National Transportation Safety Board

Office of Railroad, Pipeline, and Hazardous Materials Investigations
Washington, D.C. 20594

Factual Report of Investigation – Signal & Train Control Group

Rear-End Collision of
Washington Metropolitan Area Transit Authority
Metrorail Train No. 112 with
Stopped Metrorail Train No. 214 near the
Fort Totten Station in Washington, DC
On June 22, 2009

NTSB Accident Number: DCA-09-MR-007

EVENT

Location:	Red Line - Track B2, Chain marker 311+25
Date of Accident:	June 22, 2009
Time of Accident:	4:58 p.m. eastern daylight time
Transit Property:	Washington Metropolitan Area Transit Authority
Trains:	Inbound #112 and #214

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ACCIDENT SYNOPSIS

On Monday, June 22, 2009, about 4:58 p.m., eastern daylight time, Washington Metropolitan Area Transit Authority Metrorail train 112 collided with the rear end of stopped train 214 near the Fort Totten station in Washington, D.C. Both trains were traveling inbound on the Red Line segment of the Metrorail system towards Metro Center.

Train 112 was following train 214 and according to passenger statements from train 112, the train operator announced they were stopping because there was a train ahead; they stated they initially slowed/stopped and then began moving and collided with the rear end of train 214. There was no communication between the operators of train 112, the stopped train 214 or the Metrorail operations control center before the collision. In the collision the last car of train 214 penetrated about 50 feet into the lead car of train 112 as the lead car of train struck and overrode the last car of train 214. District of Columbia Fire and Rescue reported 9 fatalities and transporting about 52 persons to local hospitals.

The stopped train, 214, was a six-car train in passenger service consisting of two 2-car sets of 3000-series transit railcars and one 2-car set of 5000 series transit railcars operated in manual mode by one train operator. The striking train, 112, was a six-car train in passenger service consisting of three 2-car sets of 1000-series transit railcars being operated by one train operator in the automatic mode. The last rail car of train 214 (the struck train) sustained damage. The first car of train 112 was totally damaged and the second car sustained damage. WMATA Metrorail estimated the damage to the train equipment to be about $3 million. Damage to other equipment is still being evaluated.

SIGNAL & TRAIN CONTROL SYSTEM DESCRIPTION

Train operating rules and procedures for all WMATA Metrorail mainline routes are set forth in the Metrorail Safety Rules and Procedures Handbook (MSRPH). Train control supervision for the entire transit system is performed through the Operations Control Center (OCC) located in downtown Washington, DC. OCC is equipped with the monitoring, control, and communication facilities required to operate the transit system and handle emergency situations.

Train operations are governed by train control systems for train movements in both directions on two main tracks. The train control systems were designed during the WMATA Metrorail's original construction in the early 1970's. In many locations throughout the system, original train control equipment continues to be utilized. The system employs color-light signals located at interlockings. Interlockings are places where tracks join together and include track switches, associated signals and the control machinery that connects them to enable their operation and ensure safe operation. Audio frequency track circuits provide track occupancy detection and speed commands. Audio frequency track circuits are electrical systems capable of detecting the presence of a train on the tracks and providing commands to such trains regarding their speed and behavior. Interlocking locations are primarily operated automatically; but the operation of the interlocking can be requested remotely from OCC or from a local control panel in field train control rooms.

WMATA Metrorail mainline routes are divided into blocks between the terminal stations at the ends of each route. Each block is checked for train occupancy utilizing audio frequency track circuits. Tuned impedance bond devices are installed at block boundaries. The impedance bonds transmit onto the rails the coded signals generated in the train control room that are used to detect the presence of a train in a block and to signal speed commands to trains. Each block generally consists of one track circuit with an impedance bond located at each end of the track circuit. Each impedance bond generally serves as the transmitter for one track circuit and the receiver for the adjacent track circuit. Train operations on WMATA Metrorail mainline routes can be carried out in either automatic train control or manual control by a train operator. Automatic train control (ATC) consists of three control subsystems; automatic train protection (ATP), automatic train supervision (ATS) and automatic train operation (ATO). Manual control overrides ATS and ATO but does not override ATP.

