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EMF Monitoring on Amtrak's Northeast Corridor: Post-Electrification Measurements and Analysis

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Final Report
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Dr. David Fugate*, William Jacobs*

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U.S. Department of Transportation
Research and Innovative Technology Administration
John A. Volpe National Transportation Systems Center
55 Broadway
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*Electric Research & Management, Inc.
1211 Cornplanter Road
Cabot, PA 16023

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13. ABSTRACT (Maximum 200 words)

This survey of electromagnetic fields (EMF) and radiation (EMR) due to the electrification infrastructure and operations of Amtrak Acela trains on the Northeast Corridor from New Haven, CT, to Boston, MA, was performed by Electric Research & Management (ERM) with Amtrak cooperation. The Federal Railroad Administration (FRA) and Volpe National Transportation Systems Center sponsored this survey to comply with environmental requirements. EMF levels were measured as a function of frequency and location on board the locomotive, inside a passenger coach, under the catenary and along the wayside in urban and rural locations, and near 10 representative traction power substations. Observed temporal and frequency-variability on board Acela and near the wayside is common to all of the electric transportation systems. Average magnetic fields in the passenger compartment were lower than, and maxima were comparable to most other rail and maglev systems. EMF exposures of passengers onboard Acela are lowest among rail and maglev systems studied to date. Average and maximum magnetic fields in the locomotive cab were lower than most other electric rail and maglev systems. Background EMF levels increased by 1-2 orders of magnitude after rail electrification but are well below limits in all applicable human exposure safety standards.

14. SUBJECT TERMS
Northeast Corridor, Amtrak, Acela, electromagnetic fields (EMF), electromagnetic radiation (EMR), magnetic fields, electric fields, overhead catenary, electrification infrastructure, electric power substations, locomotive EMF, public exposure, environmental exposure, EMF exposure levels, EMF exposure safety standards, comparative EMF

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METRIC/ENGLISH CONVERSION FACTORS

ENGLISH TO METRIC

LENGTH (APPROXIMATE)

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

AREA (APPROXIMATE)

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

MASS - WEIGHT (APPROXIMATE)

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

VOLUME (APPROXIMATE)

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

TEMPERATURE (EXACT)

[(x-32)(5/9)] °F	=	y °C

METRIC TO ENGLISH

LENGTH (APPROXIMATE)

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

AREA (APPROXIMATE)

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

MASS - WEIGHT (APPROXIMATE)

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

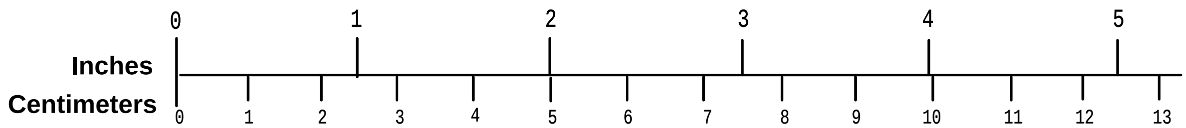
VOLUME (APPROXIMATE)

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

TEMPERATURE (EXACT)

[(9/5) y + 32] °C	=	x °F

QUICK INCH - CENTIMETER LENGTH CONVERSION



QUICK FAHRENHEIT - CELSIUS TEMPERATURE CONVERSION

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

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

Updated 6/17/98

Measuring Electric and Magnetic Fields (EMF): Common Terms

Electric fields: Electric field strength is measured in volts per meter (V/M) or in kilovolts per meter (kV/m). 1 kV = 1000 V.

Magnetic fields: Magnetic fields are measured in units of gauss (G) or tesla (T). Gauss is the unit most commonly used in the United States. Tesla is the internationally accepted scientific term. 1 T = 10,000 G. Since most environmental EMF exposures involve magnetic fields that are only a fraction of a tesla or a gauss, these are commonly measured in units of microtesla (μT) or milligauss (mG). A milligauss is 1/1,000 of a gauss. A microtesla is 1/1,000,000 of a tesla. 1 G = 1,000 mg; 1 T = 1,000,000 μT. To convert a measurement from microtesla (μT) to milligauss (mG), multiply by 10. 1 μT = 10 mG; 0.1 μT = 1 mG.

Source: The National Institute of Environmental Health Sciences (http://www.niehs.nih.gov/emfrapid/booklet/basics.htm).

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EXECUTIVE SUMMARY

Electric Research & Management, Inc. (ERM) performed a survey to quantify the levels of extremely low frequency (ELF, 3-3000 Hz) electric and magnetic fields (EMF) and radio-frequency (RF, 300 kHz to 50 GHz) electric fields near electric facilities along Amtrak's Northeast Corridor (NEC) between New Haven, Connecticut, and Boston, Massachusetts. This work was sponsored by the Federal Railroad Administration (FRA) and contracted to ERM with oversight by the Volpe National Transportation Systems Center.

The measurements were recorded to characterize the post-electrification field levels associated with operation of the Acela Express trains and associated infrastructure. These measurements are compared with pre-electrification measurements, recorded before the construction of the electric facilities, in order to fulfill the FRA 1995 Record of Decision (ROD) requirement for environmental monitoring of EMF. In addition, ELF and RF field levels were recorded on board an Acela Express train in both coach and operator's cab locations, at a wayside location during multiple train passes (including two Acela Express passes), and at an overpass and underpass. This survey was carried out during the week of September 12-18, 2005. The results from this study:

- Quantify the increase of ELF EMF in the vicinity of four types of traction power stations at representative locations (urban, rural, and environmentally sensitive) constructed to electrify the NEC section from New Haven, Connecticut to Boston, Massachusetts. The measurements were recorded at two of the four main substations (SS) (Branford and Sharon), two of the switching stations (SwS), four of the paralleling stations (PS), and the two underground 115 kV tie-lines (TLs) that supply the other two main substations.

- Characterize the ELF and RF field levels in the passenger compartment and operator's cab of an Acela Express train for comparison with earlier data (1993 Amtrak EMF survey).

- Characterize short-term ELF EMF changes associated with passing trains.

- Show that broadband RF electric field exposures at an overpass and underpass associated with passing trains are very low compared to applicable human exposure safety standards. All measurements in this study were compared with the applicable ELF/EMF and RF exposure standards.

Post-Electrification Measurement Summary

The comparison of pre- and post-electrification measurement results showed typical increases of one to two orders of magnitude for EMFs. This increase was as expected due to the introduction of the traction power stations and the electric conductors that comprise the overhead catenary system (OCS). The north end electrification system is supplied from utility 115 kV transmission lines connected to 4 main SS, 3 SwS, and 18 PS. Two of the main substations are fed by underground 115 kV single-phase TL circuits, and measurements were recorded at these underground TLs.

The largest fields were measured at the Branford and Sharon SS. These two SS are unique because the utility 115 kV transmission lines that connect to the substations pass through both of these substations.

The increase in field levels is due to the fact that most of the post-electrification measurements were in proximity to station equipment and near OCS conductors. In general, the perimeter profile measurements, recorded moving around the outside of the facility, gave the highest readings as the sensors passed near power equipment and beneath the lines running from the gantry out to the OCS.

Where post-electrification measurements were not close to the power equipment or the OCS, very little difference existed between pre- and post-electrification measurements, indicating that the impact to surrounding areas was minimal. For example, the long-term 24-hour measurements at the Noank PS and New London TL sites were very low.

Regarding the impact to nearby areas, EMFs decrease rapidly with distance, typically as the inverse of the distanced squared, or even faster in some cases. For example, one can see the rapid falloff of electric fields viewing the lateral profile plots for the Richmond SwS and Grove Beach PS sites (in appendices).

When the lateral profiles were away from the station, the recorded magnetic fields moving away from the track were all very low. For example, the magnetic field lateral profile at Grove Beach shows negligible 60 Hz magnetic fields that continue to decrease moving away from the OCS. These very low levels exist when trains are not present but increase for brief periods of time (as can be seen in the long-term measurement graphs for Richmond and Grove Beach). The next section discusses the increase in field levels and summarizes the wayside measurements.

Finally, the two TLs where measurements were recorded for this study were underground. Thus, the magnetic fields were very low as shown by the lateral profiles, and no electric fields existed due to the TLs themselves. Significant fields measured at these two TLs (New London and Warwick) sites were due to nearby distribution lines (which were present during the pre-electrification measurements) and due to the connections to either the SS or transmission lines at the ends of the TLs.

Wayside, Underpass, Overpass Measurement Findings

Wayside measurements of five train passes (two were Acela Express) showed maximum magnetic field readings of 83 mG, 15 mG, and 7 mG at distances of 5, 10, and 15 meters, respectively. Based on these results, the magnetic fields falloff with the inverse square of the distance as expected and are below 10 mG at the 15 m position. Maximum measurements at an overpass and underpass were 30 mG and 104 mG, respectively. While one would expect the fields to be higher on the overpass (due to location of OCS and feeder conductors), the magnetic fields are more dependent on the operational profile of the train and the location of traction power stations relative to the measurement location.

No significant (greater than 1 mG) VLF (3-30 kHz) or LF (30-300 kHz) magnetic fields were measured.

Measured broadband RF electric fields were relatively low, with a maximum measurement of 2 percent of the Federal Communications Commission (FCC) occupational standard at 5 meters from the track centerline.

Measured broadband RF electric fields at the overpass and underpass were near zero.

Onboard Acela Express Measurement Findings

The ELF magnetic field measurements showed significant temporal variability due to operation of the train. This variability is common to all of the electric transportation systems. The measured ELF electric fields in the passenger compartment were very low with a maximum of 52 V/m and average less than 4 V/m.

Comparison of Acela Express passenger compartment measurements with other train systems (NEC-60 Hz, NEC-25 Hz, NEC-non-electric, French TGV, Maglev TR08, New Jersey Transit) showed that the average ELF magnetic fields in the passenger compartment were lower than all other train systems except the NEC-non-electric. The maximum measured ELF magnetic fields in the passenger compartment were greater than the NEC-non-electric, New Jersey Transit, and TGV systems but less than the NEC-25 Hz, NEC-60 Hz, and Maglev TR08 systems. The maximum values occur during short-term transients.

A similar comparison of the operator's cab measurements showed that the Acela Express cab average and maximum ELF magnetic fields are lower than all of the other systems except for the NEC-non-electric system.

Exposure Assessment

The maximum ELF electric and magnetic field readings were compared with exposure limits in the American Conference of Industrial Hygienists (ACGIH) and Institute of Electrical and Electronic Engineers (IEEE) C95.6 standards. None of the limits were exceeded.

All RF readings were logged directly as a percentage of the occupational FCC standard. None of the readings were greater than 3 percent of this standard. Thus, all readings were also less than 3 percent of the IEEE C95.1 and ACGIH occupational limits. Because the general public limits are lower than the occupational by factor of 2.2, the electric field limits for the general public were similarly never exceeded.

1. Introduction

This report documents the results of a field measurement program conducted under contract to and under the supervision of the Volpe National Transportation Systems Center (Volpe Center). The goal was to determine the levels of ELF EMF near electric traction facilities along Amtrak's NEC between New Haven, Connecticut, and Boston, Massachusetts, as well as emissions of RF electromagnetic fields associated with the Advanced Civil Speed Enforcement System (ACSES) train control and communication system. These measurements were recorded to characterize the post-electrification EMFs associated with operating high-speed passenger trains, including the Acela Express, and to compare the results with pre-electrification measurements that were recorded before construction of the electric facilities. The objective was to verify compliance with EMF human exposure safety standards and with the requirements of the 1995 FRA ROD [1] for environmental EMF level monitoring. In addition, EMF and RF field levels were recorded onboard an Acela Express train during a trip between Boston, Massachusetts, and New Haven, Connecticut, and at several wayside locations during train passes.

1.1 Background

As part of a modernization program for NEC, Amtrak electrified the 156-mile northern section of the corridor between New Haven, Connecticut, and Boston, Massachusetts. The major power facilities installed as part of this electrification project were 4 traction power SS, 3 SwS, and 18 PS. The four power SS provide the interface to the commercial power system—the commercial power grid supplies these SS at 115 kV, and the SS transformers step the voltage down to 50 kV (2x25 kV) for distribution to the Amtrak electric facilities sited along the corridor. Three switching stations provide interconnection as well as a means of isolating sections of the traction system. Transformers at the 4 SS, and autotransformers at the 3 SwS and 18 PS provide power to the OCS at approximately 6-mile intervals.

As part of the permitting process, the FRA/Volpe and contractor team prepared and submitted an Environmental Impact Statement (EIS) [2] that included EMF technical studies and projected emissions and exposure. The resulting FRA ROD required pre- and post-electrification measurement studies. A previous report [3] provided the results from the measurement study that characterized the EMF levels before electrification. This report provides the post-electrification measurements results and compares them with the baseline measurement results from the pre-electrification study. This report also provides new information regarding EMF and RF levels on board an operating Acela Express train and due to passing trains.

1.2 Objectives

The objectives of this electromagnetic measurement study included the following:

- Assess the impact of electrification on EMF levels due to the OCS and associated electric equipment and facilities that provide power to electric trains operating on the NEC between New Haven, Connecticut, and Boston, Massachusetts.
- Record the short-term rise in EMF levels along wayside public access points, produced by passing electric trains.
- Measure Acela Express onboard electromagnetic levels (ELF and RF).
- Compare measurement results with applicable exposure standards for ELF and RF fields (such as the 1997 FCC, ANSI C95.1, and C95.6 standards) to evaluate safety compliance.

1.3 Measurement Approach

As directed by the Volpe Center and FRA, this measurement study consisted of four parts:

1. The first part involved post-electrification EMF measurements at a subset of traction power facility and wayside sites where pre-construction measurements were recorded. The original measurements at 36 sites each consisted of 48-hour long-term measurements at a fixed location, spatial measurements along a lateral profile moving away from the tracks, and spatial measurements around the facility fence-line perimeter. Since the 4 main SS, 3 SwS, and 18 PS are similar in design respectively, the measurement approach repeated the pre-construction measurements at 10 of the 25 traction power sites. The long-term measurements were limited to 24 hours because the train schedules for electric service are repetitive and are reduced on the weekends. The 10 sites for the post-electrification measurements were selected based on consultation with the Volpe Center to provide data from a range of settings, including urban, suburban, rural, and environmentally sensitive areas.

2. The second component of this study was train-pass measurements. The purpose of these measurements was to quantify the short-term rise and duration of EMF levels associated with passing electric trains. Detailed EMF measurements were recorded at one wayside location during multiple train passes.

3. The third component of the study involved onboard EMF and RF measurements during operation of an Acela Express train. Measurements were recorded in the passenger compartment of a passenger coach during an Acela Express trip from Boston to New Haven and in the trailing engineer's cab during the return. The EMF measurements were recorded using a polyvinyl chloride (PVC) mannequin outfitted with multiple sensors. The measurements were recorded using the U.S. Department of Transportation (DOT)/FRA protocol that was utilized for previous transportation studies.

4. The last component of this study was measurements of electromagnetic fields associated with ACSES and other data radio and cell phone communications systems. This part of

the study was performed using a Narda broadband RF probe at two locations, one overpass and one underpass, to record field levels as trains passed. This RF equipment was also used for measurements during the first three components (at power facilities, at wayside train passes, and on board the Acela Express) as described above. In this part of the study, the RF measurements were compared with applicable human RF exposure safety standards.

1.4 Report Organization

This report contains 8 chapters and 13 appendices. Chapter 1 is this introduction. Chapter 2 documents the measurement methods, including measurement locations, instrumentation, and analysis procedure. Chapters 3, 4, and 5 contain summary results from measurements at the 10 traction power facility locations, the wayside train passes (including overpass and underpass), and the onboard Acela Express measurements in the passenger compartment and operator's cab. Chapter 6 compares the maximum measured values in this study with applicable exposure standards and provides a safety assessment based on this comparison. Chapter 7 provides conclusions, and Chapter 8 contains references.

Appendices at the end of the report provide detailed measurement results. The first 10 appendices contain measurement results from each of the 10 facility locations in the order of SS, SwS, PS, and TLs (south to north in each category):

A. Branford SS
B. Sharon SS
C. Westbrook SwS
D. Richmond SwS
E. Grove Beach PS
F. Noank PS
G. Stonington PS
H. Roxbury PS
I. New London TL
J. Warwick TL

This sequence follows the pre-electrification results report, which grouped the sites based on the type of station. Each appendix for the power facility measurements is organized as follows:

1. The first page of each appendix identifies the site, the type of facility, and the milepost. It also contains dates and times of the measurements, identification of specific measurement points, comments regarding any anomalies in the measurement procedure applied at that site, and brief comments about field sources and levels detected.

2. The second page generally contains a map showing the facility location in relation to local streets and, in some cases, a photograph of the site.

3. After the site information, each appendix provides statistical summaries (minimum, maximum, median, average, standard deviation, and selected percentiles) of the

measurements and graphs showing the detailed measurement results. Graphs include the following:

a. Detail plots of the EMF conditions recorded during the long-term (24-hour) measurements at that site.
b. Detail plots of the facility perimeter magnetic and electric field measurements.
c. Detail plots of lateral profile magnetic and electric field measurements.

The last three appendices, K to M, contain the wayside train-pass EMF and RF measurement results recorded near the Midway maintenance facility, the underpass/overpass RF measurements, and the EMF and RF measurement results on board the Acela Express train, respectively.

2. Measurement and Analysis Methods

This study consisted of four measurement components:

1. Post-electrification measurements near 10 representative traction power facilities at diverse locations (two SS, two SwS, four PS, and two TLs).
2. Train pass measurements at one wayside location.
3. Measurements on board an Acela Express train in a passenger compartment and in the trailing engineer's cab.
4. Train-pass RF measurements at an overpass and an underpass.

The first section of this chapter describes the measurement approach and locations for each of these components, and the last two sections describe the measurement instrumentation and data analysis approach.

2.1 Measurement Approach

2.1.1 Post-Electrification Traction Power Facility Measurements

The approach for the post-electrification characterization was to repeat measurements at a subset of selected representative traction power station facilities at positions where pre-electrification measurements had been recorded. An identical protocol was used for these measurements. The one exception to the pre-electrification measurement protocol was that long-term measurements were recorded over 24 hours at 3-minute intervals (instead of 48 hours at 15 minute intervals, due to time constraints for the study).

The subset of sites for this study included 2 SS, 2 SwS, 4 PS, and 2 underground 115 kV single phase TL. Table 1 lists the measurement sites and Figure 1 shows their approximate locations over the entire route. The 10 sites were selected in consultation with the Volpe Center to cover a broad range of environmentally significant areas (from densely populated urban and suburban areas to sparsely populated rural and environmentally sensitive areas).

Table 1. 10 Post-Electrification Measurement Sites

Site	Name	Facility Type	Milepost	Notes
A	Branford, CT	SS	79+0191	Offset from I-95
B	Sharon, MA	SS	212+1910	Suburban area near housing
C	Westbrook, CT	SwS	103+0502	At end of light industrial business park
D	Richmond, RI	SwS	150+0807	Rural, remote location
E	Grove Beach, CT	PS	98+4600	Suburban, near trailer court and wetland
F	Noank, CT	PS	129+2653	Suburban area w/ housing, near seashore
G	Stonington, CT	PS	134+3677	Rural location, near seashore
H	Roxbury, MA	PS	226+0585	Urban location, adjacent to MBTA tracks
I	New London, CT	TL	123+2887	Along urban streets beneath interstate
J	Warwick, RI	TL	176+4943	Urban area in city of Warwick

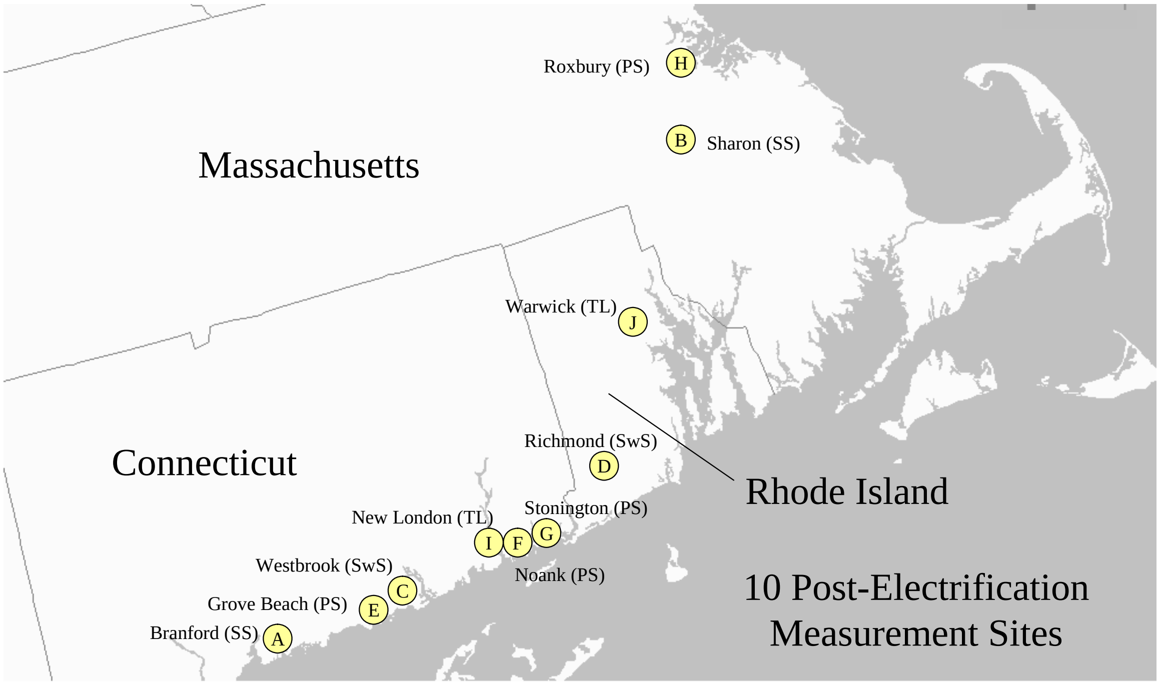

Figure 1. 10 Post-Electrification Measurement Sites that Include Two SS (A and B), Two SwS (C and D), Four PS (E to H), and Two TLs (I and J) between Boston and New Haven

At each facility, the following measurements were recorded:

- 24-hour ELF EMFs at one fixed point
- ELF electric and magnetic fields along a lateral profile perpendicular to the tracks (or TL)
- ELF EMFs around the power station facility perimeter, typically along either the fence-line or property line (which represent public access points nearest the station)
- RF broadband measurements at one fixed location near the facility

For these measurements, ERM attempted to use the identical positions at which the pre-electrification measurements were recorded.

Twenty-four hour measurements were performed by setting up the combined sensor fixture (one electric field sensor and one fluxgate sensor) at the long-term monitoring position noted in the pre-electrification report. The sensors were connected to a *MultiWave* System II box in a weatherproof container, recording was started, and the setup was left overnight. Based on the sampling configuration and size of the *MultiWave* System II memory, it was possible to store a maximum of 470 samples. The decision was made to record EMFs at 3-minute intervals to capture close to 24 hours. ERM returned the following day to remove the equipment and download the data to a laptop computer. Table 2 summarizes the 24-hour measurement locations and times.

The lateral profile and perimeter profile measurements were generally recorded at the time of the site visit during which the long-term measurements were set up. The lateral profiles were generally perpendicular to the tracks, moving away from the corridor, and the perimeter profiles were typically along fence lines or property lines depending on the site layout and accessibility. The appendices provide details of the profile locations. The measurements were made along the same profiles noted in the pre-electrification report or as close as possible. Along each of the profiles, ELF EMF readings were recorded at 10 ft (3 m) intervals (with the exception of the New London TL measurements; due to the distance, measurements were recorded at 20 foot (6.1 m) intervals). Tables 3 and 4 summarize the perimeter and lateral profile measurement locations and times.

Table 2. 24-Hour Measurement Dates and Times Listed by SS, SwS, PS, and TLs

Facility	Type	Milepost	Data App.	Start Date	Start Time	Finish Date	Finish Time	# of Samples
Branford, CT	SS	79+0191	A	16-Sep-04	15:06	17-Sep-04	14:33	470
Sharon, MA	SS	212+1910	B	13-Sep-04	10:21	14-Sep-04	9:48	470
Westbrook, CT	SwS	103+0502	C	16-Sep-04	12:15	17-Sep-04	11:42	470
Richmond, RI	SwS	150+0807	D	15-Sep-04	8:34	16-Sep-04	8:01	470
Grove Beach, CT	PS	98+4600	E	16-Sep-04	13:39	17-Sep-04	13:06	470
Noank, CT	PS	129+2653	F	15-Sep-04	11:21	16-Sep-04	10:48	470
Stonington, CT	PS	134+3677	G	15-Sep-04	10:00	16-Sep-04	9:27	470
Roxbury, MA	PS	226+0585	H	13-Sep-04	8:48	14-Sep-04	8:15	470
New London, CT	TL	123+2887	I	15-Sep-04	17:13	16-Sep-04	16:40	470
Warwick, RI	TL	176+4943	J	13-Sep-04	12:54	14-Sep-04	12:21	470

Table 3. Summary of Perimeter Measurement Locations and Times

Facility Name	Type	Milepost	Data App.	Start Date	Start Time	Profile Distance (ft)	# of Samples
Branford, CT	SS	79+0191	A	16-Sep-04	14:43	970	98
Sharon, MA	SS	212+1910	B	13-Sep-04	10:18	850	86
Westbrook, CT	SwS	103+0502	C	16-Sep-04	12:12	520	53
Richmond, RI	SwS	150+0807	D	15-Sep-04	8:25	440	45
Grove Beach, CT	PS	98+4600	E	16-Sep-04	13:26	300	31
Noank, CT	PS	129+2653	F	15-Sep-04	11:30	760	77
Stonington, CT	PS	134+3677	G	15-Sep-04	9:50	320	33
Roxbury, MA	PS	226+0585	H	13-Sep-04	8:28	310	32
New London, CT	TL	123+2887	I	15-Sep-04	15:49	4200	210
Warwick, RI	TL	176+4943	J	13-Sep-04	12:21	510	52

Table 4. Summary of Lateral Profile Measurement Locations and Times

Facility Name	Type	Milepost	Data Appendix	Start Date	Start Time	Profile Distance (ft)	# of Samples
Branford, CT	SS	79+0191	A	-	-	-	-
Sharon, MA	SS	212+1910	B	13-Sep-04	10:43:32	140	15
Westbrook, CT	SwS	103+0502	C	16-Sep-04	12:22:44	220	23
Richmond, RI	SwS	150+0807	D	15-Sep-04	8:33:33	160	17
Grove Beach, CT	PS	98+4600	E	16-Sep-04	13:36:23	200	21
Noank, CT	PS	129+2653	F	-	-	-	-
Stonington, CT	PS	134+3677	G	15-Sep-04	9:58:08	140	15
Roxbury, MA	PS	226+0585	H	13-Sep-04	8:47:06	110	12
New London, CT	TL	123+2887	I	15-Sep-04	16:36:49	120	13
Warwick, RI	TL	176+4943	J	13-Sep-04	12:30:55	800	82

2.1.2 Wayside Train Pass Measurements

EMF and RF measurements were recorded at the wayside location adjacent to the Amtrak Midway maintenance facility. Sensors were set up near milepost 127.5, located between the New London TL connection (123+2887) and the Noank PS (129+2653). Three-axis magnetic field sensors were set at distances of 16.4 ft (5 m), 32.8 ft (10 m), and 49.2 ft (15 m) meters from the closest track centerline, as shown in Figure 2. ELF vertical field, very low frequency (VLF) magnetic field, LF magnetic field, and RF probes were set at 5 meters from the track, as shown schematically in Figure 3.

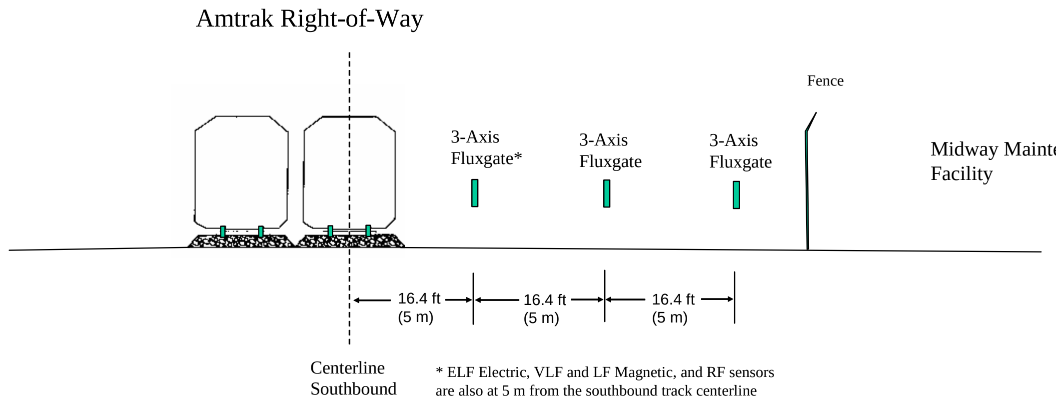

Figure 2. Sketch of ELF Magnetic Field Sensor (Three-Axis Fluxgate) Positions Used for the Train Pass Measurements, Looking West Toward New London

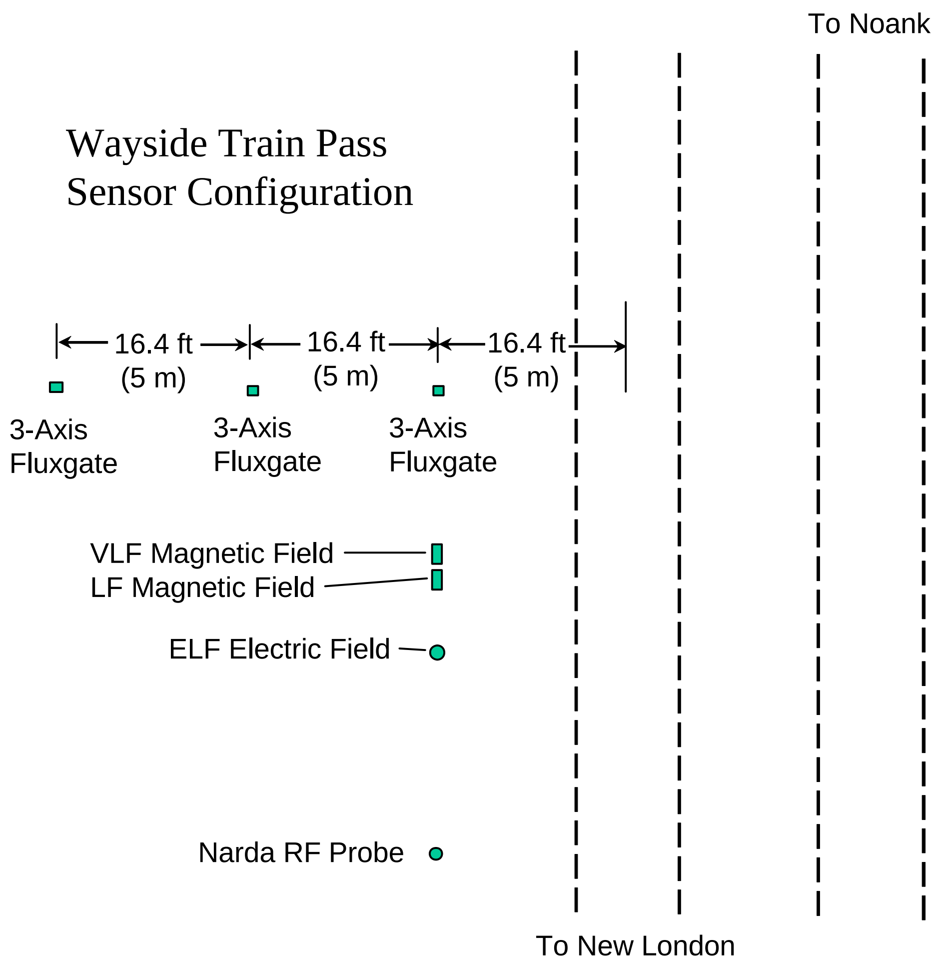

Figure 3. Plan View Sketch Showing Sensor Arrangement for Train Pass Measurements Recorded near the Midway Maintenance Facility

These measurements were recorded on the afternoon of Tuesday, September 14, 2004. Measurements were recorded at 3-second intervals for each train pass. An Amtrak flagman provided warning of approaching trains to start the measurements, and measurements were recorded for approximately 1 minute after the train had passed. Five train passes were recorded as summarized in Table 4; two of which were Acela Express trains. Figure 4 shows the passing of a southbound Acela Express.

Table 5. Summary of Recorded Train Passes Adjacent to the Midway Maintenance Facility

	Train Type	Direction	Start Time (EDT)	End Time (EDT)	Samples
1	Acela	South	14:42:18	14:45:30	65
2	Regional	South	15:04:56	15:06:29	32
3	Regional	North	15:22:29	15:23:47	27
4	Acela	South	16:29:31	16:31:16	36
5	Regional	South	16:44:21	16:46:42	49

Figure 4. A Southbound Acela Express Passes the Wayside Measurement Setup Adjacent to the Midway Maintenance Facility

2.1.3 Acela Express Onboard Measurements

ELF and RF measurements were recorded on board operating Acela Express trains on Sunday, September 12, 2004. Measurements were recorded in the passenger compartment on the trip from Boston to New Haven, and measurements were recorded in the trailing engineer's cab on the return trip to Boston.

For the ELF measurements, a sensor mannequin was used that held three three-axis fluxgate sensors for recording the static and ELF magnetic fields at head, waist, and ankle positions. The mannequin also held an ELF electric field sensor at chest height and VLF and LF magnetic field sensors at the knee position. Figure 5 shows this PVC sensor mannequin.

Cables from the sensors were connected to three *MultiWave* System II units stacked on a small cart. Data was recorded at 3-second intervals until the System II memories were filled. The data was downloaded onto a laptop computer. RF measurements were recorded using a broadband Narda electric field probe mounted on a tripod in the aisle.

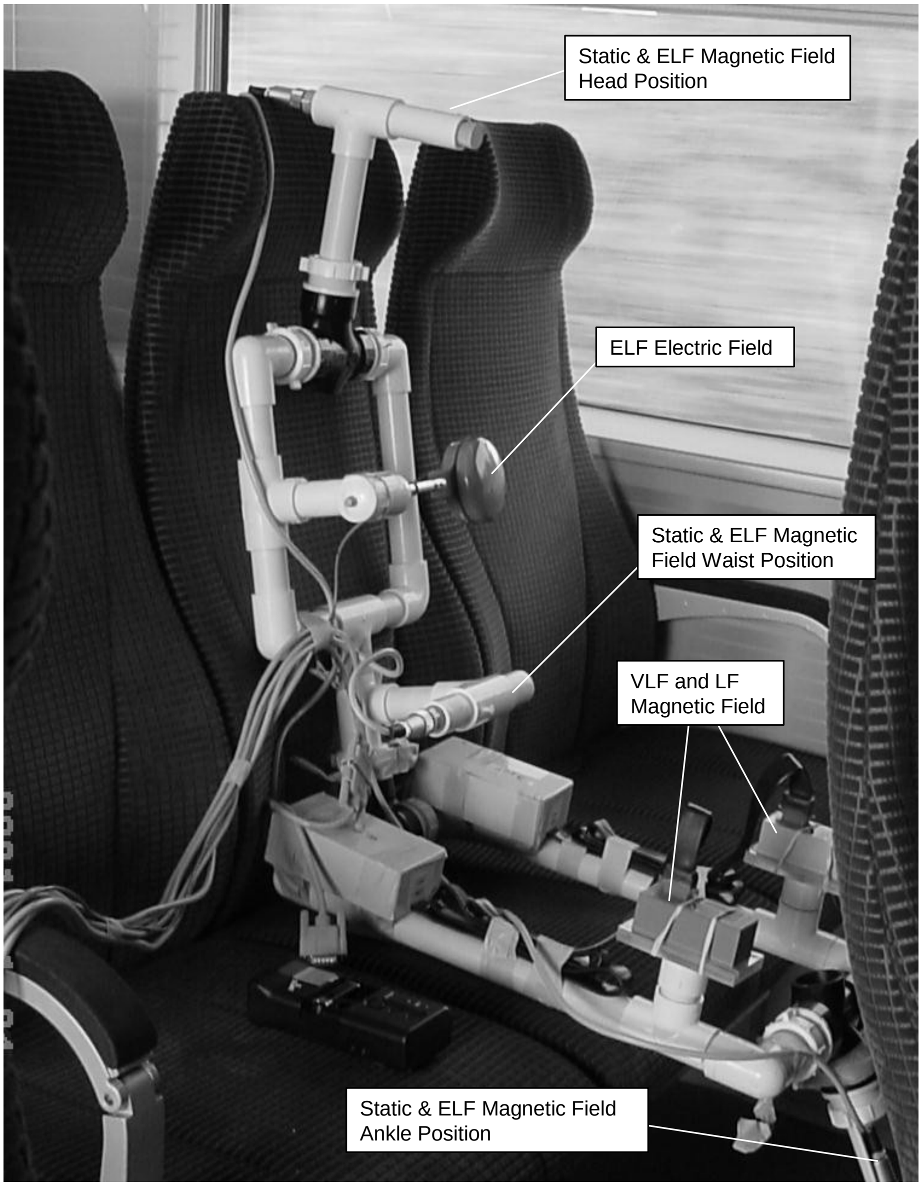

Figure 5. Sensor Mannequin Used for the Onboard Measurements. This Setup Includes Three-Axis Fluxgate Sensors at Positions that Correspond to Head, Waist, and Ankle Positions, an Electric Field Sensor at Chest Height, and VLF and LF Magnetic Field Sensors near the Knees

2.1.4 Train Pass RF Measurements at Underpass, Overpass

One component of this study involved RF measurements immediately above and below passing trains to determine exposure to the general public from onboard RF sources such as the ACSES system and possibly due to sources such as radio communications systems (if radio transmissions were being made as a train passed). Measurements were recorded at one underpass and one overpass for several passing trains to try and quantify the associated RF levels. For both locations a broadband electric field probe Narda A8722D was used to measure RF as a percentage of the 1997 FCC exposure standard from 500 kHz to 5 GHz, and a single three-axis fluxgate was used to measure static and ELF magnetic fields at the same time. Section 2.2 provides details of the instrumentation.

Figure 6. Underpass near the Midway Maintenance Facility. This Road Provides Access to the Bluff Point State Park Situated Beside the Poquonock River

The overpass used as the first of the two measurement sites was located on the Coronado Street Extension just off of Jefferson Boulevard in Warwick, Rhode Island. Three train passes were recorded at this location.

The underpass, used as the second measurement site, was located adjacent to the Midway maintenance facility on the road leading out to Bluff Point State Park beside the Poquonock River. This underpass is situated just south of the bend formed by the junction of Depot Road and Industrial Drive. Figure 6 shows a photograph of this underpass. Three train passes were recorded at this location, consisting of a southbound regional, a northbound Acela Express, and a northbound regional.

2.2 Instrumentation

The same instrumentation used for the ELF pre-electrification measurements was again used for the post-electrification measurements described in this report. All ELF magnetic field measurements were made using three-axis fluxgate magnetometers (Bartington, Model Mag-03) having a frequency response from 0 to 3000 Hz. Analog output waveform signals from all three axes were simultaneously digitized and recorded using *MultiWave* System II waveform data acquisition systems (ERM, Model MW2SYS02).

Twenty-four hour electric field measurements were made using a conductive probe mounted 1 meter above the ground surface. The probe contained an electronic charge amplifier that converted the electric-field-induced charge into an output voltage waveform suitable for recording with the *MultiWave* System II. The electric field signal was digitized simultaneously with the magnetic field signals. Figure 7 shows the long-term setup used for 24-hour measurements. The ELF electric and magnetic field sensors are mounted on a stainless steel rod, the *MultiWave* System II used to record the data is inside the weatherproof box. The system is powered by a 12-volt battery.

Short-term measurements of electric field spatial variability were made using a fiber-optic isolated, free-body dipole sensor (ERM, Model No. MW2EFL01) mounted on a 2-meter dielectric handle. The output voltage waveform signal from this electric field sensor was digitized and stored by the *MultiWave* System II unit, which was simultaneously recording the spatial variability of the magnetic field. Virtually all of the EMF measurements were made at a height of 1 meter above ground level.

Figure 7. Photograph Showing the Long-Term Measurement Configuration. The EMF Sensors are Situated in the Cylindrical PVC Unit and Connected to the MultiWave System II Data Acquisition Equipment in the Weatherproof Container. Power is Supplied from a 12-Volt Battery at the Left

In addition to the static and ELF EMF measurement equipment, a Narda 8718B meter and an A8722D electric field broadband probe were used to log RF measurements on board the Acela Express, at the 10 traction power facility sites, and during train pass measurements at the wayside location, on an overpass, and beneath the tracks at an underpass.

The Narda A8722D is a broadband isotropic electric-field probe with a shaped frequency response from 300 kHz to 50 GHz. Use of an isotropic probe means that readings are independent of probe orientation (fields in all three directions are measured and combined for a resultant value). The shaped frequency response corresponds to the 1997 FCC standard and provides direct readings as a percentage of the occupational maximum permissible exposure (MPE) from 0.3 percent to 300 percent.

The broadband electric field probe was used because the RF magnetic field probe covered a frequency range only up to 10 MHz. This cutoff frequency was too low because the primary transmit frequency of the ACSES antenna system is 27.1 MHz. Furthermore, ACSES transmissions between the train and coverage towers occur at 900 MHz.

2.3 Measurement Protocol

The measurement protocol employed in this effort was the same as performed previously for the pre-electrification measurements along the right-of-way (ROW), and in the 1993 FRA report [4]. This protocol has been used for numerous transportation EMF measurement studies, including field measurements in trains operating on and in areas near the NEC. Highlights of the protocol are as follows:

Field Components

Both the electric field and the magnetic field were recorded.

Bandwidth

EMFs were measured by the waveform capture technique using digitization rates suitable for an effective measurement bandwidth from 3 Hz to 3 kHz. In addition, the static (0 Hz) magnetic field was recorded.

Magnitude

The dynamic range of time-varying magnetic field measurements is better than 0.1 mG to 3.5 G. Static magnetic fields will be quantified over the range from 5 mG to 5 G. The dynamic range of time-varying electric field measurements is from less than 10 V/m to greater than 100 kV/m.

Frequency Spectra

All EMF measurements included provisions for spectral analysis with 6 Hz resolution. Spectral analysis was used to identify specific frequencies present in the existing fields. All long-term data is tabulated as *rms* intensities within various frequency bands to allow direct comparison to previously collected transportation field data.

Spatial Variability

Background magnetic field levels along the NEC and at some of the proposed SS, SwS, and PS locations have high spatial variability because of a wide range of electric power lines. Distribution lines and transmission lines are near several of the power station sites. The perimeter profile measurements are meant to capture spatial variability around the site, and the lateral profile is meant to capture the falloff in field levels moving away from the ROW (or TLs).

Temporal Variability

Fluctuating current in traction power facilities due to operation of trains, and load changes in the commercial power system cause temporal variability in background power-frequency magnetic fields. Long-term ELF EMF measurements were recorded over a 24-hour period.

The measurement procedure used at each measurement location employed all of the above characteristics but differed slightly in execution depending on the site.

Traction Power Stations

Measurements were recorded at the three types of traction power stations utilized on the electrification project. Specifically, the measurements were recorded at 2 of the 4 main SS, 2 of the 3 SwS, and 4 of the 18 PS. Measurements were also recorded at two of the four single-phase 115 kV TLs that connect the commercial power grid to the main traction power SS. For this study, measurements were recorded at the two 115 kV TLs that were underground.

The main traction power SS step the commercial transmission voltage of 115 kV down to 50 kV, the voltage used by the 2x25 kV OCS. The 50 kV secondary has a mid-point center tap that connects to the rails, thus forming two 25 kV circuits relative to the rails. The 25 kV circuits are connected to the catenary and to the 25 kV feeders that are strung along the tracks on support poles between the traction power SS and the SwS. Twenty-five kV is the operating voltage for electric locomotives on the north end of the Amtrak corridor.

The 25 kV catenary and feeder conductors are connected to autotransformers at the paralleling and SwS. SwS are situated midway between the main traction power SS and are different from the PS because they provide the capability to isolate sections of the OCS and feeders between the main traction power SS on either side.

Measurements were made every 10 feet (3 m) along the perimeter of the proposed property lines surrounding the selected power stations to characterize spatial variability. At a few locations, existing structures or impassable underbrush prohibited measurements along the proposed property lines. In those situations, measurements were made as near as practical to the property lines. The actual location of these perimeter profile measurements at each power supply station is recorded on the site drawing in the appendix containing data for that monitoring location.

Lateral profile measurements were also made every 10 ft (3 m) to characterize the field attenuation moving away from the tracks. Lateral profile measurements were not made at the Noank PS because of impassable brush and a steep hillside, and lateral profile measurements were not performed at the Branford SS, which was not located near the rail corridor.

The long-term 24-hour measurement location was selected to be as close as possible to the spot used for long-term measurement during the pre-electrification study.

Descriptions of the measurement locations and site anomalies on the front page of the relevant appendices identify the actual measurements made at each power station.

TL Locations

Keeping with the intent of the protocol for other power facilities, three types of measurements were made for the TLs. Perimeter measurements were made every 10 ft along both sides of the street where the New London underground TL was installed. A defined easement was not identified for the Warwick TL, so measurements were made along the approximate centerline of the proposed TL.

Lateral profile measurements were made along transects approximately perpendicular to the TL to quantify field variability at incremental distances away from the proposed TLs. At the Warwick TL location, existing buildings prevented lateral profile measurements, except at Jefferson Boulevard. Because the existing power lines differed on the east and west side of the street, lateral profile measurements were made on both sides of the street.

2.4 Data Analysis

The thousands of digitized EMF waveforms were computer analyzed using Fast Fourier Transform (FFT) techniques to obtain frequency spectra (tables of field intensity for various frequencies) for all of the waveform measurements. Data from the FFT analysis was further processed using automated computer methods to generate total *rms* field levels in various frequency bands.

EMF intensity parameters were graphed to show their spatial variability in the vicinity of the monitoring location and their variability over time. The appendix includes those graphs.

Those sample data, as well as certain other field parameters, were also reduced to tabulations of common statistical descriptors, including minimum and maximum values; 5 percent, 25 percent, 75 percent and 95 percent percentiles; median value; average (arithmetic mean) value; and standard deviation. Each appendix includes those tables.

Field intensity values at all monitoring locations of a similar type were then summarized graphically in box and whisker plots, which compare and contrast the range of field levels detected at each site. Chapter 3 of this report includes the results of this summary analysis.

3. Post-Electrification Results Summary and Comparison

This chapter summarizes the results from the post-electrification measurements recorded at the 10 traction power facility locations. For comparison, statistics from the post-electrification data sets are listed in tables beside the pre-electrification statistics from the Amtrak report [6] and graphed using box and whisker plots. The box and whisker plots are based on the 5 percent, 25 percent, 75 percent, and 95 percent percentiles calculated from the full data set for each type of ELF measurement. Appendices A to J provide detailed measurement results and diagrams showing measurement locations for each of the ten traction power facility locations.

3.1 ELF EMF Pre- and Post-Electrification Summary Tables

This section contains the statistical summary tables for the ELF magnetic and electric field data from each of the ten measurement sites as listed in Table 6. The sites are listed in the order of SS, SwS stations, PS, and TLs (from south to north along the corridor for each type). These tables provide an overall summary of the ELF magnetic and electric field results for each site study and allow for a direct comparison with the pre-electrification results. Values in the “Pre” rows are from the summary tables in the pre-electrification study while values in the “Post” rows are from the data in Appendices A to J (detailed results for each site).

Table 6. 10 Traction Power Facilities Where Post-Electrification Measurements Were Recorded

Site	Name	Facility Type	Milepost	Notes
A	Branford, CT	SS	79+0191	Offset from I-95
B	Sharon, MA	SS	212+1910	Suburban area near housing
C	Westbrook, CT	SwS	103+0502	At end of light industrial business park
D	Richmond, RI	SwS	150+0807	Rural, remote location
E	Grove Beach, CT	PS	98+4600	Suburban, near trailer court and wetland
F	Noank, CT	PS	129+2653	Suburban area near seashore
G	Stonington, CT	PS	134+3677	Rural location near seashore
H	Roxbury, MA	PS	226+0585	Urban location, adjacent to MBTA tracks
I	New London, CT	TL	123+2887	Meas. profile winds along urban streets
J	Warwick, RI	TL	176+4943	Urban area in city of Warwick

The top part of each statistical summary table contains the ELF magnetic field statistics for the three types of measurements at each site: long-term (24-hour), perimeter profile, and lateral profile. The lower part of the table provides the same information for the ELF electric field measurement results. The long-term measurement results characterize temporal variability at a fixed location near the facility, while the perimeter and lateral measurements characterize spatial variability around the facility and moving away from the tracks, respectively. All values in these tables are for the entire ELF range from 3 Hz to 3000 Hz. The appendices provide a more detailed breakout of the measurement result statistics in each frequency band.

3.1.1 SS Sites

Branford SS. This SS is located between a wooded area and I-95 near Branford, Connecticut. The Amtrak corridor is on the opposite side of I-95. Due to the distance to the tracks, no lateral profile measurement was recorded at this site. Table 7 provides detailed information on the magnetic and electric field statistics from the Branford SS.

Pre-electrification measurements all showed very low magnetic fields, 0.1 to 0.2 mG, and very low electric fields, 3 V/m on average. At the time of the pre-electrification measurements, this area was densely wooded with thick brush and downed trees. The only sources before the SS construction were the transmission line (used for the connection to SS) and a distribution line running to a nearby house. Both of these sources were sufficiently distant, such that measured fields were very low. The long-term sensor was placed near the midpoint of the east fence line, a location along the perimeter of the station, which was selected due to the proximity of the nearby house.

The new SS equipment and TL entering the SS dominate the post-electrification measurements. Due to a steep grade on all sides except for the west side, the perimeter profile was made approximately 3 ft within the station fence on all four sides. The post-electrification perimeter measurements varied from 2 mG to greater than 3 G (near station equipment), while the electric field varied from 4 V/m to approximately 1300 V/m.

Table 7. Summary Comparison Showing the Pre- and Post-Electrification ELF (3-3000 Hz) Magnetic and Electric Field Statistics from the Branford SS Measurements

Measurement Type		Minimum	Percentile Levels 5	25	50	75	95	Maximum	Average	Std. Dev.
ELF (3-3000 Hz) Magnetic Field in milligauss										
Long-Term	Pre-	0.1	0.1	0.1	0.1	0.2	0.2	0.2	0.1	0.0
	Post-	4.5	5.9	20.7	24.2	27.8	31.3	36.3	21.3	8.9
Perimeter Profile	Pre-	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0
	Post-	1.5	2.2	6.2	15.8	138.6	1166.0	3558.4	244.7	574.4
Lateral Profile	Pre-	-	-	-	-	-	-	-	-	-
	Post-	-	-	-	-	-	-	-	-	-
ELF (3-3000 Hz) Electric Field in volts per meter										
Long-Term	Pre-	1	2	2	2	2	3	47	3	4
	Post-	13	19	19	20	21	21	22	20	1
Perimeter Profile	Pre-	1	1	1	1	1	1	1	1	0
	Post-	4	5	75	200	670	974	1263	350	342
Lateral Profile	Pre-	-	-	-	-	-	-	-	-	-
	Post-	-	-	-	-	-	-	-	-	-

Sharon SS. This SS is located directly under an electric utility transmission line that feeds the SS. For the long-term measurement, the sensors were set near the base of Boston Edison Company (BECO) transmission tower number 6, the approximate center point of the SS. At the time of the pre-electrification measurements, the area around of the base of this tower was covered in thick brush, accounting for the lower alternating current (AC) electric field values recorded at that time. The AC magnetic field values are larger in the post-electrification data because of the SS being located directly under the transmission line. The pre-electrification fields were produced solely by the existing transmission line, while the post-electrification fields were the combined effect of the transmission and traction power SS. Table 8 provides detailed information on the magnetic and electric field statistics from the Sharon SS measurements.

For the pre-electrification measurements, perimeter measurements were made along the station fence line except for the southeast side. The perimeter profile for the southeast side was made approximately 30 ft inside the station fence line due to very thick brush that existed before the station was built. For the post-electrification measurements, the perimeter profile was made just inside the SS fence. The AC electric fields are slightly lower in the post-electrification data, possibly because of shielding from the fence. The AC magnetic field is significantly higher in the post-electrification data due to the SS equipment and possibly the increased load on the utility transmission line.

The lateral profile measurement was made from the tracks, through the point of the long-term measurement. The profile for the pre-electrification measurements extended into the woods approximately 270 ft. For the post-electrification measurements, the later profile terminated at the southeast fence line. The AC electric fields are much larger in the post-electrification data (median is two orders of magnitude larger and average is factor of two larger). The AC magnetic field values are significantly higher in the post-electrification data because of the SS equipment and increased load on the transmission line.

Table 8. Summary Comparison Showing the Pre- and Post-Electrification ELF (3-3000 Hz) Magnetic and Electric Field Statistics from the Sharon SS Measurements

Measurement Type		Minimum	Percentile Levels 5	25	50	75	95	Maximum	Average	Std. Dev.
ELF (3-3000 Hz) Magnetic Field in milligauss										
Long-Term	Pre-	7.5	7.6	8.6	11.7	12.5	12.8	12.9	10.8	1.9
	Post-	97.9	100.6	101.5	105.4	108.0	109.3	110.3	104.9	3.1
Perimeter Profile	Pre-	3.7	5.3	7.1	7.7	9.6	14.3	16.7	8.7	2.8
	Post-	9.0	9.9	14.7	22.3	96.0	489.6	852.0	97.4	175.1
Lateral Profile	Pre-	0.7	0.8	1.4	4.4	8.3	12.8	13.1	5.3	4.2
	Post-	36.5	37.6	65.2	213.5	578.5	710.4	743.2	315.2	271.4
ELF (3-3000 Hz) Electric Field in volts per meter										
Long-Term	Pre-	94	96	100	103	105	106	106	102	3
	Post-	682	707	710	711	720	736	744	715	9
Perimeter Profile	Pre-	5	5	170	190	376	1049	1330	325	317
	Post-	21	23	54	136	293	697	810	212	209
Lateral Profile	Pre-	4	5	5	5	309	992	1110	220	357
	Post-	34	44	331	541	817	932	953	537	309

3.1.2 SwS Sites

Westbrook SwS. This SwS is located behind a light industrial business park in Westbrook, Connecticut. The area is overgrown with trees and brush, which forms a barrier between the railroad ROW and the business park. In general, the industrial buildings and distribution lines are sufficiently distant that measured pre-electrification electric and magnetic fields were very low. For long-term measurements, the sensors were set approximately 35 ft from the nearest rail on the west property line. This location was close to trees and brush at the time of the pre-electrification measurements, but was cleared as part of the station access road at the time of the post-electrification measurements. Table 9 provides detailed information on the magnetic and electric field statistics from the Westbrook SwS measurements.

The perimeter profiles were made just outside the station fence line. The lateral profile was made starting 15 ft from the tracks, over a distance of 200 feet along the access road toward the business park.

In general, the pre-electrification EMFs were very low due to the distance to any pre-existing sources. The post-electrification EMF readings are from the SwS conductors and equipment.

Table 9. Summary Comparison Showing the Pre- and Post-Electrification ELF (3-3000 Hz) Magnetic and Electric Field Statistics from the Westbrook SwS Measurements

Measurement Type		Minimum	Percentile Levels 5	25	50	75	95	Maximum	Average	Std. Dev.
ELF (3-3000 Hz) Magnetic Field in milligauss										
Long-Term	Pre-	0.0	0.0	0.0	0.0	0.0	0.1	0.1	0.0	0.0
	Post-	0.3	0.3	0.3	0.4	0.5	3.2	18.1	0.9	1.8
Perimeter Profile	Pre-	0	0	0	0	0	0	0	0	0
	Post-	0.4	0.7	1.0	1.4	2.2	2.9	4.2	1.6	0.8
Lateral Profile	Pre-	0	0.0	0	0	0	0	0.1	0	0
	Post-	0.3	0.3	0.5	0.6	1.2	2.1	3.3	1.0	0.7
ELF (3-3000 Hz) Electric Field in volts per meter										
Long-Term	Pre-	0	0	0	0	0	0	1	0	0
	Post-	185	201	204	209	212	216	217	208	5
Perimeter Profile	Pre-	2	2	2	2	2	2	2	2	0
	Post-	2	2	11	114	355	464	661	178	188
Lateral Profile	Pre-	2	2	2	2	2	2	2	2	0
	Post-	2	2	2	2	2	116	209	19	50

Richmond SwS. The Richmond, Rhode Island, SwS is in a very rural area. Other than the station itself, the only visible field source is a small distribution line along the road that is approximately 200 ft from the tracks. The area outside the station fence is wooded. Table 10 provides detailed information on the magnetic and electric field statistics from the Richmond SwS measurements.

For long-term measurements, the sensors were set approximately 25 ft outside the station fence near the northwest corner of the property line. The perimeter profile was made outside the fence line. The AC magnetic and electric fields show a significant increase over the pre-electrification levels. Again, this is due to the operation of the SwS.

The lateral profile was made starting at a point approximately 20 ft west of the station fence, in line with the south fence line. This point is approximately 40 ft from the tracks. The profile extended through the woods and out to the nearest road, which was approximately 200 ft from the tracks. The data shows a significant increase of the AC magnetic field levels in the post-electrification data, compared to the levels in the pre-electrification data for that portion of the profile that is close to the station. However, the field levels fall off rapidly; in the area of the road, the post-electrification AC magnetic field levels are the same as the levels in the pre-electrification data. The post-electrification AC electric field levels are also significantly higher than the pre-electrification AC electric field levels. This is particularly true up to the 30-foot mark of the profile, at which point the electric field levels have dropped off significantly (see Appendix D for profile plots).

Table 10. Summary Comparison Showing the Pre- and Post-Electrification ELF (3-3000 Hz) Magnetic and Electric Field Statistics from the Richmond SwS Measurements

Measurement Type		Minimum	Percentile Levels 5	25	50	75	95	Maximum	Average	Std. Dev.
ELF (3-3000 Hz) Magnetic Field in milligauss										
Long-Term	Pre-	0.1	0.1	0.1	0.2	0.2	0.2	0.2	0.2	0.0
	Post-	0.3	0.3	0.3	0.3	0.3	0.7	1.3	0.4	0.1
Perimeter Profile	Pre-	0.2	0.2	0.2	0.2	0.2	0.3	0.3	0.2	0
	Post-	0.2	0.3	0.4	0.6	1.0	3.2	6.1	1.0	1.2
Lateral Profile	Pre-	0.2	0.2	0.2	0.2	0.3	0.3	0.3	0.3	0
	Post-	0.3	0.3	0.4	0.5	0.7	2.2	2.5	0.7	0.6
ELF (3-3000 Hz) Electric Field in volts per meter										
Long-Term	Pre-	-	-	-	-	-	-	-	-	-
	Post-	99	99	100	101	101	102	104	101	1
Perimeter Profile	Pre-	0	0	0	1	1	1	1	1	0
	Post-	5	5	6	45	298	352	379	133	144
Lateral Profile	Pre-	0	0	0	1	1	1	1	1	0
	Post-	5	5	5	5	6	50	73	12	18

3.1.3 PS

Grove Beach PS. This PS is situated beside a residential trailer park in Grove Beach, Connecticut. Distribution lines are visible within the trailer park, although they are fairly distant. The long-term measurement sensors were set up approximately 35 ft south of the tracks on the east property line. Table 11 provides detailed information on the magnetic and electric field statistics from the Grove Beach PS measurements.

