National Transportation Safety Board

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

Signal & Train Control Factual Report of Investigation – Addendum # 1

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

ERRATA[1]

Page 4, line 1 – change "each car" to read "the lead car."

Page 6, line 6 – delete "high current."

Page 7, line 30 – change "(MOC) called" to read "(MOC) also called."

Page 8, line 41 – change "conduits along an underground manhole" to "conduits and manholes along an underground duct bank."

Page 12, lines 34 through 38 – section modified to read "…and bench tested. No exceptions were noted with the condition or operation of the US&S/Ansaldo impedance bond. From postaccident testing, it was found that the US&S/Ansaldo impedance bond had a load impedance of 132.6 ohms and that the replaced GRS/Alstom impedance bond had a load impedance of 140.6 ohms. The load impedance difference at the GRS/Alstom ATP transmitter/receiver required, in some cases, the track circuit transmit power to be adjusted during the track circuit adjustment and verification process."

Page 13, line 12 - change "from the power output transistors to the heat sink assembly" to read "from the power output transistors through the heat sink assemblies."

ADDITIONAL INFORMATION

Following the on-scene investigation at Fort Totten and postaccident testing at the WMATA ATC lab, additional information was developed from the NTSB Public Hearing held on February 22 – 24, 2010 and additional interviews conducted by the signal and train control (S&TC) group on March 22 – 24, 2010.

Track Circuit Replacement Program

The first contract awarded by WMATA for the track circuit replacement program was awarded on December 20, 2002 for three locations on the outer Orange line (Cheverly, Landover and New Carrollton). The contract involved approximately 100 track circuits at those three locations. The contract specified that equipment in the train control room (transmitter/receiver modules) and equipment in the field (impedance bonds) be installed by the contractor. US&S/Ansaldo was awarded the contract and work regarding this contract commenced in 2004. During the interview of the US&S/Ansaldo Chief Technologist, he explained that the first

[1] This section contains corrections and clarifications in reference to the Signal & Train Control Factual Report of Investigation released on February 23, 2010.

contract essentially called for the new impedance bonds and the new track circuit modules to be installed at the same time. The design in the contract required the new track circuit modules to be compatible with certain equipment in the train control room that would remain in service, such as matching plug connectors, compatibility with existing power supplies, cabling and other related equipment. These compatibility tests were performed by WMATA and US&S/Ansaldo personnel, at the WMATA facilities on Telegraph Road prior to the installation of the new equipment.

The Chief Technologist further stated that WMATA requirements for right-of-way access, made it logistically difficult for US&S/Ansaldo personnel to get sufficient time to install the new impedance bonds. As a result, responsibility for installing the new impedance bonds was transferred to WMATA CIT personnel. This change of duties was also incorporated into the second contract awarded by WMATA for the track circuit replacement program.

The WMATA ATC Systems Engineer stated during his interview that he was involved in the track circuit replacement program from the origination of the specifications for the project through the approval of the products, review of the technical documentation and installation. He stated that in mid-2003, before the installation of new equipment began, he performed bench tests to verify the impedance of the new impedance bonds and compared them to the old impedance bonds. He stated he verified that the difference between the two bonds was about a ten percent difference in impedance. He stated he also bench tested a GRS/Alstom module operating with a US&S/Ansaldo impedance bond. He monitored the output using different voltage ranges, and stated there didn't seem to be much of a difference. He further stated that at three test locations at the WMATA yard facilities at Telegraph Road and at Landover, track circuits were put in for testing and operational data was monitored to ensure that there were no reliability issues associated with that setup.

The ATC Systems Engineer explained that the specifications of the contract required pre-installation safety certification (PISC) tests of all track circuit modules before installation. WMATA ATC electronics shop personnel at the Telegraph Road facility performed the PISC tests on the modules. WMATA also required the impedance bonds to be tested by US&S/Ansaldo before being shipped and accepted by WMATA. In addition, the contract required US&S/Ansaldo to submit a Hazard Mode and Effect Analysis (HMEA) for WMATA approval. The ATC Systems Engineer stated this was a typical requirement of most contractors and that US&S/Ansaldo had provided all required documentation regarding the track circuit replacement program to WMATA. He stated that the HMEA was a system level analysis and did not include the possibility of a loss of shunt detection. He further stated that this was also not included in the HMEA done on the original GRS equipment.

The first contract was completed by installing the new equipment in two phases. GRS/Alstom impedance bonds were replaced with US&S/Ansaldo impedance bonds and the track circuit was adjusted and placed in service. The GRS/Alstom ATP modules would then be replaced with US&S/Ansaldo AF800 modules. According to the WMATA Assistant Chief Engineer/Project Manager, no maintenance problems were reported through the WMATA maintenance management system regarding the installed equipment.

The second contract awarded by WMATA on December 30, 2005 for the track circuit replacement program was for an additional 22 locations on the Metrorail system. The second contract involved over 600 track circuits. US&S/Ansaldo was awarded the second contract and work regarding this contract commenced in 2006. Based on the previous WMATA testing involving equipment from different manufacturers, discussions between US&S/Ansaldo and WMATA did not identify any compatibility issues. Installation of the new equipment proceeded as established during the first contract. Installation of new equipment for the second contract of the track circuit replacement program was in progress at the time of the Fort Totten collision.

