METEORCOMM LLC

Locomotive Noise Testing

Approach, Observations, and Mitigation

Derek Edmondson

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Document Number: 00002151-A

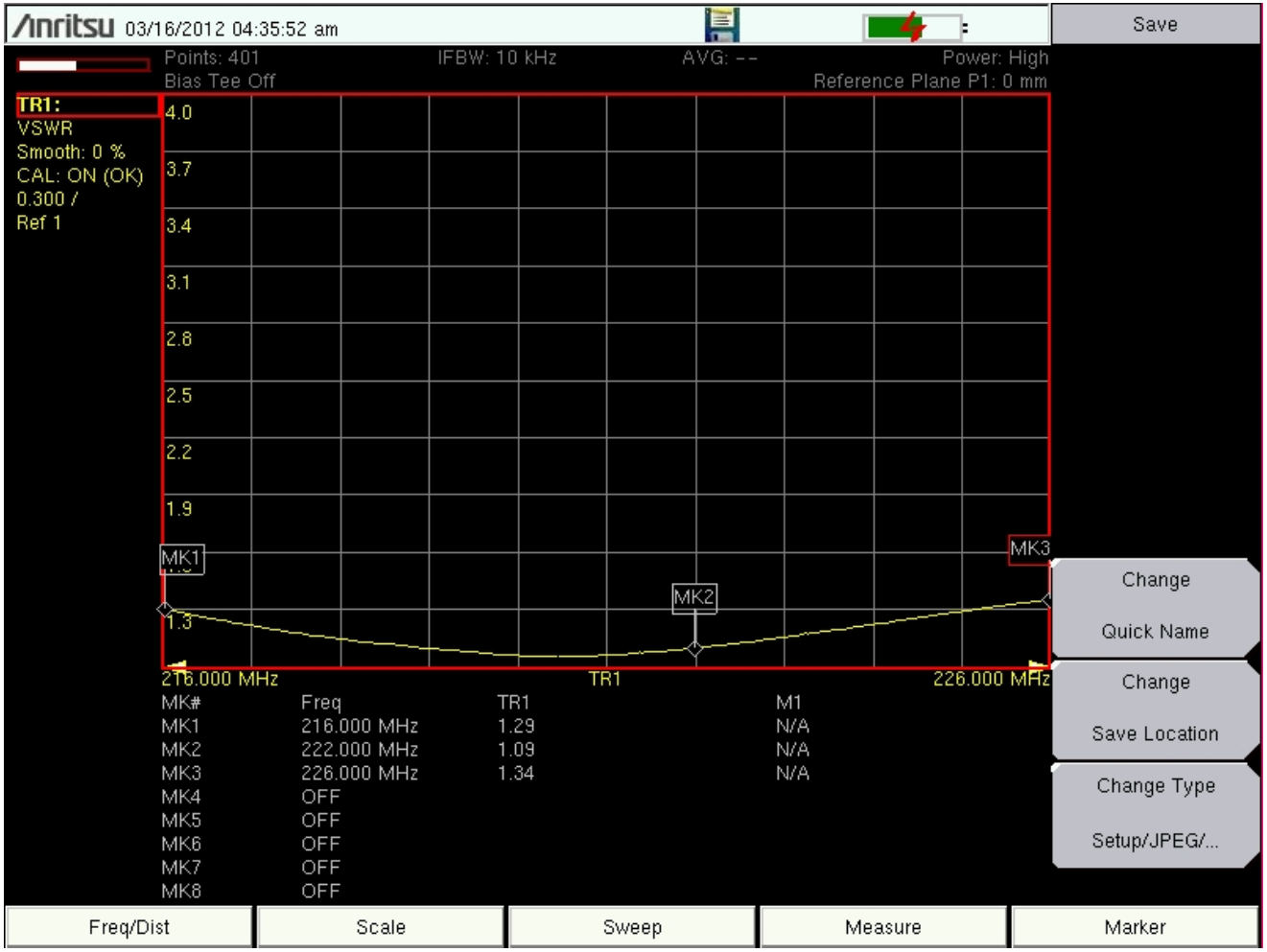
Locomotive Noise Test Battery

- Antenna VSWR
- Cable and Filter (if equipped) Insertion Loss
- Radio Antenna Port to Radio Antenna Port Isolation—Unfiltered
- Radio Antenna Port to Radio Antenna Port Isolation—Filtered
- RX Intermodulation
- TX Intermodulation
- Electro-Mechanical EMI- Twelve Locomotive Operational States
- Load Test BER (1E-4) –Ten Locomotive Operational States

Antenna VSWR

- Purpose of this Test
  - Verify Antenna Integrity on all Antennas Under Test
    - Connectors clean and intact
    - Radiating elements not compromised
  - Characterize the Band-Pass Parameters of each Antenna
    - Cohesive with signals of interest

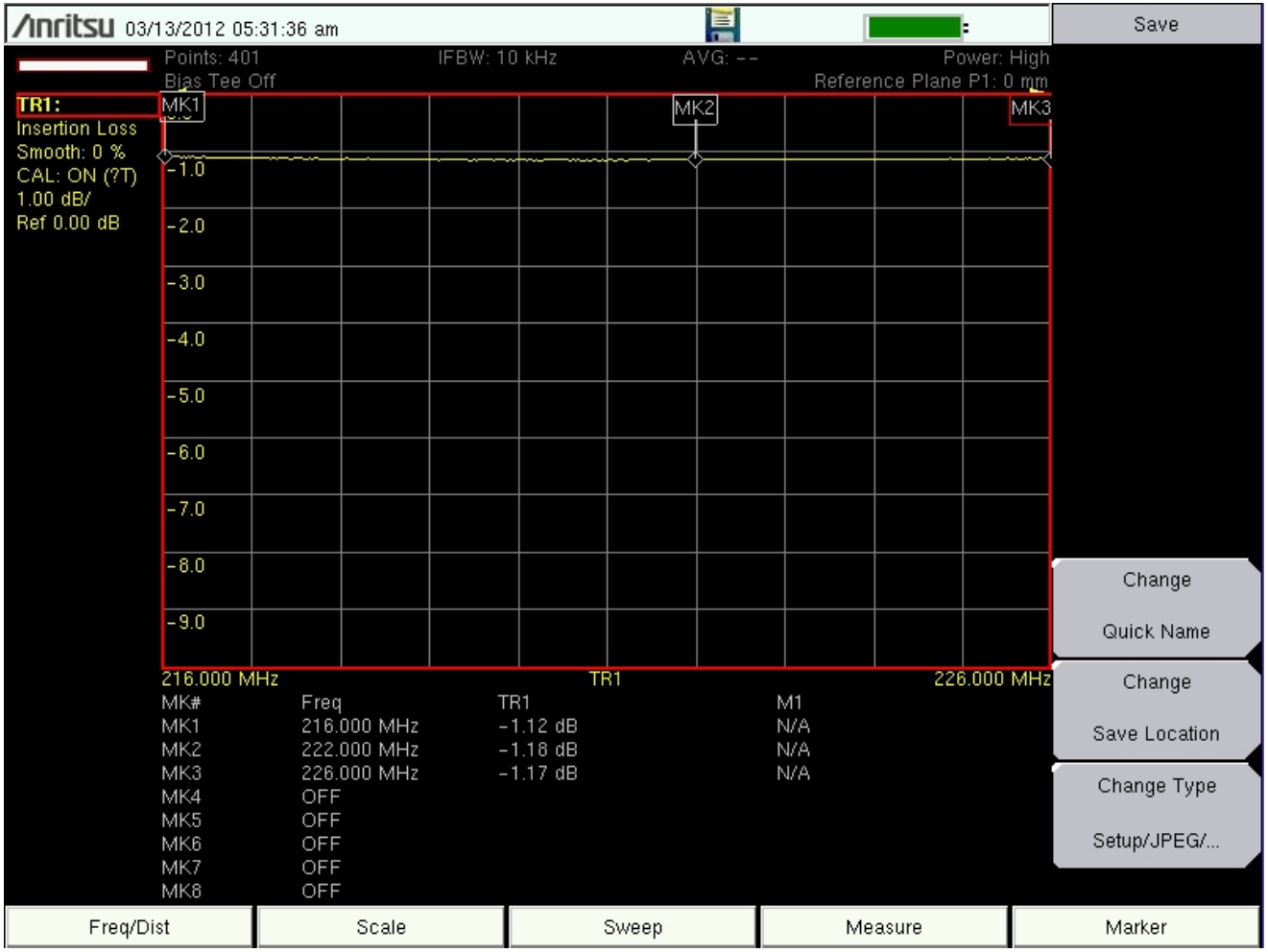
Antenna VSWR



Cable and Filter Insertion Loss

- Purpose of this Test
  - Verify Cable Integrity on all RF Cables Under Test
    - Connectors clean and intact
    - Cable not compromised by cable handling during installation
  - Characterize the Band-Pass Parameters of each Filter
    - Cohesive with signals of interest

Cable and Filter Insertion Loss

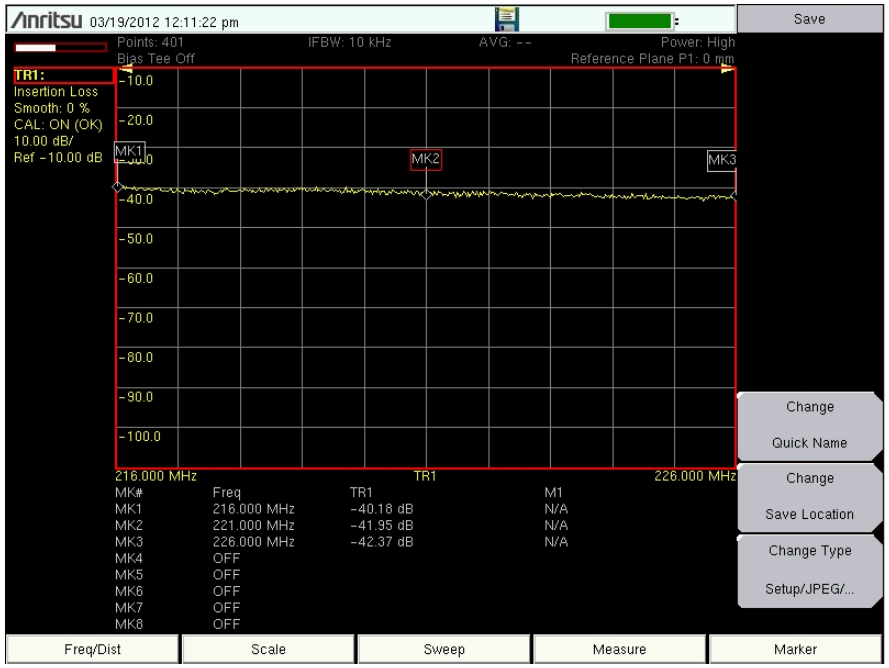


Radio Antenna Port to Radio Antenna Port Isolation

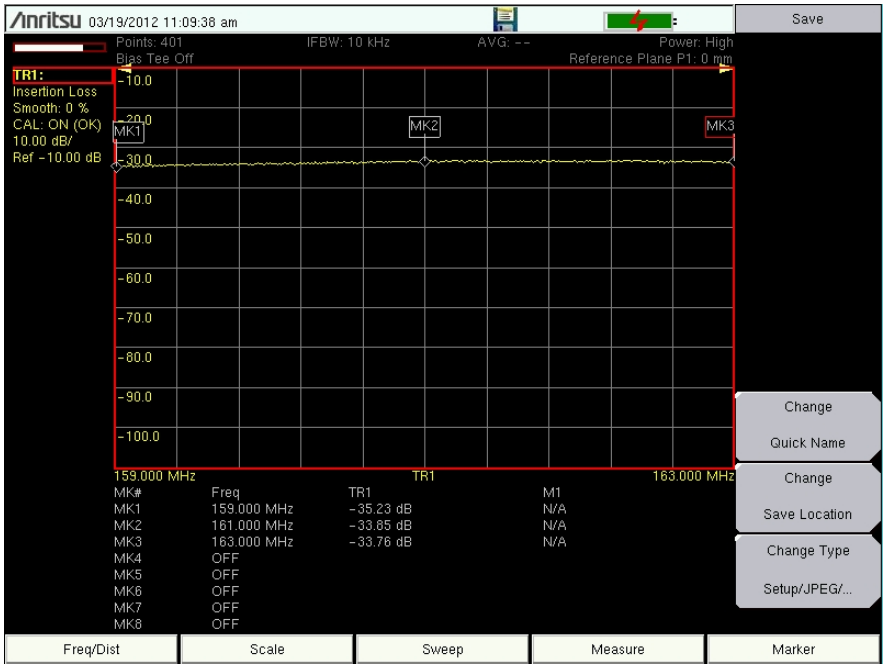
- Purpose of this Test
  - Determine Antenna to Antenna Isolation from the perspective of the Radio Port on each Radio Under Test
  - Quantify the Amplitude of any RF Energy on any expected Onboard Operating Frequency being presented to Onboard Radio Transmitters or Receivers
  - Test is Executed without Filters, and with Filters

Radio Antenna Port to Radio Antenna Port Isolation

220 MHz Energy
TX 220 Antenna (Unfiltered)
RX 161 Antenna (Unfiltered)
Isolation: ~41 dB

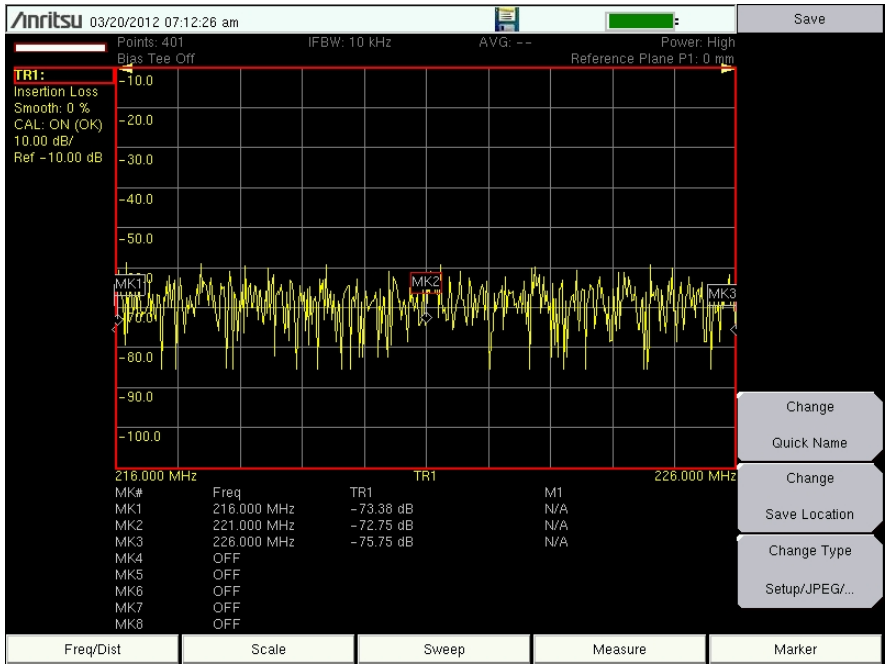


161 MHz Energy
TX 161 Antenna (Unfiltered)
RX 220 Antenna (Unfiltered)
Isolation: ~34 dB

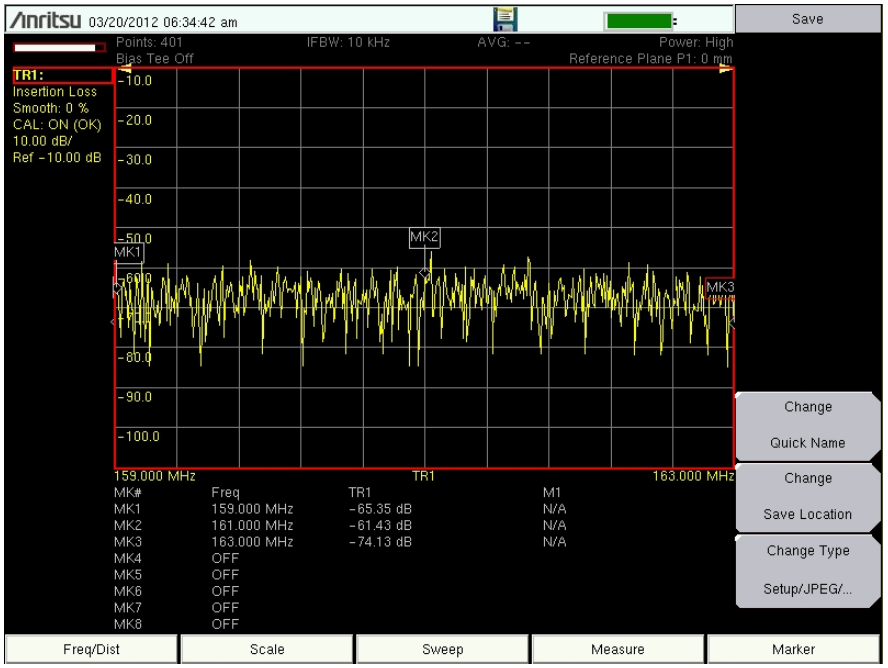


Radio Antenna Port to Radio Antenna Port Isolation

220 MHz Energy
TX 220 Antenna (Filtered)
RX 161 Antenna (Filtered)
Isolation: >60 dB (NF)

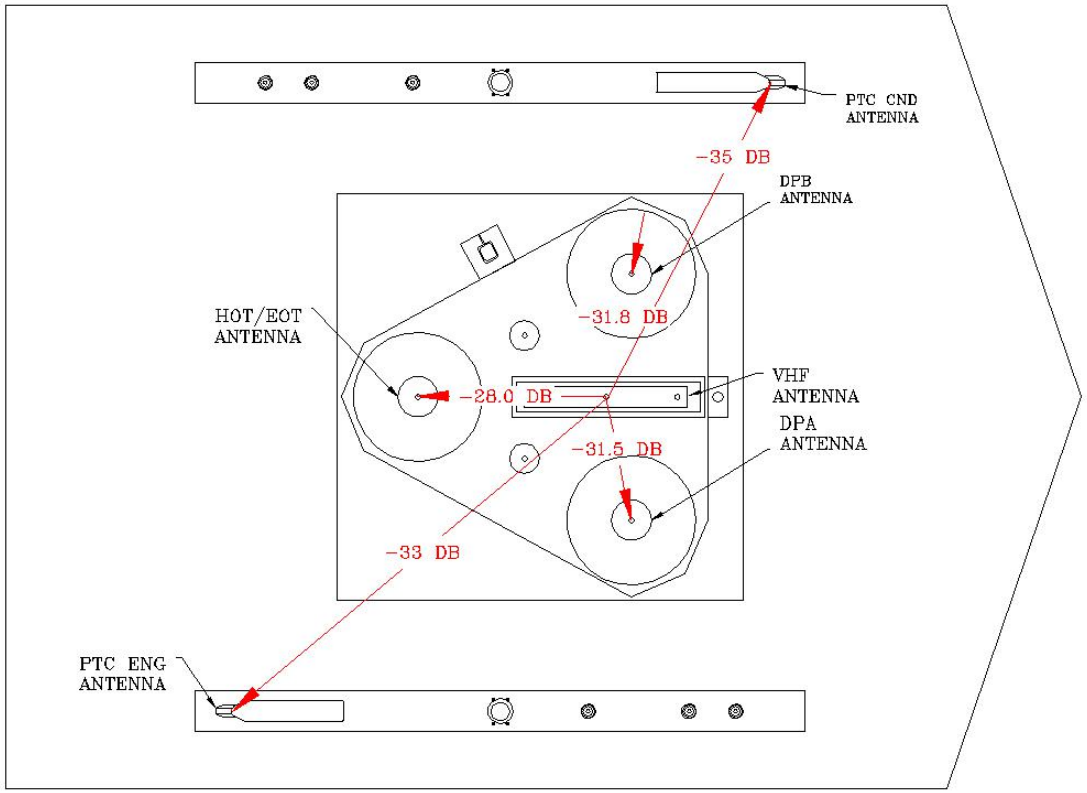


161 MHz Energy
TX 161 Antenna (Filtered)
RX 220 Antenna (Filtered)
Isolation: >60 dB (NF)



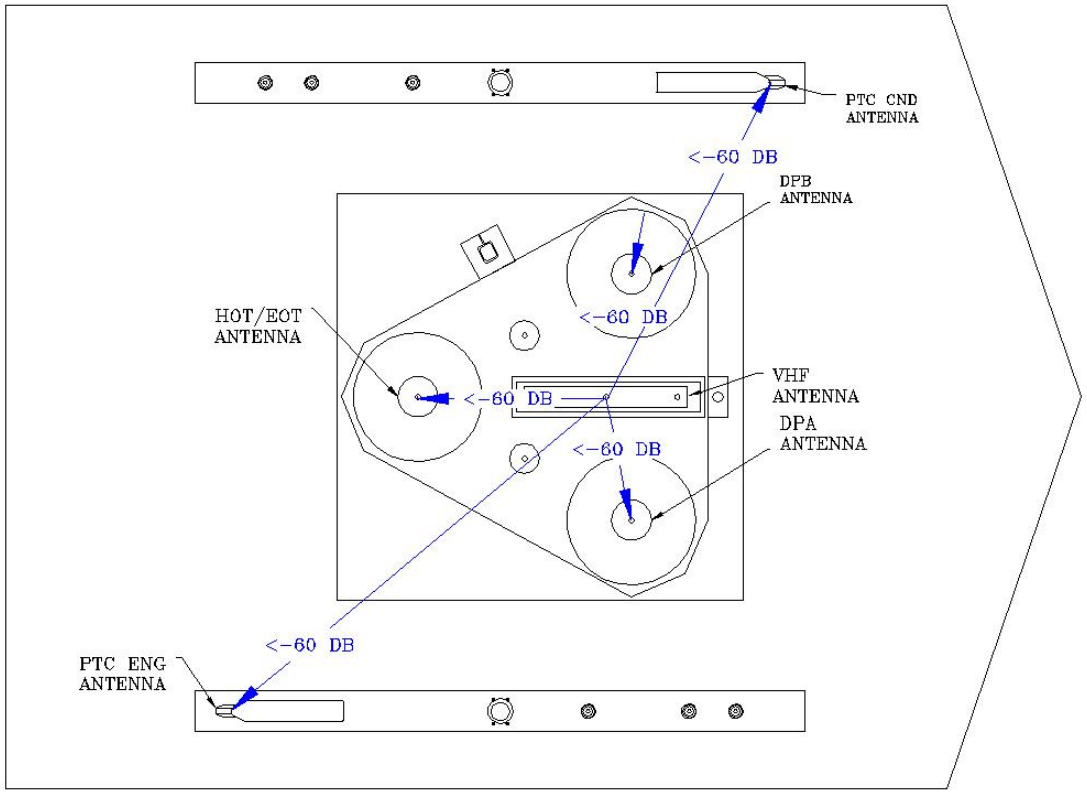
Radio Antenna Port to Radio Antenna Port Isolation

TX 161 Antenna (Unfiltered) Isolation Mapping TX Perspective



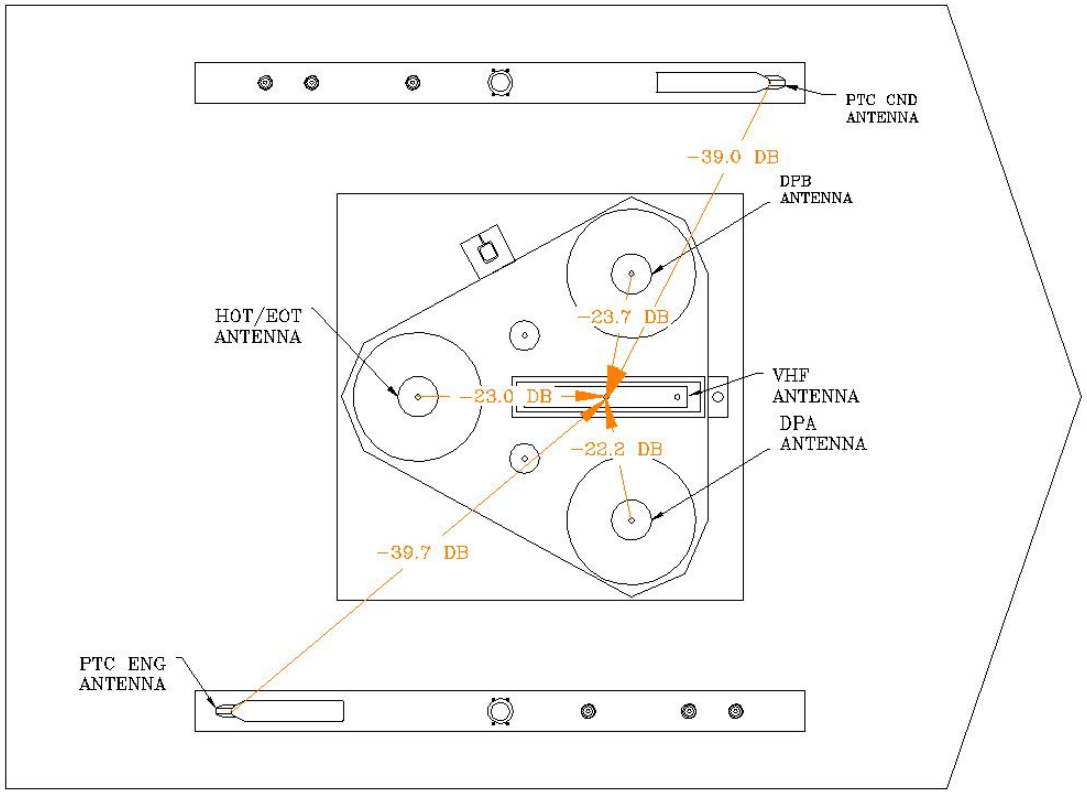
Radio Antenna Port to Radio Antenna Port Isolation

TX 161 Antenna (Filtered)
Isolation Mapping TX Perspective



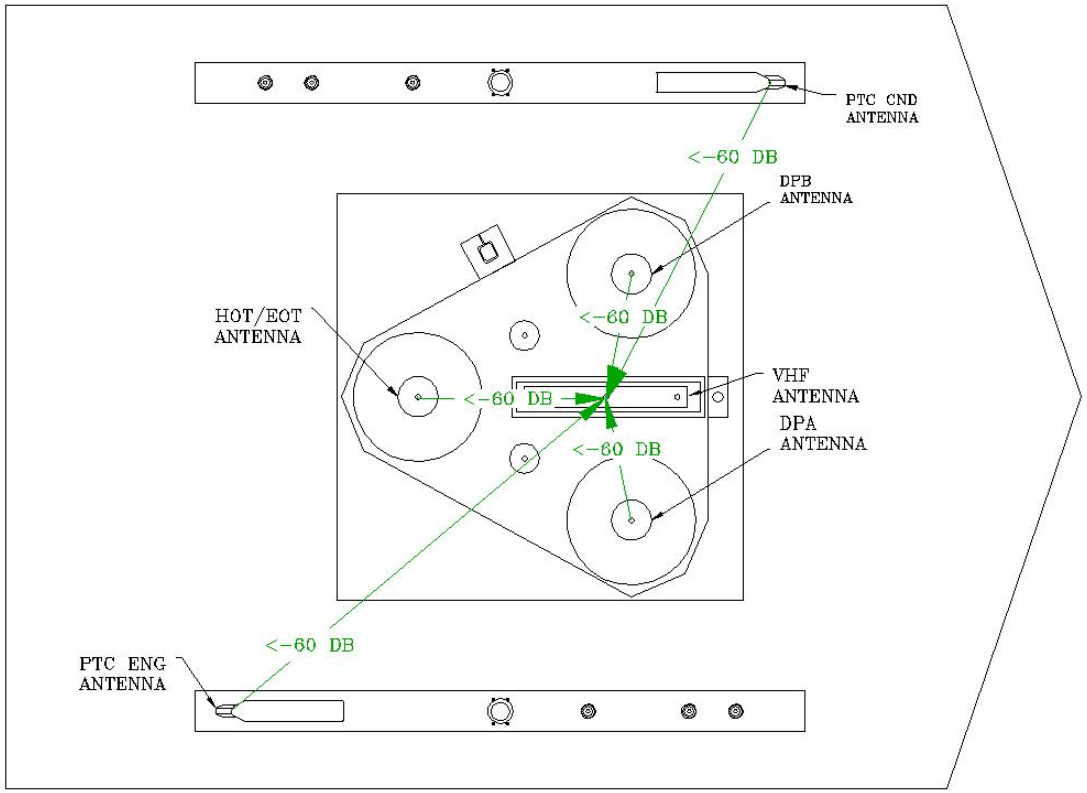
Radio Antenna Port to Radio Antenna Port Isolation