An attempt was made to make perimeter profiles measurements 3 ft outside of the station fence line. This was only possible, however, on the east and north sides. Brush and tree growth, combined with a chain-link fence paralleling the tracks, made it impossible to do the perimeter profile outside the west and south fence lines. Therefore, for these two sides, the perimeter profile was made within the station fence. For the AC EMFs, the levels recorded in the post-electrification data are significantly higher than the levels recorded in the pre-electrification data.

The lateral profile for the pre-electrification measurement study was made along the east property line, continuing south along a wooden fence that marked the edge of the trailer court property. The station fence, as well as brush growth, made repeating this profile impossible. Instead, the lateral profile for the post-electrification study was made down the center of the street in the nearby trailer park. Because the post-electrification lateral profile was 150 ft away from the PS itself, no effect of the station could be seen in the data. Although the magnetic field levels are low near the tracks, profile data shows a decrease with distance that characterizes the falloff in fields due to the OCS and feeders. The electric fields show a significant increase when compared with the pre-electrification results.

Table 11. Summary Comparison Showing the Pre- and Post-Electrification ELF (3-3000 Hz) Magnetic and Electric Field Statistics from the Grove Beach PS Measurements

Measurement Type		Minimum	Percentile Levels 5	25	50	75	95	Maximum	Average	Std. Dev.
ELF (3-3000 Hz) Magnetic Field in milligauss										
Long-Term	Pre-	0.0	0.0	0.0	0.0	0.0	0.1	0.1	0.0	0.0
	Post-	0.1	0.1	0.2	0.2	0.2	1.9	7.2	0.5	0.9
Perimeter Profile	Pre-	0.1	0.1	0.1	0.1	0.1	0.2	0.3	0.1	0.1
	Post-	0.2	0.3	0.4	0.5	0.7	1.5	2.7	0.7	0.5
Lateral Profile	Pre-	0.1	0.1	0.1	0.1	0.2	0.3	0.5	0.2	0.1
	Post-	0.2	0.3	0.5	0.6	0.7	1.1	1.2	0.6	0.3
ELF (3-3000 Hz) Electric Field in volts per meter										
Long-Term	Pre-	1	2	3	3	3	3	10	3	1
	Post-	25	99	100	102	103	104	109	101	8
Perimeter Profile	Pre-	3	3	3	3	3	3	4	3	0
	Post-	2	3	17	72	311	629	666	194	240
Lateral Profile	Pre-	3	3	3	3	3	3	3	3	0
	Post-	2	2	2	2	2	32	120	9	26

Noank PS. This station is situated close to residential areas and the shore (less than 200 m) near Noank, Connecticut. This station is near the intersection of Long Point Road and Elm Street. At the time of the pre-electrification measurements, the site was so overgrown with brush that it was inaccessible. With the exception of the station itself and the station access road, the site was little improved at the time of the post-electrification measurements. Normal profile measurements were, therefore, not possible. Instead, profiles were recorded as close as possible to the property line of the station. Table 12 provides detailed information on the magnetic and electric field statistics from the Noank PS measurements.

For the long-term measurements, the sensors were located close to the top of the hill, at the intersection of Long Point Road and Elm Street. Because of the brush and trees in this area, the AC electric field levels were below the sensitivity level of the instrumentation. In both the pre- and post-electrification data, the AC magnetic field levels were relatively low, averaging less than 0.5 milligauss. The average, however, was slightly higher in the post-electrification data.

The standard protocol used for this study dictated that perimeter measurements be made around all four sides of each site, between the fence line and property line. Because of the hillside and thick brush, the perimeter profile included walking north from the bridge on Long Point Road to the intersection on Elm Street, then continuing approximately 250 ft along Elm Street. In addition, a perimeter measurement was made along the south side of the property, between the station and the tracks.

The AC EMF levels recorded during the post-electrification measurements were significantly increased over the pre-electrification measurements, most likely due to the station itself. No lateral profiles were recorded at this site as a result of the hillside and brush.

Table 12. Summary Comparison Showing the Pre- and Post-Electrification ELF (3-3000 Hz) Magnetic and Electric Field Statistics from the Noank PS Measurements

Measurement Type		Minimum	Percentile Levels 5	25	50	75	95	Maximum	Average	Std. Dev.
ELF (3-3000 Hz) Magnetic Field in milligauss										
Long-Term	Pre-	0.2	0.2	0.2	0.2	0.2	0.3	0.5	0.2	0.1
	Post-	0.1	0.1	0.2	0.2	0.3	0.5	2.2	0.3	0.2
Perimeter Profile	Pre-	0.1	0.1	0.1	0.1	0.2	0.2	0.3	0.1	0.1
	Post-	1.2	1.5	2.5	3.4	4.6	9.7	48.1	5.0	7.1
Lateral Profile	Pre-	-	-	-	-	-	-	-	-	-
	Post-	-	-	-	-	-	-	-	-	-
ELF (3-3000 Hz) Electric Field in volts per meter										
Long-Term	Pre-	0	0	0	0	1	3	3	1	1
	Post-	0	0	0	0	0	0	0	0	0
Perimeter Profile	Pre-	0	0	0	0	0	0	0	0	0
	Post-	2	2	2	3	375	571	646	161	219
Lateral Profile	Pre-	-	-	-	-	-	-	-	-	-
	Post-	-	-	-	-	-	-	-	-	-

Stonington PS. This PS is in a rural area near Stonington, Connecticut. At the time of the pre-electrification measurements, a distribution line paralleling the tracks crossed directly over the planned station area, but it was moved over as part of the construction. For the long-term measurements the sensors were located on the east fence line, approximately 45 ft from the tracks. At the time of the pre-electrification measurements, the tall vegetation in the area attenuated the electric fields to levels too low to measure. The vegetation was cleared at the time of the post-electrification measurements, so the electric fields show a marked increase. For the AC magnetic fields, the post-electrification data shows more variability over time, as well as a slight increase, on average, over AC magnetic field levels in the pre-electrification data. Table 13 provides detailed information on the magnetic and electric field statistics from the Stonington PS measurements.

The perimeter profile was made just outside the station fence line. The AC electric field is significantly higher in the post-electrification data. The AC magnetic field is also slightly higher. These increases result from the operation of the PS.

The lateral profile was made along the east property line, from the tracks out to 200 feet. The AC electric field levels in the post-electrification data are much larger than the levels in the pre-electrification data due to the PS. The AC magnetic field levels are higher as well, but the increase is not as significant as that seen in the electric field data.

Table 13. Summary Comparison Showing the Pre- and Post-Electrification ELF (3-3000 Hz) Magnetic and Electric Field Statistics from the Stonington PS Measurements

Measurement Type		Minimum	Percentile Levels 5	25	50	75	95	Maximum	Average	Std. Dev.
ELF (3-3000 Hz) Magnetic Field in milligauss										
Long-Term	Pre-	0.1	0.1	0.1	5.4	7.0	8.4	8.8	3.6	3.5
	Post-	3.5	3.6	4.3	5.5	5.8	7.9	22.6	5.4	1.8
Perimeter Profile	Pre-	1.6	1.8	2.4	6.5	8.7	13.7	16.7	6.3	3.9
	Post-	1.9	2.1	4.5	10.0	11.1	21.8	27.1	9.3	6.0
Lateral Profile	Pre-	0.3	0.4	0.6	1.7	5.3	14	16.1	4.2	4.8
	Post-	3.2	3.9	7.7	12.5	13.9	15.6	17.3	11.0	4.3
ELF (3-3000 Hz) Electric Field in volts per meter										
Long-Term	Pre-	-	-	-	-	-	-	-	-	-
	Post-	86	117	119	121	122	123	130	120	3
Perimeter Profile	Pre-	0	0	0	0	0	0	0	0	0
	Post-	2	3	56	120	155	274	655	118	123
Lateral Profile	Pre-	0	0	0	0	0	0	0	0	0
	Post-	2	2	27	46	70	100	117	47	34

Roxbury PS. This station is in an urban environment situated above the trench that is the Amtrak and commuter rail corridor. This trench includes Massachusetts Bay Transportation Authority (MBTA) tracks with the third rail electric traction system (a direct current (DC) system). For the pre-electrification long-term measurement, the sensor was positioned a few feet from the trench at milepost 226.10, which is just outside of the south fence line. At the time of the pre-electrification measurements, this spot was just off the edge of a parking lot. It was filled with tall weeds and some small trees. For the pre-electrification measurements, the nearest field source was the MBTA line. The proximity of the trees explains the very low electric field values recorded during the pre-electrification measurements. For the post-electrification measurements, the nearest source is the paralleling station itself. Table 14 provides detailed information on the magnetic and electric field statistics from the Roxbury PS measurements.

For the post-electrification long-term measurement, the sensor was positioned a few feet to the north of the spot used for the pre-electrification measurement. For security reasons, it was placed just inside the southeast corner of the station fence. The electric field data recorded during the post-electrification measurements shows a significant increase over the pre-electrification values due to the proximity of the sensor to the station equipment, as well as the lack of trees and brush near the sensor. The post-electrification AC magnetic field also shows a significant increase over the pre-electrification data due to the proximity of the PS equipment.

The perimeter profile for the pre- and post-electrification measurements was made just outside the station fence line. The AC electric field shows a significant increase in the post-electrification data over the pre-electrification data because of the PS itself. Likewise, the AC magnetic fields increased significantly.

The lateral profile was made from the trench approximately at milepost 226+0560. The post-electrification profile was shorter than the pre-electrification profile as a result of a new chainlink fence installed on the opposite side of the street. The electric field shows an increase due to the PS. At the beginning of the lateral profile, the AC magnetic fields recorded during the post-electrification measurements are significantly higher due to the PS. These field levels, however, fall off rapidly. Field levels are identical 60 ft from the trench.

Table 14. Summary Comparison Showing the Pre- and Post-Electrification ELF (3-3000 Hz) Magnetic and Electric Field Statistics from the Roxbury PS Measurements

Measurement Type		Minimum	Percentile Levels 5	25	50	75	95	Maximum	Average	Standard Deviation
ELF (3-3000 Hz) Magnetic Field in milligauss										
Long-Term	Pre-	0.4	0.4	0.5	0.6	0.7	1.0	4.4	0.7	0.4
	Post-	3.9	5.9	7.7	9.1	12.1	15.1	21.7	10.0	3.2
Perimeter Profile	Pre-	0.4	0.4	0.4	0.4	0.5	0.6	0.7	0.5	0.1
	Post-	0.5	0.5	0.7	1.4	2.1	6.4	9.9	2.2	2.6
Lateral Profile	Pre-	0.2	0.2	0.2	0.2	0.4	0.5	0.5	0.3	0.1
	Post-	2.2	2.3	3.0	4.3	7.9	18.1	19.0	6.7	5.3
ELF (3-3000 Hz) Electric Field in volts per meter										
Long-Term	Pre-	0	0	0	1	1	2	13	1	1
	Post-	97	97	98	99	100	100	107	99	1
Perimeter Profile	Pre-	2	2	2	2	2	2	2	2	0
	Post-	4	5	7	18	57	142	205	42	50
Lateral Profile	Pre-	2	2	2	2	2	2	2	2	0
	Post-	2	3	4	6	8	9	9	6	2

3.1.4 TLs

New London TL. This TL consists of two 115 kV single-phase circuits in a concrete-encased duct bank below grade in the city streets of New London, Connecticut, in an urban environment. Overhead distribution lines exist along these streets. For the long-term measurements, the sensors were hidden in a group of small trees in a vacant lot. Due to these trees and the distance to distribution lines, the AC electric field levels were low for both sets of measurements. The AC magnetic field levels are slightly higher in the post-electrification data. Table 15 provides detailed information on the magnetic and electric field statistics from the New London TL measurements.

TL measurements were made along both sides of the roads beneath which the TL cable circuit was installed. These roads include Lewis Street, Cole Street, and Williams Street. The AC magnetic field is significantly increased along the tie-line route, presumably due to the TL itself.

In addition, a lateral profile was made across Lewis Street, one of the streets under which the TL passes. For this profile, the AC electric field levels are unchanged (underground TL produces no electric field) and the AC magnetic field levels are slightly increased.

Table 15. Summary Comparison Showing the Pre- and Post-Electrification ELF (3-3000 Hz) Magnetic and Electric Field Statistics from the New London TL Measurements

Measurement Type		Minimum	Percentile Levels 5	25	50	75	95	Maximum	Average	Std. Dev.
ELF (3-3000 Hz) Magnetic Field in milligauss										
Long-Term	Pre-	0.0	0.0	0.1	0.1	0.2	0.4	0.9	0.1	0.1
	Post-	0.1	0.1	0.2	0.2	0.3	0.4	1.3	0.2	0.1
Perimeter Profile	Pre-	0	0	0.1	0.1	0.1	0.1	0.1	0.1	0
	Post-	1.0	1.7	3.0	4.1	6.4	9.8	17.5	4.9	2.6
Lateral Profile	Pre-	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0
	Post-	0.3	0.5	0.7	1.1	1.4	2.1	2.5	1.2	0.6
ELF (3-3000 Hz) Electric Field in volts per meter										
Long-Term	Pre-	0	0	1	1	2	3	3	1	1
	Post-	0	0	0	0	0	0	0	0	0
Perimeter Profile	Pre-	2	2	2	2	3	6	6	3	2
	Post-	2	2	2	6	22	84	150	20	28
Lateral Profile	Pre-	0	0	0	0	0	0	0	0	0
	Post-	2	2	2	2	2	2	2	2	0

Warwick TL. The Warwick, Rhode Island, SS and TL are located in an urban environment. The two 115 kV single-phase circuits run in an underground concrete encased duct bank from the SS across a street (Jefferson Boulevard) and through a parking lot beside a business, connecting to a transmission line. Distribution lines are present on both sides of Jefferson Boulevard. For the long-term profile, the sensors were located between the sidewalk and the southwest corner of the SS fence. AC electric field levels were very low for both the pre- and post-electrification measurements. Table 16 provides detailed information on the magnetic and electric field statistics from the Warwick TL measurements.

The perimeter profile runs from the SS along the path of the underground TL to the transmission line. AC magnetic and electric fields show a significant increase approaching the transmission line.

The lateral profile measurements were recorded for a distance of 200 ft on both sides of the TL, running along Jefferson Boulevard The post-electrification AC electric field levels are similar to the pre-electrification levels, though the pre-electrification levels are slightly higher. The AC magnetic field levels are generally higher in the post-electrification data.

Table 16. Summary Comparison Showing the Pre- and Post-Electrification ELF (3-3000 Hz) Magnetic and Electric Field Statistics from the Warwick TL Measurements

Measurement Type		Minimum	Percentile Levels 5	25	50	75	95	Maximum	Average	Std. Dev.
ELF (3-3000 Hz) Magnetic Field in milligauss										
Long-term	Pre-	0.2	0.2	0.3	0.3	0.4	0.5	0.6	0.3	0.1
	Post-	1.5	1.6	1.9	2.4	3.7	9.3	23.9	3.5	2.8
Perimeter Profile	Pre-	0.1	0.1	0.3	0.8	1.8	19.5	20.5	3.3	6
	Post-	1.2	1.7	2.5	4.2	9.3	21.6	22.8	7.4	7.1
Lateral Profile	Pre-	0.5	0.5	0.5	0.9	1	1.2	1.5	0.8	0.3
	Post-	0.9	1.9	3.1	3.8	4.7	6.6	10.5	4.0	1.5
ELF (3-3000 Hz) Electric Field in volts per meter										
Long-term	Pre-	0	0	0	1	1	1	1	1	0
	Post-	0	0	0	0	0	0	0	0	0
Perimeter Profile	Pre-	2	3	6	12	50	824	1362	137	312
	Post-	2	2	3	8	57	481	626	99	173
Lateral Profile	Pre-	3	4	6	9	13	21	36	10	6
	Post-	2	2	4	7	9	20	26	7	5

3.2 Pre- and Post-Electrification Summary Graphs

Box and whisker plots in Figure 8, and Figures 10 to 13 compare the 5 percent, 25 percent, 75 percent, and 95 percent percentiles of the ELF magnetic and electric fields for the long-term, perimeter, and lateral profiles (Figure 9 compares the pre- and post-electrification average long-term electric field as a bar chart since almost no variation existed). In these plots, the top and bottom ends of the box represent the 25 percent and 75 percent percentiles, while the whisker plots show the 5 percent and 95 percent percentiles. For a visual comparison of statistics from each site, the pre- and post-electrification data is plotted side by side.

To generalize, changes in field levels at the measured sites predominantly resulted from the new electric power facility equipment and associated conductors. EMFs increased at nearly all sites as would be expected from construction and operation of the traction power facilities, except for two sites where slightly lower electric fields were recorded along spatial profiles.

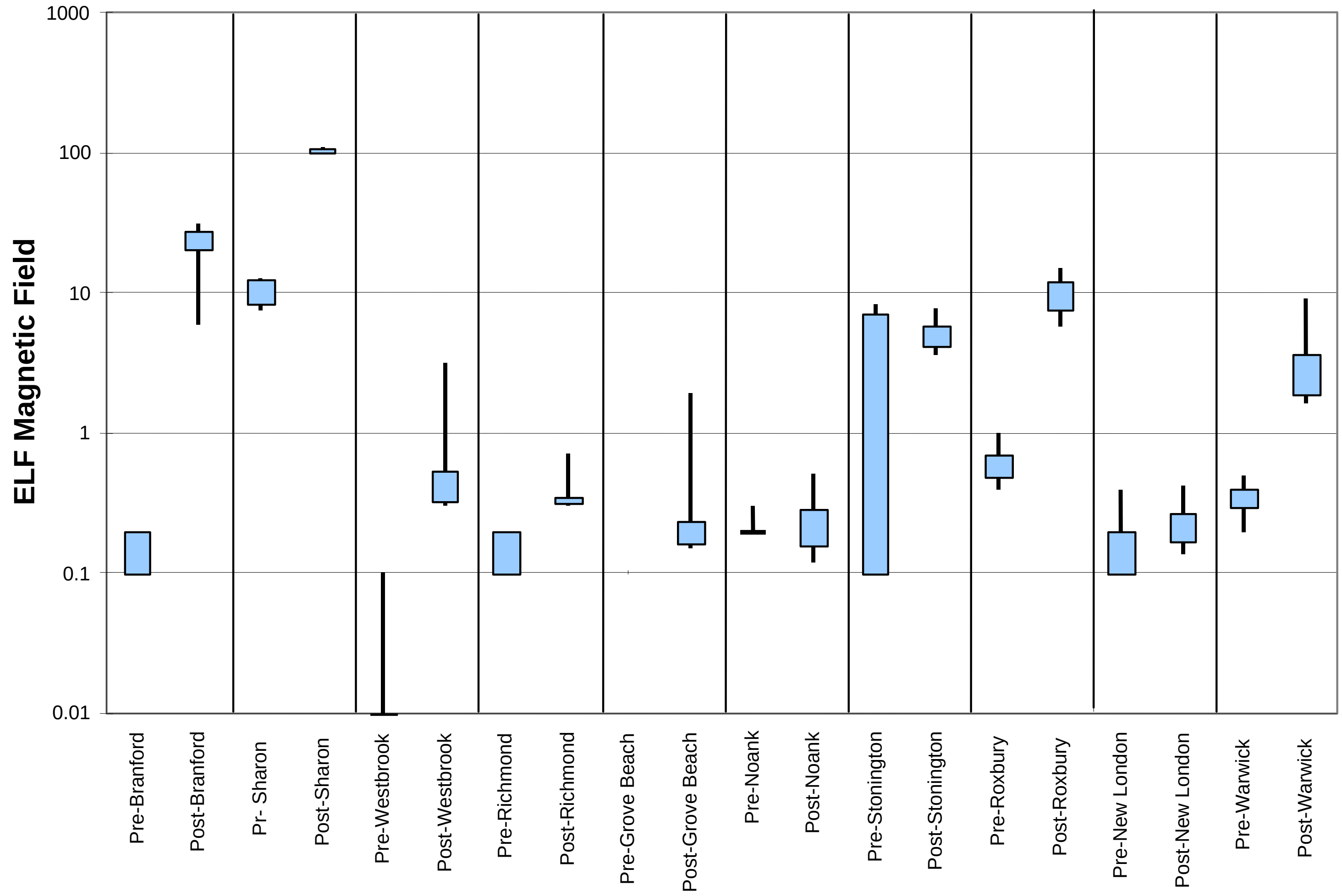

Figure 8. Comparison of the Pre- and Post-Electrification Long-Term ELF Magnetic Field (3-3000 Hz) Statistics for the 10 Traction Power Station Sites. Each Box-Whisker Plot Shows the 5 Percent, 25 Percent, 75 Percent, and 95 Percent Percentiles Calculated from the Pre- and Post-Electrification Long-Term Measurement Data

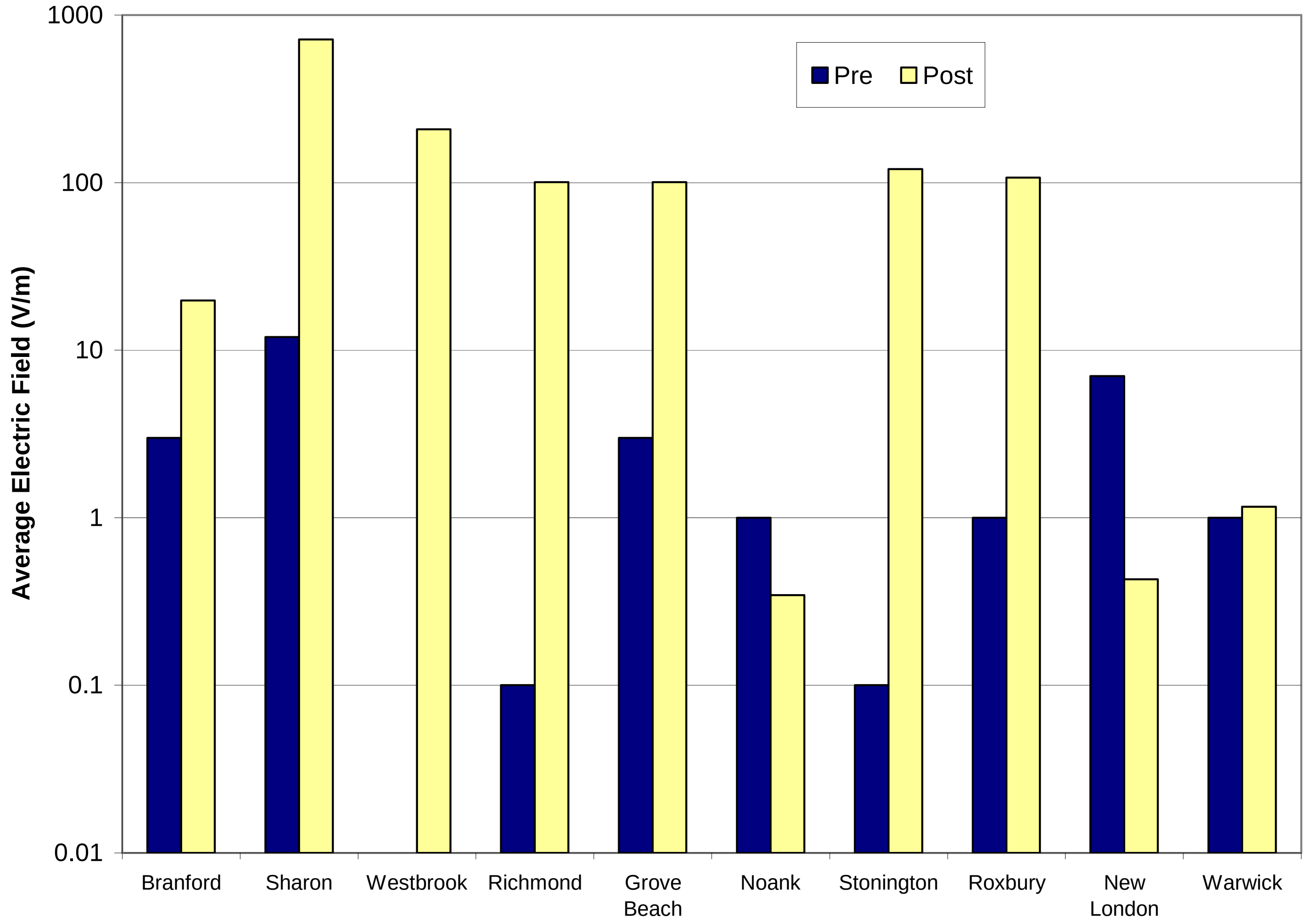

Figure 9. Comparison of the Pre- and Post-Electrification Average Electric Fields from the Long-Term Measurements at Each Traction Power Facility Site

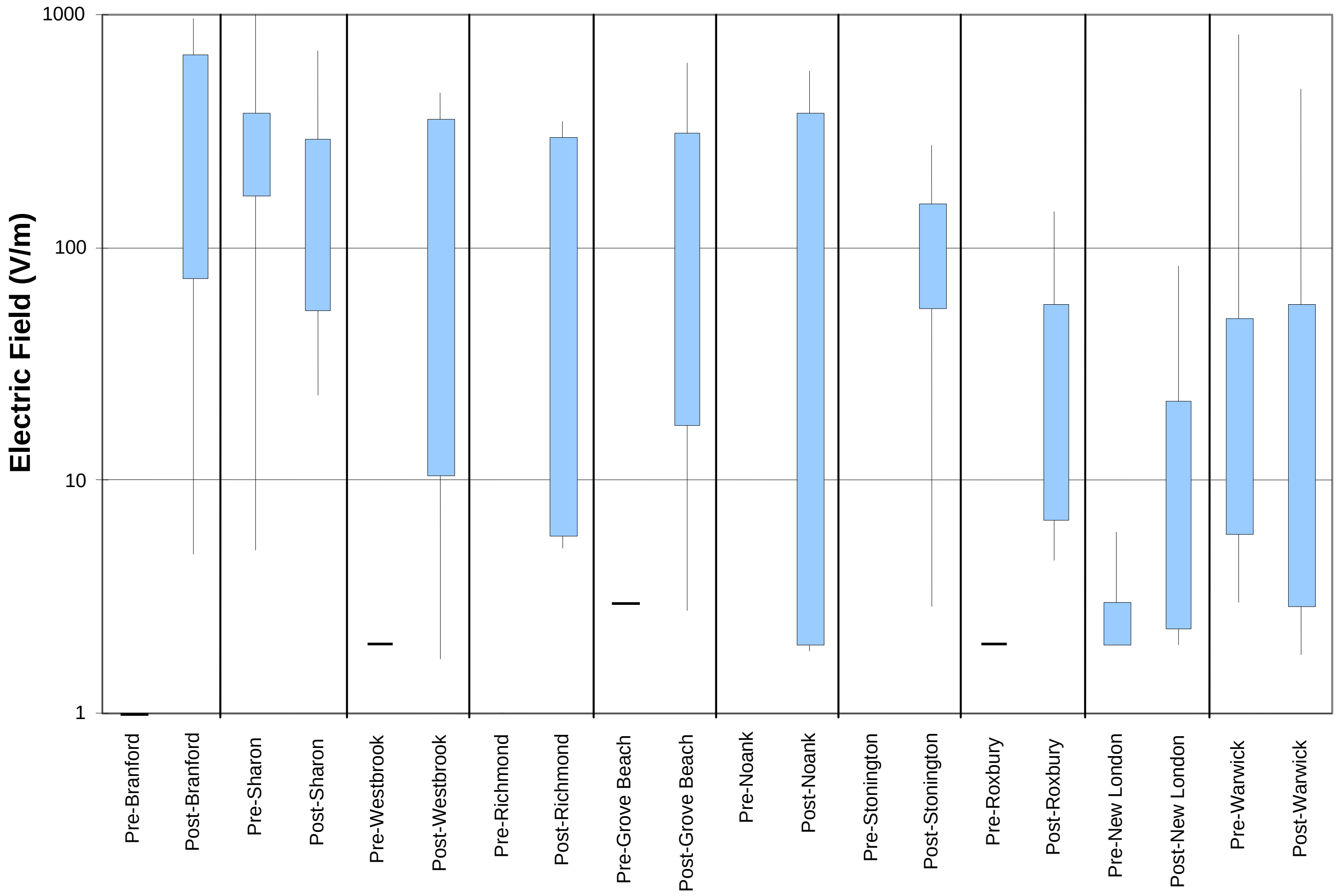

Figure 10. Comparison of the Pre- and Post-Electrification Perimeter Profile ELF Magnetic Field (3-3000 Hz) Statistics for the 10 Traction Power Station Sites. Each Box-Whisker Plot Shows the 5 Percent, 25 Percent, 75 Percent, and 95 Percent Percentiles Calculated from the Perimeter Profile Data

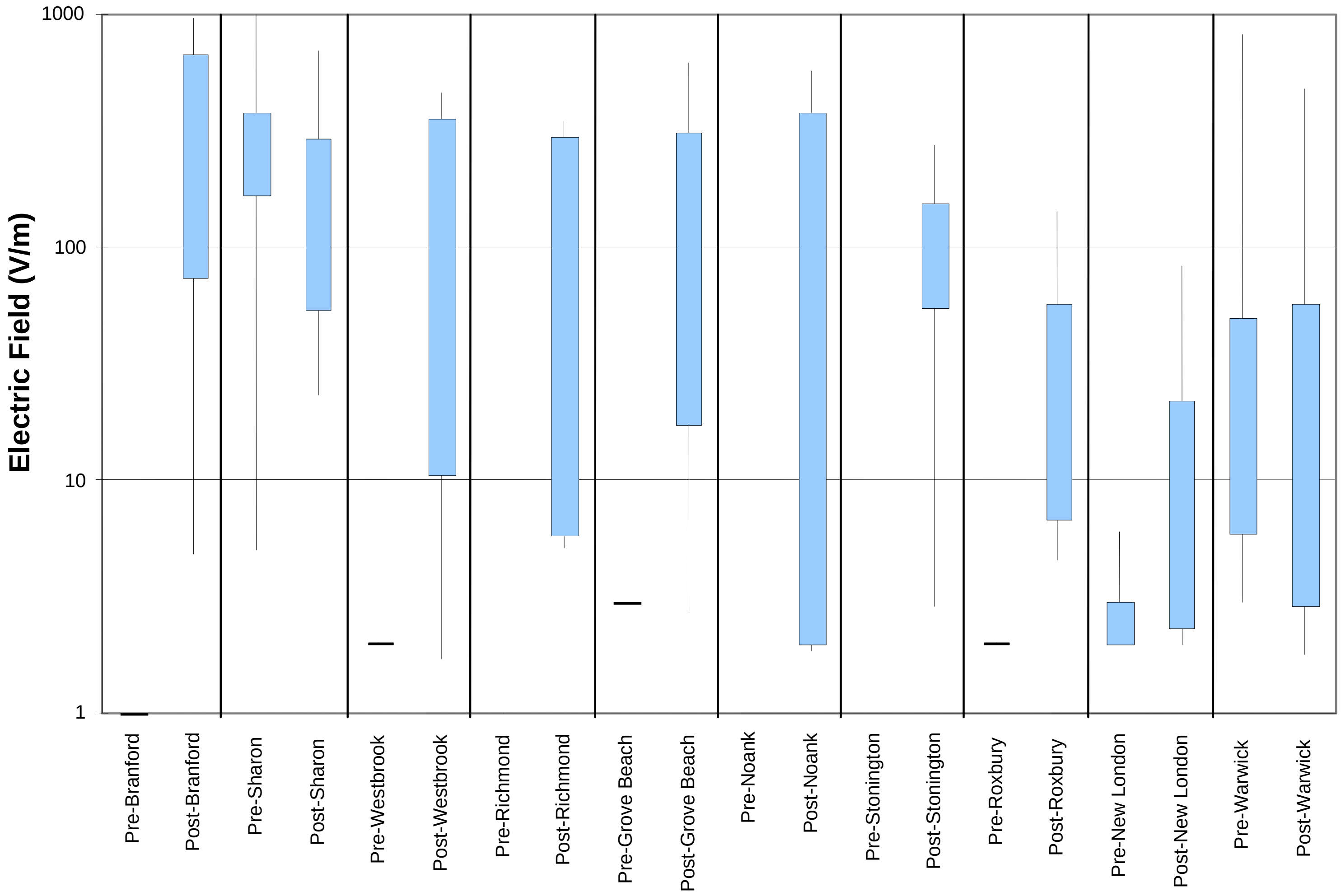

Figure 11. Comparison of the Pre- and Post-Electrification Perimeter Profile ELF Electric Field (3-3000 Hz) Statistics for the 10 Traction Power Station Sites. Each Box-Whisker Plot Shows the 5 Percent, 25 Percent, 75 Percent, and 95 Percent Percentiles Calculated from the Perimeter Profile Data

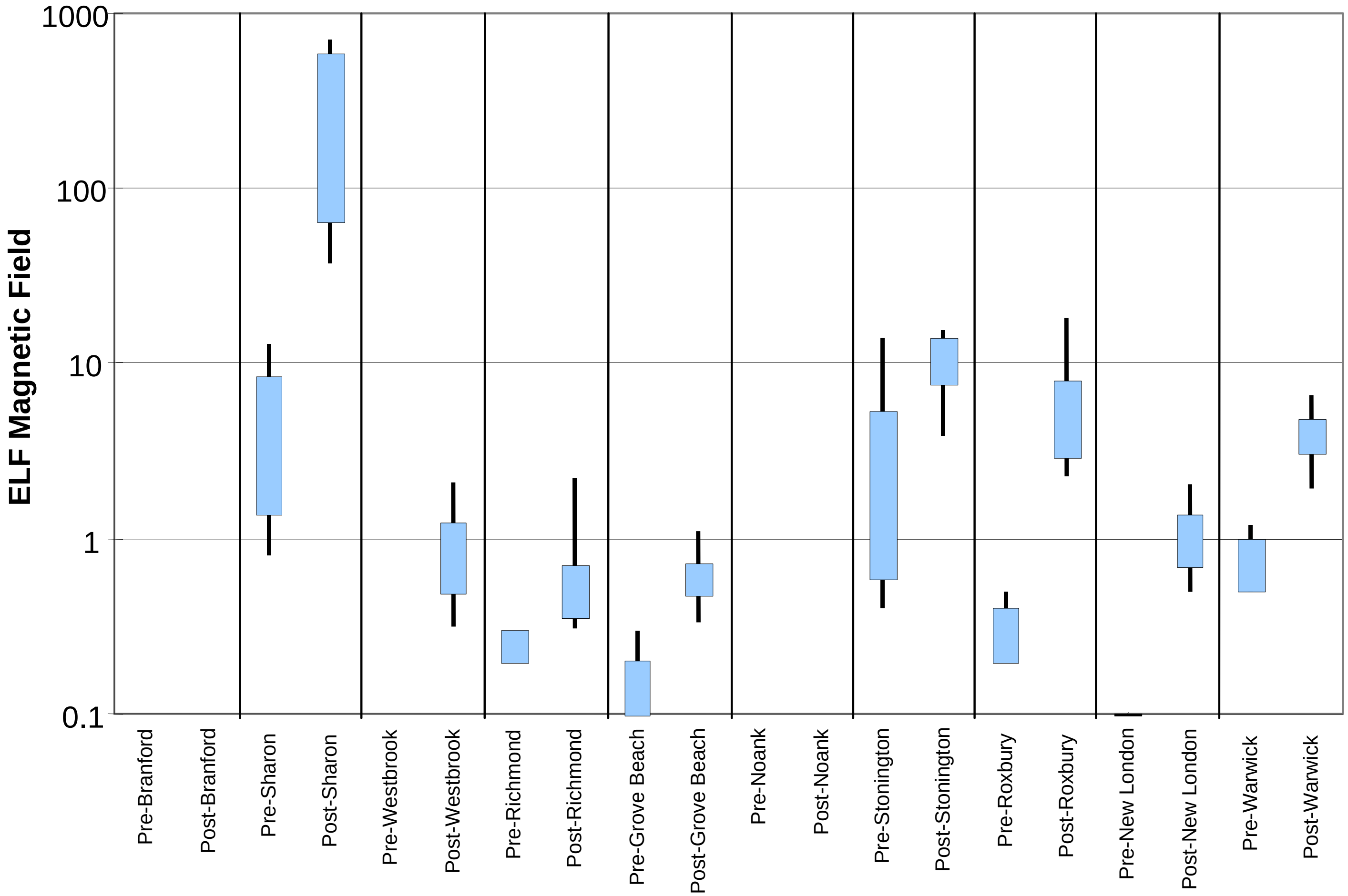

Figure 12. Comparison of the Pre- and Post-Electrification Lateral Profile ELF Magnetic Field (3-3000 Hz) Statistics for the 10 Traction Power Station Sites. Each Box-Whisker Plot Shows the 5 Percent, 25 Percent, 75 Percent, and 95 Percent Percentiles Calculated from the Lateral Profile Data

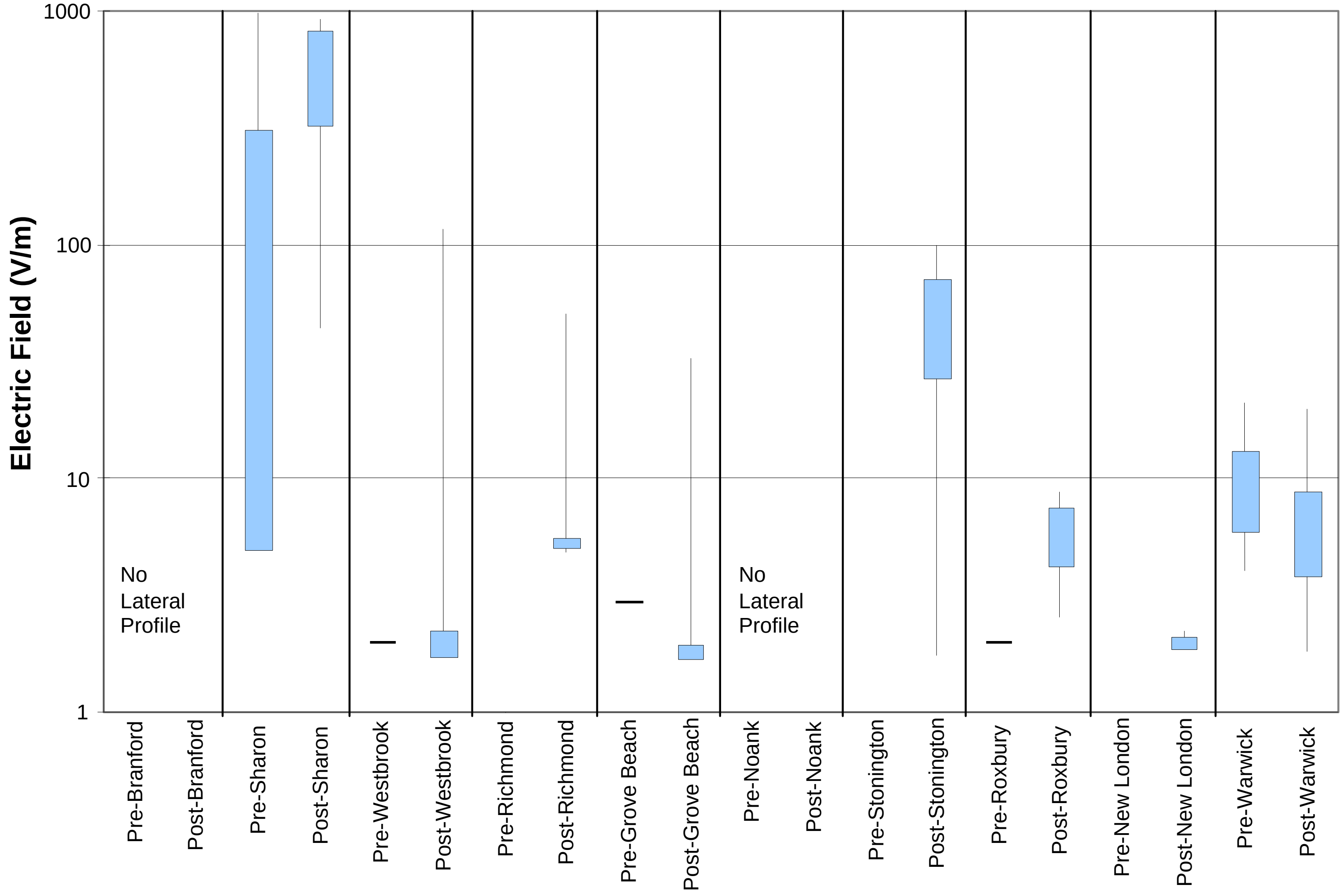

Figure 13. Comparison of the Pre- and Post-Electrification Lateral Profile ELF Electric Field (3-3000 Hz) Statistics for the 10 Traction Power Station Sites. Each Box-Whisker Plot Shows the 5 Percent, 25 Percent, 75 Percent, and 95 Percent Percentiles Calculated from the Lateral Profile Data

3.2.1 Long-Term Measurement Comparison

The long-term measurements characterize temporal variation at a fixed position. Figure 8 compares ELF magnetic field long-term measurement statistics. From Figure 8, the two SS (Branford and Sharon) appear to have the largest magnetic fields. Magnetic fields at the Branford SS are, in part, due to the fact that the TL loops through the SS. Based on a visual comparison of the pre- and post-electrification results, magnetic fields increased by about two orders of magnitude at the Branford SS, and by about one order of magnitude at the Sharon SS, Westbrook SwS, Roxbury PS, and the Warwick TL. Slight magnetic field increases are apparent at the Richmond SwS, Grove Beach, Noank, and Stonington PS, and the New London TL.

By visually comparing the pre- and post-electrification average long-term electric fields, large increases, approximately two orders-of-magnitude, can be seen at the Sharon SS, Westbrook and Richmond SwS, and at the Roxbury PS. An increase of about one order-of-magnitude can be seen at the Branford SS and Grove Beach PS. The average electric field showed little change at the Warwick TL, and appeared to decrease slightly at Noank PS and the New London TL. These last two that showed a decrease at relatively low levels, less than 10 V/m.

3.2.2 Perimeter Profile Measurement Comparison

The perimeter profile measurements characterize the spatial variation of field levels around the power facility. Figure 10 compares ELF magnetic field statistics from the perimeter profiles. In Figure 10, the largest increase in magnetic fields for the perimeter measurements was at the Branford SS, which showed an increase of approximately two orders of magnitude. The perimeter magnetic fields were highest near the filter bank equipment. One order-of-magnitude increases occurred at the Sharon SS, Westbrook SwS, Noank PS, and the two TL sites (New London and Warwick). General increases in the ELF magnetic fields occurred at the Richmond SwS, and the Grove Beach, Stonington, and Roxbury PS.

By visually comparing the pre- and post-electrification perimeter profile electric field statistics in Figure 11, one can see large increases (approximately two orders-of-magnitude) at the Branford SS, the Westbrook and Richmond SwS, and the Grove Beach, Noank, and Stonington PS. These large increases result from measurements beneath the electric lines connecting to the stations (these lines were not present during the pre-electrification study). A one order-of-magnitude increase in electric fields is seen at the New London TL; the electric fields are similar at the Warwick TL, and a slight decrease is seen for the Sharon SS (where a transmission line already existed before construction of the SS).

3.2.3 Lateral Profile Measurement Comparison

Figure 12 above compares the ELF magnetic field statistics from the lateral profile data sets. From Figure 12, magnetic fields increased by approximately two orders-of-magnitude at the Sharon SS. The Sharon SS sits directly beneath a transmission line, but this line was present during the pre-electrification measurements. The increase in magnetic fields can be attributed to the combination of the transmission line (which may have increased load) and the SS conductors and equipment. The lateral profile through the SS passed near the TL conductors that ran from the transmission line down to the station equipment.

Magnetic fields increased by approximately one order-of-magnitude at the Westbrook SwS, the Roxbury PS, and the two TL locations (New London and Warwick). A slight increase occurred in the magnetic fields at the Richmond SwS and the Grove Beach PS. Lateral profiles were not recorded at the Branford SS and the Noank PS.

Figure 13 above compares the lateral profile ELF electric field statistics. In Figure 13, the electric fields are approximately one order-of-magnitude higher at the Sharon SS, the Richmond SwS, the Stonington PS, and the New London TL. Statistics show a slight increase at the Westbrook SwS and Roxbury PS, while statistics show a slight decrease at the Grove Beach PS and the Warwick TL.

4. Train Pass Results

This chapter provides summary results from the wayside train pass measurements recorded along the tracks near the Midway maintenance facility and from measurements at an overpass location and an underpass location. Appendix K provides detailed results for the wayside measurements; Appendix L provides detailed results from the overpass and underpass.

4.1 Wayside Train Pass Results

Sensors set beside the southbound tracks were used to record magnetic and electric fields at a wayside location adjacent to the Midway maintenance facility. Fields were recorded during the passing of five trains as listed in Table 17. The following sections summarize the wayside measurement results.

Table 17. Train Passes Measured Along Tracks Adjacent to Midway Maintenance Facility

	Train Type	Direction	Start Time	End Time	Samples
1	Acela	South	14:42:18	14:45:30	65
2	Regional	South	15:04:56	15:06:29	32
3	Regional	North	15:22:29	15:23:47	27
4	Acela	South	16:29:31	16:31:16	36
5	Regional	South	16:44:21	16:46:42	49

4.1.1 ELF (3-3000 Hz) Magnetic Fields

ELF magnetic fields were recorded simultaneously at distances of 16.4 ft (5 m), 32.8 ft (10 m), and 49.2 ft (15 m) from the southbound track centerline. Figure 14 shows the maximum measured ELF magnetic field at each of the fluxgate sensor positions labeled A, B, and C for the five passes. The sensor at the third position was not recording during the fifth train pass. Maximum magnetic fields from the two southbound Acela Express passes were similar, approximately 60 mG at the first position, 10 mG at the second position, and 5 mG at the third position. The largest readings were recorded for the northbound regional train pass (83 mG, 15 mG, and 8 mG at the three positions moving away from the tracks).

Figures 15 to 19 show the maximum measured magnetic fields, by frequency band, for train passes 1 to 5, respectively. These figures show that, except for the second pass, fields are dominantly at 60 Hz.

Figure 20 is a log-log plot of the maximum magnetic field values for each pass as a function of distance from the southbound track centerline. This plot also includes a reference line illustrating an inverse square attenuation rate. This plot indicates that the fields fall off slightly faster than the inverse square of the distance. The plot also shows that the northbound regional had the largest maximum fields, the two Acela Express passes had the next highest field levels, and the southbound regional passes had the lowest values.

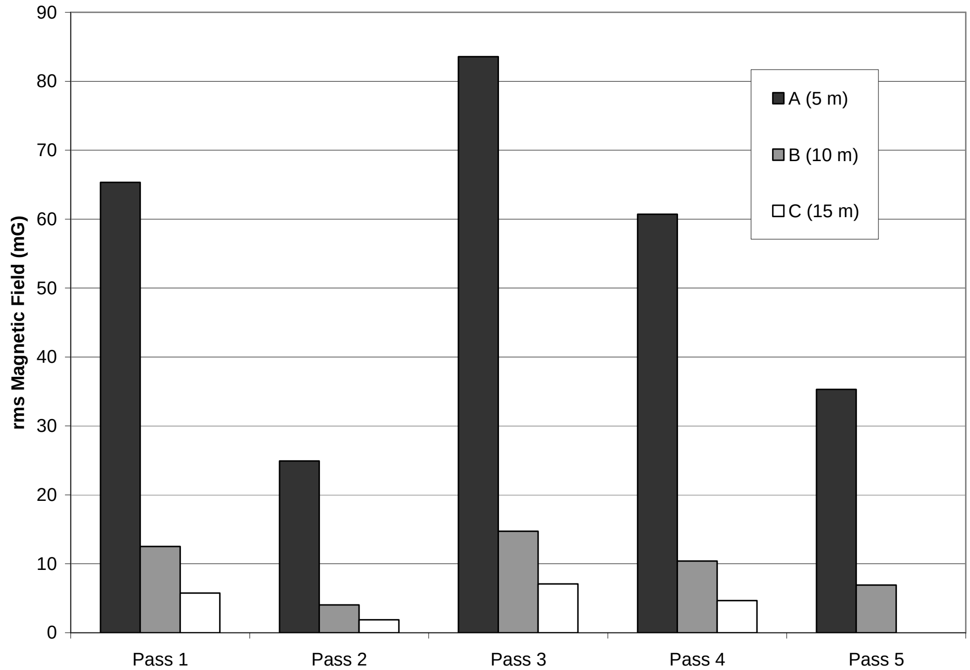

Figure 14. Maximum Measured Total ELF Magnetic Fields at the Three Positions for Each of Five Train Passes. Passes 1 and 4 were Southbound Acelas. Passes 2 and 5 were Southbound Regional Trains while Pass 3 was a Northbound Regional

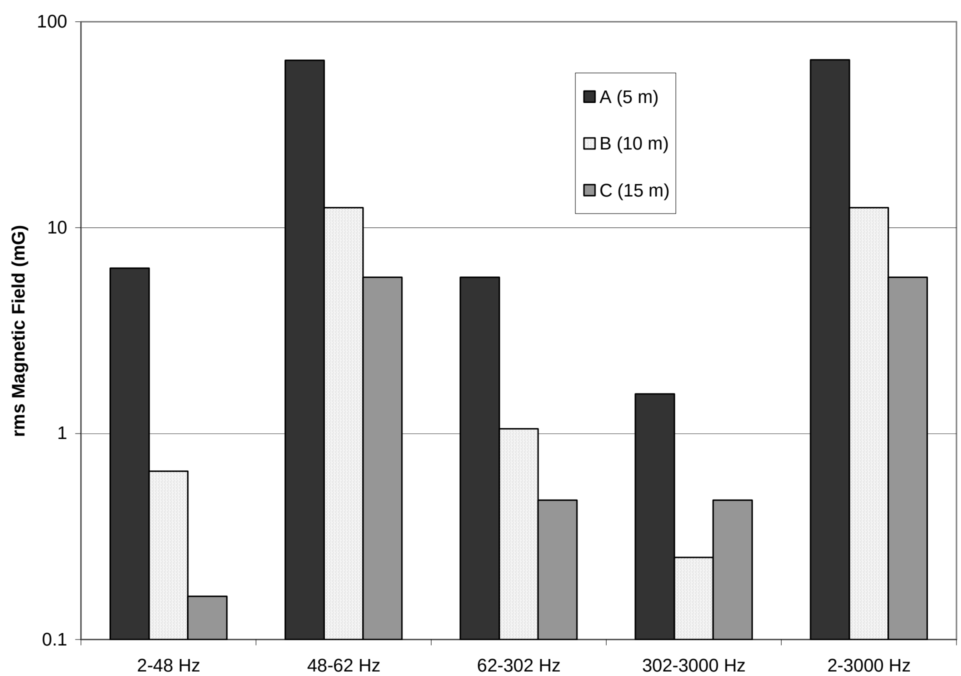

Figure 15. Maximum Magnetic Field Values from the First Train Pass (Southbound Acela) by Frequency Band

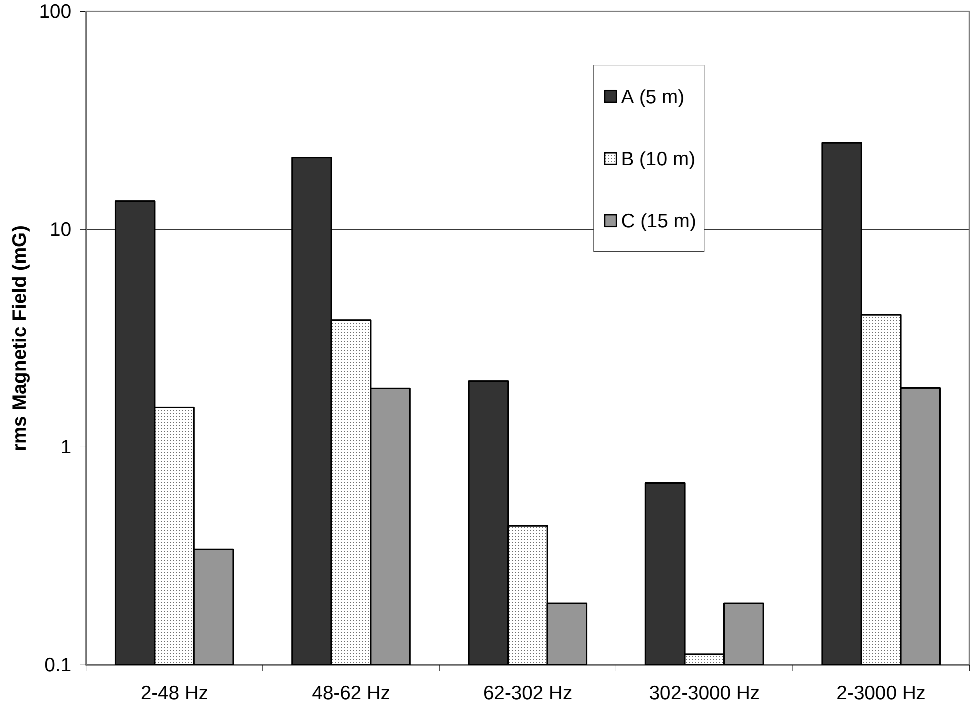

Figure 16. Maximum Magnetic Field Values from the Second Train Pass (Southbound Regional) by Frequency Band

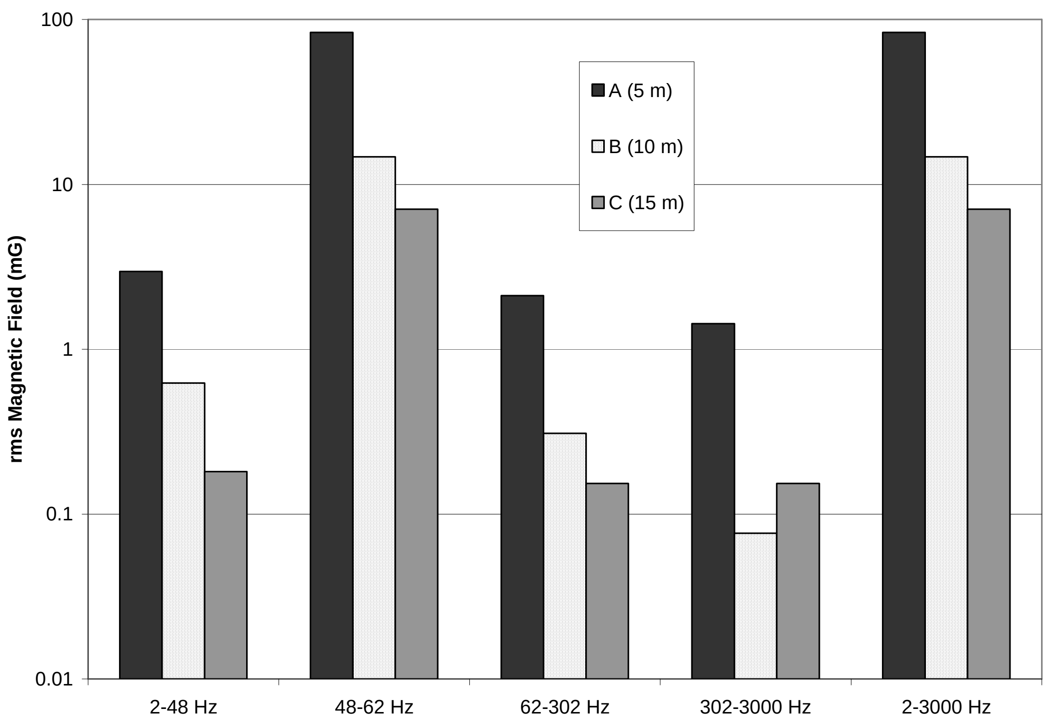

Figure 17. Maximum Magnetic Field Values from the Third Train Pass (Northbound Regional) by Frequency Band

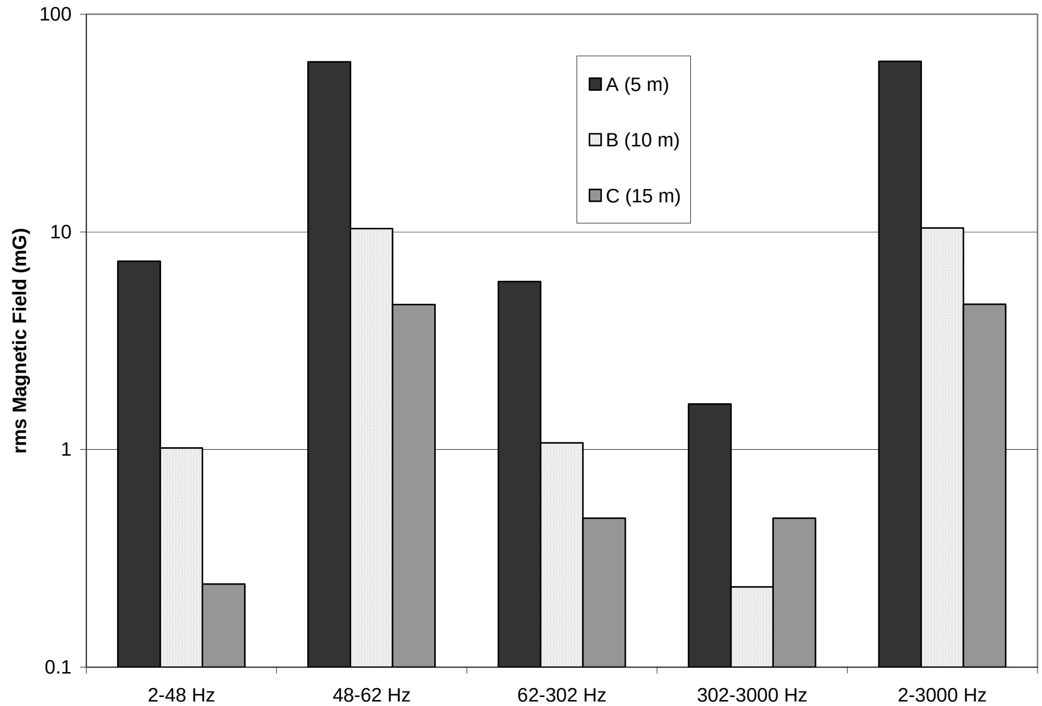

Figure 18. Maximum Magnetic Field Values from the Fourth Train Pass (Southbound Acela) by Frequency Band

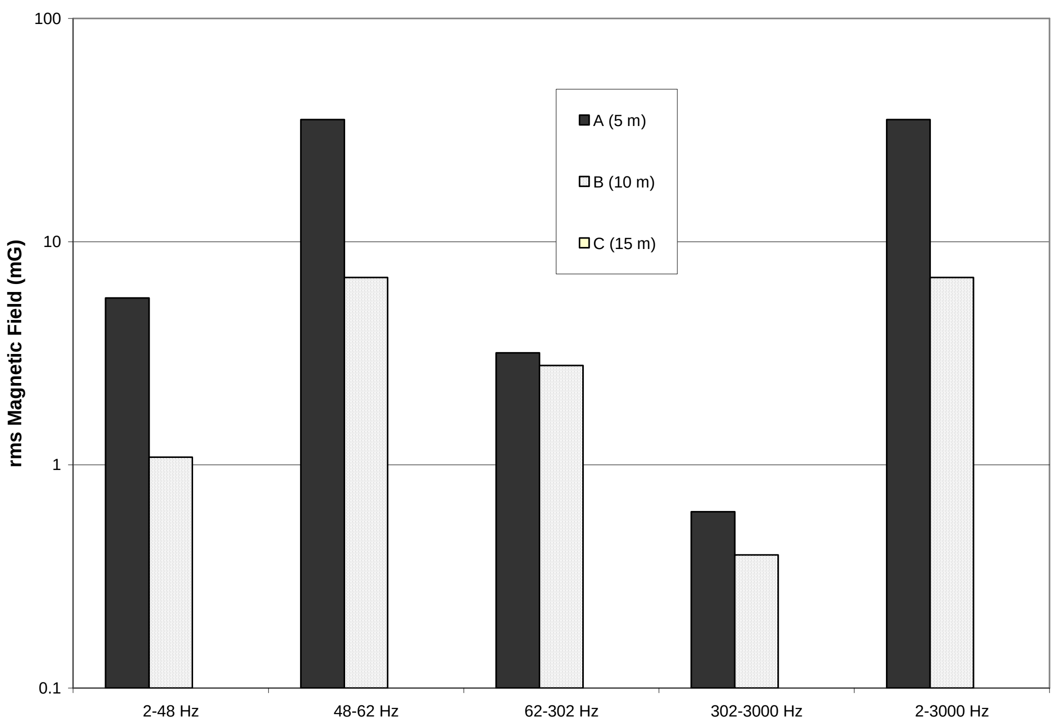

Figure 19. Maximum Magnetic Field Values from the Fifth Train Pass (Southbound Regional) by Frequency Band. The Sensor at the Third Position was not Recording During This Train Pass

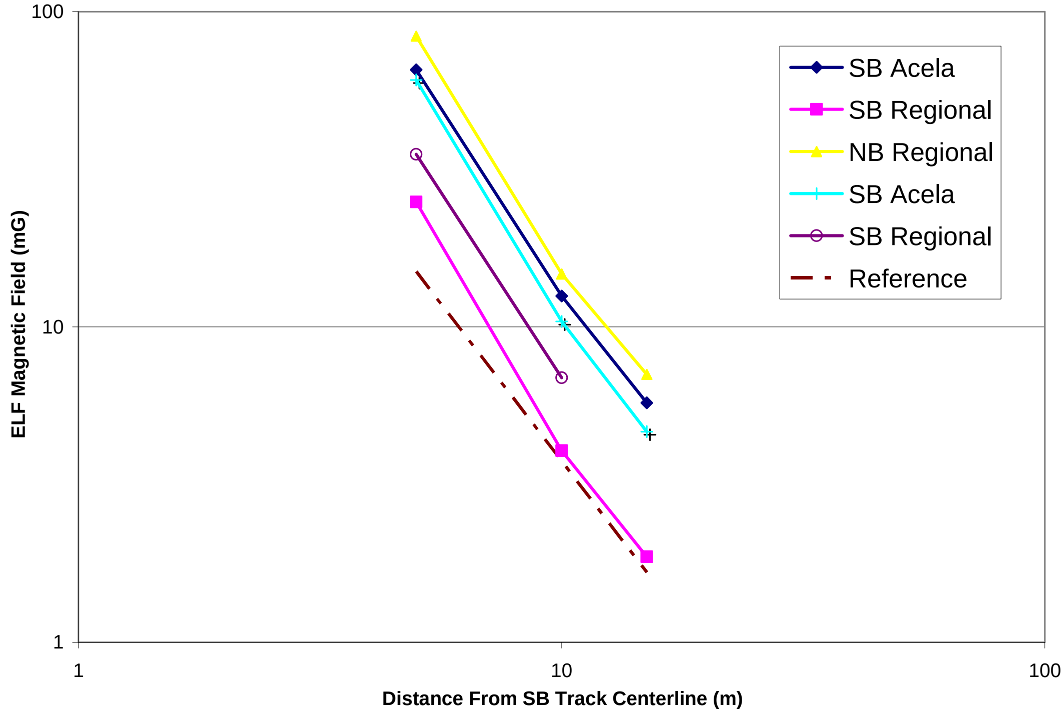

Figure 20. Maximum Measured Magnetic Fields as a Function of Position for Each of Five Train Passes. For Reference, the Bottom Line Shows Attenuation that is Inversely Proportional to the Distance Squared

Figure 21 is a surface plot of ELF resultant magnetic field measured at the 16.4 ft (5 m) position during the first train pass, a southbound Acela Express. This detail plot shows magnetic field magnitude as a function of time and frequency. In this plot, the 60 Hz component is dominant, but third and fifth harmonics are significant. Harmonics above 2 kHz are also visible in this plot. In Figure 21, the time-variation of magnetic fields does not correspond to the position of the train (i.e., maximum does not occur when the train is at the sensor location). Rather, the magnetic fields depend on the currents in the OCS and rails, and these current levels depend on the operation of the train (for example, acceleration) and the location of the autotransformers that supply electric power.