High-Current Impedance Bond Project

In preparation for eight-car train operations, the WMATA ATC Systems Engineer stated he was also involved in the high-current impedance bond project that began in 2004. WMATA requested both GRS/Alstom and US&S/Ansaldo to provide an impedance bond that could handle an increased return current to the traction power substation. Both manufacturers took their original impedance bond and modified them. According to the US&S/Ansaldo Chief Technologist, in their modification, US&S/Ansaldo essentially increased the size of the J-bar, and the impedance of the high-current impedance bond remained the same as the impedance of the other US&S/Ansaldo impedance bonds. The modified high-current impedance bonds from both manufacturers were installed throughout the Metrorail system at substation return locations.

In October 2006, the WMATA engineering bulletin regarding the use of US&S/Ansaldo impedance bonds in GRS/Alstom ATP track circuits was issued. The ATC Systems Engineer stated that although the tests at the three locations did not indicate any problems, there were some questions being raised by ATC technicians regarding the new equipment. He stated that he wanted to ensure that when a US&S/Ansaldo impedance bond was installed with a GRS/Alstom module that the track circuit was verified using three soft shunts (.06 ohm). He further stated that if they were unable to verify the track circuit during the installation, they would reinstall the old GRS/Alstom impedance bond. He stated that the concerns being raised seemed to be about the changes in the power level settings that sometimes were required to set up a track circuit. He stated that he was told that the track circuits were being verified using three shunts. He did not see a concern with the power level increase because of the slight difference in the impedance between the two bonds, as long as the track circuit verified safely using three shunts. But he stated that he wrote the bulletin to ease their concerns.

The October 2006 WMATA engineering bulletin indicated there were technical discussions with representatives from both manufacturers concerning the use of US&S/Ansaldo impedance bonds with GRS/Alstom ATP modules. In his interview, the ATC Systems Engineer stated that he discussed the matter with the GRS/Alstom Manager Train Detection Products. He stated that while the GRS/Alstom Manager did not provide any specific warnings about possible problems, he did not know enough about the equipment from the other manufacturer and could not recommend interfacing the two components. The ATC Systems Engineer further stated he could not recall specific discussions with US&S/Ansaldo personnel regarding combining equipment from different manufacturers in the same track circuit.

During the NTSB Public Hearing, GRS/Alstom provided a letter dated September 7, 2004 that was sent to all their customers. The letter had the subject line - "Impacts of the Use of Non OEM Manufactured Components." The letter mentioned a freight car derailment that was caused by the use of third party components in a GRS/Alstom switch machine as an example.

During his interview on March 23, 2010, the GRS/Alstom Site Safety Officer stated that the intention of the letter was to raise the generic concern about this type of a situation, that when you use components or material from a non-approved third party vendor, that GRS/Alstom could not accept responsibility for the design and safety. The WMATA ATC Systems Engineer stated that the 2004 GRS/Alstom letter was not brought up during their discussion regarding combining equipment from different manufacturers in the same track circuit. The GRS/Alstom Manager, Train Detection Products could not recall if the 2004 GRS/Alstom letter was discussed. The GRS/Alstom Manager however did state that when the 2004 letter was being drafted, he was aware that WMATA was using equipment from different manufacturers in the same track circuit, and that is why he asked that track circuits be specifically mentioned in the September 7, 2004 letter.

The WMATA ATC, Systems Engineer involved in the track circuit replacement program stated during his interview on March 23, 2010 that there are currently about 26 track circuits on the Metrorail system that are set up using a US&S/Ansaldo high current impedance bond with GRS/Alstom ATP modules. He further stated that there has been no loss of shunt problems involving those 26 track circuits.

Postaccident ATC Testing

Postaccident testing in the Fort Totten train control room found signal coupling between the track circuit transmitter and receiver ATP modules of track circuit B2-304. Testing eliminated the field equipment (bond line cables, impedance bonds, maintenance communication cables and the rails) as contributing to the path of the false track circuit signal[2] that was bypassing the rails of the track. During additional testing, while still working in the train control room, the S&TC group varied the power level setting on track circuit B2-304 to determine how the power level setting affected the amplitude of the false track circuit signal. The tests were done with a hard shunt in the middle of the track circuit and indicated that with the transmitter power level setting at 5%, 10%, 15%, 30%, 60% and 70% a signal could be measured in the receiver module[3]. With the transmitter power level setting at 55% and 90%, trains were observed operating through the track circuit and the track relay was energized with a train occupying track circuit B2-304.

After a basic understanding of the track circuit conditions that contributed to the signal coupling between the track circuit transmitter and receiver ATP modules was established, the field track circuit equipment was then disconnected from the modules in the train control room and simulated using a resistive load. Having the bond line cables disconnected and using

[2] The false track circuit signal was later identified as parasitic oscillation during lab testing.
[3] The signal measurements were recorded on July 23, 2009: 5%=240mV, 10%=400mV, 15%=400mV, 30%=400mV, 60%=400mV, and 70%=600mV.

resistive loads allowed flexibility to continue testing while lessening the impact that testing, done in connection with the investigation, was having on running revenue train service. With the bond lines open and resistive loads installed, the parasitic oscillations were verified as remaining the same. Testing was then able to determine that the mounting rack used for the ATP modules was part of the path that the false track circuit signal was using to bypass the intended path of the valid track circuit signal.

