

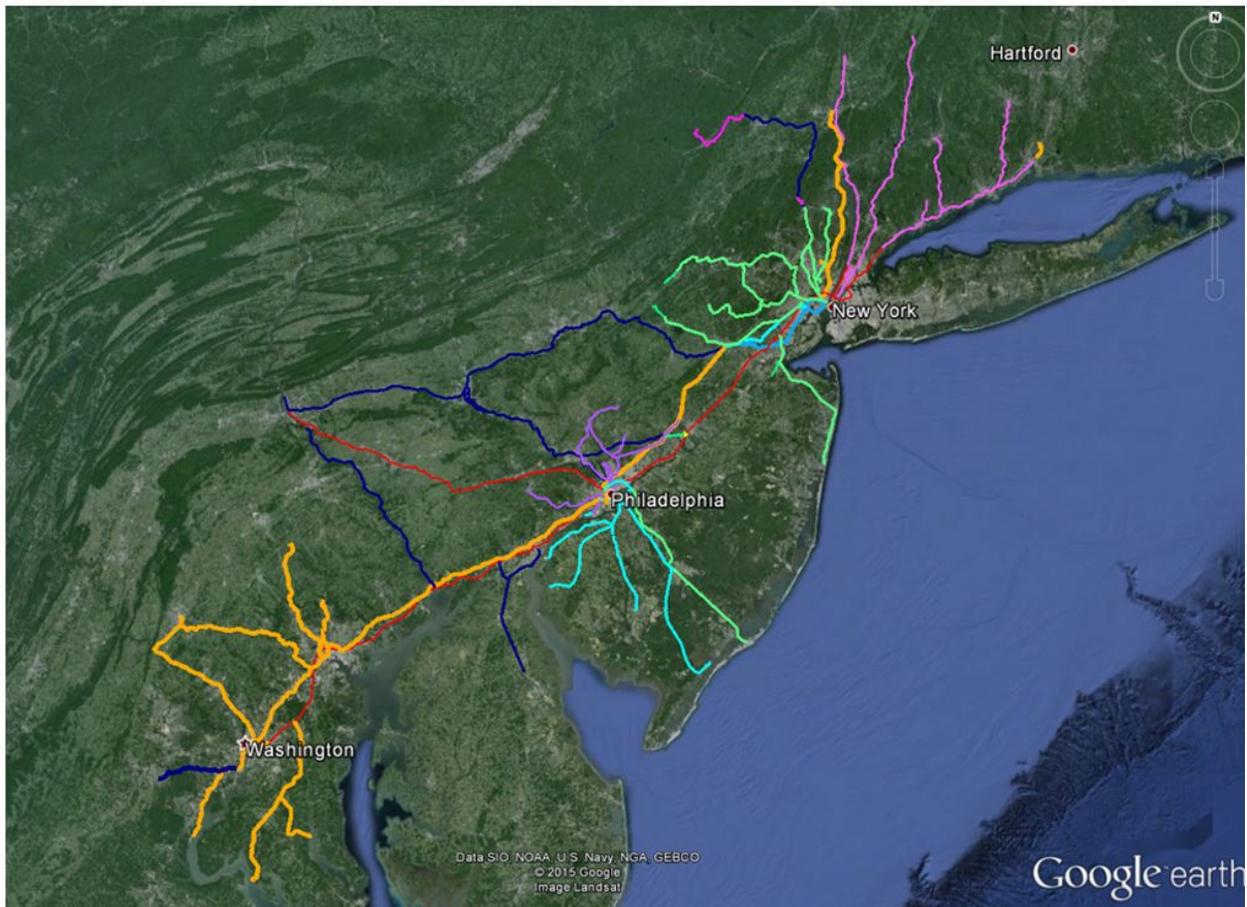


U.S. Department of
Transportation

**Federal Railroad
Administration**

Positive Train Control Desense Mitigation Test: Research Phase 1

Office of Research,
Development,
and Technology
Washington, DC 20590



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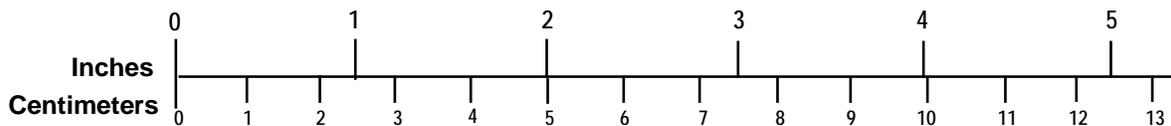
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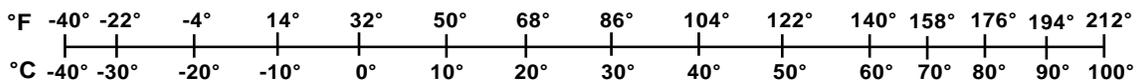
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Executive Summary

The Positive Train Control (PTC) radio desense (i.e., radio frequency desensitization) mitigation trade study, which was performed as part of the PTC Desense Mitigation Test Research project, has determined that adaptive interference canceller (AIC) technology and radio frequency (RF) filters, hardened to withstand locomotive environmental conditions, as solutions with the potential to mitigate each of the PTC radio desense scenarios that affect locomotives operating on the Northeast Corridor (NEC), with minimal impact on existing PTC system hardware and software. Additionally, the study discovered that PTC radio desense mitigation performance can be enhanced with signal cancellation via phased antenna placement in conjunction with either AIC technology or RF filters.

This study recommends that AIC technology and RF filters should undergo additional development and testing to demonstrate their ability to mitigate PTC radio desense and endure the shock, vibration, and thermal environment associated with locomotives.

The Federal Railroad Administration (FRA) funded the PTC Desense Mitigation Test Research project to:

- Define the scope of the PTC radio desense problem adversely affecting the Advanced Civil Speed Enforcement System (ACSES) and Interoperable Train Control (ITC) deployments on the NEC, where these two PTC systems are deployed in close proximity
- Identify and conduct a trade study of potential mitigation approaches to mitigate PTC radio desense
- Analyze the potential for implementing multiple candidate PTC radio desense mitigation solutions in concert to provide a more robust solution
- Provide focus on future efforts of testing PTC radio desense mitigation solutions

This project provided the following benefits to the North American railroad industry:

- Identification and preliminary assessment of potential approaches to mitigate PTC radio desense between ITC and ACSES deployments on the NEC
- Promoted cooperation on PTC deployment issues common to all NEC carriers
- Identified technologies that may benefit the railroad industry beyond the immediate communication issues on the NEC

1. Introduction

The Rail Safety Improvement Act of 2008 (RSIA 08) mandates that all Class I freight railroads, as well as all other entities that provide regularly scheduled intercity or commuter rail passenger transportation, implement Positive Train Control (PTC) systems on designated main lines with regularly scheduled passenger service or lines where designated hazardous materials are transported. PTC systems, as defined by RSIA 08, are designed to prevent:

- Train-to-train collisions
- Over-speed derailments
- Incursions into established work zone limits
- Movement of a train through a switch left in the wrong position

Since RSIA 08 was enacted, U.S. railroads have devoted a significant amount of financial and human resources to develop safe and functional PTC systems, and they have encountered an array of technical and nontechnical challenges in the design and deployment of PTC.

The railroads operating on the Northeast Corridor (NEC) are deploying two PTC systems: The Advanced Civil Speed Enforcement System (ACSES) and Interoperable Train Control (ITC), which is commonly referred to as the Interoperable Electronic Train Management System (I-ETMS^{®1}). The commuter and passenger railroads that operate on the NEC will primarily be using ACSES. The Class I freight railroads are deploying ITC nationwide and as a result, part of the NEC will use ITC. While both PTC systems use 220 megahertz (MHz) data radios, the radios are built by different manufacturers and use different communication protocols. The use of dissimilar radios that operate within the same frequency band introduces the potential for communication problems for ACSES and ITC deployments on the NEC.

In particular, concurrent use of the ACSES and ITC radios within close proximity can result in loss of messages due to radio receiver desense (i.e., a desensitization of radio frequency). Failure for messages to be received could result in PTC brake enforcements with the potential to cause severe traffic disruption, especially on the busy NEC. Throughout the NEC, ACSES and ITC will be deployed in close proximity, sometimes on the same track bed, and in some locations trains will need to transition between ACSES and ITC territory so freight and passenger trains can operate on the same track.

The NEC contains a dense network of railroads. The railroads that operate within this area recognize that collaboration and a cooperative engineering effort is required to successfully implement the dissimilar data radio networks that will support the functioning of each PTC system on the NEC.

Since July 2015, the NEC railroads, in cooperation with PTC220 LLC, have been working with the Federal Communications Commission (FCC) to reallocate their ACSES radio channels in the 220 MHz to 222 MHz range with channels in the 217 MHz to 219 MHz range in an effort to minimize the complexity of mitigating radio desense problems between ACSES and ITC. Those

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

efforts are likely to result in reallocation of the spectrum used by PTC systems on the NEC to provide a minimum of 1 MHz spectral separation between ACSES and ITC radio channels.

This document provides a trade study of potential solutions to the NEC PTC radio desense problem.

1.1 Objectives

The objective of this project was to define the scope of the PTC radio desense problem on the NEC, identify potential solutions to PTC locomotive radio desense, and perform a high-level study of potential approaches to mitigation of PTC locomotive radio desense resulting from dissimilar PTC radios operating within close geographic proximity or dissimilar PTC radios simultaneously operating on the same locomotive. Solutions that mitigate the more problematic desense cases involving locomotive radios were the primary focus, since fixed site PTC radios (wayside and base station radios) can be protected from desense through the use of filters and by proper radio network design and planning. The results and recommendations of this project are intended to focus subsequent work to develop and test candidate solutions.

1.2 Overall Approach

This project was conducted by Transportation Technology Center, Inc. (TTCI) in close cooperation with an advisory group called the NEC Communications Team. This advisory group included representatives from:

- Railroads operating on the NEC, including CSX, Norfolk Southern, Amtrak, New Jersey Transit (NJT), Long Island Rail Road (LIRR), and Metro North Railroad (MNR)
- The Federal Railroad Administration (FRA)
- Suppliers of PTC communication systems and equipment, including Wabtec Railway Electronics, General Electric (GE), and Meteorcomm Communications (MCC)

TTCI collaborated with this advisory group to identify potential approaches to mitigation of communication interference problems associated with the NEC deployments of ACSES and ITC. Current developments in communication interference mitigation technology were reviewed, as well as emerging technology that could be adapted to rail industry needs, and potential solutions offered by the railroad supply industry.

Mitigation approaches that showed potential for implementation on the NEC were documented and a trade study comparing the relative merits of each approach was developed. Using the results of this trade study, recommendations to mitigate NEC PTC radio desense issues were formulated and suggested for testing.

1.3 Scope

TTCI collaborated with railroad and railroad supply industry representatives to:

- Document the scope of the PTC radio desense problem in the NEC
- Identify potential solutions to radio interference issues that involve dissimilar PTC locomotive radios
- Document the candidate desense mitigation solutions

- Develop a trade study comparing the relative merits of each candidate solution

Potential solutions include devices that provide radio frequency (RF) isolation between affected radios or schemes that allow transmission coordination between dissimilar radios. Use of combinations of solutions to mitigate a broader range of potential communication problems was analyzed and documented.

1.4 Organization of the Report

This report is organized into six major sections:

- Section 1 provides background information on the project
- Section 2 provides overviews of the PTC system deployments on the NEC and the problems with PTC radio desense
- Section 3 defines how candidate desense mitigation solutions were evaluated in the trade study
- Section 4 contains the trade study review of the candidate desense mitigation solutions identified during the course of this project
- Section 5 is the summary of the analysis of using multiple candidate solutions in concert
- Section 6 provides a summary of project findings and recommendations for next steps

2. Problem Overview

The northeastern section of the United States is a geographic region that faces significant PTC implementation challenges. Of particular interest is the NEC, which extends from Washington, D.C. to Boston, with several lines branching into nearby states. It is one of the most heavily used and congested rail corridors within the United States. The NEC serves a passenger and intercity rail service, three Class I freight railroads, and ten commuter rail agencies:

- Amtrak
- CSX Transportation (CSX)
- Norfolk Southern Corporation (NS)
- Consolidated Rail Corporation (Conrail, owned by NS and CSX)
- Southeastern Pennsylvania Transportation Authority (SEPTA)
- Metropolitan Transportation Authority (MTA)
 - Metro-North Railroad (owned by MTA)
 - Long Island Rail Road (owned by MTA)
- New Jersey Transit (NJT)
- Massachusetts Bay Transportation Authority (MBTA)
- Shore Line East
- Maryland Rail Commuter (MARC)
- Virginia Railway Express (VRE)
- Rhode Island DOT (RIDOT)
- Delaware Department of Transportation (DelDOT)

Together, the passenger, commuter, and freight railroads that operate on the NEC collaborate to manage the current high traffic volumes, which are complicated by the significantly different operating speeds, weights, lengths, stopping patterns, etc., between the freight and passenger trains. The freight railroads sharing the tracks often run at night when a limited number of passenger trains are operating.

Amtrak, SEPTA, MNR, LIRR, and NJT, for example, are deploying ACSES. ACSES uses transponders installed in the track between the rails to communicate location-specific information to the train as it passes over. ACSES will use GE TD220x, 220 MHz data radios to communicate temporary speed restrictions (TSRs) and interlocking status.

The Class I railroads will use an Interoperable Train Control (ITC)-compliant PTC system throughout the United States. This PTC system includes ITC-compliant 220 MHz data radios and a messaging system, collectively referred to as the Interoperable Train Control Messaging (ITCM) system, developed by MCC.

The use of the two different PTC systems, ITC by the Class I railroads, and ACSES by multiple passenger and commuter lines, in the same geographic area will present challenges, especially related to the coordination of the dissimilar 220 MHz data radios used by each of the systems.

Some dissimilar radios will be located in close proximity to one another, while some may potentially be co-located; for example, an ACSES and ITC base station may both be housed in the same building with their respective antennae mounted on a single tower. Locomotives may be dual-equipped with both ACSES and ITC locomotive radios. The physical proximity of the radios is further complicated by the radios operating in the same frequency band (217 MHz to 222 MHz). When multiple radios are operating in the vicinity of one another, even on non-adjacent frequencies, the high level of 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 and is referred to as desense.

This study focuses on defining the challenges and the scope of the problem the railroads on the NEC will encounter due to the potential for desense of the radios used by the two different PTC systems, and it concentrates on the potential solutions specific to the onboard aspect of the problem.

2.1 Northeast Corridor

The Northeast region of the United States is home to 51 million people, and it is projected to reach 58 million by 2040. One fifth of the nation's gross domestic product is generated in the region. With freight, passenger, and commuter trains all sharing the same right of way, the NEC network is a complex, high-volume operating environment. The NEC was built over a period of nearly one hundred years, from 1830 to 1917. It is 457 miles long, has 17 tunnels, and 1,186 bridges. [1] The ownership of the 457-mile rail line is as follows:

- Amtrak – 363 route miles
- Connecticut DOT – 46 miles
- Massachusetts – 38 route miles
- Metro-North – 10 route miles
- CSX owns the right-of-way between Washington D.C. and Richmond [2]

The rail line spans the following states:

- Maryland
- Delaware
- Pennsylvania
- New Jersey
- New York
- Connecticut
- Rhode Island
- Massachusetts [3]

2.2 Passenger and Commuter Rail Services on the NEC

Amtrak owns the longest stretch of the corridor and provides high-speed rail services with the fastest North American train, the Acela Express, reaching speeds up to 150 mph. [2] Daily,

2,220 trains traverse sections of the NEC, with 720,000 passengers riding on various parts of the corridor. The Amtrak Acela Express and Northeast Regional services were used by 11 million passengers in 2011. [1]

After two serious train accidents in 1987 and 1990, the Federal Railroad Administration (FRA), mandated Amtrak to take steps to prevent such accidents by adding safety functions to its existing signaling system. In order to continue operations at high speeds, Amtrak was required to add enforcement of an absolute stop at home signals, and to provide enforcement of track speed and TSRs. This resulted in the development of ACSES to augment the cab signal system. [4]

ACSES works as a supplement to cab signaling and Automatic Train Control (ATC). Cab signaling displays the signal status governing train movement to the locomotive crew inside the cab, and ATC provides enforcement of speeds dictated by signal indications. The system has an onboard computer (OBC) that obtains data from passive transponders installed between the running rails. The OBC enforces temporary and permanent speed restrictions using data from the transponders and data received from back office and wayside equipment via a 220 MHz data radio network, which includes the data radios installed on the locomotive. The 220 MHz GE data radios are located at interlockings; they relay interlocking status, TSR information, and maintenance-of-way information. The data radios obtain information regarding speed restrictions from a Safety Temporary Speed Restriction Server. [4]

Most of the passenger and commuter railroads on the NEC have acquired, or plan to acquire, radio channels in the 217 MHz to 219 MHz range. In some instances, passenger and commuter railroads were unable to obtain a sufficient number of radio channels in the 217 MHz to 219 MHz band, but obtained channels in the 220 MHz to 222 MHz range. As previously noted, the NEC railroads are working with the FCC and spectrum owners in an effort to reallocate spectrum such that all ACSES users in the NEC will operate in the 217 MHz to 219 MHz band. The ACSES radios use a Time Division Multiple Access (TDMA) channel access method. Amtrak and commuter lines on the NEC (such as SEPTA and MTA) use ACSES.

2.3 Freight Rail Services on the NEC

On average, 70 freight trains operate on the NEC daily, and throughout the year they accumulate more than 14 million car miles. [1] The Class I railroads collectively chose to deploy the PTC system known as ITC, which is a locomotive-centric system composed of four segments:

- Locomotive Segment – This segment continually monitors information from the office segment of one or more railroads, as well as the wayside segment, the locomotive control settings, and onboard peripheral devices (such as Global Positioning System data). This information is assimilated and used to support enforcement of authorized train movements
- Office Segment – This segment interfaces with the back office systems of one or more railroads. A variety of operational data, such as TSRs, work zones, authorities, train identifications (IDs) and consist information is used by the ITC office segment. Secure configurations of onboard software versions, startup files, and track database versions are controlled by the office segment as well
- Wayside Segment – The wayside segment interfaces with, monitors, and reports the status of wayside devices such as switches, signals, and track hazard detectors with the

use of wayside interface units (WIUs). On the basis of the configuration of the wayside segment, this data is then transferred to the locomotive segment and office segment of the railroad

- Communications Segment – Consists of multiple wired and wireless networks, and it is customized on the basis of each railroad’s needs. The wireless network can include 220 MHz private data radio networks, railroad broadband Wi-Fi, and/or public wireless networks such as cellular. This study focuses on the challenges surrounding the use of the 220 MHz data radio networks, and in particular, the issues associated with operating two dissimilar 220 MHz radios on the same locomotive

The ITC-compliant 220 MHz data radios developed by MCC include three models: the locomotive, wayside, and base radios. Each freight railroad can customize the use and deployment of these radios to suit their operational needs. Typically, the wayside radios are located near the track so they can relay data from switches, signals, and hazard detectors to the locomotive radio, and multiple wayside radios report to a base radio. The ITC radios use a combination of TDMA and Carrier Sense Multiple Access (CSMA) channel access methods. The spectrum used by ITC radios and owned by PTC220 LLC is between 220 MHz to 222 MHz and will be discussed in a later section of the report. [5]

2.4 Desense Overview

The following cases illustrate different scenarios in which ITC systems can cause desense of ACSES systems or vice versa. Each case has its own set of problems and can be mitigated using a combination of approaches.

2.4.1 Scenarios Resulting In Locomotive Radio Desense

This study focuses on mitigation for the scenarios in which a locomotive PTC radio may be desensed by a dissimilar PTC radio. There are three scenarios in which a locomotive PTC radio may be desensed: (1) a locomotive desenses itself, (2) a locomotive desenses other locomotives, and (3) a fixed site desenses a locomotive.

2.4.1.1 Dual-Equipped Locomotive Self Desense

When a locomotive must operate at times in ITC controlled territory and at other times in ACSES controlled territory, then that locomotive must have both ITC and ACSES onboard systems and radios installed. This requires each system to have an antenna installed on the roof of the locomotive, which leads to antenna spacing between 2 to 5 feet for the dissimilar systems. If either of these radios is transmitting, the other radio onboard may be desensed and unable to receive. This is referred to as “locomotive self-desense.” Figure 1 shows an example in which the ITC system on a dual-equipped locomotive is transmitting at the same time that the ACSES onboard system is receiving. In this example, the ACSES locomotive radio is being desensed by the ITC locomotive radio.

Locomotive self-desense is primarily an issue in areas where the locomotive is transitioning from ITC to ACSES, or vice versa. In these transition zones, the dual-equipped locomotive must communicate with both ACSES and ITC base stations as the locomotive prepares to exit territory controlled by one PTC system and enter territory controlled by the other.

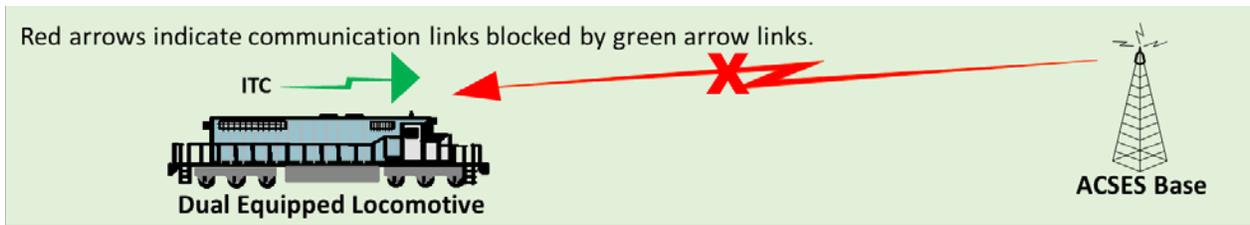


Figure 1. Locomotive Self Desense

2.4.1.2 Locomotive Desensing Locomotive

A locomotive can desense another locomotive when both of them are communicating with different PTCs systems and operating on adjacent tracks (as close as 12 feet between track centers). If a PTC data radio on one locomotive is transmitting, a radio of the other type (ACES vs. ITC) on the other locomotive may be desensed. Figure 2 shows an example in which the radio on an ITC locomotive is transmitting at the same time that the radio on an ACSES locomotive is receiving. In this example, the radio onboard the ACSES locomotive is desensed by the radio onboard the ITC locomotive.

This is an issue any place where ACSES and ITC systems are deployed in close proximity.



Figure 2. Locomotive Desensing Locomotive

2.4.1.3 Fixed Site Desensing Locomotive

A fixed site can desense a locomotive when an ACSES or ITC-equipped locomotive is operating in close proximity to a fixed site radio installation, base station or other wayside radio. When the fixed site radio is transmitting in one system, a nearby locomotive that is transmitting on the other system may be desensed. Figure 3 shows an example in which an ITC base station is transmitting at the same time that the radio on an ACSES locomotive is receiving. In this example, the radio onboard the ACSES locomotive radio is desensed by the ITC base station.

A fixed site can desense a locomotive anywhere that ACSES and ITC systems are deployed in close proximity.



Figure 3. Fixed Site Desensing Locomotive

2.4.2 Additional PTC Desense Scenarios

Although locomotive radio-related desense is the focus of this report, scenarios that cause desense in fixed site PTC radios are reviewed for completeness. There are five cases that will cause fixed site PTC radios to be desensed: (1) a base station desensing a base station; (2) a base station desensing a wayside; (3) a wayside desensing a base station; (4) locomotive desensing a base station; and (5) locomotive desensing a wayside.

2.4.2.1 Base Station Desensing Base Station

One base station can desense another base station when a base station is using one PTC system (ACSES or ITC) with a tower antenna in close proximity to another base station that is using the other PTC system with an antenna on a tower. When one base station radio is transmitting, the dissimilar radio at the other base station may be desensed as shown in Figure 4.



Figure 4. Base Station Desensing Base Station

2.4.2.2 Base Station Desensing Wayside

A base station can desense a wayside when an ACSES-equipped base station with an antenna on a tower is operating in close proximity to an ITC-equipped wayside. When the ACSES-equipped base station radio is transmitting, the ITC-equipped wayside may be desensed as shown in Figure 5.

