Positive Train Control Update

Wireless PTC Technology White Paper

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# Wireless Positive Train Control
## 2012 Update

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1.0 Introduction

Three years after our first Wireless Positive Train Control (PTC) White Paper we will re-visit the development of PTC technology, deployment by various railroads, and how different types of interference to PTC systems are addressed. This paper will focus on intermodulation and testing for PTC quality of service.

PTC technology is still developing, with several manufacturers working on their offerings in radio and software/networking solutions. The Class One Railroads have invested a great amount of time and effort, to take the lead with their PTC radio and messaging/control applications. Other vendors are also working on their own PTC offerings. A new IEEE working group has been proposed to define new PTC standards.

It could be argued that any of these PTC technologies and approaches would be suitable for the purposes, but the focus is now switching to ensuring that PTC deployments will work as planned, regardless of the manufacturer, technology implementation, and specifications.

There are several thousand trains per day operating in the US. When the PTC program is officially launched these train operations have to seamlessly transition to PTC operation without service interruptions.

Due to the complexity of the system, there could be design, communications, interference and several other issues that might affect the operation of PTC systems. When PTC Systems start to operate, there will be new issues emerging as all PTC System and Network components start to operate under stress produced by real system loading.
2.0 RF Issues Affecting PTC Systems

The main sources of RF problems that could affect PTC Systems include:

- Interference from external sources, on-channel and off channel
- Interference from internal sources, such as noise generated in the locomotive
- Intermodulation generated by on-board radios and other emitters
- Intermodulation generated by external radios
- Intermodulation generated by external sources such as rusty metal structures
- Multipath signals generated by terrain and structures near the tracks
- Multipath signals generated by other passing trains and highway vehicles
- Path obstructions between base stations and trains
- High power external interferers such as airport and marine radars, cell site
- Combinations of two or more components from sources mentioned above

Real world interference scenarios typically include various types of interference. When multiple sources of interference are combined they sometimes reach a critical mass and appear to be far more serious interference issues than they really are. Fortunately, we have the tools and means to identify, track down and address most types of interference. Multiple sources of interference can be identified and dealt with individually.

Figure 1 below outlines several different types of interference that can typically be found in and around a PTC operating environment. The diagram includes a vector called “Data Packet Transport and Delivery Environment” (DPTDE). This is not an interference type itself, but rather the combined effect of multiple interfering signals on the quality of service for PTC data packets transport and delivery.

DPTDE quality of service is the ultimate, most relevant measurement to determine how one or more interference types can affect PTC operation, and correlate different types and magnitudes of interference with PTC quality of service degradation.
This DPDT extends from the locomotive to the base station over a wireless PTC link, and beyond the base station through all the ground communications links, into the back office servers, and to the dispatchers consoles in the Dispatch Center.

DPDTE is an end-to-end measurement technique to observe the effect of external interference on the entire PTC communications system.

Figure 1
Multiple Interference Types

Figure 2 below provides additional details on the different types of interference that can be found on a mainline locomotive. In order to simplify the diagram only three radios are shown: Voice 161 MHz, PTC 220 MHz and DP 450 MHz. An actual locomotive can incorporate between sixteen to twenty antenna systems all connected to different radios and GPS receivers. It would be difficult to produce a clear diagram showing all the possible interrelations between all the on-board antenna and radio systems. There is heavy interaction between the different radio systems on a locomotive. STI-CO® has developed testing methods to identify and track to the sources different types of interference.
3.0 Interference from External Sources

External interference can be separated into two categories: On-channel and off-channel.

On-channel interference is noise or other radio transmission signals that fall right into a PTC radio channel and directly impairs its performance. It could be described as interference signals tuned to transmit on the same channel, or targeting the same channel used by the PTC radio. On-channel interference is very difficult to resolve. Sources of on-channel interference may include other radios transmitting without
authorization, or authorized radio transmissions from adjacent transmitting areas that are reaching the affected radio due to propagation, transmitted power, or elevation.