The transmitter and receiver modules for track circuit B2-304 were then removed from the Fort Totten train control room and transferred by NTSB to the WMATA ATC lab for further testing by the S&TC group. Additional ATP modules were requested to be delivered to the ATC lab for further testing. Printed circuit board and component level testing was then conducted to isolate the source of the parasitic oscillations. It was the consensus of the S&TC group that a lab setting would facilitate this level of testing and provide for the ATP modules to be energized while looking for the source without affecting other track circuits or train movements. Testing of components on the power amplifier input circuit board identified an electrolytic capacitor labeled for 2300 microfarads (μF) but only measured about 1400 μF. Replacement of the electrolytic capacitor with a new 2300 μF dampened the parasitic oscillations but did not eliminate the signal.

On August 7, 2009 WMATA emailed GRS/Alstom requesting approval to modify a printed circuit board on GRS/Alstom ATP modules to eliminate parasitic oscillations. The modification entailed installing 100 ohm resistors in series with the base of each power transistor in the power amplifier circuit. GRS/Alstom replied on August 31, 2009 that it had not had the opportunity to independently analyze and test the overall effectiveness of the proposed temporary mitigation and therefore was unable to approve the WMATA mitigation plan. WMATA responded to GRS/Alstom on September 4, 2009 and informed them that WMATA would not push forward with their proposed circuit modification without GRS/Alstom approval. WMATA also offered the Metrorail ATC system for Alstom to utilize in testing.

WMATA ENSS engineers drafted ATC technical procedures manual, T163 – GRS[/Alstom] ATP Module Parasitic Oscillation Test on August 9, 2009. Between August and September of 2009, following the work done by the NTSB S&TC group, WMATA ENSS personnel began testing other track circuits on the WMATA Metrorail system for the failure modes involving parasitic oscillations identified during the Fort Totten investigation. Testing was accomplished using the draft T163 test procedure. ENSS personnel focused their initial testing on track circuits showing timing anomalies that were compiled using their loss of shunt (LOS) tool[4]. Their testing also included additional track circuits located in the same train control rooms where testing was being done.

[4] WMATA was refining the accuracy of their LOS tool during this time, all track circuits listed were investigated although not all were identified as having LOS anomalies. Corrugated rail conditions were identified at some locations.

While the T-163 was being finalized, ENSS personnel were able to test 96 track circuits. Twenty[5] of the 96 track circuits were found to have parasitic oscillations between the transmitter module and the receiver module as was identified during the investigation of the Fort Totten rear-end collision. Table 1 lists the locations and track circuits identified by ENSS personnel. The 20 track circuits found with parasitic oscillations all had GRS/Alstom impedance bonds and GRS/Alstom ATP modules installed at the time the tests were conducted. None of the 20 track circuits were set up using equipment from different manufacturers.

Table 1: Track Circuits Identified by ENSS with Parasitic Oscillations

Station ID	Station Name	Track Circuit	Equipment Manufacturer
A04	Woodley Park Zoo	A1-108	GRS/Alstom
A04	Woodley Park Zoo	A1-116	GRS/Alstom
A06	Van Ness - UDC	A1-191	GRS/Alstom
B07	Takoma	B1-328	GRS/Alstom
B07	Takoma	B1-344	GRS/Alstom
B07	Takoma	B2-328	GRS/Alstom
B07	Takoma	B2-382	GRS/Alstom
B07	Takoma	B2-376	GRS/Alstom
B08	Silver Spring	B1-416	GRS/Alstom
C04	Foggy Bottom	C1-95	GRS/Alstom
C04	Foggy Bottom	C2-82	GRS/Alstom
C11	Potomac Yard	C1-415	GRS/Alstom
C11	Potomac Yard	C1-425	GRS/Alstom
C11	Potomac Yard	C1-465	GRS/Alstom
C11	Potomac Yard	C1-473	GRS/Alstom
C12	Braddock Road	C1-485	GRS/Alstom
C12	Braddock Road	C1-529	GRS/Alstom
K01	Courthouse	K2-170	GRS/Alstom
K01	Courthouse	K2-176	GRS/Alstom
K01	Courthouse	K2-182	GRS/Alstom

The T163 test procedure was finalized on October 21, 2009. The test procedure identifies four types of oscillations. The WMATA T-163 test procedure identifies the oscillations as follows:

> "*4.1 Oscillation type 1: Look for a clean sinusoidal audio waveform. If none of the audio waveform appearance is thickened by higher frequency oscillations, then enter the number "1" in column 2 of the data sheet. The*

[5] At the Public Hearing, the WMATA Assistant Chief Engineer/Project Manager discussed testing about 100 track circuits and finding approximately 18 percent with parasitic oscillation. The list provided by WMATA included additional track circuits that were found after the September 4, 2009 date mentioned in his testimony.

