Positive Train Control

Wireless PTC Technology Outline White Paper

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Wireless Positive Train Control

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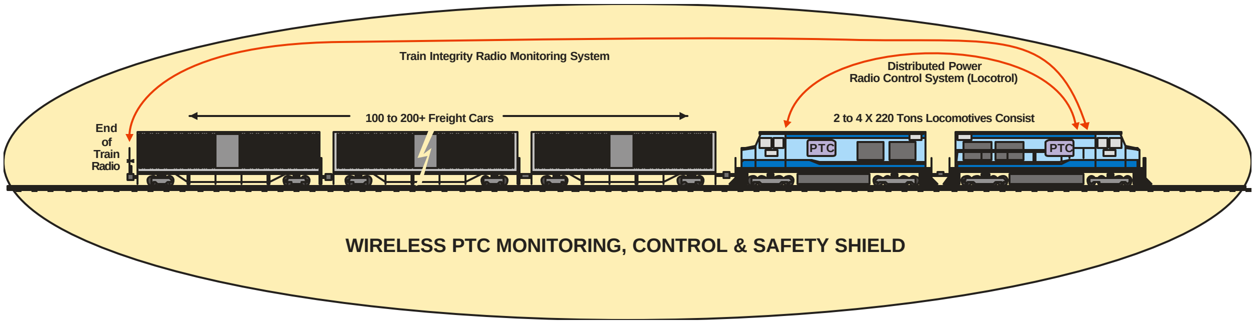
Wireless Positive Train Control

1.0 Introduction

For several years U.S. Class One Railroads and the Association of American Railroads (AAR) have been working on the development of a new train monitoring, control and safety shield concept called Positive Train Control (PTC). Several trials were conducted using different approaches to test various PTC system configuration approaches, employing various types of wireless communications networks.



More recently, four U.S. Class One railroads started to work towards a unified, interoperable concept. It will consist of a PTC system providing a monitoring, control, and safety overlay above existing train signaling and control systems. This system will communicate with and monitor trains and high-rail vehicles as they move. It will determine their exact position and speed at any time, using specialized software in fault-tolerant network operations centers to monitor multiple simultaneous train operations. Events including conflicts, loss of separation between trains, operation outside established limits and excessive speed will result in immediate action to avoid potential accidents.

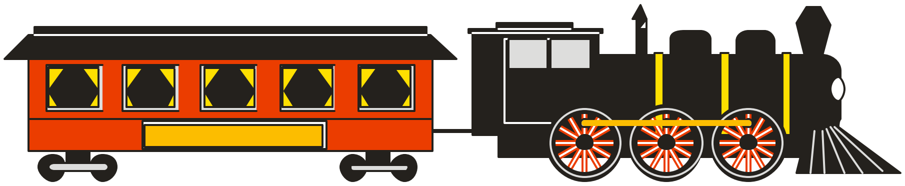
This document provides an outline of how train control and railroad communications systems evolved through the years, from early Morse key telegraph to wireless PTC systems, which have to operate 24/7/365 as mission critical, vital railroad signaling systems. Unlike voice mobile radio, PTC requires seamless radio coverage of tracks. Final PTC requirements are still being defined by the main Class One Railroads. Proof-of-concept systems might start to be deployed late in 2009 and/or early in 2010, with a reported government directive to complete PTC systems deployment by the end of 2015.

PTC will include state-of-the-art, mission critical, fault tolerant data networks and digital wireless communications systems. There are similarities between PTC and automated air traffic control systems, such as the Canadian Automated Air Traffic System (CAATS), now operational coast to coast.

Initially, PTC will be deployed as an overlay on existing train control and signaling systems, including track circuits, blocks and track side equipment. In the future, PTC will support the migration to a moving block concept where more trains can be operated over the same section of track. With PTC monitoring and maintaining train separation for safe operations, it will provide in-cab signals to locomotive engineers, and will not require physical block systems or track side signals (descriptions of track circuits and the block concept are provided in the following pages). At the end of this document a fold-out diagram shows how a typical PTC overlay would be integrated with existing railroad signaling systems.

2.0 Early Train Control Systems in the late 1800's and 1900's

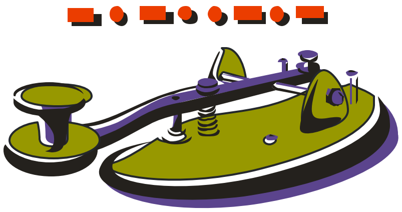
The first railroads in the late 1800's relied on telegraph wires and Morse key communications between stations and train dispatchers. Train control was performed by station masters reporting through telegraph the arrival of a train to a dispatcher, requesting by telegraph authorization for the train to proceed to the next station, and passing the authority to proceed to the engineer and conductor of the train so they could proceed. Stationmasters also communicated with each other to pass along information on the location of a train, and ensure that the tracks between two stations were clear before authorizing a train to proceed.

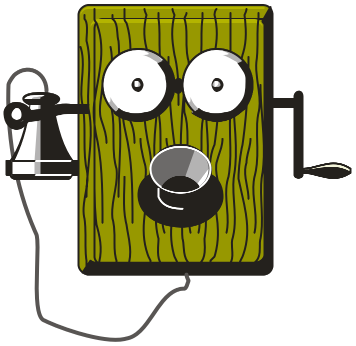


Trains had no means of communication with the train dispatcher at the main office, or with stationmasters. If a train would break down, or the track would be obstructed, the train would stop and the conductor would use a device similar to a long pole to prune trees, fitted with one or two copper hooks and a long wire to a portable Morse key telegraph box with dry batteries. Morse key telegraph systems only needed a one-wire line strung along poles placed near the track. These single-wire systems permitted the operation of Morse key telegraphs, which used direct current (DC) pulses, but were too noisy and had too much attenuation for voice frequencies to allow telephone systems to operate on them.

In some cases the pole line had two wires, carrying a magneto or local battery phone over two balanced line wires, and a Morse key telegraph on a "phantom" circuit using a center tap on both wires and ground. With these two-wire lines a portable crank-handle magneto telephone could be used by the conductor to call the nearest stationmaster or the train dispatcher to report the situation and request instructions. Telegraph wires were typically made of galvanized steel or copper.

When copper was used, it was possible to communicate with a magneto telephone over distances of up 200 miles, due to the very low attenuation of open wire lines. Morse key telegraph systems could communicate across even longer distances as they used higher voltage DC pulses.



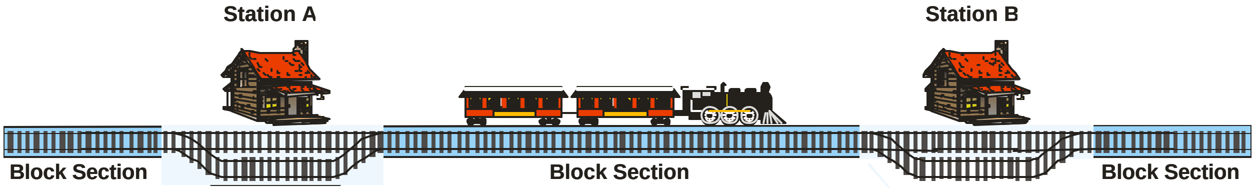


These systems continued to be used well into the 1900’s in many parts of the world. A portable magneto phone with a telescopic pole and copper hooks/clips was standard equipment for train conductors well into the 1950’s, 60’s and 70’s, until mobile and hand-held radios started to become available.

