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Positive Train Control Interoperability Test Support

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13. ABSTRACT (Maximum 200 words)

Transportation Technology Center, Inc. (TTCI) and the Federal Railroad Administration (FRA) evaluated communication performance from operation of the Advanced Civil Speed Enforcement System (ACSES) GE TD 220x MHz data radios and the Interoperable Train Control (ITC) compliant Meteorcomm Communications, LLC (MCC) 220 MHz data radios in the same geographical regions. The radio frequency (RF) evaluation included development of test plans and procedures based on railroad input and deployment details, execution of laboratory and field desensitization (desense) testing, testing for the effectiveness of a potential mitigation technique, analysis and report of results, as well as development of an analytic model to estimate the probability of message loss due to desense for typical Positive Train Control (PTC) message traffic. These tests support successful interoperation of the dissimilar PTC systems being used by freight and commuter railroads. Performance and potential interference of the RF communications networks is a critical component of interoperation between dissimilar PTC systems in revenue service due to the systems operating in the same geographic territory.

14. SUBJECT TERMS
Advanced Civil Speed Enforcement System, ACSES, Configuration Information Management, CIM, Handheld Spectrum Analyzer, HSA, Interoperable-Electronic Train Management System, I-ETMS, Interoperable Train Control, ITC, Positive Train Control, PTC, Packet Error Rate, PER, Radio Frequency, RF, Radio Under Test, RUT

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				=	1.1 short tons
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1 fluid ounce (fl oz)	=	30 milliliters (ml)	1 liter (l)	=	1.06 quarts (qt)
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Executive Summary

From March 12, 2013, through March 11, 2015, Transportation Technology Center, Inc. (TTCI) and the Federal Railroad Administration (FRA) evaluated communication performance from operation of the Advanced Civil Speed Enforcement System (ACSES) GE TD 220 MHz data radios and the Interoperable Train Control (ITC)-compliant MCC 220 MHz data radios in the same geographical regions. The radio frequency (RF) evaluation included development of test plans and procedures based on railroad input and deployment details, execution of laboratory and field desensitization (desense) testing, testing for the effectiveness of a potential mitigation technique, analysis and report of results, as well as development of an analytic model to estimate the probability of message loss due to desense for typical Positive Train Control (PTC) message traffic.

Testing of RF desense of dissimilar PTC radios at the Transportation Technology Center (TTC) quantified the potential degradation of communications system performance for dissimilar PTC radios operating in the same geographical region. The results of testing spurred the formation of the Northeast Corridor (NEC) Communications team to collaborate and clearly identify the challenges the NEC railroads face in deploying the dissimilar PTC radio networks, and to determine a comprehensive solution to promote the successful deployment of the two dissimilar PTC systems along the NEC. The (ACSES) PTC system will be deployed by commuter and passenger railroads, and the Interoperable Train Control-compliant, (ITC-compliant) PTC system called Interoperable-Electronic Train Management System (I-ETMS®[1]) will be deployed by the freight railroads.

Freight, passenger, and commuter railroads use the high-traffic NEC rail corridor. The dissimilar PTC systems being deployed by the railroads, ACSES and ITC, each uses a 220 MHz data radio from different manufacturers, with different communication protocols. The rail industry expressed concern regarding the communication issues that may arise from the use of dissimilar radios operating in close proximity and within the same frequency band. Throughout the NEC, ACSES and ITC will be deployed in close proximity, sometimes on the same track bed. Additionally, in some locations, trains will need to transition between ACSES and ITC territory in order to allow freight and passenger trains to operate on the same track.

The purpose of this research was to accomplish follow-on tasks for a previous project funded by FRA through the Railroad Research Foundation (RRF). The RRF/FRA project included the drafting of test plans and procedures for conducting interoperable PTC testing at TTC. Tasks conducted for this project included an evaluation of the TTC PTC test bed resources, identification of potential upgrades, and RF communications system performance evaluation. The RF evaluation included development of test plans and procedures based on railroad input and deployment details, execution of laboratory and field desense testing, testing for the effectiveness of a potential mitigation technique, analysis and report of results, as well as development of an analytic model to estimate the probability of message loss due to desense for typical PTC message traffic.

[1] I-ETMS is a registered trademark of Wabtec Railway Electronics.

Enhancements to the TTC PTC test bed included installation of a 220 MHz folded dipole antenna at a height of 100 feet placed on the CORE tower to support testing of co-located ACSES and ITC base stations, development of custom software to interface with the ACSES radios, and to provide nearly real-time message loss values while testing.

Results from the RF testing indicated the strong signal level at which an ITC radio signal desenses an ACSES radio, and vice versa.

In response to the data and results gathered under this project, additional follow-on projects have been awarded and initiated to test potential mitigation techniques for locomotives dual-equipped with ITC and ACSES radios, and for testing spectral allocations that have been identified by the NEC Communications team as an essential part of the solution.

1. Introduction

A Positive Train Control (PTC) interoperability test support project, funded by the Federal Railroad Administration (FRA) through the Railroad Research Foundation (RRF), was the predecessor to this project. The intent of this project was to fund related follow-on tasks to support PTC interoperability testing at the Transportation Technology Center.

1.1 Background

As the Rail Safety Improvement Act of 2008 first mandated, each Class I railroad and each entity providing regularly scheduled intercity or commuter rail passenger transportation must implement an FRA-certified PTC system on: (1) its main line over which 5 million or more gross tons of annual traffic and poison- or toxic-by-inhalation hazardous materials are transported, and (2) its main line over which intercity or commuter rail passenger transportation is regularly provided.[2] By law, a PTC system must be designed to prevent train-to-train collisions, over-speed derailments, incursions into established work zones, and the movement of a train through a switch left in the wrong position.[3]

On October 29, 2015, the Positive Train Control Enforcement and Implementation Act of 2015 (PTCEI Act) extended the original statutory deadline for implementing PTC systems from December 31, 2015, to December 31, 2018.[4] In addition, the PTCEI Act permits a railroad to request FRA's approval of an "alternative schedule" with a deadline beyond December 31, 2018, but no later than December 31, 2020, for certain non-hardware, operational aspects of PTC system implementation. The congressional mandate requires FRA to approve a railroad's alternative schedule with a deadline no later than December 31, 2020, if a railroad submits a written request to FRA that demonstrates the railroad has met the statutory criteria set forth under the PTCEI Act.

Since 2008, railroads have been faced with an array of technical and non-technical challenges in the design and deployment of PTC. For example, the Northeast Corridor (NEC) serves multiple passenger, commuter and freight rail agencies, and extends from Washington, DC to Boston, MA, with several lines branching into nearby states. Two PTC systems are being deployed by the railroads on the NEC: Advanced Civil Speed Enforcement System (ACSES) and Interoperable Train Control (ITC), which is also known as Interoperable Electronic Train Management System (I-ETMS®).[5]

Each PTC system uses a 220 MHz data radio from a different manufacturer, with different communication protocols. The use of dissimilar radios that operate within the same frequency band introduces the potential for severe communication issues for ACSES and ITC deployments within the NEC. In particular, concurrent use of the ACSES and ITC radios within close

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[2] Rail Safety Improvement Act of 2008, Pub. L. No. 110-432, § 104(a), 122 Stat. 4848 (Oct. 16, 2008), as codified at Title 49 United States Code (U.S.C.) § 20157.

[3] *See, e.g.*, 49 U.S.C. § 20157(i)(5); Title 49 Code of Federal Regulations (CFR) § 236.1005.

[4] Pub. L. No. 114-73, 129 Stat. 568, 576–82 (Oct. 29, 2015), *amending* 49 U.S.C. § 20157. *See also* The Fixing America's Surface Transportation Act, Pub. L. No. 114-94, § 11315(d), 129 Stat. 1312, 1675 (Dec. 4, 2015).

[5] I-ETMS is a registered trademark of Wabtec Railway Electronics.

proximity will cause loss of messages for the other type of radio due to receiver desensitization (desense). Throughout the NEC, ACSES and ITC will be deployed in close proximity, sometimes on the same track bed. Additionally, in some locations, trains will need to transition between ACSES and ITC territory in order to allow freight and passenger trains to operate on the same track. Trains must interoperate between different PTC systems when transitioning from one railroad to another. Interoperation includes transitioning between:

- An ITC-equipped railroad and an ACSES-equipped railroad
- Two different railroads, each equipped with ITC
- Two different railroads, each equipped with ACSES

Transitioning between similar PTC systems, for example ITC-equipped CSX Transportation (CSX) line to an ITC-equipped Norfolk Southern Corporation (NS) line, still requires interoperation as each railroad may differ in its deployment of ITC. The Federal Railroad Administration (FRA) have been investing in a PTC test bed, equipped with ACSES and ITC systems, at Transportation Technology Center (TTC) to support industry needs for developing, and testing PTC systems and related components.

1.2 Objectives

The objectives of this project revolved around supporting the needs of the railroads to successfully interoperate the dissimilar PTC systems being used by the freight and commuter railroads (i.e., ITC-compliant PTC interoperation with ACSES). One objective was to assess the PTC equipment and resources already deployed and ready to use at TTC for testing interoperability between dissimilar PTC systems, and to identify additional resources needed to enhance the PTC test bed capabilities. Performance of and potential interference among the radio frequency (RF) communications networks was identified as a critical component of interoperation between dissimilar PTC systems in revenue service due to the systems operating in the same geographic territory. The second objective of this project focused on an evaluation of communication performance from operation of the ACSES GE TD220 MHz data radios and the ITC-compliant MCC 220 MHz data radios in the same geographical regions. This objective became the more prominent of the two due to industry needs driven by the federally mandated PTC implementation deadline.

1.3 Overall Approach

Assessment of the hardware and software of the ACSES and ITC test bed at TTC was conducted, and test bed upgrades and enhancements, to support interoperability testing were identified. The communication performance evaluation began by soliciting input from the railroads of the NEC facing interoperability challenges. Information gathered included expected RF deployment details, as well as the identification of operational scenarios that could potentially degrade communications performance of either or both PTC systems. This information was used to determine the most appropriate test scenarios to be conducted in both laboratory and field setting. The test plan and test procedures were developed, laboratory and field testing was conducted, and the results are provided in Sections 3.4 and 3.5 of this report.

1.4 Scope

The following describes the scope of work conducted to meet the project objectives described above:

- Identified and documented potential test bed upgrades and resources that could be added to enhance interoperability testing capabilities at TTC.
- Collaborated with railroads of the NEC, General Electric (GE), and Meteorcomm Communications LLC (MCC) to determine laboratory and field testing environments most representative of the revenue service 220 MHz RF communications network deployments. Test plans and procedures were developed accordingly.
- Upgraded PTC test bed to support communication performance testing with the addition of antenna and antenna alignment adjustments, as well as the design and development of test software capable of interfacing with the ITC and ACSES data radios.
- Prepared TTC PTC radio laboratory facility to support communication testing, including procurement of test equipment, MCC-specific training, and MCC-loaned test equipment and software.
- Conducted laboratory and field RF desense testing, and demonstrated effectiveness of a potential mitigation technique.
- Analyzed data and summarized results from laboratory and field testing.
- Developed an analytic model to determine the probability of the message loss under typical PTC radio message traffic.
- Evaluation of communications systems did not include adjacent technologies or radios operating in other bands such as ACSES at 900 MHz, 160 MHz voice radios, cellular, Wi-Fi, etc.

1.5 Organization of the Report

This report is organized in four major sections. Section 1 is the introduction, and provides the background and context for the project with descriptions of the project objectives, overall approach, and scope. Section 2 provides a detailed summary of the work completed with a brief conclusion in Section 3.

2. Major Task Summaries

Tasks completed in this project included evaluation of PTC test bed resources and identification of potential upgrades to support interoperability testing at TTC. Efforts of this project focused on the evaluation of the effects of the geographically co-located dissimilar PTC RF networks which included; the development of test plans and procedures, preparing and conducting laboratory and field testing, data analysis, and development of the RF analytic model. The PTC test bed upgrades completed were selected to simultaneously support the RF laboratory and field testing environments, while enhancing the interoperability testing capabilities of the TTC PTC test bed.

2.1 TTC PTC Test Bed Deployments

From1997 to 1998, early development of a communication and train control test bed began at TTC. Throughout the years, FRA and TTCI have invested in the test bed, and have been expanding and upgrading test bed capabilities as communications and train control products and technologies have evolved. The communication and train control test bed, also referred to in this document as the PTC test bed, is an industry resource that provides an environment free of the challenges associated with revenue service testing used for development, testing, and/or demonstration of PTC-related technologies, equipment, and systems, such as:

- PTC braking algorithms
- Communications system performance and its impact on PTC system performance
- PTC end-of-train determination systems
- PTC train location systems
- Highway crossing protection systems
- It is envisioned that in the future, the test bed might also be used for certification and acceptance testing of new software releases for PTC systems or components
- Interoperability of PTC systems [1]

Currently, the TTC Railroad Test Track (RTT) is equipped with both the ITC and ACSES PTC systems, as well as conventional track circuit based signaling, cab signaling, and Automatic Train Control (ATC). TTCI is currently implementing an ATC-compliant signal system with cab signaling, ACSES transponders, and track database on the direct current (DC) third rail electrified Transit Test Track (TTT), to enable further types of testing beyond that achievable on the RTT PTC test bed.

2.1.1 Potential Upgrades to Support Interoperability Testing

The status of the TTC PTC test bed was evaluated and potential test bed enhancements or upgrades to support interoperability testing were identified. Interoperability testing encompasses not only interoperation between ACSES and ITC systems, but also between two ACSES systems deployed by different railroads, or two ITC systems deployed by two different freight railroads. Though two railroads may be utilizing the same PTC system, the deployment of each may vary, and it is essential that the PTC functions carry over seamlessly as a train transitions from one railroad to the next.

Table 1 provides a list of potential test bed upgrades at TTC and the corresponding benefits of each.

Table 1. Potential TTC PTC Test Bed Upgrades

Potential PTC Test Bed Upgrade	**Benefits**
Track database editing tools for ACSES	1. Allow TTCI to update the track database information as the physical ACSES test bed expands. Currently, it takes approximately 1 to4 weeks to have the supplier make track database changes. 2. Support customer needs if changes are needed quickly. 3. Allow for the intentional introduction of errors into the track database for use during customer testing.
ITC Test Laboratory Equip a laboratory with a train management computer (TMC), back office simulator, wayside interface unit (WIU) simulator, Global Positioning System (GPS) simulator, required power supplies, cables, and specially developed instrumentation to monitor and log all input and output.	1. The simulators would allow for a variety of tests to support integration of ITC by the railroads without having to use the on-track test bed. For example, the simulators could be used to allow the TMC to assume it is on the tracks, and the response of the TMC could be monitored and logged for different operational scenarios. 2. The logged input and output can be used for playback and post-simulation analysis.
Electric horns	Allow TTCI to provide functioning horn to interface with ITC systems for use during customer testing.
Small inventory of spare signaling and ITC equipment, such as: • Wayside messaging servers • Data radios • GPS and radio antenna • 5 percent of signaling equipment used	Allow TTCI to make immediate repairs in the event of equipment failure; prevent extended delays if failure occurs during a customer test.
Addition of a track turnout from the TTT to the RTT near T22 • Signaling equipment, a WIU, and support from supplier would be required for full functionality.	1. Allow for test trains to forward transition both from RTT to TTT, and back to RTT. 2. Provide approximately three miles of double track. 3. Allow TTCI to support testing transitions from one ACSES territory to another ACSES territory.
Update and configure the ACSES Office Communication Manager (OCM) to communicate with the WIUs and both the TTT and RTT track databases simultaneously.	1. Combine the track databases for RTT and TTT for simultaneous use. 2. Allow customers to test exit track WIU messages and Temporary Speed Restriction (TSR) messages when transitioning to a second ACSES-equipped track. 3. WIUs can simultaneously monitor the TTT and RTT interlockings.

2.2 Development of Desense Test Plans and Procedures

Several freight and commuter railroads operate along the NEC and are faced with the challenge of coordinating and planning the PTC system design to support implementation of the two dissimilar PTC systems, ACSES for the passenger and commuter railroads, and ITC for the freight railroads. ACSES and ITC radios both operate in the 220 MHz frequency band, which results in the potential for a receiver's sensitivity to be reduced when exposed to a high interfering RF signal level from a nearby dissimilar transmitter. The primary intent of the testing is to identify the interfering signal level that desensitizes the receiving radio under test. In addition to receiver desensitization, sideband noise from radio transmitters operating in the 220 MHz band could be present and of sufficient strength within a receiver's channel to result in interference and message loss. This is referred to as in-band interference.

During development of the test plans and procedures, TTCI collaborated with railroads of the NEC, including the freight railroads NS and CSX, the passenger railroad Amtrak, and various NEC commuter railroads. TTCI also worked closely with the radio manufacturers for each PTC system and suppliers of PTC 220 MHz radios.

Collaboration with the railroads and radio manufacturers focused on:

- Planned revenue service RF deployment details such as, antenna height, antenna location relative to track, transmit power, and planned frequencies to be used,
- Planned RF signal levels and accepted PER percent levels,
- Review of TTCI-proposed procedure for testing desense,
- Potential mitigation techniques,
- Priority of field testing scenarios, and
- Identification of support required from radio manufacturers to conduct testing at TTC.

This information was used to guide development of the test plan and procedures, which can be found in the appendix.

2.2.1 Test Procedure Summary

The main objective of the desense test procedure was to determine the interfering signal level incident upon the radio under test (RUT) receiver which resulted in a Packet Error Rate (PER) greater than or equal to 5 percent for the RUT. All tests followed a similar set of steps:

- A fixed desired signal level of -85 decibel-milliwatts (dBm) or -95 dBm at the RUT was set using attenuation on the signal emitted from the corresponding transmitter of either the ITC or ACSES system.
- The interfering signal was then introduced from a transmitter of the dissimilar PTC system, and the signal level was incrementally increased until the PER observed at the RUT was approximately 5 percent.

The 5 percent PER was established as the marker for degraded performance because it is the PER currently used for planning the ITC RF network designs and was considered a reasonable target threshold by commuter and passenger railroads of the NEC who were surveyed regarding acceptable PER for the ACSES RF networks. Many of the commuter railroads that responded design their RF networks to achieve a target coverage signal level of -85 dBm. ITC target minimum signal level is in the range of -92 to -95 dBm.

During testing, both the ITC and ACSES radios sent and received packets of information in formats similar to that of the typical PTC packets sent by each system. Transmission of such packets was used, as opposed to continuous wave testing or bit error rate testing, to most closely represent the actual RF interference environment that will exist on the NEC.

Frequency Selection

Nationally, channels used for PTC systems range from 217 MHz to 222 MHz with ITC systems utilizing 25 kHz channels, and ACSES systems utilizing 12.5 kHz channels. Information was gathered from the railroads of the NEC regarding planned spectrum usage. The ITC systems deployed by the freight railroads CSX, NS, and Conrail will use frequencies between 220 MHz to 222 MHz. The ACSES systems deployed by several commuter and passenger lines, such as New Jersey Transit (NJT), Metro-North Railroad (MNR), Long Island Rail Road (LIRR), anticipate using frequencies below 219 MHz, while Southeastern Pennsylvania Transportation Authority (SEPTA) and some Amtrak sites may operate on channels in the 220 MHz to 222 MHz range. This led to the selection of two spectral separations for testing. A 50-kHz spectral separation was selected to be representative of the worst-case scenario with the ACSES and ITC systems operating on two very close channels in the 220 MHz to 222 MHz range. A 1.1375 MHz spectral separation was selected to be representative of the worst-case scenario when an ACSES radio is operating below 219 MHz, but on a channel very close to 219 MHz while an ITC radio is operating between 220 MHz to 222 MHz, but on a channel near 220 MHz. Table 2 provides the channel frequencies for the two spectral separations tested.

Table 2. Channel Frequencies selected for the ACSES and ITC Systems

	Center frequency (MHz)	Lower frequency (MHz)	Upper frequency (MHz)	Frequency Separation (MHz)
ACSES 1 (fA1)	220.7125	220.7000	220.7250	0.0500
ITC 1 (fA2)	220.7625	220.7375	220.7875	
ACSES 2 (fA3)	218.9750	218.9625	218.9875	1.1375
ITC 2 (fA4)	220.1125	220.0875	220.1375	

Simultaneous Transmission of Packets

To accurately quantify the interfering signal level at which each receiver is desensed, it was essential to ensure that packets originating from the transmitter of the desired signal, and packets originating from the transmitter of the interfering signal were synchronized or overlapping. The multiple access methods for both radios are variants of Time Domain Multiple Access (TDMA). The frame and timeslot structures are different for the ACSES and ITC radios, and in order to ensure the transmitted messages between the dissimilar radios overlap, TTCI adapted existing software to interface with the GE radios and control the timeslots that messages are assigned for the GE radios. MCC provided software and training to allow TTCI to configure and control the timeslots that messages are assigned for the MCC radios.

2.2.2 Laboratory Testing

The desense testing conducted in the PTC Radio Laboratory at TTC was categorized into four groups:

- Desense testing – included testing many permutations of ITC radio models versus an ACSES radio.
  - A bandpass filter comprised of four cavity RF filters was used on a subset of the tests. The filter was applied to the interfering signal to reduce sideband noise outside of the interfering frequency. It was tuned with a calibrated Hewlett Packard benchtop Spectrum Analyzer and Signal Generator, model E4404B. The bandpass filter characteristics are provided in Table 3 for the two frequencies it was used for during testing.

Table 3. Bandpass Filter Characteristics

Center Pass Frequency (MHz)	Lower -3dB Point (MHz)	Upper -3dB Point (MHz)	Passband (MHz)	Insertion Loss (dB)
218.975	218.9125	219.0725	0.160	-5.7
220.1125	220.1975	220.0325	0.165	-5.6

- Duplexer testing – included repeating a subset of desense tests with a Vari-Notch® duplexer as a potential mitigation technique for desense occurring between the dissimilar radios
- Alternative software/firmware version testing – a subset of desense tests were repeated with different versions of software. Specifically, the ITC radios were tested with an older software that did not have an automatic gain control, and the GE radios were tested with the firmware upgrade 2.0.13.
- Desense threshold variability testing – desense testing was completed for four radios of each model. This provided a limited assessment of the variability of the threshold at which each radio model desensed.

Table 4 provides a summary of the laboratory tests conducted. The test scenarios highlighted yellow were repeated with four radios of each model for the desense threshold variability testing. This table and several others in the report refer to the following abbreviations:

- "Sd" for desired signal strength
- "Si" for interfering signal strength

Table 4. Summary of Laboratory Test Scenarios

	Interfering Radio	RUT	Radio Transmitting Desired Signal to RUT	Spectral Separation	Desired Signal Strength, Sd ≈ -85dBm			Desired Signal Strength, Sd ≈ -95dBm			
					w/o Bandpass on Si	w/ Bandpass on Si	Alternate Software / Firmware Version	w/o Bandpass on Si	w/ Bandpass on Si	w/ Duplexer	Alternate Software / Firmware Version
ACSES Desense ITC	ACSES	ITC Base	ITC Locomotive	50 kHz							
				1.1375 MHz	✓	✓		✓	✓	✓	
	ACSES	ITC Base	ITC Wayside	50 kHz				✓			
				1.1375 MHz	✓	✓		✓	✓		✓
	ACSES	ITC Wayside	ITC Base	50 kHz	✓			✓			
				1.1375 MHz	✓	✓		✓	✓		✓
	ACSES	ITC Loco	ITC Base	50 kHz	✓			✓			
				1.1375 MHz	✓	✓		✓	✓		
ITC Desense ACSES	ITC Base	ACSES	ACSES	50 kHz	✓			✓			
				1.1375 MHz	✓	✓	✓	✓	✓	✓	✓
	ITC Wayside	ACSES	ACSES	50 kHz	✓			✓			
				1.1375 MHz	✓	✓		✓	✓		
	ITC Loco	ACSES	ACSES	50 kHz							
				1.1375 MHz	✓	✓		✓	✓		

Figure 1 provides an overview of the physical layout of the radio network for laboratory testing. The four radios used for each given test were connected to an eight-way power splitter to allow the receiving RUT to be subject to both the desired and interfering signals simultaneously. Attenuators allowed for control of the signal level to within +/- 1 dBm. Signal strength measurements were taken with an Agilent Handheld Spectrum Analyzer (HSA), model number N9342C. Fifty ohm terminators were applied to any open connections.

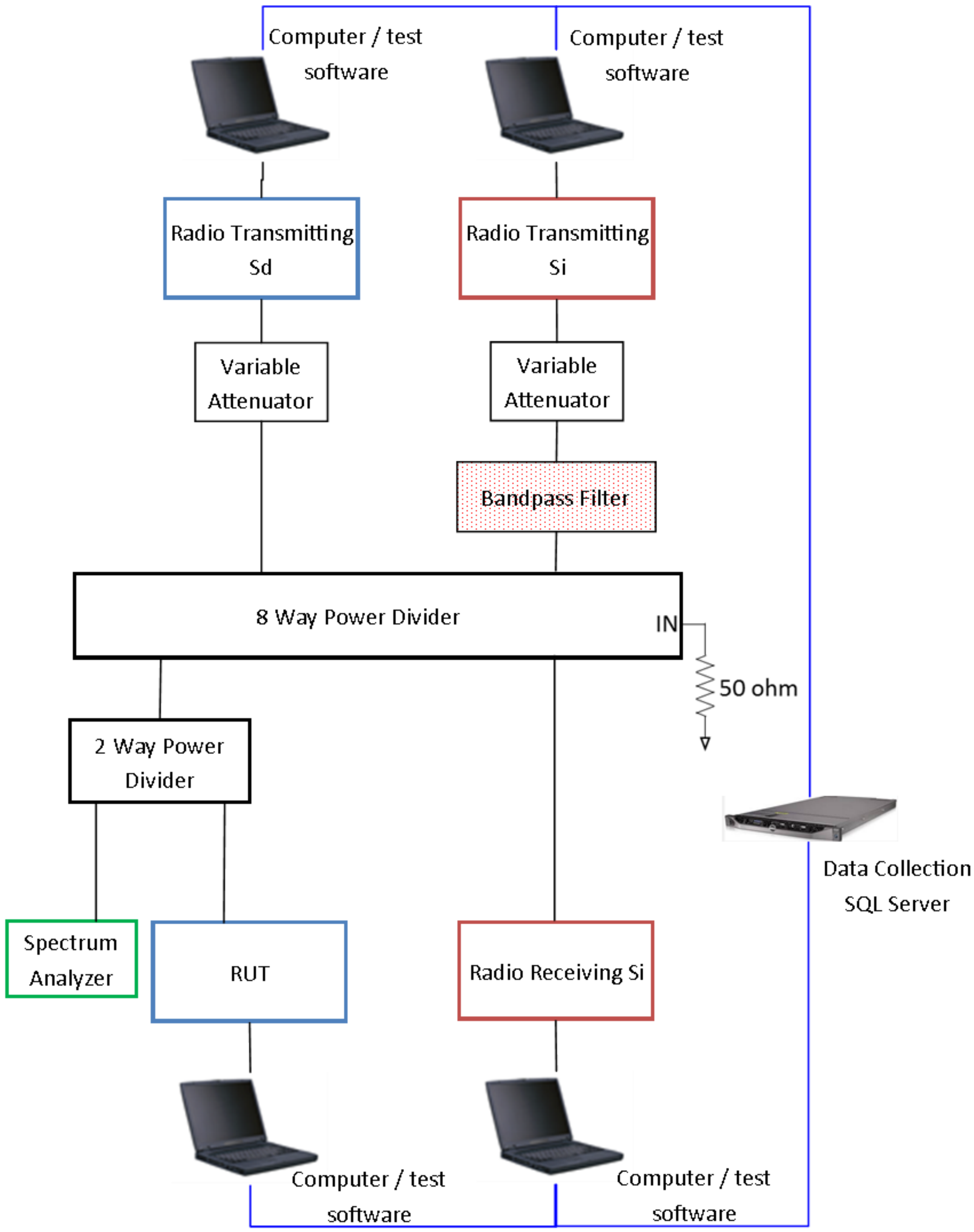

Figure 1. Standard Laboratory Test Setup

2.2.3 Field Testing

A subset of laboratory tests were conducted in the field to validate the results found in the laboratory, and these included:

- An ITC base versus an ACSES base
- An ITC wayside versus an ACSES base
- An ACSES mobile versus an ITC wayside

Additionally, testing included scenarios without a corresponding laboratory component. These involved an ACSES and ITC base station being co-located, each with an independent antenna on CORE tower. The antenna used for the ACSES system was located at a height of 60 feet, and the antenna used for the ITC system was located at a height of 105 feet. Two antenna alignments were tested, one in which the vertical nulls of the antenna were aligned to provide the maximum amount of isolation between the RF signals transmitted and/or received through the two antennae, and another in which the vertical nulls of the antenna were misaligned, thereby reducing the amount of isolation between the antennae.

