NATIONAL TRANSPORTATION SAFETY BOARD
Vehicle Recorder Division
Washington, D.C. 20594

September 3, 2015

Radio-Communication Systems - Addendum

Specialist's Factual Report
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1. EVENT SUMMARY

Location: Washington, DC
Date: January 12, 2015
NTSB Number: DCA15FR004

2. DETAILS OF INVESTIGATION

This addendum includes additional information on selected elements of the communication system maintenance history and maintenance efforts prior to and after the accident.

2.1. Maintenance History

The Comprehensive Radio Communication System (CRCS) and the Public Service Radio System (PSRS) are both maintained by WMATA personnel. Prior to January 12, 2015, the maintenance philosophy for both was the same: essentially a corrective run-to-failure model supplemented by limited spot testing. Users employing the system in day-to-day operations would report communications problems as they experience them through a trouble-ticket process. WMATA maintenance would then evaluate the problem and perform any corrective action necessary to restore system performance.

Since the CRCS and the PSRS are two separate systems, their utilization rates are different. As currently configured, the only major component these two systems have in common is the distributed antenna system. The major active components – including the Bi-Directional Amplifiers – are separate. Users communicating through one system may experience nominal service even if the other system is non-operational. This impacts the recognition time of any system degradation or failure.

The CRCS is used by WMATA personnel continuously in the process of operating and maintaining the Metro System. This represents a relatively high rate of radio performance data collection, and provides numerous opportunities for the identification of a performance problem in any segment of the CRCS system. The PSRS is used by DC emergency response personnel in the event of an unusual circumstance: fire,

smoke, medical emergency, or some activity requiring law enforcement response. This represents a relatively low rate of radio performance data collection, and provides far fewer opportunities for the identification of a performance problem in any segment of the PSRS.

Recognizing this, the DC Office of Unified Communications (OUC), together with DC Fire and Emergence Management Service (FEMS), implemented a program to perform spot-checks documenting voice quality performance of the PSRS in WMATA trains and tunnels. Prior to the January 12, 2015 accident, these checks were performed at the rate of 4 – 5 station locations every 1 – 2 months by DC OUC personnel checking communications using hand-held radios both on the station platform and while riding trains between stations. Barring duplication, this would result in a complete test of the identified underground areas over the course of about one year.[1] It was noted in the course of the investigation that certain cross-jurisdictional tunnel spaces[2] – including the Portals Tunnel leading from L'Enfant Plaza to the Pentagon – were not included in this testing program.[3]

Problems discovered in the course of routine use and/or testing were reported to WMATA via e-mail and/or telephone and entered into a trouble ticket reporting and WMATA tracking system called Maximo. Results of this reporting, covering the 4-months before and after the January 12, 2015 accident, are summarized in Tables 1 - 4.

Maximo reporting covering the 4-months leading up to the accident indicate a much higher rate of reporting for the WMATA CRCS (see table 2) than for the DC PSRS (see table 1). This is consistent with the maintenance philosophy in-place prior to the January 12 accident; whereby routine maintenance testing was essentially accomplished as a consequence of routine use. The WMATA CRCS was utilized almost continuously as the system was exercised by day during normal revenue service and overnight by maintenance personnel. The DC PSRS was utilized at a much lower rate – primarily during actual emergency responses, supplemented by spot-checks according to the DC OUC rotating test plan.

Table 1. PSRS Work Orders reported during the four months prior to January 12, 2015.

Work Order Cause	Frequency of Occurrence
Misalignment	31
Amplifier Inoperative	18
Out of Adjustment	1
Total	50

[1] DC OUC has been conducting testing for several years.
[2] Tunnels leading to or from a station that lay outside DC FEMS primary area of responsibility.
[3] *DC OUC Metro Radio Coverage Testing Tracker - January to March 2015*, DC OUC, 4 Mar 2015

Table 2. CRCS Work Orders reported during the four months prior to January 12, 2015.