RX 161 Antenna (Unfiltered) Isolation Mapping RX Perspective



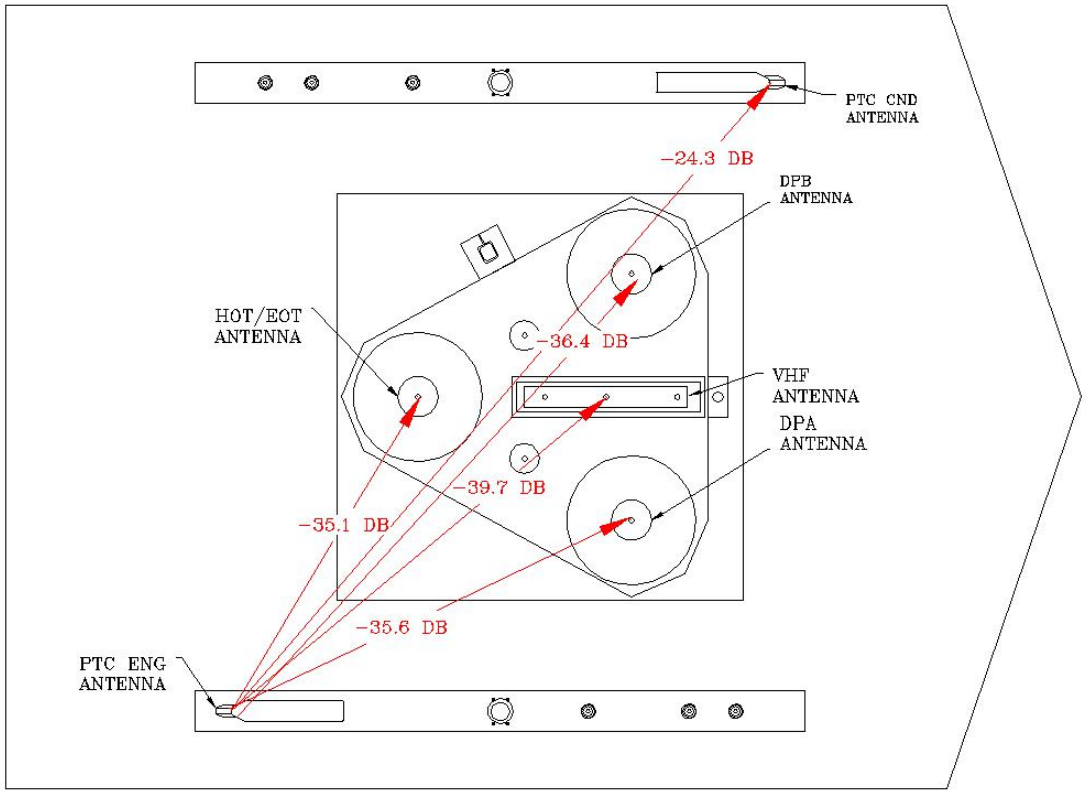
Radio Antenna Port to Radio Antenna Port Isolation

RX 161 Antenna (Filtered)
Isolation Mapping RX Perspective



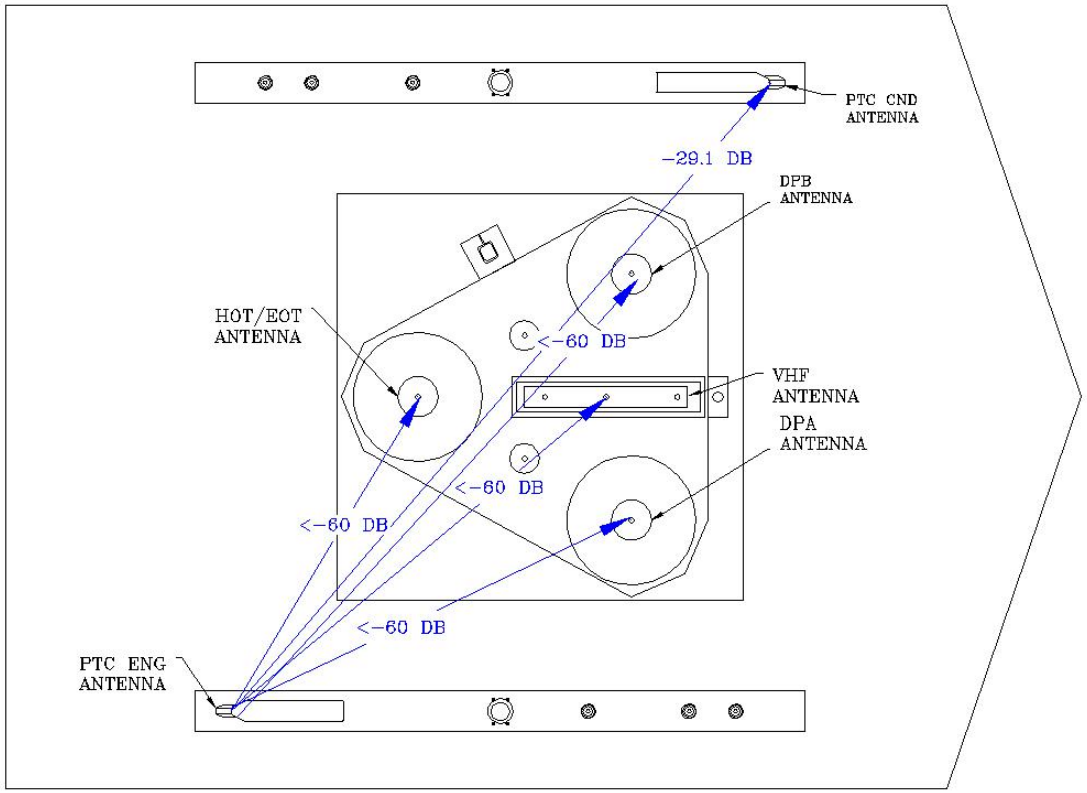
Radio Antenna Port to Radio Antenna Port Isolation

TX 220 ENG Antenna (Unfiltered)
Isolation Mapping TX Perspective



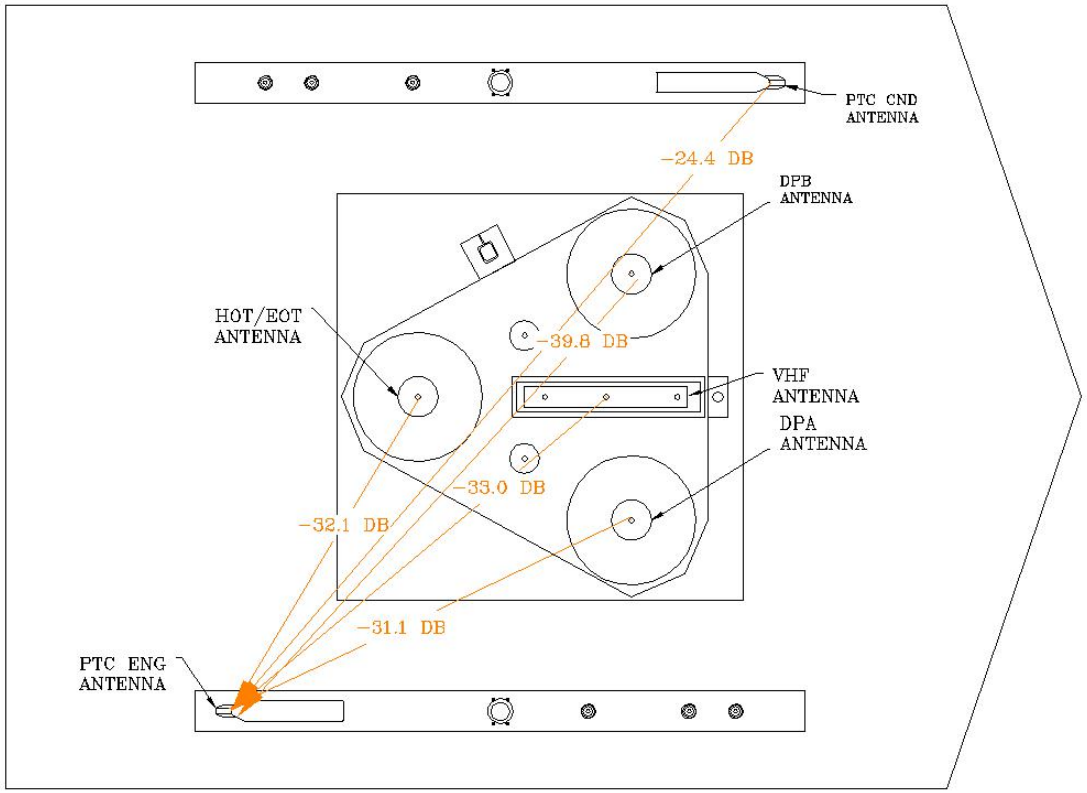
Radio Antenna Port to Radio Antenna Port Isolation

TX 220 ENG Antenna (Filtered) Isolation Mapping TX Perspective



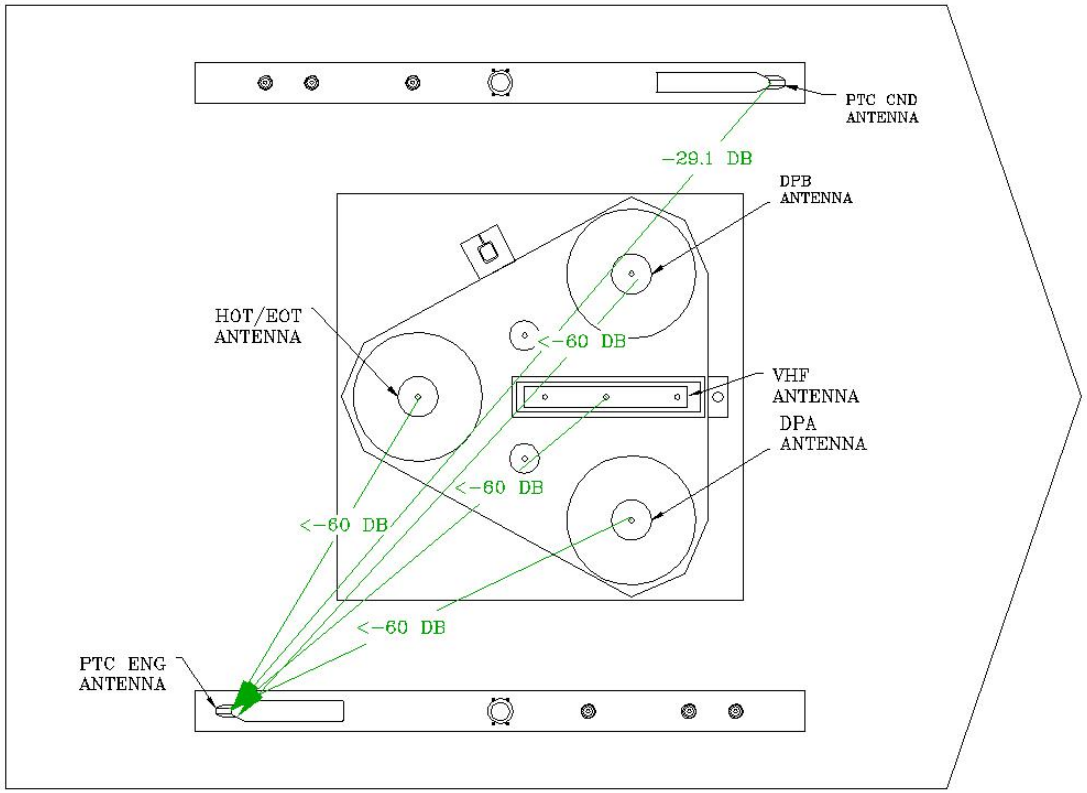
Radio Antenna Port to Radio Antenna Port Isolation

RX 220 ENG Antenna (Unfiltered)
Isolation Mapping RX Perspective



Radio Antenna Port to Radio Antenna Port Isolation

RX 220 ENG Antenna (Filtered) Isolation Mapping RX Perspective



Radio Antenna Port to Radio Antenna Port Isolation

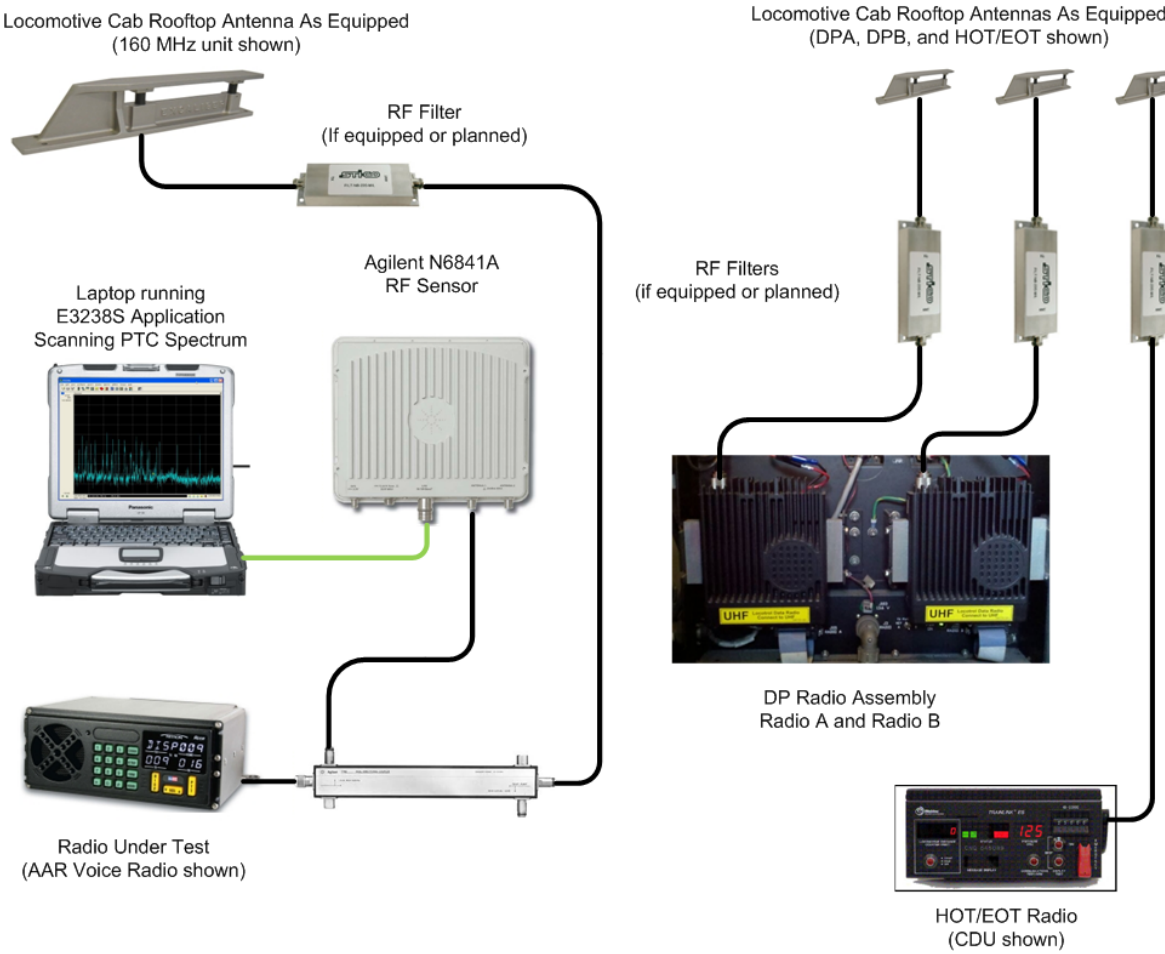
Test repeated for all Significant Contributors

- VHF Voice (161 MHz)
- PTC-A (220 MHz)
- PTC-B (220 MHz)
- DP-A (450 MHz)
- DP-B (450 MHz)
- HOT/EOT (450 MHz)

Receive Intermodulation

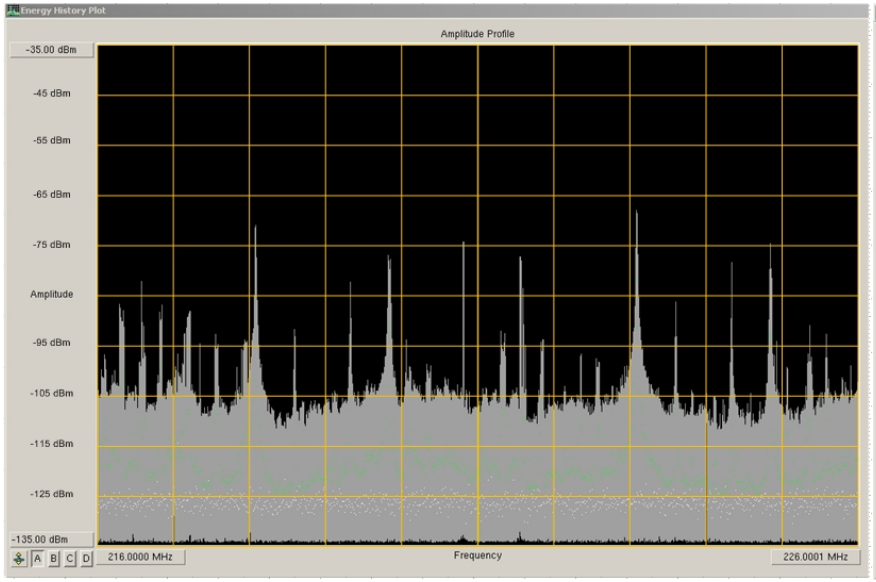
- Purpose of this Test
  - Spectrum of Interest 220 MHz
  - Quantify what, if any, undesired RF Energy will be Re-radiated from each Receiver Under Test
  - Quantify the impact of Filters on preventing, or, at least containing unwanted RF Re-radiation
  - Test is Executed without Filters, and with Filters for each of the High Power Radios Under Test (AAR Voice, HOT/EOT, DPA, DPB)

Receive Intermodulation

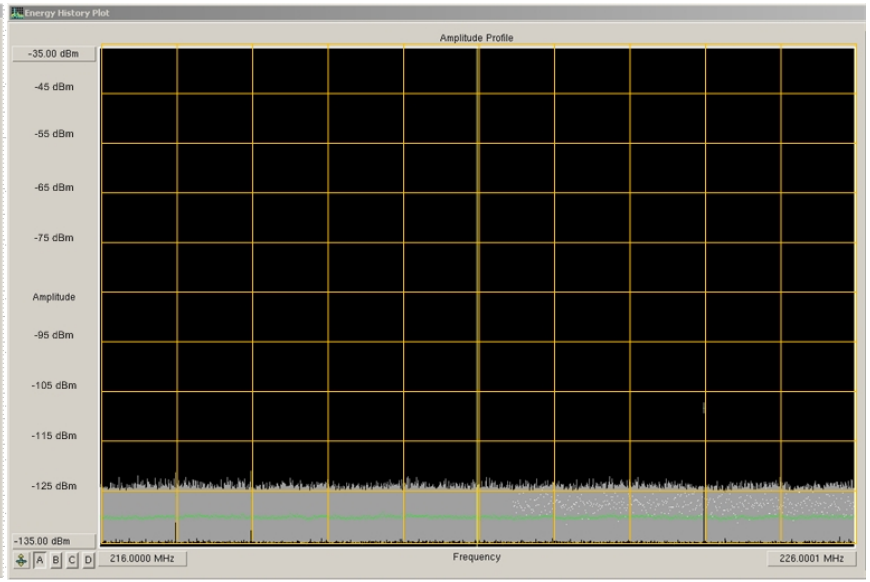


Receive Intermodulation

DPA RX: DPB TX , EOT TX, AAR Voice TX
(216 MHz to 226 MHz)



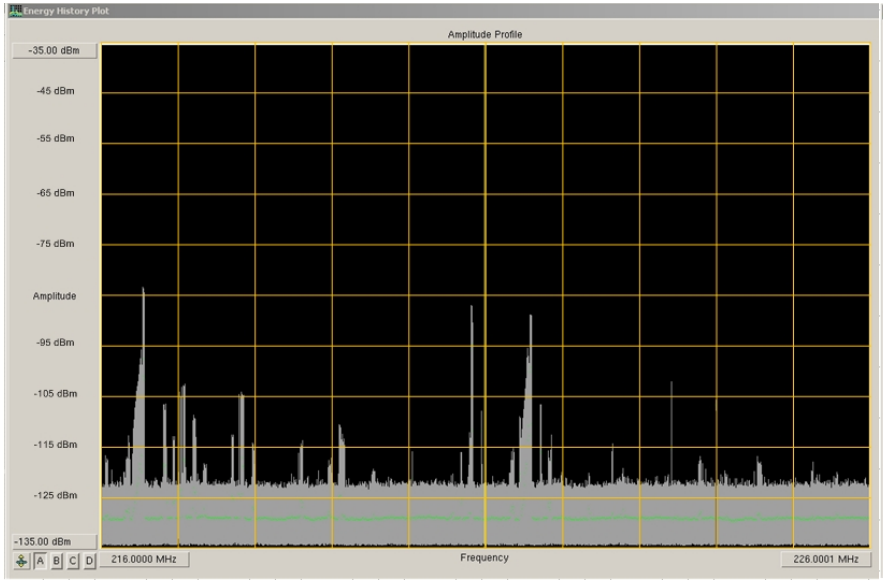
Brand “A” HOT/EOT Unfiltered



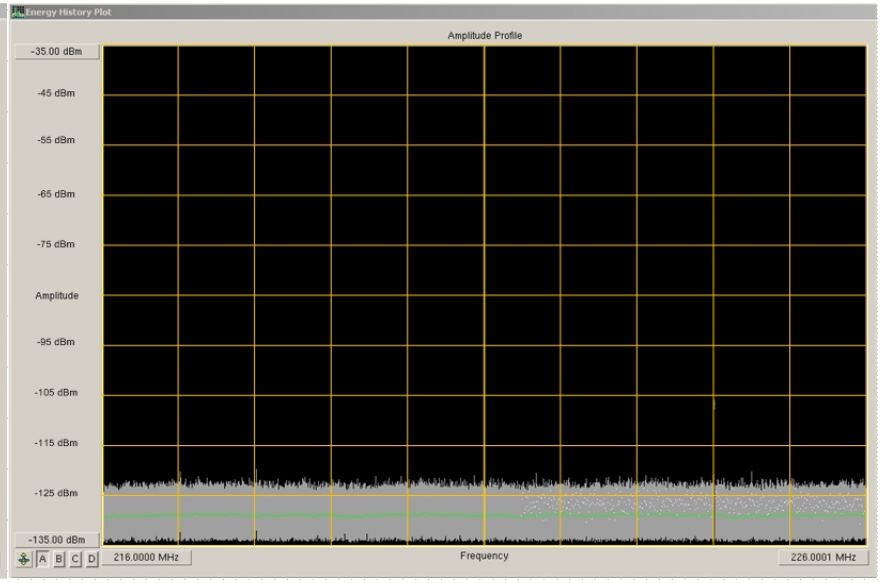
Brand “A” HOT/EOT Filtered

Receive Intermodulation

DPA RX: DPB TX , EOT TX, AAR Voice TX
(216 MHz to 226 MHz)



Brand “B” HOT/EOT Unfiltered

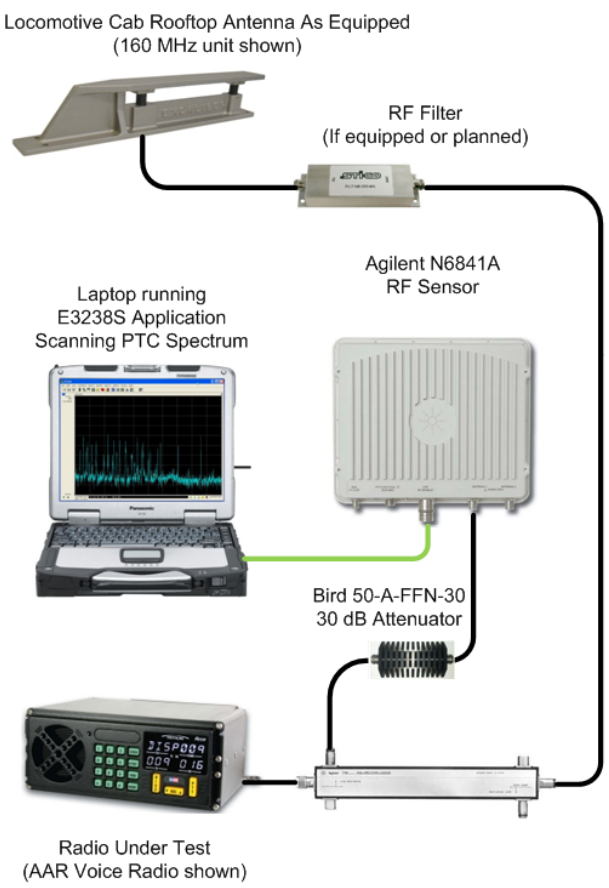


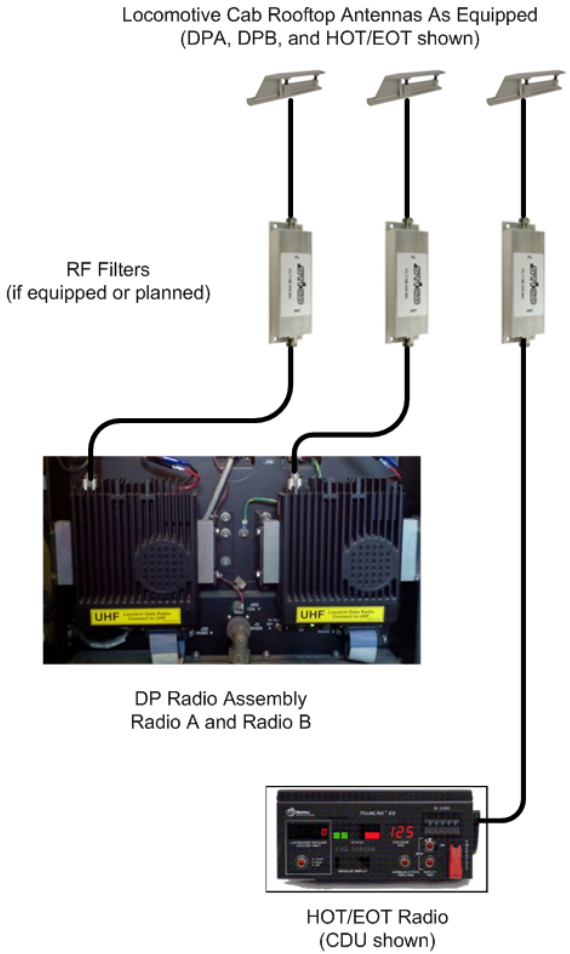
Brand “B” HOT/EOT Filtered

Transmit Intermodulation

- Purpose of this Test
  - Spectrum of Interest 220 MHz
  - Quantify what, if any, undesired RF Energy will be Re-radiated from each Transmitter Under Test
  - Quantify the impact of Filters on preventing, or, at least containing unwanted RF Re-radiation
  - Test is Executed without Filters, and with Filters for each of the High Power Radios Under Test (AAR Voice, HOT/EOT, DPA, DPB)

Transmit Intermodulation





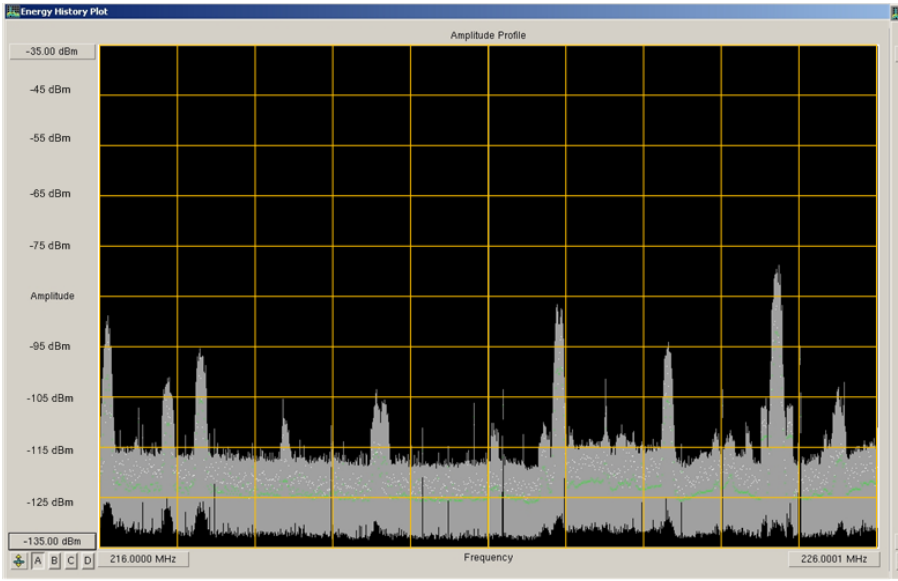
Transmit Intermodulation

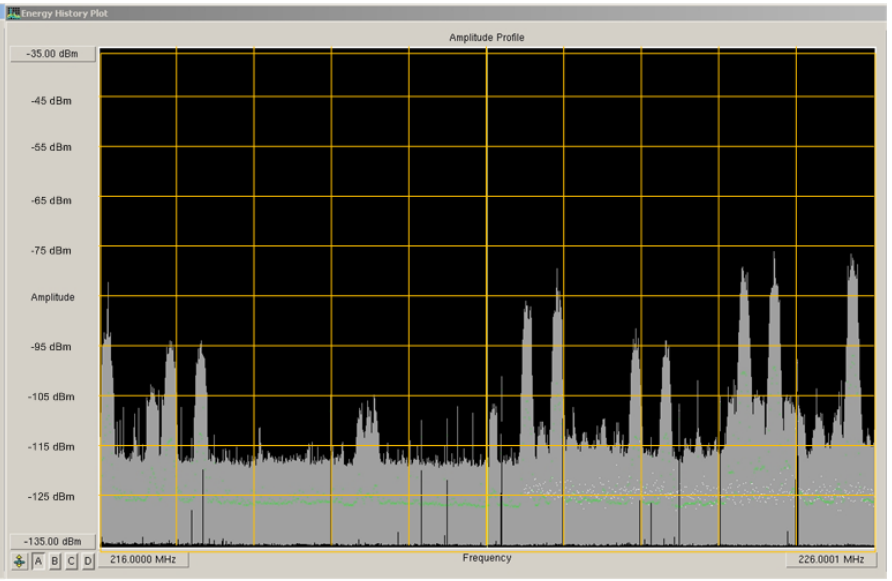
- Unexpected Discovery
  - Off-Platform Signal Sources mixing in On-Platform Radio Equipment producing significant RF Energy in PTC 220 Spectrum
  - One AAR Voice Channel Transmitting produces multiple signals of significant Amplitude in the 220 MHz spectrum.
  - Two AAR Voice Channels Transmitting produces twice as many signals of significant Amplitude in the 220 MHz spectrum.