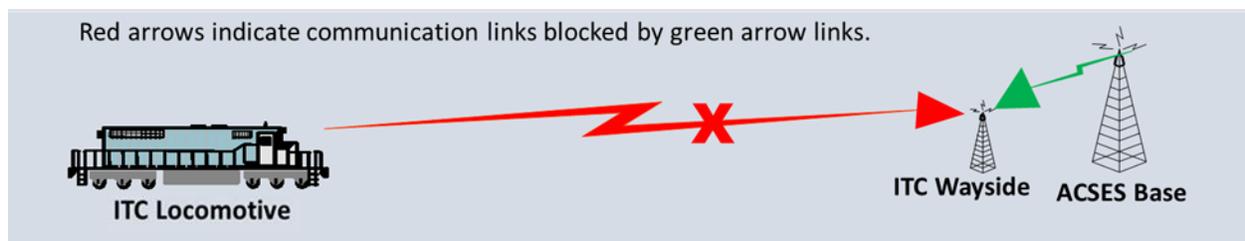


Figure 5. Base Station Desensing Wayside

2.4.2.3 Wayside Desensing Base Station

A wayside can desense a base station when an ITC-equipped wayside is operating in close proximity to an ACSES-equipped base station. When the ITC-equipped wayside radio is transmitting, the ACSES-equipped base station may be desensed as shown in Figure 6.

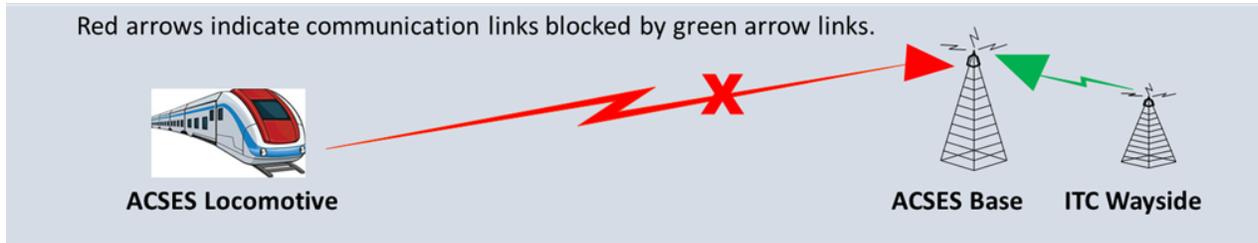


Figure 6. Wayside Desensing Base Station

2.4.2.4 Locomotive Desensing Base Station

A locomotive can desense a base station case when a locomotive is operating in close proximity to an ACSES or ITC-equipped base station. When a locomotive is using a radio to communicate via one system, radios on the base station from the other system may be desensed as shown in Figure 7.

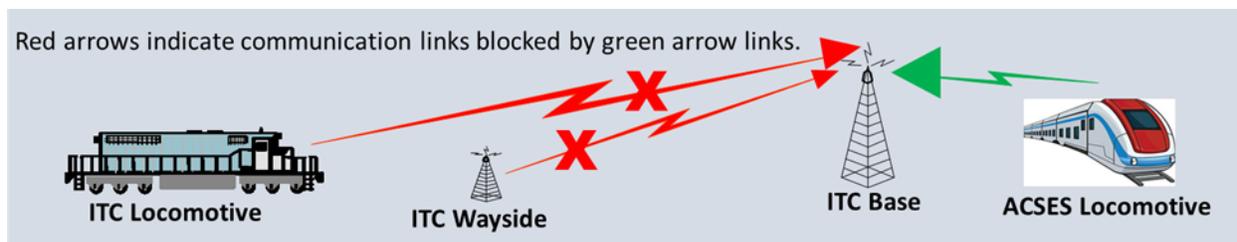


Figure 7. Locomotive Desensing Base Station

2.4.2.5 Locomotive Desensing Wayside

A locomotive can desense a wayside when an ACSES-equipped locomotive operates in close proximity to an ITC-equipped wayside. When the ACSES-equipped locomotive is transmitting, the radio on the ITC-equipped wayside may be desensed as shown in Figure 8.

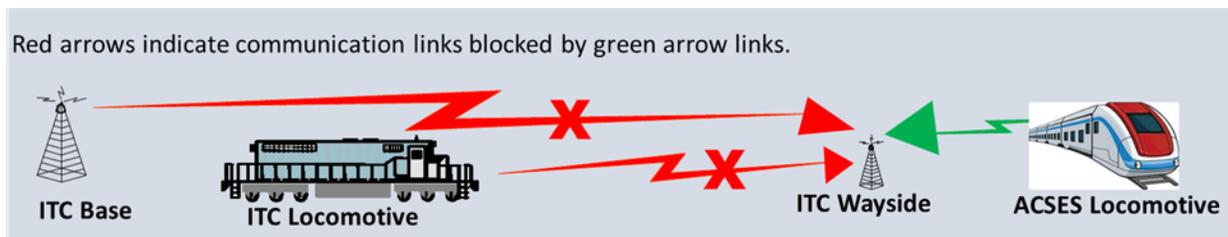


Figure 8. Locomotive Desensing Wayside

2.4.3 Additional Considerations

Desense between the differing PTC 220 MHz radios will be most common in the following deployment cases:

- Close proximity deployments — Desense can occur when dissimilar receivers and transmitters are geographically close to each other, such as when an ITC base or wayside and an ACSES base are less than approximately 1.5 miles apart.
- Dual wayside deployment — Desense can occur when both ITC and ACSES are used on the same track, with freight trains using ITC and passenger/commuter trains using

ACSES. This becomes problematic since dissimilar locomotive, base, and wayside radios can all desensitize each other depending on the circumstances.

- Transition areas — Desense occurs when trains must transition from ITC territory to ACSES territory or vice versa without the loss of PTC functionality. For these scenarios, there is a transition zone through which both radios are active on a locomotive.

The desense thresholds for ACSES and ITC radios had already been determined by laboratory testing conducted at the Transportation Technology Center (TTC) under a separate FRA-funded project. These values are used to identify requirements for candidate desense mitigation solutions as well as for planning and coordination purposes throughout the NEC (also funded under a separate FRA-sponsored project).

PTC systems must provide protection against safety hazards without disrupting railroad operations with false enforcements. As a result, high reliability is a crucial element of PTC systems, because message loss due to the communications system performance is one source of false enforcements. A PTC system performance goal is to allow a false enforcement rate of one per million train miles.

An important piece of the overall desense problem is whether or not cab signaling is used. Cab signaling provides intermediate signal aspects to equipped locomotives and is used by ACSES and ITC on the NEC. Along sections of commuter/passenger track in the NEC equipped with cab signaling, it is understood that freight locomotives will be installed with cab signaling, thus eliminating the need for WIUs to monitor intermediate signal status. For ITC systems, a WIU is still required to monitor absolute signals for PTC requirements, and this information will be conveyed to the locomotive using a 220 MHz wayside data radio or alternative communication pathways. All ITC locomotives (CSX, NS, and Conrail) and most ACSES track is equipped with, or planned to be equipped with, cab signaling. Cab signaling does not replace the PTC function of monitoring interlocking status, but it does reduce the number of WIUs required and the overall congestion of PTC RF signals in the 217 MHz to 222 MHz range.

Additionally, there can be blocking issues among radios of the same system if a receiver is trying to locate a signal from a distant transmitter with another transmitter close by. Such intra-system blocking issues are beyond the scope of this document, which focuses on desense issues between dissimilar PTC systems.

2.5 Train Transition between PTC Systems

If a dual-equipped locomotive is required to make a transition from ACSES to ITC and vice versa, the “hand-off” from one system to the dissimilar system must occur with no loss of PTC functionality and without requiring the train to slow down or stop. As a dual-equipped locomotive transitions from one PTC territory to a dissimilar PTC territory, it must successfully complete system-specific initialization procedures and have all system-specific functions operating before entering the dissimilar territory. Similarly, the PTC system associated with the territory that the locomotive is leaving must transition to a non-active mode.

2.5.1 Entry to ACSES Territory

Before entry into ACSES territory, a train must complete an onboard system departure test, to be conducted at the initial terminal, and the ACSES onboard system must be activated.

2.5.1.1 ACSES Departure Test

One requirement for entry to ACSES territory is that the ACSES-equipped locomotive must complete two departure tests: the ATC departure test and the ACSES system departure test. These tests occur while the locomotive is stationary, and typically before departing the yard or at the initial terminal. The ATC departure test consists of a series of overspeed and downgrade tests using the cab signal Aspect Display Unit (ADU), while the ACSES departure test consists of seven steps:

- Train Type Check
- Train Type Acceptance
- Antenna Check
- Magnet Valve and Alarm Check
- Permanent Suppression Check
- Positive Train Stop
- Radio check

If any step fails, the departure test must be restarted after the problem causing the initialization failures are corrected. Once the departure tests are successfully completed, the ACSES onboard segment is ready to enter ACSES territory. [6]

2.5.1.2 Activation of ACSES

A locomotive's entry into ACSES territory, or its transition from non-ACSES-controlled territory to ACSES territory, is initiated when an ACSES-equipped locomotive passes over a set of transponders. These transponders are positioned before the interlocking or control point that is the entry point to ACSES-controlled territory, and they provide the ACSES OBC the address and information related to the radio channel of the home signal's wayside encoder that is monitoring the status of the interlocking or control point that is the entry point to ACSES-controlled territory.

Once the locomotive has passed over this transponder pair, the OBC will initiate communication with, or "hail", the wayside, or the base station's ACSES radio that is interfaced to the home signal's wayside encoder. Once communication with the home signal has been established, the ACSES OBC will request the following information via the ACSES data radio link:

- Home signal status (stop or go)
- Speed limit through interlocking
- Any other pertinent data required for the onboard computer to enforce TSRs [4]

The interlocking status will be reported periodically to the locomotive OBC. The TSR dataset will be delivered to the locomotive OBC concurrent with the status updates for the home signal interlocking.

To ensure that a train in transition can safely stop if the indication for the interlocking or control point is stop, the transponder set that initiates a locomotive's entry into ACSES territory will be a minimum distance away from the home signal. This minimum distance is the "full stopping

distance” for the maximum allowed line speed plus the distance traveled in a defined amount of time (e.g., 20 seconds) at the maximum allowed line speed. Figure 9 below provides a visual for the minimum transition distance from non-ACSES territory to ACSES territory.

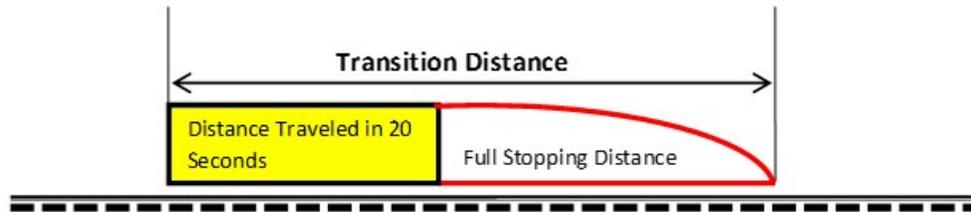


Figure 9. ACSES Minimum Stopping Distance

The ACSES locomotive onboard segment can now transition from “Non-ACSES Territory Mode” to “ACSES Territory Mode.” Before entry to ACSES territory, the ACSES locomotive onboard segment must have:

- Permissive authority to pass the home signal
- Current TSR dataset

Additionally, the ITC locomotive onboard segment must be disengaged once the locomotive has entered into ACSES-controlled territory.

2.5.2 Exit from ACSES Territory

When a locomotive leaves ACSES territory, which includes entry into ITC-controlled territory, the ACSES locomotive onboard system will need to transition from “ACSES Territory Mode” to “Non-ACSES Territory Mode.” This is accomplished by placing an ACSES transponder set at the transition point that will notify the ACSES locomotive onboard system that the train is exiting ACSES-controlled territory.

2.5.3 Entry to ITC Territory

Before entering ITC territory, the locomotive must be initialized, which typically occurs at the initial terminal, and it must transition from a disengaged state to an active state.

2.5.3.1 ITC Initialization

In order for a locomotive to enter ITC territory from non-ITC territory, and for the ITC PTC functions to be active, the onboard locomotive segment must successfully initialize.

Initialization typically takes place at the initial terminal (even in non-ITC territory) before beginning a trip, and while the train is stopped. The process is invoked by the locomotive engineer and includes the following functions:

- Authenticating the employee’s security credentials
- Selecting the railroads and the applicable track segments to be operated on according to the terminal’s paperwork or instruction. The locomotive segment verifies the active track data for each of these segments with the office segment, and downloads updates if needed. Track data includes:

- Track characteristics and geographic location
- Civil speed limits
- Location of switches, switch clearance and fouling points, wayside signals, crossings, mileposts, and relevant method of track operation
- Verifying and/or downloading active consist data, including
 - Locomotive count and hood orientation
 - Empty and loaded car counts
 - Total axle count and train length
 - Equipment speed restriction
 - Trailing tonnage
- Input of train clearance identifier for each railroad to be operated on during the trip, according to the terminal paperwork or instruction. This allows for verification of match between train crew, locomotive ID, and train symbol
- Identifying available locomotive software updates
- Verifying the departure test or the completion of departure test if required. The departure test examines the following:
 - Onboard display and input keys
 - Locomotive interfaces, such as GPS
 - Communications system
 - Brake system
 - Penalty reduction system availability
 - Sound enunciator and horn interface.

If certain conditions occur, the locomotive segment may need to be re-initialized (which must be performed after the train is stopped). If the ITC system “Cut-Out” switch must be used for any reason, such as failure of a penalty break to release, then the system must again be initialized when the switch is changed to the “Cut-In” state. If the locomotive segment enters a failed state, re-initialization will be required to resume ITC functions. [5]

2.5.3.2 Activation of ITC

As the locomotive approaches ITC-controlled territory, the ITC locomotive segment is disengaged. Disengaged means the locomotive has initialized but is not in ITC PTC territory and therefore will not provide predictive enforcements. While in the transition zone between ACSES and ITC territory, the ITC locomotive segment will need to transition from “disengaged” mode to “active mode” by performing the following tasks:

- Establish continuous polling transactions with the office segment via the ITC 220 MHz data radio network, or an alternate communication path such as cellular,

- Establish communication with the wayside segment, e.g., via the ITC 220 MHz data radio network,
- Verify the integrity of onboard track data, including track bulletins, and
- Obtain movement authority, which is issued as mandatory directive in accordance with the methods of operation of the railroad governing the entry point.

Figure 10 describes how the ITC locomotive segment transitions from disengaged to active.

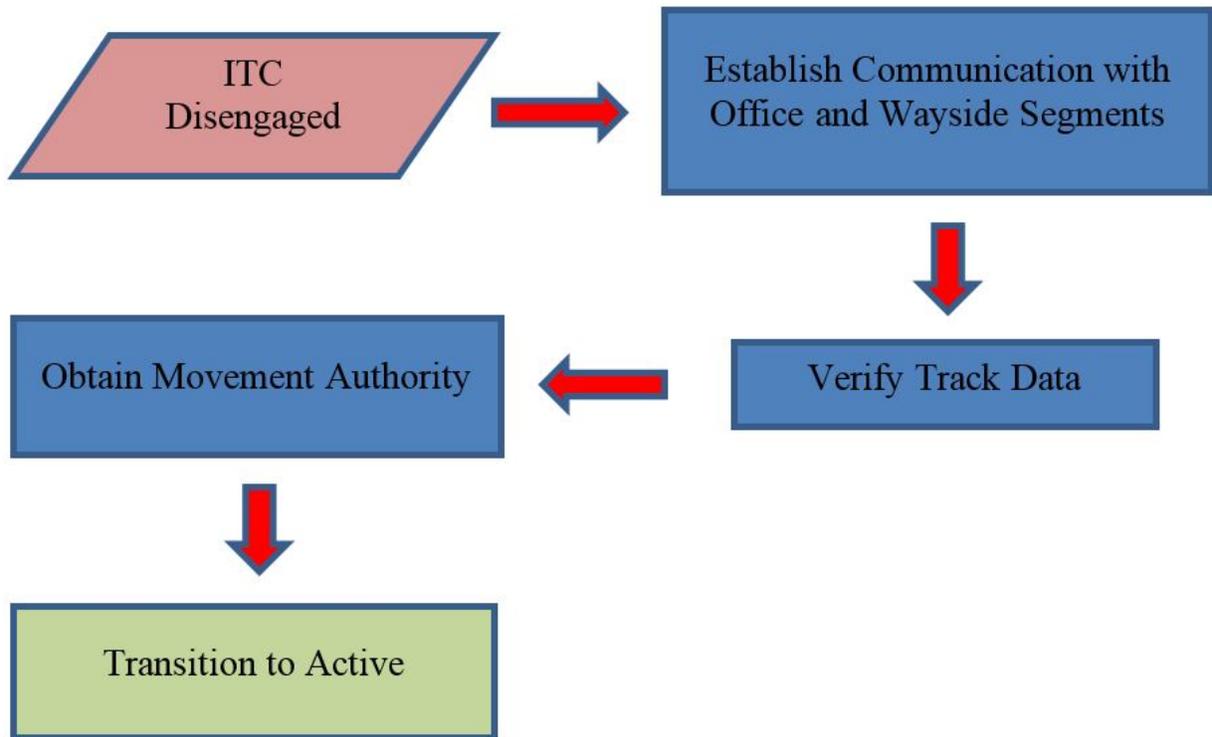


Figure 10. Locomotive Segment Transitioning from Disengaged to Active

When the locomotive is in an active state and the engineer has obtained movement authority to enter ITC-controlled territory, the train may then enter ITC-controlled territory. The minimum length of the transition zone required to support a train's transition from ACSES control to ITC control is dependent upon:

- The dynamically calculated safe braking distance that is necessary to bring the train to a stop before the transition point if needed
- The warning distance, which is dynamically calculated on the basis of a configured warning interval
- The distance that a locomotive travels at maximum train speed over the time required for the system to change from disengaged to active

The length of time required for the system to transition from disengaged to active is dependent upon the locomotive establishing communication with the base to verify and update, as needed, track, consist, and route information. Figure 11 provides a visual of the transition distance.

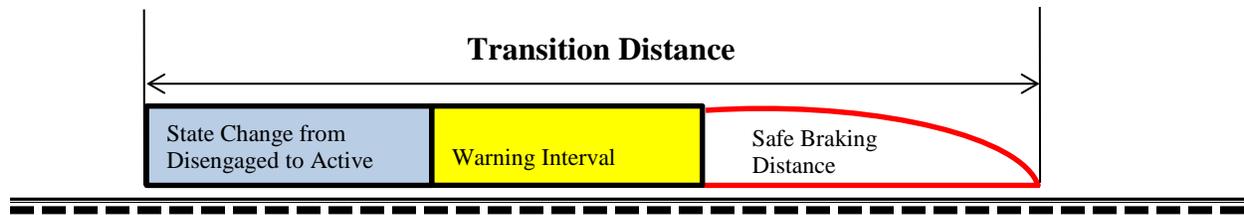


Figure 11. Transition Distance for Entering ITC Territory

If the length of the transition zone is insufficient to allow the ITC Locomotive Segment to transition to active mode while the train is traveling at track speed, then a speed reduction or train stop before entry into ITC territory will be required.

If the train does not have authority to enter ITC territory or if it has not successfully initialized to active mode, then it will not be permitted to enter ITC territory, the ITC Locomotive Segment will provide a predictive warning, and then it will enforce a stop to prevent the unauthorized entry. The operator is given a warning and if no action is taken, then ITC will send a full-service brake enforcement. The warning distance is the predicted stopping distance plus the predicted distance traveled during a configured warning time interval. These dynamically calculated and predicted values are derived from train speed, train characteristics, including current state of braking system, locomotive control settings, and track profile. [5]

2.5.4 Exit from ITC Territory

When an ITC-equipped locomotive exits ITC territory or transitions from ITC territory to ACSES-controlled territory, the ITC locomotive onboard system will need to transition from active to disengaged. During initialization, the locomotive engineer selects the railroads that will be operated on during the trip, which in turn provides information regarding entry and exit points for ITC. While in ITC territory, regular communications between the locomotive and office segments during the trip will provide updates to exit points, as needed. No specific enforcement or equipment is required to exit ITC territory. However, ITC will enforce a signal, track warrant, cab signal, or speed restriction at the exit point. Once the train leaves ITC-controlled territory, the operating mode is automatically downgraded to a disengaged state, and enforcements will no longer occur.

In addition to transition areas, there are specific radio location placement cases where desense can occur. [5]

2.6 NEC PTC Deployment Overview

As deployment of both radio systems on the NEC begins, care must be taken during equipment site selection, track selection, frequency selection and transmit power output design to ensure the most effective use of the 220 MHz spectrum. Figure 12 provides an overview of the planned deployment locations for the freight railroads operating on or near the NEC, which include CSX, NS, Conrail, and the passenger and commuter railroads that will be deploying ACSES (which include Amtrak, SEPTA, NJT, MNR, and others). For the seven abovementioned railroads, a total of 216 potential wayside stations, 378 base stations and 46 transition locations have been identified.

Figure 12 shows an overview of the currently proposed NEC ITC and ACSES track deployment areas for the railroads noted above. Each railroad is indicated by a specific color. The most congested area is in and around Philadelphia, followed by eastern New Jersey and the Interstate 95 corridor from Washington DC to Philadelphia. Plans for deployment of ITC within the NEC are, at this time, incomplete. Further work will be needed when the information is available to quantify miles of parallel track, miles of dual equipped, and traffic density; identify interlockings and transition locations; and finalize details of ACSES/ITC handover procedures.

This NEC PTC overview uses information available in May 2015. Minor changes to specific ACSES and ITC deployments within the NEC may have occurred since that time.