An ingenious device was developed to warn moving trains when there were no signals or communications available. A small shoe-polish size round metal pouch full of gunpowder would be attached to a track, producing an explosion as the locomotive rolled over it. By using several explosive pouches spaced on certain lengths of track, emergency messages could be sent to the engineer as a train would pass without stopping. One single explosion would mean "stop the train at once".

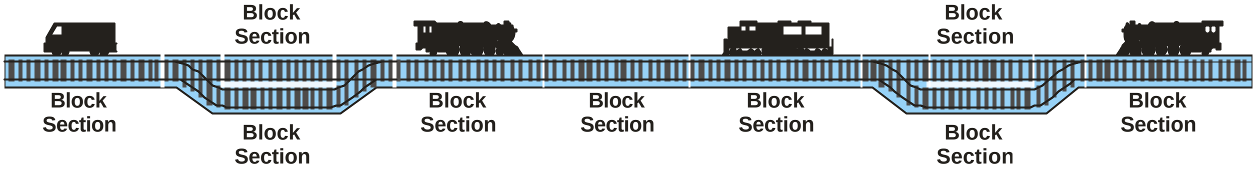
3.0 The Block Concept

A block is a section of controlled track which could be empty or occupied by a train. In the late 1800's and early 1900's a length of track between two stations was a block section. Before a stationmaster could authorize a train to proceed to the next station, he would contact that stationmaster to ensure that the train that passed before had cleared the block section and that the track was clear to send another train. This was done through simple Morse key messages exchanged back and forth between the two. When a train entered the block section, that section would be occupied until the stationmaster at the destination station reported that the train had arrived.



Although blocks were meant to be occupied only by one train at the time, exceptions could be made when two or more trains were traveling on the same direction. A certain amount of time after the first train left, a second train would be cleared to follow in the same direction, observing visual clearance to maintain a minimum distance with the preceding train.

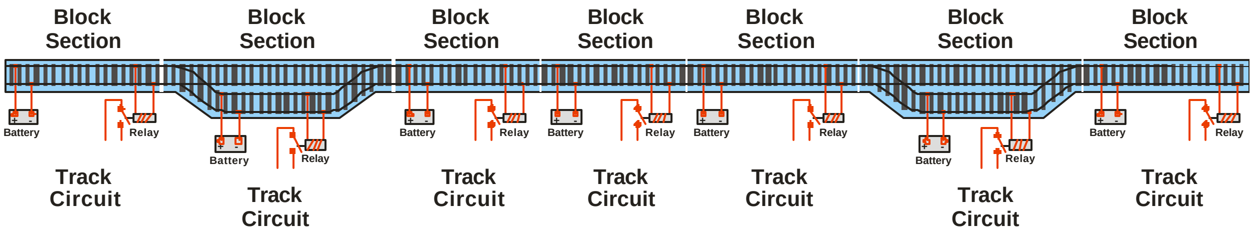
In modern times there are multiple blocks along a track, so more trains can travel at the same time. It is common practice to leave at least one block section unoccupied between moving trains.



Each train is only authorized to travel to the end of the block section it is traveling on, and must stop unless cleared to proceed to the next block section.

4.0 Track Circuits

To know which block sections are occupied and which ones are free, tracks on each block section are electrically isolated from the block sections on each side. Early track circuit systems used non-conductive fiber boards to provide mechanical continuity to the tracks, while keeping block sections isolated from each other. Modern track circuits typically use audio frequency resonant circuits tuned to each block section, allowing the use of continuously welded rails across block sections. At block section boundaries tuning bars of specific lengths are welded to each track to close the resonant circuits and separate electrically the audio frequencies from one track circuit to another.



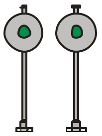
This diagram shows how a track is broken into multiple block sections, each provided with a track circuit to monitor the presence of trains. Normally a low voltage DC current flows from a battery on the left, to a relay at the other end of the track circuit, on the right. When there are no trains on the block section, the relay is continuously operated or closed. When a train "steps in" it short circuits the low voltage DC current and the relay drops off, closing a contact to indicate occupation of that block section.

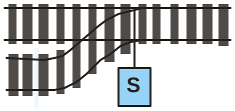
With modern tuned audio frequency circuits the operation is similar. Instead of a battery sending a DC current there is an audio generator sending a coded/modulated audio signal that travels across the block section, is demodulated at the other end, and maintains a track circuit relay operated when there are no trains on the block section. When a train steps in on the block section, the audio frequency signal is shorted out and the demodulator no longer can receive it, dropping off the track circuit relay and providing an indication that there is a train on the block section.

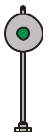
Early systems only provided local block section indication through a signal to indicate to oncoming trains if the track circuit was free or occupied by another train. In the early 1900’s track circuit information was extended to remotely located stations and signal cabins, where all signals were controlled.

5.0 Signals and Switches

In the late 1800’s signals and track switches were deployed near the tracks to control the trains. Signals and switches were mechanical devices operated by large four-foot pull levers in stations or signal cabins, pulling long steel cables or inverted "U" form steel bars over rollers to move signals that could be up to one mile away from the station or cabin. Trains move across block sections observing directions from these signals, and switch tracks following paths established by track switches. In the 1900’s some electrically powered signals and switches were deployed.







In the 1940’s Centralized Traffic Control systems (CTC) were deployed, with a backbone "code line" cable using encoded electric pulses to query and monitor track circuits and operate track switches and signals. A CTC dispatcher would control a large segment of track using electro-mechanical equipment to monitor and control all the track circuits, track switch positions and signals. The code line used ultra-secure pulse coded algorithms to prevent false indications and/or false operations. The dispatchers had in front of them a track layout console with all the stations, track circuits, switches and signals, each lighted with an indicator showing status. Signals and track switches were operated with small rotative switches by hand. Upon sending a command to a signal or switch, the code line would transmit the command, wait for acknowledgment that it was executed from the remote device, then display the updated status for the CTC dispatcher.

As code lines evolved, electric pulses and electro-mechanically coded commands were replaced by electronics using advanced, fault-tolerant data communications systems. Modern CTC systems are not constrained by distances and can be deployed across an entire country, covering track segments across thousands of miles. Electro-mechanical track layout panels with lamps and control switches were replaced by touch-screen computers providing more information and with more operational flexibility than earlier systems. A modern day CTC office is called a network operations center and is similar to many air traffic control rooms with multiple computer screens on numerous operator desks.

6.0 Token or Staff Block Systems

To augment train operations safety in the late 1800's, and used until well into the late 1900's, the token block (also called staff block or block staff) was widely deployed and used around the world. Token block was an ultra reliable signals system, not a communications system.

When a block section was the entire space between two stations, and the installation of track circuits to monitor the presence of trains was not practical or cost-effective, a token block system would be installed. It required one single pole-strung wire between the stations. Each station would have a token dispensing machine. The machines were electrically linked by the single wire between stations.

For a train to be authorized to leave, the engineer had to extract one token from the token dispensing machine, conferring to him track authority to proceed to the next station. The machine issuing the token would communicate with the similar machine in the other station and lock it out so it could not issue any tokens to trains coming in the opposite direction. The local token issuing machine could not issue another token to any trains going in that direction until the remote token machine was unlocked.