failure mode is not present for the tested track circuit and your test of this track circuit is complete. …

4.2 Oscillation type 2: If the entire waveform appears uniformly thickened as though it is out of focus, that indicates a harmless and continuous oscillation at some higher frequency (25 MHz for example). …This phenomenon may be present with other phenomena described below and if there is excessive amplitude of continuous oscillation, it might mask other oscillation types. If other bulges representing periodic bursts of oscillation appear on the waveform, then look for type 3 or type 4 oscillations. If the continuous oscillation, is the only oscillation, then record the number "2" in column 2, the measured frequency in column 3, and the measured amplitude in column 4. The failure mode is not present for the tested track circuit and your test of this track circuit is complete. …

4.3 Oscillation type 3: If the thickened portions of the waveform are consistently and only in the same region (usually at a positive and/or negative peak) then the thickened regions are local oscillations of the shared track circuit transmitter. The shared track circuit may be at risk for the parasitic oscillation failure mode, but if there are no other pulses of oscillation then the track circuit you were testing, the tested track circuit does not have the failure mode. …The failure mode is not present for the tested track circuit and your test of this track circuit is complete. However, you should begin tests of the shared track circuit immediately beginning at step #1.

4.4 Oscillation type 4: If the thickened portions of the waveform are irregular with respect to the audio frequency of the shared track circuit, (they appear at different angles/locations of the waveform) then they are coming from another transmitter, via the power distribution and rack structures, and are superimposed on the preamp of the shared track circuit transmitter. These are external oscillations for the shared track circuit transmitter. It is important to determine the source of these "pulses" that appear as thickened portions on the audio waveform."

The test procedures then direct how to identify the source of the pulses. If crosstalk between transmitters of either the tested or shared track circuit transmitter is identified then the level of the crosstalk must be determined. The procedures require:

"5.3 Measure the peak to peak amplitude of the receiver input audio frequency. …Record the value in column 7. It should be less than 400 mVolts, peak to peak.

5.3.1 If it is less than 400 mVolts peak to peak, then the track circuit is okay and the tests of the tested track circuit are complete.

5.3.2 If the value in column 7 is more than 400 mVolts peak to peak, then perform a full adjustment and retry a hard shunt in the middle of the track circuit. (This value should be affected only by power level or bias adjustments of the transmitter.)

5.3.2.1 If the level is still more than 400 mVolts peak to peak after the adjustment process then disable the track circuit receiver and replace the tested track circuit transmitter module. …"

After the T163 test procedure was finalized, WMATA TSSM ATC personnel were then trained to identify oscillations using this test procedure. From the end of October through December of 2009, TSSM ATC personnel tested 1,482 track circuits throughout the Metrorail system using the T163 test procedure. As a result of their testing, their reports listed 208 track circuits with type 3 oscillations and 82 track circuits with type 4 oscillations. Eight of the 82 track circuits with the type 4 oscillations had the receiver input audio frequency amplitude above the 400 mVolt threshold that required additional corrective action. Table 2 lists the eight locations and track circuits identified by TSSM personnel. The eight track circuits all had GRS/Alstom impedance bonds and GRS/Alstom ATP modules installed at the time the tests were conducted. None of the eight track circuits were set up using equipment from different manufacturers.

Table 2: Track Circuits Identified by TSSM that Required Corrective Action

Station ID	Station Name	Track Circuit	Equipment Manufacturer
C04	Foggy Bottom	C1-52	GRS/Alstom
C04	Foggy Bottom	C2-54	GRS/Alstom
C06	Arlington Cemetery	C2-183	GRS/Alstom
C07	Pentagon	C2-246	GRS/Alstom
C07	Pentagon	C1-355	GRS/Alstom
C10	National Airport	C2-358	GRS/Alstom
C11	Potomac Yard	C1-465	GRS/Alstom
G02	Capitol Heights	G1-423	GRS/Alstom

In October 2009 GRS/Alstom personnel demonstrated possible methods to mitigate the parasitic oscillations on WMATA, GRS/Alstom ATP track circuit modules. According to the WMATA Assistant Chief Engineer/Project Manager, GRS/Alstom demonstrated the use of insulating blocks to step the transistor heat sinks away from the module so that the transistors were on insulators and could not conduct through the heat sinks thus interrupting the path of the parasitic oscillation. They also demonstrated the use of ferrite chokes placed onto the existing cables to mitigate the parasitic oscillations. In January, ferrite chokes were installed on all of the track circuits at the Rosslyn station for further testing.

During the interview of the GRS/Alstom Manager Train Detection Products, he stated that prior to the Fort Totten accident; he had never seen the burst-type oscillations on the ATP modules. He further stated that he was aware that the amplifier could oscillate under certain types of loads and that it was very sensitive to reactive loads. He added that it was always a continuous oscillation where it just begins and doesn't stop and was considered benign because such an oscillation would not be recognized as a valid signal. He further stated that it did not affect safety, just reliability. He had never seen a continuous oscillation result in loss of train detection. He stated that his conversations with the WMATA ATC Systems Engineer did not include any discussion concerning the propensity for the transistors to oscillate when the load was changed.

