Requirements for Positive Train Control 220 MHz Locomotive Radio Filter

Revision 4
Revised November 17, 2015

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1 Background and Scope

In 2008, Congress mandated in the Rail Safety Improvement Act (RSIA), that Class I freight railroads and rail lines transporting passengers implement Positive Train Control (PTC). PTC systems are required by Congress to be designed to prevent:

- Train-to-train collisions,
- Derailments due to excessive speed,
- Unauthorized incursions by trains onto sections of track where maintenance activities are authorized, and
- The movement of trains through a track switch left in the wrong position.

Since the mandate in 2008, the railroads have devoted a significant amount of financial and human resources to develop a safe and fully-functioning PTC system. The railroads have been faced with an array of technical and non-technical challenges in the design and deployment of PTC.

Two PTC systems are being deployed by the railroads on the Northeast Corridor (NEC) rail corridor;

- Advanced Civil Speed Enforcement System (ACSES) and
- Interoperable Train Control (ITC) which is also known as Interoperable Electronic Train Management System (I-ETMS®[1]).

The commuter/passenger railroads that operate on the NEC are deploying ACSES. The Class I freight railroads are deploying ITC nationwide, including on the NEC.

Each of these PTC systems uses a 220 MHz data radio from different manufacturers, with different communication protocols. The use of dissimilar radio types that operate asynchronously within the same frequency band introduces the potential for communication problems for ACSES and ITC deployments within the NEC. In particular, concurrent use of the ACSES and ITC radios within close proximity will cause loss of messages for the other type of radio due to receiver desense. Throughout the NEC, ACSES and ITC will be deployed in close proximity, sometimes on the same track bed.

In some locations, freight trains will be equipped with both ACSES and ITC locomotive on board equipment and will transition between ACSES and ITC territory in order to allow freight and passenger trains to operate on the same track. During the transitions between ITC and ACSES controlled territories, both of the aforementioned 220 MHz radios will be in operation. This document defines the minimum requirements for radio frequency filters for use in locomotives to protect 220 MHz PTC radios from interference or desense from dissimilar radios operating within the 220 MHz band.

Each section of this document generally contains two parts: narrative text and explicit requirements. The narrative text includes background information, goals and other supplemental

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

information provided to clarify the requirements. In accordance with RFC 2119, the following terms are used to identify requirements, preferences or recommendations, and options:

- Absolute requirements contain the word “shall” and follow any narrative text associated with the requirement in a lettered list.
- Absolute prohibitions, contain the term “shall not”, and follow in a lettered list beneath the narrative text along with absolute requirements.
- Recommendations are identified as such and use the word “should” or “recommended” rather than “shall”. The use of “should” means that there may exist valid reasons in particular circumstances to ignore a particular item, but the full implications must be understood, discussed with TTCI, and carefully weighed before choosing a different course.
- Recommendations against an undesirable system feature or behavior are identified with “should not” or "not recommended." The use of these terms mean that there may exist valid reasons in particular circumstances when the particular behavior is acceptable or even useful, but the full implications should be understood and the case carefully weighed and discussed with TTCI before implementing any behavior described with this label.
- The term “may” or “optional” indicate system features or behaviors that are truly optional.

2 Applicable Documents

The following documents apply to the PTC 220 MHz Locomotive Filters to the extent used in the text of this specification:

1. AAR Manual of Standards and Recommended Practices, Section K Part V, Standard S9401, “Railroad Electronics Environmental Requirements”.
2. IETF RFC 2119 “Current Best Practices: Key words for use in RFCs to Indicate Requirement Levels”, March, 1997

3 PTC Radio Overview

3.1 ITC Radio Overview

ITC locomotive radios simultaneously monitor up to eight channels for fixed site (base and wayside) transmissions. A database within the locomotive and base station beacon transmissions contain information on ITC channels to be monitored by geographic location. The ITC locomotive onboard system uses this database and the locomotive location to determine which channels should be monitored. The channel used by an ITC 220 MHz locomotive radio to transmit is determined dynamically.