Testing involved using one of the base radios as the receiving RUT, and the dissimilar base radio as the interfering radio. An RF duplexer was tested as a potential mitigation approach for providing isolation between the transmit (Tx) signal and the receive (Rx) signal of the dissimilar bases for the co-located base testing scenarios, and was completed with the antennae aligned, as well as with the antenna misaligned. Table 5 provides the measurements of the isolation for the two antenna alignments used for testing at CORE tower. Measurements were taken with a calibrated benchtop spectrum analyzer, Agilent Model E4404B. The table shows that misaligning the antenna reduced the isolation between the two antennae by approximately 7dB at a frequency of 218.975 MHz.

Table 5. Isolation Measurements for Antennae Alignments at CORE Tower

Tx/Rx Frequency: 218.975 MHz **Channel Bandwidth: 12.5 kHz** **Tx Signal: 0 dBm**	**Rx Signal (dBm) Strength** *Rx Antenna Height: 100 ft *Tx Antenna Height: 60 ft	**Rx Signal (dBm) Strength** *Rx Antenna Height: 60 ft *Tx Antenna Height: 100 ft
Antenna Aligned	-79.7	-79.8
Antenna Misaligned	-72.1	-71.5
Tx/Rx Frequency: 220.1125 MHz **Channel Bandwidth: 25 kHz** **Tx Signal: 0 dBm**	**Rx Signal (dBm) Strength** *Rx Antenna Height: 100 ft *Tx Antenna Height: 60 ft	**Rx Signal (dBm) Strength** *Rx Antenna Height: 60 ft *Tx Antenna Height: 100 ft
Antenna Aligned	-69.8	-69.6
Antenna Misaligned	-70.3	-70.1

A summary of the field test scenarios is provided in Table 6.

Table 6. Summary of Field Test Scenarios

	Interfering Radio	RUT	Radio Transmitting Desired Signal to RUT	Spectral Separation ACSES: 218.975 MHz / ITC: 220.1125 MHz	Desired Signal Strength, Sd ≈ -95dBm			
					Antenna Aligned (applies to co-located only)	Antenna Aligned w/ Duplexer (applies to co-located only)	Antenna Misaligned(applies to co-located only)	Antenna Misaligned with Duplexer(applies to co-located only)
ACSES Desense ITC	ACSES Mobile / Loco DOT 004	ITC Wayside / Bucket Truck 40 ft	MCC Base / CORE Tower	1.1375 MHz	✓			
	ACSES Base / Bucket Truck 60 ft	ITC Base / CORE Tower	ITC Loco / Loco DOT 004	1.1375 MHz	✓			
	ACSES Base / CORE Tower Co - Located	ITC Base CORE Tower Co-located	ITC Loco / Loco DOT 004	1.1375 MHz	✓	✓	✓	✓
ITC Desense ACSES	ITC Wayside / Bucket Truck 40 ft	ACSES Base / CORE Tower	ACSES / Loco DOT 004	1.1375 MHz	✓			
	ITC Base / Bucket Truck 100 ft	ACSES Base / CORE Tower	ACSES / Loco DOT 004	1.1375 MHz	✓			
	ITC Base / CORE Tower Co-located	ACSES / CORE Tower Co-located	ACSES / Loco DOT 004	1.1375 MHz	✓	✓	✓	✓

Field testing was conducted on or near the Precision Test Track (PTT) at TTC. To facilitate field testing, radios and supporting equipment was deployed at the following locations as necessary:

- CORE tower – 120-foot communication tower served as the location for either the ACSES or ITC base, or as the tower with both bases co-located. Two 220 MHz folded dipole antennae were used on the tower; one at 60 feet for use with the ACSES radio, and the other antenna at a height of 105 feet for use with the ITC base radio.
- DOT 004 locomotive – equipped to support an ACSES or ITC mobile radio, with a 220 MHz skate antenna mounted atop the locomotive. This locomotive was positioned along the PTT as needed for each test scenario.
- Bucket truck – used as a moveable base station or ITC wayside for some of the test scenarios. A 220 MHz folded dipole antenna was secured in the bucket of the bucket truck and elevated to an appropriate height based on the requirements of the test scenario. A coaxial cable extended from the antenna in the bucket truck to a radio located and controlled from the level of the truck. The bucket was elevated to a different height depending on the radio used for testing:
    - ITC wayside – 40 feet
    - ITC base – 100 feet

- ACSES base – 60 feet

- Radio laboratory – served as a receiving ACSES or ITC Wayside radio as needed for some of the test scenarios. A 220 MHz folded dipole antenna on the rooftop of the Warehouse Laboratory Facility (WLF), with coaxial cable extending down into the laboratory to allow for connection to a radio.

Figure 2 is a map of TTC tracks; the field testing locations are identified by the red arrows. The field testing followed a similar set of steps as laboratory testing; however, the desired and interfering signal strengths were controlled by the distance between the transmitter and receiver, and with attenuators when necessary. Since signal strength was varied by the distance between the transmitter and the receiver, it was not always feasible to move the equipment distances small enough to accommodate signal strength adjustments of +/- 1 dBm. Distances were selected to achieve the objective of the test, while maintaining efficiency of testing in a field environment.

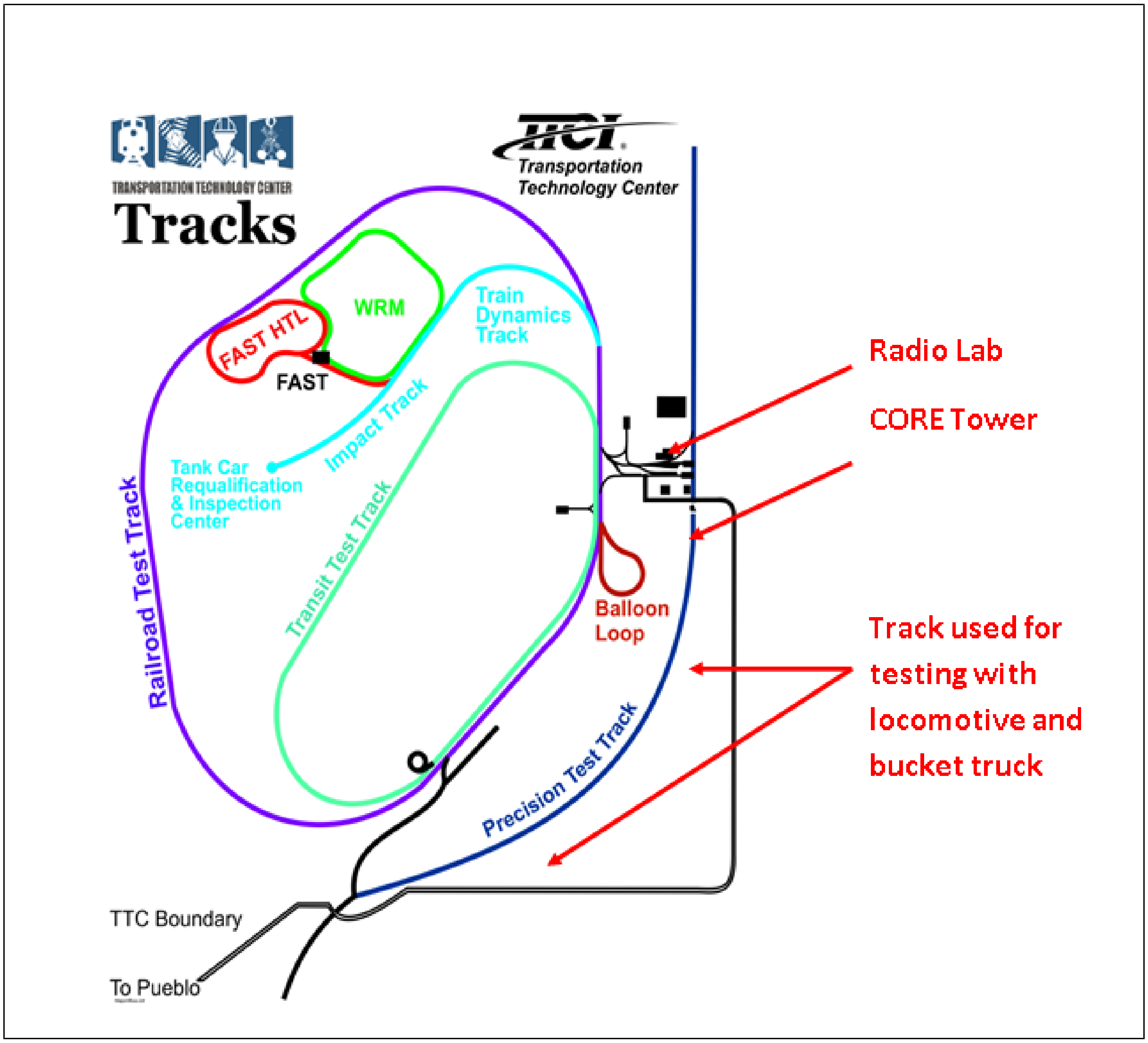

Figure 2. Physical Field Test Locations

Transmit powers from the interfering radios were as follows:

- ITC base – 75W
- ITC locomotive –50W
- ITC wayside –25W
- ACSES base – 30W
- ACSES mobile – 2W

2.3 Test Bed Upgrades and PTC Laboratory Preparation to Support Execution of Desense Test Plans and Procedures

Under this project, the PTC Test Bed at TTC was upgraded with software and hardware that enhances TTC's PTC interoperability testing capabilities. These additions supported the RF desense testing of the dissimilar ITC and ACSES radios. The following software was either adapted or developed specifically to interface to the ITC and ACSES radios:

- MCC Radio Frame Trace Manager
- Network Traffic Generator (NTG)
- Statistics Tool

The hardware upgrades included equipment to support laboratory and field RF desense testing:

- Installation of 220 MHz on CORE tower
- 220 MHz duplexer
- Ancillary testing support equipment and services

2.3.1 TTCI Developed Test Applications

The test applications developed by TTCI performed these core functions:

- Synchronization of the transmitted packets from the GE radios with the transmitted packets of the ITC radios
- Collection and organization of transmit (Tx) and receive (Rx) message information from the ACSES and ITC radios used in each test scenario into a SQL database to allow for efficient post processing
- Representation, both graphically and numerically, of PER for the RUT in nearly real time

MCC Radio Frame Trace Manager

The MCC Radio Frame Trace Manager, shown in Figure 3, was developed by TTCI to support desense testing with the MCC radios. It captures the transmitted and received message information from the MCC radios and sends it to a SQL server database for later analysis and for use with the Statistics Tool described below. For each test scenario, the user specifies the names of the test scenario, and the transmitting and receiving MCC radios. The message information saved to the database is then organized by these names allowing for clear documentation and organization of the data that is easily queried in the database.

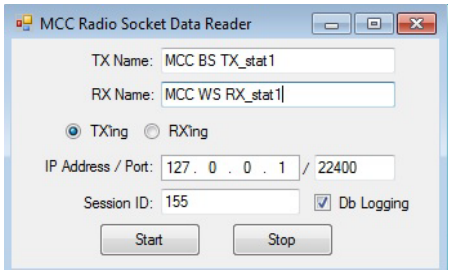

Figure 3. Screenshot from MCC Radio Frame Trace Manager

Network Traffic Generator (NTG)

The NTG was an existing TTCI developed program used for previous communication testing; Figure 4 provides a screen shot of the main screen of the NTG. The NTG was updated to interface with the GE radio and allow the user to configure packet size, packet content, and schedule in which timeslot packets are transmitted by the GE radio. It, also, allows the user to view real-time logs of transmitted and received messages. The NTG sends the transmitted and received radio message information to a SQL database. Similar to the MCC Radio Frame Trace Manager, the user specifies the names of the test scenario, and the transmitting and receiving GE radios. The saved message information is organized by the names associated with the test scenario and the radios and can be accessed for data analysis, and use by the Statistics Tool described below.

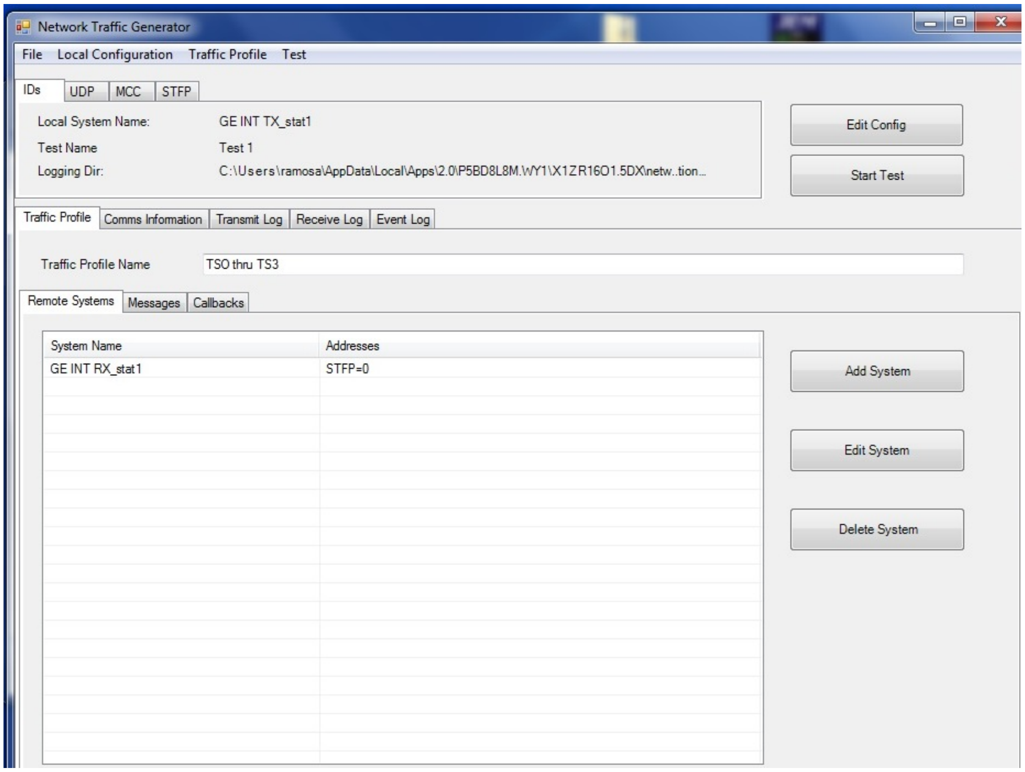

Figure 4. NTG Main Screen

Statistics Tool

The Statistics Tool is a TTCI developed program that obtains transmitted and received message data from the SQL server. The user selects the name of the test, a receiver, and corresponding transmitter used during that test, and the Statistics Tool will provide a graphical representation of the PER for the receiving radio. This real-time information provides the test engineer with a method for observing PER of the RUT while testing and improving the efficiency of testing. A screen shot from the Statistics Tool is displayed in Figure 5. The burgundy-colored line represents the PER, calculated over a user-defined period of time, which was 20 seconds for this image. The smallest refresh period the user can select is 10 seconds. The blue line represents the cumulative PER calculated using the same user-defined time interval. The total messages sent and total messages received can be seen on a separate tab.

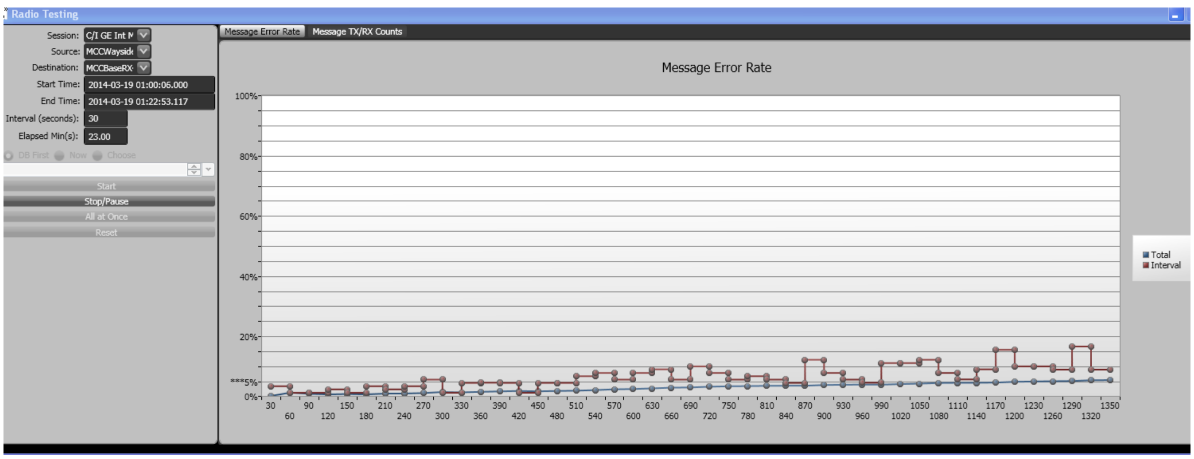

Figure 5. Statistics Tool Displaying PER

2.3.2 Test Equipment

To facilitate testing in both the laboratory and field environments, TTCI identified necessary equipment and services, which included the procurement and installation of a 220 MHz antenna, the procurement of several smaller equipment items, such as a power supply, GPS signal splitter, cable and connectors, and calibration of equipment. Additionally, equipment and services were obtained from MCC to support the testing efforts and to develop the test scripts used to synchronize the transmissions of the ITC radios with those of the ACSES radios.

220 MHz Antenna Installation at CORE Tower

A 220 MHz antenna was installed at CORE tower at a height of 60 feet. To facilitate testing of co-located ACSES and ITC base stations, a second 220 MHz antenna needed to be installed at CORE tower. An antenna of the same model as the antenna installed at 60 feet was purchased and installed at a height of 105 feet. The antenna was a Sinclair 220 MHz folded dipole antenna, model number SD212-SF3P2SNM(D00). Figure 6 identifies this antenna on the CORE tower, and provides a close-up view of the antenna.

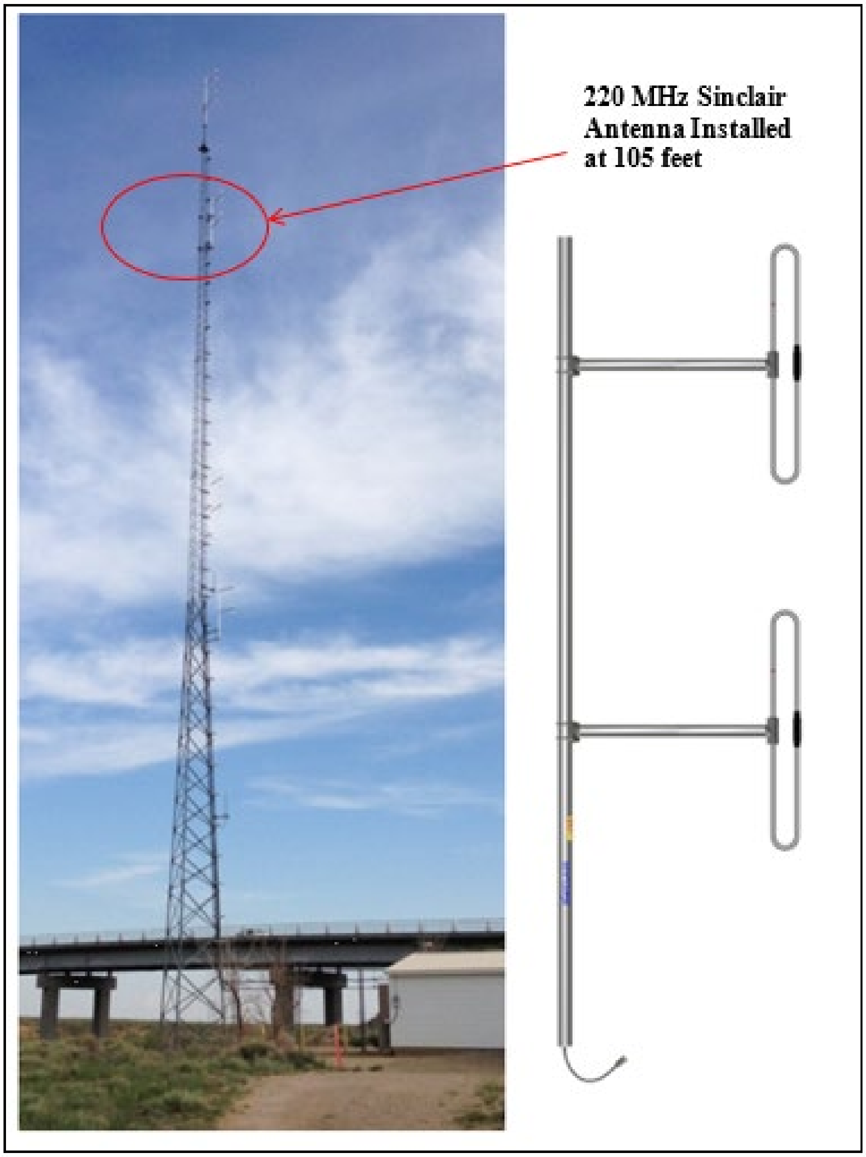

Figure 6. Sinclair 220 MHz Antenna Installed at 105 Feet on the CORE Tower at TTC

Duplexer

In collaboration with the railroads and radio manufacturers of the ACSES and ITC-compliant radios, TTCI identified a duplexer as a potential mitigation on technique for the desense that may result when an ACSES base station and ITC base station are co-located. A Vari-Notch® duplexer was custom designed by Bird Technologies to pass a 25-kHz frequency sub-band < 219 MHz to allow the ACSES radio to transmit and receive on a channel below 219 MHz, while blocking any interfering signals that would be emitted from the ITC base radio in the 220 MHz to 222 MHz. Similarly, the duplexer simultaneously allows the ITC base radio to transmit and receive in the frequency sub-band from 220 MHz to 222 MHz, while blocking interfering signals emitted from the ACSES radio that would be < 219 MHz and meet the following requirements:

- Tx/Rx 1: Passband of at least 25 kHz bandwidth < 219 MHz

    - Allowed the ACSES radio to Tx/Rx on a channel within the 25-kHz bandwidth
- Tx/Rx 2: Passband of 2 MHz bandwidth from 220 MHz to 222 MHz
    - Allowed the ITC radio to Tx/Rx on any channel between 220 MHz to 222 MHz
- Isolation: ≥ 80 dB
    - Reduced the interfering signal levels present in each of the passbands emitted from the dissimilar radio
- Insertion Loss: ≤ 6 dB

The duplexer was tuned to the specific frequencies used for testing; the duplexer characteristics are shown in Table 7.

Table 7. Duplexer Characteristics

	Center Pass Frequency (MHz)	Lower -3dB Point (MHz)	Upper -3dB Point (MHz)	Passband (MHz)	Isolation 1 MHz from Pass Frequency (dB)	Insertion Loss (dB)
Pass Low / Reject High	218.975	218.5475	219.305	0.7575	120.4	-3.1
Pass High/ Reject Low	220.0	219.7	225.1	5.4	115.7	-2.4

Calibration of Spectrum Analyzers

An Agilent HSA, model number N9342C was the primary instrument for measuring signal strength for the duration of testing. The HSA was calibrated prior to commencing any testing. The unit offers a channel scanner feature, which allows for power measurements of up to 20 channels simultaneously.

The Hewlett Packard Spectrum Analyzer and Signal Generator, model number E4404B has a tracking generator feature and was used during testing to tune the duplexer and RF filters, perform cable loss measurements and to make antenna measurements. The unit received a factory calibration prior to use during testing.

Ancillary Equipment and Services Obtained to Enhance PTC Interoperability RF Testing

Several small components were purchased to enhance the PTC Test Laboratory or test bed to support desense testing between the ACSES and ITC radios. These included:

- Upgraded computer components for four rack mountable desktop computers, including core processors, motherboards, random access memory units, cooling fans, and pluggable USB Ethernet wired network adaptors
- Number 6 grounding wire
- Astron Linear Power Supply, Variable, 25 Volts DC, model number VLS-25M
- 8-Way INStock GPS Signal Splitter, with model number GPS 800
- Garmin GPS Antenna and Receiver with model number 16x HVS

- Two 100 W, 30 dB attenuators
- Miscellaneous adaptors, and terminators
- Crimp connectors and RG 223/U cable

2.3.3 MCC Training and Loaned Equipment and Software

MCC provided laptops, software, and engineering support, and permitted TTCI to borrow locomotive radios for testing.

Test Laptops

MCC provided two Dell test laptops, which included the necessary test software to support interfacing with the ITC radios, issuing commands, executing test scripts, and logging messages:

- XtermW is a MCC proprietary variant of Xterm application. It was used to interface with the ITC radios to perform tasks such as issuing commands, loading Configuration Information Management (CIM) scripts, and updating software. This application was used to execute the custom CIM scripts developed by MCC.
- Radio Test Control System (RTCS) is a proprietary MCC application developed to simulate the back office. RTCS simulates ITC back office interaction with the ITC radios as needed to maintain base station transmissions.
- SocketShare is a MCC-developed software that allowed for multiple applications to access the message information being transmitted and received by the MCC radios. This allowed the test engineer to use XtermW to control the radios, RTCS to simulate the Information Technology (IT) back office transactions, and the MCC Radio Frame Trace Manager to log the transmitted and received message information to the SQL server.

MCC Engineering Support

MCC engineering support included training at TTC for RTCS, SocketShare, and XtermW, and collaborating with TTCI engineers to develop custom CIM scripts tailored to the needs of testing. The CIM scripts are used to configure the radio channels to transmit and receive the assignment of messages to timeslots, frame definitions, time synchronization, etc. Each time the radio firmware is initialized, it is configured per the active CIM script. The CIM scripts created for each of the three ITC radio models had custom timeslot and frame definitions to allow for synchronization of messages transmitted by the ITC and ACSES radios during testing.

The following diagrams represent the timeslot assignments of the ACSES and ITC messages, and illustrate the overlap of message traffic in time. The duty cycles vary among the three different ITC radio models, and required a different timeslot configuration for each combination. Additionally, the ITC locomotive does not transmit in the F-Frame, and it required use of the RTCS software, and custom CIM scripts to create nearly continuous transmissions during a custom sized D-frame. Figure 7, Figure 8, and Figure 9 provide the timeslot assignments for the different combinations of ITC radios with the ACSES radio. The orange shaded cells indicate the timeslots in which messages were transmitted.