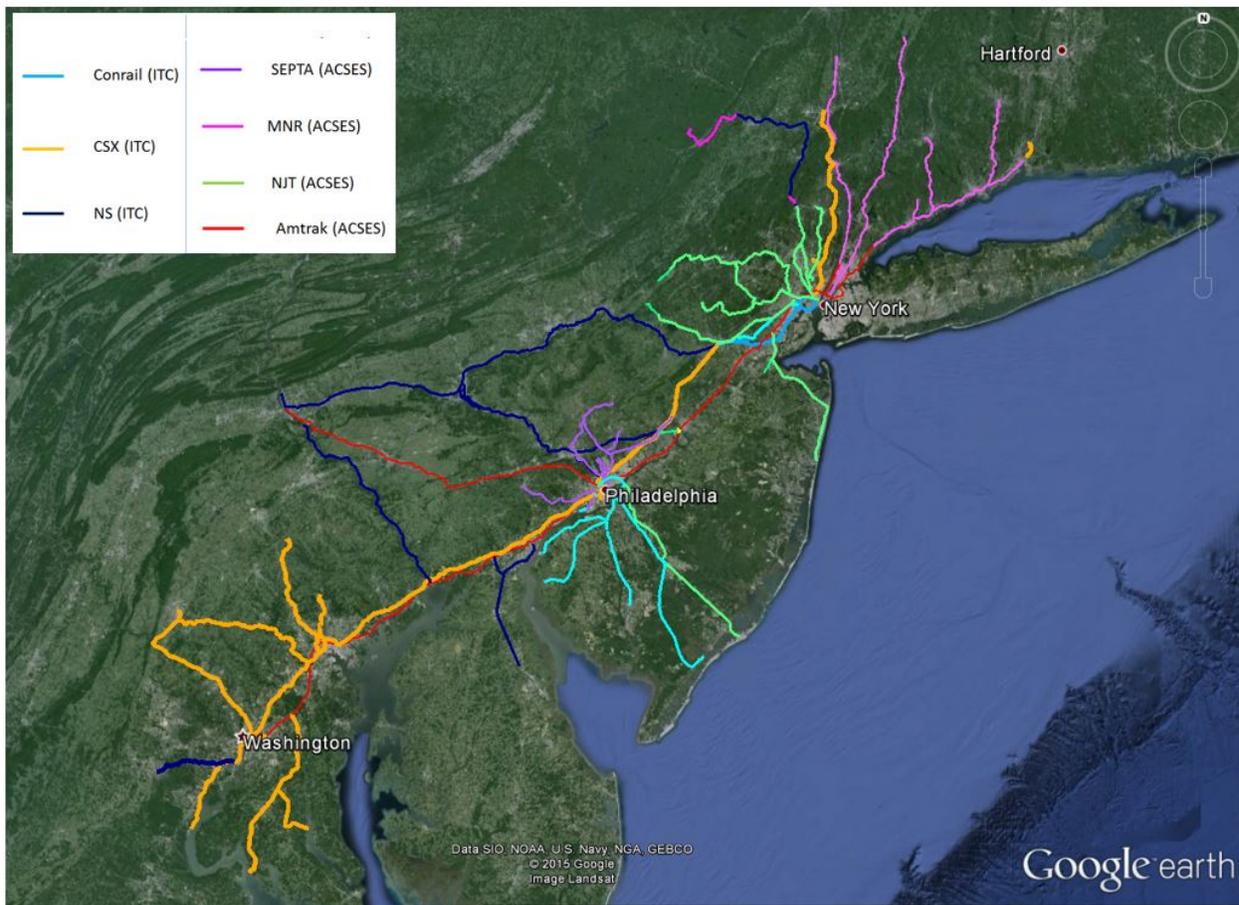


Figure 12. NEC PTC Deployment Track Overview

2.6.1 NEC PTC Spectrum Use

Nationally, channels used for PTC systems range from 217 MHz to 222 MHz. Currently, all ITC systems (including CSX, NS, and Conrail on the NEC) are planned to use frequencies above 220 MHz while most ACSES systems (NJT, MNR, LIRR) are planned to use frequencies below 219 MHz. SEPTA and some Amtrak sites are planned to have ACSES deployments using channels in the 220 MHz to 222 MHz range. As previously noted, the NEC railroads are working with the FCC and spectrum owners in an effort to reallocate spectrum such that all ACSES users in the NEC will be operating with channels in the 217 MHz to 219 MHz band. The ITC system uses

25 kHz channels while ACSES uses 12.5 kHz channels. For dissimilar radio systems using channels with spectral separation less than 1 MHz, it is more difficult, if not impractical to mitigate desensing using filters. Figure 13 shows the FCC spectrum designations for 217 MHz to 222 MHz. This spectrum includes the Automated Maritime Telecommunication System (AMTS) channel blocks A and B and the former Interactive Voice and Data Service (IVDS) channel block. PTC uses channels within this spectrum as described in the following sections.

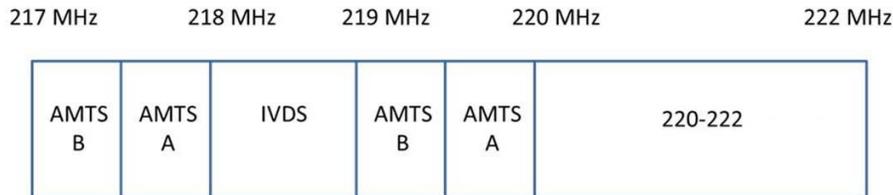


Figure 13. PTC Radio Spectrum

2.6.1.1 ITC Spectrum

PTC 220 LLC (a company jointly owned by the seven Class I railroads operating in the United States) was able to purchase spectrum in the 220 MHz to 222 MHz range for use nationwide. Table 1 shows the current channels used by ITC-compliant PTC systems. These channels are adequate to support PTC communication along lines with low to moderate density traffic; however, additional spectrum may be required to support PTC communication along high density traffic lines. In addition to the nationwide channels shown in Table 1, PTC 220 LLC has additional channels in a few limited regions.

Table 1. PTC 220 LLC Spectrum

PTC-220 Channel	Frequency (MHz)
101	220.1125
102	220.1375
113	220.4125
114	220.4375
125	220.7125
126	220.7375
127	220.7625
141	221.1125
142	221.1375
153	221.4125
154	221.4375
165	221.7125
166	221.7375
167	221.7625

2.6.1.2 ACSES Spectrum

The AMTS spectrum consists of A and B blocks within the 217 MHz to 218 MHz, each block providing 1 MHz of separation. The block of spectrum formerly known as IVDS consists of two blocks that are equally divided at 500 kHz between 218 MHz and 219 MHz. Commuter

railroads purchased spectrum from the AMTS and IVDS bands in cities and regions where available. The specific channels in this spectrum to be used by ACSES are not known at this time.

2.6.2 Freight Rail ITC Deployment

2.6.2.1 Conrail Deployment

Conrail Railroad operates over 268 miles of track spanning three states as shown in Figure 14. The Conrail PTC deployment includes 11 bases and 66 WIUs using frequencies in the 220 MHz to 222 MHz range. Conrail also has two bases operating on ACSES in New Jersey for the NJT railroad. SEPTA, NJT, Amtrak, and CSX operate on track owned by or dispatched by Conrail. The main areas of overlapping territories with ACSES systems are in and around Philadelphia with SEPTA, Amtrak and NJT; and eastern New Jersey with NJT. Conrail operates NS and CSX locomotives, and will use cab signaling as described in the NS and CSX deployments below.

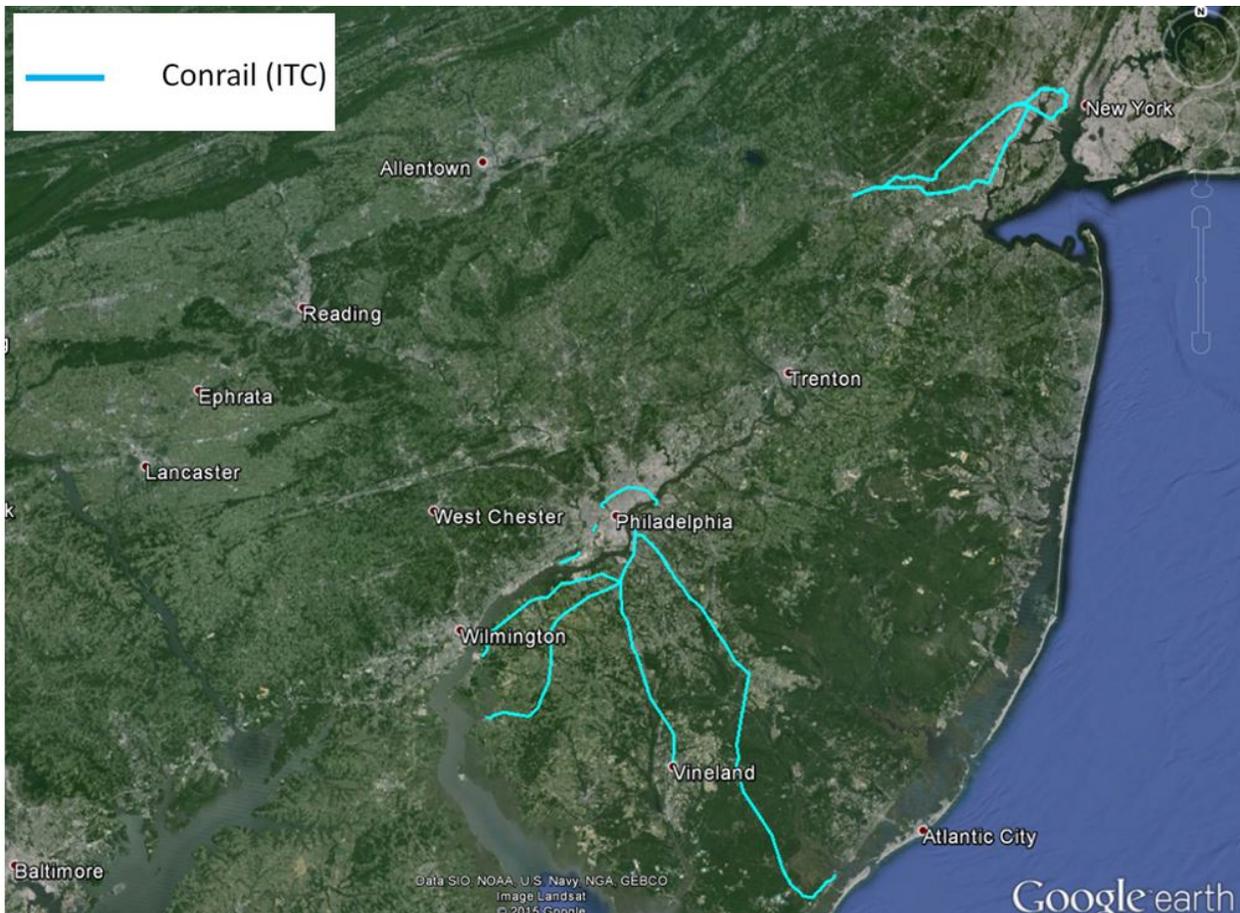


Figure 14. Conrail ITC Deployment Track

2.6.2.2 CSX Deployment

CSX Railroad operates over 672 miles of track on the NEC spanning eight states and Washington D.C., as shown in Figure 15. The CSX ITC deployment in this region includes 59 bases and 192 WIUs using frequencies in the 220 MHz to 222 MHz range. CSX will use cab signaling on all properly equipped tracks, which will eliminate the need for WIUs to monitor intermediate signals on these tracks. WIUs will monitor absolute signal status, and provide other PTC functions aside from monitoring intermediate signals. The WIUs deployed by CSX are not expected to use radios; instead, the Wayside Status Relay Service (WSRS) will convey WIU messages to locomotives via the ITC base stations. Since it is expected that CSX will not use wayside radios, the 192 WIUs mentioned above were not included in the total count of 216 wayside stations for the NEC. Additionally, CSX operates trains on the same track as Amtrak in the Philadelphia area. CSX operates in close proximity to SEPTA, NJT, and Amtrak railroads.



Figure 15. CSX ITC PTC Deployment Track

2.6.2.3 NS Deployment

NS Railroad operates over 507 miles of NEC-related track, which spans seven states and Washington D.C. (Figure 16). The NS ITC deployment in this region includes 78 bases and 150 WIUs, which use frequencies in the 220 MHz to 222 MHz range. NS will use cab signaling on all properly equipped tracks, which will eliminate the need for WIUs to monitor intermediate signals on these tracks. WIUs will be used to monitor absolute signal status, and to provide other PTC functions aside from monitoring intermediate signals. The WIUs deployed by NS may or may not use radios; if radios are not used, then WSRS will be used to convey WIU messages to the locomotive via the ITC base stations. NS operates trains on the same track as MNR in southern New York, and the railroad operates in close proximity to SEPTA, NJT and Amtrak railroads.



Figure 16. NS PTC Deployment Track

2.6.3 Passenger Rail PTC Deployment

2.6.3.1 SEPTA Deployment

SEPTA Railroad, as shown in Figure 17, operates over 121 miles of track that spans two states. The SEPTA ACSES deployment includes 61 planned base station locations using frequencies in the 220 MHz to 222 MHz range. However, if efforts to reallocate spectrum are successful, it will use channels in the 218 MHz to 219 MHz band. SEPTA operates trains on the same track as Conrail railroad in the Philadelphia area, and it operates in close proximity to NS and CSX railroads. The main areas of overlapping territories with ITC systems are in and around Philadelphia with CSX, Conrail, and NS. Currently, this is the only ACSES system that has identified the potential for using the 220 MHz to 222 MHz range in an area where that band is used by ITC systems as well.



Figure 17. SEPTA PTC Deployment Track

2.6.3.2 MNR Deployment

MNR, shown in Figure 18, operates over 304 miles of track spanning New York State and Connecticut. The railroad's planned ACSES deployment includes 92 planned base stations using frequencies in the 217 MHz to 219 MHz range. MNR operates trains on the same track as the NS railroad in the Port Jervis area of New York and uses parallel track with CSX along the Hudson River in New York.

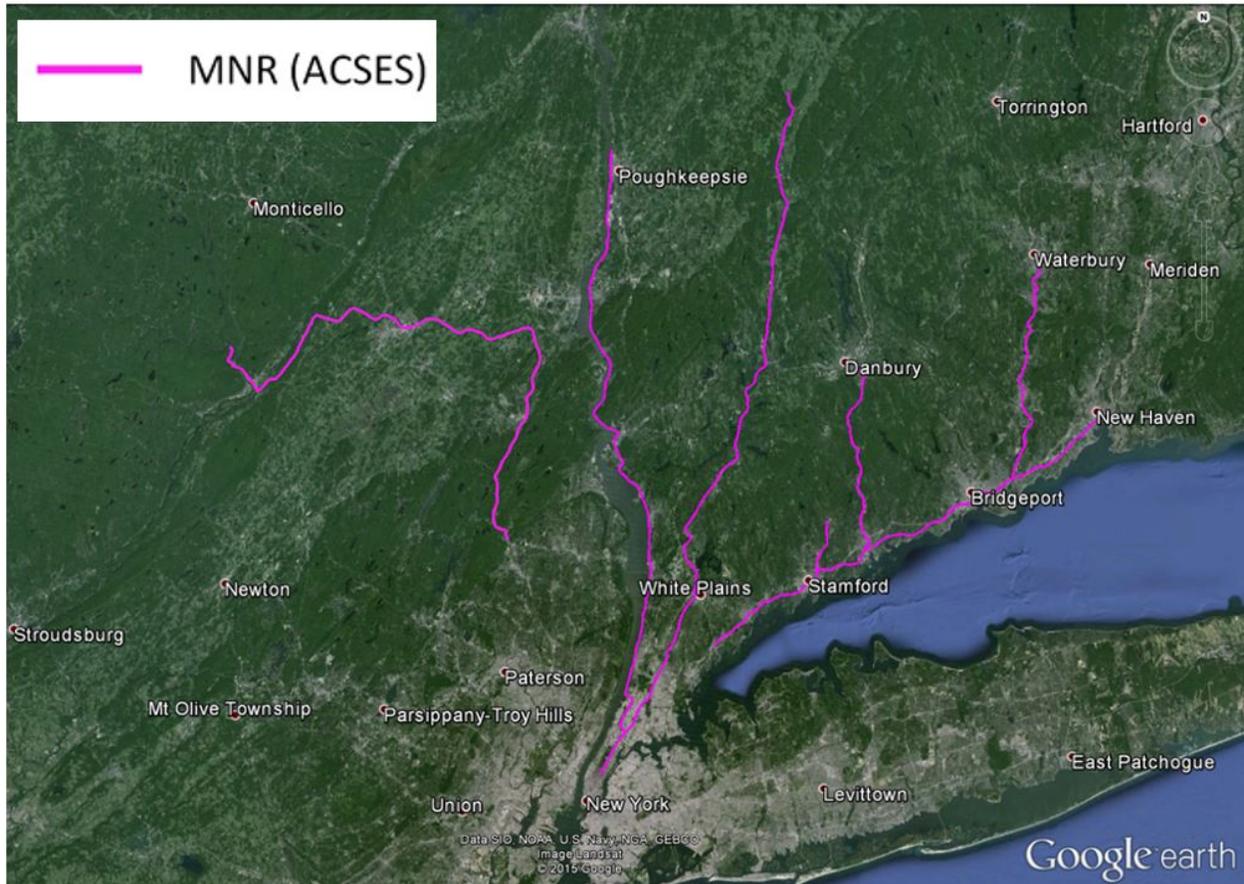


Figure 18. MNR ACSES PTC Deployment Track

2.6.3.3 NJT Deployment

NJT Railroad, shown in Figure 19, operates over 310 miles of track spanning New Jersey. The railroad's planned ACSES deployment includes 108 base stations using frequencies in the 217 MHz to 219 MHz range. NJT operates trains on the same track as Conrail railroad in New Jersey. NJT operates in close proximity to NS and CSX railroads. The main areas of overlapping territories with ITC systems are in and around Philadelphia with CSX and Conrail; and eastern New Jersey with Conrail, CSX, and NS.

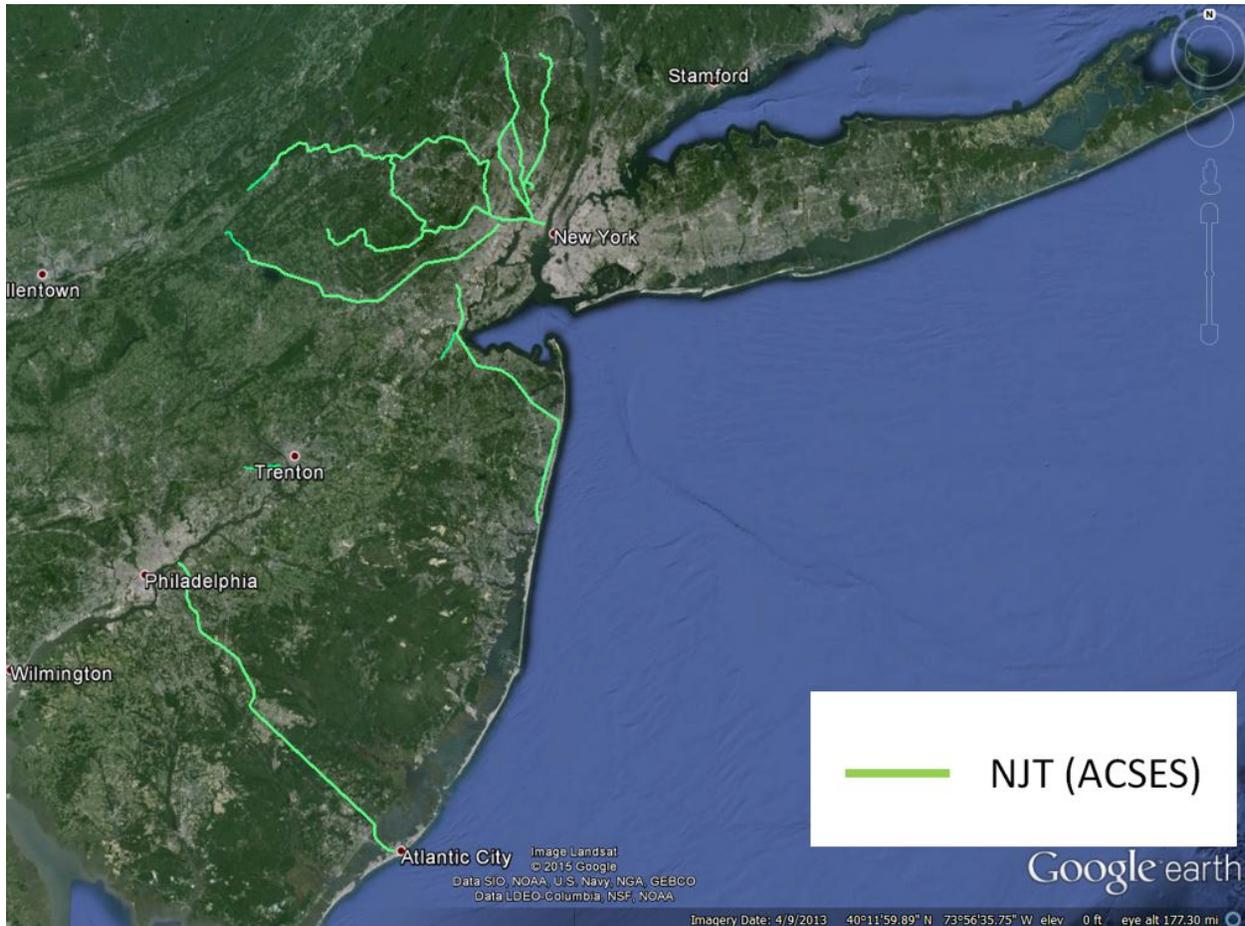


Figure 19. NJT ACSES PTC Deployment Track

2.6.3.4 Amtrak Deployment

On the NEC, Amtrak operates over 557 miles of track spanning six states and Washington D.C. The Amtrak PTC deployment, shown in Figure 20, includes 59 planned base stations using frequencies in the 217 MHz to 218 MHz range. Note that in New England north of New Haven, Connecticut, Amtrak is deploying ACSES using frequencies in the 220 MHz to 222 MHz band. However, if efforts to reallocate spectrum are successful, it will switch to the 217 MHz to 218 MHz band. Amtrak operates trains on the same track as Conrail and CSX railroads, and it operates in close proximity to NS and CSX railroads. The main areas of overlapping territories with ITC systems are in and around Philadelphia and eastern New Jersey with Conrail; from Washington D.C. to Philadelphia with CSX; from Baltimore, MD to Wilmington, DE along Interstate 95 with multiple railroads (refer to Figure 22 as an example); and from Philadelphia to Harrisburg, and Croxton Yard with NS.

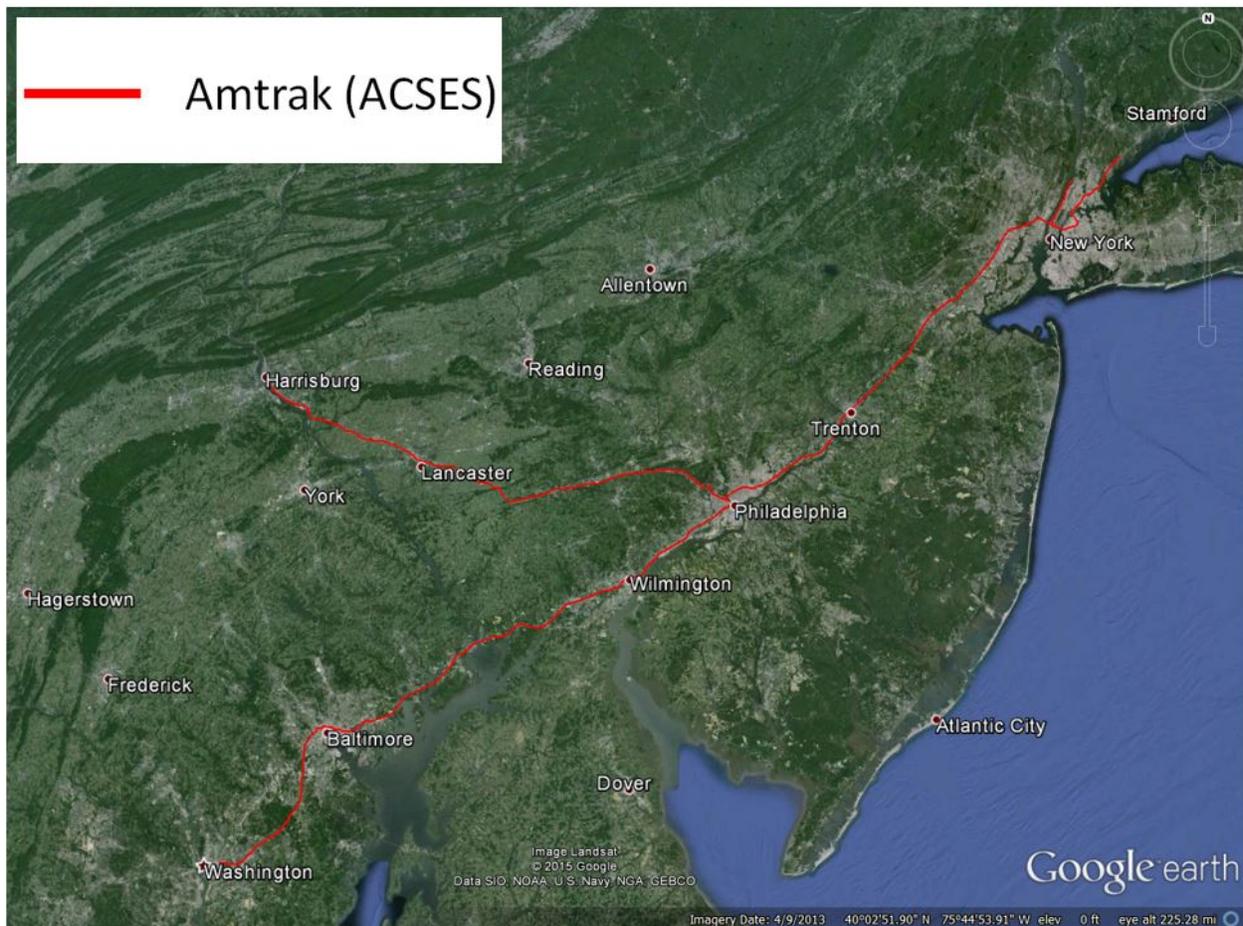


Figure 20. Amtrak ACSES PTC Deployment Track

2.7 ITC and ACSES System Interaction Use Case Examples

Regions of the NEC with dissimilar PTC radio equipment operating in close proximity, and transition points between dissimilar PTC systems are where desense of the dissimilar PTC radios is most likely to occur. Some areas of the NEC are more congested than others, and are faced with greater challenges to mitigate potential desense. For example, Philadelphia and the area near the Croxton Yard in New Jersey are two regions with multiple freight and passenger /

commuter railroads located in a small geographic area. Four system interaction cases are described in greater detail below, and include a typical close proximity case, two challenging close proximity cases, and a typical transition case.

