Testing PTC ACSES Deployments to Meet Mandated Implementation Standards

Positive train control (PTC) is a North American system of functional requirements for monitoring and controlling train movements to help prevent train-to-train collisions, derailments caused by excessive speeds, unauthorized train movements in work zones, and the movement of trains through switches left in the wrong position. Over a decade ago, Congress mandated the implementation of PTC by certain railroads in response to the Rail Safety Improvement Act of 2008 (RSIA) (the deadline of which has been extended out to December 31, 2020).

The main concept of PTC (as defined for North American Class I freight railroads) is that the train receives information about its location and where it is allowed to safely travel, also known as movement authorities. Equipment on board the train then enforces this and prevents unsafe movement. PTC systems may work in either dark territory or signaled territory, and may use GPS navigation to track train movements. [1]

Currently 42 railroads are required by statute to implement PTC systems, including Amtrak, commuter, and freight railroads. The technology is required to be implemented on approximately 60,000 miles of the 140,000-mile railroad network. [2] This will involve approximately 20,000 locomotives, 24,000 waypoints with unique digital addresses, back office servers, and new interoperable secure wireless network with more than 400,000 components (Note: this deployment does not take into account commuter light rail systems).

The vast majority of the railroads subject to the mandate are implementing one of three PTC systems. For the purposes of this application note, we will focus on the Advanced Civil Speed Enforcement Systems II (ACSES), which is intended to supplement existing train control systems to provide all required PTC functionality. In order for railroads to achieve full implementation, there are several stages of testing that must be completed – laboratory, field, and revenue service demonstration (RSD). This application note will focus on testing a PTC ACSES implementation during field and RSD to ensure that the new deployment is operating properly.

[1, 2] U. S. Department of Transportation. (2018, September 13).
The State of Positive Train Control Implementation in the United States. Retrieved October 2019 from https://www.transportation.gov/testimony/state-positive-train-control-implementation-united-states

PTC ACSES Communication Setup

PTC ACSES provides railway trains with positive enforcement of speed restrictions based on the physical characteristics of the line. The on-board components keep track of a train's position and continuously calculates a maximum safe braking curve for upcoming speed restrictions. If the train exceeds the safe braking curve, then the brakes are automatically applied. To achieve this, there is a communication chain between central control and the on-board equipment that must occur:

- The communication between the base radio unit (waypoint) and the mobile radio unit (radio installed on locomotive) starts with the central control sending ACSES commands to the base radio unit.
- The base radio unit's communications manager converts the ACSES messages to the proprietary STFP protocol and sends it to the base radio hardware. The base radio hardware converts the STFP protocol to an over-the-air (OTA) signal and transmits it to the mobile radio unit.
- The mobile radio unit receives the OTA signal, converts it to an STFP protocol, and sends it to the mobile communications manager.
- The mobile communications manager converts the STFP bit-stream into ACSES messages and performs two functions: it sends back a response message to the base radio unit as needed as well as informs the on-board PC to actuate appropriate train action in response to the ACSES message (Figures 1 and 2).

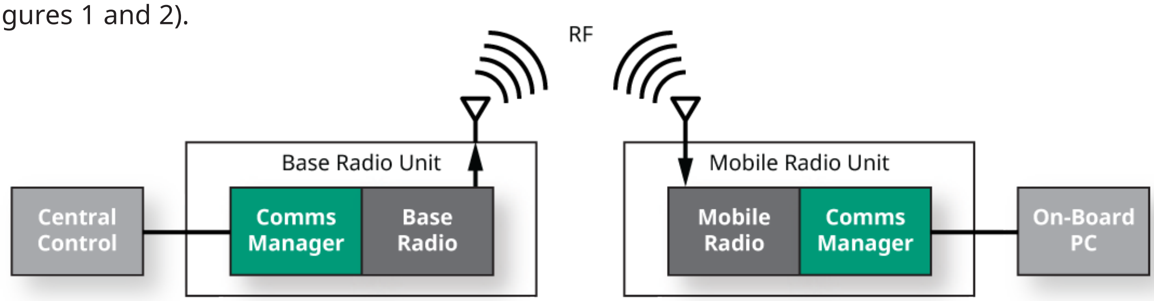

Figure 1: PTC ACSES Communications Block Diagram

While most of the PTC ACSES signals within the block diagram are in a proprietary protocol, the OTA transmission enables the capturing of the message flow (transmit and receive between the base radio unit and the mobile radio unit) and, with the correct modulation decode capabilities, testing of the PTC ACSES system quality and accuracy. There are several tests that are important to verify that signals are being transmitted properly:

- Receive Signal Strength Indicator (RSSI): tests the RF received signal strength
- Error Vector Magnitude (EVM): ascertains the quality of the received ACSES data transmitted by the system
- Per Message Bit Error Rate (BER): based on the Forward Error Control (FEC) ensures the quality of the data received on a per message basis
- Cumulative Packet Error Rate (PER): verifies signal/data quality at the packet level.