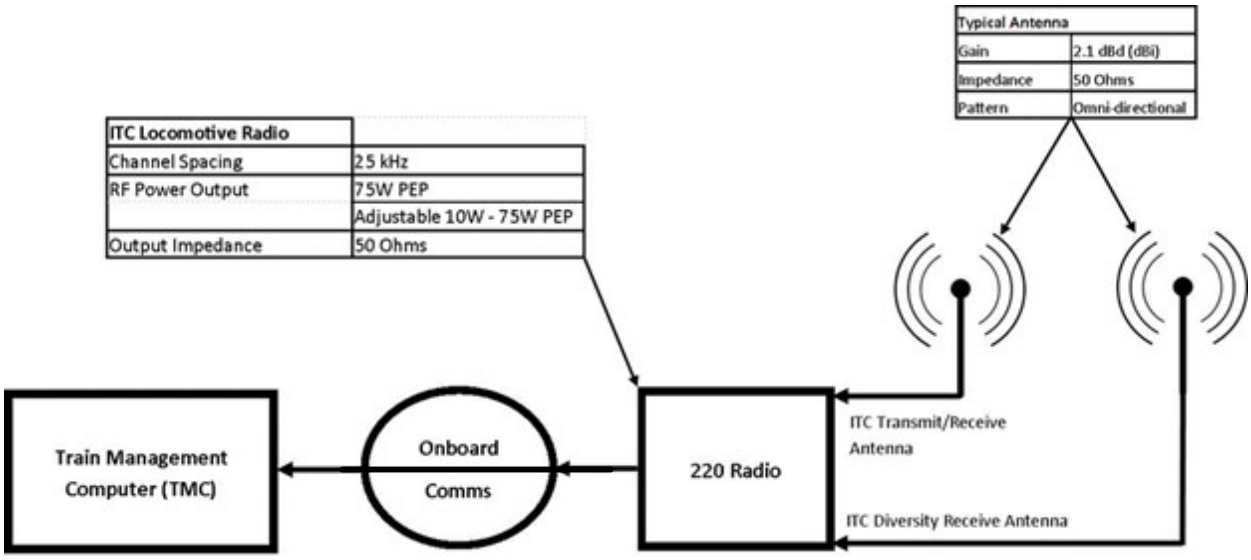

Figure 1. Block Diagram of Typical ITC 220 MHz Locomotive Radio Installation

Figure 1shows a typical ITC locomotive 220 MHz radio installation. ITC locomotive radios use two antennas: one for transmit and receive and a second for diversity receive. An ITC 220 MHz locomotive radios transmit with a peak envelope power of up to 50 W (47 dBm), average envelope power of 15 W (41.7dBm), and a maximum duty cycle of 30%. ITC base station radios transmit with a peak envelope power of up to 75 W (47.8 dBm), average envelope power of 22 W (43.4dBm), with a maximum duty cycle of 50%. ITC wayside radios transmit with a peak envelope power of 25 W, average envelope power of 9W (39.5dBm), with a maximum duty cycle of 10%.

3.2 ACSES Locomotive Radio Overview

Upon approach to an interlocking, an ACSES locomotive passes over a RF transponder embedded in the track bed. Information about the channel the ACSES 220 MHz radio is to use is programmed into this transponder. A transponder reader on the ACSES locomotive receives the ACSES radio channel information as the train passes over the transponder. The ACSES 220 MHz locomotive radio uses this information to determine the channel to use for simplex communication with the fixed site (base station) during approach to the interlocking.