TSSM ATC Maintenance Personnel Interviews

On June 27, 2009, the S&TC group conducted interviews of WMATA, TSSM ATC personnel regarding the Fort Totten accident. GRS/Alstom, US&S/Ansaldo and FRA were not parties to the investigation at that time so they did not participate in the interviews. Transcripts of the S&TC group interviews were emailed to all representatives of the S&TC group on July 24, 2009. By that date, GRS/Alstom and US&S/Ansaldo had party status and thus were included in the distribution of the interview transcripts. Second interviews of the WMATA TSSM ATC personnel were conducted on March 23, 2010.

During the interviews of WMATA ATC technicians assigned to perform preventative and corrective maintenance, when asked about track circuit compatibility issues, they discussed the change in the power level setting occasionally required to adjust track circuits when a US&S/Ansaldo impedance bond is installed. They stated that in their experience, a change in power level wasn't often required when a GRS/Alstom impedance bond was changed with an impedance bond of the same kind. One technician stated however that the transmitter signal level is much higher with a new GRS/Alstom one-piece bond when installed to replace an old GRS/Alstom two-piece bond[6].

The technicians also discussed dealing with speed command problems. They stated that because cab signal levels were not adjusted after new US&S/Ansaldo impedance bonds were installed, trains would report loss of speed commands which would require them to go out and adjust cab signal levels. They stated that installation crews would adjust the track circuit but sometimes the cab levels were never readjusted. They further did state however that during a track circuit adjustment, the procedures do not require the cab signal levels to be adjusted.

During both the June 2009 and the March 2010 interviews, the technicians discussed working in the Fort Totten area on January 10, 2008. They were performing periodic tests on track 2 and noticed that trains were stopping near signal 2 on track 1. Upon further examination, they determined that track circuit B1-245 was not detecting trains.

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[6] The 2005 Rosslyn investigation report also includes information stating that replacement of the transmitter GRS two piece impedance bond with an Alstom one piece impedance bond resulted in near double the transmitter output voltage.

The NTSB S&TC group reviewed the ATC log books, data sheets and ATC work orders for the Fort Totten train control room. Information indicates that on December 18, 2007, as part of the high-current impedance bond project, the GRS/Alstom receiver impedance bond was replaced with a US&S/Ansaldo high-current impedance bond for track circuit B1-245[7]. The transmitter power level setting was increased from 30% to 60% and the track circuit was adjusted and verified[8].

On December 24, 2007, work order #398712 was opened and reported that track circuit B1-245 was down. The log book entry for that date stated that track circuit B1-245 would not shunt with a train in the circuit. According to the log book entry, the track circuit was adjusted and verified. No data was recorded on the track circuit adjustment data sheet regarding work done on the work order.

On January 10, 2008, the entry in the log book indicated that trains were losing speeds commands approaching track circuit B1-250. It further indicated that track circuit B1-245 was not detecting trains and that the transmitter power level setting was at 70% and was changed to 60% but technicians could not adjust the track circuit such that the track relay would remain energized. CIT was notified. CIT technicians went out during their shift and inspected the track circuit. They changed the transmitter power level setting to 55% but were still unable to adjust the track circuit such that the track relay would remain energized. Track circuit B1-245 was disabled by removing the receiver board and the transmitter buffer amplifier cards. OCC and MOC were notified.

On January 11, 2008, the track circuit was re-enabled and the transmitter power level setting was changed to 30%, but the track circuit still could not be adjusted such that the track relay would remain energized. Work order #4092364 was opened to investigate reports that track circuit B1-245 could not be verified. The following day, the original GRS/Alstom impedance bond was reinstalled for track circuit B1-245. The track circuit could not be adjusted with the transmitter power level setting at 30% so it was increased to 55%. The log book entry showed that the track circuit was adjusted and verified. The changes entered in the log book were also recorded on the data sheets for the affected track circuits. On September 9, 2008, the GRS/Alstom transmitter impedance bond for track circuit B1-250 was found to be defective[9] and was replaced with another GRS/Alstom impedance bond. The log book entry showed that the track circuit was adjusted and verified.

As the high-current impedance bond project was nearing completion, a review by WMATA determined that the receiver impedance bond for track circuit B1-245 was never replaced with a high-current impedance bond. On January 10, 2009, the GRS/Alstom receiver impedance bond was replaced with a US&S/Ansaldo high-current impedance bond for track

[7] WZ-27 at chain marker 249+96
[8] The track circuit adjustment data sheet entry for this date indicates that a shunt was placed in the transmitter and receiver ends of the track circuit for verification.
[9] A review of the data on the track circuit adjustment data sheet for track circuit B1-250 indicated that the transmitter level was deteriorating and the value decreasing from 56 volts in May 2006 to 29 volts by August 2008.

circuit B1-245. The log book entry showed that the track circuit was adjusted and verified and the data was recorded on the track circuit adjustment data sheet. On April 20, 2009 the GRS/Alstom transmitter impedance bond was replaced with a US&S/Ansaldo impedance bond for track circuit B1-245. The transmitter power level setting remained at 55% and the log book showed that the track circuit was adjusted and verified.