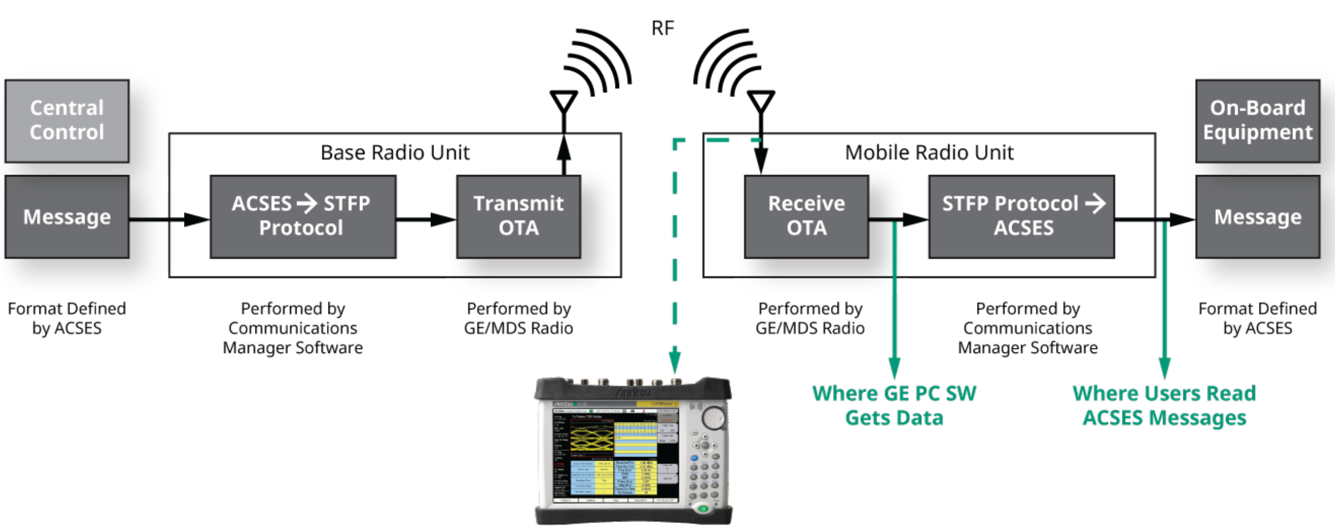

Figure 2: PTC ACSES Message Flow Block Diagram

EVM, BER, and PER combined are important in order to determine if there are high data error rates and whether they happen in bunches (packet level) or are spread out over the data stream (BER). EVM will also correlate since it shows signal quality of the bits transmitted.

To perform these tests, use of a high-performance receiver/spectrum analyzer like an Anritsu LMR Master^{TM} S412E analyzer, is ideal. These solutions provide technicians and engineers responsible for field testing with the ability to assess the performance of the PTC ACSES system by enabling several critical functions including:

- Decoding the message type, such as source of message (i.e., wayside) and destination type (i.e., office or central control)
- Capturing raw message payload data in hex (many rail system engineers are familiar with the hex messages sent and can quickly identify basic ACSES information from these hex messages)

Leveraging hex also enables other information to be captured and decoded (such as source and destination ATCS addresses, as well as time slot in frame and epoch), however, some of this information is dependent on the Comms Manager software loaded on to the radio units and the Comms manager control software on the PC side as this will determine what information is available to the rail system engineer. The ability to decode key messages is important in identifying individual trains and verifying that the ID being transmitted by a train's PTC ACSES radio is correct. This is critical to safety within the system.

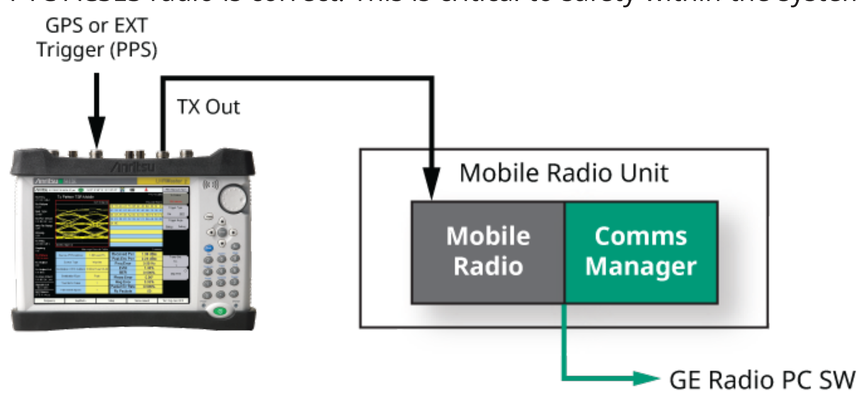

Figure 3: PTC ACSES Bench Testing Mobile Radio Block Diagram

Bench testing a mobile radio is useful to verify transmit and receive RF performance as well as troubleshoot problems with PTC ACSES radio performance. In order to bench test a PTC ACSES radio, users will need a tool that can generate specific PTC ACSES signals at various RF power levels to verify signal transmission and receive sensitivity at the radio. Users will also need to verify and validate signal quality. The use of the PTC ACSES communications manager software is also needed in addition to an analyzer and signal generator. The communications manager software will report the receive sensitivity BER of the radio (Figures 3 and 4).