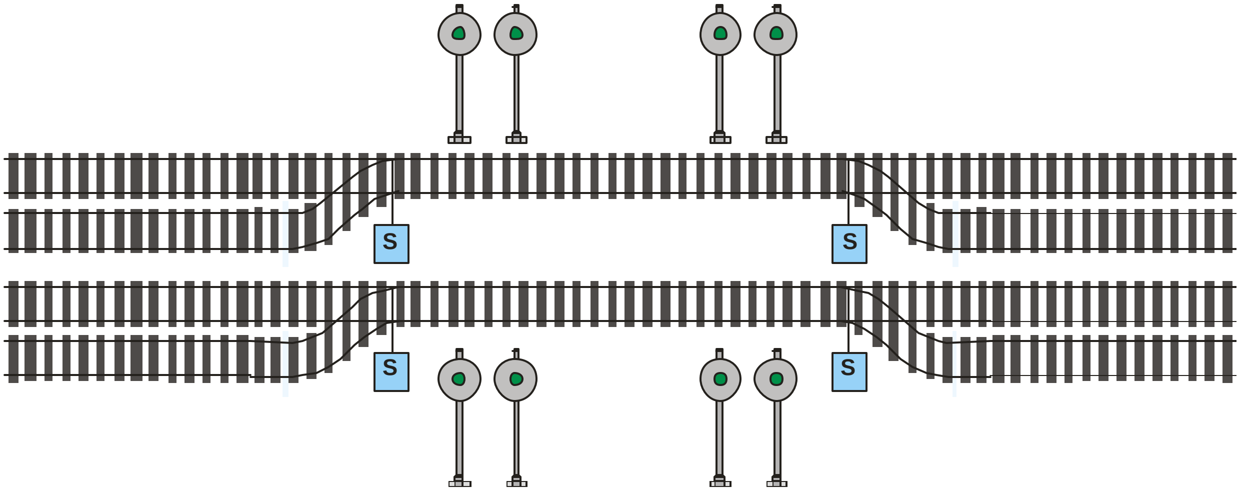
The remote token issuing machine could only be unlocked after the train arrived and the engineer or stationmaster inserted the token into a slot of the token machine. If a train did not arrive and remained for some reason on the track between two stations, no other train could be issued a token with authority to enter that section of track.

Tokens were typically brass sticks about 12" to 42" long. Most were hollow, where a copy of the track authority written by the stationmaster would be carried by the engineer using the token. Tokens were fitted with large rings about 24" in diameter, to permit train engineers to exchange tokens when passing through a station without having to stop. They would throw the token stick from the locomotive to the floor near the stationmaster, and with an extended arm would catch the ring of the new token the stationmaster offered them. When heavy 42" tokens were used by a few railroads, the engineer had to be extremely careful when throwing that big piece of metal from a speeding train, aiming for an area where there were no people or equipment that could be hit with the token.

7.0 Interlocking Systems

Simple block sections with track switches and signal deployments were relatively easy to monitor and operate safely. Only a few components had to be monitored. To increase operational safety, and also as the deployment of more complex systems advanced in the late 1800's, new safeguard systems were developed and deployed.

For instance, a layout for a nine-track/platform train station would typically involve some 160 four-foot pull levers in a signal cabin. Some levers controlled signals and others controlled track switches. The complex paths of tracks coming from another station and fanning out to the station's nine tracks, and the various types of mechanical signals used, made it extremely difficult for the operators to be totally certain that by pulling some signals and switch levers they would not create a conflict, erroneous signal indication (i.e. clear a train to turn right when the track switch is set to turn left), or put an incoming train on the path of an outgoing train.



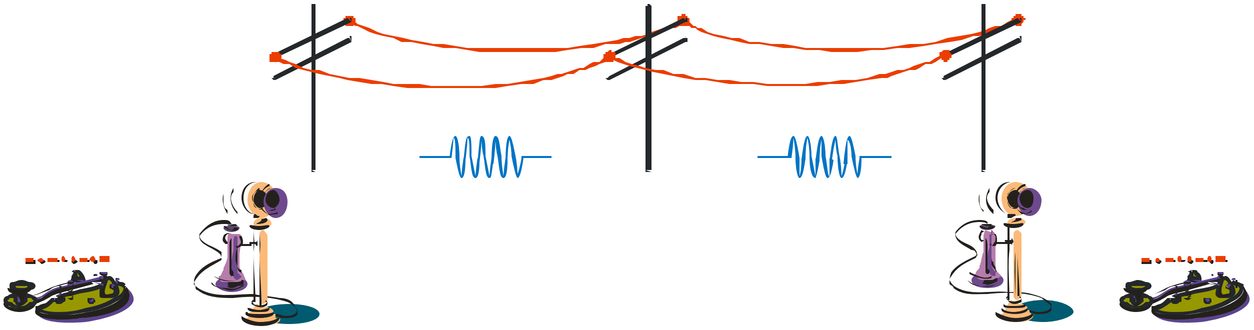
A mechanical overlay safety system was developed, called an interlocking system. For instance, under the floorboards of the signal cabin where those 160 signals and switches levers were located, there was a large matrix of steel bars that would only permit activation of signals and switches in a safe manner. If an outgoing train had a path set through the tracks to leave the station, an incoming train could not be cleared with signals and switches to cross into the outgoing train's path. The levers would be locked by the interlocking system, preventing conflicts and erroneous signal indications.

In the early 1900’s interlocking systems were commonly used across entire railroads. More complex interlocking in large stations/switching yards, simpler and smaller interlockings in stations where there were only two switches and two tracks (one main, one siding). For many years interlocking systems were built with mechanical and electro-mechanical components. They supported the deployment of the first electro-mechanical code line based CTC systems. If the code line would deliver a wrong command to clear a train to turn left while the switch was set to go right, the CTC local interlocking in the field would catch the error and not allow a wrong indication to be given by the signals.

Modern day interlocking systems are complex, redundant electronic systems, operated mostly by microprocessors and computers. The functionality and purpose have not changed much since the 1800’s.

8.0 Fixed Communications Systems

In the late 1800’s there was not much difference between communications and signals. They used Morse key telegraph to request track clearance to dispatch a train, check whether a block section was occupied or not, to send train orders to a remote station, etc. They also used the same Morse key telegraph to send and receive messages relative to the railroad operation and telegrams for the general public with the railroad operating as a communications common carrier.



The first railroad communications systems only had a single wire strung from pole to pole, running near the tracks. These circuits were extremely noisy and could not be used for anything other than for Morse key telegraph. The term "open wire line" was used for all pole mounted wire lines.

A few leading companies such as Western Electric started to develop very advanced communications systems for that time. Local battery (magneto crank handle) telephones started to be used across distances up to 250 miles, using an open wire line with two copper wires. A Morse key telegraph system would also use these lines as phantom circuits, using a middle tap on large coils and a ground at each end of the open wire line. There was also a derivative of a magneto phone called a "phonopore" that only required one wire and was mostly used on very short lines where the single wire line would not introduce much noise. The phonopore used a buzzer to call the distant station.

For dispatchers it was difficult to use magneto phones to communicate with multiple stations. They would have to deal with a party line with more than fifty stations along a track segment, requiring a substantial amount of energy (voltage, current) to simultaneously ring all the magneto phone bells in all stations, and then develop a Morse-like code (i.e. two short - three long, one short - one short rings) to alert the station that was intended to receive the call to pick up the phone, with all stations having to listen to all the coded rings to determine if the call was for them. Magneto phones were mostly used for point-to-point communications, not for train dispatching, which continued to be done by Morse key telegraph.