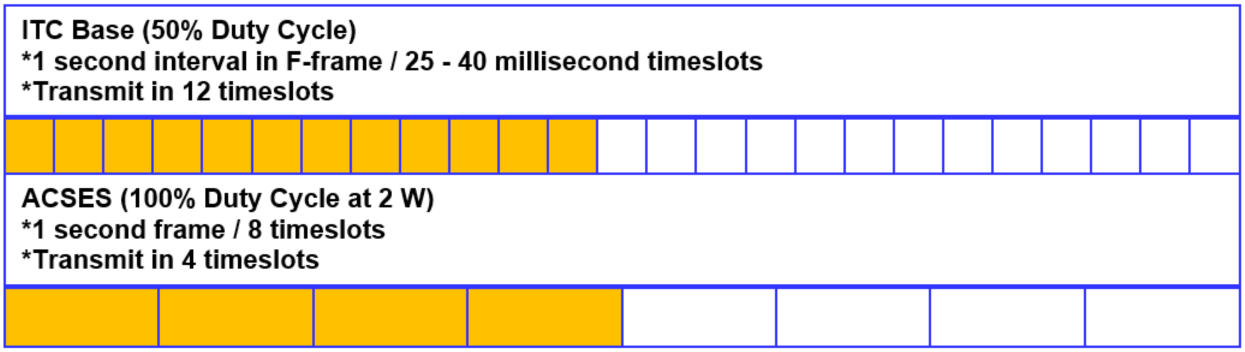

Figure 7. Timeslot Assignments for Scenarios with ITC Base and ACSES Radios Transmitting

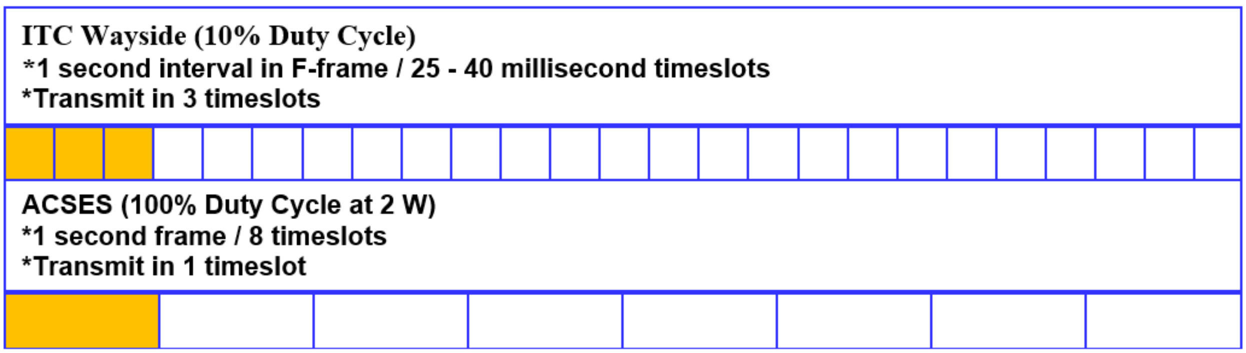

Figure 8. Timeslot Assignments for Scenarios with ITC Wayside and ACSES Radios Transmitting

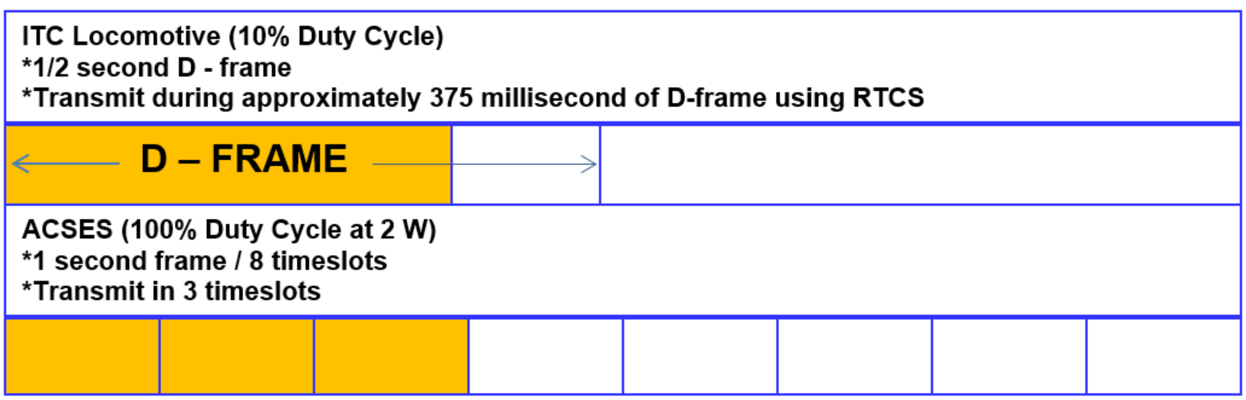

Figure 9. Timeslot Assignments for Scenarios with ITC Locomotive and ACSES Radios Transmitting

An oscilloscope was used during testing to confirm the ITC and ACSES radio messages were transmitted simultaneously. The next two photographs (Figure 10 and Figure 11) were taken of the oscilloscope screen and show the message collision as illustrated in Figure 7. Figure 10 shows the oscilloscope detecting four ACSES message envelopes. ITC messages were not being transmitted at this time.

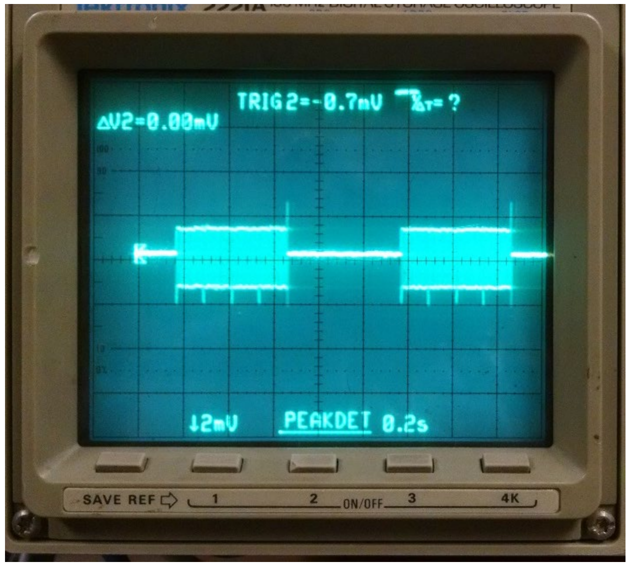

Figure 10. Oscilloscope Used to Observe ACSES Message Envelopes

Figure 11 is a photograph of the oscilloscope detecting the same four ACSES message envelopes, while also detecting 12 ITC messages overlapping the four ACSES messages in the time domain.

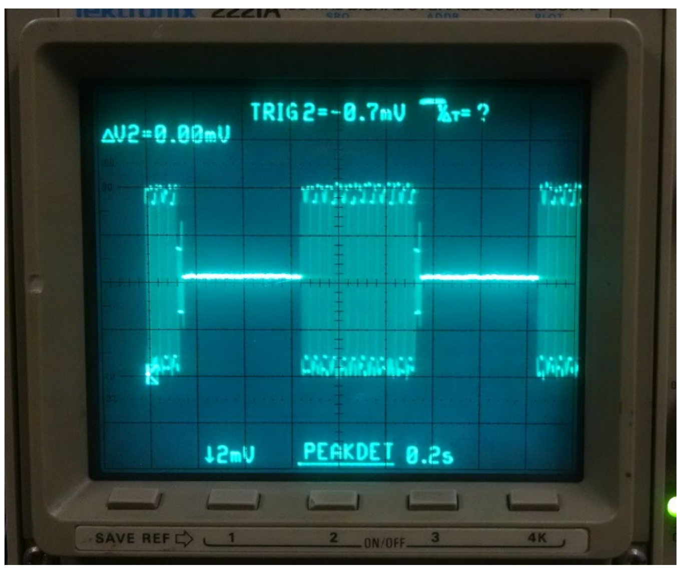

Figure 11. Oscilloscope Used to Observe the 12 ITC Messages Overlapping Four ACSES Messages in the Time Domain

2.4 Laboratory Testing Results

Laboratory testing was conducted in the PTC Laboratory at TTC, which can be seen in Figure 12. From a single location, the test engineer had access to each computer interfacing with each of the test radios, the HSA to observe signal strength in real time, and an oscilloscope to confirm simultaneous message transmissions for the ACSES and ITC radios during testing.

Figure 12. PTC Test Laboratory

As mentioned in Section 3.2.2, the laboratory testing was grouped into four categories:

- Desense testing with and without a bandpass filter on the interfering signal
- Desense testing with alternative software or firmware versions
- Desense testing with a duplexer used for mitigation
- Desense threshold variability testing

Table 8 provides the test results for all laboratory tests except the desense threshold variability tests; the desense threshold variability test results are provided in Table 9. The values show the interfering signal level that resulted in a PER for the RUT that approximated or exceeded 5 percent. To clarify, as the interfering signal strength was increased, some of the radios responded with dramatic increases in PER from below 5 percent, to well beyond 5 percent, with only a 1 dB increase in interfering signal strength.

The signal strength measurements were taken with the Agilent HSA spectrum analyzer operating in channel scanner mode, monitoring the channels used during testing. HSA measurements were logged for post processing. The signal strength representing the average of the values above the 90th percentile of those collected is the value reported for each test in Table 8. The HSA provides measurements with an accuracy of ± 1.5 dB.

Table 8. Laboratory Testing Results for All Tests Except for Desense Threshold Variability Testing

	Interfering Radio	RUT	Radio Transmitting Desired Signal to RUT	Spectral Separation	Si (dBm) resulting in PER ≈ 5% with Sd ≈ -85dBm			Si (dBm) resulting in PER ≈ 5% with Sd ≈ -95dBm			
					Si w/o Bandpass	Si w/ Bandpass on Si	Alternate Software / Firmware Version	w/o Bandpass on Si	w/ Bandpass on Si	w/ Duplexer	Alternate Software / Firmware Version
ACSES Desense ITC	ACSES	ITC Base	ITC Locomotive	50 kHz							
				1.1375 MHz	-15.2	-12.0		-20.2	-16.8	No Des.	
	ACSES	ITC Base	ITC Wayside	50 kHz				-29.7			
				1.1375 MHz	No Des.	No Des.		-18.3	-16.0		-19.6
	ACSES	ITC Wayside	ITC Base	50 kHz	-27.8			-30.4			
				1.1375 MHz	-17.0	-18.5		-18.1	-18.6		-18.8
	ACSES	ITC Loco	ITC Base	50 kHz	-27.3			-28.0			
				1.1375 MHz	-20.9	-20.1		-20.2	-20.4		
ITC Desense ACSES	ITC Base	ACSES	ACSES	50 kHz	-31.4			-38.6			
				1.1375 MHz	-24.3	-23.2	-24.5	-30.0	-26.5	No Des.	-30.5
	ITC Wayside	ACSES	ACSES	50 kHz	-33.2			-38.5			
				1.1375 MHz	-28.3	-26.8		31.5	-30.4		
	ITC Loco	ACSES	ACSES	50 kHz							
				1.1375 MHz	-23.0	-18.6		-31.0	-23.3		

2.4.1 Discussion

The following paragraphs discuss core results for the ITC receivers, ACSES receivers and duplexer testing.

ITC Receivers

The core results observed in the table for the ITC receivers are the scenarios with Sd ≈ -95dBm and without the application of a bandpass filter. ITC RF network design and planning used a target minimum signal level of -92 dBm and -95 dBm at the time of testing. Application of a bandpass filter to the interfering signal may not be a typical practice in revenue service deployments, but was used during testing to more accurately quantify true desense as opposed to in-band interference. For 9 of the 14 test scenarios that were conducted without the filter and again with the filter applied, the difference in Si resulting in a PER of 5 percent was less than 3 dB. The other five scenarios resulted in a 3.2 to 7.7 dB increase of the measured Si with the filter applied. Test results without the bandpass filter applied to the Si may reflect a combination of in-band interference and/or desense. For a spectral separation of 1.1375 MHz, the results ranged from -18.1 dBm for the ITC wayside radio, to -20.2 dBm for the ITC base and ITC locomotive radios.

For Table 8 and subsequent tables, "No Des" is the abbreviation for scenarios in which the PER for the RUT never reached or exceeded 5 percent. For the ITC base test scenarios in which "No Des" is indicated in the table, the ITC base was subjected to a maximum interfering signal strength of -7 dBm and did not exceed a PER of 5 percent; -7 dBm was the maximum interfering signal strength applied to the ITC radios to prevent possible damage to the receivers.

Comparison of the results with and without the application of the bandpass filter to the interfering signal, for both Sd ≈ -85 dBm and Sd ≈ -95 dBm, indicate some level of the spectral energy from the interfering ACSES radio may be present up to 1.1375 MHz, and affecting the ITC base receiver. With the bandpass filter in line, the ITC base tolerated interfering signal strengths up to 3.2 dB greater than without the filter in place.

An approximate 5 percent PER was observed for the ITC base and wayside radios at interfering signal strengths up to 11.3 dB weaker for Sd ≈ -95 dBm as opposed to Sd ≈ -85 dBm. The alternative software testing utilized an older software version without an automatic gain feature. It was completed without the application of the bandpass filter to the interfering signal. The results of the alternative software testing did not demonstrate notable differences from the core results as they were within the measurement error of the HSA.

Comparison of the interfering signal levels for the two spectral separations shows the ITC radios experienced an approximate 5 percent PER at signal strengths 6.4 dB to 12.3 dB weaker when the spectral separation between the interfering and desired signals was 50 kHz as opposed to 1.1375 MHz.

ACSES Receivers

The core results to observe for the ACSES radios are those with Sd ≈ -85 dBm, and without the bandpass filter applied to the interfering signal. The commuter railroads surveyed before testing reported utilizing -85 dBm as the target coverage level for RF network planning. The results ranged from -23 dBm to -28.3 dBm for the test scenarios conducted at a spectral separation of 1.1375 MHz.

Similar to the ITC radios, the application of a bandpass filter to the interfering signal resulted in the ACSES radio tolerating interfering signal levels up to 7.7 dB stronger, and may indicate some spectral energy from the ITC base and ITC locomotive radios may be present 1.1375 MHz away and affect the receiving ACSES radio.

Comparison of results for the two different desired signal strengths yields an approximate 5 percent PER for the ACSES radios at levels up to 8 dB weaker for Sd ≈ -95 dBm as opposed to Sd ≈ -85 dBm. The alternative firmware version test was conducted to provide a comparison of results for the ACSES radio when operating with the updated firmware version, 2.0.13. The test was performed without the application of the bandpass filter and does not indicate a difference in performance, as it was within the measurement error of the HSA.

Duplexer Testing

The duplexer was included in the test laboratory setup as indicated in the test procedures. The desired signal strength was set to approximately -95 dBm, and then the interfering signal strength was increased above the level that previously resulted in desense. The duplexer provided sufficient isolation of the desired and interfering signals, such that the interfering signal incident upon the RUT was not strong enough to result in desense.

2.4.2 Desense Threshold Variability Testing

Desense threshold variability testing included performing the same test procedure for four radios of each model. The intent was to provide a limited set of data to demonstrate the variation in the level of interfering signal which resulted in an approximate five percent PER, from radio to radio for a given radio model and manufacturer. For all radios tested, the Sd ≈ -95 dBm. Testing was completed without the bandpass filter applied to the Si since 9 of the 14 tests did not show an appreciable difference for measured Si with and without a filter, as discussed in Section 3.4.1. The results displayed may be a combination of in-band interference and desense. Table 9 shows the results of desense threshold variability testing; the mean and standard deviation for each radio model and manufacturer is:

- ITC base radio: -14.36 ± 0.34 dBm
- ITC wayside radio: -18.00 ± 0.74 dBm
- ITC loco radio: -20.59 ± 0.50 dBm
- ACSES radio: -23.79 ± 1.01 dBm

Table 9. Results of Desense Threshold Variability Testing

	Interfering Radio	RUT	Radio Transmitting Desired Signal to RUT	Spectral Separation	Radio 1, Si (dBm) resulting in PER ≈ 5%	Radio 2, Si (dBm) resulting in PER ≈ 5%	Radio 3, Si (dBm) resulting in PER ≈ 5%	Radio 4, Si (dBm) resulting in PER ≈ 5%	**Average in (dBm)**	**Standard Deviation (dB)**
ACSES Desense ITC, Sd ≈ -95dBm	ACSES	ITC Base	ITC Wayside	1.1375 MHz	-14.8	-13.9	-14.6	-14.2	**-14.9**	**1.1**
	ACSES	ITC Wayside	ITC Base	1.1375 MHz	-19.3	-17.2	-17.4	-18.4	**-18.0**	**0.7**
	ACSES	ITC Loco	ITC Base	1.1375 MHz	-20.6	-20.6	-21.4	-19.9	**-20.6**	**0.5**
ITC Desense ACSES Sd ≈ -85dBm	ITC Base	ACSES	ACSES	1.1375 MHz	-24.5	-24.9	-22.2	-24.1	**-23.8**	**1.0**

2.5 Field Testing Results

A small subset of laboratory test scenarios was identified for further validation with field testing; the ACSES and ITC radios were deployed in a field environment, representative of revenue service installations. Four of the field test scenarios have a corresponding laboratory component, and the results of these are provided in Table 10. The table includes the interfering signal strengths that resulted in an approximate PER of 5 percent during field testing, and the corresponding laboratory test results for comparison. To efficiently conduct field testing, it was not practical to achieve a 1 dB granularity in the adjustment of the interfering signal strength, because in most of the test scenarios it required moving the bucket truck, repositioning the bucket, and restarting transmissions. Testing was completed without the bandpass filter applied to the Si, thus the results may reflect a combination of in-band interference and/or desense. The photograph shown in Figure 13, was taken during the field test scenario in which the locomotive served as an ACSES mobile radio interfering or desensing an ITC wayside radio stationed in a bucket truck.

Table 10. Field Testing Results Non-Co-Located Test Scenarios

			Si (dBm) resulting in PER ≈ 5% with Sd ≈ -95dBm	
	Interfering Radio	RUT	Lab Testing - Si (dBm) resulting in PER ≈ 5%.	Field Testing - Si (dBm) resulting in PER ≈ 5%.
ACSES Desense ITC	ACSES Mobile / Loco DOT 004	ITC Wayside / Bucket Truck 40 ft	-18.1	-21.8
	ACSES Base / Bucket Truck 60 ft	ITC Base / CORE Tower	-20.2	-17.4
ITC Desense ACSES	ITC Wayside / Bucket Truck 40 ft	ACSES Base / CORE Tower	31.5	-29.3
	ITC Base / Bucket Truck 100 ft	ACSES Base / CORE Tower	-30	-33.5

Figure 13. Field Testing with an ACSES Radio on the Locomotive Desensing an ITC Wayside Radio

The remaining tests are the scenarios with an ITC base and ACSES base co-located, include testing with the antennae aligned and misaligned, and do not have a corresponding laboratory component. The results of the co-located test scenarios are provided in Table 11.

Table 11. Field Testing for Co-Located Test Scenarios

	Interfering Radio	RUT	Radio Transmitting Desired Signal to RUT	Spectral Separation ACSES: 218.975 MHz / ITC: 220.1125 MHz	Antenna Aligned (applies to co-located only)	Antenna Aligned w/ Duplexer (applies to co-located only)	Antenna Misaligned (applies to co-located only)	Antenna Misaligned with Duplexer (applies to co-located only)
ACSES Desense ITC Sd ≈ -102 dBm	ACSES Base / CORE Tower Co - Located	ITC Base CORE Tower Co-located	ITC Loco / Loco DOT 004	1.1375 MHz	-40.1*	No Desense*	-31.9*	No Desense*
ITC Desense ACSES Sd ≈ -95 dBm	ITC Base / CORE Tower Co-located	ACSES / CORE Tower Co-located	ACSES / Loco DOT 004	1.1375 MHz	-25.6	No Desense	-28.4	No Desense

2.5.1 Discussion

Comparison of the results for the laboratory tests and corresponding, non-co-located field tests, yields differences of 2.2 dB to 3.7 dB. During the field test scenario with the ITC base stationed on the bucket truck, and interfering with the ACSES radio located at CORE tower, the bucket truck positions included test locations near power transmission lines. The transmission lines perpendicularly pass over the PTT and access road at approximately 0.48 miles from the CORE tower. The interfering signal strength measured at the RUT was not predictable as the positions of the bucket approached and then passed the transmission lines. Due to this, additional test runs were conducted, as needed, to achieve a PER of approximately 5 percent at the RUT.

The co-located testing scenarios were similar to the base-to-base laboratory test scenarios in the respect that the same combination of radios was used to transmit and receive desired and interfering signals; however, the co-located antenna on a single tower was a test element available in only the field setting. For these test scenarios, the intent was to allow the interfering signal from the co-located base station to transmit at full power, observe whether a PER of five percent or higher occurs, and then insert a duplexer and observe for mitigation of packet loss.

The first test scenario in Table 11 was the ACSES radio at the CORE tower interfering with the ITC base radio; the testing was carried out with the antenna aligned and then with the antenna misaligned. With the desired signal strength, as received at the ITC base, approximately -95 dBm, the interfering ACSES signal was introduced and increased to the maximum possible transmit power of 30 Watts with the use of an amplifier. Table 5 shows the signal strength transmitted from the ACSES radio at the test frequency 218.975 MHz, on the 60-foot antenna, was reduced by approximately 79 dB with the antenna aligned and 72 dB with the antenna misaligned, as received at the end of the feeder cable from the 100-foot antenna. This provided sufficient isolation from the interfering ACSES signal to prevent desense at the RUT. For this particular test scenario, the test procedure was adapted during testing, in an effort to observe an approximate PER of 5 percent. The desired signal level was decreased until PER was observed at the RUT with the introduction of the interfering ACSES signal at the full 30W. The results in the table correspond to a desired signal strength of approximately -102 dBm.

For the second test scenario, the ACSES radio received the desired signal at a level of approximately -95 dBm, and was desensed with the introduction of the co-located ITC base transmitting at the full power of 75 W. A PER of 5 percent or greater was observed for testing with the antenna aligned and with the antenna misaligned. Insertion of the duplexer for all co-located test scenarios resulted in PER less than 2 percent, thereby mitigating desense and/or in-band interference at the receiving RUT.

2.6 Analytic Model

As described in Section 3.2.1, the message traffic used for both the ITC and ACSES radios during laboratory and field testing was designed to ensure the messages comprising the desired and interfering signals were transmitted simultaneously. This allowed for a more accurate measurement of desense for each RUT. To assess how desense may impact railroad operations, TTCI developed an analytic model to estimate the probability of message loss occurring in the same timeslot(s) across consecutive F-Frames, for an ITC locomotive radio operating within the coverage area of an ACSES base radio. This type of message loss may result in an operational downgrade for the locomotive.

The probability of message loss at the ITC locomotive radio due to that radio being desensed by an ACSES base station radio transmission is given by:

$$P_{message\ loss}(trains_{ACSES}) = P_{Tx\ collision}(trains_{ACSES}) \cdot P_{desense}(s_d, s_i)$$

Where:

- $P_{message\ loss}$ ($trains_{ACSES}$) is the probability of continuous F-Frame message loss resulting in an operational downgrade as a function of the number of ACSES trains operating under the same ACSES base station as the subject ITC train
- $P_{Tx\ collision}$ ($trains_{ACSES}$) is the probability that ACSES base station transmissions occur at intervals that result in continuous loss of the same portion of the F-Frame as a function of the number of ACSES trains operating under the same ACSES base station as the subject ITC train
- $P_{desense}$ (S_d, S_i) is the probability that the ITC receiver is desensed by the ACSES base station transmissions as a function of desired signal strength, S_d and interfering signal strength, S_i

For the purposes of this model, the following assumptions were made:

- Train positions are static (i.e., no train motion simulation was implemented in this model)
- Sd is fixed at -95 dBm so that radio desense data obtained during laboratory and field tests may be used
- ITC has 4-second frames in which the first second of each is the F-Frame
- ACSES frames are 6 seconds

Given the methodology developed and presented here, the assumptions can be changed to see the effect upon results.

2.6.1 Probability of Message Transmission Collision

If an ITC locomotive fails to receive a current wayside status message for a given wayside within the locomotive's horizon, the ITC onboard computer will assume the most restrictive state for that wayside, which can lead to warning of or enforcing an operational downgrade. The probability of an ACSES base radio message being transmitted at the same time as the ITC locomotive radio is receiving the critical F-Frame signal status information increases as the number of ACSES-equipped locomotives operating within the ACSES base coverage area increases.

Figure 14 is a timeslot diagram showing the 12-second Epoch and alignment of ACSES and ITC frames.

	Sec 1								Sec 2							
ACSES	G1	R1	T10	H1	T11	R2	T12	R3	G2	R4	T13	H2	T14	R5	T15	R6
ITCM	F1		F2		F3		F4		F5		F6		F7		F8	
	Sec 3								Sec 4							
ACSES	G3	R7	T16	H3	T17	R8	T18	R9	G4	R10	T1	H4	T2	R11	T3	R12
ITCM																
	Sec 5								Sec 6							
ACSES	G5	R13	T4	H5	T5	R14	T6	R15	G6	R16	T7	H6	T8	R17	T9	R18
ITCM	F1		F2		F3		F4		F5		F6		F7		F8	
ACSES	Sec 7								Sec 8							
ITCM	G1	R1	T10	H1	T11	R2	T12	R3	G2	R4	T13	H2	T14	R5	T15	R6
	Sec 9								Sec 10							
ACSES	G3	R7	T16	H3	T17	R8	T18	R9	G4	R10	T1	H4	T2	R11	T3	R12
ITCM	F1		F2		F3		F4		F5		F6		F7		F8	
	Sec 11								Sec 12							
ACSES	G5	R13	T4	H5	T5	R14	T6	R15	G6	R16	T7	H6	T8	R17	T9	R18
ITCM																

Figure 14. Timeslot Diagram of 12-Second Epoch with Alignment of ACSES and ITC Frames

Note that in Figure 14, ACSES base transmission slots T10, T4, and T16 all coincide with the same segment of the F-Frame. This means that if the ACSES base transmits in T10, T4, and T16, then that portion of the F-Frame may be blocked for consecutive frames. Likewise, the T11, T5, and T17 combination and the T12, T6, and T18 combination will block portions of the F-Frame in consecutive ITC Frames.

The probability of a single set of ACSES base transmissions that continuously interferes with a segment of the F-Frame, such as (T10, T4, T16), is referred to as an event for this model, and increases as the number of ACSES trains operating under the same ACSES base station as the subject ITC locomotive. This model has three events, denoted by A, B, and C, and each event has an equal probability of occurring, i.e., P(A)=P(B)=P(C).

$$P(A) = P[\{T10, T4, T16\}]$$

$$P(B) = P[\{T11, T5, T17\}]$$

$$P(C) = P[\{T12, T6, T18\}]$$

The Venn diagram shown in Figure 15 represents the possible combinations of events A, B, and C.

- The Square 'S" represents the total possible combinations of Tx slots used.
- 'A' represents event A occurring; corresponding to ACSES base transmissions continuously interfering on timeslots (T10, T4, T16).
- 'B' represents event B occurring; corresponding to ACSES base transmissions continuously interfering on timeslots (T11, T5, T17).
- 'C' represents event C occurring; corresponding to the probability of ACSES base transmissions continuously interfering on timeslots (T12, T6, T18).
- AB, BC, and AC are the combinations resulting in two event combinations occurring, and AB=AC=BC.
- ABC is the combinations resulting in all three event combinations occurring.

$P_{Tx\ collision}$ is the probability any of one of the three events, A, B, or C, occurring and is given by:

$$P_{Tx\ collision} = P(A)+P(B)+P(C) – P(AB) – P(BC) – P(AC) + P(ABC) = 3P(A)-3P(AB)+P(ABC).$$

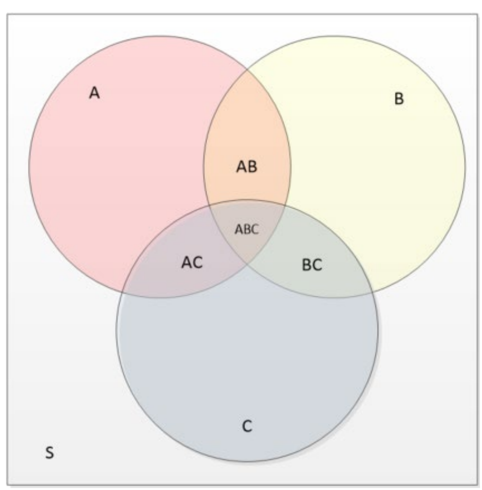

Figure 15. Venn Diagram Illustrating the Different Possible Combinations of Events A, B, and C

The curve shown in Figure 16 illustrates the relationship of the probability of consecutive F-Frame message collision as a function of the number of ACSES trains operating under the same ACSES base station as the ITC locomotive. Message loss will be dependent on the desired and interfering signal strengths received at the ITC locomotive.

