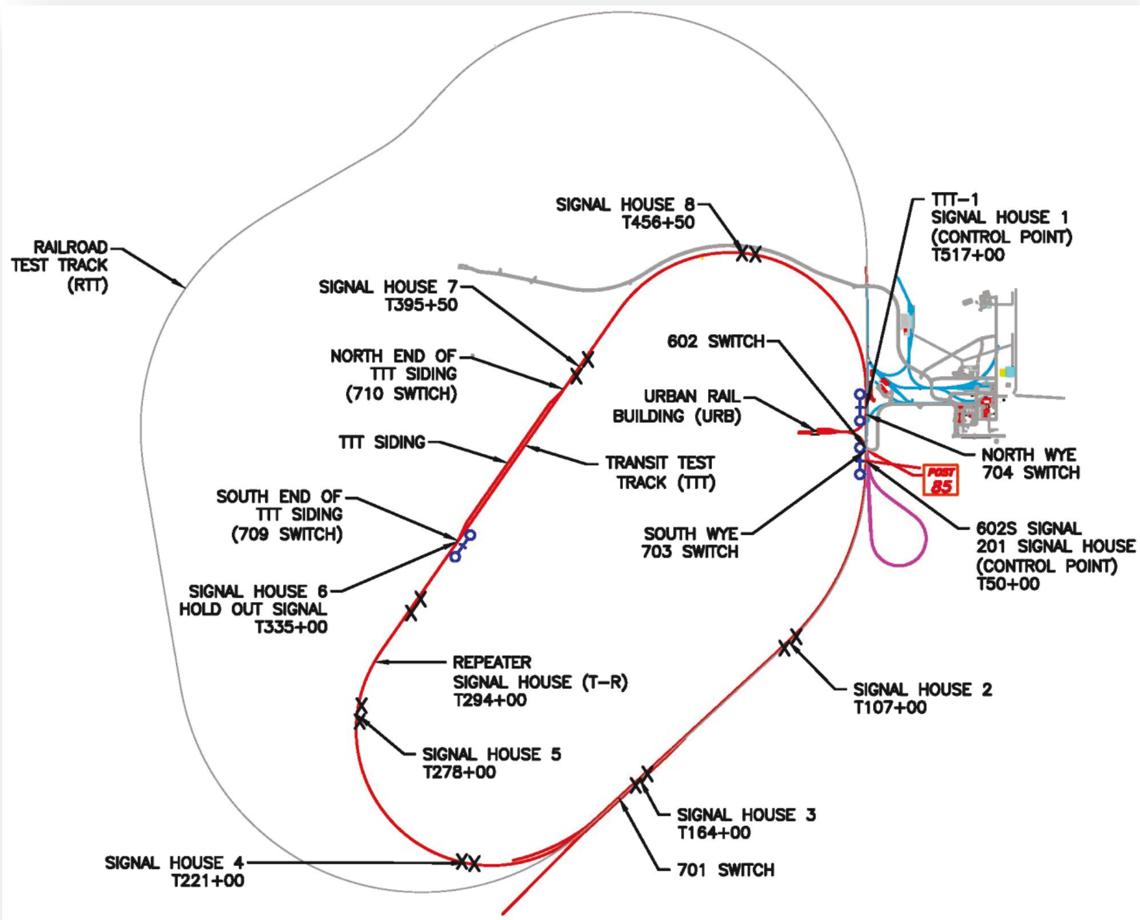
U.S. Department of Transportation

**Federal Railroad Administration**

# Signaling System and Advanced Civil Speed Enforcement System Upgrade to Transit Test Track at the Transportation Technology Center

Office of Research, Development
and Technology
Washington, DC 20590

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September 18, 2017

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13. ABSTRACT (Maximum 200 words)

The Federal Railroad Administration (FRA) and the Transportation Technology Center, Inc. (TTCI) have upgraded the Positive Train Control (PTC) Test Bed at the Transportation Technology Center (TTC) in Pueblo, CO, by adding cab signaling and Advanced Civil Speed Enforcement System (ACSES) infrastructure to the Transit Test Track (TTT). The project was conducted because of industry requests that indicated the need for a PTC Test Bed, which would use ACSES and Automatic Train Control (ATC) cab signaling on a Direct Current (DC) third rail electrified railway.

TTCI developed and implemented a design for deploying ACSES, which uses an ATC-compliant signal system with cab signaling, and ACSES transponders and track database on the TTT (which employs a DC-electrified third rail). The required structures and equipment were installed and checkouts were performed.

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| Advanced Civil Speed Enforcement System, ACSES, Audio Frequency Train Activated Circuit, AFTAC, Automatic Train Control, ATC, Control Point, Electrified Electro Code Interface, E$^2$Code, ElectroLogIXS, holdout signal, Interlocking Status Request, ISR, Permanent Speed Restriction, PSR, Positive Train Control, PTC, PTC Test Bed, Safety TSR Server, STR, Transit Test Track, TTT. | 47 |
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| 1 square yard (sq yd, yd$^2$) | = | 0.8 square meter (m$^2$) | 1 square kilometer (km$^2$) | = | 0.4 square mile (sq mi, mi$^2$) |
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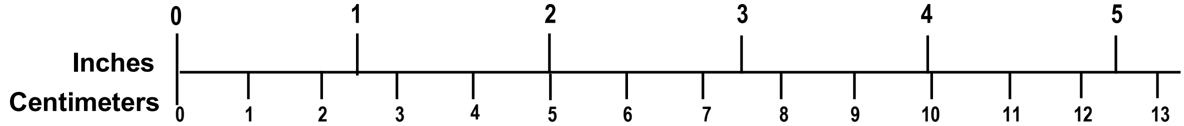


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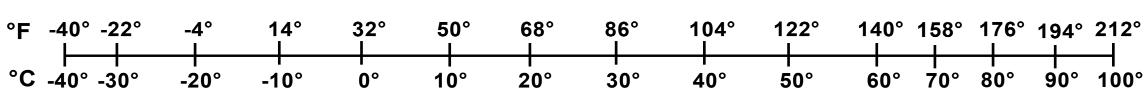


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Updated 6/17/98

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## Executive Summary

The Rail Safety Improvement Act (RSIA) of 2008 requires implementation of interoperable Positive Train Control (PTC) on the rail lines that were identified by RSIA. The scope of PTC implementation covers 60,000 miles of the national railroad network and requires significant capital expenditure.

In response to RSIA, the Federal Railroad Administration (FRA) and the Transportation Technology Center, Inc. (TTCI) have expanded the PTC Test Bed at the Transportation Technology Center (TTC) in Pueblo, CO, on the Transit Test Track (TTT). These upgrades will assist the North American railroad industry with its implementation of mandated PTC capabilities and address requests for a PTC Test Bed that uses Advanced Civil Speed Enforcement System (ACSES) and Automatic Train Control (ATC) cab signaling on a direct current (DC) third rail electrified railway.

The PTC Test Bed on the TTT provides an industry resource for testing PTC-related systems, equipment, and technologies in an environment that does not have certain constraints associated with revenue service test activities.

As developed, the PTC Test Bed at TTC provides a facility for conducting performance evaluations of PTC system segments, testing new software releases, and performing interoperability and compliance testing. For example, the PTC Test Bed can be used for proof of concept demonstrations, system development testing, and on-track (field) testing.

In 2014, FRA tasked TTCI with expanding the PTC Test Bed on the DC electrified third rail-equipped TTT. TTCI developed and implemented a design for deploying ACSES, which uses an ATC-compliant signal system to support testing of PTC systems, components, and related equipment. TTCI purchased and installed the necessary equipment and components, and successfully tested the PTC Test Bed.

A combination of system and component level testing was conducted. TTCI collaborated with Alstom and verified the proper installation of the ATC system on the PTC Test Bed. This included the verification of signal aspects, freight track codes, and cab rates operating in clockwise and counterclockwise directions. Additionally, a light-out test was conducted to confirm fail-safe logic.

TTCI implemented the required changes to components in the back office and expanded the existing ACSES Test Bed installed on the Railroad Test Track (RTT) to the TTT. An ACSES-equipped locomotive properly enforced all penalty applications and communicated with all wayside and back office equipment.

# 1. Introduction

The overall goal of Task Order (TO) 358, which was conducted under this research study, was to develop and implement a design for deploying an Advanced Civil Speed Enforcement System (ACSES) incorporating an Automatic Train Control (ATC)-compliant cab signaling component with the associated track database and stationary ACSES in-track balises, or transponders.

## 1.1 Background

The Rail Safety Improvement Act of 2008 requires implementation of interoperable Positive Train Control (PTC) on 60,000 miles of the national railroad network.

Federal Railroad Administration (FRA) and the North American railroad industry have been developing various elements for PTC systems and have been demonstrating, through system integration, various PTC system functions. To support development and testing of PTC system capabilities and resolution of PTC-related issues, FRA has guided and, along with the Transportation Technology Center, Inc. (TTCI), funded the development of a PTC Test Bed at TTC in Pueblo, CO. Recent upgrades to the PTC Test Bed at TTC have greatly enhanced the capabilities necessary to support field testing of PTC communications, interoperability, functionality verification, and performance. The PTC Test Bed has, from its initial deployment, allowed for PTC testing with trains independently powered (e.g., by diesel fuel) or powered by overhead catenary. However, industry requests indicated the need for the PTC Test Bed to handle applications involving ACSES and ATC cab signaling on direct current (DC) third rail electrified railway.

The PTC Test Bed on the Transit Test Track (TTT) was developed to provide an industry resource for testing PTC-related systems, equipment, and technologies in an environment free of certain limitations associated with revenue service test activities.