A train-wayside communication (TWC) system, part of the ATS subsystem, provides a two-way serial communication between carborne and wayside train control systems for automatic door operation and carborne passenger information displays. The wayside transmits TWC messages using track circuit transmitters. Trains receive TWC signals on board from the rails through receiver coils mounted on each car. TWC signals are transmitted from the train to the rails by a transmit loop mounted beneath the front of the lead car.

The wayside program station stop, part of the ATO subsystem, provides required control signals to allow for automatic station stops. ATO markers are a fixed frequency and interpreted in pairs as distance to go and type of desired station stop (long, center or short). About 2,700 feet from a station platform centerline, as the train traverses over passive tuned coils located between the rails, communication between an approaching train and a wayside ATO marker coil is initiated. Based on the tuned frequency of the marker, the train's ATO logic initiates a station stop. As the train continues to approach the station, it passes over additional passive tuned coils which update the distance to go and enable trains to slow and stop at a predetermined target location properly berthed along a station platform.

TRACK CIRCUIT DESCRIPTION

The ATP subsystem, working in conjunction with properly operating train functions which include vehicle propulsion and braking, provides protection against collisions and overspeed conditions. The wayside portion of the ATP subsystem includes the automatic block system and control of track switches and signals. The automatic block system detects trains and transmits speed commands to maintain train separation. Train detection and transmission of speed commands are accomplished through the use of audio (high) frequency track circuits. A code rate modulated audio frequency signal is generated in the train control room by a track circuit transmitter module. The code rate modulated signal is sent out to one end of the track circuit using a twisted pair bond cable. The bond cable connects to the transmitter impedance bond. The impedance bond is mounted between the rails and acts as a tuned coupling transformer. The code rate modulated signal then travels through the rails to a receiver impedance bond, also mounted between the rails at the other end of the track circuit. A twisted pair bond cable connects the receiver impedance bond back to a track circuit receiver module in the train control room. The track circuit receiver module filters, amplifies and checks the level of the signal from the rail and outputs energy to the coil of a track relay which completes the track circuit. Generally, the impedance bond and its bond cable serve as the receiver of one track circuit and the transmitter of the adjacent upstream track circuit.

Eight frequencies designated f1 through f8 (2100 Hz to 3900 Hz) are available for track circuit detection. Track 1 uses odd numbered frequencies, and track 2 uses even numbered frequencies. On each track, frequencies are typically used in sequential order and then repeated until the end of the track is reached. Track circuits are typically arranged for the normal direction of traffic so that trains occupying a track circuit traverse the receiver end of a track circuit before traversing the transmitter end. All mainline tracks can operate bi-directionally. Train detection is accomplished by the train wheels shunting the code rate modulated signal away from the receiver impedance bond. Shunting occurs shortly before a train arrives at the track circuit (pre-shunting) and remains in effect until briefly after a train has moved out of the track circuit (post-shunting). When the code rate modulated signal drops below a preset level, the corresponding track relay is released and this is interpreted as a train occupying the track circuit.

The coded track circuit frequency is continuously transmitted. One of two coded train frequencies is also transmitted when there is a train present and track and traffic conditions allow a train to receive a speed command. The code rate is one of six rates selected by logic circuits outside the track circuit modules and is used to modulate the track circuit frequency and selected train frequency. The track circuit frequency is transmitted during one half of the code rate cycle and, when applicable, the selected train frequency is transmitted during the other half of the code rate cycle.

Train control rooms located at each WMATA train station contain the ATP, ATS and ATO equipment. The ATP transmitter/receiver modules associated with the various track circuits that lie within the train control room boundary are mounted on racks inside the train control room. Each ATP transmitter/receiver module contains a track and train frequency transmitter and a track frequency receiver. Typically, the transmitter and receiver of the module are connected to the same impedance bond that is the boundary between the two track circuits it serves. The ATP transmitter/receiver modules installed at the time of the accident are original equipment installed when the Red Line was constructed. The ATP equipment is of early 1970's vintage.