2.7.1 Close Proximity

Currently 70 areas along the NEC have been identified in which ITC and ACSES radio equipment may be located close enough to potentially cause desense of dissimilar radios with a Packet Error Rate (PER) $\geq 5\%$. Testing completed at TTC in 2014 identified desense thresholds for the ITC and ACSES radios. On the basis of this desense threshold information, a minimum distance of 1.5 miles between ITC base stations and ACSES base stations was recommended. Similarly, a minimum distance of 0.75 miles between ITC WIUs and ACSES base stations was suggested. These distances were used to quantify the number of close proximity cases by identifying ITC bases and ACSES bases that are closer than 1.5 miles apart, and ACSES bases and ITC WIUs that are closer than 0.75 miles apart. In the following figures, the ITC WIU site locations are indicated by \odot ; the base radio site locations are indicated by Δ for the freight railroads; and \blacklozenge is used for the passenger / commuter railroads.

Figure 21 shows a typical close proximity case, where a CSX (orange) ITC base station and track is in close proximity to two MNR (pink) ACSES base stations that are approximately 0.7 mile and 0.75 mile away. The locomotives traveling on either side of the tracks will become closer to the dissimilar radios as they traverse the tracks by the shortest distance of 0.33 mile. The tracks run parallel along opposite sides of the Hudson River. Without any mitigation in place, the ITC and ACSES base stations and locomotive radios could desensitize each other.

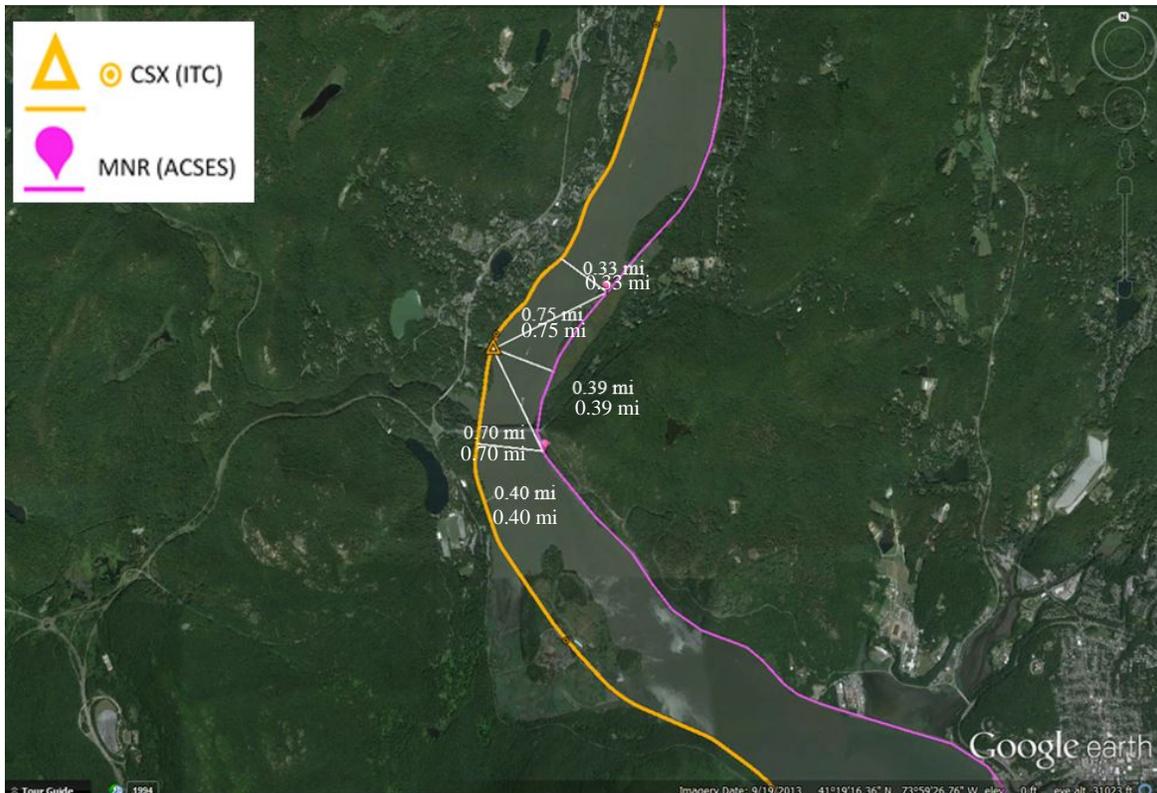


Figure 21. Typical Close Proximity Case between CSX and MNR

Figure 22 shows a more congested case in Philadelphia where multiple CSX (orange) and Conrail (light blue) ITC base stations and track, are in close proximity to SEPTA (purple) and Amtrak (red) ACSES base stations and track. In this area alone, CSX ITC base stations come within 1.2 miles, 1.1 miles, 0.47 mile, and 0.41 mile of an ACSES base. Also, Conrail (light blue) shares the track through the center of the image, east and west, with Amtrak for over seven miles. In the top portion of the figure, CSX and SEPTA run on adjacent track for over two miles. The white circles indicate the areas where a base station or multiple base stations come within one-tenth of a mile of a dissimilar system track. Identification of dissimilar radio equipment and tracks located within one-tenth of a mile from one another, rather than 1.5 miles, emphasizes the significant level of congestion in the area. Without any mitigation in place, the ITC and ACSES base stations could desensitize each other.

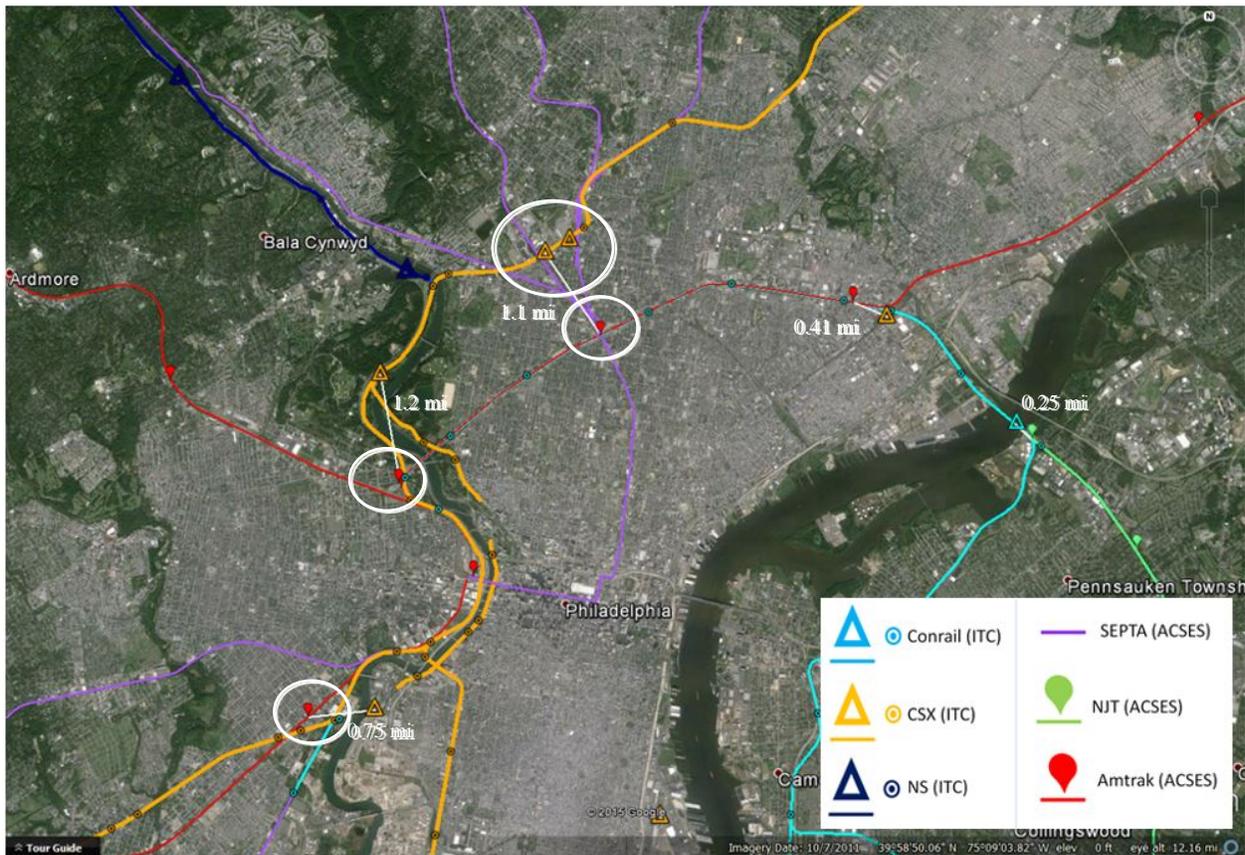


Figure 22. Challenging Case of Close Proximity between CSX, SEPTA, Conrail, and Amtrak

Figure 23 shows Croxton Yard in NJ. NS has an ITC base station located within 0.85 miles of an Amtrak (red) ACSES base station and within 0.65 mile of an NJT (green) ACSES base station. Conrail (light blue) has an ITC base station located within 0.5 mile and 0.3 mile of two NJT ACSES base stations. Also, located next to the Conrail ITC base station is the Croxton control point. The white circle in the lower part of the figure indicates where a NJT ACSES base is within one-tenth of a mile of Conrail track. Without any mitigation in place, the ITC and ACSES base stations could desensitize each other.

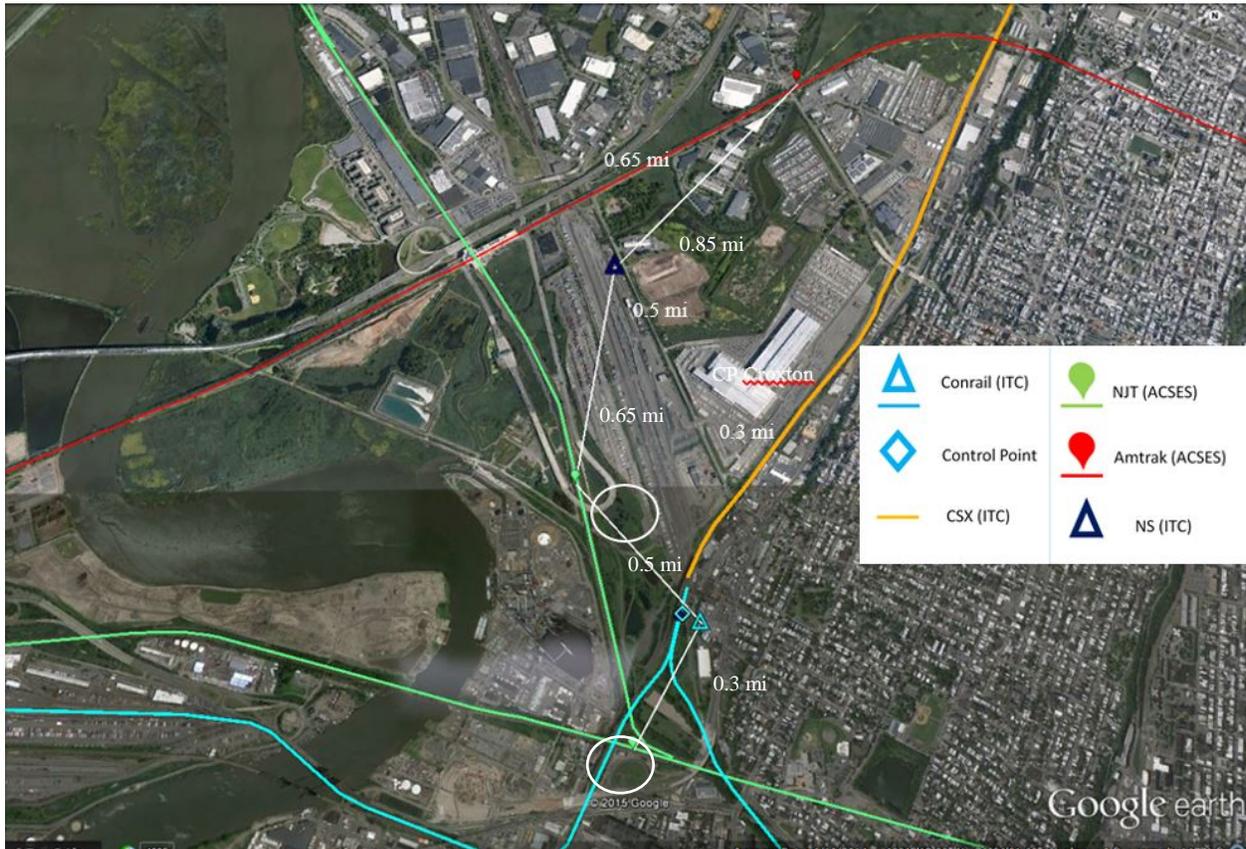


Figure 23. Challenging Case of Close Proximity at the Croxton Yard in NJ

2.7.2 Transition Locations

Currently 46 potential transition locations have been identified. A transition location is where freight rail operating on ITC is required to enter passenger rail operating on ACSES without interruption to PTC. Not all railroads have determined the exact regions of installation for ITC along NEC tracks. Transition areas become an issue because the ACSES owned and maintained track must have ITC coverage in order for freight rail to use it.

Figure 24 shows a transition area in which a NS (blue) train operating on ITC territory would need to transition onto an Amtrak (red) track operating ACSES without interruption to PTC. NS has an ITC base station located at the transition point on an Amtrak line. The white circle located on the lower left portion of the figure indicates an area where an Amtrak ACSES base station is within one-fifth of a mile from a CSX (orange) ITC WIU. Also, there is a CSX ITC base located one mile from an Amtrak ACSES base on a parallel section of track. This CSX ITC base could further complicate the desense issue when an Amtrak train is approaching the

transition point from the right, as there is a section of track on which the Amtrak train will be within 1.5 miles of two ITC base stations (NS and CSX) simultaneously. Without any mitigation in place, the ITC and ACSES systems could desensitize each other.



Figure 24. Typical Transition Case between NS and Amtrak

3. Evaluation of Candidate Solutions

Each NEC 220 MHz PTC radio desense candidate solution was scored in order to identify the solution or solutions that are most desirable to mitigate the radio desense issues in the NEC.

Evaluation criteria was selected to provide a comparative measure of the merits of the candidate solutions using available information and to provide guidance for determining candidate approaches offering sufficient benefit to merit further evaluation through testing in follow-on efforts. In addition to each of the criteria defined below, each of the candidate solutions have associated risks that may impact the overall performance, reliability, or availability of PTC operation. These risks were not included in the evaluation criteria because their impact on the overall PTC system cannot be evaluated without analysis and tests that are beyond the scope of this project and that can be addressed in follow-on projects. Such risks, as well as analysis and tests necessary to evaluate their impact of the overall PTC system, are described within the descriptions of the candidate solutions. Candidate solutions' scores are derived from the following criteria:

- Number of 220 MHz PTC desense scenarios mitigated
- Complexity of the candidate solution. Complexity of a solution is estimated by the count of:
 - Number of ITC and ACSES system segments that require hardware or software additions or modifications in order to implement the solution
 - Required modification to the ITCM locomotive communication scheduler algorithm
 - Required modification to the ITCM wayside or base station communication scheduler algorithm
 - Required modification to the ACSES locomotive communication manager
 - Required modification to the ACSES base station communication manager
 - Required modifications to, or the inclusion of additional data in, a geographic information database, such as a subdivision database, within the ITC locomotive onboard system
- Minimum spectral separation between ACSES and ITC channels required by the mitigation approach. A scale of 0 to 3 is used to assess the impact of minimum required spectral separation on the candidate solution's score. The scale used is:
 - A value of 0 indicates that no spectral separation between ACSES and ITC channels is required
 - A value of 1 indicates that spectral separation of less than 250 kHz is required
 - A value of 2 indicates that spectral separation of more than 250 kHz is required
- Reliance on alternate communication paths, such as cellular or Wi-Fi, for PTC communications. While use of alternative communication paths are suitable as a backup communication link for infrequent short durations, uncertainty of reliability and availability of alternative links deployed and maintained by third parties makes them undesirable for use over large geographic areas or for extended periods of time. The reliance on alternate communications path score is an inverse scaler of the evaluation

score, due to the potential adverse impact on ITC communication performance and availability. The scale used is:

- A value of 1 indicates no reliance on alternate communication paths.
- A value of 10 indicates reliance on alternate communication paths.
- Estimated development schedule to deployment for each candidate solution. A scale of 1 to 3 is used to assess the impact of the development schedule on the candidate solution’s score. The scale used is:
 - A value of 1 indicates that the candidate solution may be available for deployment in 6 months or less.
 - A value of 2 indicates that the time for the candidate solution to be available for deployment is greater than 6 months, but less than 12 months.
 - A value of 3 indicates that the time for the candidate solution to be available for deployment is greater than 12 months.
- Estimated development cost of candidate solution. A scale of 1 to 4 is used to assess the impact of the estimated non-recurring engineering (NRE) development costs on the candidate solution’s score. The scale used is:
 - A value of 1 indicates that the NRE cost to develop the candidate solution is expected to be less than \$100,000
 - A value of 2 indicates that the NRE cost to develop the candidate solution is expected to be greater than \$100,000, but less than \$250,000
 - A value of 3 indicates that the NRE cost to develop the candidate solution is expected to be greater than \$250,000, but less than \$500,000
 - A value of 4 indicates that the NRE cost to develop the candidate solution is expected to be greater than \$500,000.

The score for each candidate solution is derived using Equation 1:

Equation 1. Solution Scoring Equitation

$$\text{Solution Score} = \frac{\text{Number of Desense Scenarios Mitigated}}{(\text{Complexity}) + \frac{(\text{Min. Spectral Separation}) + (\text{Development Schedule}) + (\text{Development Cost})}{100}}$$

* $\frac{100}{(\text{Reliance on Alternate Comm. Path})}$

An ideal solution will:

- Mitigate all three locomotive radio desense scenarios
- Have no minimum required spectral separation
- Not rely on alternate communication paths
- Have scores for complexity, a development schedule, and development cost that equal one.
- Have the maximum solution score of 100

The solution score derived for each of the candidate solutions is a relative measure of how that solution compares to the ideal. The higher a candidate solution's score, the closer that solution is to the ideal.

4. Review of Candidate NEC PTC Desense Mitigation Solutions

The NEC Communications Team was formed as an informal industry group that explored options for mitigating 220 MHz radio desense between ACSES and ITC radios within the NEC PTC deployment areas. The objectives of the NEC Communications Team are:

- Identify 220 MHz candidate solutions for the mitigation of possible PTC operation problems resulting from desense occurring between ITC and ACSES radios operating in close proximity,
- Review those identified 220 MHz radio desense mitigation options and discuss the feasibility of implementation of each candidate solution throughout the NEC, and
- Make recommendations for 220 MHz desense mitigation approaches that should be developed and tested to demonstrate viability for deployment on the NEC.

The NEC Communications Team consists of representatives from:

- The individual railroads operating on the NEC
- PTC 220 LLC
- Wabtec Railway Electronics
- GE MDS, LLC
- MCC
- FRA
- TTCI

The NEC Communications team identified eight candidate radio desense mitigation approaches:

1. Locomotive Radio Filtering
2. Signal Cancellation via Phased Antenna Placement
3. Adaptive Interference Canceller (AIC)
4. Timeslot Coordination
5. Avoid the F-Frame
6. ACSES Radio Blanking
7. Segregated Radio Use
8. Single Locomotive Radio Use

Candidate approaches 1 through 3 mitigate desense by reducing the amplitude of the undesired signal incident on the protected radio receiver. Candidate approaches 4 through 6 attempt to coordinate ITC and ACSES radio transmission times in order to avoid radio desense. Candidate options 7 and 8 use fixed site radio filtering in conjunction with geographically restricted use of ITC and ACSES mobile radios in order to mitigate the potential for radio desense.

4.1 Fixed Site Radio Filtering

Note: Mitigations for the wayside and base station desense problems are not the focus of this project, but are discussed here for background purposes.

An external filter may be inserted between the antenna port of a radio receiver and the antenna to reduce the effective bandwidth of the receiver. In the case of PTC within the NEC, ITC deployments use channels in the 220 MHz to 222 MHz band, and many of the ACSES deployments use channels in the 217 MHz to 219 MHz band. The 1 MHz spectral separation between ITC and ACSES channels allows for the use of passive cavity high pass filters at fixed sites; with a cutoff frequency of 220 MHz to protect ITC radios from ACSES transmissions, and passive cavity low pass filters with a cutoff frequency of 219 MHz to protect ACSES radio installations from ITC transmissions. Band pass filters may be used instead of high pass or low pass filters.

Passive cavity filters are typically used in radio base station installations because they have a high power handling capability (i.e., high power transmissions will not damage the filters), relatively low insertion loss, and a high quality factor (Q). Filters without a high power handling capability require separate transmit and receive ports at the radio, so that the filter can be applied only to the receive port and avoid damage from higher power transmissions, or a transmit bypass mechanism that will shunt a higher power transmission around the filter. Testing performed at TTC demonstrated that commercially available passive cavity filters can provide 80 dB reduction to ACSES signals in the 217 MHz to 219 MHz range received at the ITC radio, and a similar reduction to ITC signals in the 220 MHz to 222 MHz range received at the ACSES radio. Isolation of 80 dB between the ACSES and ITC radios is capable of preventing desense between ITC and ACSES radios installed in close proximity.

Resonant cavity filters are suitable for use in fixed PTC radio installations, such as ACSES base stations, ITC base stations, and ITC WIU radios sites. However, conventional resonant cavity filters may be impractical for use in locomotives, due to the large physical size, and concerns about stability in high vibration and shock environments.

If, after the NEC railroads and the FCC have completed the reallocation of spectrum in the NEC, which is intended to have ACSES use channels between 217 MHz and 219 MHz and have ITC use channels between 220 MHz and 222 MHz, there are still areas where ACSES uses channels between 220 MHz to 222 MHz that are interleaved with the ITC channels, resonant cavity filters with a range of 220 MHz to 222 MHz range may not be practical to implement. Resonant cavity filters typically require 1 MHz or more spectral separation between the pass band and stop band to achieve 80 dB of attenuation of undesired signals with relatively low insertion loss. This amount of spectral separation is generally not available to ACSES channels interleaved with ITC channels in the 220 MHz to 222 MHz range. In these areas, care must be taken in the design of the ACSES and ITC radio network infrastructure to ensure sufficient physical separation between ITC fixed sites and ACSES fixed sites to prevent mutual desense of the radios. Active crystal filters with a transmit bypass switch have also been proposed, but have not yet been tested. Any equipment added in-line between the antenna and radio will incur some insertion loss. A duplexer may be used that combines two filters if both ITC and ACSES systems are at the same location and share an antenna. However, some railroads have expressed a preference to keep ACSES and ITC antennas separate, to avoid having changes to one system disrupt the other.