Compliance with the requirements associated with testing a PTC system on revenue service routes can present testers with significant challenges. Examples of challenges include the following:

- Scheduling test activities around revenue service traffic
- Obeying all operating rules or obtaining waivers (frequently a lengthy process)
- Dealing with difficulties associated with conducting stress testing (i.e., degraded equipment or high capacity performance testing)
- Experiencing operational challenges with obtaining repeatable results
- Changing vital equipment (requires lengthy verification and validation processes before retest is possible in a revenue environment)
- Conducting tests that may present unsafe conditions in a revenue service environment

Among other uses, the PTC Test Bed provides a facility that can be used for supporting development of PTC systems, conducting performance evaluations of PTC system components, and performing interoperability and compliance testing. Interoperability refers to the ability of a controlling locomotive to communicate with and respond to the host railroad’s PTC system, including uninterrupted movements over property boundaries. Examples of PTC system development might include proof of concept demonstrations, system development testing, simulations, and on-track (field) testing. Other examples of potential PTC Test Bed uses, from the past and present, include the following:

- Preliminary field trials and debugging of PTC systems
- Development and testing of improved PTC braking algorithms
- Evaluation of the impact of communications system performance and loading on PTC system performance
- Development and testing of PTC positive end of train determination systems
- Development and testing of PTC train location systems
- Over-the-air testing of PTC-related communications devices and capabilities
- Demonstrating the operation of advance activation highway crossing protection systems
- Certification and acceptance testing of PTC systems or components
- Interoperability and interchange testing of multiple PTC systems

Modifications to the PTC Test Bed have enabled it to support more generalized PTC testing, such as for interoperability, functionality verification, and performance and stress characterization.

## 1.2 Organization of the Report

This report is organized in four major sections:

*Section 1* is the introduction, which includes background on the PTC Test Bed.

*Section 2* discusses the project scope, overall approach, and the system design.

*Section 3* provides a summary of milestones and describes the upgrades in more detail.

*Section 4* provides a brief conclusion.

# 2. Project Overview

## 2.1 Scope

The scope of this project focused on the design and implementation of an ACSES deployment that uses an ATC-compliant signal system with cab signaling, and ACSES transponders and track database on the DC third rail electrified TTT. The system design included a 5-aspect cab signaling system, provided by Alstom, which also has the potential capability of operating as a 4-aspect freight signal system. The wayside signal cases contain the electronics required for 4-aspect freight signaling for the potential need in the future, but it has been configured for cab signaling mode for the purposes of this project.

## 2.2 Overall Approach

The overall approach and major tasks performed were as follows:

- Collaborated with appropriate system suppliers of ATC and ACSES systems for system design specifying signal block lengths and intermediate signal locations, location of holdout signal, and placement of ACSES transponders.
- Installed infrastructure and ground work including grounding for signal houses and trenching for communications and power cables.
- Installed insulated joints, impedance bonds, track wires, signal houses, and ACSES mounting hardware.
- Installed signal houses and connection of power and communications equipment.
- Installed signaling equipment to the signal houses (providing broken rail detection, switch monitoring, and ATC cab signaling).
- Modified signaling system at Control Points at the existing crossover to the RTT.
- Installed ACSES transponders and communication infrastructure for the TTT from the back office to existing base station locations.
- Installed and configured the TTT ACSES track database within the existing back office server.
- Developed and executed the system validation plan, completed system and component level testing, and provided a test description and supporting data.

## 2.3 Signal System Design

TTCI collaborated with Alstom to develop the signal system design. The TTT was divided into nine signal blocks, and the following design was established on the TTT at TTC. Figure 1 maps the signal system design elements.

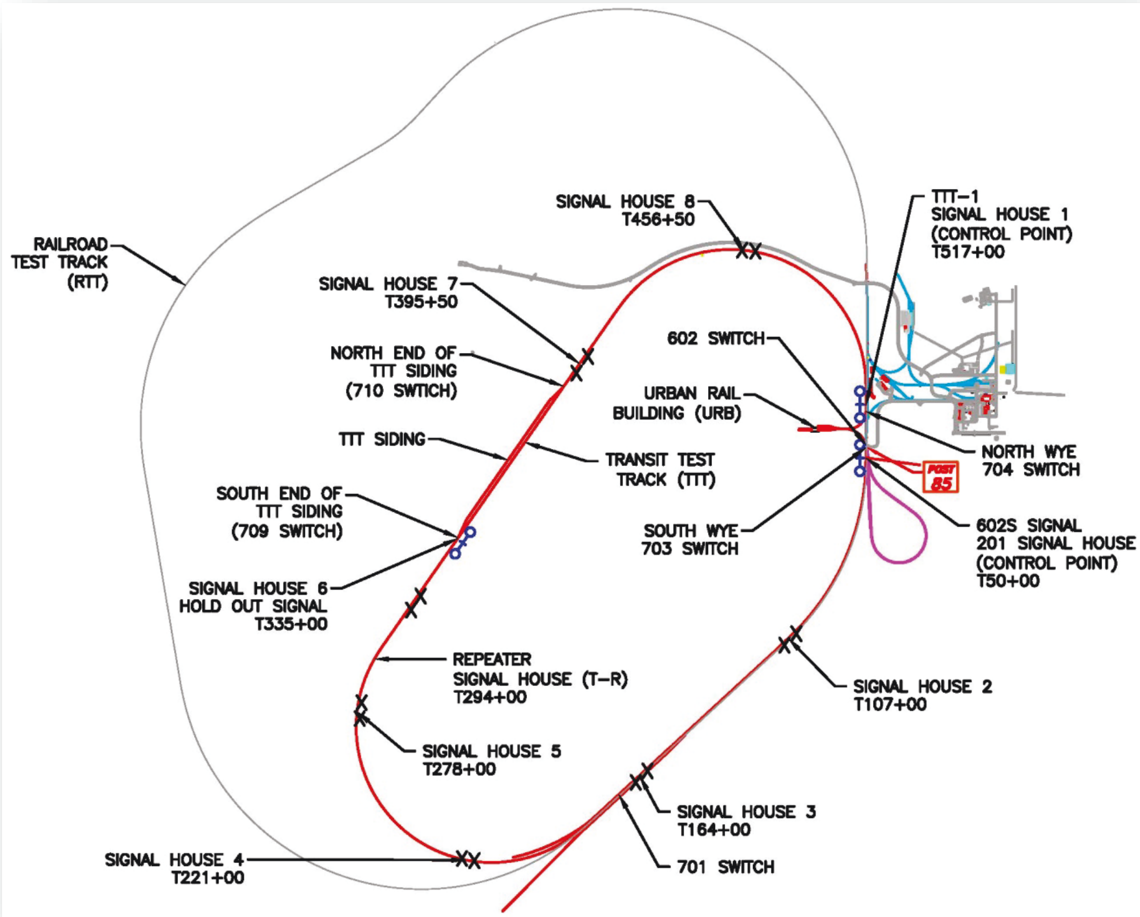


**Figure 1. Design Reference Figure**

Traveling clockwise, the system has five signal blocks between the 201 Signal House, located near T50+00 (T5), and the Holdout Signal at T335+00 (T33.5). The Holdout Signal is located approximately 50 feet south of the south end of the TTT siding. The five signal blocks between these two locations are 5,700 feet each, except for the signal block located between Signal House 5 and the Repeater Signal House.

To accommodate the ground return to the DC substation, a signal repeater was placed at approximately T294+00 (T29.4). The distance from Signal House 5 to the Repeater Signal House is 1,600 feet, and the distance from the Repeater to the Holdout Signal is 4,100 feet.

Continuing clockwise from the Holdout Signal, the next signal block was placed approximately 800 feet north of the TTT siding at T395+50 (T39.5), which resulted in the block being 6,050 feet. The subsequent two signal blocks are 6,100 feet to the TTT-1 Signal located near Signal House 1 at T517+00 (T51.7). The final block, which encompasses the limits of the Control Point interlocking, is located between T51.7 and T5, and is 1,422 feet long.

From the design provided by Alstom, the TTT-1 Signal, previously located near T520+00 (T52), and the 602S Signal, previously located near T46+20 (T4.6), needed to be relocated. Originally, these signals were used to control movement that occurred between the RTT and the TTT. The two signals were relocated and placed on the opposite sides of the 703 and the 704 switches that control movement into and out of the wye track that leads to the Urban Rail Building (URB) and now controls movement through the new Control Point. The TTT-1 Signal, located near Signal House 1, was relocated 300 feet north of its former location to T51.7 and the 602S signal, located near the 201 Signal House, was relocated 380 feet south of its former location to T5.

The location of the Holdout Signal at T33.5 is on the opposite side of the TTT from the new Control Point. The location of the Holdout Signal is feasible and can be turned into a Control Point in the future if it is decided to signal the TTT siding.

Signal Houses 2, 3, 4, 5, 7, and 8 are intermediate signal locations and have Alstom provided equipment. The signal houses are located at the following approximate locations on the TTT:

- Signal House 2 – T107+00 (T10.7)
- Signal House 3 – T164+00 (T16.4)
- Signal House 4 – T221+00 (T22.1)
- Signal House 5 – T278+00 (T27.8)
- Signal House 7 – T395+50 (T39.5)
- Signal House 8 – T456+50 (T45.6)

The cab signal system design for the TTT uses a single carrier frequency with varying code rates to indicate different signal aspects. Table 1 shows the code rates and indications for the TTT.