DETAILS OF THE INVESTIGATION

Representatives from WMATA Metrorail, Alstom Signaling, Federal Transit Administration, Ansaldo STS, Federal Railroad Administration, Tri-State Oversight Committee and NTSB participated in the field inspection and testing of the signal and train control system. The postaccident inspection did not find any indications of tampering or vandalism that would interfere with the operation of the train control systems.

Traction Power Upgrade Program

Train traction power is supplied through an electrified third rail that provides 750 volts to trains. The Red Line traction power system was originally designed to operate six-car trains. With increased ridership, WMATA Metrorail began a program to upgrade traction power substations in preparation to operate eight-car trains. Equipment was procured for the New Hampshire traction power substation, located in the vicinity of the accident, and installation took place between March 7 and June 14, 2006. The substation was upgraded from 4 megawatts to 7 megawatts. The upgrade entailed replacing two, 2-megawatt transformers with two new 2-megawatt transformers and adding a new 3-megawatt transformer. The associated ac switchgear was added for the new line up and included a new 3-megawatt rectifier.

On October 6, 2006, CENS[1] issued an Engineering Bulletin regarding the use of US&S[2] impedance bonds in GRS[3] ATP track circuits. The engineering bulletin indicated CENS had held technical discussions with US&S and Alstom engineers regarding this matter. The engineering bulletin further stated that US&S impedance bonds had been installed at three locations on the Orange line with no problems reported with track circuits using the US&S

[1] CENS was the Chief Engineer of Systems Office which was merged into Engineering Support Services (ENSS).
[2] US&S is Union Switch & Signal which changed its name to Ansaldo STS USA, Inc. on January 1, 2009.
[3] GRS is General Railway Signal which has since been acquired by Alstom Signaling, Inc.

impedance bond with the GRS ATP transmitter/receiver module. The engineering bulletin explained that after installation of US&S impedance bonds, a verification shunt test should be performed at each end of the track circuit and at the mid point of the track circuit using a .06 ohm shunt.

On December 12, 2007, as part of a traction power upgrade program, the existing GRS high current substation return impedance bond at chain marker B2-311+71 (designated WZ-14) was replaced with a US&S high current substation return impedance bond to increase return current capacity for the traction power substation. The daily entry for that date in the Fort Totten, train control room log book indicates a track circuit adjustment was performed on track circuits B2-312 and B2-304 after the US&S high current substation return impedance bond was installed. A shunt verification test was also performed and the power level was changed to 70% for track circuit B2-312. This is the receiver impedance bond for track circuit B2-304 and the transmitter impedance bond for track circuit B2-312.

Track Circuit Replacement Program

WMATA Metrorail was also working on a 4-year track circuit replacement program. GRS impedance bonds and GRS ATP modules were being replaced with US&S impedance bonds and US&S AF-800W modules. The track circuit replacement program was managed by the WMATA Metrorail, Infrastructure Renewal Programs Group (IRPG) and used WMATA Metrorail Track Structures System Maintenance (TSSM), construction, inspection and testing (CIT) crews to install new US&S impedance bonds. The CIT crew[4] would then later work with a US&S representative to replace and return to service the train control room components.

Based on the serial numbers and WMATA Metrorail records, the GRS ATP transmitter/receiver modules installed at Fort. Totten at the time of the accident were of early 1970's vintage. Some modules had been replaced since the original installation with modules of the same or similar design (early 1970's to late 1980's vintage). Some of the components used in the modules, such as printed circuit boards, had been changed since the original installation.

The first track circuit replacement contract was for the three locations on the Orange line. A second contract awarded for additional locations on the Orange/Blue and Red Lines was in the installation process at the time of the accident.

