CSX 4022
(SD40-3 – EMD)
Locomotive Noise Test Battery Report

CONTRACT NUMBER **FR-TEC-0003-11-01-00**

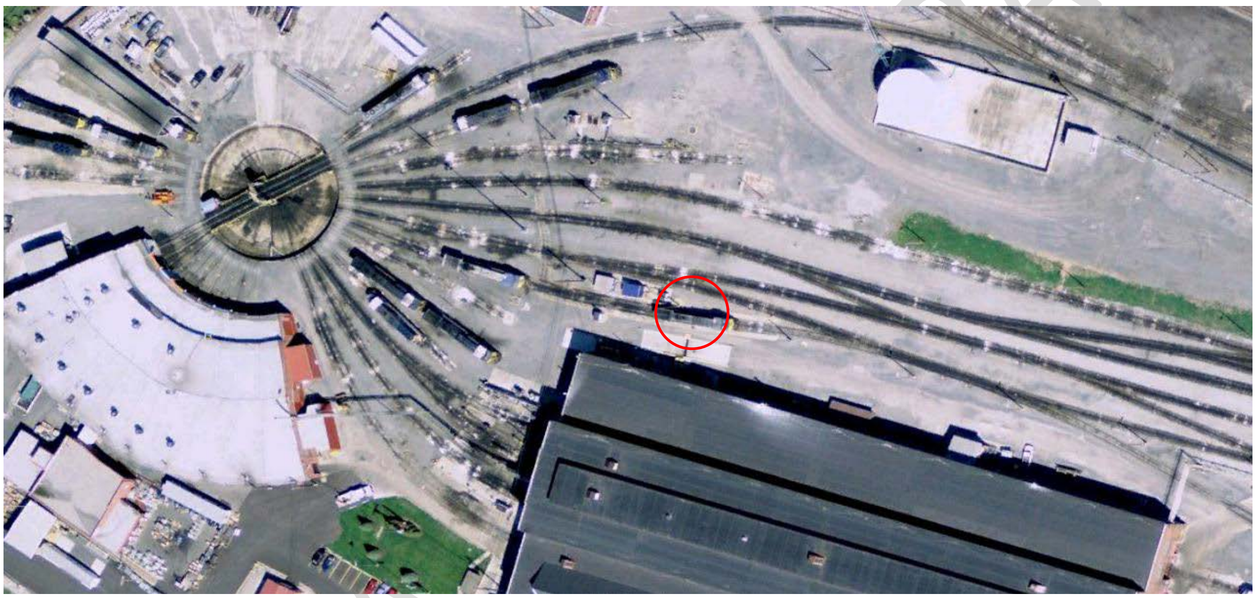
Document Number: 00002460-A

Table of Contents

Project Detail:

Contract Number	FR-TEC-0003-11-01-00
Dates of Survey	March 12th to 16th, 2012
Locations	CSX Locomotive Facility Cumberland, MD 39.628519 N LAT,-78.764285 W LON, elev. 650 feet
Test Engineers	Derek Edmondson, Chris Goetz, James Midyette

The testing location for this locomotive was in Cumberland, MD at the CSX rail yard. The locomotive was located on a siding near the maintenance building and was stationary throughout the testing period.

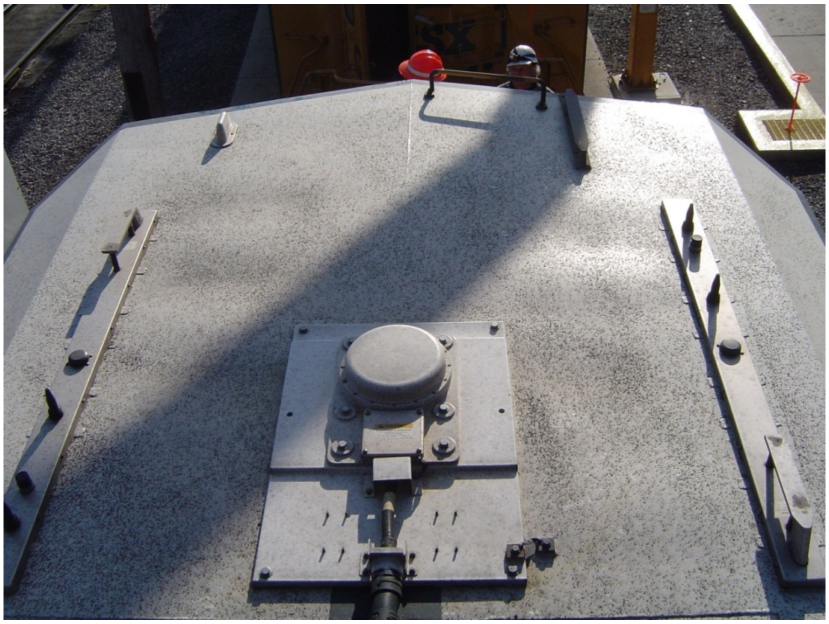


CSX Cumberland, MD Yard
Figure 1

CSX Cumberland, MD Yard

Figure 2

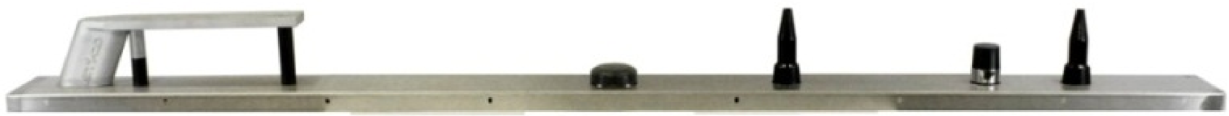
Locomotive under test CSX 4022
SD-40-3 D-E 3000 HP Road Unit
Built in 1974
Figure 3



CSX 4022 Roof Layout

Figure 4

The locomotive was outfitted with a STI-CO PTC antenna array system (part number HDLP-MB-PLLG25) which included PTC 220, CEL A, CEL B GPS and WIFI antennas, a SINCLAIR ST221-SFXSUF VHF antenna, Antenna Specialists ASP572 UHF antenna, and a MATRIX MBS2 cellular satellite GPS system.



STI-CO HDLP-MB-PLLG25
Antenna Array
Figure 5

SINCLAIR ST221-SFXSUF (F1610LP) VHF Antenna
Figure 6

Antenna Specialists ASP 572 UHF Antenna
Figure 7

Matrix MBS2 System
Figure 8

The radio systems included AAR Voice, a Quantum UHF HOT/EOT system as well as the CTI REX MDU system. The PTC radio system was not installed. A STI-CO VHF filter FILT-NB-160-MIL-U was installed standard near the VHF radio.

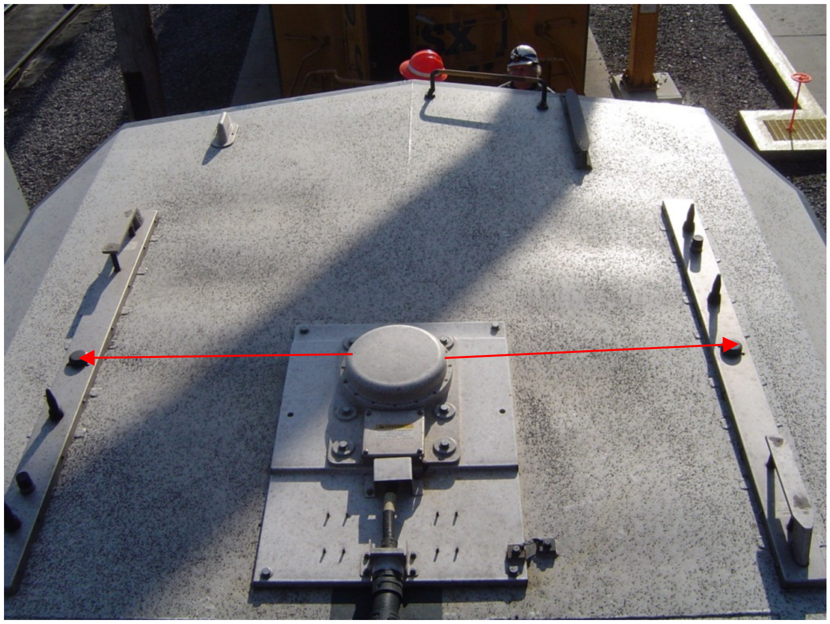
AAR Voice Radio
Figure 9

Quantum HOT/EOT Radio
Figure 10

Coleman REX MDU
Figure 11

Hardware Corrosion
Figure 12a

It was noted that the screws used to attach the antenna arrays to the mounting plates showed signed of corrosion. This was not the originally supplied hardware which was stainless steel.



MBS2 TX Proximity to GPS RX
Figure 12b

This Locomotive is equipped with a Matrix MBS2 combination Cellular and Satellite Terminal.
During testing, it was not possible to initiate a transmission with the MBS-2 to test any possible interaction with PTC equipment.
Post-testing research has revealed that the Satellite portion operates in the L-Band (TX 1626.5 MHz to 1660.5 MHz) at significant power levels (+37.5 dBm to +46.5 dBm). The PTC GPS also operates in the L-Band (1575.42 MHz), and the adjacent GPS receiver antennas will be acquiring GPS signals at ~-130dBm, while the MBS-2 will, at times, be transmitting at up to ~+46 dBm ~80 MHz up-band from the GPS operating frequency. Note that the PTC GPS Antennas are equipped with integral 40 dB LNAs. This configuration results in an RF power delta of 176 dB less than 80 MHz. While the MBS-2 is equipped with its own GPS, it is likely that such a unit would be protected by integrated filtering within the MBS-2 assembly. The PTC GPS Antennas and 40 dB LNAs enjoy no such protection. Further testing for interference and possible damage is recommended.

VSWR Test

This test is designed to collect VSWR data in several formats for use in locomotive noise and intermodulation reporting. The test involved collecting voltage standing wave ratio and return loss data in the following formats; VSWR, S1P scatter parameters, comma separated values, and a portable network graphics. It is important to know if the antenna system is properly matched to the transceiver equipment as this can be a source of intermodulation and/or standing waves in the RF system. The first set of data was collected at the RF port located closest to each antenna element in the locomotive radio frequency system to give an accurate picture of antenna matching. A second set of data recorded the VSWR at the end of the transmission line cable that connects to the radio transceiver antenna connector, including any installed filtering to show what the full system response is that is presented to the transceiver. This measurement includes all system losses.

This test helps us to characterize the bandwidth parameters of each antenna. The information is useful in determining how much the antenna element contributes to filtering out of band energy as well as whether or not the antenna is functioning correctly. The results from the VSWR testing indicated all antennas and associated components were functioning properly. The full data from this testing has been presented in Appendix A. Typical data recorded from the locomotive is presented in Table A below.

TABLE A VSWR Plots

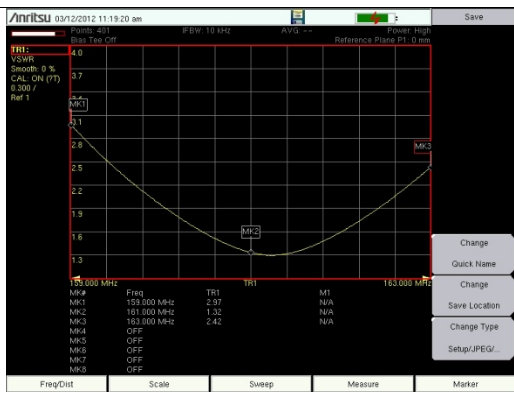
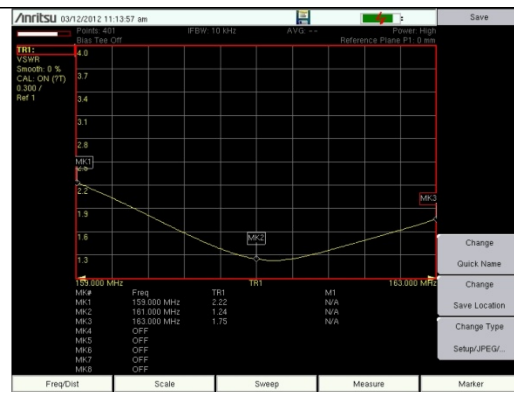
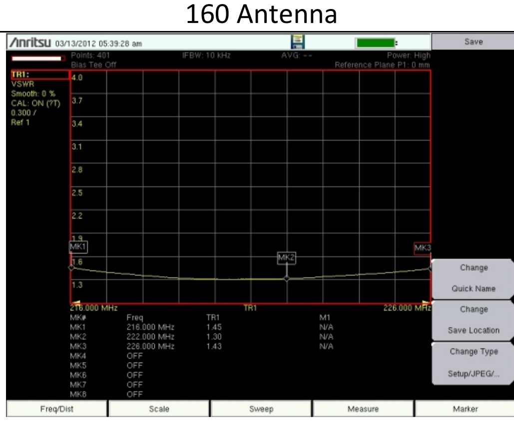
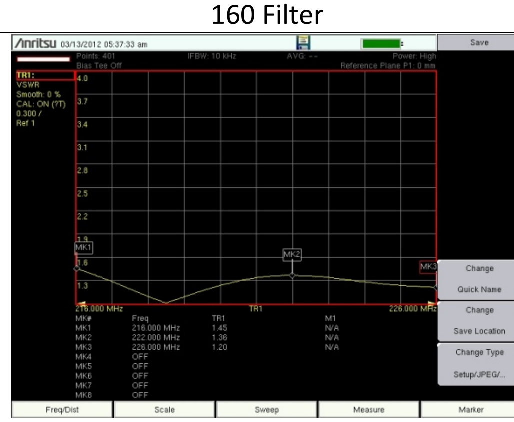
 160 Antenna	 160 Filter
 220 PTC ENG Antenna	 220 PTC ENG Filter

TABLE A VSWR Plots

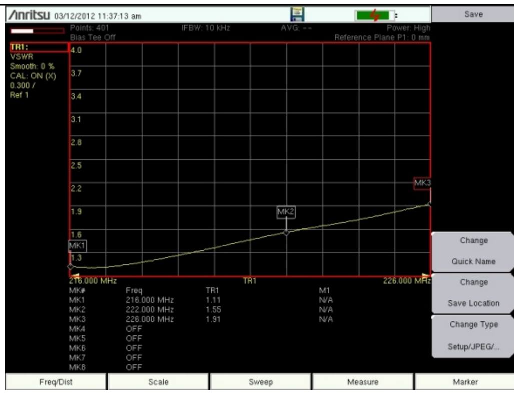
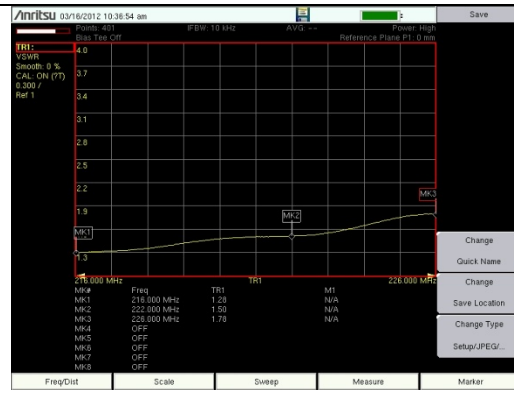
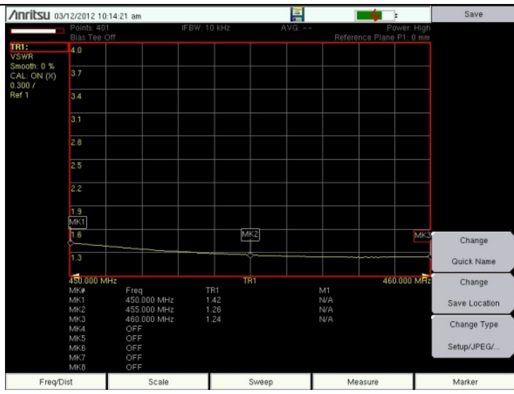
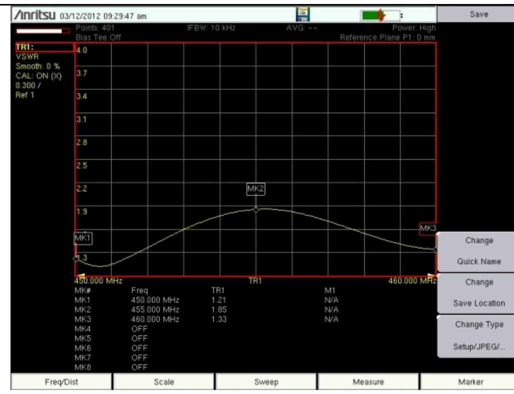
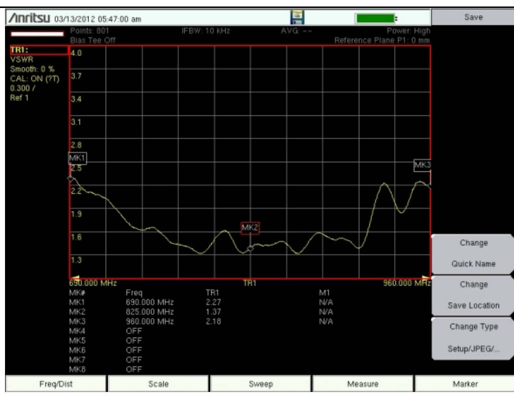
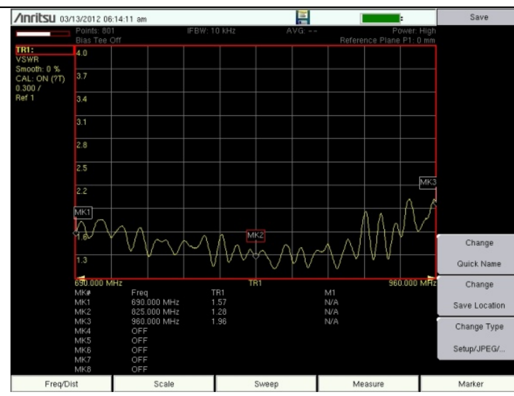
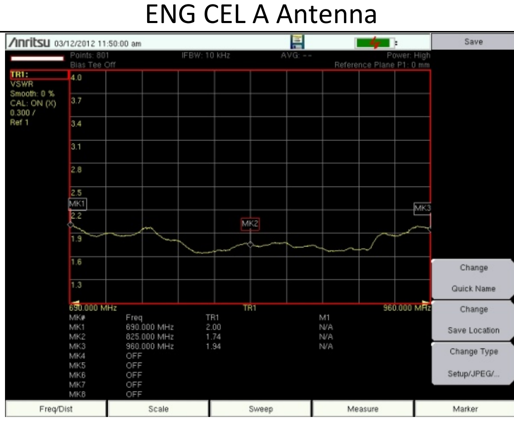
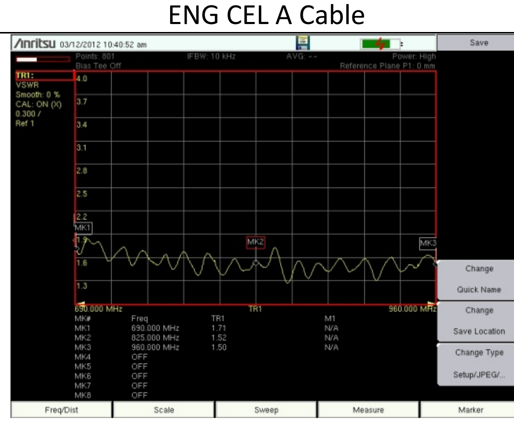
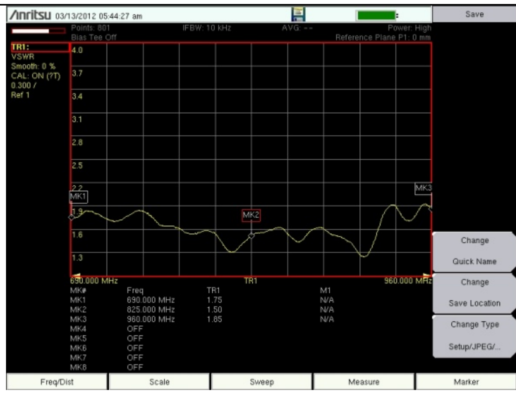
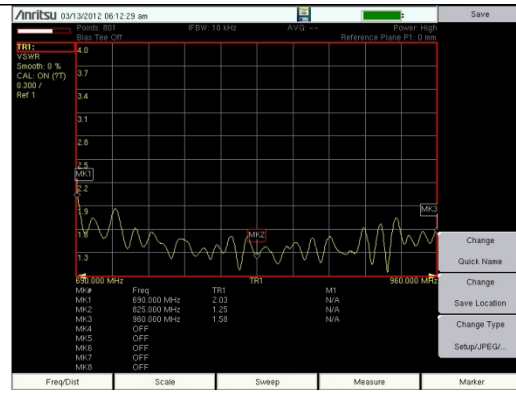
 220 PTC CND Antenna	 220 PTC CND Filter
 HOT Antenna	 HOT Antenna Filter
 ENG CEL A Antenna	 ENG CEL A Cable
 CND CEL A Antenna	 CND CEL A Cable

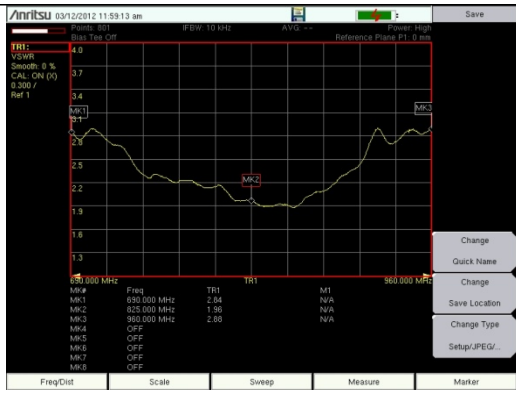
TABLE A VSWR Plots



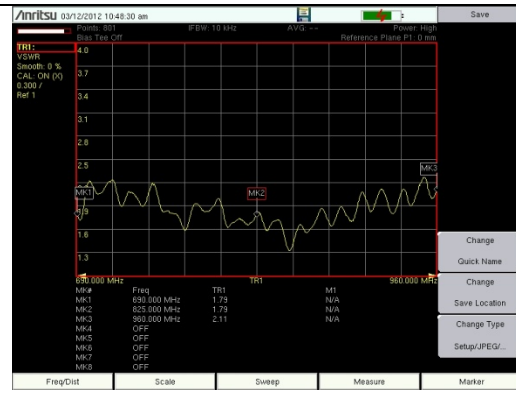
ENG CEL B Antenna



ENG CEL B Cable



CND CEL B Antenna



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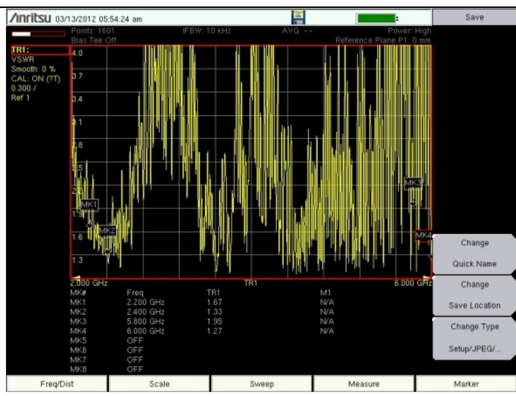
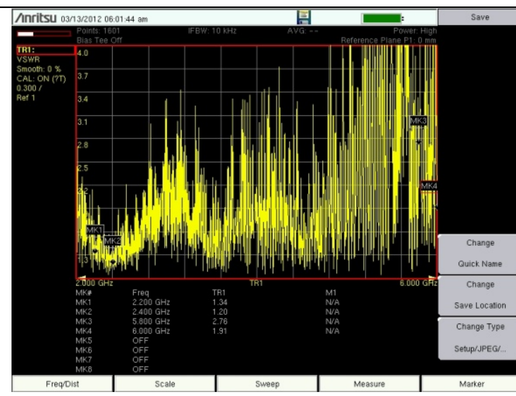
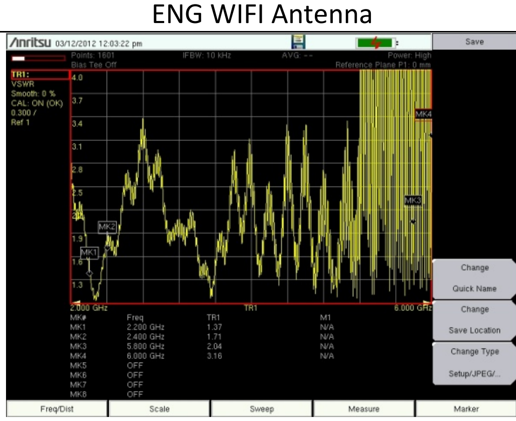


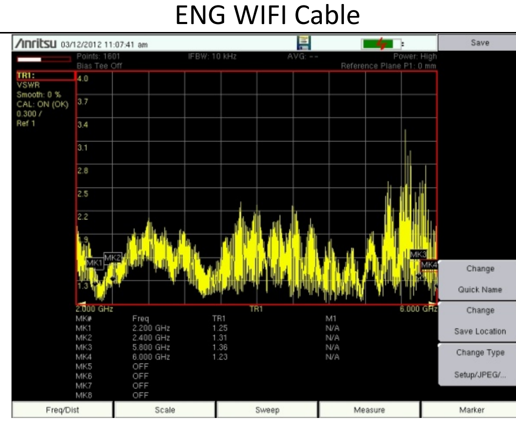
ENG WIFI Antenna



ENG WIFI Cable



CND WIFI Antenna



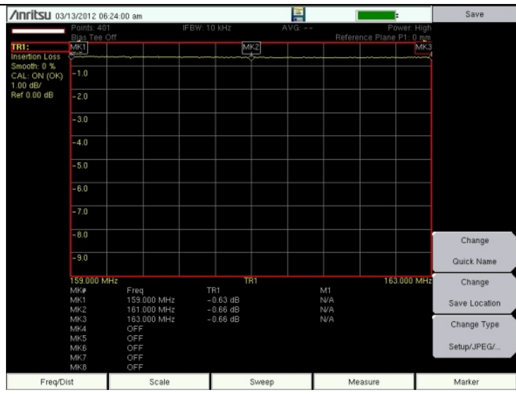
CND WIFI Cable

Insertion Loss

This test is designed to collect insertion loss data in several formats for use in locomotive noise and intermodulation reporting. The test involved collecting insertion loss data in the following formats; insertion loss in dB, S1P scatter parameters, comma separated values, and a portable network graphics. It is important to know how much loss is experienced in the system in order to determine the impact on transmitted power and intermodulation effects. The test was performed on the transmission lines by measuring the loss from the antenna connection port to the equipment port. The test is frequency specific and each cable was measured based on the appropriate frequency range.

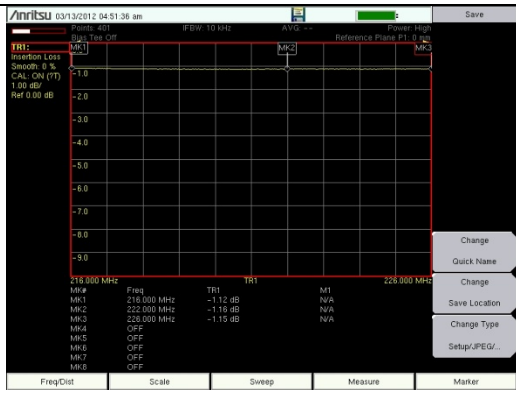
This report is useful for evaluating cable integrity and is representative of any losses that are present in the system. At the completion of this testing it was found that all on-board elements were in compliance as compared to planned values. A full report has been included in Appendix B.