Most cases of on-channel interference by other radio transmitters must be resolved by administrative measures. The source of the interference should be located, then the affected party approaches the offending party directly or through the FCC to request enforcement action. In the 220 MHz PTC band, there may be legacy users that might not have vacated this band and could transmit directly on-channel of PTC systems.

When channels in a wireless PTC system are affected by on-channel interference there are limited technical solutions. For example, filters cannot be used to stop on-channel interference. It is necessary to measure the signals and locate their source, then select the most effective type of action to address the issue.

In some cases on-channel interference to wireless PTC systems can only be overcome by deploying more base stations with less spacing between them. This will increase the transmitted PTC signal level enough that all PTC channels will operate above the interfering signals and elevated noise floors. However, this could be an expensive solution, but is probably the only way to operate PTC in areas where there is strong on-channel interference.

STI-CO® uses advanced RF Sensors that can measure and identify the type of modulation, while at the same time determining the geographic location of the transmitter with a resolution of six square feet. This approach permits the technician to identify, measure, and pinpoint with extreme precision external sources of on-channel interference for further action.

Off-channel interference is a condition where only a part of the noise or interference from other signals falls on the PTC radio channel and usually does not affect it as much as on-channel interference. Off-channel interference is less difficult to resolve in most cases. This type of interference could best be described as interference signals reaching and affecting a certain portion of the RF spectrum in the vicinity of the PTC radio channel, but not tuned to the same frequency as the PTC channel. Off-channel interference sources include the same sources causing on-channel interference as described above, plus electrical, electronic, or computing sub-systems installed in a locomotive. Other sources of intermodulation products may be generated when other
nearby radios transmit. In many large urban areas, high noise floors are sometimes reported at -85 dBm and above.

The process to find, identify and track down off-channel interference sources is similar to the one used to find on-channel interference as indicated above. Note that there are more types of actions that can be taken to mitigate the effects, including band-pass filters, different types and/or orientation of antennas, better shielded and impedance matched cables, well coupled antennas, etc.

![Diagram of external interference](image)

**Figure 3**
External Interference – On-channel and Off-channel

### 4.0 Interference from Internal Sources

Interference from internal sources is one of the strongest types of interference due to the small separation between different components or sub-systems that might cause interference. Figures 4, 5, 6 and 7 describe these types of interference.

Interference from internal sources can be separated into three main groups:

- Locomotive traction power.
- On-board computers and processors.
Alternate radio systems operating in the locomotive.

4.1 Locomotive Traction Power

Locomotive traction power sub-systems include up to four three-phase alternators, operated from one rotating axle that is also the rotating axle of the diesel engine.

Typically, one alternator with full-wave rectifier is only used to power the rotating electrical field windings of all alternators, including its own. A second alternator with full wave rectifier is used to provide 72 VDC power for on-board batteries, lights and other utility power on the locomotive. A third alternator without rectifier is used to power electric traction motors cooling fans, radiator cooling fans and other power equipment operating with synchronous AC electric motors.

Since the frequency of the power depends on the rotation speed of the main axle coupled to the diesel engine, there is a broad variation in AC frequency. In order to protect all AC fans and coolers from rotating too fast and damaging themselves, there could be a two-step “frequency basher”. When the rotation speed/frequency reaches certain values, SCRs are used to create a heavy harmonic content on the AC power from the third alternator. Then tuned circuits are used to divide the AC power frequency, reducing it to half its previous value. When the rotation speed/frequency again reaches a high value, another “divide by two” process takes place, making the AC frequency now one-quarter of the rotational frequency of the main axle. Under certain circumstances these divide by two processes can produce a very heavy harmonic content that might affect PTC and other radios.

The fourth alternator (the largest and most powerful), is the traction motors alternator. It has a full-wave rectifier and, depending on the locomotive’s AC or DC traction, is an AC power inverter and traction controller or DC traction power controller. AC locomotives started to replace DC locomotives several years ago, and there are two main types of controllers for AC traction locomotives. Older models use Gate Turn-off (GTO) thyristors, while newer models use Isolated Gate Binary Transistors (IGBTs).