Station ID	Station Name	Date of Installation Start	Date of Test Completion
D12	Landover	8/24/05	8/29/06
D11	Cheverly	9/22/05	8/11/06
D13	New Carrollton	1/04/06	8/30/06
A03	Dupont Circle	4/23/07	6/01/07
A02	Farragut North	6/04/07	7/27/07
A01	Metro Center Upper	4/23/07	6/01/07

[4] "CIT crew" in this report, refers to the ATC mechanics working during non-revenue hours on the track circuit replacement project.

B01	Gallery Place Upper	8/21/07	8/31/07
B02	Judiciary Square	9/17/07	10/30/07
D09	Minnesota Avenue	8/12/08	11/13/08
C01	Metro Center Lower	9/22/08	11/06/08
D01	Federal Triangle	9/29/08	10/23/08
B04	Rhode Island Avenue	2/02/09	6/02/09
B05	Brookland	3/30/09	5/01/09
B06	Fort Totten Upper	6/02/09	---

The GRS impedance bond at chain marker B2-304+33 was replaced by WMATA Metrorail personnel, with a US&S impedance bond during the non-revenue hours between June 16/17, 2009. This impedance bond was at the transmitter end of track circuit B2-304 (designated WZ-15).

During postaccident interviews, the CIT crew leader stated that during their shift on June 16/17, 2009, when the US&S impedance bond was installed at chain marker B2-304+33, they started their track circuit adjustment and began having problems with the track circuit. During the adjustment, track circuit B2-304 began bobbing. A bobbing track circuit is defined as when an isolated track circuit transitions from vacant, to occupied and back to vacant again. The crew leader stated the transmitter power was increased one step from 30% to 55% during the track circuit adjustment and a shunt verification test was performed at three points along the track circuit – one at each end of the track circuit and one in the middle. The crew leader then stated that the track circuit was verified and also stated observing the track relay detect each of the three shunts. The CIT crew completed their work just before the start of revenue service. Following a telephone conversation with their ATC supervisor, the crew was instructed to stay and observe two train movements before departing. The crew leader then stated that as they waited for trains to begin running, track circuit B2-304 began bobbing again. The relay driver card was changed out, but the track circuit continued bobbing.

When the first train went through, the CIT crew leader stated they did not notice any problems with the train being detected by track circuit B2-304. After the train departed the area, they noticed that track circuit B2-304 was bobbing again and that the adjacent track circuit B2-312 was also bobbing. Maintenance Operation Center (MOC) called the crew at the Fort Totten train control room to notify them about the bobbing track circuit. The crew stated they were still there and troubleshooting the bobbing track circuit. The crew observed a second train movement and again stated they did not notice any problem with the train being detected as it moved through the track circuits. Just before 6:00 am, the crew leader called MOC and notified them that they had observed two train movements through the area and did not notice any problems with train detection but that the two track circuits were still bobbing. The crew stated MOC acknowledged them and they departed back to their reporting station and went off duty afterwards. The crew leader stated that after the telephone conversation with MOC, the crew didn’t hear anything more about the bobbing track circuits until the day of the accident.

The GRS ATP modules in the Fort Totten train control room were scheduled to be replaced with US&S AF-800W modules during the week of June 22, 2009.

Maintenance Communication System

A telephone communication system jack is provided on each rack in the train control rooms and at wayside ATC installations. The communication system allows personnel in train control rooms to communicate with personnel at other train control equipment locations and rooms. The communication system is a de-energized two-wire network configured for handheld telephones to be carried by maintenance personnel accessing the right-of-way and to be plugged in to wayside telephone jacks to communicate with another handheld telephone plugged into a jack in the train control room.

The telephone lines are routed from the train control room to the field and daisy-chained to telephone jacks in every track junction box. The track junction boxes are also used to terminate the train control room bond cables and the pigtail cable connection from impedance bonds at the two ends of every track circuit along the right-of-way.