Table 3 summarizes the equipment configuration of track circuit B1-245. A review of LOS data from December 18, 2007 through January 11, 2008 indicates that track circuit B1-245 began to experience intermittent loss of train detection after the track circuit was adjusted and the power level setting changed to 60% following the installation of the US&S/Ansaldo high-current bond. The LOS data further indicate that from January 12, 2008 through January 9, 2009 the track circuit continued to exhibit intermittent loss of train detection with the power level setting at 55% and with all GRS/Alstom, equipment. Loss of train detection continued after the US&S/Ansaldo high-current receiver impedance bond was replaced on January 10, 2009 and through April 20, 2009 when the US&S/Ansaldo transmitter impedance bond for track circuit B1-245 was installed. The power level setting remained at 55% after each installation, following the track circuit adjustment and verification. The GRS/Alstom track circuit modules remained the same during this time period.

On August 15, 2009 the GRS/Alstom track circuit modules were replaced with US&S/Ansaldo track circuit modules. NTSB requested LOS event data for track circuit B1-245 from August 2009 up to January 2010; and the data does not indicate any loss of train detection with all US&S/Ansaldo equipment.

Table 3: Track Circuit Equipment Configuration

Dates	Transmitter Impedance Bond	Receiver Impedance Bond	ATP Module	Power Level	Loss of Shunt events
Original Configuration	GRS/Alstom	GRS/Alstom	GRS/Alstom	30%	None
12-18-2007 to 1-9-2008	GRS/Alstom	US&S/Ansaldo	GRS/Alstom	60%	Intermittent
1-10-2008 to 1-11-2008					Out of Service
1-12-2008 to 9-8-2008	GRS/Alstom	GRS/Alstom	GRS/Alstom	55%	Intermittent
9-9-2008 to 1-9-2009	GRS/Alstom	GRS/Alstom	GRS/Alstom	55%	Intermittent
1-10-2009 to 4-19-2009	GRS/Alstom	US&S/Ansaldo	GRS/Alstom	55%	Intermittent
4-20-2009 to 8-14-2009	US&S/Ansaldo	US&S/Ansaldo	GRS/Alstom	55%	Intermittent
8-15-2009 to 1-1-2010	US&S	US&S	US&S		None

2005 Rosslyn Incident

During the NTSB Public Hearing, the WMATA Assistant Chief Engineer/Project Manager explained the events of the 2005 near-miss incidents near Rosslyn and the WMATA investigation that was initiated afterwards. The WMATA investigation determined that a 963 foot track circuit (C2-111) located about mid-river between Foggy Bottom and Rosslyn did not detect the presence of a train when the train was in the middle of the track circuit. Logs kept in the train control room indicated no substantial change for measurements of the transmitter and receiver in the past ten years. The transmitter power level setting was not changed and remained at 70%. The Assistant Chief Engineer/Project Manager also stated that during their investigation while troubleshooting the track circuit, the only thing they could account theoretically that would be able to cause the problem they were seeing was capacitive coupling that would cause a cable fault between the transmitter and receiver bond lines. WMATA requested assistance from GRS/Alstom. He stated how the track circuit problem cleared when they cut the bundle ties at the top of the rack to examine the cables looking for any visible faults. The WMATA report concluded that a cable fault was the probable cause and stated that this was the first track circuit that had failed in that manner on the WMATA system.

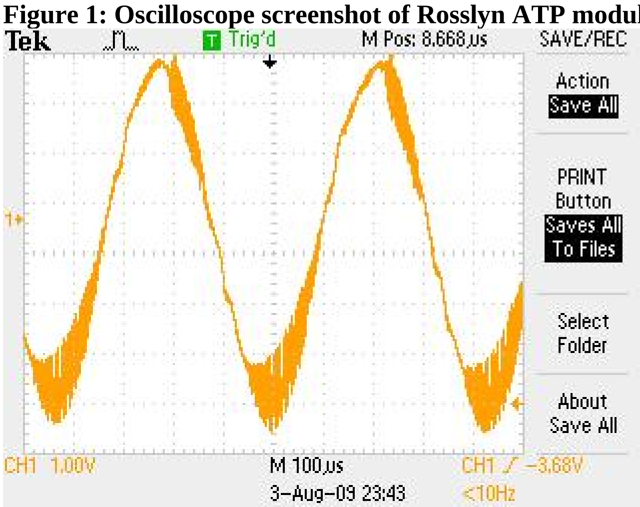
The GRS/Alstom Site Safety Officer during his interview stated that GRS/Alstom engineers participated on-scene in the WMATA investigation. He stated that while he was not present on-scene, GRS/Alstom engineers were, but they arrived after WMATA had made changes and the problem was no longer present. He stated that during the investigation, they were able to replicate the problem using the most logical theory they had and WMATA was able to say that the problem appeared to be what they had previously seen. He stated that a GRS/Alstom letter with his signature was sent to WMATA regarding the investigation. He stated that the cable fault was still a rational explanation and that without having the equipment and exact conditions anything else would be speculation.