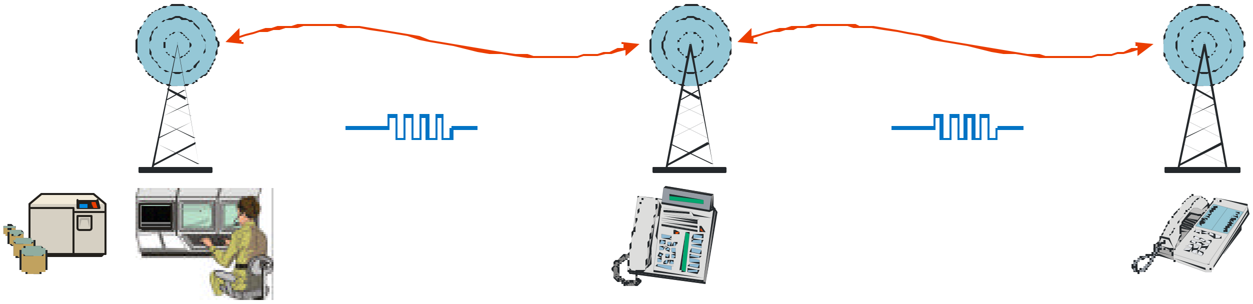
Then Western Electric developed the train control selective call system, using a long party telephone line with high impedance receivers and mechanical call detectors. The dispatchers had one spring loaded call key per station, which they would turn 90 degrees to the right and then release. As the key slowly rotated back to the idle position, the selective call equipment would output to line a string of pulses and pauses stored mechanically in the call key and read through contacts from a scored drum through a spring loaded lever. Each selective call operation would take 15 to 20 seconds.

Each call key would output a different code, pertaining to a specific station. The call key would control the release of high voltage DC pulses (440 Volts) that could travel up to 300 miles over a well maintained copper open wire line. The pulses were "rounded off" by huge transformer coils, so they sounded like soft sizzles to anyone listening or talking on the party line. The 50 or 60 stations on the line had high impedance stepping relay coils drawing little current, so all the stations could operate their decoders simultaneously without draining down the electrical pulses on the line. The dispatcher was able to talk to one station and call another one at the same time, without degrading the quality of the audio circuit.

Stations were equipped with very sensitive, low power consumption electro-mechanical decoders that would advance in steps for each pulse received from the dispatcher's call key. A ratchet mechanism would decode the pulses and would only advance to the end and ring the bell if the coded pulses from the line matched with the mechanically coded ratchet slots for that station. The bell would sound and the dispatcher would hear a single long "ringback" tone. Stations would call the dispatcher by cranking a magneto handle, generating a ringing voltage on the line that would cause the dispatchers bell to ring. Often, the dispatcher remained listening on line all the time and it was not necessary to ring the bell.

In the early 1900’s some of these decoders were used as remote controlled devices to close a switch to connect another line to the system, to open another switch, and to operate remote equipment. The dispatcher would have several calling keys named after the devices they controlled. This was a remarkable system, developed and deployed without amplifiers and making use of complex low power consumption electro-mechanical components that remained in operation for many decades. They were also very rugged, with lightning strikes and other power spikes not affecting their operation (unlike most modern systems). Some of these systems are still in use around the world.

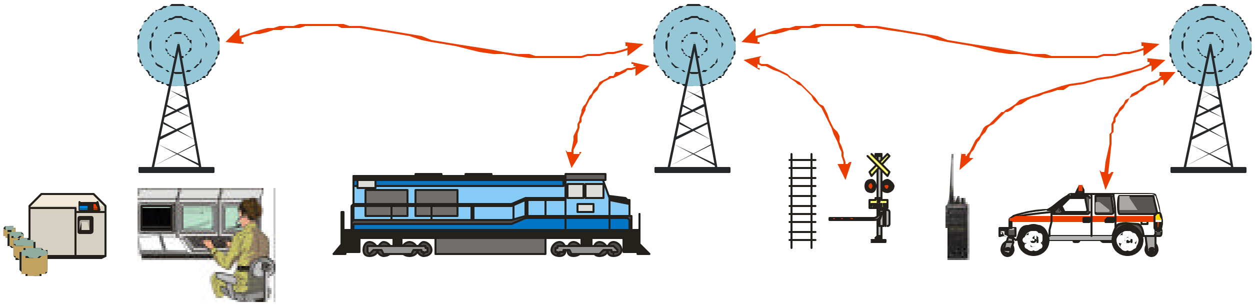
In the mid 1900’s communications systems evolved. Open wire carrier systems were capable of carrying up to 12 voice channels over a single pair of open wire copper lines. In the 1950’s and 60’s, microwave radio links started to replace open wire copper lines, and in the 70’s fiber optic systems began to be deployed across most major railroad networks.



Today, railroad communications systems operate much like small telephone companies, with advanced digital switches, digital microwave links and fiber-optic systems. As technology evolved, communications and signal systems became two distinct, separate technologies, with different rules, reliability and survivability requirements.

9.0 Mobile Radio Voice Communications Systems

Mobile radio systems started to be deployed in the 1950's and were replaced as new technologies became available. Mobile radio systems, like other railroad communications systems, are designed to provide a best effort voice communications path. They are used to communicate with trains, high-rail vehicles, train crews, conductors, and track crews. They are also fitted with modems to operate as simple telemetry systems to indicate if an automatic crossing gate system is working, or to issue a computerized voice warning to locomotive engineers as their train passes in front of a hot box detector and each axle is measured to detect higher than normal temperatures.



Railroad mobile voice radio systems in the U.S. use old analog FM radio technology. A new digital technology called NXDN was tested in 2008 and will begin to be deployed, but is not yet on main lines. It will be tested first on yards and secondary tracks. This new technology is more spectrally efficient, using only 6.25 KHz of spectrum to carry one voice channel, whereas conventional analog FM requires 25 KHz and narrow analog FM requires 12.5 KHz.

The railroad mobile radio system in the U.S. has been designed and optimized for best effort voice communications and provides the requisite level of service for voice communications in the field, including manual block/train orders, which are the only quasi-signaling service that mobile voice radio communications carry. Mobile radio systems coverage is not complete, but it does provide coverage in most areas where it is used, and keeps fulfilling its purpose day in and day out.

Digital radio NXDN technology will present a new set of challenges, as the communication between base stations and radios in the field will use digital modulation susceptible to new, not well understood propagation/coverage/interference issues. The existing mobile radio infrastructure was designed for a different technology. Railroad mobile voice radio systems are not very effective in channel utilization, with most main line voice radio channels only being utilized less than 5% of the time.

10.0 Manual Block via Voice Mobile Radio Systems

In the late 1960's and early 70's mobile radios were deployed on most locomotives and hand-held radios given to conductors and other train personnel. It was difficult to provide suitable, rugged locomotive radios in earlier times, as many locomotives were steam operated and mobile radios were not suitable for adverse environments with strong vibrations and temperature variations.

In many railroads locomotive radios facilitated the introduction of manual block or train orders. An engineer ready to start his train would radio the dispatcher, identify himself, the train, the clearance requested from mileposts XXX to YYY, and his present position. Finally, he would request authorization to start moving. Both the engineer and the dispatcher would fill in the blanks on a form, read it back to each other, and individually check every word on the form. After a few exchanges, the dispatcher would authorize the engineer to depart. The train would go on its way, not requiring signals, block sections or track circuits to operate.

The manual block method would allow the use of an early version of a moving block. The dispatcher would clear a train to a certain milepost and ask to report back. Upon reporting back, the train would be authorized to proceed to another milepost. Only then would the dispatcher authorize a second train to enter the section just cleared by the first train. The length of these sections could be arbitrary and several trains could be dispatched one after the other, each inside a virtual moving block of clearance.