4.2 Locomotive Radio Filtering

Just as filters may be applied to ACSES and ITC fixed radio sites to mitigate mutual desense between the two radio systems, filters may also be applied to locomotives to reduce the impact of desense between ACSES and ITC mobile radios. The key differences are, depending on the extent of restrictions on physical size, locomotive filters will provide less isolation for the radio being protected than fixed site filters provide, and filter stability has yet to be tested in a locomotive vibration and shock environment. The following are risks associated with using filters to mitigate desense between ACSES radios operating between 217 MHz and 219 MHz and ITC radios operating between 220 MHz and 222 MHz:

- The ability for filters to endure locomotive environmental conditions
- The ability for filters to be compact enough to fit within available locomotive space, particularly on crowded commuter locomotives
- If any ACSES deployments use channels between 220 MHz and 222 MHz, then the benefits of locomotive filters are significantly reduced or lost

As previously noted, the NEC railroads, in cooperation with PTC220 LLC, have been working with the FCC to swap ACSES radio channels in the 220 MHz to 222 MHz range with channels in the 217 MHz to 219 MHz range in an effort to reduce the complexity of mitigating radio desense problems between ACSES and ITC. These efforts are likely to result in reallocation of the spectrum used by PTC systems on the NEC to provide a minimum of 1 MHz spectral separation between ACSES and ITC radio channels.

In order to mitigate the case of an ACSES radio and ITC radio installed on a single locomotive mutually desensing one another, an estimated minimum of 56 dB attenuation to the ITC radio transmission is required to prevent an ACSES radio from being desensed, and an estimated minimum of 58 dB attenuation to the ACSES radio transmission is required to prevent the ITC radio from being desensed. These required attenuation values are based on the assumptions that the ACSES and ITC antennas are spaced 2 to 5 feet apart and each radio transmits at full power. Greater separation between the ACSES and ITC radio antennas on a locomotive would reduce the required attenuation provided by filters. Practical considerations associated with mounting antennas upon the roof of a locomotive may prevent greater antenna separation.

Filters that are practical for installation on a locomotive might not provide sufficient isolation to fully mitigate the possibility of mutual desense of ACSES and ITC radios operating on a single locomotive. In this event, locomotive radio filtering may still be beneficial in the mitigation of desense between two locomotives operating on adjacent track and mitigation of desense between a fixed site radio and a locomotive. In this scenario, the required amount of isolation to protect the dissimilar 220 MHz PTC radios would be reduced as the antennas would be spaced 12 or more feet apart as opposed to being co-located on a given locomotive. The minimum amount attenuation to the ITC radio transmissions would be reduced from 56 dB to 40 dB. The minimum amount of needed attenuation to the ACSES radio transmissions would be reduced from 58 dB to 43dB.

Amtrak has a fleet of locomotives that operate on the NEC and in the New England areas. On the NEC, the Amtrak locomotives will use channels in the 217 MHz to 219 MHz band. However, in New England, north of Hew Haven, Connecticut, Amtrak's ACSES deployment will use channels in the 220 MHz to 222 MHz band. Amtrak's ACSES deployment in New

England is not in close proximity to any ITC deployment, so use of channels in the 220 MHz to 222 MHz band is not expected to experience interference problems, and use of locomotive filters to protect the ACSES radios from desense is not needed. To support Amtrak operations on both the NEC and in New England, a filter bypass is required so that Amtrak does not filter out the desired radio signals when operating in New England. The filter bypass would be automatically activated when the ACSES radio uses channels in the 220 MHz to 222 MHz band, and deactivated when the ACSES radio uses channels in the 217 MHz to 219 MHz band.

In order to obtain information on filters suitable for use on locomotives on the NEC, TTCI prepared a Request for Information (RFI) for locomotive filters. The locomotive filter RFI included:

- Background information on NEC PTC communication issues
- Summary of ACSES and ITC 220 MHz radio frequency usage
- Preliminary locomotive filter requirements
- Technical questions regarding locomotive filter development, deployment, and budgetary costs

This RFI was submitted to filter manufacturers and the findings are incorporated into this trade study. The 220 MHz locomotive filter RFI document is contained in the appendix, but the filter manufacturer responses to the RFI were proprietary.

Analysis of the responses to the RFI identified three types of filters that might be suitable for use in locomotives: resonant cavity filters, helical cavity filters and crystal filters. Any filters to be used on locomotives must be hardened against locomotive environmental conditions such as vibration, shock, and temperature extremes per Association of American Railroads *Manual of Standards and Recommended Practices*, Section K Part V, Standard S-9401, "Railroad Electronics Environmental Requirements." [7]

Resonant cavity filters are the same type of filter commonly used in base station and fixed site radio installations. Resonant cavity filters are physically the largest of the identified filter technologies. A resonant cavity, high pass filter providing a minimum of 57.7 dB reduction in the amplitude of signals in the 217 MHz to 219 MHz band is approximately 17 inches by 5 inches by 23 inches. A similar resonant cavity, low pass filter providing a minimum of 55.4 dB reduction in the amplitude of signals in the 220 MHz to 222 MHz band was approximately 18 inches by 6 inches by 24 inches. Resonant cavity filters providing this level of isolation from undesired signals are commercially available, but require large spectral separation (approximately 1 MHz) between ACSES and ITC radio channels to achieve this amount of isolation.

Helical cavity filters are a compact variant of the resonant cavity filters used in fixed radio site installations. A helical cavity, high pass filter providing 40 dB reduction in the amplitude of signals in the 217 MHz to 219 MHz band, has the approximate dimensions of 2 inches by 6 inches by 8 inches. A similar helical cavity, low pass filter providing 40 dB reduction in the amplitude of signals in the 220 MHz to 222 MHz band has the approximate dimensions of 2 inches by 6 inches by 8 inches. Helical cavity filters providing this level of isolation from undesired signals are commercially available, but require large spectral separation

(approximately 1 MHz) between ACSES and ITC radio channels to achieve this amount of isolation.

Crystal filters offer a higher level of isolation, as much as 60 dB between semi-adjacent channels (25 kHz separation), but these filters have a significantly lower power handling capability than cavity filters. Signals from radios installed on the same locomotive may be strong enough to damage active crystal filters. Because of the low power handling capability, a transmit bypass circuit is required to prevent high power signals from entering the filter and causing damage. Crystal filters also require an active amplifier to compensate for their high insertion loss. With the active amplifier, the insertion loss is comparable to other filtering methods. Crystal filters have narrow bandwidths, so they must be rapidly tunable (e.g., with a synthesizer) to accommodate multiple different operating frequencies (channels). Since crystal filters are tunable, it is possible to implement dynamically tunable filters. In this case, a channel select signal, provided by the locomotive onboard system, would be sent to the crystal filter, which would be tuned as a narrow band pass filter centered on the channel that is being used by the PTC radio. To use dynamically tunable crystal filters, the locomotive onboard system must be modified to provide the channel select signal and add the filter hardware. Crystal filters are more susceptible to failure due to a high vibration environment than cavity filters. Crystal filters with a transmit bypass circuit are commercially available, but these will require further development to harden them against the shock and vibration conditions found on a locomotive.

A low pass (217 MHz to 219 MHz) filter would need to be installed on all ACSES locomotives operating on the NEC. The filters can be installed without modifying existing ACSES hardware, but would require additional cabling between the ACSES 220 MHz radio and antenna which would result in some signal strength loss in addition to the filter insertion loss.

Since ITC radios use a two input diversity receiver to improve performance, two units of a high pass (220 MHz to 222 MHz) filter will need to be installed on all ITC locomotives operating on the NEC. Installation of these filters will not require modification to existing ITC hardware, but some additional cabling between the ITC radio and antenna will be needed, which will result in some signal loss in addition to the filter insertion loss.

4.2.1 Locomotive Radio Filtering Scoring Summary

The overall score for locomotive radio filtering with 1 MHz spectral separation is 50. The overall score for dynamically tunable crystal filters is 33.3. Table 2 provides a summary of the evaluation criteria and scores for both of these locomotive radio filtering solutions.

Table 2. Score Locomotive Radio Filtering Summary and Scores

				Locomotive Filtering w/ 1 MHz Spectral Separation	Dynamically Tunable Crystal Filters
Desense Mitigation Coverage	Locomotive Desensing Self			Yes	Yes
	Locomotive Desense Another Locomotive			Yes	Yes
	Fixed Site Desense Loco			Yes	Yes
Complexity	ITC HW/SW Changes	Office	SW	No	No
		Onboard	Modified Geographic Database	No	No
			Radio / Communication Scheduler	No	Yes
			Additional HW or SW	Yes	Yes
		Wayside or Base Station	Radio / Communication Scheduler	No	No
	ACES HW/SW Changes	Office	SW	No	No
		Onboard	Radio / Mobile Communication Manager	No	Yes
			Additional HW or SW	Yes	Yes
		Base Station	Radio / Base Communication Manager	No	No
	Minimum Spectral Separation				1 MHz
Reliance on Alternate Communication Paths				No	No
Development Schedule				4 Monhs	< 12 Months
Development Cost Estimate				< \$100,000	< \$250,000
Evaluation Criteria Scores	Cases Mitigated			3	3
	Complexity			2	4
	Minimum Spectral Separation			2	1
	Reliance on Alt. Comm. Paths			1	1
	Development Schedule			1	2
	Development Cost			1	2
Overall Score				50.0	33.3

Cases Mitigated Score

Locomotive radio filters may be capable of mitigating all three desense scenarios affecting locomotives if there is a minimum of 1 MHz spectral separation between ACSES and ITC radio channels. Current developments between the FCC and NEC railroads regarding modification of

spectrum use suggest a high likelihood of a minimum of 1 MHz spectral separation between ITC and ACSES channels. This provides a Cases Mitigated Score of 3.

Dynamically tunable crystal filters may also be capable of mitigating all three desense scenarios for a Cases Mitigated Score of 3.

Complexity Score

Use of locomotive filters on a locomotive that is equipped to operate on both ACSES and ITC territories will require:

- One filter to be installed with ACSES locomotive onboard equipment
- Two filters to be installed with ITC locomotive onboard equipment

Since hardware is added to both ACSES and ITC locomotive onboard systems, the Complexity Score for locomotive filters is 2.

Use of dynamically tunable crystal filters on a locomotive that is equipped to operate on both ACSES and ITC territories will require:

- One filter to be installed with ACSES locomotive onboard equipment
- Modifications to ACSES locomotive onboard equipment to provide a channel select signal
- Two filters to be installed with ITC locomotive onboard equipment
- Modifications to ITC locomotive onboard equipment to provide a channel select signal

Since hardware is added to both ACSES and ITC locomotive onboard systems, the Complexity Score for locomotive filters is 4.

Minimum Spectral Separation Score

Resonant cavity and helical cavity filters require a spectral separation of at least 1 MHz between the ACSES and ITC channels. This results in a Spectral Separation Score of 2 for locomotive filters with 1 MHz spectral separation.

Dynamically tunable crystal filters require a spectral separation of at least 25 kHz between the ACSES and ITC channels. This results in a Spectral Separation Score of 1 for dynamically tunable crystal filters.

Reliance on Alternative Communication Paths Score

Use of locomotive filters, of any type, does not require changes to reliance on alternative communication paths for either ITC or ACSES. This results in a Reliance on Alternative Communication Paths Score of 1 for both locomotive filters with 1 MHz spectral separation and dynamically tunable crystal filters.

Development Schedule Score

The development time needed to harden currently available resonant cavity and helical cavity filters to the locomotive environment is estimated to be 4 months or less, resulting in a Development Schedule Score of 1 for locomotive filters with 1 MHz spectral separation.

In addition to being hardened against the locomotive environment, dynamically tunable crystal filters require modifications to ACSES and ITC locomotive onboard equipment, resulting in a Development Schedule Score of 2.

Development Cost Score

Per the filter supplier responses to the Locomotive Filter RFI, no NRE costs are identified. This results in a Development Cost Score of 0 for locomotive filters with 1 MHz spectral separation.

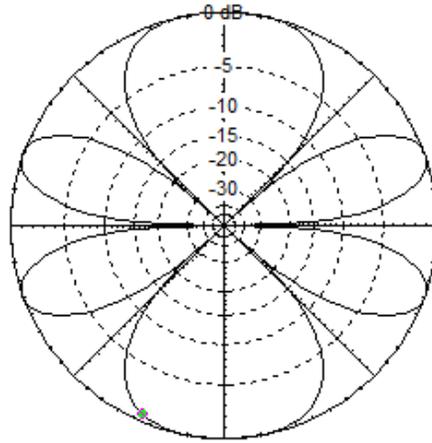
Use of dynamically tunable crystal filters requires modification to ACSES and ITC locomotive onboard equipment to provide a channel select signal. This effort is estimated to be less than \$250,000, resulting in a development cost score of 2 for dynamically tunable crystal filters.

4.3 Signal Cancellation via Phased Antenna Placement

This option uses precisely placed radio antennas to create antenna patterns with nulls that may be used to provide isolation between the ITC and ACSES radios when co-located on a locomotive. The ACSES radio on the locomotive is connected to a pair of antennas and a balun would be used to drive the antennas 180 degrees out of phase. The ACSES radio antennas would be placed one in front of the other, and an odd multiple of a half-wavelength (27 inches at 220 MHz) apart. This will provide 3 dB gain toward the front and back of the locomotive, and nulls toward the sides of the locomotive. The two ITC antennas would be placed an equal distance away from each ACSES antenna. The signals that are transmitted to and from the two ACSES antennas will cancel at the locations of the ITC antennas. No spectral separation is needed for this phased antenna approach to work.

This scheme should provide an estimated 25 dB of additional isolation between the ACSES and the ITC systems, without the need for frequency planning. The added ACSES antenna gain will increase the signal strength of the desired signal received by the ACSES receiver from sites ahead or behind the locomotive, further reducing the effect of the blocking due to the onboard ITC transmitter. With the added antenna gain, the ACSES transmitter on the locomotive could possibly be reduced by 3 dB, further reducing the potential desense it may cause to the ITC receiver. Figure 25 shows the antenna pattern for a pair of omnidirectional antennas placed 1.5 wavelengths apart (81 inches) and driven 180 degrees out of phase. The 0 dB represents 3 dB relative to a single antenna.

Total Field



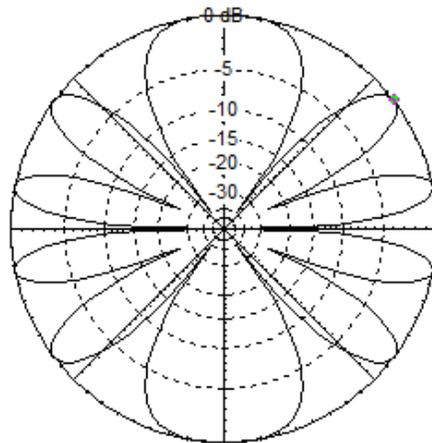
EZNEC+

220 MHz

Figure 25. Pattern for a Pair of Omnidirectional Antennas Placed 1.5 Wavelengths Apart and Driven 180 Degrees Out of Phase

Figure 26 shows the antenna pattern using a pair of ACSES antennas placed 2.5 wavelengths apart (135 inches) and driven 180 degrees out of phase.

Total Field



EZNEC+

220 MHz

Figure 26. Pattern for a Pair of Omnidirectional Antennas Placed 2.5 Wavelengths Apart and Driven 180 Degrees Out of Phase

Figure 27 shows the proposed locomotive rooftop antenna layout. In this layout, two ACSES antennas are placed 135 inches apart on the long axis of a locomotive. The primary ITC antenna and the diversity ITC antenna are placed equidistant from each ACSES antenna, and as far to the left and right as possible.

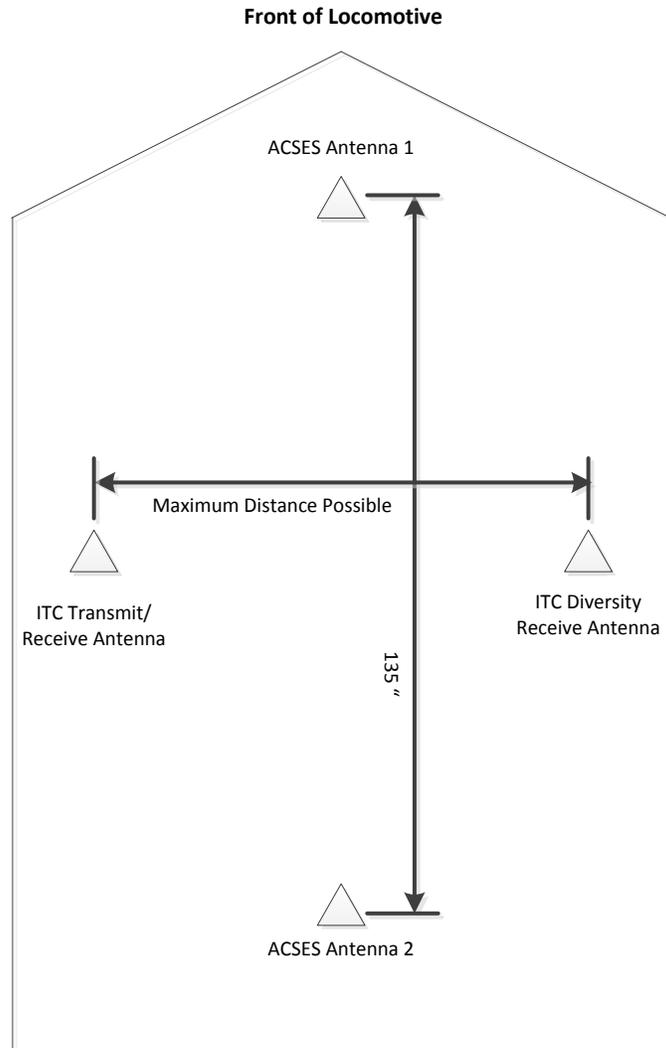


Figure 27. Proposed Locomotive Antenna Layout

Implementation of the signal cancellation via phased antenna placement approach requires precise placement of the ITC radio antennas and ACSES antennas to achieve maximum isolation, but does not require changes to existing ACSES or ITC hardware or software. An additional antenna and balun would be required for the ACSES onboard system and additional cabling between the ACSES 220 MHz radio and antennas would be needed, which will result in some signal strength loss.

Little impact on ACSES or ITC reliability is expected. Antennas are simple devices with relatively high reliability. However, there are three major potential risks associated with this approach:

- First, placement of the two ACSES antennas needed to provide isolation between the ACSES and ITC radios will result in an overall antenna pattern that decreases effective ACSES radio sensitivity in some directions. This will result in an increase of message loss between the ACSES locomotive and base station radios in certain scenarios. Tests must be performed to determine the amount of isolation provided by use of phased

antenna placement and to determine the location and width of nulls in the resultant ACSES antenna pattern.

- Second, space for antennas on the roof of locomotives is limited. Due to this and other practical considerations, precise placement of antennas may not be possible.
- Third, the phased antenna placement approach requires a balun to provide a pair of equal strength signals 180 degrees apart. Such a device may not be commercially available for the 220 MHz band. The mitigation for this risk is to develop a balun. Baluns are relatively simple passive devices and the required development time is expected to be less than 6 months.

4.3.1 Signal Cancellation via Phased Antenna Placement Scoring Summary

The overall score for signal cancellation via phased antenna placement is 16.7. Table 3 provides a summary of the evaluation criteria and score for the signal cancellation via phased antenna placement solution.

Table 3. Signal Cancellation via Phased Antenna Placement Summary and Score

Desense Mitigation Coverage	Locomotive Desensing Self		No, but 25 dB Reduction of ACSES Signal on ITC Radio	
	Locomotive Desense Another Locomotive		No	
	Fixed Site Desense Loco		No	
Complexity	ITC HW/SW Changes	Office	SW	No
		Onboard	Modified Geographic Database	No
			Radio / Communication Scheduler	No
			Additional HW or SW	No
		Wayside or Base Station	Radio / Communication Scheduler	No
	ACSES HW/SW Changes	Office	SW	No
		Onboard	Radio / Mobile Communication Manager	No
			Additional HW or SW	Yes
		Base Station	Radio / Base Communication Manager	No
	Minimum Spectral Separation			None
Reliance on Alternate Communication Paths			No	
Development Schedule			< 6 Months	
Development Cost Estimate			< \$100,000	
Evaluation Criteria Scores	Cases Mitigated		0.5	
	Complexity		1	
	Minimum Spectral Separation		0	
	Reliance on Alt. Comm. Paths		1	
	Development Schedule		1	
	Development Cost		1	
Overall Score			16.7	

Cases Mitigated

Signal cancellation via phased antenna placement provides partial mitigation for the locomotive self desense scenario. This approach does not provide any mitigation for the locomotive desensing locomotive or stop a fixed site from desensing a locomotive.

While signal cancellation via phased antenna placement will not eliminate all of the desense between ACSES and ITC radios, this approach does increase the isolation between ACSES and ITC radios, and it may be used in conjunction with another desense mitigation approach to provide a more robust solution.

Although signal cancellation via phased antenna placement, by itself, does not mitigate any desense cases, it still may have a score when used in conjunction with other mitigation approaches. Since this approach partially mitigates the locomotive self desense case, it was given a Cases Mitigated score of 0.5.

Complexity Score

Implementation of phased antenna placement is a low complexity approach since no software or hardware changes are required for either the existing ITC or ACSES system components. Use of signal cancellation via phased antenna placement requires installation of an additional ACSES antenna and a balun on locomotives that are equipped with both ACSES and ITC systems. The Complexity Score for this approach is 1.

Minimum Spectral Separation Score

Use of phased antenna placement does not require any spectral separation between ACSES and ITC channels, resulting in a Spectral Separation Score of 0.

Reliance on Alternative Communication Paths Score

Use of phased antenna placement does not require changes to communication paths or reliance on alternative communication paths for either ITC or ACSES, resulting in a Reliance on Alternative Communication Paths Score of 1.

Development Schedule Score

The time required to implement and test signal cancellation via phased antenna placement is estimated to be 6 months or less, resulting in a Development Schedule Score of 1.

Development Cost Score

There is a low cost of implementation since only one additional antenna and balun are required. This approach will use commercially available antennas. The signal cancellation via phased antenna placement approach may require the development of a balun suitable for use in a locomotive. This development is estimated to cost less than \$100,000, resulting in a Development Cost Score of 1.

4.4 Adaptive Interference Canceller

An AIC has the ability to identify potentially interfering signals that are incident upon the antenna port of a radio, separate the interfering signal from the desired signal, and then subtract (cancel) the interference signal from the overall signal incident upon the receive port of the radio. An AIC has the potential to reduce the amplitude of interfering signals by 60 dB or more. A key advantage of an AIC is that it has the ability to reduce the amplitude of interfering signals that are spectrally near the frequency of the desired signal, which gives the AIC an advantage over conventional filters, which require a large amount of spectral separation between the desired signal and interfering signal.

Additionally, an AIC is capable of identifying multiple high amplitude signals that are outside of the channel (or channels) the radio is using, then subtract those high amplitude off-channel signals from the overall signal received at the input of the radio. This approach allows the AIC to cancel interfering signals from radios off board the locomotive as well as from radios onboard the locomotive.

Figure 28 provides a conceptual high-level block diagram of an AIC.

