broadcast signals received by each of the units to differentiate valid train broadcasts from extraneous triggers.

In a preferred embodiment of the application of a railroad crossing warning system, each locomotive is provided with a tracking (GPS) device on the locomotive to calculate position, speed and heading. Each crossing is also provided with a tracking (GPS) device to calculate at least an initial position and to establish clock synchronization. The communication scheme between the locomotive and the crossing preferably allows for 2-way communication but does not require handshake, acknowledgements or complete reception of all broadcasts in order to function properly. Preferably, multiple transceivers at the crossing provide 2+ levels of redundancy.

BRIEF DESCRIPTION OF THE DRAWINGS

Figure 1 is a block diagram of a transceiver in accordance with a preferred embodiment of the communication protocol of the present invention.

Figure 2 is a schematic diagram of a processor for use with the transceiver as shown in Figure 1.

DETAILED DESCRIPTION OF PREFERRED EMBODIMENT

The details of the preferred embodiment of an autonomous vehicle collision/crossing warning system in accordance with the present invention are described in the Product Information Package for HRI-2000 and the C3 Radio Protocol for Collision Avoidance Specification which are included as attachments and the disclosures of which are hereby incorporated by reference. Figures 1 and 2 show the details of a preferred embodiment of a transceiver and its associated processor designed in accordance with the preferred embodiment of the communication protocol for the autonomous vehicle collision/crossing warning system of the present invention.

Although the preferred embodiment has been described with reference to a railroad crossing warning system, it should be understood that the present invention is equally applicable to a variety of vehicle collision/crossing warning systems, including: emergency vehicle traffic

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light override systems, automobile navigation systems, airport and construction zone vehicle tracking systems and other navigational control and warning systems.

One example of such an application is use of the autonomous collision/crossing warning system as part of a bus warning system. There are approximately 9000 locomotives in the United States. If a C3 low cost broadcast beacon in accordance with the preferred communication protocol is placed on every locomotive and a C3 receiver/transmitter XM module were to be placed on each vehicle such as a bus for purposes of warning of the proximity or potential for collision with a locomotive, a simple trajectory algorithm could warn as follows:

- Using past and present position, heading and velocity information a vehicle, such as a bus, would map its most likely future course.
- Using past and present position, heading and velocity information received from the locomotive beacon a vehicle, such as a bus, would map the locomotives most likely future position
- The vehicles intelligent collision avoidance would then give warnings such as: locomotive in nearby proximity, approaching but no projected collision and caution – paths cross.

Another example of such an application is use of the autonomous collision/crossing warning system as part of a warning system on emergency vehicles. There are multiple collisions every year between safety vehicles and commuters at lighted intersections. When a safety vehicle approaches an intersection they often slow and cross hoping either commuters saw and heard them or the safety vehicle sees the commuter. This methodology is flawed, as a historical study of intersection collisions will show. If a C3 Beacon is placed on a safety vehicle and a C3 XM module is placed at the crossing controller, the XM module can use the intelligent software as previously described to map future positions and vehicle approaches allowing for signal changes to efficiently and safely pass emergency vehicles through intersections. This approach will also allow for safety vehicles to know of each other and for an intersection to decide which vehicle is given priority if two or more are approaching at different approaches. In this final case where

two safety vehicles approach unknown to each other, the intelligent software would warn of an impending collision.

As can be seen, once an autonomous collision/crossing warning system of the present invention is installed on locomotives and then busses and safety vehicles, the system can be provided with a comprehensive, educative, alert and decision making communications software arrangement which allowing for:

- If the HRI intersection needs protection there is an efficient low cost warning system utilizing C3 XM, XS and XA technologies.
- If the HRI crossing exists or is absent, the bus will know of the locomotive from its beacon.
- If safety vehicles such as ambulances, fire trucks or police vehicles, have an installed XM it will know of the locomotives approach and be able to inform the driver of delays and let the driver select alternate paths to its destination around the blocked crossing.
- If the safety vehicles above were beacons as well, they could not only warn other safety vehicles of their approach they could safely and inexpensively tell lighted road crossings of their approach through the beacon. The crossing would hear with its XM allowing for lights to change and pass the vehicle through safely and efficiently.

Another application of the beacon communication network of the present invention is collision/crossing warning systems for maritime applications. By installing a C3 XM at each buoy or other waterway object of interest and C3 Beacons on each vessel, the buoy could listen to approach information and predict proper passage or potential errors. This potential error could then be used to alert the crew of their error and potential future problems. Expounding this farther, the same intelligent projection and collision software could be used to warn crews of the presence of other ships and impending problems yet to come.
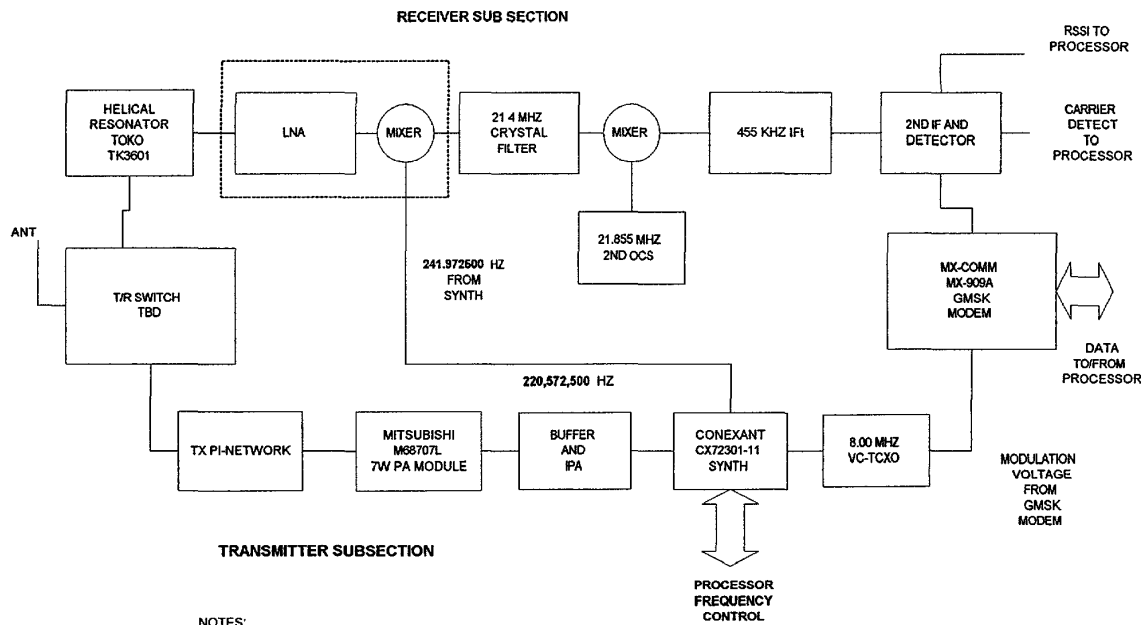
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CLAIMS

1.   The inventions as shown and described.

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ABSTRACT OF THE DISCLOSURE

An autonomous vehicle collision/crossing warning system provides for simple, inexpensive and decentralized installation, operation and maintenance of a reliable vehicle

5   collision/crossing warning system. The autonomous warning system preferably utilizes a single frequency TDM radio communication network with GPS clock synchronization, time slot arbitration and connectionless UDP protocol to broadcast messages among vehicles and components in the warning system. Adaptive localized mapping of components of interest within the warning system eliminates the need for centralized databases or coordination and

10   control systems and enables new vehicles and warning systems to be easily added to the system in a decentralized manner. Preferably, stationary warning systems are deployed as multiple self-powered units each equipped to receive broadcast messages and to communicate with the other units by a low power RF channel in a redundant master-slave configuration. The communication schemes are preferably arranged for low duty cycle operation to decrease power consumption.

RECEIVER SUB SECTION

RSSI TO
PROCESSOR

| HELICAL RESONATOR TOKO TK3601 | LNA | MIXER | 21 4 MHZ CRYSTAL FILTER | MIXER | 455 KHZ IFt | 2ND IF AND DETECTOR |

CARRIER
DETECT
TO
PROCESSOR

ANT

T/R SWITCH
TBD

241.972500 HZ
FROM
SYNTH

21.855 MHZ
2ND OCS

MX-COMM
MX-909A
GMSK
MODEM

DATA
TO/FROM
PROCESSOR

220,572,500 HZ

| TX PI-NETWORK | MITSUBISHI M68707L 7W PA MODULE | BUFFER AND IPA | CONEXANT CX72301-11 SYNTH | 8.00 MHZ VC-TCXO |

MODULATION
VOLTAGE
FROM
GMSK
MODEM

TRANSMITTER SUBSECTION

PROCESSOR
FREQUENCY
CONTROL

NOTES:
1. POWER MANAGEMENT
FEATURES NOT SHOWN

**C3 TRANS SYSTEMS LLC
HRI TRANSCEIVER BLOCK
DIAGRAM
4/2/2001 GMM**

Figure 1

C3 TRANS SYSTEMS LLC
PRELIMINARY PROCESSOR
SCHEMATIC
HRI COMMUNICATIONS SYTEM
2/15/2001

Figure 2
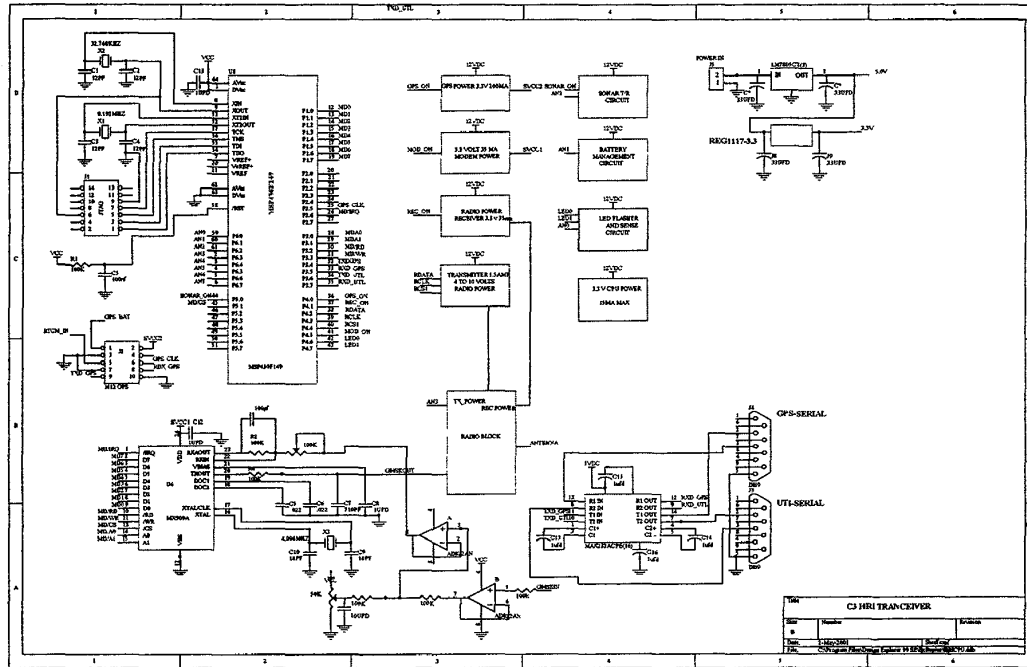
Attachment A

PRODUCT INFORMATION PACKAGE

FOR

HRI-2000

LOW-COST HIGHWAY-RAIL INTERSECTION ACTIVE WARNING SYSTEM

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HRI-2000

LOW-COST HIGHWAY-RAIL INTERSECTION ACTIVE WARNING SYSTEM

HRI-2000 System Overview

HRI-2000 system is modular in concept providing both the low cost and outstanding operational safety and performance capabilities required for highway-rail intersections. Further all systems are self-contained, powered by solar cells with battery backup, so that no costly phone line or power installations are required.

HRI-2000 system components have built in safety redundancy capabilities at the highway-rail intersection. If, for example both an advanced warning sign and a cross-buck sign were damaged in an accident the remaining undamaged signs would continue to function. The remaining functional devices would provide notification of the problem to the fault notification center, and to the next intersection, informing them that two intersection components at xxx intersection were no longer operational. If all four units of a typical installation were damaged the smart Self Updating adaptive mapping system in the locomotive would notify the engineer and the fault notification center.

HRI-2000 System Components

HRI-T Locomotive System - consist of the DGPS receiver, radio communications, processor, data logger, Smart Self Updating System (SSUS), interface to the engine for speed and direction of travel, operator interface, cell phone and modem. The radio system provides for beacon broadcasts to all HRI-2000 equipped crossing and receives information from crossings.