Postaccident inspection of several track junction boxes between Fort Totten and Takoma found many of the telephone jacks inoperative because of broken telephone jack terminals or disconnected wiring. The broken telephone jacks were found missing or unsecured inside the track junction box. Track junction boxes with missing telephone jacks had exposed mounting holes that could allow debris, rodents or moisture/condensation access into the track junction box. Telephone jacks that were found disconnected inside the track junction boxes were found with bare wire terminals exposed and laying loose inside the track junction box. Several bare wire terminals were found in close proximity to track circuit impedance bond terminal connections.

Insulation Resistance Testing

WMATA Metrorail, ATC technical procedures manual, T031-Cable Insulation Resistance Testing, dated November 25, 2008, requires all cables installed in conduits, ducts, tunnel walls and directly buried along the right-of-way, and wires and cables entering and leaving the train control rooms, equipment cases and junction boxes to be tested to measure insulation resistance from each conductor to all other conductors in the cable, and from each conductor to ground. The test is to verify that the insulation resistance for a conductor used in a power source of less than 600 volts exceeded 1 mega ohm. Wires and cables used in a power source greater than 600 volts require the insulation resistance to be greater than 10 mega ohms. This test requires applicable wires and cables to be tested every ten years or after new installations. The T031 technical procedure was new, not superseding another procedure, and was still undergoing review before final approval.

Following the accident, WMATA Metrorail was requested to provide copies of their maintenance records which included insulation resistance tests. WMATA Metrorail could not provide any insulation resistance test records and stated they did not have any insulation resistance test records because no insulation resistance testing had been conducted.

Postaccident insulation resistance tests were conducted on bond cables and telephone lines installed from the train control room to the vicinity of the two impedance bonds for track circuit B2-304for both main tracks. The cables are routed together from the train control room to the field locations through conduits along an underground manhole located between the two main tracks. For several days prior to the accident, heavy rains were reported in the Washington, DC area. Following the accident, the manhole was found partially filled with water and the bond cables and telephone lines were submerged. During the investigation, several days of dry weather was improving the insulation resistance readings for several of the bond cables. But the tests still indicated that the bond cables to impedance bond WZ-14 and WZ-38 were out of compliance with WMATA Metrorail tolerances listed in the T031 procedures[5]. As a result of the insulation resistance tests, the absolute block[6] on track 2 through the accident area to resume train operations was extended to track 1 between Fort Totten and Takoma.

A spectrum analyzer was used to hunt for stray frequencies that could be induced by outside sources and affect the track circuits. Harmonics from the 720 hertz traction power return and adjacent track circuit frequencies were observed on the bond cables for track circuit B2-304. Identified harmonics of adjacent track circuit frequencies were found on the bond cables, but at very low levels and were not found to be getting through the ATP module receiver filter. The ATP module filter is a band-pass filter designated to pass only the specific operating track circuit frequency.

The postaccident testing also indicated the maintenance communication lines were faulted to ground inside the track junction boxes along the wayside. Further investigation found that the inside of the track junction boxes were heavily rusted and the terminals of the strips were being grounded to the case of the track junction boxes through the rust. The track circuit frequency for track circuit B2-304 was also found on the communication lines with a spectrum analyzer. Further testing and monitoring of the signal determined it was not of sufficient strength to be recognized by the ATP receiver module as a valid signal.

<u>Maintenance Operations Center – Work Orders & Incident Tickets</u>

On June 17, 2009, MOC opened work order # 7169867 at 6:50 am, for a report that track circuit B2-304 was bobbing. There was no incident ticket associated with the work order. During postaccident interviews, the CIT crew stated they notified MOC that both track circuits B2-304 and B2-312 were bobbing. WMATA records did not have any work orders associated with track circuit B2-312 bobbing.

