GE MDS

SHL-050 entraNET 220 Theory of Operation
Version 1.4
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1 Introduction

This document describes some of the basics of the entraNET 220 Remote Control Locomotive (RCL) system. The system exists to enable coordinated RCL operation of many locomotives in the same area. Please also see "SHL-021 MDS entraNET 220 Interface Specification" and "SHL-028_MDS entraNET_220 Phase_V_Primer".

2 Types of Units

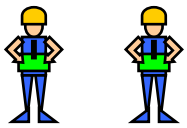
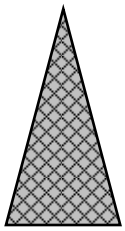
	**Locomotive Control Unit (*LCU*)** – Located aboard a locomotive, this set of equipment directly interfaces to the tractive power and air brakes of the locomotive. Within the LCU is located an MDS entraNET 220 Access Point (*AP*) and Packaged Radio Module (*PRM*). The LCU and two OCUs comprise an RCL System. The PRM in the locomotive is called the Locomotive Control Radio (*LCR*). The LCU is also known as the *RCL*.
	**Operator Control Unit (*OCU*)** – Carried by operators, this unit is the remote control for the locomotive. Two OCUs are linked to each LCU. Within the OCU is located an MDS entraNET 220 OEM Radio Module (*ORM*). The ORM is called the Operator Control Radio (*OCR*). The OCU is also known as the *RCT*.
	**Repeater** – Located in communications shacks or other structures, Repeaters receive messages from LCUs and OCUs and repeat them to increase range and robustness. Each Repeater site can contain one or up to four Repeaters, each handling up to 15 RCL systems on a specific channel. Within each Repeater is located an MDS entraNET 220 Access Point (AP) and two or three Packaged Radio Modules (PRM). The PRMs act as a Transmitter, a Main Receiver, and an optional Diversity Receiver or Sniffer Receiver.

Figure 1: Locomotive (Slug Car, no human occupancy)

Figure 2: Operators with Operator Control Units (OCUs)

Figure 3: Repeater Tower

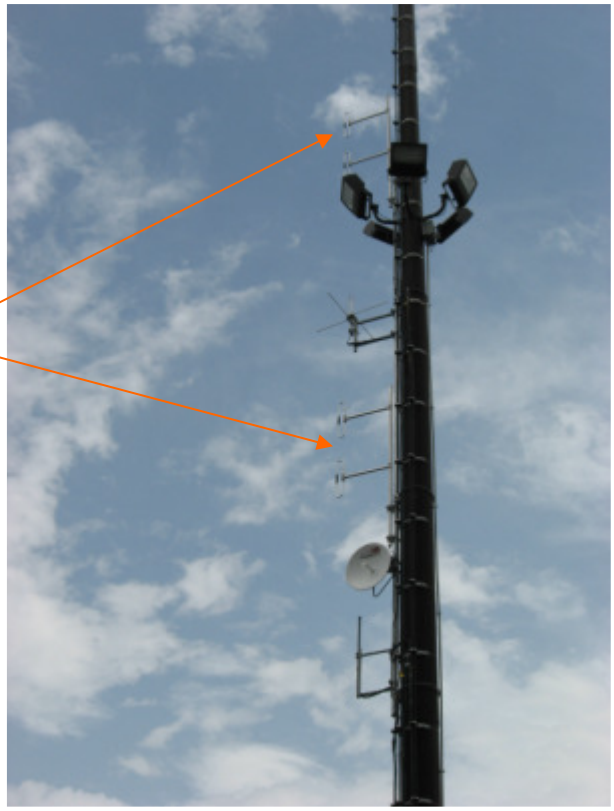
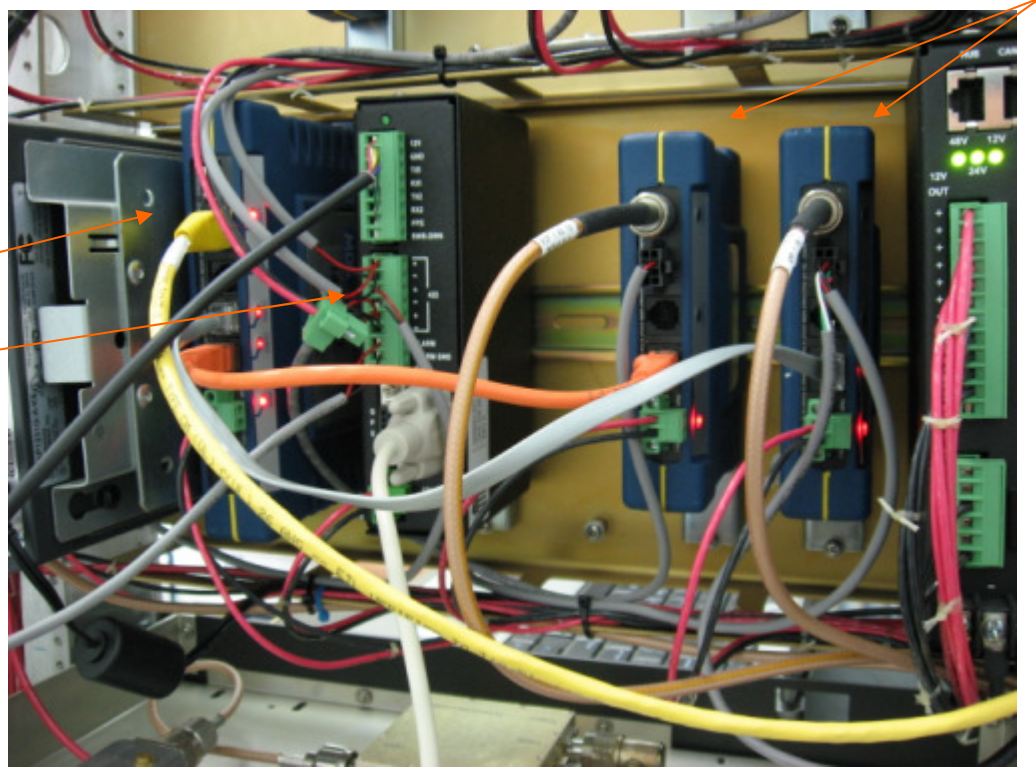