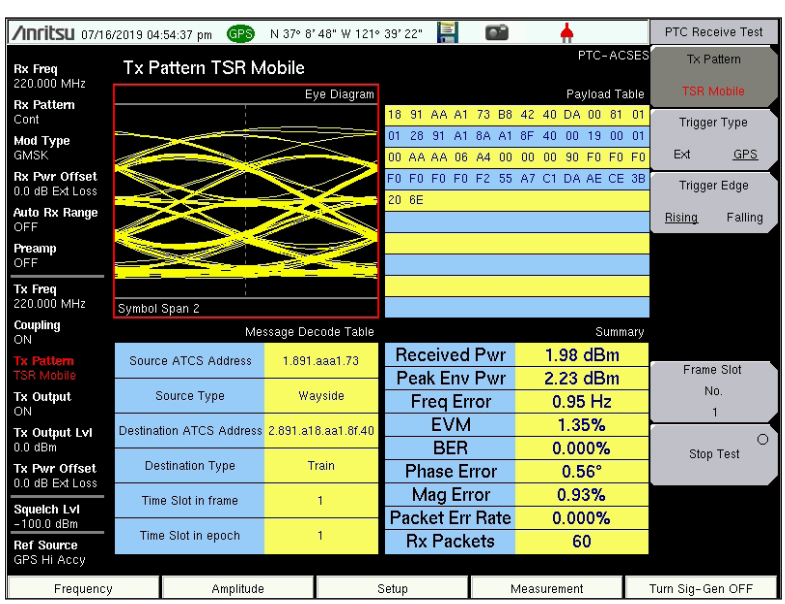

Fig. 4: PTC ACSES Signal Generator & Analyzer - Bench Testing Mobile Radio

PTC ACSES OTA Testing

OTA testing is basically the technique of capturing a signal and making a measurement between the base radio unit (waypoint) and mobile radio unit (locomotive/railcar). This is critical as this is the only way that a high-performance receiver/signal analyzer can access and analyze the otherwise secure PTC ACSES transmission. With a high-performance receiver/spectrum analyzer with PTC ACSES demodulation capabilities, along with the appropriate antenna (and possibly a filter), tuned in to the PTC ACSES transmit frequency, field engineers and technicians are able to measure and analyze the PTC ACSES signal quality and demodulate the messages (hex or ASCII) (Figures 5 and 6). This helps the field engineers validate proper PTC ACSES functionality as well as spot potential problems that the instrument can help troubleshoot.

