U.S. Department of Transportation

**Federal Railroad Administration**

# High Accuracy Global Positioning System Upgrades at Transportation Technology Center

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13. ABSTRACT (Maximum 200 words)
Transportation Technology Center, Inc. (TTCI) and the Federal Railroad Administration (FRA) upgraded and installed new equipment enabling High Accuracy Global Positioning System (HA-GPS) to the Transportation Technology Center's (TTC) existing GPS reference station. The intent was to provide a high accuracy reference "truth" dataset for demonstrating and testing equipment and systems, as well as to improve the equipment's reliability and availability. When it was originally conceived, HA-GPS technology depended on the proliferation of a nationwide network of HA-GPS base stations. However, due to recent technology advances, the need for the network of base stations is no longer required nor is it the preferred solution for providing high accuracy positional reference data.

14. SUBJECT TERMS
Differential Global Positioning System (DGPS), Global Positioning System (GPS), Global Navigation Satellite System (GNSS), GPS Receiver Interface Module (GRIM), High Accuracy Global Positioning System (HA-GPS), High Accuracy-Nationwide Differential Global Positioning System (HA-NDGPS), National Geodetic Survey (NGS), Real Time Kinematics (RTK)

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# METRIC/ENGLISH CONVERSION FACTORS

## ENGLISH TO METRIC

### LENGTH (APPROXIMATE)

| | | |
|---|---|---|
| 1 inch (in) | = | 2.5 centimeters (cm) |
| 1 foot (ft) | = | 30 centimeters (cm) |
| 1 yard (yd) | = | 0.9 meter (m) |
| 1 mile (mi) | = | 1.6 kilometers (km) |

### AREA (APPROXIMATE)

| | | |
|---|---|---|
| 1 square inch (sq in, in$^2$) | = | 6.5 square centimeters (cm$^2$) |
| 1 square foot (sq ft, ft$^2$) | = | 0.09 square meter (m$^2$) |
| 1 square yard (sq yd, yd$^2$) | = | 0.8 square meter (m$^2$) |
| 1 square mile (sq mi, mi$^2$) | = | 2.6 square kilometers (km$^2$) |
| 1 acre = 0.4 hectare (he) | = | 4,000 square meters (m$^2$) |

### MASS - WEIGHT (APPROXIMATE)

| | | |
|---|---|---|
| 1 ounce (oz) | = | 28 grams (gm) |
| 1 pound (lb) | = | 0.45 kilogram (kg) |
| 1 short ton = 2,000 pounds (lb) | = | 0.9 tonne (t) |

### VOLUME (APPROXIMATE)

| | | |
|---|---|---|
| 1 teaspoon (tsp) | = | 5 milliliters (ml) |
| 1 tablespoon (tbsp) | = | 15 milliliters (ml) |
| 1 fluid ounce (fl oz) | = | 30 milliliters (ml) |
| 1 cup (c) | = | 0.24 liter (l) |
| 1 pint (pt) | = | 0.47 liter (l) |
| 1 quart (qt) | = | 0.96 liter (l) |
| 1 gallon (gal) | = | 3.8 liters (l) |
| 1 cubic foot (cu ft, ft$^3$) | = | 0.03 cubic meter (m$^3$) |
| 1 cubic yard (cu yd, yd$^3$) | = | 0.76 cubic meter (m$^3$) |

### TEMPERATURE (EXACT)

[(x-32)(5/9)] °F = y °C

## METRIC TO ENGLISH

### LENGTH (APPROXIMATE)

| | | |
|---|---|---|
| 1 millimeter (mm) | = | 0.04 inch (in) |
| 1 centimeter (cm) | = | 0.4 inch (in) |
| 1 meter (m) | = | 3.3 feet (ft) |
| 1 meter (m) | = | 1.1 yards (yd) |
| 1 kilometer (km) | = | 0.6 mile (mi) |

### AREA (APPROXIMATE)

| | | |
|---|---|---|
| 1 square centimeter (cm$^2$) | = | 0.16 square inch (sq in, in$^2$) |
| 1 square meter (m$^2$) | = | 1.2 square yards (sq yd, yd$^2$) |
| 1 square kilometer (km$^2$) | = | 0.4 square mile (sq mi, mi$^2$) |
| 10,000 square meters (m$^2$) | = | 1 hectare (ha) = 2.5 acres |

### MASS - WEIGHT (APPROXIMATE)

| | | |
|---|---|---|
| 1 gram (gm) | = | 0.036 ounce (oz) |
| 1 kilogram (kg) | = | 2.2 pounds (lb) |
| 1 tonne (t) | = | 1,000 kilograms (kg) |
| | = | 1.1 short tons |