Work Order Cause	Frequency of Occurrence
Generic Radio Reception / Transmission Problem	40
Misalignment	18
Amplifier Inoperative	18
Antenna Problem	12
Power Supply Problem	8
Squelch Incorrect	8
Intermodulation[4] Problem	7
Connector Problem	6
Inoperative Component	5
Output Power Problem	4
Alarms / Environmental Problems	2
Installation Problems	2
Out of Adjustment	1
Total	131

Post-accident, the testing program for the PSRS was dramatically up-scaled to include testing of all underground spaces (stations and tunnels) covered by the PSRS on a weekly basis. In addition, supplemental testing is now being performed by WMATA personnel utilizing radios operating on DC FEMS frequencies. These efforts are reflected in Maximo reporting covering the 4-months immediately after the accident.

Tables 3 and 4 indicate a much higher rate of reporting for both the WMATA CRCS and the DC PSRS than seen just prior to the accident. Trouble reports for the PSRS are up approximately 270%, while trouble reports for the CRCS are up approximately 120%. Assuming that the failure rate of each system has held fairly constant over the 8-month period being reported, these increases are consistent with significant additional testing being conducted on both systems – with emphasis on the PSRS.

[4] Intermodulation refers to distortion created when two RF signals combine due to internal nonlinearities in a communication system resulting in interference with normal operation. This is usually the result of signal overload, although it can also occur due to a malfunction within the system.

Table 3. PSRS Work Orders reported during the four months after January 12, 2015.

Work Order Cause	Frequency of Occurrence
Misalignment	87
Amplifier Inoperative	77
Output Power Problem	7
Connector Problem	5
Out of Adjustment	1
Total	184

Table 4. CRCS Work Orders reported during the four months after January 12, 2015.

Work Order Cause	Frequency of Occurrence
Generic Radio Reception / Transmission Problem	96
Misalignment	81
Amplifier Inoperative	22
Antenna Problem	16
Power Supply Problem	9
Intermodulation Problem	2
Connector Problem	20
Inoperative Component	3
Output Power Problem	9
Alarms / Environmental Problems	13
Installation Problems	8
Miscellaneous	8
Total	287

In addition to these voice quality testing efforts, WMATA has implemented a process for recording and analyzing down link signal strength for the PSRS control channel covering the entire below ground footprint. This test is programmed weekly, and is designed to detect gaps in radio coverage inside tunnel spaces.

2.2. Communications in the L'Enfant Plaza Station

Maximo reporting during the 4 months prior to the accident included two trouble reports for station D03[5] with causes attributed to misalignment. In the 4 months subsequent to the accident, there were six trouble reports for station D03/F03[6] with causes attributed to misalignment and inoperative amplifiers.

[5] This designator refers to the lower level of the L'Enfant Plaza station corresponding to the Orange and Blue lines.
[6] This designator refers to the upper level of the L'Enfant Plaza station corresponding to the Yellow and Green lines.

Voice quality testing in the months prior to the January 12 accident was conducted using P-25 APX-series portable radios and XTS5000 SmartZone radios operating on the DC WM1, FG 03 and/or DC SPARE2 talk groups. The testing was conducted by transmitting from the testing site the following information: location, radio system (P-25 or SmartZone), and counting to five. In response, a confirmation transmission would be made from the radio shop. Results would be recorded as Pass, Fail, or Noisy.

Voice quality testing was conducted on the Green and Orange lines passing through L'Enfant Plaza in May, 2014. Records indicate that P-25 system communication at L'Enfant Plaza was rated a 'Pass' at all five tested locations on the Green line – the entrance inbound from Archives, platform end #1, platform middle, platform end #2, and the entrance outbound for Waterfront – as well as in the tunnels leading from Archives and to Waterfront. P-25 system communication was also rated a 'Pass' at all five tested locations on the Orange line – the entrance inbound from Smithsonian, platform end #1, platform middle, platform end #2, and the entrance outbound for Federal Center SW – as well as in the tunnels leading from Smithsonian and to Federal Center SW. No testing of the Portals tunnel leading from the L'Enfant Plaza station to the Pentagon station was reported.[i]

On August 15, 2014 the DC OUC transitioned three frequencies from the older SmartZone 4.1 system to the new P-25 system, bringing the total number of frequency allocations for the P-25 system to seven.