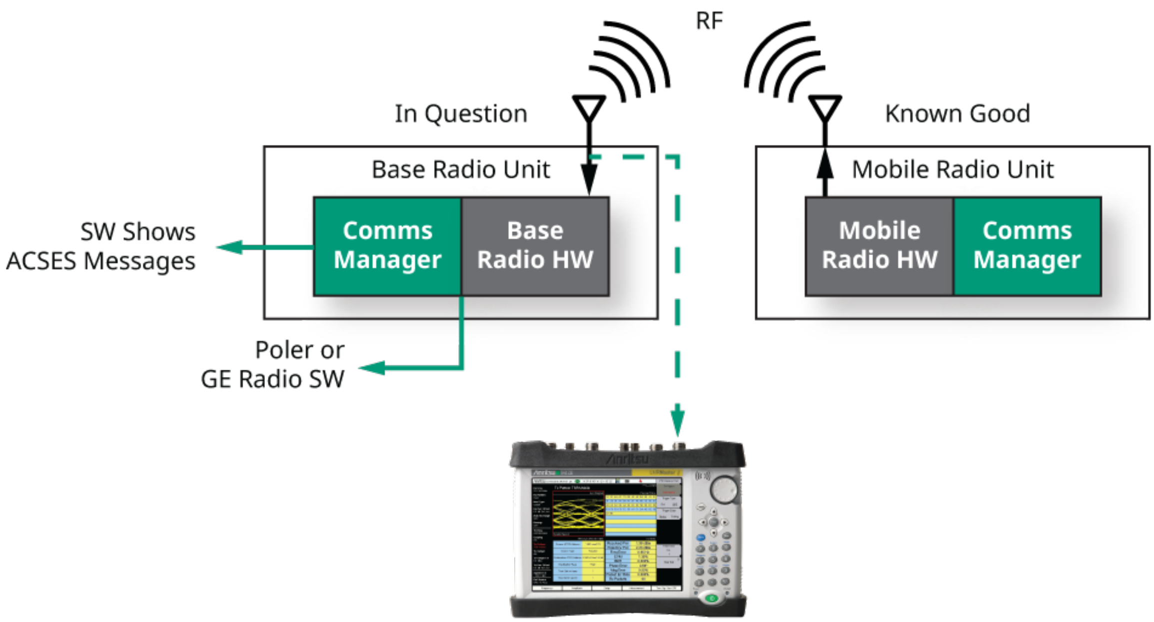

Figure 5: PTC ACSES OTA Block Diagram

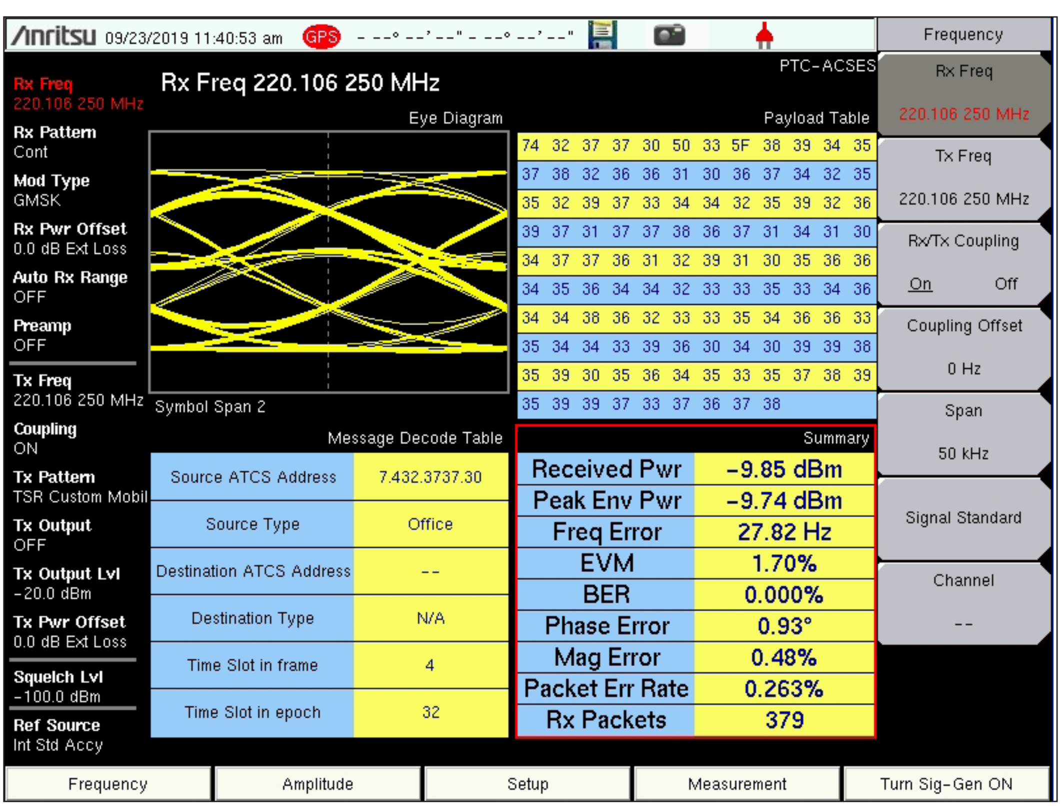

Figure 6: LMR Master S412E PTC ACSES Analyzer – OTA Test

PTC ACSES Coverage Mapping

Coverage mapping is an essential tool in assessing a PTC ACSES signal environment and ensuring proper deployment, installation, and operation. Coverage mapping is used to verify signal strength and quality over a specific area by effectively monitoring RSSI and ACPR levels as well as conducting BER mapping. In the case of PTC ACSES, coverage mapping should be conducted over the various rail lines used for passenger rail as well as integrated lines with Class 1 commercial traffic. Coverage mapping can be performed with a high-performance receiver/signal analyzer with GPS option connected to the PTC ACSES radio's antenna system to better simulate RF receive performance on the train under test through the rail network. The high-performance receiver/spectrum analyzer with mapping capabilities must also perform coverage mapping by accurately and simultaneously collecting key PTC ACSES signal quality measurements (such as EVM, BER, and RSSI data) for the PTC ACSES frequency under test, then plotting one of the parameters on to a map of the area/route being tested. As the information is in .kml format (Google maps), all three values can then be displayed on Google Maps to gain a clear insight into any areas that may need improved coverage to ensure seamless operation (Figures 7 and 8).