TABLE B Insertion Loss Plots

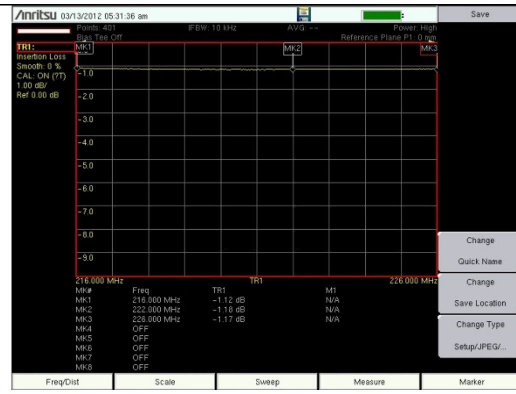


VHF 160 Cable

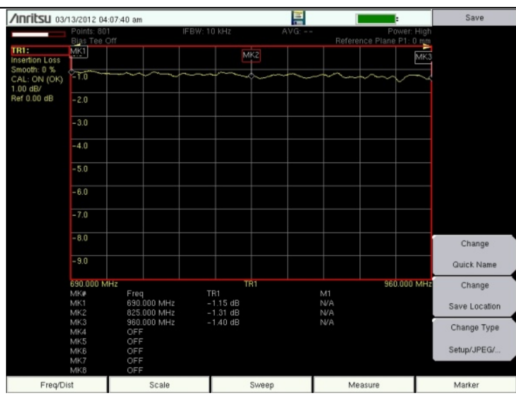
HOT / EOT Cable



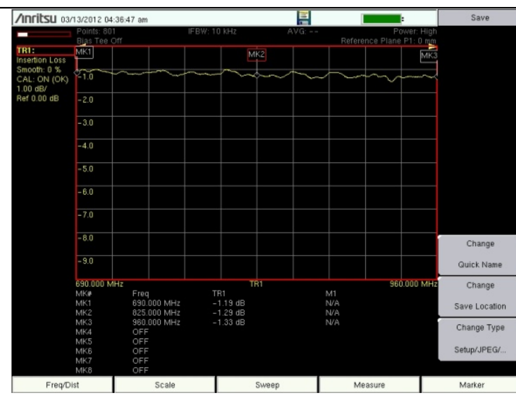
PTC ENG Cable



PTC CND Cable

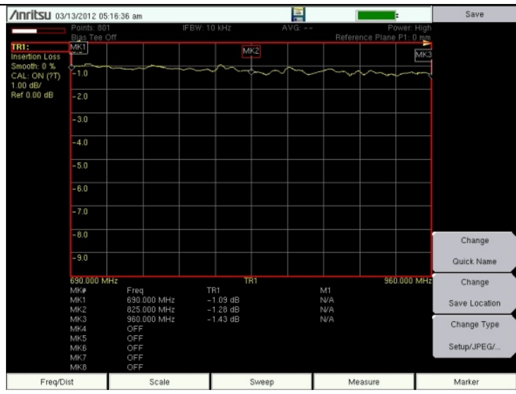


ENG CELA Cable

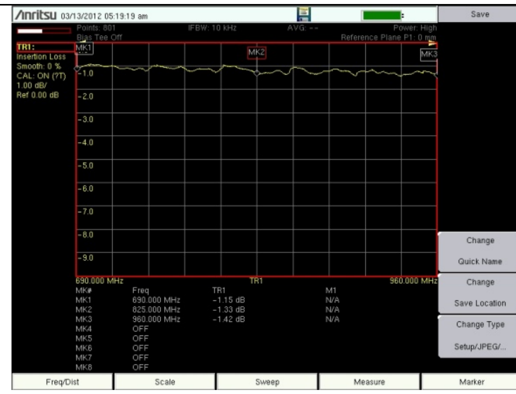


ENG CELB Cable

TABLE B Insertion Loss Plots



CND CELA Cable



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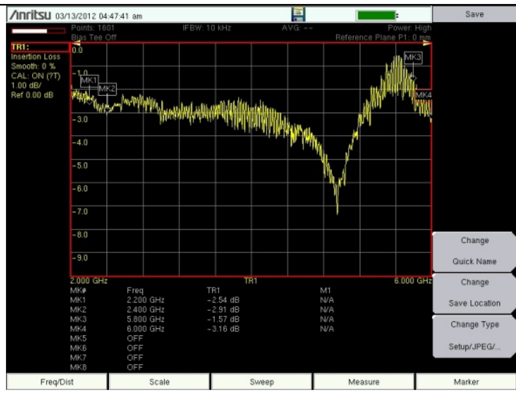
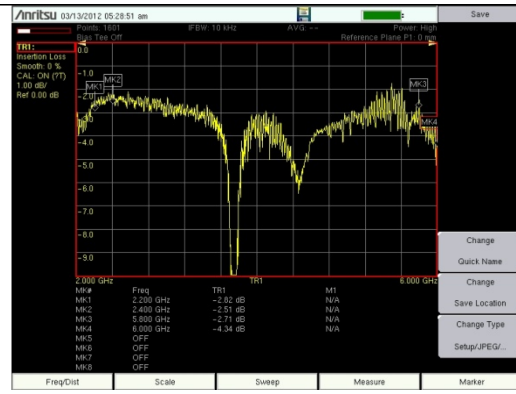


ENG WIFI Cable



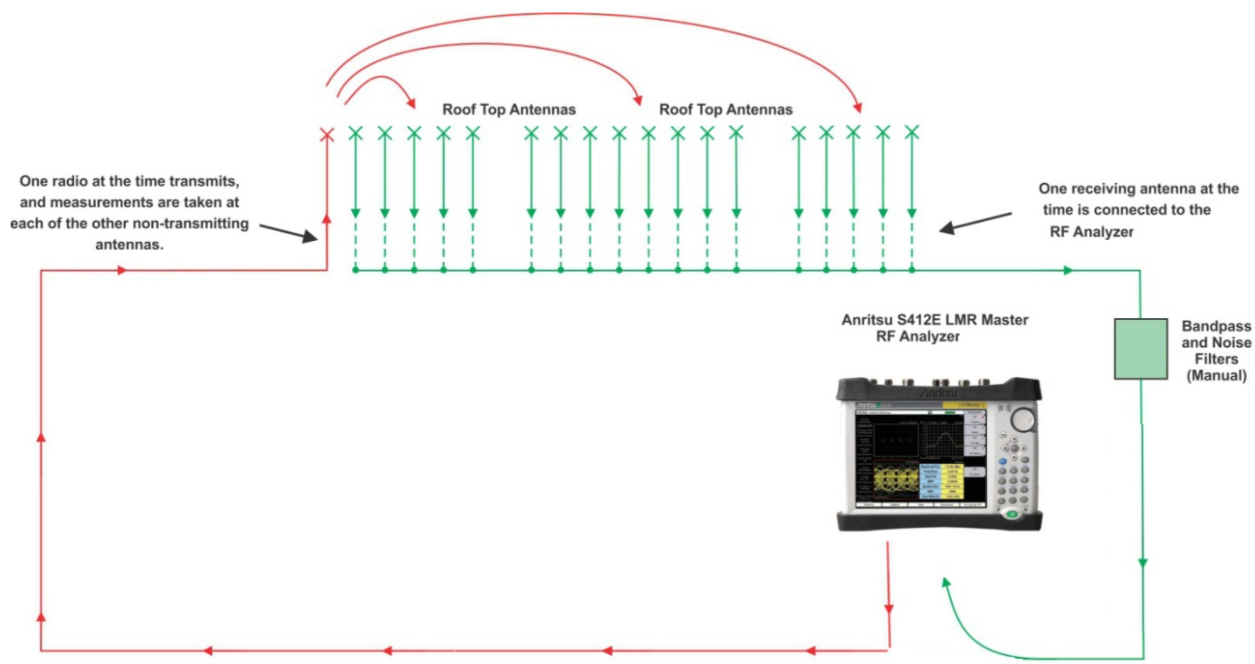
CND WIFI Cable

Antenna Isolation Test

This test is designed to collect information on the amount of free space isolation between each antenna and each other antenna. This value in decibels and is used to calculate the amount of power from each radio impacting each other radio receiver front end during transmission. High signal levels impacting the receiver front end of a radio in receive mode may cause harmful intermodulation products in proportion to the power received from the transmitting radio. The antenna isolation data is also used to determine the need for filtering in the system.

The test was performed by measuring the loss from the transmitting radio antenna to each other antenna, and the data was recorded in decibel format. The information gathered from this test correlates to the amount of intermodulation that is present in the roof environment, and possible prevention methods.

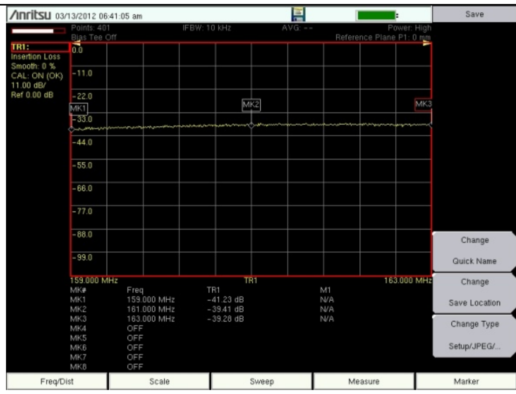
The test is executed without filters, and then executed with any filters under consideration by the Railroad.



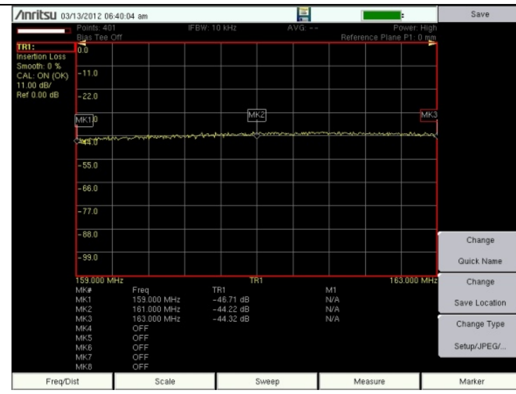
Antenna Isolation Testing Configuration
Figure 13

TABLE C Antenna Isolation Plots

AAR Voice Transmit Non-Filtered



TX 161 VHF / RX 220 ENG

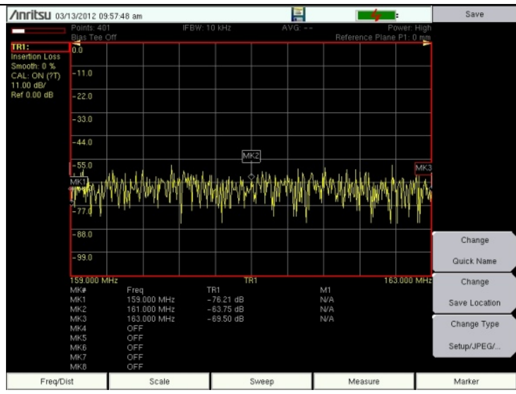


TX 161 VHF / RX 220 CON

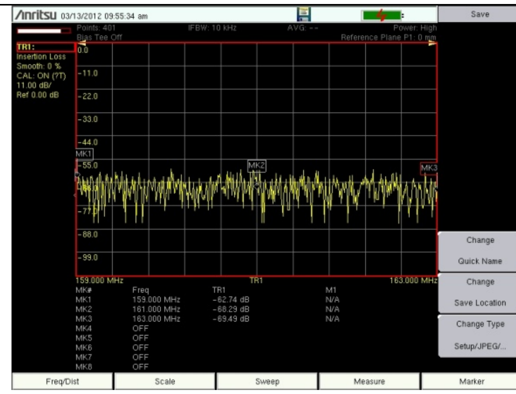
TX 161 VHF / RX 450 DPB

TABLE C Antenna Isolation Plots

AAR Voice Transmit Filtered



TX 161 VHF FILTER / RX 220 ENG FILTER



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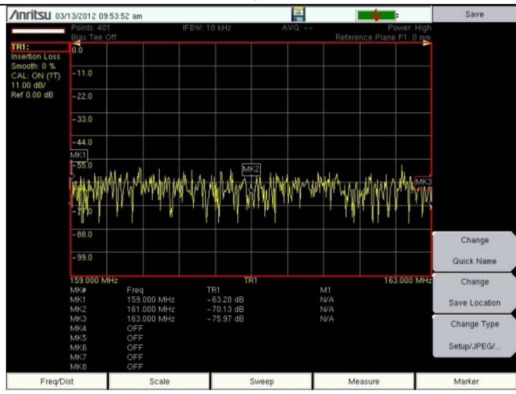

TX 161 VHF FILTER / RX 450 HOT FILTER

TABLE C Antenna Isolation Plots

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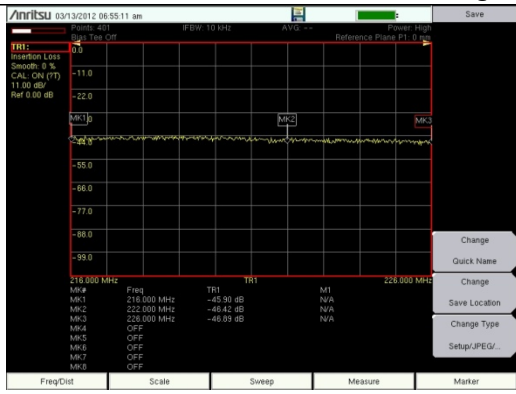

TX 220 ENG / RX 161 VHF
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TX 220 ENG / RX 220 CON
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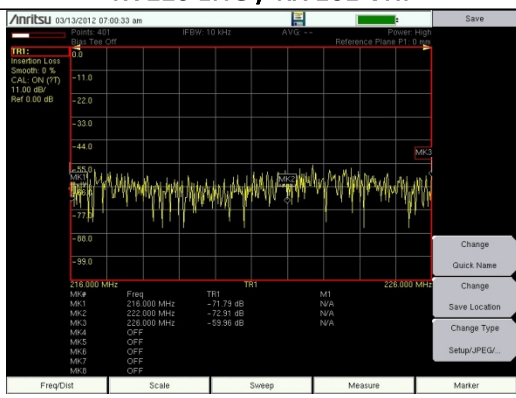

TX 220 ENG / RX 450 HOT
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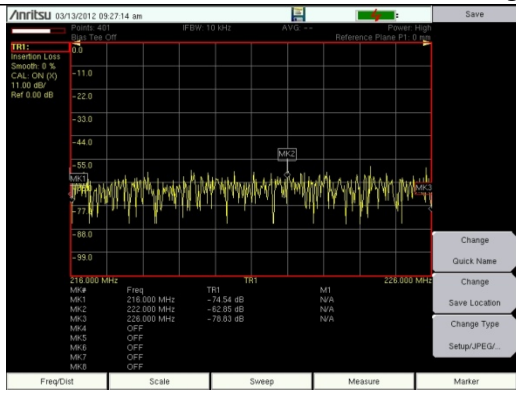
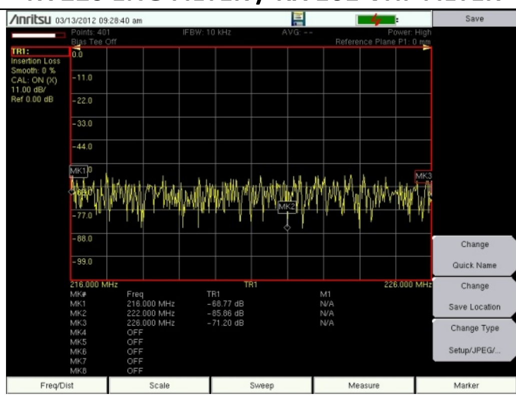
TABLE C Antenna Isolation Plots

PTC 220 Engineer Transmit Filtered



TX 220 ENG FILTER / RX 161 VHF FILTER

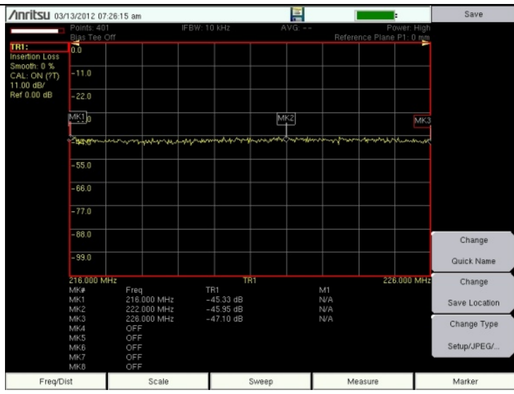
TX 220 ENG FILTER / RX 220 CON FILTER



TX 220 ENG FILTER / RX 450 HOT FILTER

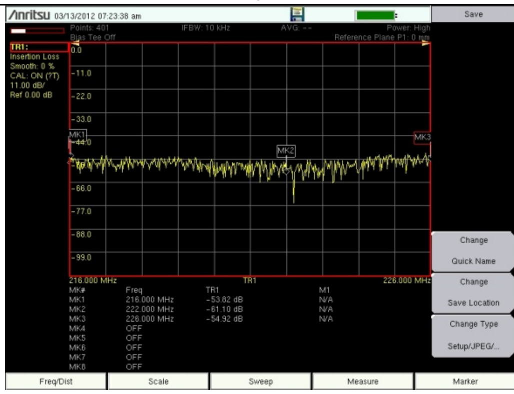
TABLE C Antenna Isolation Plots

PTC 220 Conductor Transmit Non-Filtered



TX 220 CON / RX 161 VHF

TX 220 CON / RX 220 ENG



TX 220 CON / RX 450 HOT

TABLE C Antenna Isolation Plots

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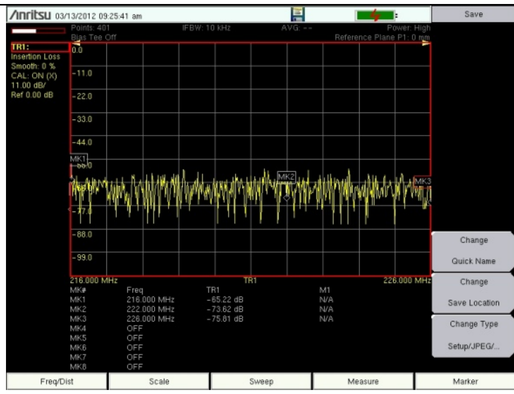
<tr><td>

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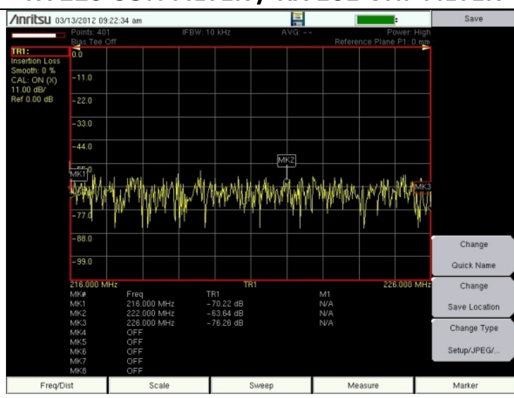
TX 220 CON FILTER / RX 220 ENG FILTER</td></tr>
<tr><td>

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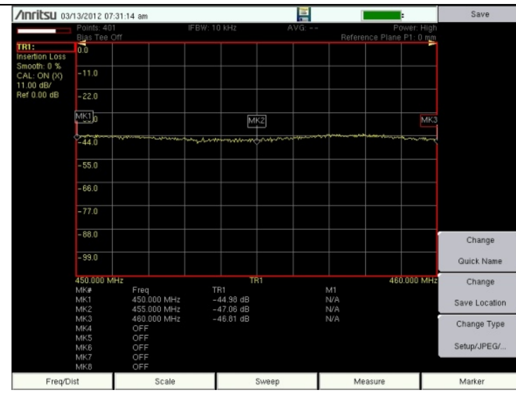
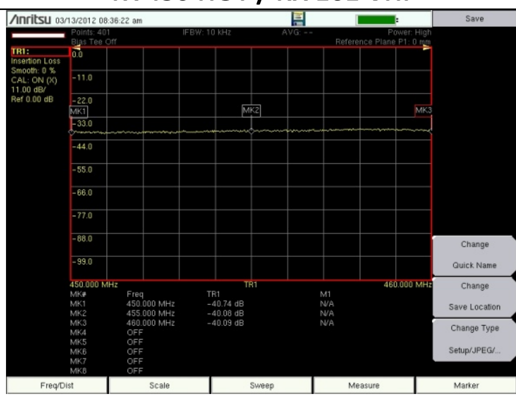
TABLE C Antenna Isolation Plots

HOT/EOT Transmit Non-Filtered

TX 450 HOT / RX 161 VHF



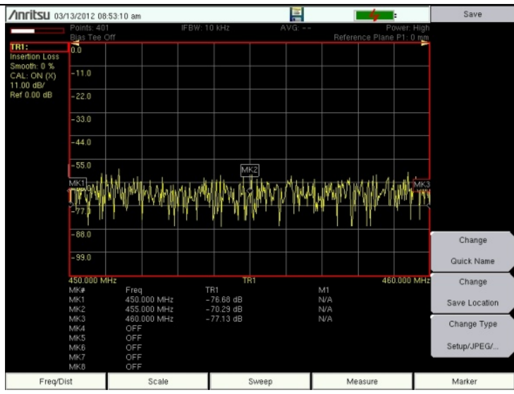
TX 450 HOT / RX 220 ENG



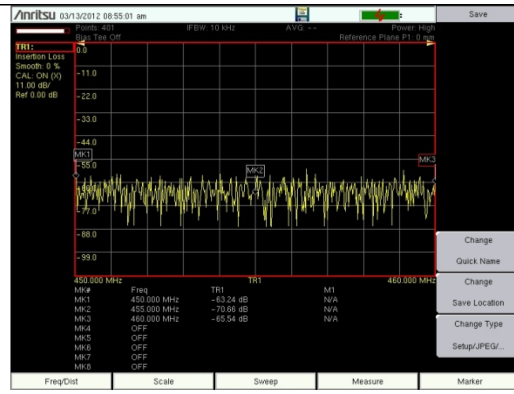
TX 450 HOT / RX 220 CON

TABLE C Antenna Isolation Plots

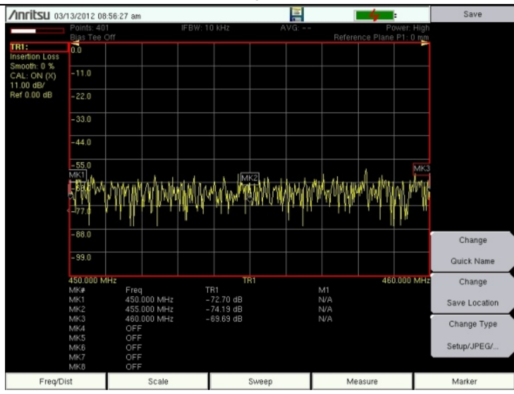
HOT/EOT Transmit Filtered



TX 450 HOT FILTER / RX 161 VHF FILTER



TX 450 HOT FILTER / RX 220 ENG FILTER



TX 450 HOT FILTER / RX 220 CON FILTER

TABLE D Antenna Isolation Chart

Receive Band	VHF 161	220 ENG	220 CON	HOT 450	ENG CEL 1 GRAY	ENG CEL 3 BLUE	ENG WIFI 2 GRN	CON CEL 2 ORG	CON CEL 4 GRN	CON WIFI 1 BLK
Transmit Band	(dBm)	(dBm)	(dBm)	(dBm)	(dBm)	(dBm)	(dBm)	(dBm)	(dBm)	(dBm)
VHF 161	TB	-39.1	-43.2	NF	-37.2	-42.4	NF	-49.0	-51.3	NF
220 ENG	-47.6	TB	-27.7	-65.6	-39.4	-35.7	NF	-43.7	-48.2	NF
220 CON	-46.3	-27.7	TB	-59.3	-44.3	-43.6	NF	-35.3	-41.8	NF
HOT 450	-35.0	-47.1	-40.0	TB	-34.7	-35.1	-59.0	-36.7	-38.4	NF
Receive Band	VHF 161 Filter	220 ENG Filter	220 CON Filter	HOT 450 Filter	ENG CEL 1 GRAY	ENG CEL 3 BLUE	ENG WIFI 2 GRN	CON CEL 2 ORG	CON CEL 4 GRN	CON WIFI 1 BLK
Transmit Band	(dBm)	(dBm)	(dBm)	(dBm)	(dBm)	(dBm)	(dBm)	(dBm)	(dBm)	(dBm)
VHF 161 Filter	TB	NF	NF	NF	-38.4	-42.7	NF	-50.8	-52.3	NF
220 ENG Filter	NF	TB	-30.5	NF	-41.1	-36.9	NF	-45.0	-48.7	NF
220 CON Filter	NF	-30.5	TB	NF	-45.8	-44.5	NF	-36.4	-43.8	NF
HOT 450 Filter	NF	NF	NF	TB	-35.2	-35.5	-59.2	-37.0	-39.0	NF

Antenna Isolation Table

The data recorded from the locomotive included both non-filtered and filtered information if the locomotive was equipped, or if future versions were to be equipped with band specific filters.

In the set of figures below, the data from the chart is represented graphically. The heads of the arrows indicate the receiver, while the tails indicate the transmitter. The “A” drawing depicts the isolation data with no filtering and indicates the relationship between antenna spacing and free space path loss with the single element as the transmission source. The “B” figures depict how the addition of the filters provides the increased isolation necessary for use on such a small ground plane area. The “C “diagrams indicate what energy is seen by the primary element from different frequency bands non-filtered, and again the “D” diagrams show the effects of filtering.

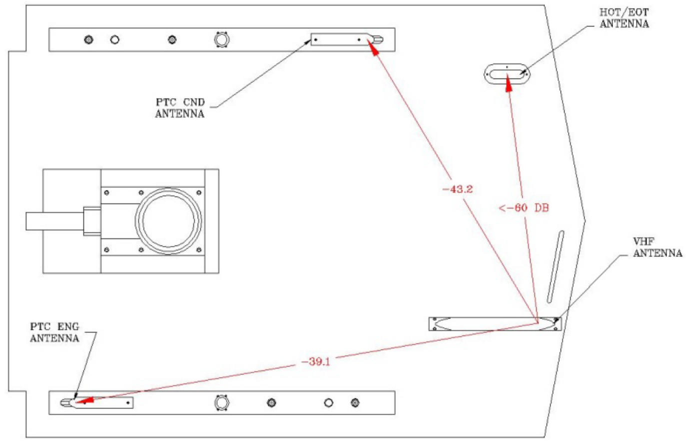
Note that measurements designated “<-60 dB” are actually below the noise floor of the instrument.

In addition to spatial separation, there are other factors to be considered such as the antenna element type, frequency response of the element, and filter performance which will contribute to out of band rejection characteristics, and these have been accounted for in the measurements discussed in this section. In the cases where there are diversity or redundant antennas spaced across the locomotive, there is reasonable symmetry in the isolation numbers which tracks with the layout of the antenna elements. The data shows the improvements in isolation that can be achieved by adding filtering to the antenna system. The results here correlate with the intermodulation data discussed later.