On August 27, 2014, the DC OUC reported PSRS communications at the L'Enfant Plaza Metro Station to be 'GOOD' at the following locations: Platform at Escalator, Platform at Tunnel, Kiosk, and Mezzanine. No concerns or issues were noted. No testing of the Portals tunnel leading from the L'Enfant Plaza station to the Pentagon station was reported.[ii]

On December 15, 2014 the DC OUC transitioned four additional frequencies from the older SmartZone 4.1 system to the new P-25 system,[7] bringing the total number of frequency allocations for the P-25 system to eleven.[iii]

On January 7, 2015, WMATA was notified that the DC Fire Department had lost radio coverage at L'Enfant Plaza. Symptoms were described as '…coverage in the stations but poor coverage in the tunnels.' WMATA notified the OUC that they had been troubleshooting a problem that may have precipitated the issue, were troubleshooting the DCPS radio coverage problem, and would keep the OUC advised.[iv] In the process of troubleshooting the DCFD radio coverage issue, WMATA requested access to the

[7] The transition to the P-25 system was completed on April 27, 2015 with the transitioning of the five remaining SmartZone 4.1 frequencies, bringing the total number of frequency allocations for the P-25 system to sixteen.

DC Equipment room where the DCPS above ground radio system interfaces with the below ground radio system. This access was to be granted on January 14, 2015.

2.2.1. Troubleshooting Efforts and Resolution

On January 14, 2015, WMATA engineers and technicians from Chief Infrastructure Services (CENI) and System Maintenance (SMNT), along with personnel from the DC OUC and Motorola Solutions, performed noise floor and signal-to-noise testing in the One Judiciary Square equipment room for the uplink from the underground feed from the Gallery Place B01 Communications Room.[v] During this effort they discovered that the original configuration and path for the uplink signal in the DC Equipment Room (see figure 1) had been modified to incorporate the new P-25 Prime site equipment while continuing to support the existing 4.1 equipment at One Judiciary Square.

The antennas, amplifiers, and transmission lines that carry communications signals in any system inherently pick up, amplify, and transmit background noise along with the intended signal. The level of background noise energy is often referred to as the *noise floor*. The desired signal must maintain some margin with respect to the noise floor to be reliably detected and decoded. The operating margin of signal-to-noise – the signal-to-noise ratio (SNR) – in the WMATA and PSRS radio systems is about 10 db.[8] Each component of the system – above ground and below ground – separately intercepts and propagates desired signals from radio operator making transmissions as well as noise from various sources including non-subscribing radios, outside electronic equipment, building alarm systems, etc. Each component – above ground and below ground – has its own set of desired signals and its own noise floor. The RF energy from each component of the PSRS is combined as shown in figure 1 by a directional coupler, and the combined signal is fed to electronics the DC Radio Equipment room.

Performance measurements indicated that the uplink levels into the DC Equipment Room were at or close to the threshold of operation for both the older SmartZone 4.1 system and the newer P-25 system. The below ground signal being uplinked into the DC Equipment room was too low, compared to the above ground signal+noise,[9] to provide reliable below ground communications. The result was intermittent PSRS communications in stations and tunnels across the entire underground system.[vi]

[8] The decibel is a logarithmic unit that expresses the ratio of two values of a physical quantity; in this case power or amplitude. A margin of 10 db corresponds to a factor of 10 ratio in power, or a factor of 3 ratio in amplitude.

[9] This refers to the total above ground signal, which contains the desired RF signal transmitted by subscriber radios, as well as undesired RF energy from external sources that falls within the receivers front end RF passband. Sources of undesired signal energy include transmitters emitting signal energy outside of their prescribed band, non-subscribing radios operating with high signal energy on nearby frequencies (or multiples / submultiples of the subscriber frequency), alarm systems, and uncorrelated noise from natural sources.