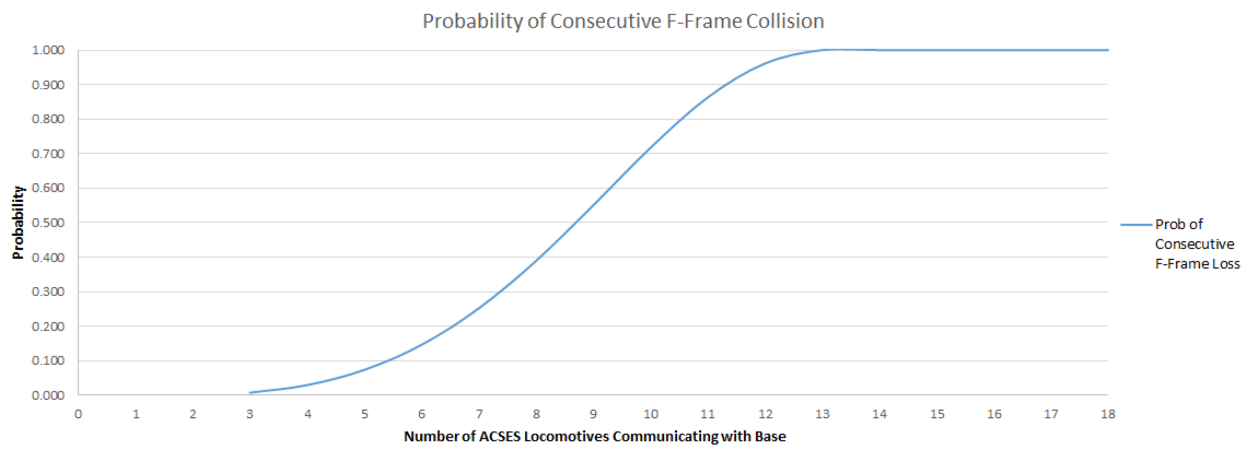

Figure 16. Probability of Consecutive F-Frame Message Collision as a Function of the Number of ACSES Trains

2.6.2 Probability of Desense

A radio subject to an interfering signal is considered desensed when the PER is greater than or equal to 5 percent (Section 3.2.1 Test Procedure Summary). The interfering signal level resulting in a 5 percent PER for the subject radio is dependent upon the desired signal strength received at that radio. The stronger the desired signal is, the stronger the interfering signal will have to be in order to cause desense. The interfering signal level is a function of the distance between the radio subject to interference and the interfering radio; for the model, this is the distance between the ITC locomotive and the interfering ACSES base. Therefore, the probability of desense is a function of the desired signal strength received by the locomotive and the distance between the locomotive and ACSES base.

PER versus Interfering Signal Level

Message collision does not guarantee message loss; the PER of the ITC locomotive radio is dependent upon the interfering signal strength of the ACSES transmissions. Laboratory data collected during the desense threshold variability testing of an ACSES radio interfering with an ITC locomotive radio was used to establish a relationship for the PER of the ITC locomotive radio as a function of ACSES signal strength. These values were collected with a desired signal of approximately -95 dBm, and are provided in Table 12.

Table 12. ITC Locomotive Radio PER versus ACSES Interfering Signal Strength

ACSES Si (dBm)	ITC Loco PER (%)		ACSES Si (dBm)	ITC Loco PER (%)
-24.570	0.740		-18.811	14.404
-23.544	1.288		-18.452	14.190
-23.440	0.739		-18.140	15.468
-23.092	2.139		-17.878	14.090
-22.465	1.420		-17.843	13.914
-22.443	1.971		-17.635	3.109
-22.283	1.298		-17.500	15.463
-21.633	2.842		-16.782	16.566
-21.482	2.500		-16.771	15.328
-21.414	0.059		-16.680	2.926
-21.379	4.801		-16.582	14.185
-20.815	2.828		-16.025	50.657
-20.648	9.068		-15.905	15.135
-20.592	9.288		-15.874	15.441
-20.550	4.846		-15.774	2.806
-19.949	6.246		-15.115	51.749
-19.867	13.901		-14.822	16.144
-19.604	9.978		-14.600	81.503
-19.448	12.701		-13.894	35.792
/-19.116	5.304		-13.501	63.828

2.6.3 Interfering Signal Strength versus Distance

The interfering signal strengths from the ACSES radio shown in Table 12 can be related to the distance the ITC locomotive is from the ACSES base. Free space path loss (FSPL) calculations were completed to provide the ACSES signal strength as a function of distance from the ACSES base station; Figure 17 is the plot of the FSPL values as the locomotive approaches an ACSES base station. These calculations can then be used to relate the inferring signal strengths obtained during laboratory testing to approximate distances from the interfering ACSES base station. The following parameters were assumed for the free space path loss calculations:

- ACSES base station antenna height: 50 feet
- ACSES base station distance from track: 25 feet
- ACSES base station power, with use of power amplifier: 32 W

- ACSES base station antenna model: SY206-SF11SNM(U)
- ITC locomotive antenna height: 17 feet
- locomotive antenna model: ST221-SF3SNF

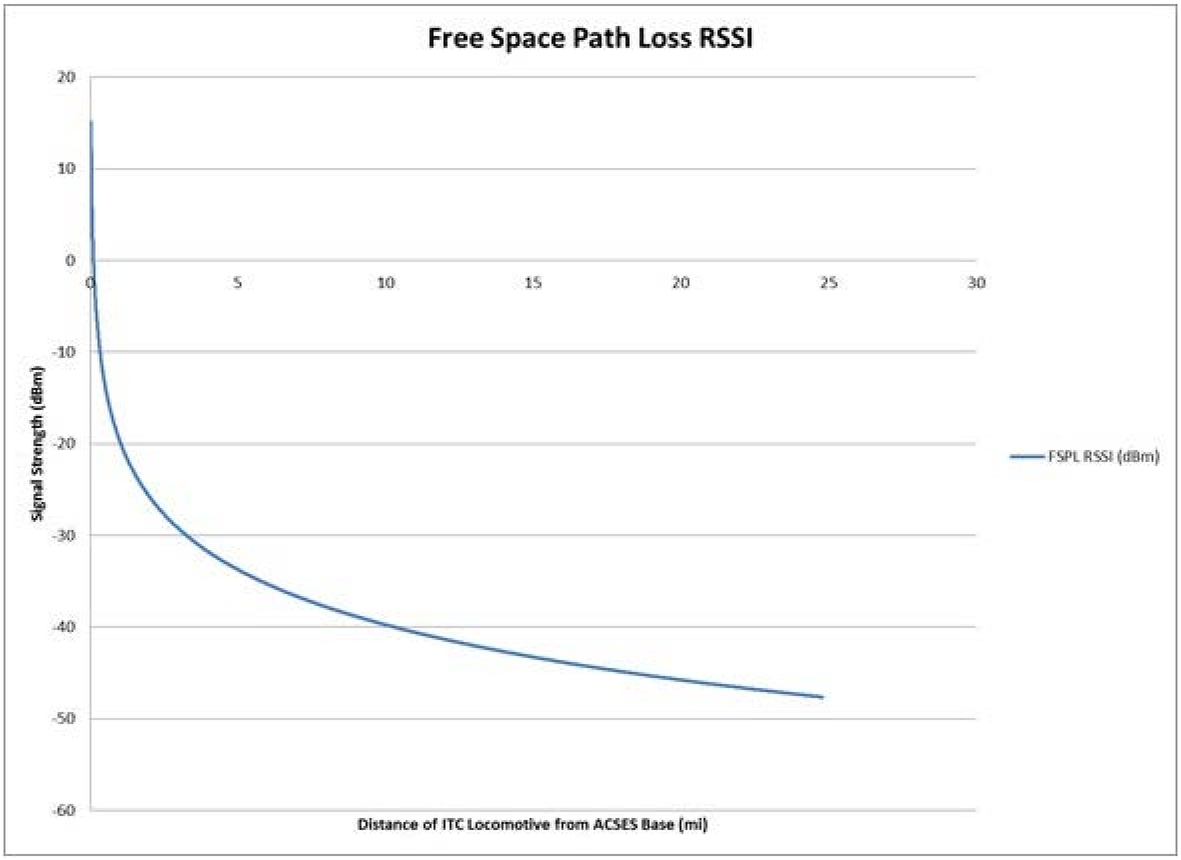

Figure 17. ACSES Interfering Signal Strength Received by ITC Locomotive vs. Distance from ACSES Base Station

The interfering signal strengths in Table 9, collected during laboratory testing for desense threshold variability were related to distance with the free space path loss calculations to provide PER as a function of distance.

Figure 18 represents the PER of the ITC locomotive as a function of distance from an ACSES base station. It is based upon the PER collected during laboratory testing, in which message collision was forced. The data points were fitted with an exponential curve, $y = 4.0252e^{-8x10^\wedge(-4x)}$, shown in red, as approximate the relationship between PER and distance from interfering signal. The fit was based on the limited data collected during this project, and since testing focused on achieving a PER of 5 percent, the majority of data collected reflects PER values of 20 percent or below. A better fit could be achieved if future testing included a more comprehensive experimental dataset, particularly for PER between 80 and 100 percent. Since the dataset is minimal beyond PER levels of 50 percent, the exponential fit curve is not extended beyond the 50 percent PER level. Multiplying the curve by the probability of message loss resulting from a given number of interfering ACSES trains, shown in Figure 19, provides a family of curves that will be discussed in the next section.

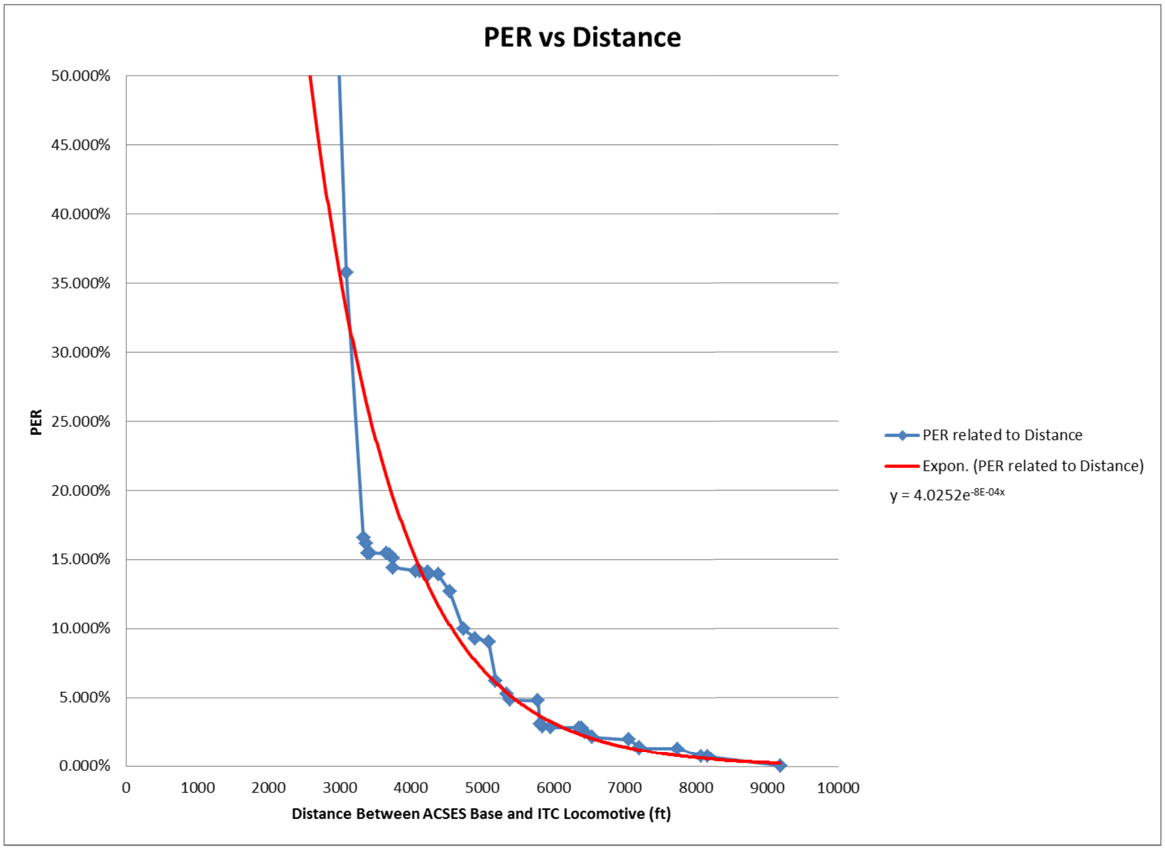

Figure 18. PER of the ITC Locomotive Radio vs Distance from ACSES Base Station

2.6.4 Probability of F-Frame Loss

The model shown in Figure 19 shows the probability of F-Frame loss due to consecutive message loss, which may result in an ITC operational downgrade along the vertical axis. The distance of the ITC locomotive from the ACSES base is displayed on the horizontal axis. Each colored curve represents a different number of ACSES locomotives communicating with the ACSES base. It can be seen that the probability of an F-Frame loss is 10 percent for an ITC locomotive operating approximately 3,400 feet from an ACSES base station. As the number of ACSES trains increases, the ITC locomotive is likely to experience the same 10 percent probability of F-Frame loss at distances further from the transmitting ACSES base station. As discussed in section 3.6.3, the experimental dataset for PER above 80 percent was incomplete and minimal above 50 percent; consequently, the curves shown in Figure 19 do not extend above a probability of 0.5.

The probability of an F-Frame loss that could result in the operational downgrade for an ITC locomotive increases sharply as distance from the base decreases, and/or as the number of communicating ACSES locomotives increases. The model illustrates the importance and necessity of identifying and developing techniques to mitigate interference between the ACSES and ITC systems that will be deployed along the NEC.

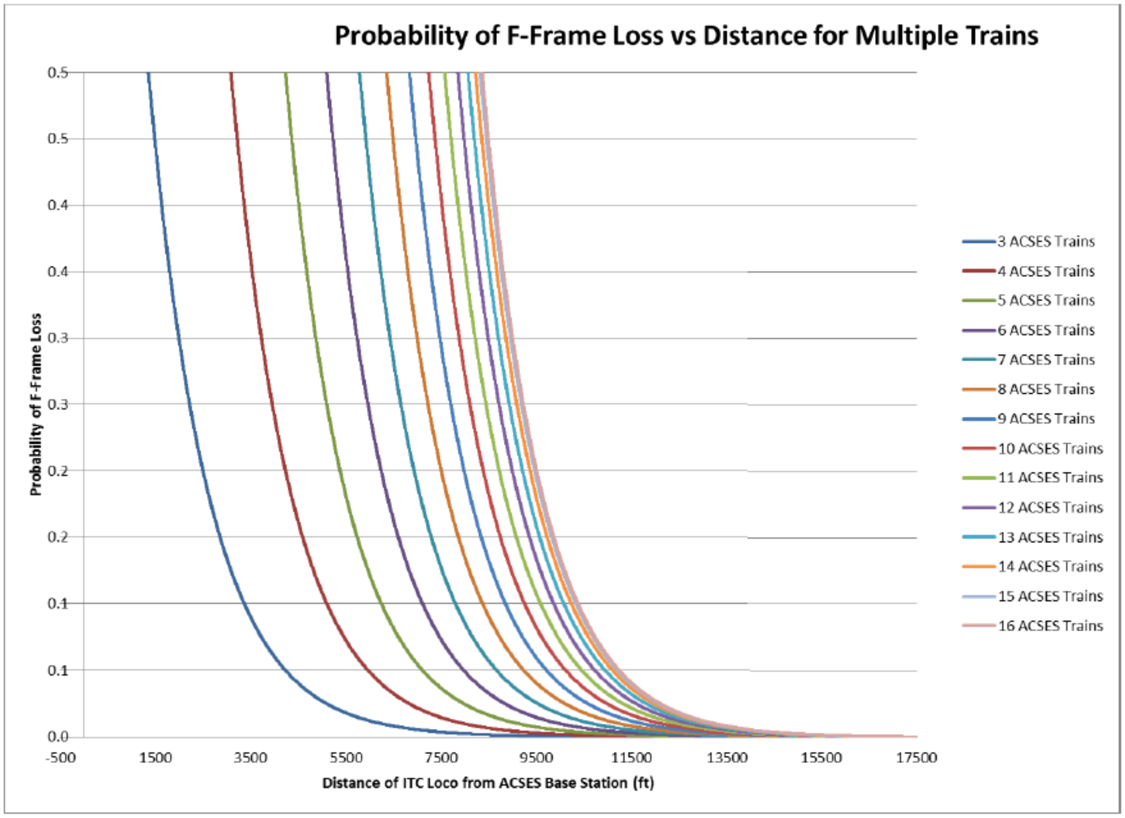

Figure 19. **Probability of ITC Locomotive Operational Downgrade Based on Distance from ACSES Base and Number of ACSES Trains**

2.7 Effect of Desense on Channel Access

The effect of desense on channel access was not conducted under this TO, as TTCI did not have visibility into the channel access protocols to obtain needed information about the transaction of messages between the ITC locomotive and ITC base when attempting to gain channel access. This included details such as, message timing, message triggers, retry rates, etc.

It is expected that channel access may be affected by desense in the same way that transmissions in the F-Frame are affected, because the modulation and front end of the radio is the same whether accessing the common or local channels, but this has not been verified.

3. Conclusion

Under this project, FRA upgraded the PTC test bed to enhance interoperability testing capabilities, and to support RF laboratory and field testing. This included physical test bed changes such as the installation of 220 MHz antenna on the CORE tower, and development of multiple test applications to interface with the ACSES radios, log ACSES and ITC messages, and to provide nearly real-time PER during laboratory testing.

RF desense testing for the ACSES and ITC radios quantified the level of interfering signal from a dissimilar radio that resulted in degraded communications performance. For a spectral separation between the ACSES and ITC radios of 1.1375 MHz, the ACSES TD220x had a PER of approximately 5 percent when subjected to an interfering ITC radio signal level of -28.3 dBm or stronger. The ITC radios had an approximate PER of 5 percent when subjected to an interfering ACSES signal level of -20.2 dBm or higher. The analytic model developed to estimate the probability of message loss under typical PTC message traffic loads indicates the negative operational impacts that may result from the operation of the dissimilar 220 MHz RF networks. An RF duplexer, capable of providing 80 dB or more of isolation between ACSES and ITC signals, demonstrated mitigation of interference and desense for ACSES and ITC radios co-located at a given communication tower.

The results of the RF testing provided information that can be used by the industry to quantify the effects that dissimilar PTC radios will have on one another. Findings from this project have spurred the rail industry to collaborate to develop a solution for the deployment of co-located ACSES and ITC, such as seen on the NEC, without degraded performance due to desense.

4. References

1. Federal Railroad Administration. (June 2015). "PTC Test Bed Upgrades to Provide ACSES Testing Support Capabilities at Transportation Technology Center." Technical Report, DOT/FRA/ORD-15/22: Washington, DC.

Appendix.
PTC Interoperability 220 MHz Radio Test Implementation Plan and Procedures

PTC Interoperability Support
220MHz Radio Test Implementation Plan and Procedures

April 2014

Presented By:

Transportation Technology Center, Inc.

A Subsidiary of the **Association of American Railroads**

55500 D.O.T. Road

P.O. Box 11130

Pueblo, Colorado, USA 81001

PTC Interoperability Support
220MHz Radio Test Implementation Plan and Procedures

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1.0 Project Title

PTC Interoperability Test Support - Radio Testing Component

2.0 Introduction

Throughout the United States, there are various segments of track in which freight trains run on passenger rail and vice versa, for instance along the Northeast Corridor (NEC), Norfolk Southern (NS) trains will run on Amtrak tracks, Union Pacific (UP) trains will run on Caltrain track in California, and CSX will run on SEPTA tracks in Pennsylvania. Also, on some corridors such as the NEC, freight trains and passenger trains run on the same route on adjacent tracks.

UP, CSX, and NS will all utilize an Interoperable Train Control-compliant (ITC-compliant) system, often referred to as ITC or I-ETMS. On the other hand, some of the passenger and commuter lines will have different implementations of positive train control (PTC), which can vary from ITC significantly. For instance Amtrak and SEPTA will use Advanced Civil Speed Enforcement System (ACSES) along their lines along the NEC.

ITC compliant radios consist of three different units, a base station, wayside unit, and a mobile unit. The ITC base station uses a Meteorcomm (MCC) radio, model number 63030-24, with a peak transmit power of 75Watts (W) and maximum duty cycle of 50%. The ITC wayside unit uses a MCC radio, model number 63010, with a peak transmit power of 25W and a maximum duty cycle of 10%. The ITC mobile unit uses a MCC radio, model number 63020, with a peak transmit power of 50W and maximum duty cycle of 30%.

ACSES radios consist of only the General Electric model TD220x radio with a transmit power of 2W to 25W and duty cycle of 100% at 2W, and 30% at operating powers greater than 2W.

For the cases in which multiple systems will operate within the same geographical area, a single base station might be equipped with multiple antennas (one per system). Likewise, certain locomotives will be equipped with both ACSES and ITC systems. Even if the systems are not co-located, there will be cases in which they will be operating in the near vicinity of each other, e.g., an ITC-equipped locomotive running by an ACSES-equipped base station. Both PTC systems' radios operate in the 217-222 megahertz (MHz) band; when a number of radios are operating in the vicinity of one another, even at different non-adjacent frequencies, the high level of radio frequency (RF) energy from one transmitter can capture the front end of a receiver, thus reducing its RF sensitivity level and in turn, its performance. This phenomenon is known as RF desensitization.

The purpose of this study is to learn the effects that the operation of ACSES and ITC radios, in the vicinity of one another, will have on the performance of the radios, specifically related to desensitization. Laboratory and field tests will be conducted to evaluate the level at which the various, mobile, locomotive and wayside receivers of the ACSES and ITC systems are subject to desensitization. The results of which will help to identify limitations in location and placement of the ACSES and ITC communications equipment for revenue service deployments. All permutations of the four dissimilar radio types will be lab tested for desense and select cases will be field tested. The result may also affect frequency assignments used by the railroads.

The test scenarios of interest can be summarized as follows:

- A locomotive transmitter desensing a base station (lab only)
- A base station desensing a locomotive receiver (lab only)
- Base stations desensing each other, co-located and non co-located, aligned/misaligned antennae, with and without a duplexer (lab and field)
- ACSES base station desensing an ITC WIU (lab only)
- ITC WIU desensing an ACSES base station (lab and field)
- ACSES locomotive desensing an ITC WIU (lab and field)
- Locomotive radios desensing each other (lab only)
    - Note: the ACSES base and mobile radios are the exact same model. Therefore, an ITC base desensing an ACSES locomotive will exhibit the same desense characteristics as an ITC base desensing an ACSES base.

This document details the plan and procedure for testing the radio component of interoperability at the Transportation Technology Center, Inc (TTCI) regarding desensitization.

2.1 Documentation

The results of this test will be documented within the final report for this project.

3.0 Scope

This document considers tests for ACSES and ITC radios operating in the 220 MHz band. Testing of other adjacent technologies or radios operating in other bands such as ACSES at 900 MHz, 160 MHz voice, cellular, Wi-Fi, etc., will not be considered here. Testing is focused only on evaluating the desense level of the various receivers of the ITC and ACSES PTC systems. The majority of the testing will be conducted in a lab environment, and a small subset has been identified for further validation with field testing.

These tests have been selected based on input from railroads of the NEC, and are considered most pertinent to PTC communication system planning for the NEC. The intent of testing is to identify the loss in performance of the radios due to desense and does not intend to characterize adjacent channel interference or sideband noise.

4.0 Preparation

In preparation for field testing of the radio interoperability between ACSES and ITC systems, the following tasks will be completed:

- Gathering of necessary input from railroads/suppliers pertaining to specific implementation plans. ITC RF network design plans for approximately -95dBm target coverage for all ITC radios while, input from the ACSES commuter railroads indicates a target coverage level of approximately -85dBm.

- Gathering of technical information on the operation of the equipment to be used in ACSES and ITC territory.
- Identification of computer software required to support testing with the ACSES and ITC radios, including existing software requiring modification, and software to be specially developed. Software will serve many functions during testing, including, interfacing with the radios, allowing the user to determine packet size and timeslot assignment, and data generation, acquisition and logging. Section 5.3 provides descriptions of the required software.
- Selection of channels for use with the ACSES radios, and application for special temporary authority (STA) with FCC for those channels. TTCI has existing authorization to operate the ITC radios on PTC220 channels, and therefore will not need to apply for a STA for channels to use with the ITC radios.
- Testing lab setup/checkout. This includes testing and calibration of the equipment for base stations and mobiles in a laboratory environment. The radios, interfacing computers, and data storage computer will be networked to a private switch via Ethernet to allow for control of radios and data collection. The computer software will be configured and tested to ensure it is functioning properly, and executing tasks as intended. The data generation and data acquisition tools will also be tested to ensure data is generated and recorded as expected. Received signal strength readings for the radio under test (RUT) will be measured with a calibrated Handheld Spectrum Analyzer (HSA) in the lab as the transmit signal level is varied using direct connection and attenuators between transmit and receive radios (no RF transmission over the air will take place in the lab). The HSA serves as a modular, multi-channel, RF signal strength meter and Global Positioning System (GPS) receiver.
- Installation of 220 MHz antenna on CORE tower.
- Testing field setup. This includes installation of the mobile, wayside, and base station radio equipment, and testing their proper functionality before performing the radio tests. Radios will be installed and operated at various locations at the Transportation Technology Center (TTC) to perform the field testing, these include:
    - a locomotive to function as a mobile radio for either ACSES or ITC
    - the CORE tower to function as a base station for either ACSES or ITC, and
    - a bucket truck to function as a moveable fixed-site station, i.e., an ITC wayside or an ACSES or ITC base station.

  At each location, the radio will be controlled, and data will be collected and logged on an interfacing computer connected via Ethernet. The data collection methods will be tested during setup to ensure data is generated and recorded as expected. Received signal strength readings will be measured and recorded at the input of the RUT using a calibrated HSA.

5.0 Implementation

5.1 Constraints

Transmission power and height above average terrain (HAAT) restrictions on the base stations and the mobiles must be observed in order to comply with FCC regulations. At the time of developing this procedure, base stations that operate in the 221 MHz - 222 MHz part of the PTC220 spectrum are restricted to transmit with an Effective Radiated Power (ERP) of 50 W and HAAT of 7 meters (m) or 22.97 feet (ft). This constraint has been considered, and the testing of ITC radio transmission effects upon an ACSES radio receiver will have the ITC radios transmitting in the lower half of the PTC-220 spectrum (220-221 MHz) to allow use of higher ERP and to represent the more challenging requirement for filters.

5.2 Frequency Selection

In order to study the impact of frequency separation between ITC and ACSES systems, two different frequency separation tests will be carried out in a laboratory setting. To begin lab testing, a 50 kHz separation will be used followed by a 1.1375 MHz frequency separation. ACSES utilizes 12.5 kHz channels, while ITC uses 25 kHz channels. Field testing will only use the 1.1375 MHz frequency separation. Frequency selection is shown in Table 1 and frequency separation is measured from center frequency to center frequency.

Table 1. Frequencies chosen for the ACSES and ITC systems.

	Center frequency (MHz)	Lower frequency (MHz)	Upper frequency (MHz)	Frequency Separation (MHz)
ACSES 1 (fA1)	220.7125	220.7000	220.7250	0.0500
ITC 1 (fA2)	220.7625	220.7375	220.7875	
ACSES 2 (fA3)	218.9750	218.9625	218.9875	1.1375
ITC 2 (fA4)	220.1125	220.0875	220.1375	

5.3 Radio and Software Preparation

All radios will be configured using computers that have specific programs installed to interface with the radios. Several programs will be utilized to support testing, some being specific to the ITC radios, some to the ACSES radios, and some programs support either radio. For most tests conducted in the lab, the logs of the transmitted and received messages will be sent and stored on a SQL Server for later analysis of packet error rate (PER). During field testing, and for a subset of lab tests, the message information will be logged locally to the computer interfacing with the radio. Figure 1 below provides a visual representation of the relationship between the radios, controlling computers, and associated programs.