Receive Band	VHF 161	220 ENG	220 CON	HOT 450	Dist. PWR A	Dist. PWR B	ATCS 900	YARD 900	ENG CEL A BLUE	ENG CEL B GRAY	ENG WIFI ORG	CON CEL A BLUE	CON CEL B GRAY	CON WIFI ORG
Transmit Band	(dBm)	(dBm)	(dBm)	(dBm)	(dBm)	(dBm)	(dBm)	(dBm)	(dBm)	(dBm)	(dBm)	(dBm)	(dBm)	(dBm)
VHF 161	TB	-33.0	-35.0	-28.0	-31.8	-31.5	-29.7	-29.8	-37.1	-39.6	NF	-37.0	-38.6	NF
220 ENG	-39.7	TB	-24.3	-35.1	-35.6	-36.4	-47.5	-46.3	-32.0	-36.0	NF	-45.7	-41.7	NF
220 CON	-39.0	-24.4	TB	-35.3	-31.1	-30.8	-48.0	-41.2	-45.0	-50.0	NF	-31.3	-32.9	NF
HOT 450	-23.0	-32.1	-38.1	TB	-19.9	-20.1	-28.9	-29.2	-25.5	-34.2	-52.4	-25.5	-31.1	-49.1
Dist. Power A	-22.2	-31.1	-41.6	-19.9	TB	-19.0	-24.8	-34.2	-23.2	-21.8	-41.5	-33.0	-35.7	-54.8
Dist. Power B	-23.7	-39.8	-29.2	-20.1	-18.9	TB	-24.7	-24.9	-34.7	-34.1	-53.0	-23.9	-29.8	-44.3
ATCS 900	-34.0	-32.1	-32.5	-30.0	-34.0	-32.5	TB	-17.6	-28.0	-30.0	-31.0	-26.8	-26.0	-32.0
YARD 900	-34.6	-32.9	-31.0	-31.1	-35.0	-31.7	-17.4	TB	-28.3	-29.4	-31.3	-26.6	-26.6	-31.0

Receive Band	VHF 161 Filter	220 ENG Filter	220 CON Filter	HOT 450 Filter	Dist. PWR A Filter	Dist. PWR B Filter	ATCS 900	YARD 900	ENG CEL A BLUE	ENG CEL B GRAY	ENG WIFI ORG	CON CEL A BLUE	CON CEL B GRAY	CON WIFI ORG
Transmit Band	(dBm)	(dBm)	(dBm)	(dBm)	(dBm)	(dBm)	(dBm)	(dBm)	(dBm)	(dBm)	(dBm)	(dBm)	(dBm)	(dBm)
VHF 161 Filter	TB	NF	NF	NF	NF	NF	-	-31.2	-39.0	-40.5	NF	-39.0	-40.2	NF
220 ENG Filter	NF	TB	-29.1	NF	NF	NF	-	-49.0	-35.7	-38.7	NF	-48.1	-45.5	NF
220 CON Filter	NF	-29.1	TB	NF	NF	NF	-	-44.6	-47.1	-55.0	NF	-34.7	-36.1	NF
HOT 450 Filter	NF	NF	NF	TB	-24.1	-23.6	-	-32.4	-32.5	-36.5	-52.6	-27.8	-36.5	-53.3
Dist. Power A Filter	NF	NF	NF	-24.1	TB	-23.5	-	-40.9	-26.2	-26.3	-44.1	-35.7	-42.0	-60.2
Dist. Power B Filter	NF	NF	NF	-23.7	-23.5	TB	-	-28.0	-35.0	-36.2	-53.7	-27.6	-36.1	-47.5

Transmit Energy is Single Frequency Band
Un-filtered

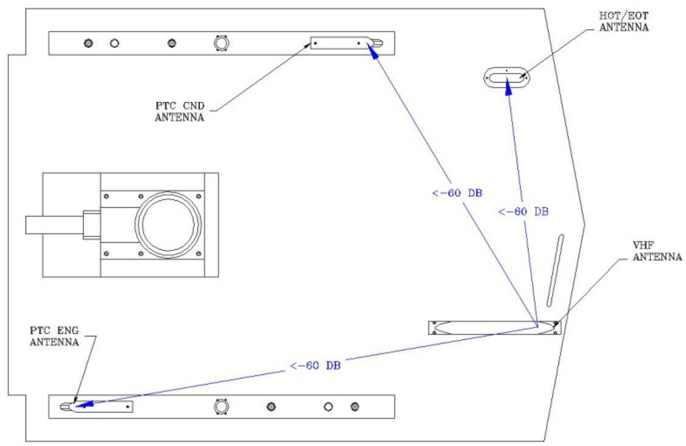


Transmit from single source
Un-filtered

Receive Band	VHF 161	220 ENG	220 CON	HOT 450	Dist. PWR A	Dist. PWR B	ATCS 900	YARD 900	ENG CEL A BLUE	ENG CEL B GRAY	ENG WIFI ORG	CON CEL A BLUE	CON CEL B GRAY	CON WIFI ORG
Transmit Band	(dBm)	(dBm)	(dBm)	(dBm)	(dBm)	(dBm)	(dBm)	(dBm)	(dBm)	(dBm)	(dBm)	(dBm)	(dBm)	(dBm)
VHF 161	TB	-33.0	-35.0	-28.0	-31.8	-31.5	-29.7	-29.8	-37.1	-39.6	NF	-37.0	-38.6	NF
220 ENG	-39.7	TB	-24.3	-35.1	-35.6	-36.4	-47.5	-46.3	-32.0	-36.0	NF	-45.7	-41.7	NF
220 CON	-39.0	-24.4	TB	-35.3	-31.1	-30.8	-48.0	-41.2	-45.0	-50.0	NF	-31.3	-32.9	NF
HOT 450	-23.0	-32.1	-38.1	TB	-19.9	-20.1	-28.9	-29.2	-25.5	-34.2	-52.4	-25.5	-31.1	-49.1
Dist. Power A	-22.2	-31.1	-41.6	-19.9	TB	-19.0	-24.8	-34.2	-23.2	-21.8	-41.5	-33.0	-35.7	-54.8
Dist. Power B	-23.7	-39.8	-29.2	-20.1	-18.9	TB	-24.7	-24.9	-34.7	-34.1	-53.0	-23.9	-29.8	-44.3
ATCS 900	-34.0	-32.1	-32.5	-30.0	-34.0	-32.5	TB	-17.6	-28.0	-30.0	-31.0	-26.8	-26.0	-32.0
YARD 900	-34.6	-32.9	-31.0	-31.1	-35.0	-31.7	-17.4	TB	-28.3	-29.4	-31.3	-26.6	-26.6	-31.0

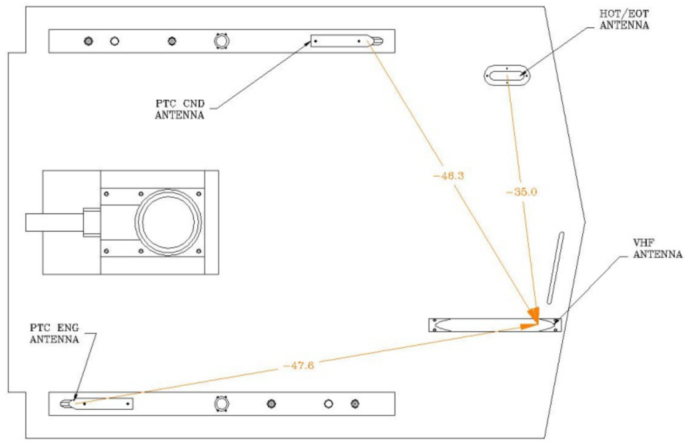
Receive Band	VHF 161 Filter	220 ENG Filter	220 CON Filter	HOT 450 Filter	Dist. PWR A Filter	Dist. PWR B Filter	ATCS 900	YARD 900	ENG CEL A BLUE	ENG CEL B GRAY	ENG WIFI ORG	CON CEL A BLUE	CON CEL B GRAY	CON WIFI ORG
Transmit Band	(dBm)	(dBm)	(dBm)	(dBm)	(dBm)	(dBm)	(dBm)	(dBm)	(dBm)	(dBm)	(dBm)	(dBm)	(dBm)	(dBm)
VHF 161 Filter	TB	NF	NF	NF	NF	NF	-	-31.2	-39.0	-40.5	NF	-39.0	-40.2	NF
220 ENG Filter	NF	TB	-29.1	NF	NF	NF	-	-49.0	-35.7	-38.7	NF	-48.1	-45.5	NF
220 CON Filter	NF	-20.1	TB	NF	NF	NF	-	-44.6	-47.1	-55.0	NF	-34.7	-36.1	NF
HOT 450 Filter	NF	NF	NF	TB	-24.1	-23.6	-	-32.4	-32.5	-36.5	-52.6	-27.8	-36.5	-53.3
Dist. Power A Filter	NF	NF	NF	-24.1	TB	-23.5	-	-40.9	-26.2	-26.3	-44.1	-35.7	-42.0	-60.2
Dist. Power B Filter	NF	NF	NF	-23.7	-23.5	TB	-	-28.0	-35.0	-36.2	-53.7	-27.6	-36.1	-47.5

Transmit Energy is Single Frequency Band
Filtered



Transmit from single source
Filtered

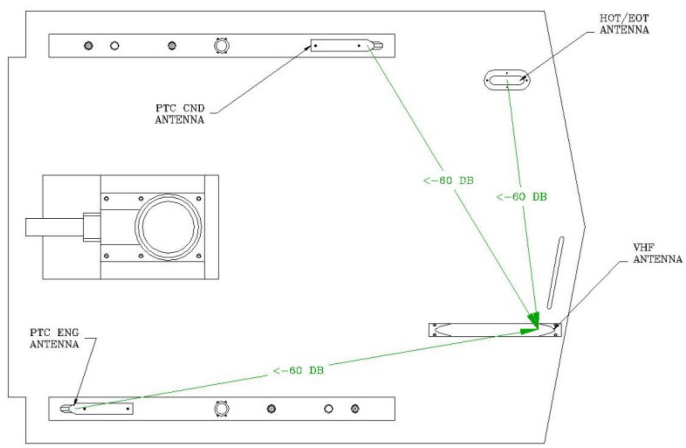
Receive Band	VHF 161	220 ENG	220 CON	HOT 450	Dist. PWR A	Dist. PWR B	ATCS 900	YARD 900	ENG CEL A BLUE	ENG CEL B GRAY	ENG WIFI ORG	CON CEL A BLUE	CON CEL B GRAY	CON WIFI ORG
Transmit Band	(dBm)	(dBm)	(dBm)	(dBm)	(dBm)	(dBm)	(dBm)	(dBm)	(dBm)	(dBm)	(dBm)	(dBm)	(dBm)	(dBm)
VHF 161	TB	-33.0	-35.0	-28.0	-31.8	-31.5	-29.7	-29.8	-37.1	-39.6	NF	-37.0	-38.6	NF
220 ENG	-39.7	TB	-24.3	-35.1	-35.6	-36.4	-47.5	-46.3	-32.0	-36.0	NF	-45.7	-41.7	NF
220 CON	-39.0	-24.4	TB	-35.3	-31.1	-30.8	-48.0	-41.2	-45.0	-50.0	NF	-31.3	-32.9	NF
HOT 450	-23.0	-32.1	-38.1	TB	-19.9	-20.1	-28.9	-29.2	-25.5	-34.2	-52.4	-25.5	-31.1	-49.1
Dist. Power A	-22.2	-31.1	-41.6	-19.9	TB	-19.0	-24.8	-34.2	-23.2	-21.8	-41.5	-33.0	-35.7	-54.8
Dist. Power B	-23.7	-39.8	-29.2	-20.1	-18.9	TB	-24.7	-24.9	-34.7	-34.1	-53.0	-23.9	-29.8	-44.3
ATCS 900	-34.0	-32.1	-32.5	-30.0	-34.0	-32.5	TB	-17.6	-28.0	-30.0	-31.0	-26.8	-26.0	-32.0
YARD 900	-34.6	-32.9	-31.0	-31.1	-35.0	-31.7	-17.4	TB	-28.3	-29.4	-31.3	-26.6	-26.6	-31.0
Receive Band	VHF 161 Filter	220 ENG Filter	220 CON Filter	HOT 450 Filter	Dist. PWR A Filter	Dist. PWR B Filter	ATCS 900	YARD 900	ENG CEL A BLUE	ENG CEL B GRAY	ENG WIFI ORG	CON CEL A BLUE	CON CEL B GRAY	CON WIFI ORG
Transmit Band	(dBm)	(dBm)	(dBm)	(dBm)	(dBm)	(dBm)	(dBm)	(dBm)	(dBm)	(dBm)	(dBm)	(dBm)	(dBm)	(dBm)
VHF 161 Filter	TB	NF	NF	NF	NF	NF	-	-31.2	-39.0	-40.5	NF	-39.0	-40.2	NF
220 ENG Filter	NF	TB	-29.1	NF	NF	NF	-	-49.0	-35.7	-38.7	NF	-48.1	-45.5	NF
220 CON Filter	NF	-29.1	TB	NF	NF	NF	-	-44.6	-47.1	-55.0	NF	-34.7	-36.1	NF
HOT 450 Filter	NF	NF	NF	TB	-24.1	-23.6	-	-32.4	-32.5	-36.5	-52.6	-27.8	-36.5	-53.3
Dist. Power A Filter	NF	NF	NF	-24.1	TB	-23.5	-	-40.9	-26.2	-26.3	-44.1	-35.7	-42.0	-60.2
Dist. Power B Filter	NF	NF	NF	-23.7	-23.5	TB	-	-28.0	-35.0	-36.2	-53.7	-27.6	-36.1	-47.5



Receive Energy is Multiple Frequency Bands
Un-filtered

Receive from multiple sources
Un-filtered

Receive Band	VHF 161	220 ENG	220 CON	HOT 450	Dist. PWR A	Dist. PWR B	ATCS 900	YARD 900	ENG CEL A BLUE	ENG CEL B GRAY	ENG WIFI ORG	CON CEL A BLUE	CON CEL B GRAY	CON WIFI ORG
Transmit Band	(dBm)	(dBm)	(dBm)	(dBm)	(dBm)	(dBm)	(dBm)	(dBm)	(dBm)	(dBm)	(dBm)	(dBm)	(dBm)	(dBm)
VHF 161	TB	-33.0	-35.0	-28.0	-31.8	-31.5	-29.7	-29.8	-37.1	-39.6	NF	-37.0	-38.6	NF
220 ENG	-39.7	TB	-24.3	-35.1	-35.6	-36.4	-47.5	-46.3	-32.0	-36.0	NF	-45.7	-41.7	NF
220 CON	-39.0	-24.4	TB	-35.3	-31.1	-30.8	-48.0	-41.2	-45.0	-50.0	NF	-31.3	-32.9	NF
HOT 450	-23.0	-32.1	-38.1	TB	-19.9	-20.1	-28.9	-29.2	-25.5	-34.2	-52.4	-25.5	-31.1	-49.1
Dist. Power A	-22.2	-31.1	-41.6	-19.9	TB	-19.0	-24.8	-34.2	-23.2	-21.8	-41.5	-33.0	-35.7	-54.8
Dist. Power B	-23.7	-39.8	-29.2	-20.1	-18.9	TB	-24.7	-24.9	-34.7	-34.1	-53.0	-23.9	-29.8	-44.3
ATCS 900	-34.0	-32.1	-32.5	-30.0	-34.0	-32.5	TB	-17.6	-28.0	-30.0	-31.0	-26.8	-26.0	-32.0
YARD 900	-34.6	-32.9	-31.0	-31.1	-35.0	-31.7	-17.4	TB	-28.3	-29.4	-31.3	-26.6	-26.6	-31.0
Receive Band	VHF 161 Filter	220 ENG Filter	220 CON Filter	HOT 450 Filter	Dist. PWR A Filter	Dist. PWR B Filter	ATCS 900	YARD 900	ENG CEL A BLUE	ENG CEL B GRAY	ENG WIFI ORG	CON CEL A BLUE	CON CEL B GRAY	CON WIFI ORG
Transmit Band	(dBm)	(dBm)	(dBm)	(dBm)	(dBm)	(dBm)	(dBm)	(dBm)	(dBm)	(dBm)	(dBm)	(dBm)	(dBm)	(dBm)
VHF 161 Filter	TB	NF	NF	NF	NF	NF	-	-31.2	-39.0	-40.5	NF	-39.0	-40.2	NF
220 ENG Filter	NF	TB	-29.1	NF	NF	NF	-	-49.0	-35.7	-38.7	NF	-48.1	-45.5	NF
220 CON Filter	NF	-29.1	TB	NF	NF	NF	-	-44.6	-47.1	-55.0	NF	-34.7	-36.1	NF
HOT 450 Filter	NF	NF	NF	TB	-24.1	-23.6	-	-32.4	-32.5	-36.5	-52.6	-27.8	-36.5	-53.3
Dist. Power A Filter	NF	NF	NF	-24.1	TB	-23.5	-	-40.9	-26.2	-26.3	-44.1	-35.7	-42.0	-60.2
Dist. Power B Filter	NF	NF	NF	-23.7	-23.5	TB	-	-28.0	-35.0	-36.2	-53.7	-27.6	-36.1	-47.5