HRI-XM Master Crossing Controller - controls the communications between itself and the crossing slave units. The HRI-XM, with GPS, also provides the primary listening communications link to the Locomotives HRI-T. The HRI-XM is mounted on the Cross Buck and includes solar power cells, batteries, and dual double sided LED lights for optimum visibility to motorists approaching the intersection. The HRI-XM contains the crossing GPS and one of two Ultra Sonic train detection sensors, which are used to validate that the crossing is occupied by a railcar, or if the crossing is clear.

HRI-XS Slave crossing Controller – is essentially the same as the HRI-XM Master Crossing controller except it does not have GPS. They both have an Ultra Sonic train detection sensors, communications radio, solar power cells, batteries and dual double-sided flashing LED lights. The HRI-X is mounted, on the other side of the track, on the Cross Buck.

HRI-XA Advanced Warning Controller - is very similar to the HRI-XS except it lacks the Ultra Sonic sensor. They "SLEEP" most of their lives and are awakened at periodic intervals to be told a train is coming and to stay awake during activation. Two are used and they are installed, on each side of the track on the advance railroad warning sign to warn drivers they are approaching a railroad crossing.

Typical HRI-2000 System Installation

The typical HRI-200 active highway-rail intersection active warning system consists of 4 controllers mounted on railroad warning signs at the intersection. The HRI-2000 system also includes a locomotive unit used by any locomotive crossing the intersection.

One HRI-T Locomotive System - Installed in the locomotive.

One HRI-XM Master Crossing Controller, with communications radio, GPS, sonic sensor, solar cell, battery pack, and dual two-way flashing lights, which is installed on the cross buck railroad warning sign.

One HRI-XS Slave crossing Controller, which is identical in function and features to HRI-XM except the HRI-XS does not require a GPS.

Two HRI-XA Advanced Warning Controllers, which is identical in function and features to HRI-XS except the HRI-XA does not require a sonic sensor.

What a driver sees at a HRI-2000 highway-rail intersection

A driver approaching a railroad crossing equipped with a HRI-2000 system will probably not be aware of any changes at first. If they look closely they might notice that the railroad approach warning sign and the cross-buck signs have solar cells and LED light units installed on them. Under most conditions these are not flashing so they are not very noticeable.

When a train is approaching the intersection, the whole picture changes dramatically. First the driver will see that the railroad approach warning sign is flashing amber at them as LED units on each side of the sign take turns flashing a amber warning. These alert the driver to an approaching train. As the driver looks a little further ahead they will see the cross-buck sign is flashing red as dual LED units take turns flashing their red warning. The driver should also be able to notice dual red flashing lights on the cross-buck sign across the tracks, for an added warning.
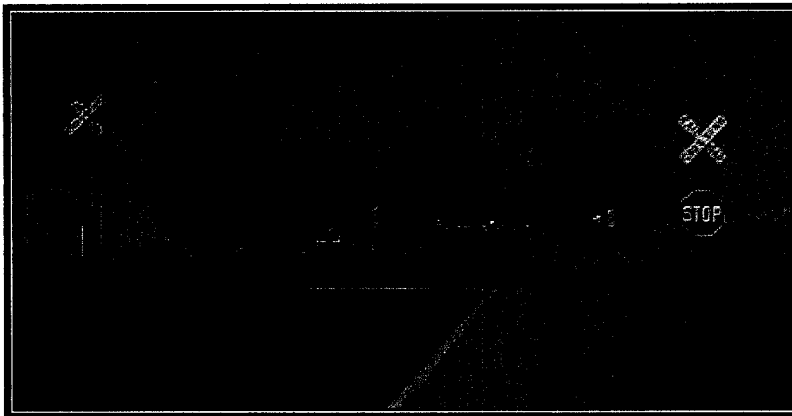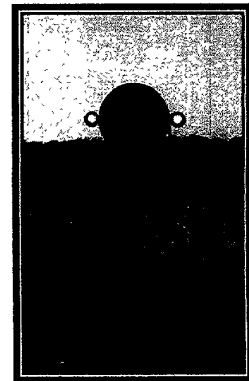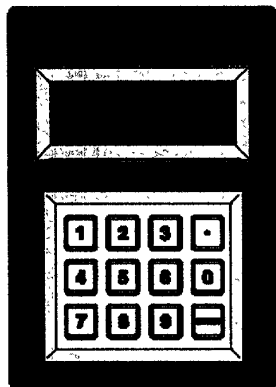
The HRI-2000 highway-rail intersection system will activate, when a train is approaching from either direction, providing a warning 30 second warning before the train arrives at the intersection. The early advance warning is intended to provide drivers with enough time to take appropriate action. The HRI-2000 systems will continue flashing until after the train has passed and railcars have cleared the intersection. In the event that one of the signs has been damaged in an accident, the other signs will still continue to operate providing their advanced warning. A system problem message will be forwarded to the fault notification center.

What a train engineer sees and does at a HRI-2000 highway-rail intersection

In a locomotive equipped with the HRI-T system, the Railroad engineer/conductor will have available a handheld (or systems mounted) Locomotive Data Entry and Display module shown below.

LOCOMOTIVE DATA ENTRY & DISPLAY

As the locomotive approaches within 30 seconds of entering an HRI-2000 equipped highway-rail intersection the HRI-T system will communicate with the intersection and activate the intersection. The engineer will receive a system-activated notice, or in case of problems (for example damage to a HRI-2000 equipped sign) the Data Display unit will notify the engineer of the problem. It will also notify the fault notification center via cell phone of the problem.

As the train approaches the intersection, the advance warning and cross-buck signs will have been activated and flashing warnings to motorists. As long as the train is in the intersection it will be sensed, and the signs will remain flashing.

The HRI-T system will also be using the Smart Self Updating System (SSUS) to poll the crossing and share the latest systems information. In this way, as the locomotive moves down the track it is also updating itself and all crossings along the line with the latest system information.

Using the SSUS will require no input on the locomotive engineers part. Furthermore, a locomotive equipped with a new HRI-T system, with SSUS, does not need to be programmed by the engineer. The HRI-T system will receive all its updated system information from the first intersection it approaches. At this time it will know what to expect as it continues down line. This information will be useful at times when all HIR-2000 components at a HRI intersection have been damaged. This unusual event of total system failure of all components at an intersection, will be known by the approaching HRI-T. The engineer will be notified as well as the fault notification center. It will in turn pass this information along to the next intersection, and thereby all trains approaching the intersections it has passed. Only, when the train is backing, and there will be a significant number of new of railcars added to the train, will the engineer need to update the HRI-T system with total number of cars.

Finally as last car of the train exits the intersection the flashing lights will be deactivated and the system will wait for the next locomotive to approach.

HRI-2000 System Technology

The HRI-2000 system is a state of the art command, control and communication system designed for Highway Rail Intersection Active Warning Systems.

The heart of the system is a Time Division multiple Access (TDMA) communications control system. This unique system permit several devices such as the locomotive, crossing, and advance warning devices to share a common radio frequency, yet not interfere with each other. TDMA is not a new technology; it has been used in cellular phone systems and military systems for years. What makes the HRI-2000 system different is, instead of having a MASTER NETWORK controller such as cell site tower, the HRI-2000 system uses precision timing derived from the GPS satellite system and pre-assigned TIMESLOTS for specific device communications activities. In this manner for example, up to 8 locomotives can communicate with an individual intersection without interfering with each other. TIMESLOTS and maintenance of precision timing lets the system operate without a MASTER NETWORK controller as is used in the previous systems mentioned.

The HRI-2000 system uses the locomotive as a platform for a BEACON which is transmitted every 4 seconds in a TIMESLOT. The BEACON contains geographic location information about the locomotives position, speed, direction of train motion and heading. This information is obtained from a precision DGPS receiver on the locomotive. Any crossing can listen to any locomotive at all times, if the locomotive is in radio range of the crossing.

The true decision process to activate the signal and advanced warning indicators is made at the crossing by the Crossing Master Controller HRI-XM referred to hereafter simply as XM. The XM mounted on the Cross Buck, contains a powerful 16 bit microcomputer, DGPS and transmitter. The XM compares its location, derived from it's onboard DGPS receiver, to that of the locomotive data derived from the BEACON transmission and decides if the train is approaching the crossing and activation needs to occur. Once activation has occurred the XM will notify the locomotive that the crossing is activated. The XM also manages the surrounding other warning devices, namely, the other Cross Buck Controller called the XS and one or more Advanced Warning Sign Controllers called the XA. The XM in management of the other crossing devices collects information about the state of each device such as battery and whether a self-test of on-board devices was successful. When the train enters the crossing, a set of Ultra-Sonic sensors one on the XM unit and one on the XS unit confirm crossing. These devices are also used to deactivate the crossing when the train has passed. The same sensors are used for train cars left on the crossing.

The key to the C3-HRI-2000 system reliability lies in the crossing sub-system. The XM, XS, and XA are virtually identical except for GPS receiver and Sonar sensors. Any crossing device can be a Crossing Master Controller in the event of an XM failure allowing partial operation. Because the C3-HRI-2000 crossing system maintains a

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continuous dialogue between devices, the devices can very quickly detect abnormal behaviors and respond with a call for help, which is referred to as MAYDAY. Any crossing device can initiate MAYDAY. This transmission is made anytime a locomotive is in listening range to the crossing even if the locomotive will never intersect the crossing. This insures prompt reporting of failed crossing devices due to the immediate call the locomotive HRI-T will place to the fault notification center.

The key to the C3-HRI-2000 low cost, high reliability Advanced Rail Intersection Warning is the low installed cost and high reliability of the system design. All crossing system components mount on existing structures with no addition construction required in most instances. All crossing devices are totally self-contained and mount as a single unit. All crossing components use extremely long life Lithium Ion battery technology, combined with a high efficiency solar panel. The overall crossing system design allows most active components to "SLEEP" in an inactive state and be awakened based on the TIMESLOT communications scheme mentioned earlier. This allows for extremely low power drain on the system, permitting smaller batteries, and solar panels. Each station or location at the crossing is totally self contained so no wiring or construction is needed to install the system. The installer's tool is a banding tool to strap the box to the post and in some cases a wrench to tighten bolts.

HRI-2000 Smart Self Updating Systems (SSUS)

In addition to the TDMA radio system used which allows multiple locomotives to talk to a single crossing at the same time, the system further provides for all locomotives to know the status of the system at all times. The HRI-T systems are equipped with a Smart Self Updating System (SSUS). The SSUS permits full system updates without any effort on the part of the Railroad and eliminates the need for a Railroad to update map data in each locomotive as crossings are added, deleted or damaged.

The SSUS works like this:

Each locomotive SSUS contains a database of the status of all known crossings. Each crossing has a copy of a smaller localized database. Each time a locomotive and crossing interact, the databases are compared and whoever has the latest information, passes this data to the other. In this manner locomotives will have the most up to date status of the system. To achieve the high reliability required in this application, any of the HRI components could communicate with the locomotive in the event of a master failure. If a locomotive is new to an intersection it will have learned of that intersection from the previous intersection. In the event of a total HRI failure from vandalism or an act of god the locomotive will have prior warning that problem, allowing a warning to the engineer and notification to the fault notification center. Locomotives, as they travel the system, will receive notifications from partially failed crossings through the MAYDAY broadcasts discussed earlier. As a result a locomotive, with a new HRI-T system can

enter its first HRI-2000 equipped highway intersection and receive the latest system updates for all systems in that area. This information is then propagated from locomotive to HRI, and vise-versa as required.

Detailed operation:

A locomotive equipped with the HRI-T system and the HRI-XM crossing master unit each have GPS location data on board. This data allow the system to know about the devices by geo-location. Knowing about the location of a crossing and knowing where the locomotive is, the system can cross check if it is approaching a crossing and has not gotten a confirmation that the crossing activated. This is the fail-safe for a totally broken crossing. In this system, if the locomotive knows about a crossing, it cannot forecast that it should have received a confirmation and warn the engineer. Typically the locomotive does not need to know there is a crossing ahead because, if the crossing is working, the locomotive beacon will cause it to activate. When the crossing activates, it sends geo-location data to the locomotive, which cause the locomotive to "discover" the presence of the crossing. This discover process cause the locomotive to learn about this "new" crossing. Data about the new crossing is placed in the locomotives database.

Using SSUS the locomotive will now propagate this new knowledge throughout the system by passing along this information to each crossing it encounters. Crossings remember only data with in a given grid size whereas locomotives remember everything. As the system is used, information will propagate and update automatically. Locomotives new to the area require no prior engineer operation and interface. Locomotives will learn what is ahead from any functional HRI's it encounters thus protecting itself from the unusual event of total HRI failure at any crossing. Locomotives can share this data with others and accurate maps of working intersections can be automatically generated. Locomotives also time stamp this information so that passage time, activation time, location and deactivation time, and location are stored for system performance evaluation. The locomotive used DGPS so this information is accurate to several feet.