Figure 4: Repeater Rack

Figure 5: MDS Repeater Equipment (AP and 2 PRMs) at Back of Left Rack



3 Basic Communications

The MDS entraNET 220 radio is a 9,600 bps data radio operating within 12.5 kHz at 2 Watts in the 220 MHz band. Bulletproof Direct Mode range of over 1 mile and Infrastructure Mode range of over 2.5 miles are typical in the Railroad environment. Signal levels around –90 dBm are fairly solid, although the sensitivity of the modem is down to –106 dBm. It operates with a Time Division Multiple Access (TDMA) Media Access Controller (MAC) that divides each second into 47 equal time slots. The time slots are used to support two Repeater beacons, 15 OCUA messages, 15 OCUB messages, and 15 LCU messages each second (47 = 2 + 15 + 15 + 15).

Each duplex Channel consists of a "B" or Base Frequency and an "M" or Mobile Frequency. The Mobile Frequency is always 1 MHz higher than the Base Frequency.

Figure 6: 220 MHz RCL Frequency Allocations

Channel	"B" or Base Frequency	"M" or Mobile Frequency	Notes
Channel 1	220.10625	221.10625	Licensed by AAR
Channel 2	220.11875	221.11875	Licensed by AAR
Channel 3	217.44625 - 220.95625	218.44625 - 221.95625	Licensed if needed specifically by area
Channel 4	217.44625 - 220.95625	218.44625 - 221.95625	Licensed if needed specifically by area

Each OCU (OCUA and OCUB) and the LCU may send one payload message per second. The message from the LCU may be directed to a single OCU or to both, but only one payload message is sent. If no payload is available, OCRs do not transmit, but LCRs continue to transmit an idle message once per second to facilitate OCR synchronization.

4 Direct Mode

In Distributed Coordination Mode (DCM, aka Direct Mode), each payload message is normally transmitted twice. A given unit alternates transmission each second between Channel 1 and Channel 2. For each channel, the unit typically transmits on both the B frequency and M frequency in randomly selected slots. Conflicts occur when the randomly selected "B" and "M" frequency transmission slots would overlap or conflict with SYNC beacon reception. In this rare case one of the two expected transmissions is skipped.

Each unit (LCR, OCRA, and OCRB) transmit in the same slot group (0-14) on a given channel and frequency, but this group selection is independent for each of the four channel and frequency combinations (BFREQ1, MFREQ1, BFREQ2, and MFREQ2). The slot group selection changes after each transmission, following a pseudo-random pattern.