Receive Energy is Multiple Frequency Bands
Filtered

Receive from multiple sources
Filtered

CSX 4022 Antenna Isolation
VHF XMIT Mapping

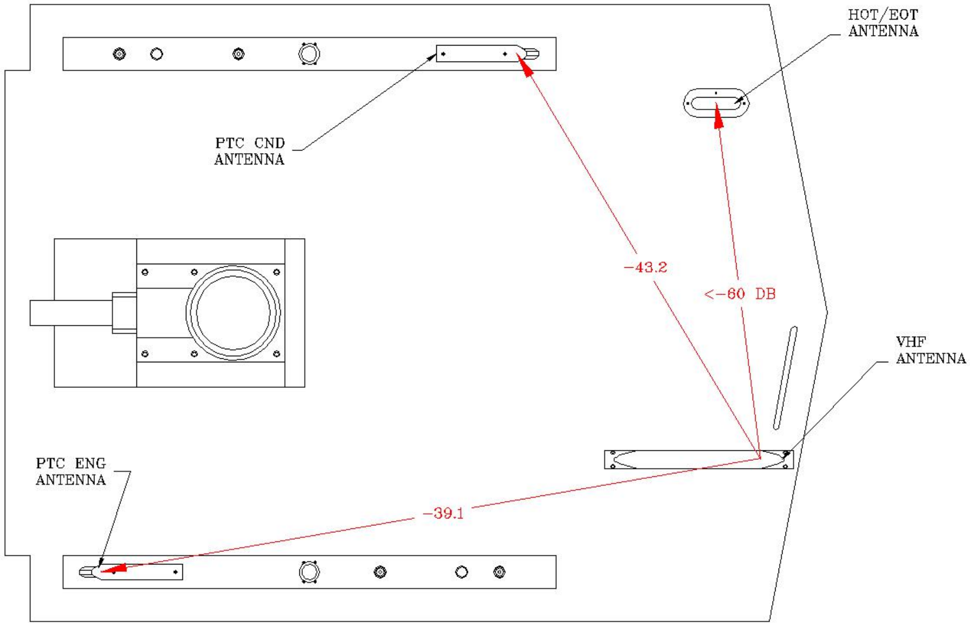


Figure 14 A
Non-Filtered

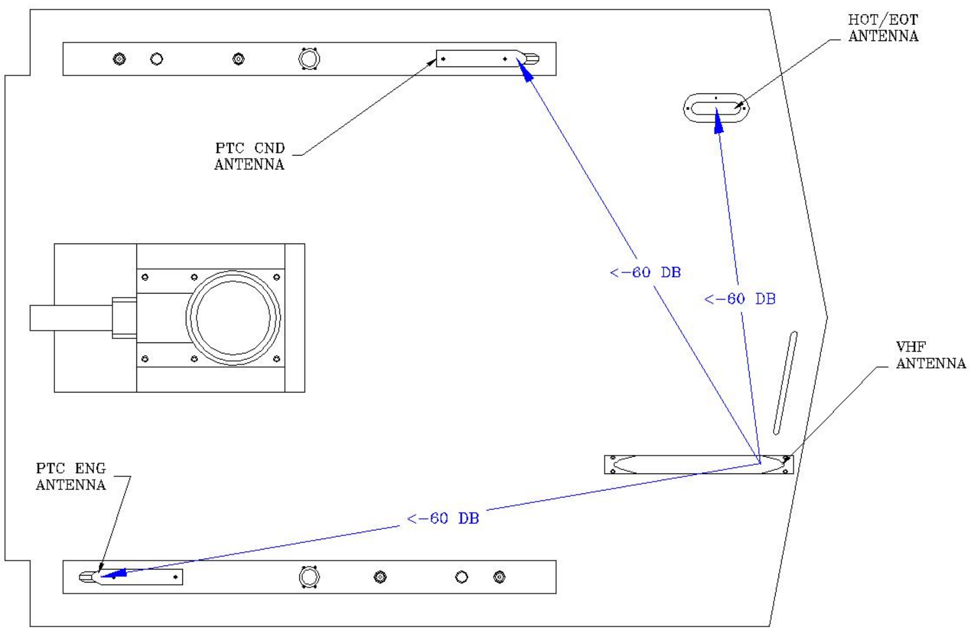


Figure 14 B
Filtered

CSX 4022 Antenna Isolation
VHF RCV Mapping

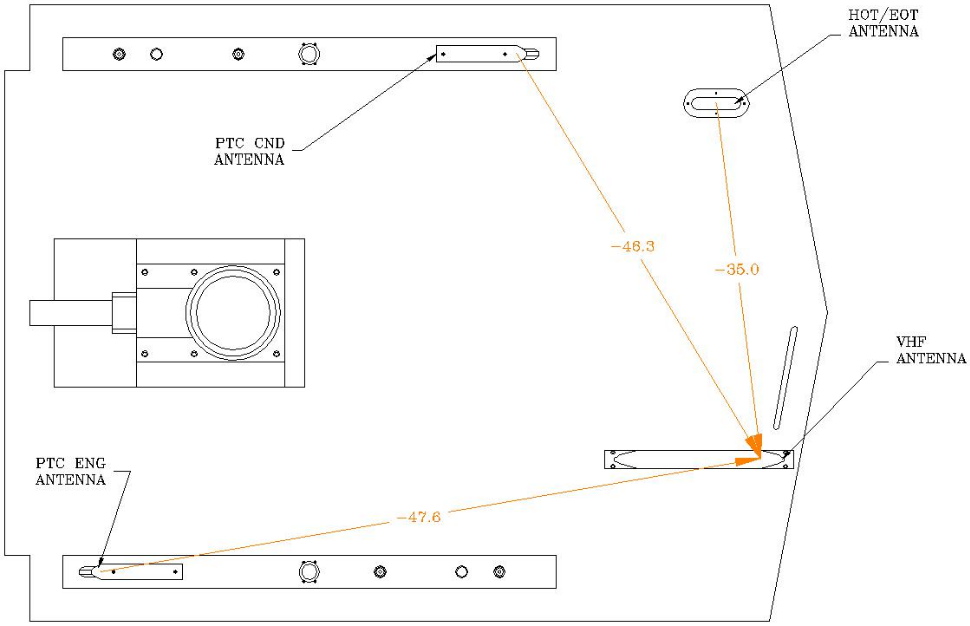


Figure 14 C
Non-Filtered

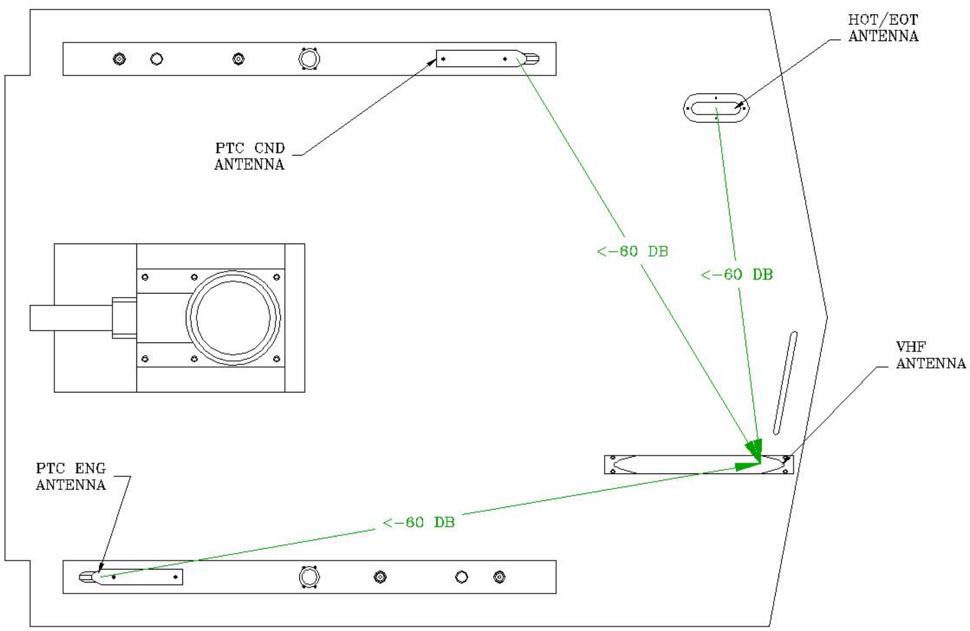


Figure 14 D
Filtered

CSX 4022 Antenna Isolation
PTC CND XMIT Mapping

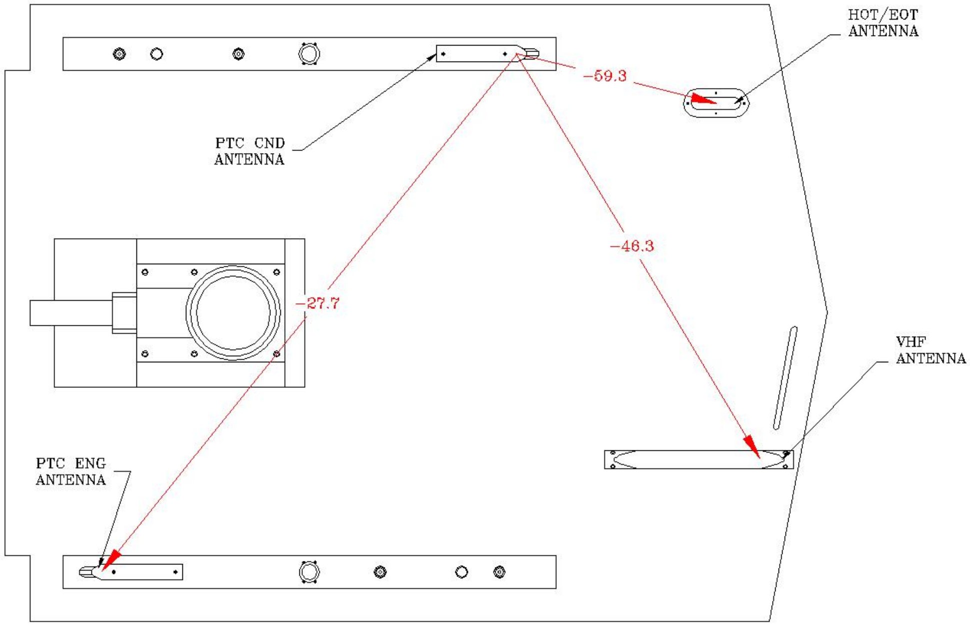


Figure 15 A
Non-Filtered

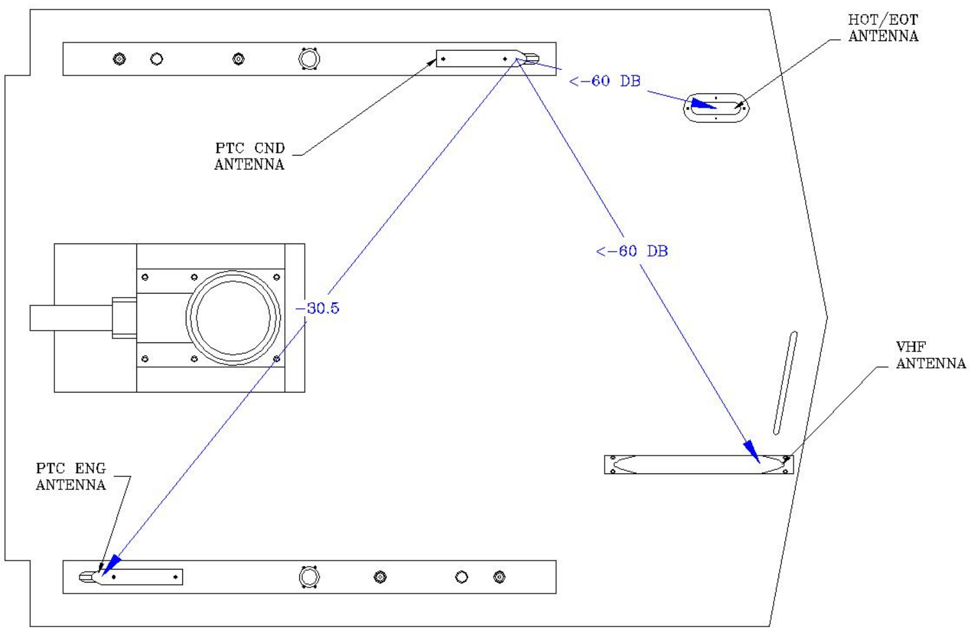


Figure 15 B
Filtered

CSX 4022 Antenna Isolation
PTC CND RCV Mapping

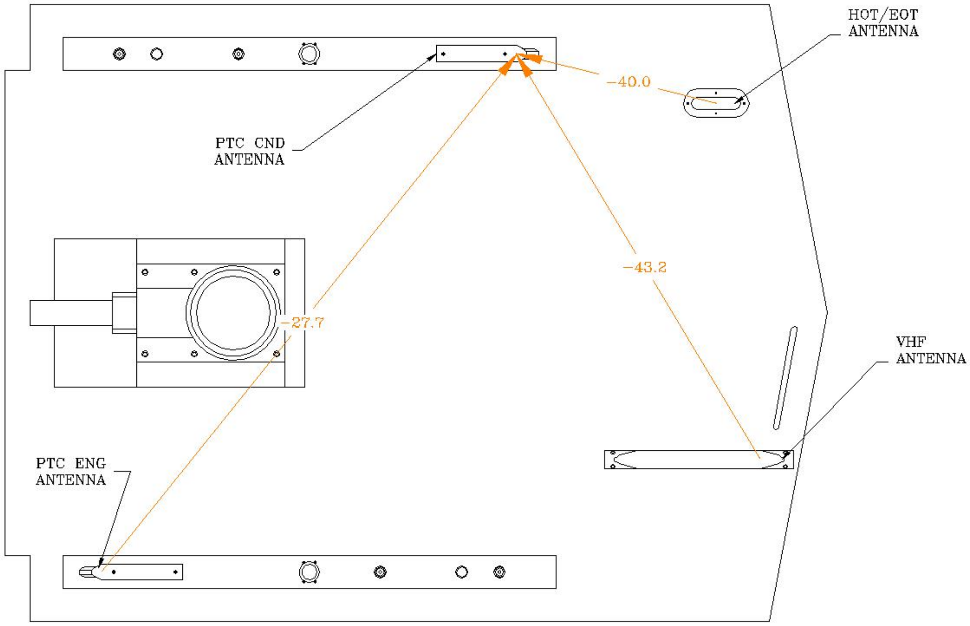


Figure 15 C
Non-Filtered

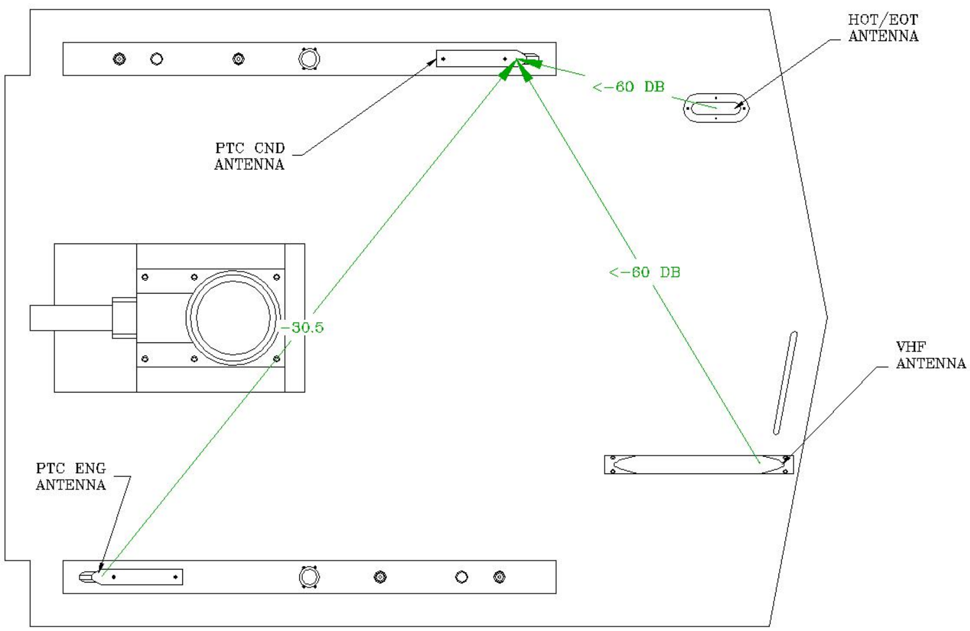


Figure 15 D
Filtered

CSX 4022 Antenna Isolation
PTC ENG XMIT Mapping

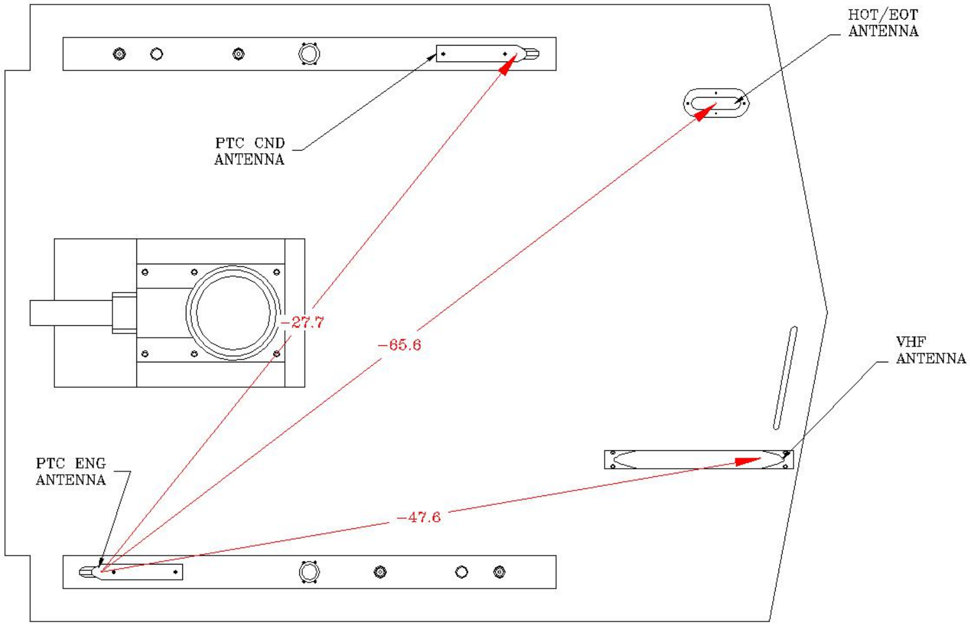


Figure 16 A
Non-Filtered

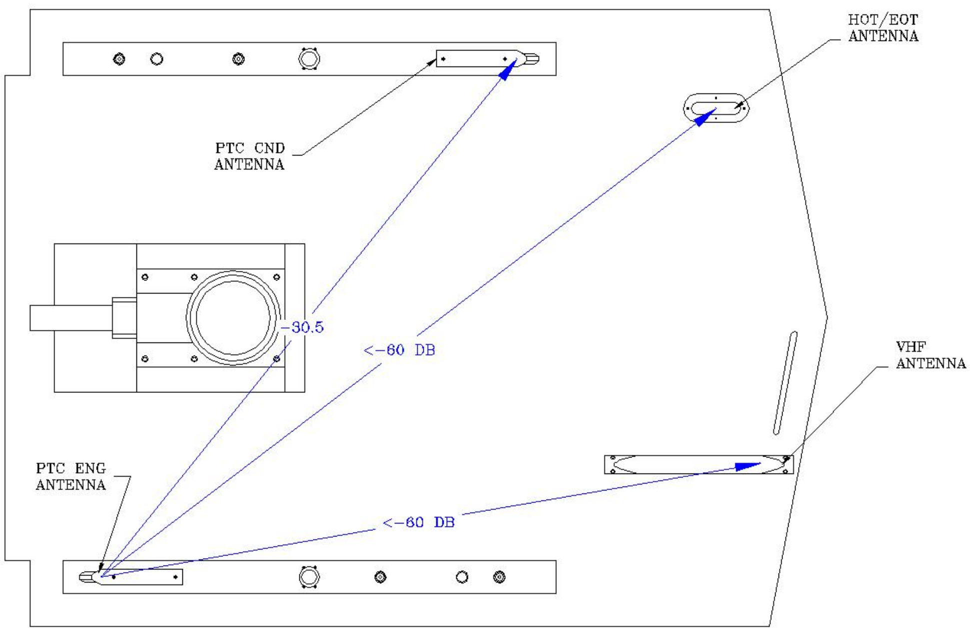


Figure 16 B
Filtered

CSX 4022 Antenna Isolation
PTC ENG RCV Mapping

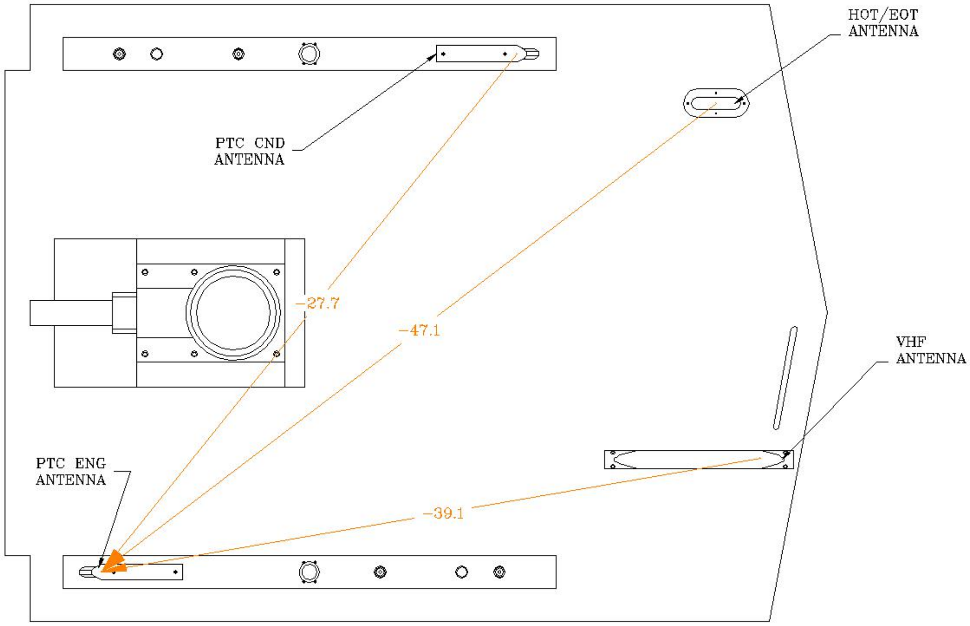


Figure 16 C
Non-Filtered

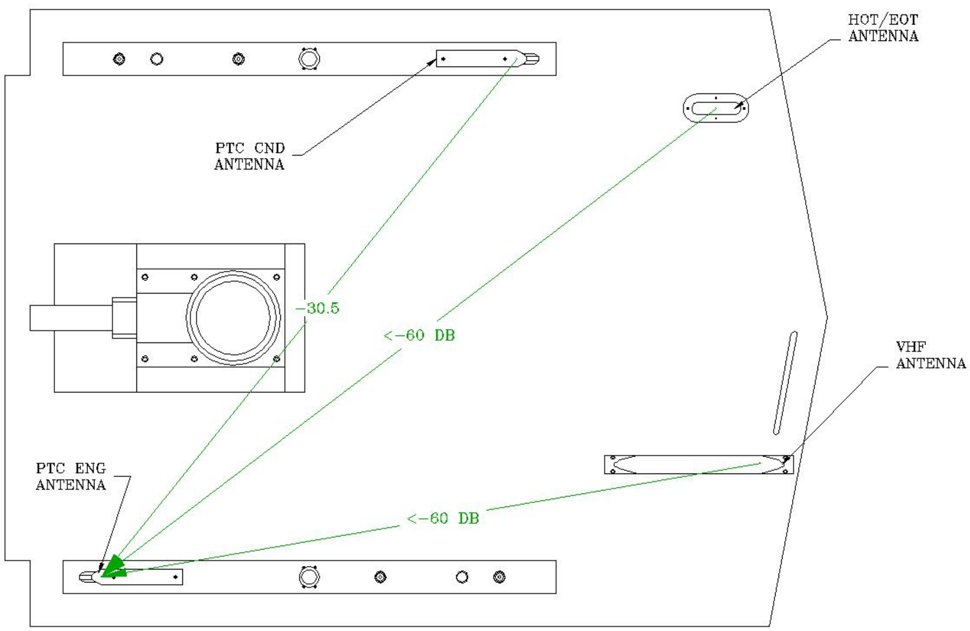


Figure 16 D
Filtered

CSX 4022 Antenna Isolation
HOT/EOT XMIT Mapping

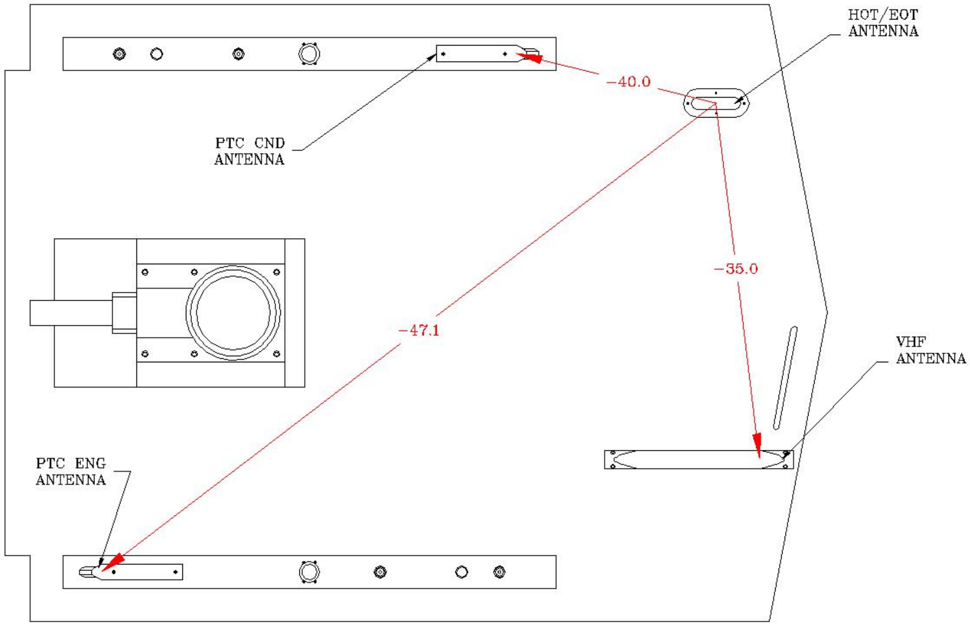


Figure 17 A
Non-Filtered

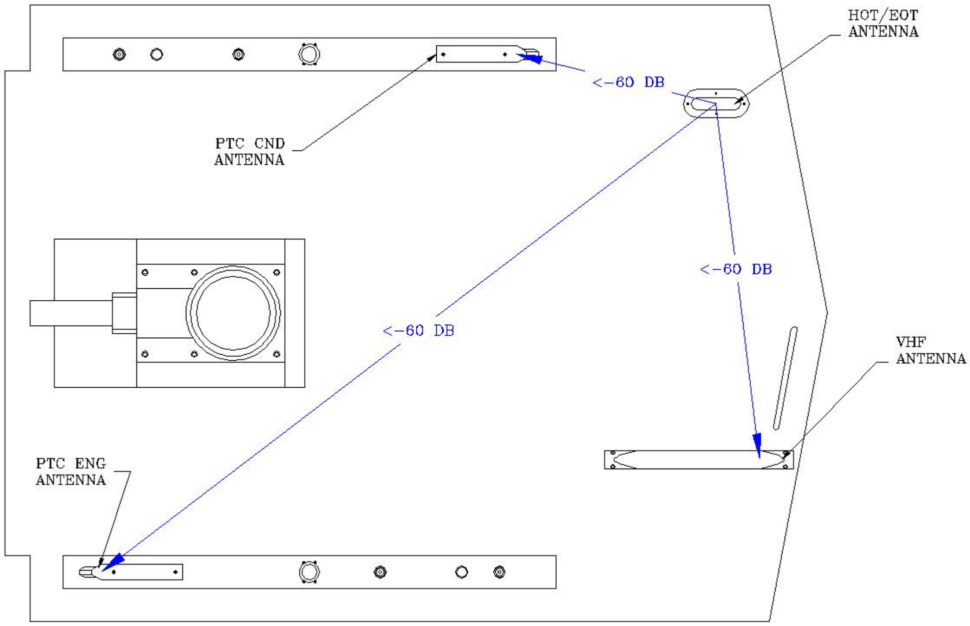


Figure 17 B
Filtered

CSX 4022 Antenna Isolation
HOT/EOT RCV Mapping

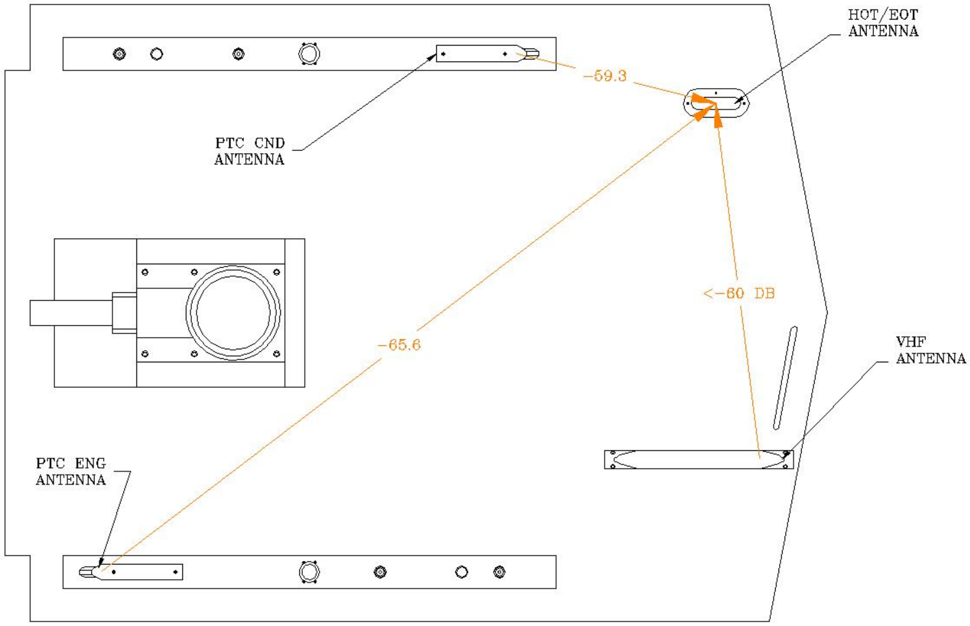


Figure 17 C
Non-Filtered

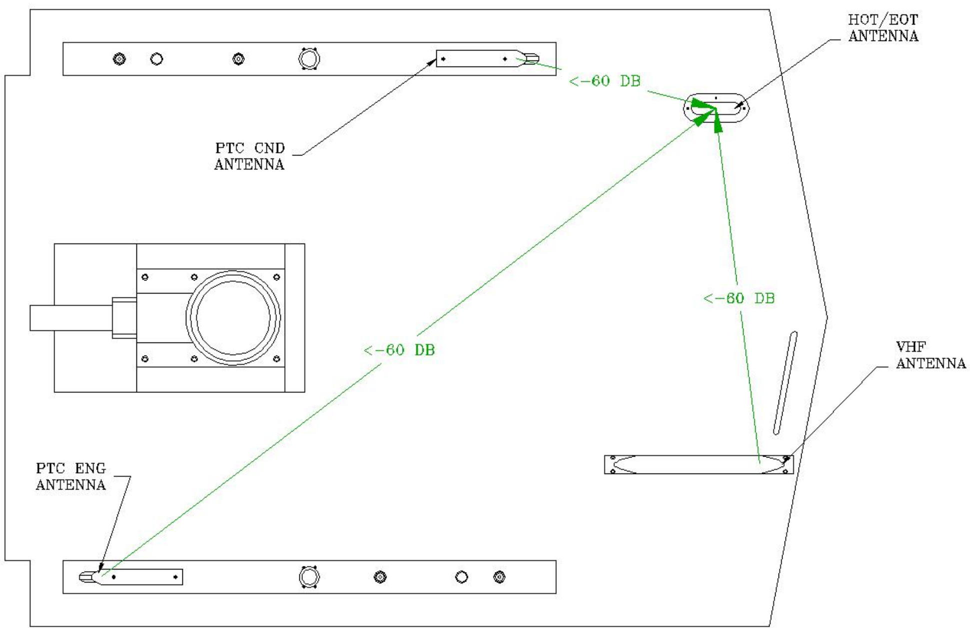


Figure 17 D
Filtered

Receive Intermodulation Test

This test provides information on intermodulation products generated at the front end of each radio receiver when it is impacted by high power signals from the transmitting radio.

Each of the on board radios transmits at nominal power, and using a dual directional coupler. The radio under test is measured for the amount of intermodulation products generated at the front end of the radio receiver and re-radiated back through the same antenna. Note that the radio under test is not transmitting.

A Dual Directional Coupler rated for a maximum power of 500 Watts was used to separately measure signals coming from the antenna to the radio receiver front end, and from the receiver front end to the antenna and subsequently transmitted as intermodulation products.

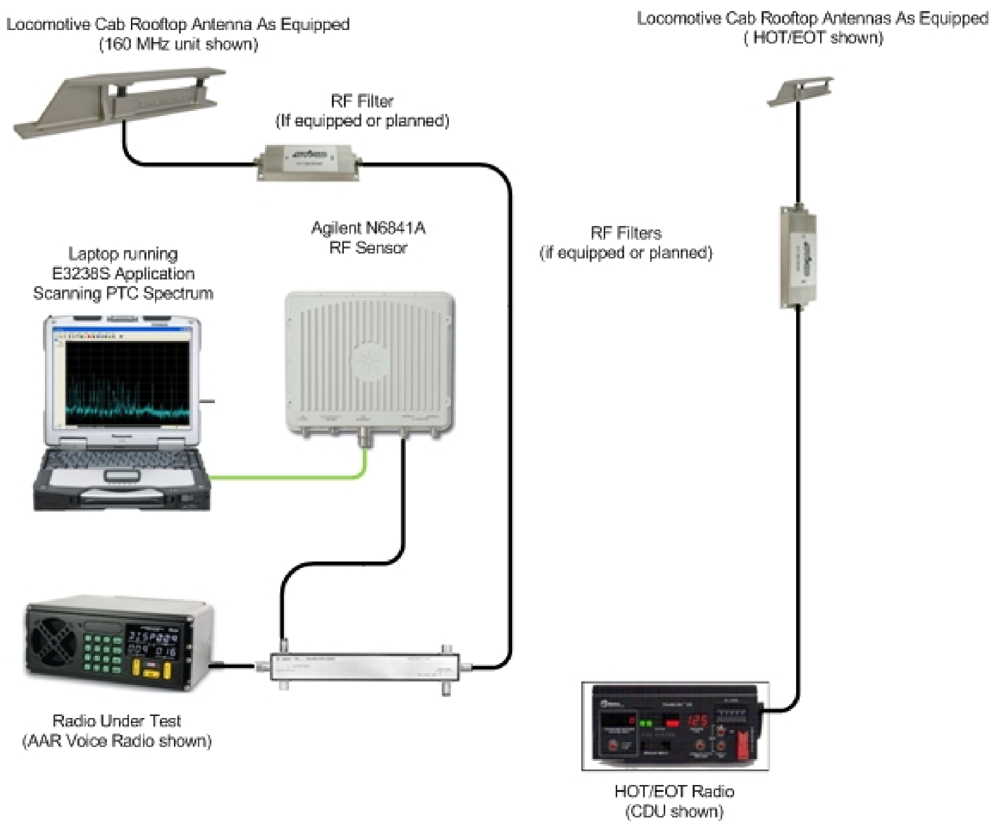
This Dual Directional Coupler has six ports, one for Antenna, one for Radio, two for 50 ohms loads, one to measure signals coming from the antenna to the radio transceiver, and one port to measure signals from the radio transceiver to the antenna.

In the IMD Test Apparatus diagram, the initial radio under test shown is the AAR Voice Radio, operating at ~ 160 MHz. Its Receiver is coupled directly to its existing transmission path, including Antenna (and Filter, if equipped or planned). The RF Sensor is coupled 20 dB down to the Receiver in the Radio under Test. The other radios of interest on the Locomotive (DPA, DPB, and HOT/EOT) are then keyed and RF energy from those radios passes through their appropriate transmission paths, including coax cable, antennas (and filters, if equipped or planned). The RF energy then propagates into the Antenna of the Radio under Test, and then into the Receiver under test. Any IMD products in the 220 MHz spectrum generated in the Receiver that would be propagated via the Antenna system are detected by use of the RF Sensor.

A permutation of the IMD Test Apparatus is configured for each of the other radios of interest (DPA, DPB, and HOT/EOT), so that each of them is connected as a Radio under Test, and the process is repeated.

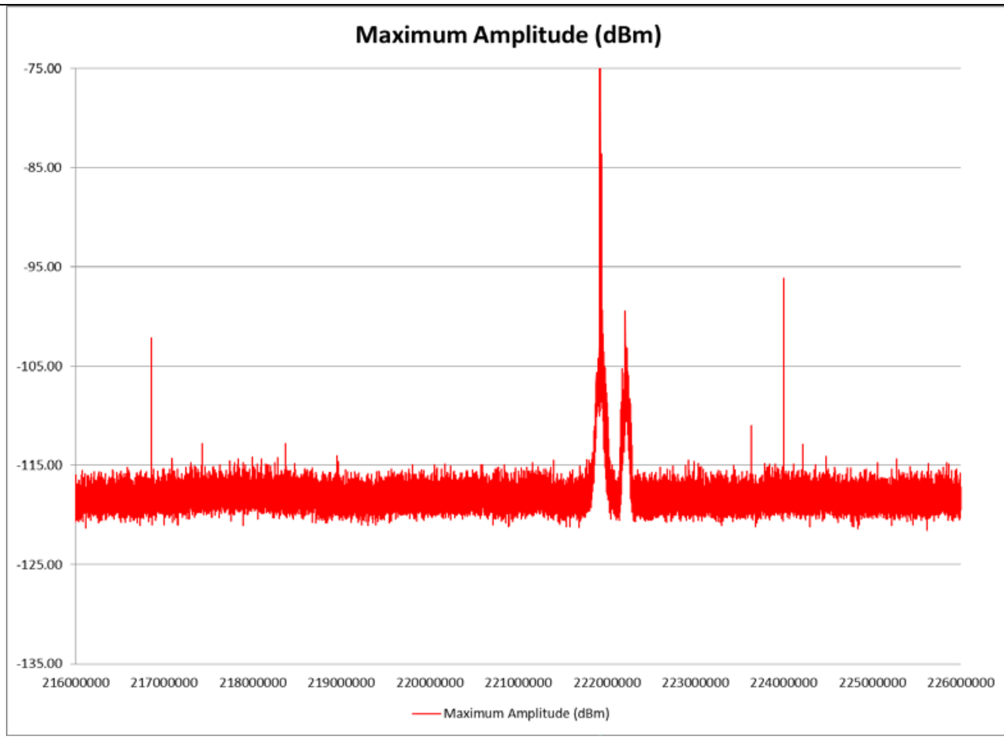
This particular locomotive was only equipped with an HOT/EOT radio and antenna, and not equipped with Distributed Power Radios or Antennas. Therefore the only systems evaluated were the VHF and the HOT/EOT. Note that without Distributed Power Radios, the issues seen in other tests involving both brands of HOT/EOT are not seen here (See BNSF 5018, CSX 985).