On June 18, 2009, ATC mechanics[7] assigned to the Red Line in the vicinity of the accident began performing preventive maintenance inspection (PMI), verification shunt tests that were scheduled to be done on a quarterly basis. ATC mechanics explained in postaccident interviews that they tested track circuit B2-304 as part of their scheduled maintenance tests. They further explained that the verification shunt test required them to place a .06 ohm shunt 10 feet inside the track circuit at the transmitter end. When their testing was complete, they noticed that track circuit B2-304 was bobbing. They stated that no adjustments were made since the weather was turning bad and the track circuit had just been verified with the shunt test. The ATC mechanics stated that they did not report that track circuit B2-304 was bobbing to MOC

[5] Both bond cables measured less than 500 kilo-ohms to ground.
[6] An absolute block is a section of track in which no train is permitted to enter while it is occupied by another train.
[7] "ATC mechanics" in this report, refers to the TSSM ATC maintenance personnel working during revenue hours.

because the problem cleared itself while they were troubleshooting. The ATC mechanics stated they were not aware of the open work order regarding track circuit B2-304.

Work order #7169867 remained open from June 17, 2009 until the day of the accident. ATC shift supervisors are responsible for reviewing open work orders for their area of responsibility on the rail system. TSSM managers review open incident tickets to ensure they are properly handled. Work order #7169867 was not associated with an incident ticket so it was never included in any list that TSSM managers review. Incident tickets are for unusual occurrences in the operating system and except for temporary speed restrictions, require initiation by transportation personnel in the OCC. Work orders may be spawned from incident tickets for maintenance action but they may also be initiated without an incident. Shift supervisors find the open work orders assigned to their field office when they log into Maximo[8].

Eighteen months of incident tickets and work orders were requested and reviewed for the area between Fort Totten and Takoma. The records indicate that on February 28, 2008 work order #4397137 was opened for track circuit B2-304 bobbing. The work order indicated the work order was finished on September 6 and closed on September 26, 2008. The work order entries did not contain any information concerning remedial action taken to correct the bobbing track circuit.

ATC Maintenance Test & Inspection Procedures

WMATA, preventive maintenance inspection (PMI) 11000 – High Frequency Track Circuits, dated February 24, 1982 delineates the requirements for ATP track circuit adjustments. After a track circuit adjustment, PMI 11000 requires a track circuit to be verified by placing a .06 ohm shunt ten feet inside the transmit end of the track circuit. If the relay drops away, then the track circuit is considered as shunting properly.

The WMAT, ATC System Integrity Maintenance Practices, dated March 25, 2003 has a section on safety certification tests. In that section, track circuit verification tests are specified to be conducted whenever components of a track circuit are replaced or adjusted and a functional test of the track circuit must verify that the track relay will drop away when a .06 ohm shunt is installed between the running rails of the track. For double rail track circuits the test shunt is specified to be installed 10 feet inside the transmitter end.

The October 6, 2006 WMATA Metrorail, Engineering Bulletin regarding the use of US&S impedance bonds in GRS ATP track circuits explained that after installation, a verification shunt test should be performed at each end of the track circuit and at the mid point of the track circuit using a .06 ohm shunt. This engineering bulletin addressed track circuits where US&S impedance bonds were installed on track circuits with GRS ATP modules.

WMATA Metrorail, ATC technical procedures manual, T111-Track Circuit Quarterly Shunt Test, dated December 23, 2008 detailed procedures to verify that a track circuit will show occupancy with the presence of a train in the circuit. For an audio frequency track circuit, the test requires a .06 ohm shunt, 10 feet inside the transmitter end, a .06 ohm shunt halfway

[8] Maximo is a WMATA Metrorail database.

between the transmitter and receiver and a .06 ohm shunt 10 feet inside the receiver end of the track circuit. The track circuit is verified when each and all three of the shunts causes the track relay to drop. The T111 procedure is in draft status and had not been signed off by the Assistant Chief Engineer, ENSS and the Assistant General Superintendent, TSSM

During postaccident interviews, discussions regarding track circuit verification procedures indicated different procedures being used among the TSSM field maintenance/construction personnel. The CIT crew leader stated that for PMI-track circuit verification, they were only required to use one shunt placed 10 feet inside the transmitter end. But that for replacement impedance bond, track verification, her preference was to shunt in three places on the track circuit. A CIT supervisor provided instructions that he assembled for CIT crews installing US&S impedance bonds. In the instructions there is a section on track circuit adjustment, verification, and cab signal level testing. That section references PMI 11000 – High Frequency Track Circuits adjustments procedures for GRS ATP modules.