**Table 1. TTT Signal Aspects and Code Rates**

| Aspect | Code Rate | Indication |
|---|---|---|
| Clear (125) | 180/- | Clear to proceed at maximum track speed |
| Cab Speed (60) | 270/- | Clear to proceed and not to exceed 60 mph |
| Approach Limited | 120/- | Prepare to diverge at prescribed turnout speed |
| Approach | 75/- | Proceed and prepare to stop at next signal; train exceeding 40 mph, reduce speed to 40 mph immediately |
| Stop | -/- | For holdout signals and Control Points, stop and do not proceed; for intermediates signals, stop and proceed at restricted speed |

## 2.4 Signal System Installation

From the initial design developed by TTCI and Alstom, TTCI categorized the equipment and installation requirements for this project by location. To meet the requirements, TTCI completed the following:

I. Signal House 1 – Control Point_TTT-1 (T51.7)
   a. Excavated and prepared the ground
   b. Placed concrete slab foundation
   c. Relocated the TTT-1 signal and insulated joints 300 feet north from their former locations
      i. Installed a new signal foundation, positioned the TTT-1 signal mast, and placed the required signal head
   d. Purchased, installed, and grounded the signal house
   e. Pulled power and communications to the signal house
   f. Installed insulated joints at the 704 turnout
   g. Installed a derail at the 704 turnout
   h. Installed track wire
   i. Installed impedance bonds
   j. Installed the 704 switch controller
   k. Installed terminal boards
   l. Installed battery, battery charger, and power distribution hardware and wiring
   m. Moved the Audio Frequency Train Activated Circuit (AFTAC) II 2.3KHz receiver board and the AFTAC II 38Hz subtone board from Signal House 302 to Signal House 1
   n. Installed equipment provided by Alstom
      i. Prewired equipment rack
      ii. AFTAC II Receiver chassis
      iii. ElectroLogIXS
      iv. Two Electrified Electrocode Systems
   o. Installed Alstom application software and worked with Alstom on checkout of system

II. Signal House 2, 3, 4, 5, and 8 – Intermediate Signal Locations (TTT Location – T10.7, T16.4, T22.1, T27.8, T45.6)

a. Excavated and prepared the ground
b. Placed concrete slab foundation
c. Purchased, installed, and grounded the signal house
d. Pulled power to signal house
e. Installed insulated joints
f. Installed track wire
g. Installed impedance bonds
h. Installed terminal boards
i. Installed battery, battery charger, and power distribution hardware and wiring
j. Installed equipment provided by Alstom
    i. Prewired equipment rack
    ii. ElectroLogIXS
    iii. Two Electrified Electrocode Systems
k. Installed Alstom application software and worked with Alstom on checkout of system

III. Repeater Signal House_T-R (T29.4)

a. Excavated and prepared the ground
b. Placed concrete slab foundation
c. Purchased, installed, and grounded the signal house
d. Pulled power to signal house
e. Installed insulated joints
f. Installed track wire
g. Installed impedance bonds
h. Installed terminal boards
i. Installed battery, battery charger, and power distribution hardware and wiring
j. Installed equipment provided by Alstom
    i. Prewired equipment rack

    ii. ElectroLogIXS
    iii. Two Electrified Electrocode Systems

  k. Installed Alstom application software and worked with Alstom to checkout the system

IV. Signal House 6_Holdout Signal (T33.5)

  a. Excavated and prepared the ground
  b. Placed concrete slab foundation
  c. Purchased, installed, and grounded the signal house
  d. Pulled power and communications to the signal house
  e. Installed signal foundation, mast, and required signals
  f. Clamped and locked the 709 Switch in normal position
  g. Installed insulated joints
  h. Installed track wire
  i. Installed impedance bonds
  j. Installed the 709 switch controller
  k. Installed a permanent derail to prevent fouling of the TTT track
  l. Installed terminal boards
  m. Installed battery, battery charger, and power distribution hardware and wiring
  n. Installed equipment provided by Alstom
    i. Prewired equipment rack
    ii. 9-slot ElectroLogIXS
    iii. Two electrocode systems
  o. Installed Alstom application software and worked with Alstom on checkout of system

V. Signal House 7_TTT siding – north end (T39.5)

  a. Excavated and prepared the ground
  b. Placed concrete slab foundation
  c. Purchased, installed, and grounded the signal house
  d. Pulled power to signal house
  e. Clamped and locked the 710 Switch in the normal position

f. Installed a permanent derail to prevent fouling of the TTT track
g. Installed the 710 switch controller
h. Installed insulated joints
i. Installed track wire
j. Installed impedance bonds
k. Installed terminal boards
l. Installed battery, battery charger, and power distribution hardware and wiring
m. Installed equipment provided by Alstom
    i. Prewired equipment rack
    ii. 4-slot ElectroLogIXS
    iii. Two Electrified Electrocode systems
n. Installed Alstom application software and worked with Alstom on checkout of system

VI. Signal House 602 Modifications
a. Installed equipment provided by Alstom
    i. Two cab signal generators
b. Installed Alstom application software and worked with Alstom on checkout of system

VII. Signal House 302 Modifications
a. Added a yellow and green B-head LED signal to the 101 and 302 signal
b. Wired the signal heads into the existing Rack 1
c. Added a new AFTAC II transmitter board to the existing AFTAC II chassis
d. Installed insulated joints near the 704 derail
e. Installed track wires

VIII. Signal House 85 Modifications
a. Installed insulated joints to the 703 turnout
b. Installed a derail to the 703 turnout
c. Moved the AFTAC II 2.3KHz transmitter box to Signal House 201
d. Installed a new AFTAC II transceiver for the 703 track circuit

IX. Signal House 201 Modifications

   a. Relocated the TTT 602 signal and insulated joints 380 feet south from its former location
      i. Installed a new signal foundation, positioned the TTT 602 signal mast, and placed the required signal heads
   b. Installed insulated joints
   c. Installed track wire
   d. Installed impedance bonds
   e. Installed the 703 switch controller
   f. Installed terminal boards
   g. Installed battery, battery charger, and power distribution hardware and wiring
   h. Installed equipment provided by Alstom
      i. Prewired equipment rack
      ii. AFTAC II Receiver chassis
      iii. ElectroLogIXS
      iv. Two Electrified Electrocode Systems
   i. Installed the AFTAC II 2.3KHz transmitter box from House 85
   j. Wired the signal head into the ElectroLogIXS in Rack 1
   k. Installed Alstom application software and worked with Alstom on checkout of system

X. Manual Switch Locations (Screech Loop, etc.)

   a. Installed insulated joints
   b. Installed impedance bonds
   c. Installed the 701 switch controller
   d. Installed track wires
   e. Installed a permanent derail to prevent fouling of the TTT track

## 2.5 ACSES System Design and Installation

Typical ACSES territory is equipped with transponders informing the passing locomotives of the current block's civil speed limits, permanent speed restrictions (PSR), and distant signal communication information. Track charts and required ACSES site information were provided to Siemens to update the back-office server track database. Eleven transponder pairs were installed on the TTT and five additional pairs were installed on track entering/exiting the TTT (shown and represented by a "XX" in Figure 1). Transponder pairs were placed near each signal house and two transponder pairs were placed at each interlocking location for the system to identify if the passing locomotive is entering/exiting the interlocking. The five additional pairs of transponders were installed at the TTT crossover to the RTT, near the north and south wye to the URB, and on each end of the TTT siding.

The ACSES system for the TTT was designed, developed, and implemented for all directions of travel. Additional system information, shown below, addresses communication, monitoring of signals and switches, and how the track is defined in the track database.

- Direction of travel
    - Up direction references traveling with an increasing milepost
    - Down direction references traveling with a decreasing milepost
    - Up direction is clockwise dictated as Signal 1
    - Down direction is counterclockwise dictated as Signal 2
- Track database
    - TTT is Track 2 as defined per the track database, which allows TTCI the capability to add and transmit temporary speed restrictions (TSR) to ACSES equipped locomotives
- Communications
    - System designed to provide information to request interlocking statuses (IS) and TSRs
        - Base station information
        - Wayside Interface Unit (WIU) information
        - Radio frequency information
        - Associated railroad information

# 3. Detailed Design and Installation

TTCI enhanced the existing capabilities of the PTC Test Bed at TTC by completing the signal and ACSES system design and installation on the DC third rail electrified TTT. The installation included specifying signal block lengths and intermediate signal locations, the location of the Holdout Signal, an upgraded Control Point at the RTT/TTT crossover, and the placement of ACSES transponders. Additional equipment necessary for installation included insulated joints, impedance bonds, track wires, signal masts and signal heads at the holdout location, additional signal heads at the TTT/RTT Control Point, signal houses, Alstom prewired equipment racks, batteries, and battery chargers. There were four existing locations that required equipment upgrades and nine locations that required new equipment to complete the PTC Test Bed improvements. The following sections describe the process for completing these enhancements.

## 3.1 Excavation and Groundwork

Each of the nine new sites were prepared and cleared of all obstructions and vegetation before the concrete slab foundations could be poured. The necessary areas were excavated, and layers of structural fill were placed to a depth of 18 inches to provide a consistent base before the construction of the foundations. To avoid differential compaction, each layer could not exceed 9.0 inches. The structural fill was water compacted with a powered tamper to achieve maximum compaction and optimum moisture content. See Figures 2 and 3 for Nuclear Gauge Density Tests (compaction tests) completed at each site by Kleinfelder.

| | | | Field | | | | Laboratory | | | | Specifications | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Test No. | Probe Depth, in. | Approximate Location | Depth Below FSG, ft | Wet unit Weight Pcf. | Dry Unit Weight, Pcf. | Water Content | Proctor No. | Lab Maximum Dry Density, pcf | Optimum Water Content % | Relative Comp. % | Specified Min. Compaction % | Specified Min Water Content % | Specified Max. Water Content % |
| 1 | 8 | Signal House #3 | Gr. | 129.4 | 125.1 | 3.4 | S3325 | 130.9 | 7.8 | 95 | 95 | N/A | N/A |
| 2 | 8 | Signal House #2 | Gr. | 131.2 | 126.6 | 3.6 | S3325 | 130.9 | 7.8 | 96 | 95 | N/A | N/A |
| 3 | 8 | Signal House #4 | Gr. | 128.5 | 123.4 | 4.1 | S3325 | 130.9 | 7.8 | 94 | 95 | N/A | N/A |
| 4 | 8 | Signal House #5 | Gr. | 122.4 | 117.7 | 4.0 | S3325 | 130.9 | 7.8 | 90 | 95 | N/A | N/A |
| 5 | 8 | Signal House #6 | Gr. | 128.4 | 124.4 | 3.2 | S3325 | 130.9 | 7.8 | 95 | 95 | N/A | N/A |
| 6 | 8 | Signal House #7 | Gr. | 127.4 | 123.2 | 3.4 | S3325 | 130.9 | 7.8 | 94 | 95 | N/A | N/A |

**Figure 2. Nuclear Gauge Density Tests for Signal Houses 2, 3, 4, 5, 6, and 7**

| | | | Field | | | | Laboratory | | | | Specifications | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Test No. | Probe Depth, in. | Approximate Location | Depth Below FSG, ft | Wet unit Weight Pcf. | Dry Unit Weight, Pcf. | Water Content | Proctor No. | Lab Maximum Dry Density, pcf | Optimum Water Content % | Relative Comp. % | Specified Min. Compaction % | Specified Min Water Content % | Specified Max. Water Content % |
| 7 | 8 | SIGNAL HOUSE #8 | Gr. | 129.5 | 125.3 | 4.2 | 3325 | 130.9 | 7.8 | 96 | 95 | N/A | N/A |
| 8 | 8 | SIGNAL HOUSE #9 | Gr. | 1290 | 124.9 | 3.3 | 3325 | 130.9 | 7.8 | 95 | 95 | N/A | N/A |
| 9 | 8 | SIGNAL HOUSE #1 | Gr. | 129.3 | 125.8 | 3.5 | 3325 | 130.9 | 7.8 | 96 | 95 | N/A | N/A |

**Figure 3. Nuclear Gauge Density Tests for Signal Houses 1, 8, and 9**

### *3.1.1 TTT Access Road Improvements*

It was determined that road improvements were needed for ease of access to meet the needs of installation and maintenance to each of the sites. Road improvements were completed in the following locations:

- From T20 to T25
- From T45 to T50.5

See Figures 4 and 5 for the condition of the TTT access road before and after road improvements.