Figure 7: Unit-to-Unit Communications In Direct Mode Each Second

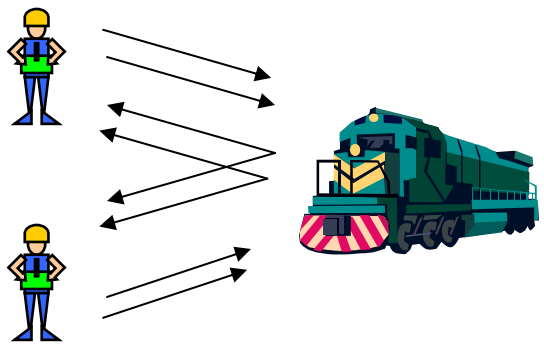
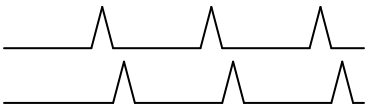
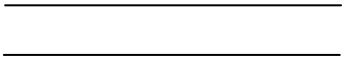
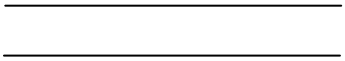
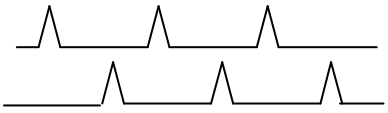


Figure 8: Example of Direct Mode Transmissions from a Single RCL System (OCUA, OCUB, LCU)

Chan, Freq	RF Power vs. Time, Sec 1	RF Power vs. Time, Sec 2
Ch1, BFreq Ch1, MFreq		
Ch2, BFreq Ch2, MFreq		

Note: Messages are sent on a different slot group on each frequency each second.

5 Infrastructure Mode

In Infrastructure Mode, each remote unit transmits one message per second on a single Channel's M Frequency, in the same time slot each second. This message is received directly by its destination and also by one or more repeaters. The infrastructure retransmits any messages it hears around 8 timeslots or 168 ms later. The Repeaters listen on a single channel's M frequency and transmit on the B frequency via the repeater that heard the destination unit the best during the previous second.