### VOLUME (APPROXIMATE)

| | | |
|---|---|---|
| 1 milliliter (ml) | = | 0.03 fluid ounce (fl oz) |
| 1 liter (l) | = | 2.1 pints (pt) |
| 1 liter (l) | = | 1.06 quarts (qt) |
| 1 liter (l) | = | 0.26 gallon (gal) |
| 1 cubic meter (m$^3$) | = | 36 cubic feet (cu ft, ft$^3$) |
| 1 cubic meter (m$^3$) | = | 1.3 cubic yards (cu yd, yd$^3$) |

### TEMPERATURE (EXACT)

[(9/5) y + 32] °C = x °F

## QUICK INCH - CENTIMETER LENGTH CONVERSION

| Inches | 0 | 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|---|---|

| Centimeters | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|

## QUICK FAHRENHEIT - CELSIUS TEMPERATURE CONVERSIO

| °F | -40° | -22° | -4° | 14° | 32° | 50° | 68° | 86° | 104° | 122° | 140° | 158° | 176° | 194° | 212° |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| °C | -40° | -30° | -20° | -10° | 0° | 10° | 20° | 30° | 40° | 50° | 60° | 70° | 80° | 90° | 100° |

For more exact and or other conversion factors, see NIST Miscellaneous Publication 286, Units of Weights and Measures. Price $2.50 SD Catalog No. C13 10286

Updated 6/17/98

## Contents

## Illustrations

## Executive Summary

Transportation Technology Center, Inc. (TTCI) and the Federal Railroad Administration (FRA) have upgraded and installed new equipment at the GPS reference station at the Transportation Technology Center (TTC), which has enabled its High Accuracy Global Positioning System (HA-GPS) to provide a high accuracy reference "truth" dataset for demonstrating and testing equipment and systems. Throughout this report, the term "HA-GPS" refers to centimeter precision in the accuracy of the measurements being recorded, rather than the specific system or technology.

Initially, the HA-GPS project at TTC was developed to independently test the feasibility of the high accuracy portion of the High Accuracy-Nationwide Differential Global Positioning System's (HA-NDGPS) ability to achieve sub-decimeter positional accuracy with relatively minor modifications to an existing NDGPS site.

HA-GPS technology, as originally conceived, depended on the implementation of a nationwide network of HA-GPS base stations. Due to the availability of recent technology, the network of base stations is no longer required, nor is it the preferred solution for providing high accuracy positional reference data.

As a result, this project added a number of upgrades to the existing GPS site at TTC, including improving the site's equipment plus its reliability and availability to better support testing activities and capabilities at TTC.

The upgrades were completed, and the site now provides users with the capability to test new technologies and products, such as high precision location determination, before they are put into full operational service.

# 1. Introduction

The ability to provide highly accurate reference positional systems is of great value for many of the technology development and evaluation activities that are conducted at the Federal Railroad Administration's (FRA) Transportation Technology Center (TTC). Positive Train Control (PTC) and similar advanced technologies in the railroad industry depend on accurate determination of the position of locomotives and other mobile assets. It is critical to be able to provide an accurate reference positional dataset when developing and testing these technologies. This report describes recent improvements to the GPS reference station located at TTC, conducted under FRA Task Order 351.

## 1.1 Background

Under Task Orders 234 and 316, research and upgrades were conducted, and the initial High Accuracy Global Positioning System (HA-GPS) site at TTC was developed to independently test the feasibility of the high accuracy portion of the High Accuracy-Nationwide Differential Global Positioning System's (HA-NDGPS) ability to achieve sub-decimeter positional accuracy with relatively minor modifications to an existing NDGPS site. The high accuracy capability had the potential to provide a viable positioning solution for railroad systems, to the extent that it could have been used for testing train control systems and for more timely and efficient collection of track feature information needed for generating and maintaining track databases that support train control operations and other railroad applications.

A prototype HA-GPS base station was constructed at TTC to broadcast carrier code and phase measurement data (at one kilowatt and 458 kilohertz (kHz)) to remote users to obtain sub-decimeter Real Time Kinematic (RTK) GPS positional solutions within a 200 nautical mile radius of the base station.

The HA-GPS system worked by collecting GPS measurement data from the constellation of satellites in view. The data was compressed by a Trimble proprietary software program, GPS Receiver Interface Module (GRIM), and then modulated onto a 458 kHz carrier wave that would be transmitted to the user. On the user end, a beacon receiver collected the broadcast data, and then the data was decompressed by GRIM, converted to Radio Technical Commission for Maritime Services, messages 18/19, (RTCM 18/19), and inputted into the user's GPS receiver where it was combined and processed to obtain a decimeter level RTK solution.

In earlier FRA-funded efforts, the HA-GPS broadcasting base station at the TTC was used to assess the relationship between user distance from the base station (baseline) and user-derived positional accuracy. Furthermore, the feasibility of using HA-GPS as a mapping solution as well as determining the effects of an energized overhead catenary on the performance of HA-GPS as a position determination system were investigated.