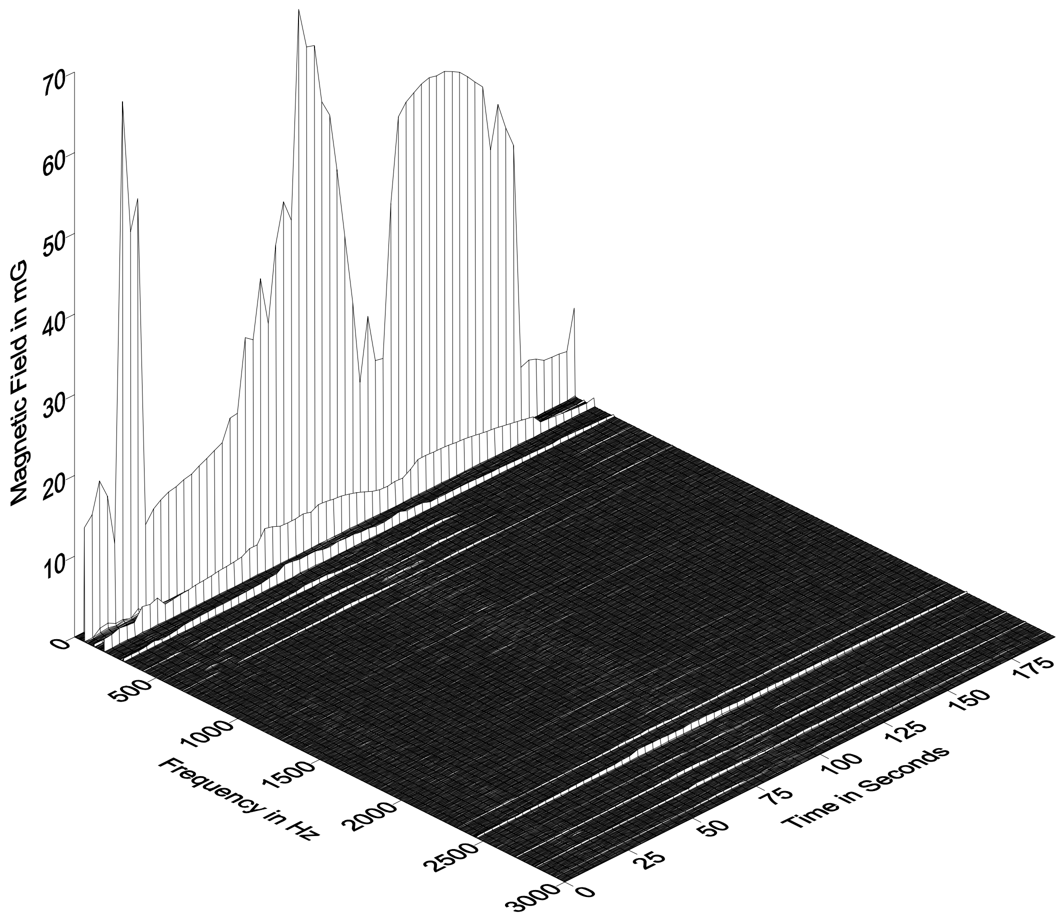

Figure 21. Surface Plot of ELF Resultant Magnetic Field Measured at the 16.4 ft (5 m) Position. 60 Hz is Dominant, with third (180 Hz) and fifth (300 Hz) Harmonics Visible. Harmonics above 2 kHz are Also Visible

4.1.2 ELF Electric Fields

ELF vertical electric fields were measured at 16.4 ft (5 m) from the southbound track centerline with each train pass. The dominant field at this position is believed to be from the overhead 25 kV feeder (that is one side of the 2x25 kV system providing power to the autotransformers at the PS and SwS). The electric fields are predominantly 60 Hz.

The electric field actually dipped with each train pass due to the shading effect of the metallic train as it passed the sensor. The dip in the electric field was not as strong with a northbound train because of the increased distance from the sensor.

Figure 22 shows the minimum and maximum measured ELF electric fields for each of the five train passes. The smaller shading effect from the northbound train (third pass) due to its increased distance from the sensor is visible by comparing the minimum values.

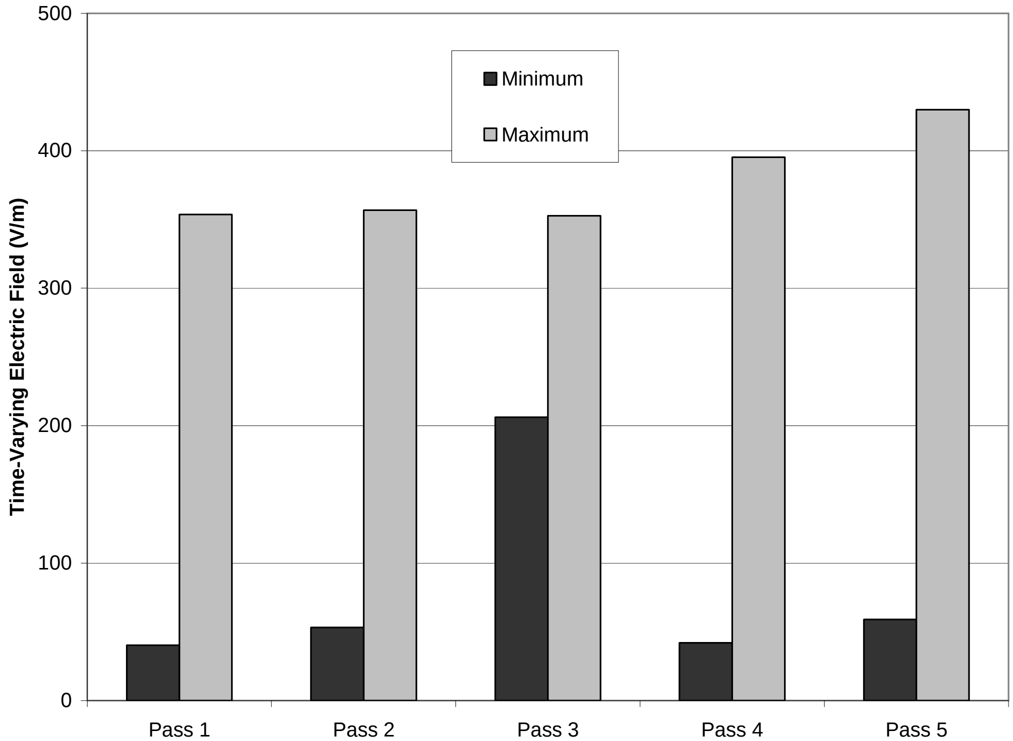

Figure 22. Maximum and Minimum ELF Electric Fields for Each Train Pass as Measured at 16.4 ft (5 m) from the Southbound Track Centerline

4.1.3 VLF and LF Magnetic Fields

No significant VLF and LF magnetic fields were measured at 16.4 ft (5 m) from the southbound track centerline. All measured values were at or below the noise level of the sensors (less than 1 mG).

4.1.4 RF Measurements

RF field levels were recorded at 1-second intervals with a Narda meter and broadband RF electric-field probe during the train passes. The recorded readings were generally low, with a few readings reaching 2 percent of the occupational FCC standard as listed in Table 18 and shown in Figure 23. No large spikes associated with a passing train, however, were visible.

Table 18. Minimum and Maximum Broadband RF Electric Field Readings by Train Pass

Pass	Train Type	Travel Direction	Minimum Percent Occupational FCC	Maximum Percent Occupational FCC	Sample Count
1	Acela	South	0.00	1.58	497
2	Regional	South	0.00	0.00	85
3	Regional	North	0.00	2.19	520
4	Acela	South	0.00	2.06	381
5	Regional	South	0.00	1.16	257

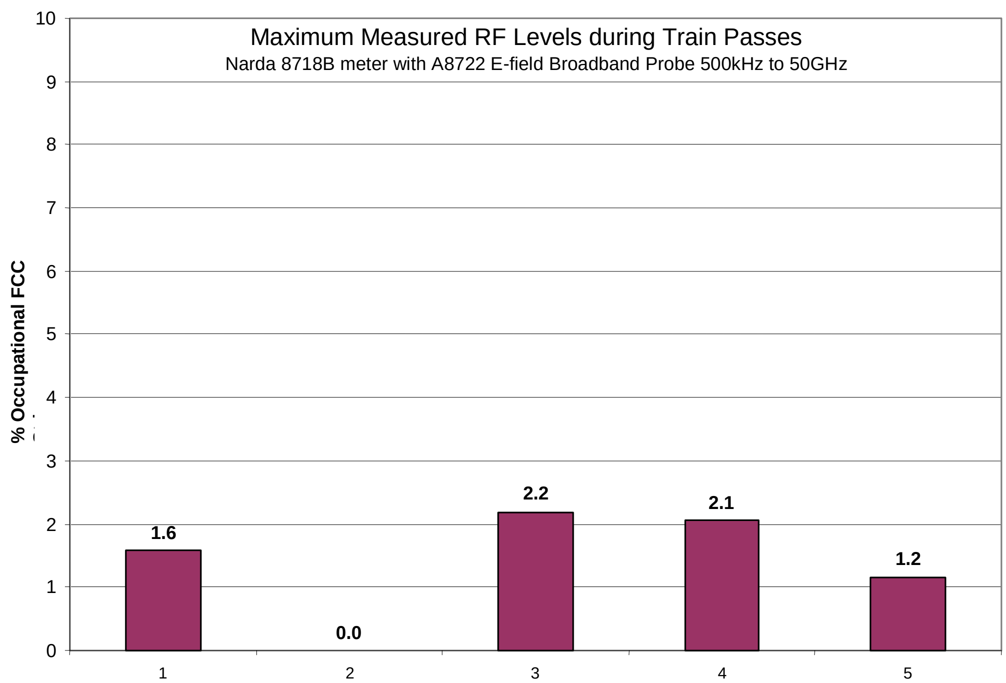

Figure 23. Maximum Measured RF Electric Fields for Each Train Pass as a Percentage of the Occupational 1997 FCC Exposure Standard

4.2 Underpass and Overpass Measurements

RF measurements were recorded at an underpass and overpass to determine RF exposure levels for the general public. For reference, ELF magnetic fields were also recorded as the trains passed.

4.2.1 Underpass Results

Measurements were recorded at milepost 127+1625 near Midway, Connecticut. The Narda broadband electric field probe A8722D and one three-axis fluxgate sensor were situated beneath the underpass at the east curb. This underpass is on the road that leads out to Bluff Point State

Park beside the Poquonock River. Four train passes were recorded at this location, as summarized in Table 19.

Table 19. Summary of Measured Train Passes at the Underpass Location

Pass	Train Type	Direction	Start Time	End Time	Samples
1	Regional	South	9:08:07	9:09:13	38
2	Acela	North	9:22:07	9:26:33	145
3	Regional	North	9:36:33	9:38:16	56
4	Freight	North	10:08:33	10:10:51	76

The RF results were essentially zero, well below the noise floor of the electric field probe. No large values or spikes were recorded with the RF broadband probe. Increases in the ELF magnetic fields were dependent on the operation profile of the train in the vicinity of the underpass and the location of autotransformers that supply power to the catenary system. Table 20 summarizes the ELF magnetic field results from the single fluxgate sensor beneath the underpass for all four train passes.

Table 20. Underpass ELF Magnetic Field Results

Band	Pass	Minimum (mG)	Maximum (mG)
Static	1	507	513
	2	505	515
	3	500	561
	4	503	513
2-48 Hz	1	0.0	2.9
	2	0.0	6.4
	3	0.0	3.6
	4	0.0	0.9
48-62 Hz	1	0.6	4.6
	2	0.3	104.7
	3	0.5	55.3
	4	0.2	7.6
62-302 Hz	1	0.1	0.6
	2	0.1	4.9
	3	0.2	9.7
	4	0.0	0.4
302-3000 Hz	1	0.0	0.2
	2	0.0	1.1
	3	0.1	4.8
	4	0.0	0.1
2-3000 Hz	1	0.7	5.2
	2	0.3	104.7
	3	0.7	56.4
	4	0.3	7.6

4.2.2 Overpass Results

RF measurements were recorded at milepost 176+2730, an overpass on Coronado Road Extension just off of Jefferson Boulevard in Warwick, Rhode Island. This overpass is just south of the Warwick SS. The Narda broadband electric field probe A8722D and one three-axis fluxgate sensor were situated on the south curb of the overpass. Significant aluminum shields (solid plates) were present along the walkways to prevent contact with the 25 kV lines just below the overpass. Measurements were recorded as two trains passed as shown in Table 21.

Table 21. Measured Train Passes at the Overpass Location

Train Type	Direction	Start Time	End Time	Samples
Regional	Northbound	15:43:34	15:44:26	30
Regional	Southbound	16:03:41	16:05:32	60

As with the underpass, the measured RF levels were essentially zero, well below the noise floor of the electric field probe. No large values or spikes were recorded with the RF broadband probe. The ELF magnetic fields showed an increase associated with the catenary currents. Due to the proximity of the Warwick SS, it was expected that, when the train is south of the underpass, a large amount of current flows south to the train (causing significant ELF magnetic fields at the overpass). Conversely, when the train is north of the overpass, magnetic fields should be relatively low, since most current will travel from the Warwick SS directly to the train and very little will run to the train from the East Greenwich PS because of the distance. Table 22 summarizes the ELF magnetic field results from the single fluxgate sensor on the overpass for the two train passes.

Table 22. Overpass ELF Magnetic Field Results

Band	Pass	Minimum (mG)	Maximum (mG)
Static	1	927	940
	2	929	938
2-48 Hz	1	0.0	4.2
	2	0.0	1.0
48-62 Hz	1	1.2	22.0
	2	0.8	29.3
62-302 Hz	1	0.5	2.9
	2	0.5	1.5
302-3000 Hz	1	0.1	0.2
	2	0.1	0.2
2-3000 Hz	1	1.3	22.0
	2	1.1	29.4

5. Acela Express Onboard Measurements

This chapter presents summary results from the measurements recorded on board an Acela Express train. The measurements were recorded in two locations: in the passenger compartment of a coach car and in the trailing operator's cab. These results from the Acela Express are compared with other train measurement results (from the U.S. DOT/FRA reports "Electromagnetic Field Characteristics of the Transrapid TR08 Maglev System" [3] and "Comparison of Magnetic and Electric Fields of Conventional and Electrified Transportation Systems" [4]). Appendix M provides detailed results from the onboard measurements.

5.1 Passenger Compartment Results

Table 23 provides a summary of the static and time-varying EMFs as measured in the passenger compartment of an Acela Express coach car. Static magnetic fields showed a significant variation, with peak fields larger than 1000 mG. Static fields were highest near the floor at the ankle position, decreasing in magnitude, moving from the waist to the head sensor positions.

Table 23. Summary of Static and Time-Varying Magnetic and Electric Fields Measured in the Passenger Compartment of an Operating Acela Express

Band	Sensor Position	Minimum	Maximum	Average	Standard Deviation	% Coefficient of Variation
Static (mG)	Head	343	1055	685	104	15
	Waist	408	1183	771	114	15
	Ankle	738	1429	1048	112	11
2-48 Hz (mG)	Head	0.1	217.5	7.4	15.9	214
	Waist	0.1	173.7	8.6	16.0	186
	Ankle	0.1	122.6	10.9	18.0	165
48-62 Hz (mG)	Head	0.5	119.4	15.9	19.4	122
	Waist	0.5	106.5	14.0	16.0	115
	Ankle	0.4	101.4	12.8	14.1	110
62-302 Hz (mG)	Head	0.1	25.0	1.2	2.0	161
	Waist	0.1	20.2	1.2	1.9	159
	Ankle	0.1	17.7	1.3	2.0	147
302-3000 Hz (mG)	Head	0.0	12.3	0.5	1.0	209
	Waist	0.0	10.1	0.5	1.0	195
	Ankle	0.0	8.8	0.6	1.0	174
2-3000 Hz (mG)	Head	1.4	237.6	19.2	23.9	124
	Waist	1.5	190.5	18.4	21.3	116
	Ankle	1.3	138.5	19.1	21.2	111
E Field (V/m)	Chest	1.8	52.2	3.9	3.4	87

Figure 24 shows the average time-varying (AC) magnetic fields from the passenger compartment measurements at the head, waist, and ankle sensor positions, by frequency band. Figure 25 shows a similar chart for the maximum values.

For the average time-varying fields, the largest measured component was in the power frequency band (60 Hz). For the maximum time-varying magnetic fields, the largest component was in the 2-48 Hz band, an indication of large transients associated with operation of the train. These charts indicate that not much difference exists in field magnitudes between the head, waist, and ankle sensor positions. The average values are nearly identical. The maximum values show a slight decrease moving from head to ankle.

Figures 26 to 28 show the minimum, maximum, and average in each frequency band for the head, waist, and ankle sensor positions, respectively. These plots show the range of measured magnetic fields by frequency band for each sensor position individually.

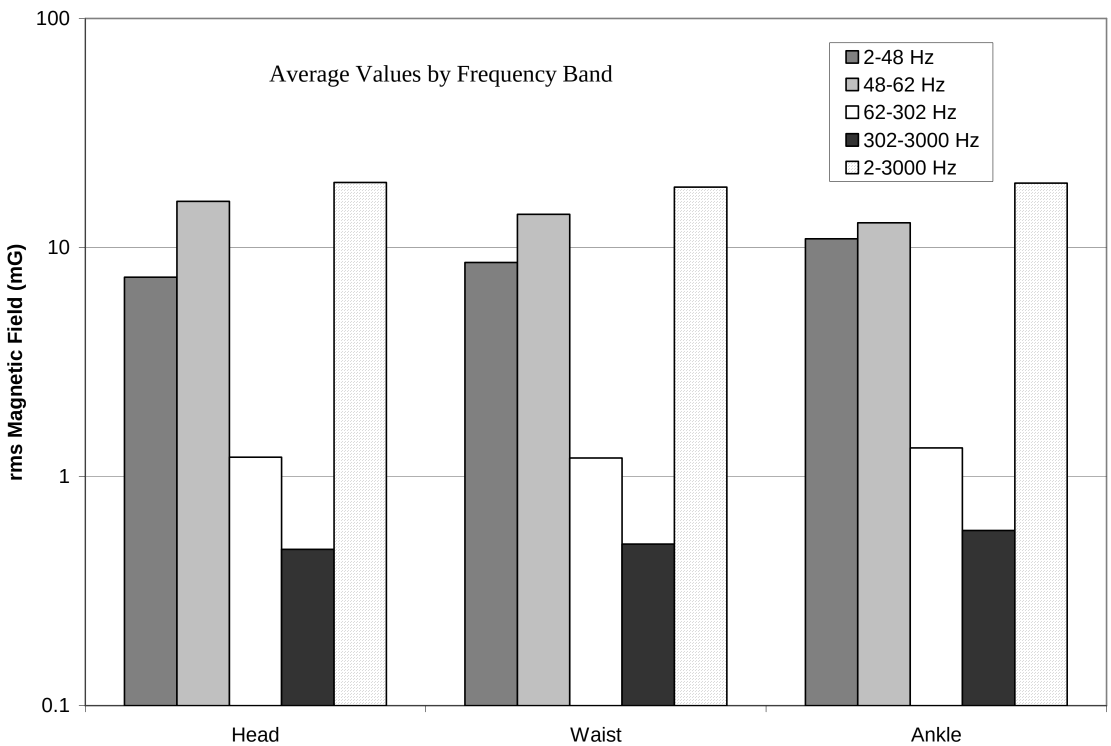

Figure 24. Chart of Average Measured Magnetic Fields in the Passenger Compartment in Each Frequency Band for the Three Sensor Positions

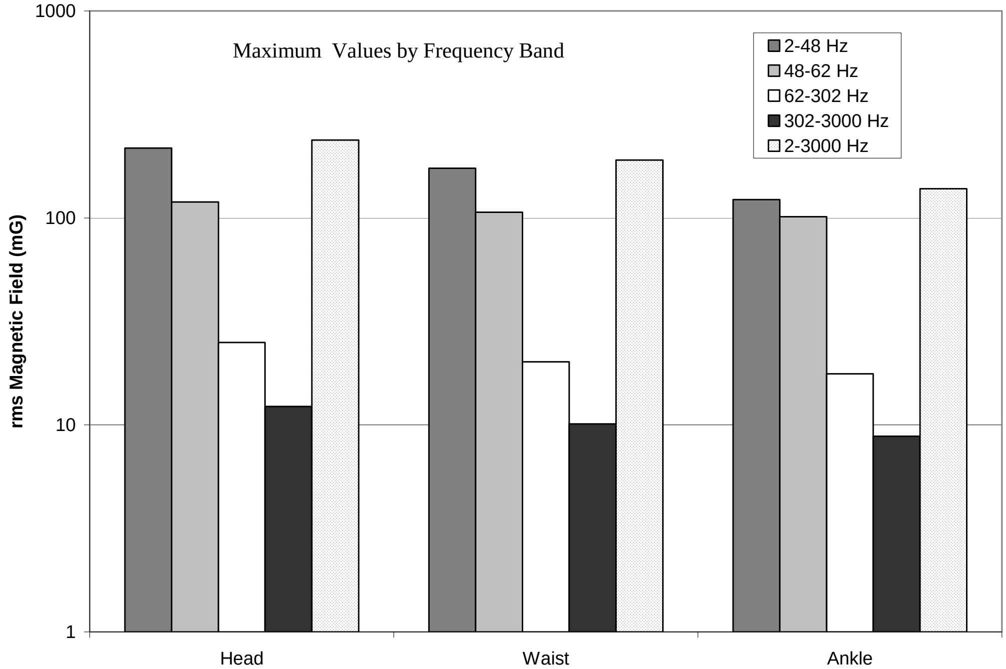

Figure 25. Chart of Maximum Measured Magnetic Fields in Each Frequency Band for the Three Sensor Positions

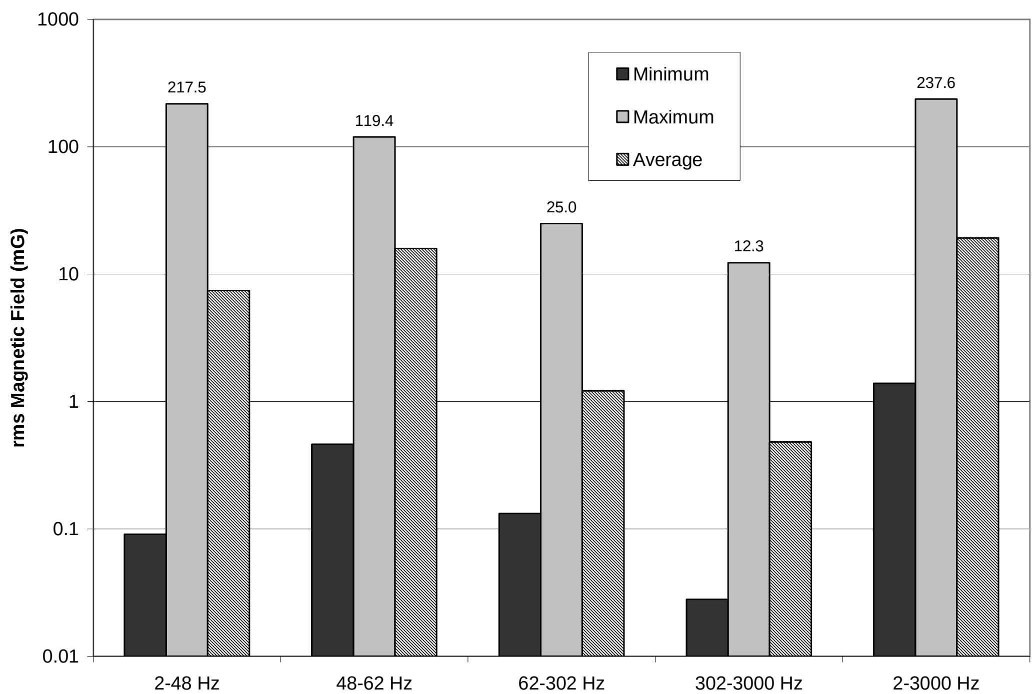

Figure 26. Chart Showing Minimum, Maximum, and Average of the Onboard Passenger Compartment Magnetic Fields by Each Frequency Band, as Measured at the Head Sensor Position

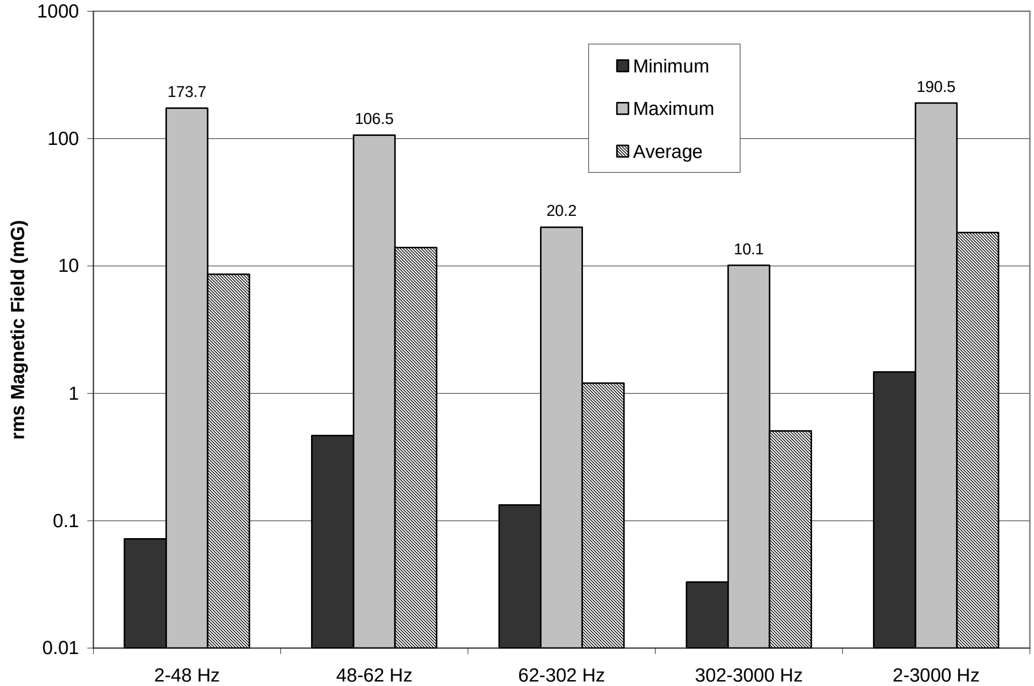

Figure 27. Chart Showing Minimum, Maximum, and Average of the Onboard Passenger Compartment Magnetic Fields by Each Frequency Band, as Measured at the Waist Sensor Position

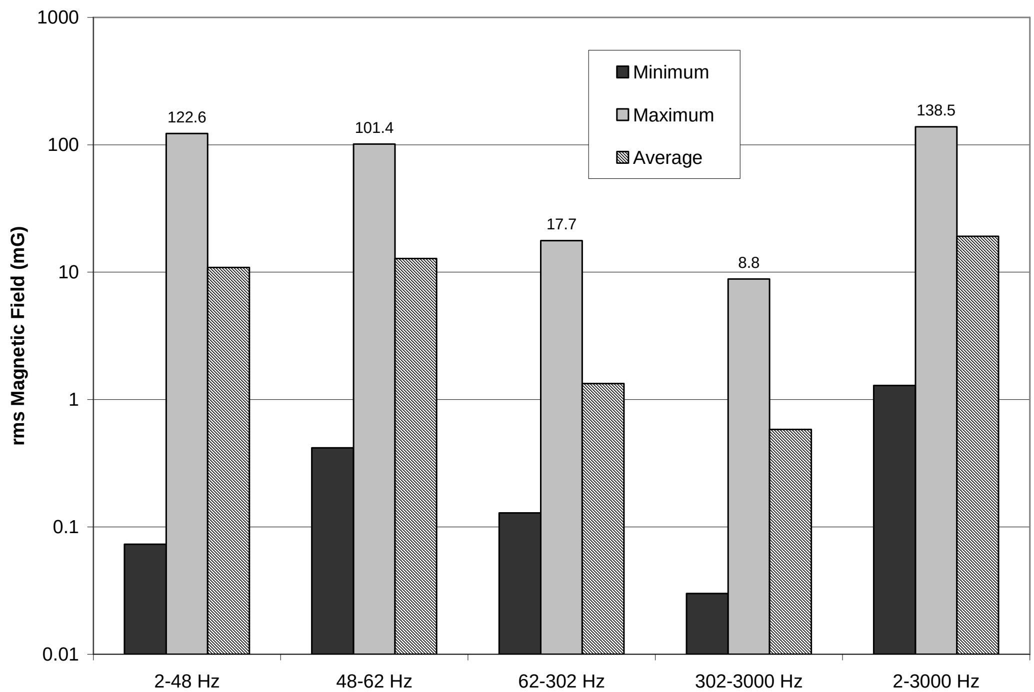

Figure 28. Minimum, Maximum, and Average of the Onboard Passenger Compartment Magnetic Fields as Measured at the Ankle Position

In the passenger compartment, ELF electric fields were measured at the chest position on the sensor mannequin. The minimum, maximum, and average ELF electric fields as measured in the passenger compartment were 1.8 V/m, 52.2 V/m, and 3.9 V/m, respectively.

Measured VLF and LF magnetic fields at the knee positions were at or below the noise floor of the sensors (<0.5 mG). Similarly, RF electric fields measured in the aisle were at or below the noise floor of the broadband probe (<0.3 percent of the occupational FCC standard).

5.2 Results from the Trailing Engineer's Cab

Measurements were recorded in the left seat of the engineer's cab in the trailing Acela Express power car during a portion of the trip from New Haven to Old Saybrook. Data was recorded over a period of approximately 12 minutes.

Because one *MultiWave* System II unit did not operate properly, ELF magnetic fields were recorded at two positions instead of three, specifically the head and ankle positions.
Table 24 summarizes the engineer's cab magnetic field results.

The static magnetic fields were lower in the engineer's cab than in the passenger compartment, possibly because of a shielding effect from steel in the Acela Express locomotive. Comparing static fields at the head and ankle positions, fields were lower at the ankle position near the cab floor. The highest time-varying fields were similar in magnitude in the 2-48 Hz band and the 48-62 Hz band, with the largest average time-varying fields occurring at the power frequency of 60 Hz, ranging from 10 to 20 mG. These levels are similar to the average levels measured in the passenger compartment.

Table 24. Summary Table of ELF Magnetic Fields in the Operator's Cab of the Trailing Acela Express Locomotive at the Head and Ankle Positions

Band	Sensor Position	Minimum	Maximum	Average	Standard Deviation	Coefficient of Variation
Static (mG)	Head Ankle	253 45	594 412	546 299	38 58	6.9 19.4
2-48 Hz (mG)	Head Ankle	0.5 1.8	60.2 22.7	4.3 7.8	4.5 3.7	104.2 46.8
48-62 Hz (mG)	Head Ankle	1.4 0.9	57.8 48.4	19.1 13.6	12.6 8.2	65.8 60.6
62-302 Hz (mG)	Head Ankle	0.3 0.5	8.4 11.1	1.3 2.2	0.7 1.4	54.8 64.5
302-3000 Hz (mG)	Head Ankle	0.1 0.2	4.2 3.8	0.4 0.7	0.3 0.7	84.7 96.6
2-3000 Hz (mG)	Head Ankle	2.2 4.0	61.5 49.1	20.2 16.7	12.5 7.6	62.1 45.8

Figure 29 shows the average magnetic fields from the engineer's cab measurements at the head and ankle sensor positions, by frequency band. Figure 30 shows a similar chart for the maximum values. Figures 31 and 32 show the minimum, maximum, and average magnetic fields in each frequency band for the head and ankle positions, respectively. Figure 33 is a three-dimensional surface plot of the time-varying magnetic fields as a function of time and frequency. This figure indicates varying frequencies toward the upper end of the ELF range.

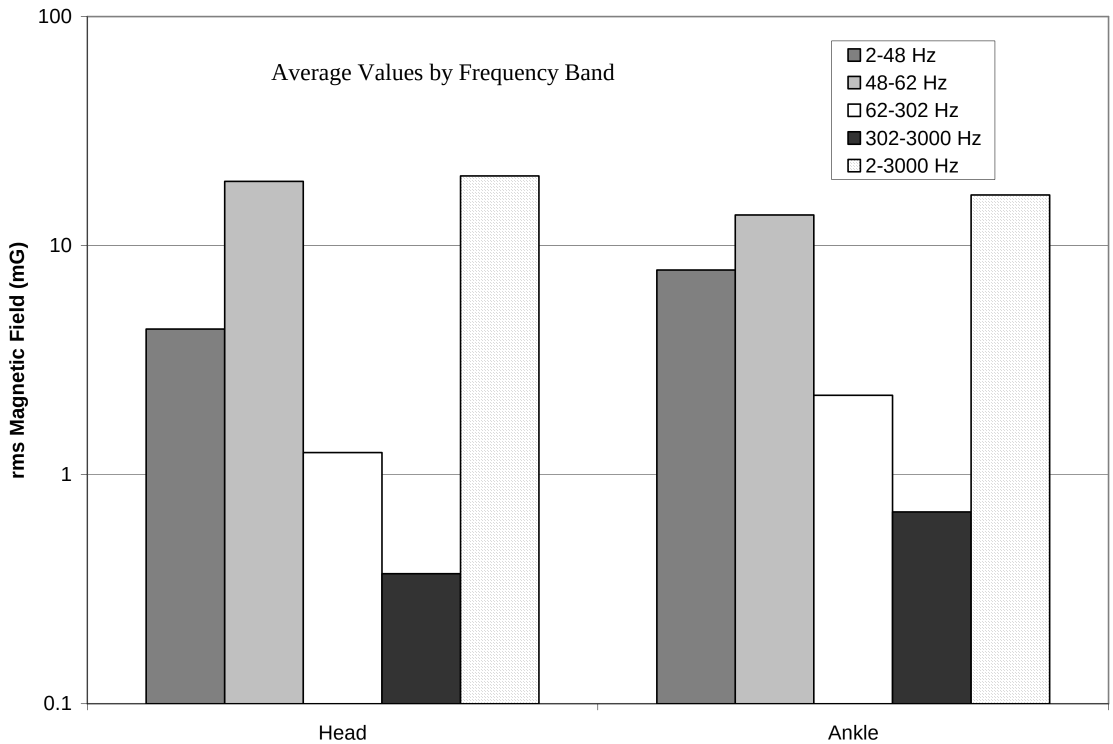

Figure 29. Chart of Average Measured Magnetic Fields in Each Frequency Band for the Head and Ankle Sensor Positions in the Trailing Engineer's Cab

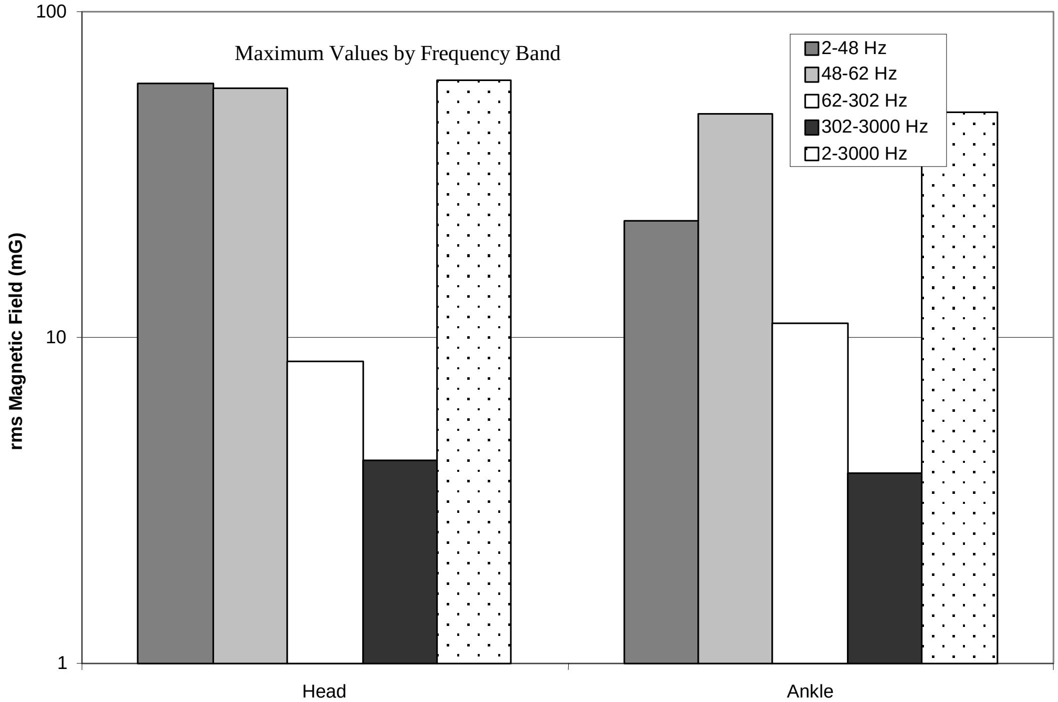

Figure 30. Chart of Maximum Measured Magnetic Fields in Each Frequency Band for the Head and Ankle Sensor Positions in the Trailing Engineer's Cab

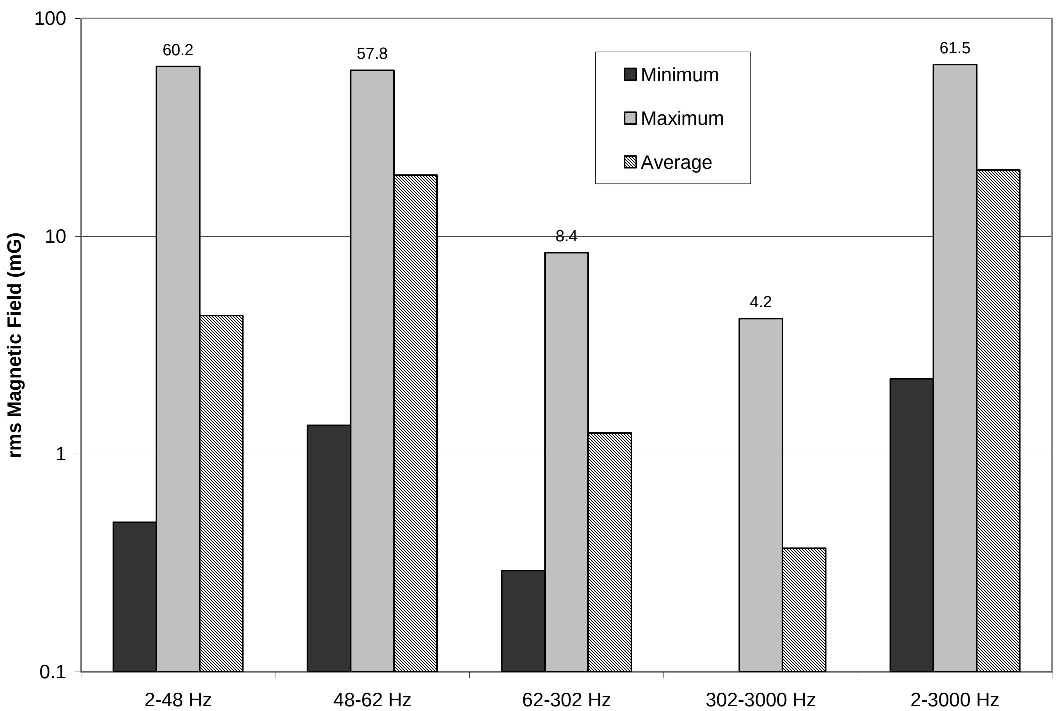

Figure 31. Chart Showing Minimum, Maximum, and Average of the Onboard Engineer's Cab Magnetic Fields by Each Frequency Band, as Measured at the Head Sensor Position

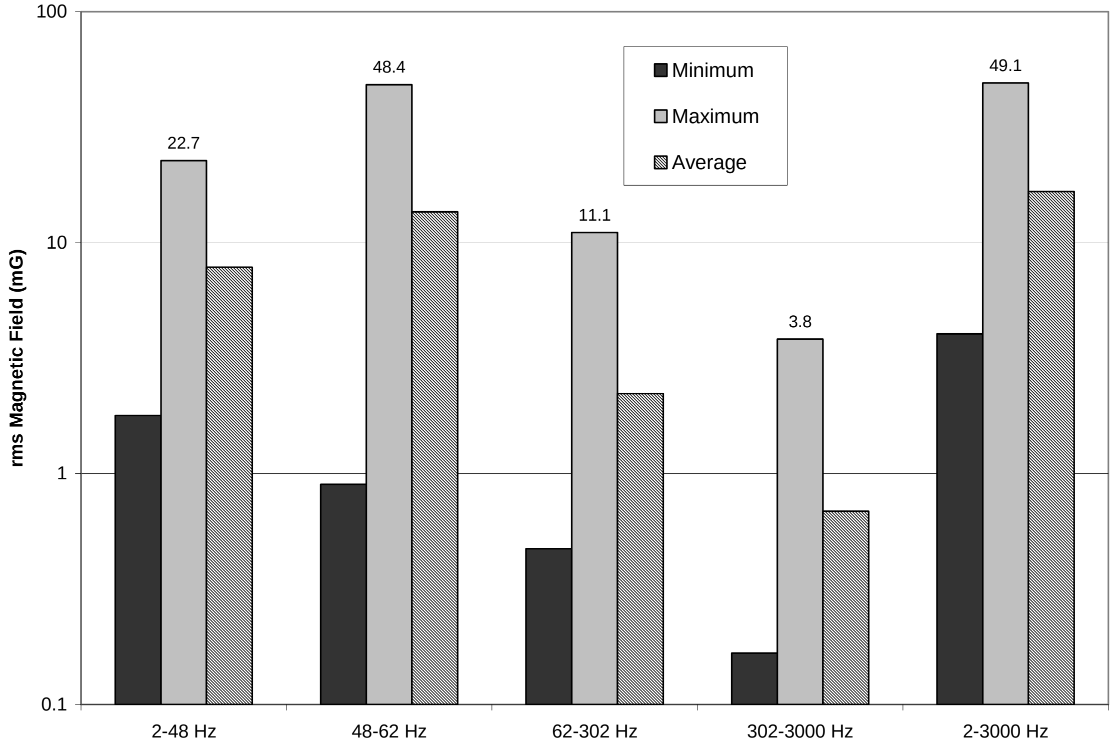

Figure 32. Chart Showing Minimum, Maximum, and Average of the Onboard Engineer's Cab Magnetic Fields by Each Frequency Band, as Measured at the Ankle Sensor Position

RF readings were also recorded using the electric field RF probe, A8722D, mounted on a tripod set in the middle of the cab. RF readings were logged at 1-second intervals with the Narda 8718B meter. The RF readings were higher than in the passenger compartment, with a maximum reading of 2.6 percent of the occupational FCC standard and an average of 1 percent.

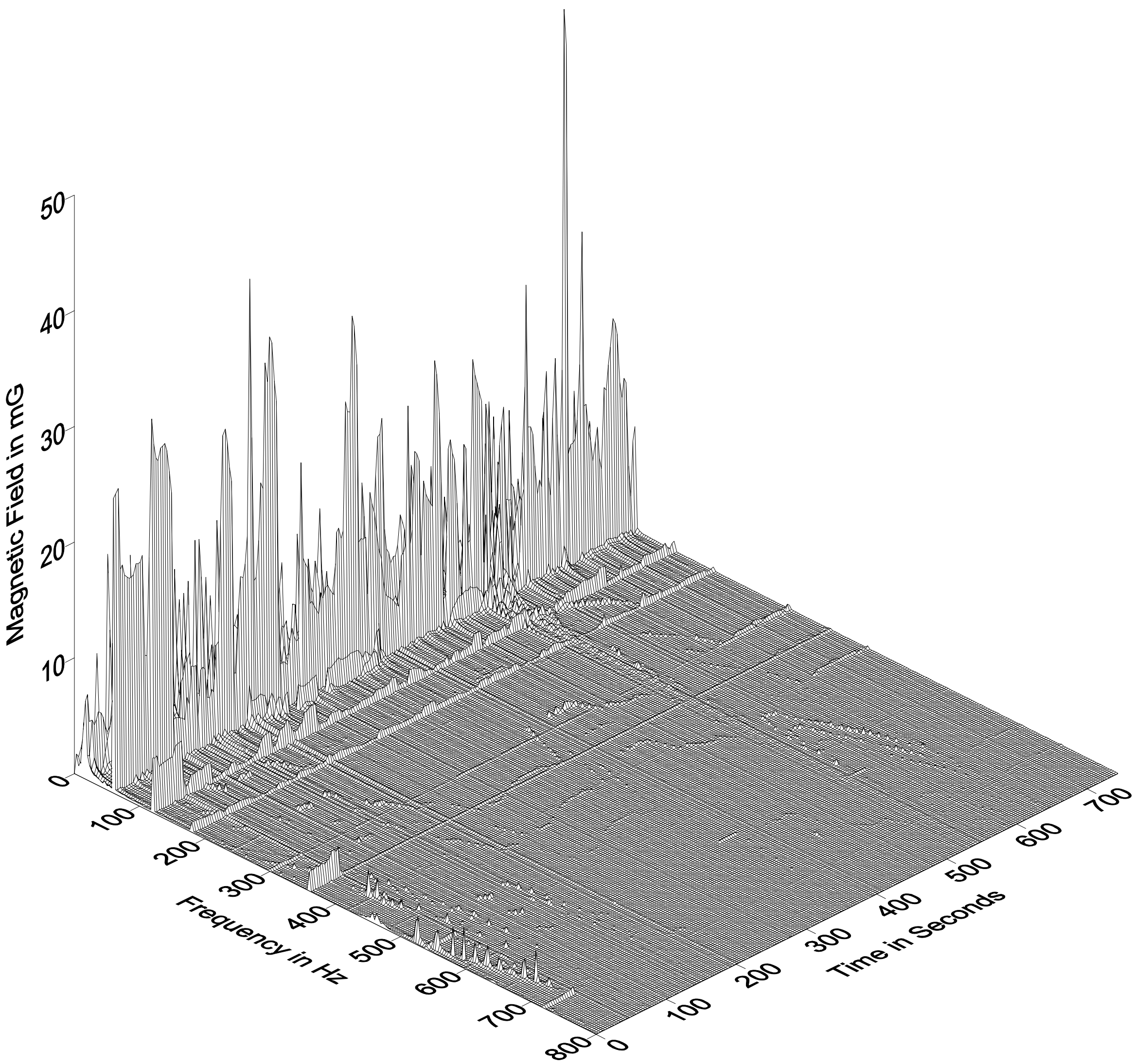

Figure 33. Time-Varying Magnetic Field at the Ankle Position in the Trailing Operator's Cab as a Function of Time and Frequency

5.3 Comparison of Measured Magnetic Fields with Other Train Systems

This section compares the measured magnetic fields in the passenger compartment and operator's cab of the Acela Express with similar measurements on other train systems as documented in references [3] and [4]. The train systems previously measured are:

- Amtrak NEC 25 Hz system (Washington to New York)
- Amtrak NEC 60 Hz system (New York to New Haven)
- Amtrak NEC non-electric (New Haven to Boston), before electrification
- New Jersey Transit North Jersey Coast Line system (Matawan to Long Branch)
- French TGV high-speed rail system
- Maglev TR08 prototype on German test track

Table 25 lists the static and time-varying magnetic fields as measured in the passenger compartment of the Acela Express train and other previously measured trains. The top value is the average magnetic field in each of the frequency bands and the value in parenthesis is the maximum. The columns are arranged by frequency with the first column showing static (DC) fields, the second showing fields from 3 Hz to 48 Hz, the third column from 48 Hz to 62 Hz, the fourth column from 62 Hz to 300 Hz, and the high frequency column from 300 Hz to 3000 Hz. The last column is the total ELF time-varying magnetic field from 3 Hz to 3000 Hz. For a graphic comparison of the passenger compartment magnetic fields, Figure 34 is a bar chart of the static fields (average and maximum) for each train system, and Figure 35 is a bar chart of the total AC magnetic fields (average and maximum) for each train system.

Table 25. Average and (Maximum) Measured Magnetic Fields by Frequency Band as Measured in the Passenger Compartment of Various Train Systems

System	Static	Low Frequencies	Power Frequencies	Power Harmonics	High Frequencies	AC
Acela	835 (1429)	9.0 (217.5)	14.2 (119.4)	1.3 (25.0)	0.5 (12.3)	18.9 (237.6)
NEC - 25 Hz	606 (1763)	132.0 (776.0)	6.0 (41.4)	16.2 (95.2)	2.7 (14.7)	133.8 (782.1)
NEC - 60 Hz	630 (1039)	1.4 (12.2)	52.0 (407.0)	5.7 (43.9)	1.4 (12.8)	52.5 (408.4)
NEC - Non-Electric	569 (1033)	1.4 (6.7)	4.8 (26.3)	0.7 (5.9)	0.2 (1.9)	5.2 (26.5)
NJT Long Branch	734 (1016)	1.6 (13.0)	18.2 (107.1)	2.5 (17.7)	0.7 (3.6)	18.6 (108.8)
TGV-A	545 (962)	23.3 (106.2)	30.5 (164.7)	2.7 (10.4)	1.5 (5.4)	43.2 (165.0)
TR08 Maglev	585 (2168)	39.7 (309.7)	3.9 (49.6)	10.1 (45.9)	1.8 (19.4)	41.9 (311.6)

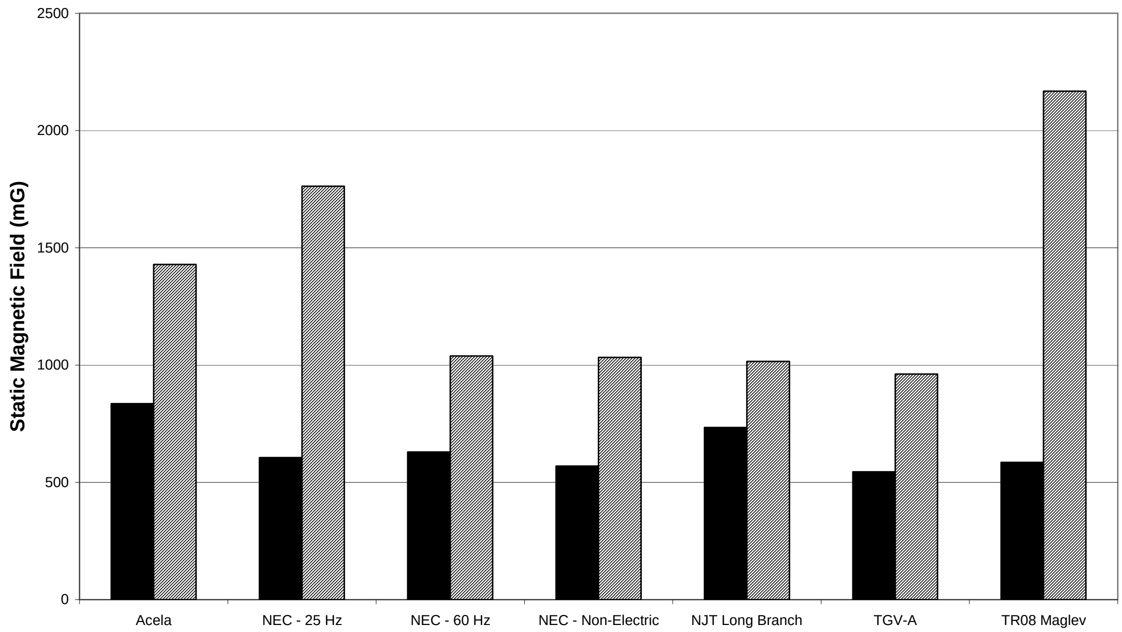

Figure 34. Comparison of Average and Maximum Static (DC) Magnetic Fields as Measured in the Passenger Compartment of Different Train Systems

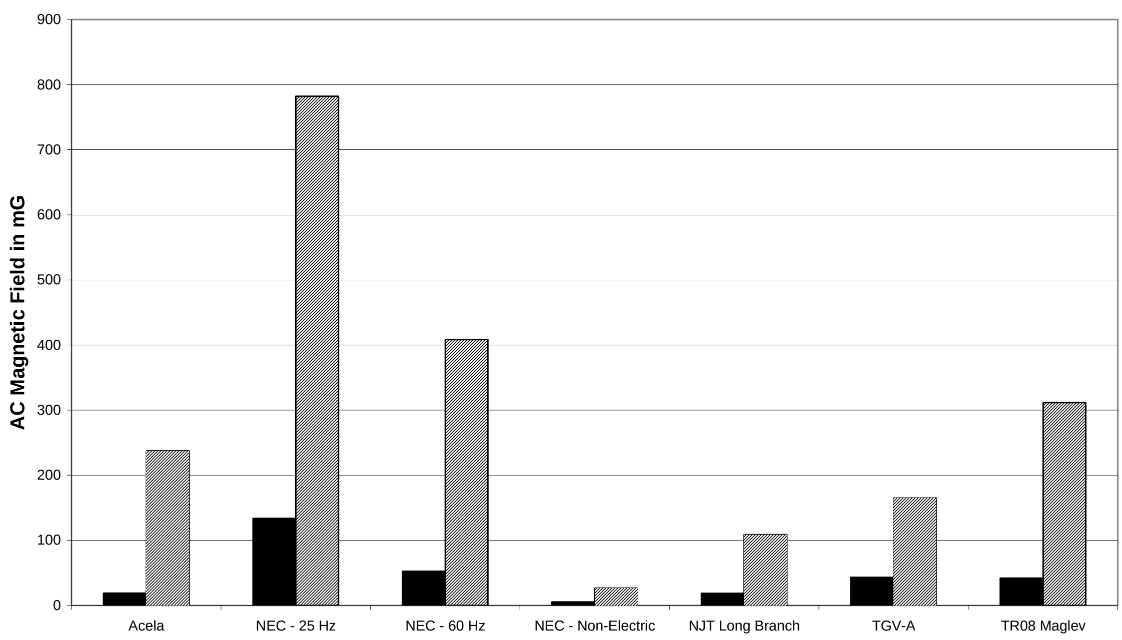

Figure 35. Comparison of Average and Maximum ELF Time-Varying (AC) Magnetic Fields as Measured in the Passenger Compartment of Different Train Systems

Similarly, Table 26 lists the static and time-varying magnetic fields measured in the operator's cab of the Acela Express locomotive and in the operator's cab of other trains. For a graphic comparison of the operator's cab magnetic fields, Figure 36 is a bar chart of the operator's cab static fields (average and maximum) for each train system, and Figure 37 is a bar chart of the operator's cab total AC magnetic fields (average and maximum) for each train system.