**Figure 4. TTT Access Road Before Road Improvements**

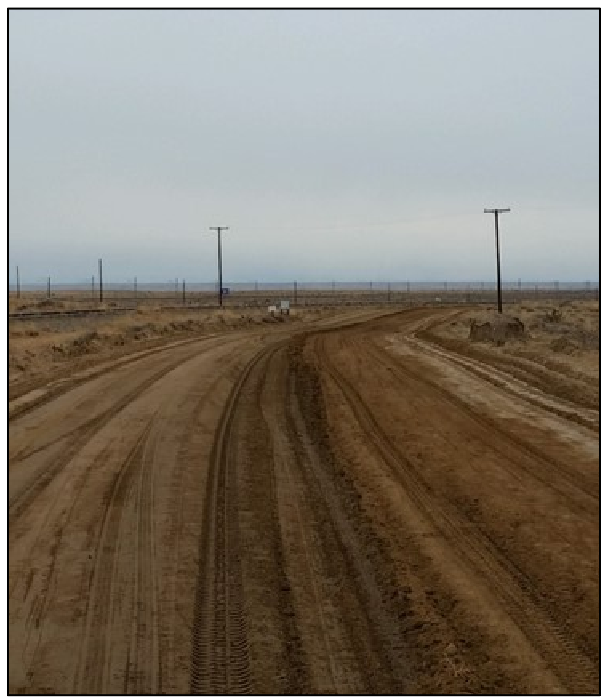

**Figure 5. TTT Access Road After Road Improvements**

## 3.2 Concrete Slab Foundations

Once excavation and groundwork was completed, 13-foot by 25-foot by 6-inch concrete slabs were placed with temperature and shrinkage reinforcing steel. The concrete mix for each slab met the minimum requirement of 4,000 pounds per square inch (psi). Figure 6 depicts one of the completed concrete slabs.

**Figure 6. Concrete Slab Foundation**

## 3.3 Signal Houses

The signal houses were ordered from Zircon Container Company; each signal house is 8-foot by 20-foot by 8.5-foot. Since the signal houses weigh approximately 6,500 pounds and to allow 4.5 feet of walking area near the office and storage doors, each signal house was offset on the reinforced concrete slabs as seen in Figure 7 and 8, and were placed with the office door facing away from the TTT.

## 3.4 Erosion Control Measures

Recycled erosion control measure material was placed at each signal house location; see Figure 8. Once the signal houses were installed and grounded, the erosion control material was spread to a 1-foot wide by 4-inch deep area around the concrete foundation.

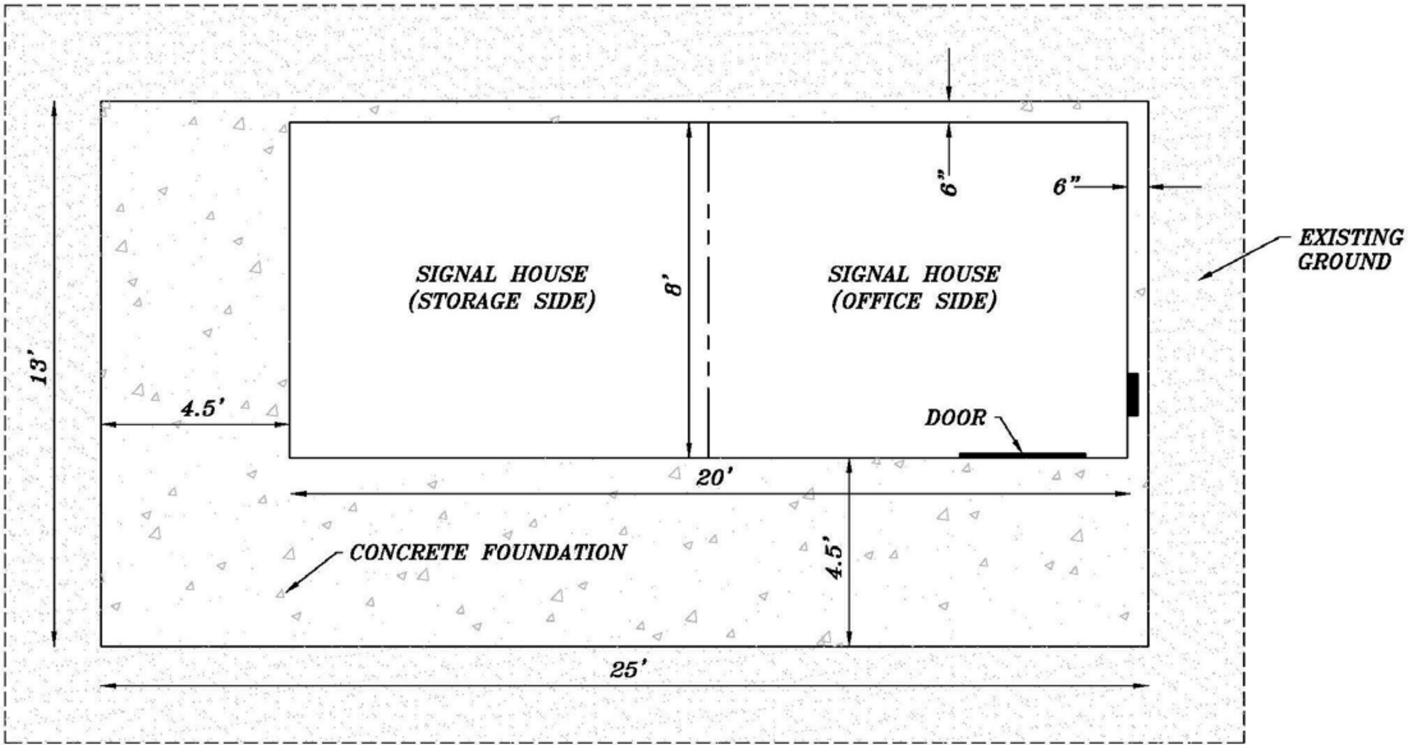


**Figure 7. Placement and Dimensions of Signal Houses**

**Figure 8. Signal House and Erosion Control Material**

## 3.5 Power and Communications

The placement of the signal houses and equipment required the installation of primary and secondary power to the nine installed signal house locations. The following was installed:

- Approximately 4,700 feet of single phase 7,967V (Volts) and 2,400V Delta primary power in 2-inch conduit
- Approximately 6,900 feet of single phase 7,967V Delta primary power on overhead power poles
- Approximately 600 feet of single phase aluminum conductor steel-reinforced cable (ACSR) 7,620V Wye primary power on overhead power poles
- Eight 25 KVA (kilo volt-ampere) transformers and 240/120V secondary power to the signal house locations

Additionally, fiber optic communications was required and installed. Fiber optic cable was installed in 2-inch conduit to the Holdout Signal, Signal House 6, located at T33.5 and to the Control Point, Signal House 1, located at T51.7.

## 3.6 Insulated Joints and Impedance Bonds

Insulated joints and DC impedance bonds were installed on the TTT to establish the track signal blocks; see Figure 9. Appendix A contains aspect charts provided by Alstom that show locations of all insulated joints and impedance bonds.

**Figure 9. Installation of Insulated Joints and Impedance Bonds**

## 3.7 Control Point, Holdout Signal, Intermediate Signal Locations

New signal houses were installed at T10.7, T16.4, T22.1, T27.8, T29.4, T39.5, and T45.6 for housing the intermediate signal equipment. The new signal house located at T51.7 and the 201 Signal House, located near T5, contain the upgraded Control Point equipment for the RTT/TTT crossover, and the new signal house at T33.5 houses the Holdout Signal equipment. Alstom equipment racks, and equipment for block communications and control of the signal aspects located at T51.7, T5, and T33.5 were designed, purchased, and installed. Figures 10, 11, and 12 show the installation of the signal stands that support the required signal heads and cover both clockwise and counterclockwise travel. Clockwise travel is monitored at the Control Point, Signal House 1 at T51.7, and counterclockwise travel is monitored at the Control Point, 201 Signal House at T5. The signal stand located near T33.5, Holdout Signal, covers both clockwise and counterclockwise travel.

**Figure 10. Signal Stand Installation at T51.7 (Control Point)**


**Figure 11. Signal Stand Installation at T5 (Control Point)**

**Figure 12. Signal Stand Installation at T33.5 (Holdout Signal)**

## 3.8 Block Signaling

As previously stated, the signal houses on the TTT contain the electronics required for 4-aspect freight block signaling that provides broken rail and track occupancy detection should the need arise in the future to add signal masts and lights.

## 3.9 Signal Equipment

Alstom material and equipment racks were installed in the signal houses around the TTT as shown in Figure 13. Along with the equipment, TTCI received, reviewed the project responsibilities, and completed the installation of all signaling equipment per the site drawings in Appendix A.

**Figure 13. Signal House Equipment Rack**

### *3.9.1 Equipment*

TTCI installed prewired signaling equipment racks provided by Alstom. Rack layout drawings, wiring diagrams, track and signal plans, aspect charts, and other information related to the equipment racks are included in Appendix A. A brief description of the main components in the equipment racks is provided below.