Database: The database contains the geo-location and track direction through the crossing. The crossing knows its location from its own on-board GPS, so as soon as a new crossing is turned on it has this data with no human intervention. This is stored as 4 bytes for milli-arc-seconds of latitude, 4 bytes for milli-arc-seconds of longitude and two bytes indicating compass direction of the rails through the crossing. In the last two bytes the crossing status is also encoded. It has been estimated that there 260,000 crossings in the US, therefore to store the entire US crossing database requires less that 3 megabytes of flash memory in the locomotive while the crossings will only store a localized map of their individual surroundings.

Database update: The worst case scenario is where a new locomotive, who knows nothing, encounters its first crossing. To download all 3 megabytes of data from the crossing to the locomotive at 4800 baud is impractical, therefore the system uses to its advantage the fact that the locomotive cannot be in California and Maine at the same

time. In our case it is in Minnesota, so only data that is within a grid of one degree by one degree, is actual exchanged during the dialogue. This would typically be less than a few hundred crossings. As the locomotive progress towards California, and through HRI-2000 equipped crossings, it will continue to compare its database. This is accomplished through the use of a Cyclic Redundancy Check (CRC) of its database for a given grid or area with the same (CRC) from the crossing it is passing. If they match the databases are the same and no update is needed, if they differ then they exchange the latest data during passage.

Database format: Data is stored in the crossings based on a 1 degree, which is approximately 60 NM by 60 NM or a 69 by 69 statute mile grid. The crossing data has the crossing in the center of the grid. The locomotive receives the location of the crossing and uses this location to generate a CRC on the same grid data and then compares this with the CRC sent from the crossing. If the databases match, no exchange occurs, if not then an update exchange takes place based on the latest data. The latest data is determined by comparing all locomotive time stamped entries with-in the prescribed grid with the database time stamp from the crossing. The device with the latest data sends this data to the other.

See illustration below: This is a pictorial representation of the data contained in the locomotive database and the crossing. In this example the locomotive is receiving information new information from the crossing. CRC = Cyclic Redundancy Check.
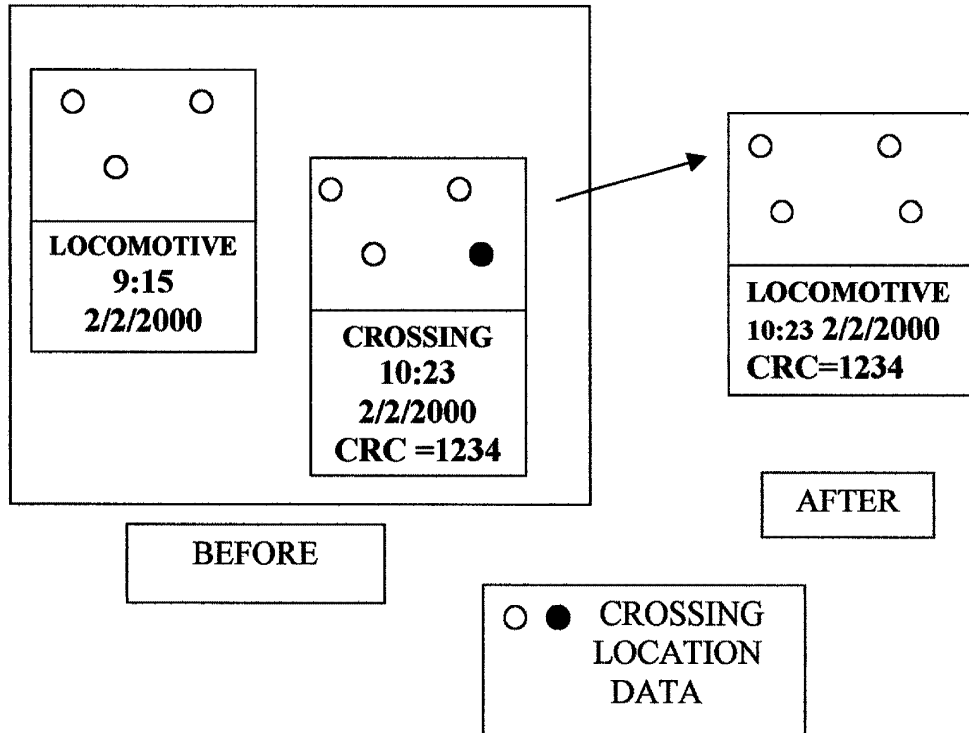
HRI-2000 System Architecture & Communications

OVERVIEW:

The HRI-2000 system architecture is based on a Time Division Multiple Access (TDMA) wireless communications system using a dedicated radio frequency for transmission of data between the locomotive(s) and crossing(s) (see Figure 1). The HRI-2000 further uses precision Differential Global Positioning System (DGPS) navigation methods to determine distance of the locomotive or train from an individual crossing. All arrival and departure calculations are done at the individual crossing sites. The locomotive's HRI-2000 system is primarily responsible for generating a BEACON broadcast used in the crossing arrival and departure calculations. The BEACON conveys latitude, longitude, heading, speed, length and backing status. The locomotives HRI-2000 system is also responsible for collecting and storing status data from working crossings and relaying fault notifications from failed crossing.

The HRI-2000 system architecture makes optimum use of power, hardware and communications bandwidth to provide a safer more effective system for advanced warning activation. The use of DGPS provides precise location of locomotives and precision timing for communications. The system also uses the number of train cars to compute end of train location relative to the crossing.

COMMUNICATIONS:

Precision DGPS timing is used to synchronize the HRI-200 intersection radio network and provide for TDMA (Time Division Multiple Access) control of communications within the HRI-2000 System. All field devices use TDMA and the radio network to allow for minimum power consumption through the use of a concept referred to as "SLEEP". The concept of "SLEEP" permits devices to essentially go into " hibernation" and consume very low power, then awaken at appropriate times to respond to communications from other devices. This SLEEP architecture permits very economical implementation of battery and solar power systems for field devices. Use of the SLEEP architecture enables lower installed costs while maintaining the six-sigma design goals.

LOCOMOTIVE SYSTEM - HRI-T

The HRI-T locomotive components are shown in (Figure 2). These consist of the DGPS receiver, radio communications, processor, data logger, interface to the engine for speed and direction of travel, operator interface, cell phone and modem. The DGPS operates in a DGPS mode to provide <5 meter RMS fixes on location. The radio system provides for beacon broadcasts to all HRI-2000 equipped crossing and receives information from crossings. A processor provides control of radio communications, generates position information and logs data for system performance evaluation. The Engine interface to the processor provides accurate low velocity train position data for use in dead reckoning. A keypad and display provides a means for the train crews to monitor the system and enter data about the train such as number of cars, as needed. A cell phone modem is used to report system faults and for doing data collection remotely.

The HRI-T processor controls the transmission of beacons to surrounding HRI-2000 Crossings. It uses precise DGPS derived timing to transmit these beacons and network status data at the correct time interval or TIMESLOT. The crossings listen in appropriate TIME SLOTS for HRI-T beacon broadcasts. The TIMESLOT control also insures the HRI-T Beacon does not unintentionally interfere with local crossing system communications, as the crossing system communicates within itself during different time interval than the HRI-T Beacon broadcast.

CROSSING SYSTEMS:

The HRI-2000 Crossing System is shown in (Figure 3). It consists of a **Master Crossing Controller (HRI-XM), a Slave Crossing Controller (HRI-XS)** and one or more **Advanced Warning Sign Controllers (HRI-XA)**. The HRI-XM (master) controls the communications between itself and the crossing slave units and provides the primary listening communications link to the **Locomotive(s) HRI-T** unit. The HRI-XM is mounted on the intersection cross buck and contains its own solar power system, battery pack, sonar, GPS communications, and two double sided Red LED Flashers which can be seen from both sides of the tracks. The HRI-XM and HRI-XS are essentially the same, except the HRI-XM has GPS. They both have an Ultra Sonic train detection sensors, which are used to validate that the crossing is occupied by a railcar or the crossing is clear. The ultra sonic sensors "PING" and analyze the returned echo to establish that the crossing is clear or occupied. This method is used to activate the crossing controllers if a railcar is left on the crossing and to time the train entrance and exit from the crossing for evaluation purposes. They may also be used to determine, in conjunction with the precision navigation system on the locomotive, where the actual end of train is, i.e. real length of train.

The HRI-XA (advanced warning controller) is very similar to the HRI-XS except it lacks the Ultra Sonic sensor. They "SLEEP" most of their lives and are awakened at periodic intervals to be told a train is coming and stay awake during activation. They also depend

on the TIMESLOT strategy used by the rest of the system to conserve energy. All crossing devices maintain time synchronization to the HRI-XM GPS derived clock. This insures accurate TIMESLOT management by all devices.

All HRI-2000 Crossing sub systems, have built in diagnostics to verify that flashers work and the status of the batteries are known at all times for all devices. Upon approach of a train, the crossing devices wake up and remain in a state of alert until the train has passed. The TIMESLOT strategy insures that a wakeup cycle occurs every 4 seconds corresponding to the HRI-XT BEACON transmission. The speed of the train and the distance at which the radio network communicates gives a several minute margin between the HRI-XT wake up and the crossing activation.

Any non-functioning crossing device(s) are detected and an alarm is sent in a special TIME SLOT called the MAYDAY mode. There are typically four HRI-2000 System devices per crossing; including one HRI-XM, one HRI-XS, and two HRI-XA devices to act as MAYDAY senders in the event of a detected crossing failure. The HRI-2000 System can detect lost HRI-XM function by any of the crossing slave (HRI-XS and HRI-XA) devices, because of periodic polling between master and slave devices. If the slave devices detect a number of missed polls by their master, they will enter a MAYDAY mode in which they will take turns, to maximize battery life, sending the MAYDAY broadcast to any locomotives in the area. All remaining slave units will continue to function, and any remaining device can control the intersection. In the event the Master containing the GPS has failed, slave devices will resynchronize their time-base communications by using HRI-XT beacon derived timing allowing proper TIMESLOT operation. This feature insures that faults get reported as soon as possible, even if the locomotive detecting the MAYDAY broadcast is not dealing with the failed intersection. The MAYDAY is sent on a higher power, i.e. 2 watts to insure maximum range. Further, the MAYDAY is only active during times the HRI-2000 crossing hears a beacon broadcast from a locomotive. MAYDAY broadcasts include geo-location data of the failed crossing. This information is then relayed via the cell phone modem in the locomotive to the designated responders.

HRI-2000 System Technology Features

1. **TIME DIVISION MULTIPLE ACCESS** method for controlling radio network, time synchronization through the use of precision timing derived from a Global Positioning Satellite System on both locomotive and crossing systems. This system permits several devices to actively communicate in the area of a single device and not interfere with that device. This feature is important when the system is deployed in the vicinity of several devices using a shared radio frequency.
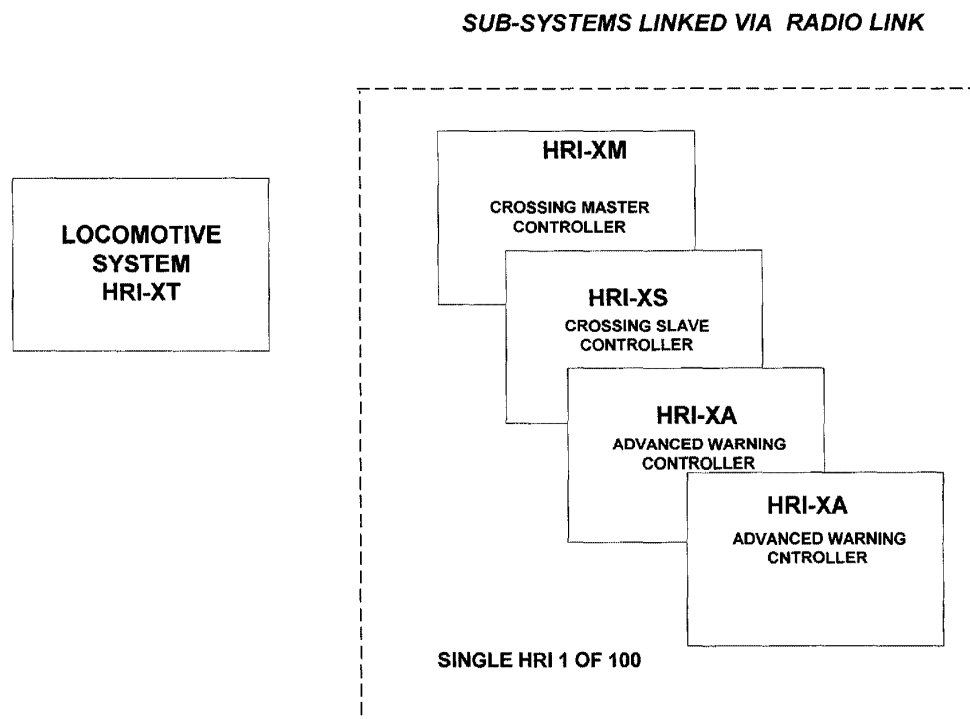
2. **NETWORK CONTROL** is based on TIMESLOT network transmissions, so HRI-2000 crossing units only need be "AWAKE" during certain time intervals, i.e. every 4 seconds. This permits 3 seconds sleep out of every 4 seconds (less than 25% duty cycle) to maximize battery power. The system provides for redundant operations in the event of controller failures at the HRI-2000.