Table 26. Comparison of Magnetic Fields as Measured in the Operator's Cab of Various Train Systems

System	Static	Low Frequencies	Power Frequencies	Power Harmonics	High Frequencies	AC
Acela	441 (594)	5.8 (60.2)	16.7 (57.8)	1.7 (11.1)	0.5 (4.2)	18.7 (61.5)
NEC - 25 Hz	648 (1555)	41.2 (247.4)	11.7 (52.8)	5.5 (26.7)	1.4 (5.9)	46.0 (250.9)
NEC - 60 Hz	435 (992)	2.1 (19.0)	26.8 (174.3)	3.9 (19.5)	1.2 (7.1)	27.4 (174.7)
NEC - Non-Electric	330 (767)	1.0 (12.1)	0.4 (2.2)	1.0 (3.9)	1.0 (5.3)	1.9 (12.7)
NJT Long Branch	319 (445)	1.3 (12.5)	31.1 (122.6)	3.8 (17.2)	1.2 (3.8)	31.5 (123.7)
TGV-A - 50 Hz Double	795 (1149)	18.0 (50.2)	87.3 (366.6)	16.6 (68.3)	4.4 (11.9)	94.2 (367.7)
TGV-A - 50 Hz Single	611 (897)	16.4 (54.5)	37.4 (159.8)	2.6 (9.2)	2.0 (5.2)	43.2 (160.8)
TR08 Maglev	388 (1253)	45.6 (257.8)	8.4 (71.7)	49.3 (119.0)	4.3 (14.0)	74.3 (259.7)

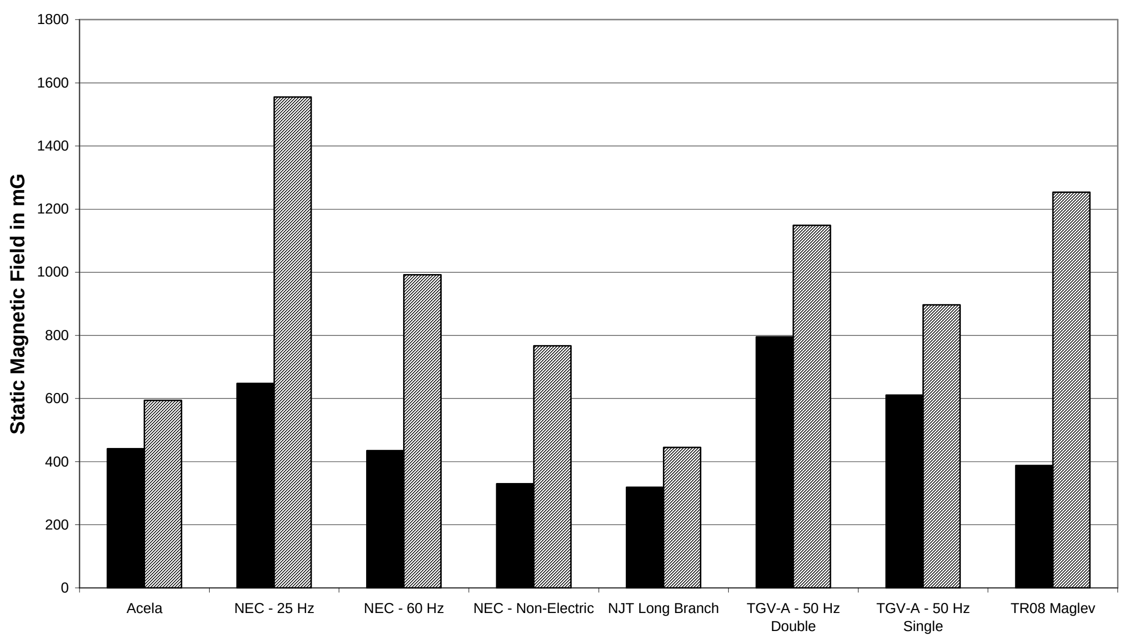

Figure 36. Comparison of Average and Maximum Static (DC) Magnetic Fields as Measured in the Operator's Cab of Different Train Systems

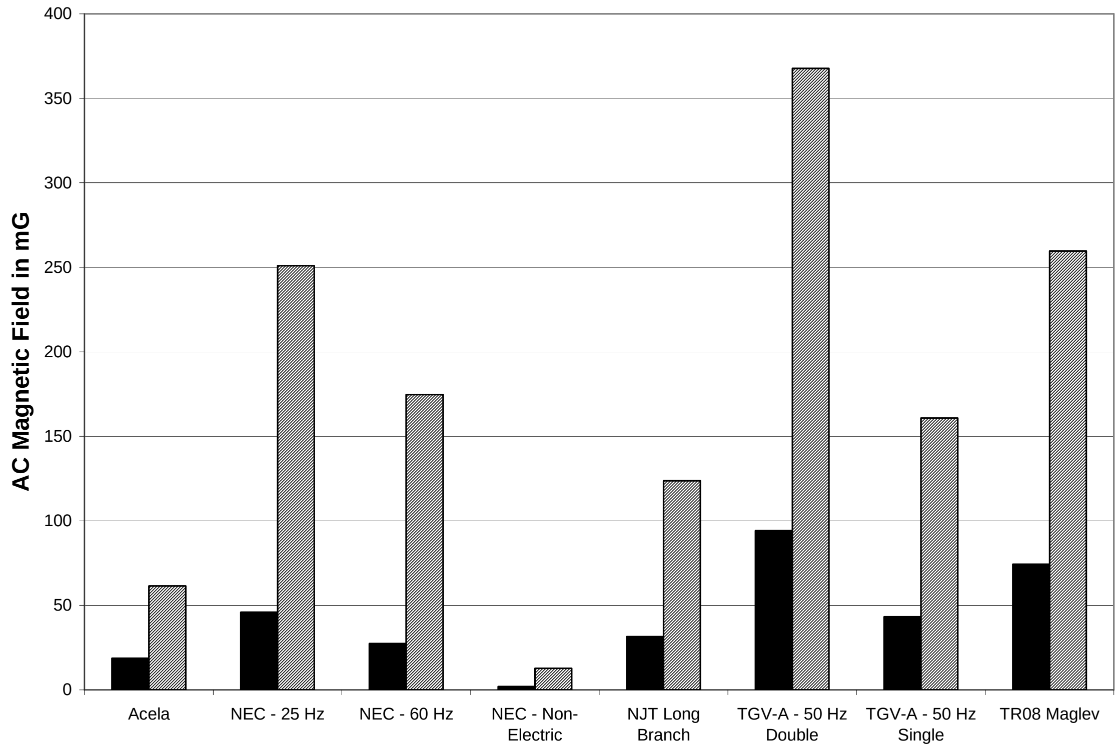

Figure 37. Comparison of Average and Maximum ELF Time-Varying (AC) Magnetic Fields as Measured in the Operator's Cab of Different Train Systems

6. Comparison of Measurement Results with Exposure Standards

In this chapter, the maximum measured electric and magnetic field levels measured in this study are compared with ELF and RF exposure guidelines. The standards utilized for this comparison are:

- ACGIH TLVs [7]
- IEEE Std. C95.6 (for ELF) [8]
- IEEE Std. C95.1 (for RF) [9]
- 1997 FCC MPEs (for RF) [10]

The following sections provide the maximum measured electric and magnetic fields as a function of frequency and compare these levels with the applicable safety exposure standards.

6.1 Summary of ELF Exposure Limits

The two sets of relevant exposure limits for ELF magnetic and electric fields are the occupational TLVs [8] published by ACGIH and the MPE limits published in C95.6, "IEEE Standard for Safety Levels with Respect to Human Exposure to Electromagnetic Field, 0-3 kHz." The IEEE standard has MPEs for controlled (occupational) areas and for uncontrolled (general public) areas.

To simplify the evaluation, the most stringent TLVs or MPEs within a frequency band are utilized for comparison with the maximum measured fields in each frequency band. Table 27 shows the occupational TLVs (ACGIH only provides guidance for occupational exposure) and the C95.6 MPEs for controlled and uncontrolled environments. Magnetic field limits are listed for DC, 60 Hz, 300 Hz, and 3000 Hz; electric field limits are listed for 60 Hz (since all electric fields are dominantly at the power frequency). The DC magnetic field limits are listed in units of G, the ELF magnetic field limits are listed in units of mG, and the electric field limits are listed in units of V/m.

Table 27. Controlled and Uncontrolled Exposure Limits at DC and Specific Frequencies in the ELF Range for ACGIH Guidelines and IEEE C95.6 Standard

Controlled/Occupational Exposure					
	Magnetic Fields				Electric Fields
Frequency	**DC** (G)	**60 Hz** (mG)	**300 Hz** (mG)	**3000 Hz** (mG)	**60 Hz** (V/m)
ACGIH TLVs	600	10000	2000	2000	25000
IEEE C95.6 MPEs	3530	27100	27100	6867	20000

General Public/Uncontrolled Exposure					
	Magnetic Fields				Electric Fields
Frequency	**DC** (G)	**60 Hz** (mG)	**300 Hz** (mG)	**3000 Hz** (mG)	**60 Hz** (V/m)
ACGIH TLVs	NA	NA	NA	NA	NA
IEEE C95.6 MPEs	1180	9040	9040	2290	5000

In reviewing the limits in Table 27, the ACGIH TLVs are lower than even the general public C95.6 MPEs except at 60 Hz. At 60 Hz, the C95.6 public exposure limit is 9040 mG, while the ACGIH limit is 10,000 mG, a difference of only about 10 percent. To simplify the comparison tables, only ACGIH TLVs will be used to evaluate the maximum measured values as percentages of the ACGIH guidelines. Based on the relatively low levels of all measurements, the comparison with only the ACGIH TLVs is not an issue.

6.2 Post-Electrification Measurements at 10 Traction Power Facility Locations

This section contains 10 tables that provide an evaluation of the maximum measured magnetic fields at the 10 traction power facility locations. The maximum magnetic fields in each frequency band are listed for each of the three types of measurements: long-term 24-hour measurements; perimeter profile measurements, and lateral profile measurements. All magnetic field values in these tables are listed in units of mG. Percentages of the ACGIH TLVs from Table 27 are posted in a column beside the maximum readings. Magnetic fields in the first two bands (3-57 Hz and 57-63 Hz) are compared with the 60 Hz ACGIH TLV, magnetic fields in the third band are compared with the 300 Hz ACGIH TLV, and magnetic fields in the fourth band are compared with the 3000 Hz ACGIH TLV.

Table 28. Maximum Measured Magnetic Fields at the Branford SS

Branford	Long-Term (24-hr)		Perimeter Profile		Lateral Profile	
Frequency	Max (mG)	% ACGIH	Max (mG)	% ACGIH	Max (mG)	% ACGIH
Static (DC)	1046	0.17%	696	0.12%	-	-
3-57 Hz	0.6	0.01%	10.5	0.11%	-	-
57-63 Hz	43.5	0.43%	3558.1	35.58%	-	-
63-303 Hz	1.9	0.09%	39.6	1.98%	-	-
303-3000 Hz	0.8	0.04%	6.8	0.34%	-	-

In comparing the magnetic field tables, the largest readings were recorded at the two SS on the perimeter profiles (moving around the station). The largest reading was the 3558 mG value recorded near equipment along the perimeter profile at the Branford Substation, which corresponds to approximately 36 percent of the ACGIH TLV at 60 Hz. The next largest reading is 851 mG at the Sharon SS. This corresponds to approximately 9 percent of the ACGIH TLV at 60 Hz. Except for these two readings, the maximum measured values at these ten sites are all well below the ACGIH TLVs and thus well below the general public and occupational C95.6 MPEs. Although the largest reading at the Branford SS was near the filter bank equipment, a portion of the magnetic fields at these two SS is due to commercial power lines—at Branford, the TL loops through the SS, and at Sharon, the transmission line passes directly over the SS.

Table 29. Maximum Measured Magnetic Fields at the Sharon SS

Sharon	Long-Term (24-hr)		Perimeter Profile		Lateral Profile	
Frequency	Max (mG)	%ACGIH	Max (mG)	%ACGIH	Max (mG)	%ACGIH
Static (DC)	574	0.10%	574	0.10%	551	0.09%
3-57 Hz	1.7	0.02%	2.3	0.02%	3.7	0.04%
57-63 Hz	110.2	1.10%	851.9	8.52%	743.0	7.43%
63-303 Hz	6.0	0.30%	12.9	0.64%	18.9	0.95%
303-3000 Hz	3.5	0.18%	4.3	0.21%	3.2	0.16%

Table 30. Maximum Measured Magnetic Fields at the Westbrook SwS

Westbrook	Long-Term (24-hr)		Perimeter Profile		Lateral Profile	
Frequency	Max (mG)	%ACGIH	Max (mG)	%ACGIH	Max (mG)	%ACGIH
Static (DC)	530	0.09%	538	0.09%	539	0.09%
3-57 Hz	0.2	0.00%	2.4	0.02%	3.2	0.03%
57-63 Hz	17.7	0.18%	4.1	0.04%	0.4	0.00%
63-303 Hz	3.3	0.16%	0.8	0.04%	0.5	0.03%
303-3000 Hz	1.5	0.08%	0.2	0.01%	0.3	0.01%

Table 31. Maximum Measured Magnetic Fields at the Richmond SwS

Richmond	Long-Term (24-hr)		Perimeter Profile		Lateral Profile	
Frequency	Max (mG)	% ACGIH	Max (mG)	% ACGIH	Max (mG)	% ACGIH
Static (DC)	842	0.14%	561	0.09%	539	0.09%
3-57 Hz	0.3	0.00%	6.0	0.06%	2.4	0.02%
57-63 Hz	1.2	0.01%	2.6	0.03%	0.2	0.00%
63-303 Hz	0.2	0.01%	1.0	0.05%	0.4	0.02%
303-3000 Hz	0.1	0.01%	0.5	0.03%	0.2	0.01%

Table 32. Maximum Measured Magnetic Fields at the Grove Beach PS

Grove Beach	Long-Term (24-hr)		Perimeter Profile		Lateral Profile	
Frequency	Max (mG)	% ACGIH	Max (mG)	% ACGIH	Max (mG)	% ACGIH
Static (DC)	516	0.09%	563	0.09%	542	0.09%
3-57 Hz	0.2	0.00%	2.5	0.03%	1.2	0.01%
57-63 Hz	7.2	0.07%	0.5	0.01%	0.2	0.00%
63-303 Hz	1.3	0.07%	0.6	0.03%	0.2	0.01%
303-3000 Hz	0.4	0.02%	0.3	0.01%	0.1	0.00%

Table 33. Maximum Measured Magnetic Fields at the Noank PS

Noank	Long-Term (24-hr)		Perimeter Profile		Lateral Profile	
Frequency	Max (mG)	% ACGIH	Max (mG)	% ACGIH	Max (mG)	% ACGIH
Static (DC)	543	0.09%	730	0.12%	-	-
3-57 Hz	0.1	0.00%	6.0	0.06%	-	-
57-63 Hz	2.2	0.02%	47.9	0.48%	-	-
63-303 Hz	0.2	0.01%	3.0	0.15%	-	-
303-3000 Hz	0.1	0.01%	1.1	0.06%	-	-

Table 34. Maximum Measured Magnetic Fields at the Stonington PS

Stonington	Long-Term (24-hr)		Perimeter Profile		Lateral Profile	
Frequency	Max (mG)	% ACGIH	Max (mG)	% ACGIH	Max (mG)	% ACGIH
Static (DC)	532	0.09%	529	0.09%	539	0.09%
3-57 Hz	0.4	0.00%	4.7	0.05%	12.4	0.12%
57-63 Hz	22.5	0.23%	27.0	0.27%	14.6	0.15%
63-303 Hz	1.7	0.08%	1.5	0.07%	1.9	0.09%
303-3000 Hz	0.6	0.03%	0.5	0.02%	0.9	0.05%

Table 35. Maximum Measured Magnetic Fields at the Roxbury PS

Roxbury (PS)	Long-Term (24-hr)		Perimeter Profile		Lateral Profile	
Frequency	Max (mG)	% ACGIH	Max (mG)	% ACGIH	Max (mG)	% ACGIH
Static (DC)	520	0.09%	556	0.09%	581	0.10%
3-57 Hz	7.5	0.08%	0.9	0.01%	7.9	0.08%
57-63 Hz	21.6	0.22%	18.8	0.19%	5.5	0.06%
63-303 Hz	2.7	0.13%	2.3	0.12%	1.7	0.09%
303-3000 Hz	3.0	0.15%	2.8	0.14%	1.7	0.08%

Table 36. Maximum Measured Magnetic Fields at the New London TL

New London	Long-Term (24-hr)		Perimeter Profile		Lateral Profile	
Frequency	Max (mG)	% ACGIH	Max (mG)	% ACGIH	Max (mG)	% ACGIH
Static (DC)	530	0.09%	623	0.10%	553	0.09%
3-57 Hz	0.9	0.01%	9.4	0.09%	2.1	0.02%
57-63 Hz	1.3	0.01%	14.8	0.15%	1.7	0.02%
63-303 Hz	0.1	0.01%	5.7	0.28%	0.6	0.03%
303-3000 Hz	0.1	0.00%	1.1	0.06%	0.1	0.01%

Table 37. Maximum Measured Magnetic Fields at the Warwick TL

Warwick	Long-Term (24-hr)		Perimeter Profile		Lateral Profile	
Frequency	Max (mG)	% ACGIH	Max (mG)	% ACGIH	Max (mG)	% ACGIH
Static (DC)	520	0.09%	540	0.09%	598	0.10%
3-57 Hz	0.6	0.01%	6.1	0.06%	5.7	0.06%
57-63 Hz	23.9	0.24%	22.7	0.23%	7.9	0.08%
63-303 Hz	3.7	0.19%	4.2	0.21%	6.6	0.33%
303-3000 Hz	0.6	0.03%	0.8	0.04%	1.2	0.06%

Table 38 shows the maximum measured 60 Hz electric fields at each site and compares the value with the ACGIH electric field TLV. The largest readings were measured at the Sharon SS along the lateral profile (which crosses directly beneath a transmission line).

Table 38. Maximum Measured 60 Hz Electric Fields at Each of the 10 Measurement Sites

Site	Long-Term (24-hr) Max (V/m)	Long-Term (24-hr) % ACGIH	Perimeter Profile Max (V/m)	Perimeter Profile % ACGIH	Lateral Profile Max (V/m)	Lateral Profile % ACGIH
Branford SS	131	0.52%	1263	5.05%	-	-
Sharon SS	744	2.97%	810	3.24%	953	3.81%
Westbrook SwS	217	0.87%	661	2.64%	209	0.84%
Richmond SwS	104	0.41%	379	1.52%	73	0.29%
Grove Beach PS	109	0.44%	666	2.67%	120	0.48%
Noank PS	0	0.00%	646	2.58%	-	-
Stonington PS	130	0.52%	655	2.62%	117	0.47%
Roxbury PS	107	0.43%	205	0.82%	9	0.04%
New London TL	0	0.00%	150	0.60%	2	0.01%
Warwick TL	0	0.00%	626	2.50%	26	0.10%

6.3 Wayside, Overpass, and Underpass Measurements

Table 39 lists the maximum measured magnetic fields as a function of sensor position from the wayside measurements. Compared to the ACGIH TLV, the maximum readings are all less than 1 percent.

The maximum measured electric field at the wayside was 430 V/m. This corresponds to approximately 9 percent of the 60 Hz C95.6 general public MPE.

Table 39. Maximum Measured Magnetic Fields at the Three Wayside Sensor Positions

Position	5m		10m		15m	
Frequency	(mG)	% ACGIH	(mG)	% ACGIH	(mG)	% ACGIH
Static	619	0.10%	531	0.09%	540	0.09%
2-48 Hz	13.5	0.14%	1.5	0.02%	0.3	0.00%
48-62 Hz	83.5	0.84%	14.7	0.15%	7.1	0.07%
62-302 Hz	5.7	0.29%	2.8	0.14%	0.5	0.03%
302-3000 Hz	1.6	0.08%	0.4	0.02%	0.5	0.03%

Table 40 lists the maximum measured magnetic fields at the overpass and underpass. One would expect the overpass readings to be larger as a result of the proximity to the OCS. The readings, however, will be dependent on the currents drawn by the trains combined with any shielding effects from steel in the overpass/underpass structure.

Table 40. Maximum Measured Magnetic Fields at the Overpass/Underpass

	Overpass		Underpass	
Frequency	(mG)	%ACGIH	(mG)	%ACGIH
Static	940	0.16%	561	0.09%
2-48 Hz	4.2	0.04%	6.4	0.06%
48-62 Hz	29.3	0.29%	104.7	1.05%
62-302 Hz	2.9	0.15%	9.7	0.49%
302-3000 Hz	0.2	0.01%	4.8	0.24%

6.4 Onboard Acela Express Measurements

Finally, Table 41 lists the maximum measured magnetic fields on board the Acela Express, first in the passenger compartment and second in the operator's cab of the trailing locomotive. The passenger compartment would be considered a general public area, and the operator's cab would be a controlled/occupational location. The largest magnetic fields were recorded in the passenger compartment in the low frequency band 3-57 Hz, with the next largest fields at the power frequency of 60 Hz. However, the largest magnetic fields were approximately 2 percent of the ACGIH 60 Hz TLV and thus also well below the C95.6 MPEs for occupational and general public areas.

Table 41. Maximum Measured Magnetic Fields On Board the Acela Express

	Passenger Compartment		Operator's Cab	
Frequency	Max (mG)	% ACGIH	Max (mG)	% ACGIH
Static (DC)	1429	0.24%	594	0.10%
3-57 Hz	217.5	2.18%	60.2	0.60%
57-63 Hz	119.4	1.19%	57.8	0.58%
63-303 Hz	25	1.25%	11.1	0.56%
303-3000 Hz	12.3	0.62%	4.2	0.21%

Electric fields were recorded in the passenger compartment only, with a maximum reading of 52 V/m. This corresponds to 1 percent of the C95.6 60 Hz electric field MPE of 5000 V/m.

6.5 RF Exposure Assessment

The RF measurements in this study were recorded using a broadband isotropic electric field probe with a shaped frequency response, from 500 kHz to 50 GHz that corresponded to the 1997 FCC occupational standard. The electric field readings were recorded directly as a percentage of the FCC occupational standard. The FCC MPEs are identical to the IEEE C95.1 and ACGIH limits for electric fields, up to 1.5 GHz. The FCC occupational electric field exposure limits remain constant above 1.5 GHz, while C95.1 and ACGIH limits continue increasing proportionally with frequency up to 3 GHz. Thus, the FCC electric field occupational limit is more stringent above 1.5 GHz, which means that, if the FCC limits are met, then the occupational C95.1 and ACGIH limits are also met.

To evaluate compliance with public exposure, the controlled and uncontrolled limits are different by a factor of approximately 2.2, with the uncontrolled limits being the more stringent (lower by factor of 2.2). Thus, readings of 44 percent of occupational FCC limits would correspond to 100 percent of general public/uncontrolled limits for ACGIH and C95.1.

The maximum RF electric-field readings were 2.19 percent at the wayside and 2.6 percent in the operator's cab of the trailing Acela Express locomotive. These values are percentages of the occupational FCC limit. Multiplying the wayside reading by a factor of 2.2 converts it to a percentage of the public exposure limits for the FCC, ACGIH, and C95.1 standards (which are all identical up to 1.5 GHz). Thus, the 2.19 percent wayside reading corresponds to 4.8 percent of the uncontrolled/public exposure limits.

7. Findings and Conclusions

The measurement results from this study:

- Quantify the increase of ELF EMFs in the vicinity of traction power stations constructed to electrify the NEC section from New Haven, Connecticut, to Boston, Massachusetts.

- Characterize the ELF and RF field levels in the passenger compartment of an Acela Express train and in the engineer's cab of a trailing Acela Express locomotive.

- Characterize short-term ELF EMF changes associated with passing trains.

- Show that broadband RF electric fields, at an overpass and underpass, associated with passing trains are very low compared to human exposure standards.

7.1 Post-Electrification Measurement Conclusions

The comparison of pre- and post-electrification measurement results showed typical increases of one to two orders-of-magnitude for EMFs. This increase was as expected due to the introduction of the electric power stations and the electric conductors that comprise the OCS. The largest fields were measured at two of the main SS (Branford and Sharon). However, a portion of the magnetic fields at both SS result from commercial power lines—at Branford, the TL loops through the SS, and at Sharon, the commercial power line passes directly over the SS.

The increase in field levels results from the fact that most of the post-electrification measurements were in proximity to station equipment and near OCS conductors. In general, the perimeter profile measurements, recorded while moving around the outside of the facility, gave the highest readings as the sensors passed near power equipment and beneath the lines running from the gantry out to the OCS.

Where post-electrification measurements were not close to the power equipment or the OCS, very little difference existed between pre- and post-electrification measurements, indicating that the impact to surrounding areas was minimal. For example, the long-term 24-hour measurements at the Noank PS and the New London TL sites were very low.

Regarding the impact to nearby areas, EMFs decrease rapidly with distance, typically as the inverse of the distanced squared or faster in some cases. For example, one can see the rapid falloff of electric fields by viewing the lateral profile plots for the Richmond SwS and Grove Beach PS.

When the lateral profiles were away from the power station, the recorded magnetic fields moving away from the track were all very low. For example, the magnetic field lateral profile at Grove Beach shows almost negligible 60 Hz magnetic fields that continue to decrease moving away from the OCS. These very low levels exist when trains are not present but increase for brief periods of time (as can be seen in the long-term measurement graphs for Richmond and Grove

Beach). The next section discusses the increase in field levels summarizing the wayside measurements.

Finally, the two TLs where measurements were recorded for this study were encased in concrete underground. Thus, the magnetic fields were very low as shown by the lateral profiles, and no electric fields existed due to the TLs themselves. Significant fields measured at these two TL sites (New London and Warwick) resulted from nearby distribution lines and to the connections to either the substation or transmission lines.

7.2 Wayside, Underpass, Overpass Measurements

Wayside measurements of five train passes (two were Acela Express locomotives) showed maximum magnetic field readings 83 mG, 15 mG, and 7 mG at distances of 5, 10, and 15 meters, respectively. Based on these results, the magnetic fields falloff with the inverse square of the distance as expected and are below 10 mG at the 15 m position. Maximum measurements at an overpass and underpass were 30 mG and 104 mG, respectively. While one would expect the fields to be higher on the overpass (due to location of OCS and feeder conductors), the magnetic fields are more dependent on the operational profile of the train and the location of power stations relative to the measurement location.

No significant (greater than 1 mG) VLF (3-30 kHz) or LF (30-300 kHz) magnetic fields were measured.

Measured broadband RF electric fields were relatively low, with a maximum measurement of 2 percent of the FCC occupational standard at 5 meters from the track centerline.

Measured broadband RF electric fields at the overpass and underpass were near zero.

7.3 Onboard Acela Express Measurements

The ELF magnetic field measurements showed significant temporal variability due to operation of the train. This variability is common to all of the electric transportation systems. The measured ELF electric fields in the passenger compartment were very low with a maximum of 52 V/m and average less than 4 V/m.

Comparison of Acela Express passenger compartment measurements with other train systems (NEC-60 Hz, NEC-25 Hz, NEC-non-electric, French TGV, Maglev TR08, New Jersey Transit) showed that the average ELF magnetic fields in the passenger compartment were lower than all other train systems except the NEC-non-electric and that the maximum measured ELF magnetic fields were greater than the NEC-non-electric, New Jersey Transit, and TGV systems but less than the NEC-25 Hz, NEC-60 Hz, and Maglev TR08 systems. Figures 38 and 39 provide a summary comparison of passenger compartment average and maximum *rms* time-varying magnetic fields in the defined frequency bands for each of the studied rail systems.

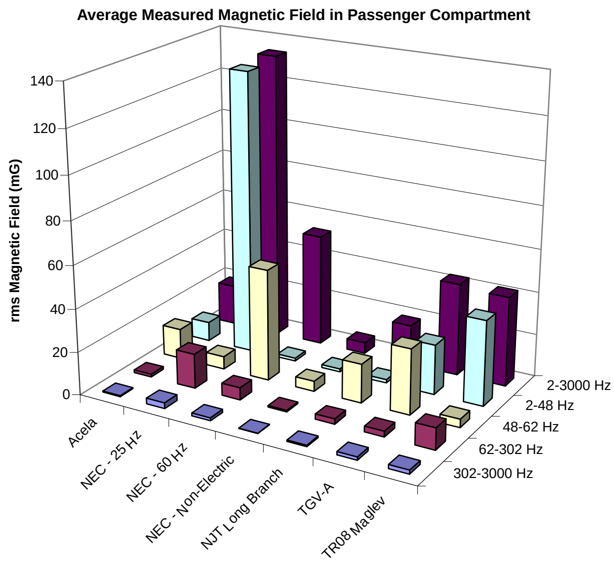

Figure 38. Average Measured Passenger Compartment rms Magnetic Fields (mG) in Each of the Defined Frequency Bands for Different Transportation Systems

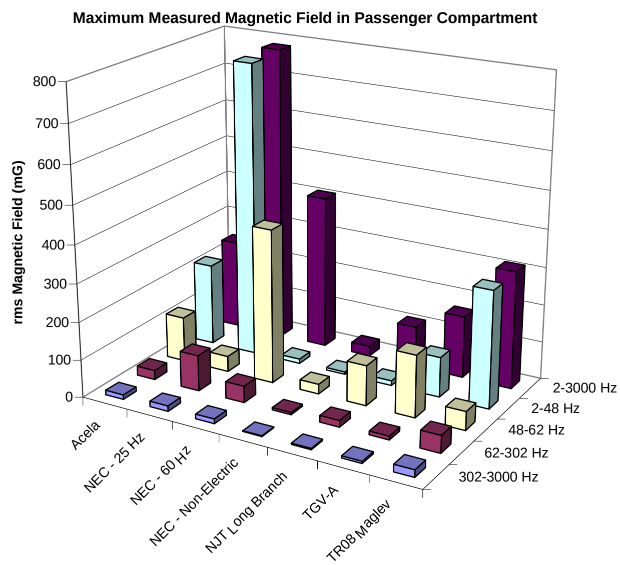

Figure 39. Maximum Measured Passenger Compartment rms Magnetic Fields (mG) in Each of the Defined Frequency Bands for Different Transportation Systems

A similar comparison of the operator's cab measurements showed that the Acela Express cab average and maximum ELF magnetic fields are lower than all of the other systems except for the NEC-non-electric system. Figures 40 and 41 provide a summary comparison of operator's cab average and maximum time-varying magnetic fields.

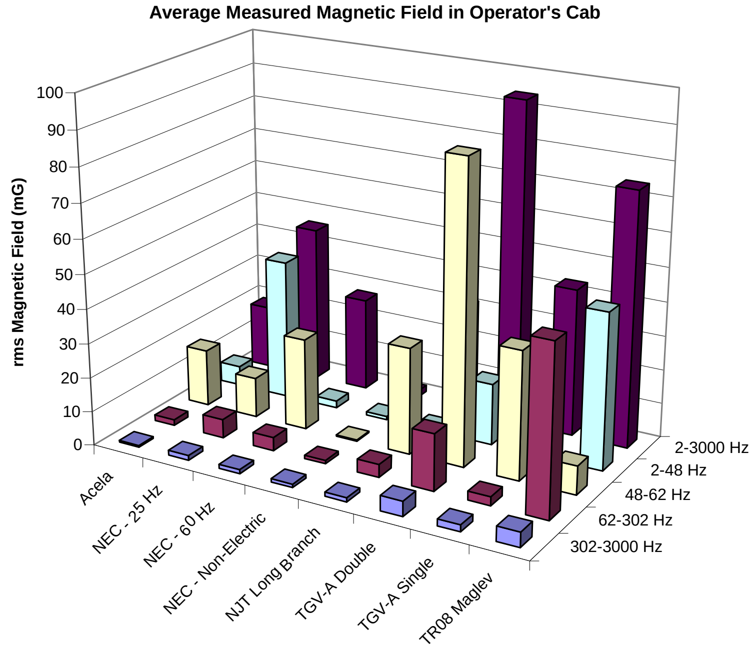

Figure 40. Average Measured Operator's Cab rms Magnetic Fields (mG) in Each of the Defined Frequency Bands for Different Transportation Systems

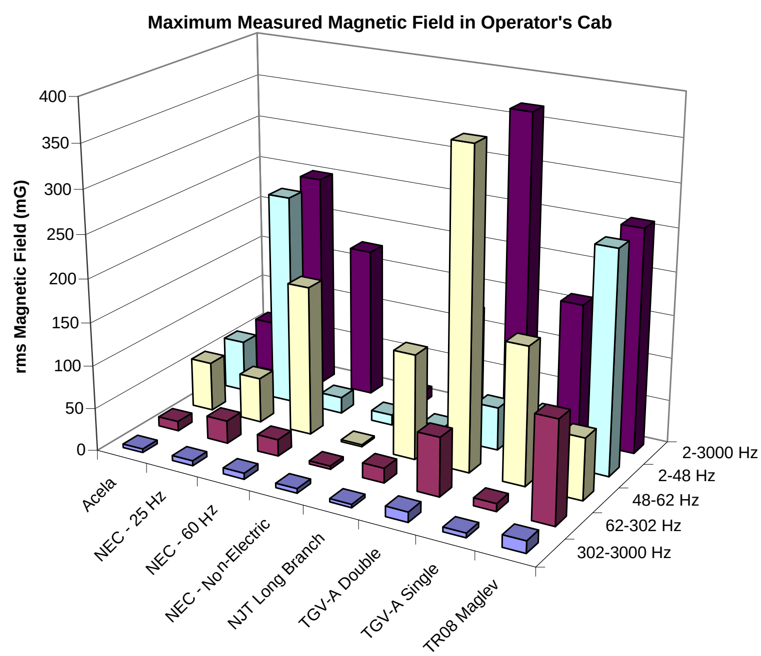

Figure 41. Maximum Measured Operator's Cab rms Magnetic Fields (mG) in Each of the Defined Frequency Bands for Different Transportation Systems

7.4 Exposure Assessment

The maximum ELF electric and magnetic field readings were compared with exposure limits in the ACGIH and IEEE C95.6 standards. None of the limits were exceeded.

All electric field RF readings were logged directly as a percentage of the occupational FCC standard. None of the readings were greater than 3 percent of this standard. Thus, all readings were also less than 3 percent of the IEEE C95.1 and ACGIH occupational limits. Because the general public limits are lower by a factor of 2.2, the electric field limits for general public were similarly never exceeded.

7.5 Magnetic Fields from Other Sources

The magnetic field characteristics from electric transportation systems are relatively complex as illustrated by the time-frequency three-dimensional plots (for example, see Figures 21 and 33 in previous chapters) of measurement data. Because of differences in time, frequency, and spatial characteristics, it is difficult to directly compare the magnetic fields in this study with other sources. To provide some perspective on the magnitudes presented in this report, however, this section lists some typical magnetic field levels from other typical magnetic field sources, such as home appliances, occupational equipment, and electric power lines. This magnetic field information is from two sources [11][12] that can be found online at the National Institute of Environmental Health Sciences (NIEHS) EMF RAPID Web site: http://www.niehs.nih.gov/emfrapid/.

Appliances: Figure 42 shows measured median and maximum magnetic fields from a number of common appliances as measured at 1 ft from the appliance as compared with the average and maximum magnetic fields measured in the passenger compartment of the Acela Express. Due to the typical size of a home appliance, magnetic fields from appliances are generally localized and fall off rapidly with distance. Reference [11] also provides median and maximum magnetic field levels at other distances from the appliances.

Occupational Sources: The *Questions and Answers—EMF in the Workplace* reference [12] lists ranges of magnetic fields from spot readings that characterize field levels associated with different occupational equipment. For example, magnetic fields at a desk in a government office are listed as ranging from 0.1 to 7 mG, magnetic fields as measured at the chest of a nurse in a hospital intensive care unit are listed as 0.1 to 220 mG, and the magnetic fields in a steel foundry control room for an arc furnace range from 170 to 1700 mG (when the furnace electrodes are energized). Other spot readings and additional information regarding measured average workday magnetic field levels are listed for a number of occupations, including sewing machine operator, machinist, electrician, and welder.

Electric Power Lines: A summary of typical transmission line magnetic fields (from Bonneville Power Administration data) in the EMF Questions & Answers booklet on the NIEHS EMF RAPID Web site shows typical 60 Hz magnetic fields ranging from 10 to 100 mG range directly beneath the lines, 5 to 30 mG fields at the edge of ROW which is approximately 50-65 ft (15 or 20 m) from the line, and 1 to 15 mG at 100 ft (30 m) from the line. Magnetic fields from distribution lines might range from 10-20 mG directly beneath main feeders and are typically less than 10 mG directly beneath lateral lines.

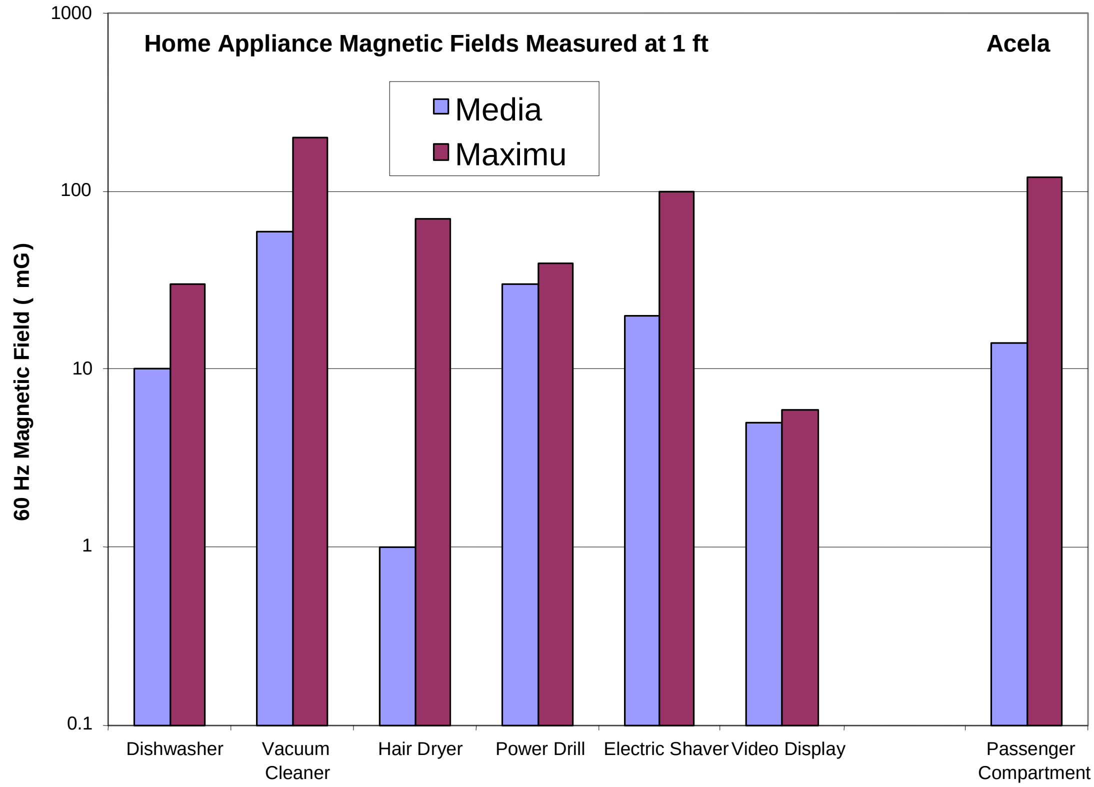

Figure 42. Median and Maximum Measured Magnetic Fields at 1 Ft from Typical Appliances (Listed at the NIEHS EMF RAPID Web site) Along with the Average and Maximum Measured 60 Hz Magnetic Fields Measured in the Acela Express Passenger Compartment

8. References

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[4] Comparison of Magnetic and Electric Fields of Conventional and Advanced Electrified Transportation Systems. DOT-VNTSC-FRA-93-13, NTIS, Springfield VA, August 1993.

[5] Magnetic and Electric Field Testing of the Amtrak Northeast Corridor and New Jersey Transit/North Jersey Coast Line Rail Systems, Volume I: Analysis, DOT-VNTSC-FRA-93-4.1, NTIS, Springfield, VA, April 1993.

[6] EMF Monitoring on Amtrak's Northeast Corridor, Final Report. Amtrak Contract No. PMMM 6311-001, Project No. 1452-13, August 1999.

[7] 2004 Threshold Limit Values (TLVs) for Chemical Substances and Physical Agents and Biological Exposure Indices (BEIs), American Conference of Governmental Industrial Hygienists.

[8] IEEE Std. C95.6-2002, Standard for Safety Levels with Respect to Human Exposure to Electromagnetic Fields, 0-3 kHz, IEEE Standards Coordinating Committee 28. IEEE International Committee on Electromagnetic Safety on Non-Ionizing Radiation, October 2002.

[9] IEEE Std. C95.1-1999, Standard for Safety Levels with Respect to Human Exposure to Radio-Frequency Electromagnetic Fields, 3 kHz to 300 GHz, IEEE Standards Coordinating Committee 28. IEEE International Committee on Electromagnetic Safety on Non-Ionizing Radiation, December 1998.

[10] Evaluating Compliance with FCC Guidelines for Human Exposure to Radio-Frequency Electromagnetic Fields, FCC Office of Engineering and Technology. OET Bulletin 65, Edition 97-01, August 1997, p.67.

[11] EMF Questions & Answers, The National Institute of Environmental Health Sciences (NIEHS). Electric and Magnetic Fields Research and Public Information Dissemination Program, June 2002.

[12] Questions and Answers—EMF in the Workplace, The National Institute of Environmental Health Sciences (NIEHS). Electric and Magnetic Fields Research and Public Information Dissemination Program, September 1996.

Appendix A
Branford, CT, Substation

Milepost 079+0191

Location Type: Suburban, behind housing, offset from I-95.

24-Hour Measurements:

Start:	9/16/04 15:06:53 EDT
Finish:	9/17/04 14:33:53 EDT
Sample Interval:	3 minutes
No. of Samples:	470
Location:	5 feet inside fence, centered on the east side of the SS closest to the nearby houses.

Perimeter Profile Measurements:

Start:	9/16/04 14:43:11 EDT
Sample Interval:	10 foot
No. of Samples:	98
Location:	Around perimeter of SS.

Site Anomalies: No lateral profile was recorded because the substation is not adjacent to tracks.

Field Characteristics: Long-term measurements showed that the static magnetic fields were constant and that the 60 Hz magnetic fields varied significantly. At one point, a large step change from 7 to 33 mG occurred, as if a significant operational change occurred. The perimeter profile showed large magnetic fields greater than 1000 mG on the west and north sides of the fence line due to SS equipment. Largest AC fields were measured beside the filter bank equipment.

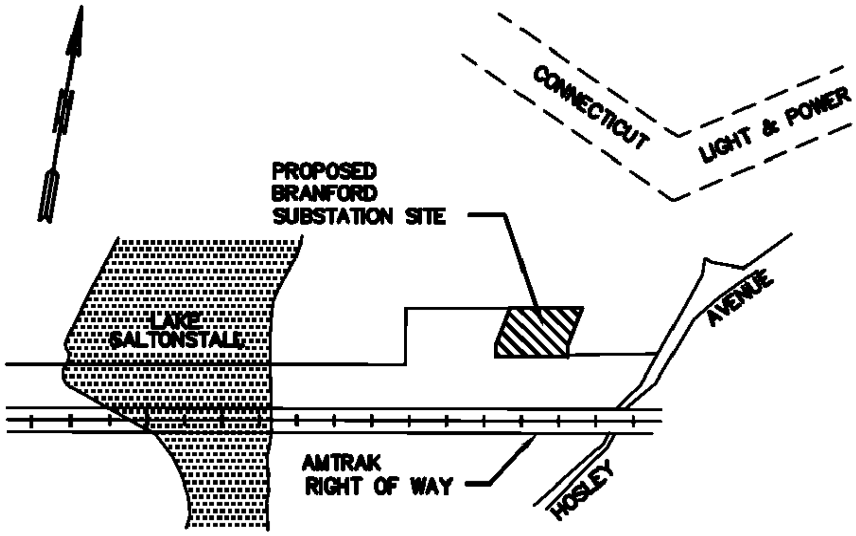


Figure A1. Vicinity Map of Branford SS Site Showing Relative Location of the Connecticut Light & Power Transmission Line

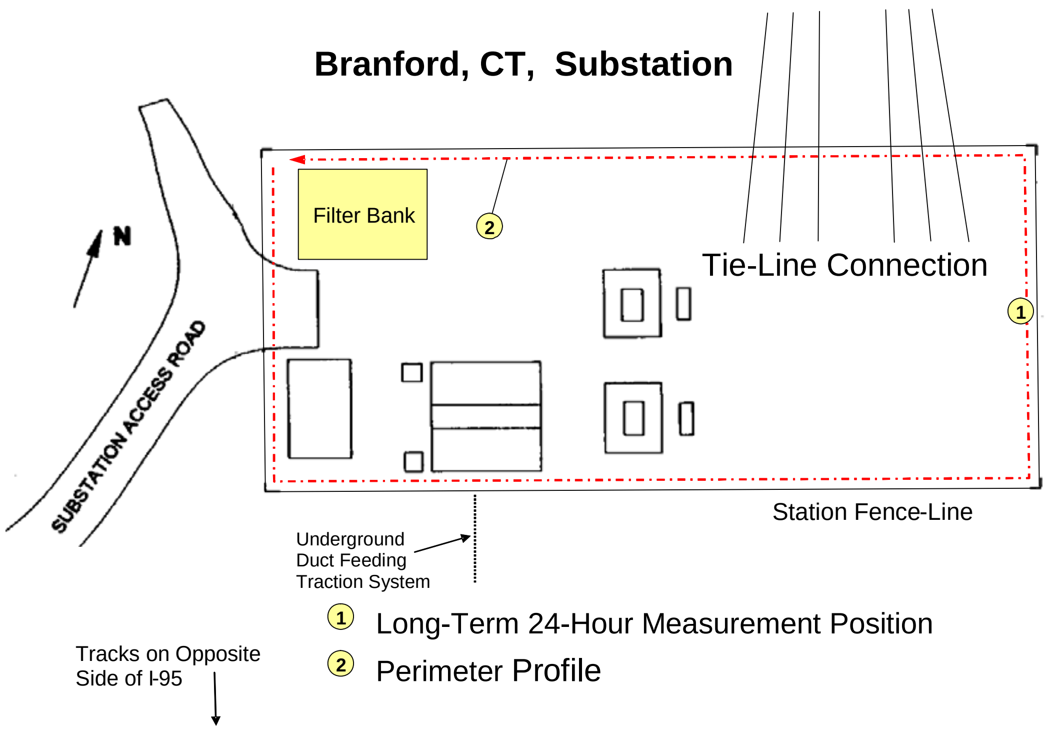


Figure A2. Sketch Showing Approximate Measurement Location at the Branford SS

Figure A3. Entrance to Branford SS Showing Filter Bank Equipment

Table A1. Summary Statistics for 24-Hour Field Measurements at Branford SS

Field Parameter	Minimum	Percentile Levels 5	25	50	75	95	Maximum	Average	Standard Deviation
Static Magnetic Field in milligauss									
Total	527	528	528	528	529	530	530	528	0.7
ELF Magnetic Field in milligauss									
3-57 Hz	0.0	0.0	0.0	0.1	0.1	0.2	0.4	0.1	0.1
57-63 Hz	4.5	5.9	20.7	24.2	27.7	31.3	36.3	21.3	8.9
63-303 Hz	0.2	0.3	0.3	0.3	0.4	0.5	0.6	0.4	0.1
303-3000 Hz	0.1	0.1	0.1	0.1	0.2	0.3	0.4	0.1	0.1
3-3000 Hz	4.5	5.9	20.7	24.2	27.8	31.3	36.3	21.3	8.9
ELF Electric Field in volts per meter									
3-3000 Hz	140.3	197.9	201.7	211.3	218.6	220.9	231.4	209.4	9.8

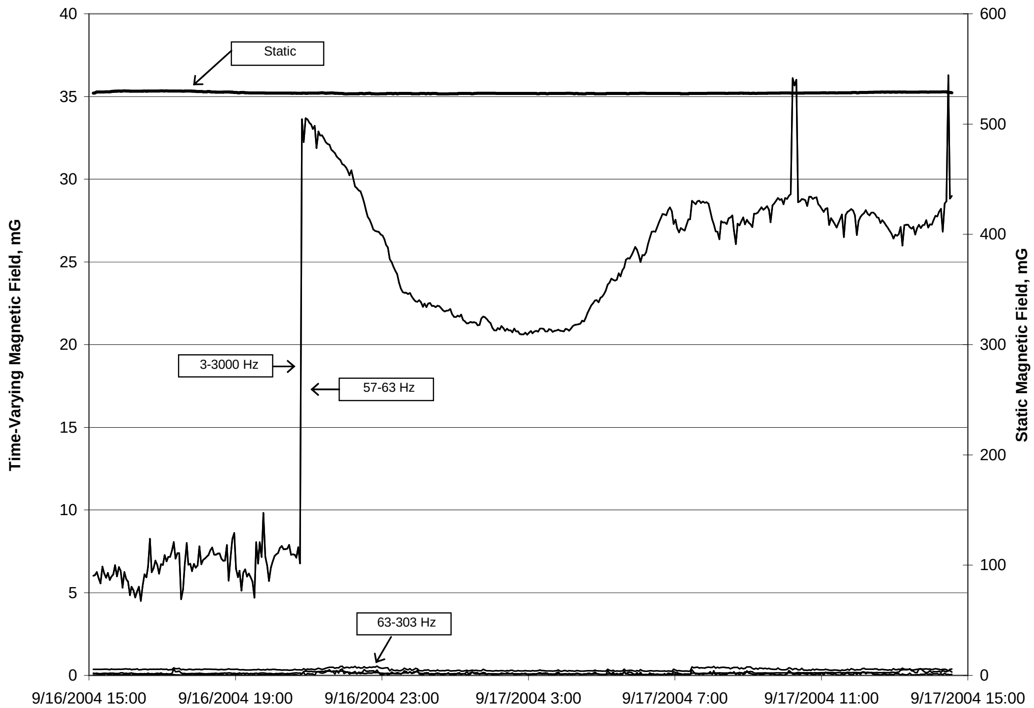


Figure A4. 24-Hour Fluctuation of Static and Time-Varying Magnetic Field Levels at the Branford SS

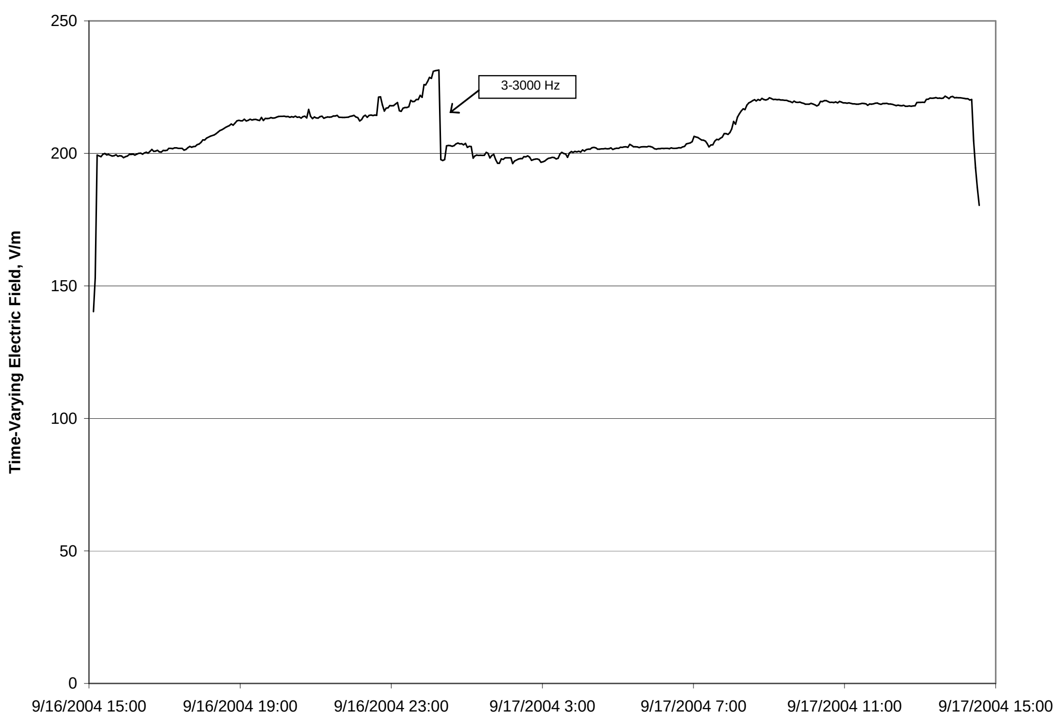


Figure A5. 24-Hour Fluctuation of Time-Varying Electric Field Levels at the Branford SS

Table A2. Summary Statistics for Perimeter Profile ELF Field Measurements at the Branford SS

Field Parameter	Minimum	Percentile Levels 5	25	50	75	95	Maximum	Average	Standard Deviation
Static Magnetic Field in milligauss									
Total	408	429	480	505	512	528	696	495	35.9
ELF Magnetic Field in milligauss									
3-57 Hz	0.1	0.3	0.5	0.7	1.4	5.9	10.5	1.5	2.0
57-63 Hz	1.3	1.9	6.1	15.8	138.6	1165.9	3558.1	244.6	574.4
63-303 Hz	0.2	0.3	0.4	0.6	2.2	14.2	39.6	3.3	6.4
303-3000 Hz	0.1	0.1	0.1	0.2	1.3	3.7	6.8	0.9	1.3
3-3000 Hz	1.5	2.2	6.2	15.8	138.6	1166.0	3558.4	244.7	574.4
ELF Electric Field in volts per meter									
3-3000 Hz	4.1	4.8	75.5	199.5	669.6	974.0	1262.9	350.0	342.2

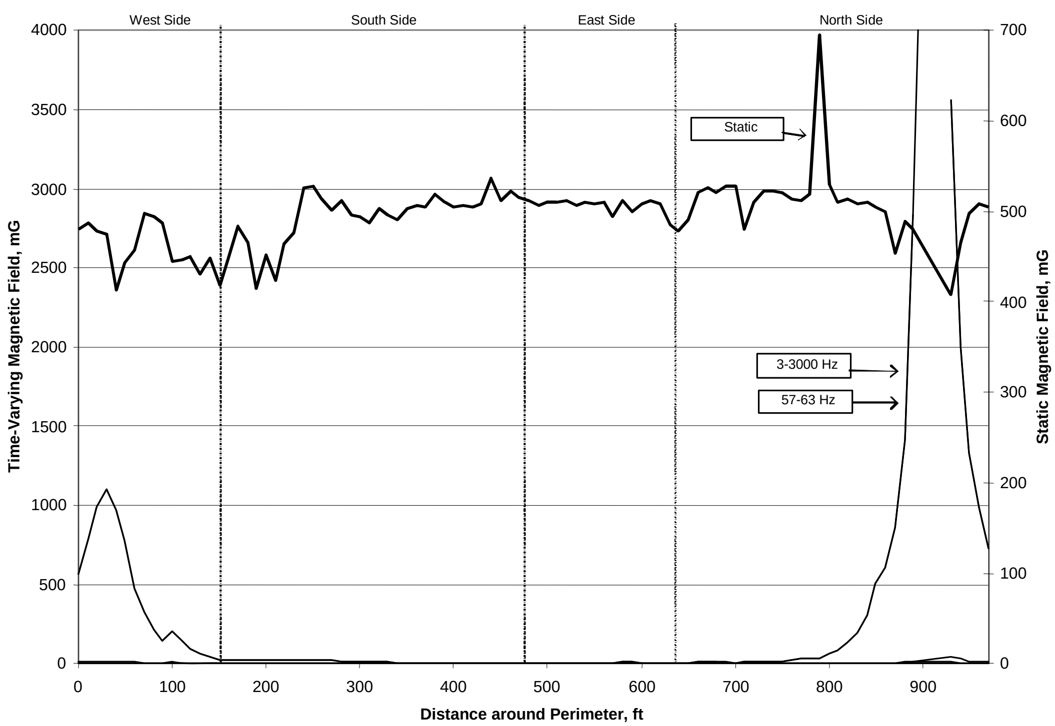


Figure A6. Static and Time-Varying Magnetic Field Levels around the Perimeter of the Branford SS

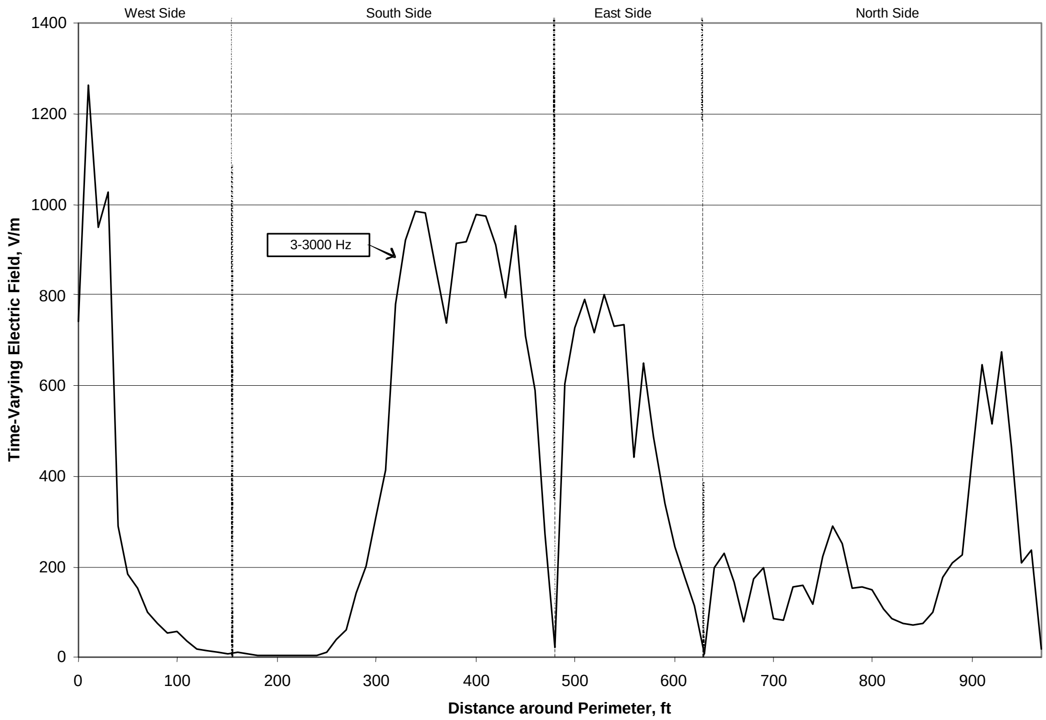


Figure A7. Time-Varying Electric Field Levels around the Perimeter of the Branford SS

Appendix B
Sharon, CT, Substation

Milepost 212+1910

Location Type: Suburban

24-hour Measurements:

Start:	9/13/04 10:21:41 EDT
Finish:	9/14/04 09:48:41 EDT
Sample Interval:	3 minutes
No. of Samples:	470
Location:	Near middle of SS, beneath transmission line.

Perimeter Profile Measurements:

Start:	9/13/04 10:18:28 EDT
Sample Interval:	10 foot
No. of Samples:	86
Location:	Around SS fence line starting with northwest side.

Lateral Profile Measurements:

Start:	9/13/04 10:43:32 EDT
Sample Interval:	10 foot
No. of Samples:	15
Location:	At milepost 212+1912. Started at fence closest to tracks, moving away from tracks toward opposite side of SS away from corridor.

Site Anomalies: This SS is situated directly beneath a transmission line as shown in Figure 50. This transmission line provides power to the electric traction system through the Sharon SS. The long-term sensor was placed near the base of the tower near the middle of the SS.

Field Characteristics: At the long-term position, magnetic fields are dominated by the transmission line. Thus, they are relatively constant on the order of 100 mG, though a slight decrease is seen at night and early morning. Static magnetic fields are very constant. ELF electric field beneath the power line is relatively constant as expected.

The transmission line magnetic and electric fields are seen in the perimeter measurements on the two sides that cross beneath the line.