Figure 9: Infrastructure Mode, Direct Path, M Frequency

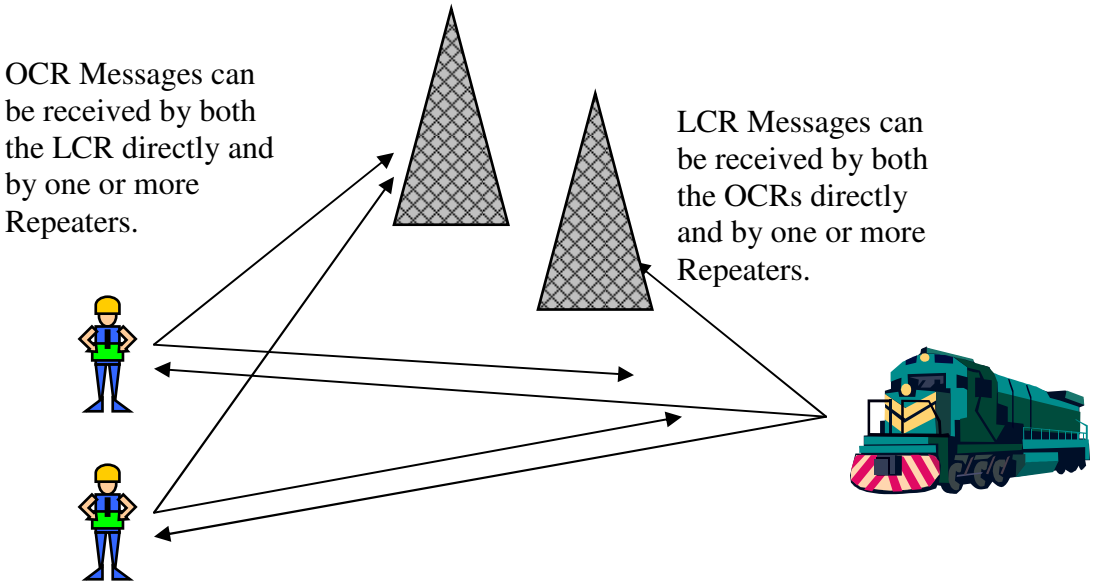


Figure 10: Infrastructure Mode, Repeated Path, B Frequency

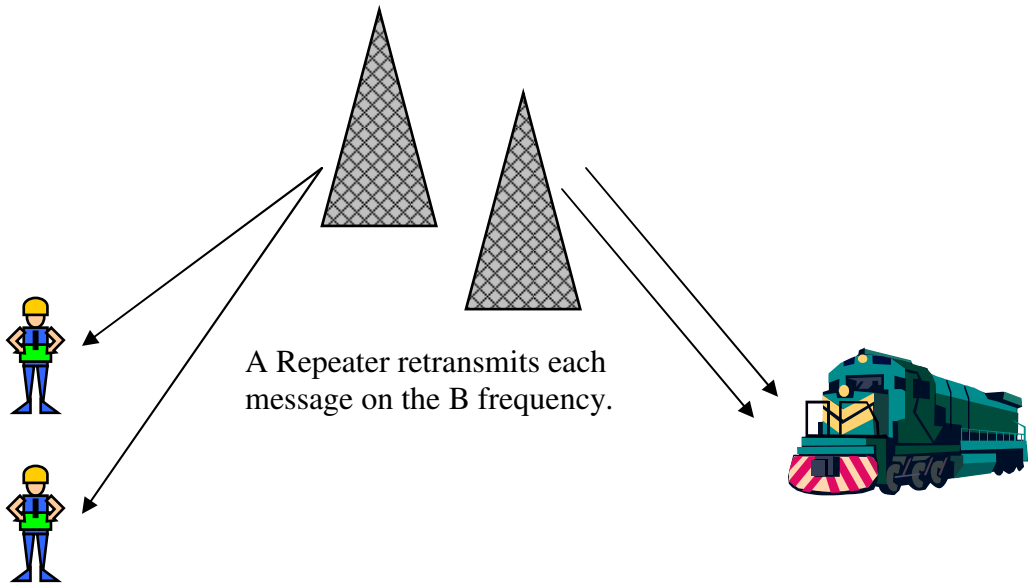
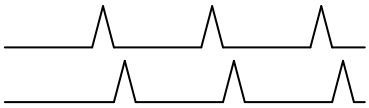
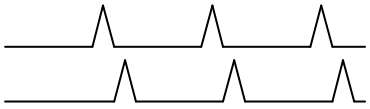


Figure 11: Infrastructure Mode Transmissions by Remote Units (M) and Repeaters (B)

Channel, Frequency	RF Power vs. Time, Sec 1	RF Power vs. Time, Sec 2
Ch X, M Freq Ch X, B Freq		

The Repeater infrastructure also transmits beacons twice per second in slots 8 and 20 that advertise the yard boundaries, free/busy time slots, and other repeater frequencies available in the area. LCRs listen to these beacons to identify whether they should enter CCM. The LCR must be geographically within an ellipse that is configured in size, position, and rotation at the RCS. Further, the LCR must receive the Repeater beacons strong enough. If empty slots are advertised, the LCR requests a randomly selected slot. If the Infrastructure grants access, the LCR commands its OCRs to enter Infrastructure, however both modes operate simultaneously until there is positive acknowledgement that the transition has succeeded. The table on the following page illustrates the allocation for each of the 47 time slots on the M frequency and B frequency each second.