During postaccident interviews, TSSM, ATC mechanics working on the Red Line stated using PMI 11000 – High Frequency Track Circuits adjustments procedures for GRS modules. They further stated having no procedures to adjust or to verify track circuits when US&S impedance bonds were installed with GRS ATP modules. Neither the CIT crew leader nor the ATC mechanics interviewed mentioned the October 6, 2006 engineering bulletin during their interviews. The CIT supervisor mentioned he was aware of an engineering bulletin, but understood the engineering bulletin only applied to high current substation return impedance bonds and did not apply to regular impedance bonds.

WMATA provides form PM-1, Track Circuit Adjustment to record all track circuit adjustments and verifications performed under the PMI 11000 procedure. Column seven of the form is labeled Shunt Test and provides two columns to place a check to indicate if a shunt was used on the transmitter end and/or the receiver end of the track circuit. The form is contradictory to the October 2006, Engineering Bulletin since it does not provide the option to indicate if three shunts were used for track circuit shunt verification as specified in the bulletin. The draft T111 procedure is intended to supersede the PMI 11000 procedure and includes a data sheet with columns to check up to eight verification shunts depending on track configuration.

ATC Recorded Data

Information from the WMATA train control equipment is acquired by a remote terminal unit (RTU) also located in the train control room. The RTU data is communicated to the AIM computer system located at OCC. The AIM computer system queries the RTUs in the field approximately once every second. The raw data bits received from the field eventually get translated into a database file and stored in the reporting server.

Postaccident train control historical data were reviewed and indicate that at approximately 1:33 am on December 12, 2007 track circuit B2-304 was down. The data correspond to the date and time the high current substation return impedance bond at chain marker B2-311+71 was replaced. This is the B2-304 track circuit receive impedance bond. The data further indicate that about five hours later, track circuit B2-304 began bobbing between train movements. The bobbing continued intermittently until the day of the accident. Train movements were detected and the track circuit bobbing was between train movements, which indicated false train occupancies.

Postaccident data from the morning of June 17, 2009 indicate track circuit B2-304 was performing irregularly during the time the track circuit adjustment and verification process was conducted. Because of the frequent bobbing of track circuit B2-304, the shunt verification tests could not be verified to confirm the CIT crew leader statements made in the postaccident interview. According to the postaccident data, the performance of track circuit B2-304 changed significantly just prior to the arrival of the first train. From the time the impedance bond was replaced, the track circuit was bobbing and the track relay was seldom energized for more than 30 seconds between drop outs. Nine minutes before the arrival of the first train, the track circuit began staying energized for minutes at a time and was only bobbing for a second or two. The data further indicate that train detection failed for the first and nearly every train during the entire occupancy of track circuit B2-304 after the impedance bond was replaced on June 17, 2009 until the time of the accident.

ATP Receiver/Transmitter Modules

Postaccident inspection of the signal equipment in the train control room at the Fort Totten station identified the B2-304TR electromechanical vital relay for track circuit B2-304 to be out of correspondence with the physical location of the accident trains. The track relay was energized with both accident trains still shunting the occupied track circuit. After removal of the accident wreckage, track circuits in the vicinity of the collision were tested using a 0.06 ohm and a hardwire shunt. Track circuits B2-344, 336, 328, 322 and 312 were tested with a single 0.06 ohm shunt at three different locations, at the transmitter end, in the middle and at the receiver end of the track circuit. All track relays de-energized in response to the detection of each shunt. Track circuit B2-304was then tested and detected a 0.06 ohm shunt at the transmitter end of the circuit. The track circuit however failed to detect a 0.06 ohm or a hardwire shunt in the middle of the track circuit. With a shunt (0.06 ohm or hardwire) at the receiver end, the track circuit was intermittently detecting the shunt, momentarily de-energizing the relay and then energizing the relay and not detecting the shunt.