Sharon, MA, Substation

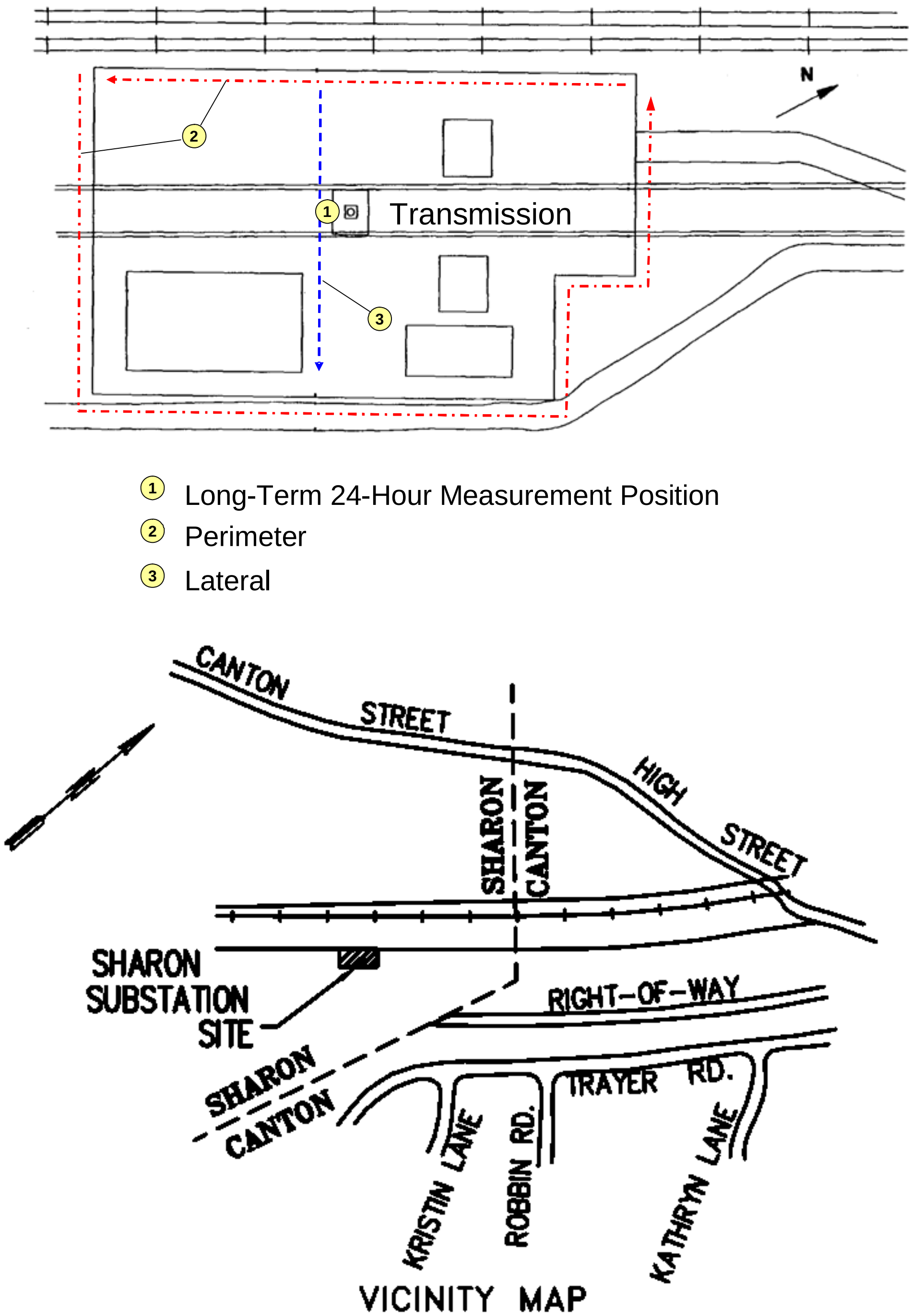


Figure B1. Sketch Showing Approximate Measurement Locations (top) and Street Map Showing the General Location of the Sharon SS (bottom)

Figure B2. Sharon SS Looking Southwest, Tracks are at Far Right

Table B1. Summary Statistics for 24-Hour Field Measurements at Sharon SS

Field Parameter	Minimum	Percentile Levels 5	25	50	75	95	Maximum	Average	Standard Deviation
Static Magnetic Field in milligauss									
Total	570	571	571	572	572	573	574	572	0.8
ELF Magnetic Field in milligauss									
3-57 Hz	0.1	0.1	0.2	0.4	0.5	0.9	1.7	0.4	0.3
57-63 Hz	97.8	100.5	101.4	105.4	108.0	109.3	110.2	104.9	3.1
63-303 Hz	2.2	2.3	2.4	2.5	2.9	3.7	6.0	2.7	0.5
303-3000 Hz	0.9	1.0	1.0	1.0	1.1	2.7	3.5	1.2	0.6
3-3000 Hz	97.9	100.6	101.5	105.4	108.0	109.3	110.3	104.9	3.1
ELF Electric Field in volts per meter									
3-3000 Hz	7280.3	7540.6	7574.2	7590.0	7683.5	7856.4	7935.2	7632.6	96.9

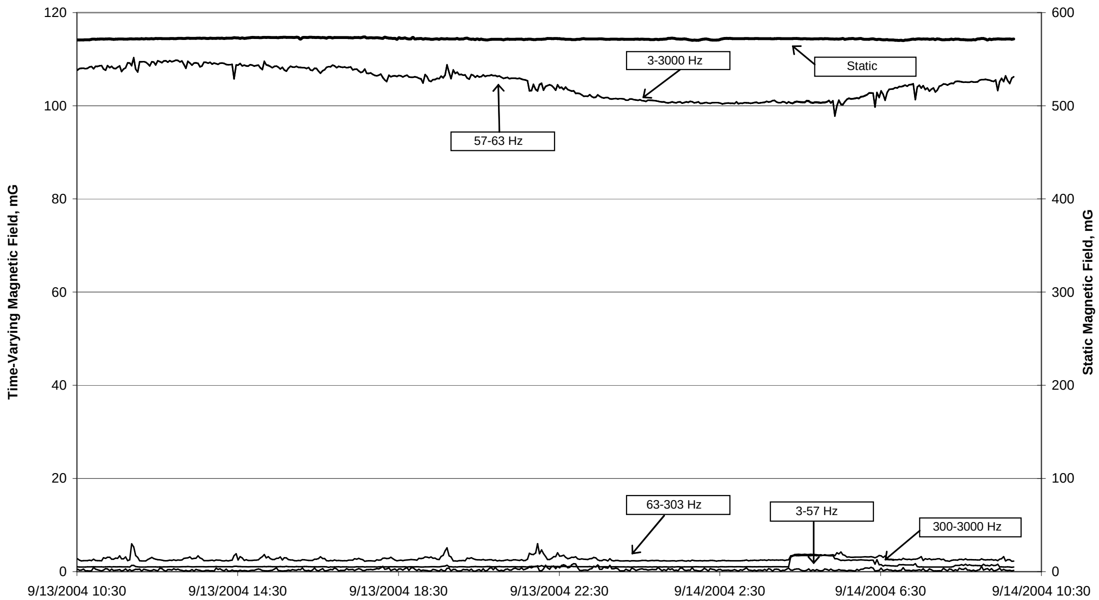


Figure B3. 24-Hour Fluctuation of Static and Time-Varying Magnetic Field Levels at the Sharon SS

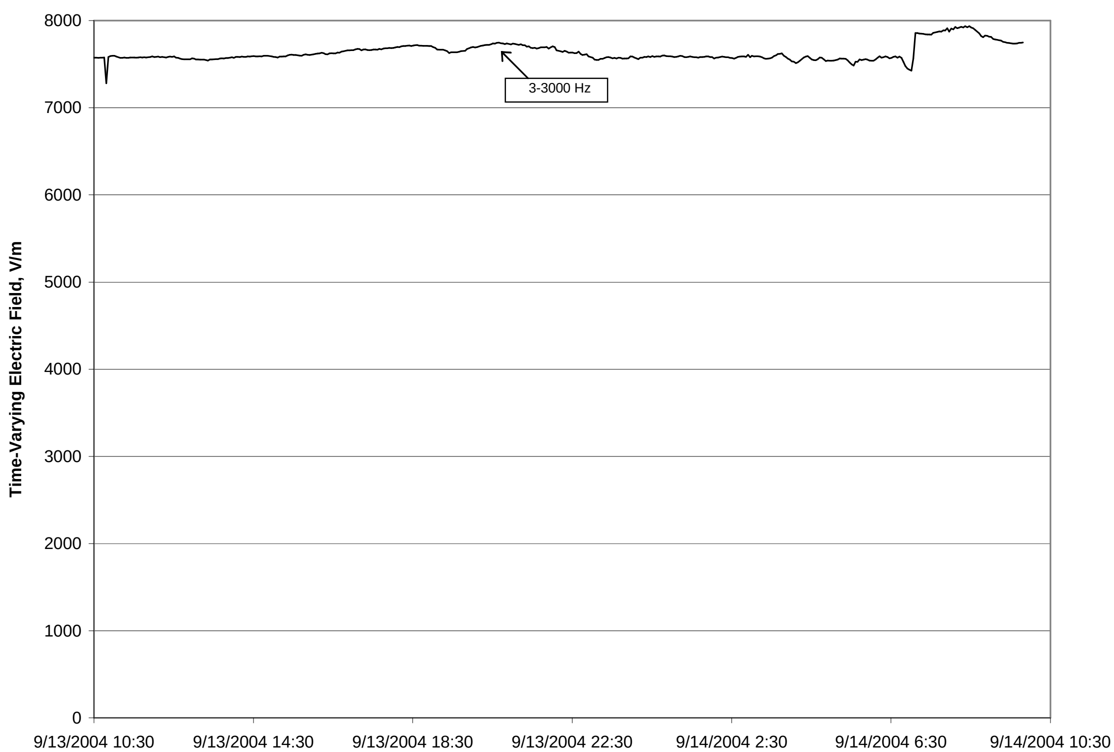


Figure B4. 24-Hour Fluctuation of Time-Varying Electric Field Levels at the Sharon SS

Table B2. Summary Statistics for Perimeter Profile ELF Field Measurements at the Sharon SS

Field Parameter	Minimum	Percentile Levels 5	25	50	75	95	Maximum	Average	Standard Deviation
Static Magnetic Field in milligauss									
Total	378	453	499	510	515	534	574	504	28.5
ELF Magnetic Field in milligauss									
3-57 Hz	0.1	0.3	0.4	0.6	1.1	1.9	2.3	0.8	0.5
57-63 Hz	9.0	9.7	14.7	22.3	95.8	489.6	851.9	97.2	175.1
63-303 Hz	0.2	0.3	0.7	1.6	2.9	9.2	12.9	2.4	2.8
303-3000 Hz	0.1	0.1	0.1	0.4	1.5	2.7	4.3	0.8	0.9
3-3000 Hz	9.0	9.9	14.7	22.3	96.0	489.6	852.0	97.4	175.1
ELF Electric Field in volts per meter									
3-3000 Hz	20.5	23.4	54.2	136.1	293.4	696.9	810.4	212.1	208.6

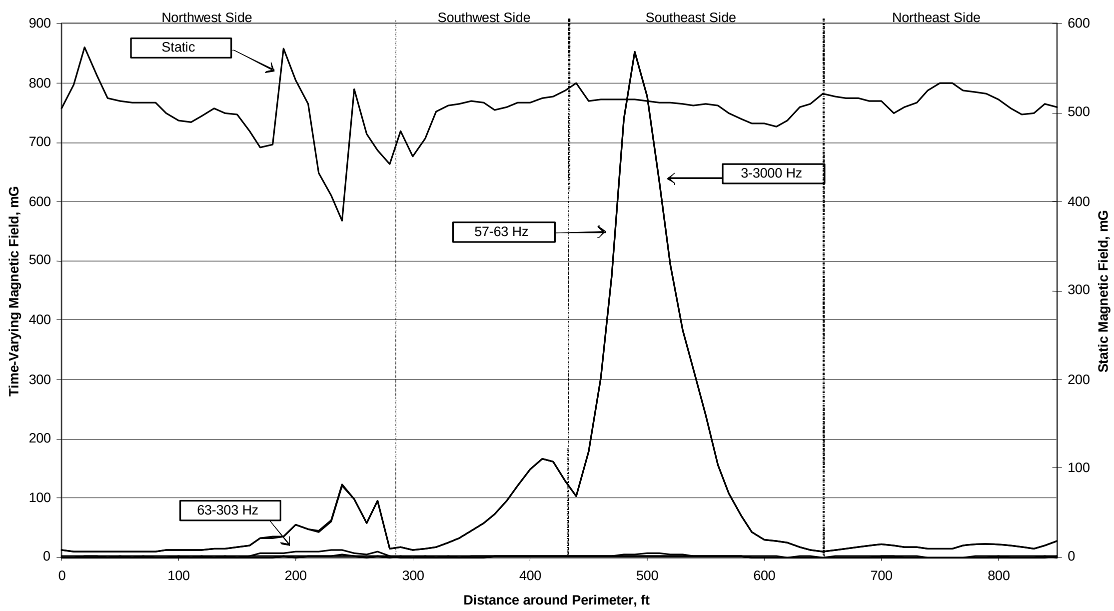


Figure B5. Static and Time-Varying Magnetic Field Levels around the Perimeter of the Sharon SS

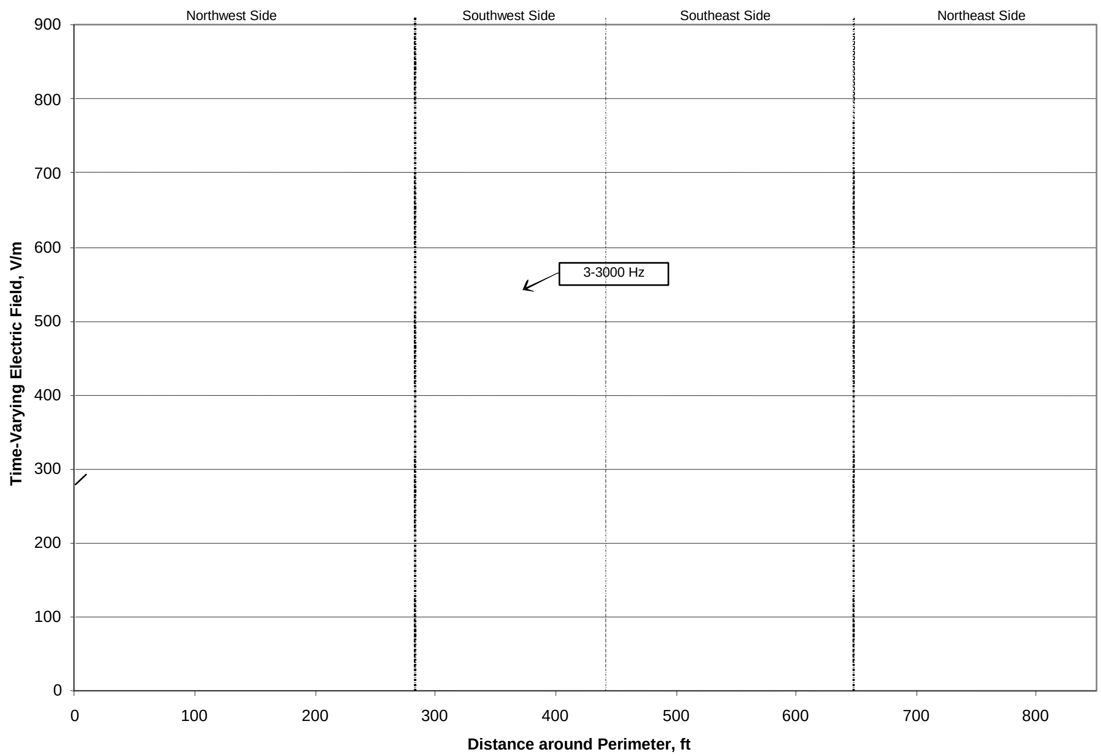


Figure B6. Time-Varying Electric Field Levels around the Perimeter of the Sharon SS

Table B3. Summary Statistics for the Lateral Profile Field Measurements at the Sharon SS

Field Parameter	Minimum	Percentile Levels 5	25	50	75	95	Maximum	Average	Standard Deviation
Static Magnetic Field in milligauss									
Total	458	470	501	512	527	540	551	510	24.8
ELF Magnetic Field in milligauss									
3-57 Hz	0.3	0.3	0.4	1.2	1.8	3.1	3.7	1.3	1.0
57-63 Hz	36.4	37.4	65.1	213.5	578.4	710.2	743.0	315.0	271.4
63-303 Hz	2.1	2.1	3.1	4.9	11.0	16.9	18.9	7.4	5.5
303-3000 Hz	0.7	0.9	1.1	1.7	2.2	2.7	3.2	1.7	0.7
3-3000 Hz	36.5	37.6	65.2	213.5	578.5	710.4	743.2	315.2	271.4
ELF Electric Field in volts per meter									
3-3000 Hz	33.6	44.3	330.9	540.5	816.7	932.4	953.4	536.5	308.7

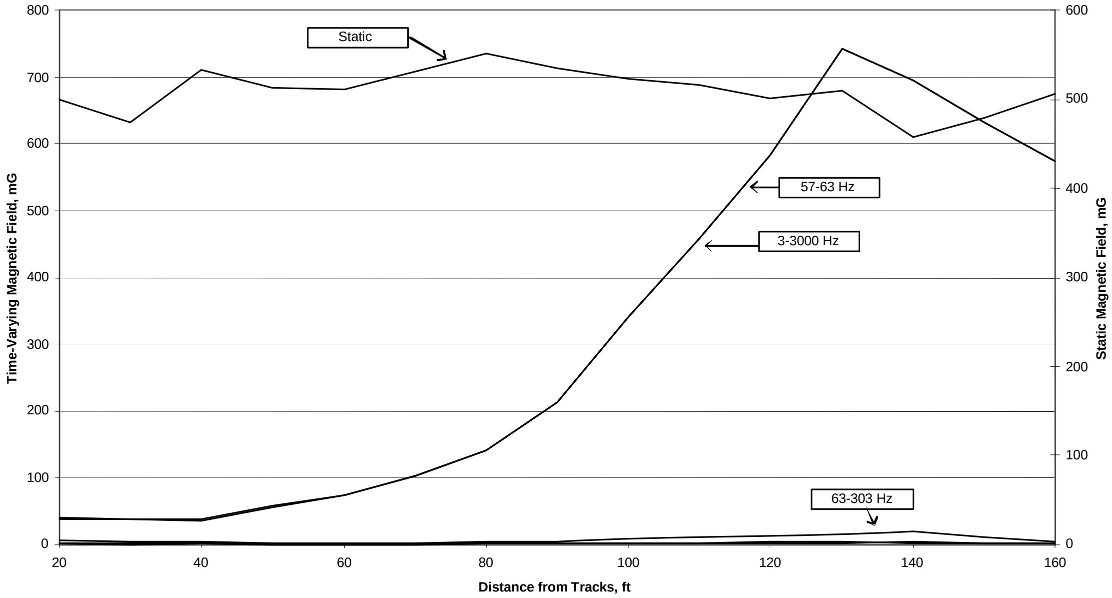


Figure B7. Lateral Profile of Static and Time-Varying Magnetic Field Levels at the Sharon SS

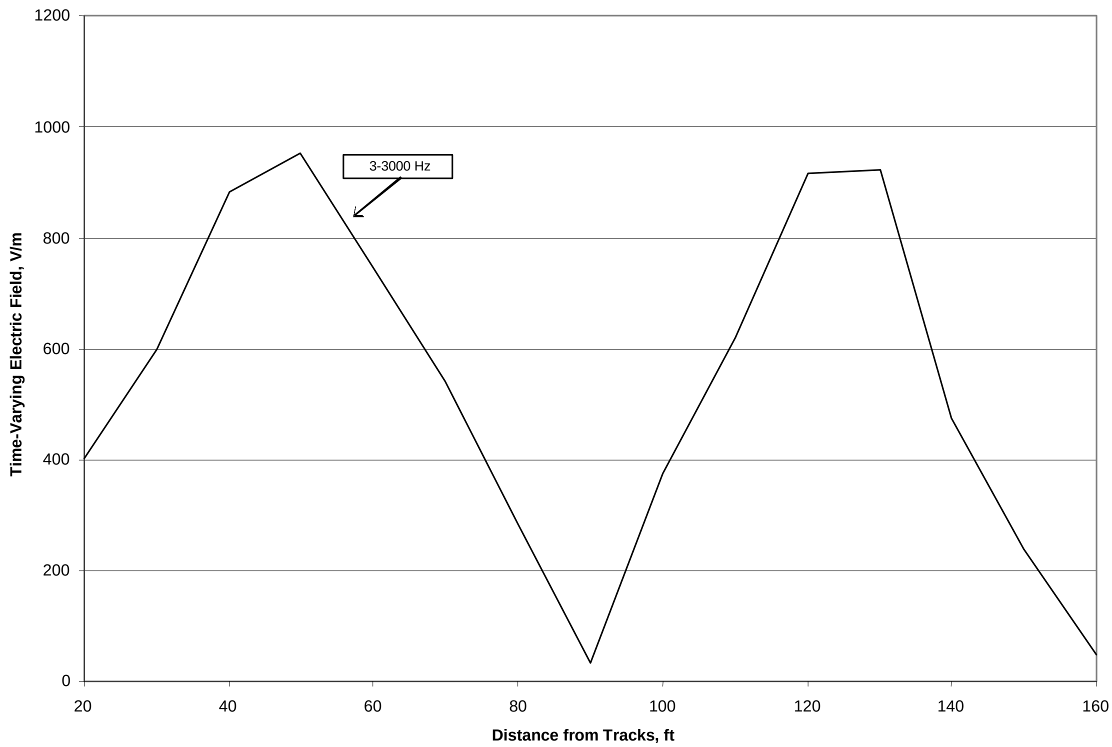


Figure B8. Lateral Profile of Time-Varying Electric Field Levels at the Sharon SS

Appendix C
Westbrook, CT, Switching Station

Milepost 103+0502

Location Type: Near industrial business park (approx. 400 feet).

24-Hour Measurements:

Start:	9/16/04 12:15:14 EDT
Finish:	9/17/04 11:42:14 EDT
Sample Interval:	3 minutes
No. of Samples:	470
Location:	In front of the west fence-line, approximately 35 feet from closest rail.

Perimeter Profile Measurements:

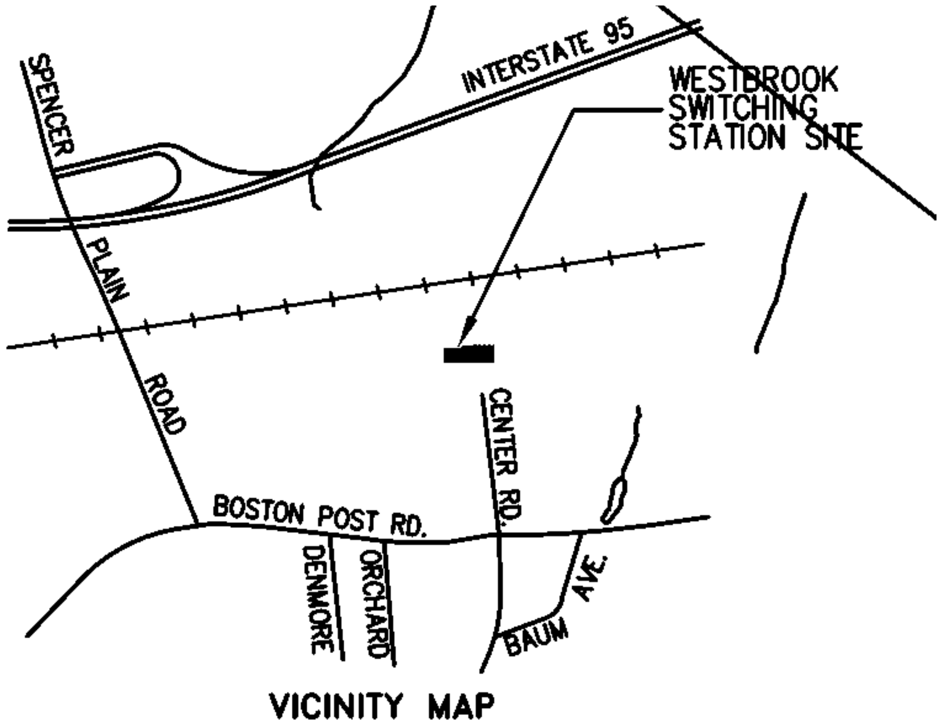
Start:	9/16/04 12:12:08 EDT
Sample Interval:	10 foot
No. of Samples:	53
Location:	15 feet outside south fence-line and 3 feet outside east, north, and west fence-lines.

Lateral Profile Measurements:

Start:	9/16/04 12:22:44 EDT
Sample Interval:	10 foot
No. of Samples:	23
Location:	Start from tracks near milepost 103+0350, running perpendicular from the tracks (south) out the access road.

Site Anomalies: The closest buildings are in a light industrial park, approximately 400 feet from the station.

Field Characteristics: Magnetic fields during the long-term measurement period are less than 1 mG, with spikes up to 20 mG due to train operation. A quiet period is seen in the early morning hours. Perimeter measurements show levels that correspond to overhead lines connecting to the station and to station equipment. The lateral profile for the electric field shows the usual rapid falloff moving away from the tracks.



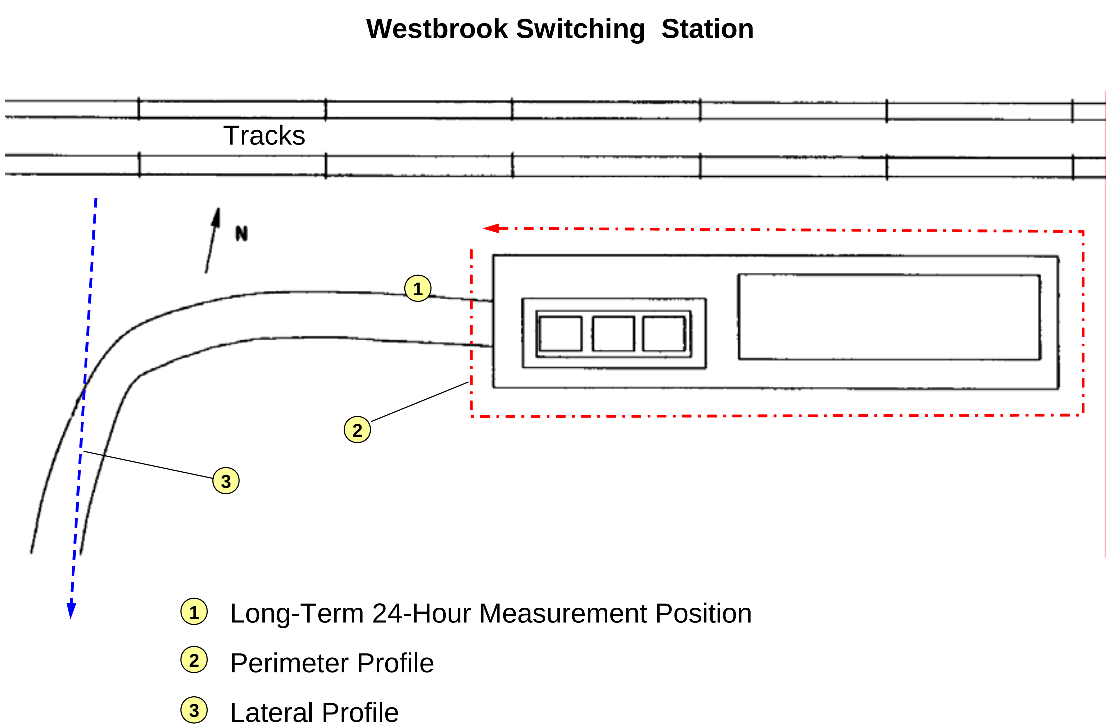


Figure C1. Vicinity Map for the Westbrook SwS (top) and a Sketch Showing Approximate Measurement Locations at the Site (bottom)

Table C1. Summary Statistics for 24-Hour Field Measurements at Westbrook SwS

Field Parameter	Minimum	Percentile Levels 5	25	50	75	95	Maximum	Average	Standard Deviation
Static Magnetic Field in milligauss									
Total	524	529	529	529	530	530	530	529	0.5
ELF Magnetic Field in milligauss									
3-57 Hz	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.0	0.0
57-63 Hz	0.1	0.2	0.2	0.3	0.4	3.2	17.7	0.8	1.8
63-303 Hz	0.2	0.2	0.3	0.3	0.3	0.4	3.3	0.3	0.2
303-3000 Hz	0.0	0.0	0.0	0.0	0.0	0.1	1.5	0.1	0.1
3-3000 Hz	0.3	0.3	0.3	0.4	0.5	3.2	18.1	0.9	1.8
ELF Electric Field in volts per meter									
3-3000 Hz	1956.6	2131.3	2162.0	2213.1	2247.4	2284.2	2300.8	2204.6	52.9

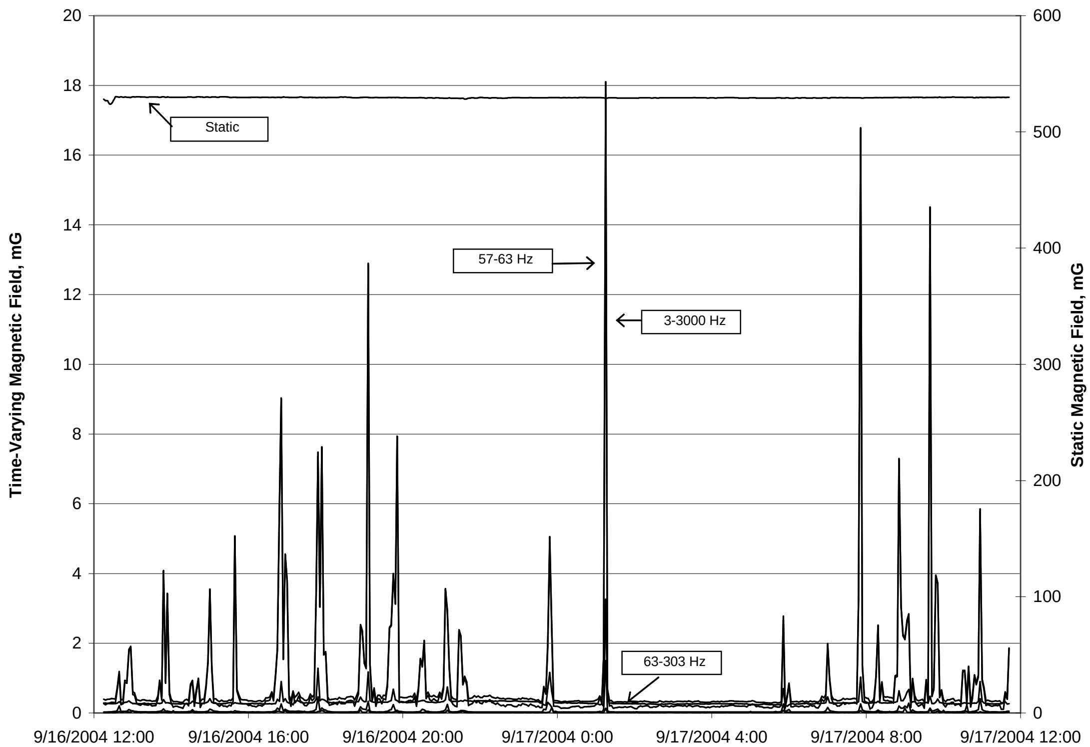


Figure C2. 24-Hour Fluctuation of Static and Time-Varying Magnetic Field Levels at the Westbrook SwS

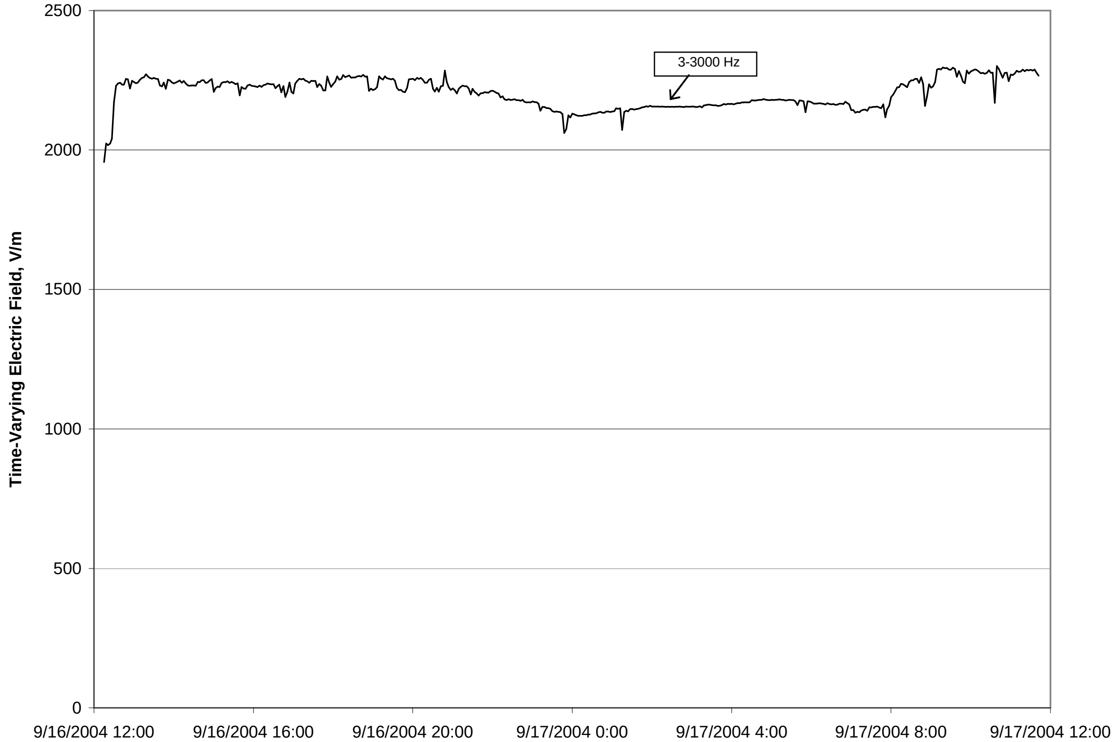


Figure C3. 24-Hour Fluctuation of Time-Varying Electric Field Levels at the Westbrook SwS

Table C2. Summary Statistics for Perimeter Profile ELF Field Measurements at the Westbrook SwS

Field Parameter	Minimum	Percentile Levels 5	25	50	75	95	Maximum	Average	Standard Deviation
Static Magnetic Field in milligauss									
Total	348	372	432	483	494	520	538	462	48.3
ELF Magnetic Field in milligauss									
3-57 Hz	0.1	0.2	0.3	0.6	0.8	1.5	2.4	0.6	0.5
57-63 Hz	0.3	0.3	0.6	1.2	1.8	2.7	4.1	1.3	0.8
63-303 Hz	0.2	0.2	0.3	0.4	0.5	0.8	0.8	0.4	0.2
303-3000 Hz	0.0	0.0	0.1	0.1	0.1	0.2	0.2	0.1	0.1
3-3000 Hz	0.4	0.7	1.0	1.4	2.2	2.9	4.2	1.6	0.8
ELF Electric Field in volts per meter									
3-3000 Hz	1.6	1.7	10.7	113.6	355.2	464.2	661.0	178.2	188.2

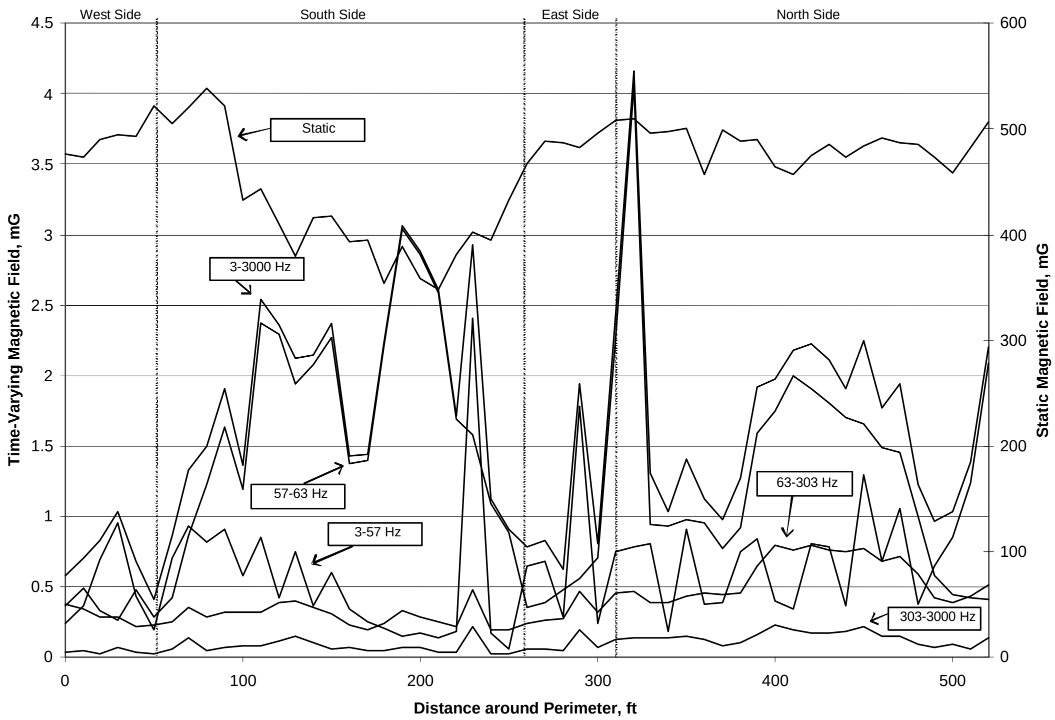


Figure C4. Static and Time-Varying Magnetic Field Levels around the Perimeter of the Westbrook SwS

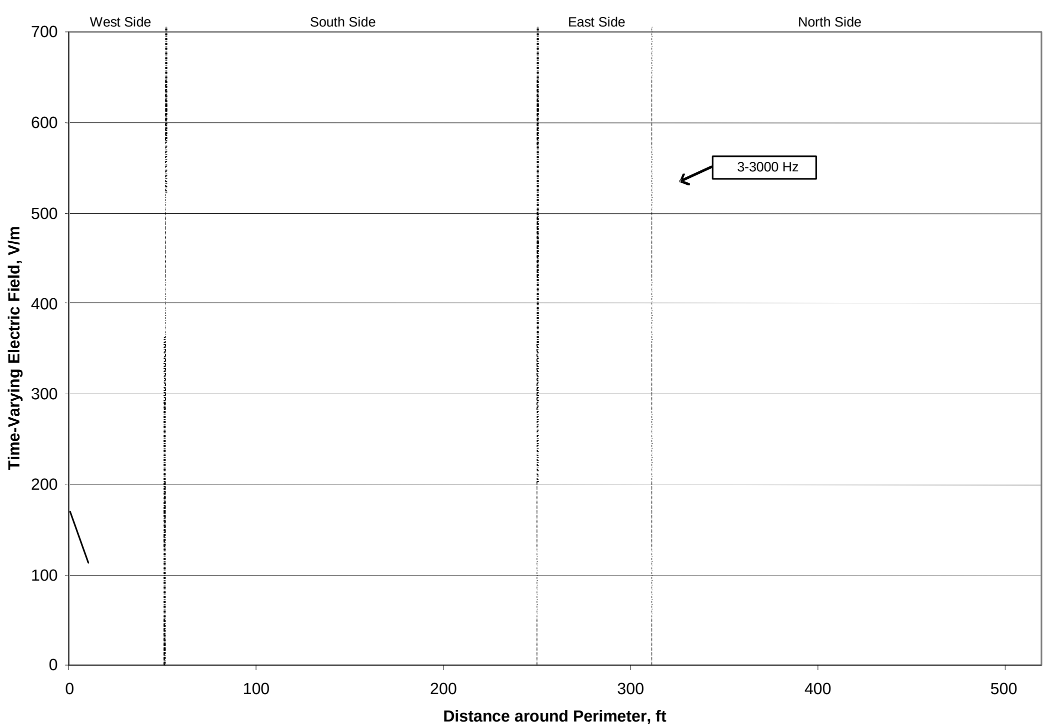


Figure C5. Time-Varying Electric Field Levels around the Perimeter of the Westbrook SwS

Table C3. Summary Statistics for the Lateral Profile Field Measurements at the Westbrook SwS

Field Parameter	Minimum	Percentile Levels 5	25	50	75	95	Maximum	Average	Standard Deviation
Static Magnetic Field in milligauss									
Total	530	531	536	536	537	538	539	536	2.1
ELF Magnetic Field in milligauss									
3-57 Hz	0.2	0.3	0.4	0.5	1.2	2.0	3.2	0.9	0.7
57-63 Hz	0.1	0.1	0.1	0.2	0.2	0.3	0.4	0.2	0.1
63-303 Hz	0.1	0.1	0.1	0.2	0.3	0.4	0.5	0.2	0.1
303-3000 Hz	0.0	0.0	0.0	0.1	0.1	0.2	0.3	0.1	0.1
3-3000 Hz	0.3	0.3	0.5	0.6	1.2	2.1	3.3	1.0	0.7
ELF Electric Field in volts per meter									
3-3000 Hz	1.7	1.7	1.8	1.8	2.2	116.4	209.4	19.2	49.6

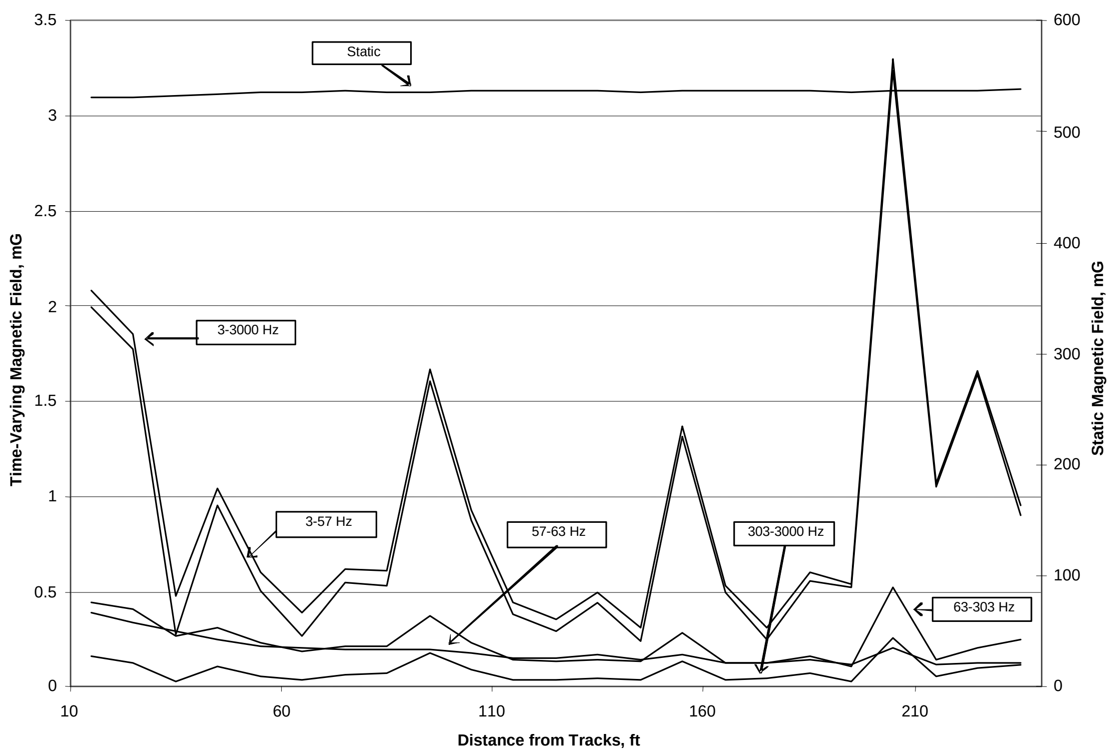


Figure C6. Lateral Profile of Static and Time-Varying Magnetic Field Levels at the Westbrook SwS

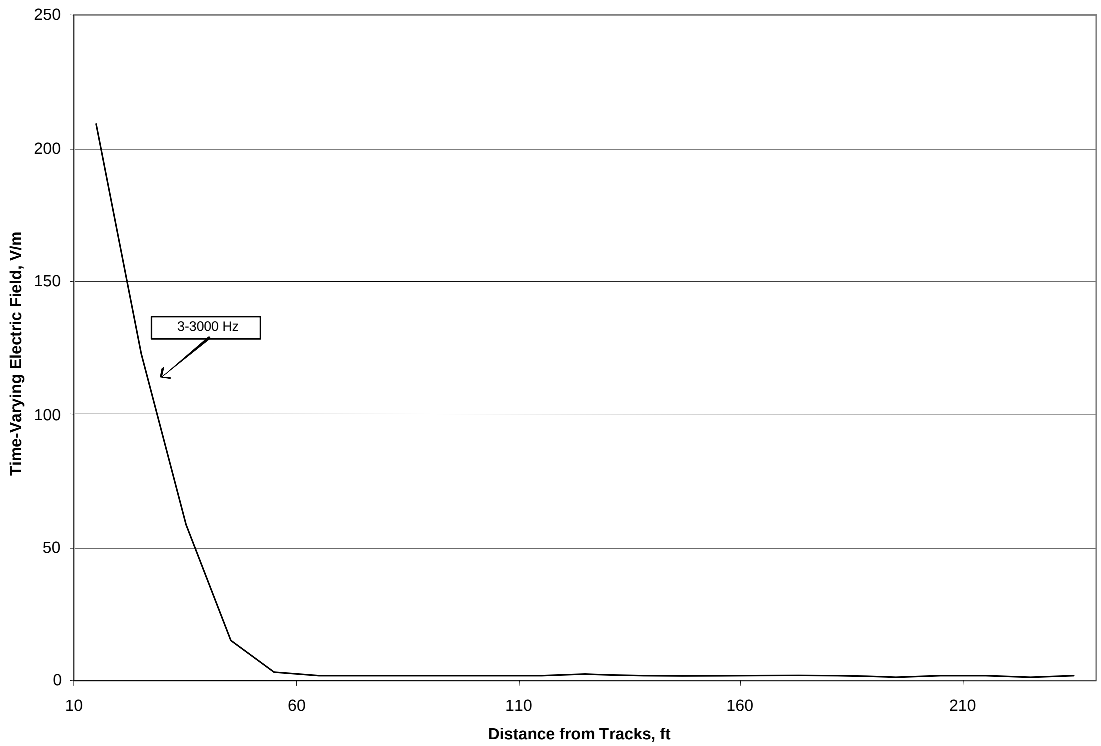


Figure C7. Lateral Profile of Time-Varying Electric Field Levels at the Westbrook SwS

Appendix D
Richmond, RI, Switching Station

Milepost 150+0807

Location Type: Rural

24-Hour Measurements:

Start:	9/15/04 08:34:07 EDT
Finish:	9/16/04 08:01:07 EDT
Sample Interval:	3 minutes
No. of Samples:	470
Location:	At northwest corner of property line.

Perimeter Profile Measurements:

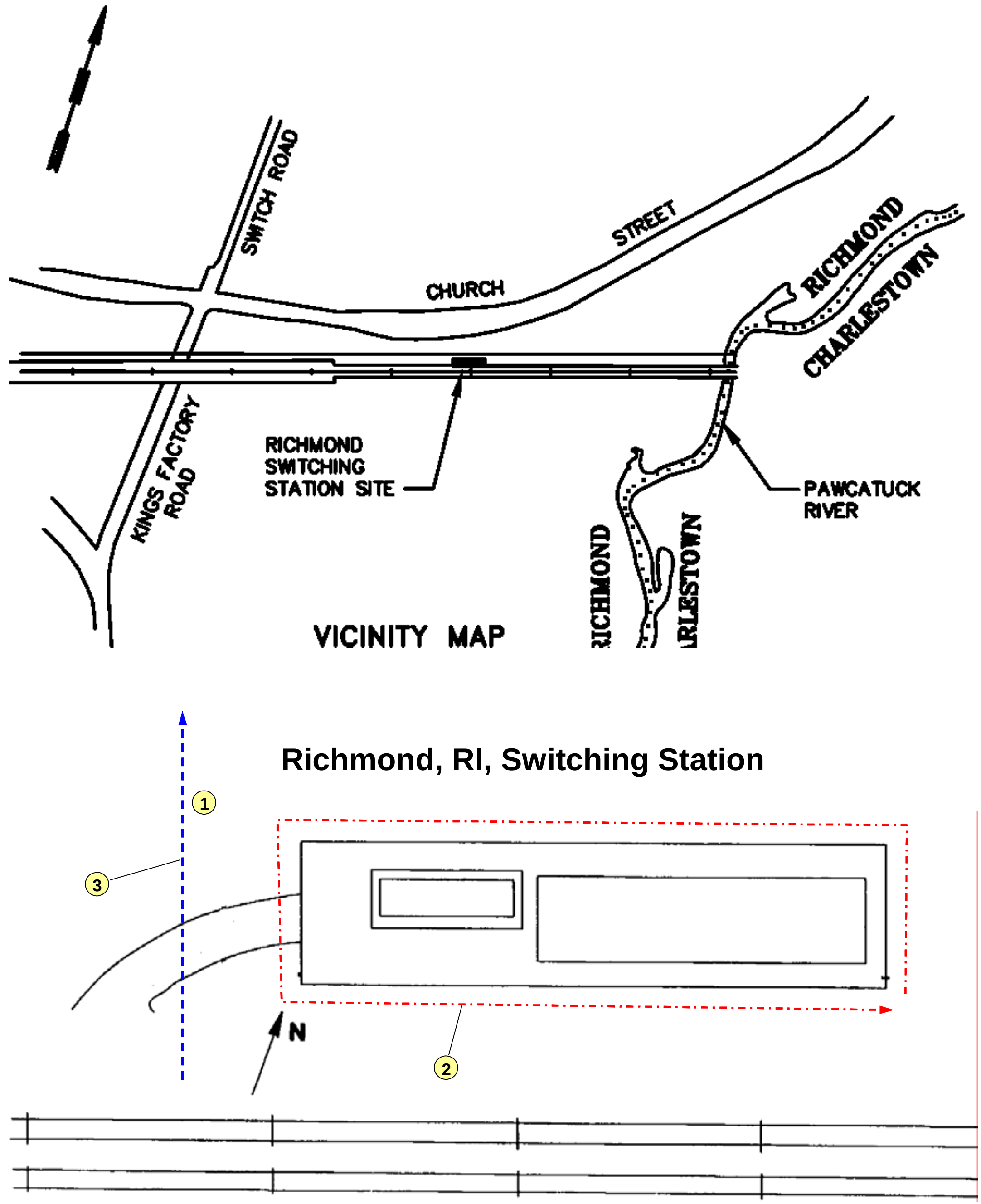
Start:	9/15/04 08:25:50 EDT
Sample Interval:	10 foot
No. of Samples:	45
Location:	3 feet outside the fence-line.

Lateral Profile Measurements:

Start:	9/15/04 08:33:33 EDT
Sample Interval:	10 foot
No. of Samples:	17
Location:	On west property line.

Site Anomalies: Very wooded area for lateral profile. The lateral profile ended at the road beneath a distribution line.

Field Characteristics: The static magnetic field as measured at the long-term position was relatively constant. The time-varying magnetic fields during long-term measurements were low, on the order of 0.5 mG with occasional spikes to 1.2 mG. Magnetic fields measured on the perimeter and lateral profiles were also quite low. The overhead power lines (connecting to the SwS and running along the corridor) are visible in the measured electric field results from the perimeter and lateral profiles.



① Long-Term 24-Hour Measurement Position
② Perimeter
③ Lateral

Figure D1. Vicinity Map (top) Showing Local Roads and Sketch (bottom) Showing Measurement Locations at the Richmond SwS

Figure D2. Richmond SwS

Table D1. Summary Statistics for 24-Hour Field Measurements at Richmond SwS

Field Parameter	Minimum	Percentile Levels 5	25	50	75	95	Maximum	Average	Standard Deviation
Static Magnetic Field in milligauss									
Total	816	817	818	822	823	823	842	821	2.7
ELF Magnetic Field in milligauss									
3-57 Hz	0.2	0.2	0.2	0.2	0.3	0.3	0.3	0.2	0.0
57-63 Hz	0.1	0.1	0.1	0.1	0.2	0.6	1.2	0.2	0.2
63-303 Hz	0.1	0.1	0.1	0.2	0.2	0.2	0.2	0.2	0.0
303-3000 Hz	0.0	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.0
3-3000 Hz	0.3	0.3	0.3	0.3	0.3	0.7	1.3	0.4	0.1
ELF Electric Field in volts per meter									
3-3000 Hz	1046.6	1049.8	1053.0	1064.3	1069.0	1072.3	1093.1	1061.7	8.6

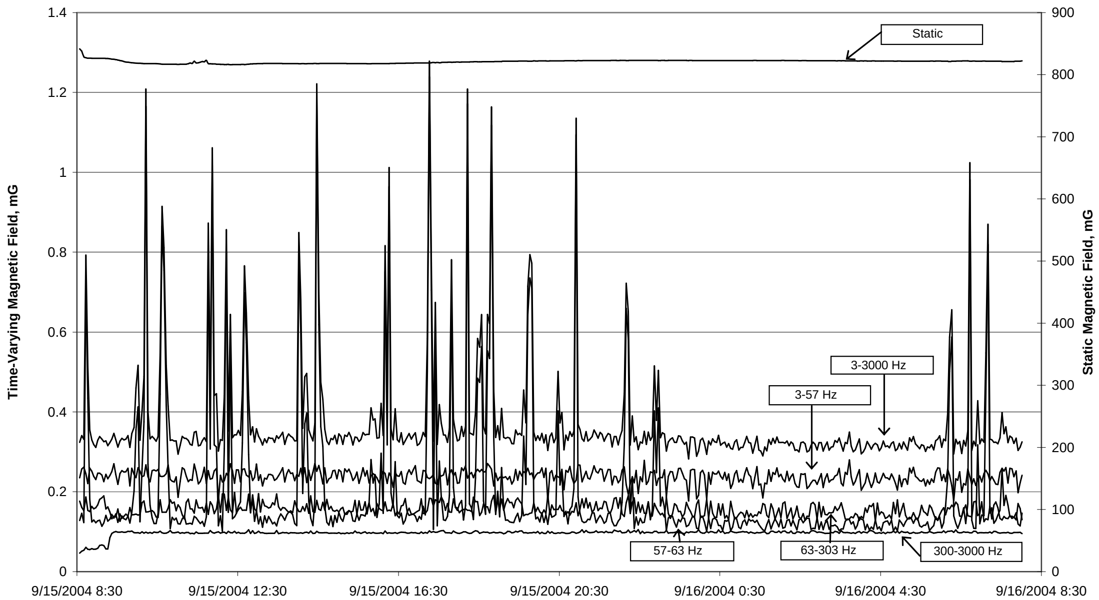


Figure D3. 24-Hour Fluctuation of Static and Time-Varying Magnetic Field Levels at the Richmond SwS

Table D2. Summary Statistics for Perimeter Profile ELF Field Measurements at the Richmond SwS

Field Parameter	Minimum	Percentile Levels 5	25	50	75	95	Maximum	Average	Standard Deviation
Static Magnetic Field in milligauss									
Total	405	422	497	512	524	548	561	502	36.8
ELF Magnetic Field in milligauss									
3-57 Hz	0.1	0.1	0.3	0.4	0.6	2.9	6.0	0.7	1.1
57-63 Hz	0.1	0.1	0.2	0.2	0.4	2.2	2.6	0.5	0.7
63-303 Hz	0.1	0.1	0.1	0.1	0.2	0.4	1.0	0.2	0.2
303-3000 Hz	0.0	0.0	0.0	0.0	0.1	0.2	0.5	0.1	0.1
3-3000 Hz	0.2	0.3	0.4	0.6	1.0	3.2	6.1	1.0	1.2
ELF Electric Field in volts per meter									
3-3000 Hz	4.9	5.1	5.9	44.6	298.0	351.7	379.0	132.8	144.4

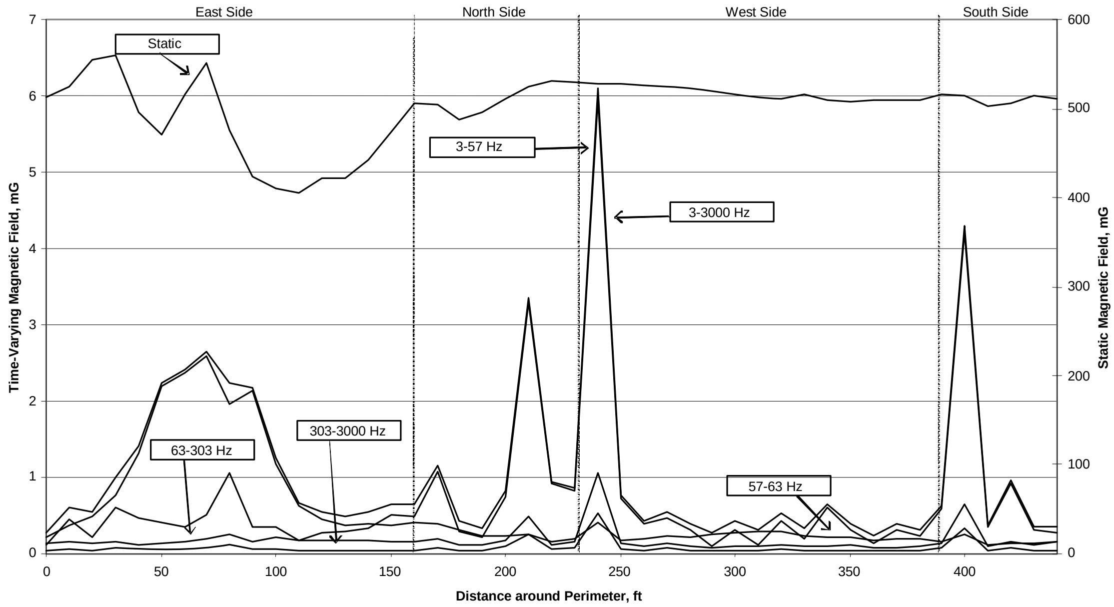


Figure D4. Static and Time-Varying Magnetic Field Levels around the Perimeter of the Richmond SwS

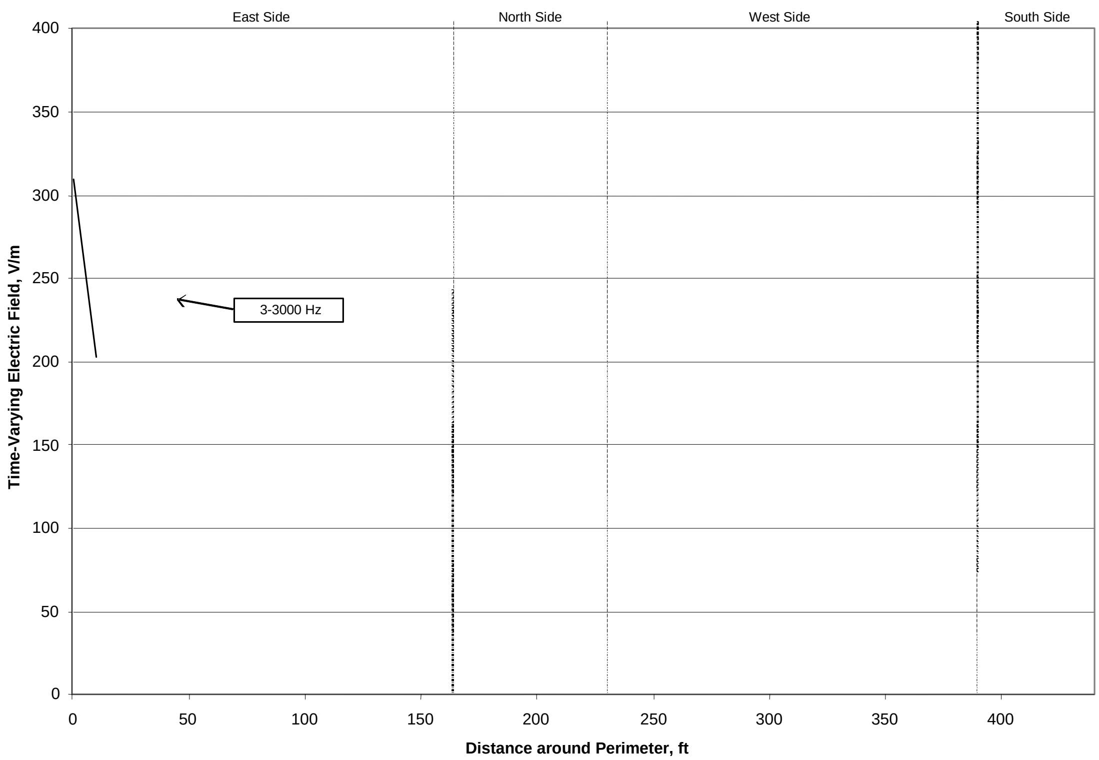


Figure D5. Time-Varying Electric Field Levels around the Perimeter of the Richmond SwS

Table D3. Summary Statistics for the Lateral Profile Field Measurements at the Richmond SwS

Field Parameter	Minimum	Percentile Levels 5	25	50	75	95	Maximum	Average	Standard Deviation
Static Magnetic Field in milligauss									
Total	513	515	526	535	537	538	539	530	8.7
ELF Magnetic Field in milligauss									
3-57 Hz	0.2	0.3	0.3	0.4	0.7	2.2	2.4	0.7	0.6
57-63 Hz	0.1	0.1	0.1	0.1	0.1	0.2	0.2	0.1	0.0
63-303 Hz	0.1	0.1	0.1	0.1	0.1	0.2	0.4	0.1	0.1
303-3000 Hz	0.0	0.0	0.0	0.0	0.1	0.1	0.2	0.1	0.0
3-3000 Hz	0.3	0.3	0.4	0.5	0.7	2.2	2.5	0.7	0.6
ELF Electric Field in volts per meter									
3-3000 Hz	4.8	4.8	5.1	5.2	5.5	50.3	72.6	11.6	18.4

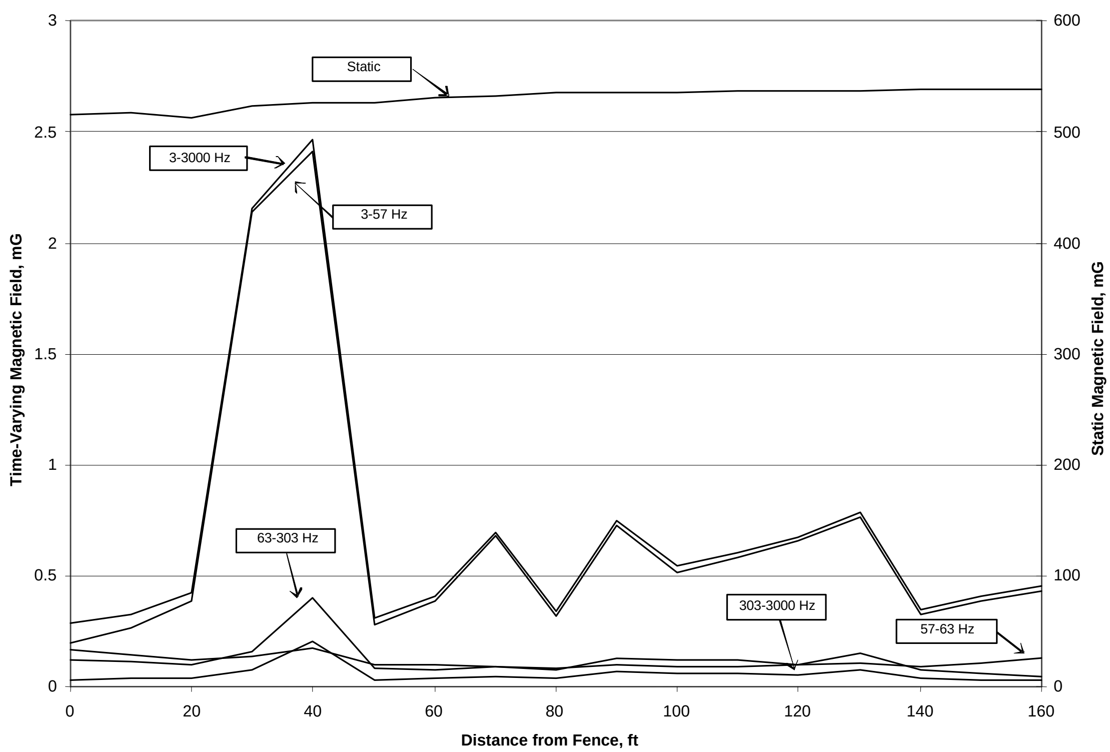


Figure D6. Lateral Profile of Static and Time-Varying Magnetic Field Levels at the Richmond SwS

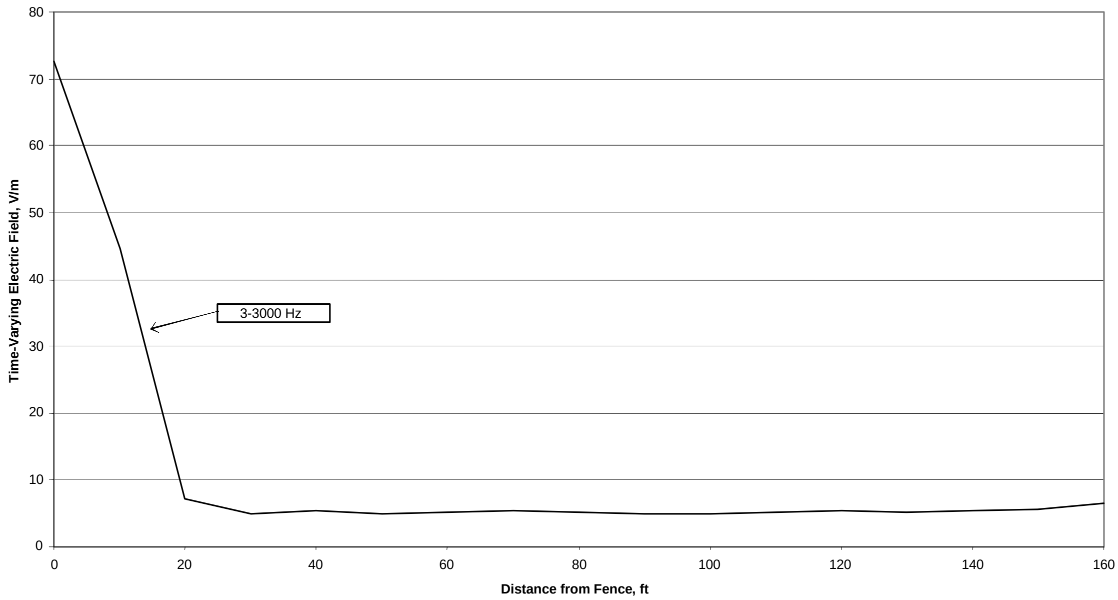


Figure D7. Lateral Profile of Time-Varying Electric Field Levels at the Richmond SwS

Appendix E
Grove Beach, CT, Paralleling Station

Milepost 098+4600

Location Type: Suburban, near trailer park.