The future of the HA-GPS technology, as originally conceived, depended on the proliferation of a nationwide network of HA-GPS base stations. However other technologies, such as RTK Surveying, have become available and are more widely used. They are capable of providing the same level of positional accuracy without the need for a network of base stations. Thus, the HA-GPS technology is no longer the preferred solution for providing high accuracy reference positional data.

## 1.2 Organization of the Report

This report is organized in four major sections. Section 1 is this introduction, which includes the background of the HA-GPS site. Section 2 provides an overview of the upgrades made to the HA-GPS site. Section 3 describes the upgrades in more detail, and Section 4 provides a brief conclusion.

# 2. Project Overview

## 2.1 Objectives

The project upgraded and installed new equipment to the GPS reference station at TTC so that it can be used to provide a high accuracy reference “truth” dataset for demonstrating and testing equipment and systems. Railroads, potential railroad vendors, and the Transportation Technology Center, Inc. (TTCI) are now able to demonstrate and test their position location equipment on track at TTC with this capability. New technologies and products (e.g., those that emerge as PTC systems evolve and mature) can be tested before putting them into full operational service.

## 2.2 Overall Approach

The project consisted of adding a number of upgrades and new equipment to the existing site, including:

- Enabling the site to provide Real Time Kinematics (RTK)-representative position measurement accuracies – 1 centimeter plus 1 part in $10^6$ of the distance between the base station and the rover. On TTC track, expected horizontal position accuracies are on the order of ~2 centimeters. The RTK technique allows for high performance global positioning when used in the vicinity of a base station. RTK surveys are kinematic surveys that have a communication link between the base receiver and the rover.
- Upgrading the site’s equipment environmental protection (HVAC and alarming) to be consistent with current industry standards for remote communications sites.
- Adding to the current inventory of remote GPS receivers for RTK testing support.
- Investigating and gathering data to provide high quality survey monuments for location measurement equipment calibration and checkout.
- Improving the site’s equipment and its reliability and availability to better support TTC testing activities.

## 2.3 Scope

To provide the capabilities mentioned above, the scope of the project included the nine upgrades listed below:

1. Installation of an integrity monitoring GPS station with a permanent reference station-quality antenna and mast with a cable management system in the TTC Core Area to provide redundancy of communications and power between Posts 85 and 100, as well as improved cable management for future permanent and temporary equipment installations.
2. Investigation of and data gathering for potentially adding several National Geodetic Survey (NGS) first order survey monuments at TTC to enable GPS site verification and customer location measurement equipment calibration. Survey monuments are markers placed at key points on the earth’s crust. First order monuments are accurate to a distance of 1:100,000 and second order monuments are accurate to a distance of 1:50,000.

3. Procurement of additional RTK rover units to support train position determination for on-site rail industry testing.
4. Addition of an industrial-quality heating, ventilating and air conditioning (HVAC) unit for the equipment house.
5. Addition of a site backup power generator.
6. Insulation of the equipment house.
7. Addition of a data communications link between the GPS site and TTC's Operations building.
8. Gathering information and providing training for two TTCI Communications and Train Control (C&TC) engineers to determine the best method to upgrade the HA-GPS at TTC
9. Updating site "as built" drawings and interconnect diagrams.

## 3. Major Task Summaries

### 3.1 Integrity Monitoring GPS Station

An integrity monitoring GPS station with a permanent reference station-quality antenna and mast was purchased and installed at Post 85 in the TTC Core Area. Post 85 has a bungalow that is currently used by several PTC projects and houses equipment used for I-ETMS and a railroad crossing. Figure 1 shows a map of the core area of TTC, with the Post 85 integrity monitoring station location indicated. Figure 2 shows the Trimble R8 Global Navigation Satellite System (GNSS)/R6/5800 receiver and Trimble TSC3 handheld data collector that were set up as a base station to collect continuous static data every 5 seconds for 8 hours. The data was post-processed to determine if it was clean and had minimal interference. Results showed minimal interference in the data, and the integrity monitor was installed on the Post 85 Bungalow (Figure 3).