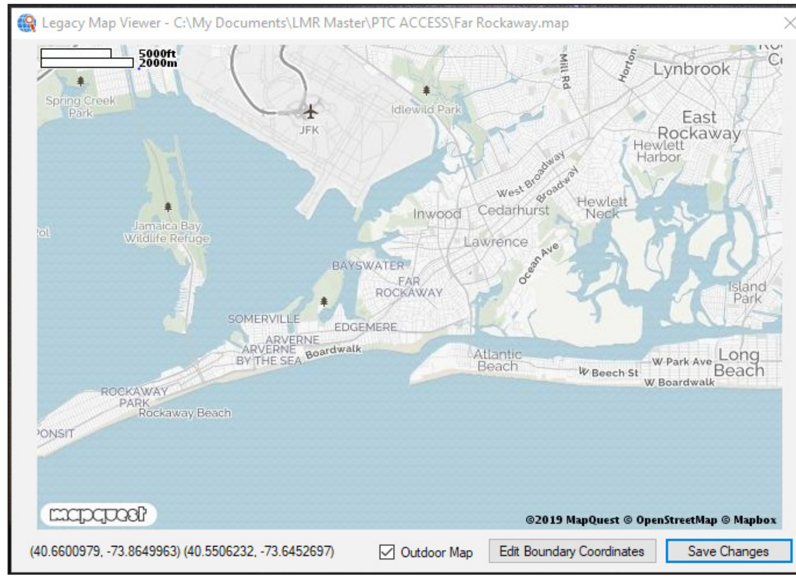

Figure 7: Anritsu easyMap Tool

Anritsu's easyMap™ tool can be used to locate the map area of interest and then convert and save the map into a format that can be loaded into Anritsu's handheld instruments – in this case the LMR Master™ S412E high-performance receiver/spectrum analyzer (Figure 7 and 8). After collecting the data with the LMR Master solution, the saved .klm file can be imported into Google Maps and the PTC ACSES data (EVM, BER, RSSI) can be displayed in a coverage heat map based on the recorded data, time, date and GPS position.

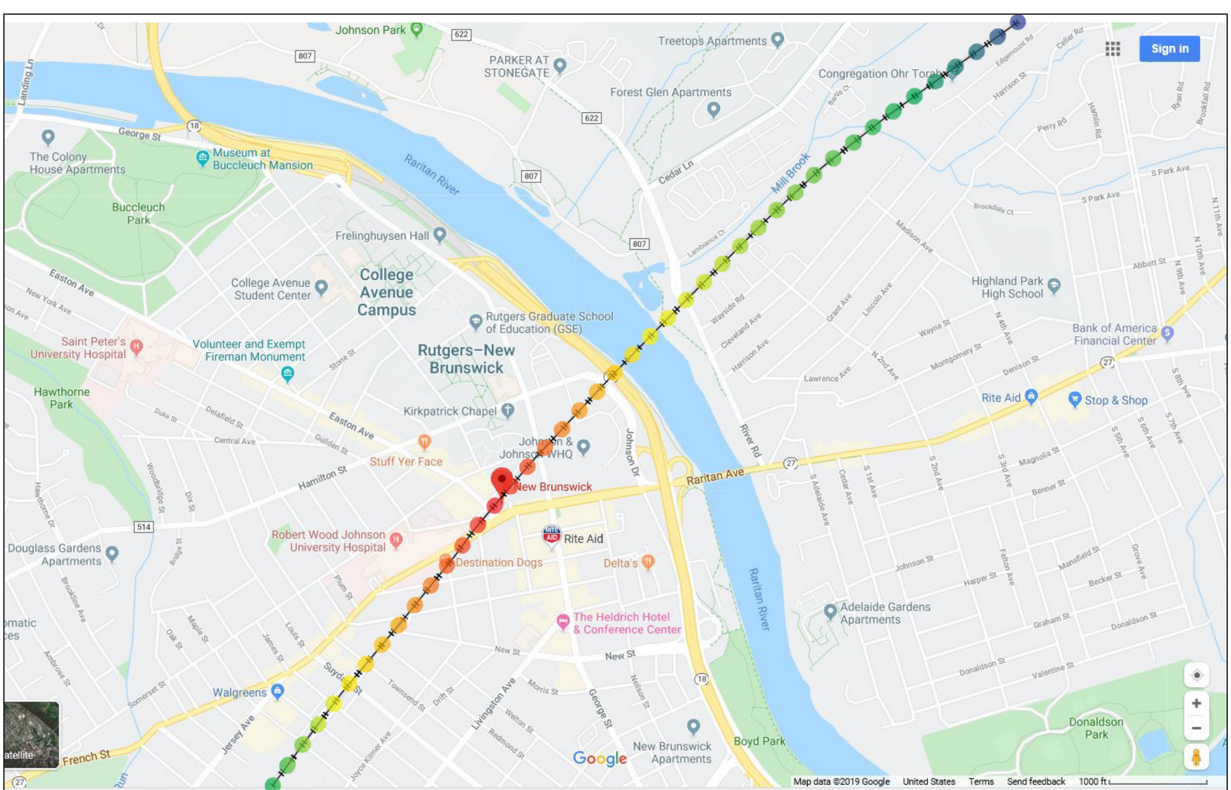

Figure 8: PTC ACSES Coverage Mapping Using Google Maps

Additional Measurements Critical to PTC ACSES Testing

When testing a PTC ACSES deployment, tools like the LMR Master S412E analyzer should also provide additional measurement options to ensure that a complete evaluation is conducted.