3. **TWO WAY POSITIVE CONFIRMATION** wireless communications links between locomotive and crossing indicating activation, deactivation and status of data.

4. **CROSSING CONTROLLERS** are programmed to measure distance to the train and activate the HRI-2000 crossing system. The crossing system has quadruple redundancy built in to allow operation of functioning devices within the crossing at all times. This permits partial crossing operation in spite of major failures at the crossing.

5. **"CELL STYLE TDMA ARCHITECTURE"** enables inter-crossing communications without interference from/to other nearby crossings. Dual power radio transceivers, for inter-crossing communications, minimize the load on the solar power systems to maximize battery life. Low power transmissions (<100 mw) are used for inter-crossing communications while higher power transmissions (2 watts) are used for MAYDAY broadcasts.

6. **MULTIPLE LOCOMOTIVES ARE SUPPORTED** dealing with a single HRI-2000 Crossing. Individual crossing master controllers can screen out locomotives, which are in the area, but on different courses that will not intersect the crossing.

7. **SOLAR POWER/ BATTERY PACK'S** operate crossing systems 100% of the time. The battery pack is designed to provide 5 full days of operation with minimal solar input. The battery pack uses state of the art long life, low temperature operation AGM(Absorbed Glass Mat) Sealed Lead Acid.

8. **AUTOMATIC FAULT NOTIFICATION** of malfunctioning crossings detected by the locomotives is communicated via Cell Phone Modem/Pager.

9. **DATA COLLECTION CAPABILITIES** on each locomotive. Data is collected and stored in non-volatile memory for post processing on a PC. Collected data is transmitted via cell phone at the end of the day.

10. **HIGH ACCURACY GLOBAL POSITIONING SATELLITE SYSTEM** location with or without use of Coast Guard Global Positioning Satellite system differential transmissions. The System uses USCG DGPS Broadcast data when available or it can fall back on local generated, pseudo range, error data from the master-crossing controller. This data is included in transmissions from the master-

crossing controller to the locomotive and will be used by the locomotive GPS receiver to correct for range errors in its receiver, if needed. This is an important feature as DGPS data is not available in all locations. For this specific operational test there is adequate coverage, as long as the St. Paul USCG DGPS Station is operational.

11. **HANDHELD OPERATOR KEYBOARD AND DISPLAY** allows for verification of crossing operation in advance of the train reaching the crossing. This gives the train crew extra time to respond to unprotected crossings. The Keyboard Display is also used to enter number of cars for train length in backing situations.

12. **POSITIVE "TRAIN ON CROSSING"** identification through the use of dual ultrasonic sensors on cross-bucks. This detection method will be used for operational test verification of the train entering and leaving crossing times. The same feature is used to confirm cars left on crossing.

13. **MINIMUM POWER "SLEEP MODE"** is included on all solar powered devices for power conservation. Accurately timed, wake up for communications synchronization, is maintained by all devices with a precision time base source at each device. Corrections are sent from master crossing controller periodically to correct for time base drift. All time information is obtained via DGPS and is accurate to microseconds. The communications system design allows generous margins for time errors before system performance is affected.

14. **GREAT CIRCLE NAVIGATION METHOD** is used in all navigation calculations for increased accuracy.

15. **EASE OF SERVICE** is maintained in all micro-controllers used in locomotive and crossing systems . All controllers are high performance low power 16 bit processors units and are interchangeable for ease of service. Field replacement can be performed in a matter of minutes

16. **ROADSIDE HARDWARE** is mounted on existing sign or cross-buck posts. No additional site construction work is anticipated, however each existing sign needs to be evaluated for its placement and sturdiness.
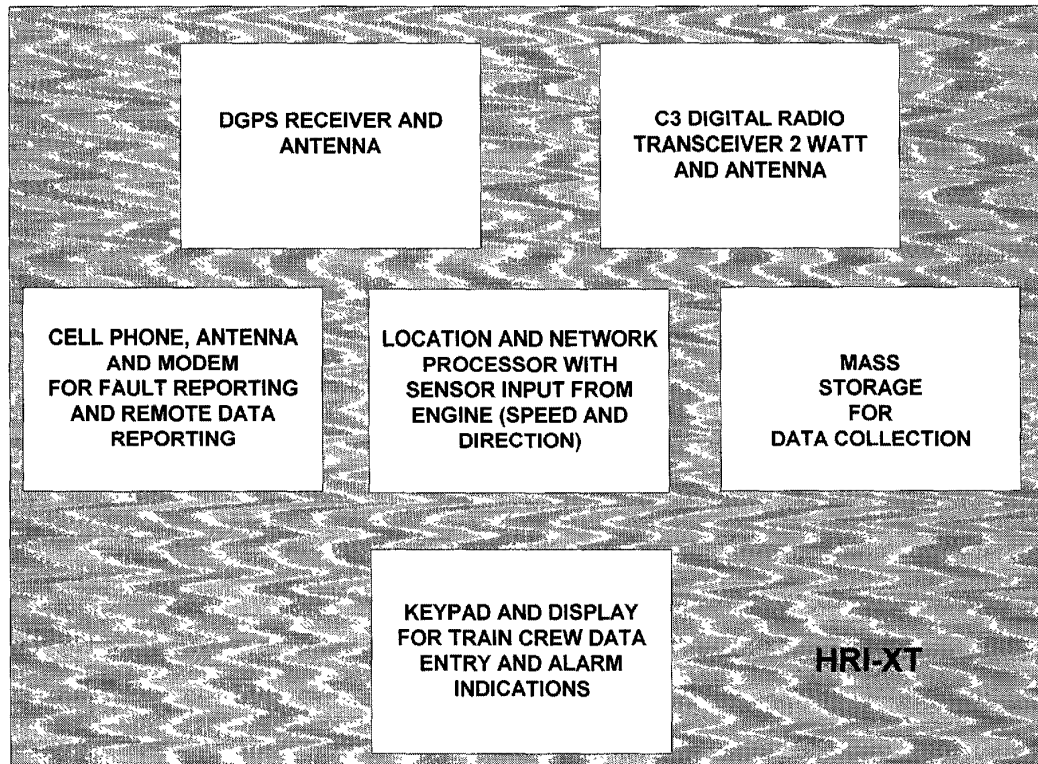
HRI-2000 System Diagrams

The C3 Trans Systems LLC active warning system for low-cost highway-rail intersections includes the following major sub-system:

SUB-SYSTEMS LINKED VIA RADIO LINK

```
                         ┌─────────────────────────────────────────┐
                         │   ┌──────────────────────┐              │
                         │   │       HRI-XM         │              │
┌────────────────────┐   │   │  CROSSING MASTER     │              │
│                    │   │   │   CONTROLLER         │              │
│    LOCOMOTIVE      │   │   │   ┌──────────────────┴───┐          │
│     SYSTEM         │   │   │   │      HRI-XS          │          │
│     HRI-XT         │   │   │   │  CROSSING SLAVE      │          │
│                    │   │   └───┤   CONTROLLER         │          │
└────────────────────┘   │       │   ┌──────────────────┴───┐      │
                         │       │   │      HRI-XA          │      │
                         │       │   │ ADVANCED WARNING     │      │
                         │       └───┤   CONTROLLER         │      │
                         │           │   ┌──────────────────┴───┐  │
                         │           │   │      HRI-XA          │  │
                         │           │   │ ADVANCED WARNING     │  │
                         │           └───┤   CNTROLLER          │  │
                         │               │                      │  │
                         │   SINGLE HRI 1 OF 100                │  │
                         │               └──────────────────────┘  │
                         └─────────────────────────────────────────┘
```

HRI BASIC BLOCK DIAGRAM
MAJOR SUB-SYSTEMS
(FIGURE 1)

The LOCOMOTIVE portion of the system is shown below:

DGPS RECEIVER AND ANTENNA	C3 DIGITAL RADIO TRANSCEIVER 2 WATT AND ANTENNA
CELL PHONE, ANTENNA AND MODEM FOR FAULT REPORTING AND REMOTE DATA REPORTING	LOCATION AND NETWORK PROCESSOR WITH SENSOR INPUT FROM ENGINE (SPEED AND DIRECTION)
	MASS STORAGE FOR DATA COLLECTION
	KEYPAD AND DISPLAY FOR TRAIN CREW DATA ENTRY AND ALARM INDICATIONS

HRI-XT

C3 TRANS SYSTEM LOCOMOTIVE HRI BLOCK DIAGRAM (FIGURE 2)

The locomotive system consists of the following components shown in Figure 2:
- DGPS receiver and antenna.
- 2 watt digital radio and antenna for communications with Crossing Master Controllers
- Keyboard and display for Train Crew information and data entry.
- Location and Network Processor for information processing,
- Removable Flash Memory for archival data collection.

HRI-2000

BEACON BROADCAST LOCOMOTIVE SYSTEM

1 on each approach

ANT

ADVANCEDWARNING
SIGN
C-3 TRANSCEIVER AND
CONTROLLER
LED FLASHER
SOLAR POWER

HRI-XA

ANT

ANT

C-3 Trans Systems
Variable Power
Output
220mhz 2-watt
Transceiver
Data Radio

GPS
Receiver

C3 Computer
System
16 BIT based
with Flash Memory

SOLAR PANEL
BATTERY
POWER SUPPLY
L-ION

HRI-XM

UltraSonic
Train on
Crossing
Detection

CROSSING MASTER CONTROLLER

UltraSonic
Train on
Crossing
Detection

ANT

ANT

ADVANCED WARNING
SIGN
C-3 TRANSRECEIVER
AND CONTROLLER
LED FLASHER
SOLAR POWER

C3 Computer
System
16 BIT based
with Flash Memory

C-3 Trans Systems
100mw
Transceiver
Data Radio

SOLAR PANEL
BATTERY
POWER SUPPLY
L-ION

HRI-XA

HRI-XS

1 on each approach

CROSSING SLAVE CONTROLLER

HIGHWAY RAILROAD INTERSECTION BLOCK DIAGRAM (FIGURE 3)

C3 TRANS SYSTEM HIGHWAY RAIL INTERSECTION SYSTEM COMMUNICATIONS OVERVIEW BLOCK DIAGRAM

MASTER
SLAVE
MASTER
SLAVE

LOCOMOTIVE SYSTEM 2 WATT TRANSCEIVER 220 MHZ

CROSSING SYSTEM MASTER TRANSCEIVER .1-2WATT POWER

CROSSING SYSTEM SLAVE TRANSCEIVER .1-2WATT POWER

ADVANCE WARNING SYSTEM TRANSCEIVER .1-2WATT POWER

ADVANCE WARNING SYSTEM TRANSCEIVER .1-2WATT POWER

LOCOMOTIVE SYSTEM / CROSSINGS
USES 2 WATTS
MESSAGES FROM LOCOMOTIVE
1. (LS/CS) BEACON WITH SP/POS DATA
2. (LS/CS) ACK
3. (LS/CS) UPLOAD DATA

MESSAGES TO LOCOMOTIVE (LOW POWER)
1.(CS/LS) CROSSING ACTIVATED
2.(CS/LC) CROSSING DEACTIVATED
3.(CS/LS) UPLOADED DATA
4.(CS/LS) MAYDAY

CROSSING / ADVANCE WARNING COMMUNICATIONS LINK USES LOW POWER 100 MW DATA RADIO

MESSAGES:

1. (CS/AW) ENTER STANDBY MODE

2. (CS>AW) ACTIVATE WARNING
   (AW>CS) ACK + HEALTH DATA

3. (CS>AW) DE-ACTIVATE WARNING
   (AW>CS) ACK + HEALTH DATA

COMMUNICATION FLOW DIAGRAM
(FIGURE 4)

HRI-2000 System Communications Requirements

HRI-2000 System use 1 narrow band FM channel in the VHF or UHF band. This is a licensed frequency with a power r of 2 watts. All transmitters are considered mobile units. The system uses 2 watts for locomotive BEACON broadcasts and 100 mw for crossing intercommunications. Crossings use 2 watts for its MAYDAY transmissions, when attempting to notify a nearby locomotive. Multiple transmitters are managed through the use of a TDMA control scheme using DGPS timing corrections for Network synchronization.