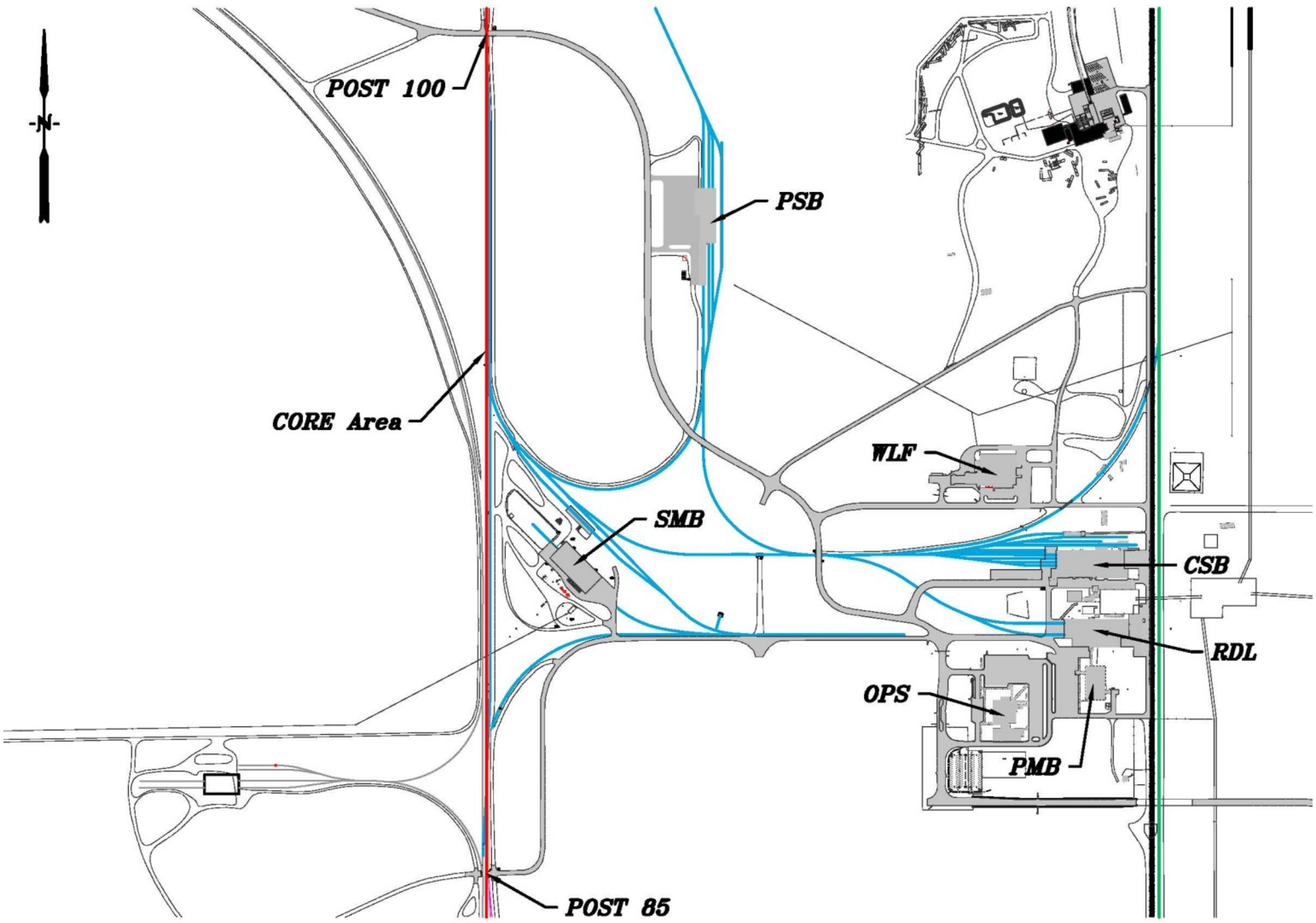



**Figure 1. TTC Core Area**

**Figure 2. Trimble R8 GNSS/R6/5800 Receiver/Trimble TSC3 Handheld Data Collector**

**Figure 3. Integrity Monitoring GPS Station (Post 85 Bungalow)**

## 3.2 Cable Management System

A cable management system was purchased from Furukawa Electric Group and installed between Posts 100 and 85 to provide protection for cables used for redundancy of power and communications in the TTC Core Area. The cable management system is an environmentally-friendly, recycled plastic cable tray made from flame-retardant plastic that can self-extinguish if caught on fire. The cable management system was installed in such a way that the lids can be removed easily and additional cable can be placed within the system in the future. Figure 4 shows a section of the cable management system installed along the RTT looking south from Post 100.

**Figure 4. Cable Management System**

## 3.3 National Geodetic Survey (NGS) First Order Survey Monuments

TTCI researched the possibility of upgrading and adding additional National Geodetic Survey (NGS) monuments. TTC currently has five existing NGS survey monuments onsite; two of the five are first order horizontal monuments with a minimum distance accuracy of 1:100,000, and the remaining three are second order horizontal monuments with a minimum distance accuracy of 1:50,000. Figure 5 shows the locations of the existing NGS survey monuments. Horizontal NGS survey monuments provide geodetic latitudes and longitudes in the North American Datum reference system and are very accurate. These NGS monuments must have a permanent horizontal stability with respect to the Earth's crust. Due to the precision of the existing NGS survey monuments, research showed that additional monuments would not be significantly beneficial to the future of HA-GPS at TTCI. As a result, FRA and TTCI removed the installation of additional NGS monuments from the project scope.