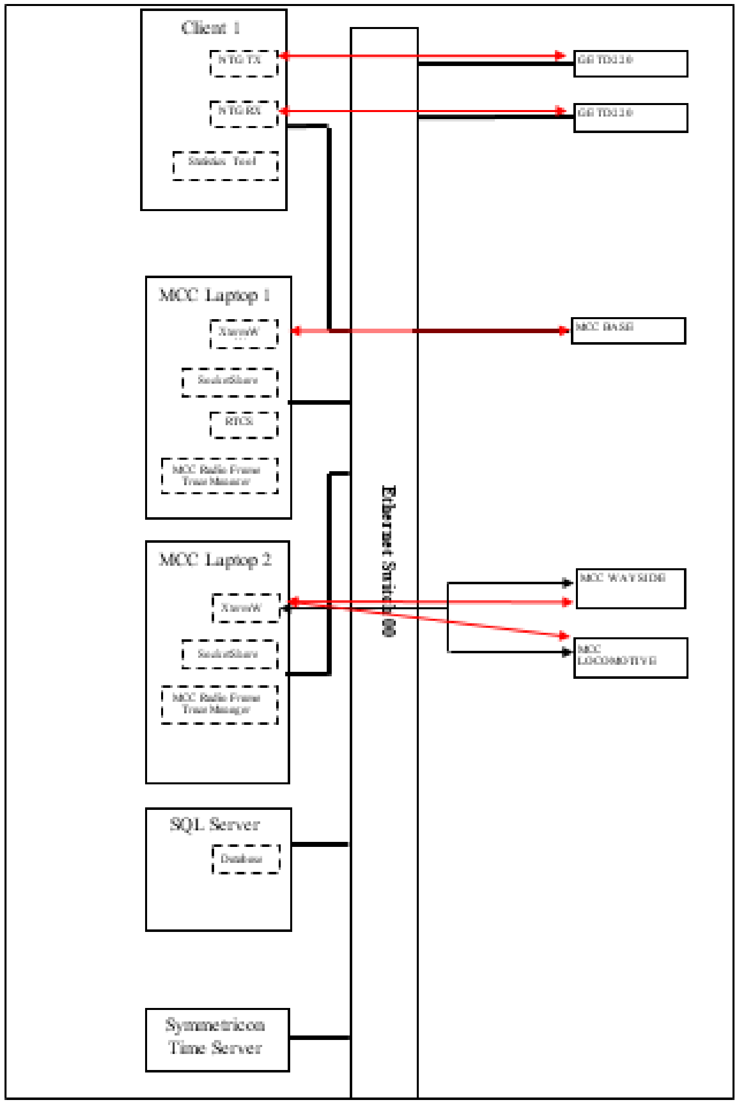

Figure 1. Visual representation of relationship between radios, controlling computers, and associated software.

5.3.1 ITC Radios and Supporting Computer Software and Scripts

Two laptops will be provided by MCC to be used for interfacing with the ITC radios for issuing commands, running programs necessary to support testing, and logging messages. XtermW, SocketShare, RTCS, and the MCC Radio Frame Trace Manager are the programs utilized on the MCC laptops to support testing. These will be utilized to interface with the ITC radios during both lab and field tests.

SocketShare

SocketShare is a proprietary MCC application that will allow multiple port access to the ITC radios, and is the first program to be started when preparing for testing. It will enable three applications, RTCS, XtermW, and the MCC Radio Trace Frame Manager, to simultaneously access the data stream from an ITC radio.

XtermW

XtermW is a MCC proprietary variant of Xterm application. XtermW interfaces with the ITC radios to perform such tasks as issuing commands, loading configuration information management (CIM) scripts, and updating software. It will be used to run scripts that will define the radio settings, the packets, and the transmission rate of the packets.

Software Versions

The ITC radios are software-defined radios. Updates to the software are made by loading software images onto the radios via XtermW. The following MCC 63000 software image files will be utilized for testing:

- 01041403.A17/01041403.A18
- 01042002.A17/01042002.A18

The images with A17 suffix are to be used with the ITC wayside radios, while the images with an A18 suffix are to be used with the ITC base and locomotive radios.

CIM Scripts

CIM scripts are used to configure the transmit and receive channels for the radios, the assignment of messages to timeslots, time synchronization, etc. Each time the radio firmware is initialized, it is configured per the active CIM script. MCC developed the CIM scripts with custom timeslot assignments to support testing with the three ITC radio models.

RTCS

RTCS is a proprietary MCC application developed to simulate the back office. RTCS simulates ITC back office interaction with the ITC radios as needed to maintain base station transmissions.

MCC Radio Frame Trace Manager

The MCC Radio Frame Trace Manager is a TTCI-developed program and will be used to capture the transmitted and received message information from the ITC radios and send it to the SQL server for later analysis.

5.3.2 GE Radio and Supporting Computer Software

A Dell server will be used for interfacing with the ACSES radios to issue commands, run programs necessary to support testing, and log messages while in the lab. Putty, the Network Traffic Generator (NTG), and a Statistics Tool will be used to support testing. This server and a Dell laptop, will be used for interfacing with the mobile radio, and will be utilized during field testing.

Putty

Putty is an open source SSH and telnet client that will be used to create a secure shell (SSH) to the radio, to access the radio configuration menu and tools.

Firmware Versions

The GE radios may have available firmware updates at different times. These can be updated by accessing the radio's menu system with putty. The following firmware versions will be utilized for testing:

- 1.5.8
- 2.0.13

The same firmware versions apply to ACSES radios used as base radios, and those used as mobile radios.

Network Traffic Generator

The NTG is a TTCI-developed program that interfaces with the ACSES radio and allows the user to configure packets size, packet content, and schedule in which timeslots packets are transmitted by the ACSES radio. It also allows the user to view real-time logs of transmitted and received messages. During lab testing, the NTG will send the transmitted and received radio message information to the SQL Server in real-time. The message information stored in the SQL Server can then be used with the Statistics Tool program to provide nearly real-time feedback to the test engineer regarding packet loss rates, or it can be used in later analysis.

5.3.3 Statistics Tool

The Statistics Tool is a TTCI-developed program that obtains transmitted and received message data from the SQL server. It provides a graphical representation of the PER during testing in nearly real-time, as well as the total number of packets transmitted and total number of packets received.

5.4 Operation Sequence

Testing will be conducted in two stages. In the first stage, a more comprehensive set of tests will be conducted in the PTC Lab at TTC. During the second stage, a selected number of scenarios will be deployed and tested in the field at TTC.

5.4.1 Test Variables

The test scenarios will be comprised of various combinations of the control variables:

- <u>RUT</u> will be one of the GE TD 220x, ITC base, ITC wayside, or ITC mobile.
- <u>Radio Transmitting the Desired Signal</u> will be a radio of the similar PTC system as the RUT.
- <u>Radio Transmitting the Interfering Signal</u> will be a radio of the dissimilar PTC system as the RUT.

- Desired Signal level (Sd), received at the RUT. This will be produced by the transmission of packets from a radio of the similar PTC system. Two fixed desired signal levels will be tested, -85 dBm and -95 dBm.
- Spectral separation between the transmitted desired signal and the transmitted interfering signal. Two spectral separations will be used for testing, 50 kHz and 1.1375 MHz.
- Software/firmware version. Two software versions will be utilized for testing with the ITC radios, and two firmware versions will be utilized for testing with the ACSES radios.
- Application of a bandpass filter to the interfering signal. This will be used to remove possible sideband or spurious emissions from the interfering signal in order to ensure that only true desensing is measured.
- Insertion of a duplexer as a potential mitigation technique for desense between an ACSES and an ITC base co-located at a given tower.

For each test scenario formed by selected combinations or permutations of the variables above, a similar set of steps will be followed with the independent and dependent variables as follows:

- Independent variable: the interfering signal strength received at the antenna port of the RUT. The interfering signal will be produced by a transmitter of the dissimilar PTC system.
- Dependent variable: the PER for the RUT.

5.4.2 Procedure Overview and Development

The general procedure for both lab and field testing will be to first set the desired signal strength as measured at the input of the RUT to a fixed level, per the test scenario. Then introduce and incrementally increase the interfering (undesired) signal level from the dissimilar ITC or ACSES radio, until the PER of the RUT is approximately 5%; at this point, communications performance will considered to be degraded.

During testing, both the ITC and ACSES radios will transmit packets of information in formats similar to that of the typical PTC packets sent by each system. Transmission of such packets will be used, as opposed to continuous wave testing, to most closely represent the actual RF interference environment that will exist on the NEC. For both radios, the message size is equal to the maximum for the TDMA slot. This will result in message size equal to packet size such that message error rate (MER) equals PER.

The 5% PER was established as the marker for degraded performance because it is the PER currently used for planning the ITC RF network designs and was considered a reasonable target threshold by commuter and passenger railroads of the NEC who were surveyed regarding acceptable PER for the ACSES RF networks. Many of the commuters that responded design their RF networks to achieve a target coverage signal level of -85 dBm. ITC target minimum signal level is in the range of -92 to -95 dBm.

The data gathered both in the lab and field will be used to quantify the relationship between interfering signal strength, intended signal strength, and the PER. The effect of spectral separation on the PER will also be quantified, to the extent feasible within the constraints of available test channels and project scope.

5.4.3 Simultaneous Message Traffic

To accurately quantify the interfering signal level at which each receiver is desensed, packets originating from the transmitter of the desired signal, and packets originating from the transmitter of the interfering signal will be synchronized or overlapping to the greatest extent possible. The channel access method for the ACSES radio is a Time Domain Multiple Access (TDMA) scheme under the control of a communications manager device, while the ITC radios use multiple channel access schemes, including Fixed Time Division Multiple Access (FTDMA), Dynamic Time Division Multiple Access (DTDMA), and Carrier Sense Multiple Access (CSMA). The frame and timeslot structures are different for the ACSES and ITC radios. In order to ensure the transmitted messages between the dissimilar radios overlap, the NTG will be adapted and used to determine timeslot assignment for ACSES messages while, custom scripts provided by MCC will provide frame and timeslot sizes and timeslot assignment of ITC messages such that the ACSES and ITC messages are transmitted simultaneously.

The following diagrams represent the timeslot assignments for ACSES and ITC messages, and illustrate the overlap of message traffic in time. The duty cycles are different for the three different ITC radio models, and will require a different timeslot configuration for each combination. Additionally, the ITC locomotive does not transmit in the F frame, and will require use of the RTCS software, and custom CIM scripts to create nearly continuous transmission during a custom sized D-frame. Figure 2, Figure 3, and Figure 4 provide the timeslot assignments for the different combinations of ITC radios with the ACSES radio. The orange shaded cells indicate the timeslots in which messages will be transmitted.

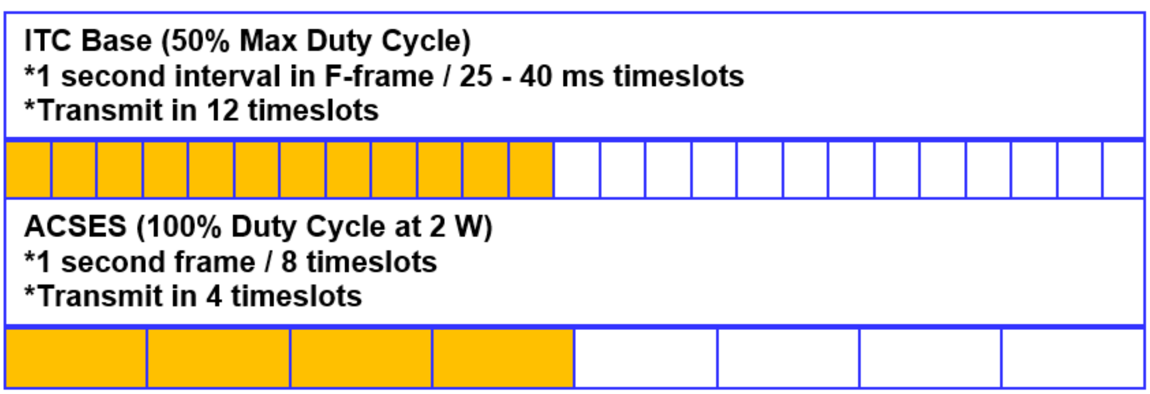

Figure 2. Timeslot assignments for scenarios with ITC Base and ACSES radios transmitting.

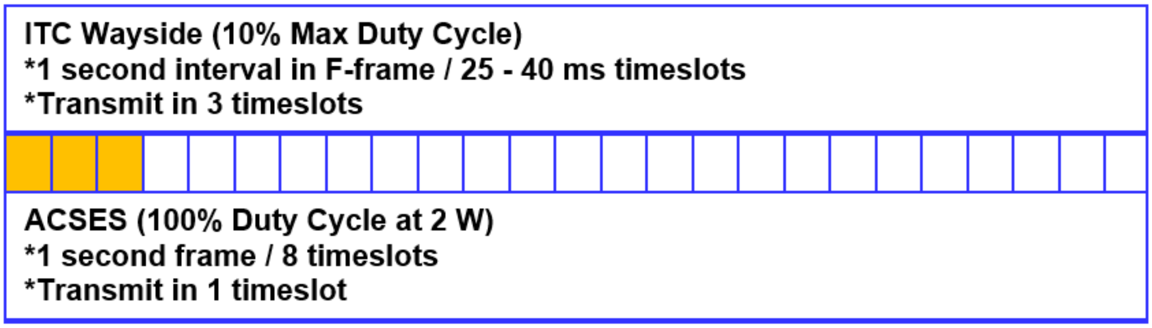

Figure 3. Timeslot assignments for scenarios with ITC wayside and ACSES radios transmitting.

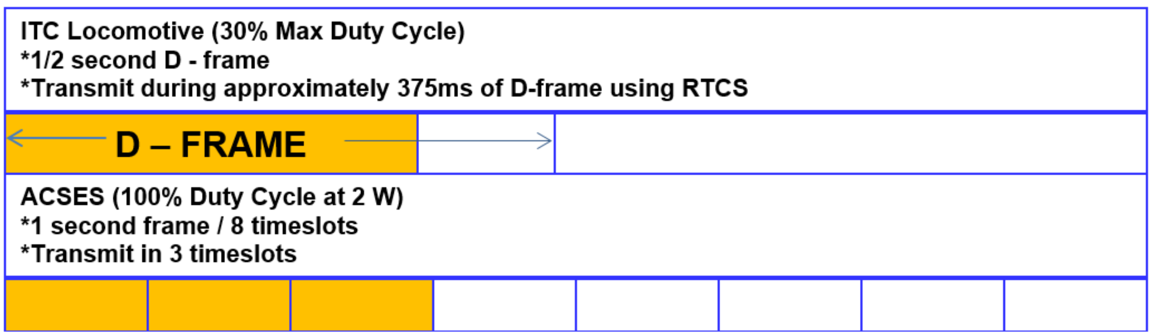

Figure 4. Timeslot assignments for scenarios with ITC locomotive and ACSES radios transmitting.

Figure 3 shows the ITC wayside radio will be transmitting for three 40ms timeslots per second. To protect the ITC wayside radio from damage in the event the duty cycle limit is exceeded, the MCC engineer will include a feature in the wayside radio CIM script(s) to stop transmissions prior to the radio reaching unsafe temperatures.

5.4.4 Lab Testing Scenarios and Setup

The desensitization testing to be conducted in the PTC Radio Lab at TTC can be categorized into 4 groups:

- Desense testing – will include testing combinations and permutations of ITC radio models versus an ACSES radio, two spectral separations, two desired signal strengths, and with and without a bandpass filter
- Alternative software/firmware version testing – a subset of desense tests will be repeated with different versions of software. Specifically, the ITC radios will be tested with an older software version that did not have an automatic gain control function, and the ACSES radios will be tested with a firmware upgrade.
- Duplexer testing – will include repeating a subset of desense tests with a vari-notch duplexer as a potential mitigation technique for desense occurring between the dissimilar radios.

- Desense threshold variability testing - desense testing will be completed for four radios of each model. This provides a limited assessment of the variability of the threshold at which each radio model desenses.

Table 2 below provides a summary of the tests to be conducted in the lab. The cells highlighted yellow will each be repeated with four different receivers of the same model for the variability testing.

Table 2. Lab Test Scenarios

	Interfering Radio	RUT	Radio Transmitting Desired Signal to RUT	Spectral Separation	Desired Signal Strength, Sd ≈ -85dBm			Desired Signal Strength, Sd ≈ -95dBm			
					w/o Bandpass on Si	w/ Bandpass on Si	Alternate Software / Firmware Version	w/o Bandpass on Si	w/ Bandpass on Si	w/ Duplexer	Alternate Software / Firmware Version
ACSES Desense ITC	ACSES	ITC Base	ITC Locomotive	50 kHz							
				1.1375 MHz	✓	✓		✓	✓	✓	
	ACSES	ITC Base	ITC Wayside	50 kHz				✓			
				1.1375 MHz	✓	✓		✓	✓		✓
	ACSES	ITC Wayside	ITC Base	50 kHz	✓			✓			
				1.1375 MHz	✓	✓		✓	✓		✓
	ACSES	ITC Loco	ITC Base	50 kHz	✓			✓			
				1.1375 MHz	✓	✓		✓	✓		
ITC Desense ACSES	ITC Base	ACSES	ACSES	50 kHz	✓			✓			
				1.1375 MHz	✓	✓	✓	✓	✓	✓	✓
	ITC Wayside	ACSES	ACSES	50 kHz	✓			✓			
				1.1375 MHz	✓	✓		✓	✓		
	ITC Loco	ACSES	ACSES	50 kHz							
				1.1375 MHz	✓	✓		✓	✓		

Five different lab setups will be utilized during testing, the schematic diagram for each is provided in the figures below. A brief description of the test scenarios that the schematic applies to is provided below each figure along with the Lab Test Parameter Table reference. The Lab Test Parameter Table contains the information relevant to each test scenario and is referenced in the test setup, preconditions, and procedures tables in section 5.4.5. The Lab Test Parameter Table is an embedded spreadsheet provided directly after the test procedures. Depending on the scenario, the RUT will be an ACSES or an ITC radio. The radios will be interconnected through a power divider and terminated with matched loads. An attenuator will be placed between the power divider and each one of the radios in order to control the transmit signal strength (desired and interfering) at the RUT. These signal levels will be monitored with the HSA. Prior to commencing testing and periodically during testing, the setup will be checked to identify and mitigate significant stray signal leakage.

The RUT will receive messages from its corresponding transmitter. The message logs of the transmitted and received messages will be collected and stored either locally on the interfacing computer, or on the SQL Server database for later analysis. During testing, the statistics tool program will access the SQL database to obtain received and transmitted message counts to display PER values in nearly real-time.

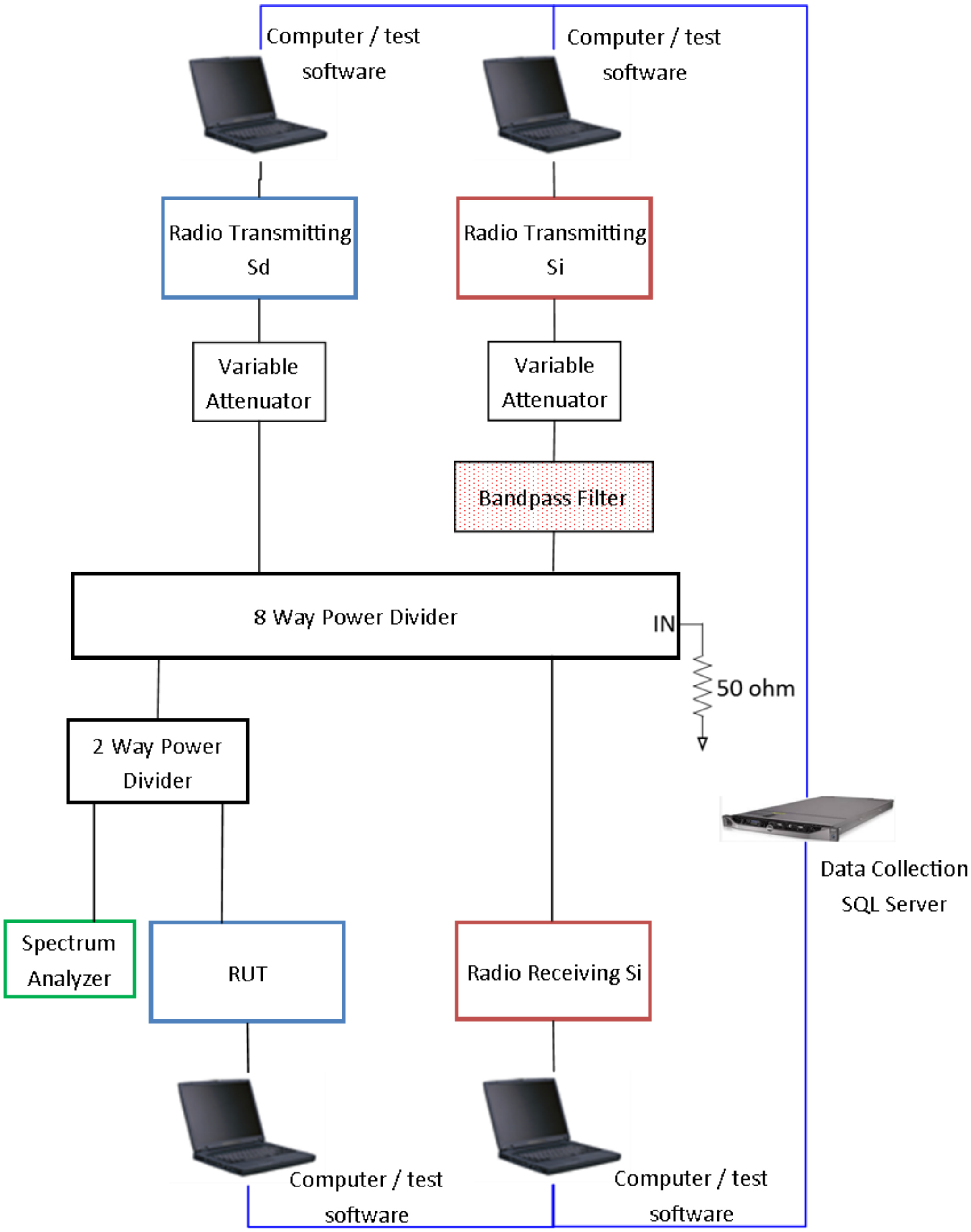

Figure 5. Standard lab test setup

This will be the standard lab setup. The bandpass filter will be included on applicable test scenarios.

Lab Test Parameter Table – Test Setup references:

- Standard
- Standard w/ Bandpass

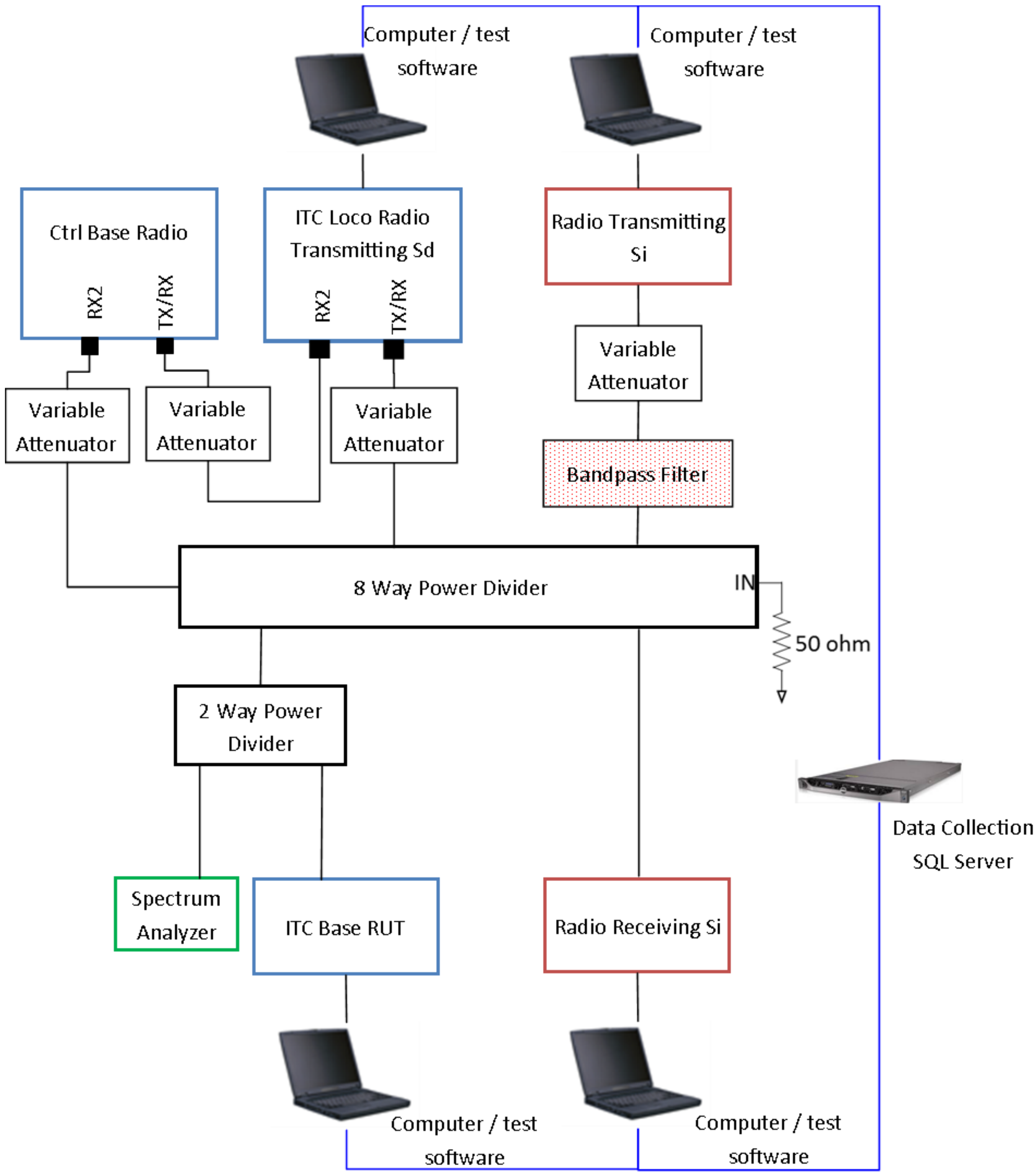

Figure 6. Lab setup for scenarios with ITC locomotive radio transmitting the desired signal.

This will be the lab test setup for scenarios requiring the ITC locomotive radio to transmit the desired signal. The bandpass filter will be included on applicable test scenarios.