HRI-2000 Other System Components

SOLAR CELLS

The Solarex SX-30 is a multi-crystal solar electric. Solarex's new SX module series provides cost-effective photovoltaic power for general use. They operate DC loads directly or, in an inverter-equipped system, AC loads. They are suitable for single or multiple-module systems and, with 36 polycrystalline cells in series, charge batteries efficiently in virtually any climate. Their materials, design and construction reflect Solarex's quarter-century of experience. Applications of these modules, which generate peak power ranging from 10 to 85 watts, encompass virtually all applications where photovoltaic are a feasible energy source.

The Solarex brand was chosen for its history in the traffic industry, its 10 warranty (90% original output after 10 years) and because it is the product which is square. This square panel will offer a very small profile compared to other manufactures.

To chose the MSX-30, C3 did a power analysis using the past 20 years of typical solar data for central Minnesota. It was calculated that a panel at 55 degrees mounting angle, pointing south would give a design which is fully charged at all times. Our batteries are used as backup power and night operation. The panel is oversized to ensure we maintain 100% charge at all times. We will use a long life battery but the design will not cycle the battery charge. The solar calculations were done with the intent of the batteries only functioning as backup.

LED FLASHERS

The LED flashers selected were chosen for their bright light, and low power consumption for use on solar cell applications. They are available in either Red or Amber.

C3 TRANS
SYSTEM
HRI FLASHER
4 $^5/_{16}$ "MODULES
RED AND
AMBER
12V .44 AMP

3/4 "
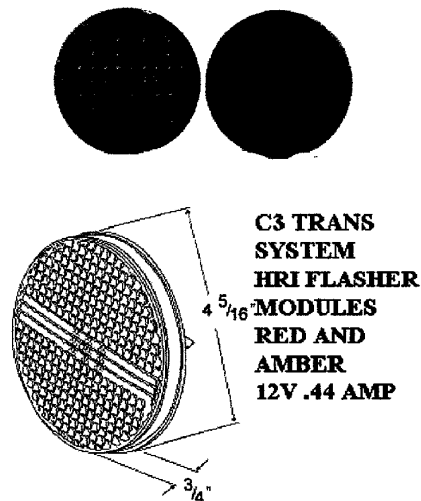
Sealed AGM BATTERIES

The Concord SunXtender PVX1234T battery was specifically designed to meet the needs of tomorrow's advanced remote solar and communications devices. This is an extended life deep cycle battery rated for –40C to 72C operation. Its typical application is for remote telecommunication repeaters and navel beacons.

The Model PVX1234T combines a high capacity with a convenient narrow footprint to provide as superior energy solution for a wide variety of portable electronic devices. The specified capacity for this design in 34A-H, which is well beyond the required 5 day autonomy,

Note: System components may vary slightly, from those shown, as new technology and new components become available, or to fit special conditions.

HRI-2000 Systems Installation

At the Intersection
Each HRI-XM, XS, and XA system unit to be installed at the crossing is totally self-contained so no wiring, communications, or construction is needed to install the system. The installer's tool is a banding tool to strap the box to the post and in some cases a wrench to tighten bolts.

In the locomotive
Each HRI-T system is self-contained. They can be firmly mounted in the locomotive cab, or not, depending on the Railroads needs. As described the Locomotive Data Entry and Display unit is hand held.

For questions or additional details contact:

C3 Trans Systems LLC
368 West County Road D
New Brighton, Minnesota 55112
Ph (631) 638-0365
Fax (651) 633-4036
Email info@c3trans-systems.com

Attachment B

C3 Radio Protocol for Collision Avoidance
C3 Confidential

Definitions and description:

1)   BAUD: Bits of Data per Second

2)   Byte: 8 Bits of data representing an asci character or a number of 0-255

3)   Communications protocol for MX909A RF Chip Set is Mobitex
         Frame Header(1 only per xmit) / Data Blocks(0-32 per xmit)
         Header (7 bytes):   (56 bits)
                                              16 bits of bit sync (MXCOM recommends a 32 bit prelude warm-up)
                                              16 bits of frame sync
                                              16 bits of control byte (this is 2 bytes of user info if no Mobitex)
                                              8 bits if forward error correction
         Data Blocks (30 bytes):   (240 bits)
                                              18 bytes of data
                                              2 bytes of CRC for the above 18 bytes
                                              4 bits of FEC per byte for 80 bits total of above
         Minimum xmit is header only for 56 bits, 16 bit control byte of our data. Each additional 240 bits
         has 18 bytes of data. For each header we can allow 32 consecutive data blocks.

4)   A typical 4800-baud data xmit follows:
                                              Header only is 56 bits at 4800 baud for 12ms
                                              Data block is 240 bits at 4800 baud for 50ms

         Header + Data = 62 ms + 2ms guard = 64 ms total. When we add our 1ms dead band between
         transmits we have 65ms total.

Per MXCOM technical support – Keith @ 1-800-638-5577
1)   We first have receiver do carrier detect
2)   We next interrupt processor to tell it a carrier is present
3)   Processor now tells 909 to watch the bit sync and measure phase and amplitude – lock in
         This should be more then the 16 bits the manual shows. Use a recommended 32 minimum.
4)   No the 909 receivers know what to look for and will lock in on the Frame Sync when it arrives.
5)   We can use the 16 bit control data if we do not adhere to the mobile text protocol.

Special notes on Latitude and Longitude:
The earth is divided into a grid work for referencing absolute position. The equator goes around the middle
of Earth like a belt. It divides our planet into the Northern Hemisphere and the Southern Hemisphere. The
equator is a line of **latitude.** Latitudes are also called **parallels** since they run East and West. Parallels
measure distance north and south. Their are 90 degrees of latitude in the northern hemisphere and 90 in the
southern. Another set of imaginary lines helps us measure distance east and west. These are lines of
longitude. Each line of longitude runs from the North Pole to the South Pole. These lines are also called
meridians. The longitude is divided 360 degrees around the earth.

Longitude: One degree is 69 miles at the equator, measuring east/west, 40 miles in MN
Latitude: One degree is 60 miles in Minnesota, measuring north/south

C3 Radio Protocol for Collision Avoidance
C3 Confidential

### Definitions and description (Continued):

30mph = 44 ft per second. If we use a 2 second window we have 88 feet (1/60 mile) between transmits. This should work with a train moving fast since changes in speed should be slow based upon inertia. However, when a train is sitting on a track by an intersection we need to quickly update speed changes. One second would be a great beacon time for zero to 2 miles per hour and now in the intersection. There is no perfect solution.
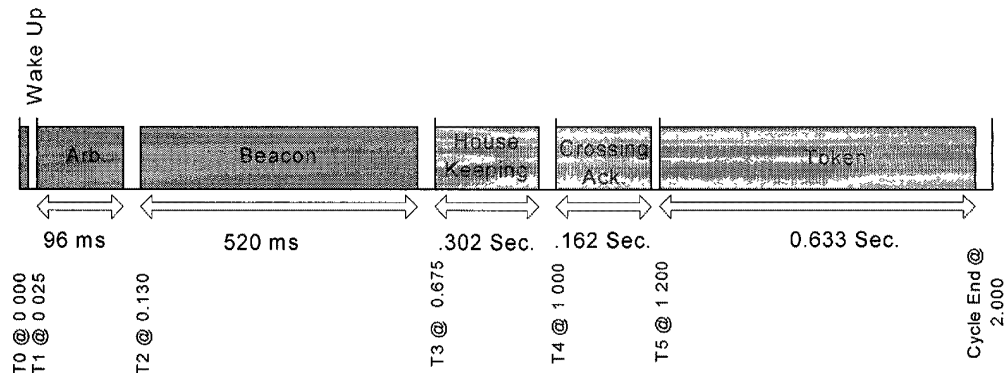
Overview of HRI Communication Windows

Detailed information for each timing window follows. All units will be synchronized to the GPS clock but things will not be 1ns of accuracy. We need a guard band around every timing window. If we say each unit may drift a maximum of 1ms then we are required to have a 2ms guard, or 1ms on both sides.

Communication details – Guard Band
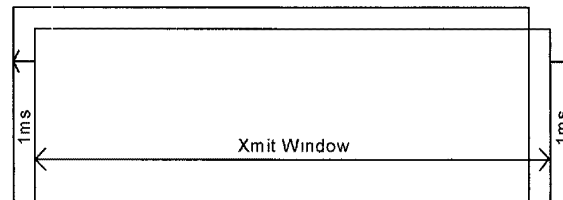
For each transmit we have it could occur 1ms early or 1ms late from the nominal expected window. If I am going to have a 10 ms total window I must have a maximum receive window of 10ms + 1ms + 1ms = 12ms plus a dead band between transmits.

Communication details – Dead Band

From one transmit to the next we will have a dead band of 1ms. This time will let the processor receive and decode the last communication. This will also let our processor act as a state machine of 1000, 1ms timed functions.
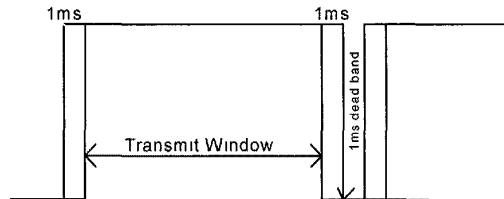
T0 – Wake Up at "0ms:"

This is a special short window at time T0. **Any** device that will **transmit** any data must use this window first to tell the HRI – "wake up and listen". If a HRI hears this window it knows to listen more. If a HRI master wants to talk to its slaves it must use this window to tell them to wake up and listen. Every locomotive broadcasts in this window prior to sending the beacon. Typically our intersections will only listen to this and can sleep the other part of their days away.
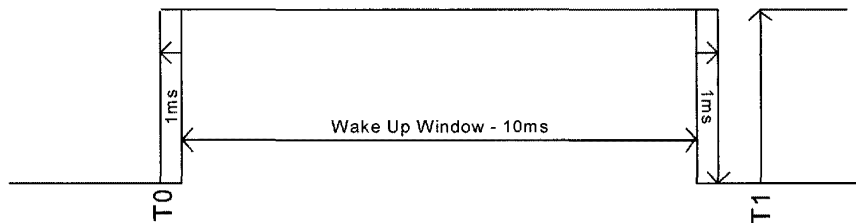
T0 lasts for 1ms + 10ms + 1ms +1ms dead band for 13ms, which gives T1 at 13ms or beyond. I will pick 25 ms for now to give flexibility in the wakeup if required later In 10ms we are not able to send out our header, which takes 12ms. This wakeup is just a carrier detect and lock.

T1 – Locomotive Arbitration window at "25ms":

General Info:

    This protocol allows 8 locomotives in any communication grid. This scheme uses the beginning interval of the BEACON transmission from the locomotive to encode the active channels that are being used. This encoding is our network protocol, which allows the locomotives to chose the correct channel for data xmit. The first half of this time slot does the locomotive arbitration while the second half is the actual beacon transmit. If we add a locomotive it will cost 12ms + 67ms for 79ms total.

T1 overview:
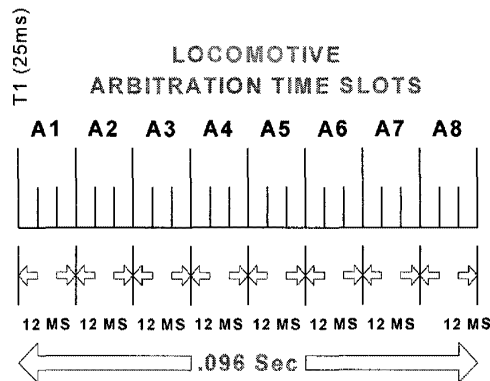
The arbitration is done with a 2ms carrier detect
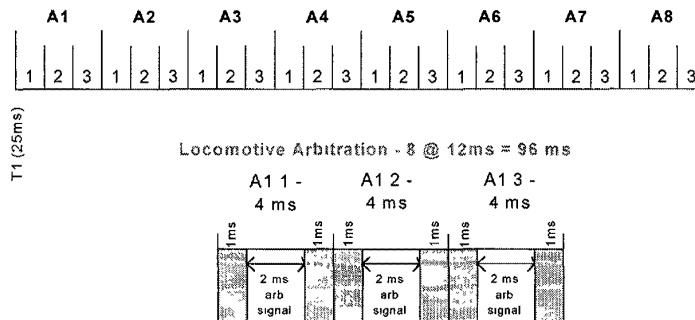
A1 expanded view - 3 @ 4ms = 12ms

A1-A8 are divided in to 3, 4ms windows each for 24 sub windows. The total Arbitration is .096 seconds.

Locomotive Arbitration Example (8 maximum in communication):

1)   If locomotive #1 is in time slot A1 then it will randomly xmit its arbitration beacon in 1 of the 3 sub slots of A1 while listening to all other 23 slots. Using this procedure the Locomotive will know:
    A)   Is their another Locomotive in the same slot?
    B)   What time slots are used?