The WMATA ATC Systems Engineer stated in his interview that he also participated in the 2005 Rosslyn investigation and that at the conclusion of their investigation, all equipment associated with track circuit C2-111 was replaced. The GRS/Alstom ATP modules and GRS/Alstom impedance bonds were replaced along with their associated bond lines. He stated that he held on to the GRS/Alstom ATP modules and kept them in his office for further examination. He stated he performed a spectrum analysis of them but explained that because his spectrum analyzer was limited to 100 kilohertz, he would not have been able to observe if any oscillations were present. Examination and testing of the cable bond lines did not identify the cause of the suspected cable fault.

During the Fort Totten investigation, the S&TC group learned that the Rosslyn modules were still stored in the WMATA ATC Systems Engineer's office and requested them for testing in the ATC lab at the Carmen Turner Facilities. On August 3, 2009, the Rosslyn modules were installed on the test rack. The S&TC group, using the same test equipment, observed parasitic oscillations between the transmitter module and the receiver module. A screen shot of the parasitic oscillations was captured and also recorded in the log book that was maintained by the S&TC group (figure 1).

In November 2009, NTSB requested WMATA review historical occupancy data for the Rosslyn track circuit, C2-111. WMATA responded that block occupancy data was collected for operational incidents where train locations were required. In response to the NTSB request, WMATA reviewed archived data from previous WMATA investigations. The archives included electronic and printed occupancy data for track circuit C2-111 going back to October 31, 1989. Records indicate that track circuit C2-111 was placed in service in 1977, but data was only available to 1989.

Figure 1: Oscilloscope screenshot of Rosslyn ATP modules



The archived occupancy data indicates that track circuit C2-111 was intermittently indicating vacant during train occupancy going back to 1988. Track circuit C2-111 had GRS/Alstom impedance bonds and GRS/Alstom ATP modules installed at the time it was put in service and at the time of the 2005 Rosslyn incident. Track circuit C2-111 was never set up using equipment from different manufacturers.

<u>Manufacturer Recommended Maintenance for GRS/Alstom Track Circuit Modules</u>

GRS/Alstom recommended guidance[10] for maintenance of the GRS Generation II automatic train control modules outlines a series of quarterly maintenance testing focused on maintaining the stability of specific system parameters. These parameters include track circuit transmitter frequency, modulation, and power level; and the track circuit receiver passband and sensitivity level.

Once per quarter, a check is to be made of the transmit power level for the track circuit train occupancy detection signal. This is the signal used to sense the presence of a train within the boundaries of the block defined by the transmitter and receiver impedance bonds. The maintenance schedule calls for making an RMS voltage measurement and recording the result on the ATP module data sheet. If the voltage level is found to be "radically" different from previous readings, the procedure calls for an adjustment to be made to the module.

[10] GRS Automatic Train Control System – Wayside Equipment Operation and Maintenance Manual, Section 10.

Once per quarter, a check is to be made of the transmit carrier[11] frequencies of the track circuit signals. The maintenance schedule calls for making a frequency measurement and recording the result on the ATP module data sheet. If the frequency is found to be outside of the tolerances specified in the procedure, a replacement of the defective subsystem is called for. No adjustment of the carrier frequency is possible.

Once per quarter, a check is to be made of the transmit modulation[12] frequency (code-rate) of the track circuit train occupancy detection signal. The maintenance schedule calls for making a frequency measurement and recording the result on the ATP module data sheet. If the frequency is found to be outside of the tolerances specified in the procedure, a replacement of the defective subsystem is called for. No adjustment of the modulation frequency (code-rate) is possible.

Once per quarter, a check is to be made of the center frequency and passband characteristics of the track circuit receiver input filter. The maintenance schedule calls for making a voltage measurement with a known signal input at the center frequency of the receiver passband. Additional voltage level measurements are required with a known signal input at frequencies above and below the center frequency in order to characterize the bandwidth of the filter. All results are to be recorded on the ATP module data sheet. If either the filter attenuation at center frequency or the width of the filter in Hz is found to be outside of the tolerances specified in the procedure,[13] a replacement of the defective subsystem is called for. No adjustment of the input filter is possible.

Once per quarter, a check is to be made of the receiver sensitivity level for the track circuit train occupancy detection signal. The maintenance schedule calls for making several peak-to-peak voltage measurements using an oscilloscope[14] and recording the result on the ATP module data sheet. If the voltage levels are found to be "radically" different from previous readings, the procedure calls for adjustments to be made to the module.

[11] The carrier frequency is the main frequency used to carry signal energy from the transmitter to the receiver. This will be a sinusoidal waveform of constant frequency and peak-to-peak amplitude in the case of an unmodulated signal. Eight carrier frequencies are available for track circuit train occupancy detection: 2100, 2320, 2580, 2820, 3100, 3370, 3660, and 3900 Hz.

[12] The modulation frequency is the frequency by which the much higher carry signal is modified in order to convey information. In the case of the WMATA track occupancy system, modulation is accomplished using a 50% duty cycle square-wave signal with a period varying from 333 ms to 46 ms (3.0 to 21.5 Hz). This modulation scheme is referred to as the code-rate, based on the 6 distinct modulation frequencies (code-rates) permitted in the design: 3.9, 4.6, 6.83, 10.1, 15.3, and 21.5 Hz.