Note that the spur at 224.000 MHz appears to be an artifact of the RF Sensor, and should be ignored.



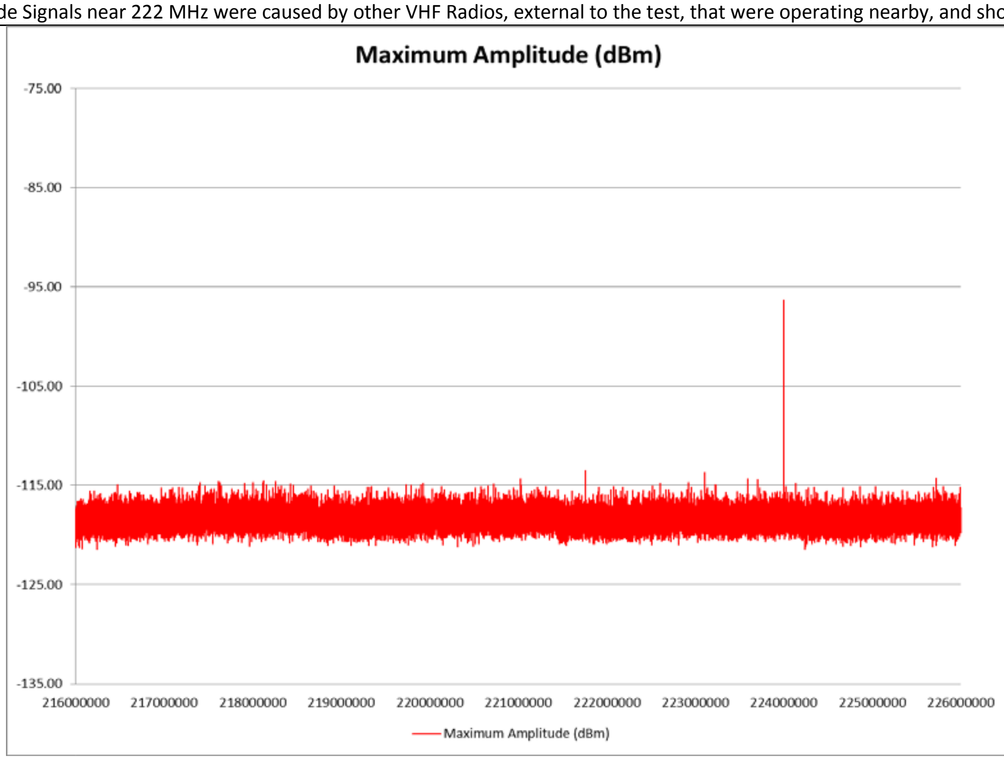
Receive Intermodulation Testing Configuration
Figure 20

VHF RECEIVE



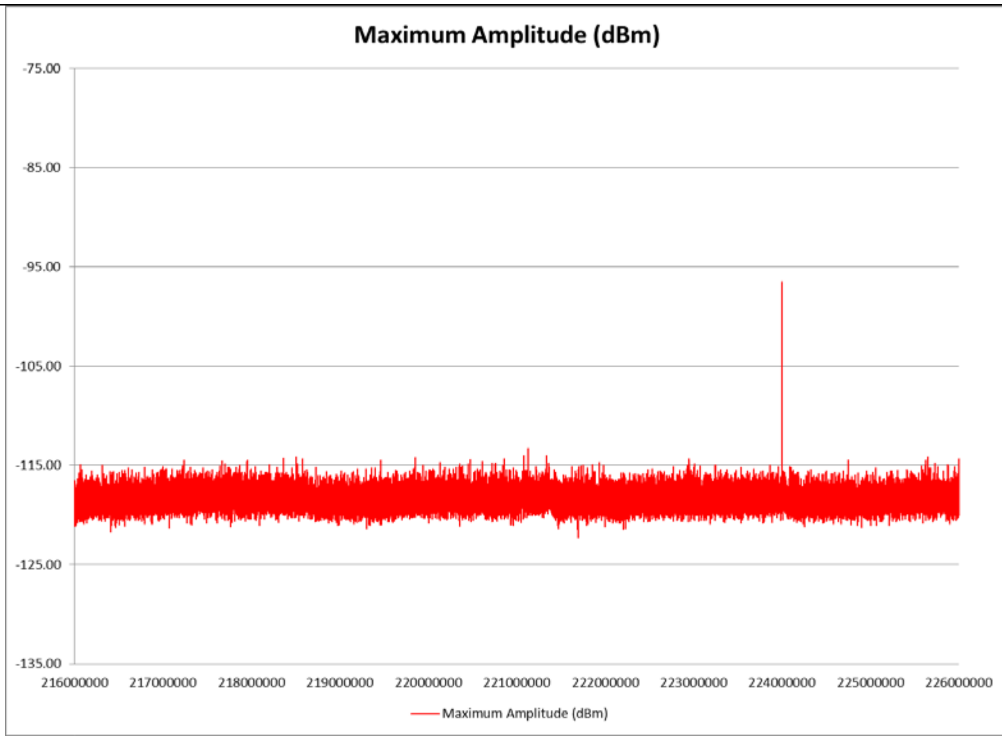
VHF RX HOT/EOT TX Non-Filtered (note spur near 217 MHz)

(High Amplitude Signals near 222 MHz were caused by other VHF Radios, external to the test, that were operating nearby, and should be ignored)

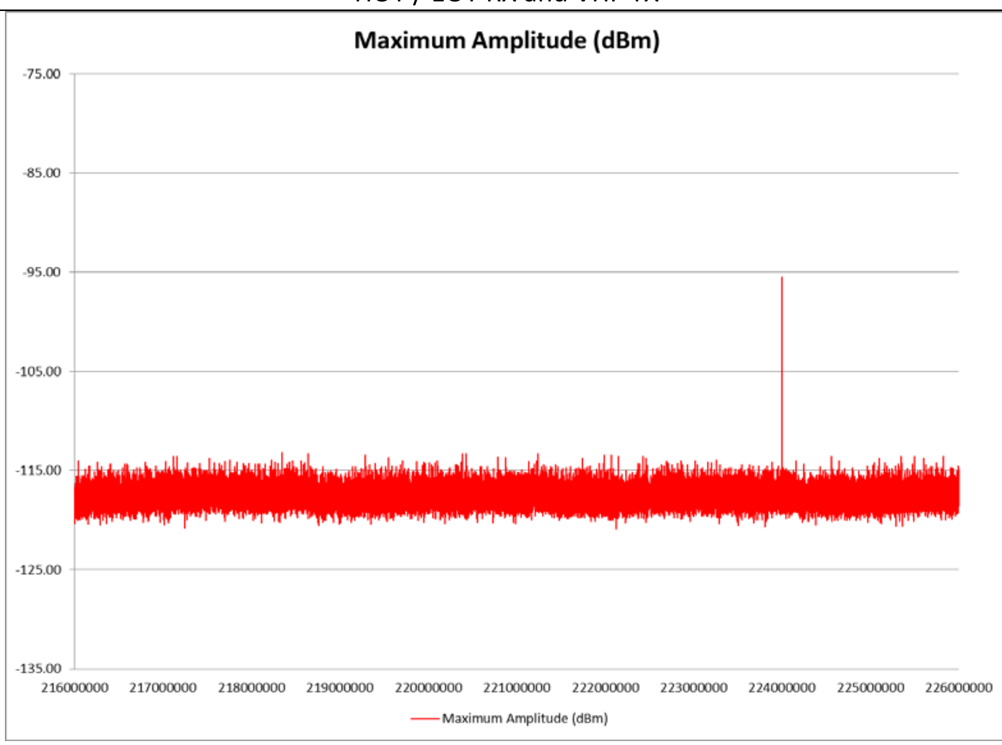


VHF RX HOT/EOT TX Filtered

HOT/EOT RECEIVE



HOT / EOT RX and VHF TX



HOT / EOT RX and VHF TX Filtered

Transmit Intermodulation Test

This test provides information on intermodulation products produced by multiple radio transmissions at the same time. Several radios on a locomotive, such as Voice 161 MHz, PTC 220 MHz, DP A UHF or DP B UHF, HOT UHF and SPEC 200 900 MHz, may transmit simultaneously. These simultaneous transmissions may occur on two, three, or more radios at the same time.

Two, three, four or more on-board radios combined in different groups transmit simultaneously. Each of the radios transmits at nominal power, and using a dual directional coupler, each other non-transmitting radio is measured for the magnitude of signals received from the transmitting radios entering through the antenna, and for the amount of intermodulation products generated at the front end of the radio receiver and re-transmitted through the same antenna.

A Dual Directional Coupler rated for a maximum power of 500 Watts is used to separately measure signals radiated by the antenna to the radio receiver front end, and then from the receiver front end to the antenna, and subsequently re-transmitted as intermodulation products.

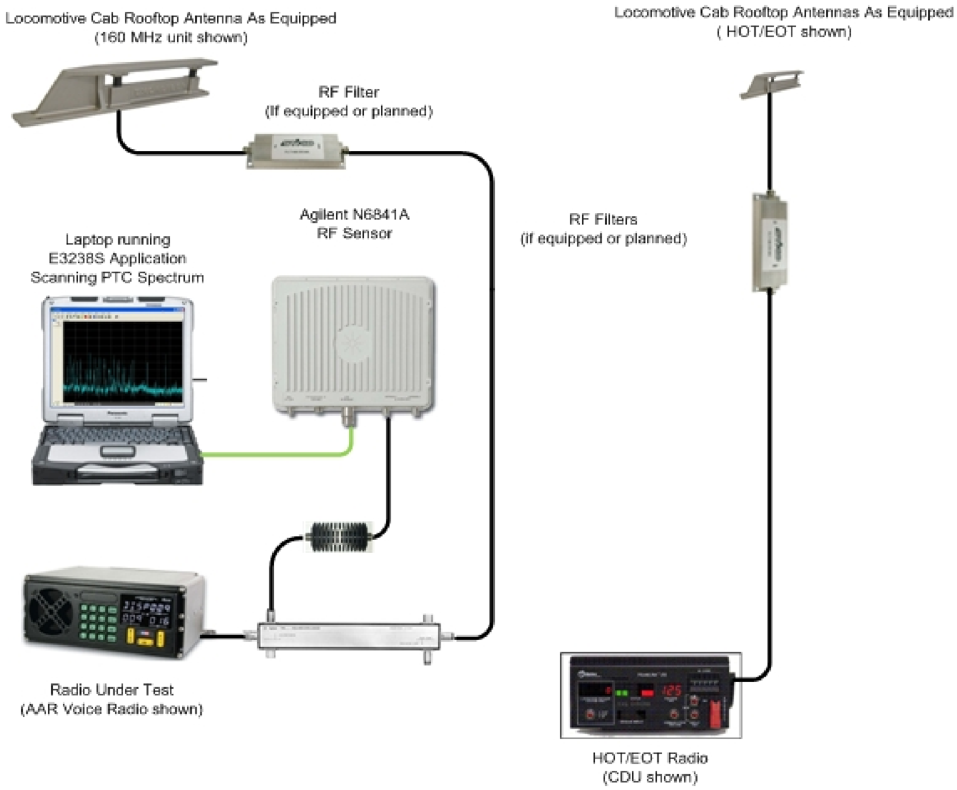
This Dual Directional Coupler has six ports, one for Antenna, one for Radio, two for 50 ohms loads, one to measure signals coming from the antenna to the radio transceiver, and one port to measure signals from the radio transceiver to the antenna.

In the IMD Test Apparatus diagram, the initial radio under test shown is the AAR Voice Radio, operating at ~ 160 MHz. Its Transmitter is coupled directly to its existing transmission path, including Antenna (and Filter, if equipped or planned). The RF Sensor is coupled 20 dB down (or more, as needed to protect the RF Sensor) to the Transmitter in the Radio under Test. The other radios of interest on the Locomotive (DPA, DPB, and HOT/EOT) are then keyed and RF energy from those radios pass through their respective existing transmission paths, including Antennas (and Filters, if equipped or planned). The RF energy then propagates into the Antenna of the Radio under Test, and then into the Transmitter under test. Any IMD products in the 220 MHz spectrum generated in the Transmitter that would be propagated via the Antenna system are measured by the RF Sensor.

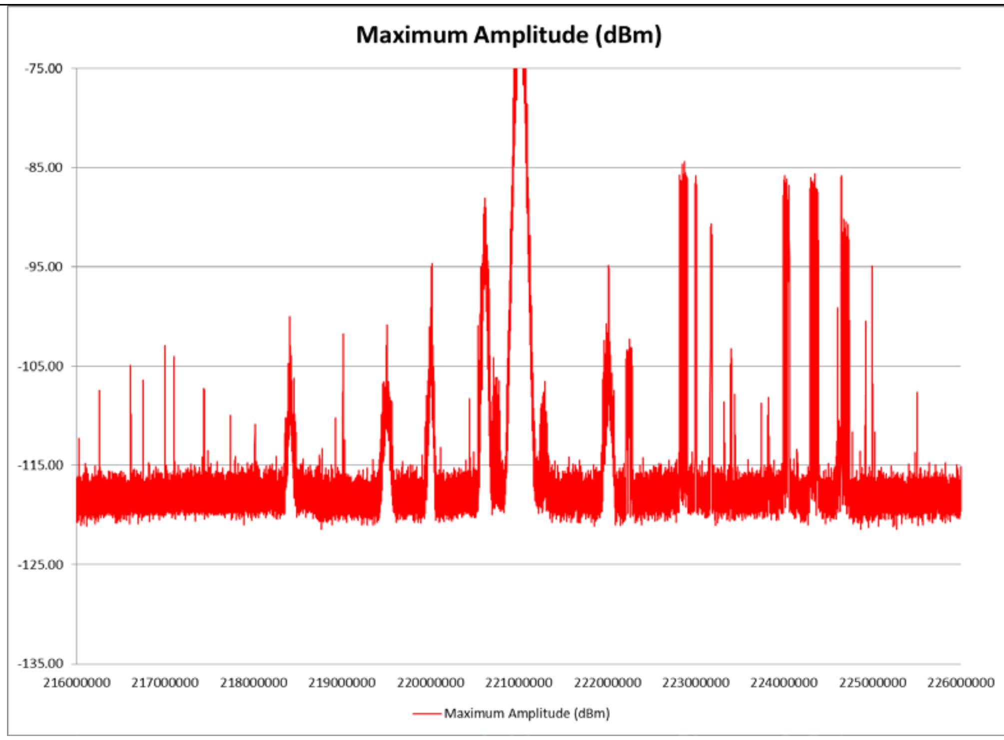
A permutation of the IMD Test Apparatus is configured for each of the other radios of interest (DPA, DPB, and HOT/EOT), so that each of them is connected as a Radio under Test, and the process is repeated.

This particular locomotive was only equipped with an HOT/EOT radio and antenna, and not equipped with Distributed Power Radios or Antennas. Therefore the only systems evaluated were the VHF and the HOT/EOT. Note that without Distributed Power Radios, the issues seen in other tests involving both brands of HOT/EOT are not seen here (See BNSF 5018, CSX 985).

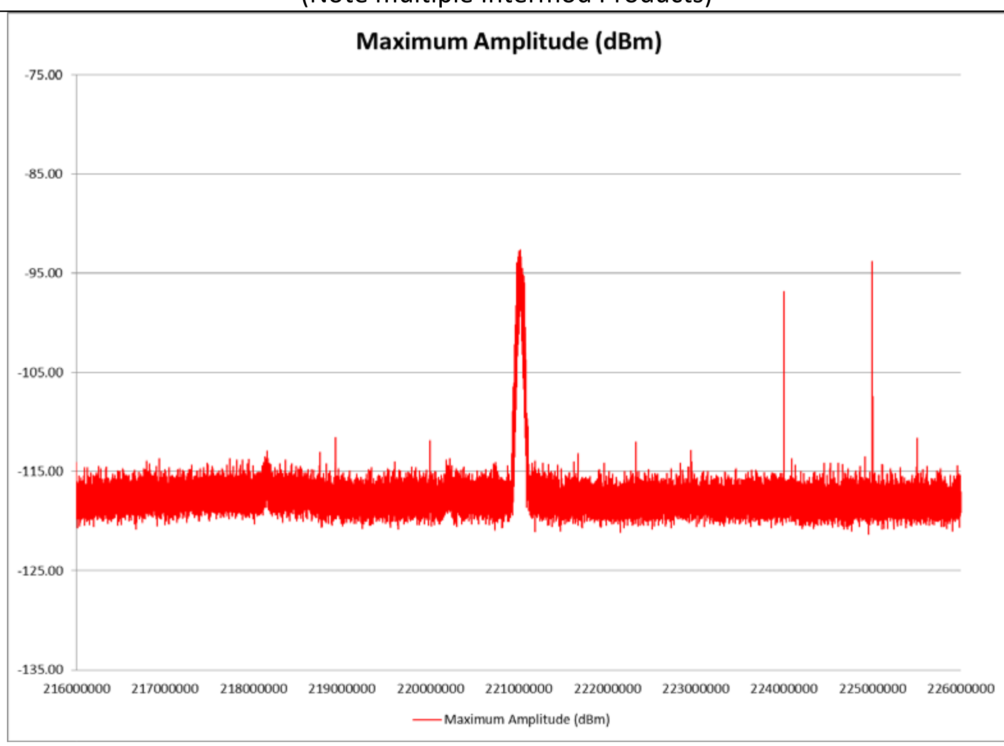
Note that the spur at 224.000 MHz appears to be an artifact of the RF Sensor, and should be ignored.



Transmit Intermodulation Testing Configuration
Figure 21



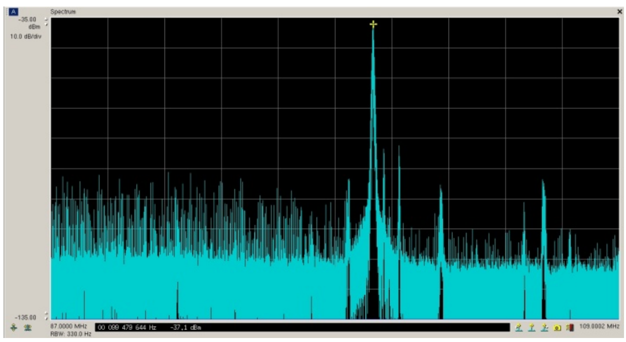
VHF TX and HOT/EOT TX Non-Filtered
(Note multiple Intermod Products)

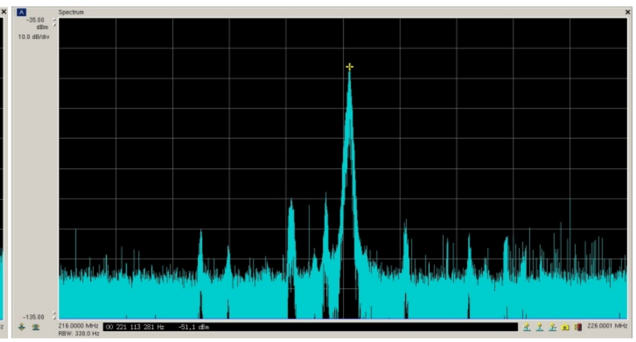


VHF TX and HOT/EOT TX Filtered
(Note Significant reduction in number of IntermOdulation Products and Amplitude reduction at 221 MHz)

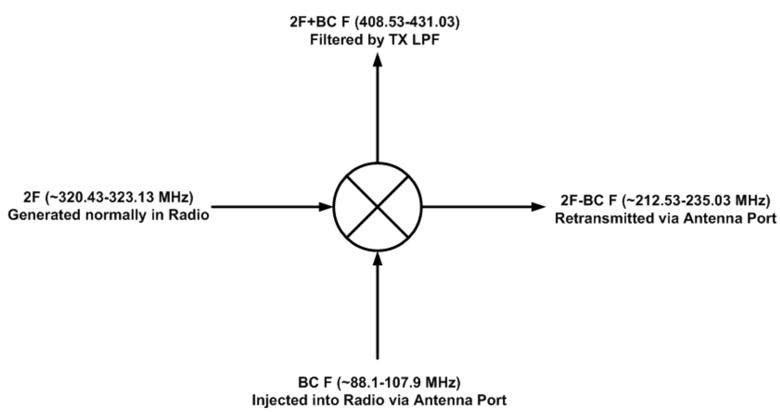
Transmit Intermodulation—Additional RFI

When transmitting on the AAR VHF Voice Radio, Significant RF Energy was measured in the 220 MHz Band. Testing on AAR Channel 13 (160.305MHz) produced a signal at ~221.11 MHz, 150 kHz to 200 kHz wide, at ~-50 dBm. Other signals were also present in the 220 MHz band varying in Amplitude from ~-105 dBm to ~-95 dBm. The Signals were Analog, and therefore could be demodulated, and were found to be carrying Broadcast Programming Audio. A scan of the FM Broadcast Band revealed signals with matching traffic. Traffic intercepted at ~221.11 MHz at ~-50 dBm matched, in real time, traffic intercepted at 99.5 MHz at ~-35 dBm. The Intermodulation Product relationship to the frequencies intercepted is 2A-B=C, where A is 160.305 MHz, B is 99.5 MHz and C=221.11 MHz. The plate on the left, below, captured the FM Broadcast Band from 88.1 MHz to 107.9 MHz. The plate on the right, below, captured the 220 MHz Band from 216 MHz to 226 MHz while using the AAR VHF Voice Radio to transmit on AAR Channel 13 (160.305 MHz).



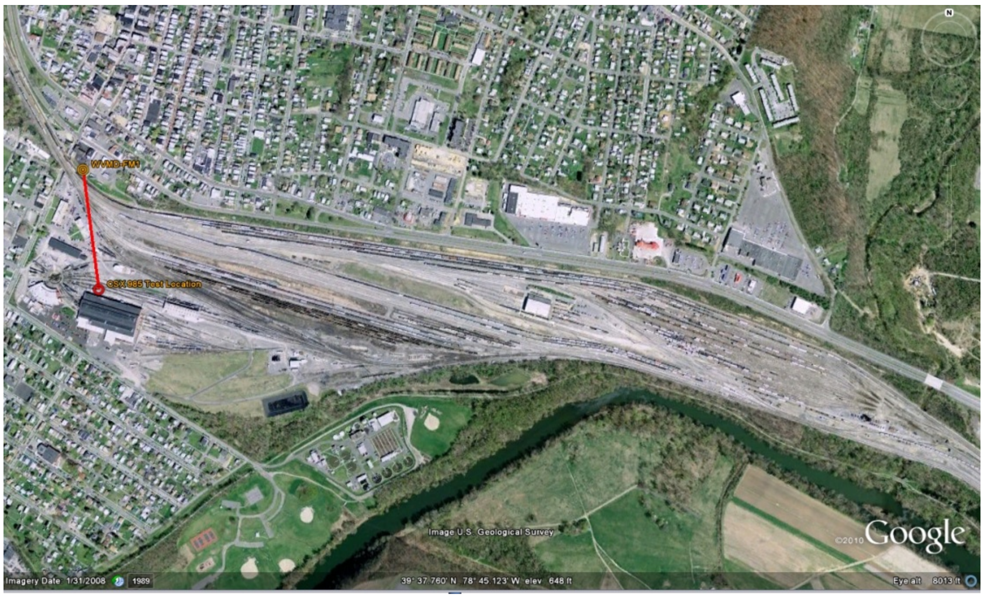


It is likely that the Intermodulation Products are being generated in the Power Amplifier stage of the AAR VHF Voice Radio. Most Land Mobile Radios employ a Low Pass Filter for FCC Compliance (to filter the 2nd and 3rd harmonics normally present in the Power Amplifier stage of any radio transmitter). A Band Pass Filter, with sharp cutoffs, would be a better choice than a Low Pass Filter, from a technical perspective, but economic concerns are involved in the decision to use a Low Pass Filter with a gradual cutoff (in order to control costs). Because of this, there is nothing in the radio’s design to inhibit the FM Broadcast signals from entering the radio via the antenna port. Congruently, the lack of a steep cutoff in the Low Pass Filter allows 220 MHz products generated in the Power Amplifier stage to exit the radio via the antenna port, and are thus reradiated at a significant level.



Typically, conversion loss is 10 dB to 15 dB, and antenna inefficiencies at 220 MHz probably account for 3 dB to 6 dB more of loss. Thus, 99.5 MHz at -35 dBm in produces ~221.11 MHz at -50 dBm out.

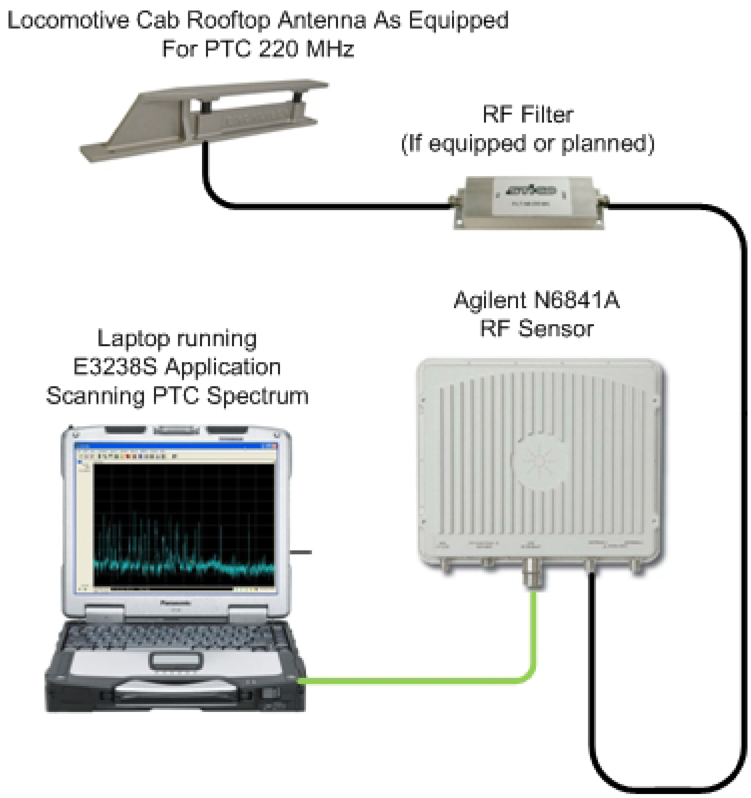
Further investigation of FM Broadcast contribution reveled that, according to FCC records, WVMD (99.5 MHz) is licensed to the West Virginia Radio Corporation of the Alleghenies and is authorized to operate an FM Booster, at a power of 1200 Watts ERP using a non-directional circularly polarized antenna system. While relatively low powered by Broadcast standards, the facility is within 1050 feet of the Test location for CSX 985 at the CSX Cumberland Yard, as shown below.