Manual block / train orders can also be used when the main signal system malfunctions or breaks down. It cannot handle as many trains, but can ensure that they keep moving. It still is very effective on lightly traveled track segments. On main lines either automatic signals and/or CTC were used to manage the larger train traffic that moved over them. There are many railroads around the world still using manual block systems today.

11.0 Wayside Equipment and Fault Equipment Detectors

There are several types of equipment and devices deployed along the tracks to ensure safe and efficient operation of trains.

Wayside or track-side equipment might include:

- Signals, switches and track circuits in non-CTC track segments
- Level crossing gates
- Electric power presence/failure in remote equipment sites

Under the common denomination of "fault equipment detectors" there could be a variety of devices which might include:

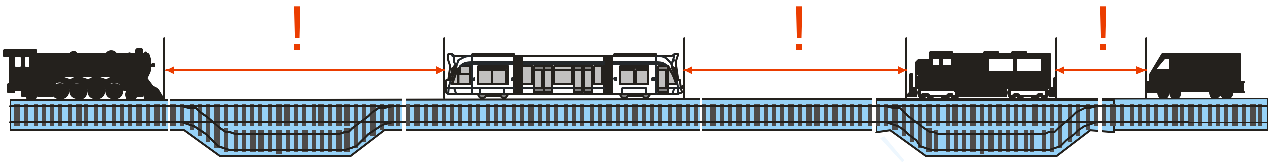
- Hot box detectors to identify bearings on wheel axles that overheat and might cause an accident
- Flat wheel detectors to identify wheels that might contain flat areas due to skidding when braking
- Track integrity detectors in areas where floods, rockslides or other events could break the tracks
- Extreme temperature sensors to warn of temperatures that might break or bend a rail
- Snow pillows around the track area to determine the depth of the snow and warn for avalanches
- Water on the track detectors near rivers or lakes that might overflow
- Landslide or rockslide detectors in areas near unstable slopes around the tracks

Many of these devices or equipment are not normally connected to a communications network, fixed or radio. But some of them, such as hot box detectors, might be equipped with a local radio to broadcast to the engineer's radio in the locomotive the condition of the axles on his train, highlighting any axles that might have a temperature higher than certain level.

12.0 Vital Systems

Communications systems continued to evolve separately from train control systems. Signal and train control systems are vital and mission critical, whereas communications systems are mostly a best effort to relay a message or set up a conversation between two or more parties. If a communications system were to fail it would most likely not affect the operational safety of trains.

A signal system cannot be allowed to fail, so signal systems were developed and deployed with a much higher degree of fault tolerance, for safe operation 24 hours a day, every day of the year. The high cost of signal systems reflects this different level of service. A good communications system would probably cost only three to five percent of the cost of a CTC signal system to serve the same track segment. Even a more complex wireless PTC system will cost significantly less than a conventional CTC signaling system.



Vital systems consist of several components, including ultra safe signaling systems designed for operation around the clock with no failures. Design parameters and operational procedures are developed so there are no single point of failure components or sub-systems. This criteria is applied to mechanical, electrical, electronic and radio communications sub-systems, as well as to operational procedures.

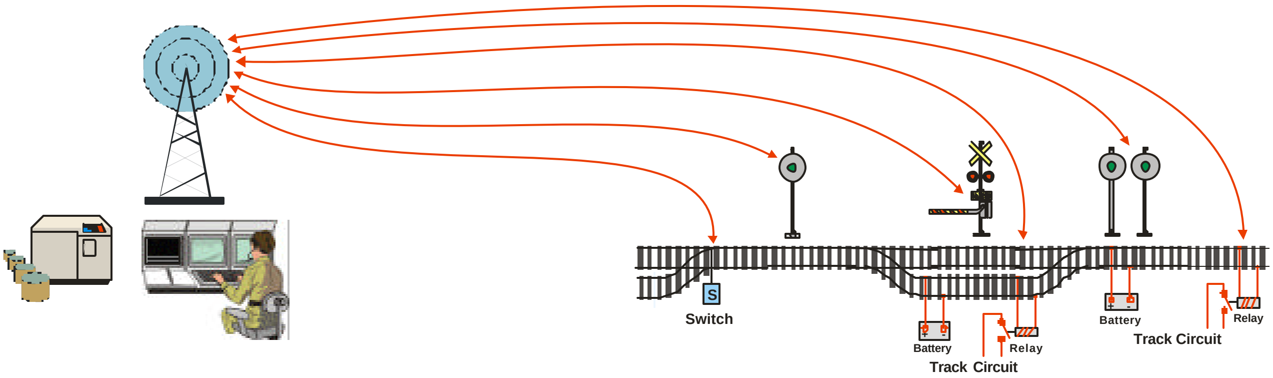
As an example, for a track circuit to be guaranteed to operate when a train is occupying it, the train has to have at least 14 axles to ensure that it will properly short the rails to indicate track occupation. If a consist with two locomotives weighing 220 tons each operates over a track circuit, it would not qualify to operate the track circuit because there are only 12 axles, and the locomotives consist/train would have to be cleared manually as a small, light high-rail vehicle.

Vital systems will impose severe constraints in the design, development and operation of wireless PTC systems, with mobile digital radio systems having to meet requirements that no other communications system had to comply with in any railroad.

13.0 ATCS - Advanced Train Control Systems

In the 1980's, after several years of U.S. and Canadian technical committees discussions and definitions of standards, a new revolutionary technology was introduced. It was the first time that radio communications were used to carry vital train control data, monitor remote devices and execute remote commands. Six narrow band FM channels were allocated in the 900 MHz band, each capable of carrying 9.6 Kb/s low speed data. Advanced Train Control Systems (ATCS) was conceived as a fixed digital radio link between multiple base stations along the tracks of a railroad, to communicate, monitor and control trackside or wayside equipment including signals, switches, track circuits, hot box detectors, level crossing systems and other devices.

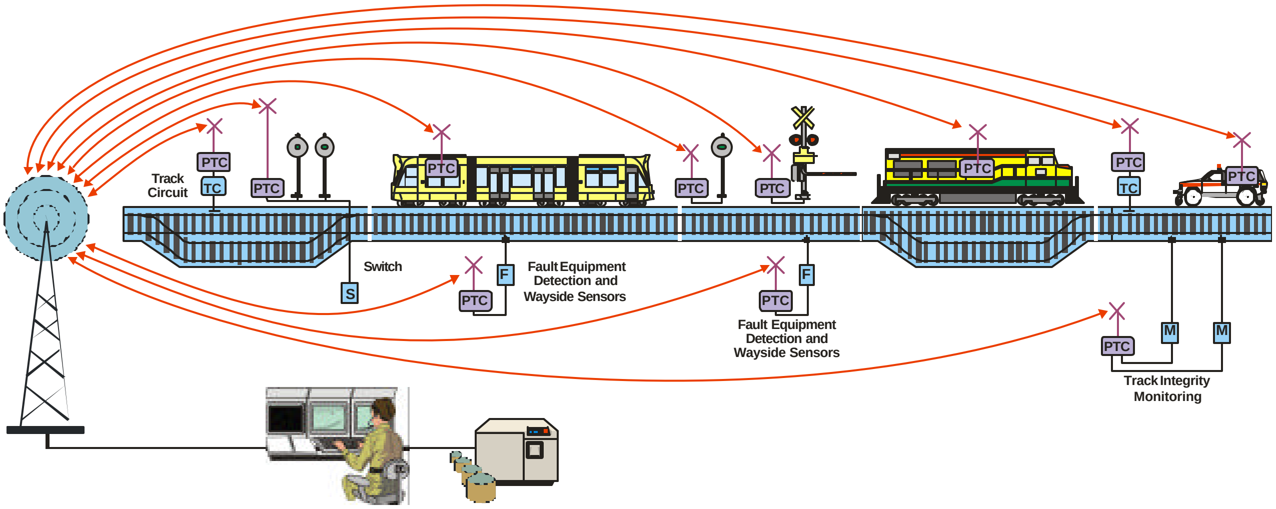
Because ATCS uses fixed stations (base stations and field/wayside equipment), it is easier to plan/forecast what the radio propagation/coverage/interference parameters will be. Once installed and aligned, ATCS will provide reliable service over time, with little or no propagation/coverage/ interference issues affecting its operation. If ATCS would be used in a mobile environment, a completely different set of RF factors and issues would come into play.