[13] The procedure specifies for attenuation at the center frequency to be less than 50%. Passband attenuation is required to be greater than 50% over the center frequency level, for signals with frequency beyond about ±55 Hz from center frequency.

[14] An oscilloscope is a piece of electronic test equipment designed to graphically display, in real time, the variation of voltage with time. A properly adjusted oscilloscope would display an unmodulated carrier frequency as a sine wave with a fixed frequency and peak-to-peak voltage level.

WMATA Scheduled Maintenance for GRS/Alstom Track Circuit Modules

WMATA Metrorail scheduled maintenance of the automatic train control system is provided in technical procedure manuals and engineering bulletins. The purpose of the preventive maintenance inspection is to verify that the ATP track circuit adjustments are correct and have not changed since the last time preventive maintenance was performed and to ensure that when a shunt (.06 ohm) is placed at designated points within a track circuit, the associated track relay is de-energized.

Once per quarter, a check is to be made of the transmit power level selection jumpers in the ATP plug coupler. The percentage is to be recorded in the track circuit adjustment data sheet (PM-I). If the power level does not agree with the previous recorded data, a note of the discrepancy is also entered.

Once per quarter, a check is to be made of the ATP track receiver level. The voltage level is to be recorded in the track circuit adjustment data sheet (PM-I). If the measured voltage level has drifted by more than 10% from the value recorded when the last full track circuit adjustment was made, a full track circuit adjustment must be performed.

Once per quarter or whenever a track circuit change is made that affects its operation, verification of a track circuit must be performed using a .06 ohm shunt placed at designated points within a track circuit, to ensure that the associated track relay is de-energized. Result of the track circuit verification is to be recorded in the track circuit adjustment data sheet (PM-I). If a track circuit does not shunt properly, a full track circuit adjustment must be performed.

A full track circuit adjustment is to be made whenever there has been a change that affects the operation of the track circuit. WMATA has also implemented a test to check GRS/Alstom track circuits for potential parasitic oscillation failures. The test procedure indicates the frequency of the test is as directed.

Vital Automatic Train Control System

The WMATA automatic train control system in the original Red Line is nearly 40-years old. In their April 2, 2010 submission to the NTSB investigation, GRS/Alstom stated that with proper maintenance and monitoring, the GRS/Alstom audio frequency track circuit is as reliable, safe and trustworthy today as it was 40 years ago.

The WMATA automatic train control system is a vital system. The ATC system is required to operate under a ‘fail-safe’ principle, whereby known failure modes should result in the system going to its most restrictive or safe state. The investigation determined that WMATA track circuits can violate the fail-safe principle as a result of two different conditions: the presence of corrugated rail, and the presence of certain types of parasitic oscillation in the track circuit transmitter. Both failures are enabled, in part, by the coding scheme (50% duty cycle on/off keying) used by the track circuit receiver to discriminate between the intended track circuit signal and any spurious signal that could mimic a valid signal. Arcing in the presence of corrugated rail can create harmonics that effectively mimic this signal and are accepted by the receiver via the normal intended signal path.[15] Parasitic oscillation in the track circuit transmitter can create a signal that effectively mimics this signal by entering the receiver following an unintended signal path.[16] In each case the receiver detector is responding correctly as designed, by giving an indication that it 'sees' a signal meeting its criterion for validity.

Neither the recommended maintenance schedule provided in section 10 of the GRS Automatic Train Control System – Wayside Equipment Operation and Maintenance Manual nor the WMATA technical procedure manuals/engineering bulletins specified the measurement of detailed signal waveform parameters such as total harmonic distortion and spectral frequency distribution.

End of S&TC Factual Report – Addendum #1

[15] The rapid gain and loss of electrical contact as the wheels pass over the corrugations results in sparking. This sparking generates a broadband signal in a manner very similar to that used by the early spark-gap transmitters. A portion of this signal will fall within the receiver input filter passband and be received by the associated track circuit receiver. This signal is modulated by the corrugations in the rail, and depending on train speed and corrugation shape can mimic the code-rate (50% duty cycle, on/off keying) used by the WMATA track circuit train detection system. If the sparking is of high enough intensity, sufficient signal energy can be generated to spoof the receiver into indicating that the track circuit is vacant. As a practical matter, this only occurs if the train is traveling at a certain range of speeds, and the effect will disappear if the train significantly changes speed or stops. As a result corrugated rail is not considered by WMATA to be a critical safety issue.

[16] Parasitic oscillation in a transmitter – triggered in synchrony with the proper code rate – can create a modulated high frequency (HF) signal capable of bypassing the internal safeguards designed to be effective against spurious audio frequency signals. Under certain conditions his HF signal can propagate within the structures in the train control room, and induce a response in the associated track circuit receiver. The result is the production of an input signal at the detector of the associated track circuit receiver that mimics the code-rate for that block, causing the track circuit to return a 'vacant' indication.