In order to increase the uplink signal, WMATA increased the uplink signal plus noise levels 18 dB by removing attenuation already present in the system. To evaluate the effect of this change, WMATA and OUC personnel performed radio checks along Yellow / Green line between, and inside, the Gallery Place, Archives, and L'Enfant Plaza stations. All station and tunnel checks passed. WMATA personnel then conducted measurements of the combined above and below ground noise floor and verified that the modification caused no apparent increase in the combined noise floor. SNR measurements were made using an Anritsu Site Master S412E Spectrum Analyzer. A portable radio transmitting on 809 MHz showed a 30 dB SNR at the L'Enfant Plaza station. This was necessary to ensure that the change did not adversely impact the reliability of above ground communications. It was concluded that the uplink levels coming into One Judiciary Square from the below ground PSRS system would need to be continuously monitored and balanced relative to the levels coming from above ground to ensure that noise level from one component of the system – above or below ground – did not exceed the noise level from the other component. No definitive conclusion was drawn concerning why the 18 dB modification was necessary.

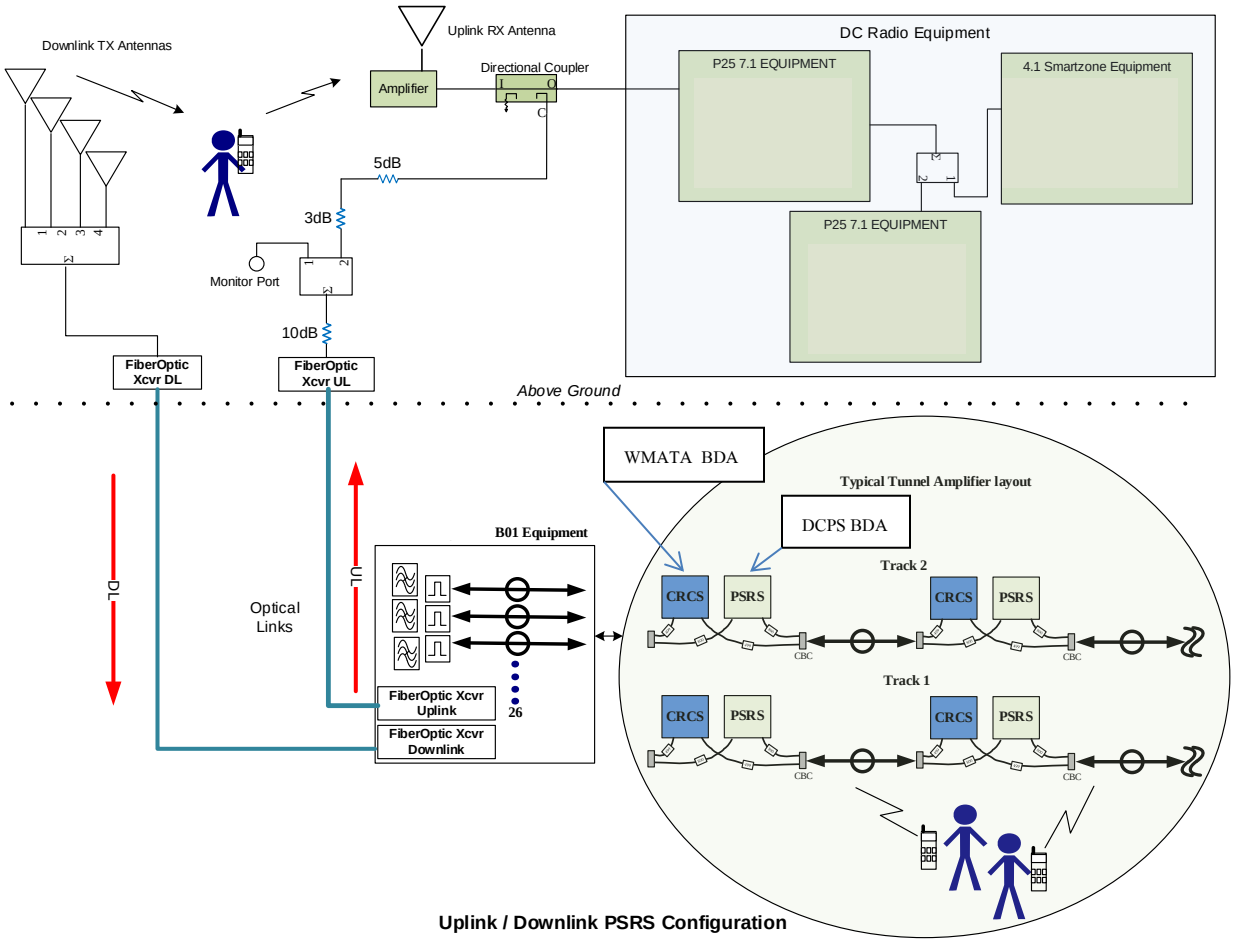

Figure 1. Uplink / Downlink configuration for the WMATA / DCPS communication system

Post-accident testing of the PSRS was increased dramatically to ensure that all locations in the underground system were tested once per week. In addition, RF signal strength testing was conducted in January and April to verify that signal levels were adequate throughout the underground system.

Uplink levels were checked at 32 different locations in the underground system on January 15. Uplink levels were checked again at 37 different locations on April 15. In each case signal levels within stations were checked while operating from the middle of the station platform. On January 15, three of the 32 tested locations failed the signal strength test. On April 15, six of the 37 tested locations failed the signal strength test. Farragut West and McPherson were the only two locations that consistently failed both tests. L'Enfant Plaza on the Orange line platform passed both tests. L'Enfant Plaza on the Green line passed the January test, but failed the April test.