Several rairoads installed ATCS systems, with different levels of deployment. Soon it became evident that railroads had many more devices to interconnect than the six ATCS channels could support. It appears that ATCS systems deployed and in operation have been working well for many years. Now it is time to start planning the replacement of the first generation of ATCS systems in operation, and most railroads are looking with interest at PTC as a potential replacement for fixed ATCS systems. Also, the high cost of ATCS radio base stations have caused some railroads to defer replacement of ATCS systems for the future.

14.0 Wireless PTC

PTC systems are mission critical, fault tolerant vital signaling systems connected via digital radios to mobile and fixed railroad equipment. When deployed, PTC will provide interoperability between all the participating railroads. Trains from any railroad will be able to operate on the tracks of any other railroad, without ever losing contact with their own network operations center. There are several similarities between wireless PTC and automated air traffic control systems managing air traffic today.



PTC systems integrate many of the signal and communications technologies described in previous sections. Wireless PTC will provide a "safety shield" around all trains and other equipment to monitor the proper functioning of all existing signal systems, and human operation of these systems. If existing equipment malfunctions or ceases to operate, or if human factors result in a potential safety/rules violation, PTC can immediately intervene slowing down or stopping one or more trains. PTC can replicate all signals and other critical information inside locomotive cabs, providing additional information to engineers.

In the future, wireless PTC may be used as the only vital signaling system, with no need for external block systems, signals or other equipment currently used in signaling systems. PTC can establish moving blocks around trains, providing sufficient separation between moving trains to ensure maximum track utilization. All signals will be displayed inside the locomotives.

There are seven separate committees from U.S. Class One Railroads working in the definition of wireless PTC requirements. This is work in progress. PTC will directly support, monitor, control and include the functionality of:

Train Control: PTC will continually monitor trains, exchanging information with Train Management Computers (TMC) and gathering precise speed and position information from GPS/TMC. PTC will have a copy of train orders, number of cars, weight, route and track characteristics along the route, including speed restrictions, curves, grades and crossings. Track authority (permission to occupy and move on a sector of track) will be continuously updated as train dispatchers and train control computers at the network operation center issue and modify train orders and operate signals.

Block Sections: With information from train control above, PTC will monitor and enforce compliance with train orders and signals, ensuring the train operates only on the block sections it is authorized to occupy and move on.

Track Circuits: In addition to information provided from track circuits on the tracks, PTC will provide dispatchers and train control computers precise, real time position of the train on the track. In "dark territory", where there are no track circuits, PTC will be the only real-time train location information source.

Signals: The aspect of all signals on the tracks will be extended through the TMC to an on-board computer display showing all signals ahead of the train, including those that are not physically visible due to terrain, curves or visual distance. If a signal is not observed, PTC will immediately apply corrective action programmed for that event, from slowing down the train to a safe speed to the application of full emergency brakes to stop the train in the shortest possible distance. At the same time it will visually and audibly warn the engineer and report the event to the dispatcher and the train control computers.

Switches: PTC will query and monitor the status of track switches ahead and behind the train (i.e., the train is moving back and forth to add or drop off cars). This status will be reported to the engineer, the dispatcher and the train management computers.

Interlocking Systems: The PTC System will work with the dispatcher, train control computers and TMC to continuously monitor and identify potential conflicts between signals and switches, train orders issued to the train, and train orders other trains are using, authorized speed and maximum speed possible on that sector of track. If any conflicts or potential conflicts would be detected, PTC will immediately apply corrective action as programmed for that event, slowing down or stopping the train, and notifying the engineer, dispatcher and train control computers.

Wayside Equipment and Fault Equipment Detectors: All wayside/trackside equipment will be continuosly monitored by PTC, which will automatically query equipment ahead and behind the train. PTC will issue alerts in cases such as when an automatic crossing gate is not working or a hot box detector reports some axles slightly above a certain temperature level. It will also apply corrective action in cases such as when a track integrity monitor reports a possible track breakage due to floods or extreme heat, or a hot box detector reports an axle in the train with a temperature exceeding safe operating levels, or a flood warning sensor detects the presence of water on the tracks.

ATCS - Advanced Train Control Systems: Advanced train control systems can be indirectly queried by the wireless PTC system through the train management computer at the network operations center (ATCS and PTC radios are on different Radio Bands and each operates with its own protocol). This will be done as part of normal queries ahead and behind the train that PTC makes to track circuits, signals and switches, to enforce the interlocking principle as it was described above under "Interlocking Systems". As PTC systems continue to be deployed, they will very likely replace the existing ATCS equipment and take over ATCS functionality.

15.0 Digital Mobile Radio Communications Systems

The development and deployment of PTC systems presents formidable challenges in some areas. The three main components of PTC systems are the train control computers interoperable PTC software in the network operations center, the fault tolerant interoperable fixed digital networks, and the digital mobile radio communications systems.

The first two sub-systems, interoperable PTC software and fault tolerant interoperable fixed digital networks can be designed, developed and deployed with low technical risk. From previous experience (in railroad and air traffic control), there is a large base of knowledge on how to write the requisite interoperable PTC code and on how to design self-healing, fault tolerant fixed digital networks. The development of these two components can be undertaken in a very deterministic way, with final features and functionality results very close to what was planned.

Digital mobile radio communications systems present a number of challenges; there are no similar systems in operation on which these new sub-systems can be modeled. This will most likely be the less deterministic, highest technical risk area in the entire PTC development. It is assumed the 220/221 MHz radio frequency band will be used for wireless PTC.

The following list includes issues that should be considered not as hard stops, but rather points that will require extra analysis, ingenuity and effort to resolve. They are listed in alphabetical order since there is not enough information yet to list them in order of priority. Some of these issues might have been already addressed, and some resolved, by the multiple U.S. Class One Railroad committees working on PTC requirements and definition.

Antennas, Antenna Coupling Units, and Antenna Tower Structures Issues:

- *Mobile and Fixed Antennas* pose several challenges. The 220 MHz is a relatively new band and there are no established product lines for these bands. Several vendors are just now starting to produce new 220 MHz antennas. One year ago, TESSCO®, a leading wireless distributor in this field, only had one 220 MHz antenna listed. This was an NMO mount omnidirectional antenna. In comparison, antennas for the 150 MHz band filled numerous pages in the TESSCO® catalog.

- ***Mobile Antenna On-board Interference Rejection*** can be a major issue for antennas installed on locomotives, in a very hostile interference environment with transients from multiple on board sources. The size, placement, and interference rejection design of an antenna and feed line are critical factors that will affect the performance of 220 MHz wireless PTC radios.