Arbitration Details continued:

C)   If locomotive A and locomotive B are in Beacon slot 1 they randomly xmit their arbitration in one of the 3 arbitration sub slots, A1.1 – A1.3. If locomotives hear other locomotives in their arbitration window they know 2 or more locomotives are in the same beacon interval – this is bad. They next figure out who was 1st, 2nd and so on. The first sub-slot will stay in the first beacon time window. The second will take the second beacon channel and the third the next
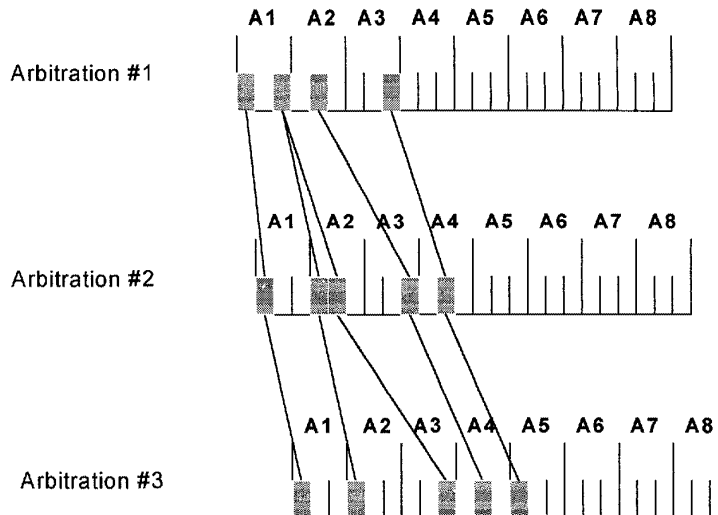
In arbitration 1 of the above example, we have 4 known locomotives. Two or more are in A1, one is in A2 and at least 1 is in time slot A3

Arbitration 1:
The first locomotive was A1.1. This locomotive will stay in slot since he was the first device to use an arbitration slot. The locomotive in time slot A1.3 will move to A2 since he was the second device to arbitrate a position. This proceeds through all 8 locomotives. Each Beacon window following arbitration will reflect the choices shown in Arbitration 2.

Arbitration 2:
After arbitration #1 the locomotives use the assigned beacon position. They will then re-arbitrate again at random positions 1-3 of their time slot in arbitration#2 as shown above. The locomotive in time slot #1 believes he is the only one in one and the first in a string of arbitrations so he will stay there. The locomotive in A2.1 discovers he is the first in A2 and will stay there as well. The locomotive in A2.3 discovers he was the third and thus should be in beacon slot A3 and will move to this slot. The locomotive in slot A3.3 discovers he was the fourth and thus should be in A4 and will move over to this slot. This proceeds down through all slots and locomotives. After arbitration #2 the locomotives use the assigned beacon position.
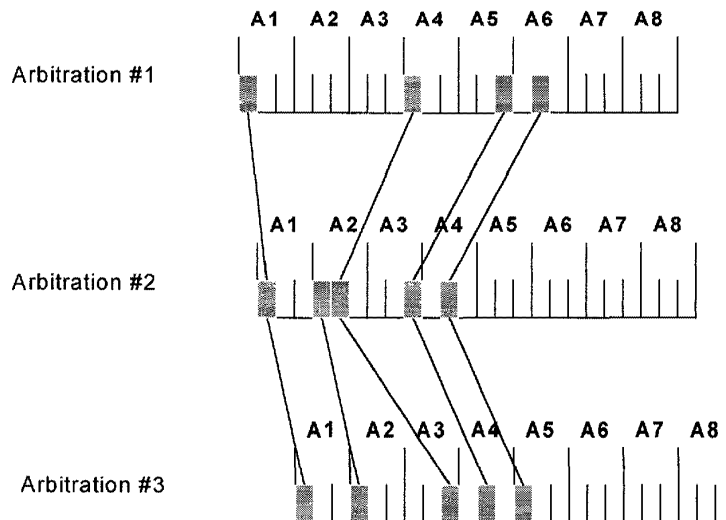
Arbitration 3:
Each Locomotive will re-arbitrate again at random positions 1-3 of their time slot in. This set of locomotives will all use the beacon channel they are in and will randomly select sub slots 1-3 of their arbitration window for each subsequent arbitration.

Arbitration Details continued:

2)   If a wake up is received, the crossing knows to listen to arbitration. The master HRI will now know many trains are dialoging and in what beacon slots to listen. If no arbitration occurs but A0 was used the HRI knows a master HRI is going to transmit or an acknowledge will occur.

3)   Use the GPS lat and long as the seed for the random number generator.

**Example of arbitration when locomotives in the middle drop out.**

In the above example we have a situation where we previously had 6 locomotives but now have only 4. For some reason, 2 dropped out of communication range. These two are either permanently out or range or will fade back in soon. Either way, the algorithm is the same. The first arbitration slot goes to A1, the second to A2 and so on. We see that in Arbitration #2 the locomotive which was their fades back in. This will force all locomotives after this one to move down one and let this new guy in. It should be noted that in this fad in and out case of 1 locomotive we will not lose many communication since they see the problem and immediately adjust their beacon and re-arbitrate again every cycle.

Finally – the crossing always knows what slot to listen in and only need wake up for the A0 wake up call every time. By default any locomotive all by it self will be in slot A1 and beacon #1

T2 –Beacon window details:
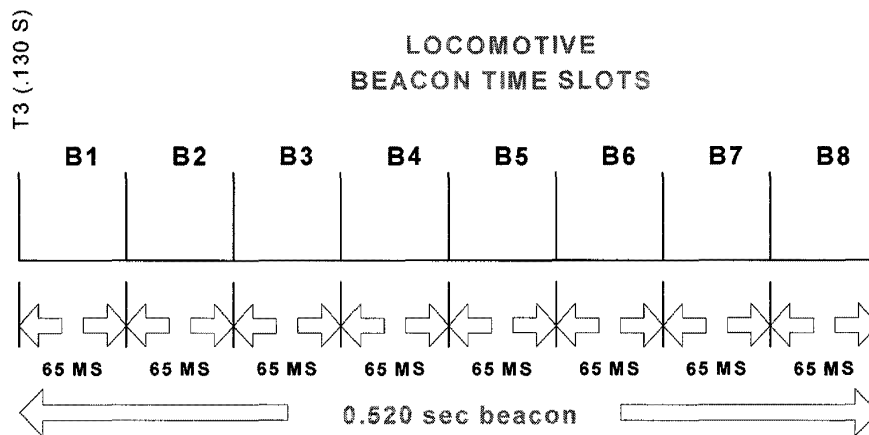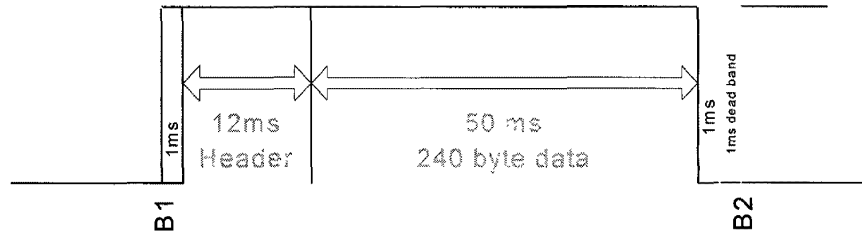
The beacon is after the arbitration and the Locomotive time slot takes into consideration the arbitration results. Every locomotive will xmit a header followed by a data block containing the position, heading and speed.
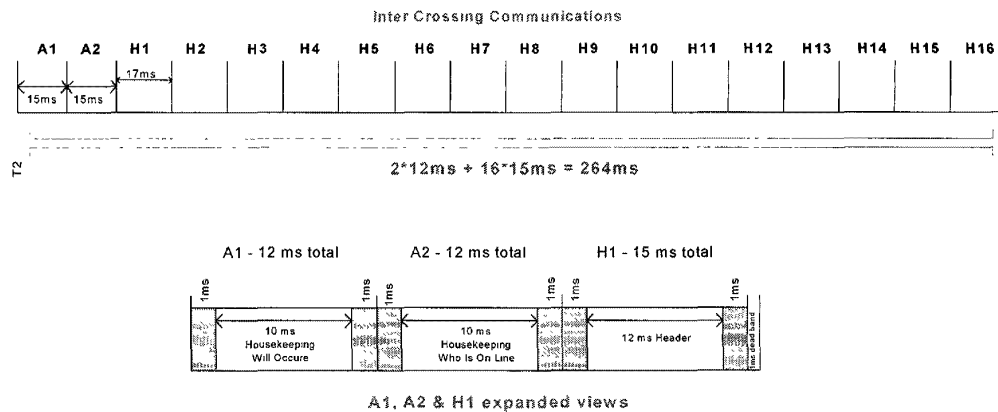
T3 – Inter Crossing Communications (housekeeping):

All housekeeping will be done **at low power**, approximately 100mw. This will drastically limit the range of communication and cross talk. We have no real control of the installations, number of devices per crossing or distance between crossings. We thus must have another arbitration protocol to clean up our communication and optimization. The concept is for every crossing in range of each other to have a specific time slot. We must pick a maximum number of crossing devices per area. In this protocol we are limited to 16 devices in any 300-meter range. Clusters can overlap and will have unique ID's. The housekeeping is used for status, light on, lights off and so on. It should be noted that the locomotives have a special 0.6 seconds for arbitration whereas the HRI have no special arbitration time. This happens so seldom since they are stationary we can do it in our command structure.

Housekeeping continued:

Inter Crossing Communications

2*12ms + 16*15ms = 264ms

A1 - 12 ms total   A2 - 12 ms total   H1 - 15 ms total

A1, A2 & H1 expanded views

Installation details of Crossings:

- During instillation the XM, XS & XA's will be told what they are. The XM will also be told what their crossing is as a system. In the below example every device would know it is an XM, XS, XA1 or XA2 for 4 devices total. The time slot selection will follow this structure of XM, XS, XA1 & XA2. This is very important to simplify the intercrossing communication protocol.
- During installation of East West running tracks the XM will always be on the North side and the XS will always be on the South side. During installation of North South running tracks the XM will always be on the West side and the XS will always be on the East side.
- The first XA from the master on the north/west side will be programmed to XA1, second XA2 and so on.
- The first unit on the south/east side would be the next sequential number, XA3 in this example. We continue increasing as we add XA's.
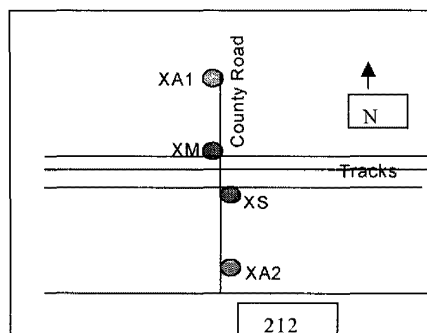
## Housekeeping Command Protocol:

No T0 Wakeup – No Housekeeping:
To conserve power everyone turns on at T0 to see if anything is going on. In the following case nothing is going on so after 12ms everyone goes back to sleep for the remainder of the 2 second communication cycle. This gives a .6% wakeup duty when nothing is happening.

C3 Radio Protocol for Collision Avoidance
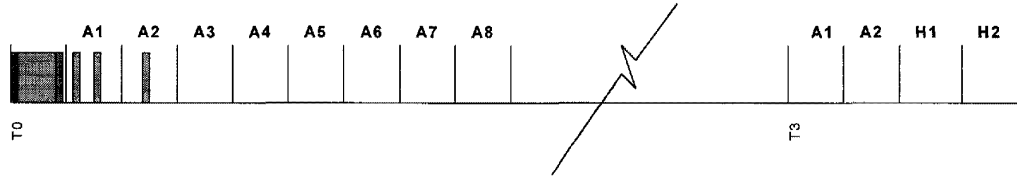# C3 Confidential

No T0 Wakeup - so everything is quiet

A1 A2 H1 H2

T0   T3
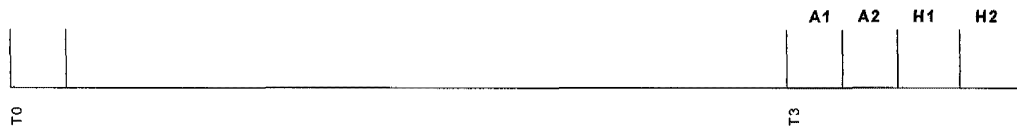
T0 Wakeup – No Housekeeping:
Again, at T0 everyone wakes up and listens. In the following example we see a T0 wakeup. At this time we do not know if it is a locomotive, housekeeping or both. Everyone must listen to the beacon arbitration. We see 3 of the 24 slots utilized so we know we must listen to Beacon 1, 2 & 3 for there are 3 locomotives. At T3, we wakeup and listen to see if any crossing communications are required. We see no A1 Wakeup so we sleep again.