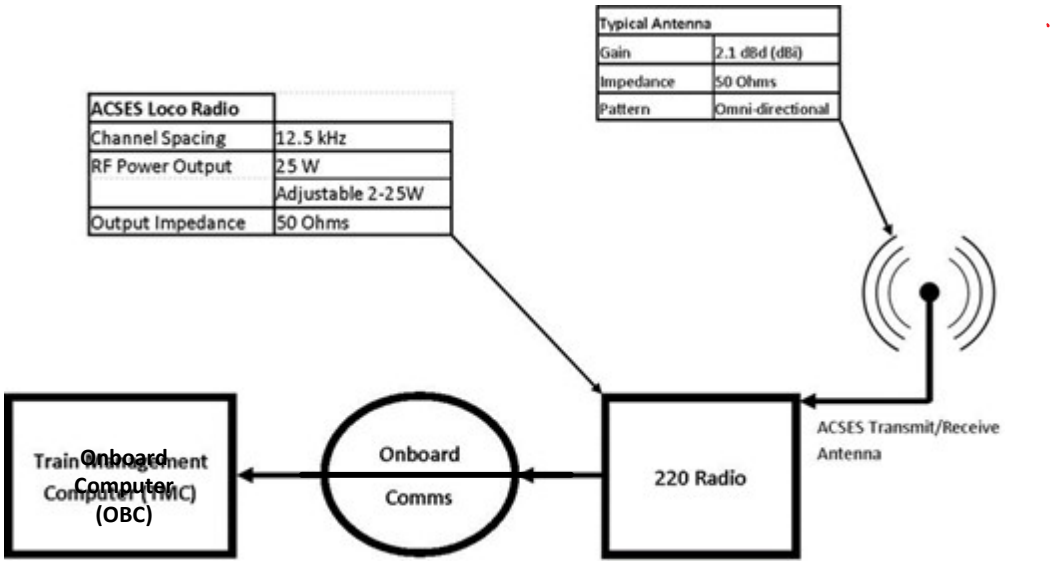

Figure 2. Block Diagram of Typical ACSES 220 MHz Locomotive Radio Installation

Figure 2 shows a typical ACSES 220 MHz locomotive radio installation. ACSES locomotive radios use a single antenna for transmit and receive. ACSES 220 MHz locomotive and base station radios transmit with a peak power of up to 20 W (43 dBm) with a maximum duty cycle of 100%. ACSES base stations may be configured with antennas that result in an effective radiated power (ERP) of up to 75 W (47.8dBm). Data messages transmitted by ACSES radios have a transmission duration of 128 mS. Base stations may transmit multiple messages with 128 mS intervals between each.

3.3 ITC 220 MHz Spectrum

Table 1 provides a list of channels currently used by for ITC deployments in the NEC. Other channels may be added at a later time. Each of the ITC channels are 25 kHz wide with channel centers as specified in Table 1.

Table 1. ITC 220 MHz Radio Channels

ITC 220 MHz Radio Channels	
Channel f_o (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

3.4 ACSES 220 MHz Spectrum

Amtrak and regional commuter railroad deployments of ACSES use spectrum in the 217 MHz to 219 MHz band, with the exception of the Amtrak ACSES deployment north of New Haven Connecticut which uses channels in the 220 MHz to 222 MHz band.

The following sections provide details of the ACSES spectrum use.

3.4.1 Amtrak Spectrum

The Amtrak ACSES deployment spans the entire NEC and extends north of the NEC into New England. Individual trains operate in both north and south of New Haven, Connecticut, so they will need to capable of using all of the channels shown in tables 2 and 3.

Table 2 provides a list of channels, by center frequency and bandwidth, used by Amtrak for ACSES in the NEC south of New Haven, Connecticut. Throughout this region, Amtrak's ACSES deployment may be in close proximity to ITC deployments.

Table 2. Amtrak 220 MHz Radio Channels South of New Haven, Connecticut

Amtrak ACSES 220 MHz Radio Channels South of New Haven, Connecticut	
Channel f_o (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

Table 3 provides a list of channels, by center frequency and bandwidth, used by Amtrak for ACSES in New England, north of New Haven, Connecticut. Throughout this region, Amtrak's ACSES deployments are not in close proximity to ITC deployments.

Table 3. Amtrak 220 MHz Radio Channels North of New Haven, Connecticut

Amtrak ACSES 220 MHz Radio Channels North of New Haven, Connecticut	
Channel f_o (MHz)	Channel BW (kHz)
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

The Amtrak ACSES system will utilize frequencies between 217 MHz - 219 MHz when operating south of New Haven, Connecticut. In this territory, ITC is also deployed for freight railroad operations. Since the ITC channels range from 220 MHz - 222 MHz, filtering is required to pass 217 MHz to 219 MHz for ACSES radios, while rejecting 220 MHz to 222 MHz. However, once Amtrak trains move north of New Haven, Connecticut, and transition out of the combined ACSES and ITC regions, it will use the ACSES channels between 220 MHz to 222 MHz. This means that the filter stopping the ITC channels will need to be automatically cut out, or be bypassed, when Amtrak trains are north of New Haven in the ACSES-only regions.

3.4.2 Commuter Railroad Spectrum

Individual commuter railroad deployments of ACSES span metropolitan or regional areas of the NEC. Trains associated with each commuter railroad operate within that railroad's ACSES deployment territory.

Commuter railroad ACSES deployments will use any, or all, of the eighty contiguous 12.5 kHz channels between 218.0 MHz and 219.0 MHz.

3.5 PTC Locomotive Radio Desense Scenarios

Three primary problem scenarios are identified in which locomotive radio desense may occur within areas in which ITC and ACSES are both deployed.