- ***Mobile Antenna Field Interference Rejection and Assembly*** has to be carefully planned and included in the antenna design. It might be necessary to design a non-conventional space diversity and/or circular polarization, and/or phase diversity antenna array to mitigate fading due to several factors, including delay spread/inter-symbol interference. Conventional antennas will travel through digital signal nulls if only one antenna is used and radios will experience complete signal loss. PTC requires seamless radio coverage so the effect of traveling through signal nulls has to be mitigated to a point where signal reception will not be lost under any circumstance.

- ***Antenna Coupling Units*** Unlike the traditional 50, 150, 450, 800 and 900 MHz bands, antenna filters, duplexers, combiners, amplifiers, signal distributors and other similar components are not readily available, even though there is a small selection that is starting to grow as more vendors take an interest in the 220 MHz band. There is no data or knowledge base to forecast how a new 220 MHz radio will behave/interact with other co-located radios operating on the 50, 150 and 450 MHz bands. Senior RF antenna planners/installers over the years have developed a knowledge base of what goes with what. There is tried and true, field proven experience on how to operate several radios on one site, selecting the right brand and model for each antenna coupling unit component. Most railroad radio towers are already crowded with multiple antennas from radios operating on many bands, except in 220 MHz. While 220 MHz antenna performance and interaction/interference can be forecasted by modeling, there is no guarantee that actual field performance will match the forecasted results. This is a high technical risk area, since it will be difficult/impossible in most cases to re-locate, remove or change other antennas and antenna coupling units already installed in thousands of base station towers.

- ***Fixed Antenna Advanced Electrical Characteristics*** Antenna development for the 50, 150, 450, 800 and 900 MHz Land Mobile Radio (LMR) bands has traditionally been focused on mobile voice radio systems operating with non-critical levels of service. In comparison, antennas developed for cellular and PCS applications in 1.9 GHz bands and above are much more sophisticated devices designed to provide a significantly higher degree of service. Some examples include 45 degree "V" shaped phase diversity antennas with one element used for Tx

/ Rx with a duplexer and the other element 90 degrees away in phase, used for phase diversity Rx. PCS antennas also have special mechanical features to mitigate/eliminate nulls below/near the antenna base due to the shape of the beam, and for even round beam down tilting by advancing the phase on the top elements, with respect to the lower elements on a broad shaped or omnidirectional beam. LMR antennas lack these features. 220 MHz antennas, for seamless reception, will have to be designed and built to meet similar requirements as modern PCS antennas.

- Antenna Tower Structures present several challenges. There are placement constraints and there are also weight restrictions. A 2007 ruling on antenna structures documented on ANSI/TIA-222-G-1 might apply to many of the installed base station towers, which might not meet the new structural requirements but could be "grandfathered" until a new antenna is added or the tower structure altered in any way. Serious consideration must be given to replacing several separate antennas with a new multi-band antenna, resolving placement and potential interference issues, as well as reducing the weight on the tower structure.

- Requirements Placed by Antennas on Digital Radio Design It is extremely difficult to operate a mobile PTC radio with only one mobile antenna, which will travel through signal nulls causing total signal reception loss. As described above, an array with more than one antenna will be necessary, and this will require that a separate Rx input be provided for each of the Rx antennas in the array. This will directly impact the design of the digital radio receiver. Also, fixed base station and wayside antennas will require special antenna arrays. Even though these antennas are fixed, the large mass of trains passing nearby will create traveling nulls as reflections move with the trains and create delay spread/inter-symbol interference on stationary receive antennas. Fixed radio receiver design will also be impacted by antenna arrays.

Coverage Issues

Mobile radio communications systems currently used for voice communications can operate with non-critical levels of service, as they make a best effort attempt to provide voice communications, typically sufficient in the environment they are designed for.

Railroad mobile voice radio systems have been in place for many years and users know where the poor coverage spots are located along the tracks. They avoid them or wait until they exit the area to communicate. Since the current 160 MHz radios used for voice communications use legacy analog FM modulation, poor coverage or interference often results in some degraded voice quality, noise or "sparklies" on the speaker. There are few complete signal loss events.

However, the new NXDN 6.25 kHz digital radios now being deployed for railroad voice communications will present new challenges, as they use digital modulation and can totally cease to operate in the presence of interference or low signal input due to fading or other reasons.

These same challenges will also affect PTC digital radios. The most critical areas are around built-up cities, where a larger number of trains operate and also where commuter trains run with many thousands of passengers.

These areas have very high levels of noise/spikes from multiple sources, as well as interference from many other radio systems operating in the area. In addition, there are many non-terrain structures and reflective surfaces that are not documented on software propagation programs used to forecast coverage.

It is practically impossible to forecast precise digital radio performance in this urban environment using even the highest grade terrain data base, such as one degree resolution. Even using a top of the line program used by cellular carriers for PCS propagation analysis and doing vector tracing around each base station will not produce an accurate rendition of the real coverage and digital radio performance.

It is possible to have good, seamless coverage with an Rx signal level from -60 to -85 dBm throughout the track area to be covered, and with a noise floor of -135 dBm, and still have many areas where signal nulls will occur and total loss of received digital signal will result.

There are several reasons why even the best propagation/coverage analysis software cannot forecast or find these areas. The finest propagation analysis coverage software will try to find the signal nulls using a high resolution terrain data base and, projecting up to one thousand vectors from each of the base stations of the system, determine where along the tracks there will be reflections from the original base or from any other bases that can mix with the direct signal from a base station and cause interference that could result in signal loss.

But even a one degree resolution terrain data base will not include all structures that exist in a built-up area that can cause more damaging reflections than any terrain features (i.e., large billboards, new structures continuously under construction, etc.).

In addition, in a railroad environment propagation/coverage is critical on and around the tracks where large steel masses continually pass at high speed. The mass of these moving trains combines with reflections from structures and from moving vehicles on nearby freeways in some cases. A large freight train moving at 60 miles per hour will cause a string of signal nulls traveling at 60 miles per hour to pass in front of a receiver's antenna, and each null will be sufficient to cause a complete loss of received signal.

Propagation analysis software is a useful tool to get a feeling for what the overall propagation, coverage, and interference could be in an section of track to be surveyed. But no propagation software can accurately provide a working model to resolve propagation, coverage, and interference issues for seamless digital radio coverage in 220 MHz in urban areas.

Antenna design, special antenna arrays (as described before) and careful radio receiver design will have to be combined to provide a working combination to operate wireless PTC digital radios in urban areas. It will be indispensable to carry out multiple field measurements, and in addition to signal level coverage and noise floor, record for every linear foot of track figures for carrier to interference ratios. Propagation analysis software can be used to confirm general assumptions, but it will not be able to provide an accurate forecast of design parameters.