Lab Test Parameter Table – Test Setup references:

- Loco Tx Sd
- Loco Tx Sd w/ Bandpass

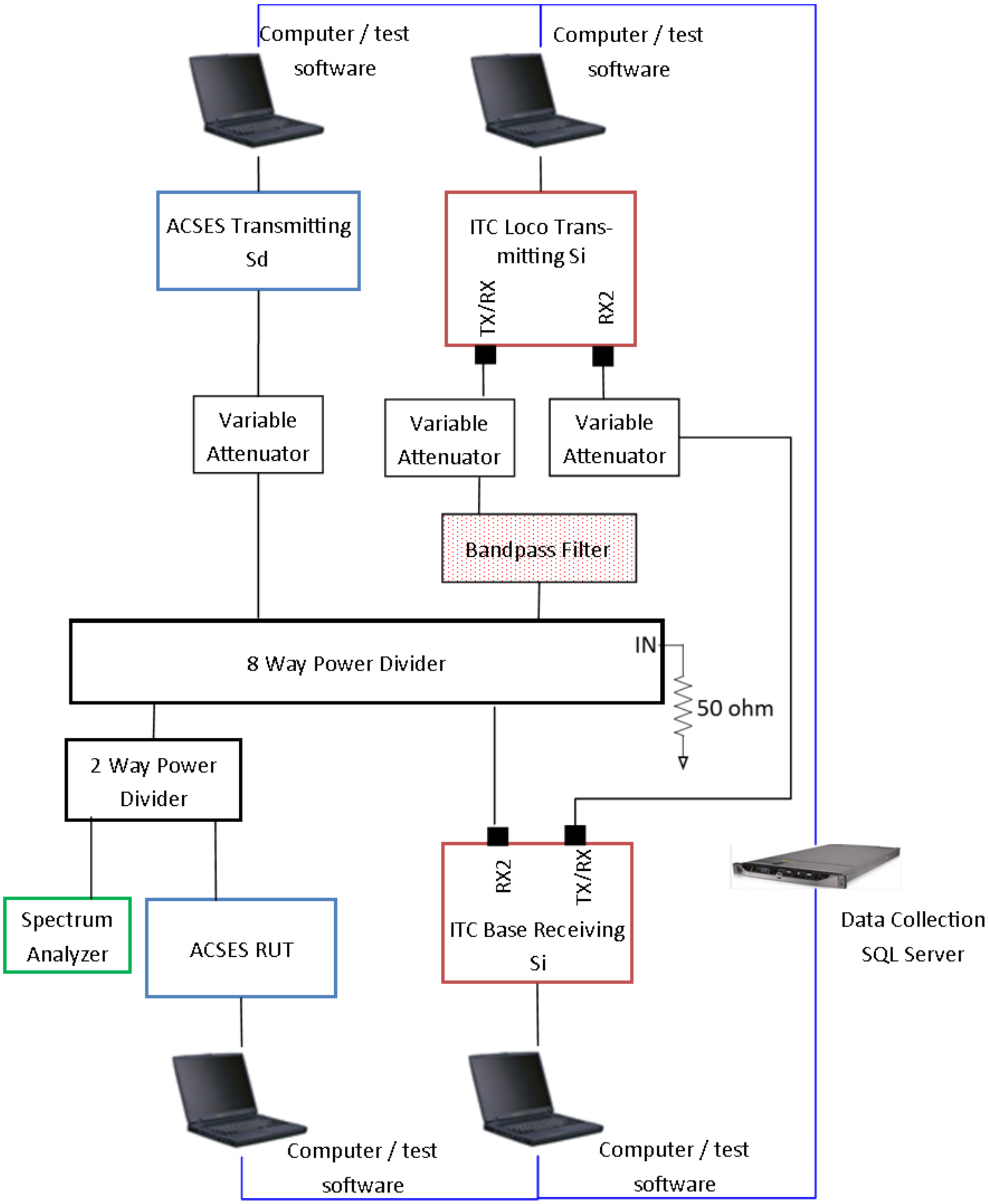

Figure 7. Lab test setup for scenarios with ITC locomotive radio transmitting the interfering signal.

This will be the lab test setup for scenarios requiring the ITC locomotive radio to transmit the interfering signal. The bandpass filter will be included on applicable test scenarios.

<u>Lab Test Parameter Table – Test Setup references:</u>

- Loco Tx Si

- Loco Tx Si w/ Bandpass

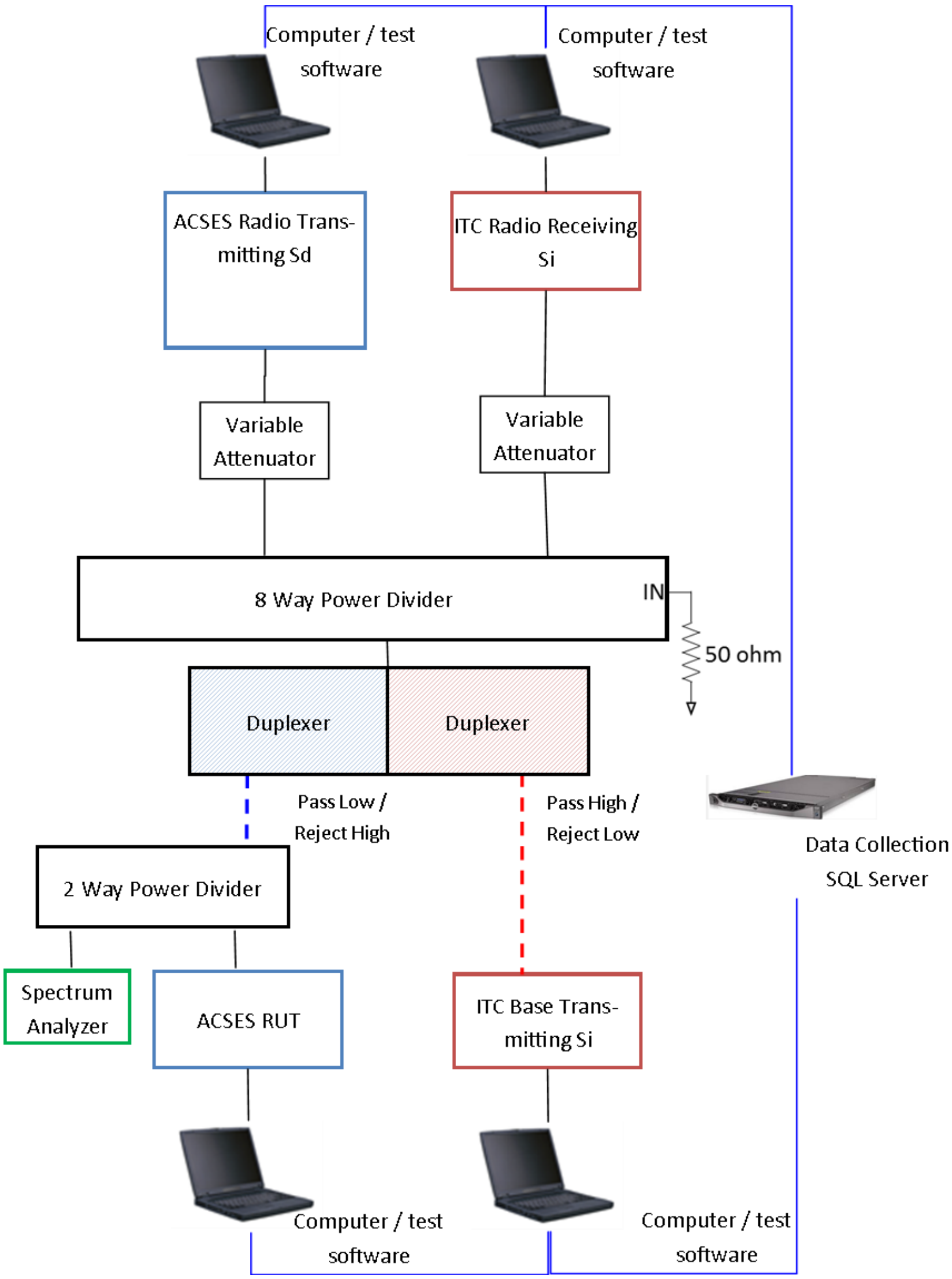

Figure 8. Lab test setup for duplexer testing with an ITC base radio transmitting the interfering signal.

This will be the lab test setup for duplexer testing with an ACSES RUT, and an ITC base radio transmitting the interfering signal.

<u>Lab Test Parameter Table – Test Setup reference:</u>

- Duplexer ACSES RUT

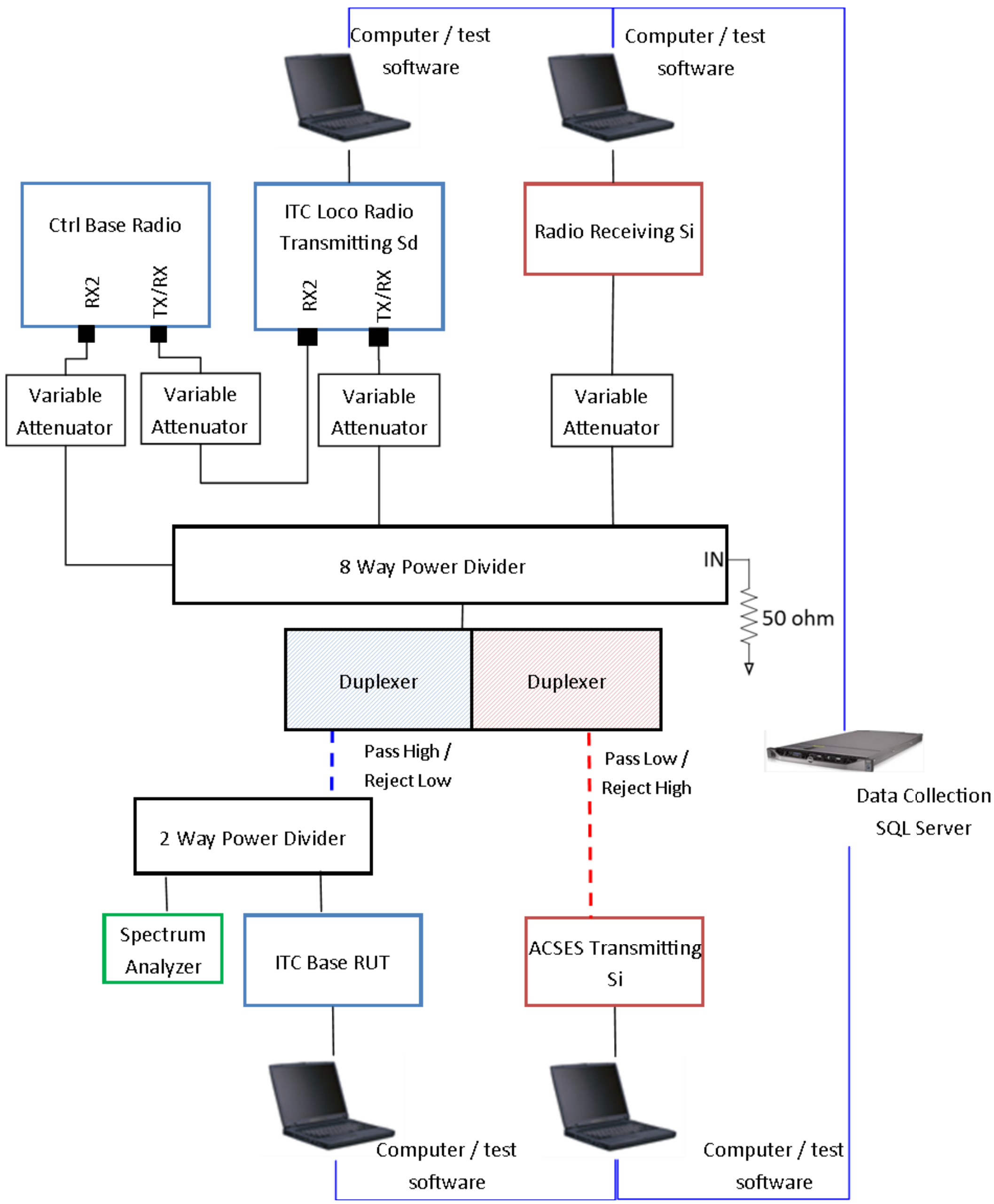

Figure 9. Lab test setup for duplexer testing with an ACSES radio transmitting the interfering signal.

This will be the lab test setup for duplexer testing with an ITC locomotive transmitting the desired signal to the ITC base RUT, and the ACSES radio transmitting the interfering signal.

<u>Lab Test Parameter Table – Test Setup reference:</u>

- Duplexer ITC RUT

Test Components

- Radio Transmitting Sd
    - This radio will be of the similar PTC system as the receiving RUT; it will transmit the desired signal, by transmitting messages to be received by the receiving RUT.
- Radio Transmitting Si
    - This radio will be of the dissimilar PTC system as the receiving RUT; it will transmit the interfering signal, by transmitting messages during the same time as the radio transmitting the desired signal.
- Control Base
    - The control base will be used for test scenarios in which the locomotive must transmit the desired signal to the ITC base. In order for the ITC locomotive to transmit, it must have two-way communication with an ITC base radio. To accommodate this without subjecting the RUT to both ITC base and ITC loco transmissions, a second ITC base, referred to as the control base will be used to provide the required two-way communication. The ITC control base TX/RX port will be directly connected to the ITC locomotive's RX2 connector. The loco TX/RX1 will be connected to a port on the 8-way power divider, and then the RX2 port of the ITC control base will be connected to a port on the 8 way power divider.
- Attenuators
    - Several attenuators are available to be used during testing to achieve the appropriate signal level and to protect equipment from high RF signal levels. This includes fixed attenuators rated for high power levels and variable attenuators, with granularity of 1dB, to make fine adjustments on the signal level.
- Bandpass Filter
    - A bandpass filter comprised of four cavity RF filters will be used on a subset of the tests. The filter will be applied to the interfering signal to reduce sideband noise outside of the interfering frequency. It will be tuned with a calibrated Hewlett Packard benchtop Spectrum Analyzer and Signal Generator, model E4404B. The characteristics are provided in Table 3 below for the two frequencies it will be used for during testing.

Table 3. Bandpass Filter Characteristics

Center Pass Frequency (MHz)	Lower -3dB Point (MHz)	Upper -3dB Point (MHz)	Passband (MHz)	Insertion Loss (dB)
218.975	218.9125	219.0725	0.160	-5.7
220.1125	220.1975	220.0325	0.165	-5.6

- 8-Way Power Divider
    - A 50 ohm, Pasternack power splitter, model number PE2002, will provide the combining network for the interfering and desired signals.
- A 2-Way Power Divider

- A 50 ohm, Pasternack power splitter, model number PE2000, will be connected to one of the 8 ports on the 8-way power splitter with an RG 223 coaxial cable. One port will then be connected to the receiver of the RUT, while the other port will be connected to the Agilent HSA to allow the test engineer to simultaneously monitor the interfering and desired RF signal levels as received at the antenna port of the RUT.

- Spectrum Analyzer
  - The HSA, model number N9342C will be connected to one of the output ports of the 2-way power splitter via coaxial cable, and the RUT under test will be connected to the other port. This will allow for measurement of the desired and interfering RF signal levels with the HSA, as received at the antenna port of the RUT.
- RUT (receiver)
  - This radio will be of the similar PTC system as the transmitting RUT; it will receive the desired signal, which is in the form of transmitted messages sent by the RUT.
- Radio Receiving Si
  - This radio will be of the dissimilar PTC system as the transmitting RUT; it will receive the interfering signal, which is in the form of transmitted packets sent by the interfering radio.
- Data Collection SQL Server
  - The NTG program and the MCC Radio Frame Trace Manager are configured to transmit packet information to the SQL server from the ACSES and the ITC radios, respectively. The following information is sent to the SQL server and compiled into a table.
    - Source ID- Identifier from the transmitting radio
    - Destination ID- Identifier from the receiving radio
    - Session ID- Corresponds to the test matrix to define settings
    - Message Type- Identifies the radio sending packet and which packet in set
    - Message ID- The packet's unique identifier
    - Message Length- length of the message
    - Payload Length- length of the message received
    - Transmission Time- Time the message was transmitted accurate to the second
    - Reception Time- Time the message was received accurate to the second
    - Payload- message transmitted

- This information is stored into two different tables, a transmit table and a receive table. These tables contain the data that will later be analyzed to determine the true packet error rate.

- Duplexer
  - A custom-designed duplexer, designed by Bird Technologies, will be included for test as a potential mitigation technique for the desense that may result when an ACSES base station and ITC base station are co-located. It will pass a 25 kHz frequency sub-band <219 MHz to allow the ACSES radio to transmit and receive on a channel below 219 MHz, while blocking any interfering signals that would be emitted from the ITC base radio in the 220 MHz to 222 MHz. Similarly, it will allow the ITC base radio to transmit and receive in the frequency sub-band from 220 MHz to 222 MHz, while blocking interfering signals emitted from the ACSES radio that would be <219 MHz. The duplexer characteristics are provided below in Table 4.

Table 4. Duplexer Characteristics

	Center Pass Frequency (MHz)	Lower -3dB Point (MHz)	Upper -3dB Point (MHz)	Passband (MHz)	Isolation 1 MHz from Pass Frequency (dB)	Insertion Loss (dB)
Pass/Low / Reject High	218.975	218.5475	219.305	0.7575	120.4	-3.1
Pass High / Reject Low	220.0	219.7	225.1	5.4	115.7	-2.4

- Interfacing computers
  - Interfacing computers and associated software for supporting testing are described in section 5.3.

5.4.5 Lab Testing Procedures

Table 5 and Table 6 provide the steps for setup, preconditions, and the test procedure. For each test scenario, one or more of the steps in setup or setting the preconditions will be changed and then the procedure will be carried out. The applicable setup and preconditions for each test scenario are given in the embedded Excel files.

Table 5. Lab Test Setup and Preconditions

Setup	**Task**	Lab Test Parameter Table Reference
	Identify radio to transmit desired signal to the RUT	Radio to Tx Sd
	Identify receiving RUT	RUT
	Identify radio to transmit interfering signal	Radio to Tx Si

<table>
<tr><th rowspan="3">Setup</th><th>Task</th><th>Lab Test Parameter Table Reference</th></tr>
<tr><td>Identify radio to receive interfering signal</td><td>Radio to Rx Si</td></tr>
<tr><td>Connect radios, attenuators, and measurement equipment according to setup name identified to the right.
Include bandpass filter if indicated in setup name.
Ensure attenuators selected are rated for the max transmit power and provide suitable level of attenuation such that the max signal level an antenna port could be subject to is ≤ -7 dBm.</td><td>Test Setup</td></tr>
<tr><td></td><td colspan="2">Configure the HSA as follows:
Mode: Channel Scanner set to monitor:
Frequency 218.975MHz, Channel Width 12.5kHz
Frequency 220.1125MHz, Channel Width 25kHz
Frequency 220.7125MHz, Channel Width 12.5kHz
Frequency 220.7625MHz, Channel Width 25kHz
Set Max Hold to 180s.
The Measure Interval is set to On.
The Measure Type is set to 200ms.
The Measure Rule will be set to Accuracy.</td></tr>
</table>

<table>
<tr><th rowspan="4">Procedures</th><td colspan="2"></td></tr>
<tr><td>Load or confirm appropriate ACSES firmware version for transmitting and receiving ACSES radios.</td><td>ACSES Firmware Version</td></tr>
<tr><td>Load appropriate NTG script for transmitting ACSES radio.</td><td>ACSES Tx NTG Script</td></tr>
<tr><td>Load appropriate NTG script for receiving ACSES radio.</td><td>ACSES Rx NTG Script</td></tr>
</table>

Procedures		
	Load or confirm appropriate ACSES firmware version for transmitting and receiving ACSES radios.	ACSES Firmware Version
	Load or confirm appropriate MCC software version for transmitting and receiving ITC radios. • A17 suffix – for wayside radios • A18 suffix – for locomotive and base radios	ITC Software Version
	Load or confirm appropriate CIM script for transmitting ITC radio.	ITC Tx CIM Script
	Load or confirm appropriate CIM script for receiving ITC radio.	ITC Rx CIM Script
	For scenarios utilizing an ITC control base: load or confirm appropriate CIM script for ITC base radio utilized as a control base. Confirm the ITC software version is 01042002.A18.	ITC Ctrl Base CIM Script
	Confirm ACSES receiving and transmitting radios are set to the appropriate frequency.	ACSES Tx/Rx Frequency
	Confirm ITC receiving, transmitting, and control base (when applicable) radios are set to the appropriate frequency by viewing the frequency configuration information in the CIM scripts.	ITC Tx/Rx Frequency

Table 6. Lab Test Procedure

Test Procedure		
Step	**Description**	**Additional Information**
1	Power on all radios and ensure all radios are not transmitting	
2	Baseline measurement of PER for RUT and desired signal strength only: • Begin transmitting the desired signal. • Adjust the attenuator level such that the desired signal strength received at the RUT is -85dBm or -95dBm	• This will serve as a baseline test, verifying the performance of the radio is not compromised prior to the

Test Procedure		
	as identified in “Fixed Sd” of the Lab Test Parameter Table. • Log transmitted messages, received messages, and channel scanner values in CSV format for ≥ 5 minutes. • While logging, observe the cumulative PER of the RUT with the Statistics Tool for an expected PER between 0 - 1%. • Stop transmissions after logging is completed.	introduction of the interferer.
3	Dynamic adjustment of interfering signal: • Begin transmitting the desired signal with attenuation adjusted as identified in Step 2 for the appropriate received signal strength. • Begin transmitting the interfering signal with attenuation set such that the interfering signal strength measured at the HSA is -40dBm. • While monitoring the PER of the RUT with the Statistics Tool, dynamically adjust the attenuation to the interfering signal strength until a PER of approximately 5% is observed. • Stop transmissions.	
4	Measurement of PER and static interfering signal strength: • Adjust attenuation to the interfering radio such that the interfering signal strength will be 3 dB weaker than what was identified in step 3 to yield a PER of approximately 5%. • Begin transmitting the interfering and desired signals. • Log transmitted messages, received messages, and channel scanner	• For test scenarios utilizing the control base, the messages received and/or transmitted by the control base do not need to be logged.

Test Procedure		
	values in CSV format for ≥ 5 minutes. • While logging, observe the cumulative PER of the RUT with the Statistics Tool for an expected PER between 0 - 1%. • Stop transmissions after logging is completed.	
5	Measurement of PER and increased static interfering signal strength: • Adjust attenuation to the interfering radio such that the interfering signal strength 1dB stronger than what was tested in Step 4. • Begin transmitting the interfering and desired signals. • Log transmitted messages, received messages, and channel scanner values in CSV format for ≥ 5 minutes. • While logging, observe the cumulative PER of the RUT with the Statistics Tool. • Stop transmissions after logging is completed.	• For test scenarios utilizing the control base, the messages received and/or transmitted by the control base do not need to be logged.
6	Repeat step 5 until the observed cumulative PER for the RUT is ≥ 6%.	

5.4.6 Field Testing Scenarios

A subset of lab tests are to be validated in the field, and these include an ITC base versus an ACSES base, an ITC wayside versus an ACSES base, and an ACSES mobile versus an ITC wayside. Field testing will also include scenarios that do not have a corresponding lab component; these scenarios will utilize an ITC base station and an ACSES base station with antennae co-located on a single tower. Two different antenna alignments will be used for testing.

Field testing will be conducted at a single spectral separation, 1.1375 MHz, with the same frequencies as selected for lab testing; the ACSES radios will use 218.975 MHz and the ITC radios will use 220.1125 MHz. All field testing will be conducted without the bandpass filter that is to be used for lab testing to reduce potential sideband interference from the interfering signal. The performance of the RUT will be tested at a single fixed desired signal level of -95 dBm. The field test scenarios are summarized in Table 7.

Table 7. Field Test Scenarios

	Interfering Radio	RUT	Radio Transmitting Desired Signal to RUT	Spectral Separation ACSES: 218.975 MHz / ITC: 220.1125 MHz	Desired Signal Strength, Sd ≈ 95dBm			
					Antenna Aligned (applies to co-located only)	Antenna Aligned w/ Duplexer (applies to co-located only)	Antenna Misaligned(applies to co-located only)	Antenna Misaligned with Duplexer(applies to co-located only)
ACSES Desense ITC	ACSES Mobile / Loco DOT 004	ITC Wayside / Bucket Truck 40 ft	MCC Base / CORE Tower	1.1375 MHz	✓			
	ACSES Base / Bucket Truck 60 ft	ITC Base / CORE Tower	ITC Loco / Loco DOT 004	1.1375 MHz	✓			
	ACSES Base / CORE Tower Co - Located	ITC Base CORE Tower Co-located	ITC Loco / Loco DOT 004	1.1375 MHz	✓	✓	✓	✓
ITC Desense ACSES	ITC Wayside / Bucket Truck 40 ft	ACSES Base / CORE Tower	ACSES / Loco DOT 004	1.1375 MHz	✓			
	ITC Base / Bucket Truck 100 ft	ACSES Base / CORE Tower	ACSES / Loco DOT 004	1.1375 MHz	✓			
	ITC Base / CORE Tower Co-located	ACSES / CORE Tower Co-located	ACSES / Loco DOT 004	1.1375 MHz	✓	✓	✓	✓

5.4.7 Field Testing Locations and Setup

The same radios tested in the lab, and a significant portion of the equipment and computer software used to support lab testing, will be utilized and configured appropriately for field testing. Field testing will be conducted on or near the Precision Test Track (PTT) at TTC. The PTT is approximately 7 miles long, and testing will utilize 4.7 miles of the track. To facilitate field testing, radios and supporting equipment will be deployed as necessary at the following locations: CORE tower, DOT 004 locomotive, bucket truck stationed alongside the PTT, and the radio lab. Figure 10 identifies the PTT and testing locations at TTC.

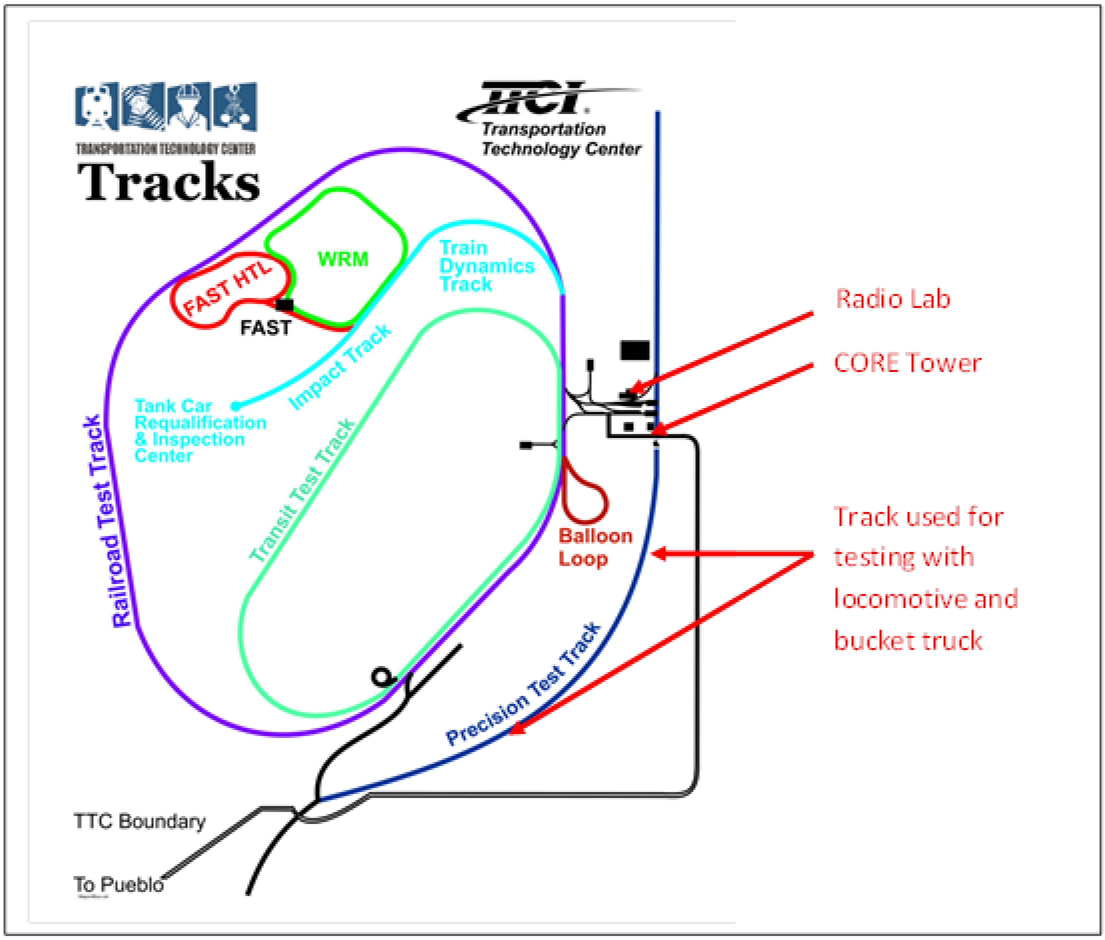

Figure 10. PTT track and testing locations at TTC.

A description of each testing location will be provided below. The applicable test setup schematic diagrams at each location will be included along with the Field Test Parameter Table reference. Similar to the lab test section, the field test setup, precondition, and procedure tables reference the Field Test Parameter table, which contains information relevant to carry out each field test scenario. The Field Test Parameter Table is an embedded spreadsheet located directly after the field test procedure tables.

The CORE tower will be the central location for field testing, as it can serve as both an ACSES and an ITC base station for many of the test scenarios. The following computers will be utilized at CORE tower:

- TTCI Dell Server to interface with and support testing with the ACSES radio.
- MCC laptop to interface with and support testing with the ITC base radio.

All other test locations are considered to be running remotely with respect to CORE tower, and a laptop will be utilized to interface with and support testing of the radio at each testing location.