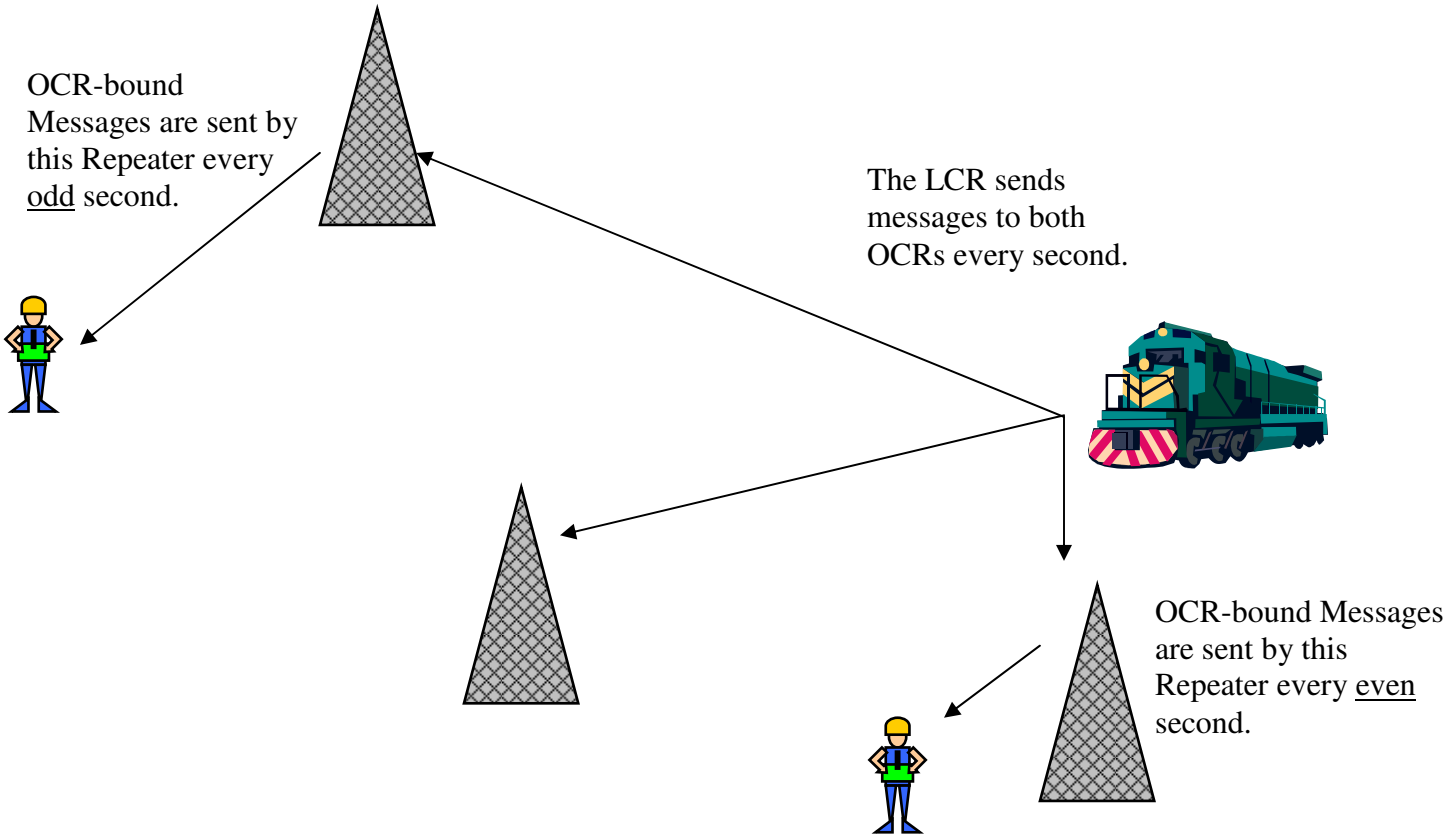
Figure 12: Time Slot Map

Timeslot	M Freq	B Freq
0	RCLguard	LCU7
1	OCUA0	LCU8
2	OCUA1	LCU9
3	OCUA2	LCU10
4	OCUA3	LCU11
5	OCUA4	LCU12
6	OCUA5	LCU13
7	OCUA6	LCU14
8	RCLrx	RCLtx
9	OCUA7	OCUA0
10	OCUA8	OCUA1
11	OCUA9	OCUA2
12	OCUA10	OCUA3
13	OCUA11	OCUA4
14	OCUA12	OCUA5
15	OCUA13	OCUA6
16	OCUA14	OCUA7
17	OCUB0	OCUA8
18	OCUB1	OCUA9
19	OCUB2	OCUA10
20	OCUB3	RCLtx
21	OCUB4	OCUA11
22	OCUB5	OCUA12
23	OCUB6	OCUA13
24	OCUB7	OCUA14
25	OCUB8	OCUB0
26	OCUB9	OCUB1
27	OCUB10	OCUB2
28	OCUB11	OCUB3
29	OCUB12	OCUB4
30	OCUB13	OCUB5
31	OCUB14	OCUB6
32	LCU0	OCUB7
33	LCU1	OCUB8
34	LCU2	OCUB9
35	LCU3	OCUB10
36	LCU4	OCUB11
37	LCU5	OCUB12
38	LCU6	OCUB13
39	LCU7	OCUB14
40	LCU8	LCU0
41	LCU9	LCU1
42	LCU10	LCU2
43	LCU11	LCU3
44	LCU12	LCU4
45	LCU13	LCU5
46	LCU14	LCU6
0	RCLguard	LCU7
1	OCUA0	LCU8
2	OCUA1	LCU9
3	OCUA2	LCU10
4	OCUA3	LCU11
5	OCUA4	LCU12
6	OCUA5	LCU13
7	OCUA6	LCU14
8	RCLrx	RCLtx

6 Repeater Communities

Up to 10 Repeaters can work together in a "Community" to form a larger coverage area. The Repeaters communicate with one another using a separate backhaul network. One unit is configured as the Repeater Coordination Server (RCS) by setting the RCS IP address to 127.0.0.1. The remaining Repeaters are configured as Satellites by setting the RCS IP address to the real network IP address of the RCS. Each Satellite sends every message received over the air to the RCS. The RCS then uses an algorithm to decide which one of the Repeaters in the Community will repeat each given message. The RCS uses the Repeater that heard the message's *destination* unit the strongest during the previous second. If the destination is both OCUs, the RCS will alternate between the best Repeater for OCUA and the best Repeater for OCUB every other second.