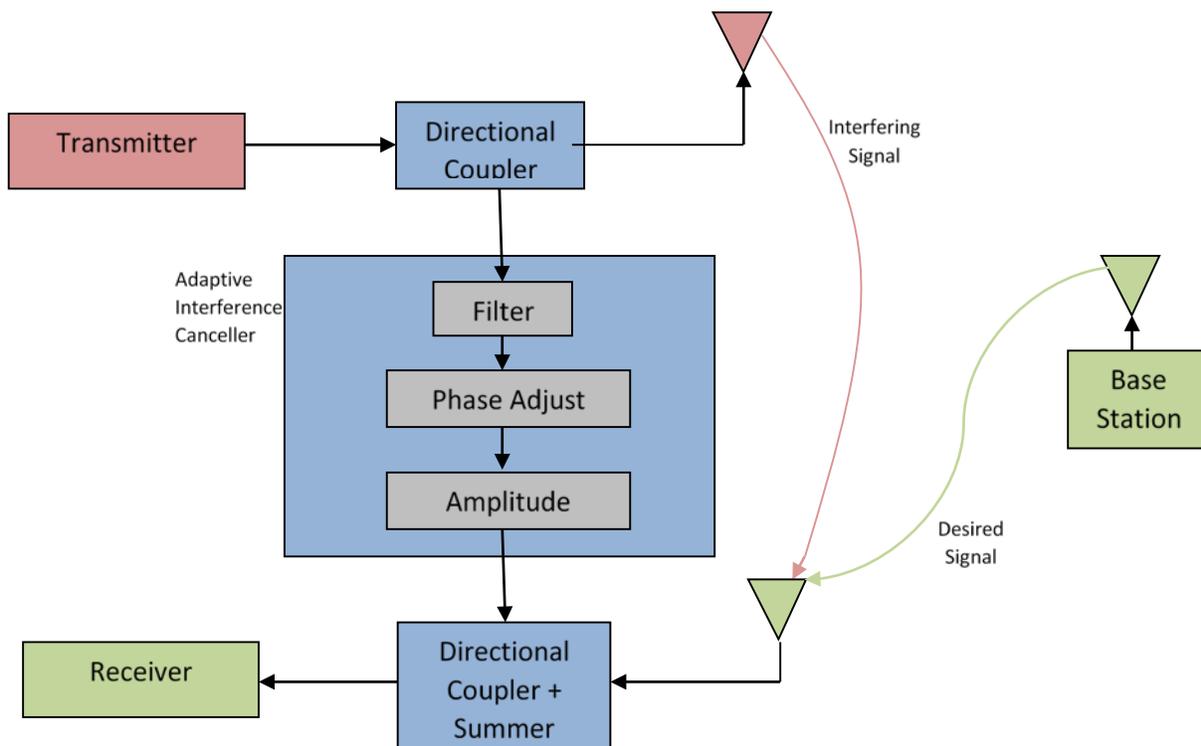


Figure 28. Conceptual Block Diagram of AIC

The AIC would be placed in-line between the antenna and receiver of each radio/antenna pair, requiring no modification to existing receivers or antennas. Adaptive interference cancellation functions by subtracting the co-site interfering transmitter signal from the received spectrum, allowing the receiver to recover the weaker desired signal.

At a high level, an AIC cancels an interfering signal from a co-located radio as follows:

- The AIC uses the signal from the transmitting radio as a reference for the signal to be canceled in the receiver.
- The reference signal is adaptively scaled and phase shifted to maximize effectiveness of cancellation.
- The scaled and phase shifted reference signal is subtracted from the signal at the receiving radio, which cancels the strong signal from the nearby transmitter and preserves the desired weak signal.

In order to obtain information on AIC technology suitable for use in the NEC, TTCI prepared a Request for Information (RFI) for locomotive AICs. The locomotive AIC RFI included:

- Background information on NEC PTC communication issues
- Summary of ACSES and ITC 220 MHz radio frequency usage
- Preliminary locomotive AIC requirements
- Technical questions regarding locomotive filter development, deployment, and budgetary costs

This RFI was issued to AIC manufacturers by CSX and findings are incorporated into this trade study. However, the AIC manufacturer responses to the RFI were proprietary.

An AIC would be required on any locomotive operating on the NEC that may be exposed to radio desense. The AIC is active at all times, thus there is no need to enable the AIC upon entry onto the NEC or bypass the AIC upon exit from the NEC.

While military applications of AICs have been encouraging, whether or not sufficient amount of isolation is achievable in this application needs to be verified by test.

4.4.1 AIC Scoring Summary

The overall score for the AIC is 31.6. Table 4 provides a summary of the evaluation criteria and score for the AIC.

Table 4. AIC Summary and Score

Desense Mitigation Coverage	Locomotive Desensing Self		Yes	
	Locomotive Desense Another Locomotive		Yes	
	Fixed Site Desense Loco		Yes	
Complexity	ITC HW/SW Changes	Office	SW	No
		Onboard	Modified Geographic Database	No
			Radio / Communication Scheduler	No
			Additional HW or SW	Yes
		Wayside or Base Station	Radio / Communication Scheduler	No
	ACSES HW/SW Changes	Office	SW	No
		Onboard	Radio / Mobile Communication Manager	No
			Additional HW or SW	Yes
		Base Station	Radio / Base Communication Manager	No
	Minimum Spectral Separation			250 kHz
Reliance on Alternate Communication Paths			No	
Development Schedule			11 to 14 Months	
Development Cost Estimate			\$1M	
Evaluation Criteria Scores	Cases Mitigated		3	
	Complexity		2	
	Minimum Spectral Separation		1	
	Reliance on Alt. Comm. Paths		1	
	Development Schedule		2.5	
	Development Cost		4	
Overall Score			31.6	

Cases Mitigated

An AIC potentially provides mitigation of the three desense scenarios affecting locomotives and receives a Cases Mitigated Score of 3.

Complexity Score

An AIC will be required on any locomotive operating within the NEC that may be exposed to radio desense. It is possible that a single AIC package may be used to protect both the ACSES and the ITC radios on a dual-equipped locomotive. Since this approach requires the addition of a single component per locomotive, the Complexity Score for this approach is 1.

Minimum Spectral Separation Score

An AIC may require a minimum of 250 kHz spectral separation between ACSES and ITC channels, resulting in a Spectral Separation Score of 1.

Reliance on Alternative Communication Paths Score

Use of AIC does not require changes to communication paths or reliance on alternative communication paths for either ITC or ACSES, resulting in a Reliance on Alternative Communication Paths Score of 1.

Development Schedule Score

Development time for a production AIC system is estimated to be 11 to 14 months, resulting in a Development Schedule Score of 2.5.

Development Cost Score

The AIC is adapted from a high reliability military application. NRE costs on the order of \$1 million are expected to develop AIC systems suitable for locomotive use in the NEC, resulting in a Development Cost Score of 4.

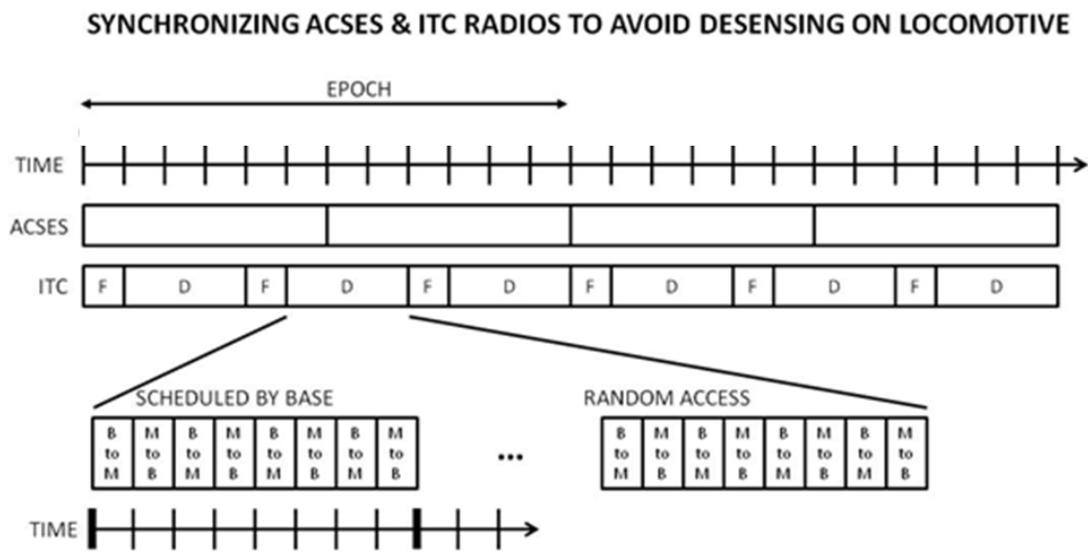
4.5 Timeslot Coordination

The basic idea of timeslot coordination is to prevent each radio onboard a dual-equipped locomotive from transmitting during the other radio's most critical listening time in its frame. A key objective is to minimize the amount of modification required to either type of radio. Since the ACSES radio TDMA frame is flexible and under control of the communications manager software, it should not require any changes to the radio itself, but will require changes to the ACSES mobile communications manager (MCM) and ACSES base communications manager (BCM). This approach has a low impact on the total radio throughput since it allows both radios (ACSES and ITC) to transmit simultaneously and both to receive simultaneously. However, due to reduced flexibility in ITC radio scheduling, there is some loss of throughput for the ITC system.

The ITC 220 MHz radio TDMA superframe is composed of the F-Frame and the D-Frame. The F-Frame is used for communicating signal as well as switch status information, and has a fixed assignment of frequency and timeslot for each WIU. The messages transmitted during the F-Frame are the most important for ITC operation, and as such, it is critical that the F-Frame is protected. In this approach, the ACSES radio onboard any and all ACSES locomotives cannot

be allowed to transmit during the F-Frame. By preventing ACSES locomotive radios from transmitting during the F-Frame, the locomotive self desense and locomotive desensing locomotive cases are mitigated during the F-Frame. Protection of F-Frame messages is the fundamental concept of this approach, at least for the initial phase.

The D-Frame is used by ITC primarily for communication between locomotive and the ITC back office server. The D-Frame is a combination of request/scheduled and random access messages, and its retransmission protocols may allow for ITC system tolerance to a small number of collisions between the ITC and ACSES radios during the ITC D-Frame. If message loss in the D-Frame is high enough to cause degradation of ITC system performance, then both ACSES and ITC radios could alternate timeslots for transmission (as ACSES currently does) so both radios on a locomotive transmit at the same time in the D-Frame, as shown in Figure 29. Alternatively, the D-Frame could be organized into one larger (multi-message) base-to-mobile time-block and one mobile-to-base time-block per D-Frame to more easily coordinate transmit and receive, as shown in Figure 30.

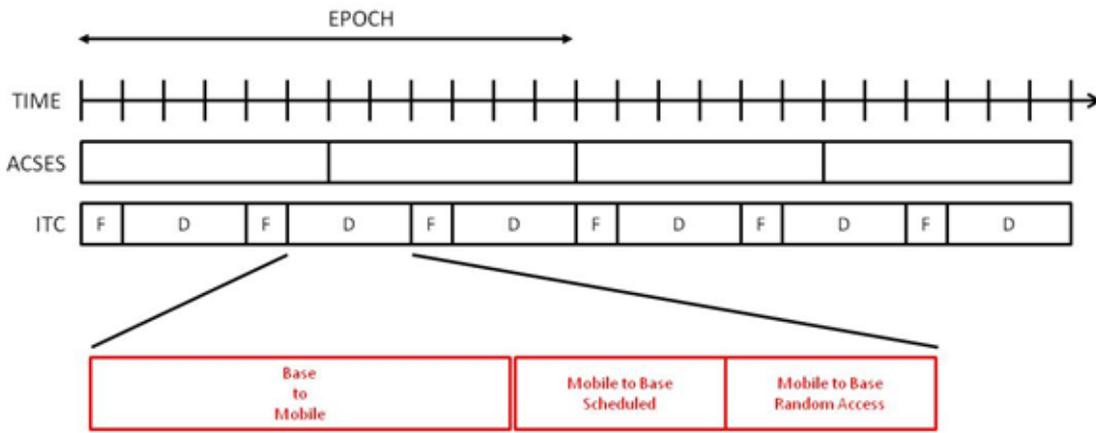


Objective: Have ITC and ACSES locomotive radios listen at the same time and transmit at the same time to avoid desensing each other.

- Achieve nearly full capacity of both radios on a locomotive rather than ITC and ACSES having to operate serially.
- BCM and MCM would not allow ACSES locomotive radio to transmit during the F-Frame.
- D-Frame could be managed independently for ITC and ACSES.
- First portion of D-Frame could be scheduled by base and remainder could allow spontaneous locomotive transmissions.
- ITC base station, including common channel would be correspondingly synchronized.

Figure 29. Timeslot Synchronization Overview

**SYNCHRONIZING ACSES & ITC RADIOS TO AVOID DESENSING ON LOCOMOTIVE
ALTERNATIVE D-FRAME TO ALLOW MORE FLEXIBLE TIMESLOT SCHEDULING**



**ACSES RADIO WOULD MATCH THESE LARGE TX/RX BLOCK PARTITIONS
AND WOULD BE SILENT DURING F-FRAME.**

Figure 30. Alternative D-Frame Timeslot Coordination Approach

In the first phase of implementation, the ACSES BCM and MCM would be modified to schedule ACSES slots so that ACSES locomotive radios never transmit during the ITC F-Frame. This would protect both ACSES and ITC locomotive radios from desense by the other radio during the F-Frame. During this phase of implementation, no changes would be made to coordinate ITC and ACSES locomotive transmissions during the D-Frame to prevent desense. The ITC radio would dynamically manage the D-Frame as it does currently, and both radios would rely on retransmission protocols to help mitigate D-Frame message loss.

The second phase of timeslot coordination would be implemented if analysis or experience demonstrates that message loss for ACSES and ITC is unacceptably high during the time corresponding to the ITC D-Frame. In Phase 2 of the timeslot coordination implementation, the ITC radio transmission scheduler would be modified to coordinate transmission to and from a locomotive to occur during alternating timeslots, aligning with those of the ACSES radios. This is also illustrated in Figure 29.

Since timeslot coordination only needs to be used by ITC locomotives when they are operating on the NEC, Phase 2 will also likely need to implement a geographic database that can be used by the ITC radio transmission scheduler to identify where timeslot coordination should be used.

The current ACSES TDMA frame and the ITC TDMA superframe (F-Frame and D-Frame) have durations of differing lengths. Implementation of timeslot coordination will require coordination of transmission over an epoch consisting of a common denominator of multiple ACSES frames and ITC superframes. Each ACSES TDMA frame within this epoch would have different transmit and receive slot assignments.

The primary risk of timeslot coordination is that this approach may increase the probability of desense of ITC locomotive radios by ACSES base station radios operating in close proximity. This is due to ACSES base station radios only transmitting during times when ITC locomotive radios are receiving. Transmission from a base station in close proximity may prevent a locomotive radio from receiving messages from a more distant base station. There is also a risk that some reduction of radio throughput may occur for the ITC system due to reduced flexibility in radio transmission scheduling, but this reduction of throughput is less than the reduction of throughput incurred by operating both ITC and ACSES with a single radio.

Analysis is needed to quantify the probability of message collisions for ITC D-Frame and ACSES slots. If the probability of message loss due to desense in the D-Frame is significant enough to reduce the performance of the PTC systems, then coordination of the D-Frame and ACSES slots is warranted. Additionally, analysis is also needed to quantify the amount by which base station radios deployed near track will cause an increase in the incidence of locomotive radio desense.

4.5.1 Timeslot Coordination Scoring Summary

The overall score for timeslot coordination of only the F-Frame is 25. The overall score for timeslot coordination of both the F-Frame and the D-Frame is 18.2. Table 5 provides a summary of the evaluation criteria and scores for the Timeslot Coordination solution.

Table 5. Timeslot Coordination Summary and Score

				Timeslot Coordination of only F-Frame	Timeslot Coordination of F-Frame and D-Frame
Desense Mitigation Coverage	Locomotive Desensing Self			Yes, During F-Frame. Interference may occur during D-Frame	Yes
	Locomotive Desense Another Locomotive			Yes, During F-Frame. Interference may occur during D-Frame	Yes
	Fixed Site Desense Loco			No	No
Complexity	ITC HW/SW Changes	Office	SW	No	No
		Onboard	Modified Geographic Database	No	Yes
			Radio / Communication Scheduler	No	Yes
			Additional HW or SW	No	No
		Wayside or Base Station	Radio / Communication Scheduler	No	Yes
	ACSES HW/SW Changes	Office	SW	No	No
		Onboard	Radio / Mobile Communication Manager	Yes	Yes
			Additional HW or SW	No	No
		Base Station	Radio / Base Communication Manager	Yes	Yes
	Minimum Spectral Separation				None
Reliance on Alternate Communication Paths				No	No
Development Schedule				< 12 Months	20 Months
Development Cost Estimate				<\$250k	<\$500k
Evaluation Criteria Scores	Cases Mitigated			1.5	2
	Complexity			2	5
	Minimum Spectral Separation			0	0
	Reliance on Alt. Comm. Paths			1	1
	Development Schedule			2	3
	Development Cost			2	3
Overall Score				25.0	18.2

Cases Mitigated

Coordinating only the ITC F-Frame mitigates locomotive self desense while the ITC locomotive radio is receiving critical F-Frame messages. This is a partial mitigation, but since it protects the most critical messages, a Cases Mitigated Score of 0.75 was assigned.

Timeslot coordination of both the ITC F-Frame and ITC D-Frame mitigates the locomotive self desense and locomotive desense locomotive scenarios resulting in an assigned Cases Mitigated Score of 2.

Complexity Score

Timeslot coordination of only the F-Frame requires:

- Modification to ACSES MCM
- Modification to ACSES BCM

This results in a Complexity Score of 2.

Timeslot coordination of both the ITC F-Frame and ITC D-Frame requires:

- Addition of geographic database in the ITC locomotive to identify where timeslot coordination is used
- Modification to ITC locomotive communication scheduler
- Modification to ITC base station communication scheduler
- Modification to ACSES MCM
- Modification to ACSES BCM

This results in a Complexity Score of 5.

Minimum Spectral Separation Score

Timeslot coordination does not require any spectral separation between ACSES and ITC channels, resulting in a Spectral Separation Score of 0.

Reliance on Alternative Communication Paths

Use of timeslot coordination does not require changes to communication paths or reliance on alternative communication paths for either ITC or ACSES, resulting in a Reliance on Alternative Communication Paths Score of 1.

Development Schedule Score

Development time for timeslot coordination of only the F-Frame is expected to be less than 12 months, resulting in a Development Schedule Score of 2.

Modifications to the ITCM message scheduling algorithm to accept a limited degree of frame control from an ACSES Communications Manager or to adjust D-Frame schedule a priori to be compatible with the coordinated timeslot frame will require significant effort and time to develop and test.

Development time for Timeslot Coordination of the F-Frame and the D-Frame is expected to be 20 months, resulting in a Development Schedule Score of 3.

Development Cost Score

Timeslot coordination of only the F-Frame requires modification of the ACSES communications managers. The NRE costs of Timeslot Coordination of only the F-Frame, is estimated to be less than \$250,000, resulting in a Development Cost Score of 2.

Timeslot coordination of both the F-Frame and D-Frame requires modification of both the ACSES communications managers and the ITCM messaging scheduling algorithms. The ITCM message scheduling algorithm is highly complex, and the overall performance of the ITCM network is dependent upon its efficient operation. Modification of the ITCM message scheduling algorithm will require a relatively high level of effort and testing. Cost of implementing full timeslot coordination between ACSES and ITC is estimated to be \$500,000, resulting in a Development Cost Score of 3.

4.6 Avoid the F-Frame

The Avoid the F-Frame approach is similar to the first phase of timeslot coordination as previously described. Avoid the F-Frame will prevent the ACSES and ITC radios onboard a dual-equipped locomotive from transmitting during the other radio’s most critical listening time in its respective frame. A key objective of this approach is to mitigate the locomotive self desense case with minimum changes to ACSES or ITC software or equipment.

Figure 31 is a timing diagram showing the alignment of two ACSES TDMA frames and three ITCM superframes. The ACSES locomotive radio transmits during slots designated with H (Hailing) and R (Base receiving). An ACSES base station transmits during slots labeled T and G (response to hailing).

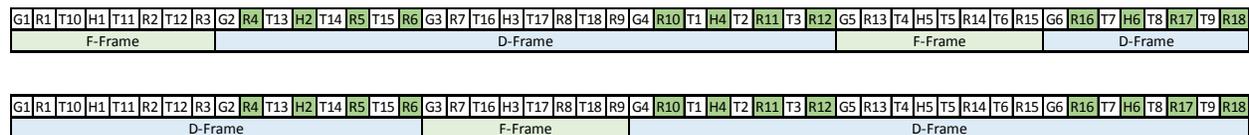


Figure 31. ACSES Timeslots That Do Not Interfere With F-Frame

In Figure 31 it can be seen that if the ACSES radio on dual locomotives transmits only in slots [H2, H4, H6] and [R4, R5, R6, R10, R11, R12, R16, R17,R18], which are highlighted in green in the figure, then the ACSES locomotive radio will not interfere with the ITC locomotive radio reception of ITC F-Frame transmissions.

Avoid the F-Frame retains the existing timeslot scheduling structure of the ACSES TDMA frame, whereas the “F-Frame timeslot coordination” portion of the timeslot coordination approach requires a restructuring of the ACSES TDMA frame to ensure that no locomotives transmit during the F-Frame. This provides mitigation of the locomotive self desense case with a potentially simpler implementation path than the “F-Frame timeslot coordination” portion of the timeslot coordination approach. Unlike the “F-Frame timeslot coordination” portion of the Timeslot Coordination approach, this Avoid the F-Frame does not mitigate the locomotive desense locomotive case.

Implementation of Avoid the F-Frame is accomplished with a modification to the BCM and a modification to the ACSES MCM.

Modification to the ACSES BCM consists of:

- The BCM obtains the railroad identifier field from the address (or other mechanism to identify dual-equipped locomotive)
- If the BCM identifies that the hailing locomotive is from a railroad that uses dual-equipped locomotives on the NEC then the BCM assigns that ACSES locomotive radio a slot from the set [R4, R5, R6, R10, R11, R12, R16, R17, R18]
- Else proceed as normal
- Optional – the BCM gives preference to slots [R1, R2, R3, R7, R8, R9, R13, R14, R15] to locomotives equipped only with ACSES

Modification to the ACSES MCM is required only on dual-equipped locomotives and consists of restricting the ACSES hailing transmissions to slots in the set [H2, H4, H6].

The Avoid the F-Frame Approach does not require any modification to ITC hardware or software.

The Avoid the F-Frame approach mitigates the case where the ACSES and ITC radios on a dual-equipped locomotive desense one another. However, the solution does not mitigate any loss of ITC F-Frame messages which occur when ITC locomotive radios are desensed by transmissions from nearby ACSES-only locomotives or ACSES base stations. The loss of ITC F-Frame messages is greatest in areas where nine or more ACSES locomotives are communicating with ACSES base stations.

However, by mitigating the locomotive self-desense scenario, which is more severe, the Avoid the F-Frame approach can be implemented in conjunction with locomotive filters to obtain robust protection of locomotive radios. In this case, the isolation requirement for locomotive filters is reduced by as much as 15 dB, which will increase the possibility of obtaining suitable locomotive filters.

Analysis is needed to quantify the probability of message collisions for ITC D-frame and ACSES slots. If the probability of message collision in the D-Frame is significant enough to reduce the performance of the PTC systems, then coordination of the D-Frame and ACSES slots is warranted. Also, analysis is needed to quantify the probability of ITC F-Frame message loss resulting from ITC locomotive radios being desensed by transmission from ACSES locomotives and bases operating in close proximity, similar to the risk described with the timeslot coordination approach.

If analysis shows that F-Frame message loss due to transmissions from ACSES locomotives operating in close proximity is unacceptably high, or that D-Frame timeslot coordination is required, then the approach described in the Timeslot Coordination section should be used rather than the Avoid the F-Frame approach.

4.6.1 Avoid the F-Frame Scoring Summary

The overall score for the Avoid the F-Frame approach is 15. Table 6 provides a summary of the evaluation criteria and score for the Avoid the F-Frame approach.

Table 6. Avoid the F-Frame Summary and Score

Desense Mitigation Coverage	Locomotive Desensing Self		Yes, During F-Frame. Interference may occur during D-Frame	
	Locomotive Desense Another Locomotive		No	
	Fixed Site Desense Loco		No	
Complexity	ITC HW/SW Changes	Office	SW	No
		Onboard	Modified Geographic Database	No
			Radio / Communication Scheduler	No
			Additional HW or SW	No
	Wayside or Base Station	Radio / Communication Scheduler	No	
	ACES HW/SW Changes	Office	SW	No
		Onboard	Radio / Mobile Communication Manager	No
			Additional HW or SW	No
		Base Station	Radio / Base Communication Manager	Yes
	Minimum Spectral Separation			None
Reliance on Alternate Communication Paths			No	
Development Schedule			< 12 Months	
Development Cost Estimate			< \$250k	
Evaluation Criteria Scores	Cases Mitigated		0.75	
	Complexity		1	
	Minimum Spectral Separation		0	
	Reliance on Alt. Comm. Paths		1	
	Development Schedule		2	
	Development Cost		2	
Overall Score			15.0	

Cases Mitigated

Avoid the F-Frame alone mitigates the locomotive self desense when the locomotive radio is receiving critical F-Frame messages. Since this approach does not protect the D-Frame, it is a partial mitigation, but since it protects the most critical messages, a Cases Mitigated Score of 0.75 was assigned.