All computers, both at CORE and at remote testing locations, are time synchronized regularly with wireless cellular network cards. All transmit and receive message information will be logged locally to the computer connected to each radio in the test scenario. These logs will later be collected, and analyzed to determine PER. The same computer software used in the lab testing will be used to support field testing, with the exception of the MCC Radio Frame Trace Manager and the Statistics Tool. These will not be used because all message information is will be logged locally. Since the Statistics Tool will not be used during field testing, a real-time method for observing accurate PER is not possible. However, the test engineer can observe for large differences in the number of packets received in the following manner:

- For ACSES radios, Putty will be used to view the radio message statistics page on the GE radio menu. This provides a running tally of messages received. Since a known number of messages will be transmitted per second for each given test scenario, the test engineer will observe the running tally for an indication that the expected messages are not being received.
- For the ITC radios, the XtermW terminal window displays message information for each message as it is received by the RUT. The number of messages transmitted per second is known, and the test engineer will observe for missing messages.

Prior to commencing field testing, a RF survey will be completed from the CORE tower at TTC for a minimum 12-hour period to identify unexpected transmissions present in the 220 MHz band. The feeder cable from the 220 MHz antenna at a height of 105ft on the CORE tower, will be connected to the input port on the HSA, and will log data for the length of the survey period.

CORE Tower

The CORE tower, is a 120ft tall tower approximately 165ft from the PTT; it will serve as an ACSES base station and an ITC base station. The tower has two Sinclair 220 MHz folded dipole antennae, model number SD212-SF3P2SNM(D00), installed at heights of 60ft and 105ft. The antenna at a height of 60ft will be used for the ACSES base station, and the antenna at 105ft will be used for the ITC base station.

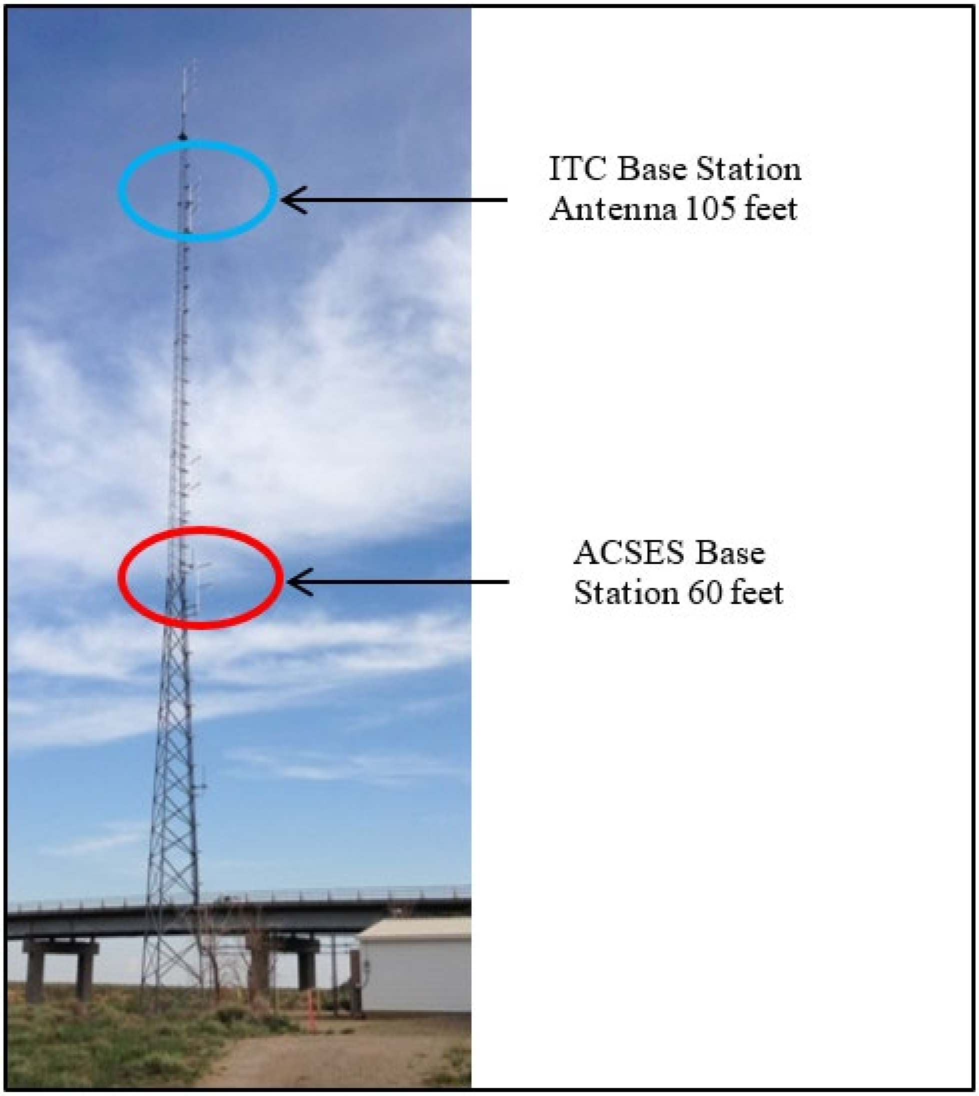

Figure 11. CORE Tower, 220 MHz Antenna at 105ft and 60ft.

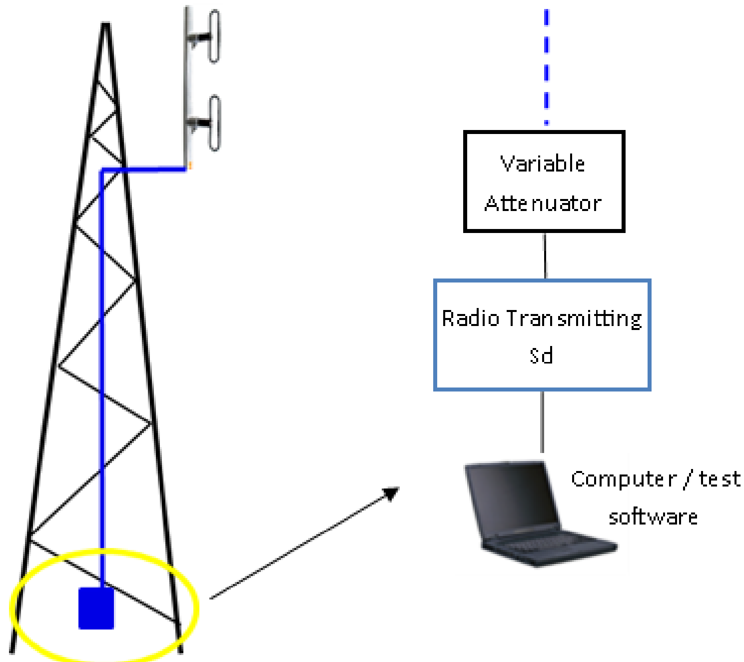

Figure 12. Schematic diagram for scenarios in which the radio transmitting Sd will be located at CORE tower.

Figure 12 provides the schematic diagram for field test scenarios that will utilize the CORE tower to transmit the desired signal.

Field Test Parameter Table – Test Location reference:

- CORE Tx Sd

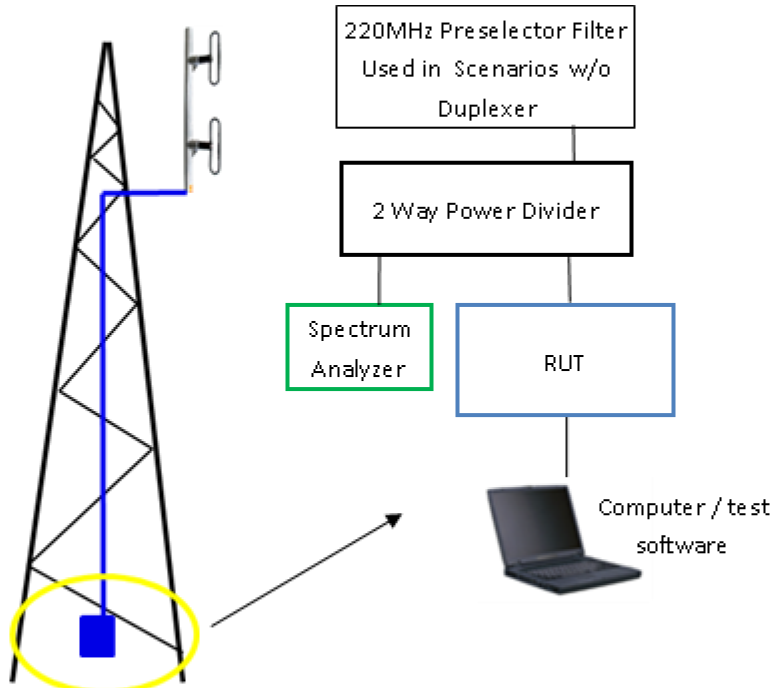

Figure 13. Schematic diagram for scenarios in which the RUT will be located at CORE tower, does not apply to co-located scenarios.

Figure 13 provides the schematic diagram for field test scenarios that will utilize the CORE tower for the RUT. This does not include scenarios with the ITC base and ACSES radios co-located at CORE tower.

Field Test Parameter Table – Test Setup reference:

- CORE RUT

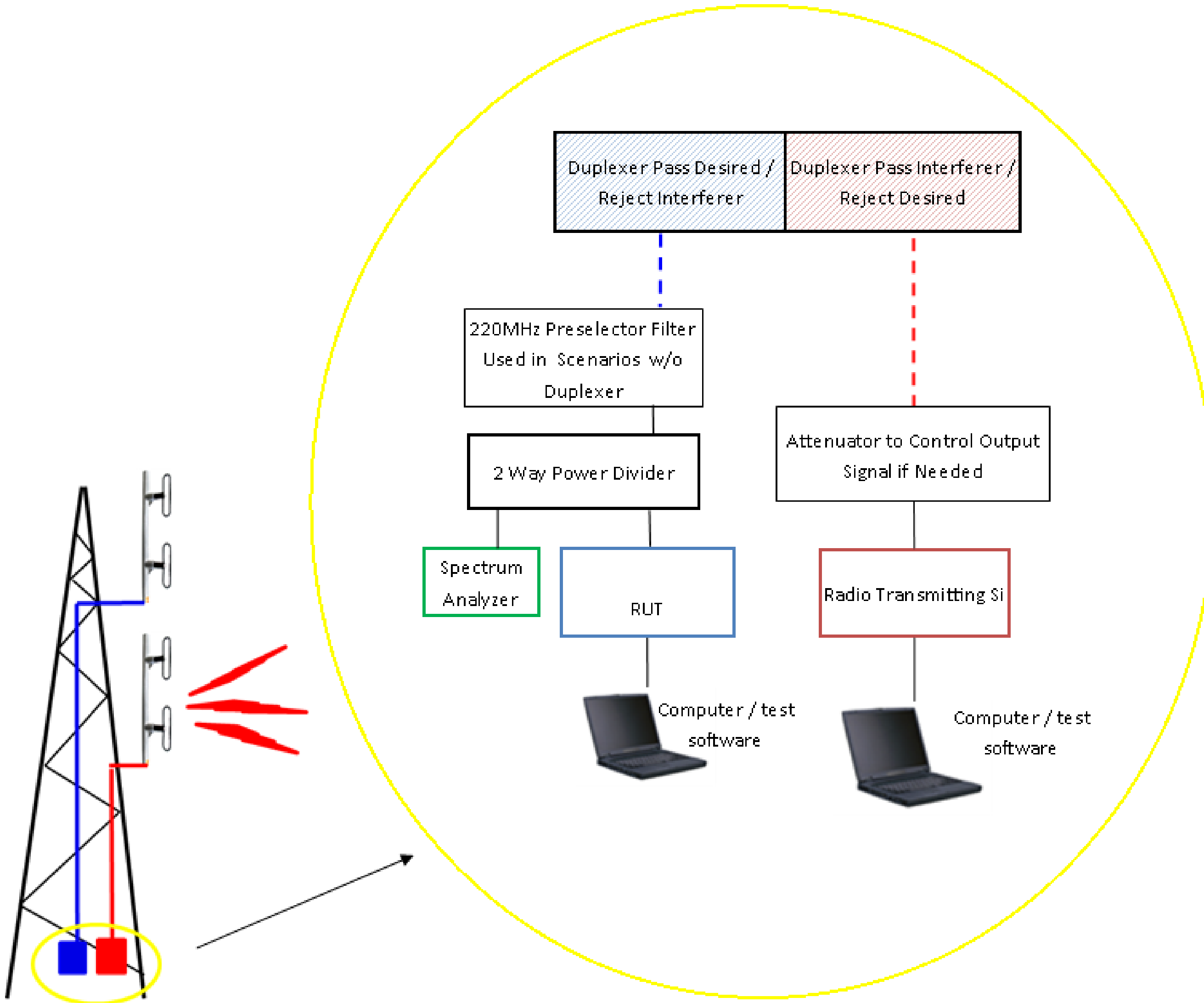

Figure 14. Schematic diagram for co-located testing scenarios, with and without the duplexer.

Figure 14 provides the schematic diagram for field test scenarios in which the CORE tower will serve as a base station for both ACSES and ITC, with one radio as the interferer while the other will serve as the RUT. The duplexer will be inserted during a step in the Field Test Procedure. This diagram is applicable to test scenarios in which the antennae are aligned or misaligned on the CORE tower.

<u>Field Test Parameter Table – Test Location reference:</u>

- CORE Co-located

DOT 004 Locomotive

The DOT 004 is a TTCI-owned locomotive, equipped with both ITC and ACSES onboard equipment, radios, and a Sti-Co 220 MHz skate antenna, model number HDLP-

NB-220, installed on top of the locomotive cab. The DOT 004 will be utilized as an ACSES mobile radio or as an ITC mobile radio, separately, as required for each test scenario.

For the test scenarios that use the DOT 004 as the ITC mobile radio sending the desired signal to the ITC base station, the ITC mobile must receive control packets from an ITC base station in order to continue transmitting. Since the ITC base station at the CORE tower serves as the RUT during these test scenarios, allowing it to transmit would subject the HSA to damaging signal levels. To prevent this, an additional ITC base radio, referred to as the ITC control base, will be located on the DOT 004 with the ITC mobile. It will transmit to the ITC mobile via a closed RF network using coaxial cables and attenuators.

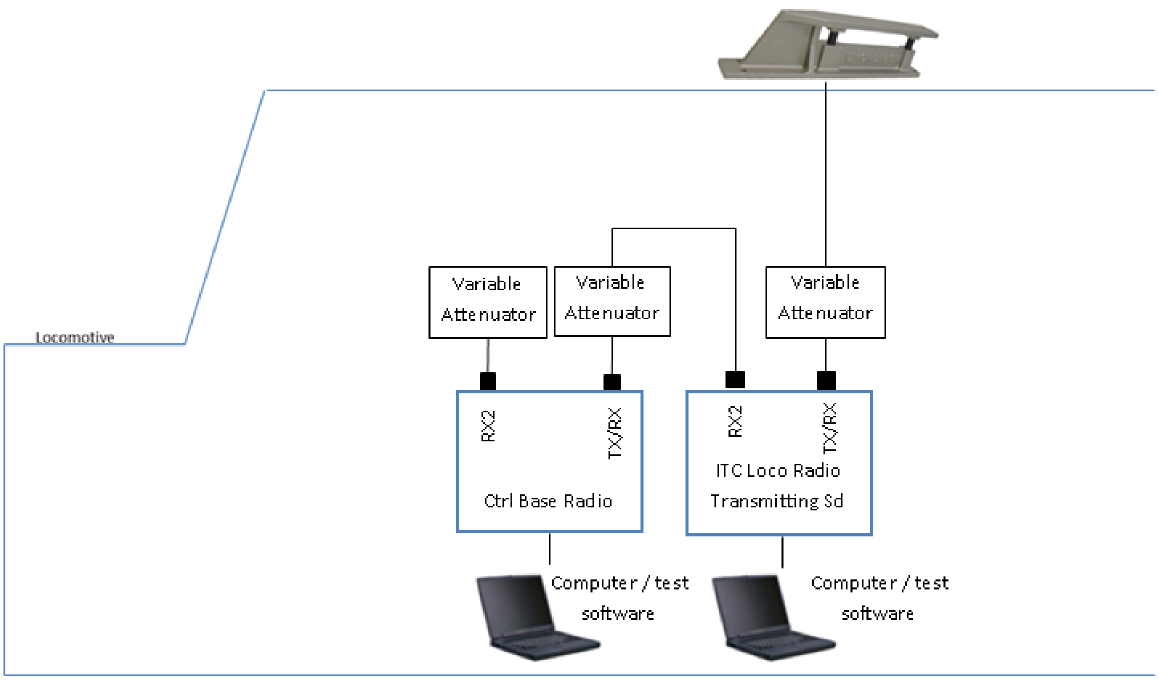

Figure 15. Schematic diagram for field test scenarios in which the DOT 004 locomotive will be utilized to transmit the ITC Sd signal.

Figure 15 provides the schematic diagram for field test scenarios in which the ITC desired signal will be transmitted at the DOT 004 locomotive.

<u>Field Test Parameter Table – Test Location reference:</u>

- Loco ITC Tx

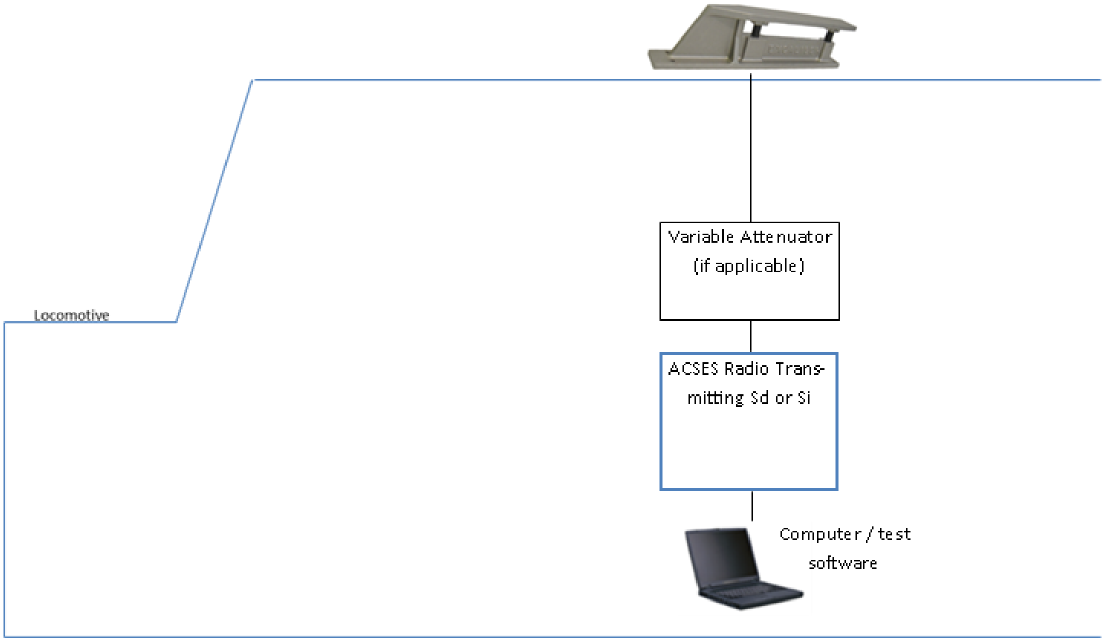

Figure 16. Schematic diagram for field test scenarios that will use the DOT 004 locomotive to transmit either ACSES Sd or ACSES Si signals.

Figure 16 provides the schematic diagram for field test scenarios in which the ACSES radio will transmit the desired or interfering signals from the DOT 004 locomotive.

Field Test Parameter Table – Test Location reference:

- Loco ACSES Tx

Bucket Truck

Some of the test scenarios will require ITC base, wayside, and ACSES base stations to be moveable. A bucket truck will be used to accommodate this requirement. A 220 MHz folded dipole antenna, model number SD212-SF3P2SNM(D00), will be carefully mounted in the bucket, such that the antenna is plumb when the bucket is elevated. The bucket will be raised to different heights depending on the type of radio used in the test scenario:

- ITC Wayside – 40ft
- ITC Base – 100ft
- ACSES Base - 60ft

A gas–powered generator will provide AC power to an AC to DC power converter to supply power to the radio required for each test scenario. The radio, power supply and controlling computer will remain near ground level with the truck, while an LMR 400 cable of sufficient length will be used to connect the radio to the antenna, thereby allowing the antenna to be raised to the appropriate height via the bucket truck.

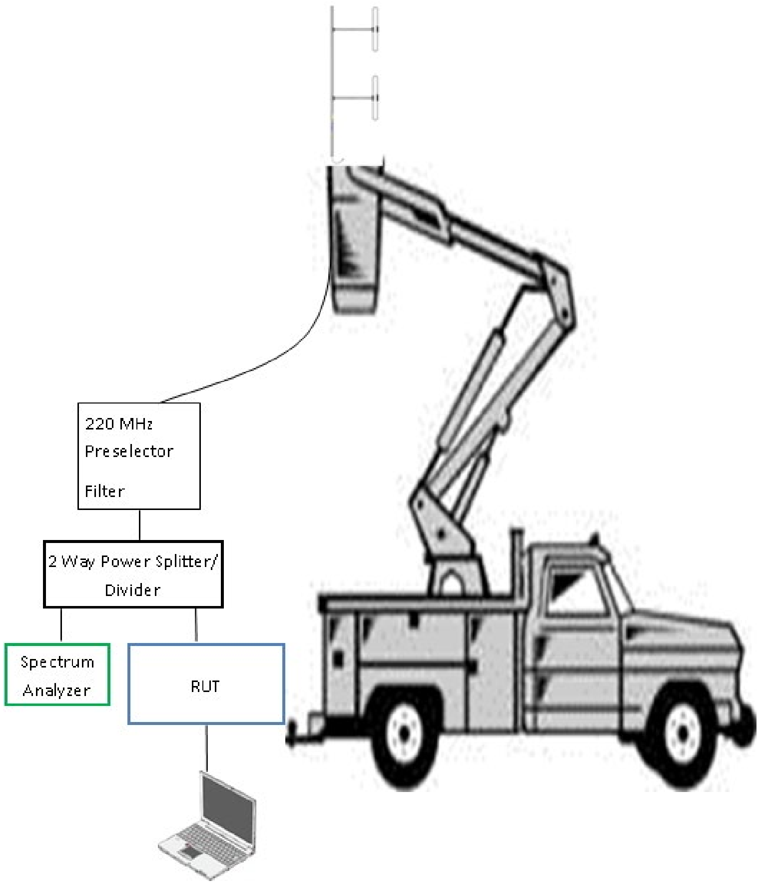

Figure 17. Schematic diagram for field test scenarios in which the bucket truck will be used to station the RUT.

Figure 17 for field test scenarios in which the bucket truck will be used to station the RUT.

<u>Field Test Parameter Table – Test Location reference:</u>

- Bucket RUT

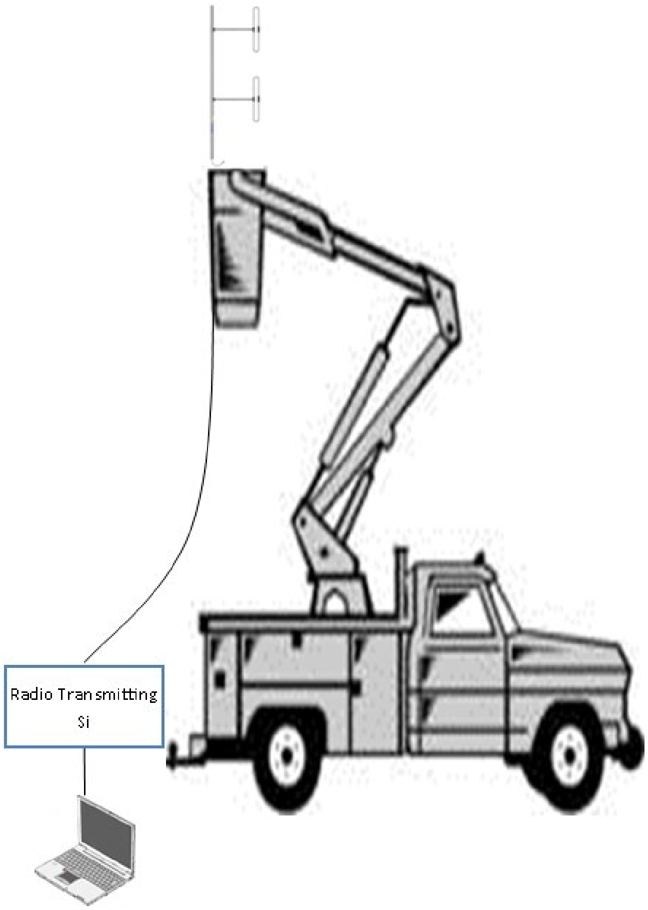

Figure 18. Schematic diagram for field test scenarios in which the bucket truck is used to station the interfering ACSES, ITC base, or ITC wayside radio.

Figure 18 provides the schematic diagram for field test scenarios in which the bucket truck will be used to station the ACSES, ITC wayside, or ITC base radios.

Field Test Parameter Table – Test Location reference:

- Bucket Si

Radio Lab

The radio lab is used to support lab testing of the ACSES and ITC radios as described above, and will also serve a role during field testing as a receiving ACSES radio or a receiving ITC Wayside radio for some of the test scenarios. A Sinclair 220 MHz folded dipole antenna, model number SD212-SF3P2SNM(D00), is installed on the rooftop of the Warehouse Lab Facility (WLF), with coaxial cable extending down into the lab to allow for connection to a radio.

A schematic diagram is not included for this location as its only function is to receive and log messages from the interfering transmitter.

Field Overview Diagrams

The following diagrams provide an overview of how the transmitters of the interfering and desired signals will be positioned with respect to each other and to the RUT. The Field Test Parameter Table references these diagrams. The Field Test Parameter Table reference will be provided below each diagram.

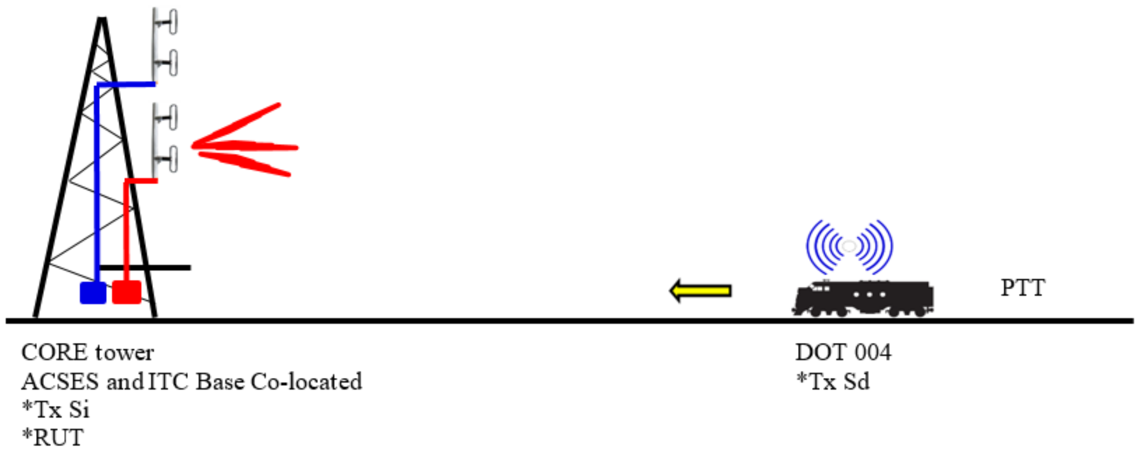

Figure 19. Positioning overview for co-located test scenarios.