If the FM Broadcast signal is strong enough, other entry points into the radio should be considered. Such entry points may be through induction along the DC Power leads, the Microphone/Handset leads, the Control leads, or even the cases of the Control Head and the RF Deck. Mitigation may include Ferrite Toroids, RF Chokes, or Bypass Capacitors, or some combination, such as a Pi Network. Finger Stock or Braid may be needed to treat the RF Deck or Control Head cases for RF integrity. Similar consideration for Base Stations, Control Stations and Mobiles (Hyrail Radios) is recommended, especially in locations where high-level FM Broadcast signals are present. Portables (hand-held radios) are also capable of significant contribution, especially if operated near the PTC 220 MHz Locomotive Antennas. However, treating Portables is not usually feasible due to physical limitations and operational realities. Further testing is recommended to capture the entire scope of what is happening.

EMI Testing

The testing results indicated some increase in the noise floor level while operating through the start-up and shut-down phases. There were not significant variations while changing through the various power conditions. A very minor difference between the conductor and engineer side noise floor (only about 1-2 dB) was detected during testing. This may be attributed to the physical location of the antenna feed point relative to some on-board power sources, the pattern characteristic differences between the two antennas, or the routing of the two different cable bundles.

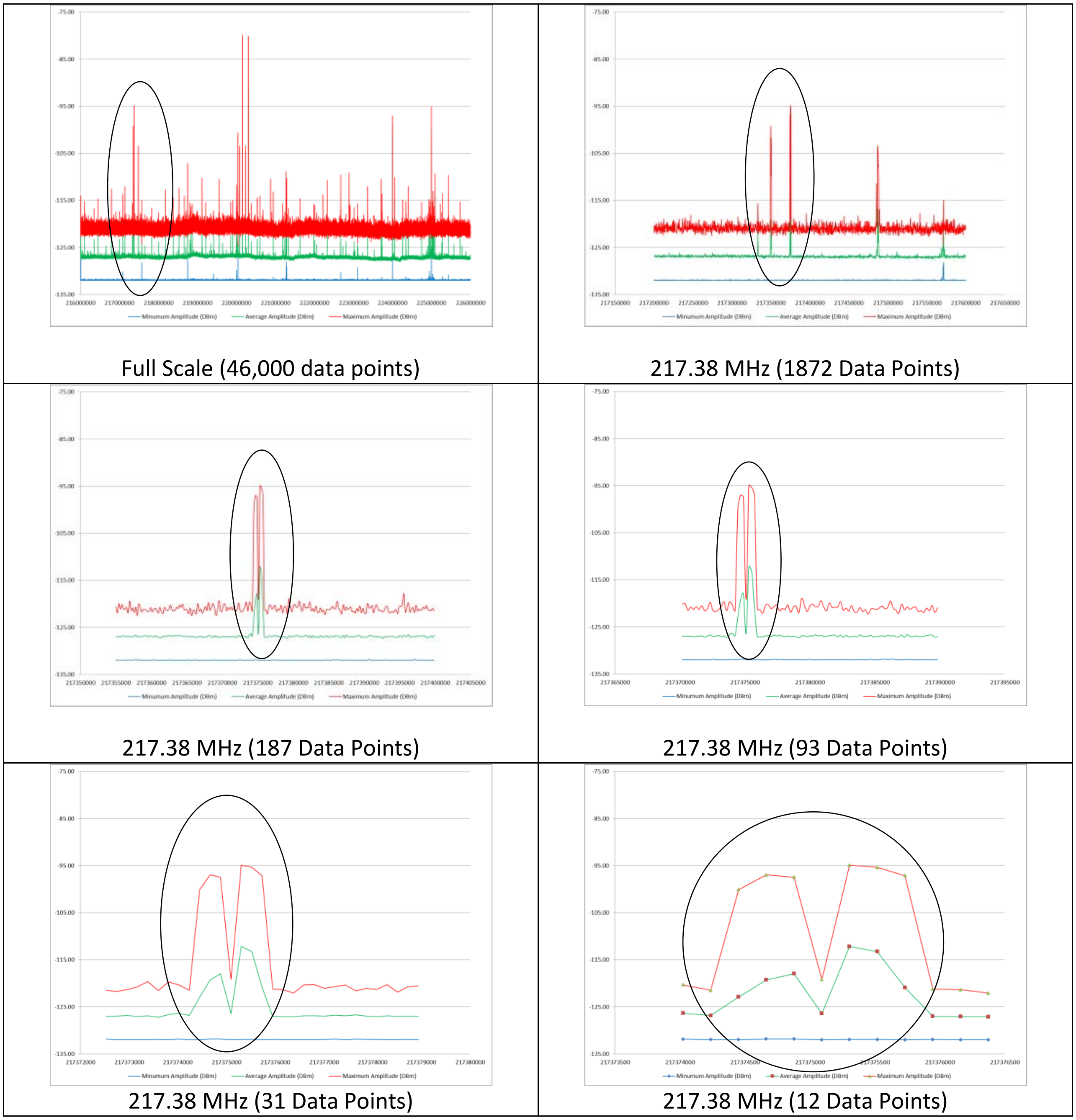


EMI Testing Configuration
Figure 22

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O
1	Frequency	Bandwidth	Number Sweeps	Intercepts	Detections	Minumum Amplitude (DBm)	Average Amplitude (DBm)	Maximum Amplitude (DBm)	Minimum Bandwidth	Average Bandwidth	Maximum Bandwidth	Minimum Duration	Average Duration	Maximum Duration	Percent Occupancy
2	216000214	214	1314	85	10.00	-131.57	-125.99	-120.80	213.62	213.62	213.62	0.05	0.01	0.06	6.5%
3	216000427	214	1341	254	29.00	-131.92	-126.97	-120.89	213.62	213.62	213.62	0.05	0.01	0.27	18.9%
4	216000641	214	1334	330	60.00	-131.98	-126.83	-121.90	213.62	213.62	213.62	0.05	0.01	0.30	24.7%
5	216000855	214	1339	288	48.00	-131.80	-127.21	-121.00	213.62	213.62	213.62	0.05	0.01	0.20	21.5%
6	216001068	214	1341	190	23.00	-131.98	-126.77	-121.79	213.62	213.62	213.62	0.05	0.01	0.23	14.2%
7	216001282	214	1342	545	131.00	-131.94	-124.90	-119.33	213.62	214.01	427.25	0.05	0.02	0.38	40.6%
8	216001495	214	1340	420	92.00	-131.87	-125.24	-119.77	213.62	214.13	427.25	0.05	0.02	0.20	31.3%
9	216001709	214	1334	174	16.00	-131.86	-126.68	-120.89	213.62	214.85	427.25	0.05	0.00	0.11	13.0%
10	216001923	214	1342	361	71.00	-131.98	-126.29	-120.77	213.62	213.62	213.62	0.05	0.02	1.45	26.9%
11	216002136	214	1336	406	82.00	-131.95	-125.97	-119.31	213.62	213.62	213.62	0.05	0.01	0.25	30.4%
12	216002350	214	1342	252	39.00	-131.94	-126.71	-121.37	213.62	213.62	213.62	0.05	0.01	0.11	18.8%
13	216002564	214	1329	262	41.00	-131.98	-127.02	-122.01	213.62	213.62	213.62	0.05	0.01	0.16	19.7%
14	216002777	214	1341	329	59.00	-131.98	-125.90	-119.16	213.62	214.27	427.25	0.05	0.01	0.16	24.5%
15	216002991	214	1338	463	102.00	-131.92	-125.54	-119.63	213.62	213.62	213.62	0.05	0.02	0.27	34.6%
16	216003204	214	1340	307	59.00	-131.84	-125.81	-120.77	213.62	213.62	213.62	0.05	0.01	0.16	22.9%
17	216003418	214	1342	305	48.00	-131.71	-126.40	-119.80	213.62	214.32	427.25	0.05	0.01	0.16	22.7%
18	216003632	214	1341	301	53.00	-131.80	-126.54	-120.70	213.62	213.62	213.62	0.05	0.01	0.20	22.4%
19	216003845	214	1337	289	56.00	-131.98	-127.10	-120.43	213.62	214.36	427.25	0.05	0.01	0.22	21.6%
20	216004059	214	1336	308	58.00	-131.97	-127.08	-122.06	213.62	213.62	213.62	0.05	0.01	0.27	23.1%
21	216004273	214	1338	298	53.00	-131.98	-126.85	-120.96	213.62	214.34	427.25	0.05	0.01	0.20	22.3%
22	216004486	214	1339	332	65.00	-131.80	-127.04	-121.12	213.62	213.62	213.62	0.05	0.01	0.33	24.8%
23	216004700	214	1341	381	75.00	-131.98	-126.40	-121.15	213.62	213.62	213.62	0.05	0.02	0.23	28.4%
24	216004913	214	1335	277	44.00	-131.97	-127.08	-120.32	213.62	213.62	213.62	0.05	0.01	0.11	20.7%
25	216005127	214	1337	296	49.00	-131.98	-127.02	-121.40	213.62	213.62	213.62	0.05	0.01	0.22	22.1%
26	216005341	214	1341	327	65.00	-131.97	-127.02	-119.80	213.62	213.62	213.62	0.05	0.01	0.16	24.4%
27	216005554	214	1342	293	52.00	-131.98	-126.89	-121.16	213.62	213.62	213.62	0.05	0.01	0.20	21.8%
28	216005768	214	1335	311	56.00	-131.87	-127.15	-121.00	213.62	214.31	427.25	0.05	0.01	0.11	23.3%
29	216005981	214	1338	293	54.00	-131.98	-126.86	-120.96	213.62	214.35	427.25	0.05	0.01	0.13	21.9%
30	216006195	214	1342	312	59.00	-131.97	-126.99	-120.94	213.62	213.62	213.62	0.05	0.02	1.45	23.2%
31	216006409	214	1338	302	55.00	-131.98	-127.35	-122.10	213.62	214.33	427.25	0.05	0.01	0.16	22.6%
32	216006622	214	1342	322	60.00	-131.98	-127.00	-121.25	213.62	214.29	427.25	0.05	0.01	0.25	24.0%
33	216006836	214	1339	296	49.00	-131.92	-127.08	-122.56	213.62	213.62	213.62	0.05	0.01	0.25	22.1%
34	216007050	214	1341	325	63.00	-131.97	-127.04	-121.10	213.62	214.94	427.25	0.05	0.01	0.23	24.2%
35	216007263	214	1336	313	64.00	-131.98	-127.22	-121.77	213.62	213.62	213.62	0.05	0.01	0.31	23.4%

Energy File Data Format
Engine Off State
Figure 23

This is a sample of the data captured on each locomotive, each excel file is approximately 10 MB, comprised of 46000 frequency information points and the associated amplitude, duration, bandwidth and percent occupancy information.



Full Scale (46,000 data points)

217.38 MHz (1872 Data Points)

217.38 MHz (187 Data Points)

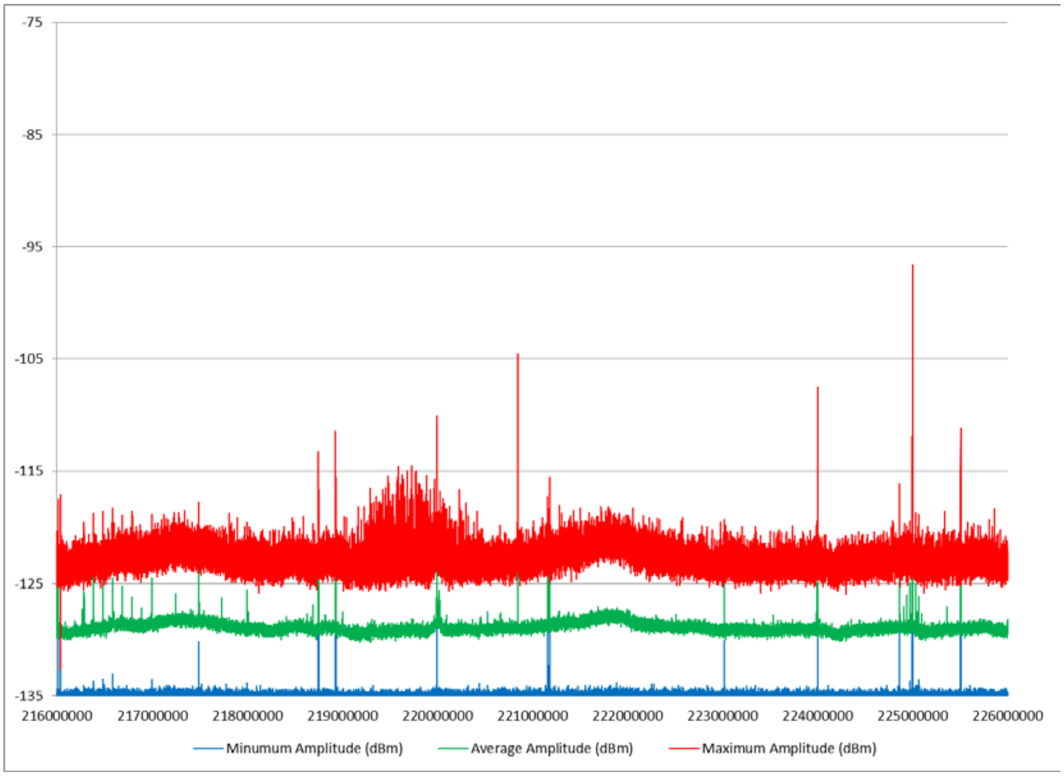
217.38 MHz (93 Data Points)

217.38 MHz (31 Data Points)

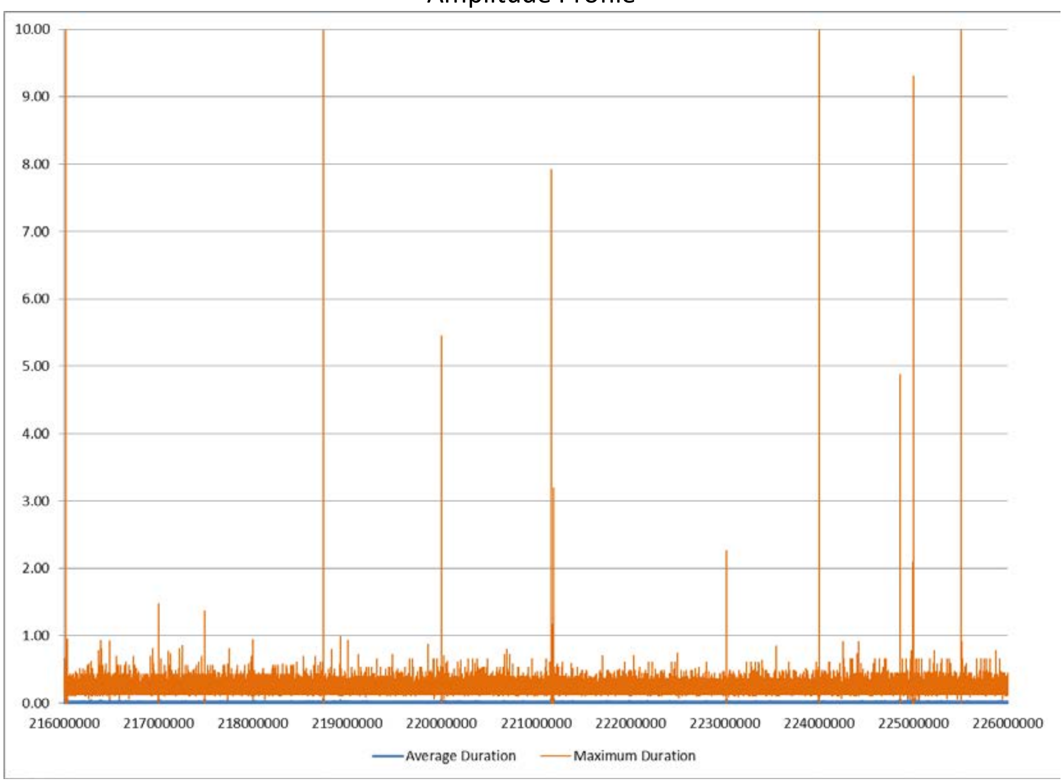
217.38 MHz (12 Data Points)

Figure 24

The following charts represent XY scatter chart with lines in EXCEL. Because of the amount of information shown in each chart the data might appear to be a spectrograph exported from a spectrum analyzer, rather than a record of the signal amplitude levels or duration information extracted and plotted from the energy history files that it actually represents. In Figure 24, three different resolutions of the information have been created to show the individual data points and how they are interconnected.