24-Hour Measurements:

Start:	9/16/04 13:39:01 EDT
Finish:	9/17/04 13:06:01 EDT
Sample Interval:	3 minutes
No. of Samples:	470
Location:	Approximately 35 feet south of track on east property line.

Perimeter Profile Measurements:

Start:	9/16/04 13:26:34 EDT
Sample Interval:	10 foot
No. of Samples:	31
Location:	3 feet outside north fence-line, and 1 foot inside the west, south, and east fence-lines.

Lateral Profile Measurements:

Start:	9/16/04 12:30:55 EDT
Sample Interval:	10 foot
No. of Samples:	21
Location:	Started 10 feet from the track at milepost 98+4790 and walked perpendicular to the track on the centerline of the road in the Grove Beach trailer park.

Site Anomalies: Due to heavy brush undergrowth and fence placement, the lateral profile was shifted to run along the trailer park road.

Field Characteristics: Static magnetic field is constant for the long-term measurements, while the time-varying magnetic fields appear to show spikes because of train operation. The magnetic fields are very low, with spikes from 4 to 7 mG. A quiet period is visible from 1:30 a.m. to 5:30 a.m. The electric field is constant, with two periods of spikes downward. The second set of spikes may result from Amtrak personnel passing close to the sensor when they visited the site at lunchtime just before the 24-hour period was completed. Perimeter and lateral magnetic fields were very low. Perimeter and lateral electric fields show increases beneath the station power lines.

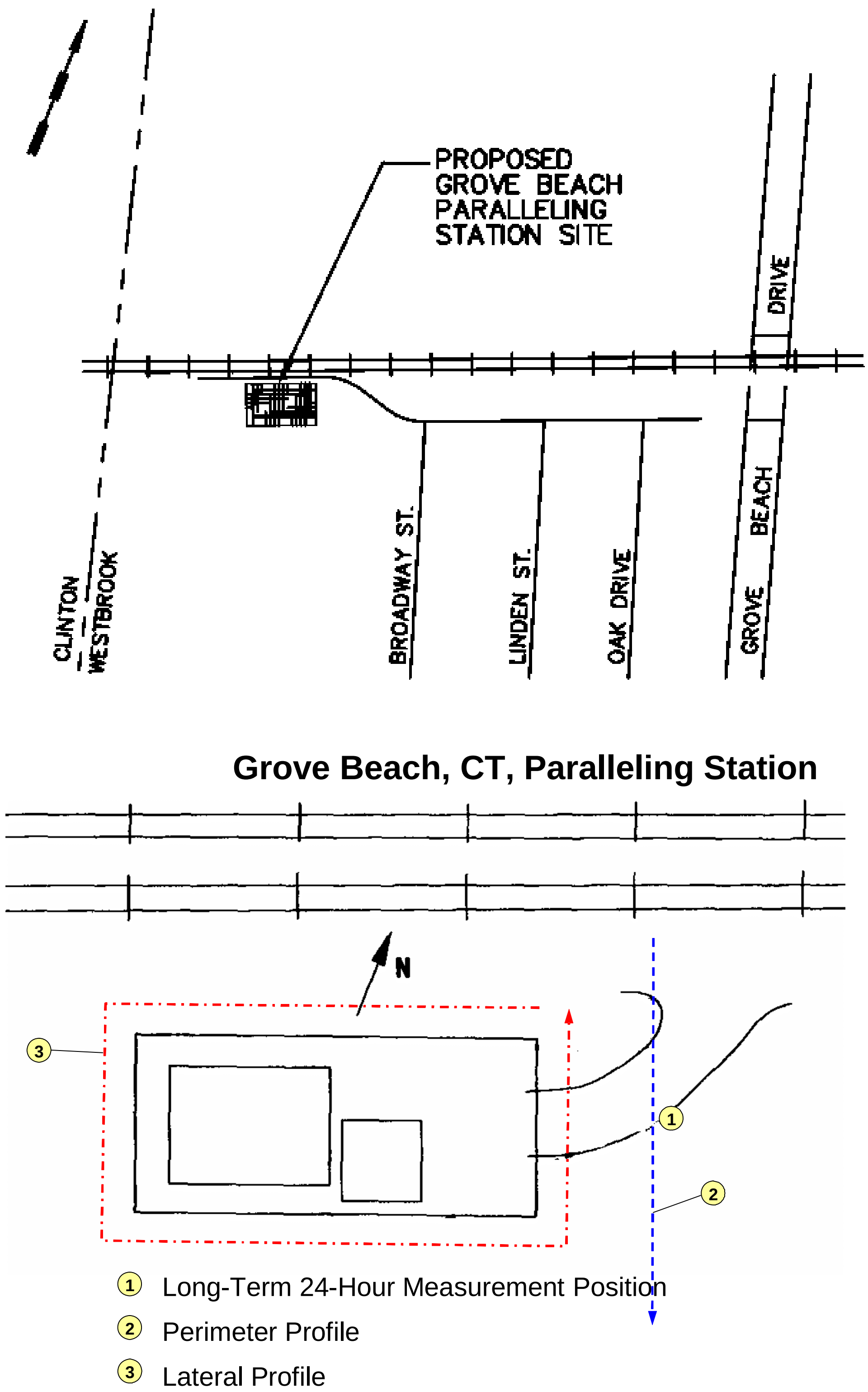


Figure E1. Vicinity Map (top) and Sketch Showing Measurement Locations (bottom) at Grove Beach PS

Table E1. Summary Statistics for 24-Hour Field Measurements at Grove Beach PS

Field Parameter	Minimum	Percentile Levels 5	25	50	75	95	Maximum	Average	Standard Deviation
Static Magnetic Field in milligauss									
Total	509	512	513	513	513	515	516	513	0.7
ELF Magnetic Field in milligauss									
3-57 Hz	0.0	0.0	0.0	0.1	0.1	0.1	0.2	0.1	0.0
57-63 Hz	0.1	0.1	0.1	0.2	0.2	1.9	7.2	0.4	0.9
63-303 Hz	0.0	0.0	0.1	0.1	0.1	0.2	1.3	0.1	0.1
303-3000 Hz	0.0	0.0	0.0	0.0	0.1	0.1	0.4	0.1	0.0
3-3000 Hz	0.1	0.1	0.2	0.2	0.2	1.9	7.2	0.5	0.9
ELF Electric Field in volts per meter									
3-3000 Hz	261.7	1042.7	1061.1	1077.2	1084.7	1098.8	1150.2	1063.0	82.8

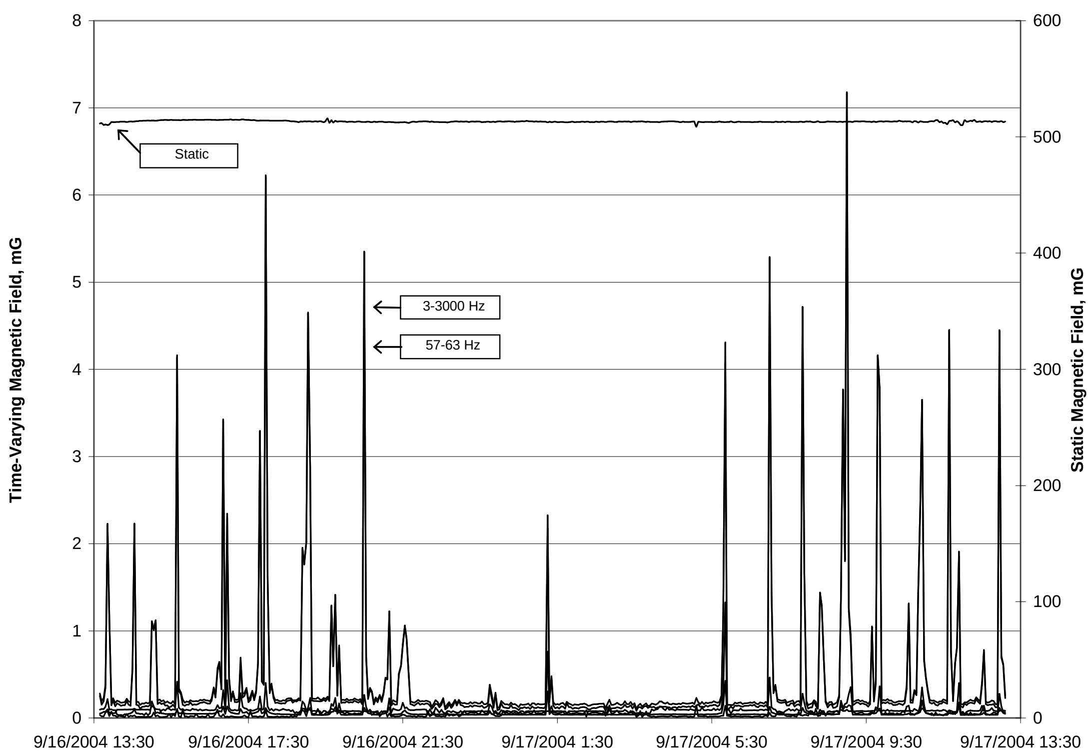


Figure E2. 24-Hour Fluctuation of Static and Time-Varying Magnetic Field Levels at the Grove Beach PS

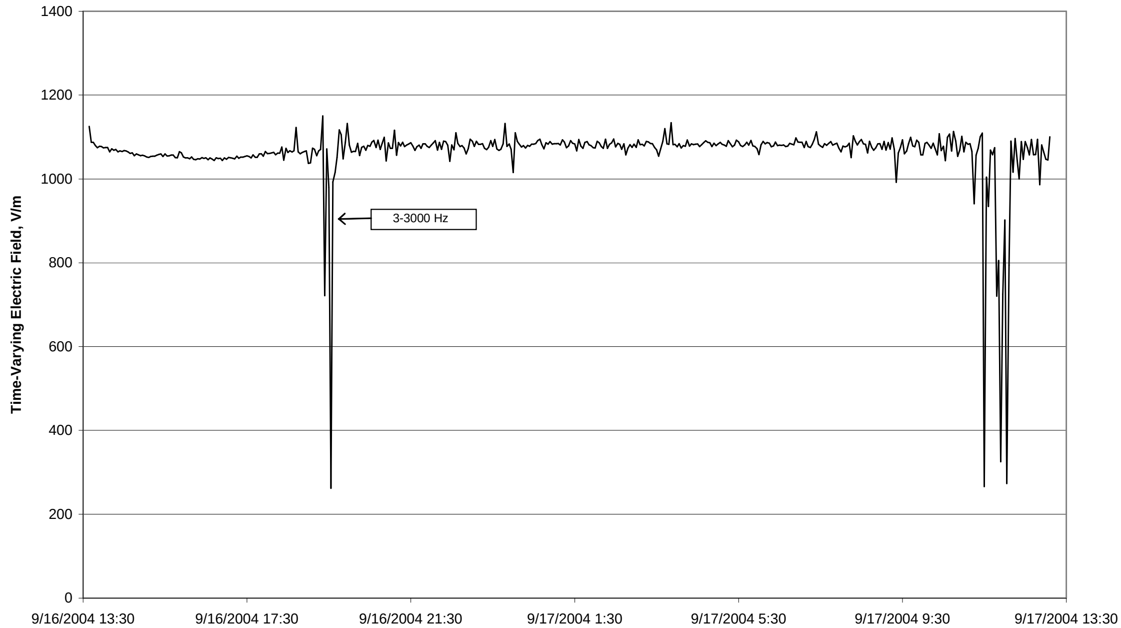


Figure E3. 24-Hour Fluctuation of Static and Time-Varying Magnetic Field Levels at the Grove Beach PS

Table E2. Summary Statistics for Perimeter Profile ELF Field Measurements at the Grove Beach PS

Field Parameter	Minimum	Percentile Levels 5	25	50	75	95	Maximum	Average	Standard Deviation
Static Magnetic Field in milligauss									
Total	411	423	469	489	512	529	563	486	35.9
ELF Magnetic Field in milligauss									
3-57 Hz	0.1	0.2	0.3	0.4	0.6	1.4	2.5	0.6	0.5
57-63 Hz	0.1	0.1	0.1	0.2	0.3	0.5	0.5	0.2	0.1
63-303 Hz	0.1	0.1	0.1	0.2	0.3	0.4	0.6	0.2	0.1
303-3000 Hz	0.0	0.0	0.0	0.1	0.1	0.1	0.3	0.1	0.0
3-3000 Hz	0.2	0.3	0.4	0.5	0.7	1.5	2.7	0.7	0.5
ELF Electric Field in volts per meter									
3-3000 Hz	1.7	2.7	17.5	72.3	311.5	629.3	666.4	194.2	239.7

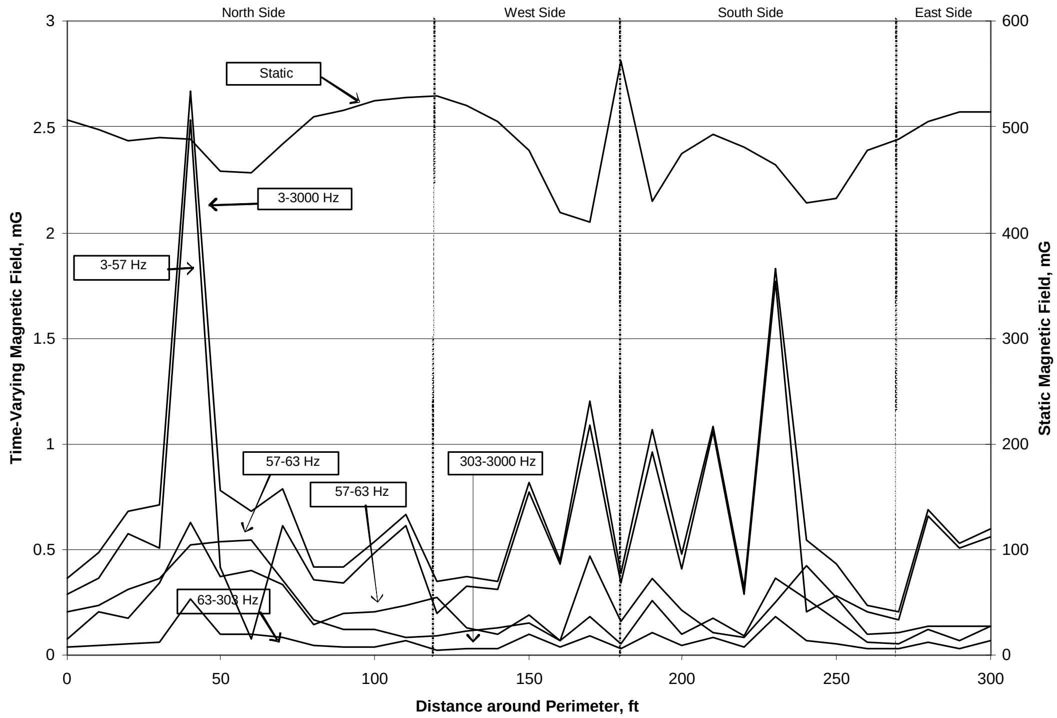


Figure E4. Static and Time-Varying Magnetic Field Levels around the Perimeter of the Grove Beach PS

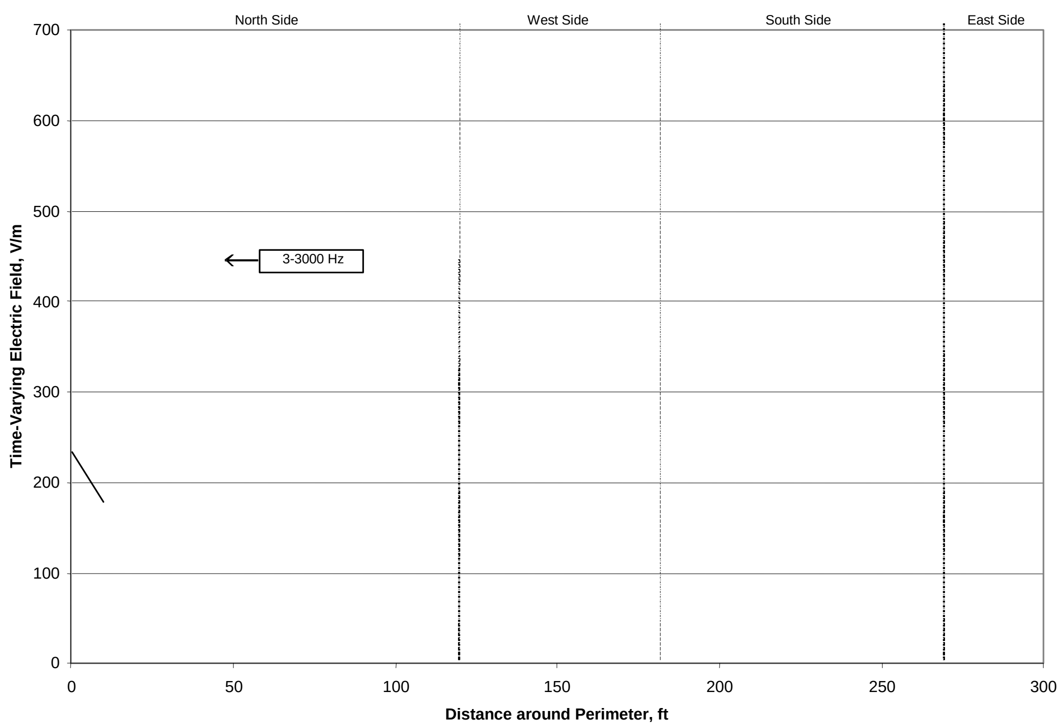


Figure E5. Time-Varying Electric Field Levels around the Perimeter of the Grove Beach PS

Table E3. Summary Statistics for the Lateral Profile Field Measurements at the Grove Beach PS

Field Parameter	Minimum	Percentile Levels 5	25	50	75	95	Maximum	Average	Standard Deviation
Static Magnetic Field in milligauss									
Total	515	522	534	538	541	541	542	535	7.3
ELF Magnetic Field in milligauss									
3-57 Hz	0.2	0.3	0.5	0.5	0.7	1.1	1.2	0.6	0.3
57-63 Hz	0.0	0.0	0.0	0.1	0.1	0.2	0.2	0.1	0.1
63-303 Hz	0.0	0.0	0.1	0.1	0.1	0.2	0.2	0.1	0.0
303-3000 Hz	0.0	0.0	0.0	0.1	0.1	0.1	0.1	0.1	0.0
3-3000 Hz	0.2	0.3	0.5	0.6	0.7	1.1	1.2	0.6	0.3
ELF Electric Field in volts per meter									
3-3000 Hz	1.7	1.7	1.7	1.8	1.9	32.4	119.7	9.0	26.2

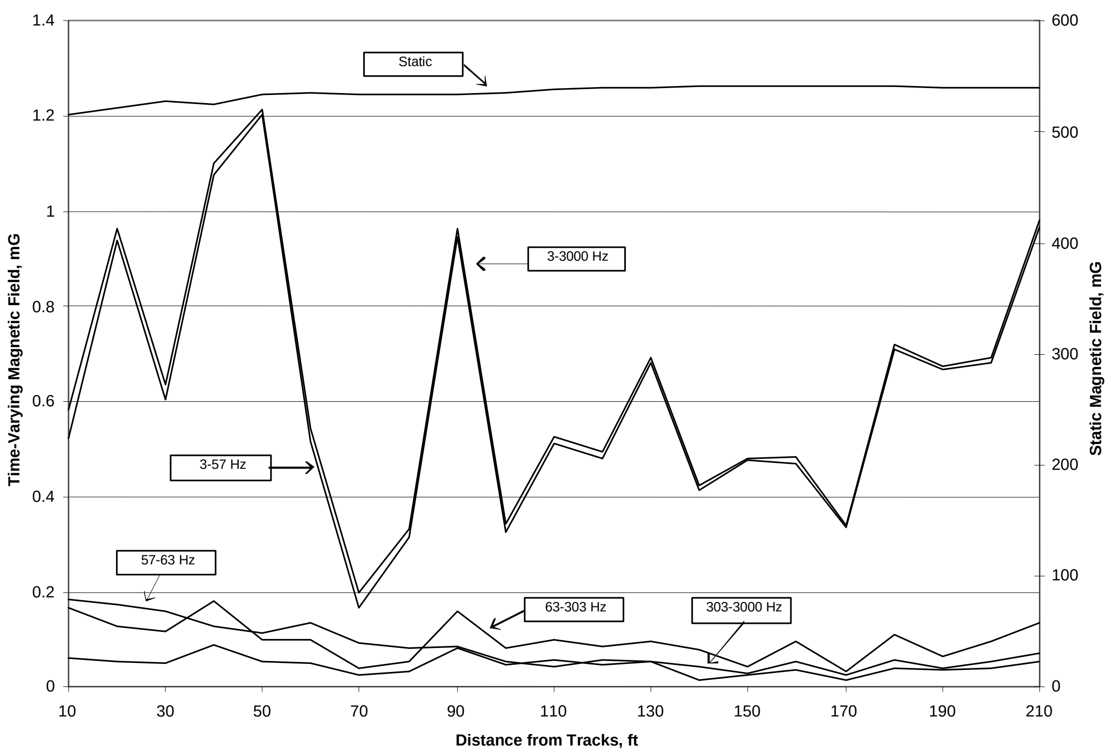


Figure E6. Lateral Profile of Static and Time-Varying Magnetic Field Levels at the Grove Beach PS

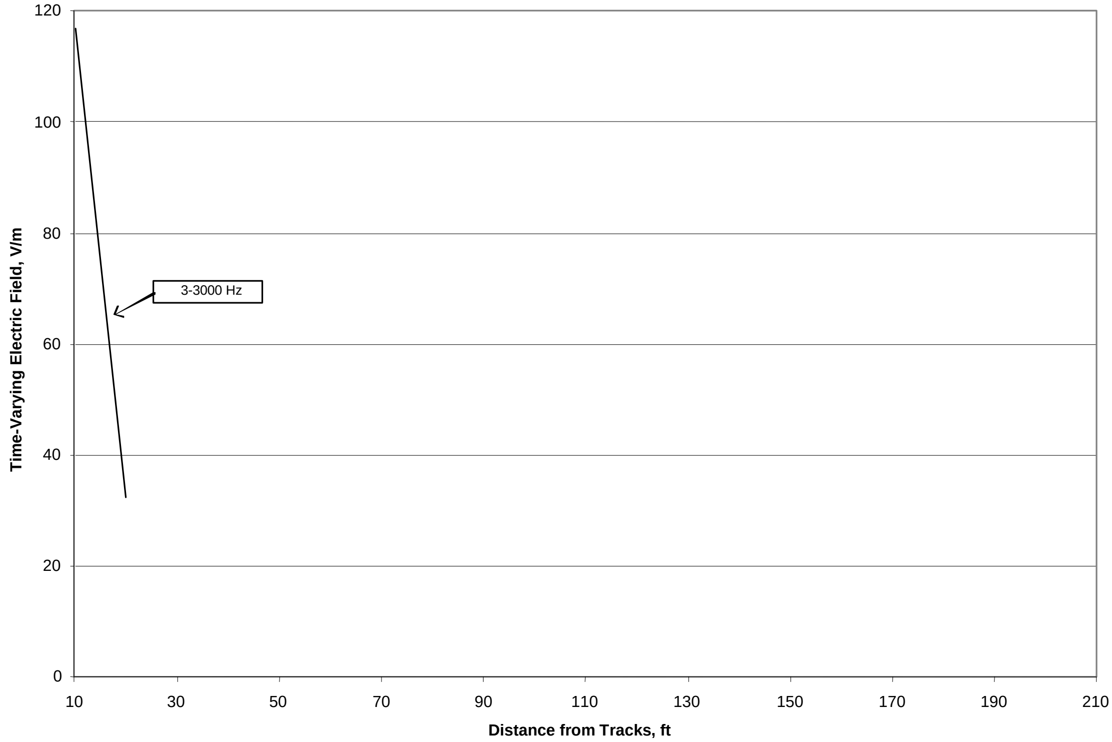


Figure E7. Lateral Profile of Time-Varying Electric Field Levels at the Grove Beach PS

Appendix F
Noank, CT, Paralleling Station

Milepost 129+2653

Location Type: Suburban

24-Hour Measurements:

Start:	9/15/04 11:21:28 EDT
Finish:	9/14/04 10:48:28 EDT
Sample Interval:	3 minutes
No. of Samples:	470
Location:	10 feet southeast of the intersection at Groton Long Point Road and Elm Street.

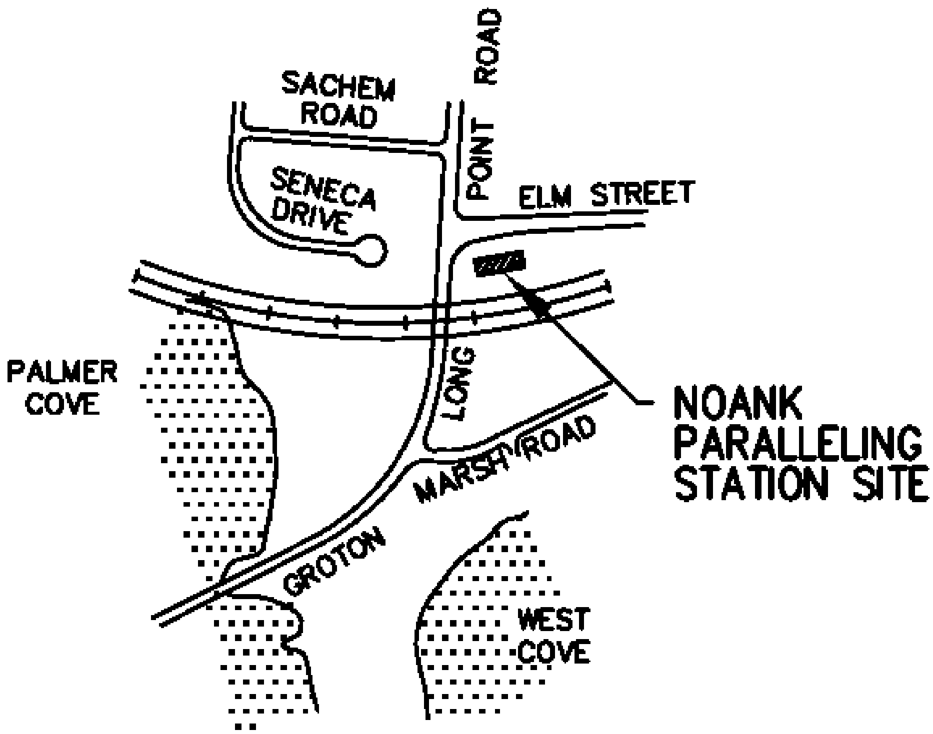
Perimeter Profile Measurements:

Start:	9/15/04 11:30:21 EDT
Sample Interval:	10 foot
No. of Samples:	77
Location:	On bike path located on the east side of Groton Long Point Road continuing around the bend onto the south side of Elm Steet. The profile went 15 feet north of the track, starting at the bridge abutment for Groton Long Point Road and continuing a total distance of 300 feet.

Lateral Profile Measurements: No lateral measurement profile at Noank due to underbrush and steep hill.

Site Anomalies: This site is overgrown with brush so that it was impossible to make the normal perimeter and later profile measurements. The long-term measurement location was close to trees.

Field Characteristics: The long-term magnetic fields show rail activity during the day and a quiet period at night from about 11:00 p.m. to 6:00 a.m. the next morning. Long-term electric fields were very low. The perimeter profile results showed a peak field of about 40 mG when passing below the station lines connecting to the track overhead catenary system.



Noank, CT, Paralleling Station

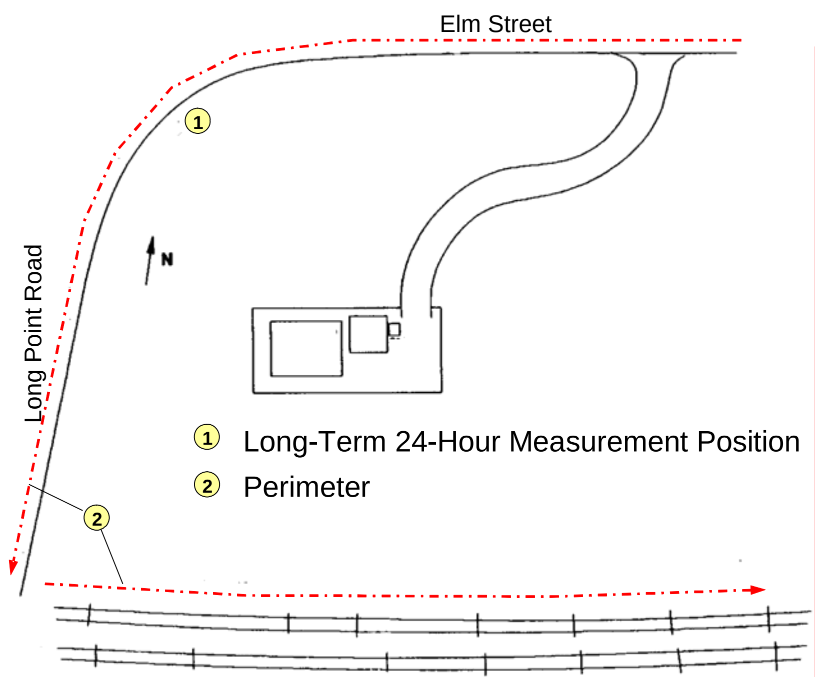


Figure F1. Vicinity Map (top) and Sketch Showing Measurement Locations at the Noank PS

Figure F2. Noank PS on Hill above Amtrak Corridor

Table F1. Summary Statistics for 24-Hour Field Measurements at Noank PS

Field Parameter	Minimum	Percentile Levels 5	25	50	75	95	Maximum	Average	Standard Deviation
Static Magnetic Field in milligauss									
Total	539	542	542	542	542	542	543	542	0.4
ELF Magnetic Field in milligauss									
3-57 Hz	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0
57-63 Hz	0.1	0.1	0.2	0.2	0.3	0.5	2.2	0.3	0.2
63-303 Hz	0.0	0.0	0.0	0.0	0.0	0.1	0.2	0.0	0.0
303-3000 Hz	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0
3-3000 Hz	0.1	0.1	0.2	0.2	0.3	0.5	2.2	0.3	0.2
ELF Electric Field in volts per meter									
3-3000 Hz	0.1	0.3	0.3	0.4	0.4	0.4	0.4	0.3	0.0

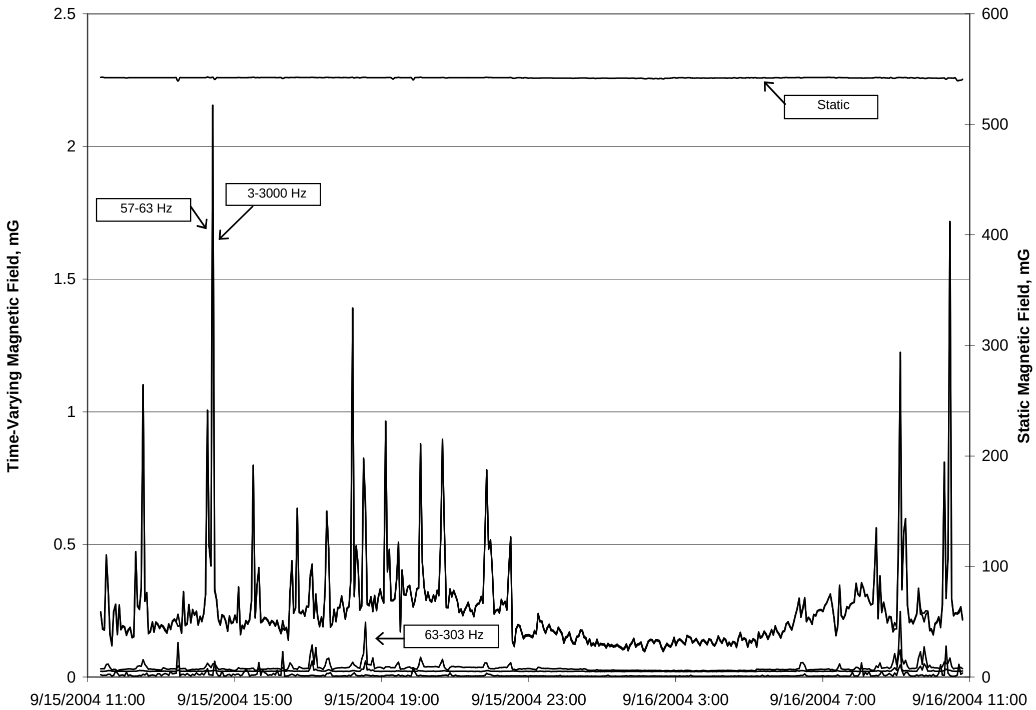


Figure F3. 24-Hour Fluctuation of Static and Time-Varying Magnetic Field Levels at the Noank PS

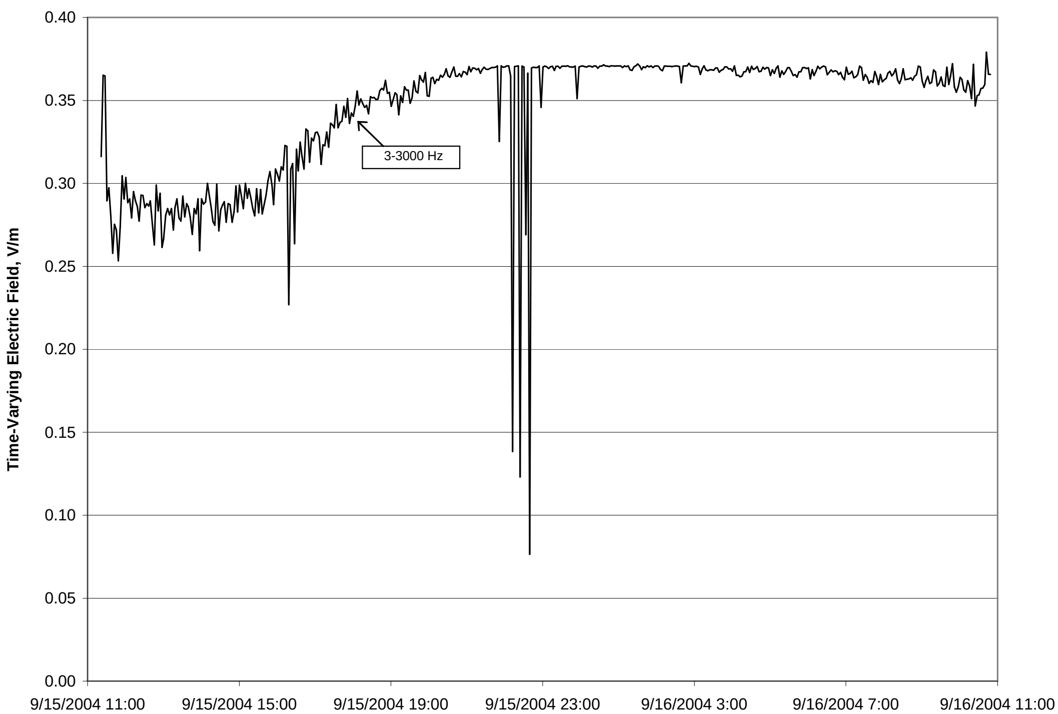


Figure F4. 24-Hour Fluctuation of Time-Varying Electric Field Levels at the Noank PS

Table F2. Summary Statistics for Perimeter Profile ELF Field Measurements at the Noank PS

Field Parameter	Minimum	Percentile Levels 5	25	50	75	95	Maximum	Average	Standard Deviation
Static Magnetic Field in milligauss									
Total	442	503	528	537	540	581	730	538	33.1
ELF Magnetic Field in milligauss									
3-57 Hz	0.2	1.1	1.8	2.6	3.6	4.9	6.0	2.7	1.3
57-63 Hz	0.1	0.2	0.5	1.2	2.4	9.7	47.9	3.1	7.5
63-303 Hz	0.1	0.1	0.3	0.5	0.8	1.2	3.0	0.6	0.5
303-3000 Hz	0.0	0.1	0.2	0.2	0.4	0.5	1.1	0.3	0.2
3-3000 Hz	1.2	1.5	2.5	3.4	4.6	9.7	48.1	5.0	7.1
ELF Electric Field in volts per meter									
3-3000 Hz	1.8	1.9	2.0	3.4	374.7	571.2	646.1	161.1	218.7

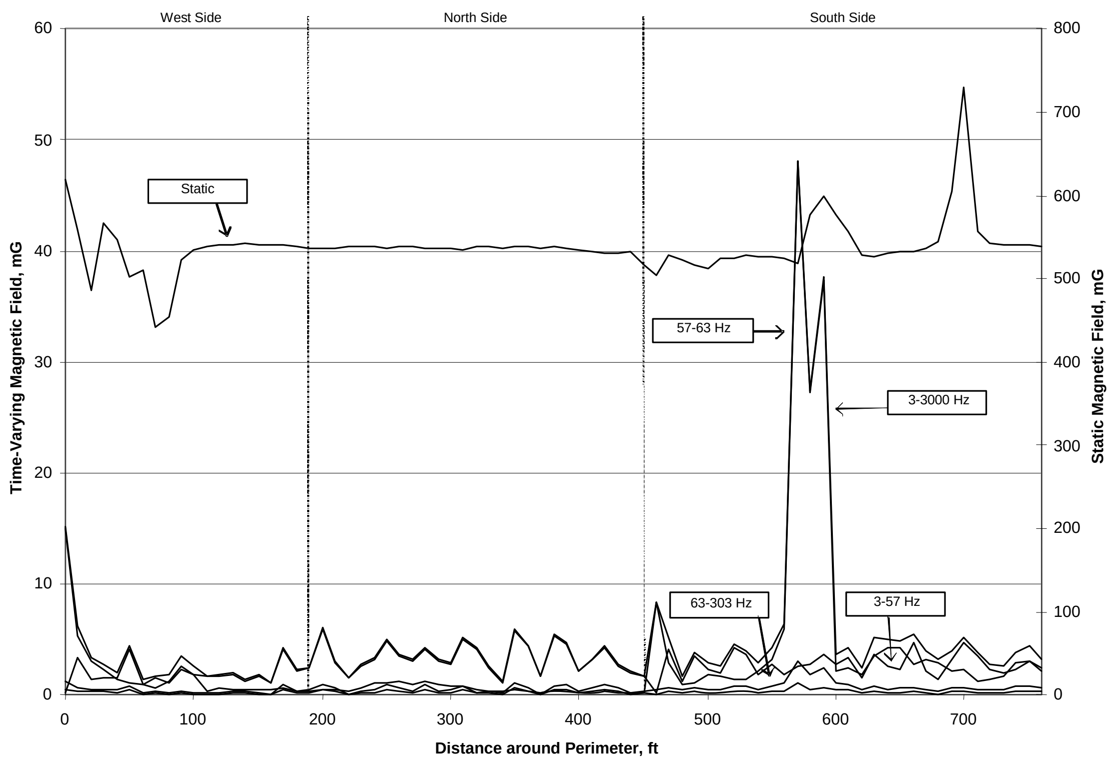


Figure F5. Static and Time-Varying Magnetic Field Levels around the Perimeter of the Noank PS

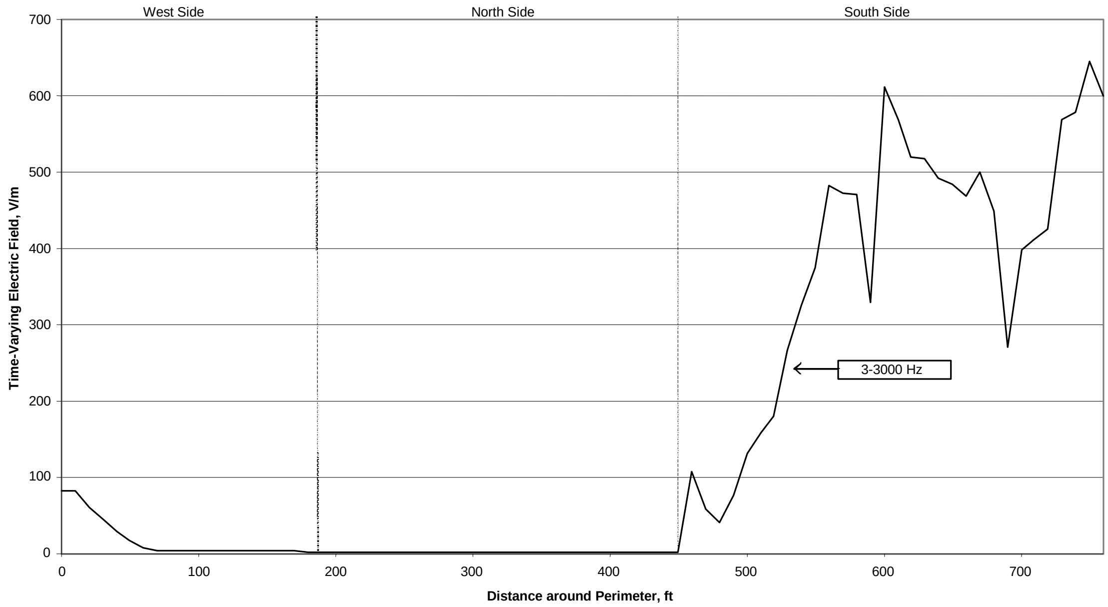


Figure F6. Time-Varying Electric Field Levels around the Perimeter of the Noank PS

Appendix G
Stonington, CT, Paralleling Station

Milepost 134+3677

Location Type: Rural

24-Hour Measurements:

Start:	9/15/04 10:00:46 EDT
Finish:	9/16/04 09:27:46 EDT
Sample Interval:	3 minutes
No. of Samples:	470
Location:	In front of the entrance gate to the PS, approximately 45 feet from the tracks, on the east property line.

Perimeter Profile Measurements:

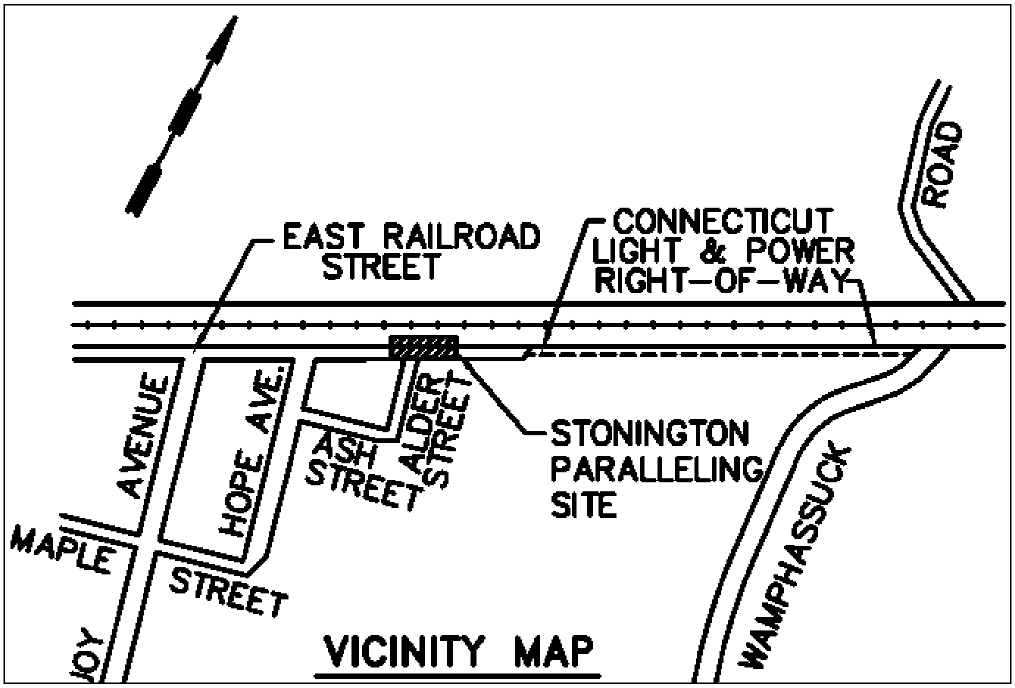
Start:	9/15/04 09:50:43 EDT
Sample Interval:	10 foot
No. of Samples:	33
Location:	3 feet outside the station fence.

Lateral Profile Measurements:

Start:	9/15/04 09:58:08 EDT
Sample Interval:	10 foot
No. of Samples:	15
Location:	Starting 10 feet from the tracks, heading along the east property line to 150 feet from the tracks.

Site Anomalies: An overhead distribution line that was directly over the site at the time of the pre-electrification measurements had been moved approximately 40 feet south of the power station.

Field Characteristics: The long-term magnetic fields were about 5 mG with spikes from 10 mG to 20 mG that are apparently due to trains. A quiet period is visible in the long-term magnetic field measurement plot, from about 11:00 p.m. to 6:00 a.m. The long-term electric field is essentially constant with several spikes. Perimeter magnetic and electric field results appear to correspond to the location of electrical connections to the station and equipment inside the fence-line.