Beacon Only - No Housekeeping

A1 A2 A3 A4 A5 A6 A7 A8   A1 A2 H1 H2

T0   T3

T0 Wakeup With Housekeeping:
Again, at T0 everyone wakes up and listens. In the following example we see a T0 wakeup. At this time we do not know if it is a locomotive, housekeeping or both. Everyone must listen to the beacon arbitration. We see no arbitrations so we sleep through the beacon timeframe. At T3, we wakeup and listen to see if any crossing communications are required. We see A1 is used but A2 is not so we listen to our masters only.

No Beacon - Just Housekeeping

A1 A2 A3 A4 A5 A6 A7 A8   A1 A2 H1 H2

T0   T3
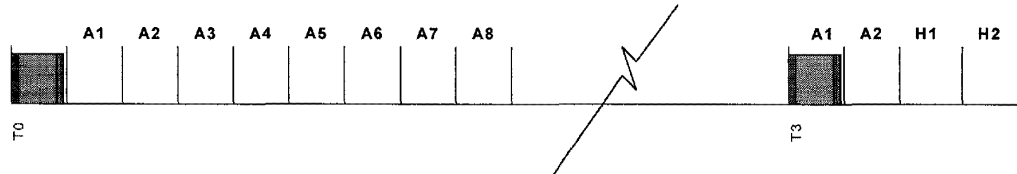
In the above example we could have had a beacon as well – it makes no difference to the A1 wakeup. If an XM master wants to talk he must do a wakeup at T0 and T3.A1.
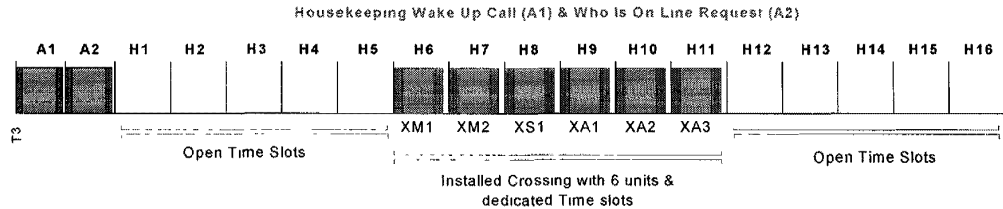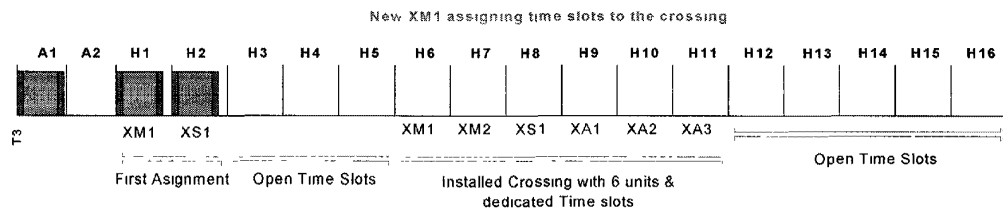
Housekeeping Command Protocol (Continued):

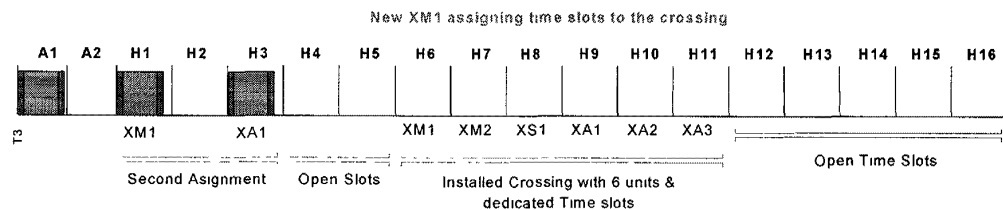### Time Slot Selection Details of Crossings:

1) On first power up, the crossing master will transmit a status request in the second arbitration slot. This is done at the 100-mw-power level to see all local crossings in radio range with a programmed time slot. Every crossing with a time slot answers with status in its time slot. The new HRI warnings will not answer since they do not have time slot. This teaches the master what is going on in his small 100mw world.

Housekeeping Wake Up Call (A1) & Who Is On Line Request (A2)

| A1 | A2 | H1 | H2 | H3 | H4 | H5 | H6 | H7 | H8 | H9 | H10 | H11 | H12 | H13 | H14 | H15 | H16 |

Open Time Slots

XM1 XM2 XS1 XA1 XA2 XA3

Installed Crossing with 6 units & dedicated Time slots

Open Time Slots

2) Now our XM1 knows the open time slots are (H1-H5 & H12-H16). The XM1 was preprogrammed with this HRI size and configuration (say 4 XM1/XS1/XA1/XA2). The XM1 will now pick the first open slot and program its slaves 1 by 1 verifying proper time slot progression. In this example, the XM1 will program and receive positive confirmation of XS1. The XM1 will specify it is talking to any un-programmed XS1 and will tell the XS1 what its set time slot will be. The XS1 immediately takes the time slot and responds to the XM1 with the echo of its program command in it programmed slot. The XS1 will now only answer the XM1 in time slot H1. The XS1 knows who programmed it and who it should listen to from this point forward.

New XM1 assigning time slots to the crossing

| A1 | A2 | H1 | H2 | H3 | H4 | H5 | H6 | H7 | H8 | H9 | H10 | H11 | H12 | H13 | H14 | H15 | H16 |

XM1 XS1

XM1 XM2 XS1 XA1 XA2 XA3

Open Time Slots

First Asignment   Open Time Slots

Installed Crossing with 6 units & dedicated Time slots

After the new XM1 is able to communicate with the XS1 it will communicate with the XA1 (next on its control list). This process will follow the same protocol. To save power during installation the XM1 should be the last device to be powered up allowing quick setup and less transmits of setup. Every device must know what it is and every master must know the total HRI configuration.

New XM1 assigning time slots to the crossing

| A1 | A2 | H1 | H2 | H3 | H4 | H5 | H6 | H7 | H8 | H9 | H10 | H11 | H12 | H13 | H14 | H15 | H16 |

XM1 XA1

XM1 XM2 XS1 XA1 XA2 XA3

Open Time Slots

Second Asignment   Open Slots

Installed Crossing with 6 units & dedicated Time slots

This will proceed until the XM1 believes all is well and everyone is programmed. The XM can verify final installation by asking for status and hearing back from his HRI units. Only his units will answer since all XA's and XS's only listen to the master whom programmed them and answer this master.

Housekeeping Command Protocol (Continued):

GPS coordinate programming:

At this time the XM1 must program all units in this HRI with the proper installed GPS coordinates. This GPS data is only programmed on the first power up configuration and is only used for master failure backup. To do this we use 8 transmits with a command telling the XS & XA's what is coming. The XM1 will then send a command telling all future devices at this crossing what the command and byte are – say longitude 4, Byte 4 of longitude. Every device in the network will echo back the command they just received so the master knows if things are ok.

XM1 Sending GPS Data followed by XS & XA echo of data
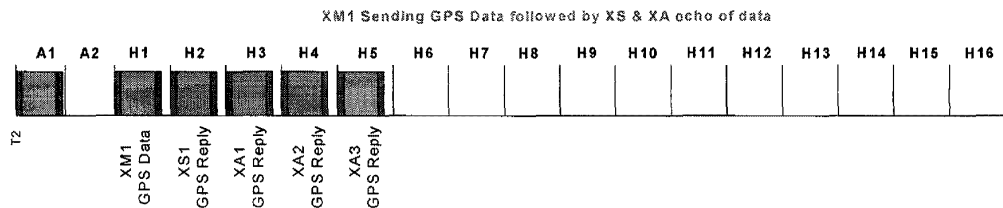
After any unit receives its geo-position it will immediately respond with an acknowledge command so the XM1 can verify everyone was programmed correctly. If the XM1 does not get a proper response from the HRI it will know there was a problem and will resend the GPS byte in error.

T4 Locomotive Acknowledge From HRI MX:

This basic T4 communication window is for sending the locomotive our status and so on. This is done at high power and needs to be flexible for many crossings in our 2-mile radius. If we pick and assign time slots we will dedicate a huge block of time to a window used seldom and almost never by 2 or more at a time. We will also never pick enough – 10 crossings, 20 crossings 100 crossings, who is to say? To make this short and simple, yet flexible, we will arbitrate randomly on 8 widows and the first 2 requests will get the Acknowledge windows.

When we respond we need to transmit the position since the crossing just replies to all locomotives in general and the locomotive decides what to do with this information. We do this communication from the crossing to the locomotive after the housekeeping because we can quickly and efficiently answer status In the same timing window. The only time I wake up and listen to this window is if I want to use it. If I am not talking to a locomotive, I just sleep away this section. We will seed our random number generator by when we first turned on our crossing from a locomotive activation or projected activation.
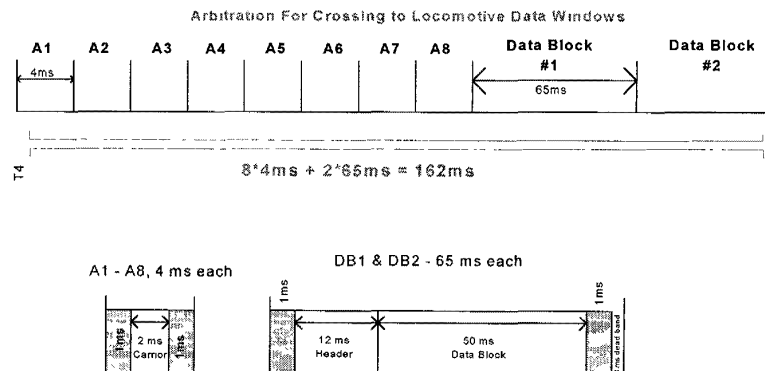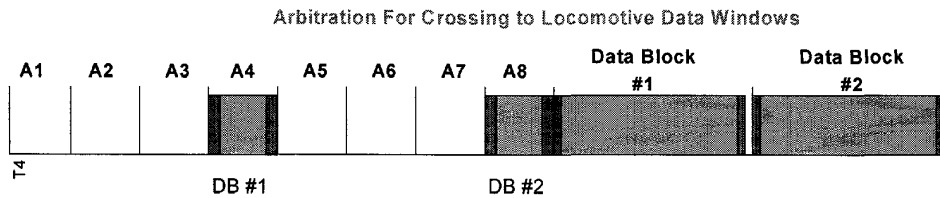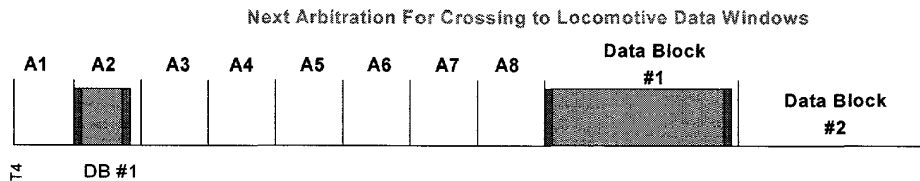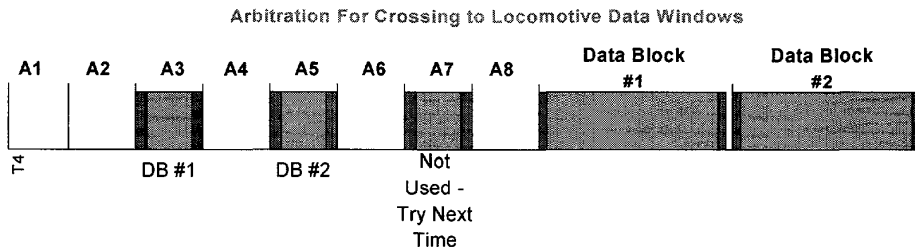

Expanded Window Details

T4 Locomotive Acknowledge From HRI MX (Continued):

Arbitration For Crossing to Locomotive Data Windows

In the above example, we have two HRI Crossing master XM's. Each of these XM's wants to transmit some information to a Locomotive. These two XM's will randomly select a position A1 through A8 based on the seed of the locomotive arrival at the crossing. These two crossings were the only ones requesting to communicate so they both get to talk in the acknowledgement windows.