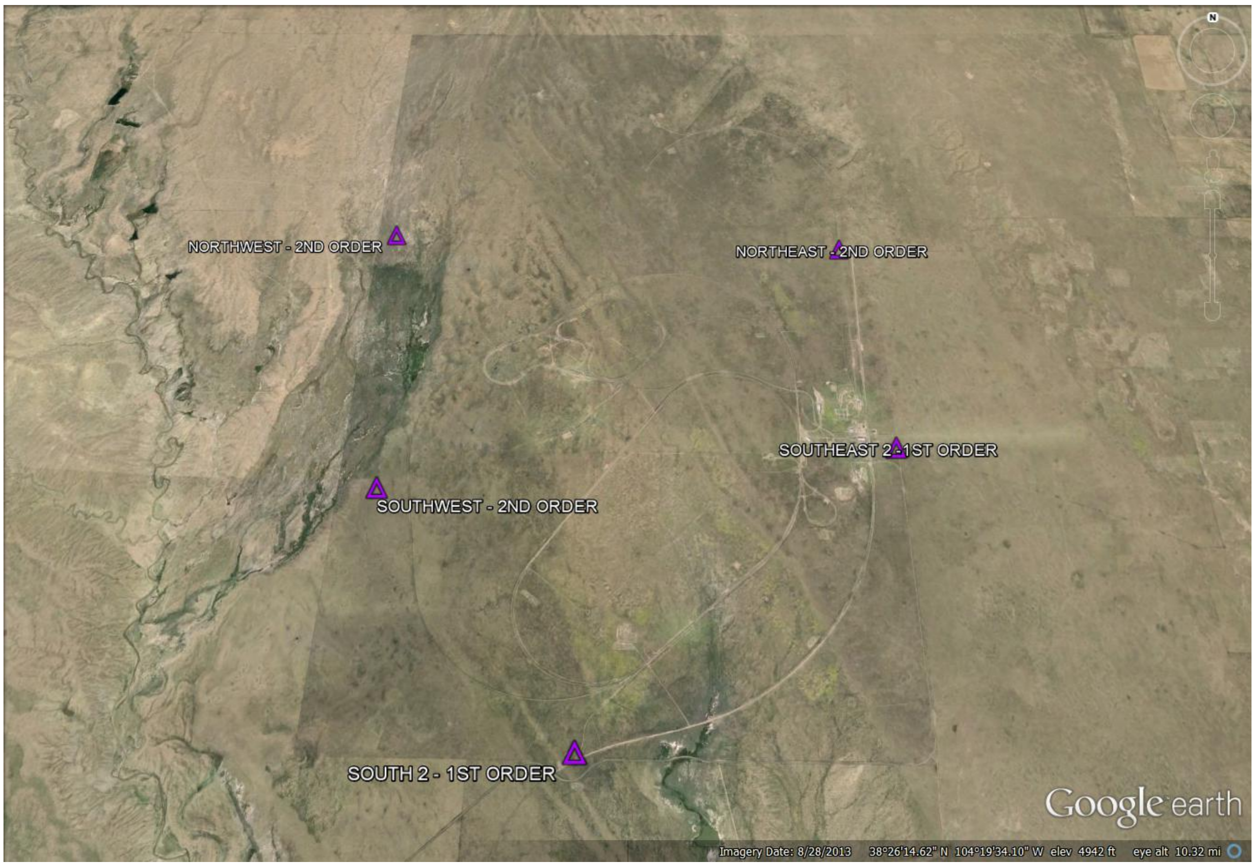



**Figure 5. Existing NGS Survey Monuments**

## 3.4 Additional RTK Rover Units

Six additional RTK Rover units were purchased to provide RTK Testing support. RTK Rovers are portable devices that are used to record GPS coordinates. The rovers allow GPS readings to be taken in more locations where previous equipment would have failed. The RTK aspect allows for real time high precision positioning. Figure 6 shows a Trimble Zephyr Model 2 GPS Antenna/SPS555H GPS Receiver and Figure 7 shows Zephyr Geodetic Model 2 GPS Antenna/SPS855 GPS Receiver. This purchase included the following equipment:

- GNSS, SPS555H Precise Antenna, No Radio. These kits come with antenna - GPS, Zephyr Model 2, L1/L2/L5/G1/G2 Rover and with 3-foot long cables.
    - The SPS 555H precise antenna works in unison with the SPS855 to give heading and speed for what it is mounted to, such as a locomotive. The SPS855 receives GPS and Ultra High Frequency (UHF) radio signals that are in 450-470 MHz range and corrects the position to RTK positional accuracy of 1 centimeter horizontal and 2 centimeters vertical.
- Cable - GPS, 30m, TNC/TNC RIGHT ANGLE
    - These longer cables allow the SPS555H receiver to connect to the Zephyr antenna.
- GNSS, SPS855, 403-473 MHz
    - The SPS855 has an internal radio that works in unison with the SPS555H; as stated above.
- GLONASS, SPSx5x/SPS88x/SPS985, Construction
    - This option upgraded the SPS555H and SPS855 to be able to track Russian Satellites.
- Precise Rover, SPS985/SPS855, Construction
    - This option upgraded the SPS855 to have the highest accuracy positioning, which is identical to the accuracy of the SPS555H.
- Antenna - GPS, Zephyr Model 2, L1/L2/L5/G1/G2 Geodetic
    - These antennas are connected to the SPS855; they are not sold as kits and were purchased separately.
- External Radio Antenna, 450-470MHz
    - This external antenna allows the SPS855 to receive correctional data from the base station that is being received in the 450-470 MHz UHF radio signal.
- SPS985/SPS855 Con, Heading and Moving Base
    - This upgrade allows the SPS855 to receive correctional data from the SPS555H.

RTK surveys are kinematic surveys that have a communication link between the base receiver and the rover. Data can either be collected on a stop-and-go basis or with continuous logging. The data is collected, processed, and logged with a RTK survey, which occurs in the field and instantly delivers centimeter-level results. The advantage of using RTK surveying is that it is very fastand accurate, and the data is processed in real time in a local coordinate system. The additional RTK rover units will be available for future testing, enabling accurate positioning and tracking.


**Figure 6. Zephyr Model 2 GPS Antenna/SPS555H GPS Receiver**


**Figure 7. Zephyr Geodetic Model 2 GPS Antenna/SPS855 GPS Receiver**

### 3.5 Installation of Industrial-Quality HVAC Unit and Equipment House Insulation

An industrial-quality HVAC unit was installed in the HA-GPS equipment house. The unit installed is a 24,000 British Thermal Unit (BTU) mini split system with a heat pump rated to 10 degrees and has backup electric heat. Also, the equipment house was insulated with 1-inch Polystyrene board, with R-value equaling 13.0. The board has a reflective foil facing, which makes it an exceptional insulator when radiant heat is used. Figure 8 shows the HVAC unit and insulation installed in the equipment house.


**Figure 8. HVAC Unit and Insulation installed in the Equipment House**

## 3.6 Site Backup Power Generator

Figure 9 shows the site backup power generator installed near the equipment house at the HA-GPS site. The generator is a John Deere 4045TF280, diesel fuel, engine driven generator with an automatic transfer switch (ATS). If the site encounters a power failure, the ATS will count 3 seconds and will signal the generator to start. Cranking time of the generator may take approximately 4 seconds until the generator reaches acceptable voltage and frequency. The maximum period of time the HA-GPS site may be without power is less than 10 seconds, and the generator is capable of running for a period of 48 hours. The backup power generator will keep GPS site equipment running and available to support testing at all times.


**Figure 9. Site Backup Power Generator**

## 3.7 Data Communications Link

Figure 10 shows the data communications fiber link installed between the HA-GPS site and TTC's Operations building to receive and transmit information through TTCI's local area network.