### 3.9.1.1 ElectroLogIXS

The ElectroLogIXS, shown in Figure 14, is a main component of all equipment racks placed in the signal houses around the TTT, except for the equipment rack located in the 201 Signal House. The ElectroLogIXS is capable of ground fault detection, train detection, broken rail detection, light out protection, approach lighting control, alternating current (AC) power off detection, cab signal output control, track switch controller protection (with vital two-wire inputs), and home relay drives for release of electric locked switches. The ElectroLogIXS sends and receives coded pulses through the track at each end of the block. DC track circuits are used to input and export code pulses on and off the track. To detect trains, the tracks are used as conductors. The ElectroLogIXS devices placed at both ends of the control block use the coded pulses to communicate with each other and synchronize the systems to alternately send and receive data in both directions. The hardware protection and software detection schemes are used to guarantee that the communications and system signaling are reliable.

Train signaling is accomplished through sequential control and illumination of track-side aspects. Information that is received within the ElectroLogIXS consists of coded signals from the track circuits, inputs from relay contacts or other solid-state devices with digital outputs. Reliable inputs are read and processed by several microprocessors that provides reliable control outputs.


**Figure 14. ElectroLogIXS**

### 3.9.1.2 Electrified Electro Code Interface

Figure 15 shows the Electrified Electro Code Interface, which is used to transfer DC signals from the Electro Code into coded AC tone burst signals for the electric track circuits. Bidirectional code pulses, at 156 Hz, are used within the Electrified Electro Code. Bidirectional code pulses provide track integrity and signaling information. Transmitted tone bursts are produced across the rails, and the track circuit is terminated by using insulated joints and impedance bonds. The Electrified Electro Code is always used in conjunction with an Electro Code, given that it uses proven track concepts that are used in DC-coded track to electrified traction territory.

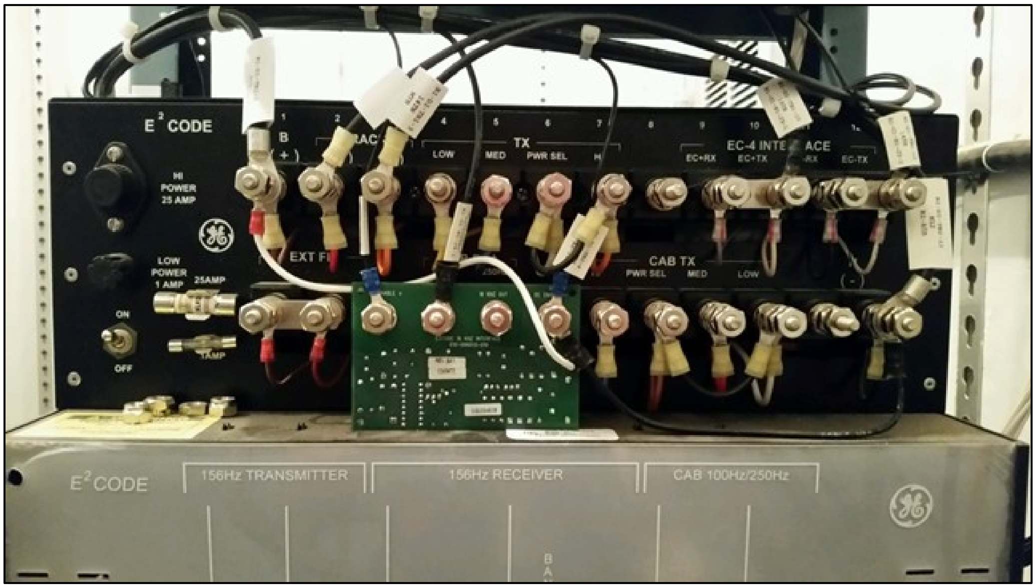


**Figure 15. Electrified Electro Code Interface**

#### *3.9.1.3 Audio Frequency Train Activated Circuit – Model II (AFTAC II)*

Located at Signal House 1 and the 201 Signal House, the AFTAC II is a frequency modulation (FM) audio overlay system. The system was designed to take the place of the existing circuits that are controlling the warning devices at a highway/railroad grade crossing. The AFTAC II indicates whether a train is occupying a track circuit and is installed to monitor turnouts and main line at Control Point locations.

The AFTAC II system is a multifaceted system that has a receiver and a transmitter within the same compact enclosure. The system has a reduced amount of required modules; the internal subtone oscillator can be transferred from the transmitter module to the subtone converter module simply by changing a wire jumper inside the enclosure that permits the signal maintainer to replace a defective subtone converter module with a different frequency module. This can be accomplished without changing the transmitter module; thus, the AFTAC II cabinet can be used as a single transmitter, a single receiver, one transmitter and one receiver, or as two receivers; see Figure 16.


**Figure 16. AFTAC II**

#### *3.9.1.4 Cab Signal Generator*

Two cab signal generators were installed in the 602 Signal House. Cab signal generators receive pulse width modulated (PWM) coded input signals from wayside equipment. The cab signal generators modulate the signal onto low frequency AC carriers, which produce cab signals; see Figure 17.


**Figure 17. Cab Signal Generator**

### *3.9.2 ATC Signal System Testing*

A combination of system and component level testing was conducted to verify proper installation on the PTC Test Bed. Initially, the existing RTT signal system's software was updated to integrate the new Control Point and movement that occurs between the RTT and the TTT into the logic to ensure proper system communication. The signal blocks on the TTT were calibrated using a railroad tester multimeter that provides a wide range of electrical measurements. The signal blocks were calibrated to transmit and receive between 4.5 and 5 volts for block signaling, and between 2.5 and 3.75 amps for ATC cab signaling. Track Input Simulator (TIS) boxes, designed to transmit and receive E-Code and Electrocode track circuit signals, were temporarily used to test all of the track signals and the logic. TIS boxes were used to simulate freight track codes and to verify that the Control Point and Holdout Signal aspects associated with each signal code were correct. TTCI and Alstom also verified that the signal aspects, freight track codes, and cab rates were working in the clockwise and counterclockwise directions on the TTT, per the TTT aspect charts provided in Appendix A. Furthermore, a light out test was conducted to confirm fail-safe logic.

## 3.10 ACSES Design

ACSES is a PTC system primarily used on the Northeast Corridor (NEC) designed to work in conjunction with the ATC Cab Signal system to prevent:

- Train-to-train collisions
- Overspeed derailments
- Unauthorized incursions into an established work zone
- Movement through a main line switch in the improper position

To support additional types of testing, the existing ACSES Test Bed installed under TO 314 [1] was expanded to the TTT under TO 358. The TTT offers the ability to test with third rail power in addition to the existing catenary system installed on the RTT.

The following subsections describe the back office, wayside, and onboard segments used by the ACSES design on the TTT.

### *3.10.1 ACSES Back Office Segment*

TO 358 required changes to components in the back office segment to support ACSES operations on the TTT. Those changes were made to the Field Simulator providing Interlocking Status Messages (ISM) and to the Safety TSR Server (STS) emulator used to report TSRs.

The Field Simulator is a modeling program developed by Wabtec, formerly Convergent Communications Inc. (CCI), used to accurately represent Wayside Interface Units (WIUs) in revenue service. Upon request, the Field Simulator provides Interlocking Status (IS) information by monitoring switch and signal indications to ACSES-equipped locomotives. The Onboard Computer (OBC) uses the ISM to either override or enforce the Positive Train Stop (PTS) at the interlocking in question.

Under TO 314, TTCI worked with CCI to complete the Field Simulator's configuration and message routing requirements. The configuration and routing information allows the Field Simulator to receive Interlocking Status Requests (ISRs) from a locomotive and transmit ISMs back to the same locomotive. Under TO 358, TTCI updated the Field Simulator to include the TTT and the WIU that monitors its interlocking. Figure 18 shows a screen shot of the Field Simulator including the TTT. The image shows the TTT being cleared from left to right through the interlocking (shown by the green track) while being monitored by "Encoder 6."

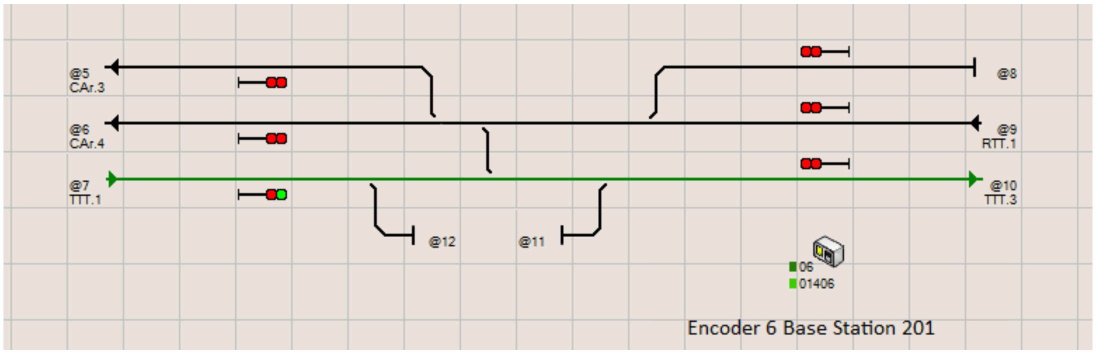


**Figure 18. TTT Field Simulator**

The STS emulator provides the ACSES back office functionality by storing and transmitting all TSR data to the requesting locomotive. Like the Field Simulator, the STS emulator was configured under TO 314 to receive and transmit all TSR information to the locomotive. TO 358 required TTCI to update the track database to include the TTT. To accomplish this objective, TTCI provided Siemens with:

- TTT track charts for grade and location information
- Train type specific civil speeds
- PSRs
- WIU and radio address information
- PTS information

Siemens compiled the data and provided TTCI an updated track database file including the TTT. Figure 19 shows the layout of the ACSES TTT track database. A key for the figure is provided below:

- Grey Boxes – Transponder
- Red Lines – Track
- IXL – Interlocking location
- DS – Distant signal (transponders informing locomotive of upcoming IXL)
- Yellow Box – PSR information per train type
- Speed Restriction Curve – transponder informing locomotive of upcoming speed reduction
- Track Location – Provided in feet and miles