Voice quality testing results were reported on nine dates between January 13 and February 27, 2015.[vii] Additionally, signal strength testing results were reported on January 22-23, 2015. This effort encompassed over 1100 underground radio checks covering 41 stations, and identified 49 instances where the voice quality check was rated a 'Fail'. The L'Enfant Plaza station was reported as a 'Pass' for each test conducted.[10]

2.3. Future Maintenance Plans

On March 19, 2015, the Metropolitan Washington Council of Governments published a report concerning the communications failures occurring in conjunction with the DCFD response to the L'Enfant Plaza Smoke in the Tunnel accident.[viii] This report included an overview of Metrorail PSRS testing and corrective actions, and outlined work that WMATA, in conjunction with the six jurisdictions that it serves,[11] was doing to develop an enhanced testing protocol to improve the detection of communication issues in the below ground system. A new testing protocol was developed and pilot tested. This protocol was adopted in a revision of the WMATA and Metropolitan Washington Council of Governments (MWCOG) Metrorail Transit – Fire/Rescue Emergency Procedures Policy Agreement 2015.[ix]

2.3.1. New Testing Protocols

The policy set down in the WMATA / MWCOG agreement specified the use of a telecommunication industry standard[12] criterion for evaluating radio communication

[10] On one instance it was reported that the voice quality check failed on the first attempt but passed on the second attempt.
[11] District of Columbia, Alexandria, Arlington County, Fairfax County, Montgomery County, and Prince George's County.
[12] This standard has been promulgated by the Telecommunications Industry Association (TIA).

system performance called the Delivered Audio Quality (DAQ) measure. DAQ attempts to obtain a quantitative measure of received voice audio quality based on the qualitative impression radio users. A seven-tier scoring system is used as shown in Table 5.

Table 5. Delivered Audio Quality (DAQ) criterion.

Digital Audio Quality (DAQ)	
DAQ 1:	Unusable. Speech present but not understandable.
DAQ 2:	Understandable with considerable effort. Frequent repetition required due to noise and/or distortion.
DAQ 3:	Understandable with slight effort. Occasional repetition required.
DAQ 3.4:	Understandable with little or no repetition required. Some noise or distortion may be present.
DAQ 4:	Easily understandable. Little noise or distortion.
DAQ 4.5:	Easily understandable. Rare occasions of noise or distortion.
DAQ 5:	Perfect reproduction. No discernible noise or distortion.