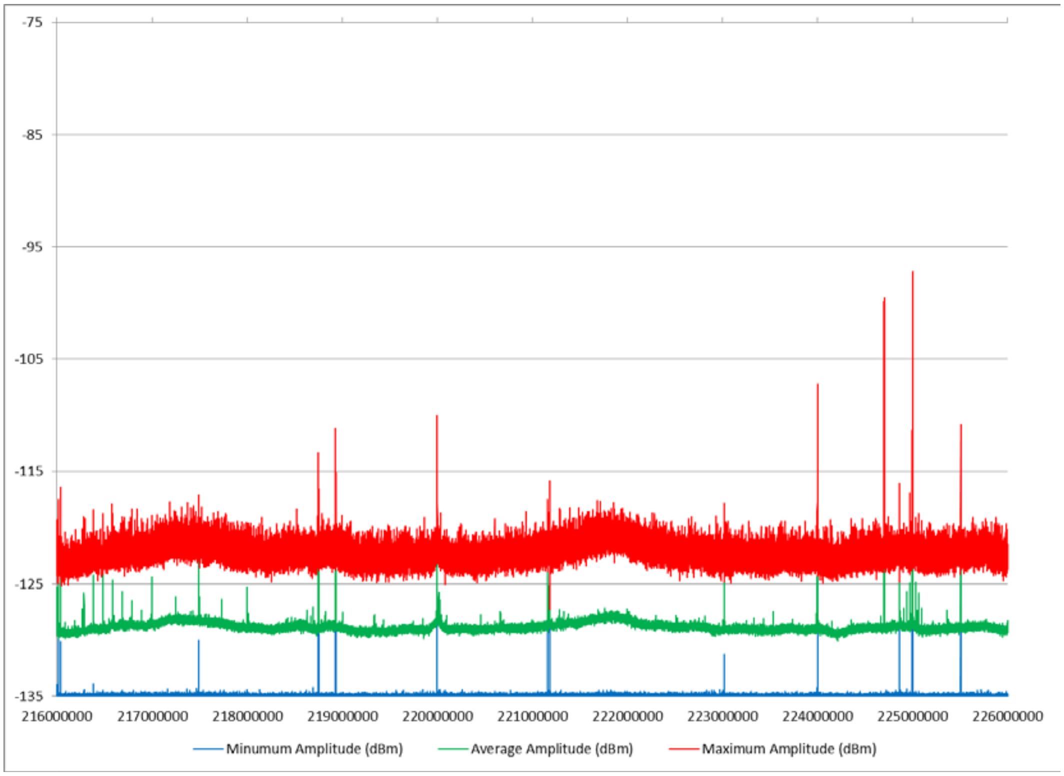
Amplitude Profile



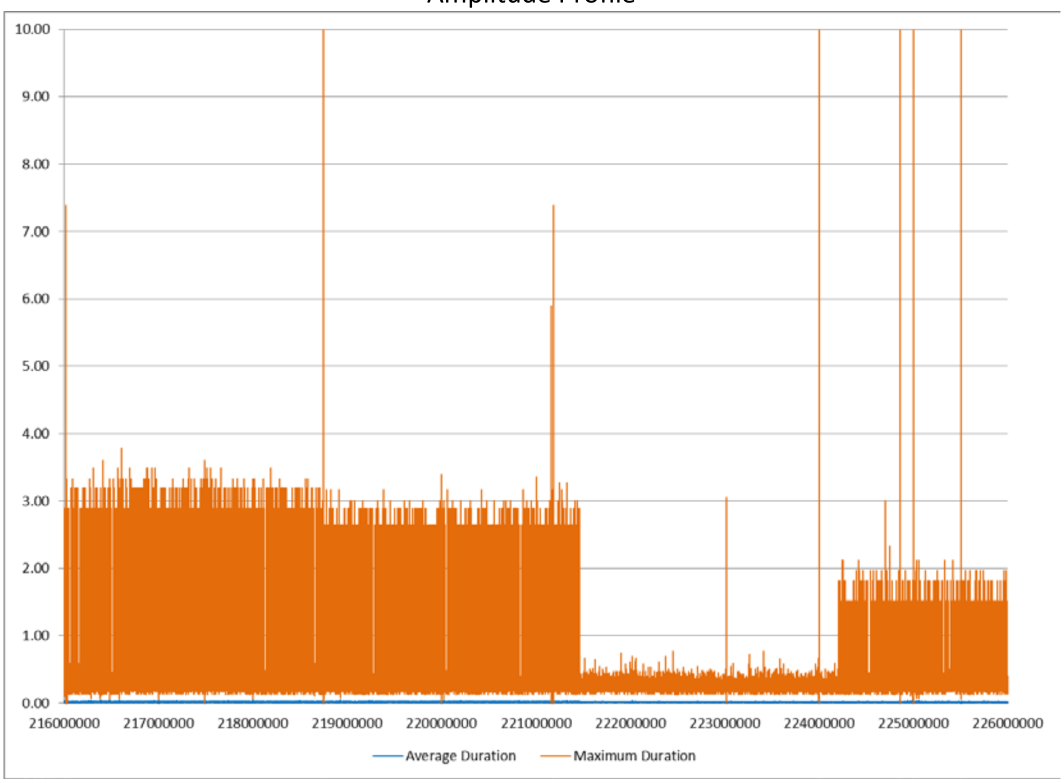
Duration Profile

CSX 4022 Engine Off State

Figure 25



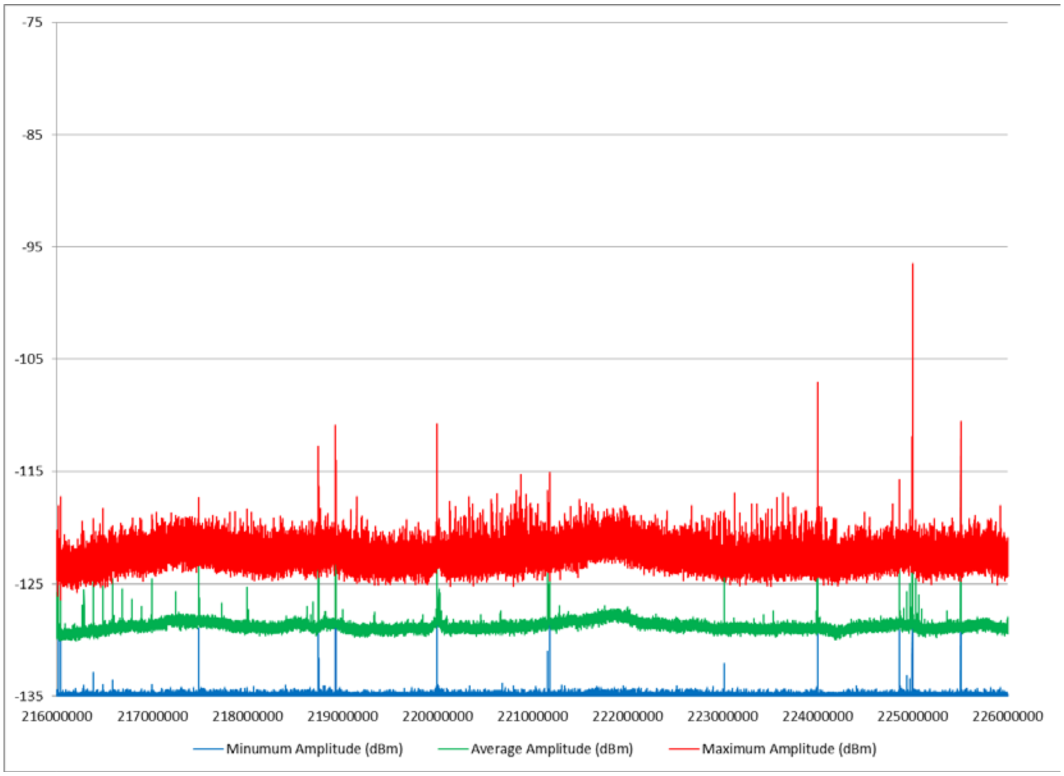
Amplitude Profile



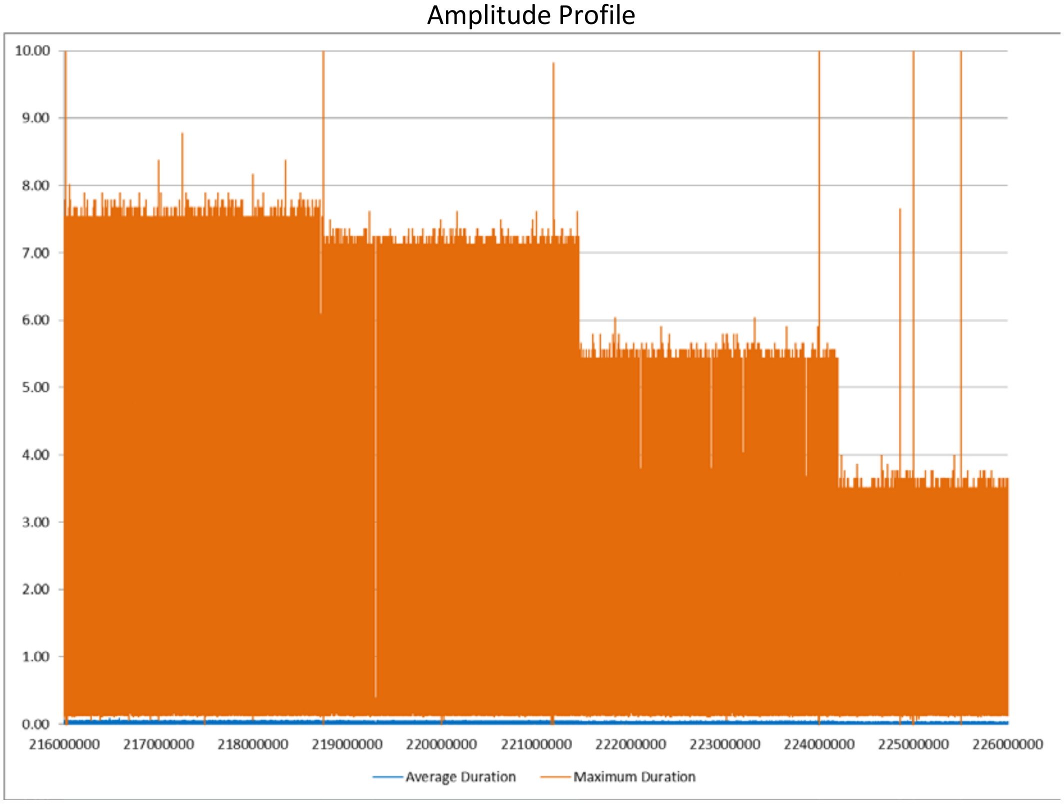
Duration Profile

CSX 4022 Startup Sequence

Figure 26



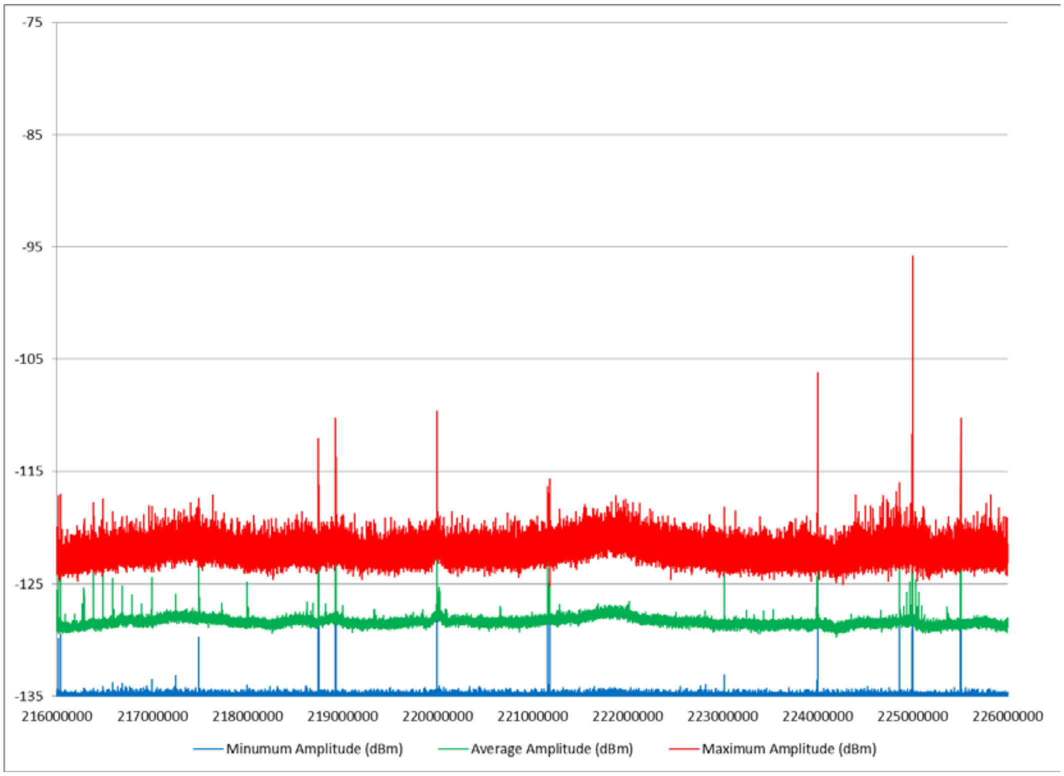
Amplitude Profile



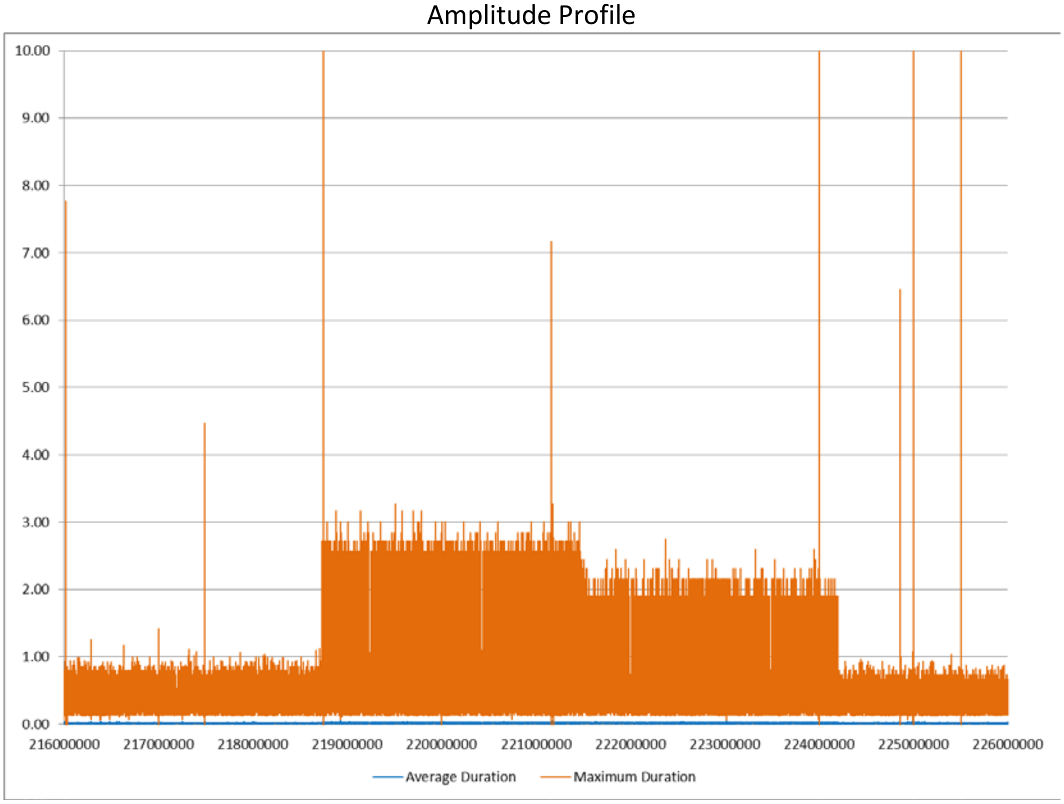
Duration Profile

CSX 4022 Engine Idle

Figure 27



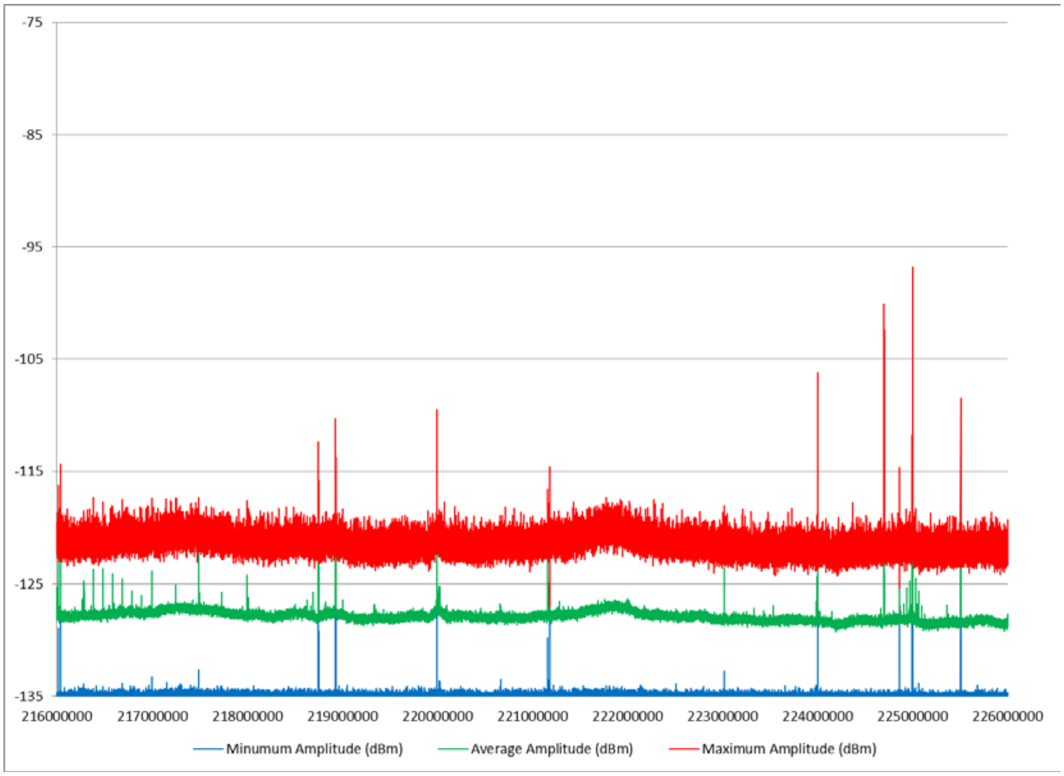
Amplitude Profile



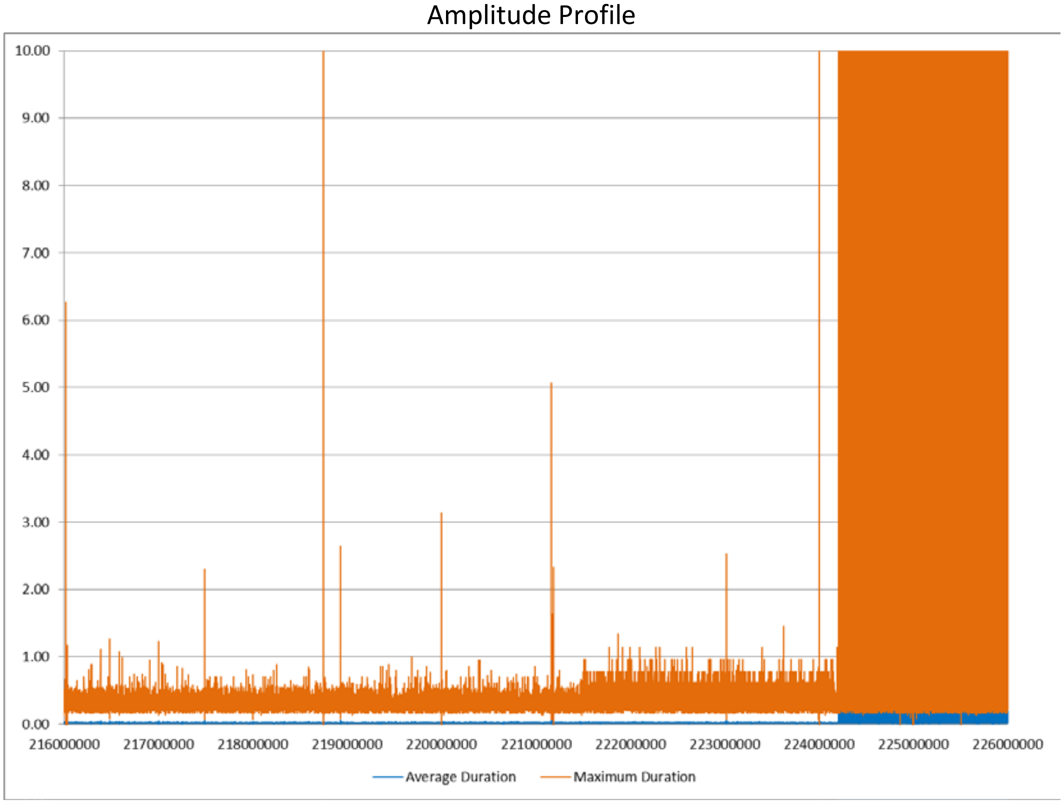
Duration Profile

CSX 4022 Notch 1

Figure 28



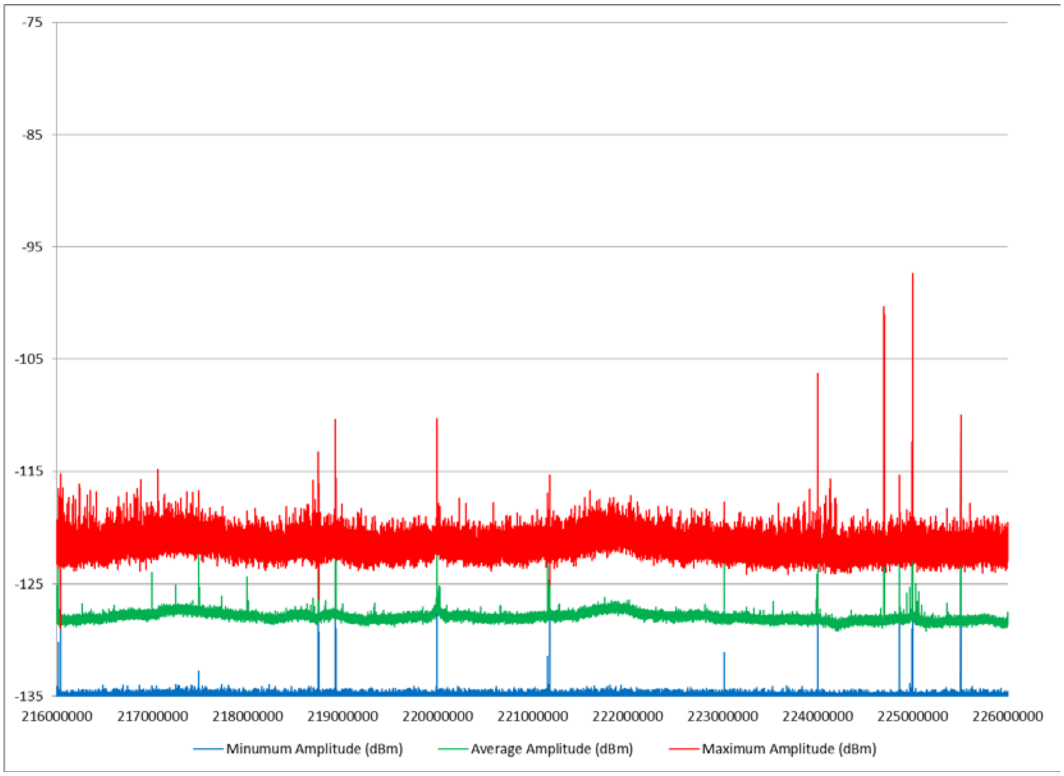
Amplitude Profile



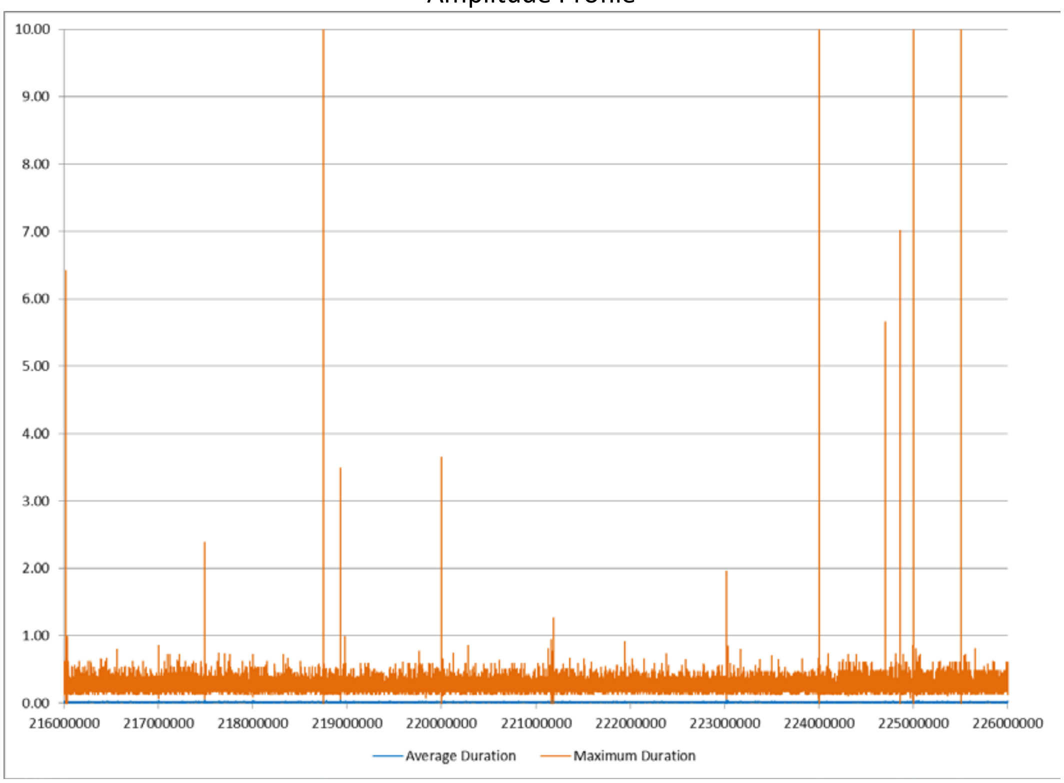
Duration Profile

CSX 4022 Notch 2

Figure 29



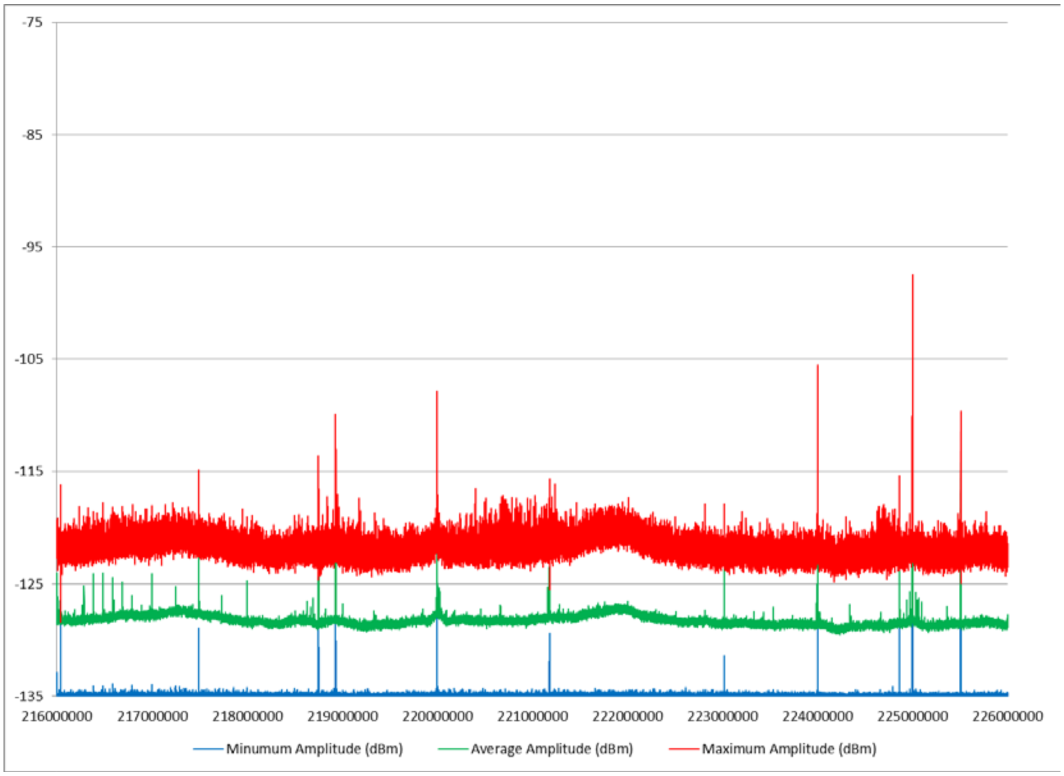
Amplitude Profile



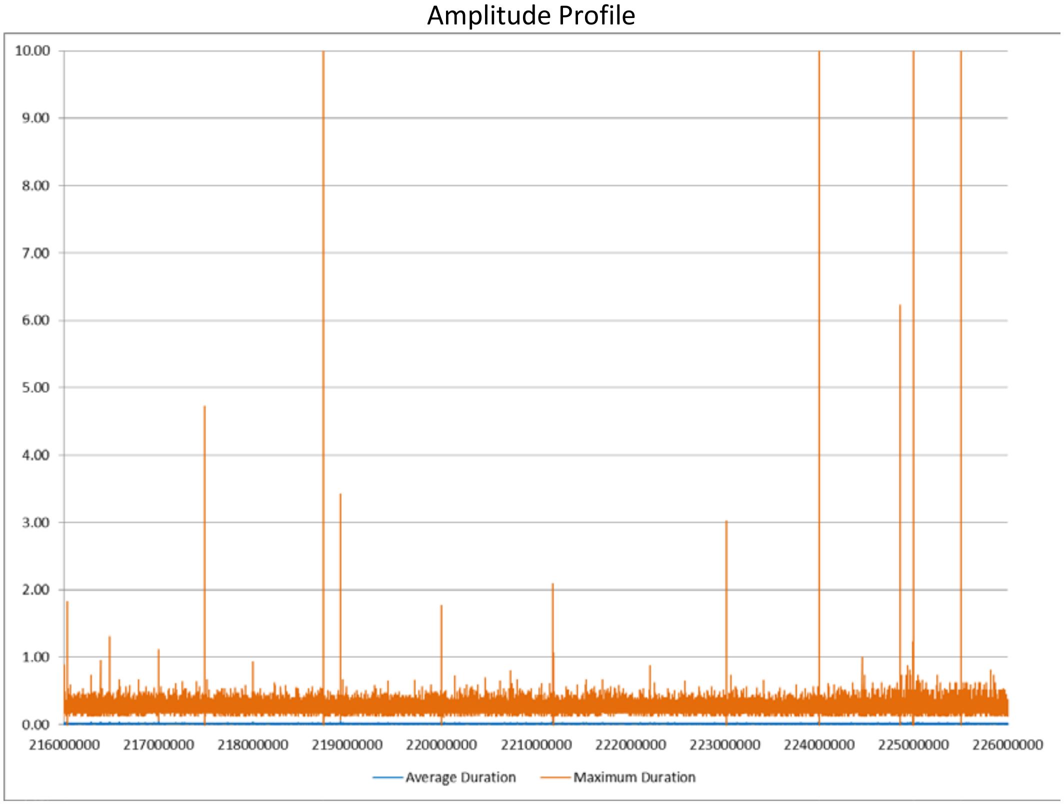
Duration Profile

CSX 4022 Notch 3

Figure 30



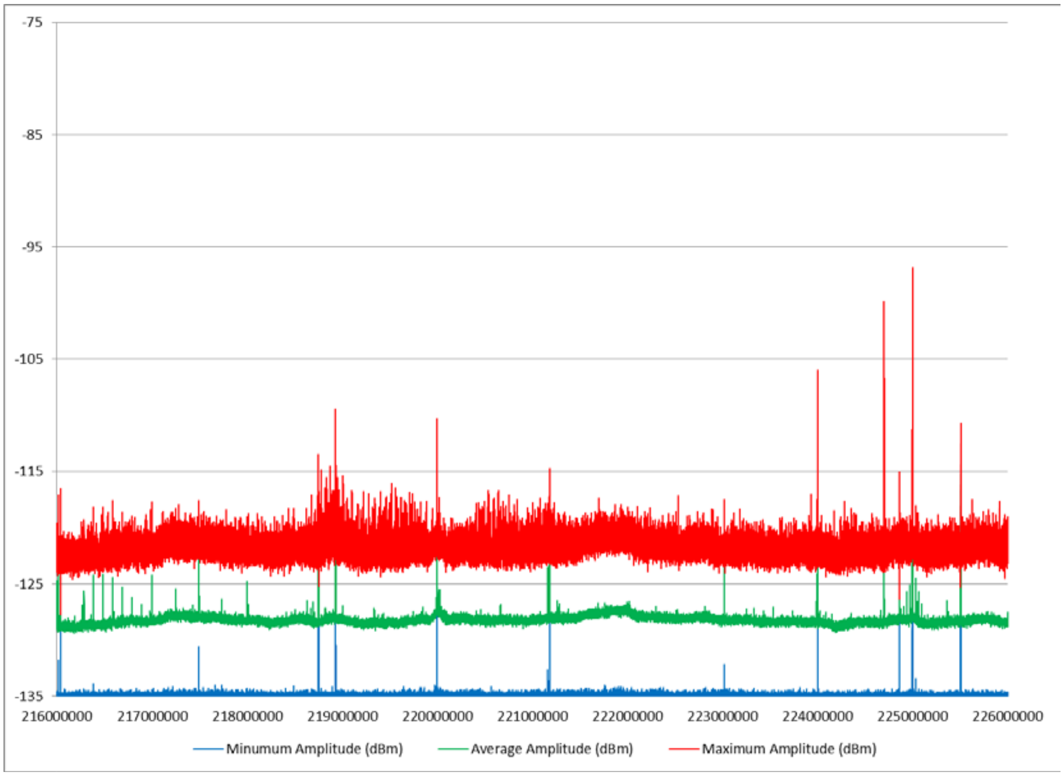
Amplitude Profile



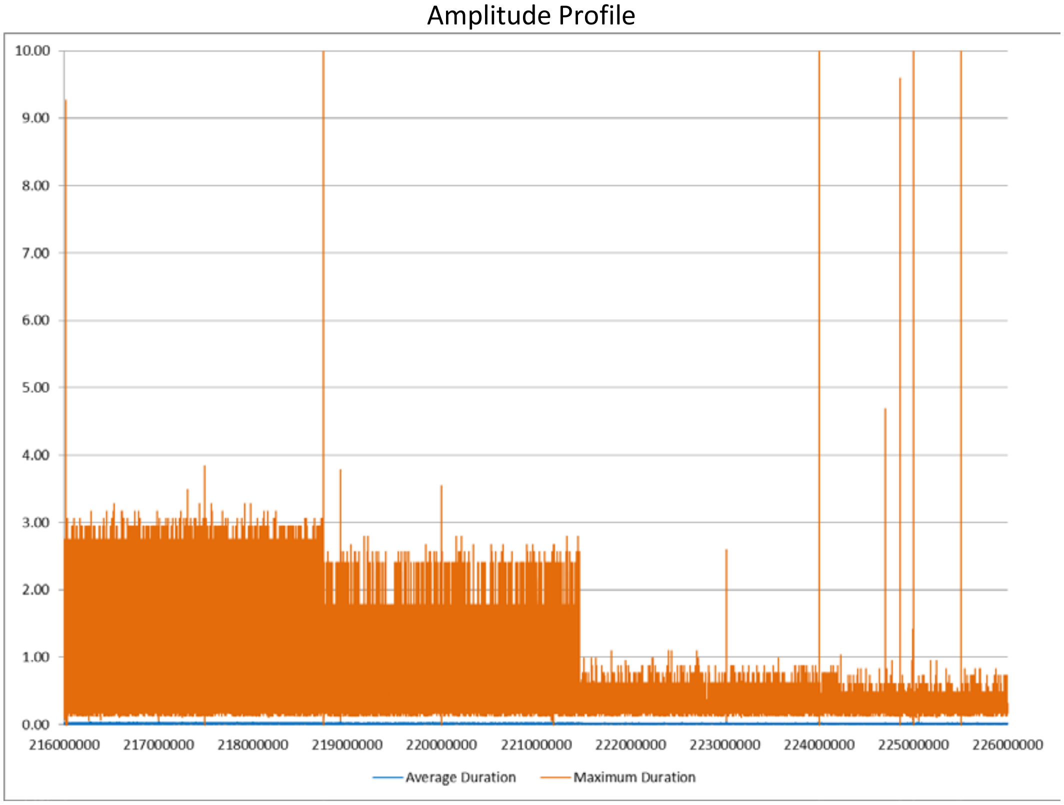
Duration Profile

CSX 4022 Notch 4

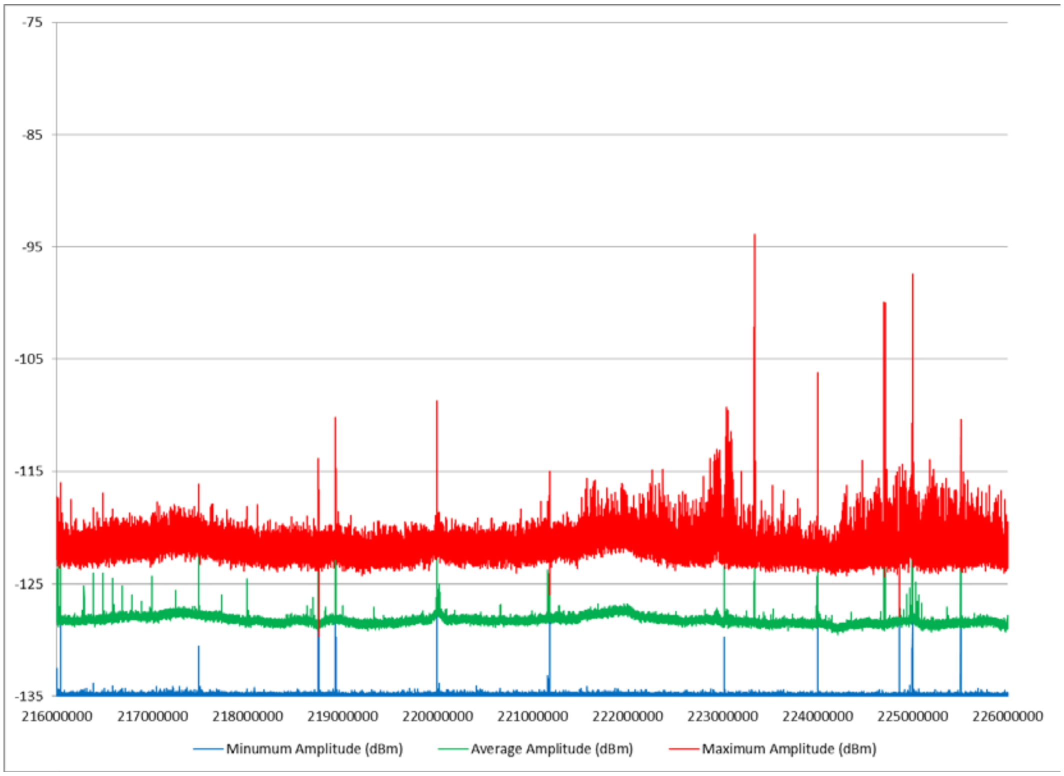
Figure 31



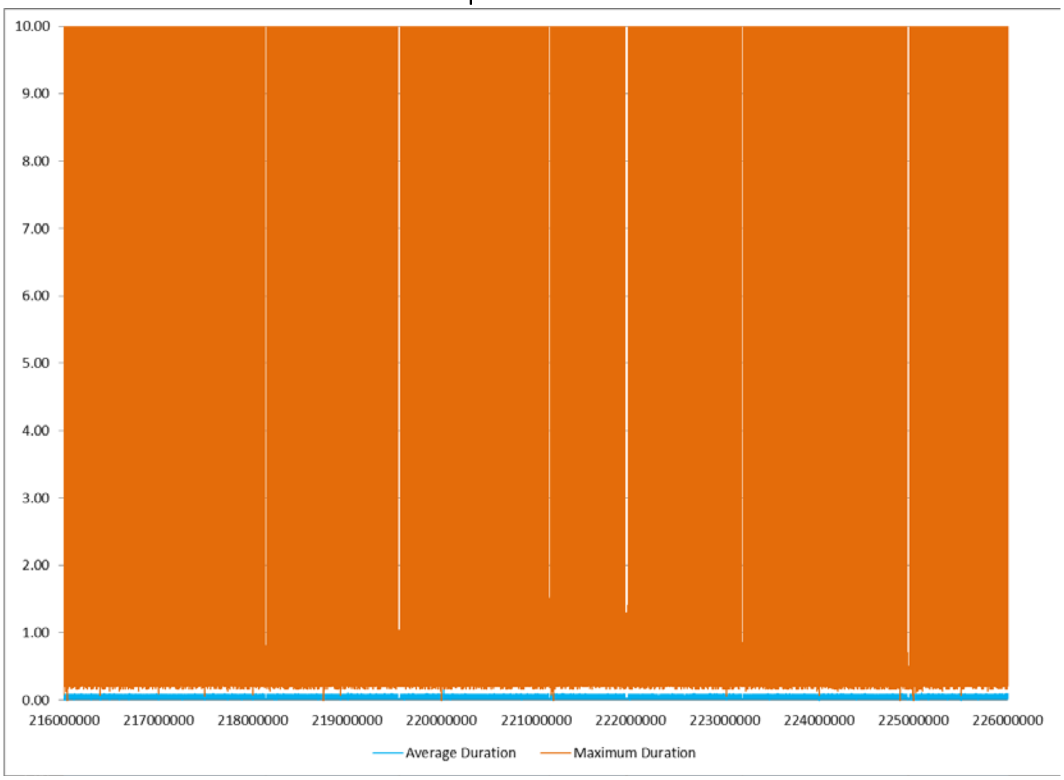
Amplitude Profile



Duration Profile
CSX 4022 Notch 5
Figure 32



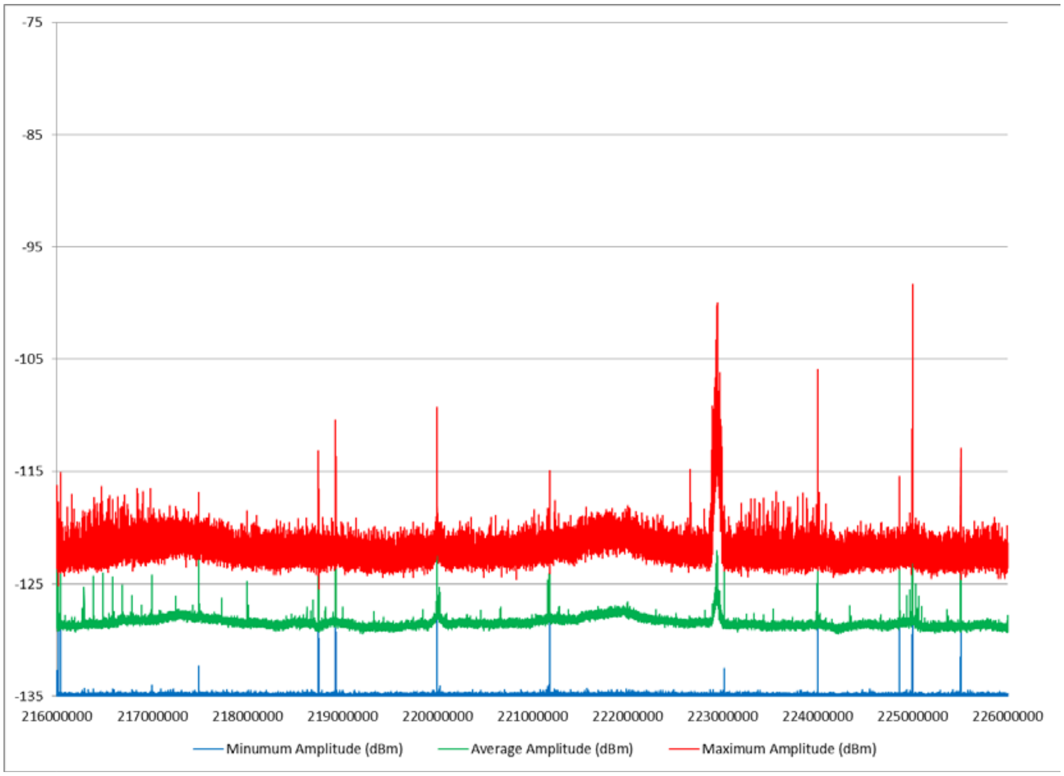
Amplitude Profile



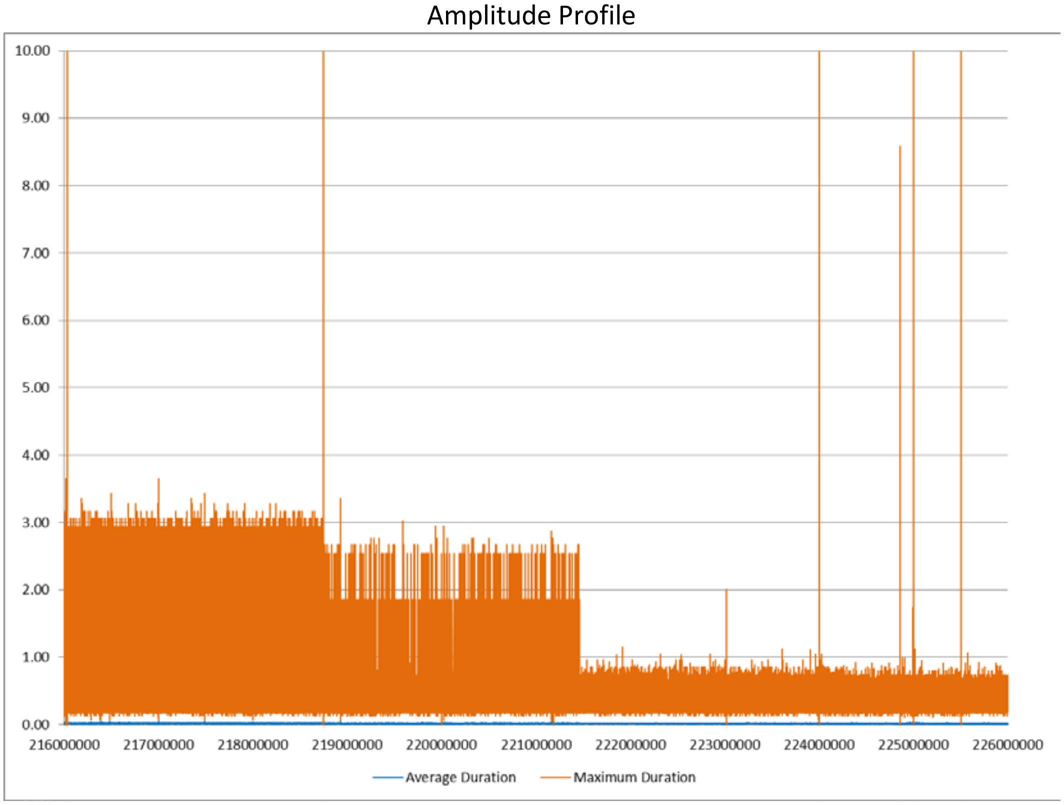
Duration Profile

CSX 4022 Notch 6

Figure 33



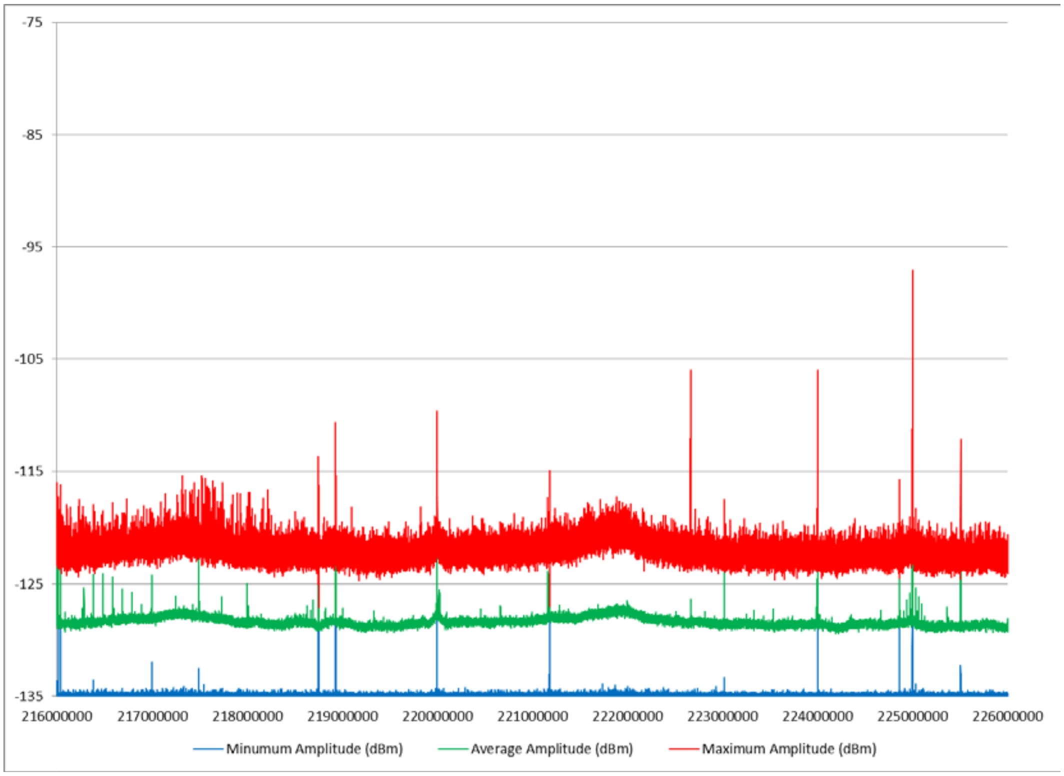
Amplitude Profile



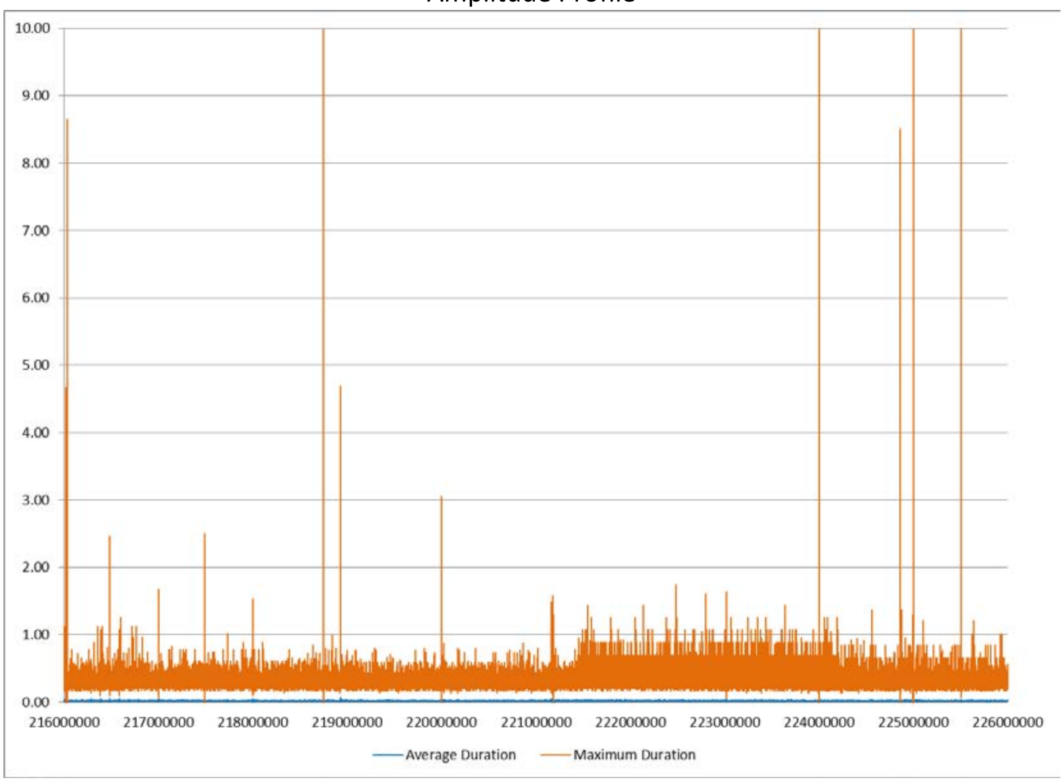
Duration Profile

CSX 4022 Notch 7

Figure 34



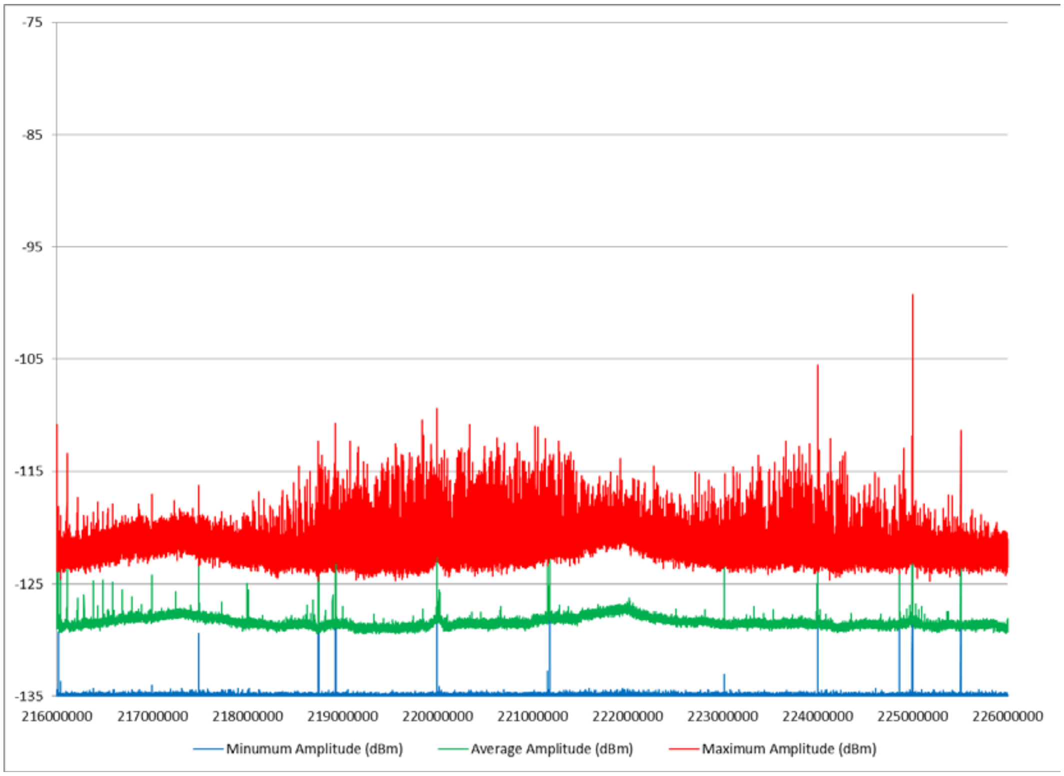
Amplitude Profile



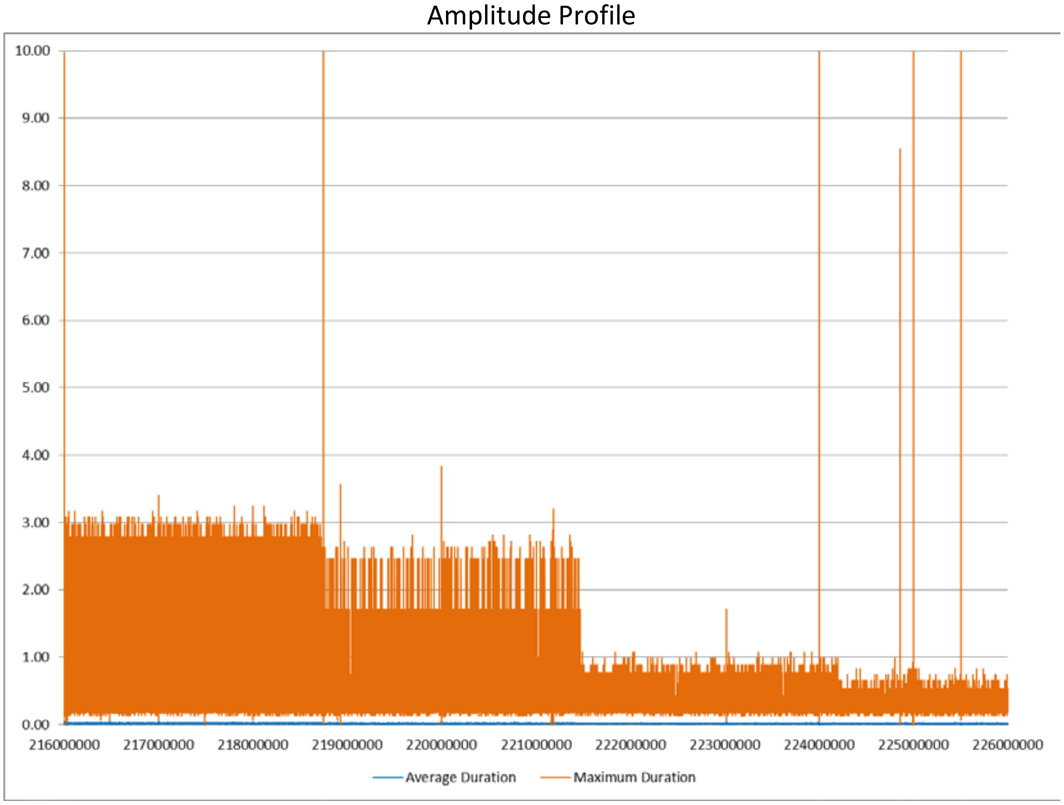
Duration Profile

CSX 4022 Notch 8

Figure 35



Amplitude Profile



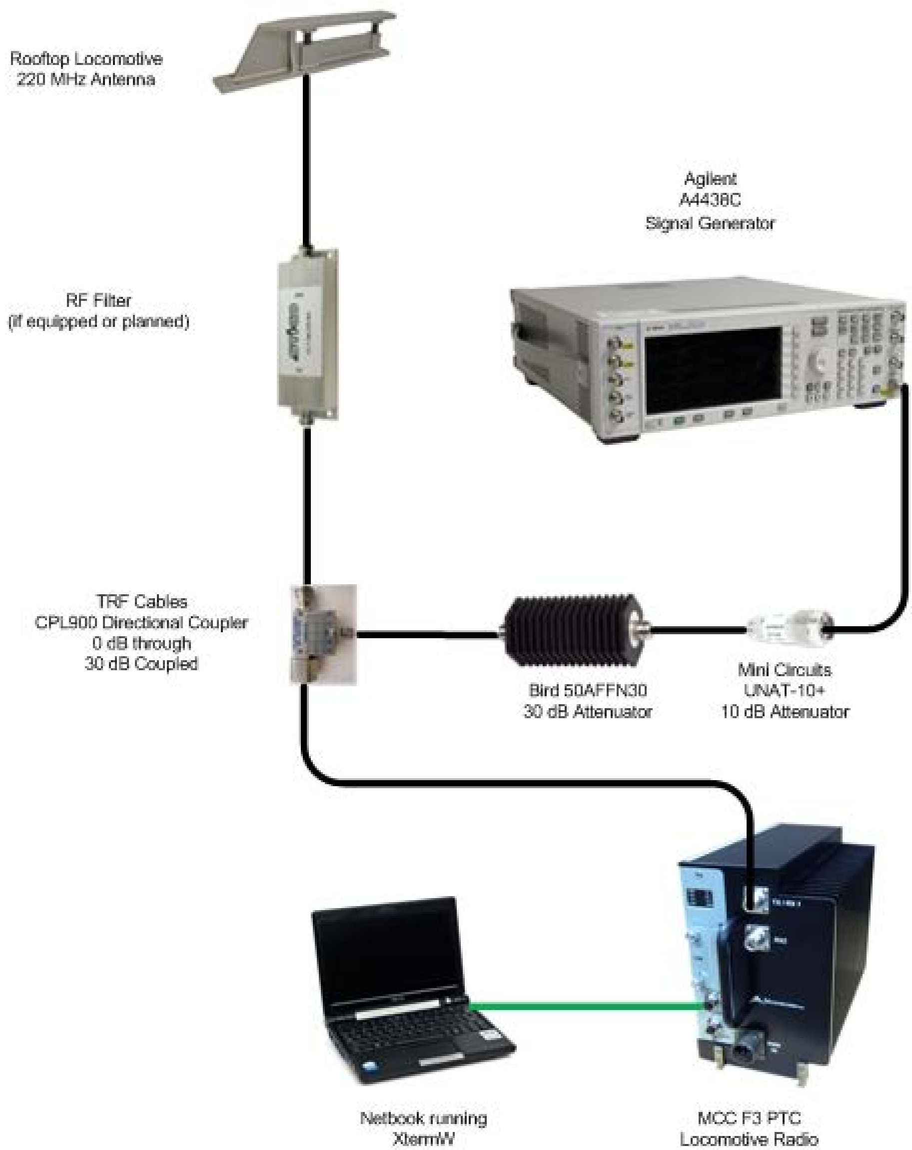
Duration Profile

CSX 4022 Shutdown Sequence

Figure 36

BER Testing

The purpose of this test is to determine the impact on receiving PTC transmissions in the locomotive noise environment, with the focus on capturing the minimum signal level needed for radio network planning. To accomplish this, a PTC Locomotive Radio (F3) was connected through a Directional Coupler to a Signal Generator equipped with an attenuator pad, and to the worse-case locomotive PTC Antenna. See Figure 37 below.



BER Testing Configuration
Figure 37

The PTC Radio's design is based on a Receiver noise floor of -123 dBm, and a C/N ratio (for sustaining a BER of E-4) of 11 dB, and a C/I (for sustaining a BER of E-4) of 14 dB.

To establish a baseline, the PTC Antenna was disconnected from the Directional Coupler port, and the port was terminated. This effectively isolated the radio from the noise environment. The Signal Generator was configured to send a Test Pattern, and the signal level was set so that a BER of E-4 was sustainable. In this configuration, the PTC Radio was able to report a BER of E-4 at -113 dBm. Note that this radio, under these test conditions, was performing slightly better than spec with a C/N of 10 dB.

The PTC Antenna was then reconnected, and the test was repeated for each of ten Locomotive Operational States (Engine Off, Idle, and Notches 1 through 8). The limitations of the test do not permit reliable BER measurements for brief conditions such as Startup Sequence and Shutdown Sequence, so these two locomotive operational states were not tested.

The worse-case level observed for a reliable BER of E-4 was -107 dBm.

The following table shows the observed minimum signal levels required to sustain a BER of E-4 for the Baseline, and for the ten Locomotive Operational States.

TABLE E BER Test Results

Locomotive State	BER E-4 Level
Radio Isolated	-113
Off	-109
Idle	-108
Notch 1	-108
Notch 2	-107
Notch 3	-107
Notch 4	-107
Notch 5	-107
Notch 6	-107