Figure 13: Infrastructure Message Delivery When OCUs are Best Heard Under Different Repeaters



7 Time Synchronization

The Locomotive has its own GPS Pulse Per Second (PPS) that drives into the radio and synchronizes the radio's concept of the 47 time slots. Without this synchronization, Direct Mode would be 50% as efficient because on average each transmission would collide with two time slots with the time slot boundaries uncorrelated. In Infrastructure Mode, the LCR derives its timing by receiving the Repeater beacons. In both modes, the OCRs synchronize to the LCR's direct and repeated transmissions.

8 Diagnostics

The most important mechanism for getting information about system performance is by using a USB Flash Drive in the locomotive. The GETS black box has a USB socket into which a memory stick is typically inserted. This socket is connected to the MDS AP. The logs from this stick should be retrieved. They contain every message the LCR sent and received. Depending on the size, the USB stick can contain several days of data. If preparing a new stick for use, an empty file called "dologging" should be created. Care must be taken to ensure there is no extension in this file name. Be aware that Windows usually omits known extensions from directory lists, so while the file may appear to have no extension, it may just be hidden.

The AP and LCR on a GETS-outfitted locomotive are enclosed within a black metal box. The LCR COM2 serial port and the AP Ethernet port require special cables from GETS for access.

Access Points are best accessed using Telnet. The IP address of the Locomotive AP is typically 10.10.9.30. Keep in mind that the IP configuration of the PC used to Telnet to an AP must be appropriate (i.e. on the same subnet) for this address.

From the AP, the Event Log and Configuration can be uploaded via the AP's menu to a laptop running a TFTP server. If logged in as root, you can also issue the "cat /var/log/messages" command, but this log is cleared periodically so if too stale, it may not have much information.

Either the OCR or LCR may be in data mode when you connect to the COM2 port. To escape from data mode, type "+ + +", three plus signs in a row.

The key pieces of information to get from the LCR are the current alarms (ALARM), the event log (LOG SHOW), and the configuration (CONFIG SHOW).

The OCR command line can be accessed offline via COM2 using an interface board if the radio is removed from the OCU. GETS has a method to access the serial port via Hyperterminal over an infrared adapter without opening the OCU. To do this, you power on the OCU, wait for the LCD display to clear after the initial splash screen, and then press 5 buttons simultaneously (the top, front, and bottom black buttons on the left, and the top and front buttons on the right).

Figure 14: LCU PRM Alarms

Alarm Text	Meaning
Booting Up	Normal when PRM starts up.
Image 1/2 running	Normal when PRM starts up. Indicates which image is active.
Booted to OS_Start	Normal when PRM starts up.
NMEA Data Not Present	Timeout waiting for data from MDS AP. If this alarm is set and not cleared within a several seconds, it can indicate a problem with the GPS NMEA data path to the MDS PRM and/or AP.
Outside a Repeater Yard	Infrastructure beacons were heard and properly decoded, but the locomotive is not operating within the yard the beacons describe.
Radio board alarm condition	Abnormal, almost always indicates PPS missing or inverted. Always accompanied by additional information, see below.
Radio MAC No GPS	The PPS timing pulse is missing.
Radio MAC Inverted GPS	The PPS timing pulse is inverted.

9 Firmware Upgrades

Repeater upgrades are performed via the Access Point by upgrading the AP and then rebooting, at which time the AP upgrades the Packaged Radio Modules automatically. You need only upgrade the Repeater APs. AP upgrades are commanded via the AP menu. A TFTP Server (such as the one GE MDS provides) accepts firmware requests and delivers them to the AP.

LCU radio and AP upgrades used to be performed via the LCU Access Point by upgrading the AP and then rebooting, at which time the AP upgraded the Packaged Radio Module automatically. This is no longer true. The LCU radio (PRM) is now first upgraded via the Remote Upgrade Utility, and then the LCU AP is upgraded using a TFTP server.

OCR upgrades can be performed over the air or by using the Remote Upgrade Application via direct serial connection with an interface board.

After upgrading, it is important to check the Radio or Access Point's configuration vs. the defaults on http://supportcentral.ge.com/products/sup_products.asp?prod_id=236425 within the firmware folder.