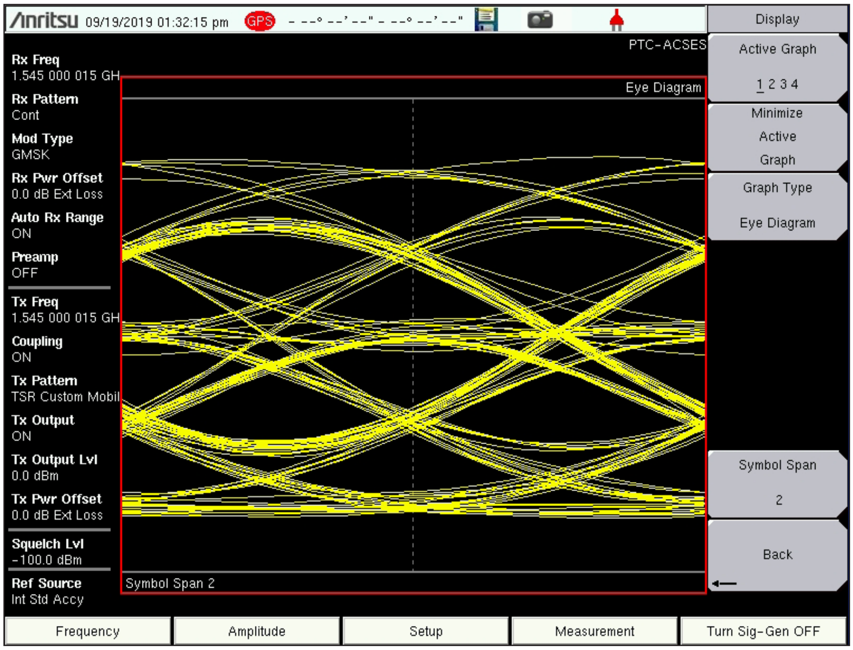

Figure 9: PTC ACSES Eye Diagram

Eye Diagram – an eye diagram provides a clear visual check on the signal integrity of the PTC ACSES signal under test (Figure 9). It is a representation of what the currently measured RF performance would do to a digital data stream (PTC ACSES). Figure 9 represents a clean eye diagram that indicates good RF performance. If there is an RF performance issue with the PTC ACSES signal, the distinctive eyes would be harder to identify since it would have more lines and look noisier, with a closed eye appearance.

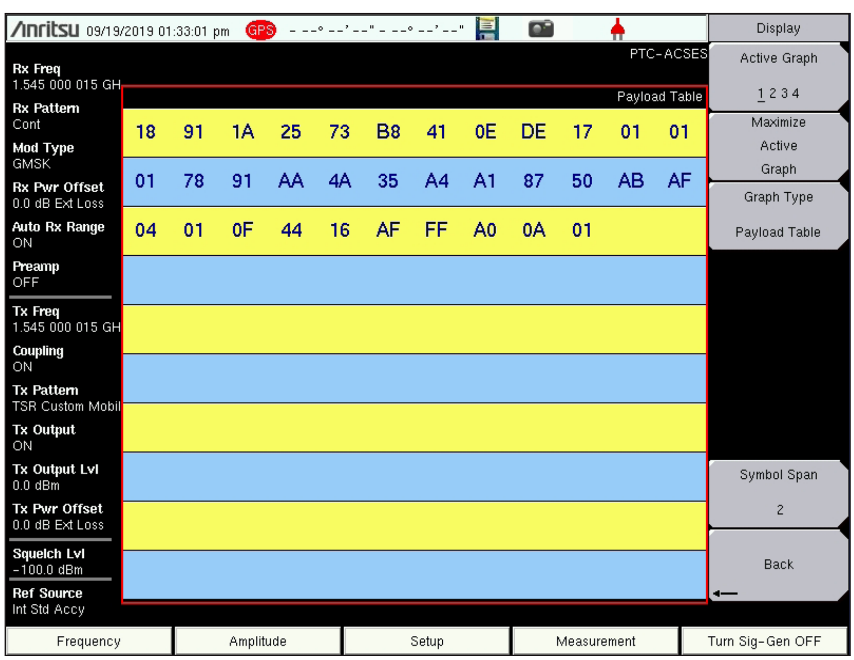

Figure 10: PTC ACSES Payload Table

Payload Table – a PTC ACSES payload table (Figure 10) displays the raw hex data collected. A railroad system engineer can then use the payload table to see if the hex messages received are the expected values from either the waypoint or mobile radio assigned to specific trains. This helps verify that the PTC ACSES response from the train is consistent with what the PTC ACSES back office system is tracking.

