METEORCOMM LLC

ITCR Final Test Report
Intermodulation Testing
BNSF 5109

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Revision history

Revision	Date	Summary of Changes	Contributors	DCN
1.0	06/23/2011	Release to FRA new template/disclaimer/footers	dag	00002520-A

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Project Detail

Contract number	FR-TEC-0003-11-01-00
Dates of Test	May 30th to June 3rd, 2011
Locations	BNSF Interbay Locomotive Facility 47 39’ 13.18 N LAT, 122 22’ 55.62” W LON, elev. 31 ft
Test Engineer	Ramon Abelleyro

Executive Summary

During several testing sessions from May 12 to June 3, 2011, information was gathered on potential sources of intermodulation from on-board and external radio transmitters.

No strong evidence of non-locomotive external intermodulation was detected, but it cannot be ruled out at this time. One of the reasons is that very strong local signals from other on-board radios were present and measured on board the locomotive, making it difficult to evaluate external signals that could have been present at a much lower power level. The extremely high signal levels appear to be the result of very close spacing of twenty separate antennas on the locomotive roof, installed within a flat area 57 inches wide by 54 inches front to back.

These multiple high power signals reach the 220 MHz radio antennas, as well as every other radio on board the locomotive, generating several events that require additional testing to analyze. It appears that there could be two, three or more waves of intermodulation products as signals from one radio enter other radios. Even if other radios are not transmitting at the time, there is potential for significant generation of intermodulation products that could mask external intermodulation from FM radios.

There is very low isolation between the twenty antennas on the locomotive roof, resulting in signals transmitted from any radio reaching each other radio receiver at very high power levels. When high power signals enter a radio front end, they find a non-linearity and beat into intermodulation products, which go back through the antenna and are transmitted again to each other radio in the locomotive. This condition generates a “forest of signals” across the spectrum, affecting the entire 220 MHz band, as well as most of the other bands from 50 MHz to 1,000 MHz. When signals from a transmitting radio reach at high power levels other radios that are also transmitting at the same time, more severe intermodulation products are produced and, in addition, transmitted back through the antenna to other radios.

A new testing system and protocol are being developed to measure more precisely the exact amounts of power that arrive at each radio receiver or transmitter when one radio transmits, and how much of that power is reflected back and on what frequencies through the antenna of each radio. This will provide the requisite data to reliably determine the levels of internally generated intermodulation.

Background

The GE Dash-9 BNSF 5109 Locomotive has a GE eight-antenna COMM Handler in the center of the roof, with two GE antenna rails located on each side of the COMM Handler.

See Table 1 for typical antenna configurations.

Table 1: Typical Antenna Configurations

#	Antenna Type	Watts TX
1	COMM Handler 160 MHz Voice Radio	40 Watts TX
2	COMM Handler 450 MHz Distributed Power LOCOTROL Radio A	30 Watts TX
3	COMM Handler 450 MHz Distributed Power LOCOTROL Radio B	30 Watts TX
4	COMM Handler 450 MHz End of Train Radio	2 Watts TX
5	COMM Handler 800 MHz Cellular Radio	0.6 Watts TX
6	COMM Handler 900 MHz Frequency Hopping Yard Radio	2 Watts TX
7	COMM Handler 900 MHz ATCS Radio (Not always equipped)	? Watts TX
8	COMM Handler 1.5 GHz GPS receive only antenna	-------------
9	Antenna Rail/Bar 1 220 MHz Radio	20 Watts TX
10	Antenna Rail/Bar 1 700 MHz/800 MHz/1,900 MHz Cellular Modem 1	1 Watt TX
11	Antenna Rail/Bar 1 700 MHz/800 MHz/1,900 MHz Cellular Modem 2	1 Watt TX
12	Antenna Rail/Bar 1 2.4 GHz PTC Wireless LAN	0.5 Watts TX
13	Antenna Rail/Bar 1 5.8 GHz Wireless LAN	0.5 Watts TX
14	Antenna Rail/Bar 1 1.5 GHz GPS receive only antenna	------------
15	Antenna Rail/Bar 2 220 MHz Radio	20 Watts TX
16	Antenna Rail/Bar 2 700 MHz/800 MHz/1,900 MHz Cellular Modem 1	1 Watt TX
17	Antenna Rail/Bar 2 700 MHz/800 MHz/1,900 MHz Cellular Modem 2	1 Watt TX
18	Antenna Rail/Bar 2 2.4 GHz PTC Wireless LAN	0.5 Watts TX
19	Antenna Rail/Bar 2 5.8 GHz Wireless LAN	0.5 Watts TX
20	Antenna Rail/Bar 2 1.5 GHz GPS receive only antenna	------------

Except for antennas number 8, 14, and 20, which are receive-only GPS radios, the other 17 radios can receive or transmit.

All of the above radios are turned on and receiving at all times when a locomotive is in operation. Each radio transmits and receives independently of every other radio, and, during normal operations, there is no provision to operate certain radios at certain times and certain other radios at other times. Each of the 17 transmitters operates randomly, alone or simultaneously with one or more of the remaining transmitters. Whenever one of the 17 transmitting radios activates its transmitter, its signals reach all the other radio receivers, including the three GPS receivers. Each of these receivers is affected in a different way by the transmitted signals, generating intermodulation products sent back through the antenna. If more than one radio transmits at the same time, more complex intermodulation products will result.

Several waves of intermodulation are possible, as multiple radios generate intermodulation products that go back through their antennas and hit each other radio, repeating the process.

Identifying Internal and External Sources of Intermodulation

To isolate, identify and quantify each internal and external source of intermodulation. It is necessary to start with intermodulation generated by on-board radios. This intermodulation is significantly higher in power levels than any external intermodulation that might be coming, for instance, from FM radio stations. A typical scenario could include on-board generated signals at levels between 60 and 70 dB above those of external signals from sources such as FM radio stations.

A ratio of 60 dB of one signal above another signal indicates that the higher (on-board) signal is one million times more powerful than the lower (external, i.e. FM radio stations). A ratio of 70 dB indicates the higher on-board signal would be ten million times more powerful than the external signals from, say, FM radio stations.

During BNSF 5109 testing it has not been possible to discern between the levels of internal and external signals, due to the high power of on-board radios' generated signals and resulting high level of intermodulation products. There could be intermodulation products from external sources such as FM radio stations, but they are most likely masked out by the strong internal intermodulation produced by on-board radios.

A new testing procedure has been developed and it will be implemented starting with the next locomotive to be tested, which will probably be UP4620, an SD70M locomotive. This test procedure is still being developed and may include the following components:

- Individual 'victim' radio receiver/transmitter measurement of the amount of energy entering the radio when any other on-board radios transmit.
- Individual on-board 'victim' radio receiver/transmitter measurement of the amount of energy returned back through the antenna and re-transmitted, identifying the power and frequency of each intermodulation product signal generated.

- Analysis of combined signals and intermodulation products produced by one or more on-board 'victim' radios when they are hit by signals from other on-board radios transmitting.
- Development of a 'chart of harmonics' showing all the signals generated by different combinations of on-board radios transmitting, hitting other on-board radios, and producing intermodulation sub-products.
- Measurement of the impact on 220 MHz PTC radio reception when one or more types of intermodulation are present, from internal and external sources. Use of Bit Error Rate monitoring instruments to observe real impairment caused to 220 MHz PTC digital radio reception by various types of internal and external intermodulation sub-products.

Table 2: Data Table

Transmitting Band		**VHF 161**	**VHF 161 w/Filter**	**EOT 450**	**Dist. Power A**	**Dist. Power B**	**WABTEC DL 900**
Frequency (MHz)		**161.565**	**161.565**	**452.9375**	**452.9375**	**457.9375**	**902-928**
Output Power (dBm)		**45.4**	**45.4**	**35.44**	**44.8**	**44.8**	**33.42**
	VSWR						
Receiving Band		(dBm)	(dBm)	(dBm)	(dBm)	(dBm)	(dBm)
VHF 161		-	-	+9.61	+19.23	+21.87	-2.59
VHF 161 w/Filter		-	-	-45.00	-32.02	-33.25	NF
220 ENG		+1.95	+0.94	-16.36	-1.57	-7.80	-11.64
220 ENG w/Filter		- 87.0	-87.00	NF	NF	NF	NF
220 CON		+3.25	+1.04	-20.67	-9.87	-0.40	-12.93
220 CON w/Filter		- 90.0	-90.00	NF	NF	NF	NF
EOT 450			+12.90	-	+20.28	+21.85	-2.45
Dist. Power A		-	+12.45	+11.43	-	+25.80	-4.78
Dist. Power B		-	+11.63	+11.64	+25.63	-	-2.25
WABTEC DL 900		+ 4.45	-	+2.19	+5.70	+14.00	-
WIFI ENG		-	-	-12.00	+5.93	-0.60	-19.10
WIFI CON		-	-	-14.28	-2.70	+5.72	-5.37

NF = Noise Floor (-) = No Data Available

Here is an example of excessive power reaching other radios when one radio transmits.