Transmit Intermodulation

One AAR Voice Channel Transmitting produces multiple signals of significant Amplitude in the 220 MHz spectrum

Two AAR Voice Channels Transmitting produces twice as many signals of significant Amplitude in the 220 MHz spectrum



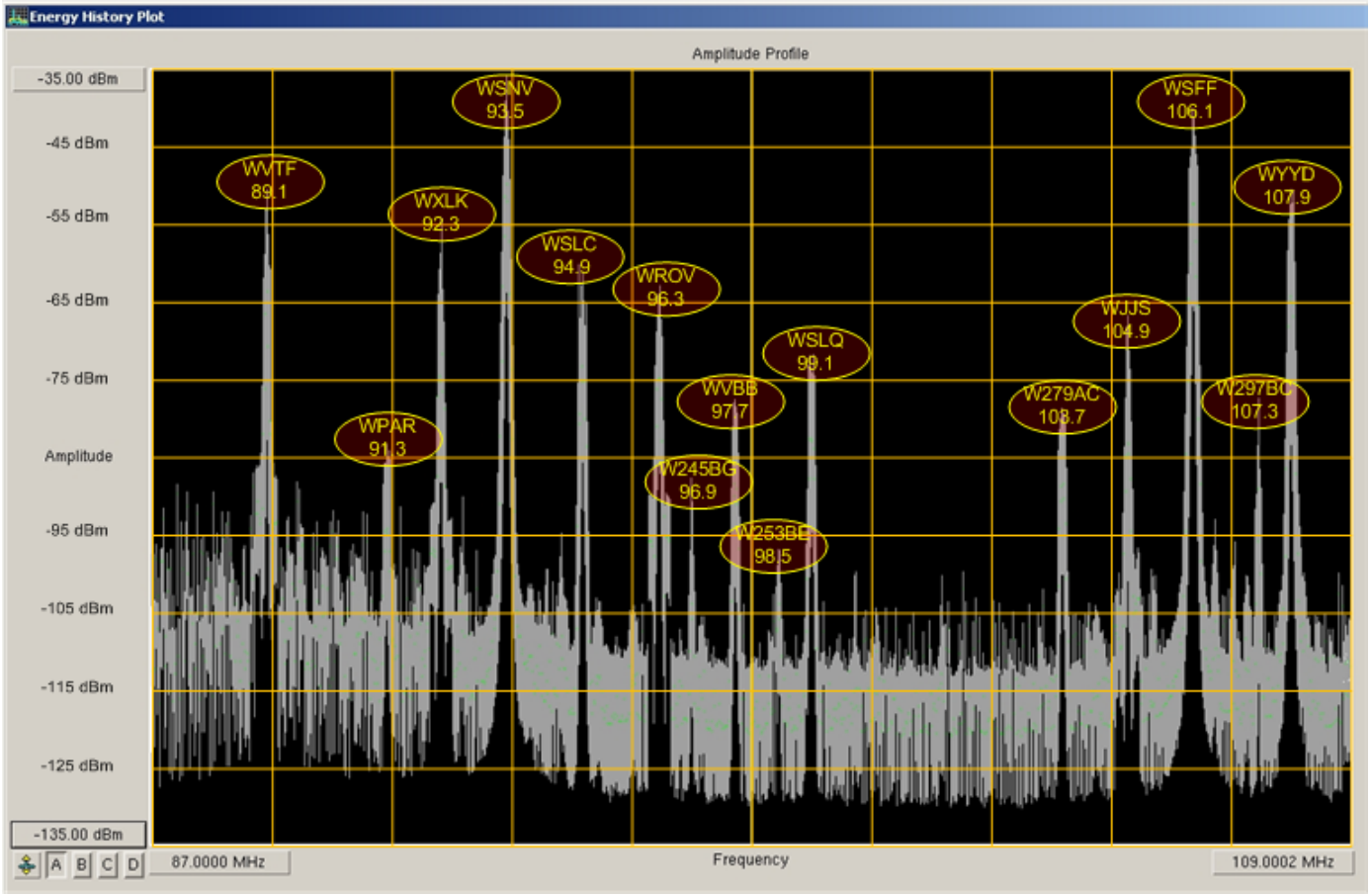


Transmit Intermodulation

- Unexpected Discovery
  - Signal Characteristics
    - Multiple signals 216 MHz to 226 MHz
    - About 150 kHz – 200 kHz wide
    - Analog—so can be demodulated
    - Demodulates to Broadcast Programming Audio
    - Broadcast Programming Audio matches Local FM Broadcasters
    - Fits the 2A-B=C relationship
      - (A--AAR VHF Voice)
      - (B--FM Broadcast)
      - (C--IMD Product)

Transmit Intermodulation

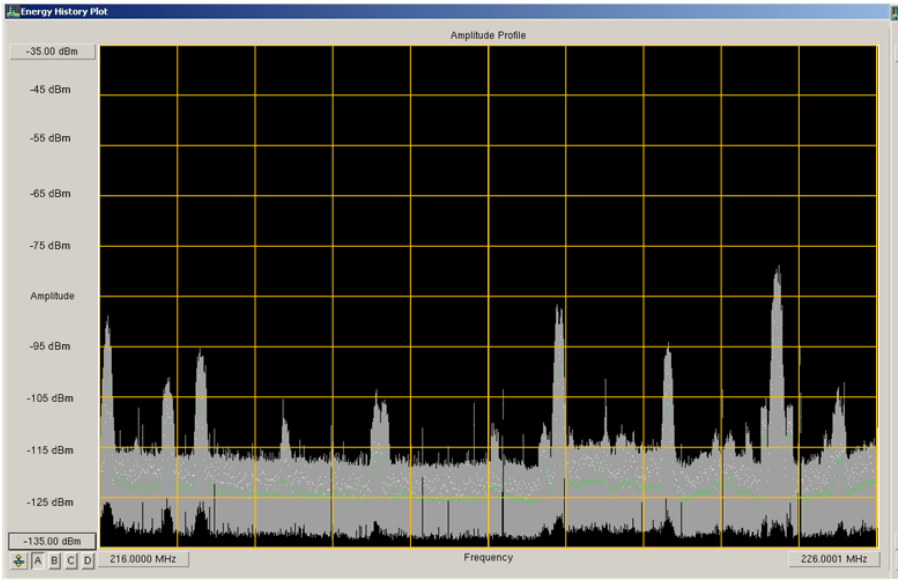
Some Exploration and Research of Local FM Broadcast Spectrum
(88.1 MHz to 107.9 MHz)

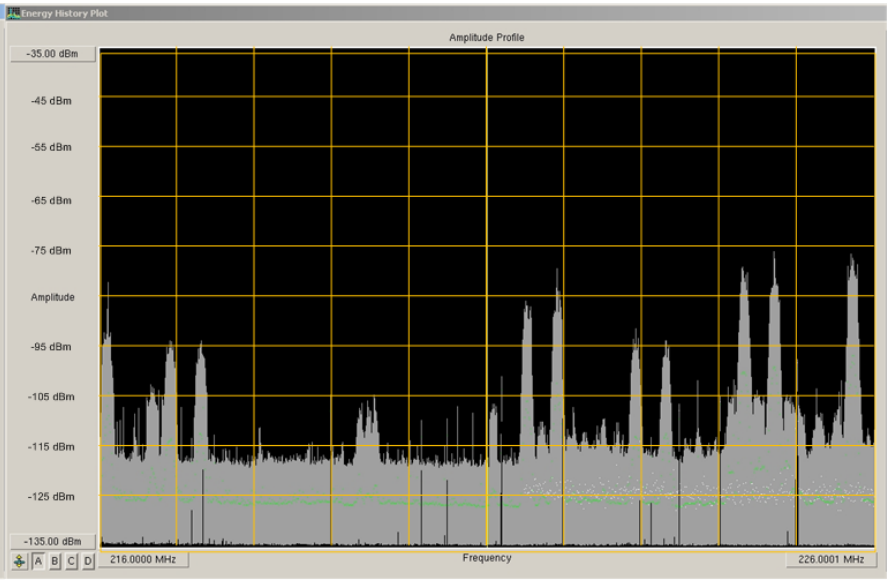


Transmit Intermodulation

One AAR Voice Channel Transmitting produces multiple signals of significant Amplitude in the 220 MHz spectrum

Two AAR Voice Channels Transmitting produces twice as many signals of significant Amplitude in the 220 MHz spectrum

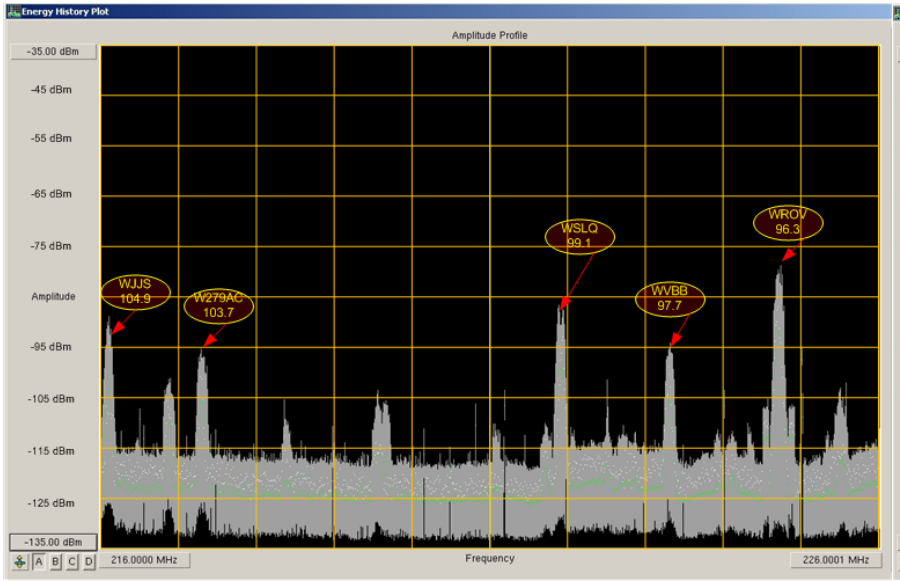


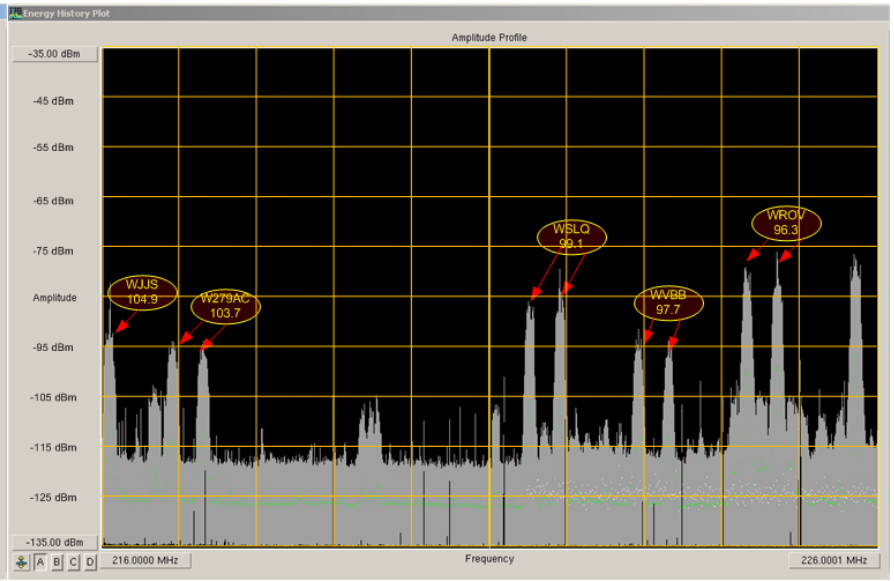


Transmit Intermodulation

One AAR Voice Channel Transmitting produces multiple signals of significant Amplitude in the 220 MHz spectrum

Two AAR Voice Channels Transmitting produces twice as many signals of significant Amplitude in the 220 MHz spectrum





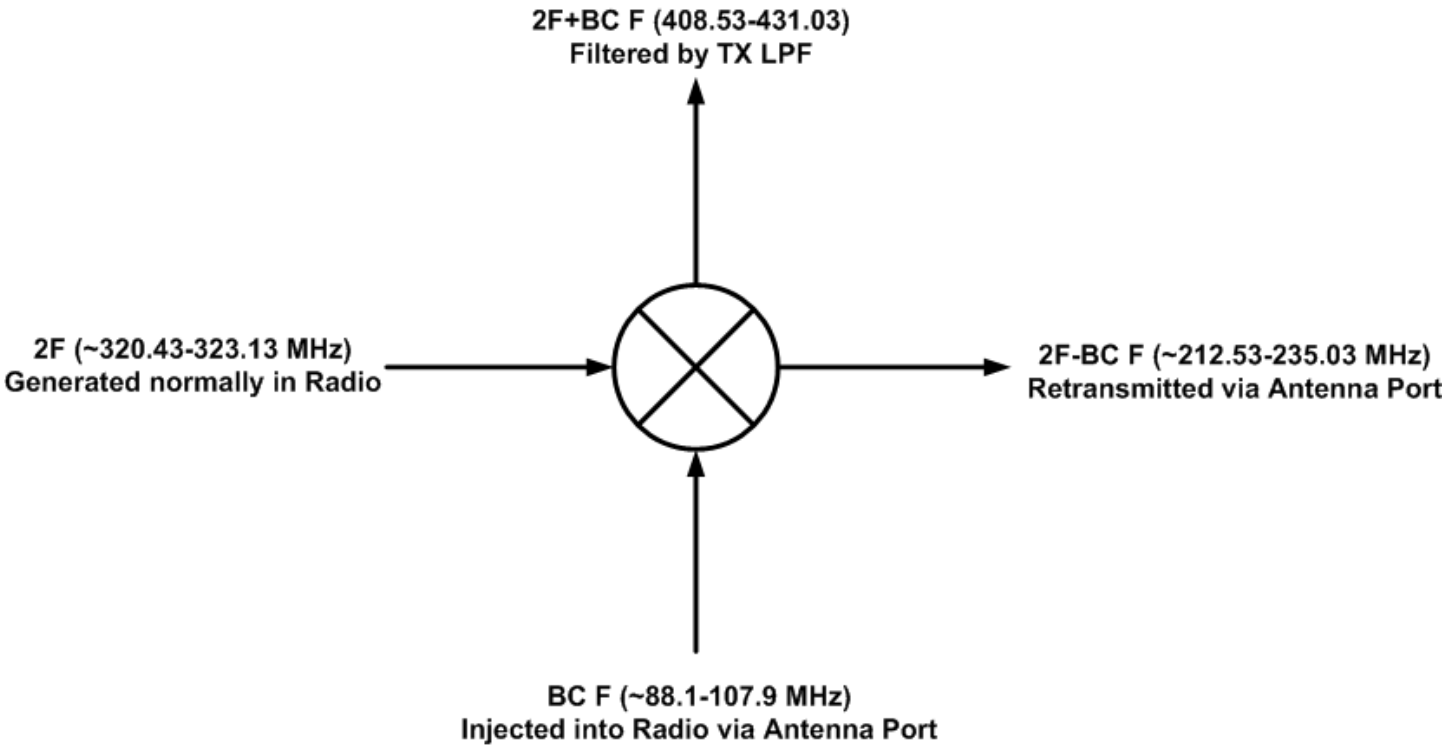
Transmit Intermodulation

Probable Mechanism of Intermodulation Generation

- Most Land Mobile Radios, including the AAR Voice and Distributed Power Radios, employ a TX PA Design using a LPF for suppressing 2nd and 3rd Harmonic Frequencies.
- Since the purpose is to suppress Harmonic Frequencies, a LPF in lieu of a BPF is usually used for economic reasons
- The LPF must pass the high end of the Radio's Frequency Coverage Design—for most VHF LMR Radios, it must Pass 138 MHz to 174 MHz
- The LPF usually has a cutoff somewhere near the 2nd Harmonic Frequency—for the AAR Voice Radio, it is probably in the range of 250 MHz to 300 MHz
- Nothing in the LPF design inhibits RF Energy ingress at Broadcast Frequencies 88.1 MHz to 107.9 MHz
- The LPF appears to pass RF Energy up to at least 226 MHz quite efficiently