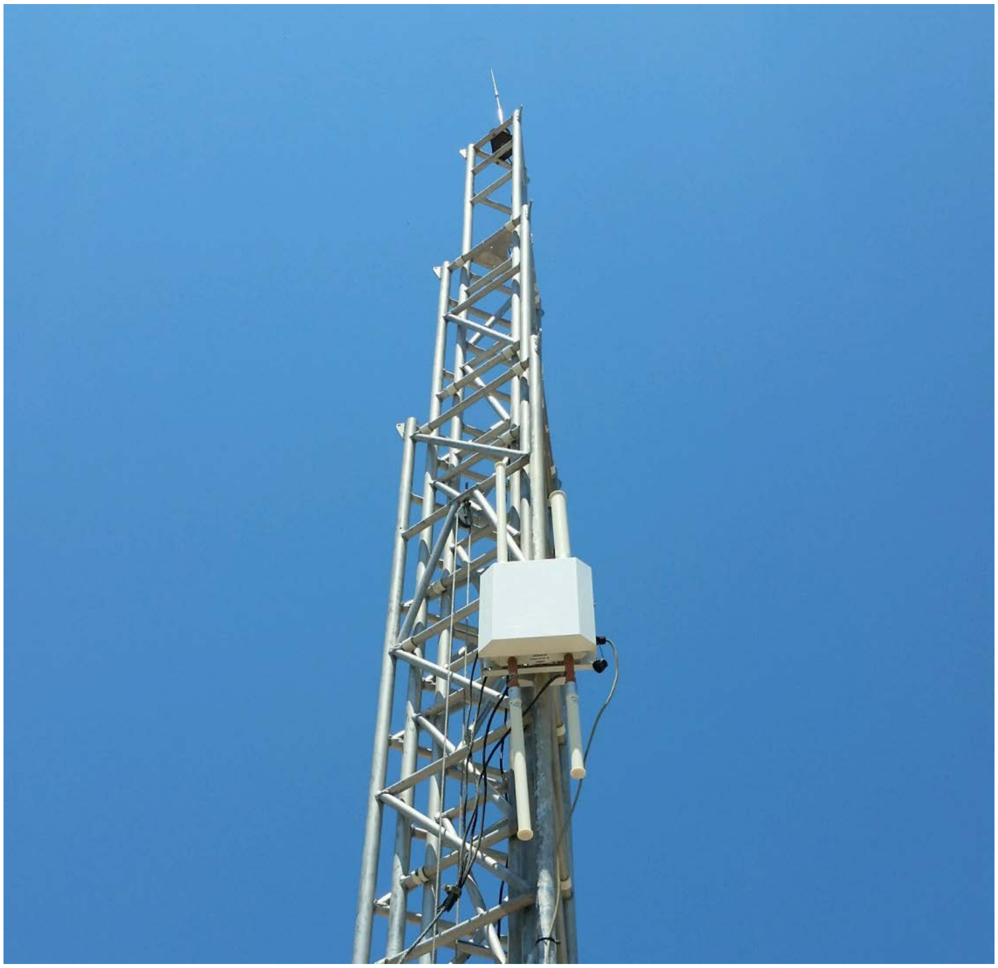
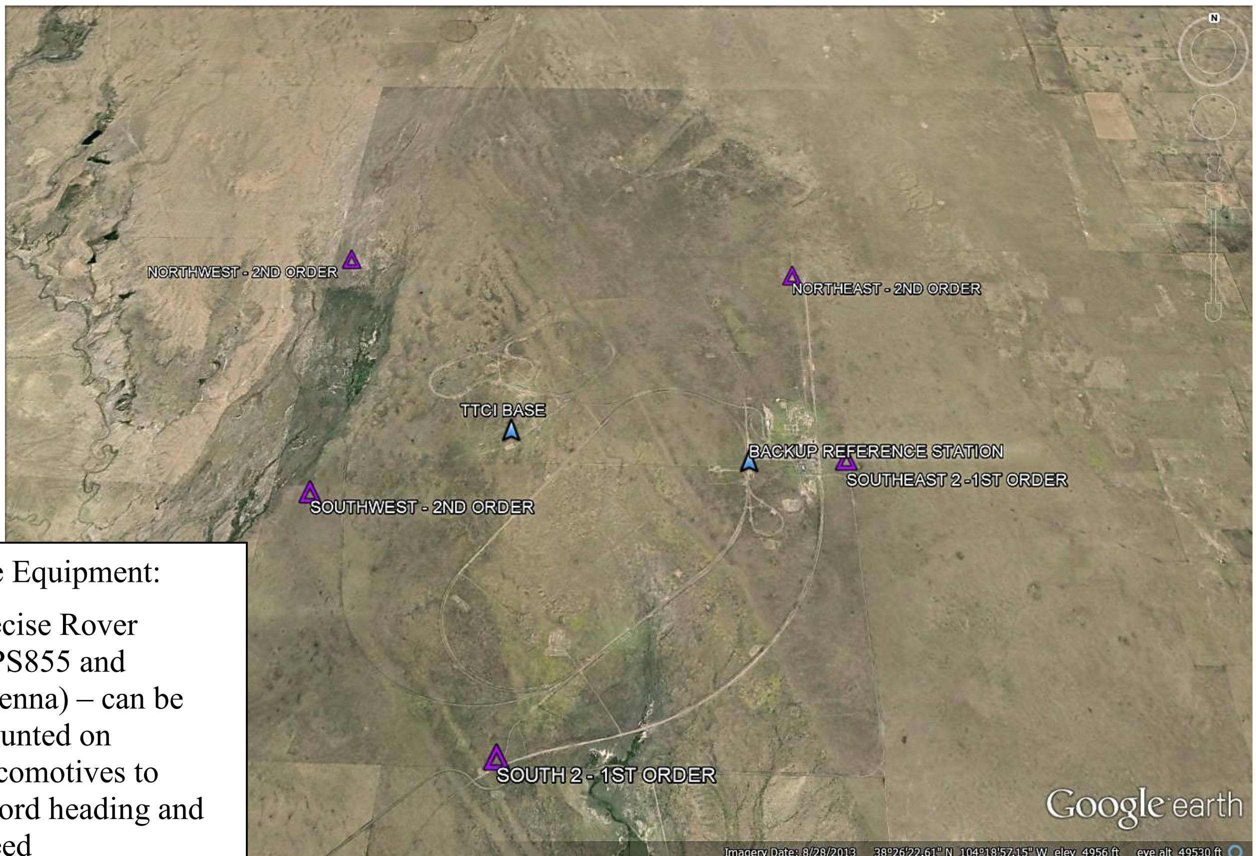