AC traction locomotives can reduce slipping, which is momentary loss of traction contact with the tracks when pulling heavy loads. An AC traction locomotive can modulate the
traction power to avoid wheel slipping, pulling more freight than a similar DC traction locomotive.

STI-CO® developed several approaches to measure and record various types of interference produced by AC and DC traction power. GTO traction controllers produce a different type of interference than IGBT traction controllers, which are reported to produce the strongest type of interference due to their extremely short switching times and large power controlled by each IGBT device.

![Figure 4](image-url)

**Figure 4**
Interference from Locomotive Internal Sources

### 4.2 On-board Computers and Processors

There are several on-board computers and processors on modern locomotives. Each one is equipped with internal clock and frequency generators, but some incorporate complex switching power supplies that can also be a source of interference. These industrial grade computers are much better designed and built than desktop and business computers. They can operate over a broader temperature range, in the presence of shock and vibrations, and tolerate wide voltage variations in the power supply.
But most of these industrial computers are not designed to operate without emitting some amount of interference, from the computer components themselves and/or from their complex power supplies. The RF noise floors in large cities are continuously degrading, with noise power climbing due in great part to large quantities of computers and processors being deployed by industrial, commercial and residential users.

Multiple on-board computers and processors on-board a locomotive can cause various types of interference that alone or combined can affect the performance of PTC radios. STI-CO® uses a combination of instruments to identify and track down interference that may be caused by on-board computers, processors and power supplies.

4.3 On-board Radio Systems

Other on-board radio systems operating in the locomotive could include up to sixteen radios and twenty radio antennas on a modern locomotive. For example, a typical locomotive outfitted with PTC equipment has an integrated cab roof antenna platform with eight antennas, plus two sidebars or rails with six antennas each.

All antennas are located a short distance from each other due to the physical constraints of the roof structure. The RF signals transmitted from one radio can interfere with the other radios, including PTC. This interference is not normally a concern in that other
radio systems are not mission critical like PTC radios. If HOT/EOT radios or DP radios fail to receive some data packets they will recover with the next data session, if a voice radio is briefly interfered, the users will repeat what they were not able to communicate the first time. But PTC radios must be able to receive all the PTC beacon signals transmitted, or trains might be forced to make an automatic stop.

STI-CO® developed multiple approaches using innovative combinations of instruments and RF components such as directional couplers to identify the type and track down the interference to each of the sources.

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**Figure 6**
Interference from Other On-board Radio Systems

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### 5.0 Intermodulation Generated by On-board Radios and Other Emitters

This type of intermodulation can affect PTC channels as on-channel and off-channel interference. Certain combination of the on-board radios transmitting simultaneously can place an interfering signal directly into a PTC channel, or can produce a combination of frequencies that includes the PTC channel in its spectrum footprint.

In a locomotive with several radios operating on different frequencies, the best protection against intermodulation is to insert one band-pass filter on the antenna cable, between the radio and the antenna. STI-CO® designed a filter product line specifically to address the unique problems faced on-board locomotives.
STI-CO® also developed and introduced an innovative way to measure the intermodulation products generated at the front end of each of the radios in a locomotive. A Dual Directional Coupler integrated with other RF instruments is used to measure individually each radio’s intermodulation products sent back to the antenna when the radio is “hit” by strong signals from other radios with antennas located in close proximity.

![Diagram](image)

**Figure 7**
Intermodulation generated by on-board radios and other emitters

### 6.0 Intermodulation Generated by External Radios

There could be several sources in different places, including locomotives in a yard transmitting simultaneously, base stations with two or more radios transmitting at the same time, and other fixed and mobile radios not part of the railroad network.