3.5.1 Dual-equipped Locomotive Self Desense

When a locomotive must operate in territory controlled by ITC and at other times in territory controlled by ACSES, then that locomotive must have both ITC and ACSES onboard systems and radios installed. This requires each system to have antennas installed on the roof of the locomotive, resulting in antenna spacing between two to five feet for the dissimilar systems. If either of these radios is transmitting, the other radio on board may be desensed and unable to receive. This is subsequently referred to as the "locomotive self desense" case. Figure 3 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 desensitized by the ITC locomotive radio.

The locomotive self desense case 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 needs to communicate with base stations for both ACSES and ITC as the locomotive prepares to exit territory controlled by one PTC system and enter territory controlled by the other.

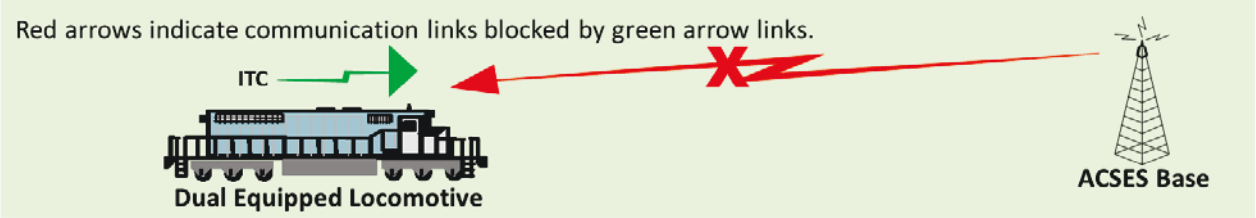

Figure 3. Locomotive Self Desense

3.5.2 Locomotive Desensing Locomotive

The "locomotive desensing locomotive" case occurs when two locomotives, one communicating with an ACSES system and one communicating with an ITC system, are 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. Figure 4 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 on board the ACSES locomotive is desensitized by the radio on board the ITC locomotive.

The locomotive desensing locomotive case is an issue anywhere that ACSES and ITC systems are deployed in close proximity.

Figure 4. Locomotive Desensing Locomotive

3.5.3 Fixed Site Desensing Locomotive

The "fixed site desensing a locomotive" case occurs 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, a radio of the other type on the locomotive may be desensed. Figure 5 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 on board the ACSES locomotive radio is desensitized by the ITC base station. The fixed site desensing locomotive case is an issue anywhere that ACSES and ITC systems are deployed in close proximity.

Figure 5. Fixed Site Desensing Locomotive

4 PTC 220 MHz Locomotive Radio Filter Requirements

The requirements presented are based on testing of a limited number of radio samples, and therefore do not allow for potential variations in radio performance from sample to sample. Consequently, it is advised that those implementing a PTC system add margin to the filter requirements, especially in regard to the amount of isolation each filter is to provide. The requirements for 220 MHz locomotive filters are defined in two tiers. Filters that meet Tier 1 requirements also satisfy Tier 2 requirements.

4.1 Tier 1 220 MHz Filter Functional Requirements

Tier 1 requirements define 220 MHz filters capable of mitigating the worst desense scenario as described in section 3.7.1 "Dual Equipped Locomotive Self Desense". In this case the filters need to protect the radios from desense in the situation where the ACSES and ITC radio antennas are installed on a single locomotive at distances as close as 2 feet apart. In this scenario, the expected ITC signal received at the ACSES radio is +30.8 dBm. Under the same conditions, the ACSES signal received at the ITC radio is +27.7 dBm.

220 MHz locomotive filters that satisfy Tier 1 requirements are needed to protect PTC radios from desense on locomotives that are equipped with both ACSES and ITC onboard systems.

4.1.1 Tier 1 Functional Requirements for 220 MHz ITC Locomotive Radio Filter

a) The ITC 220 MHz locomotive filter shall have a passband of sufficient bandwidth to simultaneously pass all ITC channels shown in Table 1.

b) The ITC 220 MHz locomotive filter shall have a stop band of sufficient bandwidth to simultaneously stop all ACSES channels between 217 MHz and 219 MHz defined in section 3.4 of this document.

c) The minimum attenuation to signals in the ITC 220 MHz locomotive filter stop band shall be 57.7 dB.

d) The ITC 220 MHz locomotive filter shall, at a minimum, be capable of withstanding a transmit (at radio port) power of 50 Watts with a 30% duty cycle.

e) The ITC 220 MHz locomotive filter shall have a minimum received (at antenna port) power rating of 0.6 Watts with a 100% duty cycle.