Transmit Intermodulation

Probable Mechanism of Intermodulation Generation



Transmit Intermodulation

AAR Channel	Frequency	WVTF		WPAR		WXLK		WSNV		WSLC		WROV		W245BG	
1	160.1250	89.1	231.1500	91.3	229.1300	92.3	227.9500	93.5	226.7500	94.9	225.3500	96.3	223.9500	96.9	223.3500
2	160.1400	89.1	231.1800	91.3	229.1600	92.3	227.9800	93.5	226.7800	94.9	225.3800	96.3	223.9800	96.9	223.3800
3	160.1550	89.1	231.2100	91.3	229.1900	92.3	228.0100	93.5	226.8100	94.9	225.4100	96.3	224.0100	96.9	223.4100
4	160.1700	89.1	231.2400	91.3	229.2200	92.3	228.0400	93.5	226.8400	94.9	225.4400	96.3	224.0400	96.9	223.4400
5	160.1850	89.1	231.2700	91.3	229.2500	92.3	228.0700	93.5	226.8700	94.9	225.4700	96.3	224.0700	96.9	223.4700
6	160.2000	89.1	231.3000	91.3	229.2800	92.3	228.1000	93.5	226.9000	94.9	225.5000	96.3	224.1000	96.9	223.5000
7	160.2150	89.1	231.3300	91.3	229.3100	92.3	228.1300	93.5	226.9300	94.9	225.5300	96.3	224.1300	96.9	223.5300
8	160.2300	89.1	231.3600	91.3	229.1600	92.3	228.1600	93.5	226.9600	94.9	225.5600	96.3	224.1600	96.9	223.5600
9	160.2450	89.1	231.3900	91.3	229.1900	92.3	228.1900	93.5	226.9900	94.9	225.5900	96.3	224.1900	96.9	223.5900
10	160.2600	89.1	231.4200	91.3	229.2200	92.3	228.2200	93.5	227.0200	94.9	225.6200	96.3	224.2200	96.9	223.6200
11	160.2750	89.1	231.4500	91.3	229.2500	92.3	228.2500	93.5	227.0500	94.9	225.6500	96.3	224.2500	96.9	223.6500
12	160.2900	89.1	231.4800	91.3	229.2800	92.3	228.2800	93.5	227.0800	94.9	225.6800	96.3	224.2800	96.9	223.6800
13	160.3050	89.1	231.5100	91.3	229.3100	92.3	228.3100	93.5	227.1100	94.9	225.7100	96.3	224.3100	96.9	223.7100
14	160.3200	89.1	231.5400	91.3	229.3400	92.3	228.3400	93.5	227.1400	94.9	225.7400	96.3	224.3400	96.9	223.7400
15	160.3350	89.1	231.5700	91.3	229.3700	92.3	228.3700	93.5	227.1700	94.9	225.7700	96.3	224.3700	96.9	223.7700
16	160.3500	89.1	231.6000	91.3	229.4000	92.3	228.4000	93.5	227.2000	94.9	225.8000	96.3	224.4000	96.9	223.8000
17	160.3650	89.1	231.6300	91.3	229.4300	92.3	228.4300	93.5	227.2300	94.9	225.8300	96.3	224.4300	96.9	223.8300
18	160.3800	89.1	231.6600	91.3	229.4600	92.3	228.4600	93.5	227.2600	94.9	225.8600	96.3	224.4600	96.9	223.8600
19	160.3950	89.1	231.6900	91.3	229.4900	92.3	228.4900	93.5	227.2900	94.9	225.8900	96.3	224.4900	96.9	223.8900
20	160.4100	89.1	231.7200	91.3	229.5200	92.3	228.5200	93.5	227.3200	94.9	225.9200	96.3	224.5200	96.9	223.9200
21	160.4250	89.1	231.7500	91.3	229.5500	92.3	228.5500	93.5	227.3500	94.9	225.9500	96.3	224.5500	96.9	223.9500
22	160.4400	89.1	231.7800	91.3	229.5800	92.3	228.5800	93.5	227.3800	94.9	225.9800	96.3	224.5800	96.9	223.9800
23	160.4550	89.1	231.8100	91.3	229.6100	92.3	228.6100	93.5	227.4100	94.9	226.0100	96.3	224.6100	96.9	224.0100
24	160.4700	89.1	231.8400	91.3	229.6400	92.3	228.6400	93.5	227.4400	94.9	226.0400	96.3	224.6400	96.9	224.0400
25	160.4850	89.1	231.8700	91.3	229.6700	92.3	228.6700	93.5	227.4700	94.9	226.0700	96.3	224.6700	96.9	224.0700
26	160.5000	89.1	231.9000	91.3	229.7000	92.3	228.7000	93.5	227.5000	94.9	226.1000	96.3	224.7000	96.9	224.1000
27	160.5150	89.1	231.9300	91.3	229.7300	92.3	228.7300	93.5	227.5300	94.9	226.1300	96.3	224.7300	96.9	224.1300
28	160.5300	89.1	231.9600	91.3	229.7600	92.3	228.7600	93.5	227.5600	94.9	226.1600	96.3	224.7600	96.9	224.1600
29	160.5450	89.1	231.9900	91.3	229.7900	92.3	228.7900	93.5	227.5900	94.9	226.1900	96.3	224.7900	96.9	224.1900
30	160.5600	89.1	232.0200	91.3	229.8200	92.3	228.8200	93.5	227.6200	94.9	226.2200	96.3	224.8200	96.9	224.2200
31	160.5750	89.1	232.0500	91.3	229.8500	92.3	228.8500	93.5	227.6500	94.9	226.2500	96.3	224.8500	96.9	224.2500
32	160.5900	89.1	232.0800	91.3	229.8800	92.3	228.8800	93.5	227.6800	94.9	226.2800	96.3	224.8800	96.9	224.2800
33	160.6050	89.1	232.1100	91.3	229.9100	92.3	228.9100	93.5	227.7100	94.9	226.3100	96.3	224.9100	96.9	224.3100
34	160.6200	89.1	232.1400	91.3	229.9400	92.3	228.9400	93.5	227.7400	94.9	226.3400	96.3	224.9400	96.9	224.3400
35	160.6350	89.1	232.1700	91.3	229.9700	92.3	228.9700	93.5	227.7700	94.9	226.3700	96.3	224.9700	96.9	224.3700
36	160.6500	89.1	232.2000	91.3	230.0000	92.3	229.0000	93.5	227.8000	94.9	226.4000	96.3	225.0000	96.9	224.4000
37	160.6650	89.1	232.2300	91.3	230.0300	92.3	229.0300	93.5	227.8300	94.9	226.4300	96.3	225.0300	96.9	224.4300
38	160.6800	89.1	232.2600	91.3	230.0600	92.3	229.0600	93.5	227.8600	94.9	226.4600	96.3	225.0600	96.9	224.4600
39	160.6950	89.1	232.2900	91.3	230.0900	92.3	229.0900	93.5	227.8900	94.9	226.4900	96.3	225.0900	96.9	224.4900
40	160.7100	89.1	232.3200	91.3	230.1200	92.3	229.1200	93.5	227.9200	94.9	226.5200	96.3	225.1200	96.9	224.5200
41	160.7250	89.1	232.3500	91.3	230.1500	92.3	229.1500	93.5	227.9500	94.9	226.5500	96.3	225.1500	96.9	224.5500
42	160.7400	89.1	232.3800	91.3	230.1800	92.3	229.1800	93.5	227.9800	94.9	226.5800	96.3	225.1800	96.9	224.5800
43	160.7550	89.1	232.4100	91.3	230.2100	92.3	229.2100	93.5	228.0100	94.9	226.6100	96.3	225.2100	96.9	224.6100
44	160.7700	89.1	232.4400	91.3	230.2400	92.3	229.2400	93.5	228.0400	94.9	226.6400	96.3	225.2400	96.9	224.6400
45	160.7850	89.1	232.4700	91.3	230.2700	92.3	229.2700	93.5	228.0700	94.9	226.6700	96.3	225.2700	96.9	224.6700
46	160.8000	89.1	232.5000	91.3	230.3000	92.3	229.3000	93.5	228.1000	94.9	226.7000	96.3	225.3000	96.9	224.7000
47	160.8150	89.1	232.5300	91.3	230.3300	92.3	229.3300	93.5	228.1300	94.9	226.7300	96.3	225.3300	96.9	224.7300
48	160.8300	89.1	232.5600	91.3	230.3600	92.3	229.3600	93.5	228.1600	94.9	226.7600	96.3	225.3600	96.9	224.7600
49	160.8450	89.1	232.5900	91.3	230.3900	92.3	229.3900	93.5	228.1900	94.9	226.7900	96.3	225.3900	96.9	224.7900
50	160.8600	89.1	232.6200	91.3	230.4200	92.3	229.4200	93.5	228.2200	94.9	226.8200	96.3	225.4200	96.9	224.8200
51	160.8750	89.1	232.6500	91.3	230.4500	92.3	229.4500	93.5	228.2500	94.9	226.8500	96.3	225.4500	96.9	224.8500
52	160.8900	89.1	232.6800	91.3	230.4800	92.3	229.4800	93.5	228.2800	94.9	226.8800	96.3	225.4800	96.9	224.8800
53	160.9050	89.1	232.7100	91.3	230.5100	92.3	229.5100	93.5	228.3100	94.9	226.9100	96.3	225.5100	96.9	224.9100
54	160.9200	89.1	232.7400	91.3	230.5400	92.3	229.5400	93.5	228.3400	94.9	226.9400	96.3	225.5400	96.9	224.9400
55	160.9350	89.1	232.7700	91.3	230.5700	92.3	229.5700	93.5	228.3700	94.9	226.9700	96.3	225.5700	96.9	224.9700
56	160.9500	89.1	232.8000	91.3	230.6000	92.3	229.6000	93.5	228.4000	94.9	227.0000	96.3	225.6000	96.9	225.0000
57	160.9650	89.1	232.8300	91.3	230.6300	92.3	229.6300	93.5	228.4300	94.9	227.0300	96.3	225.6300	96.9	225.0300
58	160.9800	89.1	232.8600	91.3	230.6600	92.3	229.6600	93.5	228.4600	94.9	227.0600	96.3	225.6600	96.9	225.0600
59	160.9950	89.1	232.8900	91.3	230.6900	92.3	229.6900	93.5	228.4900	94.9	227.0900	96.3	225.6900	96.9	225.0900
60	161.0100	89.1	232.9200	91.3	230.7200	92.3	229.7200	93.5	228.5200	94.9	227.1200	96.3	225.7200	96.9	225.1200
61	161.0250	89.1	232.9500	91.3	230.7500	92.3	229.7500	93.5	228.5500	94.9	227.1500	96.3	225.7500	96.9	225.1500
62	161.0400	89.1	232.9800	91.3	230.7800	92.3	229.7800	93.5	228.5800	94.9	227.1800	96.3	225.7800	96.9	225.1800
63	161.0550	89.1	233.0100	91.3	230.8100	92.3	229.8100	93.5	228.6100	94.9	227.2100	96.3	225.8100	96.9	225.2100
64	161.0700	89.1	233.0400	91.3	230.8400	92.3	229.8400	93.5	228.6400	94.9	227.2400	96.3	225.8400	96.9	225.2400
65	161.0850	89.1	233.0700	91.3	230.8700	92.3	229.8700	93.5	228.6700	94.9	227.2700	96.3	225.8700	96.9	225.2700
66	161.1000	89.1	233.1000	91.3	230.9000	92.3	229.9000	93.5	228.7000	94.9	227.3000	96.3	225.9000	96.9	225.3000
67	161.1150	89.1	233.1300	91.3	230.9300	92.3	229.9300	93.5	228.7300	94.9	227.3300	96.3	225.9300	96.9	225.3300
68	161.1300	89.1	233.1600	91.3	230.9600	92.3	229.9600	93.5	228.7600	94.9	227.3600	96.3	225.9600	96.9	225.3600
69	161.1450	89.1	233.1900	91.3	230.9900	92.3	229.9900	93.5	228.7900	94.9	227.3900	96.3	225.9900	96.9	225.3900
70	161.1600	89.1	233.2200	91.3	231.0200	92.3	230.0200	93.5	228.8200	94.9	227.4200	96.3	226.0200	96.9	225.4200
71	161.1750	89.1	233.2500	91.3	231.0500	92.3	230.0500	93.5	228.8500	94.9	227.4500	96.3	226.0500	96.9	225.4500
72	161.1900	89.1	233.2800	91.3	231.0800	92.3	230.0800	93.5	228.8800	94.9	227.4800	96.3	226.0800	96.9	225.4800
73	161.2050	89.1	233.3100	91.3	231.1100	92.3	230.1100	93.5	228.9100	94.9	227.5100	96.3	226.1100	96.9	225.5100
74	161.2200	89.1	233.3400	91.3	231.1400	92.3	230.1400	93.5	228.9400	94.9	227.5400	96.3	226.1400	96.9	225.5400
75	161.2350	89.1	233.3700	91.3	231.1700	92.3	230.1700	93.5	228.9700	94.9	227.5700	96.3	226.1700	96.9	225.5700
76	161.2500	89.1	233.4000	91.3	231.2000	92.3	230.2000	93.5	229.0000	94.9	227.6000	96.3	226.2000	96.9	225.6000
77	161.2650	89.1	233.4300	91.3	231.2300	92.3	230.2300	93.5	229.0300	94.9	227.6300	96.3	226.2300	96.9	225.6300
78	161.2800	89.1	233.4600	91.3	231.2600	92.3	230.2600	93.5	229.0600	94.9	227.6600	96.3	226.2600	96.9	225.6600
79	161.2950	89.1	233.4900	91.3	231.2900	92.3	230.2900	93.5	229.0900	94.9	227.6900	96.3	226.2900	96.9	225.6900
80	161.3100	89.1	233.5200	91.3	231.3200	92.3	230.3200	93.5	229.1200	94.9	227.7200	96.3	226.3200	96.9	225.7200
81	161.3250	89.1	233.5500	91.3	231.3500	92.3	230.3500	93.5	229.1500	94.9	227.7500	96.3	226.3500	96.9	225.7500
82	161.3400	89.1	233.5800	91.3	231.3800	92.3	230.3800	93.5	229.1800	94.9	227.7800	96.3	226.3800	96.9	225.7800
83	161.3550	89.1	233.6100	91.3	231.4100	92.3	230.4100	93.5	229.2100	94.9	227.8100	96.3	226.4100	96.9	225.8100
84	161.3700	89.1	233.6400	91.3	231.4400	92.3	230.4400	93.5	229.2400	94.9	227.8400	96.3	226.4400	96.9	225.8400
85	161.3850	89.1	233.6700	91.3	231.4700	92.3	230.4700	93.5	229.2700	94.9	227.8700	96.3	226.4700	96.9	225.8700
86	161.4000	89.1	233.7000	91.3	231.5000	92.3	230.5000	93.5	229.3000	94.9	227.9000	96.3	226.5000	96.9	225.9000
87	161.4150	89.1	233.7300	91.3	231.5300	92.3	230.5300	93.5	229.3300	94.9	227.9300	96.3	226.5300	96.9	225.9300
88	161.4300	89.1	233.7600	91.3	231.5600	92.3	230.5600	93.5	229.3600	94.9	227.9600	96.3	226.5600	96.9	225.9600
89	161.4450	89.1	233.7900	91.3	231.5900	92.3	230.5900	93.5	229.3900	94.9	227.9900	96.3	226.5900	96.9	225.9900
90	161.4600	89.1	233.8200	91.3	231.6200	92.3	230.6200	93.5	229.4200	94.9	228.0200	96.3	226.6200	96.9	226.0200
91	161.4750	89.1	233.8500	91.3	231.6500	92.3	230.6500	93.5	229.4500	94.9	228.0500	96.3	226.6500	96.9	226.0500
92	161.4900	89.1	233.8800	91.3	231.6800	92.3	230.6800	93.5	229.4800	94.9	228.0800	96.3	226.6800	96.9	226.0800
93	161.5050	89.1	233.9100	91.3	231.7100	92.3	230.7100	93.5	229.5100	94.9	228.1100	96.3	226.7100	96.9	226.1100
94	161.5200	89.1	233.9400	91.3	231.7400	92.3	230.7400	93.5	229.5400	94.9	228.1400	96.3	226.7400	96.9	226.1400
95	161.5350	89.1	233.9700	91.3	231.7700	92.3	230.7700	93.5	229.5700	94.9	228.1700	96.3	226.7700	96.9	226.1700
96	161.5500	89.1	234.0000	91.3	231.8000	92.3	230.8000	93.5	229.6000	94.9	228.2000	96.3	226.8000	96.9	226.2000
97	161.5650	89.1	234.0300	91.3	231.8300	92.3	230.8300	93.5	229.6300	94.9	228.2300	96.3	226.8300	96.9	226.2300

AAR Channel	WVBB		W253BE		WSLQ		W279AC		WJJS		WSFF		W297BC		WYYD	
1	97.7	222.5500	98.5	221.7500	99.1	221.1500	103.7	216.5500	104.9	215.3500	106.1	214.1500	107.3	212.9500	107.9	212.3500
2	97.7	222.5800	98.5	221.7800	99.1	221.1800	103.7	216.5800	104.9	215.3800	106.1	214.1800	107.3	212.9800	107.9	212.3800
3	97.7	222.6100	98.5	221.8100	99.1	221.2100	103.7	216.6100	104.9	215.4100	106.1	214.2100	107.3	213.0100	107.9	212.4100
4	97.7	222.6400	98.5	221.8400	99.1	221.2400	103.7	216.6400	104.9	215.4400	106.1	214.2400	107.3	213.0400	107.9	212.4400
5	97.7	222.6700	98.5	221.8700	99.1	221.2700	103.7	216.6700	104.9	215.4700	106.1	214.2700	107.3	213.0700	107.9	212.4700
6	97.7	222.7000	98.5	221.9000	99.1	221.3000	103.7	216.7000	104.9	215.5000	106.1	214.3000	107.3	213.1000	107.9	212.5000
7	97.7	222.7300	98.5	221.9300	99.1	221.3300	103.7	216.7300	104.9	215.5300	106.1	214.3300	107.3	213.1300	107.9	212.5300
8	97.7	222.7600	98.5	221.9600	99.1	221.3600	103.7	216.7600	104.9	215.5600	106.1	214.3600	107.3	213.1600	107.9	212.5600
9	97.7	222.7900	98.5	221.9900	99.1	221.3900	103.7	216.7900	104.9	215.5900	106.1	214.3900	107.3	213.1900	107.9	212.5900
10	97.7	222.8200	98.5	222.0200	99.1	221.4200	103.7	216.8200	104.9	215.6200	106.1	214.4200	107.3	213.2200	107.9	212.6200
11	97.7	222.8500	98.5	222.0500	99.1	221.4500	103.7	216.8500	104.9	215.6500	106.1	214.4500	107.3	213.2500	107.9	212.6500
12	97.7	222.8800	98.5	222.0800	99.1	221.4800	103.7	216.8800	104.9	215.6800	106.1	214.4800	107.3	213.2800	107.9	212.6800
13	97.7	222.9100	98.5	222.1100	99.1	221.5100	103.7	216.9100	104.9	215.7100	106.1	214.5100	107.3	213.3100	107.9	212.7100
14	97.7	222.9400	98.5	222.1400	99.1	221.5400	103.7	216.9400	104.9	215.7400	106.1	214.5400	107.3	213.3400	107.9	212.7400
15	97.7	222.9700	98.5	222.1700	99.1	221.5700	103.7	216.9700	104.9	215.7700	106.1	214.5700	107.3	213.3700	107.9	212.7700
16	97.7	223.0000	98.5	222.2000	99.1	221.6000	103.7	217.0000	104.9	215.8000	106.1	214.6000	107.3	213.4000	107.9	212.8000
17	97.7	223.0300	98.5	222.2300	99.1	221.6300	103.7	217.0300	104.9	215.8300	106.1	214.6300	107.3	213.4300	107.9	212.8300
18	97.7	223.0600	98.5	222.2600	99.1	221.6600	103.7	217.0600	104.9	215.8600	106.1	214.6600	107.3	213.4600	107.9	212.8600
19	97.7	223.0900	98.5	222.2900	99.1	221.6900	103.7	217.0900	104.9	215.8900	106.1	214.6900	107.3	213.4900	107.9	212.8900
20	97.7	223.1200	98.5	222.3200	99.1	221.7200	103.7	217.1200	104.9	215.9200	106.1	214.7200	107.3	213.5200	107.9	212.9200
21	97.7	223.1500	98.5	222.3500	99.1	221.7500	103.7	217.1500	104.9	215.9500	106.1	214.7500	107.3	213.5500	107.9	212.9500
22	97.7	223.1800	98.5	222.3800	99.1	221.7800	103.7	217.1800	104.9	215.9800	106.1	214.7800	107.3	213.5800	107.9	212.9800
23	97.7	223.2100	98.5	222.4100	99.1	221.8100	103.7	217.2100	104.9	216.0100	106.1	214.8100	107.3	213.6100	107.9	213.0100
24	97.7	223.2400	98.5	222.4400	99.1	221.8400	103.7	217.2400	104.9	216.0400	106.1	214.8400	107.3	213.6400	107.9	213.0400
25	97.7	223.2700	98.5	222.4700	99.1	221.8700	103.7	217.2700	104.9	216.0700	106.1	214.8700	107.3	213.6700	107.9	213.0700
26	97.7	223.3000	98.5	222.5000	99.1	221.9000	103.7	217.3000	104.9	216.1000	106.1	214.9000	107.3	213.7000	107.9	213.1000
27	97.7	223.3300	98.5	222.5300	99.1	221.9300	103.7	217.3300	104.9	216.1300	106.1	214.9300	107.3	213.7300	107.9	213.1300
28	97.7	223.3600	98.5	222.5600	99.1	221.9600	103.7	217.3600	104.9	216.1600	106.1	214.9600	107.3	213.7600	107.9	213.1600
29	97.7	223.3900	98.5	222.5900	99.1	221.9900	103.7	217.3900	104.9	216.1900	106.1	214.9900	107.3	213.7900	107.9	213.1900
30	97.7	223.4200	98.5	222.6200	99.1	222.0200	103.7	217.4200	104.9	216.2200	106.1	215.0200	107.3	213.8200	107.9	213.2200
31	97.7	223.4500	98.5	222.6500	99.1	222.0500	103.7	217.4500	104.9	216.2500	106.1	215.0500	107.3	213.8500	107.9	213.2500
32	97.7	223.4800	98.5	222.6800	99.1	222.0800	103.7	217.4800	104.9	216.2800	106.1	215.0800	107.3	213.8800	107.9	213.2800
33	97.7	223.5100	98.5	222.7100	99.1	222.1100	103.7	217.5100	104.9	216.3100	106.1	215.1100	107.3	213.9100	107.9	213.3100
34	97.7	223.5400	98.5	222.7400	99.1	222.1400	103.7	217.5400	104.9	216.3400	106.1	215.1400	107.3	213.9400	107.9	213.3400
35	97.7	223.5700	98.5	222.7700	99.1	222.1700	103.7	217.5700	104.9	216.3700	106.1	215.1700	107.3	213.9700	107.9	213.3700
36	97.7	223.6000	98.5	222.8000	99.1	222.2000	103.7	217.6000	104.9	216.4000	106.1	215.2000	107.3	214.0000	107.9	213.4000
37	97.7	223.6300	98.5	222.8300	99.1	222.2300	103.7	217.6300	104.9	216.4300	106.1	215.2300	107.3	214.0300	107.9	213.4300
38	97.7	223.6600	98.5	222.8600	99.1	222.2600	103.7	217.6600	104.9	216.4600	106.1	215.2600	107.3	214.0600	107.9	213.4600
39	97.7	223.6900	98.5	222.8900	99.1	222.2900	103.7	217.6900	104.9	216.4900	106.1	215.2900	107.3	214.0900	107.9	213.4900
40	97.7	223.7200	98.5	222.9200	99.1	222.3200	103.7	217.7200	104.9	216.5200	106.1	215.3200	107.3	214.1200	107.9	213.5200
41	97.7	223.7500	98.5	222.9500	99.1	222.3500	103.7	217.7500	104.9	216.5500	106.1	215.3500	107.3	214.1500	107.9	213.5500
42	97.7	223.7800	98.5	222.9800	99.1	222.3800	103.7	217.7800	104.9	216.5800	106.1	215.3800	107.3	214.1800	107.9	213.5800
43	97.7	223.8100	98.5	223.0100	99.1	222.4100	103.7	217.8100	104.9	216.6100	106.1	215.4100	107.3	214.2100	107.9	213.6100
44	97.7	223.8400	98.5	223.0400	99.1	222.4400	103.7	217.8400	104.9	216.6400	106.1	215.4400	107.3	214.2400	107.9	213.6400
45	97.7	223.8700	98.5	223.0700	99.1	222.4700	103.7	217.8700	104.9	216.6700	106.1	215.4700	107.3	214.2700	107.9	213.6700
46	97.7	223.9000	98.5	223.1000	99.1	222.5000	103.7	217.9000	104.9	216.7000	106.1	215.5000	107.3	214.3000	107.9	213.7000
47	97.7	223.9300	98.5	223.1300	99.1	222.5300	103.7	217.9300	104.9	216.7300	106.1	215.5300	107.3	214.3300	107.9	213.7300
48	97.7	223.9600	98.5	223.1600	99.1	222.5600	103.7	217.9600	104.9	216.7600	106.1	215.5600	107.3	214.3600	107.9	213.7600
49	97.7	223.9900	98.5	223.1900	99.1	222.5900	103.7	217.9900	104.9	216.7900	106.1	215.5900	107.3	214.3900	107.9	213.7900
50	97.7	224.0200	98.5	223.2200	99.1	222.6200	103.7	218.0200	104.9	216.8200	106.1	215.6200	107.3	214.4200	107.9	213.8200
51	97.7	224.0500	98.5	223.2500	99.1	222.6500	103.7	218.0500	104.9	216.8500	106.1	215.6500	107.3	214.4500	107.9	213.8500
52	97.7	224.0800	98.5	223.2800	99.1	222.6800	103.7	218.0800	104.9	216.8800	106.1	215.6800	107.3	214.4800	107.9	213.8800
53	97.7	224.1100	98.5	223.3100	99.1	222.7100	103.7	218.1100	104.9	216.9100	106.1	215.7100	107.3	214.5100	107.9	213.9100
54	97.7	224.1400	98.5	223.3400	99.1	222.7400	103.7	218.1400	104.9	216.9400	106.1	215.7400	107.3	214.5400	107.9	213.9400
55	97.7	224.1700	98.5	223.3700	99.1	222.7700	103.7	218.1700	104.9	216.9700	106.1	215.7700	107.3	214.5700	107.9	213.9700
56	97.7	224.2000	98.5	223.4000	99.1	222.8000	103.7	218.2000	104.9	217.0000	106.1	215.8000	107.3	214.6000	107.9	214.0000
57	97.7	224.2300	98.5	223.4300	99.1	222.8300	103.7	218.2300	104.9	217.0300	106.1	215.8300	107.3	214.6300	107.9	214.0300
58	97.7	224.2600	98.5	223.4600	99.1	222.8600	103.7	218.2600	104.9	217.0600	106.1	215.8600	107.3	214.6600	107.9	214.0600
59	97.7	224.2900	98.5	223.4900	99.1	222.8900	103.7	218.2900	104.9	217.0900	106.1	215.8900	107.3	214.6900	107.9	214.0900
60	97.7	224.3200	98.5	223.5200	99.1	222.9200	103.7	218.3200	104.9	217.1200	106.1	215.9200	107.3	214.7200	107.9	214.1200
61	97.7	224.3500	98.5	223.5500	99.1	222.9500	103.7	218.3500	104.9	217.1500	106.1	215.9500	107.3	214.7500	107.9	214.1500
62	97.7	224.3800	98.5	223.5800	99.1	222.9800	103.7	218.3800	104.9	217.1800	106.1	215.9800	107.3	214.7800	107.9	214.1800
63	97.7	224.4100	98.5	223.6100	99.1	223.0100	103.7	218.4100	104.9	217.2100	106.1	216.0100	107.3	214.8100	107.9	214.2100
64	97.7	224.4400	98.5	223.6400	99.1	223.0400	103.7	218.4400	104.9	217.2400	106.1	216.0400	107.3	214.8400	107.9	214.2400
65	97.7	224.4700	98.5	223.6700	99.1	223.0700	103.7	218.4700	104.9	217.2700	106.1	216.0700	107.3	214.8700	107.9	214.2700
66	97.7	224.5000	98.5	223.7000	99.1	223.1000	103.7	218.5000	104.9	217.3000	106.1	216.1000	107.3	214.9000	107.9	214.3000
67	97.7	224.5300	98.5	223.7300	99.1	223.1300	103.7	218.5300	104.9	217.3300	106.1	216.1300	107.3	214.9300	107.9	214.3300
68	97.7	224.5600	98.5	223.7600	99.1	223.1600	103.7	218.5600	104.9	217.3600	106.1	216.1600	107.3	214.9600	107.9	214.3600
69	97.7	224.5900	98.5	223.7900	99.1	223.1900	103.7	218.5900	104.9	217.3900	106.1	216.1900	107.3	214.9900	107.9	214.3900
70	97.7	224.6200	98.5	223.8200	99.1	223.2200	103.7	218.6200	104.9	217.4200	106.1	216.2200	107.3	215.0200	107.9	214.4200
71	97.7	224.6500	98.5	223.8500	99.1	223.2500	103.7	218.6500	104.9	217.4500	106.1	216.2500	107.3	215.0500	107.9	214.4500
72	97.7	224.6800	98.5	223.8800	99.1	223.2800	103.7	218.6800	104.9	217.4800	106.1	216.2800	107.3	215.0800	107.9	214.4800
73	97.7	224.7100	98.5	223.9100	99.1	223.3100	103.7	218.7100	104.9	217.5100	106.1	216.3100	107.3	215.1100	107.9	214.5100
74	97.7	224.7400	98.5	223.9400	99.1	223.3400	103.7	218.7400	104.9	217.5400	106.1	216.3400	107.3	215.1400	107.9	214.5400
75	97.7	224.7700	98.5	223.9700	99.1	223.3700	103.7	218.7700	104.9	217.5700	106.1	216.3700	107.3	215.1700	107.9	214.5700
76	97.7	224.8000	98.5	224.0000	99.1	223.4000	103.7	218.8000	104.9	217.6000	106.1	216.4000	107.3	215.2000	107.9	214.6000
77	97.7	224.8300	98.5	224.0300	99.1	223.4300	103.7	218.8300	104.9	217.6300	106.1	216.4300	107.3	215.2300	107.9	214.6300
78	97.7	224.8600	98.5	224.0600	99.1	223.4600	103.7	218.8600	104.9	217.6600	106.1	216.4600	107.3	215.2600	107.9	214.6600
79	97.7	224.8900	98.5	224.0900	99.1	223.4900	103.7	218.8900	104.9	217.6900	106.1	216.4900	107.3	215.2900	107.9	214.6900
80	97.7	224.9200	98.5	224.1200	99.1	223.5200	103.7	218.9200	104.9	217.7200	106.1	216.5200	107.3	215.3200	107.9	214.7200
81	97.7	224.9500	98.5	224.1500	99.1	223.5500	103.7	218.9500	104.9	217.7500	106.1	216.5500	107.3	215.3500	107.9	214.7500
82	97.7	224.9800	98.5	224.1800	99.1	223.5800	103.7	218.9800	104.9	217.7800	106.1	216.5800	107.3	215.3800	107.9	214.7800
83	97.7	225.0100	98.5	224.2100	99.1	223.6100	103.7	219.0100	104.9	217.8100	106.1	216.6100	107.3	215.4100	107.9	214.8100
84	97.7	225.0400	98.5	224.2400	99.1	223.6400	103.7	219.0400	104.9	217.8400	106.1	216.6400	107.3	215.4400	107.9	214.8400
85	97.7	225.0700	98.5	224.2700	99.1	223.6700	103.7	219.0700	104.9	217.8700	106.1	216.6700	107.3	215.4700	107.9	214.8700
86	97.7	225.1000	98.5	224.3000	99.1	223.7000	103.7	219.1000	104.9	217.9000	106.1	216.7000	107.3	215.5000	107.9	214.9000
87	97.7	225.1300	98.5	224.3300	99.1	223.7300	103.7	219.1300	104.9	217.9300	106.1	216.7300	107.3	215.5300	107.9	214.9300
88	97.7	225.1600	98.5	224.3600	99.1	223.7600	103.7	219.1600	104.9	217.9600	106.1	216.7600	107.3	215.5600	107.9	214.9600
89	97.7	225.1900	98.5	224.3900	99.1	223.7900	103.7	219.1900	104.9	217.9900	106.1	216.7900	107.3	215.5900	107.9	214.9900
90	97.7	225.2200	98.5	224.4200	99.1	223.8200	103.7	219.2200	104.9	218.0200	106.1	216.8200	107.3	215.6200	107.9	215.0200
91	97.7	225.2500	98.5	224.4500	99.1	223.8500	103.7	219.2500	104.9	218.0500	106.1	216.8500	107.3	215.6500	107.9	215.0500
92	97.7	225.2800	98.5	224.4800	99.1	223.8800	103.7	219.2800	104.9	218.0800	106.1	216.8800	107.3	215.6800	107.9	215.0800
93	97.7	225.3100	98.5	224.5100	99.1	223.9100	103.7	219.3100	104.9	218.1100	106.1	216.9100	107.3	215.7100	107.9	215.1100
94	97.7	225.3400	98.5	224.5400	99.1	223.9400	103.7	219.3400	104.9	218.1400	106.1	216.9400	107.3	215.7400	107.9	215.1400
95	97.7	225.3700	98.5	224.5700	99.1	223.9700	103.7	219.3700	104.9	218.1700	106.1	216.9700	107.3	215.7700	107.9	215.1700
96	97.7	225.4000	98.5	224.6000	99.1	224.0000	103.7	219.4000	104.9	218.2000	106.1	217.0000	107.3	215.8000	107.9	215.2000
97	97.7	225.4300	98.5	224.6300	99.1	224.0300	103.7	219.4300	104.9	218.2300	106.1	217.0300	107.3	215.8300	107.9	215.2300

Transmit Intermodulation

Part 90	Current PTC 220 Spectrum Available	Requires no Regulatory Change to Acquire
Part 80	Current AMTS Spectrum under consideration for PTC use	Requires Regulatory Change to Acquire
Part 97	Current Amateur 220 Spectrum	Rail Industry may receive Interference Complaints requiring Mitigation Efforts
IRAC	US Government Agencies and Military Spectrum	Rail Industry may receive Interference Complaints requiring Mitigation Efforts
Part 73	Broadcast Television (VHF TV Channel 13)	Rail Industry may receive Interference Complaints requiring Mitigation Efforts
IRAC	SPASUR RADAR Tracks Orbital Objects and Re-Entry Debris	Rail Industry may receive Interference Complaints requiring Mitigation Efforts