Arbitration For Crossing to Locomotive Data Windows

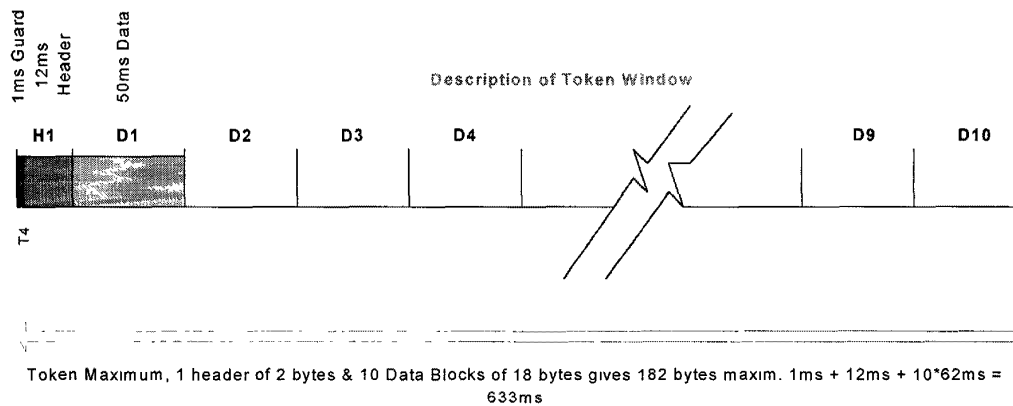Next Arbitration For Crossing to Locomotive Data Windows

In this example we have three requests for the acknowledge window from and HRI XM to a Locomotive. We are only able to do two of these and the third must wait until the next window.

T5 Token description:

This basic T5 Token communication window is for sending large block of data quickly. This is accomplished by using 1 guard band and header followed by 10 streamlined data blocks.

Token Maximum, 1 header of 2 bytes & 10 Data Blocks of 18 bytes gives 182 bytes maxim. 1ms + 12ms + 10*62ms = 633ms

A typical 8 crossing data map would be 4 long., 4 lat, by 8 for 64 bytes + 40 unknown for 100 maxim.

C3 HRI Beacon Command Details:

Header is 7 bytes, with 2 bytes free for commands

Byte # 1 (command)
0x00 – Standard Beacon with Position, Speed & Heading only.
0x01 – Beacon with Position, Speed, Heading and a Token request
0x02 –
0x03 –
0x04 –
0x05 –
0x06 –
0x07 –
0x08 –
0x09 –

Byte #2 (data)
Locomotive CRC for a map centered on my current coordinates.

Data Block is 30 bytes with 18 bytes free for commands

Byte #1	Latitude Byte #4
Byte #2	Latitude Byte #3
Byte #3	Latitude Byte #2
Byte #4	Latitude Byte #1
Byte #5	Longitude Byte #4
Byte #6	Longitude Byte #3
Byte #7	Longitude Byte #2
Byte #8	Longitude Byte #1
Byte #9	Speed Byte #1
Byte #10	Heading Byte #2
Byte #11	Heading Byte #1
Byte #12	
Byte #13	
Byte #14	
Byte #15	
Byte #16	
Byte #17	
Byte #18	

C3 HRI Housekeeping XM Master Commands:

The Housekeeping only uses the 7 byte Header, with 2 bytes free for commands.

Byte # 1 (command)

Byte #2 (Data)

0x00 – Status Request
N/A (xxxxxxxx)
Bit 7, 1 = LED's on, 0 = LED's off
Bit 6, 1 = Bat SOC >90%, 0 = Bat SOC <90%
Bit 5,
Bit 4,
Bit 3,
Bit 2,
Bit 1,
Bit 0,

0x01 – Resynchronize Time — N/A (xxxxxxxx)
0x02 – Turn on — 0-xx.x seconds to on (0-25.5)
0x03 – Turn off — 0-xx.x seconds to off (0-25.5)
0x04 – Latitude 4 — Byte 4 of 4-byte latitude
0x05 – Latitude 3 — Byte 3 of 4-byte latitude
0x05 – Latitude 3 — Byte 2 of 4-byte latitude
0x06 – Latitude 1 — Byte 1 of 4-byte latitude
0x07 – Longitude 4 — Byte 4 of 4-byte latitude
0x08 – Longitude 3 — Byte 3 of 4-byte latitude
0x09 – Longitude 2 — Byte 2 of 4-byte latitude
0x0a – Longitude 1 — Byte 1 of 4-byte latitude
0x0b – Battery Status — N/A (xxxxxxxx)

0x0c – Program Housekeeping Slot
(dip switch on slaves programs)
(this same information)

Bit 7,   0 = XA, 1 = XS

Bit 6,5,4   000 = Unit 1
001 = Unit 2
010 = Unit 3
011 = Unit 4
100 = Unit 5
....

Bit 3,2,1,0   0000 = Housekeeping Slot 0
0001 = Housekeeping Slot 1
0010 = Housekeeping Slot 2
0011 = Housekeeping Slot 3
0100 = Housekeeping Slot 4
0101 = Housekeeping Slot 5
0110 = Housekeeping Slot 6
0111 = Housekeeping Slot 7
...

C3 HRI Housekeeping XS & XA responses:

The Housekeeping only uses the 7 byte Header, with 2 bytes free for commands. The XS & XA's answer every command in their appropriate time slot. These devices have an 8 pin dip-switch telling them what they are so they know what to listen for on power up.

Byte # 1 (command)
> 0x00 – Status Reply

Byte #2 (Data)
> Bit 7 – Battery voltage is > 90% SOC (1), (0) if low
> Bit 6 – Lights are on (1), (0) if off
> Bit 5 –

Byte # 1 (command)	Byte #2 (Data)
0x01 – GPS Time Synchronized	xxxxxxxx
0x02 – Turn on in	0 – xx.x seconds received
0x03 – Turn off in	0 – xx.x seconds received
0x04 – Latitude 4 received	Byte 4 of 4-byte latitude
0x05 – Latitude 3 received	Byte 3 of 4-byte latitude
0x05 – Latitude 2 received	Byte 2 of 4-byte latitude
0x06 – Latitude 1 received	Byte 1 of 4-byte latitude
0x07 – Longitude 4 received	Byte 4 of 4-byte latitude
0x08 – Longitude 3 received	Byte 3 of 4-byte latitude
0x09 – Longitude 2 received	Byte 2 of 4-byte latitude
0x0a – Longitude 1 received	Byte 1 of 4-byte latitude
0x0b – Battery Status	xx.x volts (00.0 – 25.5)
0x0c – Program Housekeeping Slot	Device type, and slot is echoed back. (This XS or XA knows who programmed it and who to listen to in the future)

C3 Radio Protocol for Collision Avoidance
C3 Confidential

C3 HRI Acknowledgement XM responses:

The Acknowledgement uses the Header and 1 data block. The XM's arbitrate 1 of 2 beacon windows prior to any acknowledgement.

Header is 7 bytes, with 2 bytes free for commands

Byte # 1 (command)

0x00 –	Status Ack – No token (tells train I am here and see you)
	This is sent 45 seconds prior to train arrival.
0x01 –	Map Ack & Token request (send my map to train)
0x02 –	Bad Beacon Ack – No Token (tell trains your arb is bad)
0x03 –	

Byte #2   CRC for the map currently contained in RAM

Data Block is 30 bytes with 18 bytes free for commands

Byte #1	Latitude Byte #4
Byte #2	Latitude Byte #3
Byte #3	Latitude Byte #2
Byte #4	Latitude Byte #1
Byte #5	Longitude Byte #4
Byte #6	Longitude Byte #3
Byte #7	Longitude Byte #2
Byte #8	Longitude Byte #1
Byte #9	Status
Byte #10	Data of last map update
Byte #11	CRC for above
Byte #12	(If Bad Beacon Ack. Tell 1-8 beacon window)
Byte #13	
Byte #14	
Byte #15	
Byte #16	
Byte #17	
Byte #18	

Example – locomotive beacons:

1) A locomotive is just passing time and heading down the track – nothing is around and it is in beacon slot 1
   - At time T0 it will use the wake up followed by Arbitration slot A1.
   - It will next randomly pick a sub slot of A1.a – A1.c and listen to all 27 remaining arbitration slots.
   - It will discover that it is the only locomotive around and thus stay in beacon slot #1
   - In the Beacon #1 Header the locomotive will xmit command 0x00 and its ID. This is a Beacon only transmission. This would leave the token open for the next locomotive or intersection to use. The token is grabbed by whoever takes it first.
   - In the Beacon #1 Data block it will xmit position, heading and speed.
   - The locomotive always is listening when it is not transmitting so it will just listen until it either arbitrates with another train or it is replied to from an intersection.

2) This single locomotive has approached a single intersection and now receives and acknowledge. This assumes the HRI master is functional.
   - All the same as above – just a simple beacon.
   - The intersection has been programmed and arbitrated so I will skip these issues. This HRI is fully set up for position, housekeeping and acknowledge. We look at the Beacon and see if it is time to respond or not. If not we sit and watch the locomotive approach and verify proper vectors and so on. When the Locomotive is 45 ± 1 seconds it is time to act as follows.
   - In time slot T3 the HRI XM will transmit control command 0x02 – Turn On - with 10-13 seconds countdown to the HRI's in the same time slot.
   - In the XS and XA slots for this crossing we receive back 0x01 – Status Reply xxxxxxxx.
   - The HRI XM looks at the replies to verify everyone is working and received the turn on command.
   - If the XM sees an error it can retransmit the turn on command a second time and watch the replies. This can be done 3 times to ensure we have more then 1 chance to do a correct xmit from the master to all intersections.
   - By 35 seconds from arrival I must acknowledge the locomotive. I will reply in the acknowledge slot T4 as arbitrated in this slot. I return my HRI Status in the control block of the header and Position in the data block. The Locomotive will display my status accordingly. If a HRI unit has failed we never try to turn it on again after an acknowledge to the locomotive.

3) This single locomotive has approached a single intersection and now receives and acknowledge. This assumes the HRI master functions but the XS or XA failed.
   - All the same as above – just a simple beacon.
   - The intersection has been programmed and arbitrated so I will skip these issues. This HRI is fully set up for position, housekeeping and acknowledge. We look at the Beacon and see if it is time to respond or not. If not we sit and watch the locomotive approach and verify proper vectors and so on. When the Locomotive is 45 ± 1 seconds it is time to act as follows.
   - In time slot T3 the HRI XM will transmit control command 0x02 – Turn On - with 10-13 seconds countdown to the HRI's in the same time slot.
   - In the XS and XA slots for this crossing we receive back 0x01 – Status Reply xxxxxxxx.
   - The HRI XM looks at the replies to verify everyone is working and received the turn on command. The XM will immediately know there is and error and a unit is nonfunctional.
   - The XM can retransmit the turn on command a second time and watch the replies. This can be done 3 times to ensure we have more then 1 chance to do a correct xmit from the master to all intersections.

- By 35 seconds from arrival I must acknowledge the locomotive. I will reply in the acknowledge slot T4 as arbitrated in this slot. I return my HRI Status in the control block of the header and Position in the data block. The Locomotive will now know I have and error and will call in the problem. MY HRI will function to the best of its abilities less whatever has failed.

4) This single locomotive has approached a single intersection and now receives and acknowledge. This assumes the HRI master failed but the XS functioned.
    - All the same as above – just a simple beacon.
    - The intersection has been programmed and arbitrated so I will skip these issues. This HRI is fully set up for position, housekeeping and acknowledge. We look at the Beacon and see if it is time to respond or not. If not we sit and watch the locomotive approach and verify proper vectors and so on. When the Locomotive is 45 ± 1 seconds it is time to act as follows.
    - In time slot T3 the HRI XM did not transmit – it has failed.
    - The XS and XA's know there is a problem but do nothing.
    - During the next timing window slot T3 the HRI XM again does not transmit – it has failed.
    - The XS and XA's know there is a problem but do nothing.
    - During the third timing window slot T3 the HRI XM again does not transmit – it has failed.
    - The XS and XA's know there is a problem. The XS will now set itself to the XM housekeeping slot and act as a master.
    - In the next timing interval The HRI XS is now an XM and it will transmit control command 0x02 – Turn On - with 2 –5 seconds. The XM will immediately know if the other devices function and will respond accordingly.
    - By 30 seconds from arrival the XM must acknowledge the locomotive. I will reply in the acknowledge slot T4 as arbitrated in this slot. I return my HRI Status in the control block of the header and Position in the data block. The Locomotive will now know I have and error and will call in the problem. MY HRI will function to the best of its abilities less whatever has failed.

5) This single locomotive is approaching our intersection. When the HRI responds with an Ack. the HRI CRC for the map is forwarded as well. The Locomotive will look at the acknowledge location of the HRI and CRC. Then it will calculate its CRC and verify both databases match. If there is a CRC error calculated by the locomotive the following occurs.
    - During the next timing cycle the locomotive will request the token if it is open.
    - Once the locomotive receives the token it will dump the crossings coordinates and the 7 HRI's it has in memory along with date and CRC data.
    - Now the Crossing will updated or any part of the mapping, which is out of date.
    - During the next timing cycle the HRI will xmit its status for the locomotive to verify CRC.

Example – Housekeeping: