US Department
of Transportation
**Federal Railroad
Administration**

Research Results

**RR00-03
AUGUST 2000**

Analysis of Antennas to Improve Differential Global Positioning System (DGPS) Reception on Locomotives

SUMMARY

The Federal Railroad Administration (FRA) Office of Research and Development sponsored a research investigation to improve DGPS signal reception in the locomotive electromagnetic interference (EMI) environment. The main objective of this investigation was to test whether a new Starlink prototype E-field antenna designed to significantly reduce EMI effects surrounding operating AC and DC locomotives performed as intended (see Figure 1). During the testing, the performance of the Starlink prototype balanced E-field cone antenna was compared to that of a standard off-the-shelf Starlink H-field loop antenna (MBA2). The antennas were placed in various locations on the roof of the test locomotives. Overall, the Starlink E-field cone antenna performed significantly better than the off-the-shelf Starlink H-field loop antenna, increasing the signal-to-noise ratio (SNR) by 10 dB. It was determined by prior tests that a 10 dB increase in the SNR is sufficient for the Nationwide Differential Global Positioning System (NDGPS) Service to work effectively on railroads. The NDGPS Service will broadcast differential correctors for GPS throughout the nation on the radio beacon band 285 kHz - 325 kHz.

Figure 1. View of Starlink E-field and H-field Antennas Mounted on the Roof of a Locomotive.

BACKGROUND

Conducted on February 15 - 16, 2000, the test was performed on new GE 6000 AC locomotives in intermodal service with the Union Pacific Railroad. The locomotives were operating between North Platt, NE and Cheyenne, WY.

This test was the latest of several studies of the EMI environment surrounding locomotives that ENSCO has conducted under tasking from the FRA in support of both the Positive Train Separation (PTS) and NDGPS projects. The principal goal of these tests is to characterize the EMI fields surrounding operating locomotives in the 250 kHz to 350 kHz frequency band. Since EMI fields vary between locomotive types, characterization of EMI fields will facilitate vendors' ability to design solutions to the EMI problem. Another objective has been to test the performance of new antennas designed specifically to reduce the effects of EMI. Reducing the effects of EMI experienced by railroads will improve DGPS signal reception.

INSTALLATION AND TEST RESULTS

On the first day of testing, the test equipment was installed on a train pulled by five AC6000CW locomotives. The antennas were installed on the roof of the third locomotive from the front. This position was considered one of the worst since there were two locomotives in the front and two in the back of where the antenna was mounted. However, despite the undesirable placement, the E-field antenna consistently reduced the EMI (see Figure 2).

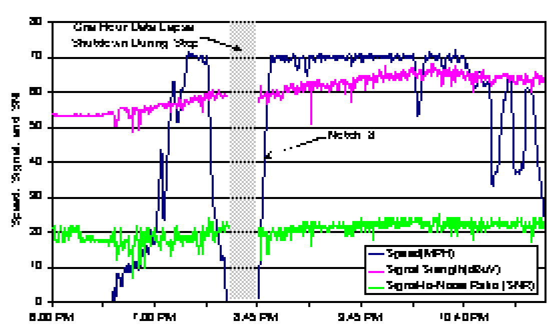

Figure 2. Test Data Collected on the Union Pacific (UP) Railroad, February 15, 2000.

The DGPS receiver was tuned to the Whitney, NE NDGPS station and received a high signal strength (55 to 65 dBuV). The H-field antenna noise component on average was 20 times stronger than the noise component of the E-field antenna.

On the second day of testing, the test equipment was installed on a train pulled by three locomotives. The antennas were mounted on the roof of the third locomotive from the front. Similar test results were experienced. The SNR stayed above 20 dB except when the antenna was switched to the H-field loop antenna (see Figure 3). When the H-field antenna was in use, the SNR dropped to approximately 10 dB. Towards the end of the test run, the receiver was tuned from the Whitney NDGPS broadcast at 310 kHz to the Omaha, NE broadcast at 298 kHz. Even at the lower signal strength, DGPS signals continued to be received (see Figure 3). On both test days, increased speed of the locomotive did not significantly increase EMI noise (see Figures 2 and 3).

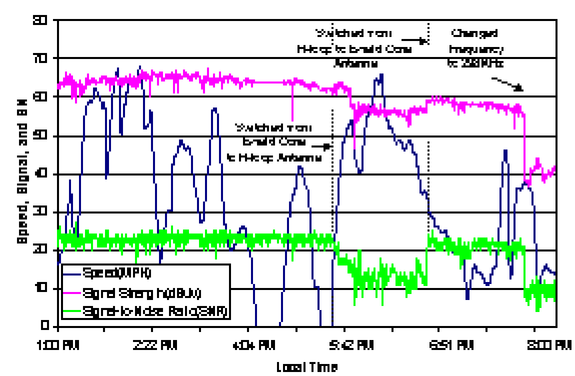

Figure 3. Test Data Collected on the UP, February 16, 2000, Using the E-field Antenna.

PRIOR EMI INVESTIGATIONS

In June and July 1997, ENSCO measured DGPS signal coverage (from Appleton, Washington, the first NDGPS station) operating locomotives on both the Union Pacific (UP) and Burlington Northern Santa Fe (BNSF) railroads along the Columbia River Gorge. Results of these tests indicate that the Appleton NDGPS station is operating properly, but the locomotives themselves are a significant source of electromagnetic interference in the 285-325 kHz NDGPS broadcast band. Thus, the effective range of the Appleton beacon is less for railroad locomotive operation than for other transportation modes. The EMI was strongest when the locomotive was pulling hard or braking hard. Also, a secondary area of investigation grew out of the investigation of DGPS signal strength in the Portland, OR area. A difference was noted between the performance of the Starlink DGPS receiver on the short train used for PTS testing on the UP and the longer revenue freight train used for PTS testing on the BNSF. Subsequently, a test was performed to assess this "length of train" effect. After testing on coal trains of various lengths in the Baltimore, MD Bayview Yard, it was concluded that the length of the test train has little effect on the performance of an NDGPS receiver.

Additional testing was conducted to characterize the locomotive EMI. Tests were performed at the Erie, PA locomotive factory of GE Transportation Systems from March 31 to April 3, 1998. Several conclusions were reached as a result of the Erie, PA testing. It was concluded that the EMI was broadband in the NDGPS band and that there were generally higher levels of EMI surrounding the AC locomotive tested than surrounding the DC locomotive tested. Another conclusion was that if the EMI from two or more antennas is not correlated, the antenna outputs can be summed to increase the overall signal-to-noise ratio.

In January of 1999, Starlink and ENSCO, under funding from the FRA, tested a new E-field antenna design at the Livingston Rebuild Center, Inc. (LRC) facility at Richland, Washington. The antenna was a newly developed Starlink prototype helix E-field design with EMI canceling characteristics. During a week of testing, the new antenna performed well on the LRC refurbished DC locomotive used during testing, offering a conservative 15 dB SNR improvement over standard off-the-shelf H-field antennas.

Prior to the latest testing, additional testing was conducted on AC and DC road locomotives at CSXT's Communications-Based Train Management (CBTM) testbed from October 19, 1999 to October 22, 1999. Emphasis was placed on testing AC locomotives because they tend to generate higher levels of EMI in the NDGPS broadcast band than DC locomotives. The primary goal of the testing, however, was to draw final conclusions on the most effective antenna and receiver technology for reliable NDGPS railroad locomotive use.

The CBTM testbed runs from Augusta, GA to Spartanburg, SC. However, because of the lower than expected signal strength from the two NDGPS stations in the area, the test was conducted on only the southern half of the testbed from Augusta, GA to Greenwood, SC. The only NDGPS signal available along that route is from the Savannah, GA broadcast station.

Four separate tests were conducted on various AC and DC locomotives in actual service. The revenue trains on which the tests were performed were typical, consisting of a lead locomotive and one or more trailing locomotives). The test equipment was installed on the locomotive trailing behind the lead. At least two antennas and as many as four were installed on the test locomotive roof on each test. The antennas were mag-mounted and cables were temporarily secured.

The four tests conducted at the CBTM testbed demonstrated that the Starlink E-field cone antenna out-performed the standard off-the shelf H-field loop antenna by 10 dB or more. In addition, the tests demonstrated excellent overall DGPS reception onboard road locomotives in a locality where the DGPS beacon signal level was only a few dB's above the Federal (USCG) minimum (37.5 dBuV/m). The poorest performance of this test series was observed on the fourth test on an AC 4400CW, yet even then the receiver was in DGPS mode for 78% of the time that the train was moving.

CONCLUSIONS

EMI studies to date have characterized EMI fields surrounding different types of current road locomotives. Three of the most recent studies have successfully demonstrated that antennas specially designed to reduce the effects of locomotive EMI, such as the Starlink prototype E-field cone antenna, significantly minimize noise to allow for adequate reception of DGPS signals.

ACKNOWLEDGMENTS

The Union Pacific (UP), Burlington Northern Santa Fe, Conrail, and CSX railroads, along with GE Transportation Systems and the Livingston Rebuild Center (LRC) contributed to the success of these tests. Leading the tests and analyses were ENSCO, Inc. and Starlink, Inc.

CONTACT

Richard Shamberger
Federal Railroad Administration
Office of Research & Development
1120 Vermont Avenue, NW - Mail Stop 20
Washington, DC 20590
TEL (202) 493-6371
FAX (202) 493-6333
e-mail: richard.shamberger@fra.dot.gov

KEYWORDS: antennas, electromagnetic interference (EMI), NDGPS and DGPS reception, locomotives, signal-to-noise-ratio (SNR).