16.0 Wireless PTC Typical System Diagram

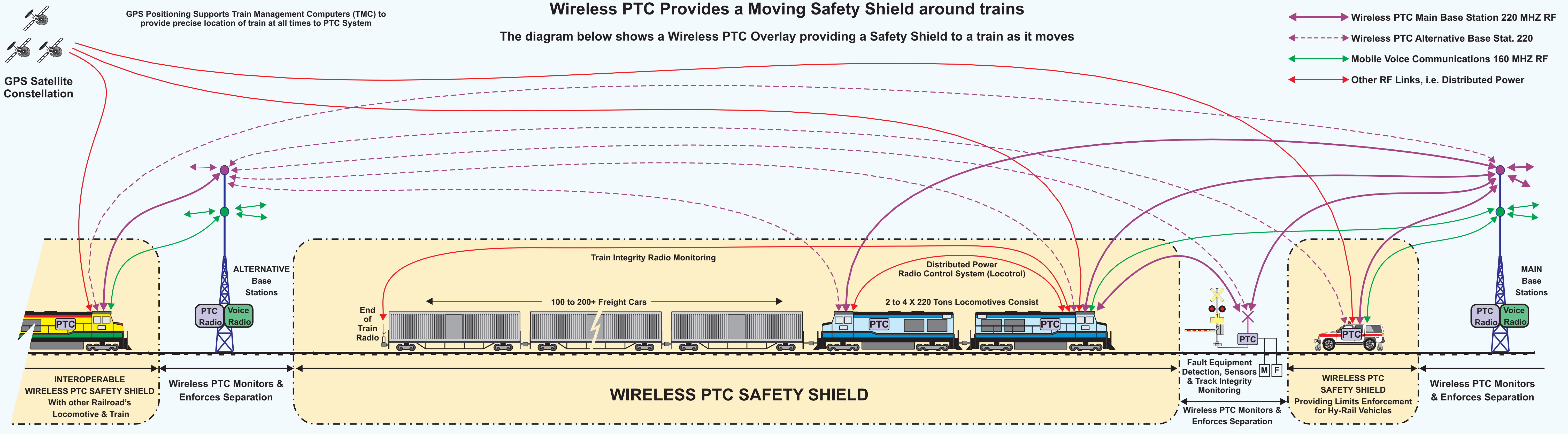
The attached diagram provides an outline of a typical PTC system. The upper section shows how a PTC safety shield is created around trains, locomotives and high-rail vehicles traveling on the tracks. This safety shield moves with the trains as they travel on the tracks. The size of the safety shield around the train and the spacing between trains are defined by PTC configuration rules, which include the type of train, length, weight, track characteristics (such as flat terrain, grade, curve, etc.). Radio coverage is redundant, with a main and alternative base stations providing radio coverage on the tracks. PTC uses digital data radios (purple). Voice radios (green) may be co-located on the same towers with PTC equipment. Freight trains have their own radio systems (red) to monitor train integrity with end-of-train devices and to simultaneously operate several locomotives, known as distributed power (DP) radios. GPS satellite receivers and train management computers are used to determine exact train position on the tracks. All trains and high-rail vehicles carry mobile PTC radios.

The lower section of the diagram shows PTC equipment deployed around a track crossing with Railroad A and Railroad B. Fixed PTC radios are attached to signals, switches, track circuits, track monitoring equipment, level crossings and fault equipment detectors located near the tracks. Network operations centers (NOCs) and track circuits for Railroad A are shown in light blue color, NOCs and track circuits for Railroad B are shown on light orange color. Each railroad is shown with a main and an alternative PTC radio base station. The entire track areas for each railroad will be covered by both main and alternative base stations. PTC radio coverage is shown as light blue "clouds" around the tracks for each of the railroads.The NOCs for Railroad A and Railroad B are linked by high speed data communications to provide interoperability for a "visiting" train from another railroad to use the local PTC radio system and the local NOC to then communicate with its own remote NOC.

In the future, PTC systems will support moving block operation with no track circuits, physical block systems or signals. Block systems will be dynamically allocated in a similar way to a safety shield around the train, and signals will be provided to the engineer inside the cab.

Wireless PTC Provides a Moving Safety Shield around trains

The diagram below shows a Wireless PTC Overlay providing a Safety Shield to a train as it moves

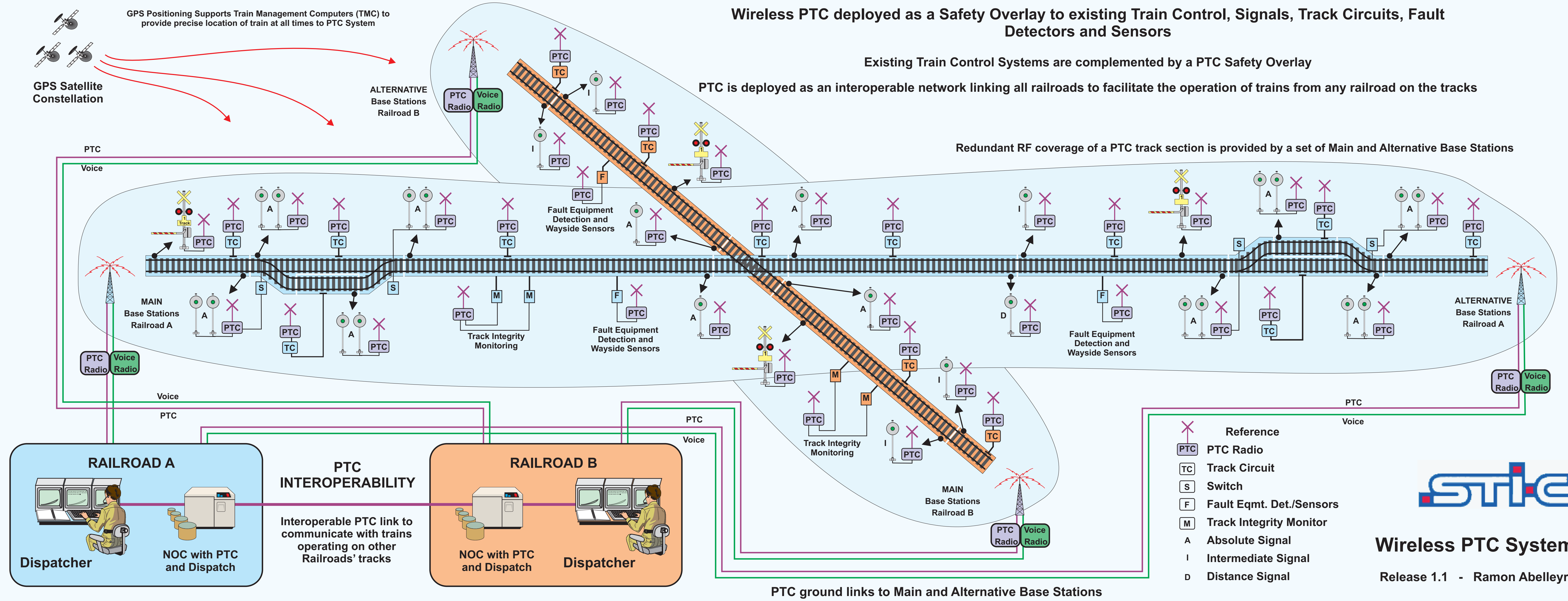


Wireless PTC deployed as a Safety Overlay to existing Train Control, Signals, Track Circuits, Fault Detectors and Sensors

Existing Train Control Systems are complemented by a PTC Safety Overlay

PTC is deployed as an interoperable network linking all railroads to facilitate the operation of trains from any railroad on the tracks

Redundant RF coverage of a PTC track section is provided by a set of Main and Alternative Base Stations



PTC ground links to Main and Alternative Base Stations

✕	Reference
PTC	PTC Radio
TC	Track Circuit
S	Switch
F	Fault Eqmt. Det./Sensors
M	Track Integrity Monitor
A	Absolute Signal
I	Intermediate Signal
D	Distance Signal

STICO

Wireless PTC System Outline

Release 1.1 - Ramon Abelleyro - 4/14/09