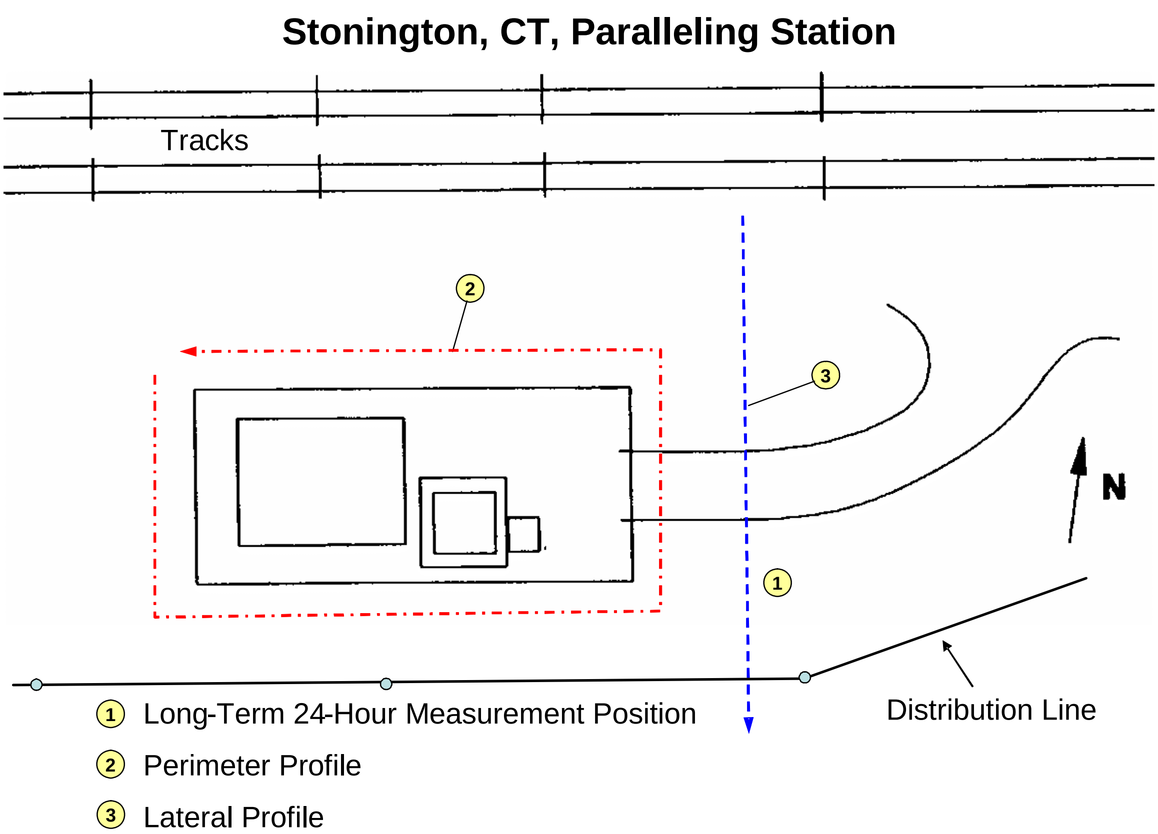


Figure G1. Vicinity Map (top) and Sketch Showing Measurements Locations (bottom) at the Stonington PS

Figure G2. Stonington PS

Table G1. Summary Statistics for 24-Hour Field Measurements at Stonington PS

Field Parameter	Minimum	Percentile Levels 5	25	50	75	95	Maximum	Average	Standard Deviation
Static Magnetic Field in milligauss									
Total	529	529	529	529	530	530	532	529	0.6
ELF Magnetic Field in milligauss									
3-57 Hz	0.0	0.0	0.0	0.0	0.0	0.1	0.4	0.0	0.0
57-63 Hz	3.5	3.6	4.3	5.5	5.8	7.9	22.5	5.4	1.8
63-303 Hz	0.2	0.2	0.2	0.2	0.2	0.4	1.7	0.3	0.1
303-3000 Hz	0.0	0.0	0.0	0.0	0.1	0.1	0.6	0.1	0.0
3-3000 Hz	3.5	3.6	4.3	5.5	5.8	7.9	22.6	5.4	1.8
ELF Electric Field in volts per meter									
3-3000 Hz	909.2	1242.0	1264.4	1279.3	1296.0	1304.8	1373.2	1276.5	32.7

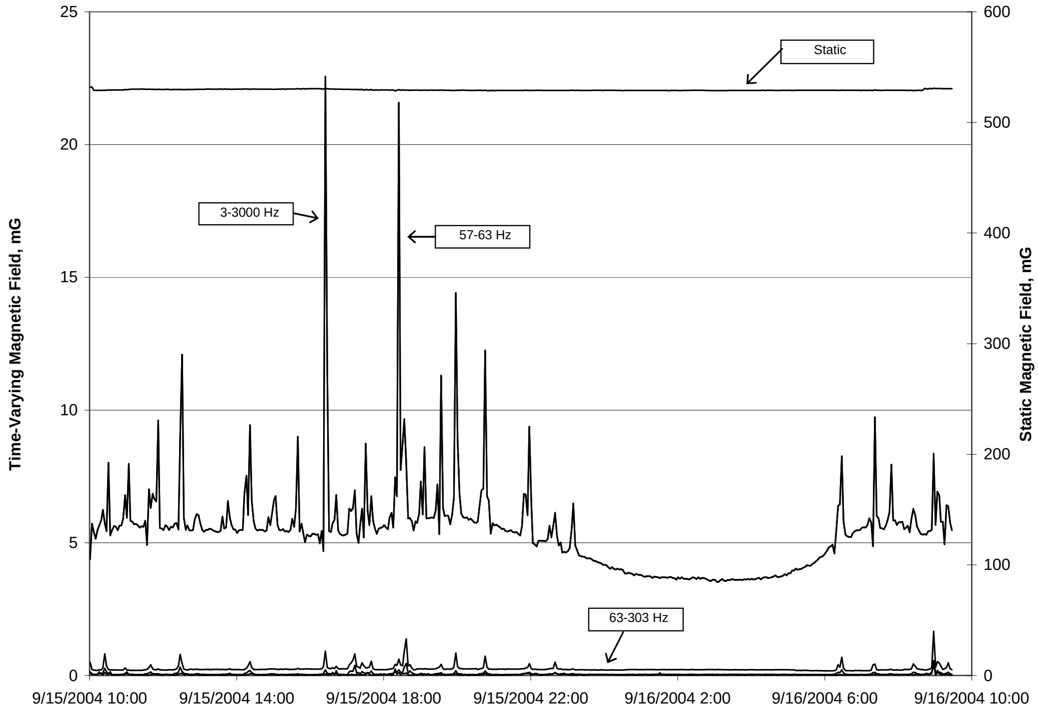


Figure G3. 24-Hour Fluctuation of Static and Time-Varying Magnetic Field Levels at the Stonington PS

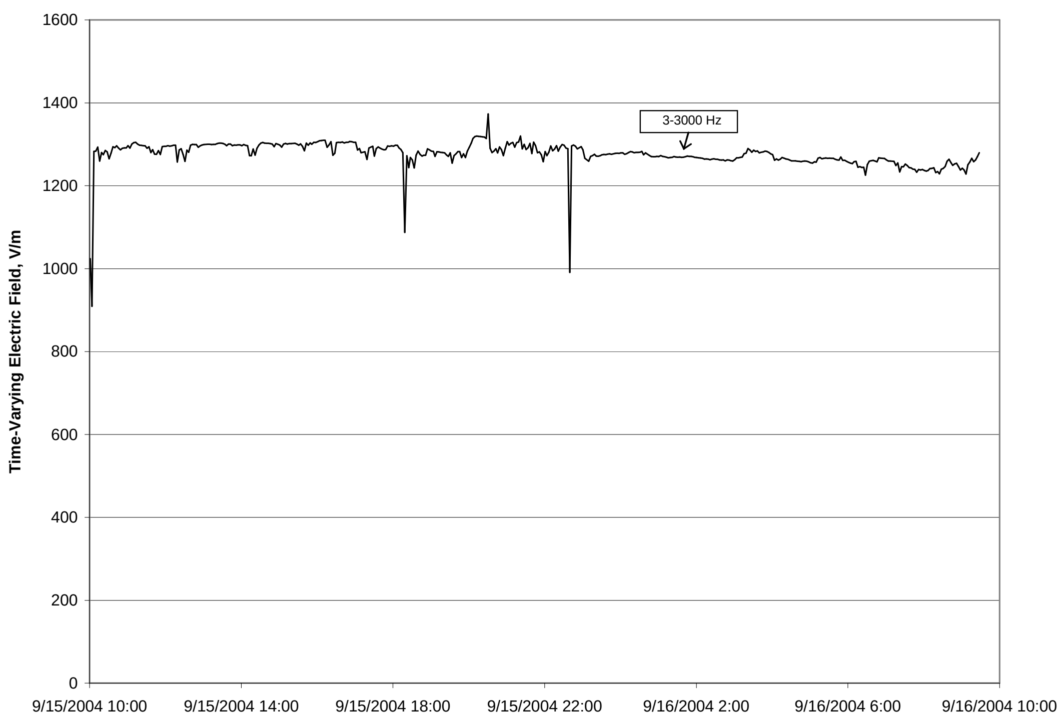


Figure G4. 24-Hour Fluctuation of Time-Varying Electric Field Levels at the Stonington PS

Table G2. Summary Statistics for Perimeter Profile ELF Field Measurements at the Stonington PS

Field Parameter	Minimum	Percentile Levels 5	25	50	75	95	Maximum	Average	Standard Deviation
Static Magnetic Field in milligauss									
Total	468	475	495	510	521	525	529	506	17.3
ELF Magnetic Field in milligauss									
3-57 Hz	0.1	0.2	0.3	0.4	0.7	1.9	4.7	0.7	0.9
57-63 Hz	1.8	2.1	4.5	10.0	11.0	21.7	27.0	9.2	6.0
63-303 Hz	0.2	0.2	0.3	0.4	0.4	1.2	1.5	0.5	0.3
303-3000 Hz	0.0	0.0	0.1	0.1	0.1	0.4	0.5	0.1	0.1
3-3000 Hz	1.9	2.1	4.5	10.0	11.1	21.8	27.1	9.3	6.0
ELF Electric Field in volts per meter									
3-3000 Hz	1.9	2.9	55.5	120.5	155.1	274.2	654.9	118.0	123.0

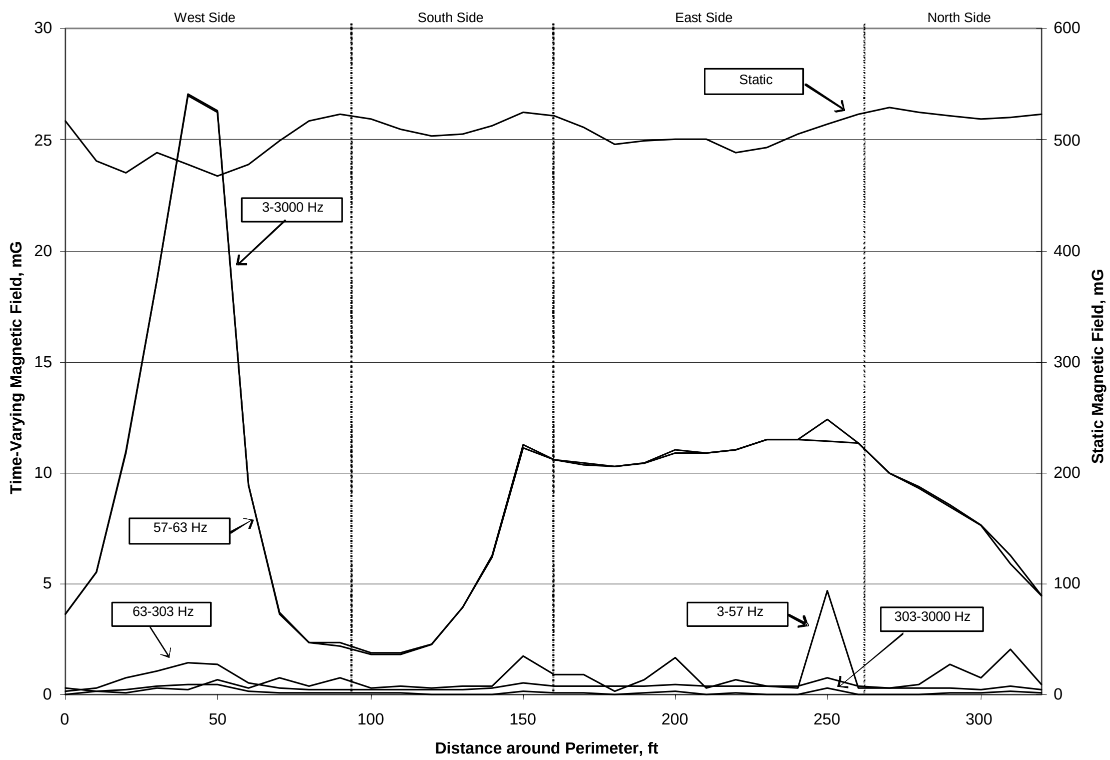


Figure G5. Static and Time-Varying Magnetic Field Levels around the Perimeter of the Stonington PS

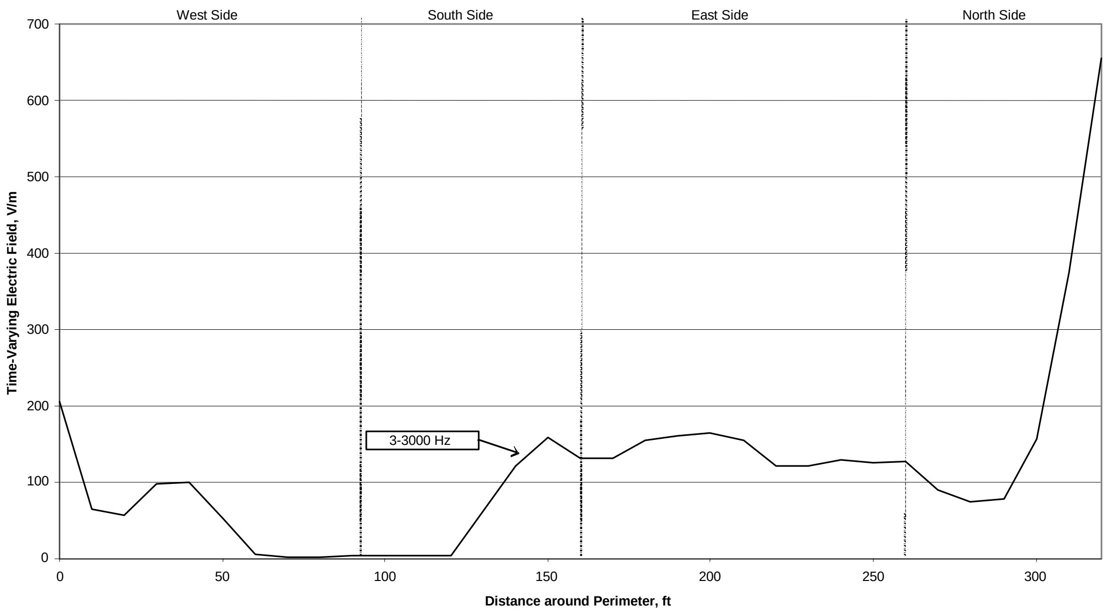


Figure G6. Time-Varying Electric Field Levels around the Perimeter of the Stonington PS

Table G3. Summary Statistics for the Lateral Profile Field Measurements at the Stonington PS

Field Parameter	Minimum	Percentile Levels 5	25	50	75	95	Maximum	Average	Standard Deviation
Static Magnetic Field in milligauss									
Total	496	497	509	529	533	538	539	522	15.3
ELF Magnetic Field in milligauss									
3-57 Hz	0.2	0.2	0.4	0.9	1.1	6.2	12.4	1.7	3.1
57-63 Hz	3.2	3.9	7.7	12.1	13.4	14.5	14.6	10.5	3.9
63-303 Hz	0.1	0.1	0.3	0.4	0.5	1.1	1.9	0.5	0.4
303-3000 Hz	0.0	0.0	0.1	0.1	0.1	0.5	0.9	0.2	0.2
3-3000 Hz	3.2	3.9	7.7	12.5	13.9	15.6	17.3	11.0	4.3
ELF Electric Field in volts per meter									
3-3000 Hz	1.7	1.7	27.2	46.2	70.4	100.0	116.6	47.4	34.1

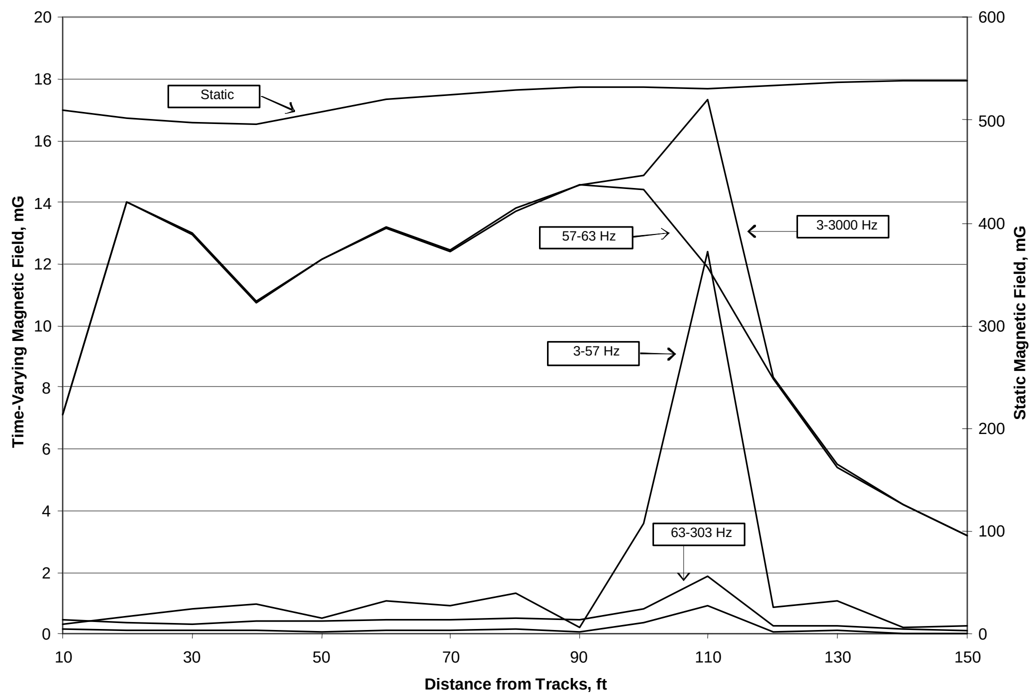


Figure G7. Lateral Profile of Static and Time-Varying Magnetic Field Levels at the Stonington PS

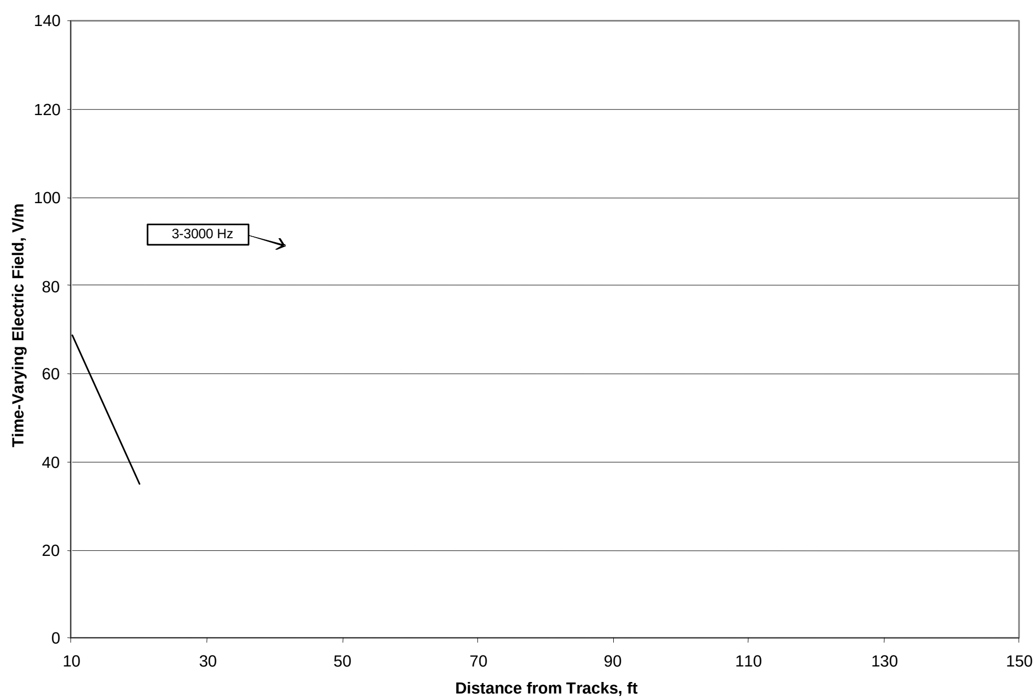


Figure G8. Lateral Profile of Time-Varying Electric Field Levels at the Stonington PS

Appendix H
Roxbury, MA, Paralleling Station

Milepost 226+0585

Location Type: Urban setting, NEC also contains MBTA tracks at this point.

24-Hour Measurements:

Start:	9/13/04 08:48:45 EDT
Finish:	9/14/04 08:15:45 EDT
Sample Interval:	3 minutes
No. of Samples:	470
Location:	Approximately 3 feet inside southeast corner of fence.

Perimeter Profile Measurements:

Start:	9/13/04 08:28:55 EDT
Sample Interval:	10 foot
No. of Samples:	32
Location:	Approximately 3 feet outside fence on south, west, and north property lines.

Lateral Profile Measurements:

Start:	9/13/04 08:47:06 EDT
Sample Interval:	10 foot
No. of Samples:	12
Location:	At milepost 226+560. Starting at corridor trench perpendicular to tracks for a distance of 110 feet out to street.

Site Anomalies: The PS is situated in an urban environment, near parking lots and against the corridor trench that is utilized by both Amtrak and the MBTA commuter rail. The long-term sensor was placed inside the northwest corner of the fence line. Many field sources existed in the area.

Field Characteristics: As with the pre-electrification measurements, the static magnetic fields had far more temporal variability at this site because of the DC electric traction currents in the MBTA lines adjacent to the Amtrak corridor, which varied in intensity in relation to fluctuating traction power needs of trains operating in that power block. The 24-hour data appears to show a quiet time at night when the traction system is not operating.

At the fixed location, the extreme low frequency magnetic fields generally ranged from 5 to 15 mG with occasional spikes near 20 mG. For all measurements, the field was principally 60 Hz, and the average magnetic field seemed to increase at night. Only one large peak was captured in the 3-57 Hz, on the order of 7.5 mG, due to sudden changes in the field produced by the MBTA traction current when a train was passing the measurement point.

Perimeter measurements showed a spatial peak centered on station equipment and increasing fields towards the corridor on both ends of the station. The lateral profile also shows this attenuation moving away from the corridor, falling from 10 mG at the edge of trench down to 2 mG at a distance of 30 feet.

The long-term electric field measured at the fixed position was relatively high because of station power equipment. The field was nearly constant (see Table H1). The spatial profiles show variation of the electric field, also due to the station equipment, but at much lower levels as a result of shielding provided by the station fence.

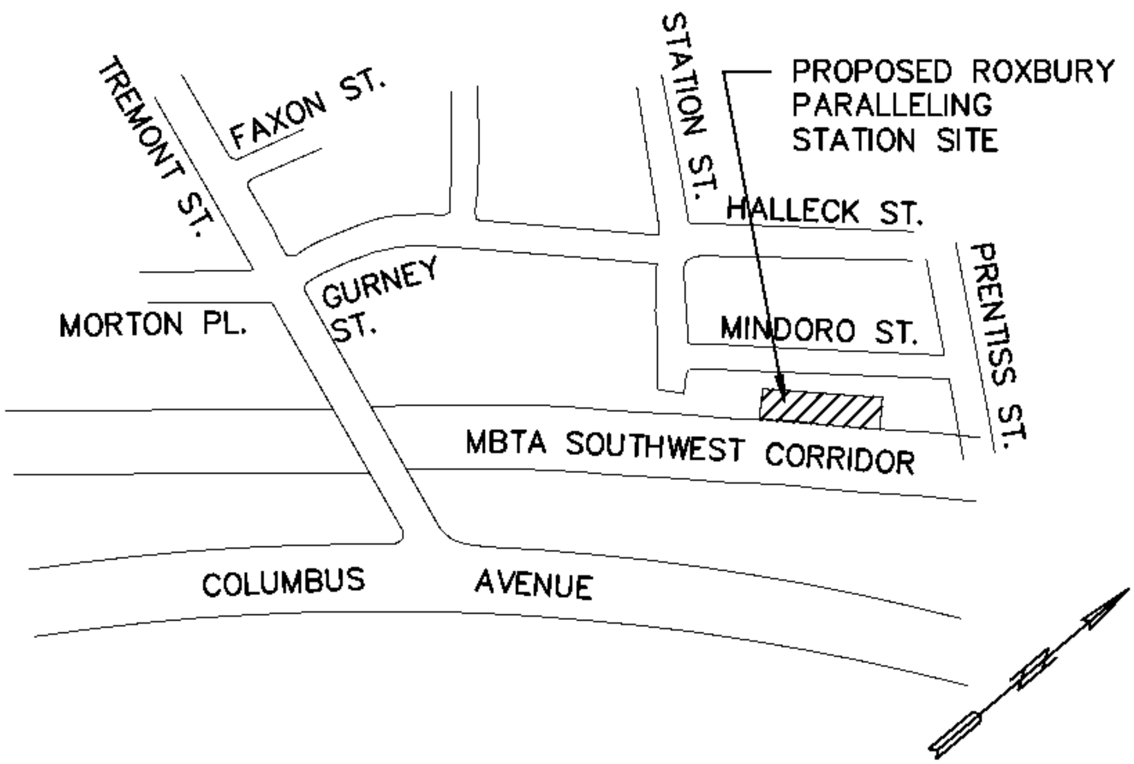
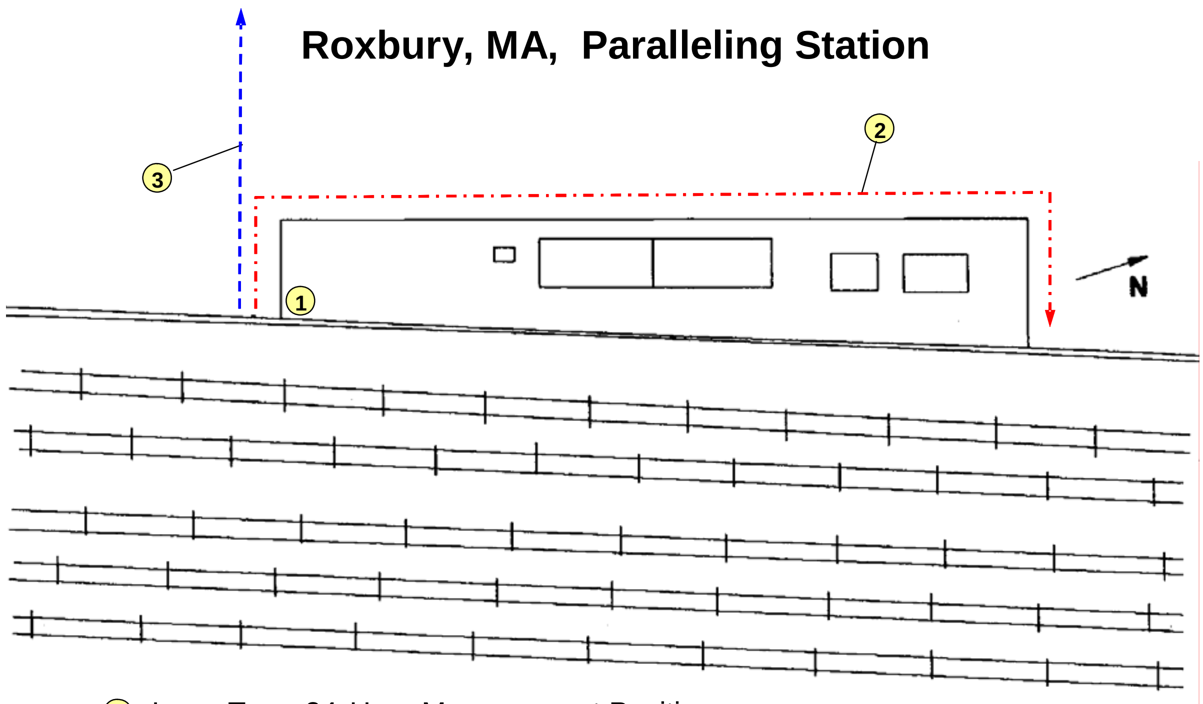


Figure H1. Vicinity Map from Construction Drawing Showing Roxbury PS Location Relative to Nearby Streets



1 Long-Term 24-Hour Measurement Position

2 Perimeter Profile

3 Lateral Profile

Figure H2. Sketch Showing Approximate Measurement at the Roxbury PS

Table H1. Summary Statistics for 24-Hour Field Measurements at Roxbury PS

Field Parameter	Minimum	Percentile Levels 5	25	50	75	95	Maximum	Average	Standard Deviation
Static Magnetic Field in milligauss									
Total	332	404	442	453	468	493	520	453	27.1
ELF Magnetic Field in milligauss									
3-57 Hz	0.0	0.0	0.1	0.1	0.2	0.7	7.5	0.2	0.4
57-63 Hz	3.7	5.5	7.4	8.8	11.8	14.8	21.6	9.7	3.2
63-303 Hz	0.8	0.9	1.0	1.1	1.3	1.4	2.7	1.2	0.2
303-3000 Hz	0.8	1.3	1.6	2.1	2.4	2.6	3.0	2.0	0.4
3-3000 Hz	3.9	5.9	7.7	9.1	12.1	15.1	21.7	10.0	3.2
ELF Electric Field in volts per meter									
3-3000 Hz	1027.6	1031.1	1036.2	1051.4	1057.6	1063.0	1131.3	1048.4	11.9

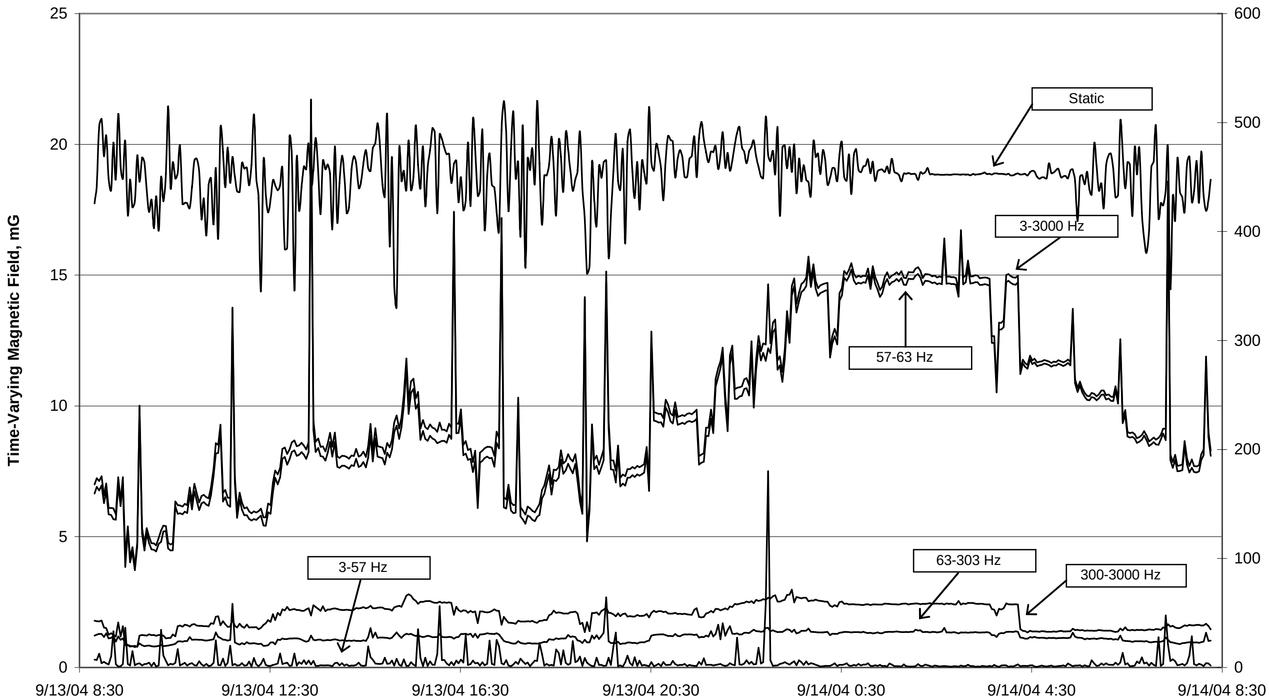


Figure H3. 24-Hour Fluctuation of Static and Time-Varying Magnetic Field Levels at the Roxbury PS

Table H2. Summary Statistics for Perimeter Profile ELF Field Measurements at the Roxbury PS

Field Parameter	Minimum	Percentile Levels 5	25	50	75	95	Maximum	Average	Standard Deviation
Static Magnetic Field in milligauss									
Total	318	417	518	525	536	563	581	513	64.6
ELF Magnetic Field in milligauss									
3-57 Hz	0.2	0.2	0.3	0.4	0.8	4.6	7.9	1.2	2.2
57-63 Hz	0.3	0.3	0.5	0.7	1.8	4.3	5.5	1.5	1.6
63-303 Hz	0.1	0.1	0.1	0.2	0.4	1.1	1.7	0.3	0.5
303-3000 Hz	0.1	0.2	0.3	0.3	0.4	1.1	1.7	0.4	0.4
3-3000 Hz	0.5	0.5	0.7	1.4	2.1	6.4	9.9	2.2	2.6
ELF Electric Field in volts per meter									
3-3000 Hz	2.3	2.6	4.3	6.0	7.5	8.7	9.1	5.8	2.3

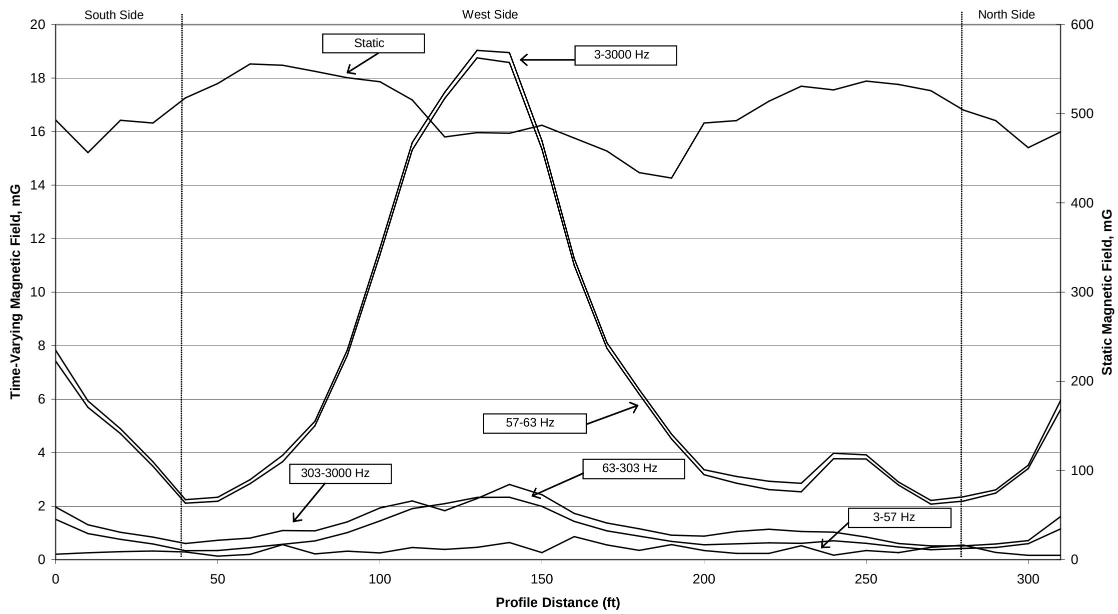


Figure H4. Static and Time-Varying Magnetic Field Levels around the Perimeter of the Roxbury PS

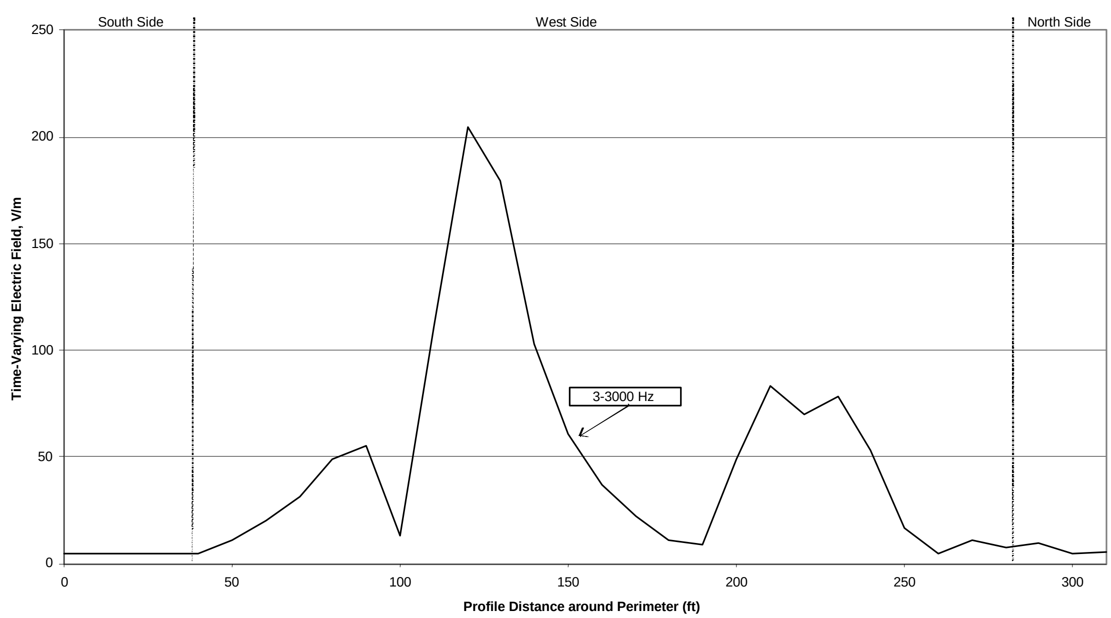


Figure H5. Time-Varying Electric Field Levels around the Perimeter of the Roxbury PS

Table H3. Summary Statistics for the Lateral Profile Field Measurements at the Roxbury PS

Field Parameter	Minimum	Percentile Levels 5	25	50	75	95	Maximum	Average	Standard Deviation
Static Magnetic Field in milligauss									
Total	318	417	518	525	536	563	581	513	64.6
ELF Magnetic Field in milligauss									
3-57 Hz	0.2	0.2	0.3	0.4	0.8	4.6	7.9	1.2	2.2
57-63 Hz	0.3	0.3	0.5	0.7	1.8	4.3	5.5	1.5	1.6
63-303 Hz	0.1	0.1	0.1	0.2	0.4	1.1	1.7	0.3	0.5
303-3000 Hz	0.1	0.2	0.3	0.3	0.4	1.1	1.7	0.4	0.4
3-3000 Hz	0.5	0.5	0.7	1.4	2.1	6.4	9.9	2.2	2.6
ELF Electric Field in volts per meter									
3-3000 Hz	2.3	2.6	4.3	6.0	7.5	8.7	9.1	5.8	2.3

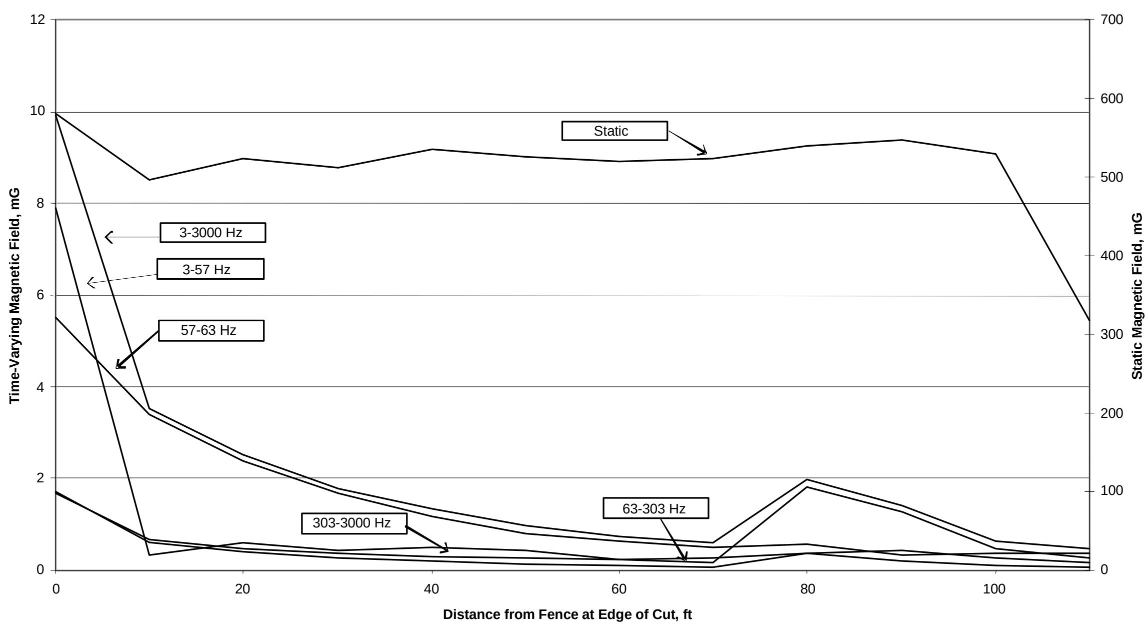


Figure H6. Lateral Profile of Static and Time-Varying Magnetic Field Levels at the Roxbury PS

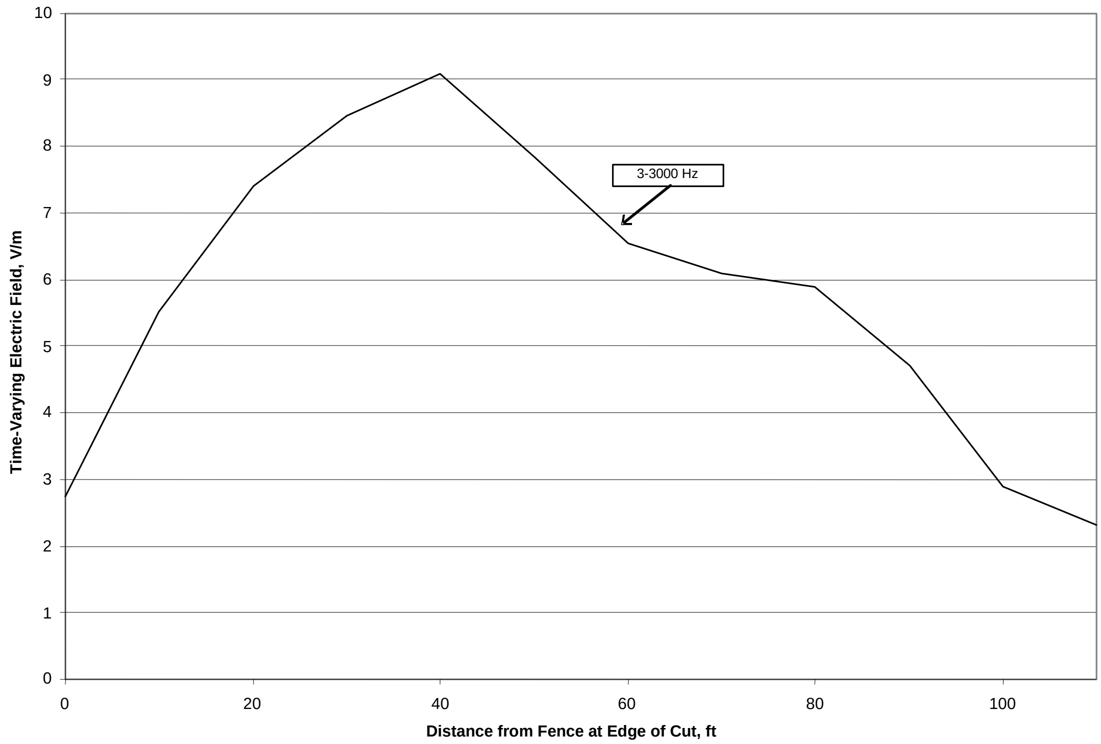


Figure H7. Lateral Profile of Time-Varying Electric Field Levels at the Roxbury PS

Appendix I
New London, CT, Tie-Line

Milepost 123+2887

Location Type: The TL is underground, running beneath urban streets.

24-Hour Measurements:

Start:	9/15/04 17:13:30 EDT
Finish:	9/16/04 16:40:30 EDT
Sample Interval:	3 minutes
No. of Samples:	470
Location:	16 feet north of Lewis Street, 135 feet west of Crystal Avenue.

Perimeter Profile Measurements:

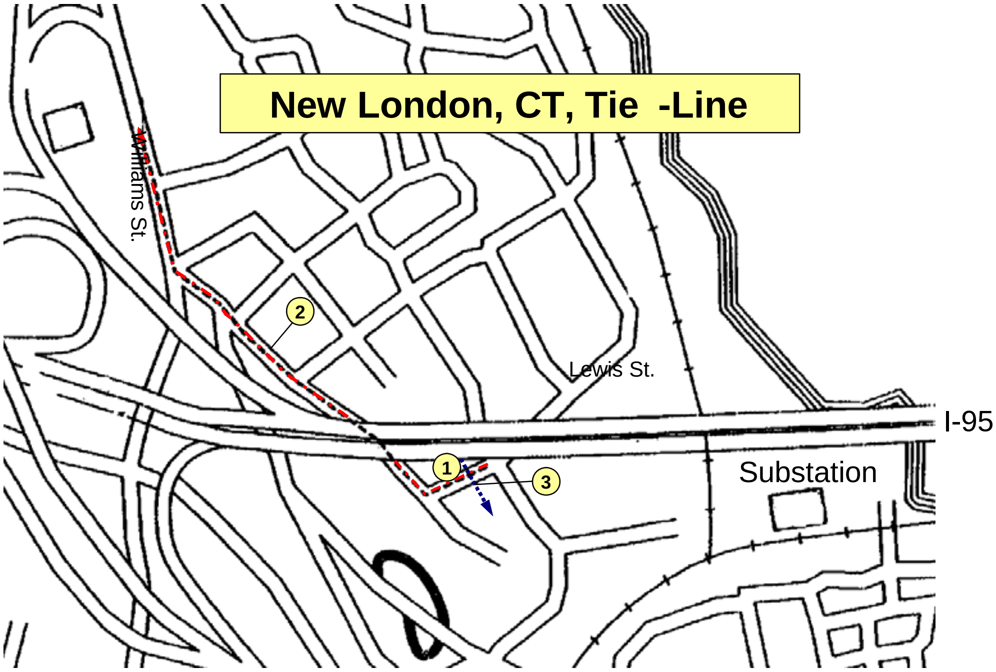
Start:	9/15/04 15:49:10 EDT
Sample Interval:	20 foot
No. of Samples:	210
Location:	Started beneath the interstate on south sidewalk of Lewis Street heading west, then north on west side of Winthrop, Cole, and Williams Streets. Then return on opposite side (east and north sides).

Lateral Profile Measurements:

Start:	9/15/04 16:36:49 EDT
Sample Interval:	10 foot
No. of Samples:	13
Location:	Crossing Lewis Street, from north to south,135 feet west of Crystal Avenue.

Site Anomalies: Urban environment with distribution lines. The underground line runs along city streets.

Field Characteristics: The measured electric and magnetic fields at the long-term locations show very low levels. Fields along the TL profile are mostly due to overhead distribution lines. Magnetic fields from the underground TL are barely visible in the lateral profile.



① Long-Term 24-Hour Measurement Position

② Perimeter Profile

③ Lateral Profile

Figure I1. Sketch Showing Measurement Locations along the New London TL

Table I1. Summary Statistics for 24-Hour Field Measurements near the New London TL

Field Parameter	Minimum	Percentile Levels 5	25	50	75	95	Maximum	Average	Standard Deviation
Static Magnetic Field in milligauss									
Total	528	529	529	529	529	529	530	529	0.2
ELF Magnetic Field in milligauss									
3-57 Hz	0.0	0.0	0.0	0.0	0.0	0.0	0.9	0.0	0.0
57-63 Hz	0.1	0.1	0.2	0.2	0.3	0.4	1.3	0.2	0.1
63-303 Hz	0.0	0.0	0.0	0.1	0.1	0.1	0.1	0.1	0.0
303-3000 Hz	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0
3-3000 Hz	0.1	0.1	0.2	0.2	0.3	0.4	1.3	0.2	0.1
ELF Electric Field in volts per meter									
3-3000 Hz	0.0	0.0	0.0	0.2	0.7	1.4	2.5	0.4	0.5

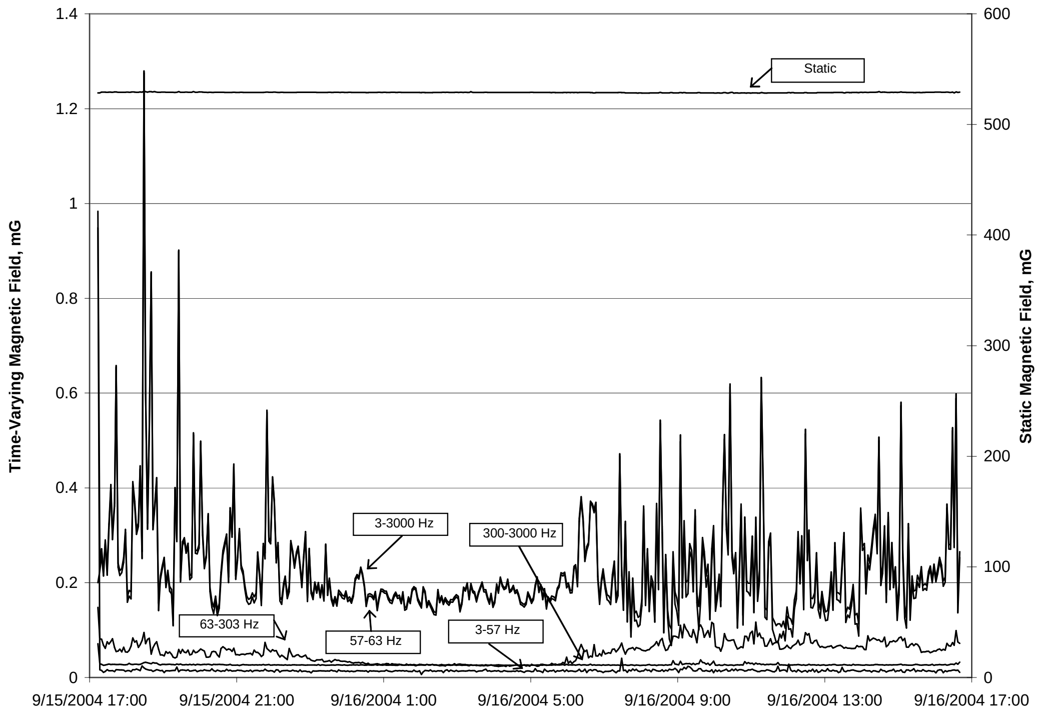


Figure I2. 24-Hour Fluctuation of Static and Time-Varying Magnetic Field Levels near the New London TL

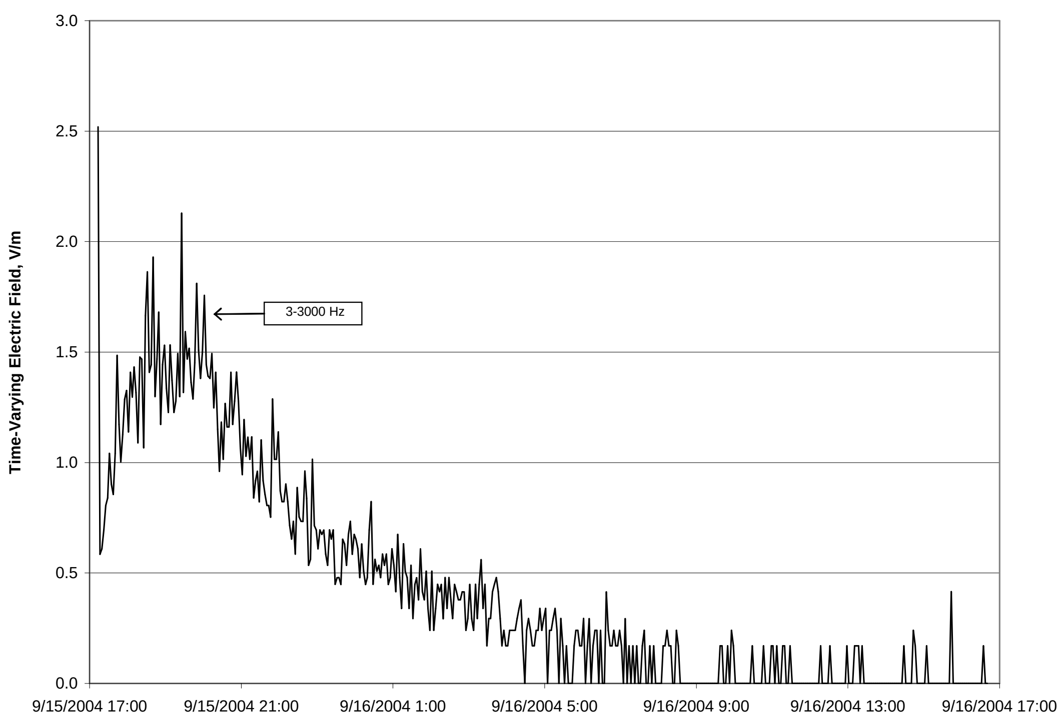


Figure I3. 24-Hour Fluctuation of Time-Varying Electric Field Levels near the New London TL

Table I2. Summary Statistics for Perimeter Profile ELF Field Measurements near the New London TL

Field Parameter	Minimum	Percentile Levels 5	25	50	75	95	Maximum	Average	Standard Deviation
Static Magnetic Field in milligauss									
Total	449	513	534	540	548	573	623	541	20.2
ELF Magnetic Field in milligauss									
3-57 Hz	0.2	1.4	2.4	3.5	4.9	7.4	9.4	3.9	1.9
57-63 Hz	0.2	0.4	0.6	0.9	2.1	7.7	14.8	2.1	2.5
63-303 Hz	0.2	0.3	0.5	0.7	1.1	2.6	5.7	1.0	0.8
303-3000 Hz	0.0	0.1	0.2	0.3	0.4	0.7	1.1	0.3	0.2
3-3000 Hz	1.0	1.7	3.0	4.1	6.4	9.8	17.5	4.9	2.6
ELF Electric Field in volts per meter									
3-3000 Hz	1.9	2.0	2.3	6.2	21.9	83.8	150.2	19.6	28.1

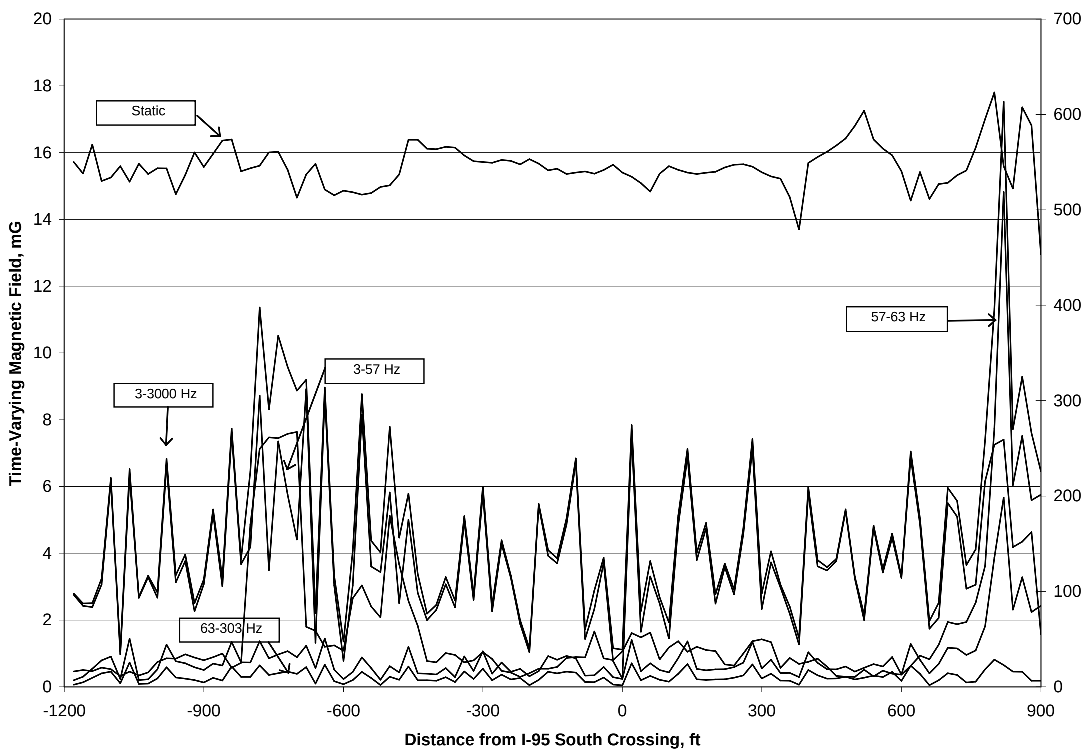


Figure I4. Static and Time-Varying Magnetic Field Levels along the New London TL on the South and West Sides of the Streets

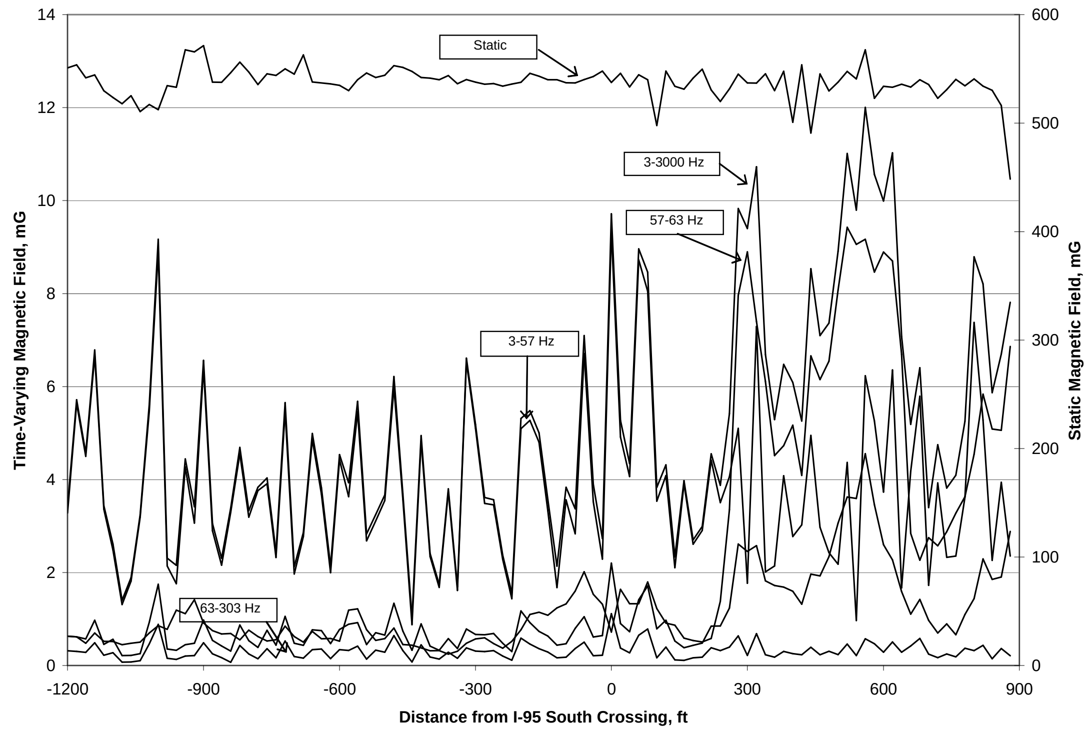


Figure I5. Static and Time-Varying Magnetic Field Levels along the New London TL on the East and North Sides of the Streets

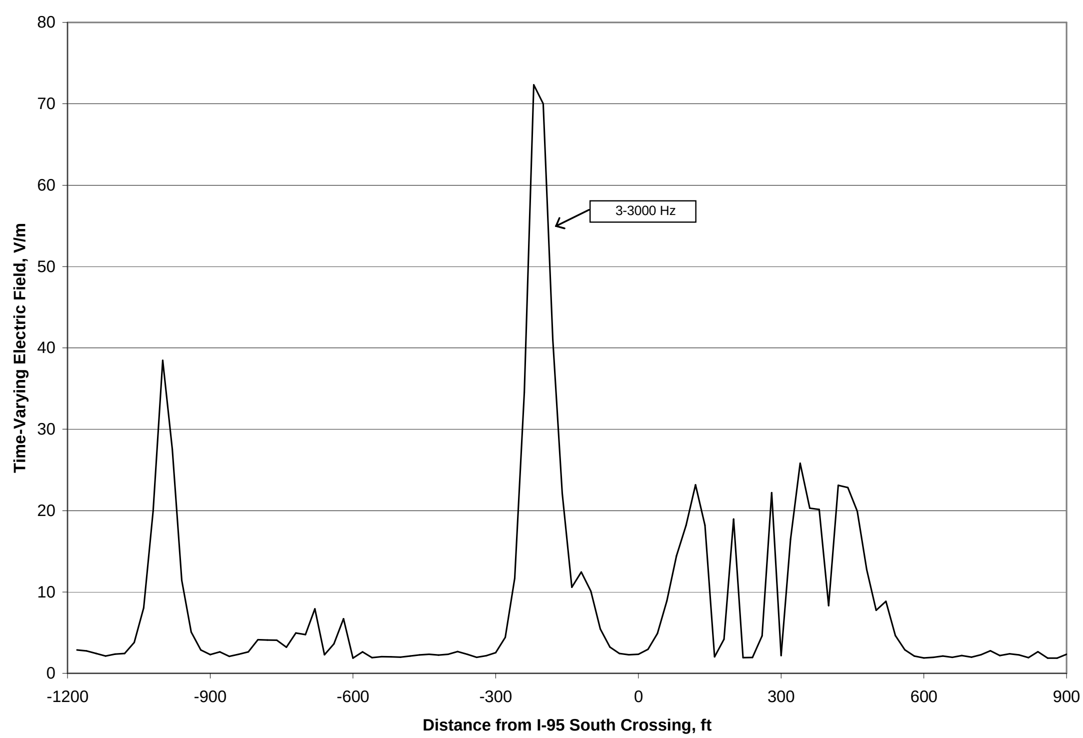


Figure I6. Time-Varying Electric Field Levels along the New London TL on the South Side of the Streets

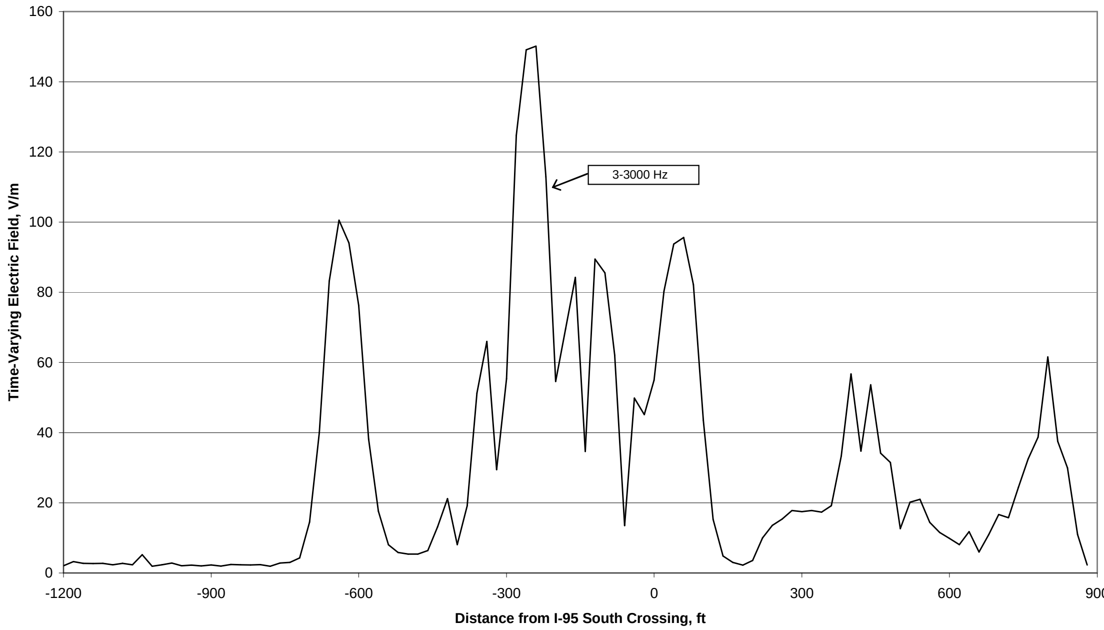


Figure I7. Time-Varying Electric Field Levels along the New London TL on the North Side of the Streets

Table I3. Summary Statistics for the Lateral Profile Field Measurements near the New London TL

Field Parameter	Minimum	Percentile Levels 5	25	50	75	95	Maximum	Average	Standard Deviation
Static Magnetic Field in milligauss									
Total	511	512	523	535	542	552	553	533	14.5
ELF Magnetic Field in milligauss									
3-57 Hz	0.1	0.1	0.2	0.7	0.9	1.9	2.1	0.7	0.6
57-63 Hz	0.2	0.2	0.4	0.6	1.0	1.4	1.7	0.7	0.4
63-303 Hz	0.1	0.1	0.1	0.2	0.3	0.5	0.6	0.2	0.2
303-3000 Hz	0.0	0.0	0.1	0.1	0.1	0.1	0.1	0.1	0.0
3-3000 Hz	0.3	0.5	0.7	1.1	1.4	2.1	2.5	1.2	0.6
ELF Electric Field in volts per meter									
3-3000 Hz	1.8	1.9	1.9	1.9	2.1	2.2	2.3	2.0	0.1

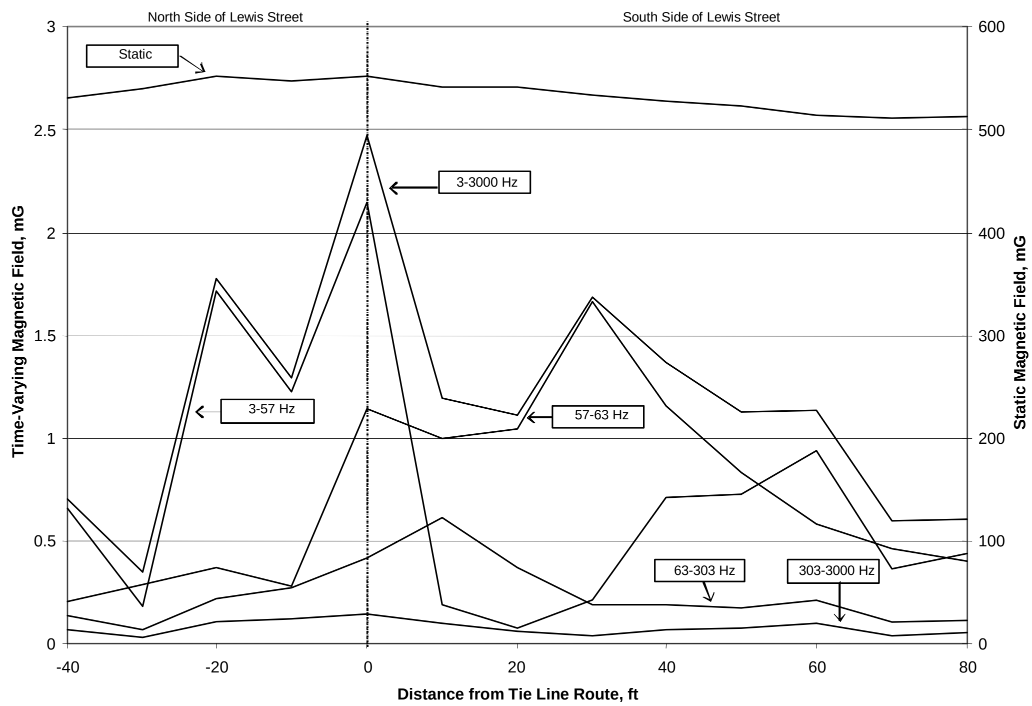


Figure I8. Lateral Profile of Static and Time-Varying Magnetic Field Levels near the New London TL

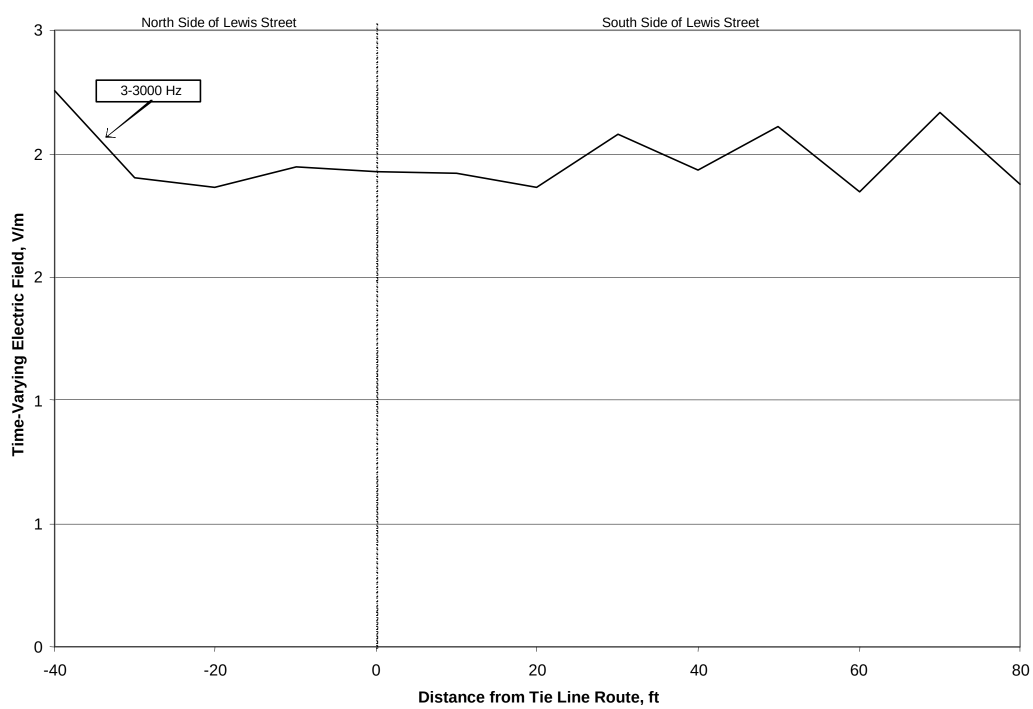


Figure I9. Lateral Profile of Time-Varying Electric Field Levels near the New London TL

Appendix J
Warwick, RI, Tie-Line

Milepost 176+4943

Location Type: Urban

24-Hour Measurements:

Start:	9/13/04 12:54:24 EDT
Finish:	9/14/04 12:21:24 EDT
Sample Interval:	3 minutes
No. of Samples:	470
Location:	On SS side of street, beyond sidewalk.