In theory there are formulas that can help to carry out an intermodulation analysis taking into consideration all the frequencies that may be transmitted by radios located within a specific area. But in the real world of locomotive operations it is not possible to anticipate which radios could be transmitting near the locomotive as it travels through urban and rural areas across the country. There is no effective formula to anticipate the type of intermodulation interference that can affect a PTC radio on board a locomotive.
It is possible to measure the presence of intermodulation interference as a locomotive moves, but the intermodulation will change continuously and it would be difficult to design and deploy a system to mitigate it. The best protection would be to use band-pass filters, the same ones installed to prevent intermodulation from internal sources, as described above. However, if interference is on-channel it could be difficult to resolve.

![Intermodulation generated by external radios](image)

**Figure 8**
Intermodulation generated by external radios

7.0 Intermodulation Generated by Non-powered External Sources

It can be generated by non-radio emitters located in the locomotive, or from external sources not on-board the locomotive. Any semi-conductor (diode) could be a source of interference when radiated with RF energy. For instance, the rusty hinges of a locomotive washroom across from the radio room can produce intermodulation signals in difficult to predict frequencies, an oxidized (rusty) joint or bolt can also act like a diode.

External rusty metal structures such as unpainted chain link fences, unpainted radio towers at base stations, and any other rusty metal structures can react to RF radiation producing intermodulation interference in frequencies that may fall into the PTC band.

Since most of these rusty structures are fixed and do not move around, it is possible to develop a strategy to use instruments to detect and find these intermodulation
interference sources. To eliminate these intermodulation sources it will be necessary to remove rust from metal surfaces and joints, and thoroughly paint the metal structure to prevent it from acting as a semiconductor. There is very little that can be done to protect PTC radios in the locomotive against this type of intermodulation interference.

**Figure 9**
Intermodulation generated by external sources oxidized metal structures

### 8.0 Multipath Signals Generated by Terrain and Structures Near the Tracks

Propagation prediction software terrain and structures databases provide information on how reflecting surfaces will impact the PTC radio path. Propagation prediction software can work with several base stations at the same time, developing a combined propagation and multipath model based on terrain and structures databases.

Multipath interference is caused by multiple reflections of an original PTC radio signal arriving at the receiving antenna at different times. Signals will have different phases and delays and may cancel each other, causing momentary loss of PTC signals.

Databases cannot include all terrain and structures, for example, a new building is erected or a large metal sign with a commercial ad is placed near the PTC radio path. The only way to detect multipath interference in a real-world PTC base stations and locomotives environment is to measure with an integrated, mobile instrument system.
A good approach to mitigate multipath could be to measure PTC signal reception on each of the two antennas to find the best placement/spacing for the roof antennas.

9.0 Multipath Signals from Other Passing Trains and Highway Vehicles

This type of interference is extremely difficult to predict, as it is produced by a group of highway and rail vehicles that constantly changes as the locomotive moves. Any large metal surface will act as a reflector for PTC signals. Large trucks and vans on highways, and freight cars or other locomotives on rails will produce different and moving types of multipath interference that may cause brief interruptions on PTC communications.

A good approach to evaluate this would be to measure PTC reception using two antennas on the roof of the cab that are attached with magnets and moved around to determine the best placement and separation to use for the PTC antennas.

Some PTC radio receiver specifications and configuration of the diversity inputs might need to be altered to provide better PTC radio communications performance when multipath interference occurs. If possible, place one PTC antenna on the right side of the locomotive and another PTC antenna on the left side of the locomotive. Multipath
interference would only affect one of the two sides at a time, since it will be coming from structure/terrain reflections on the right or on the left side of the tracks.

![Diagram of multipath signals](image)

**Figure 11**
Multipath signals generated by other passing trains and highway vehicles

### 10.0 Path Obstructions between Base Stations and Trains

In theory, all path obstructions between base stations and trains are accounted for and addressed when the new wireless PTC system is planned. In the real world, foliage, new structures and new buildings invade the PTC radio path from time to time, and can cause degradations or interruptions in the PTC radio path and communications.