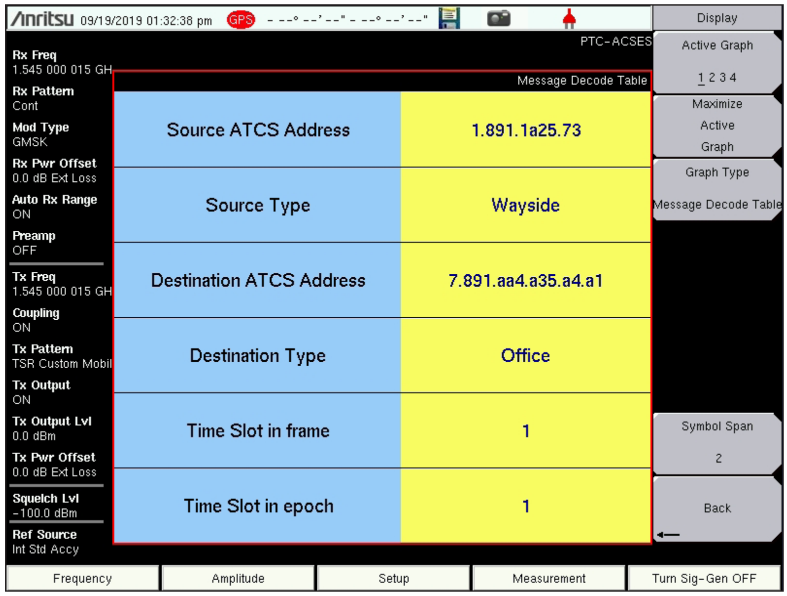

Figure 11: PTC ACSES Message Decode Table

Message Decode Table - this table helps determine what type of message is being received and transmitted by the various waypoints and mobile radios. Figure 11 displays the specific information for the source ATS address, source type, destination ATCS address, destination type, and time slot in frame and time slot in epoch, which help verify that the radios on the train or wayside (track) are sending the correct response and reply information through the PTC system.

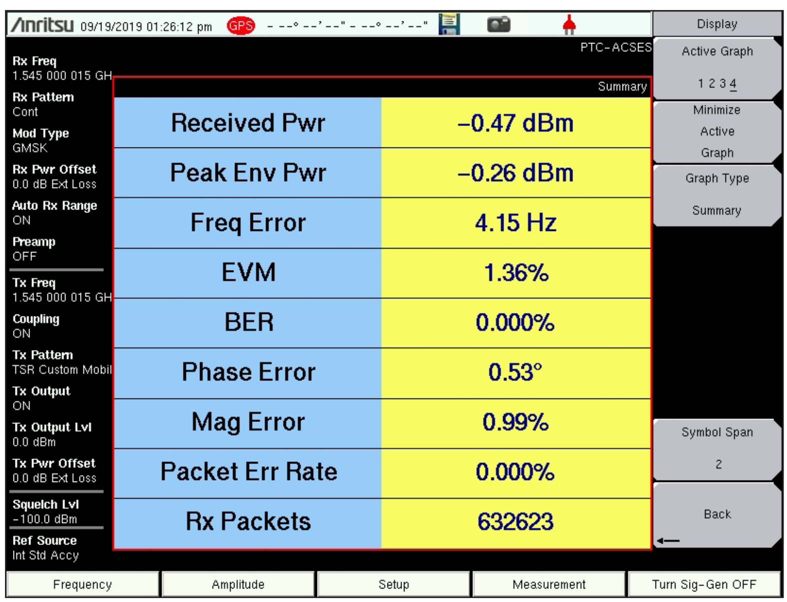

Figure 12: PTC ACSES Summary Table

Summary Table – this table displays key measured RF performance and signal quality measurements. Received power, peak envelope power, and frequency error measure RF received and transmit power as well as center frequency accuracy. It also shows key signal quality measurements including:

- EVM – a combination of two values, phase error and magnitude error, that determines the vector from ideal to actual measured value
- BER and PER - show the errors in the digital data stream; BER shows the raw bit stream errors and PER defines them at the packet level
- Phase and magnitude (Mag) error – components of the EVM measurement, phase error shows how close to the ideal location is the phase change happening (bits 1 & 0 determined) while magnitude error determines the amplitude error from ideal
- Rx Packets – this shows the number of packets received during the measurement