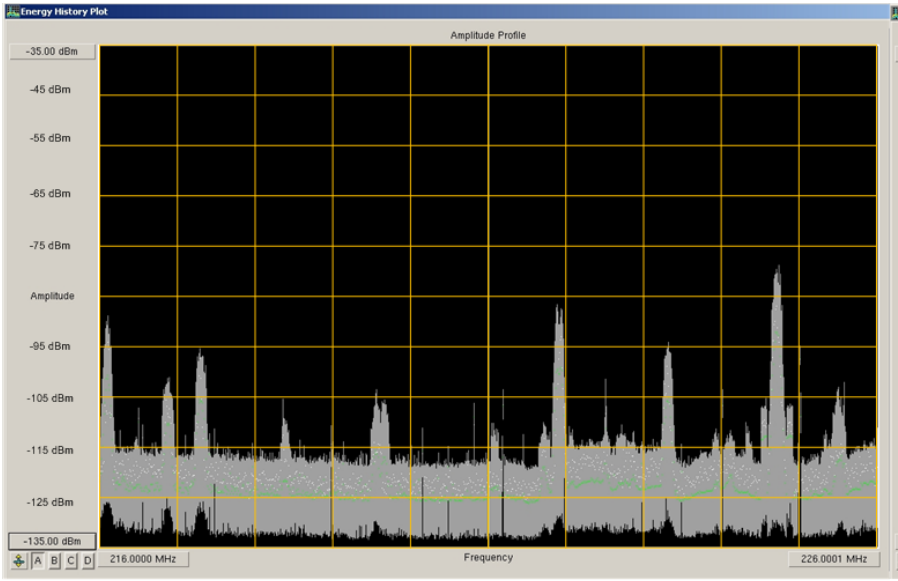
Transmit Intermodulation

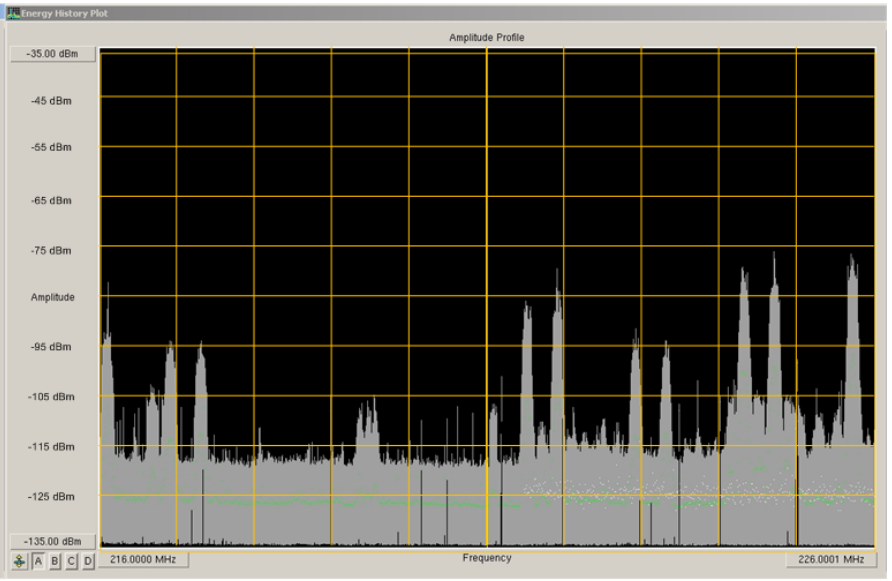
AAR Channel	Frequency	WVTF		WPAR		WXLK		WSNV		WSLC		WROV		W245BG		WVBB		W253BE		WSLQ		W279AC		WJJS		WSFF		W297BC		WYYD	
1	160.1250	89.1	231.1500	91.3	229.1300	92.3	227.9500	93.5	226.7500	94.9	225.3500	96.3	223.9500	96.9	223.3500	97.7	222.5500	98.5	221.7500	99.1	221.1500	103.7	216.5500	104.9	215.3500	106.1	214.1500	107.3	212.9500	107.9	212.3500
2	160.1400	89.1	231.1800	91.3	229.1600	92.3	227.9800	93.5	226.7800	94.9	225.3800	96.3	223.9800	96.9	223.3800	97.7	222.5800	98.5	221.7800	99.1	221.1800	103.7	216.5800	104.9	215.3800	106.1	214.1800	107.3	212.9800	107.9	212.3800
3	160.1550	89.1	231.2100	91.3	229.1900	92.3	228.0100	93.5	226.8100	94.9	225.4100	96.3	224.0100	96.9	223.4100	97.7	222.6100	98.5	221.8100	99.1	221.2100	103.7	216.6100	104.9	215.4100	106.1	214.2100	107.3	213.0100	107.9	212.4100
4	160.1700	89.1	231.2400	91.3	229.2200	92.3	228.0400	93.5	226.8400	94.9	225.4400	96.3	224.0400	96.9	223.4400	97.7	222.6400	98.5	221.8400	99.1	221.2400	103.7	216.6400	104.9	215.4400	106.1	214.2400	107.3	213.0400	107.9	212.4400
5	160.1850	89.1	231.2700	91.3	229.2500	92.3	228.0700	93.5	226.8700	94.9	225.4700	96.3	224.0700	96.9	223.4700	97.7	222.6700	98.5	221.8700	99.1	221.2700	103.7	216.6700	104.9	215.4700	106.1	214.2700	107.3	213.0700	107.9	212.4700
6	160.2000	89.1	231.3000	91.3	229.2800	92.3	228.1000	93.5	226.9000	94.9	225.5000	96.3	224.1000	96.9	223.5000	97.7	222.7000	98.5	221.9000	99.1	221.3000	103.7	216.7000	104.9	215.5000	106.1	214.3000	107.3	213.1000	107.9	212.5000
7	160.2150	89.1	231.3300	91.3	229.3100	92.3	228.1300	93.5	226.9300	94.9	225.5300	96.3	224.1300	96.9	223.5300	97.7	222.7300	98.5	221.9300	99.1	221.3300	103.7	216.7300	104.9	215.5300	106.1	214.3300	107.3	213.1300	107.9	212.5300
8	160.2300	89.1	231.3600	91.3	229.1600	92.3	228.1600	93.5	226.9600	94.9	225.5600	96.3	224.1600	96.9	223.5600	97.7	222.7600	98.5	221.9600	99.1	221.3600	103.7	216.7600	104.9	215.5600	106.1	214.3600	107.3	213.1600	107.9	212.5600
9	160.2450	89.1	231.3900	91.3	229.1900	92.3	228.1900	93.5	226.9900	94.9	225.5900	96.3	224.1900	96.9	223.5900	97.7	222.7900	98.5	221.9900	99.1	221.3900	103.7	216.7900	104.9	215.5900	106.1	214.3900	107.3	213.1900	107.9	212.5900
10	160.2600	89.1	231.4200	91.3	229.2200	92.3	228.2200	93.5	227.0200	94.9	225.6200	96.3	224.2200	96.9	223.6200	97.7	222.8200	98.5	222.0200	99.1	221.4200	103.7	216.8200	104.9	215.6200	106.1	214.4200	107.3	213.2200	107.9	212.6200
11	160.2750	89.1	231.4500	91.3	229.2500	92.3	228.2500	93.5	227.0500	94.9	225.6500	96.3	224.2500	96.9	223.6500	97.7	222.8500	98.5	222.0500	99.1	221.4500	103.7	216.8500	104.9	215.6500	106.1	214.4500	107.3	213.2500	107.9	212.6500
12	160.2900	89.1	231.4800	91.3	229.2800	92.3	228.2800	93.5	227.0800	94.9	225.6800	96.3	224.2800	96.9	223.6800	97.7	222.8800	98.5	222.0800	99.1	221.4800	103.7	216.8800	104.9	215.6800	106.1	214.4800	107.3	213.2800	107.9	212.6800
13	160.3050	89.1	231.5100	91.3	229.3100	92.3	228.3100	93.5	227.1100	94.9	225.7100	96.3	224.3100	96.9	223.7100	97.7	222.9100	98.5	222.1100	99.1	221.5100	103.7	216.9100	104.9	215.7100	106.1	214.5100	107.3	213.3100	107.9	212.7100
14	160.3200	89.1	231.5400	91.3	229.3400	92.3	228.3400	93.5	227.1400	94.9	225.7400	96.3	224.3400	96.9	223.7400	97.7	222.9400	98.5	222.1400	99.1	221.5400	103.7	216.9400	104.9	215.7400	106.1	214.5400	107.3	213.3400	107.9	212.7400
15	160.3350	89.1	231.5700	91.3	229.3700	92.3	228.3700	93.5	227.1700	94.9	225.7700	96.3	224.3700	96.9	223.7700	97.7	222.9700	98.5	222.1700	99.1	221.5700	103.7	216.9700	104.9	215.7700	106.1	214.5700	107.3	213.3700	107.9	212.7700
16	160.3500	89.1	231.6000	91.3	229.4000	92.3	228.4000	93.5	227.2000	94.9	225.8000	96.3	224.4000	96.9	223.8000	97.7	223.0000	98.5	222.2000	99.1	221.6000	103.7	217.0000	104.9	215.8000	106.1	214.6000	107.3	213.4000	107.9	212.8000
17	160.3650	89.1	231.6300	91.3	229.4300	92.3	228.4300	93.5	227.2300	94.9	225.8300	96.3	224.4300	96.9	223.8300	97.7	223.0300	98.5	222.2300	99.1	221.6300	103.7	217.0300	104.9	215.8300	106.1	214.6300	107.3	213.4300	107.9	212.8300
18	160.3800	89.1	231.6600	91.3	229.4600	92.3	228.4600	93.5	227.2600	94.9	225.8600	96.3	224.4600	96.9	223.8600	97.7	223.0600	98.5	222.2600	99.1	221.6600	103.7	217.0600	104.9	215.8600	106.1	214.6600	107.3	213.4600	107.9	212.8600
19	160.3950	89.1	231.6900	91.3	229.4900	92.3	228.4900	93.5	227.2900	94.9	225.8900	96.3	224.4900	96.9	223.8900	97.7	223.0900	98.5	222.2900	99.1	221.6900	103.7	217.0900	104.9	215.8900	106.1	214.6900	107.3	213.4900	107.9	212.8900
20	160.4100	89.1	231.7200	91.3	229.5200	92.3	228.5200	93.5	227.3200	94.9	225.9200	96.3	224.5200	96.9	223.9200	97.7	223.1200	98.5	222.3200	99.1	221.7200	103.7	217.1200	104.9	215.9200	106.1	214.7200	107.3	213.5200	107.9	212.9200
21	160.4250	89.1	231.7500	91.3	229.5500	92.3	228.5500	93.5	227.3500	94.9	225.9500	96.3	224.5500	96.9	223.9500	97.7	223.1500	98.5	222.3500	99.1	221.7500	103.7	217.1500	104.9	215.9500	106.1	214.7500	107.3	213.5500	107.9	212.9500
22	160.4400	89.1	231.7800	91.3	229.5800	92.3	228.5800	93.5	227.3800	94.9	225.9800	96.3	224.5800	96.9	223.9800	97.7	223.1800	98.5	222.3800	99.1	221.7800	103.7	217.1800	104.9	215.9800	106.1	214.7800	107.3	213.5800	107.9	212.9800
23	160.4550	89.1	231.8100	91.3	229.6100	92.3	228.6100	93.5	227.4100	94.9	226.0100	96.3	224.6100	96.9	224.0100	97.7	223.2100	98.5	222.4100	99.1	221.8100	103.7	217.2100	104.9	216.0100	106.1	214.8100	107.3	213.6100	107.9	213.0100
24	160.4700	89.1	231.8400	91.3	229.6400	92.3	228.6400	93.5	227.4400	94.9	226.0400	96.3	224.6400	96.9	224.0400	97.7	223.2400	98.5	222.4400	99.1	221.8400	103.7	217.2400	104.9	216.0400	106.1	214.8400	107.3	213.6400	107.9	213.0400
25	160.4850	89.1	231.8700	91.3	229.6700	92.3	228.6700	93.5	227.4700	94.9	226.0700	96.3	224.6700	96.9	224.0700	97.7	223.2700	98.5	222.4700	99.1	221.8700	103.7	217.2700	104.9	216.0700	106.1	214.8700	107.3	213.6700	107.9	213.0700
26	160.5000	89.1	231.9000	91.3	229.7000	92.3	228.7000	93.5	227.5000	94.9	226.1000	96.3	224.7000	96.9	224.1000	97.7	223.3000	98.5	222.5000	99.1	221.9000	103.7	217.3000	104.9	216.1000	106.1	214.9000	107.3	213.7000	107.9	213.1000
27	160.5150	89.1	231.9300	91.3	229.7300	92.3	228.7300	93.5	227.5300	94.9	226.1300	96.3	224.7300	96.9	224.1300	97.7	223.3300	98.5	222.5300	99.1	221.9300	103.7	217.3300	104.9	216.1300	106.1	214.9300	107.3	213.7300	107.9	213.1300
28	160.5300	89.1	231.9600	91.3	229.7600	92.3	228.7600	93.5	227.5600	94.9	226.1600	96.3	224.7600	96.9	224.1600	97.7	223.3600	98.5	222.5600	99.1	221.9600	103.7	217.3600	104.9	216.1600	106.1	214.9600	107.3	213.7600	107.9	213.1600
29	160.5450	89.1	231.9900	91.3	229.7900	92.3	228.7900	93.5	227.5900	94.9	226.1900	96.3	224.7900	96.9	224.1900	97.7	223.3900	98.5	222.5900	99.1	221.9900	103.7	217.3900	104.9	216.1900	106.1	214.9900	107.3	213.7900	107.9	213.1900
30	160.5600	89.1	232.0200	91.3	229.8200	92.3	228.8200	93.5	227.6200	94.9	226.2200	96.3	224.8200	96.9	224.2200	97.7	223.4200	98.5	222.6200	99.1	222.0200	103.7	217.4200	104.9	216.2200	106.1	215.0200	107.3	213.8200	107.9	213.2200
31	160.5750	89.1	232.0500	91.3	229.8500	92.3	228.8500	93.5	227.6500	94.9	226.2500	96.3	224.8500	96.9	224.2500	97.7	223.4500	98.5	222.6500	99.1	222.0500	103.7	217.4500	104.9	216.2500	106.1	215.0500	107.3	213.8500	107.9	213.2500
32	160.5900	89.1	232.0800	91.3	229.8800	92.3	228.8800	93.5	227.6800	94.9	226.2800	96.3	224.8800	96.9	224.2800	97.7	223.4800	98.5	222.6800	99.1	222.0800	103.7	217.4800	104.9	216.2800	106.1	215.0800	107.3	213.8800	107.9	213.2800
33	160.6050	89.1	232.1100	91.3	229.9100	92.3	228.9100	93.5	227.7100	94.9	226.3100	96.3	224.9100	96.9	224.3100	97.7	223.5100	98.5	222.7100	99.1	222.1100	103.7	217.5100	104.9	216.3100	106.1	215.1100	107.3	213.9100	107.9	213.3100
34	160.6200	89.1	232.1400	91.3	229.9400	92.3	228.9400	93.5	227.7400	94.9	226.3400	96.3	224.9400	96.9	224.3400	97.7	223.5400	98.5	222.7400	99.1	222.1400	103.7	217.5400	104.9	216.3400	106.1	215.1400	107.3	213.9400	107.9	213.3400
35	160.6350	89.1	232.1700	91.3	229.9700	92.3	228.9700	93.5	227.7700	94.9	226.3700	96.3	224.9700	96.9	224.3700	97.7	223.5700	98.5	222.7700	99.1	222.1700	103.7	217.5700	104.9	216.3700	106.1	215.1700	107.3	213.9700	107.9	213.3700
36	160.6500	89.1	232.2000	91.3	230.0000	92.3	229.0000	93.5	227.8000	94.9	226.4000	96.3	225.0000	96.9	224.4000	97.7	223.6000	98.5	222.8000	99.1	222.2000	103.7	217.6000	104.9	216.4000	106.1	215.2000	107.3	214.0000	107.9	213.4000
37	160.6650	89.1	232.2300	91.3	230.0300	92.3	229.0300	93.5	227.8300	94.9	226.4300	96.3	225.0300	96.9	224.4300	97.7	223.6300	98.5	222.8300	99.1	222.2300	103.7	217.6300	104.9	216.4300	106.1	215.2300	107.3	214.0300	107.9	213.4300
38	160.6800	89.1	232.2600	91.3	230.0600	92.3	229.0600	93.5	227.8600	94.9	226.4600	96.3	225.0600	96.9	224.4600	97.7	223.6600	98.5	222.8600	99.1	222.2600	103.7	217.6600	104.9	216.4600	106.1	215.2600	107.3	214.0600	107.9	213.4600
39	160.6950	89.1	232.2900	91.3	230.0900	92.3	229.0900	93.5	227.8900	94.9	226.4900	96.3	225.0900	96.9	224.4900	97.7	223.6900	98.5	222.8900	99.1	222.2900	103.7	217.6900	104.9	216.4900	106.1	215.2900	107.3	214.0900	107.9	213.4900
40	160.7100	89.1	232.3200	91.3	230.1200	92.3	229.1200	93.5	227.9200	94.9	226.5200	96.3	225.1200	96.9	224.5200	97.7	223.7200	98.5	222.9200	99.1	222.3200	103.7	217.7200	104.9	216.5200	106.1	215.3200	107.3	214.1200	107.9	213.5200
41	160.7250	89.1	232.3500	91.3	230.1500	92.3	229.1500	93.5	227.9500	94.9	226.5500	96.3	225.1500	96.9	224.5500	97.7	223.7500	98.5	222.9500	99.1	222.3500	103.7	217.7500	104.9	216.5500	106.1	215.3500	107.3	214.1500	107.9	213.5500
42	160.7400	89.1	232.3800	91.3	230.1800	92.3	229.1800	93.5	227.9800	94.9	226.5800	96.3	225.1800	96.9	224.5800	97.7	223.7800	98.5	222.9800	99.1	222.3800	103.7	217.7800	104.9	216.5800	106.1	215.3800	107.3	214.1800	107.9	213.5800
43	160.7550	89.1	232.4100	91.3	230.2100	92.3	229.2100	93.5	228.0100	94.9	226.6100	96.3	225.2100	96.9	224.6100	97.7	223.8100	98.5	223.0100	99.1	222.4100	103.7	217.8100	104.9	216.6100	106.1	215.4100	107.3	214.2100	107.9	213.6100
44	160.7700	89.1	232.4400	91.3	230.2400	92.3	229.2400	93.5	228.0400	94.9	226.6400	96.3	225.2400	96.9	224.6400	97.7	223.8400	98.5	223.0400	99.1	222.4400	103.7	217.8400	104.9	216.6400	106.1	215.4400	107.3	214.2400	107.9	213.6400
45	160.7850	89.1	232.4700	91.3	230.2700	92.3	229.2700	93.5	228.0700	94.9	226.6700	96.3	225.2700	96.9	224.6700	97.7	223.8700	98.5	223.0700	99.1	222.4700	103.7	217.8700	104.9	216.6700	106.1	215.4700	107.3	214.2700	107.9	213.6700
46	160.8000	89.1	232.5000	91.3	230.3000	92.3	229.3000	93.5	228.1000	94.9	226.7000	96.3	225.3000	96.9	224.7000	97.7	223.9000	98.5	223.1000	99.1	222.5000	103.7	217.9000	104.9	216.7000	106.1	215.5000	107.3	214.3000	107.9	213.7000
47	160.8150	89.1	232.5300	91.3	230.3300	92.3	229.3300	93.5	228.1300	94.9	226.7300	96.3	225.3300	96.9	224.7300	97.7	223.9300	98.5	223.1300	99.1	222.5300	103.7	217.9300	104.9	216.7300	106.1	215.5300	107.3	214.3300	107.9	213.7300
48	160.8300	89.1	232.5600	91.3	230.3600	92.3	229.3600	93.5	228.1600	94.9	226.7600	96.3	225.3600	96.9	224.7600	97.7	223.9600	98.5	223.1600	99.1	222.5600	103.7	217.9600	104.9	216.7600	106.1	215.5600	107.3	214.3600	107.9	213.7600
49	160.8450	89.1	232.5900	91.3	230.3900	92.3	229.3900	93.5	228.1900	94.9	226.7900	96.3	225.3900	96.9	224.7900	97.7	223.9900	98.5	223.1900	99.1	222.5900	103.7	217.9900	104.9	216.7900	106.1	215.5900	107.3	214.3900	107.9	213.7900
50	160.8600	89.1	232.6200	91.3	230.4200	92.3	229.4200	93.5	228.2200	94.9	226.8200	96.3	225.4200	96.9	224.8200	97.7	224.0200	98.5	223.2200	99.1	222.6200	103.7	218.0200	104.9	216.8200	106.1	215.6200	107.3	214.4200	107.9	213.8200
51	160.8750	89.1	232.6500	91.3	230.4500	92.3	229.4500	93.5	228.2500	94.9	226.8500	96.3	225.4500	96.9	224.8500	97.7	224.0500	98.5	223.2500	99.1	222.6500	103.7	218.0500	104.9	216.8500	106.1	215.6500	107.3	214.4500	107.9	213.8500
52	160.8900	89.1	232.6800	91.3	230.4800	92.3	229.4800	93.5	228.2800	94.9	226.8800	96.3	225.4800	96.9	224.8800	97.7	224.0800	98.5	223.2800	99.1	222.6800	103.7	218.0800	104.9	216.8800	106.1	215.6800	107.3	214.4800	107.9	213.8800
53	160.9050	89.1	232.7100	91.3	230.5100	92.3	229.5100	93.5	228.3100	94.9	226.9100	96.3	225.5100	96.9	224.9100	97.7	224.1100	98.5	223.3100	99.1	222.7100	103.7	218.1100	104.9	216.9100	106.1	215.7100	107.3	214.5100	107.9	213.9100
54	160.9200	89.1	232.7400	91.3	230.5400	92.3	229.5400	93.5	228.3400	94.9	226.9400	96.3	225.5400	96.9	224.9400	97.7	224.1400	98.5	223.3400	99.1	222.7400	103.7	218.1400	104.9	216.9400	106.1	215.7400	107.3	214.5400	107.9	213.9400
55	160.9350	89.1	232.7700	91.3	230.5700	92.3	229.5700	93.5	228.3700	94.9	226.9700	96.3	225.5700	96.9	224.9700	97.7	224.1700	98.5	223.3700	99.1	222.7700	103.7	218.1700	104.9	216.9700	106.1	215.7700	107.3	214.5700	107.9	213.9700
56	160.9500	89.1	232.8000	91.3	230.6000	92.3	229.6000	93.5	228.4000	94.9	227.0000	96.3	225.6000	96.9	225.0000	97.7	224.2000	98.5	223.4000	99.1	222.8000	103.7	218.2000	104.9	217.0000	106.1	215.8000	107.3	214.6000	107.9	214.0000
57	160.9650	89.1	232.8300	91.3	230.6300	92.3	229.6300	93.5	228.4300	94.9	227.0300	96.3	225.6300	96.9	225.0300	97.7	224.2300	98.5	223.4300	99.1	222.8300	103.7	218.2300	104.9	217.0300	106.1	215.8300	107.3	214.6300	107.9	214.0300
58	160.9800	89.1	232.8600	91.3	230.6600	92.3	229.6600	93.5	228.4600	94.9	227.0600	96.3	225.6600	96.9	225.0600	97.7	224.2600	98.5	223.4600	99.1	222.8600	103.7	218.2600	104.9	217.0600	106.1	215.8600	107.3	214.6600	107.9	214.0600
59	160.9950	89.1	232.8900	91.3	230.6900	92.3	229.6900	93.5	228.4900	94.9	227.0900	96.3	225.6900	96.9	225.0900	97.7	224.2900	98.5	223.4900	99.1	222.8900	103.7	218.2900	104.9	217.0900	106.1	215.8900	107.3	214.6900	107.9	214.0900
60	161.0100	89.1	232.9200	91.3	230.7200	92.3	229.7200	93.5	228.5200	94.9	227.1200	96.3	225.7200	96.9	225.1200	97.7	224.3200	98.5	223.5200	99.1	222.9200	103.7	218.3200	104.9	217.1200	106.1	215.9200	107.3	214.7200	107.9	214.1200
61	161.0250	89.1	232.9500	91.3	230.7500	92.3	229.7500	93.5	228.5500	94.9	227.1500	96.3	225.7500	96.9	225.1500	97.7	224.3500	98.5	223.5500	99.1	222.9500	103.7	218.3500	104.9	217.1500	106.1	215.9500	107.3	214.7500	107.9	214.1500
62	161.0400	89.1	232.9800	91.3	230.7800	92.3	229.7800	93.5	228.5800	94.9	227.1800	96.3	225.7800	96.9	225.1800	97.7	224.3800	98.5	223.5800	99.1	222.9800	103.7	218.3800	104.9	217.1800	106.1	215.9800	107.3	214.7800	107.9	214.1800
63	161.0550	89.1	233.0100	91.3	230.8100	92.3	229.8100	93.5	228.6100	94.9	227.2100	96.3	225.8100	96.9	225.2100	97.7	224.4100	98.5	223.6100	99.1	223.0100	103.7	218.4100	104.9	217.2100	106.1	216.0100	107.3	214.8100	107.9	214.2100
64	161.0700	89.1	233.0400	91.3	230.8400	92.3	229.8400	93.5	228.6400	94.9	227.2400	96.3	225.8400	96.9	225.2400	97.7	224.4400	98.5	223.6400	99.1	223.0400	103.7	218.4400	104.9	217.2400	106.1	216.0400	107.3	214.8400	107.9	214.2400
65	161.0850	89.1	233.0700	91.3	230.8700	92.3	229.8700	93.5	228.6700	94.9	227.2700	96.3	225.8700	96.9	225.2700	97.7	224.4700	98.5	223.6700	99.1	223.0700	103.7	218.4700	104.9	217.2700	106.1	216.0700	107.3	214.8700	107.9	214.2700
66	161.1000	89.1	233.1000	91.3	230.9000	92.3	229.9000	93.5	228.7000	94.9	227.3000	96.3	225.9000	96.9	225.3000	97.7	224.5000	98.5	223.7000	99.1	223.1000	103.7	218.5000	104.9	217.3000	106.1	216.1000	107.3	214.9000	107.9	214.3000
67	161.1150	89.1	233.1300	91.3	230.9300	92.3	229.9300	93.5	228.7300	94.9	227.3300	96.3	225.9300	96.9	225.3300	97.7	224.5300	98.5	223.7300	99.1	223.1300	103.7	218.5300	104.9	217.3300	106.1	216.1300	107.3	214.9300	107.9	214.3300
68	161.1300	89.1	233.1600	91.3	230.9600	92.3	229.9600	93.5	228.7600	94.9	227.3600	96.3	225.9600	96.9	225.3600	97.7	224.5600	98.5	223.7600	99.1	223.1600	103.7	218.5600	104.9	217.3600	106.1	216.1600	107.3	214.9600	107.9	214.3600
69	161.1450	89.1	233.1900	91.3	230.9900	92.3	229.9900	93.5	228.7900	94.9	227.3900	96.3	225.9900	96.9	225.3900	97.7	224.5900	98.5	223.7900	99.1	223.1900	103.7	218.5900	104.9	217.3900	106.1	216.1900	107.3	214.9900	107.9	214.3900
70	161.1600	89.1	233.2200	91.3	231.0200	92.3	230.0200	93.5	228.8200	94.9	227.4200	96.3	226.0200	96.9	225.4200	97.7	224.6200	98.5	223.8200	99.1	223.2200	103.7	218.6200	104.9	217.4200	106.1	216.2200	107.3	215.0200	107.9	214.4200
71	161.1750	89.1	233.2500	91.3	231.0500	92.3	230.0500	93.5	228.8500	94.9	227.4500	96.3	226.0500	96.9	225.4500	97.7	224.6500	98.5	223.8500	99.1	223.2500	103.7	218.6500	104.9	217.4500	106.1	216.2500	107.3	215.0500	107.9	214.4500
72	161.1900	89.1	233.2800	91.3	231.0800	92.3	230.0800	93.5	228.8800	94.9	227.4800	96.3	226.0800	96.9	225.4800	97.7	224.6800	98.5	223.8800	99.1	223.2800	103.7	218.6800	104.9	217.4800	106.1	216.2800	107.3	215.0800	107.9	214.4800
73	161.2050	89.1	233.3100	91.3	231.1100	92.3	230.1100	93.5	228.9100	94.9	227.5100	96.3	226.1100	96.9	225.5100	97.7	224.7100	98.5	223.9100	99.1	223.3100	103.7	218.7100	104.9	217.5100	106.1	216.3100	107.3	215.1100	107.9	214.5100
74	161.2200	89.1	233.3400	91.3	231.1400	92.3	230.1400	93.5	228.9400	94.9	227.5400	96.3	226.1400	96.9	225.5400	97.7	224.7400	98.5	223.9400	99.1	223.3400	103.7	218.7400	104.9	217.5400	106.1	216.3400	107.3	215.1400	107.9	214.5400
75	161.2350	89.1	233.3700	91.3	231.1700	92.3	230.1700	93.5	228.9700	94.9	227.5700	96.3	226.1700	96.9	225.5700	97.7	224.7700	98.5	223.9700	99.1	223.3700	103.7	218.7700	104.9	217.5700	106.1	216.3700	107.3	215.1700	107.9	214.5700
76	161.2500	89.1	233.4000	91.3	231.2000	92.3	230.2000	93.5	229.0000	94.9	227.6000	96.3	226.2000	96.9	225.6000	97.7	224.8000	98.5	224.0000	99.1	223.4000	103.7	218.8000	104.9	217.6000	106.1	216.4000	107.3	215.2000	107.9	214.6000
77	161.2650	89.1	233.4300	91.3	231.2300	92.3	230.2300	93.5	229.0300	94.9	227.6300	96.3	226.2300	96.9	225.6300	97.7	224.8300	98.5	224.0300	99.1	223.4300	103.7	218.8300	104.9	217.6300	106.1	216.4300	107.3	215.2300	107.9	214.6300
78	161.2800	89.1	233.4600	91.3	231.2600	92.3	230.2600	93.5	229.0600	94.9	227.6600	96.3	226.2600	96.9	225.6600	97.7	224.8600	98.5	224.0600	99.1	223.4600	103.7	218.8600	104.9	217.6600	106.1	216.4600	107.3	215.2600	107.9	214.6600
79	161.2950	89.1	233.4900	91.3	231.2900	92.3	230.2900	93.5	229.0900	94.9	227.6900	96.3	226.2900	96.9	225.6900	97.7	224.8900	98.5	224.0900	99.1	223.4900	103.7	218.8900	104.9	217.6900	106.1	216.4900	107.3	215.2900	107.9	214.6900
80	161.3100	89.1	233.5200	91.3	231.3200	92.3	230.3200	93.5	229.1200	94.9	227.7200	96.3	226.3200	96.9	225.7200	97.7	224.9200	98.5	224.1200	99.1	223.5200	103.7	218.9200	104.9	217.7200	106.1	216.5200	107.3	215.3200	107.9	214.7200
81	161.3250	89.1	233.5500	91.3	231.3500	92.3	230.3500	93.5	229.1500	94.9	227.7500	96.3	226.3500	96.9	225.7500	97.7	224.9500	98.5	224.1500	99.1	223.5500	103.7	218.9500	104.9	217.7500	106.1	216.5500	107.3	215.3500	107.9	214.7500
82	161.3400	89.1	233.5800	91.3	231.3800	92.3	230.3800	93.5	229.1800	94.9	227.7800	96.3	226.3800	96.9	225.7800	97.7	224.9800	98.5	224.1800	99.1	223.5800	103.7	218.9800	104.9	217.7800	106.1	216.5800	107.3	215.3800	107.9	214.7800
83	161.3550	89.1	233.6100	91.3	231.4100	92.3	230.4100	93.5	229.2100	94.9	227.8100	96.3	226.4100	96.9	225.8100	97.7	225.0100	98.5	224.2100	99.1	223.6100	103.7	219.0100	104.9	217.8100	106.1	216.6100	107.3	215.4100	107.9	214.8100
84	161.3700	89.1	233.6400	91.3	231.4400	92.3	230.4400	93.5	229.2400	94.9	227.8400	96.3	226.4400	96.9	225.8400	97.7	225.0400	98.5	224.2400	99.1	223.6400	103.7	219.0400	104.9	217.8400	106.1	216.6400	107.3	215.4400	107.9	214.8400
85	161.3850	89.1	233.6700	91.3	231.4700	92.3	230.4700	93.5	229.2700	94.9	227.8700	96.3	226.4700	96.9	225.8700	97.7	225.0700	98.5	224.2700	99.1	223.6700	103.7	219.0700	104.9	217.8700	106.1	216.6700	107.3	215.4700	107.9	214.8700
86	161.4000	89.1	233.7000	91.3	231.5000	92.3	230.5000	93.5	229.3000	94.9	227.9000	96.3	226.5000	96.9	225.9000	97.7	225.1000	98.5	224.3000	99.1	223.7000	103.7	219.1000	104.9	217.9000	106.1	216.7000	107.3	215.5000	107.9	214.9000
87	161.4150	89.1	233.7300	91.3	231.5300	92.3	230.5300	93.5	229.3300	94.9	227.9300	96.3	226.5300	96.9	225.9300	97.7	225.1300	98.5	224.3300	99.1	223.7300	103.7	219.1300	104.9	217.9300	106.1	216.7300	107.3	215.5300	107.9	214.9300
88	161.4300	89.1	233.7600	91.3	231.5600	92.3	230.5600	93.5	229.3600	94.9	227.9600	96.3	226.5600	96.9	225.9600	97.7	225.1600	98.5	224.3600	99.1	223.7600	103.7	219.1600	104.9	217.9600	106.1	216.7600	107.3	215.5600	107.9	214.9600
89	161.4450	89.1	233.7900	91.3	231.5900	92.3	230.5900	93.5	229.3900	94.9	227.9900	96.3	226.5900	96.9	225.9900	97.7	225.1900	98.5	224.3900	99.1	223.7900	103.7	219.1900	104.9	217.9900	106.1	216.7900	107.3	215.5900	107.9	214.9900
90	161.4600	89.1	233.8200	91.3	231.6200	92.3	230.6200	93.5	229.4200	94.9	228.0200	96.3	226.6200	96.9	226.0200	97.7	225.2200	98.5	224.4200	99.1	223.8200	103.7	219.2200	104.9	218.0200	106.1	216.8200	107.3	215.6200	107.9	215.0200
91	161.4750	89.1	233.8500	91.3	231.6500	92.3	230.6500	93.5	229.4500	94.9	228.0500	96.3	226.6500	96.9	226.0500	97.7	225.2500	98.5	224.4500	99.1	223.8500	103.7	219.2500	104.9	218.0500	106.1	216.8500	107.3	215.6500	107.9	215.0500
92	161.4900	89.1	233.8800	91.3	231.6800	92.3	230.6800	93.5	229.4800	94.9	228.0800	96.3	226.6800	96.9	226.0800	97.7	225.2800	98.5	224.4800	99.1	223.8800	103.7	219.2800	104.9	218.0800	106.1	216.8800	107.3	215.6800	107.9	215.0800
93	161.5050	89.1	233.9100	91.3	231.7100	92.3	230.7100	93.5	229.5100	94.9	228.1100	96.3	226.7100	96.9	226.1100	97.7	225.3100	98.5	224.5100	99.1	223.9100	103.7	219.3100	104.9	218.1100	106.1	216.9100	107.3	215.7100	107.9	215.1100
94	161.5200	89.1	233.9400	91.3	231.7400	92.3	230.7400	93.5	229.5400	94.9	228.1400	96.3	226.7400	96.9	226.1400	97.7	225.3400	98.5	224.5400	99.1	223.9400	103.7	219.3400	104.9	218.1400	106.1	216.9400	107.3	215.7400	107.9	215.1400
95	161.5350	89.1	233.9700	91.3	231.7700	92.3	230.7700	93.5	229.5700	94.9	228.1700	96.3	226.7700	96.9	226.1700	97.7	225.3700	98.5	224.5700	99.1	223.9700	103.7	219.3700	104.9	218.1700	106.1	216.9700	107.3	215.7700	107.9	215.1700
96	161.5500	89.1	234.0000	91.3	231.8000	92.3	230.8000	93.5	229.6000	94.9	228.2000	96.3	226.8000	96.9	226.2000	97.7	225.4000	98.5	224.6000	99.1	224.0000	103.7	219.4000	104.9	218.2000	106.1	217.0000	107.3	215.8000	107.9	215.2000
97	161.5650	89.1	234.0300	91.3	231.8300	92.3	230.8300	93.5	229.6300	94.9	228.2300	96.3	226.8300	96.9	226.2300	97.7	225.4300	98.5	224.6300	99.1	224.0300	103.7	219.4300	104.9	218.2300	106.1	217.0300	107.3	215.8300	107.9	215.2300