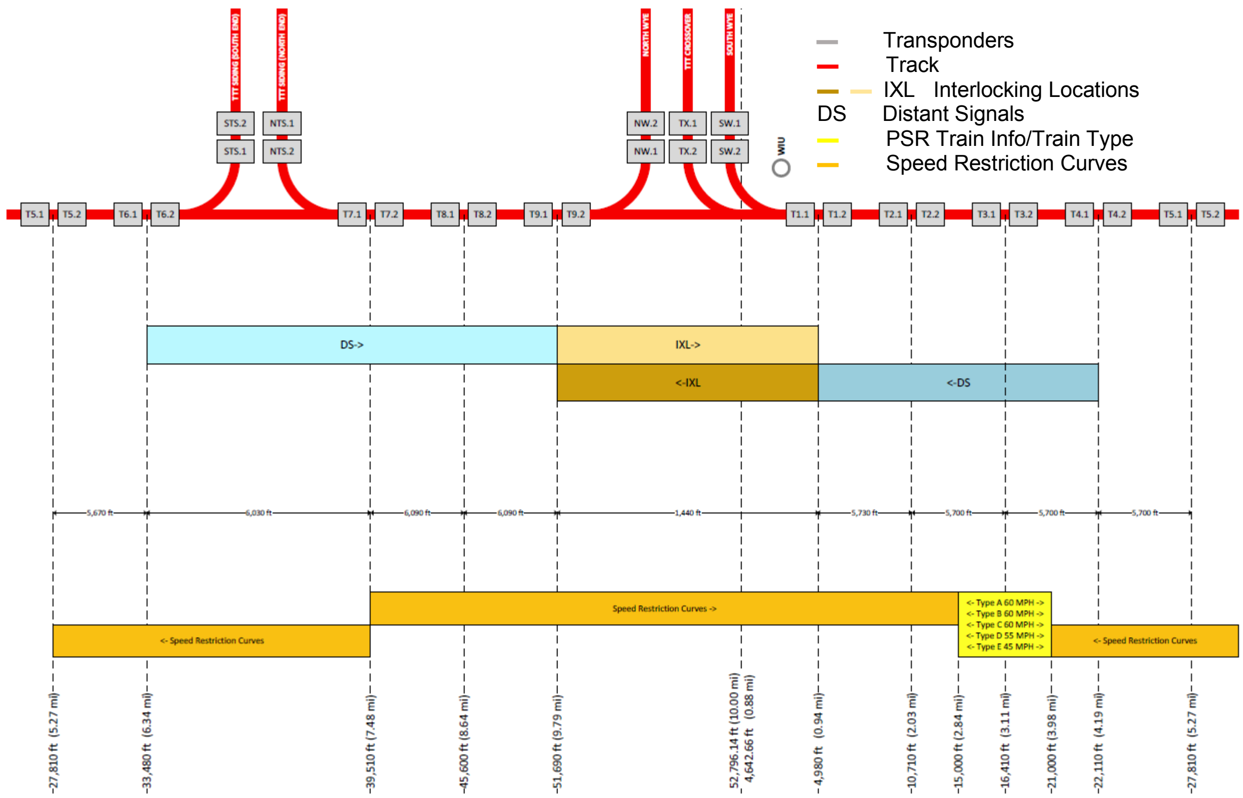


**Figure 19. ACSES TTT Track Database Layout**

The TTT Track Database description can be seen in Appendix B.

### 3.10.2 ACSES Wayside Segment

This section describes the changes made to the wayside infrastructure and use of existing components that provide the capability to support ACSES operations on the TTT. The wayside segment at TTCI includes transponders and communications network.

### 3.10.3 Transponders

Transponders are passive devices designed to transmit track and PTC information to ACSES-equipped locomotives. Figure 20 shows a pair of transponders installed at TTC.

**Figure 20. Transponder Pair**

The transponder track locations are dictated by the TTT track database installed in the STS emulator. The database required nine pairs of transponders on the TTT and five pairs of transponders on track to exit or enter the TTT. The five transponder pairs located on exit/entrance track locations automatically cut-out or cut-in the ACSES system if leaving or entering ACSES-equipped territory. The nine pairs of transponders on the TTT provide additional track and system information including:

- Location information
- Linking distance to the next set of transponders Safety Server Emulator
- Civil speed information per train type
- Radio information for ISRs and Temporary Speed Restriction Requests (TSRRs)

The TTT civil speeds including PSRs per train type on the TTT are provided in Table 2.

**Table 2. ACSES Train Types**

| Train Type | Description | Line Speed on TTT | PSR on TTT |
|---|---|---|---|
| A | High speed trainset with tilting | 70 mph | 60 mph |
| B | High speed trainset without tilting | 70 mph | 60 mph |
| C | Commuter rail | 70 mph | 60 mph |
| D | Locomotive with mail/express | 65 mph | 55 mph |
| E | Freight operations | 50 mph | 45 mph |

Once TTCI received the TTT track database from Siemens, the STS emulator was used to extract each transponder Cyclic Redundancy Check (CRC) file required for programming. The transponder programmer, Figure 21, was purchased on a project and provided TTCI the ability to program and install the transponders onsite.


**Figure 21. Transponder Programmer**

Additional information detailing the layout and information programmed into each transponder installed on the TTT can be found in the Transponder Database Layout Description document in Appendix B.

### *3.10.4 Communications Network*

During the ACSES Test Bed installation on TO 314, TTCI installed the communication infrastructure used for ACSES testing independent of the track being used. The two primary components included a wireless network and fiber optic back haul network to the back office.

The wireless network provided the communication link to and from the locomotive for both TSR and IS information. ACSES II was initially developed using a 900 MHz wireless network and was later updated to the 220 MHz network with the implementation of PTC. To support both methods of communication, TTCI installed two 900 MHz and two 220 MHz base stations during the performance of TO 314. The 900 MHz base stations consist of EF Johnson Viking VX 900-MHz LTR Repeater radios and operate on channel 3 of the Advanced Train Control System (ATCS) network. Channel 3 defines base station transmissions at 935.9875 MHz and receives transmissions at 896.9875 MHz. The 220 MHz base stations operate General Electric (GE) TD220-MHz radios transmitting and receiving messages at 219.275 MHz. Each base station provides sufficient coverage to support testing on both the RTT and TTT at TTC.

The fiber optic back haul network connects the base stations to the BO through the Office Communication Manager (OCM). The OCM routes all ACSES messages to and from the base stations and BO programs. Figure 22 shows a high-level block diagram of the ACSES communication network and routes for TSR and IS information.

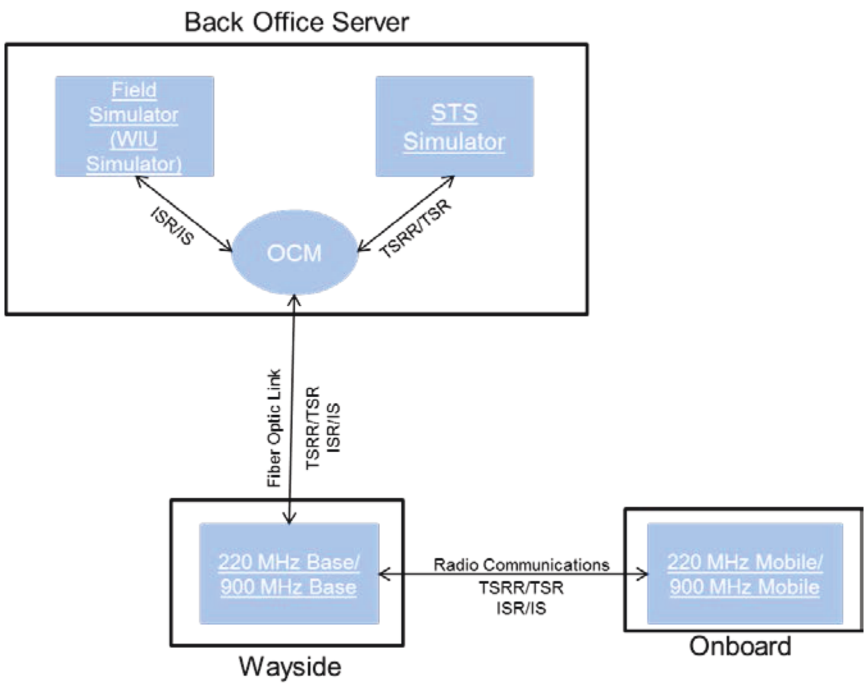


**Figure 22. High-Level ACSES Communication Architecture**

### *3.10.5 ACSES Onboard Segment*

The ACSES onboard segment provided by Siemens includes the OBC, axle generator, Aspect Display Unit (ADU), transponder scanner antenna, track receivers, and radio communication equipment. TTCI equipped two locomotives with the vital onboard ACSES equipment under TO 314. These locomotives were unchanged and used to validate the system installation on the TTT.

## 3.11 ACSES Checkout Testing

This section provides a test description and the supporting data used to verify the TTT ACSES installation. The information is organized into three sections: test description, ACSESView data, and CabView data. The test description section describes the method in which TTCI verified proper installation of ACSES and ATC system components. The ACSESView section gives an overview of the program and ACSES data gathered from TTT testing. Finally, the CabView section provides an overview of the program and ATC data gathered from TTT testing.

### *3.11.1 Test Description*

A combination of system and component level testing was used to verify proper ACSES installation on the TTT. Items that were tested include:

- Transponder information
- Transponder location
- PTS location
- PTS message override

- PSR location
- Warning and braking curve calculations
- ISM and TSR messages
- ATC cab signal functionality

Component level testing was conducted on transponders to verify that programmed messages were transmitted at optimal signal strength. This testing was completed before installing them on the TTT.

The remaining items were verified through system level testing on the TTT. Data was gathered while an ACSES equipped locomotive completed three successful laps in both the clockwise and counterclockwise directions.

### *3.11.2 ACSESView Data*

ACSES data collected during testing was reviewed using Siemens' ACSESView software. ACSESView provides a Graphical User Interface (GUI) to monitor or troubleshoot the system. For this section, data will be provided from the transponder message window, radio message window, and braking curve graph within the program's display options.