Complexity Score

Avoid the F-Frame requires modification of the ACSES BCM and the ACSES MCM.

Modifications required in these two components are simpler as compared to the Timeslot Coordination approach, but still results in a Complexity Score of 2.

Minimum Spectral Separation Score

The Avoid the F-Frame approach does not require any spectral separation between ACSES and ITC channels, resulting in a Spectral Separation Score of 0.

Reliance on Alternative Communications Path(s):

This approach does not change the ITC or ACSES communication paths resulting in a Reliance on Alternative Communication Paths Score of 1.

Development Schedule Score

A time schedule for implementation of Avoid the F-Frame is, at this time, undefined, but given the simplicity of the approach, it is expected to require less time to implement than phase 1 of timeslot coordination, since this approach does not require restructuring of the ACSES 6 second TDMA frame. Implementation is assumed to take less than 12 months, resulting in a Development Schedule Score of 2.

Development Cost Score

The NRE costs of Avoid the F-Frame is estimated to be less than \$250,000 resulting in a Development Cost Score of 2.

4.7 ACSES Radio Blanking

In this approach, short transmissions from the ITC locomotive radios are scheduled to be sent during the interval after the locomotive's ACSES radio message body is transmitted and before the transmission of the error control portion of the ACSES slot, as shown in Figure 32. To accomplish this, the ACSES radio transmissions are blanked (RF transmit power zeroed) during unused portions of the message. When the ACSES locomotive radio is blanked, the ITC locomotive radio will not be desensed and ITC base station transmissions may be received. This approach is based on the assumption that messages from the locomotive to a base station are very short and of fixed duration, or can be made short and of fixed duration, in transition zones and in areas where ACSES and ITC are closely deployed.

Using this approach, transmissions from each radio will not desense the other radio if the following changes are made:

- Modification of the ITC base station radio transmission scheduling algorithms to transmit only during the blank periods in the ACSES timeslots
- Modification of the ITC wayside radio transmission scheduling algorithms to transmit only during the blank periods in the ACSES timeslots
- Modification of the ITC locomotive radio transmission scheduling algorithms to transmit only during the blank periods in the ACSES timeslots
- Modification of the ITC locomotive radio so it is capable of determining locomotive location and accessing radio blanking location data to determine when transmission timing needs to be modified to support radio blanking
- Implementation of radio blanking database that defines geographic locations in which ITC 220 MHz radios need to modify transmission scheduling to support radio blanking
- Modification of ACSES radios to blank the unused portion of all ACSES radio transmissions

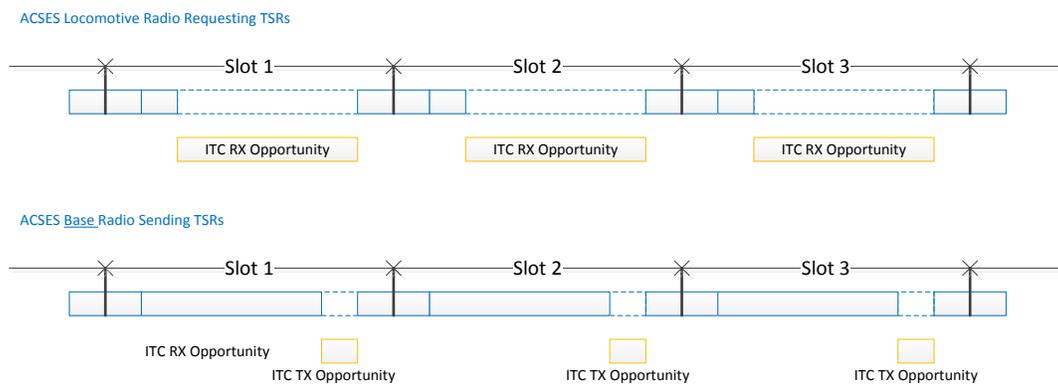


Figure 32. ITC Transmission Opportunities Using ACSES Radio Blanking

The risk of the Radio Blanking approach is that the changes to the MCC scheduling algorithm will be extensive and result in a loss of flexibility for the ITC system to adapt to changing traffic conditions. Additionally, the ACSES Radio Blanking approach will not fully resolve the 220 MHz desense problem since the transmission of long messages may still result in radio desense.

To evaluate possible increase in undesired enforcements, an analysis of the probability of message loss due to long message transmissions by ACSES and ITC systems should be performed.

4.7.1 ACSES Radio Blanking Scoring Summary

The overall score of the ACSES Radio Blanking approach is 13.6. Table 7 provides a summary of the evaluation criteria and score for the ACSES Radio Blanking approach.

Table 7. ACSES Radio Blanking Summary and Score

Desense Mitigation Coverage	Locomotive Desensing Self		Yes, for short messages. Interference may occur during long messages.	
	Locomotive Desense Another Locomotive		Yes, for short messages. Interference may occur during long messages.	
	Fixed Site Desense Loco		Yes, for short messages. Interference may occur during long messages.	
Complexity	ITC HW/SW Changes	Office	SW	No
		Onboard	Modified Geographic Database	Yes
			Radio / Communication Scheduler	Yes
			Additional HW or SW	No
		Wayside or Base Station	Radio / Communication Scheduler	Yes
	ACSES HW/SW Changes	Office	SW	No
		Onboard	Radio / Mobile Communication Manager	Yes
			Additional HW or SW	No
		Base Station	Radio / Base Communication Manager	Yes
	Minimum Spectral Separation			None
Reliance on Alternate Communication Paths			No	
Development Schedule			> 12 Months	
Development Cost Estimate			<\$500k	
Evaluation Criteria Scores	Cases Mitigated		1.5	
	Complexity		5	
	Minimum Spectral Separation		0	
	Reliance on Alt. Comm. Paths		1	
	Development Schedule		3	
	Development Cost		3	
Overall Score			13.6	

Cases Mitigated

ACSES Radio Blanking provides mitigation for each of the desense cases affecting locomotive PTC radios, with the exception of long message transmissions as noted above. Even though this approach provides mitigation for each of the three desense cases affecting the locomotive, the Cases Mitigated Score is 2, since desense may occur when long messages must be transmitted.

Complexity Score

ACSES Radio Blanking requires:

- Modification of the ITC base station radio transmission scheduling algorithms to transmit only during the blank periods in the ACSES timeslots
- Modification of the ITC wayside radio transmission scheduling algorithms to transmit only during the blank periods in the ACSES timeslots
- Modification of the ITC locomotive radio transmission scheduling algorithms to transmit only during the blank periods in the ACSES timeslots
- Modification of the ITC locomotive radio capable of determining locomotive location and accessing radio blanking location data to determine when transmission timing needs to be modified to support radio blanking
- Implementation of radio blanking database that defines geographic locations in which ITC 220 MHz radios need to modify transmission scheduling to support radio blanking
- Modification of ACSES radios to blank the unused portion of all ACSES radio transmissions

This results in a Complexity Score of 6.

Minimum Spectral Separation Score

The ACSES Radio Blanking approach does not require any spectral separation between ACSES and ITC channels, resulting in a Spectral Separation Score of 0.

Reliance on Alternative Communication Paths Score

There are no changes to communication paths required for either ACSES or ITC. The Reliance on Alternative Communication Paths Score for this approach to desense mitigation is 1.

Development Schedule Score

The primary challenge for this option will be the time required to implement software to force the ITC radios to only transmit during the blank periods in the ACSES radio transmissions. Software development and test will need to be completed before conducting tests to validate the approach.

The estimated development time for a deployment ready implementation of the ACSES Radio Blanking approach is expected to be greater than 12 months, resulting in a Development Schedule Score of 3.

Development Cost Score

The ACSES Radio Blanking approach does not require modification of the ACSES or ITCM message timeslot use algorithms, but it will require modifications of the ITCM message scheduling algorithm offset transmission times to periods when the ACSES radios are not expected to be transmitting. Modification of the ITCM message scheduling algorithm is expected to require a moderate level of effort. The cost of implementing the ACSES Radio Blanking Approach is estimated to be less than \$500,000, resulting in a Development Cost Score of 3.

4.8 Segregated Radio Use

In the Segregated Radio Use option, the ITC locomotive and fixed site radios are only allowed to transmit within ITC territory and the ACSES locomotive and fixed site radios are only allowed to transmit in ACSES territory. This restriction upon radio use by territory is intended to segregate radio use by territory. For example, a locomotive that only travels on ACSES territory will only be equipped with the complete ACSES onboard system, including an ACSES 220 MHz radio, and if a locomotive only travels on ITC territory, then it will only be equipped with the complete ITC locomotive onboard system including an ITC 220 MHz radio. Locomotives that travel on both ITC and ACSES territories will be equipped with complete ACSES and ITC onboard systems.

Segregation of radio use mitigates the locomotive self desense case since only the ACSES or ITC locomotive radio is used at any time. Segregation of radio use does not mitigate the cases of a locomotive radio being desensed by a base station or by another locomotive in areas where ITC and ACSES are deployed in close proximity.

When either an ITC or ACSES fixed site radio is deployed close to the other system's territory, filtering will be used to minimize potential desense between those fixed site radios. This filtering will also help prevent desense of fixed site radios by nearby locomotive radio transmissions. ACSES and ITC fixed site radios should also be located away from the track to avoid desense of locomotive radios by those fixed sites.

Transitions between ACSES and ITC territories will require specific procedures to ensure that PTC radios are not desensed. The process differs depending upon whether the train is approaching ITC or ACSES territory. These PTC transition procedures are:

- When a train is operating in ACSES territory and approaching a transition to ITC territory:
 - The ITC 220 MHz locomotive radio will be on, but ITCM will not route any outbound messages to that radio. This will allow the receipt of ITC WIU messages, but will prevent any transmission by the ITC 220 MHz locomotive radio. The areas in which the ITC 220 MHz radio is not allowed to transmit are referred to as quiet zones.
 - The ACSES 220 MHz locomotive radio will be fully functional.
 - ITC messages outbound from the locomotive that are required to prepare the train to enter ITC territory will automatically be routed over alternate ITC communication links, such as cellular or Wi-Fi. This means that the reliance on

cellular coverage at these approach areas would be more critical since the ITC 220 MHz radio message transport would not be available as a backup.

- When a train is operating in ITC territory and is approaching a transition to ACSES territory:
 - On the approach to ACSES territory, the ACSES radio will be turned off, but the ITC radio will be fully functional.
 - ACSES messages outbound from the locomotive will be routed over the ITC 220 MHz radio via ITCM. Likewise, inbound messages from the ACSES wayside and ACSES back office will also be routed over the ITC 220 MHz radio network via ITCM.

Implementing this approach requires the following:

- An ACSES back office gateway will need to be implemented to transport ACSES TSR messages and other mandatory directives to dual-equipped locomotives over the ITC 220 MHz radio via ITCM
- An ACSES wayside gateway to transport interlocking status and signal aspect over the ITC 220 MHz radio via ITCM
- An ITCM locomotive gateway to route incoming ACSES messages transported via ITCM communication links to the ACSES locomotive onboard system, and to route ACSES locomotive messages to the appropriate ACSES gateway
- A modified ITCM communication link manager that is capable of determining locomotive location and accessing quiet zone data to determine if the ITC 220 MHz radio may be used
- Implementation of a quiet zone database that defines geographic locations in which ITC 220 MHz radios cannot be used

Additional quiet zones may be implemented in areas in which ITC and ACSES are deployed in close proximity, and desense of ITC and ACSES locomotives by fixed sites and by other locomotive radios results in unacceptable PTC message loss or an increase in false enforcements by either PTC system. Adding a quiet zone would be accomplished by adding the boundary information for the new quiet zone into the aforementioned quiet zone database.

There are two key risk areas associated with this desense mitigation approach; use of quiet zones, and complexity of implementation.

The use of quiet zones to mitigate desense between ACSES and ITC radios in areas of close deployment proximity has the following risks:

- Due to the amount and proximity of ACSES and ITC territory on the NEC, there is a possibility that most of the NEC territory will need to be designated as quiet zones.
- The overall availability of ITC deployments on the NEC may be reduced within quiet zones because one of the primary ITC communication links, ITC 220 MHz radios, cannot be used.

- For quiet zone areas in which reliance on cellular or other alternative ITCM communication links to support ITC operation is not feasible, there will be a reduction in ACSES and ITC system reliability due to desense resulting from the use of the ITC 220 MHz radio.

The complexity of this solution, in terms of the components that need to be developed, modified, and maintained presents the following risks:

- There is a risk that this approach will require an unacceptably long time to develop and test.
- The ACSES back office gateway and ACSES wayside gateways will need to be integrated with ITCM. This integration may significantly increase the complexity of the ACSES segments.
- Implementation of quiet zones will require a database defining the locations and boundaries of the quiet zones. This database will need to be included in all ITC-equipped locomotives operating on the NEC. Verification that this database is up to date and error free will be required before an ITC-equipped locomotive enters the NEC. There is a risk that this verification process will add significant complexity to the PTC system, ITC or ACSES, responsible for performing the database verification.
- The quiet zone database, as well as the modified ITCM system that implements the quiet zones will need to be deployed in all ITC locomotives that may operate on the NEC. There is risk that this requirement will be imposed on all ITC locomotives.
- Long term agreements among railroads (and other users of 220 MHz spectrum) for the maintenance of the quiet zone database will need to be obtained. The implementation of this approach may be delayed due to the time required to obtain such agreements.

Before development of this approach, an analysis should be conducted to evaluate the probability of undesired enforcements due to message collisions in areas where cellular coverage is inadequate in quiet zones and the ITC 220 MHz radios must be used. If this analysis shows an increase of undesired enforcements is likely, then this approach may not be feasible.

4.8.1 Segregated Radio Use Scoring Summary

The overall score of the Segregated Radio use approach is 2.3. Table 8 provides a summary of the evaluation criteria and score for the segregated radio use approach.

Table 8. Segregated Radio Use Summary and Score

Desense Mitigation Coverage	Locomotive Desensing Self			Yes
	Locomotive Desense Another Locomotive			Yes, Assuming ITC System Use of Alternative Communication Path
	Fixed Site Desense Loco			Yes, Assuming ITC System Use of Alternative Communication Path
Complexity	ITC HW/SW Changes	Office	SW	Yes
		Onboard	Modified Geographic Database	Yes
			Radio / Communication Scheduler	Yes
			Additional HW or SW	No
		Wayside or Base Station	Radio / Communication Scheduler	No
	ACES HW/SW Changes	Office	SW	Yes
		Onboard	Radio / Mobile Communication Manager	Yes
			Additional HW or SW	Yes
		Base Station	Radio / Base Communication Manager	No
	Minimum Spectral Separation			
Reliance on Alternate Communication Paths				Yes
Development Schedule				> 12 Months
Development Cost Estimate				<\$500k
Evaluation Criteria Scores	Cases Mitigated			3
	Complexity			7
	Minimum Spectral Separation			0
	Reliance on Alt. Comm. Paths			10
	Development Schedule			3
	Development Cost			3
Overall Score				2.3

Cases Mitigated

Since only one radio is in operation on a locomotive at any time, the solution will mitigate the possibility that the locomotive desenses itself. Use of quiet zones in areas provides mitigation to the remaining desense scenarios affecting a locomotive. This results in a Cases Mitigated Score of 3.

Complexity Score

Segregated radio use requires:

- An ACSES back office gateway to transport ACSES TSR messages and other mandatory directives to dual-equipped locomotives via ITCM
- An ACSES wayside gateway to transport interlocking status and signal aspect over ITCM
- An ITCM locomotive gateway to route incoming ACSES messages via ITCM to the ACSES locomotive onboard system, and to route ACSES locomotive messages to the appropriate ACSES gateway
- A modified ITCM communication link manager that is capable of determining locomotive location and accessing quiet zone data to determine if the ITC 220 MHz radio may be used
- Implementation of quiet zone database that defines geographic locations in which ITC 220 MHz radios cannot be used

This results in a Complexity Score of 5.

Spectral Separation Score

Segregated radio use does not require any spectral separation between ACSES and ITC channels, resulting in a Spectral Separation Score of 0.

Reliance on Alternative Communications Path(s) Score:

Use of ITC 220 MHz radios will be restricted when ITC-equipped locomotives and dual-equipped locomotives are operating within defined quiet zones. While in quiet zones, these locomotives will be reliant upon alternative ITC communication paths. The Reliance on Alternative Communication Paths Score for this approach to desense mitigation is 10.

Development Schedule Score

The Segregated Radio approach may be field implementable in a minimum of 12 months, resulting in a Development Schedule Score of 3.

Development Cost Score

The NRE costs of the Segregated Radio Use approach is estimated to be less than \$500,000, resulting in a Development Cost Score of 3.

4.9 Single Locomotive Radio

In the Single Locomotive Radio option, both ITC and ACSES radio networks operate in ACSES territory but only one radio is used by locomotives to transmit and receive messages. In this option, a locomotive that only travels on ACSES territory will only be equipped with the complete ACSES onboard system, including an ACSES 220 MHz radio. If a locomotive only travels on ITC territory, then it will only be equipped with the complete ITC locomotive onboard system including an ITC 220 MHz radio. Locomotives that travel on both ITC and ACSES territories will be equipped with both ACSES and ITC onboard systems, but will only have the ITC communications system (ITC Messaging and ITC Radios) installed.

Use of only a single radio on a locomotive mitigates the locomotive self desense case, but does not mitigate the cases of a locomotive radio being desensed by a base station or by another locomotive in areas where ITC and ACSES are deployed in close proximity. In order to prevent ITC bases from interfering with ACSES locomotive radios, quiet zones need to be established in which no ITC transmission will occur from fixed sites and locomotive radios. These quiet zones will span locations where both ACSES and ITC are deployed in close proximity as well as within transition zones between ITC and ACSES operation.

While within quiet zones, ITC message traffic for all ITC system segments (base stations, waysides, and locomotives) will need to be routed over alternative communication links available to ITCM, such as cellular or Wi-Fi, rather than over the 220 MHz ITC radio. In areas where alternative ITCM communication link coverage is unavailable or unreliable, then the ITC 220 MHz radio must be used, and reliable operation of both ACSES and ITC systems in that area will depend on the possibility that desense between ACSES and ITC radios will be of short duration due to movement of locomotives.

To support the operation of these dual-equipped locomotives in ACSES territory, the following new software components are needed:

- An ACSES back office gateway will need to be implemented to transport ACSES TSR messages and other mandatory directives to dual-equipped locomotives over ITCM (using 220 MHz radios, cellular, Wi-Fi, or other alternative ITCM communication link)
- An ACSES wayside gateway to transport interlocking status and signal aspect over ITCM (using cellular, Wi-Fi or other alternative ITCM communication link since ITC 220 MHz radios cannot be used in quiet zones near interlockings).
- An ITCM locomotive gateway to route incoming ACSES messages transported via ITCM communication links to the ACSES locomotive onboard system, and to route ACSES locomotive messages to the appropriate ACSES gateway
- A modified ITCM communication link manager for use in all ITC locomotives that operate on the NEC, that is capable of determining locomotive location and accessing quiet zone data to determine if the ITC 220 MHz radio may be used
- Implementation of a quiet zone database that defines geographic locations in which ITC 220 MHz radios cannot be used

There are two key risk areas associated with this desense mitigation approach: use of quiet zones, and complexity of implementation.

The use of quiet zones to mitigate desense between ACSES and ITC radios in areas of close deployment proximity and in transition zones between ACSES and ITC operation has the following risks:

- Due to the amount and proximity of ACSES and ITC territory on the NEC, there is a possibility that most of the NEC territory will be designated as quiet zones.
- The overall availability of ITC deployments on the NEC may be reduced within quiet zones because one of the primary ITC communication links, ITC 220 MHz radios, cannot be used.
- In quiet zone areas which rely on cellular, or other alternative ITCM communication links to support ITC operation is not feasible, there will be a reduction in ACSES and ITC system reliability due to desense resulting from the use of the ITC 220 MHz radio.

The complexity of this solution, in terms of the components that need to be developed, modified, and maintained presents the following risks:

- There is risk that this approach will require an unacceptably long time to develop and test.
- The ACSES back office gateway and ACSES wayside gateways will need to be integrated with ITCM. This integration may significantly increase the complexity of the ACSES segments.
- Implementation of quiet zones will require a database defining the locations and boundaries of the quiet zones. This database will need to be included in all ITC-equipped locomotives operating on the NEC. Verification that this database is up to date and error free will be required before an ITC-equipped locomotive enters the NEC. There is a risk that this verification process will add significant complexity to the PTC system, ITC or ACSES, responsible for performing the database verification.
- The quiet zone database as well as the modified ITCM system that implements the quiet zones, will need to be deployed in all ITC locomotives that may operate on the NEC. There is a risk that this requirement will be imposed on all ITC locomotives.
- Long term agreements among railroads, and other nearby users of 220 MHz spectrum, for the maintenance of the quiet zone database will need to be obtained. The implementation of this approach may be delayed due to time required to obtain such agreements.

Before development of this approach, an analysis should be conducted to evaluate the probability of undesired enforcements due to message collisions in areas where cellular coverage is inadequate in quiet zones and the ITC 220 MHz radios must be used. If this analysis shows an excessive increase of undesired enforcements is likely, then this approach may not be feasible.

4.9.1 Single Radio Use Scoring Summary

The overall score of the Single Radio Use approach is 2.3. Table 9 provides a summary of the evaluation criteria and score for the single locomotive radio use solution.

Table 9. Single Radio Use Summary and Score

Desense Mitigation Coverage	Locomotive Desensing Self		Yes	
	Locomotive Desense Another Locomotive		Yes, Assuming ITC System Use of Alternative Communication Path	
	Fixed Site Desense Loco		Yes, Assuming ITC System Use of Alternative Communication Path	
Complexity	ITC HW/SW Changes	Office	SW	Yes
		Onboard	Modified Geographic Database	Yes
			Radio / Communication Scheduler	Yes
			Additional HW or SW	No
		Wayside or Base Station	Radio / Communication Scheduler	No
	ACSES HW/SW Changes	Office	SW	Yes
		Onboard	Radio / Mobile Communication Manager	Yes
			Additional HW or SW	Yes
		Base Station	Radio / Base Communication Manager	No
	Minimum Spectral Separation			None
Reliance on Alternate Communication Paths			Yes	
Development Schedule			> 12 Months	
Development Cost Estimate			<\$500k	
Evaluation Criteria Scores	Cases Mitigated		3	
	Complexity		7	
	Minimum Spectral Separation		0	
	Reliance on Alt. Comm. Paths		10	
	Development Schedule		3	
	Development Cost		3	
Overall Score			2.3	

Cases Mitigated

Since only one radio is in operation on a locomotive at any time, the case of a locomotive desensing itself is fully mitigated. Use of quiet zones in areas provides mitigation to the remaining desense scenarios affecting a locomotive. This results in a Cases Mitigated Score of 3.

Complexity Score

Single radio use requires:

- An ACSES back office gateway to transport ACSES TSR messages and other mandatory directives to dual-equipped locomotives via ITCM
- An ACSES wayside gateway to transport interlocking status and signal aspect over ITCM
- An ITCM locomotive gateway to route incoming ACSES messages via ITCM to the ACSES locomotive onboard system, and to route ACSES locomotive messages to the appropriate ACSES gateway
- A modified ITCM communication link manager that is capable of determining locomotive location and accessing quiet zone data to determine if the ITC 220 MHz radio may be used
- Implementation of quiet zone database that defines geographic locations in which ITC 220 MHz radios cannot be used

This results in a Complexity Score of 5.

Minimum Spectral Separation Score

Use of the single locomotive radio approach does not require any spectral separation between ACSES and ITC channels, resulting in a Spectral Separation Score of 0.

Reliance on Alternative Communications Path(s) Score:

Use of ITC 220 MHz radios will be restricted when ITC-equipped locomotives and dual-equipped locomotives are operating within quiet zones. While in quiet zones, these locomotives will be reliant upon alternative ITC communication paths. The Reliance on Alternative Communication Paths Score for this approach to desense mitigation is 10.