4.1.2 Tier 1 Functional Requirements for 220 MHz ACSES Locomotive Radio Filter

a) The ACSES 220 MHz locomotive filter shall have a passband of sufficient bandwidth to simultaneously pass all ACSES channels between 217 MHz and 219 MHz defined in section 3.4 of this document.

b) The ACSES 220 MHz locomotive filter shall have a stop band of sufficient bandwidth to simultaneously stop all ITC channels shown in Table 1.

c) The minimum attenuation to signals in the ACSES 220 MHz locomotive filter stop band shall be 60.8 dB.

d) The ACSES 220 MHz locomotive filter shall, at a minimum, be capable of withstanding a transmit (at radio port) power of 20 Watts with a 100% duty cycle.

e) The ACSES 220 MHz locomotive filter shall have a minimum received (at antenna port) power rating of 1.2Watts with a 30% duty cycle.

4.2 Tier 2 220 MHz Filter Requirements

Tier 2 requirements define 220 MHz filters capable of mitigating the desense scenario described in section 3.7.2 “Locomotive Desensing Locomotive”. In this case the filters need to protect an ACSES or ITC radio from desense in the situation where the other type of radio is transmitting on a locomotive located on an adjacent track. Distance between track centers of adjacent track may be as close as 12 feet. In this scenario, the expected ITC signal received at the ACSES radio is +15.6 dBm. Under the same conditions, the ACSES signal received at the ITC radio is +12.7 dBm.

220 MHz locomotive filters that satisfy Tier 2 requirements are needed to protect PTC radios from desense on locomotives that are equipped to operate with either ACSES or ITC, but not both.

4.2.1 Tier 2 Functional Requirements for 220 MHz ITC Locomotive Radio Filter

a) The ITC 220 MHz locomotive filter shall have a passband of sufficient bandwidth to simultaneously pass all ITC channels shown in Table 1.

b) The ITC 220 MHz locomotive filter shall have a stop band of sufficient bandwidth to simultaneously stop all ACSES channels between 217 MHz and 219 MHz defined in section 3.4 of this document.

c) The minimum attenuation to signals in the ITC 220 MHz locomotive filter stop band shall be 42.7 dB.

d) The ITC 220 MHz locomotive filter shall, at a minimum, be capable of withstanding a radio transmit (at radio port) power of 50 Watts with a 30% duty cycle.

e) The ITC 220 MHz locomotive filter shall have a minimum received (at antenna port) power rating of 20 milliwatts with a 100% duty cycle.

4.2.2 Tier 2 Functional Requirements for 220 MHz ACSES Locomotive Radio Filter

a) The ACSES 220 MHz locomotive filter shall have a passband of sufficient bandwidth to simultaneously pass all ACSES channels between 217 MHz and 219 MHz defined in section 3.4 of this document.

b) The ACSES 220 MHz locomotive filter shall have a stop band of sufficient bandwidth to simultaneously stop all ITC channels shown in Table 1.

c) The minimum attenuation to signals in the ACSES 220 MHz locomotive filter stop band shall be 45.6 dB.

d) The ACSES 220 MHz locomotive filter shall, at a minimum, be capable of withstanding a radio transmit (at radio port) power of 20 Watts with a 100% duty cycle.

e) The ACSES 220 MHz locomotive filter shall have a minimum received (at antenna port) power rating of 40 milliwatts with a 30% duty cycle.

4.3 Additional Functional Requirements for both Tier 1 and Tier 2 Filters

This section defines functional requirements that apply to all 220 MHz locomotive filters in addition to the Tier 1 and Tier 2 functional requirements.

4.3.1 Amtrak 220 MHz Locomotive Filter Bypass

Amtrak locomotives may operate in New England, north of New Haven, Connecticut, as well as in the NEC. When operating in New England, the ACSES radios on the Amtrak locomotives use channels in the 220 MHz to 222 MHz band as shown in Table 3. Additionally, when operating in this territory, the 220 MHz ACSES radios on the Amtrak locomotives are not at risk of being desensed by nearby ITC radios. In this territory, the 220 MHz locomotive filter needs to be cut out, or bypassed.

It is desirable that the 220 MHz locomotive filter includes a mechanism to automatically bypass the filter when the ACSES radio uses channels shown in Table 3. If the filter cannot automatically detect when channels in Table 3 are used by the ACSES radio, then a binary cut in/out signal may be provided.