When the 160 MHz voice radio transmits at +45.4 dBm, its signal reaches the antennas of other radios at the following levels, far above their threshold (approximately) at – 110 dBm. See Table 3 for examples.

Table 3: Examples of Excess Power Reaching Other Radios

Antennas	Threshold
220 antenna engineer side	+ 1.95 dBm, this is 111.95 dB above threshold
220 antenna conductor side	+3.25 dBm, this is 113.25 dB above threshold
450 End of Train antenna	+ 12.9 dBm (Even using a 160 MHz filter), 112.9 dB above threshold
450 DP Radio A	+ 12.45 dBm (Even using a 160 MHz filter), 112.45 dB above threshold
450 DP Radio B	+ 11.63 dBm (Even using a 160 MHz filter), 111.63 dB above threshold
900 Event Recorder	+ 4.45 dBm, this is 114.45 dB above threshold

- When the 160 MHz radio transmits, signal levels in excess of 110 dB above threshold reach the other radios.
- A typical RF rule is that whenever a signal 60 dB above the threshold of a radio receiver is present, the radio receiver stops operating, even if signals are off frequency.
- These powerful signals from the 160 MHz radio enter each of the other radios, reach a non-linearity at their LNA front ends, beat in frequency and come back up through the antenna and transmit to the air intermodulation products that cause severe interference with all radios.

Effects of Filters to Increase Isolation between Antennas on Intermodulation Sub-products

Different types of filters will be used on several radios to measure their effect on the levels and density/quantity of intermodulation sub-products, and on the spectrum of signals populating the chart of harmonics.

This will not be a mitigation effort, filters will be used only to the necessary extent to be able to look and measure deeper than it would otherwise be possible without filters and/or other antenna isolation techniques.

For instance, to observe and measure potential intermodulation sub-products generated when 160 MHz voice radio transmitted signals mix with FM radio stations in the area, it will be necessary to increase the isolation between the 160 MHz radio antenna and the other nineteen on-board antennas to reduce on-board produced intermodulation sub-products.

Filters, attenuators and other isolation improvement components will also be used on the measurement instruments themselves to operate sensitive instruments in an environment with extremely high power signals that might distort measurements and potentially damage some instruments.

While testing BNSF 5109, it was not possible to obtain usable data during intermodulation signals monitoring and recording using an Agilent RF Sensor, due to the high level of signals present and multiple intermodulation sub-products produced by on-board equipment. This will be avoided in the future by equipping Agilent RF Sensors instruments with several filters and attenuators to extend the usable range of sensitive instruments.

Use of Agilent RF Sensors and Conventional Instruments

A combination of instruments will be used, including fast signal acquisition and logging Agilent RF Sensors to obtain precise readings on multiple signals and intermodulation sub –products.

Testing Automation

Testing BNSF 5109 required the allocation of substantial labor over time. Every effort is being made to use what has been learned from BNSF 5109 testing to develop more efficient, faster testing procedures. One potential improvement being evaluated is the use of semi-automated test equipment with automatic recording of measured data, with Agilent RF Sensors being used to log all the data collected for later evaluation and analysis. As testing becomes more complex, new approaches are being developed to reduce/eliminate multiple steps involving repetitive manual operations such as plugging and unplugging multiple RF connectors.

Conclusions

With BNSF 5109, it was not possible to observe and record signals other than high power transmissions and intermodulation products produced by on-board radios. The high power of transmitted signals and intermodulation sub-products in and around the locomotive effectively acted as a barrier to observe other potential intermodulation sub-products at a much lower level for example, those that would have been produced by the combination of on-board radios with external sources such as FM radio stations.

The main reason was the number of antennas placed in very close proximity, and the lack of any measures to increase the isolation between antennas, for instance, using filters.

From what was learned during testing of BNSF 5109 for Intermodulation, a new approach and testing procedures are being developed to use for future field testing of other locomotives. This process will be reviewed again after the next locomotive, UP4620 SD70M, is tested, starting almost immediately after the completion of this report.

Testing results from UP 4620 will be of particular interest to compare them with those from BNSF 5109, due to the unique antenna platform used on UP 4620. The COMM Handler and antenna Rails/Bars have been eliminated and replaced by a unique antenna platform design.

Signatures

Test Engineer

Signature: ______________________________

Name: Ramon Abelleyro

Date: June 16th, 2011

Reviewed / Certified

Signature: ______________________________

Name: ______________________________

Date: ______________________________