Transmit Intermodulation

One AAR Voice Channel Transmitting produces multiple signals of significant Amplitude in the 220 MHz spectrum

Two AAR Voice Channels Transmitting produces twice as many signals of significant Amplitude in the 220 MHz spectrum

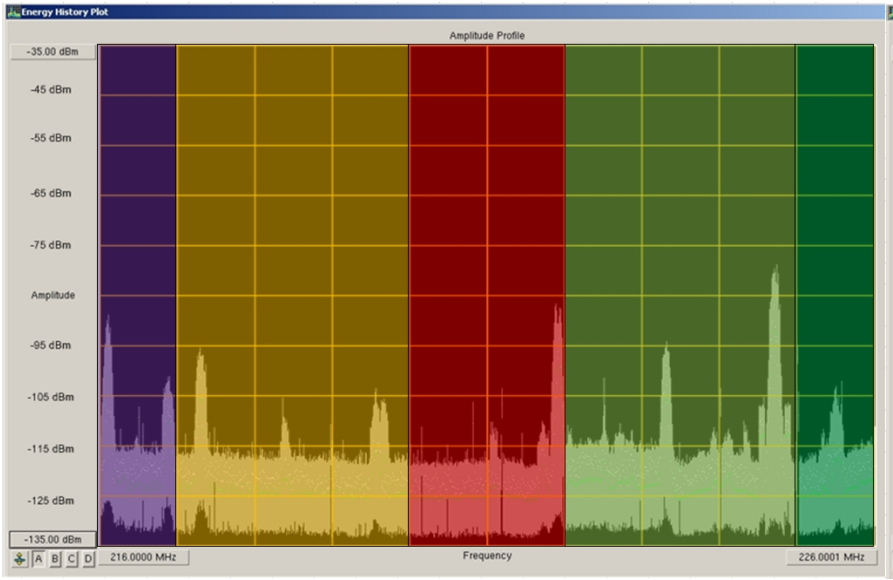


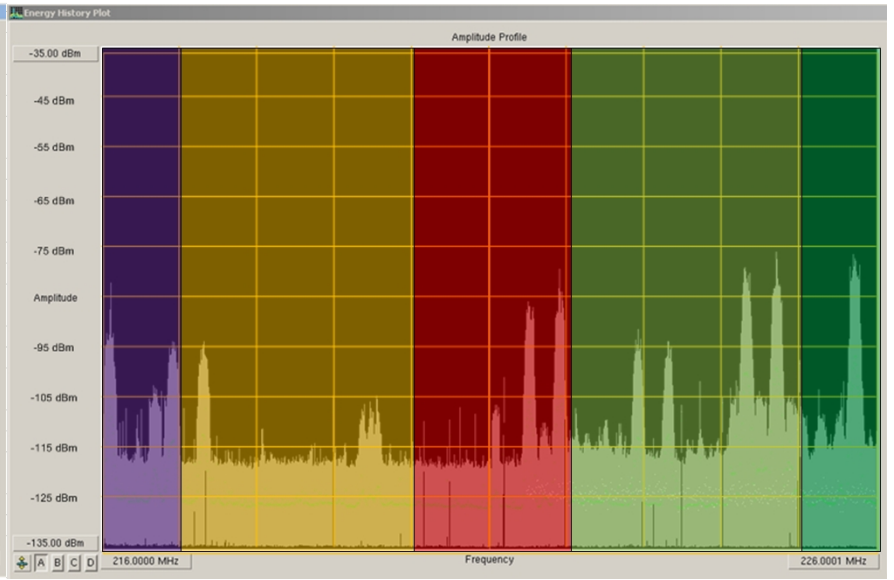


Transmit Intermodulation

One AAR Voice Channel Transmitting produces multiple signals of significant Amplitude in the 220 MHz spectrum

Two AAR Voice Channels Transmitting produces twice as many signals of significant Amplitude in the 220 MHz spectrum





Transmit Intermodulation

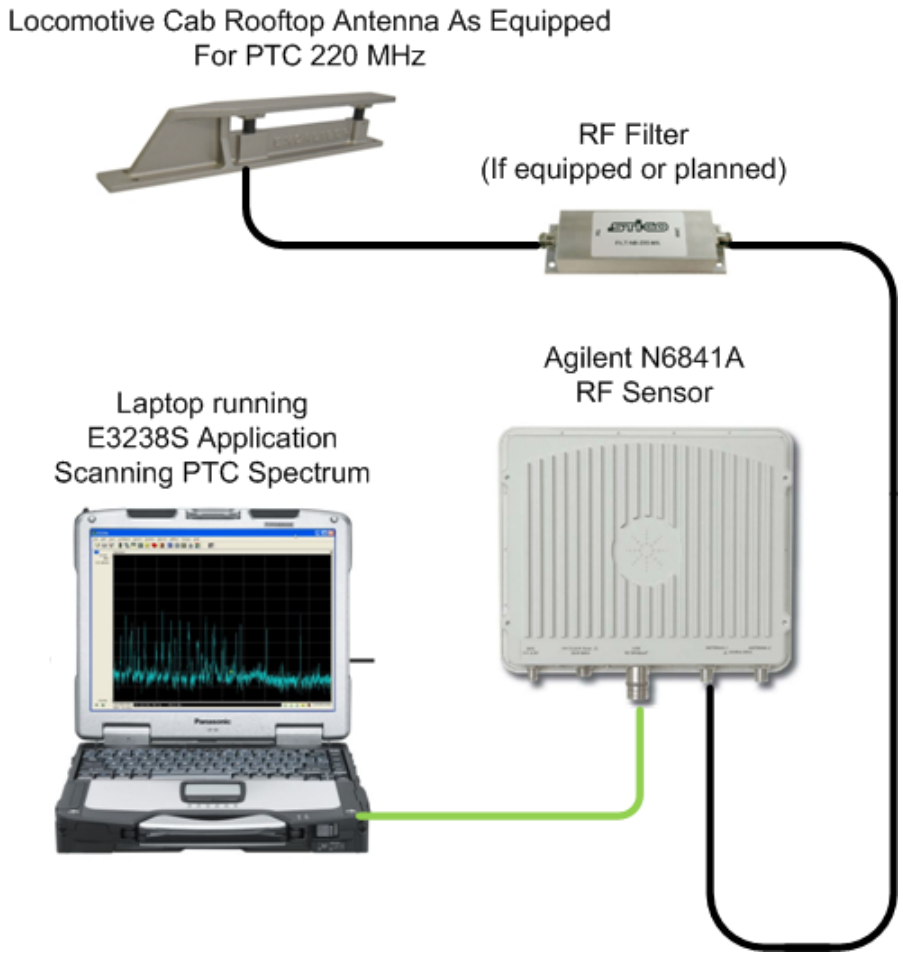
Possible Mitigation

- Filter all VHF Base Stations, Control Stations, Repeaters, and Mobiles for FM Broadcast Rejection—may not stop very strong FM Broadcast Signals ingressing through points other than the Antenna Port
- May require additional mitigation on Radio RF Deck cases (such as finger-stock or braid)—requires subject matter expertise and possibly expensive
- Filtering of Portables is physically unwieldy, and subject to frequent damage—mitigation may require Operational Changes
- Coordinate PTC 220 channels with AAR VHF Voice Channels against existing proximal FM Broadcasters—difficult in Congested Areas—and does not address Interference to other Radio Services
- Deploy PTC 220 Base Stations in Yards—may require WSRS for Waysides outside of the yard to Mitigate Blocking—and does not address Interference to other Radio Services

Electro-Mechanical EMI

- Purpose of this Test
  - Spectrum of Interest 220 MHz
  - Characterize any Electromagnetic Energy Generated by On-Platform Locomotive Electro-Mechanical Equipment
  - Twelve Locomotive Operational States Tested
    - Engine Off, Startup Sequence, Idle, Static Load Notches 1 through 8, Shutdown Sequence
  - Domains Quantified
    - Frequency
    - Amplitude
    - Duration
    - Bandwidth

Electro-Mechanical EMI

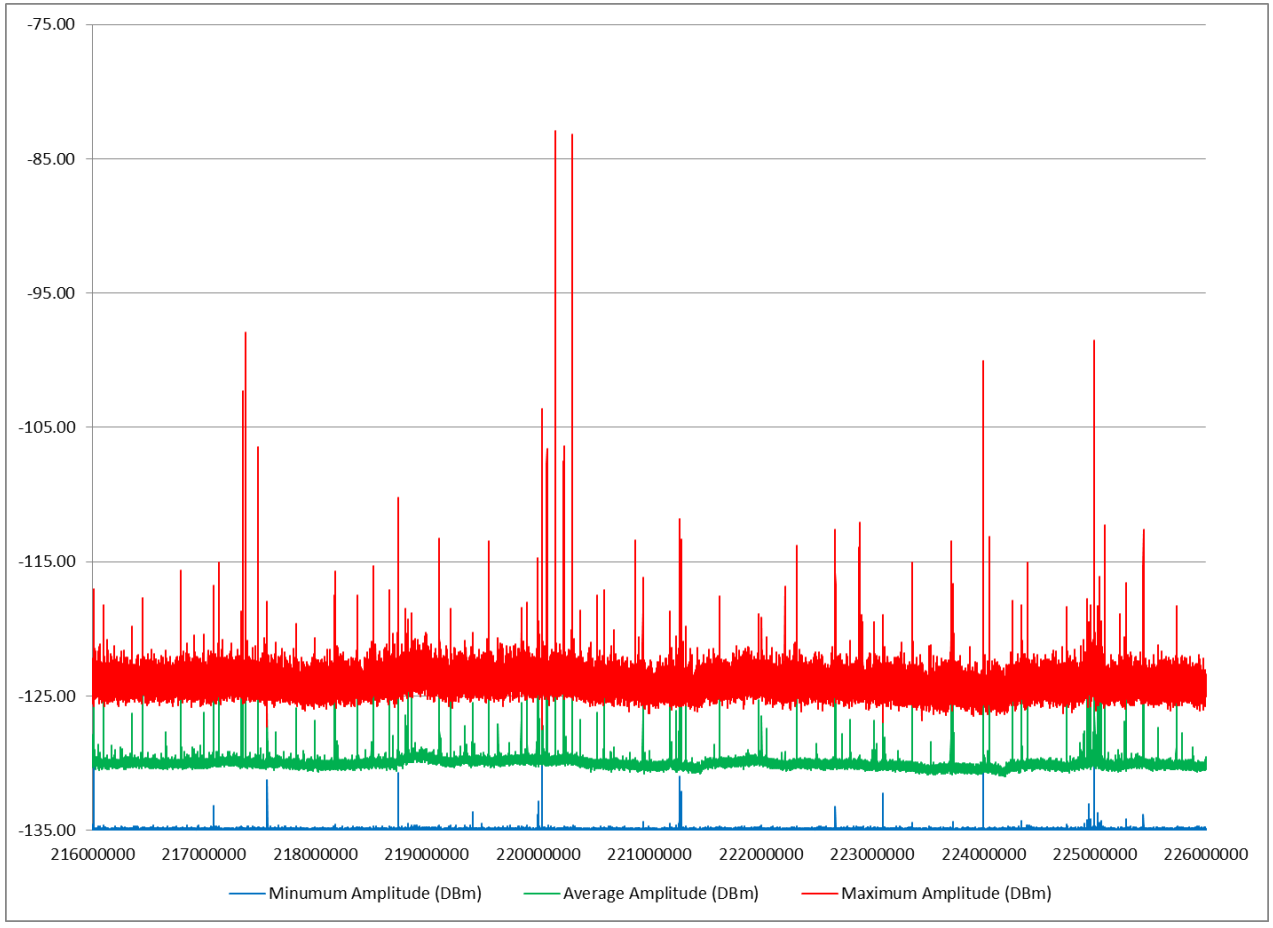


Electro-Mechanical EMI

	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%

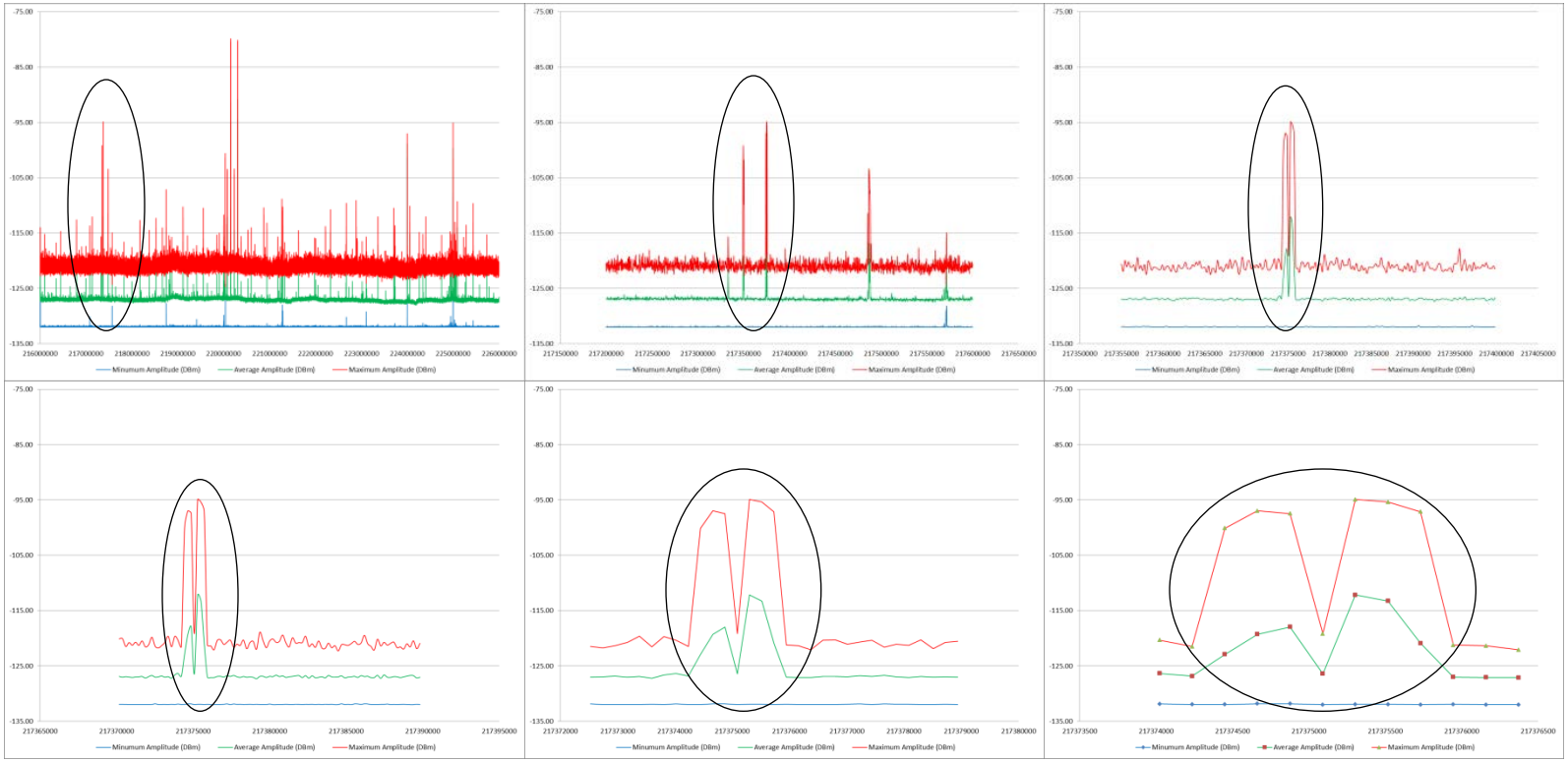
Electro-Mechanical EMI

Sample Amplitude Profile Chart



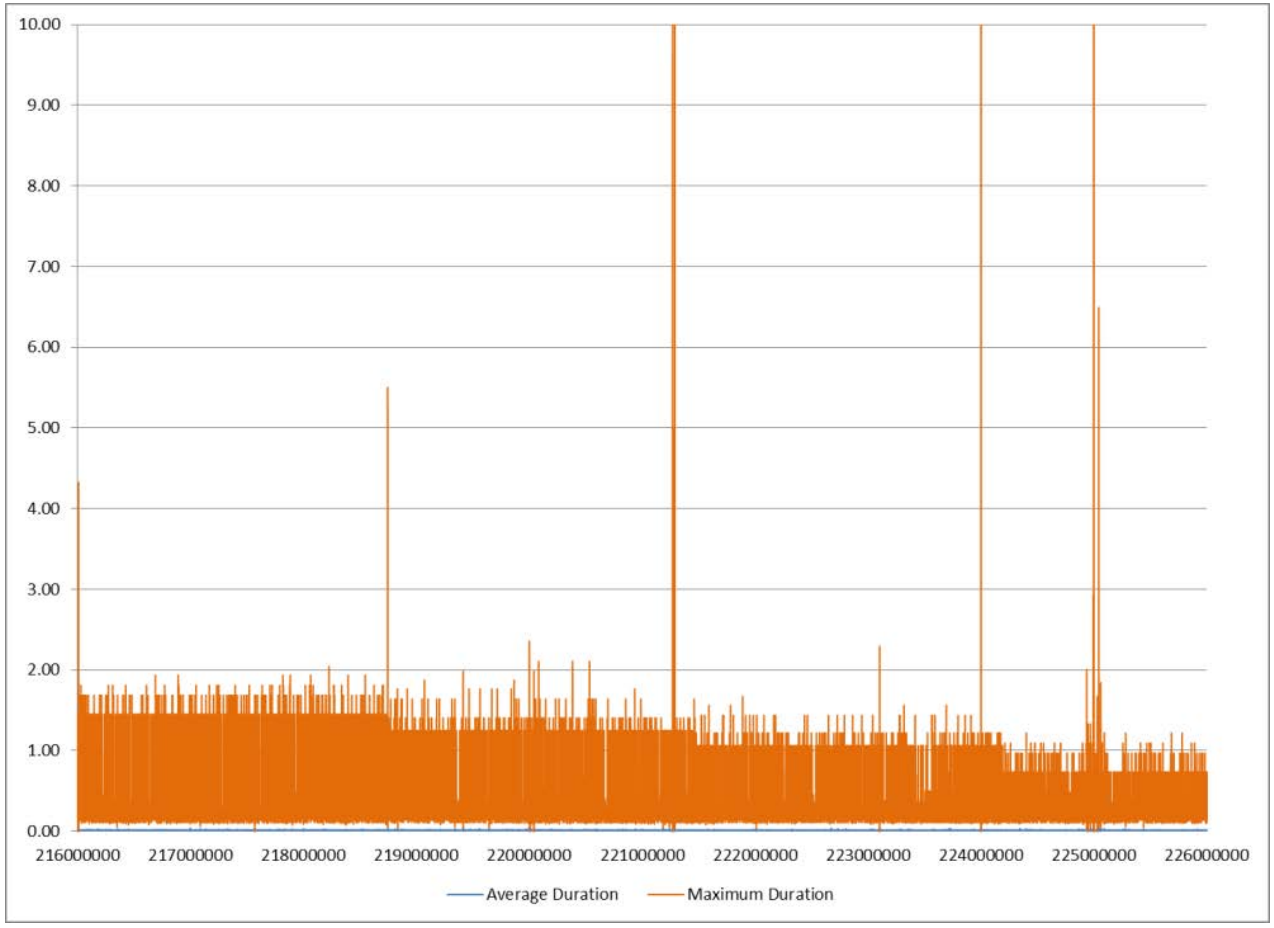
Electro-Mechanical EMI

Interpreting the Data Chart



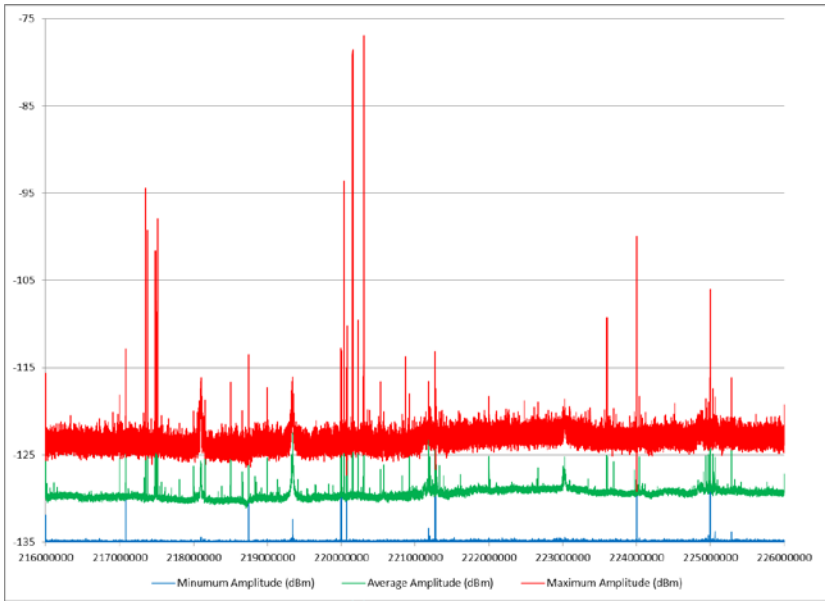
Electro-Mechanical EMI

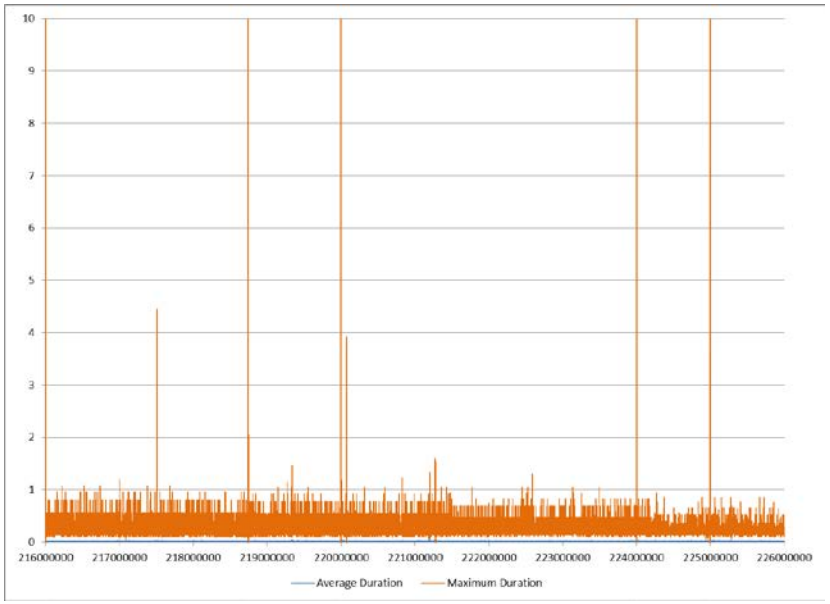
Sample Duration Profile Chart



Electro-Mechanical EMI

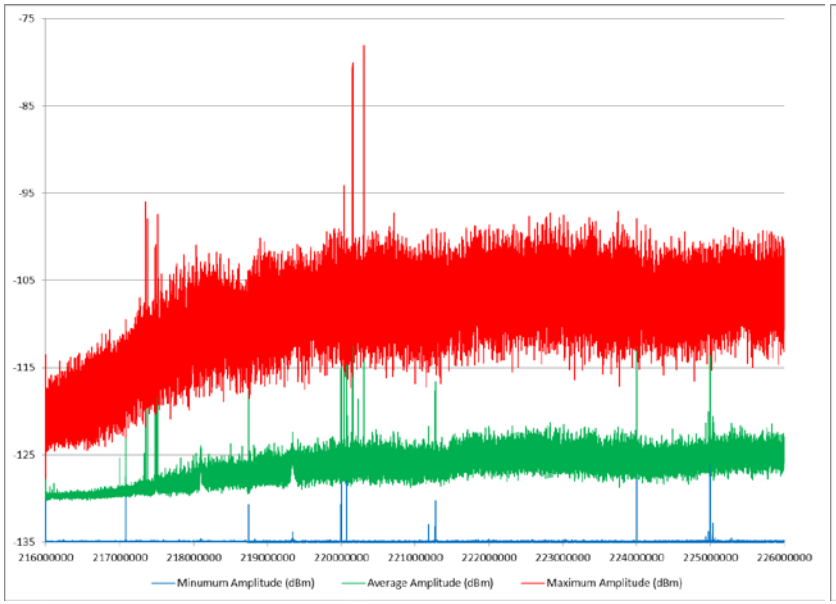
Locomotive Operational State – Engine Off