One of the best approaches is to carry out drive tests along the tracks, after the PTC system is deployed and before it is placed into service. Then, at least twice a year it is a good idea to carry out a drive test along each of the lines equipped with PTC.

Modern test equipment, including RF sensors used by STI-CO®, can measure and record signal levels along the tracks for storage and comparison with previous readings. Data can be parsed for automatic analysis to flag changes in signal strength as path obstructions occur. At that point someone can investigate the reasons for changes in path attenuation. The most common cause is foliage growth, which is relatively simple to
resolve. However, there could be new structures, towers, and buildings that can affect the PTC radio path. In some cases base stations might need to be relocated.

![Path obstructions between base stations and trains](image)

**Figure 12**
Path obstructions between base stations and trains

### 11.0 High Power External Interferers, Airport and Marine Radars, Cell Sites

There are many external high-power sources of interference that might affect a PTC radio channel. For example, a Cable TV distribution network in an urban area could have un-terminated taps or other cables or components leaking RF signals. These RF leaks are then broadcast with high power and could fall directly or through intermodulation on a PTC radio channel.

Other interferers are radars, civilian and military, that put out a large amount of RF energy. This energy is not in the same frequency than PTC radio channels operate, but due to the high-transmitted power intermodulation interference is more likely to occur through metal structures that can be some distance from the radar transmitter. Cell sites are often shared with other radio systems in lower frequencies and there is a possibility that they might create interference in the PTC radio channel frequency. This is more likely to happen if there are any faulty RF components in the cell tower.

All these sources of interference are relatively easy to locate and address, since they are fixed it is possible to use a RF sensor with Geolocation features to find them.
12.0 Combinations of Two or More Components from Above Sources

Often different interference types are combined and perceived as a large critical mass of interference issues that appears to be difficult to address and resolve. For example, two or more intermodulation interference issues could be present, combined with other RF issues such as local interference from the locomotive equipment, multipath, and external high power interference. The resulting interference could be quite complex.

Each one of the interference components has to be isolated and addressed separately. There are instruments available to do this, but the test engineers operating them need to have experience in identifying and troubleshooting combined sources of interference.

Sometimes it is not possible to find the individual sources using instruments, but analyzing secondary symptoms/RF issue "signatures" that alert the test engineer where the root of the problem could be. For example, it is important to have the right instruments to track down intermodulation created by radio systems operating far away in frequency from the PTC radio channel frequency, so test engineers can reverse engineer the intermodulation and track it to its sources.
13.0 Correlation of Interference Types and Magnitudes to PTC Link Degradation

There are many suitable instruments available today to find, identify and track down the issues described. However, finding and measuring the various sources of interference, noise, intermodulation, etc, might not be sufficient.

Through careful measurement techniques it might be possible to identify and categorize each RF issue as a type and magnitude of interference, for example “locomotive noise magnitude 8.3”, “intermod interference magnitude 6.0”, etc. What this does not allow us to do is to correlate the type and magnitude of the RF issue with the effect it has on the PTC communications link or, in other words, what is the degree of impairment or degradation of the quality of service on a PTC System when a certain type and magnitude of RF issue occurs.

STI-CO® proposes to use an “End-to-End” PTC quality of service or data packet transport and delivery performance, from the Dispatcher to the Back Office Servers, through ground links to the PTC Base Station, and on a Wireless Link to a Locomotive, correlating type and magnitude of interference signals with PTC data degradation.
14.0 Testing Procedures

For PTC systems RF testing, an RF Sensor that is much faster than the fastest Spectrum Analyzers, can simultaneously analyze with no gaps up to 20 MHz of spectrum, and can identify most types of RF modulation.

This RF Sensor was developed for use by government agencies to intercept hidden, difficult to capture signals, and it lends itself well to find, identify and track down RF issues that might affect PTC communications. In addition, using three to five RF Sensors in a group it is possible to determine where the source of a signal is, with a resolution of about six by six feet.