The B2-304TR vital relay along with other associated vital relays was tested for compliance with their performance criteria. All fifteen vital relays were found to be operating within specifications. The two US&S impedance bonds for track circuit B2-304 were swept to check the tuning frequency and were determined to be in compliance with manufacturer specifications. During the investigation, the US&S transmitter impedance bond at chain marker B2-304+33 was removed for inspection and bench testing. It was noted that the US&S impedance bond had a load impedance of approximately double the replaced GRS impedance bond. The load impedance difference at the GRS ATP transmitter/receiver typically required the track circuit transmit power to be changed during the track circuit adjustment and verification process. No exceptions were noted with the condition or operation of the US&S impedance bond.

In the train control room at the Fort Totten station, track circuit ATP card file modules and plug-in printed circuit boards are mounted on racks and are original equipment manufactured by GRS when the Metrorail Red Line was constructed. Track circuit B2-304 transmitter and receiver modules use the f4 frequency (2820 hertz) for the track circuit audio frequency. Track circuit B2-304 measured approximately 738 feet in length.

Postaccident testing found signal coupling between the track circuit transmitter and receiver ATP modules contributed to the associated track relay to remaining energized, despite the stopped accident trains shunting the track circuit. Testing found parasitic oscillations, generated by the power output transistors[9] (emitter-follower oscillations) of the track circuit transmitter coupled into the track circuit receiver and produced a false track circuit signal that bypassed the rails of the track. The oscillations were found to be at a high frequency, greater than 2 megahertz, and low amplitude, significantly less than 2 volts peak-to-peak when measured at the V-in/com terminals. The amplitude of the oscillations was found to vary significantly depending upon the transmitter power level was changed. The parasitic oscillations were coupled from the power output transistors to the heat sink assembly through capacitive coupling, and thereby to the power distribution circuits. The oscillations then migrate through the rack and module structures to other modules which share the same power source and chassis rack structure. The parasitic oscillations then couple to the input of the power amplifier on the transmitter section of the receiver track circuit. Although each ATP module contains mu in which the oscillations originated.

The oscillations were not continuous and only occurred when a power transistor signal had reached an amplitude at which it was prone to oscillation, usually at or near a positive or negative alternation peak. The oscillations therefore occurred in pulses driven by and carried on the audio signal. The pulses were observed to occur on the positive or negative alternations of the audio frequency signal, or both positive and negative, depending on which of the four individual power output transistors were oscillating. Because the oscillations were affected by the signal amplitude they were only present when the track circuit was transmitting and therefore the oscillations were synchronized with any coded signal coming back from the track. Once the oscillations were coupled to the transmitter's power amplifier in the module that shares the receiver of the track circuit, transmitter's power amplifier amplified the pulses. This resulted in synchronized pulses of another intermediate frequency around 25 kilohertz on the output of the amplifier. Since the transmitter's power amplifier didn't have the frequency response to amplify the higher mega hertz oscillations, it instead rings in a quickly decaying waveform at about 25 to 40 kilohertz. The amplified pulses of decaying kilohertz are coupled directly to the input of the track circuit receiver, where the input filter received the pulses which are at the correct period to be interpreted as the correct audio frequency. When the amplitude of the pulses was sufficient, an output was generated from the receiver amplifier to signal the relay driver to energize the track relay.

End of S&TC Factual Report

[9] The power output transistors each consist of a two-transistor amplifier circuit on one chip. The power output transistors are configured in a push-pull emitter follower amplifier that drives the output transformer. Each half of the push pull amplifier uses a matched pair of power output transistors in parallel. Each pair of power output transistors is mounted on one of two heat sinks attached to the rear panel of the module.