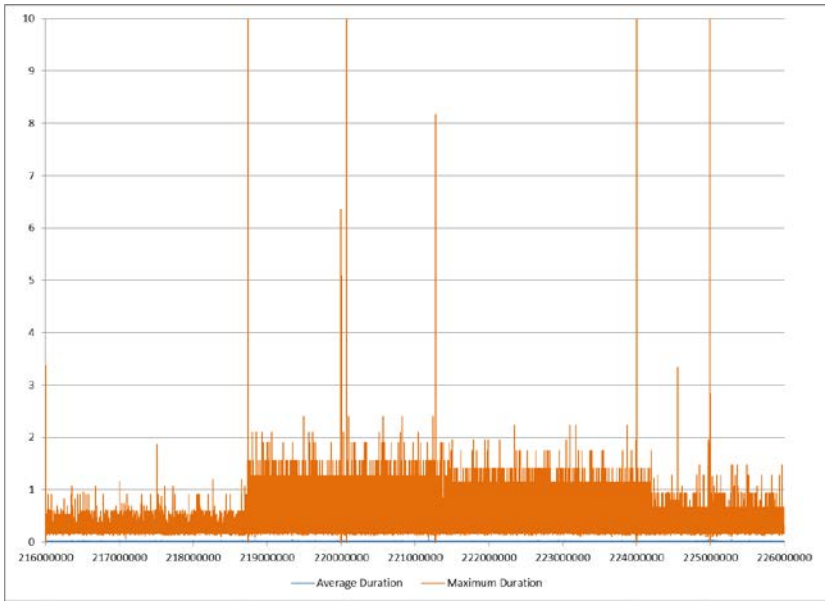




Electro-Mechanical EMI

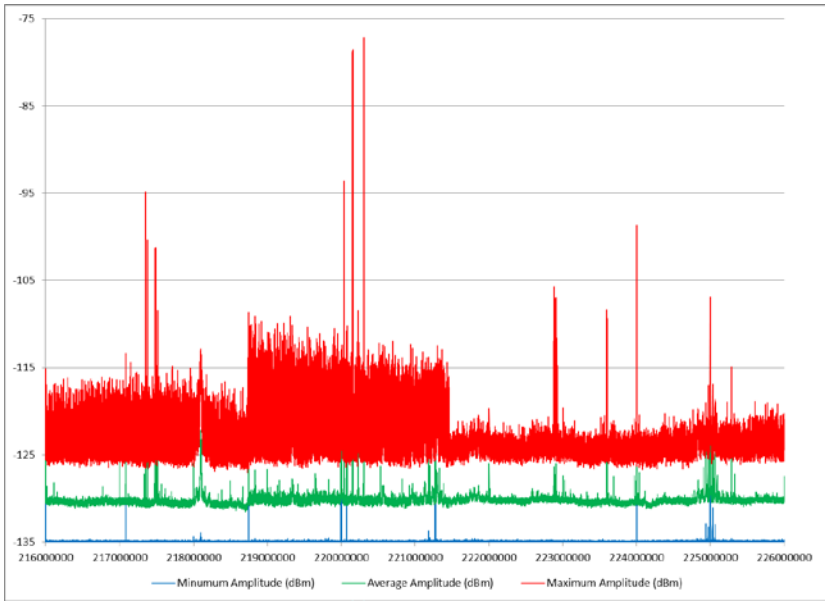
Locomotive Operational State – Startup Sequence