While some PTC radios might be able to provide some level of indication of what their performance/quality of service is, this is not the main function of PTC radios. Some integrated RF Analyzers instruments recently introduced include a PTC signal generator and PTC signal decoder with Bit Error Rate measurement.

The PTC signal generator is a calibrated signal generator (not a simple tracking generator), separate from the PTC signal demodulator/receiver/BER measuring set.
If a PTC signal generator is outfitted with a linear power amplifier, it is possible to use it as a PTC base station transmitter. Using another similar instrument on a locomotive or train as a PTC receiver and BER meter it is possible to observe and correlate the occurrence and type of RF issues (through the RF sensor) with the degree of impairment these RF issues cause to the PTC communications link, including measuring these impairments as variations in the Bit Error Rate of the received PTC signals. This can provide real-world correlation between RF issues and the effect they have on PTC communications.

Doing this permits real world testing of PTC systems even before the PTC radios are ready and/or PTC systems deployed. Instruments with PTC generators and decoders/BER meters use standard PTC communications data links and can provide a very accurate rendition of how a PTC radio system will operate when deployed.

15.0 The Testing Process

In some cases it is difficult and time consuming to select locomotives or trains to undergo RF testing, customers have to agree on the type of testing to be done, then look for, find and allocate locomotives or trains, and separate them from service for periods of time from two to several weeks. Testing engineers have to be sent to railroad yards and carry out a number of RF tests on the selected locomotives or trains.

This process does not lend itself well to testing many locomotives or trains, since it is only possible to test a handful of them and assume that the units tested will be an appropriate representation of the thousands of locomotives and trains operating in the field. To obtain more representative test results for a complete fleet it would be better to test a few hundred locomotives and trains, but this is not currently feasible due to the time and expenses associated with setting up and testing each locomotive and/or train.

To address this problem STI-CO® has developed and is internally testing a new concept using a remote access instrument box that can be quickly deployed on any locomotive or train as an unattended RF Signals Monitor, no specialized test engineers are required to deploy or retrieve this device to/from locomotives (still in the conceptual/beta testing stage as this equipment is not being offered yet).
Through a dual wireless broadband communications link using Verizon LTE and SPRINT EVDO wireless access, the remote access instrument box is controlled and operated remotely by STI-CO® test engineers from a central location.

The remote access instrument box includes a suite of instruments, as well as a two-way radio link using a standard railroad 161 MHz radio operating in conventional FM or digital NXDN mode. This provides instant two-way communications between STI-CO® test engineers at a central testing location and railroad staff, engineer/conductor and dispatch center using the 161 MHz radio channels.

The concept of operation for this remote access instrument box is to deploy it in less than an hour on the second locomotive in a consist, and let it run by remote control as the train moves from city to city or across the country.

All types of interference, noise, intermodulation and other RF impairments found along the way will be registered and stored in a solid state server that is part of the remote access instrument box. When the train arrives at its destination the remote access instrument box will be removed from the locomotive or train without a need to for test engineers on site.

This will allow the testing of a large number of locomotives and trains faster and at less cost than testing with specialized test engineers on site, and it will not be necessary to separate the locomotives or trains from service to carry out the testing. The remotely controlled test equipment will be deployed and retrieved by railroad radio techs or electricians on locomotives that do not have to be withdrawn from service for testing.

When RF issues are detected and it appears that they might be coming from the locomotive itself, the locomotive will be tagged for comprehensive testing later, similar to the current testing now being done on locomotives. But only those locomotives identified as having potential RF issues will need to be tested.

When RF issues are detected near the tracks as the locomotives or trains move through, several attempts will be made to identify and track down those RF issues remotely by the test engineers in the central testing facility. If additional on site testing would be required, a team of test engineers will travel to the site to carry out manual testing similar to what is being done today.
An example of deployment of test engineers would be to geographically locate the source of interfering signals from equipment (radars, cell towers, etc), or location of unauthorized transmitters interfering with PTC communications, using several RF Sensors controlled from a central location.