**Figure 10. Data Communications Link**

Survey monuments, or geodetic markers, are objects placed in the ground to mark key survey points on the Earth's surface and are established when performing a geodetic or land survey. Survey monuments are anticipated to be permanent, are precisely measured, and are often parts of triangular surveys. Survey monuments were essential before the development of the GPS System and are used to provide initial coordinates for new GPS structures. Often, monuments are used in construction to precisely place a new building. The existing HA-GPS base station at TTC used survey monuments to set the exact location (latitude and longitude, plus elevation) of the antenna structure, which is used to improve the accuracy of nearby GPS equipment.

GNSS satellites are arranged in an array that covers the majority of North America, with overlap of service to prevent gaps in service. The HA-GPS antenna receives information from the satellites and also broadcasts a correction for anyone using the system in the surrounding area. The GPS system on site uses this broadcast to accurately pinpoint locations with mobile rovers. Mobile rovers, such as the SPS855 receive information from the satellites in orbit, but due to atmospheric effects and other unavoidable interference, they would be unable to give more than about a half meter accuracy. The base station receives the same information and uses that, along with the benchmarked coordinates to provide a correction that it sends out to the mobile receivers. This correction allows the mobile receivers to have an accuracy of 1 centimeter horizontal and 2 centimeters vertical.




Mobile Equipment:

Precise Rover (SPS855 and antenna) – can be mounted on Locomotives to record heading and speed

**Figure 11. Survey Monuments, GPS Bases**

## 3.8 GPS Training

Two TTCI engineers attended a 4-day training course, Course 346: GPS/GNSS Operation for Engineers & Technical Professionals: Principles, Technology, Applications and Intro to Basic DGPS Concepts, through NavtechGPS [1]. The purpose of training was to provide information and understanding for the design and development of the methodology and equipment needed to provide HA-GPS at TTC. This training allowed the engineers to determine the best method to upgrade the HA-GPS at TTC, as well as further understand how the field of GPS may be changing. Exposure to how other industries are currently using HA-GPS may allow for future collaborations.

The course included the following:

- A comprehensive introduction to GPS, system concepts, an introduction to differential GPS (DGPS), design, operation, implementation and applications.
- Detailed information on the GPS signal, its processing by the receiver, and the techniques by which GPS obtains position, velocity, and time.
- Current information on the status, plans, schedule and capabilities of GPS, as well as of other satellite-based systems with position velocity and time determination applications.
- Information to fill in technical information gaps for individuals working in the GPS and GNSS fields.

Each engineer was provided with a printed copy and an electronic copy of all course notes.

## 4. Conclusion

Task Order 351 added a number of upgrades to the High Accuracy Global Positioning System (HA-GPS) site. These included purchasing and installing necessary components and equipment as well as adding to the current Real Time Kinematics (RTK) rover unit inventory. The site now provides reliable RTK surveying with centimeter-level accuracy, and six additional RTK rover units. Additional upgrades included the placement of an integrity monitoring GPS station in the Transportation Technology Center (TTC) Core Area, the installation of a heating, ventilation and air conditioning (HVAC) unit, insulation of the equipment house, a site backup power generator, and a data communications link to satisfy the development and testing needs of TTC site users. These upgrades will provide users with the capability to test their new technologies and products before putting them into full operational service.

## References

1. http://www.navtechgps.com/events/course_346_details/

## Abbreviations and Acronyms

| | |
|---|---|
| ATS | Automatic Transfer Switch |
| BTU | British Thermal Unit |
| C&TC | Communications and Train Control |
| DGPS | Differential Global Positioning System |
| FRA | Federal Railroad Administration |
| GNSS | Global Navigation Satellite System |
| GPS | Global Positioning System |
| GRIM | GPS Receiver Interface Module |
| HA-GPS | High Accuracy Global Positioning System |
| HA-NDGPS | High Accuracy-Nationwide Differential Global Positioning System |
| HVAC | Heating, Ventilating and Air Conditioning |
| MHz | megahertz |
| NGS | National Geodetic Survey |
| PTC | Positive Train Control |
| RTCM | Radio Technical Commission for Maritime Services |
| RTK | Real Time Kinematics |
| TO | Task Order |
| TTC | Transportation Technology Center (the site) |
| TTCI | Transportation Technology Center, Inc. (the company) |
| UHF | Ultra High Frequency |