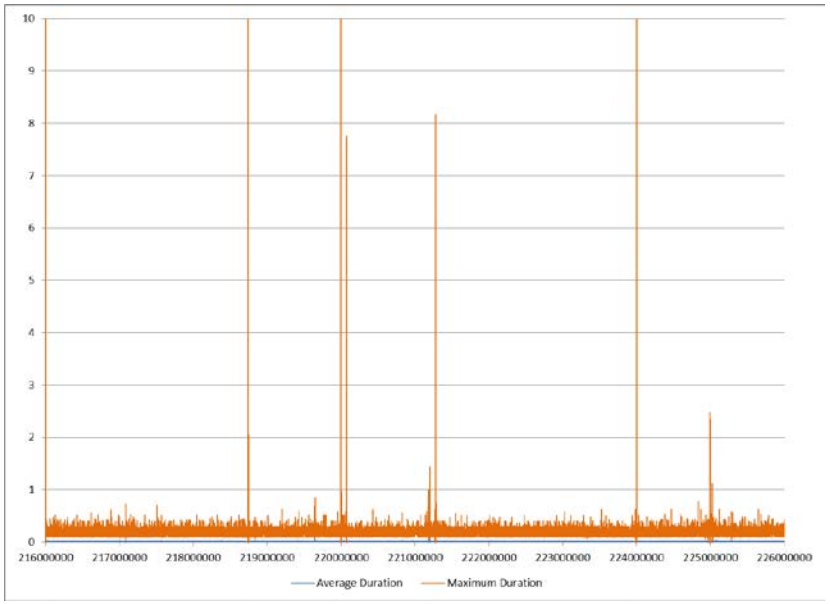




Electro-Mechanical EMI

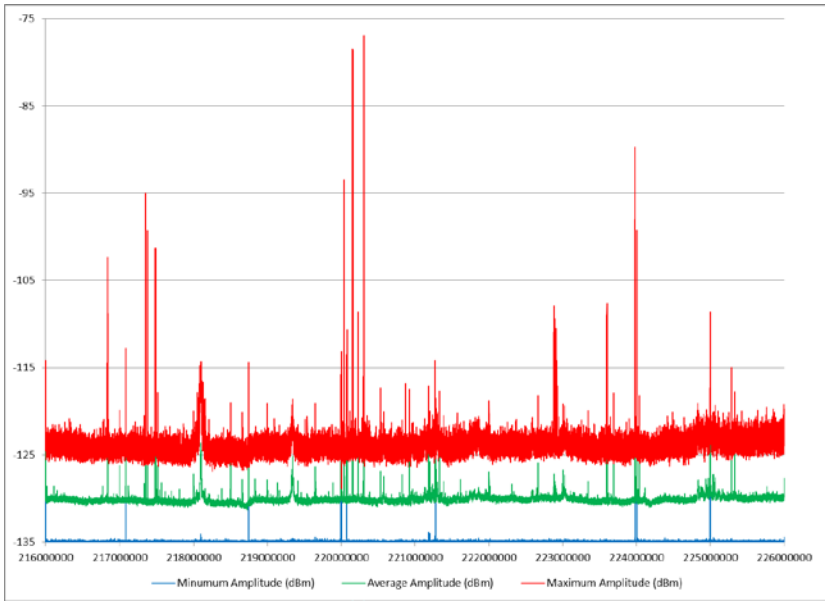
Locomotive Operational State – Idle

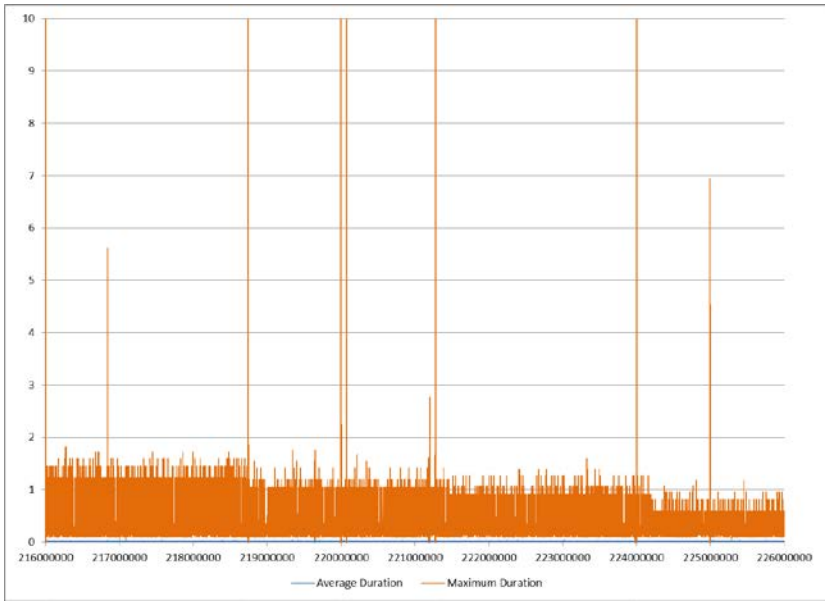




Electro-Mechanical EMI

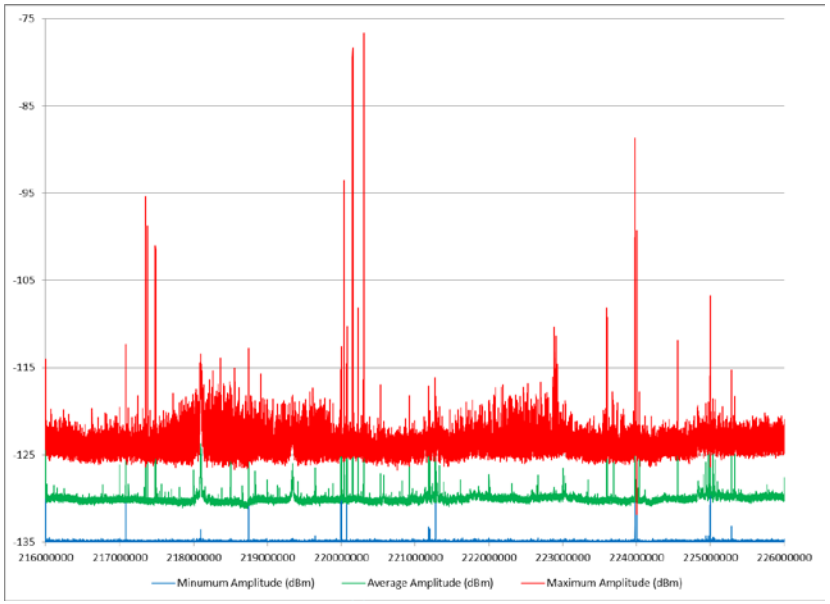
Locomotive Operational State – Notch 1

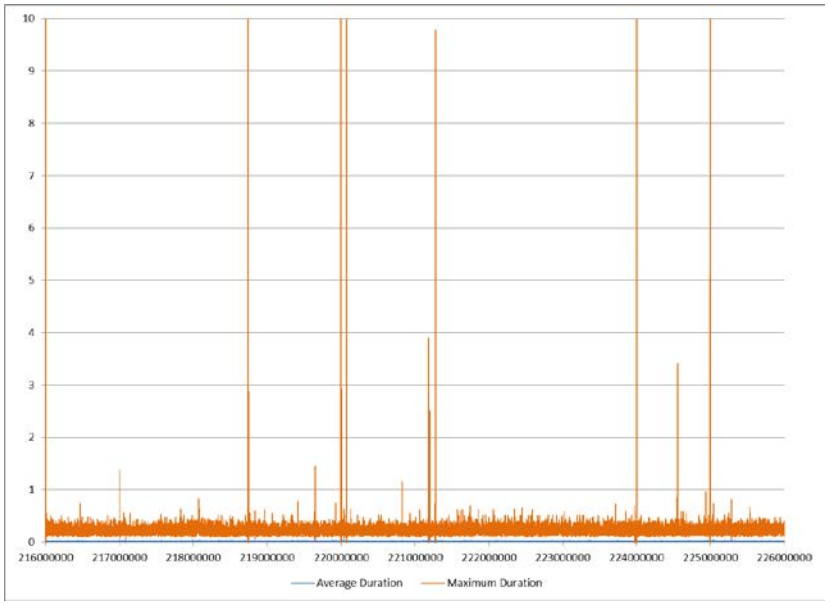




Electro-Mechanical EMI

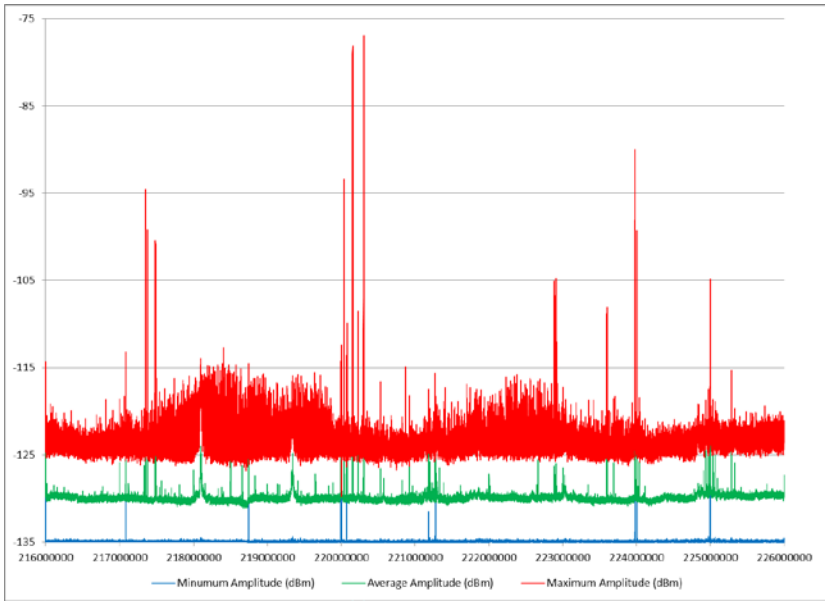
Locomotive Operational State – Notch 2

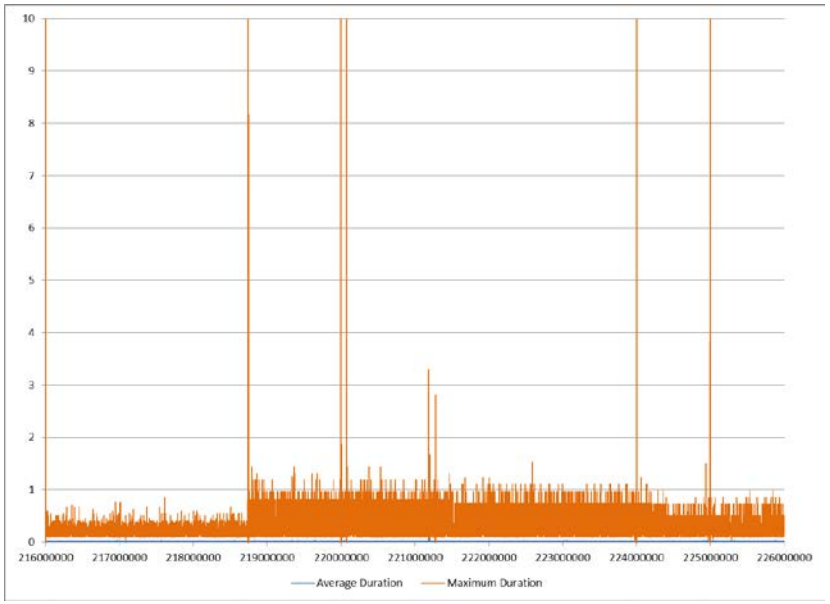




Electro-Mechanical EMI

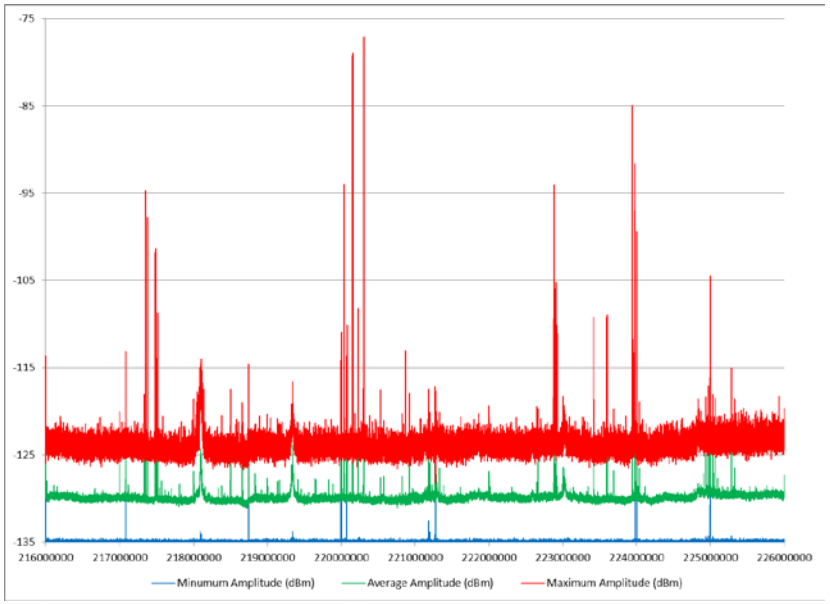
Locomotive Operational State – Notch 3

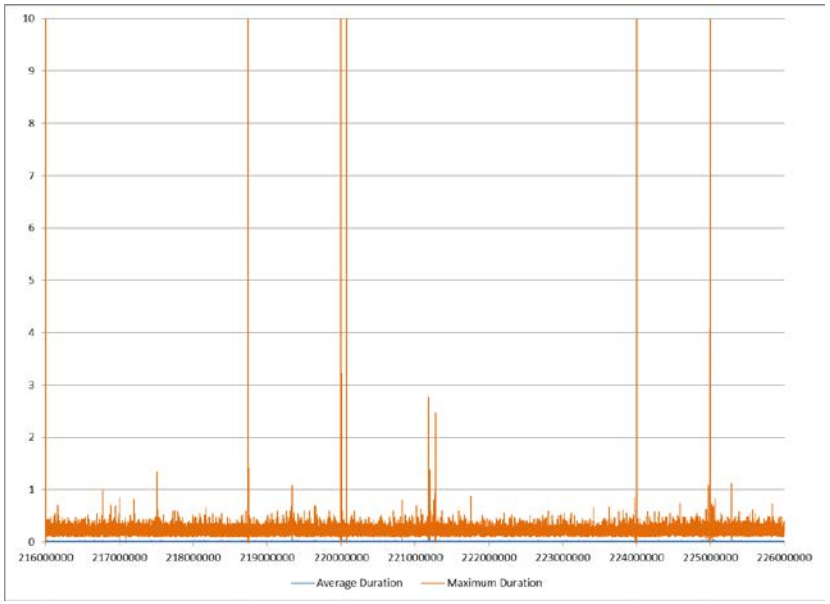




Electro-Mechanical EMI

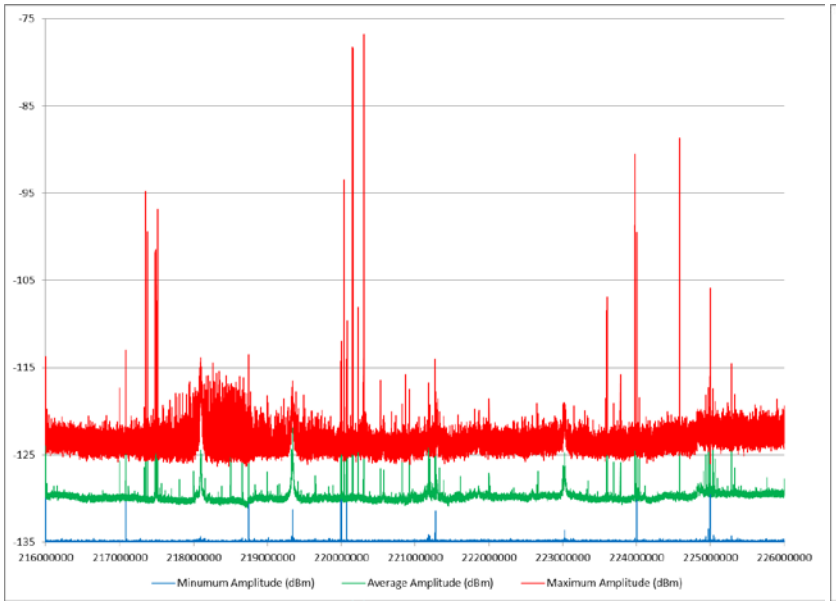
Locomotive Operational State – Notch 4

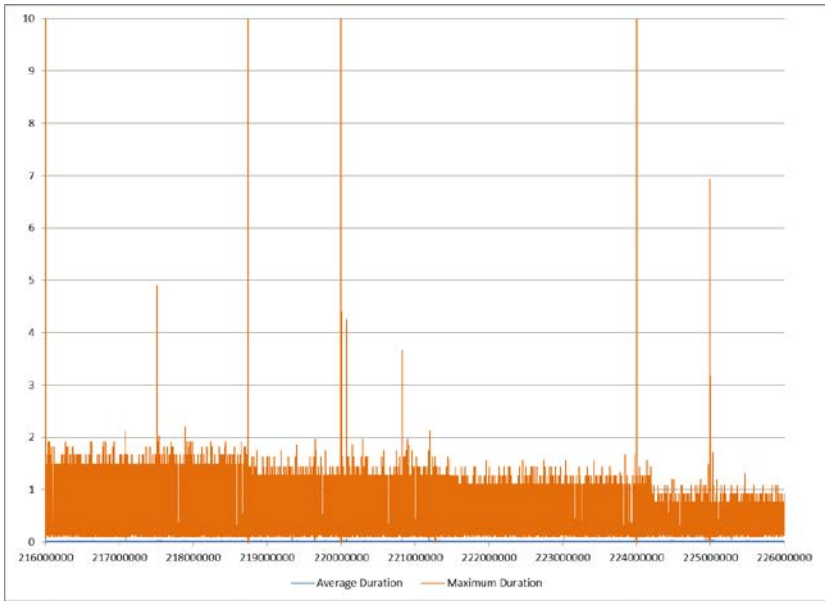




Electro-Mechanical EMI

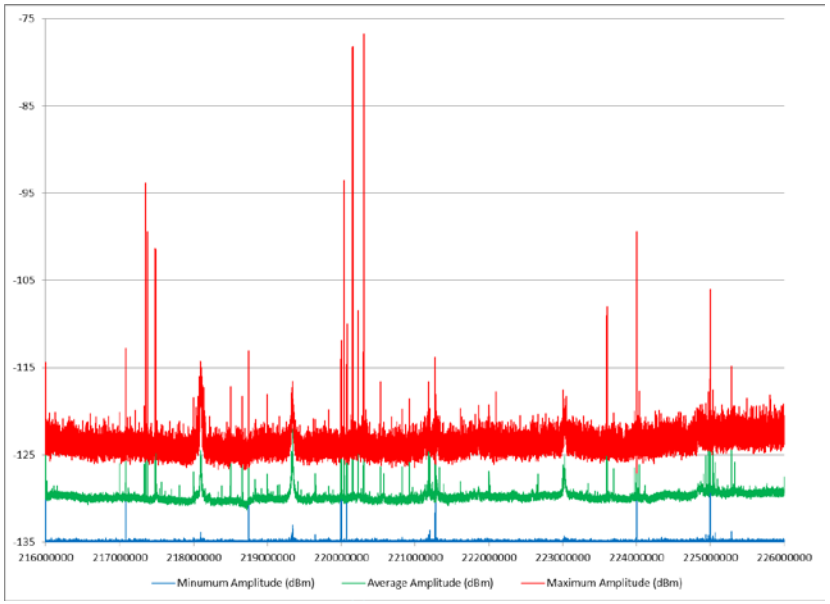
Locomotive Operational State – Notch 5

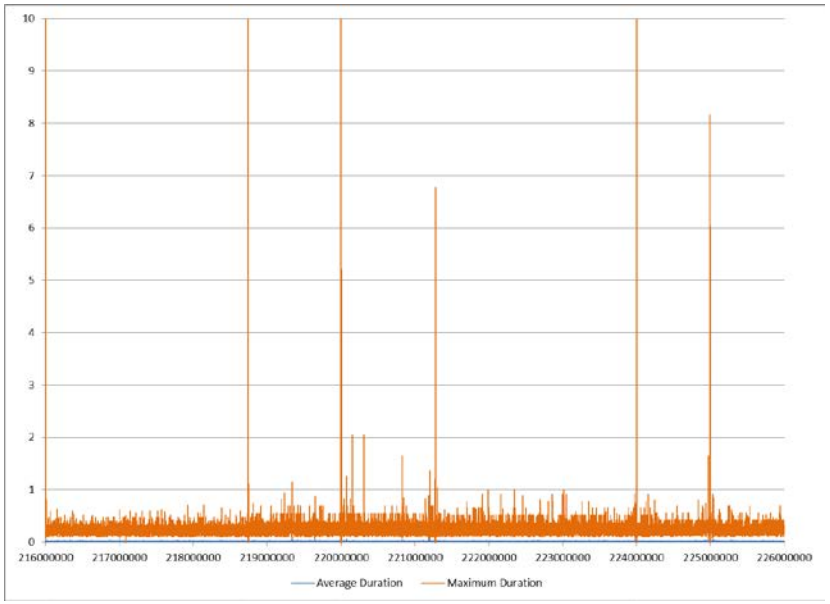




Electro-Mechanical EMI

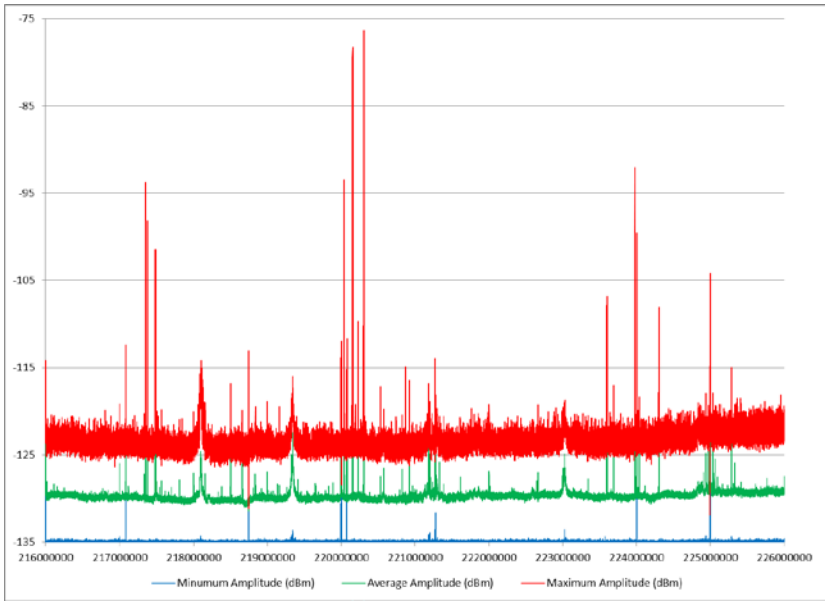
Locomotive Operational State – Notch 6

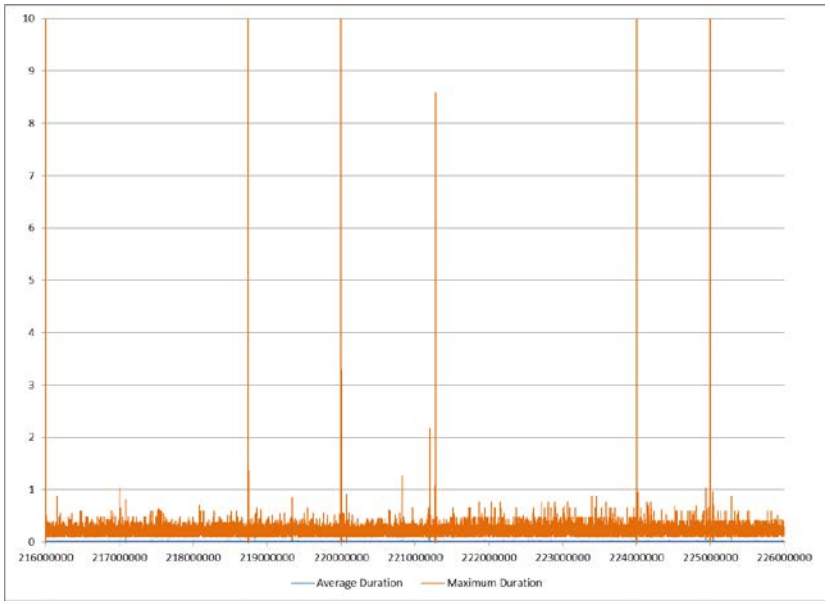




Electro-Mechanical EMI

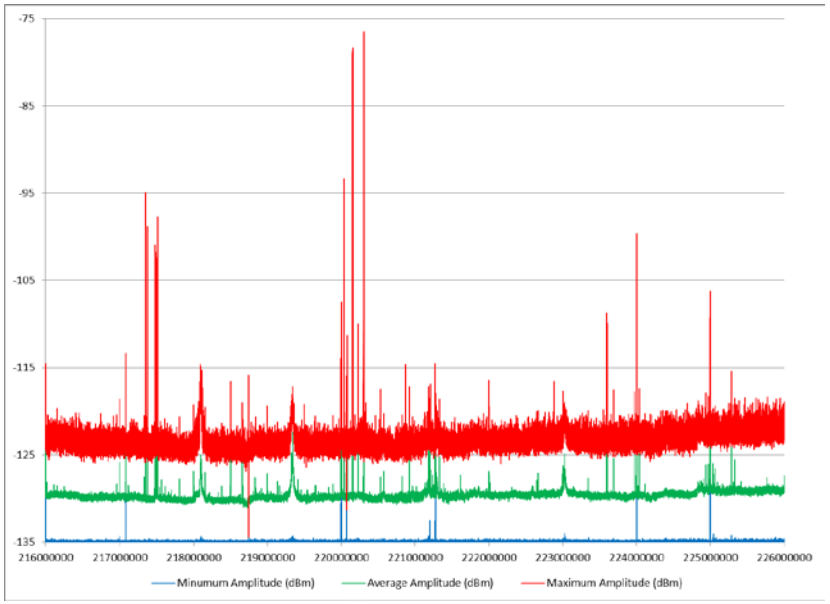
Locomotive Operational State – Notch 7

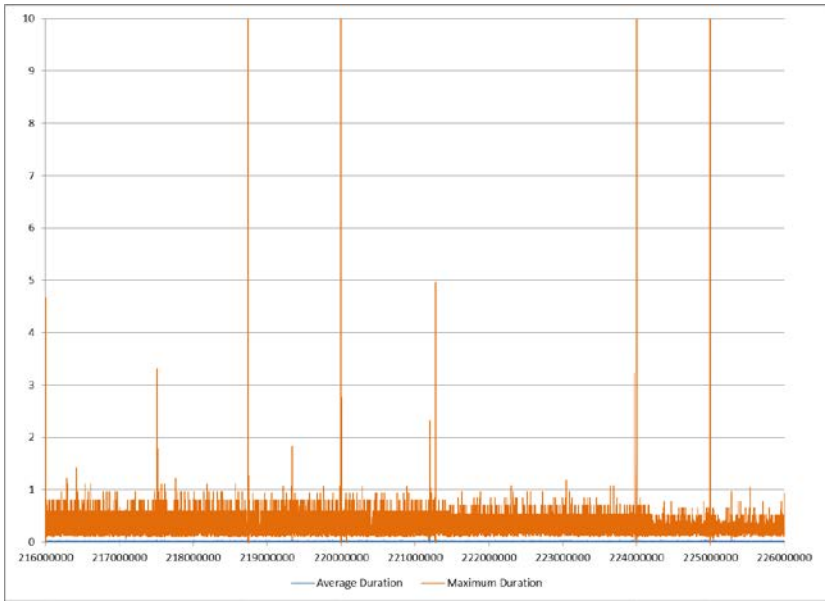




Electro-Mechanical EMI

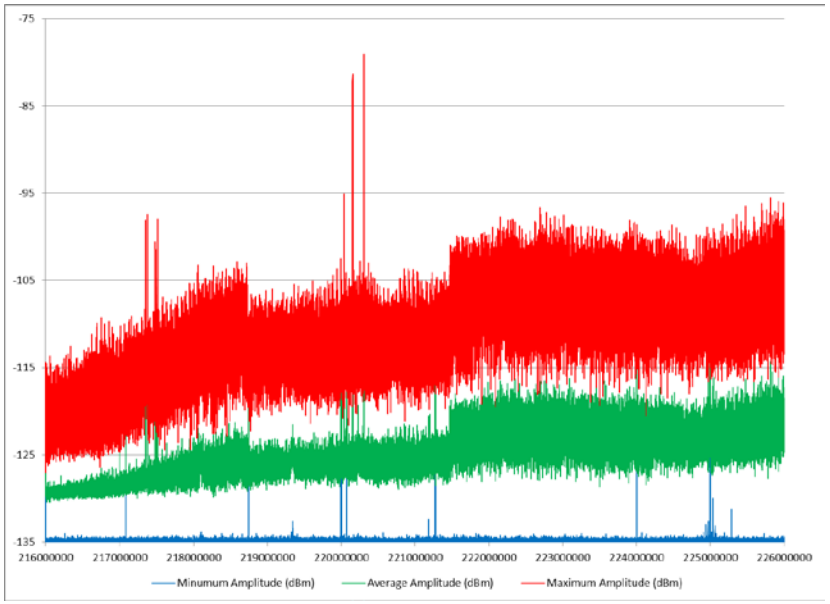
Locomotive Operational State – Notch 8

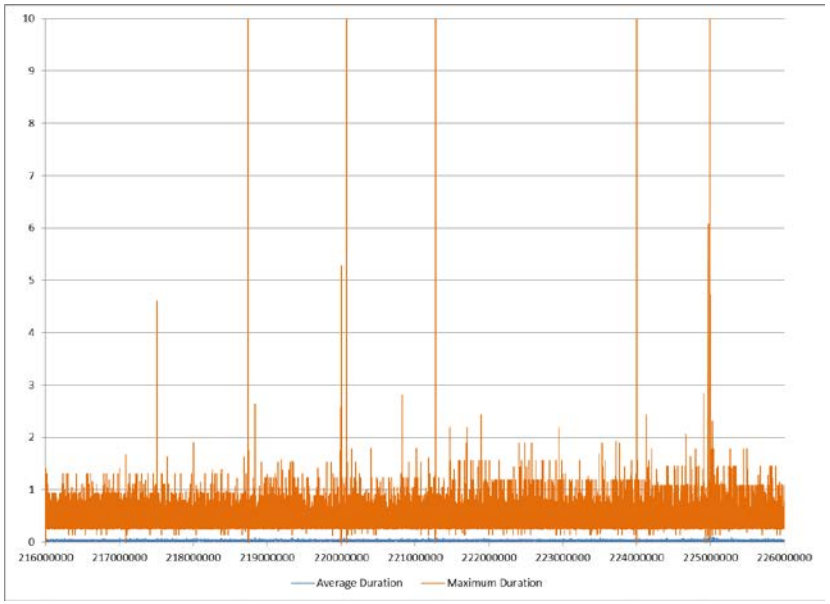




Electro-Mechanical EMI

Locomotive Operational State – Shutdown Sequence





Electro-Mechanical EMI

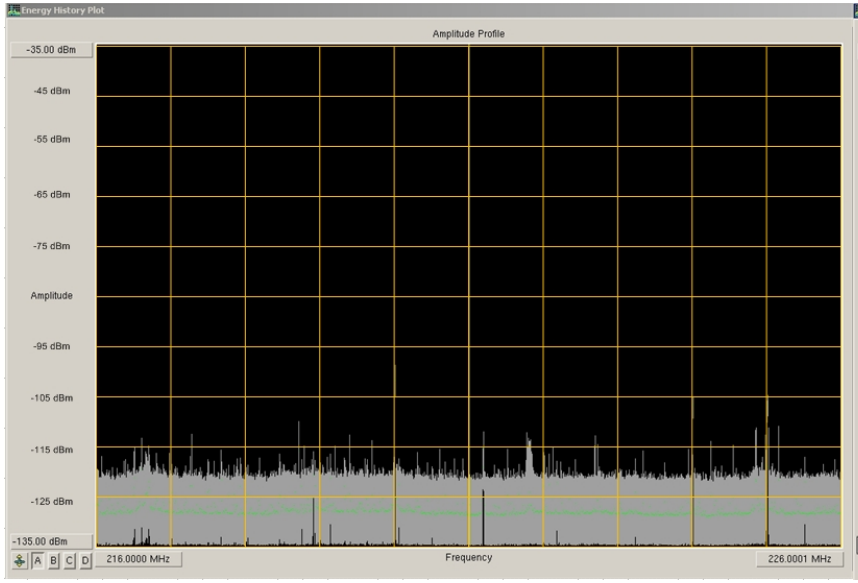
- Unexpected Discovery
  - Prestart Warning Bell prior to Startup Sequence generates significant EMI Noise in 220 MHz Spectrum
  - Identical Bell in Cab intended for signaling between crews in a consist does not generate significant EMI Noise
  - Observed on Dash 9s and Evolution Series Locomotives
  - Acoustical Observation: Warning Bell sounds like a buzzer or contactor possibly operating at the same time
  - Further Testing with OEM recommended TCP to determine source of EMI Noise and possible Mitigation such as arc suppression treatment, or migration to solid state warning devices

Electro-Mechanical EMI

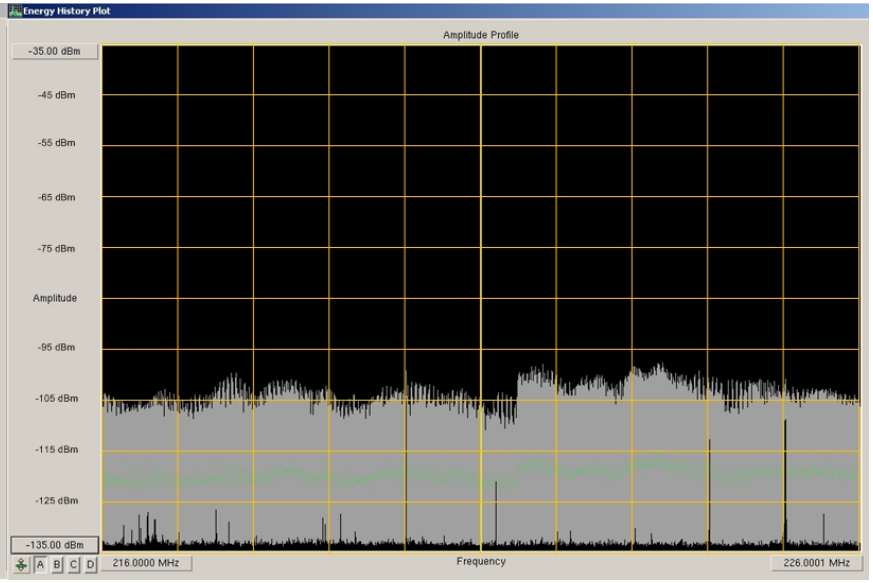
The Bell

Electro-Mechanical EMI

ES44ACH Engine Off
216 MHz to 226 MHz



ES44ACH Warning Bell
216 MHz to 226 MHz

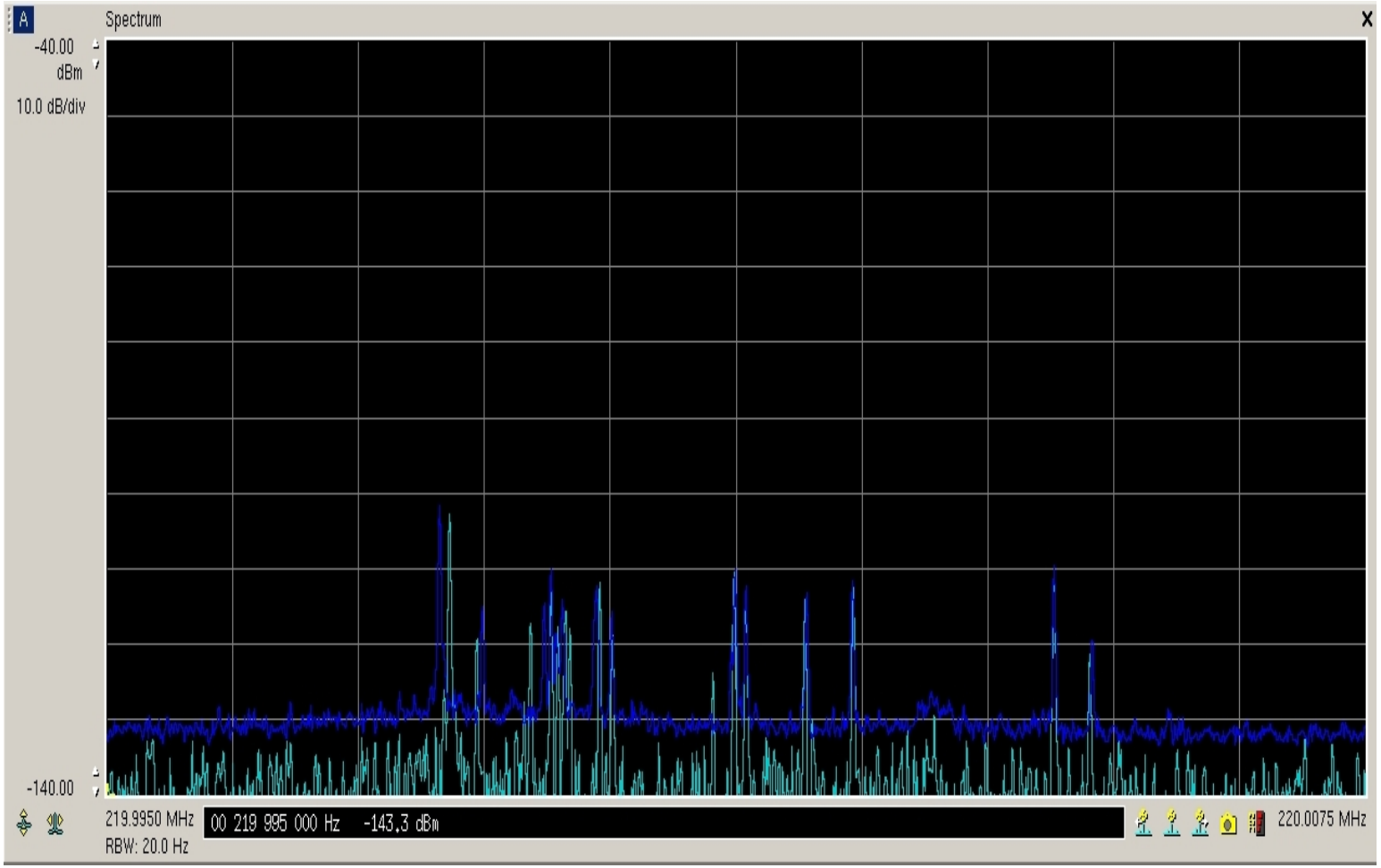


Electro-Mechanical EMI

- Unexpected Discovery
  - Multiple Discrete Signals discovered within a 12.5 kHz segment of PTC Spectrum
  - Generated by Onboard Power Supplies
    - One signal isolated to Cab Signal Power Supply
    - Others present until BCCB Breaker Disengaged
    - Appear to vary slightly in Frequency, perhaps due to Load or Thermal conditions
    - Signals similar in character detected from other Locomotives nearby and these frequencies varied somewhat across the PTC 220 Spectrum
    - Observations Suggest that these may be tunable, perhaps OEM can tune them out of PTC Spectrum

Electro-Mechanical EMI

On Board Power Supply Generated Artifacts

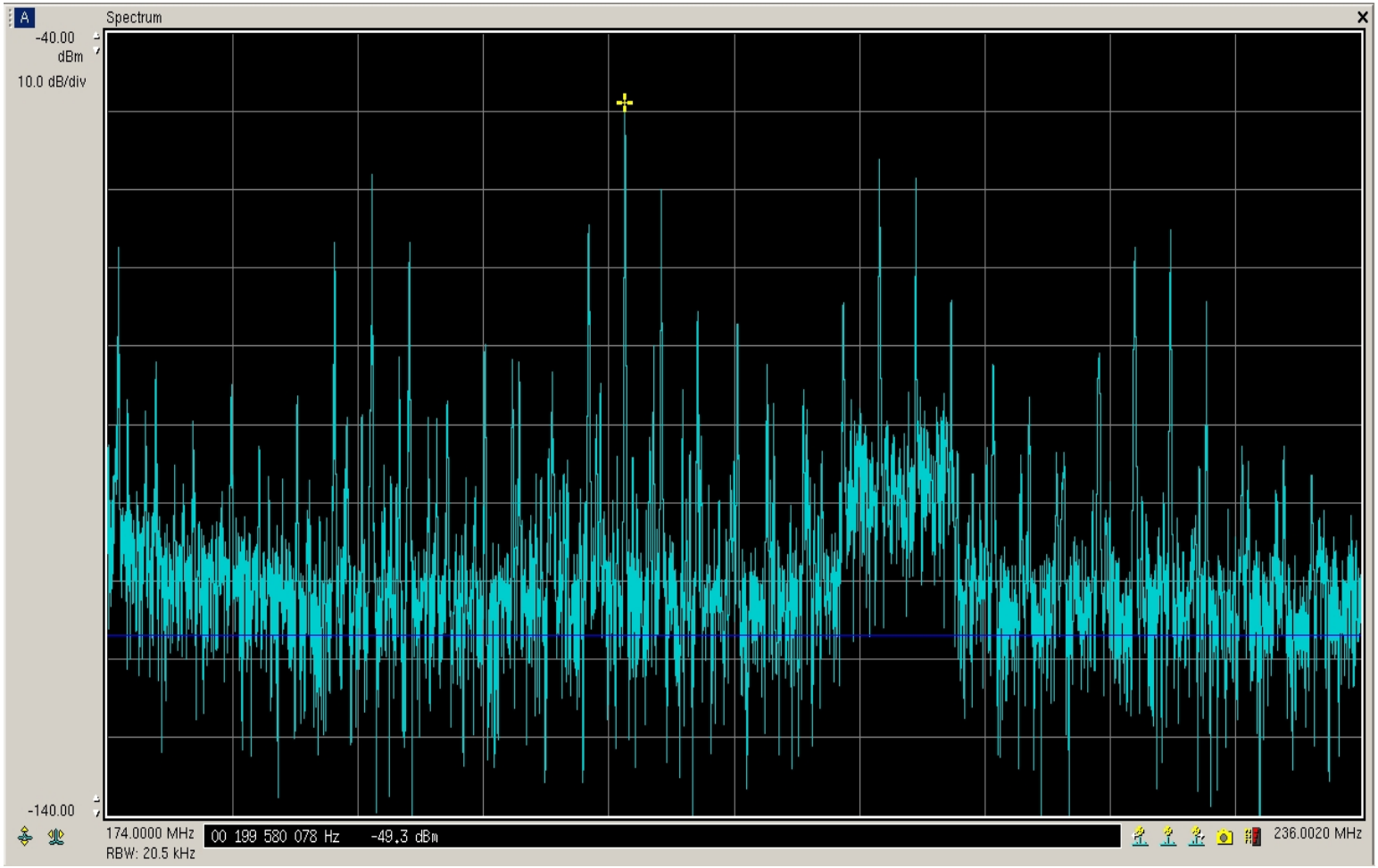


Electro-Mechanical EMI

- Unexpected Discovery
  - Intermittent and initially unexplainable RFI encountered while Testing
  - Off-Platform and Off-premises Drive Test Investigation revealed Signal Leakage from Local Cable Company Infrastructure

Electro-Mechanical EMI

Off Platform Investigation RFI from Local Cable Company



Electro-Mechanical EMI

Off Platform Investigation RFI from Local Cable Company

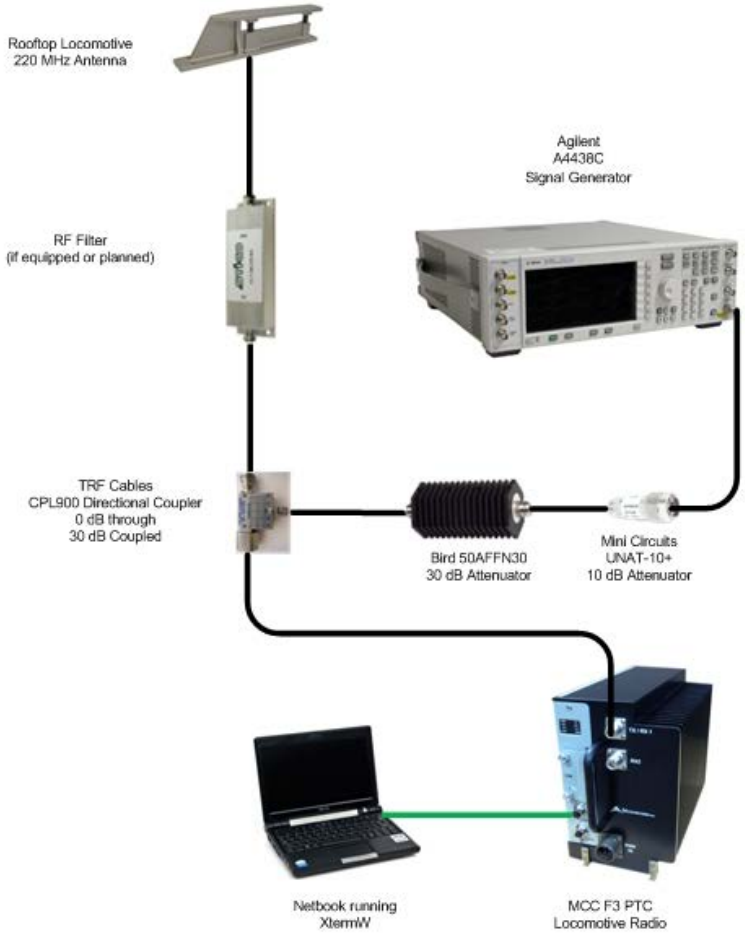
Electro-Mechanical EMI

Off Platform Investigation RFI from Local Cable Company

BER Test

- Purpose of this Test
  - Determine the impact of Electromechanical EMI on PTC Radio Reception from the perspective of the Locomotive Radio Receiver
  - Using PN9 packets with FEC over DQPSK
    - Antenna and Filter Disconnected from Directional Coupler (and open port terminated) establishing a Baseline and verifying Radio Specification Compliance
    - Antenna and Filter Reconnected for Testing
    - Resetting Amplitude as needed to sustain a BER of E-4 throughout Ten Locomotive Operational States

BER Test



BER Test

	Isolated	Off	Idle	Notch 1	Notch 2	Notch 3	Notch 4	Notch 5	Notch 6	Notch 7	Notch 8
44CW-9	NTD	NTD	NTD	NTD	NTD	NTD	NTD	NTD	NTD	NTD	NTD
SD70M	NTD	NTD	NTD	NTD	NTD	NTD	NTD	NTD	NTD	NTD	NTD
44CW-9	-113	-105	-104	-103	-104	-104	-105	-103	-104	-104	-103
C44ACCTE	-113	-107	-104	-103	-103	-105	-106	-105	-105	-104	-104
SD40-3	-113	-109	-108	-108	-107	-107	-107	-107	-107	-107	-107
ES44ACH	-113	-105	-104	-104	-103	-103	-103	-103	-103	-103	-103
SD70M	-113	-109	-108	-107	-107	-106	-109	-109	-109	-109	-106
D9-40CW	-113	-105	-103	-103	-103	-103	-103	-103	-103	-103	-103

Locomotive Noise Testing

- Conclusions
  - Proximity of Antennas in limited Cab Rooftop Space Exacerbates RFI Generation
  - RF Filtering of On-Board Significant Contributor Radios is Imperative to mitigate On-Platform Generated RFI
  - Significant Contributors are 161 Voice, DP-A, DP-B, HOT/EOT, PTC
  - Off Platform RF Sources, such as FM Broadcasters, need to be mitigated through Onboard Filtering and Filtering in the Yard where needed
  - Non-Intentional Radiators, such as Switching Power Supplies and arc-producing devices, need to be considered and addressed
  - Using the BER Test, Locomotive Noise number can be determined to be 10 dB
  - PTC RF Network design limit of -103 dBm for Wayside and Base Signal levels at Trackside

Questions

- If you have any questions, please contact our Service Desk (https://support.meteorcomm.com/home)