<u>Field Test Parameter Table –Overview reference:</u>

- Co-located

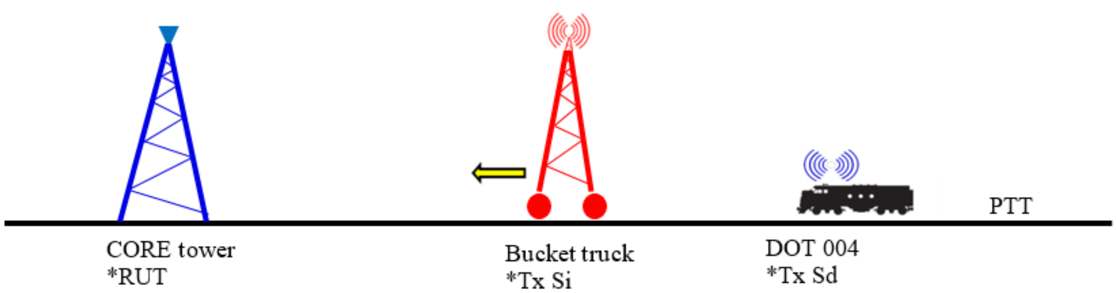

Figure 20. Positioning overview for scenarios in which the interfering signal will be stationed on the bucket truck.

<u>Field Test Parameter Table –Overview reference:</u>

- Bucket Tx Si

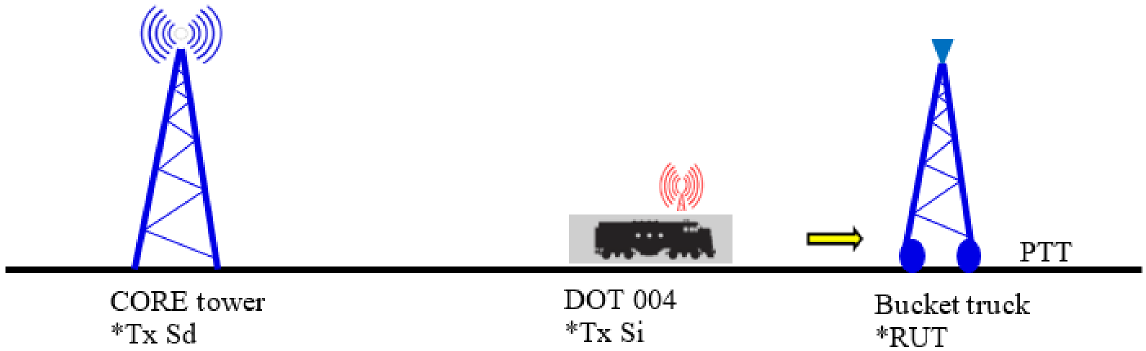

Figure 21. Positioning overview for scenarios in which the bucket truck will be the RUT and the interfering signal will be stationed on the locomotive.

<u>Field Test Parameter Table –Overview reference:</u>

- Loco Tx Si

5.4.8 Field Test Procedures

Table 8. Field Testing Setup and Preconditions

Setup	**Task**	Field Test Parameter Table Reference
	Identify radio to transmit desired signal to the RUT. • Testing location/setup schematic for radio transmitting desired signal to RUT. • Antenna height. • TX Power • Use of 30 Watt power amplifier	Radio to Tx Sd Sd Tx Test Location Sd Tx Antenna Height (ft) Sd Tx Output Power (W) Sd Tx 30 Watt PA (yes/no)
	Identify receiving RUT. • Testing location/setup schematic for RUT. • Antenna height.	RUT RUT Test Location RUT Antenna Height (ft)
	Identify radio to transmit interfering signal. • Testing location/setup schematic for radio transmitting interfering signal.	Radio to Tx Si Si Tx Test Location Si Tx Test Location

Setup	Task	Field Test Parameter Table Reference
	• Antenna height. • TX Power • Use of 30 Watt power amplifier	Sd Tx 30 Watt PA (yes/no)
	Identify radio to receive interfering signal. • Testing location/setup schematic for radio transmitting interfering signal. • Antenna height.	Radio to Rx Si Si Rx Test Location (no diagrams for this – only a location specified) Si Rx Antenna Height (ft)
	Confirm the intended positioning, in general, of the radios transmitting the desired and interfering signals and the RUT. Connect radios, attenuators, and measurement equipment according to setup schematic identified for each testing location. • Attenuators may be used for adjusting the desired or interfering signal strengths in some test scenarios.	Overview
	Configure the HSA as follows: Mode: Channel Scanner set to monitor: • Frequency 218.975MHz, Channel Width 12.5kHz • Frequency 220.1125MHz, Channel Width 25kHz • Frequency 220.7125MHz, Channel Width 12.5kHz • Frequency 220.7625MHz, Channel Width 25kHz Set *Max Hold* to **180s**. The *Measure Interval* is set to **On.** The *Measure Type* is set to **200ms**. The *Measure Rule* will be set to **Accuracy**.	

Preconditions		
	Load or confirm appropriate ACSES firmware version for transmitting and receiving ACSES radios is 2.0.13	n/a
	Load appropriate NTG script for transmitting ACSES radio.	ACSES Tx NTG Script
	Load appropriate NTG script for receiving ACSES radio.	ACSES Rx NTG Script
	Load or confirm appropriate ITC software version for transmitting and receiving ITC radios, including scenarios using the control base are: • 01042002.A17 suffix – for wayside radios • 01042002.A18 suffix – for locomotive and base radios	n/a
	Load or confirm appropriate CIM script for transmitting ITC radio.	ITC Tx CIM Script
	Load or confirm appropriate CIM script for receiving ITC radio.	ITC Rx CIM Script
	For scenarios utilizing an ITC control base: load or confirm appropriate CIM script for ITC base radio utilized as a control base.	ITC Ctrl Base CIM Script
	Confirm ACSES receiving and transmitting radios set to 218.975 MHz.	
	Confirm ITC receiving, transmitting, and control base (when applicable) radios are set to 220.1125 MHz by viewing the frequency configuration information in the CIM scripts.	

Table 9. Field Test Procedure Non Co-located

Field Test Procedure for Non Co-located Test Scenarios		
Step	**Description**	**Additional Information**
1	Power on all radios and ensure all radios are not transmitting	
2	Identification of radio positioning and attenuation to achieve a desired signal strength of -95dBm: • For all scenarios either the RUT or the radio transmitting the desired signal, will be located at CORE tower with the other radio located on the DOT 4 locomotive operating on the PTT south of CORE tower, or on a bucket truck positioned on the PTT access road, south of the CORE tower. The radio used south of CORE tower should be positioned a distance away that is estimated to produce a desired signal strength of -95dBm as measured at the input port of the RUT. • Attenuation will be applied at the transmitting radio if required to achieve a signal strength of -95dBm at the RUT while keeping all test radios within TTC property boundaries. • Begin transmitting desired signal to the RUT. • Observe the desired signal strength on the HSA, as measured at the RUT. • Adjust the location of the radio along the PTT, or apply attenuation on the transmitting radio to achieve a signal strength of -95dBm at the RUT in order to keep all radios on TTC property. • Stop transmissions.	
3	Baseline measurement of PER for RUT and desired signal strength only: • Maintain the positions of the RUT and the radio transmitting the desired signal identified in Step 2, and any applied attenuation to achieve the desired signal strength of -95dBm. • Begin transmitting the desired signal.	• This will serve as a baseline test, verifying the performance of the radio is not compromised prior to the introduction of the interferer.

Field Test Procedure for Non Co-located Test Scenarios		
Step	**Description**	**Additional Information**
	• Log transmitted messages, received messages, and channel scanner values in CSV format for ≥ 5 minutes. • Visually monitor the received messages on the RUT. Expected PER is 0-1%. • Record the GPS location of the radio located on or along the PTT. • Stop transmissions after logging is completed.	• For test scenarios utilizing the control base, the messages received and/or transmitted by the control base do not need to be logged.
4	Identification of radio positioning to identify an interfering signal strength 5 – 10 dB weaker than the threshold identified in lab testing: • Maintain the positions of the RUT and the radio transmitting the desired signal identified in Step 2, and any applied attenuation to achieve the desired signal strength of -95dBm. • Position the interfering radio a distance from the RUT estimated to result in an interfering signal strength less than the threshold identified in lab. • Begin transmitting the desired signal. • Begin transmitting the interfering signal. • Observe the interfering signal strength on the HSA, as measured at the RUT. • Adjust the position of the interfering radio to achieve an interfering signal strength 5 - 10dB weaker than identified in the lab. o For scenarios with the interfering radio mounted in the bucket truck, this will require stopping all radios, repositioning the bucket truck, and then beginning transmissions again. • Stop transmissions.	• Similar to lab testing, the threshold for desense will be identified, by first introducing the interfering signal at a sufficiently weak signal, that no packets are lost. In subsequent test steps, the interfering signal strength will be increased until an observable PER ≥ 5% is achieved.
5	Measurement of PER and static interfering signal strength:	• For test scenarios utilizing the control base, the

Field Test Procedure for Non Co-located Test Scenarios		
Step	**Description**	**Additional Information**
	• Maintain positions of all the test radios as configured in Step 3, and applied attenuation. • Begin transmitting the interfering and desired signals. • Log transmitted messages, received messages, and channel scanner values in CSV format for ≥ 5 minutes. • Observe the interfering signal strength on the HSA, as measured at the RUT. • Visually monitor the received messages on the RUT. Expected PER is 0-1%. • Record the GPS location of the interfering radio. • Stop transmissions after logging is completed.	messages received and/or transmitted by the control base do not need to be logged.
6	Measurement of PER and increased static interfering signal strength: • Change the location of the radio transmitting the interfering signal, such that it is closer to the RUT to increase the interfering signal strength by approximately 1-3dB. • Begin transmitting the interfering and desired signals. • Log transmitted messages, received messages, and channel scanner values in CSV format for ≥ 5 minutes. • Observe the interfering signal strength on the HSA, as measured at the RUT. • Visually monitor the received messages on the RUT. The intent is to observe whether the number of dropped messages is clearly beyond 5%. • Record the GPS location of the interfering radio. • Stop transmissions after logging is completed.	• For test scenarios utilizing the control base, the messages received and/or transmitted by the control base do not need to be logged.

Field Test Procedure for Non Co-located Test Scenarios		
Step	**Description**	**Additional Information**
7	Repeat step 5 until the observed PER for the RUT is easily recognized to be ≥ 5%.	

Table 10. Field Test Procedure Co-located

Field Test Procedure for Co-located Test Scenarios		
Step	**Description**	**Additional Information**
1	Power on all radios and ensure all radios are not transmitting	
2	Identification of radio positioning and attenuation to achieve a desired signal strength of -95dBm: • For all scenarios, the RUT will be located at CORE tower, and the radio transmitting the desired signal will be located on the DOT 4 locomotive operating on the PTT south of CORE tower. The radio used on the DOT 4 should be positioned a distance away that is estimated to produce a desired signal strength of -95dBm, as measured at the input port of the RUT. • Begin transmitting the desired signal to the RUT. • Observe the desired signal strength on the HSA, as measured at the RUT. • Adjust the location of the radio along the PTT, or attenuation on the transmitting radio to achieve a signal strength of -95dBm at the RUT while keeping the transmitter of the desired signal on TTC property. • Stop transmissions.	
3	Baseline measurement of PER for RUT and desired signal strength only:	• This will serve as a baseline test, verifying

Field Test Procedure for Co-located Test Scenarios		
Step	**Description**	**Additional Information**
	• Maintain the position of the radio transmitting the desired signal identified in Step 2, and any applied attenuation to achieve the desired signal strength of -95dBm. • Begin transmitting the desired signal. • Log transmitted messages, received messages, and channel scanner values in CSV format for ≥ 5 minutes. • Visually monitor the received messages on the RUT. Expected PER is 0-1%. • Record the GPS location of the radio located on or along the PTT. • Stop transmissions after logging is completed.	the performance of the radio is not compromised prior to the introduction of the interferer. • For test scenarios utilizing the control base, the messages received and/or transmitted by the control base do not need to be logged.
4	Introduction of interfering signal for co-located base scenarios. • Maintain the position of the radio transmitting the desired signal as identified in Step 2. • Place attenuation on the antenna feeder line cable that connects to the interfering radio as a precaution to prevent subjecting the RUT to damaging signal levels. • Begin transmitting the interfering and desired signals. • Observe the interfering signal strength on the HSA, as measured at the RUT. • Stop transmissions. • Remove attenuation from interfering transmitting radio, if it will not result in	

Field Test Procedure for Co-located Test Scenarios		
Step	**Description**	**Additional Information**
	exposing the RUT to damaging signal levels (likely all attenuation can be removed).	
5	Measurement of PER and static interfering signal strength: • Maintain the position of the radio transmitting the desired signal as identified in Step 2. • Maintain the amount of attenuation applied at the transmitter of the interfering signal, if any, from Step 3. • Begin transmitting the interfering and desired signals. • Log transmitted messages, received messages, and channel scanner values in CSV format for ≥ 5 minutes. • Observe the interfering signal strength on the HSA, as measured at the RUT. • Visually monitor the received messages on the RUT for PER ≥ 5%. • Stop transmissions after logging is completed.	• Note the isolation between the 60ft and 105ft antennae on CORE tower may be sufficient to prevent desense between the RUT and the radio transmitting the interfering signal. • For test scenarios utilizing the control base, the messages received and/or transmitted by the control base do not need to be logged.
6	Insertion of the duplexer and adjustment of attenuation to achieve a desired signal strength of -95dBm: • Maintain the position of the radio transmitting the desired signal identified in Step 2	

Field Test Procedure for Co-located Test Scenarios		
Step	**Description**	**Additional Information**
	• Insert the duplexer into the test setup identified in the test location in the Field Test Parameter Table as *CORE* ***Co-Located.*** • Begin transmitting desired signal to the RUT. • Observe the desired signal strength on the HSA, as measured at the RUT. • Adjust the attenuation on the transmitting radio to achieve a signal strength of -95dBm at the RUT. • Stop transmissions.	
7	Baseline measurement of PER for RUT and desired signal strength with duplexer in line: • Maintain the adjusted attenuation level determined in Step 5 to achieve the desired signal strength of -95dBm with the duplexer in line. • Begin transmitting the desired signal. • Log transmitted messages, received messages, and channel scanner values in CSV format for ≥ 5 minutes. • Visually monitor the received messages on the RUT. Expected PER is 0-1%. • Stop transmissions after logging is completed.	• This will serve as a baseline test with duplexer inserted into the RF network.
8	Measurement of PER and static interfering signal strength with the duplexer inserted: • Maintain the adjusted attenuation level determined in Step 5 to achieve the desired signal strength of -95dBm with the duplexer in line. • Remove any attenuation from interfering transmitting radio.	• For test scenarios utilizing the control base, the messages received and/or transmitted by the control base do not

Field Test Procedure for Co-located Test Scenarios		
Step	**Description**	**Additional Information**
	• Begin transmitting the interfering and desired signals. • Log transmitted messages, received messages, and channel scanner values in CSV format for ≥ 5 minutes. • Observe the interfering signal strength on the HSA, as measured at the RUT. • Visually monitor the received messages on the RUT for PER. Expected PER is 0-1%. Stop transmissions after logging is completed.	need to be logged.

The above procedure is applicable to test scenarios in which the antennae are aligned or misaligned on the CORE tower. The embedded Excel file provides the differences in test parameters for aligned vs. misaligned test scenarios.

5.5.3.1 Validation Testing

N/A

5.5.3.2 Endurance Testing

N/A

5.5.3.3 Safety Margin Tests

5.5 Operation Locations

Tests will be performed with radios installed and operated in three different environments as described in section 5.4.6.

- a locomotive to function as a mobile radio for either ACSES or ITC
- the CORE tower to function as a base station for either ACSES or ITC, and
- a bucket truck to function as a moveable fixed-site station, i.e. an ITC wayside or an ACSES or ITC base station.

For test scenarios utilizing the bucket truck, it will be positioned at various locations along the access roads of the PTT, south of the CORE tower. The locomotive used during testing will travel along the PTT, which will allow for the mobile radios to come quite close to the fixed-site stations which will be located at the CORE tower or along the access road of the PTT.

5.5.6 Special Support

MCC will provide laptops equipped with XTermW, and custom software to support testing at TTC. MCC engineering services will be obtained to develop custom CIM scripts to ensure message overlap between the ACSES and ITC radios.

5.5.7 Instrumentation Types

n/a

5.5.8 Measurement Definitions

The following measurements will be taken during the field test for each test run:

- Received signal strength: this is to be measured and recorded with the Handheld Spectrum Analyzer. The configuration of the HSA is located in the test procedure tables above.
- Packet error rate (PER): represents the ratio of successfully received messages to number of messages sent.
- Position of the mobile equipment: to be determined by the handheld GPS. The mobile test setup will be allowed to dwell at multiple locations; particularly, in the region that desense is beginning to be detected as the distance between the RUT and the interfering radio is decreased. This will help to avoid position recording errors due to any latency in the GPS equipment. The Garmin 530HCx hand held GPS was used to collect position information with an accuracy of $\pm$ 9ft.

5.5.9 Data Collection Schematics

None.

6.0 Instrumentation Identification

6.1 Base or Wayside Station Instrumentation List

For each base station (ACSES and ITC) or ITC wayside the instrumentation includes:

- 1 Radio (ITC base or wayside for ITC and ACSES for ACSES)
- 1 Message generation tool (NTG/ XtermW)
- 1 Message logging tool (NTG/ XtermW)
- 1 Power amplifier
- 1 Front-end RF filter (utilized when role is RUT)
- 1 GPS system
- 1 Dipole antenna
- 1 Feeder cables and jumper cable
- 1 Data acquisition tool
- 1 Power supply
- 1 DC-to-DC converter

- 1 or more attenuators of sufficient power rating (utilized in a subset of test scenarios)
- 1 Agilent HSA (utilized when role is RUT)
- 1 Two –way power splitter (utilized when role is RUT)

6.2 Mobile Station Instrumentation List

For each mobile station (ACSES and ITC) the instrumentation includes:

- 1 radio (ITC for ITC and ACSES for ACSES)
- 1 message generation tool
- 1 message logging tool
- 1 GPS system
- 1 omnidirectional skate antenna
- 1 Front-end RF filter (utilized when role is RUT)
- 1 jumper cable
- 1 data acquisition tool
- 1 power supply
- DC-to-DC converter
- 1 or more attenuators of sufficient power rating (utilized in a subset of test scenarios)
- 1 Ethernet switch
- 1 Agilent HSA (utilized when role is RUT)
- 1 Two –way power splitter (utilized when role is RUT)

6.3 Special Instrumentation List

None.

7.0 Photography and Video

7.1 Photography Requirements

Photographs will be taken of the lab and field setups; including photographs of the mobile units, the base station units and towers, and the bucket truck base station. Images will be captured as the mobile unit comes in close proximity with the base station. The photographs, or a subset thereof will be included in the final report.

7.2 Video Requirements

None.

8.0 Transportation Technology Center, Inc. Requirements

8.1 Facility Requirements

Bucket truck will be serve as a moveable base station.

8.2 Track Requirements

The test scenario described in section 5.4.7 will be tested using a locomotive along the Precision Test Track (PTT) at the TTC.

8.3 Labor/Personnel Requirements

The following personnel will be required to setup, perform, and analyze the results from the tests planned:

- Lead Test engineer: The lead test engineer will be responsible for organizing and managing test activities, including providing test plans, procedures, and data sheets to test personnel, and ensuring test activities can be performed in a safe manner. It will also be the responsibility of the lead test engineer to oversee setup of the instrumentation, and recording or ensuring necessary data is recorded.
- Test engineer(s): The test engineer(s) will be responsible for operating and controlling the radio and interfacing computers at his or her assigned test location. It will be the responsibility of the test engineer(s) to communicate all pertinent information to the lead test engineer, and record appropriate data for the given test location and role.
- Test controller: The test controller will be in charge of the actual tests and all movements of the test consist. This includes ensuring all safety rules, test plans, and other instructions are followed by all test personnel. The test controller will be the point of communication between the test engineers and the locomotive engineer and any other test personnel. The test controller will coordinate all train moves with the proper personnel in the Operations Control Center (OCC), and ensure safe test conditions at all times. Finally, the test controller will keep a detailed log of the test activities.
- Locomotive engineer: The locomotive engineer will execute train moves as necessary for test setup, switching, and test functions.
- Bucket truck operator: The bucket truck operator will be in charge of driving and deploying the bucket truck in the field.

8.4 Equipment Requirements

The following equipment will be required for the field tests:

- One locomotive capable of supporting ACSES and ITC mobile radio systems.
- One bucket truck capable of supporting ACSES and ITC base radio systems.

8.5 Material Requirements

None.

8.6 Special Requirements

None.

9.0 Restoration and/or Dismantling

9.1 Facility Restoration

None.

9.2 Track Restoration

None.

9.3 Equipment Disposition

None.

9.4 Material Disposition

None.

9.5 Special Equipment Disposition

None.

10.0 Data Requirements

10.1 Data Types

The following data will be collected during this field test:

- Signal strength measured with spectrum analyzer
- Message error rate
- GPS position of the mobile equipment

10.2 Recording Techniques

In every test scenario, received signal strength will be collected with the HSA, and recorded to a memory stick. Message error rate will be determined posttest and will utilize the message logs recorded during test. Position of the mobile and base equipment will be recorded using a handheld Garmin GPS receiver.

10.3 Data Analysis

Data processing will determine the PER and received signal strength for each test step requiring measurement of the desired signal only, or the combined interfering and desired signals.

10.3.1 PER

The message data collected for each test will be processed using MATLAB to obtain a PER. All messages will be time stamped and timeslots synchronized by GPS receiver or a received GPS signal from a base radio. Message composition, type and time transmitted / received will be logged locally or on the SQL server.
The PER will be calculated for both the static desired signal tests and the static interference tests, and will quantify the number of desired packets that are not received

by the RUT. To accurately determine the PER during the static interference tests, it will be necessary to isolate the time that all the radios start and stop transmitting and receiving. Utilizing the message log information for each radio associated with the test, the time at which all radios have started to transmit and receive will be selected. Similarly, identifying the earliest time that transmissions cease or a radio is no longer logging receiving messages, ensures PER is calculated during the period when all desired packets are subject to the interfering signal. The PER will be the number of desired packets transmitted compared to the number of packets received by the RUT. The equation to calculate the packet error rate is below.

$$PER = \left(1 - \left(\frac{received}{transmitted}\right)\right) * 100\ \%$$

The messages transmitted and received by ITC locomotive radios will not be logged to the SQL server because the MCC Radio Frame Trace Manager does not support logging of these types of message. However, XtermW has a logging feature, and all pertinent message information will be saved locally on the MCC laptops for later analysis. Since the message information will not be in the same format as the message information logged to the SQL tables, an additional program has been written and will be used in analyzing these files. It will extract only the packets sent between radios, and then compile the time signatures for each packet as described above. This ensures packets are only counted during the time the interferer is present. The PER will then be calculated using the same equation as above.

10.3.2 Received Signal Strength

The Agilent HSA will be used to measure the signal strength of the desired signal and the interfering signal. The channel scanner feature will be utilized, with each testing frequency being monitored simultaneously. During static tests the HSA measurements are logged to a USB drive and later analyzed. The signal strength representing the average of the values above the 90th percentile of those collected will be used for reporting purposes.

10.4 Reports

Documentation of the test results will be included in a final report for the project.

11.0 Safety

TTCI has a very successful safety record. Strict operating and safety rules will be followed during the work described in this proposal.

A pre-test meeting will be held before any physical work is started. Safety and quality issues will be addressed at this meeting.

A safety and job briefing will be held prior to start of testing each day, with subsequent job briefings throughout the day if required by a change in the work plan.

The bucket truck side supports will be deployed before raising the bucket.

12.0 Work Schedule

Lab testing – September 2014 thru April 2015

Field testing – October 2014 thru November 2014

Data analysis – May 2015

Report Writing – June 2015 thru October 2015

13.0 Quality Assurance

TTCI is committed to providing products and/or services that meet and/or exceed the customers' specified contractual and project requirements. TTCI recognizes that in order to provide and maintain a consistently high quality in the work it undertakes, an effective Quality Management System is necessary so as to ensure that proper communication, work control, and accountable records are generated for all work undertaken.

It is the policy, therefore, of TTCI to control and conduct its business of consultancy and test services in the railway transportation arena by means of a formalized system of modern quality management that conforms to the requirements of ISO 9001–2000. Through the QMS, TTCI is able to ensure that our products and services meet or exceed our customers' expectations.

In order to ensure our entire organization supports the quality process, TTCI sponsors an employee led Quality Resource Team (QRT). The mission of the QRT is to "To promote customer satisfaction by providing effective training, education, and communication tools for Team TTCI." The QRT works directly with TTCI's marketing team to identify customer satisfaction issues and help resolve them. The QRT also provides period refresher training to TTCI employees in science of Continuous Quality Improvement, Customer Satisfaction, and the implementation of problem solving tools.

14.0 Support Specialties

N/A

Abbreviations and Acronyms

Abbreviations	Acronyms
ACSES	Advanced Civil Speed Enforcement System
AC	Alternating Current
CIM	Configuration Information Management
CORE	Centrally Located
CSMA	Carrier Sense Multiple Access
CSV	Comma Separated Values
dB	Decibel
dBm	Decibel Milliwatts
DOT	Department of Transportation
Sd	Desired Signal
DC	Direct Current
D Frame	Dynamic Frame
DTDMA	Dynamic Time Division Multiple Access
ft	Feet
F Frame	Fixed Frame
FTDMA	Fixed Time Division Multiple Access
GE	General Electric
GPS	Global Positioning System
HSA	Handheld Spectrum Analyzer
ID	Identification
Si	Interfering Signal
I-ETMS	Interoperable-Electronic Train Management System
ISO	International Organization for Standardization
ITC	Interoperable Train Control
kHz	kiloHertz
MHz	megaHertz
MER	Message Error Rate
MCC	Meteorcomm Communications, LLC

Abbreviations	Acronyms
ms	Millisecond
NTG	Network Traffic Generator
NS	Norfolk Southern
NEC	Northeast Corridor
PER	Packet Error Rate
PTC	Positive Train Control
PA	Power Amplifier
PTT	Precision Test Track
QMS	Quality Management System
QRT	Quality Resource Team
RF	Radio Frequency
RG	Radio Guide
RTCS	Radio Test Control System
RUT	Radio Under Test
Rx	Receive
s	Seconds
SEPTA	Southeastern Pennsylvania Transportation Authority
SQL	Structured Query Language
TDMA	Time Domain Multiple Access
TTC	Transportation Technology Center
TTCI	Transportation Technology Center, Inc.
Tx	Transmit
Ohm	Unit of Electrical Resistance
USB	Universal Serial Bus
W	Watt
WIU	Wayside Interface Unit
WLF	Warehouse Lab Facility

Abbreviations and Acronyms

Acronym	Abbreviations
ACSES	Advanced Civil Speed Enforcement System
ATC	Automatic Train Control
CIM	Configuration Information Management
CSMA	Carrier Sense Multiple Access
dB	Decibel
dBm	Decibel-milliwatts
DC	Direct Current
DTDMA	Dynamic Time Division Multiple Access
FRA	Federal Railroad Administration
FSPL	Free Space Path Loss
FTDMA	Fixed Time Division Multiple Access
GE	General Electric
GPS	Global Positioning System
HAS	Handheld Spectrum Analyzer
I-ETMS	Interoperable-Electronic Train Management System
IT	Information Technology
ITC	Interoperable Train Control
LIRR	Long Island Rail Road
MCC	Meteorcomm Communications, LLC
MNR	Metro-North Railroad
NEC	Northeast Corridor
NJT	New Jersey Transit
NS	Norfolk Southern
NTG	Network Traffic Generator
OCM	Office Communications Manager
PER	Packet Error Rate
PTC	Positive Train Control
PTT	Precision Test Track
RF	Radio Frequency
RRF	Railroad Research Foundation

Acronym	Abbreviations
RSIA	Rail Safety Improvement Act
RTCS	Radio Test Control System
RTT	Railroad Test Track
RUT	Radio Under Test
Rx	Receive
SEPTA	Southeastern Pennsylvania Transportation Authority
TCCO	Train Control, Communications, and Operations
TDMA	Time Domain Multiple Access
TMC	Train Management Computer
TSR	Temporary Speed Restriction
TTC	Transportation Technology Center (the site)
TTCI	Transportation Technology Center, Inc. (the company)
TTT	Transit Test Track
Tx	Transmit
WIU	Wayside Interface Unit
WLF	Warehouse Laboratory Facility