10 Glossary

Term	Definition
AAR	American Association of Railroads – the organization that brings together standards for all US and Canadian railroads to follow. The body that purchased two nation-wide frequency pairs on 220 MHz for RCL use.
AP	Access Point – The non-radio MDS product that is used in locomotives and repeaters.
Cattron	Cattron Group International – An RCL Vendor
Diversity Receiver	The MDS PRM within a Repeater that is connected to a separate antenna from the main Repeater Receiver and gives a different radio path for receiving RCL messages. In most current Repeater installations, this PRM is used instead as a Sniffer
GETS	General Electric Transportation Systems, Aka General Electric Global Signaling – An RCL Vendor
GPS	Global Positioning System – Also used to refer to the unit that uses signals from orbiting satellites to calculate the position and time.
Grey Ghost	Another term for a Slug Car.
Job	Roughly speaking, a bunch of instructions to build up a train of freight cars. Also used to refer to the switching locomotive used for the job.
LCR	Locomotive Control Radio – The MDS Packaged Radio Module aboard the locomotive used to send/receive remote control locomotive messages.
LCU	Locomotive Control Unit – The RCL Vendor equipment that interfaces with the locomotive's air and mechanical control system to actuate motion of the locomotive. The LCU is also known as the RCL.
MDS	Microwave Data Systems – An RCL radio manufacturer.
NMEA	National Marine Electronics Association – Also used to refer to the position and time data that is output from a GPS receiver and used by the MDS equipment to discern if the radio is within the geographic zone of a Repeater community.
OCR	Operator Control Radio – The MDS OEM Radio Module that is housed within the OCU.
OCU	Operator Control Unit – The belt pack control box that the operator uses to command acceleration, deceleration, and other parameters of the locomotive. The OCU is also known as the RCT.
Power	Another term for a locomotive.
PPS	Pulse Per Second – a timing signal output by a GPS receiver to accurately discipline the time slot structure used by the MDS radio.
PRM	Packaged Radio Module – The MDS radio product that is used in locomotives and repeaters.
RCL	Remote Control Locomotive – the application that uses radios and a feedback control system to run locomotives at a desired speed with belt packs while untethered from the locomotive. Also used to refer to the locomotive itself.
Receiver	The MDS PRM within a Repeater that is used for receiving RCL messages over the air.
Repeater	A UPRR-integrated system including an MDS AP and three PRMs that among other things receives radio messages output by OCRs and LCRs and retransmits them over the air.
Slug Car	A retrofitted locomotive that is designed to operate without a crew onboard.
Sniffer	A device or application that listens to all over the air messages and displays or stores them.
Transmitter	The MDS PRM within a Repeater that is used for transmitting RCL messages over the air.
UPRR	Union Pacific Railroad

11 Quiz

1. In DCM, how many messages per second does the LCR send over the air?
    a. 1
    b. 2
    c. 4
    d. None of the above
2. In CCM, how many messages per second does the OCR send over the air?
    a. 1
    b. 2
    c. 4
    d. None of the above
3. The two Nationwide Channels for RCL licensed by the AAR are:
    a. 220.10625/221.10625 and 220.15625/221.15625
    b. 220.10625/221.10625 and 220.11875/221.11875
    c. 220.10625/221.10625 and 217.8/218.8
    d. None of the above
4. A Sniffer is used to
    a. Receive all messages sent by other units on a given frequency
    b. Transmit test messages over the air so other unit's receivers can be evaluated
    c. Receive all messages sent by other units on any frequency
    d. None of the above
5. A Grey Ghost is
    a. An OCU that is not linked to any locomotive
    b. A wayside device
    c. A locomotive that is not meant for occupancy
    d. None of the above
6. Each entraNET 220 radio is designed to:
    a. Output 2 Watts RF power
    b. Receive down to –120 dBm
    c. Include a GPS receiver
    d. All of the above
7. The GPS network is used for the entraNET 220 RCL system to
    a. Identify the position of the locomotive
    b. Precisely time the TDMA frame at the locomotive
    c. Precisely time the TDMA frame at the repeater
    d. All of the above
8. MDS firmware upgrades in the locomotive now occur
    a. By upgrading the PRM first, then the AP
    b. By upgrading the PRM only
    c. By upgrading the AP only
    d. None of the above
9. The MDS AP can be upgraded by
    a. TFTP
    b. Serial Port
    c. USB Flash Drive
    d. All of the above
10. Of the 47 time slots in the TDMA frame
    a. 30 are for OCUs, and 17 are for LCUs
    b. 15 are for OCUs, 30 are for LCUs, and 2 are for beacons
    c. 30 are for OCUs, 15 are for LCUs, and 2 are for beacons
    d. None of the above