Note: Negotiations are currently underway between NEC railroads, the FCC, and spectrum holders to reallocate channels in the 217 MHz to 218 MHz band in New England, North of New Haven, Connecticut, in order to eliminate the need for this filter bypass mechanism.

a) The ACSES 220 MHz locomotive filter should provide a filter bypass mechanism.

b) The ACSES 220 MHz locomotive filter should automatically be bypassed when the ACSES radio uses any channel as shown in Table 3.

c) The ACSES 220 MHz locomotive filter shall have a maximum insertion loss of 0.5 dB across the entire 217 MHz to 222 MHz band when bypassed.

d) The time to switch between bypass and non-bypass modes shall not exceed 50 nS.

4.4 Interface Requirements for 220 MHz ACSES and ITC Locomotive Filters

This section defines interface requirements that apply to all 220 MHz locomotive filters.

4.4.1 220 MHz Locomotive Filter Connector

RF interconnects between 220 MHz locomotive radios and antennas are N-type receptacle. Since the 220 MHz locomotive radio filters are to be installed in line between the locomotive radios and antennas, the same connector type should be used.

a) An ACSES 220 MHz locomotive radio filter shall have an N-type receptacle connector to provide interconnect with the locomotive 220 MHz ACSES radio.

b) An ACSES 220 MHz locomotive radio filter shall have an N-type receptacle connector to provide interconnect with the locomotive 220 MHz ACSES antenna.

c) An ITC 220 MHz locomotive radio filter shall have an N-type receptacle connector to provide interconnect with the locomotive 220 MHz ITC radio.

d) An ITC 220 MHz locomotive radio filter shall have an N-type receptacle connector to provide interconnect with a locomotive 220 MHz ITC antenna.

4.4.2 220 MHz Locomotive Filter Impedance

Both ITC and ACSES 220 MHz locomotive radios, as well as the associated antennas have a characteristic input and output impedance of 50 Ω. 220 MHz locomotive filters need to have a matching characteristic impedance.

a) An ITC 220 MHz locomotive radio filter shall have an impedance of 50 Ω at the radio interconnect port.

b) An ITC 220 MHz locomotive radio filter shall have an impedance of 50 Ω at the antenna interconnect port.

c) An ACSES 220 MHz locomotive radio filter shall have an impedance of 50 Ω at the radio interconnect port.

d) An ACSES 220 MHz locomotive radio filter shall have an impedance of 50 Ω at the antenna interconnect port.

4.4.3 220 MHz Locomotive Filter Insertion Loss

a) An ITC 220 MHz locomotive radio filter shall have a maximum insertion loss of 2.5 dB.

b) An ACSES 220 MHz locomotive radio filter shall have a maximum insertion loss of 2.5 dB.

c) The ITC 220 MHz locomotive radio filter shall not degrade receiver noise figure by more than the specified insertion loss.

d) The ACSES 220 MHz locomotive radio filter shall not degrade receiver noise figure by more than the specified insertion loss.

4.4.4 220 MHz Locomotive Filter VSWR

a) An ITC 220 MHz locomotive radio filter shall have shall have a VSWR of 1.5:1 or better.

b) An ACSES 220 MHz locomotive radio filter shall have shall have a VSWR of 1.5:1 or better.

4.5 Environmental Requirements

220 MHz locomotive filters, as all electrical and electronic equipment installed in a locomotive in North America, will need to comply with the locomotive environmental requirements as defined in the AAR Manual of Standards and Recommended Practices, Section K Part V, Standard S-9401, “Railroad Electronics Environmental Requirements”.

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

- Temperature
  Max = +70º C, with up to 5 minutes at +100º C when in a tunnel,
  Min = -40º C.
- 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.

Note that the shock and vibration environment on a locomotive requires very rugged electronics.

a) An ITC 220 MHz locomotive radio filter shall comply with locomotive environmental requirements as defined in the AAR Manual of Standards and Recommended Practices, Section K Part V, Standard S-9401, “Railroad Electronics Environmental Requirements”.

b) An ACSES 220 MHz locomotive radio filter shall comply with locomotive environmental requirements as defined in the AAR Manual of Standards and Recommended Practices, Section K Part V, Standard S-9401, "Railroad Electronics Environmental Requirements".

4.6 Size Requirements

In general, space within locomotives suitable for installation of radio equipment and RF filters is limited and varies depending upon the locomotive model and by the railroad that owns the locomotive. Specific requirements for locomotive filter size will be defined by the individual railroads purchasing equipment. For the purpose of this specification, it is recommended that 220 MHz locomotive radio filters be implemented to be as compact as possible.