Transponder information was verified using the transponder message window as seen in Figure 23. This window provides the decoded transponder messages that correspond to the Track Database file seen in pages 8-15 of Appendix B. Figure 23 relates to Transponder T8.1 and T8.2 on page 12 of Appendix B.

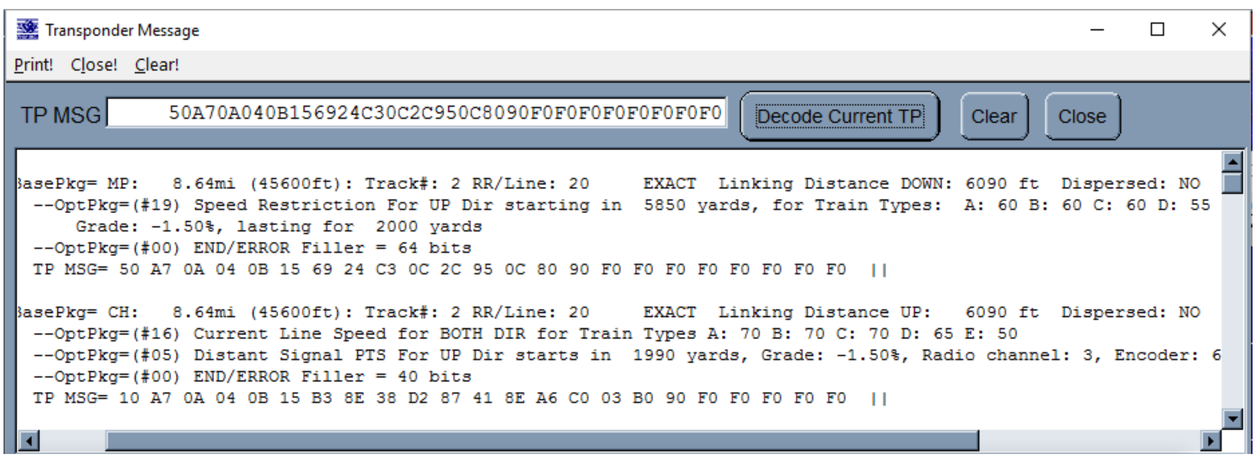


**Figure 23. Transponder Reading**

The remaining transponders were successfully read by the locomotive and will be seen in the braking curve graph (see below).

ISM and TSR messages were monitored using the radio message window in ACSESView. This window displays all transmitted and received radio messages as seen in Figure 24.

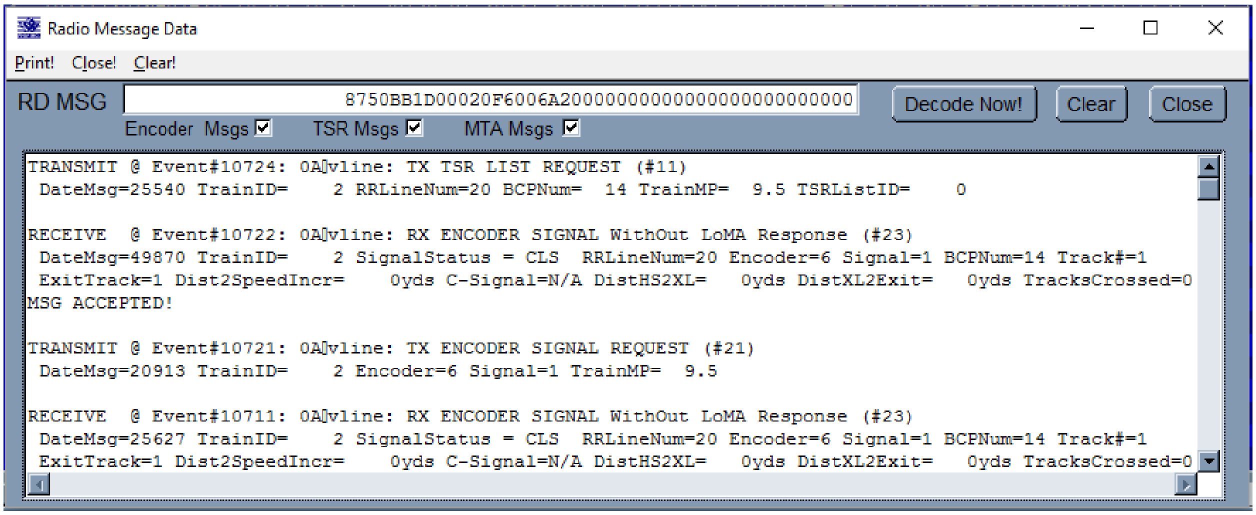


**Figure 24. ACSES Radio Communications**

Figure 24 shows the locomotive's ISRs seen as "TX Encoder Signal Request," received ISM seen as "RX Encoder Signal," and TSRR seen as "TX TSR List Request." In this instance, the received ISM provides the PTS override message seen as the "SignalStatus – CLS" informing the locomotive it is cleared through the interlocking at line speed. The locomotive additionally received the TSR list and was seen as "RX TSR List Response," but it is not shown in the figure. The radio message window showed that the transponders successfully triggered ACSES radio communications around the TTT.

The braking curve graph window was used to verify the remaining test items: transponder locations, PTS location, PSR location, and warning and braking curve calculations. Table 3 provides an additional description of the variables within the legend seen in the braking curve graphs in Figures 25 and 26.

**Table 3. Graph Variable Description**

| Variables | Description |
|---|---|
| X-Axis | Milepost |
| Y-Axis | Speed |
| Speed | Locomotive speed |
| Track Limit | Track speed allowed for train type |
| Alert Curve | Speed at which audible alert is sounded for civil speed limits |
| Brake Curve | Speed at which a penalty brake is applied for civil speed limits |
| PTS Alert Curve | Speed at which audible alert is sounded for a PTS |
| PTS Brake Curve | Speed at which a penalty brake is applied for a PTS |
| PTS Target | Location of the PTS |
| Link Target | Location the system expects to pass a transponder set |
| Transponder (TP) Set | Actual location of transponder set after locomotive has passed |

Figure 25 shows a successful lap completed in the clockwise direction on the TTT and is read from left to right. The X axis is used to track the train's location in reference to the milepost. The Y axis tracks the train speed in miles per hour. The graph first verifies the location of transponders by comparing the Link Target and TP Set. The locations of the actual transponder readings (TP Set) match the locations of the expected transponder locations (Link Target) verifying proper installation for all transponder sets on the TTT.

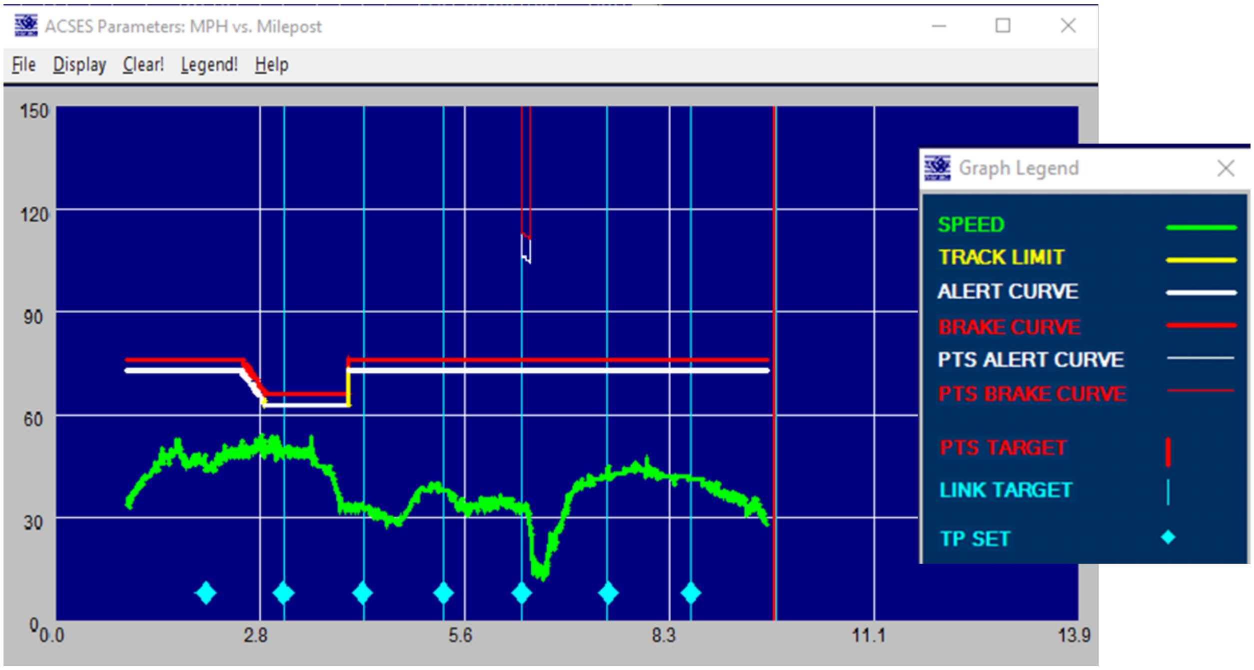


**Figure 25. Braking Curve Graph – Clockwise Direction**

The second item verified by the braking curve graph is the PTS location. The PTS location is related to the PTS Target illustrated by the vertical red line near Milepost 10 in Figure 25. Upon receiving the PTS information from transponders in track, the onboard segment successfully set the PTS target before the Control Point's absolute signal and began calculating a PTS alert and braking curve. The alert and braking curves are removed near Milepost 6 after the system successfully received an ISM with a PTS override.

The final item verified by Figure 25 was the PSR location. As the locomotive approached Milepost 2.8, the onboard segment successfully calculated the alert and braking curves before the start of the PSR. PSR information was obtained from the in-track transponders and properly enforced the train-dependent speed restriction between Mileposts 2.8 and 4.0.

ACSES testing was complete once the ACSES-equipped locomotive successfully verified all items in the counterclockwise direction. Figure 26 shows the braking curve graph for the successful counterclockwise test lap and is read from right to left.