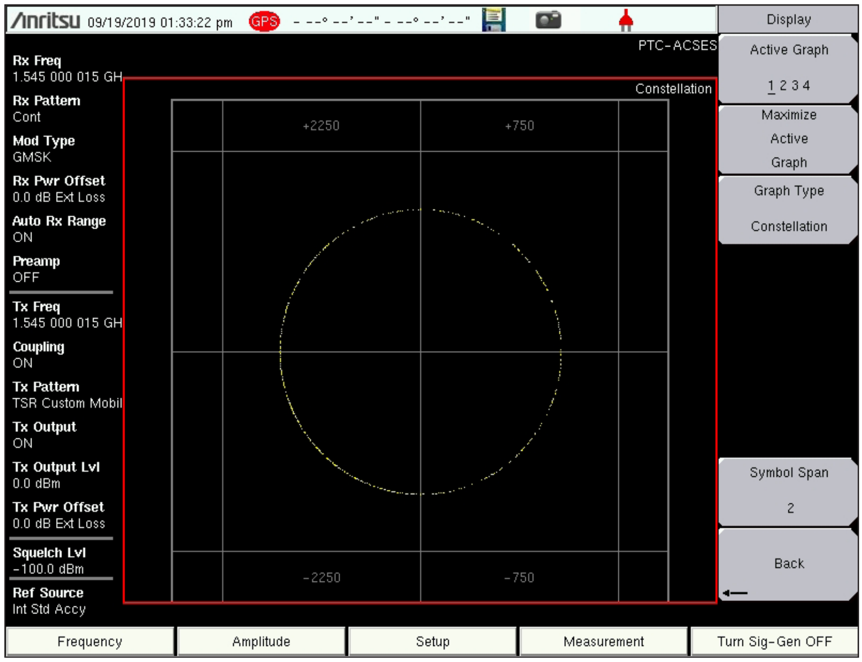

Figure 13: PTC ACSES Constellation Diagram

Constellation Diagram – shown in Figure 13, this uses Gaussian Minimum Shift Keying (GSMK) modulation and will look very similar to those familiar with GSM signals. The GMSK modulation will look like a ring, as it is only a phase shifting component. Due to the differing RF conditions over the network the system will see phase and magnitude errors, thus EVM can also be measured. If the image does not look like a ring, and you see a distorted constellation diagram with both phase and amplitude errors, this can be an indicator that there are possible modulation problems with the PTC ACSES radio. This can lead to high BER and PER errors that can mean messaging errors with that hardware. If a radio is found to have these types of issues, it's a good idea to replace it and then either be bench tested for possible troubleshooting or returned to the vendor.

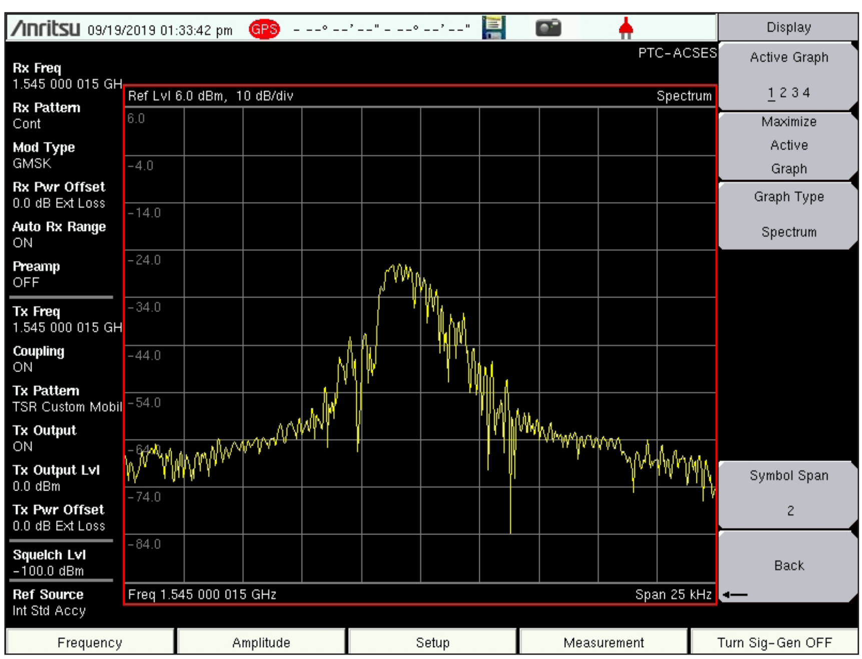

Figure 14: PTC ACSES Spectrum Display

Spectrum Display – this is optimized for the narrow span PTC ACSES signal. It is useful in determining if the engineer conducting the measurement is centered on a PTC ACSES signal and if there are any interfering signals present (Figure 14).

Summary

PTC ACSES is an important addition and mandate for rail safety that will prevent train-to-train collisions, protect against speeding, and enforce speed restrictions. With the Congressional mandate to have PTC ACSES systems fully compliant and functional by December 31, 2020, it is important for railways to perform tests to ensure their deployments meet all requirements. Anritu’s LMR Master S412E high-performance receiver/spectrum analyzer is the perfect instrument to validate PTC ACSES deployments as well as troubleshoot and maintain them to ensure they are working properly. With its multi-function capabilities, the LMR Master S412E solution has various tools available to help system engineers validate their PTC ACSES signal coverage and quality as well as provide the benefit of a signal generator to verify radio sensitivity.

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