11. It is important for the LCU to have correct PPS timing from a GPS receiver so that
    a. It can receive beacons with a strong enough signal
    b. It can time the TDMA frame to avoid colliding with more than one slot in DCM
    c. It knows its position
    d. None of the above
12. The RCS's RCS IP address is set to
    a. 10.10.9.30
    b. DHCP
    c. 127.0.0.1
    d. None of the above
13. The over the air data rate of the entraNET 220 is
    a. 106 kbps
    b. 9600 bps
    c. 1024 kbps
    d. None of the above
14. You would probably expect to see an LCU logged on a repeater with an RSSI around
    a. –90 to –55 dBm
    b. –130 to –55 dBm
    c. –70 to –30 dBm
    d. None of the above
15. If I'm troubleshooting an LCU, I need
    a. A laptop
    b. One or more special cables from the RCL vendor
    c. To read the data off the USB stick from the radio enclosure
    d. All of the above
16. If I'm troubleshooting a repeater, I need
    a. A UPRR telecoms representative
    b. A Sniffer and a laptop
    c. A GPS receiver
    d. All of the above
17. If I'm troubleshooting an OCU, I need
    a. Another OCU
    b. A GPS receiver
    c. A Torx driver
    d. None of the above
18. If I don't have power for my job, what am I missing
    a. A slug car
    b. A locomotive
    c. 72 VDC
    d. None of the above
19. In a repeater community, I need
    a. An RCS and 1 to 9 satellites
    b. An RCS and 0 to 9 satellites
    c. 10 satellites
    d. None of the above
20. Ideally, each message from a given OCU or LCU gets transmitted this number of times over the air
    a. 1 or 2
    b. 2
    c. 3
    d. None of the above
21. Bonus: Why does MDS make radios for the RCL application?

12 Answer Key

22. In DCM, how many messages per second does the LCR send over the air?
    a. 1
    b. 2
    c. 4
    d. None of the above
23. In CCM, how many messages per second does the OCR send over the air?
    a. 1
    b. 2
    c. 4
    d. None of the above
24. The two Nationwide Channels for RCL licensed by the AAR are:
    a. 220.10625/221.10625 and 220.15625/221.15625
    b. 220.10625/221.10625 and 220.11875/221.11875
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    d. None of the above
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    a. Receive all messages sent by other units on a given frequency
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    c. Receive all messages sent by other units on any frequency
    d. None of the above
26. A Grey Ghost is
    a. An OCU that is not linked to any locomotive
    b. A wayside device
    c. A locomotive that is not meant for occupancy
    d. None of the above
27. Each entraNET 220 radio is designed to:
    a. Output 2 Watts RF power
    b. Receive down to –120 dBm
    c. Include a GPS receiver
    d. All of the above
28. The GPS network is used for the entraNET 220 RCL system to
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    a. By upgrading the PRM first, then the AP
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    b. 15 are for OCUs, 30 are for LCUs, and 2 are for beacons
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32. It is important for the LCU to have correct PPS timing from a GPS receiver so that
    a. It can receive beacons with a strong enough signal
    b. It can time the TDMA frame to avoid colliding with more than one slot in DCM
    c. It knows its position
    d. None of the above
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    b. DHCP
    c. 127.0.0.1
    d. None of the above
34. The over the air data rate of the entraNET 220 is
    a. 106 kbps
    b. 9600 bps
    c. 1024 kbps
    d. None of the above
35. You would probably expect to see an LCU logged on a repeater with an RSSI around
    a. –90 to –55 dBm
    b. –130 to –55 dBm
    c. –70 to –30 dBm
    d. None of the above
36. If I'm troubleshooting an LCU, I need
    a. A laptop
    b. One or more special cables from the RCL vendor
    c. To read the data off the USB stick from the radio enclosure
    d. All of the above
37. If I'm troubleshooting a repeater, I need
    a. A UPRR telecoms representative
    b. A Sniffer and a laptop
    c. A GPS receiver
    d. All of the above
38. If I'm troubleshooting an OCU, I need
    a. Another OCU
    b. A GPS receiver
    c. A Torx driver
    d. None of the above
39. If I don't have power for my job, what am I missing
    a. A slug car
    b. A locomotive
    c. 72 VDC
    d. None of the above
40. In a repeater community, I need
    a. An RCS and 1 to 9 satellites
    b. An RCS and 0 to 9 satellites
    c. 10 satellites
    d. None of the above
41. Ideally, each message from a given OCU or LCU gets transmitted this number of times over the air
    a. 1 or 2
    b. 2
    c. 3
    d. None of the above
42. Bonus: Why does MDS make radios for the RCL application? To make money!