**Figure 26. Braking Curve Graph – Counterclockwise Direction**

### *3.11.3 CabView Data*

ATC cab signal data collected during testing was reviewed using Siemens' CabView software. CabView provides a GUI to monitor or troubleshoot the system. For this section, data is provided from the Display Input/Output (I/O) Window.

The CabView program was used to review the data obtained while testing in the clockwise and counterclockwise directions. The Display I/O Window provides the cab signal information being received by the locomotive's track receivers and can be seen in Figure 27.

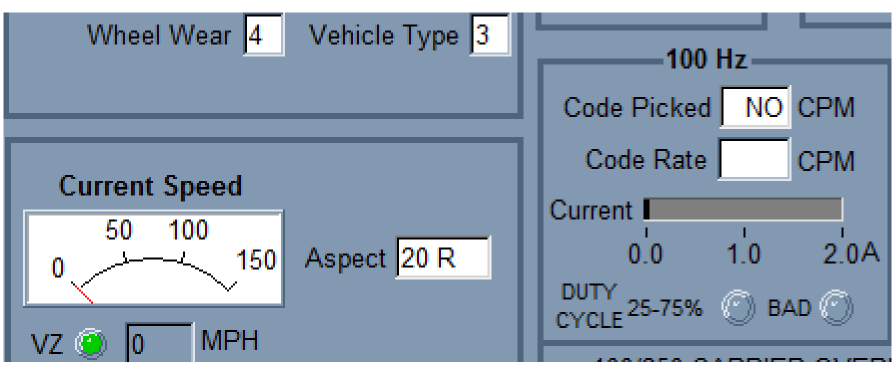


**Figure 27. Display I/O Window**

Figure 28 provides the code picked and the signal strength of the frequency obtained from the rail. The locomotive successfully obtained all frequencies as designed while operating clockwise and counterclockwise around the TTT. The TTT cab signal system uses a single 100 Hz carrier frequency with code rates relating to four signal aspects: Clear 125, Cab Speed 60, Approach, and Restricted. Figure 28 shows the locomotive successfully reading the Clear 125 signal by receiving code 180.

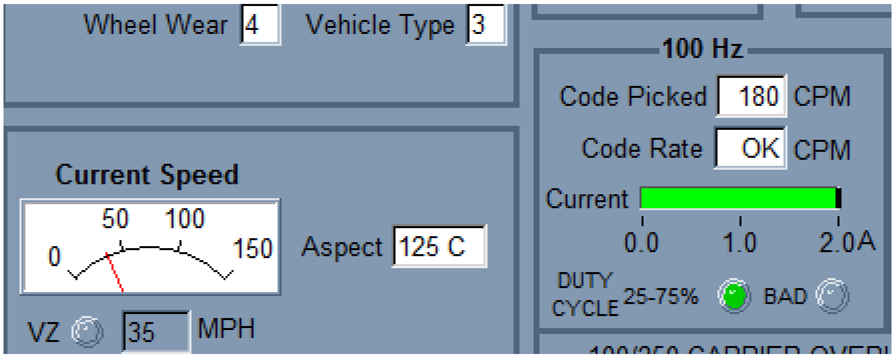


**Figure 28. Clear 125 Signal**

Figure 29 shows the locomotive successfully reading the Cab Speed 60 Signal by receiving code 270.

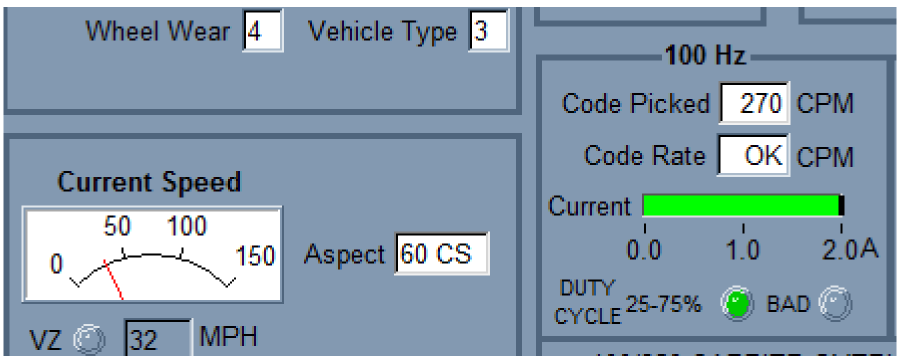


**Figure 29. Cab Speed 60 Signal**

Figure 30 shows the locomotive successfully reading an Approach Signal by receiving code 75.

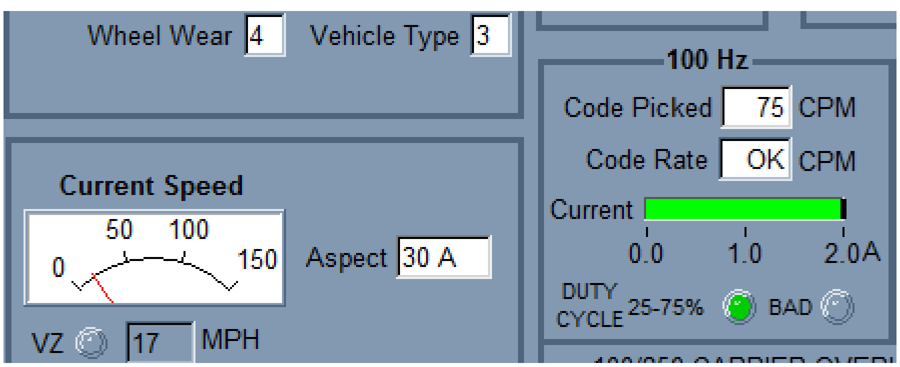


**Figure 30. Approach Signal**

Figure 31 shows the locomotive successfully reading a Restricted Signal by receiving a no code.

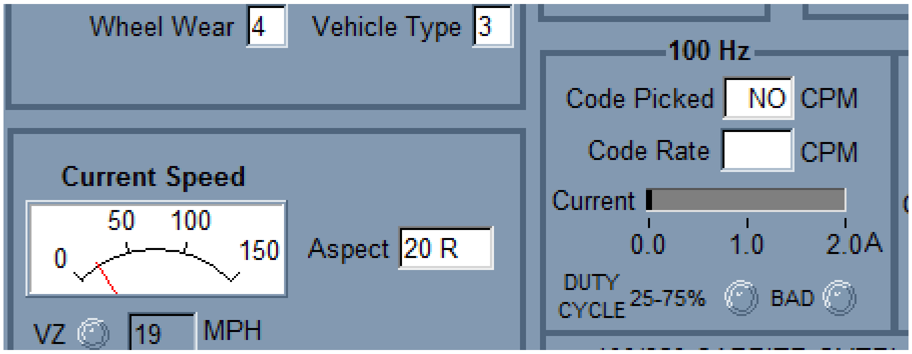

Figure 31. Restricted Signal

# 4. Conclusion

Under FRA's Task Order 358, TTCI successfully expanded the PTC Test Bed on the DC third rail electrified TTT by implementing an ACSES system that uses an ATC-compliant signal system to support testing of PTC systems, components, and related equipment to represent conditions found in a revenue service environment. TTCI acquired and installed the necessary components and equipment including insulated joints, impedance bonds, signal masts and heads, transponders, and prewired signaling equipment racks.

System and component level testing was conducted to verify proper installation of equipment on the PTC Test Bed. TTCI, with the support of Alstom, demonstrated that the ATC-compliant signal system functioned according to the documents provided by Alstom. TTCI successfully implemented the required changes for the expanded ACSES Test Bed. An ACSES-equipped locomotive properly enforced all tested penalty applications and communicated with all wayside and back office equipment, effectively meeting the requirements of Task Order 358.

# 5. References

1. Sheehan, R., Gacnik, J., Gage, S., Morgan, R. (June 2015). PTC Test Bed Upgrades to Provide ACSES Testing Support Capabilities at Transportation Technology Center. DOT/FRA/ORD-15/22, Contract DTFR 53-11-D-00008, Task Order 314, Federal Railroad Administration, Washington, DC. Available at: https://www.fra.dot.gov/eLib/details/L16480#p1_z5_gD_lRT_y2015_m6.

## Abbreviations and Acronyms

| | |
|---|---|
| AC | Alternating Current |
| ACSES | Advanced Civil Speed Enforcement System |
| ACSSR | Aluminum Conductor Steel-Reinforced |
| ADU | Aspect Display Unit |
| AFTAC | Audio Frequency Train Activated Circuit II |
| ATC | Automatic Train Control |
| ATCS | Advanced Train Control System |
| CCI | Convergent Communications Inc. |
| CPM | Continuous Phase Modulation |
| CRC | Cyclic Redundancy Check |
| DC | Direct Current |
| DS | Distant Signal |
| FM | Frequency Modulation |
| FRA | Federal Railroad Administration |
| GE | General Electric |
| GUI | Graphical User Interface |
| I/O | Input/Output |
| IS | Interlocking Status |
| ISM | Interlocking Status Message |
| ISR | Interlocking Status Request |
| IXL | Interlocking Location |
| KVA | Kilo Volt-Ampere |
| NEC | Northeast Corridor |
| OBC | Onboard Computer |
| OCM | Office Communication Manager |
| PSI | Pounds per Square Inch |
| PSR | Permanent Speed Restriction |
| PTC | Positive Train Control |
| PTS | Positive Train Stop |
| PWM | Pulse Width Modulated |

| | |
|---|---|
| RTT | Railroad Test Track |
| STS | Safety TSR Server |
| TIS | Track Input Simulator |
| TO | Task Order |
| TP | Transponder |
| TSR | Temporary Speed Restriction |
| TSRR | Temporary Speed Restriction Request |
| TTC | Transportation Technology Center (the site) |
| TTCI | Transportation Technology Center, Inc. (the company) |
| TTT | Transit Test Track |
| URB | Urban Rail Building |
| V | Volt |
| WIU | Wayside Interface Unit |

# Appendix

- Appendix A – (Alstom Aspect Chart), *internal document provided by* Alstom. Available at https://www.fra.dot.gov/eLib/Details/L19018.
- Appendix B – (Transponder Database Layout Description – TTT Loop), *internal document provided by Siemens*. Available at https://www.fra.dot.gov/eLib/Details/L19019.