Development Schedule Score

The primary schedule challenge for this option will be the time required to implement software to disable ACSES and ITC radio transmission in appropriate locations and implementing the ITC network gateway to support dual-equipped locomotives operating in ACSES territories. Software development and testing will need to be completed before conducting tests to validate the approach.

The segregated radio approach may be field implementable in a minimum of 12 months, resulting in a Development Schedule Score of 3.

Development Cost Score

The NRE costs of the Single Radio Use approach is estimated to less than \$500,000, resulting in a Development Cost Score of 3.

5. Use of Multiple Candidate NEC PTC Desense Mitigation Solutions

Multiple discrete desense mitigation solutions may be used in concert to provide a more comprehensive desense mitigation solution for the NEC PTC deployments. In order to assess the viability and benefit of using multiple desense mitigation approaches in concert, two key factors need to be considered:

1. Whether the desense mitigation approaches are compatible or not
2. The overall desense mitigation coverage provided by the combined desense mitigation approaches

If the desense mitigation approaches are incompatible with each other, or if the use of multiple approaches does not provide complete mitigation of each of the identified desense scenarios, then implementation of these approaches together is not viable in terms of level of effort to implement and benefits received.

Table 10 provides a summary of the compatibility and desense mitigation coverage for each pair of identified desense mitigation solutions.

Table 10. Use of Multiple Desense Mitigation Solutions Summary

	Locomotive Radio Filtering	Phased Antenna Placement	Adaptive Interference Canceller	Timeslot Coordination of F-Frame Only	Timeslot Coordination of F-Frame and D-Frame	Avoid The F-Frame	ACES Radio Blanking	Segregated Radio	Single Locomotive Radio
Locomotive Radio Filtering		Yes ^{1,2}	Yes ¹	Yes ¹	Yes ¹	Yes ¹	Yes ¹	Yes ¹	Yes ¹
Phased Antenna Placement			Yes ^{2,3}	No ⁴	No ⁴	No ⁴	No ⁴	No ⁴	No ⁴
Adaptive Interference Canceller				Yes ³	Yes ³	Yes ³	Yes ³	Yes ³	Yes ³
Timeslot Coordination of F-Frame Only					NC ⁷	NC ⁷	No ⁵	No ⁸	No ⁸
Timeslot Coordination of F-Frame and D-Frame						NC ⁷	No ⁵	No ⁸	No ⁸
Avoid The F-Frame							No ⁵	No ⁸	No ⁸
ACES Radio Blanking	Key							No ⁶	No ⁶
Segregated Radio	Yes - All Desense Scenarios are Fully Mitigated. No - Desense Scenarios Not Fully Mitigated NC - Approaches are Not Compatible								NC ⁹
Single Locomotive Radio									

Notes from Table 10:

1. Locomotive radio filtering is compatible with each of the other candidate desense mitigation solutions. Since locomotive radio filtering alone has the potential to fully mitigate all identified desense scenarios, use in conjunction with other desense mitigation approaches is unnecessary.
2. Signal cancellation via phased antenna placement may reduce the interfering signal level in the locomotive self desense scenario by 25 dB. This approach may be used in conjunction with locomotive radio filters and AIC if these approaches are unable to fully mitigate the locomotive self desense scenario alone.
3. AIC is compatible with each of the other candidate desense mitigation solutions. Since AIC alone has the potential to fully mitigate all identified desense scenarios, use in conjunction with other desense mitigation approaches is unnecessary.
4. Signal cancellation via phased antenna placement does not provide additional desense mitigation coverage when used with other approaches that mitigate the locomotive self desense scenario.
5. ACSES radio blanking may be used in conjunction with timeslot coordination and Avoid the F-Frame to provide some mitigation to the fixed site desense locomotive scenario. Use of these approaches together does not provide complete desense mitigation coverage since ACSES radio blanking does not mitigate the potential for desense when long messages are transmitted.
6. ACSES radio blanking may be used in conjunction with segregated radio use and single locomotive radio use to provide some mitigation to the fixed site desense locomotive and locomotive desense locomotive scenarios, thus potentially reducing the need for quiet zones. Use of these approaches together does not provide complete desense mitigation coverage since ACSES radio blanking does not mitigate the potential for desense when long messages are transmitted.
7. Timeslot coordination and Avoid the F-Frame desense mitigation approaches are variants of timeslot coordination approaches. As such, these are not compatible to use together.
8. Use of a timeslot coordination desense mitigation approach may be used in conjunction with segregated radio use or single locomotive radio use, but does not improve desense mitigation coverage over using timeslot coordination alone.
9. Segregated radio use and single locomotive radio use are both approaches that attempt to mitigate desense by only allowing one 220 MHz PTC locomotive radio to be used at a time. These approaches cannot be implemented together.

6. Summary and Conclusion

Table 11 provides a summary of the evaluation criteria for each of the eight candidate solutions (including both implementation phases of timeslot coordination) and the resultant solution score per Equation 1.

Table 11. PTC Desense Mitigation Score Summary

			Locomotive Filtering w/ 1 MHz Spectral Separation	Dynamically Tunable Crystal Filters	Phased Antenna Placement	Adaptive Interference Canceller (AIC)	Timeslot Coordination of only F-Frame	Timeslot Coordination of F-Frame and D-Frame	Avoid The F-Frame	Radio Blanking	Segregated Radio	Single Locomotive Radio Use	
Desense Mitigation Coverage	Locomotive Desensing Self		Yes	Yes	No, but 25 dB Reduction of ACSSES Signal on ITC Radio	Yes	Yes, During F-Frame. Interference may occur during D-Frame	Yes	Yes, During F-Frame. Interference may occur during D-Frame	Yes, for short messages. Interference may occur during long messages.	Yes	Yes	
	Locomotive Desense Another Locomotive		Yes	Yes	No	Yes	Yes, During F-Frame. Interference may occur during D-Frame	Yes	No	Yes, for short messages. Interference may occur during long messages.	Yes, Assuming ITC System Use of Alternative Communication Path	Yes, Assuming ITC System Use of Alternative Communication Path	
	Fixed Site Desense Loco		Yes	Yes	No	Yes	No	No	No	Yes, for short messages. Interference may occur during long messages.	Yes, Assuming ITC System Use of Alternative Communication Path	Yes, Assuming ITC System Use of Alternative Communication Path	
Complexity	ITC HW/SW Changes	Office - SW	No	No	No	No	No	No	No	No	Yes	Yes	
		Modified Geographic Database	No	No	No	No	No	Yes	No	Yes	Yes	Yes	
		Onboard - Radio / Communication Scheduler	No	Yes	No	No	No	Yes	No	Yes	Yes	Yes	
		Additional HW or SW	Yes	Yes	No	Yes	No	No	No	No	No	No	
	ACSSES HW/SW Changes	Wayside or Base Station - Radio / Communication Scheduler	No	No	No	No	No	Yes	No	Yes	No	No	
		Onboard - SW	Office - SW	No	No	No	No	No	No	No	No	Yes	Yes
			Radio / Mobile Communication Manager	No	Yes	No	No	Yes	Yes	No	Yes	Yes	Yes
Additional HW or SW	Yes	Yes	Yes	Yes	No	No	No	No	Yes	Yes			
Base Station - Radio / Base Communication Manager	No	No	No	No	Yes	Yes	Yes	Yes	Yes	No	No		
Minimum Spectral Separation			1 MHz	25 kHz	None	250 kHz	None	None	None	None	None	None	
Reliance on Alternate Communication Paths			No	No	No	No	No	No	No	No	Yes	Yes	
Development Schedule			4 Months	< 12 Months	< 6 Months	11 to 14 Months	< 12 Months	20 Months	< 12 Months	> 12 Months	> 12 Months	> 12 Months	
Development Cost Estimate			< \$100,000	< \$250,000	< \$100,000	\$1M	<\$250k	<\$500k	< \$250k	<\$500k	<\$500k	<\$500k	
Evaluation Criteria Scores	Cases Mitigated		3	3	0.5	3	1.5	2	0.75	1.5	3	3	
	Complexity		2	4	1	2	2	5	1	5	7	7	
	Minimum Spectral Separation		2	1	0	1	0	0	0	0	0	0	
	Reliance on Alt. Comm. Paths		1	1	1	1	1	1	1	1	10	10	
	Development Schedule		1	2	1	2.5	2	3	2	3	3	3	
	Development Cost		1	2	1	4	2	3	2	3	3	3	
Overall Score			50.0	33.3	16.7	31.6	25.0	18.2	15.0	13.6	2.3	2.3	

On the basis of the results shown in Table 11, the following candidate solutions stand out as having the potential to mitigate all of the desense scenarios affecting locomotives operating on the NEC:

- Locomotive radio filtering with 1 MHz spectral separation (score 50)
- Dynamically tunable crystal filter assemblies (score 33.3)
- AIC (score 31.6)

Note that there are risks, however, with use of any of these solutions in this application. Additionally, signal cancellation via phased antenna placement can be used in conjunction with either locomotive radio filtering or AIC to augment the ability for those approaches to mitigate the locomotive self desense case if needed.

In order to resolve the risks and determine an appropriate path forward, next steps for the mitigation of 220 MHz PTC radio desense on the NEC are recommended:

- Acquire and test the functional and environmental performance of 220 MHz locomotive radio filters, including resonant cavity filters, helical cavity filters, and dynamically tunable crystal filter assemblies, to demonstrate whether such filters are capable of mitigating all of the desense scenarios affecting locomotives on the NEC, as well as to demonstrate whether such filters are capable of surviving the locomotive shock, vibration, and temperature environment. A project for TTCI to specify, acquire, and test 220 MHz locomotive radio filters has been funded by the FRA and is underway.
- Acquire and test the functional and environmental performance of an AIC to demonstrate whether such a device is capable of mitigating all of the desense scenarios affecting locomotives on the NEC as well as to demonstrate whether an AIC is capable of surviving the locomotive shock, vibration, and temperature environment. A project for TTCI to specify, acquire, and test an AIC has been funded by the FRA and is underway.
- Conduct analysis and test of signal cancellation via phased antenna placement to determine the amount of isolation provided by use of phased antenna placement, determine the location and width of nulls in the resultant ACSES antenna pattern, and determine the extent to which the location of the nulls in the resultant ACSES antenna pattern will have a detrimental effect on ACSES system performance. A project to analyze and test signal cancellation via phased antenna placement should be conducted as a contingency in the event that 220 MHz locomotive filters alone, or an AIC alone, is unable to fully mitigate the locomotive self desense case.

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Abbreviations and Acronyms

ACSES	Advanced Civil Speed Enforcement System
ADU	Aspect Display Unit
AIC	Adaptive Interference Canceller
AMTS	Advanced Mobile Telephone Systems
ATC	Automatic Train Control
BCM	Base Communications Manager
CSMA	Carrier Sense Multiple Access
CSX	CSX Railroad
dB	Decibel
dBm	Decibel-milliwatts
DelDOT	Delaware Department of Transportation
Desense	Desensitization
DOT	Department of Transportation
FCC	Federal Communications Commission
FRA	Federal Railroad Administration
GE	General Electric
I-ETMS	Interoperable Electronic Train Management System
ITC	Interoperable Train Control
ITCM	Interoperable Train Control Messaging
IVDS	Interactive Video and Data Services
kHz	Kilohertz
LIRR	Long Island Rail Road
MARC	Maryland Rail Commuter
MBTA	Massachusetts Bay Transportation Authority
MCC	Meteorcomm LLC
MCM	Mobile Communications Manager
MHz	Megahertz
MNR	Metro-North Railroad
MTA	Metropolitan Transportation Authority

NEC	Northeast Corridor
NJT	New Jersey Transit
NRE	Nonrecurring Engineering
NRTC	National Rural Telecommunications Cooperative
NS	Norfolk Southern
OBC	Onboard Computer
PTC	Positive Train Control
RF	Radio Frequency
RFI	Request for Information
RIDOT	Rhode Island DOT
SEPTA	Southeastern Pennsylvania Transportation Authority
TDMA	Time Division Multiple Access
TMC	Train Management Computer
TSR	Temporary Speed Restriction
TTC	Transportation Technology Center (the site)
TTCI	Transportation Technology Center, Inc. (the company)
VRE	Virginia Railway Express
WEU	Wayside Encoder Unit
WIU	Wayside Interface Unit
WSRS	Wayside Status Relay Service

***Request for Information
for
Positive Train Control
220 MHz Locomotive Radio Filter***

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1. Background and Problem Overview

In specific regions of the North East Corridor (NEC) two distinct varieties of Positive Train Control (PTC) systems are being deployed: Interoperable Train Control (ITC) and Advance Civil Speed Enforcement System (ACSES). ITC, which is also known as I-ETMS®, is primarily being deployed by freight railroads, and ACSES is being deployed by commuter and passenger railroads.

ITC and ACSES both use data radio networks operating between 217 MHz and 222 MHz to communicate essential information to and from locomotives. Locations exist where trains will need to transition between ITC and ACSES control. In these transition zones, a train will need to be in communication with both ITC and ACSES off-board sites, causing both radios to be in operation concurrently on board the same locomotive. This concurrent operation of the two radios results in times when one of the radios is transmitting while the other is trying to receive, resulting in the receiving radio becoming de-sensitized and unable to receive essential messages. To maintain reliable communication, each of the PTC radios on a locomotive needs to receive signals with a strength as low as -95 dBm while in close proximity to another radio that is transmitting at +40 dBm to +50 dBm. Experimental results have shown that desense of the receiving radio can occur if the interfering signal strength is -30 dBm or higher.

Two filter sets are needed:

1. Filter A will pass ACSES transmissions while stopping ITC transmissions.
2. Filter B will pass ITC transmissions while stopping ACSES transmissions.

1.1 Operation Scenarios

Four primary problem scenarios are identified in which radio desense may occur within areas in which ITC and ACSES are both deployed. These scenarios are:

- A. ITC and ACSES radios both installed on the same locomotive with antennas for each installed on the locomotive cab roof two to five feet apart. If either of these radios is transmitting, then the other radio may be desensed. This is subsequently referred to as “self desense” case. (Worst Case)
- B. Two locomotives operating on adjacent tracks (as close as 12 feet between track centers). If a radio on one locomotive is transmitting, a radio of the other type (ACSES vs. ITC) on the other locomotive may be desensed.
- C. A locomotive is operating in close proximity to a wayside installed radio with an antenna on a short tower. When the wayside radio is transmitting, a radio of the other type on the locomotive may be desensed.

- D. A locomotive is operating in close proximity to a base station radio installation with an antenna on a tower. When the base station radio is transmitting, a radio of the other type on the locomotive may be desensed.

1.2 ACSES and ITC PTC Channels

Table 1 is a list of channels used by Amtrak for ACSES in the North East Corridor. Each of the ACSES channels are 12.5 kHz wide with channel centers as specified in table 1. Table 2 is a list of channels used by Norfolk Southern and CSX freight railroads for ITC in the North East Corridor. Each of the ITC channels are 25 kHz wide with channel centers as specified in table 2.

ACSES Frequencies	
fo (MHz)	Channel BW (KHz)
217.0125	12.5
217.0250	12.5
217.0375	12.5
217.0500	12.5
217.0625	12.5
217.0750	12.5
217.0875	12.5
Forty Contiguous Channels Between 218.5 MHz and 219 MHz	12.5
220.25625	12.5
220.26875	12.5
220.28125	12.5
220.29375	12.5
220.94375	12.5
221.25625	12.5
221.26875	12.5
221.29375	12.5

Table 12. ACSES Channels

ITC Frequencies	
fo (MHz)	Channel BW (kHz)
220.1125	25
220.1375	25
220.4125	25
220.4375	25
220.7125	25
220.7375	25
220.7625	25
221.1125	25
221.1375	25
221.4125	25
221.4375	25
221.7125	25
221.7375	25
221.7625	25

Table 13. ITC Channels

Additional ACSES channels in the 217 MHz to 219 MHz band may be added in the future.

1.2.1 Alternate ACSES and ITC PTC Channel Scheme

Instances will exist in which the ACSES systems will utilize frequencies between 217 MHz and 219 MHz when operating in regions in which ITC is also present for freight railroad operations. Since the ITC channels range from 220 MHz to 222 MHz, filtering could be designed to pass 217 MHz to 219 MHz for ACSES (while rejecting 220 MHz to 222 MHz), and another filter to pass 220 MHz to 222 MHz (while rejecting 217 MHz to 219 MHz) for ITC without needing to accommodate the ACSES channels that range from 220 MHz to 222 MHz. However, once the ACSES-equipped locomotive transitions out of the combined ACSES and ITC regions, it will need to utilize the ACSES frequencies between 220 MHz to 222 MHz. This means that the filter passing ACSES channels will need to be automatically cut out in the ACSES-only regions, such that the ACSES radio can receive frequencies in the 220 MHz to 222 MHz band.

1.3 Radio Transmit Power

ACSES locomotive radios transmit with a constant envelope power of up to 25 W.

ITC locomotive radios transmit with a peak envelope power of 50 W, but the transmit power link budget assumes an average power of 14.8 Watts, and this will be used for signal strength calculations.

1.4 Radio Blocking

When the Signal of Interest (SOI) is -95 dBm or less the ACSES locomotive radio (GE/MDS TD 220) was observed to be blocked by an ITC locomotive radio signal with a peak envelope power of -30 dBm, where both signal levels are measured at the ACSES radio RF input.

When the Signal of Interest (SOI) is -95 dBm or less the ITC radio was observed to be blocked by an ACSES locomotive radio signal with a peak envelope power of -20dBm, although the blocking threshold of -30 dBm is recommended by the radio designer (MCC) for the purposes of filter design. Both signal levels are measured at the ITC radio RF input.

2. 220 MHz Locomotive Radio Filter Requirements

There are two possible levels of filter needs on the dual-equipped locomotive. One for the case in which a mitigation technique cannot be identified to solve the locomotive self-desense that will occur from the antennas being co-located on the locomotive. This would require the highest level of isolation from the filters. If the self-desense on the locomotive can be mitigated by a technique such as time slot coordination, then the filter isolation requirements would be reduced to a level needed to protect locomotive radios from a dissimilar radio which is on a locomotive operating on a parallel track or from a wayside radio installation near the track.

2.1 Locomotive Self-Desense Not Mitigated

If the locomotive self-desense case is not mitigated by an alternative technique, then the filters will need to protect the radios in the situation where the ACSES and ITC radio antennas are installed on a single locomotive at distances as close as 2 feet apart as described in Scenario A. The expected ITC signal received at the ACSES radio is +25.4 dBm, and under the same conditions, the ACSES signal received at the ITC radio is +27.7 dBm.

2.1.1 Minimum Filter Response

Filter A shall:

- attenuate ITC channels, as described in section 1.2, by a minimum of 56 dB.
- pass ACSES channels, as described in section 1.2, with a maximum 2.5 dB loss.

Filter B shall:

- attenuate ACSES channels, as described in section 1.2, by a minimum of 58 dB.
- pass ITC channels, as described in section 1.2, with a maximum 2.5 dB loss.

2.1.2 Minimum Filter Response for Alternate ACSES and ITC PTC Channel Scheme

Filter A Alternate shall:

- pass ACSES channels from 217 MHz to 219 MHz, with a maximum 2.5 dB loss,
- attenuate ITC channels, as described in section 1.2, by a minimum of 56 dB when cut-in.
- have a maximum loss of 0.5 dB across the entire 217 Mhz to 222 MHz band when cut out.
- Cut out automatically when in ACSES-only regions.

Filter B Alternate shall:

- Pass ITC channels, as described in section 1.2, with a maximum loss of 2.5 dB.
- Attenuate ACSES channels from 217 MHz to 219 MHz, by a minimum of 58 dB,
- Have a maximum loss of 0.5 dB across the entire 217 Mhz to 222 MHz band when cut out,
- Cut out automatically when in ACSES-only regions.

2.2 Locomotive Self-Desense Mitigated

If the locomotive self-desense case is mitigated by an alternative technique, then the filters will need to protect the radios in the Scenario B situation where the ACSES and ITC radio antennas will be as close as 12 feet. In this case, the expected ITC signal received at the ACSES radio is +10.3 dBm, and under the same conditions, the ACSES signal received at the ITC radio is +12.7 dBm.

2.2.1 Minimum Filter Response – Locomotive Self Desense Mitigated

Filter A shall:

- Attenuate ITC channels, as described in section 1.2, by a minimum of 40 dB
- Pass ACSES channels, as described in section 1.2, with a loss of 2.5 dB.

Filter B shall:

- Attenuate ACSES channels, as described in section 1.2, by a minimum of 43 dB.
- Pass ITC channels, as described in section 1.2, with a loss of 2.5 dB.

2.2.2 Minimum Filter Response for Alternate ACSES and ITC PTC Channel Scheme - Locomotive Self Desense Mitigated

Filter A Alternate shall:

- Pass ACSES channels from 217 MHz to 219 MHz, with a maximum 2.5 dB loss,
- Attenuate ITC channels, as described in section 1.2, by a minimum of 40.

Filter B Alternate shall:

- Pass ITC channels, as described in section 1.2, with a maximum loss of 2.5 dB.
- Attenuate ACSES channels from 217 MHz to 219 MHz, by a minimum of 43 dB.

2.3 Environmental Requirements

Following are key operating environmental requirements representing the locomotive onboard conditions.

- Temperature
 - Max = +70 EC, with up to 5 minutes at +100 EC when in a tunnel,
 - Min = -40 EC.
- Humidity (non-condensing)
 - Max = 95%,
 - Min = 40%.
- Vibration
 - 5 to 10 Hz = 7.6 mm p-p,
 - 10 to 50 Hz = 1.5 G peak,
 - 50 to 100 Hz = 1.5 G peak,
 - 100 to 200 Hz = 1.5 G peak.
- Mechanical Shock
 - 10 G peak.

Additional characteristics of the locomotive onboard environment, including EMI requirements, can be found in AAR Manual of Standards and Recommended Practices, Section K – Part I, Railway Electronics. Note that the shock and vibration environment on a locomotive requires very rugged electronics.

3. Questions for Prospective Filter Suppliers

1. What are the expected physical dimensions of:
 - Filter A,
 - Filter A Alternate
 - Filter B, and
 - Filter B Alternate?
2. What is the expected filter insertion loss?
3. If the filters have dynamically configurable pass bands and stop bands, , what is the time required for the filter to reconfigure?
4. The ITC radio, as previously described, uses a diversity antenna. Will two units of Filter B or Filter B Alternate be required (i.e. one filter on the primary antenna, and a second filter on the diversity antenna)?
5. What is the expected lead time for hardening filters to the locomotive environment?
6. It is possible that a 217-219 LPF or BPF for Filter A and 220-222 MHz HPF or BPF for Filter B will meet most needs? At a later time that Filter A may need to be configured as a LPF plus additional 12.5 kHz BPFs in the 220-222 MHz range; is this a software change, or would the HW need to be modified as well?
7. If the filter is dynamically configurable, or programmable, what is the interface for filter programming or selecting filter channels?
8. Since ACSES radios are simplex, is it possible to implement a system that will detect the channel an ACSES locomotive radio is transmitting on, and then dynamically apply a BPF to that channel alone?
9. Some Amtrak locomotives operate in territory where ACSES uses frequencies in the 220MHz to 222 MHz band. While operating in this territory, the ACSES radios on the Amtrak locomotives are not at risk of being desensed by nearby ITC radios. In this territory, Filter A Alternate needs to be automatically cut-out, or bypassed. Describe an approach to automatically cut-out, or bypass, Filter A Alternate. The filter system shall have a maximum loss of 0.5 dB across the entire 217 MHz to 222 MHz band when bypassed.
10. What would be the budgetary ROM unit cost in quantities of 25, 100, and 500 for:
 - Filter A,
 - Filter B,
 - Filter A Alternate,

- Filter B Alternate, and
- Automatic Filter Bypass as described in question 9,

each meeting all requirements described in this document? A “unit” is defined as the filter, necessary installation components, and required external components such as circulators, RF switches, etc.