Notch 7	-107
Notch 8	-107

Summary:

SWR Testing:

The VSWR performance for most of the antenna elements was as expected. Adding the cable to the system provides for more insertion loss, which effectively improved the SWR as depicted in the plots on pages 9 thru 11. VSWR performance also appears acceptable when the antennas were used in conjunction with the filter, indicating that the systems in their entirety were functioning properly. A bad NMO antenna base was found on engineer side through VSWR testing. After review by the manufacturer it was determined that a cold solder joint in the base connection had caused the issue. The antenna bar was replaced before the data presented in this report was taken.

Insertion Loss Testing:

Save for the WIFI systems, the insertion loss data indicates that a nominal level (around 1-1.5 dB) is introduced into each system by the cable. The level of insertion loss measured is compatible with the expected performance of the coaxial cable. As depicted in the WIFI plots on page 40, a considerable level of insertion loss was introduced to the system by the coaxial cable.

Antenna Isolation Testing:

Ideally, with the goal of a noise and IMP free system, the isolation between the elements would be as great as possible. A substantially greater amount of isolation between the off-band elements was noted when the filters were in place, providing a strong case for the use of filters. Without the filters in place, the level of isolation detected was as expected considering the distance between the elements, the resonance of the elements, and various obstructions and pattern distorters (reflectors) present on the locomotive roof. Filtering of all significant contributor radios is emphatically recommended. Significant contributor radios include AAR VHF Voice, Distributed Power UHF A, Distributed Power UHF B, HOT, and both branches of the PTC 220 Radio. Although this Locomotive is not currently equipped with Distributed Power, filters must be considered should those radios be installed in the future. Additional Testing with the OEM of the MBS-2 (Matrix) is recommended to test interference to, and survivability of, the PTC GPS Antennas and integrated LNAs.

Receive Intermodulation Testing:
There are clearly some limitations in both designs of the HOT/EOT Radios. While the actual mechanism is not clear, both of the radio designs permit significant Intermodulation products to be reradiated in the 220 MHz band. The problem is corrected with appropriate filtering. In fact, filtering of all significant contributor radios is emphatically recommended.

Transmit Intermodulation Testing:
Significant Intermodulation Products were generated by off-platform FM Broadcast signals mixing in the Power Amplifier stage of the AAR VHF Voice Radio. Mitigation will require deep FM Broadcast Rejection (notch filtering), probably on the order of 70 dB. More aggressive and controlled testing is recommended. Filtering of all significant contributor radios is emphatically recommended.

EMI testing:

Electromechanically generated power plant noise during the twelve Locomotive Operational States (Engine Off, Startup Sequence, Idle, Notches 1 through 8, and Shutdown Sequence) were less disruptive than expected. In fact, this Locomotive was the quietest, electromechanically, of any Locomotive tested so far.

BER Testing:
Since the EMI Noise is an on-platform phenomenon, any EMI produced travels with the PTC Radio Receivers. While this Locomotive exhibited a worse-case noise number of 6 dB, the testing of all other locomotives, to date, has established a worse case noise number of 10 dB, and this should be accounted for in the PTC Locomotive Radio Receive Path Link Budget.