A DAQ of 3.4 or higher is required for a 'Pass' under the new testing protocol. WMATA and the DC OUC will collaborate on conducting testing for the underground PSRS system to agree upon points of demarcation. DC Fire and EMS departments will report test results to WMATA using a web-based portal hosted by WMATA, and WMATA will report back these results and the status of corrective actions via the same reporting system. Jurisdictions will also be provided with a monthly PSRS summary report. Test results will be incorporated into the WMATA maintenance work order system, MAXIMO, to provide for tracking and provision of corrective action status reports to the reporting jurisdiction.

Testing of the below ground PSRS will be conducted at least weekly in the District of Columbia, and bi-weekly in the other six jurisdictions. Six points of testing are designated within each station: entrance, kiosk, mezzanine, and the platform. The entire length of the inbound and outbound tunnels (from the end of one station to the entrance of the next station) form two additional test 'points' designated for that station. Testing is conducted by personnel using portable radios by contacting the dispatcher on their radios when at the designated test point. Both user and dispatcher will record the perceived voice audio quality as received using the DAQ scale. A DAQ score of 3.4 or greater will be recorded as a 'Pass', and a DAQ score of less than 3.4 will be recorded as a 'Fail' and immediately reported to WMATA though the web-based portal.

Practically, testing will be conducted by personnel entering a station, assessing each point in the station, then boarding a Metrorail train and proceeding to the next station down the line while testing the tunnel communication point from within the car.

Importantly, all testing will be conducted by assessing consecutive stations until reaching the adjoining station of the next system.
WMATA has also implemented a weekly signal strength scan of the control channel covering all below ground tunnel segments. This is done by having a technician ride the train and log data concerning control channel signal characteristics using a spectrum analyzer. All jurisdictions are covered under this test.

2.4. Plans to Upgrade the System

WMATA has plans to upgrade their radio system to a 700 MHz P-25[13] trunk radio system with ISSI[14] capabilities. The Wide Area Network (WAN) capability provided by the ISSI allows for extending the coverage area for portable and mobile radios (subscriber units) that are roaming outside their native coverage area. This extended coverage area can be important for first responders providing assistance to nearby jurisdictions during an emergency. Frequency allocation has been obtained and the acquisition effort is now in the Request for Proposal (RFP) stage.

Design elements call for a 16-frequency system capable of TDMA[15] with public safety grade DAQ 3.4 quality voice transmission. The system is intended to act as one simulcast cell servicing the entire WMATA coverage area, and will expand below ground coverage to include all public and private spaces. The new system will move all active electronics outside of the rail right of way to ease maintenance restrictions. New bi-directional amplifiers (BDA) will provide advanced diagnostic and health-monitoring features. Each BDA will be independently fed via fiber optic cable to provide higher bandwidth and increased reliability.

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[i] Attachment 1 - OUC MetroRadio Test Sample Weekly Report - 29 May 2015.
[ii] Attachment 2 - FEMS - Metro Radio Test final - 27 August 2014.
[iii] Attachment 3 - Fire and EMS Radio Upgrade – 15 December 2014.
[iv] Email - L'Enfant Notification Prior to Incident.
[v] Attachment 4 - Summary Report for PSRS Adjustments at One Judiciary Square - 28 January 2015.
[vi] Attachment 5 - DC PSRS Radio Checks - 29 December 2014 to 5 January 2015.
[vii] Attachment 6 - DC OUC Metro Radio Coverage Testing Tracker - January to March 2015.
[viii] Attachment 7 - Public Safety Radio System Communication Testing and Regional Response Protocol for the Metrorail System – 19 March 2015.
[ix] Attachment 8 - 2015 Metro Fire Rescue Policy Agreement

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[13] The Association of Public-Safety Communications Officials (APCO) has created a set of voluntary standards for digital public safety radio that include specifications for a Common Air Interface (CAI) including an encoding format for digital voice and a standard for trunk radio operation. The P-25 standard is the same standard that the DC PSRS is using.
[14] The Inter RF Subsystem Interface (ISSI) is an open standard that enables RF subsystems from different manufacturers to be interconnected into a wide area network so that users on different networks can communicate with one other.
[15] Time Division Multiple Access is a digital multiplexing method permitting the allocation of voice transmission data to one of several (two, in this case) time slots to increase the carrying capacity of a subscriber communication system.