Perimeter Profile Measurements:

Start:	9/13/04 12:21:44 EDT
Sample Interval:	10 foot
No. of Samples:	52
Location:	Start at sidewalk adjacent to SS, follow underground route, across the street, and through a parking lot.

Lateral Profile Measurements:

Start:	9/13/04 12:30:55 EDT
Sample Interval:	10 foot
No. of Samples:	82
Location:	Started on west side of Jefferson Boulevard 200 feet south of underground TL, recorded for 400 feet heading north. Returned south on east side of Jefferson Boulevard.

Site Anomalies: Urban environment with distribution lines. The underground line passes beneath a major street and through a parking lot beside a business.

Field Characteristics: During the long-term measurements, the static magnetic field was relatively constant. Time-varying magnetic fields ranged from 2 to 15 mG, with the largest fields being at the 60 Hz power frequency. Electric fields were relatively low at the long-term measurement location. Magnetic fields along the TL ranged from 2 to 10 mG, increasing to 20 mG at the transmission line connection. The electric field is relatively low along the TL because of its underground configuration, increasing only at the transmission line connection.

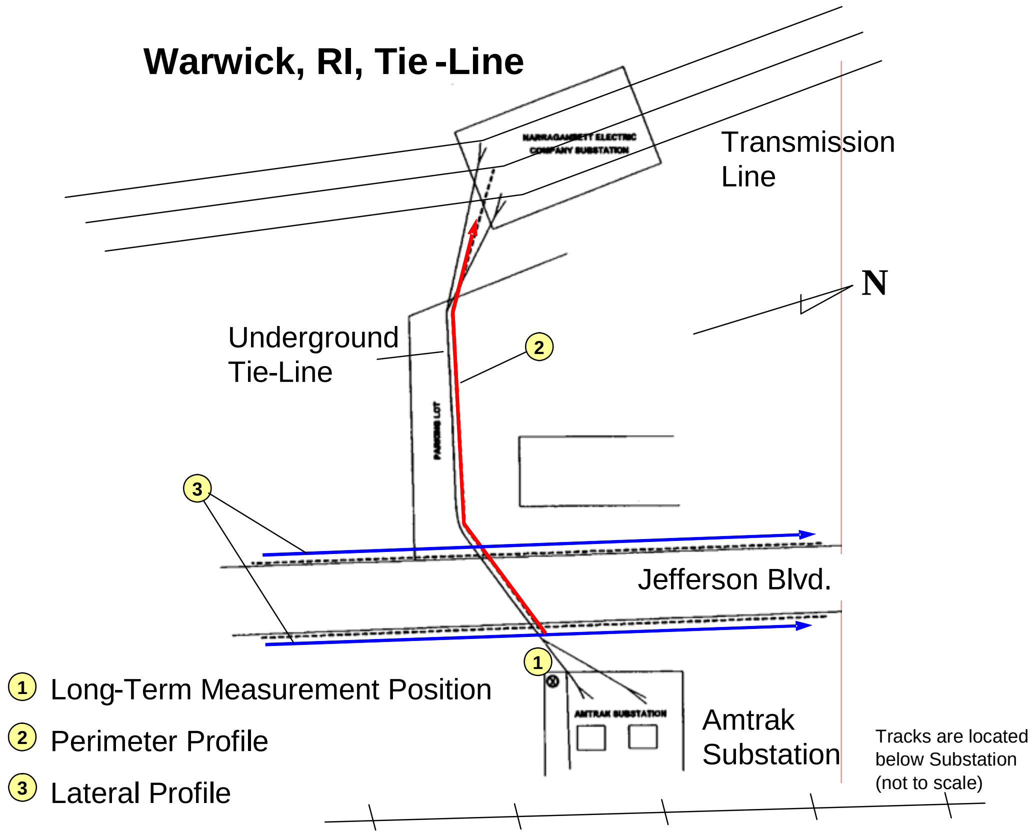


Figure J1. Sketch Showing Measurement Locations at Warwick TL

Table J1. Summary Statistics for 24-Hour Field Measurements near Warwick TL

Field Parameter	Minimum	Percentile Levels 5	25	50	75	95	Maximum	Average	Standard Deviation
Static Magnetic Field in milligauss									
Total	505	506	506	507	507	508	520	507	0.9
ELF Magnetic Field in milligauss									
3-57 Hz	0.0	0.0	0.0	0.0	0.1	0.1	0.6	0.0	0.0
57-63 Hz	0.9	1.1	1.5	2.0	3.4	9.1	23.9	3.1	2.9
63-303 Hz	0.6	1.0	1.1	1.2	1.3	1.7	3.7	1.3	0.3
303-3000 Hz	0.2	0.2	0.2	0.3	0.3	0.4	0.6	0.3	0.0
3-3000 Hz	1.5	1.6	1.9	2.4	3.7	9.3	23.9	3.5	2.8
ELF Electric Field in volts per meter									
3-3000 Hz	0.0	0.0	0.3	1.0	2.1	2.6	2.7	1.2	0.9

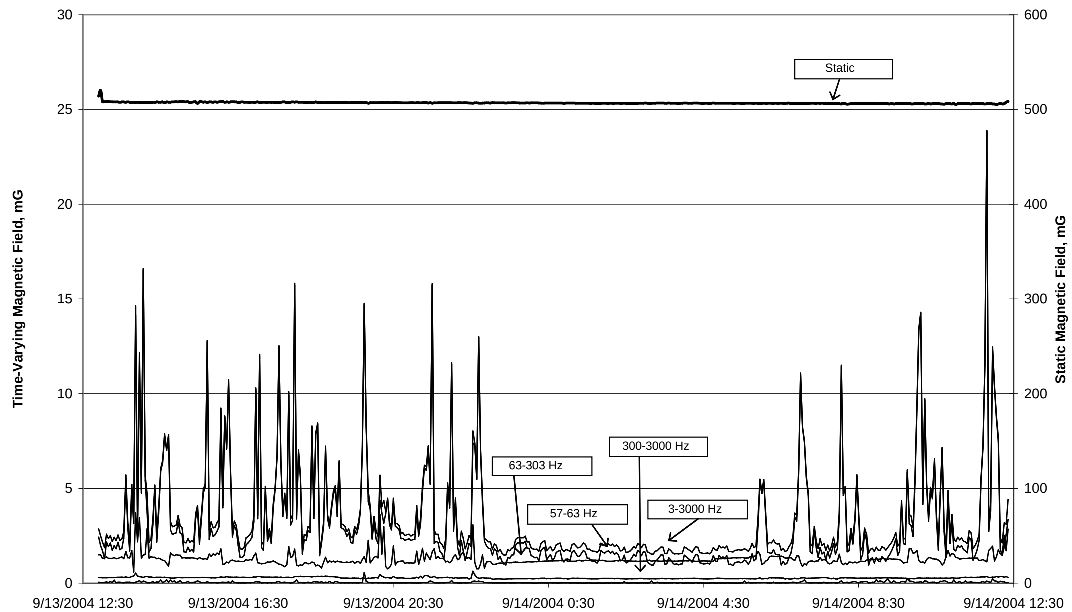


Figure J2. 24-Hour Fluctuation of Static and Time-Varying Magnetic Field Levels near the Warwick TL

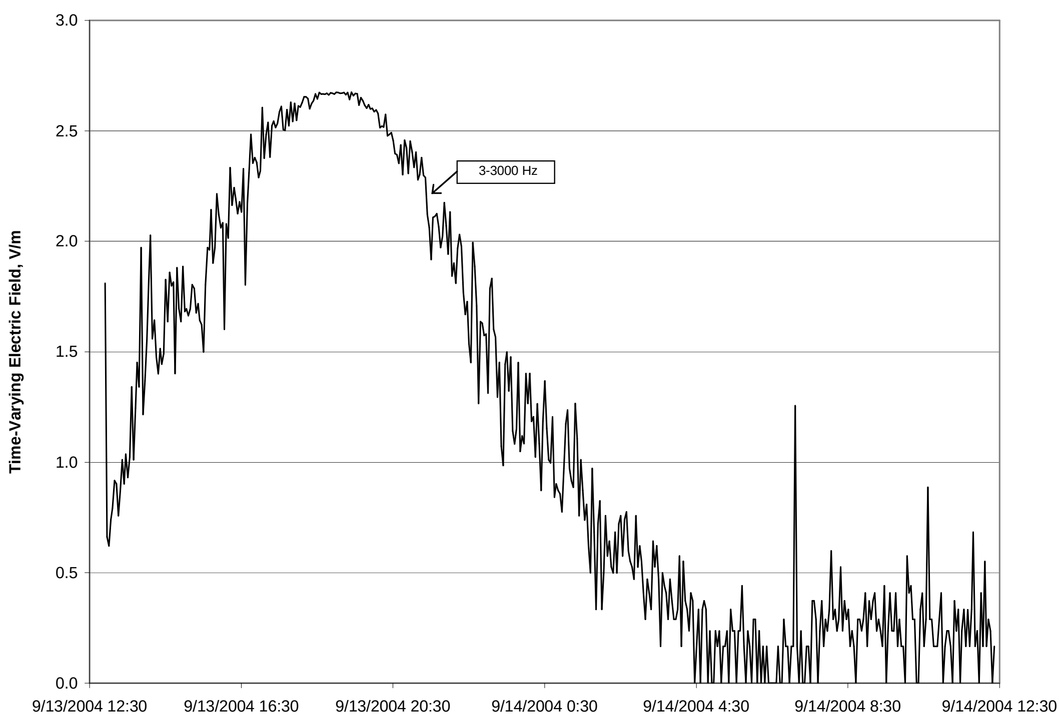


Figure J3. 24-Hour Fluctuation of Time-Varying Electric Field Levels near the Warwick TL

Table J2. Summary Statistics for Perimeter Profile ELF Field Measurements near the Warwick TL

Field Parameter	Minimum	Percentile Levels 5	25	50	75	95	Maximum	Average	Standard Deviation
Static Magnetic Field in milligauss									
Total	498	519	531	536	538	539	540	532	8.2
ELF Magnetic Field in milligauss									
3-57 Hz	0.2	0.6	1.4	2.1	3.2	5.1	6.1	2.4	1.4
57-63 Hz	0.8	0.8	1.0	2.0	8.5	21.5	22.7	6.0	7.7
63-303 Hz	0.1	0.2	0.5	0.7	1.1	2.5	4.2	0.9	0.8
303-3000 Hz	0.1	0.1	0.1	0.2	0.4	0.6	0.8	0.3	0.2
3-3000 Hz	1.2	1.7	2.5	4.2	9.3	21.6	22.8	7.4	7.1
ELF Electric Field in volts per meter									
3-3000 Hz	1.7	1.8	2.9	8.2	57.0	481.4	625.8	98.5	172.9

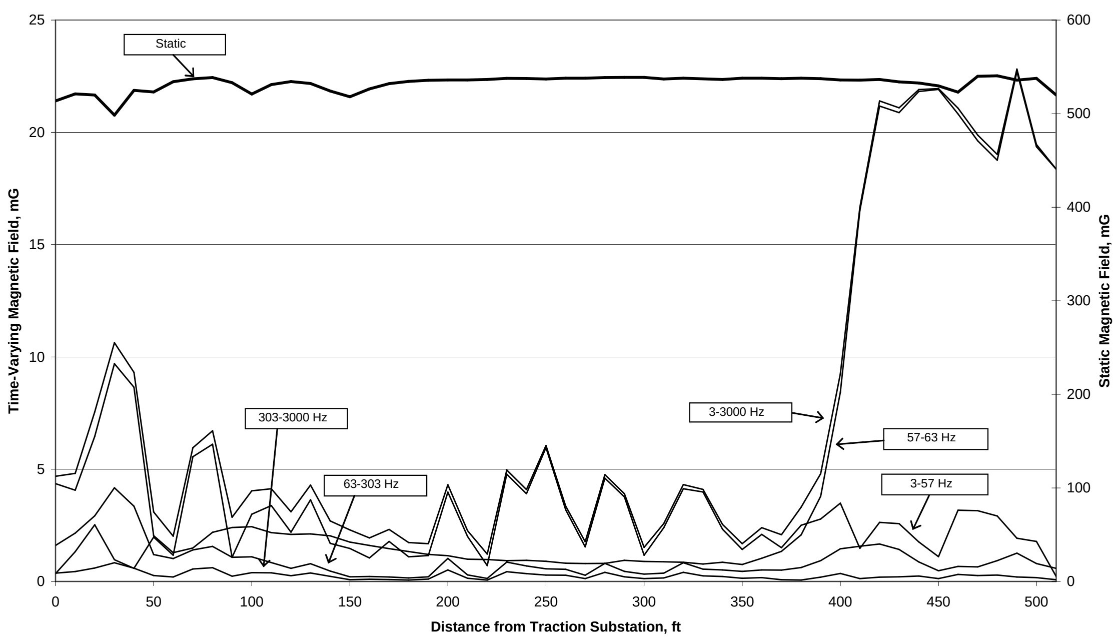


Figure J4. Static and Time-Varying Magnetic Field Levels along the TL, from the SS to the Transmission Line

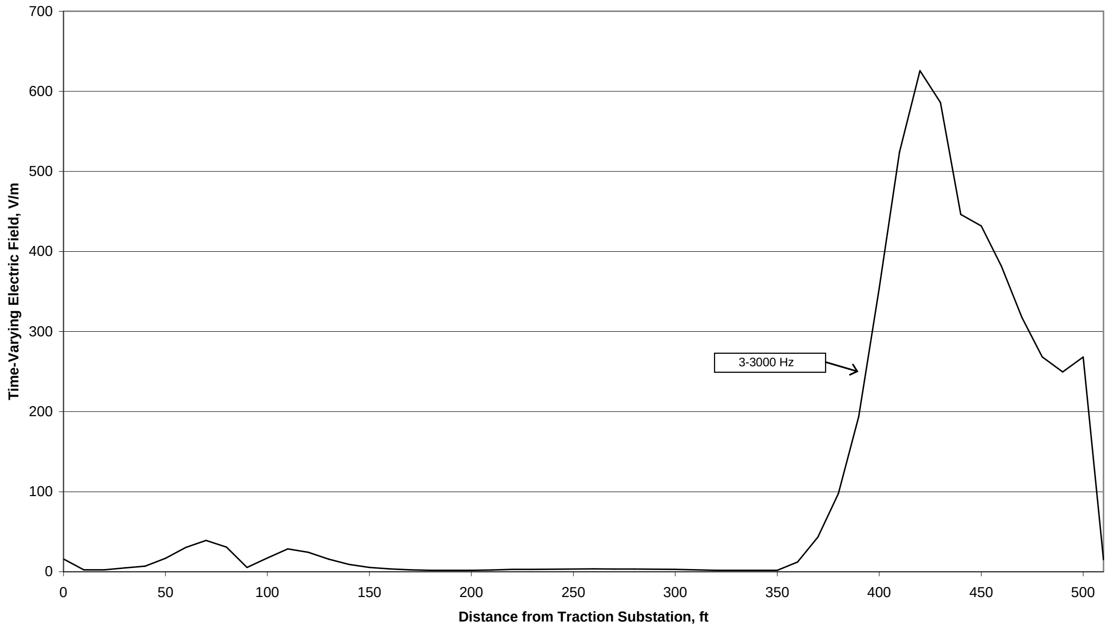


Figure J5. Time-Varying Electric Field Levels along the TL, from the SS to the Transmission Line

Table J3. Summary Statistics for the Lateral Profile Field Measurements near the Warwick TL

Field Parameter	Minimum	Percentile Levels 5	25	50	75	95	Maximum	Average	Standard Deviation
Static Magnetic Field in milligauss									
Total	473	523	533	535	538	548	598	535	13.1
ELF Magnetic Field in milligauss									
3-57 Hz	0.1	1.0	1.7	2.6	3.4	4.7	5.7	2.6	1.2
57-63 Hz	0.9	1.1	1.9	2.7	3.0	4.5	7.9	2.7	1.2
63-303 Hz	0.2	0.4	0.6	0.8	1.2	1.9	6.6	1.0	0.8
303-3000 Hz	0.0	0.1	0.2	0.3	0.4	0.5	1.2	0.3	0.2
3-3000 Hz	0.9	1.9	3.1	3.8	4.7	6.6	10.5	4.0	1.5
ELF Electric Field in volts per meter									
3-3000 Hz	1.6	1.8	3.9	6.7	8.8	19.9	26.1	7.3	5.2

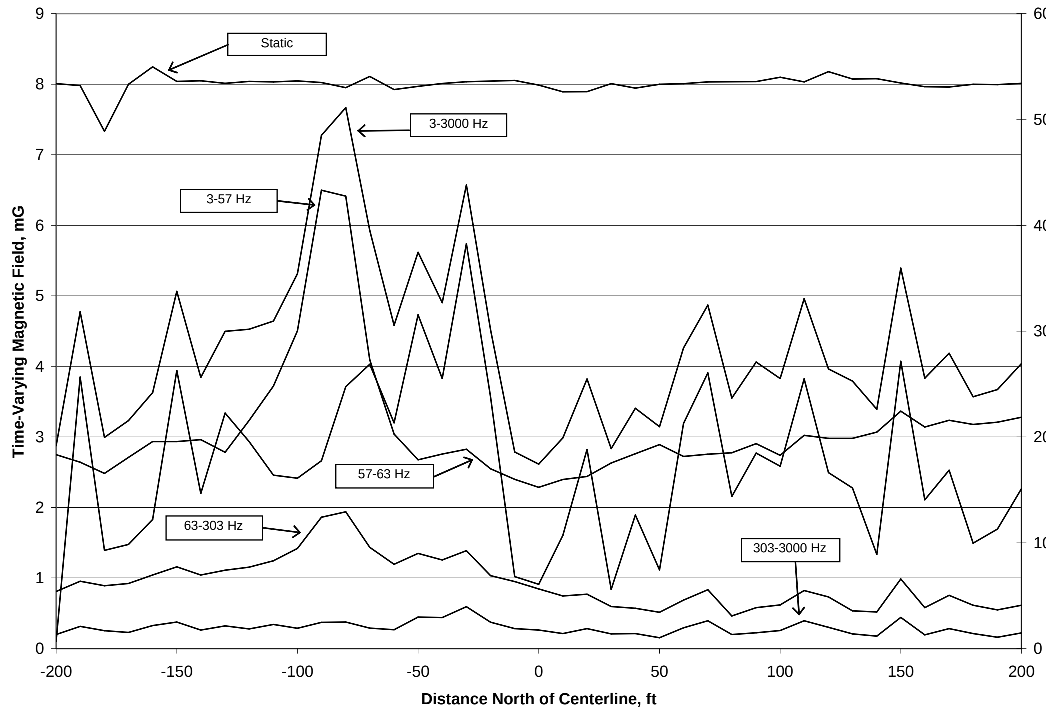


Figure J6. Lateral Profile along the West Side of Jefferson that Crosses over the Underground TL. Plot Shows Static and Time-Varying Magnetic Field Levels

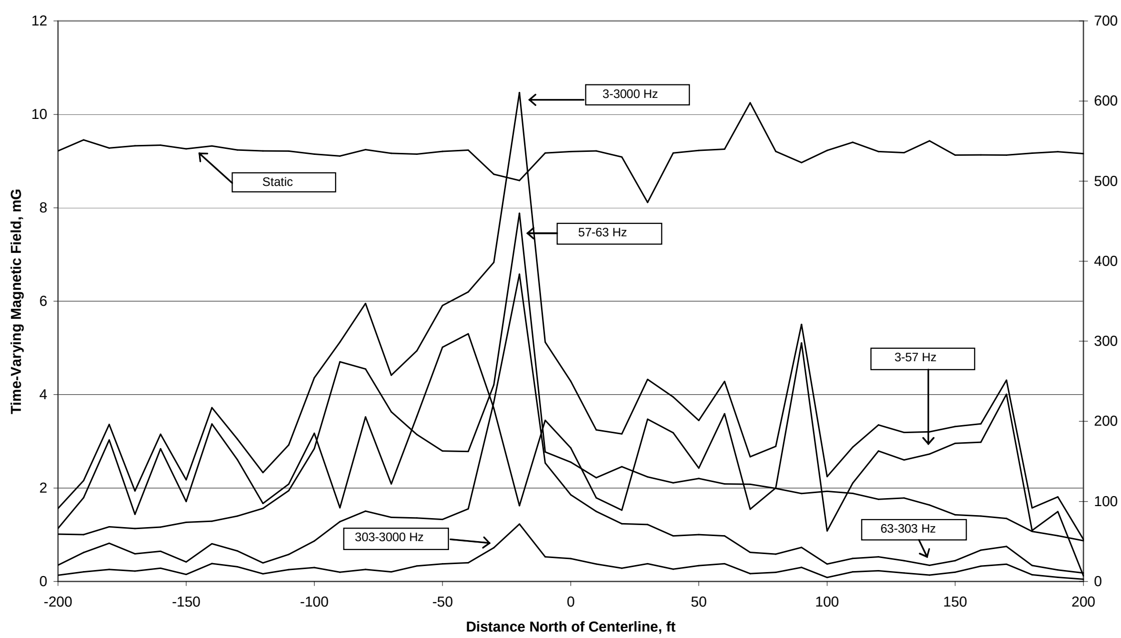


Figure J7. Lateral Profile slong the West Side of Jefferson that Crosses over the Underground TL. Plot Shows Static and Time-Varying Magnetic Field Levels

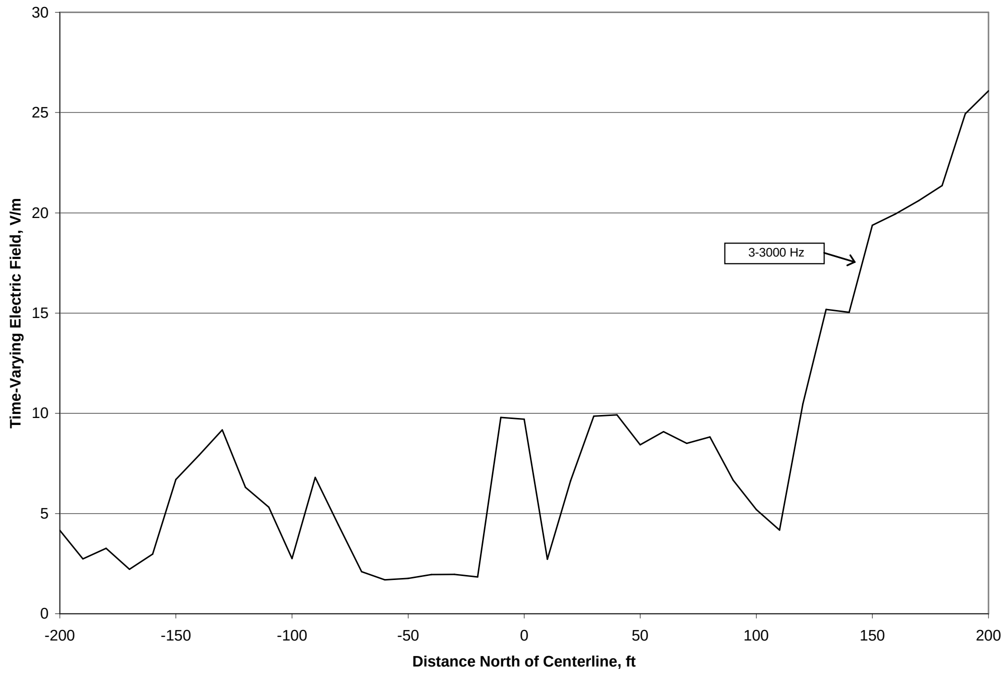


Figure J8. Lateral Profile Showing Time-Varying Electric Field Levels Crossing the Warwick TL on the West Side of Jefferson

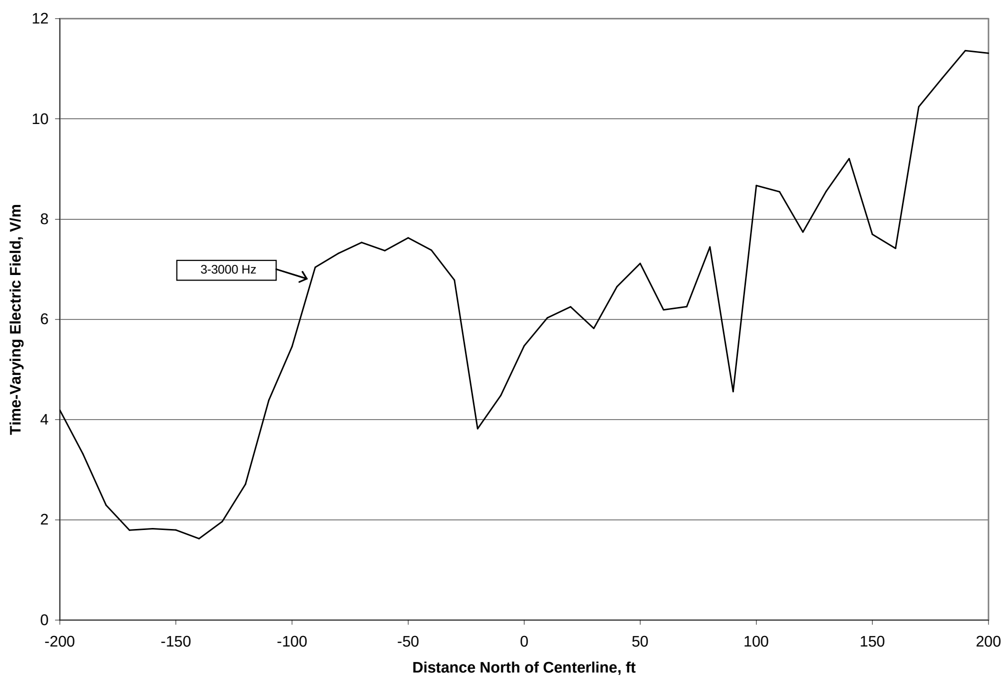


Figure J9. Lateral Profile of Time-Varying Electric Field Levels Crossing the Warwick TL on the East Side of Jefferson

Appendix K
Wayside Train Pass Measurements

Milepost 127+2595

Location Type: Wayside adjacent to Midway maintenance facility.

Table K1. Train Passes Measured along Tracks Adjacent to Midway Maintenance Facility

	Train	Direction	Start (EDT)	Stop (EDT)	Samples
1	Acela	Southbound	15:04:56	15:06:29	32
2	Regional	Southbound	15:04:56	15:06:29	32
3	Regional	Northbound	15:22:29	15:23:47	27
4	Acela	Southbound	16:29:31	16:31:16	36
5	Regional	Southbound	16:44:21	16:46:42	48

Figure K1. Photograph of Passing Northbound Regional Train (third measured pass). The RF Probe Mounted on a Tripod is Visible just beyond the Flagman

Sensor Arrangement: For ELF magnetic fields, three fluxgate magnetic field sensors were set at 5, 10, and 15 meters from the centerline of the southbound rails. ELF electric field, VLF and LF magnetic field, and RF sensors were also placed 5 m from the southbound rail centerline but offset laterally along the trackside.

Field Characteristics: For each train pass, a statistical table summarizes the ELF magnetic and electric field measurements. Next, three graphs display ELF magnetic fields by frequency band at the 5-meter position, the ELF electric field, and then the total time-varying field for all three positions (to show attenuation with distance).

Passing train causes perturbation of the earth's static magnetic field, and the transient is picked up in 2-48 Hz band. The passing train also causes the electric field to dip due to the shading effect of the metallic train. This effect is stronger on the southbound trains because they are closer to the sensors. The maximum magnetic fields depend on the current on the catenaries flowing past the measurement point. The field characteristics at any wayside location are a combination of the train operation, number of trains, and the distance to autotransformers at either end. VLF and LF magnetic fields were near zero.

RF field levels measured with the Narda meter and broadband electric-field probe were generally quite low, with a few readings reaching 2 percent of the occupational FCC standard as shown in Figure K2. However, no large spikes associated with a passing train were visible.

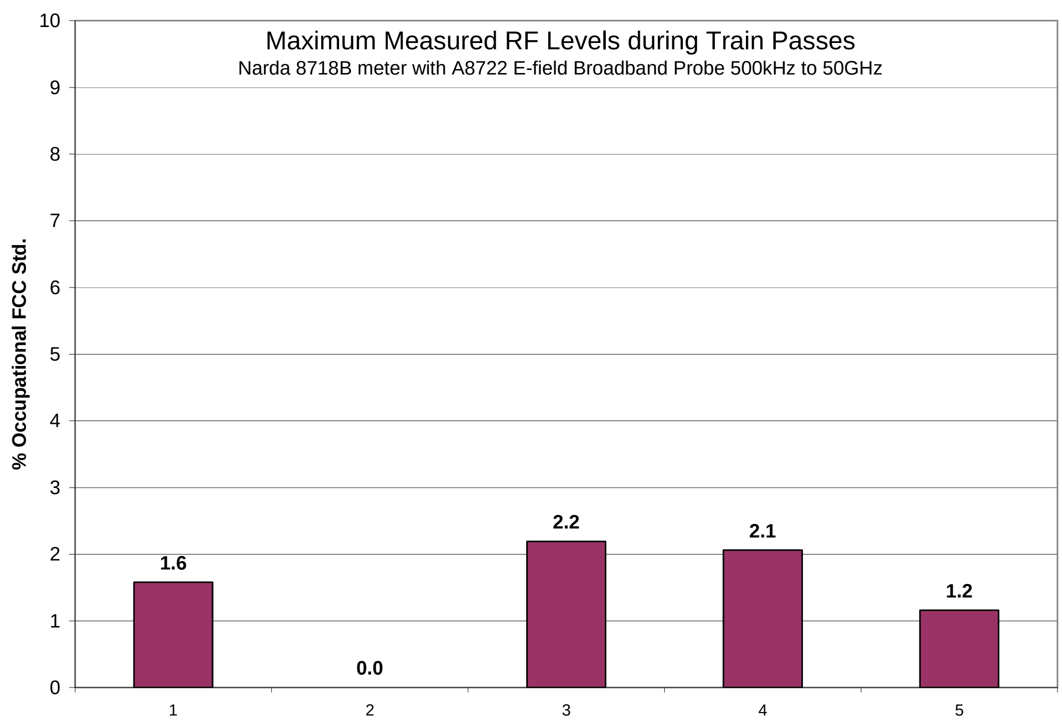


Figure K2. Summary of Maximum RF Readings for the Five Wayside Train Passes

Each of the following appendix subsections contains the ELF results for the respective train pass data sets.

K.1 Southbound Acela, Train Pass 1

Table K2. ELF Magnetic and Electric Field Statistics for Southbound Acela Express

Pass 1-Acela Southbound

Band	Position	Minimum	Maximum
Static (mG)	A - 5 m	583	608
	B - 10 m	523	528
	C - 15 m	537	538
2-48 Hz (mG)	A - 5 m	0.0	6.4
	B - 10 m	0.0	0.7
	C - 15 m	0.0	0.2
48-62 Hz (mG)	A - 5 m	6.1	65.1
	B - 10 m	1.8	12.5
	C - 15 m	0.9	5.7
62-302 Hz (mG)	A - 5 m	0.9	5.7
	B - 10 m	0.3	1.1
	C - 15 m	0.2	0.5
302-3000 Hz (mG)	A - 5 m	0.3	1.6
	B - 10 m	0.1	0.3
	C - 15 m	0.1	0.5
2-3000 Hz (mG)	A - 5 m	6.2	65.3
	B - 10 m	1.8	12.5
	C - 15 m	0.9	5.7
E Field (V/m)	A - 5 m	40.4	353.6

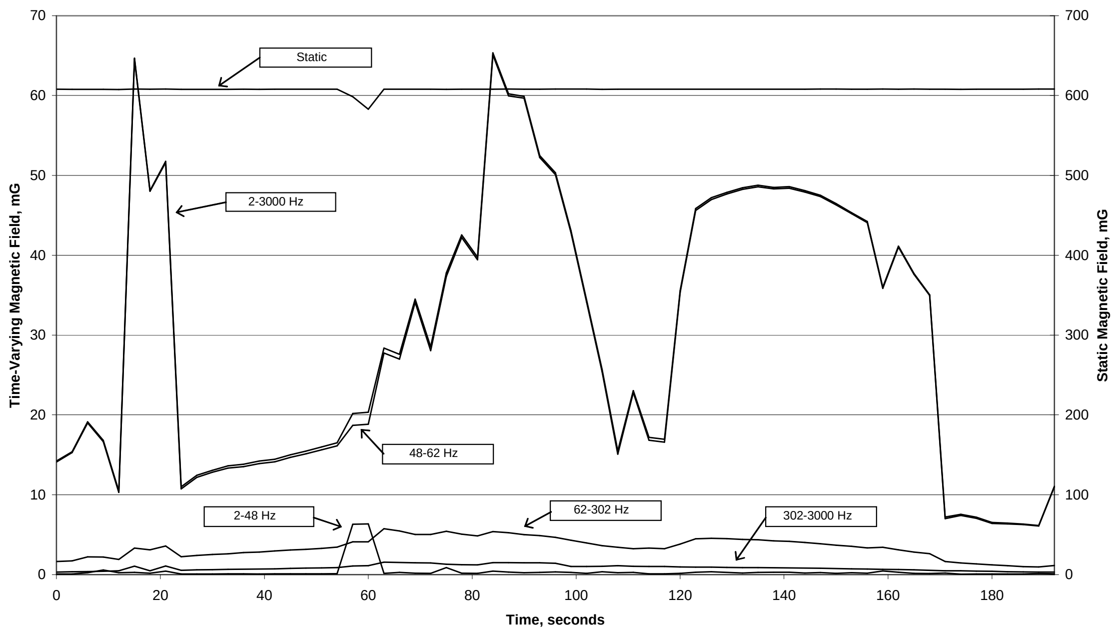


Figure K3. Short-Term Variation of Static and Time-Varying Magnetic Field Levels Measured at the Closest Position (5 Meters) for a Passing Southbound Acela Express. The Dip in the Static Field Indicates the Time at Which the Train Passed the Sensors

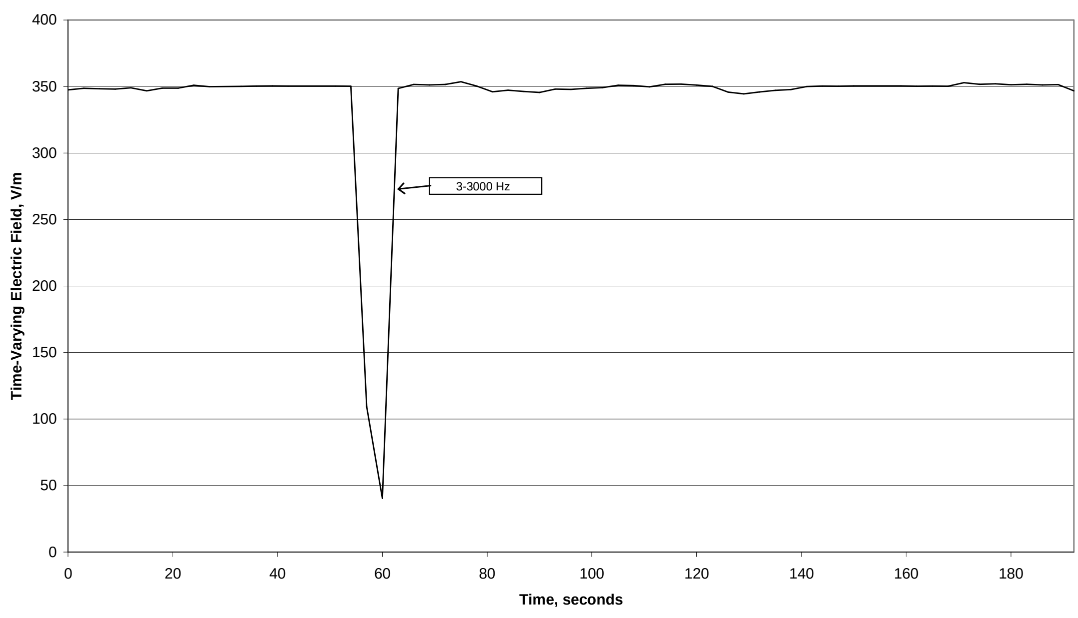


Figure K4. Short-Term Variation of ELF Electric Field Levels Measured at 5 Meters from the Southbound Rail Centerline Due to a Passing Southbound Acela Express. The Relatively Constant Electric Field is Due to the 25 kV Overhead Conductor, and the Dip is Due to Shading of the Electric Field as the Train Passes

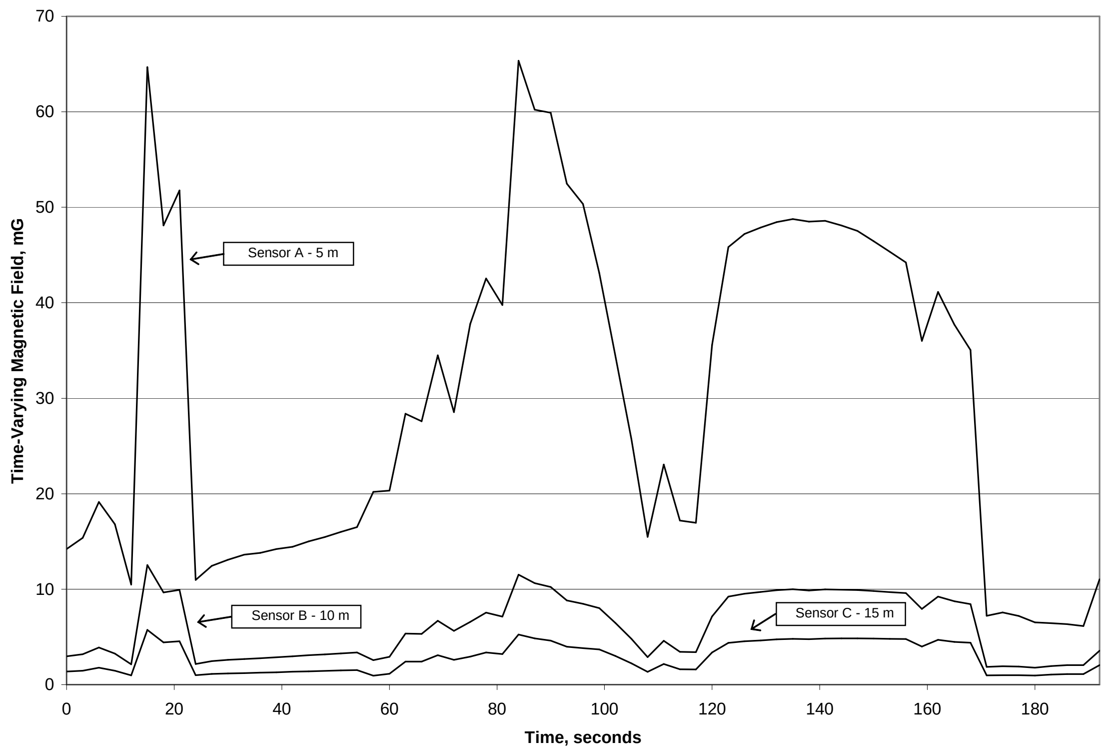


Figure K5. Time-Varying Magnetic Field Levels at 5, 10, and 15 Meters from the Southbound Track Centerline Due to Passing of a Southbound Acela Express. This Plot Shows the Rapid Attenuation of the Magnetic Fields with Increasing Distance from the Track

K.2 Southbound Regional, Train Pass 2

Table K3. ELF Magnetic and Electric Field Statistics for Southbound Regional Train

Pass 2-Regional Southbound

Band	Position	Minimum	Maximum
Static (mG)	A - 5 m	586	616
	B - 10 m	523	529
	C - 15 m	536	539
2-48 Hz (mG)	A - 5 m	0.1	13.5
	B - 10 m	0.0	1.5
	C - 15 m	0.0	0.3
48-62 Hz (mG)	A - 5 m	5.2	21.3
	B - 10 m	1.0	3.8
	C - 15 m	0.5	1.9
62-302 Hz (mG)	A - 5 m	0.5	2.0
	B - 10 m	0.1	0.4
	C - 15 m	0.1	0.2
302-3000 Hz (mG)	A - 5 m	0.3	0.7
	B - 10 m	0.0	0.1
	C - 15 m	0.1	0.2
2-3000 Hz (mG)	A - 5 m	5.3	24.9
	B - 10 m	1.0	4.0
	C - 15 m	0.5	1.9
E Field (V/m)	A - 5 m	53.1	356.7

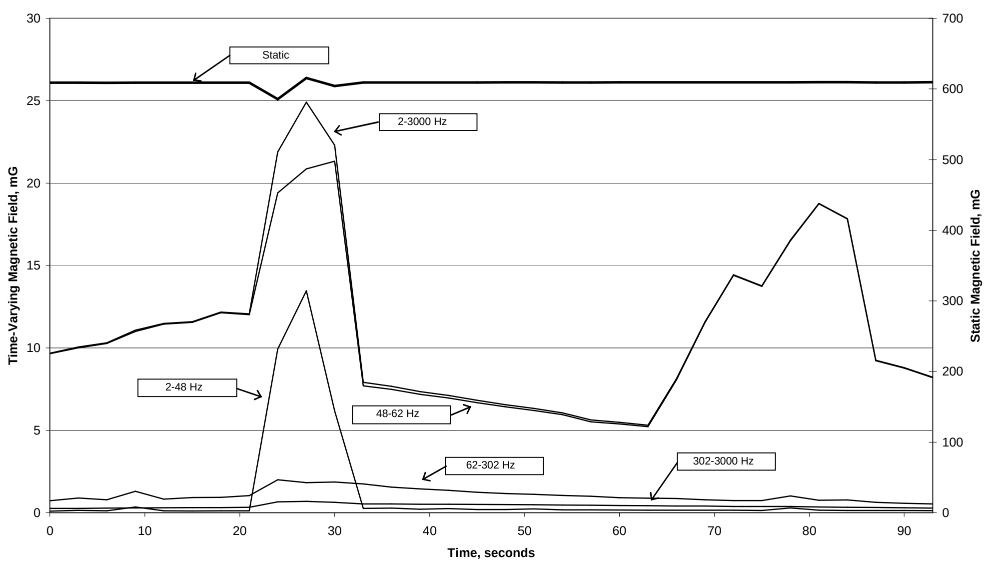


Figure K6. Short-Term Variation of Static and Time-Varying Magnetic Field Levels Measured at the Closest Position (5 Meters) for a Passing Southbound Regional Train. The Dip in the Static Field Indicates the Time at Which the Train Passed the Sensors

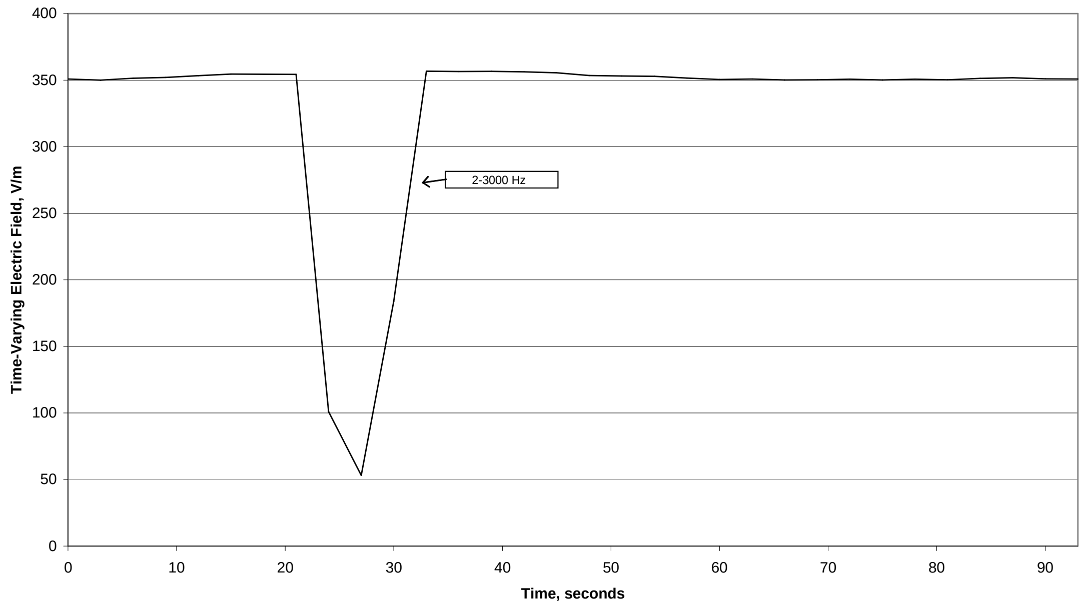


Figure K7. Short-Term Variation of ELF Electric Field Levels Measured 5 Meters from the Southbound Rail Centerline Due to a Passing Southbound Regional. The Relatively Constant Electric Field is Due to the 25 kV Overhead Conductor, and the Dip is Due to shading of the Electric Field as the Train Passes

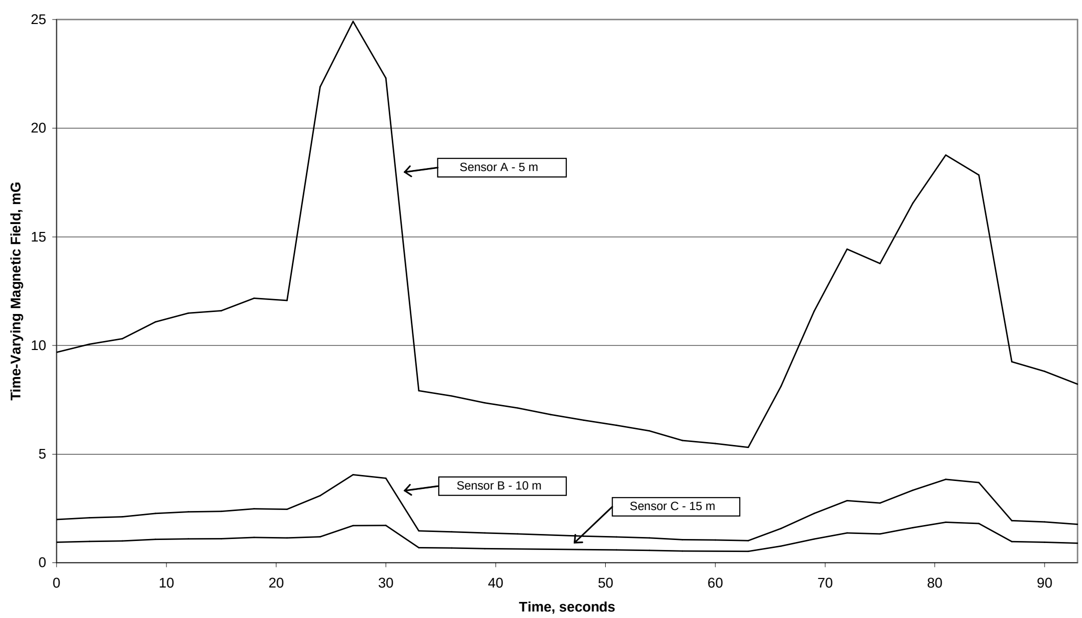


Figure K8. Time-Varying Magnetic Field Levels at 5, 10, and 15 Meters from the Southbound Track Centerline Due to Passing of a Southbound Regional Train. This Plot Shows the Rapid Attenuation of the Magnetic Fields with Increasing Distance from the Track

K.3 Northbound Regional, Train Pass 3

Table K4. ELF Magnetic and Electric Field Statistics for Northbound Regional Train

Pass 3-Regional Northbound

Band	Position	Minimum	Maximum
Static (mG)	A - 5 m	604	611
	B - 10 m	527	530
	C - 15 m	538	540
2-48 Hz (mG)	A - 5 m	0.1	3.0
	B - 10 m	0.0	0.6
	C - 15 m	0.0	0.2
48-62 Hz (mG)	A - 5 m	2.3	83.5
	B - 10 m	0.5	14.7
	C - 15 m	0.3	7.1
62-302 Hz (mG)	A - 5 m	0.4	2.1
	B - 10 m	0.1	0.3
	C - 15 m	0.1	0.2
302-3000 Hz (mG)	A - 5 m	0.1	1.4
	B - 10 m	0.0	0.1
	C - 15 m	0.1	0.2
2-3000 Hz (mG)	A - 5 m	2.3	83.6
	B - 10 m	0.5	14.7
	C - 15 m	0.3	7.1
E Field (V/m)	A - 5 m	206.2	352.7

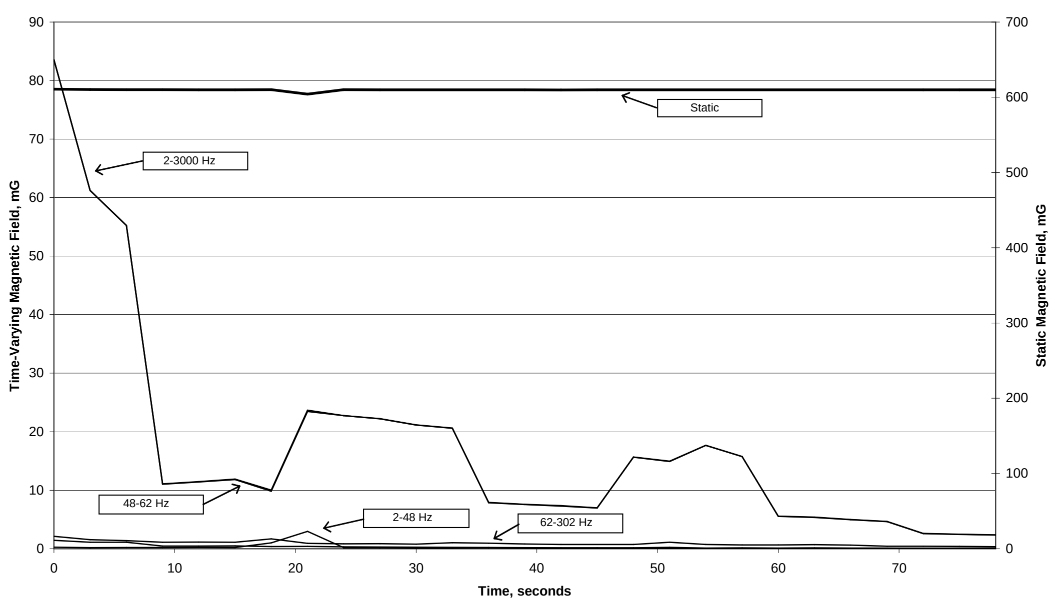


Figure K9. Short-Term Variation of Static and Time-Varying Magnetic Field Levels Measured at the Closest Position (5 Meters) for a Passing Northbound Regional Train. The Slight Dip in the Static Field Indicates the Time at Which the Train Passed the Sensors

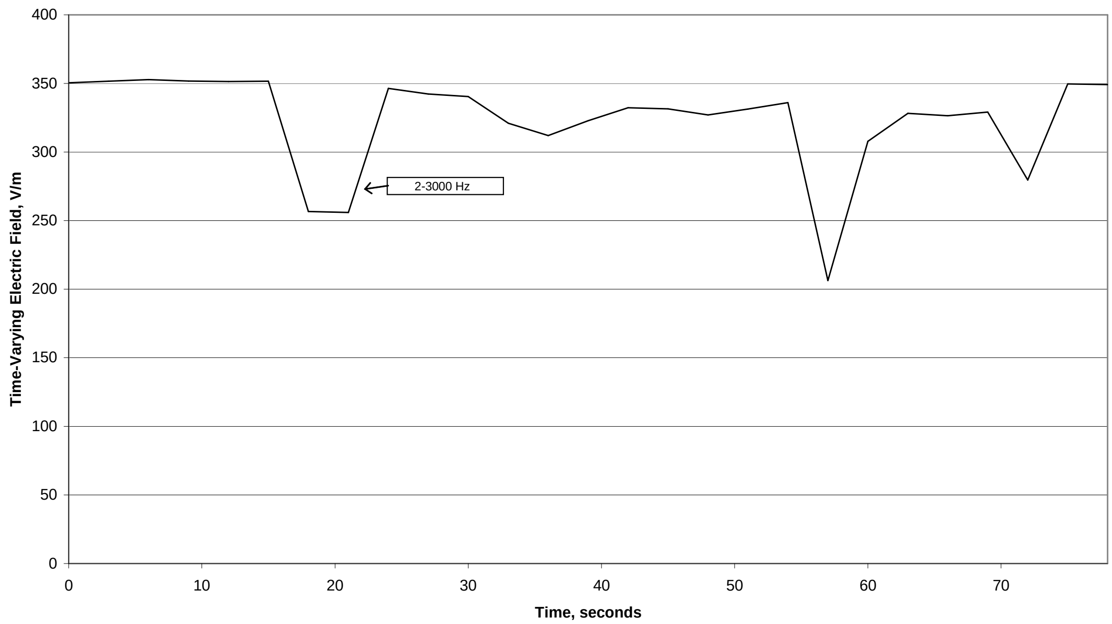


Figure K10. Short-Term Variation of ELF Electric Field Levels Measured at 5 Meters from the Southbound Rail Centerline Due to a Passing Northbound Regional

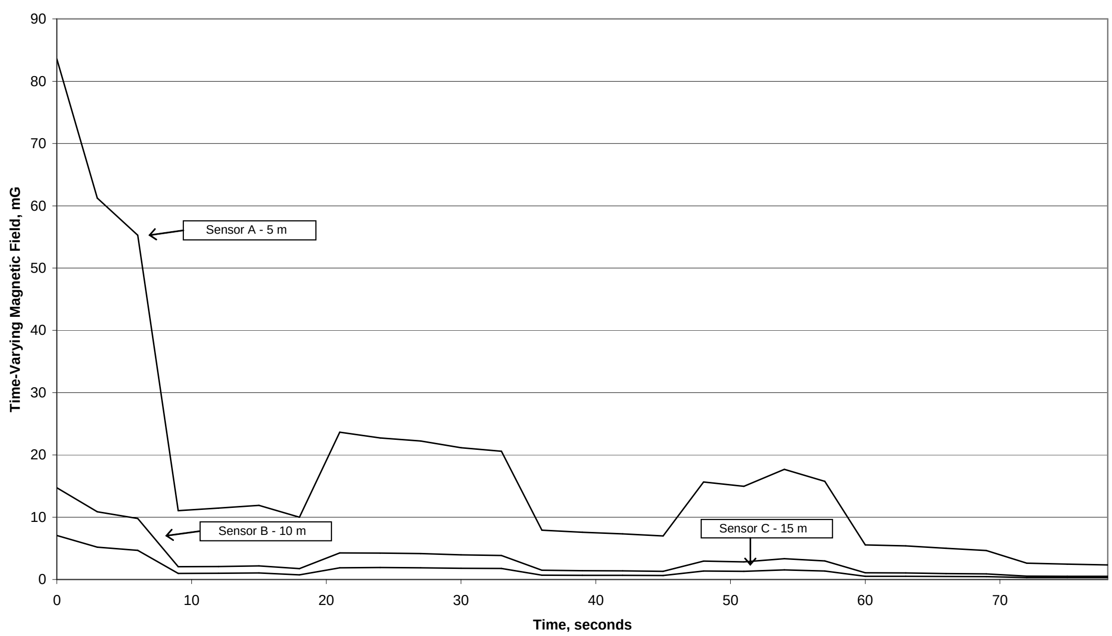


Figure K11. Time-Varying Magnetic Field Levels at 5, 10, and 15 Meters from the Southbound Track Centerline Due to Passing of a Northbound Regional Train. This Plot Shows the Rapid Attenuation of the Magnetic Fields with Increasing Distance from the Track

K.4 Southbound Acela, Train Pass 4

Table K5. ELF Magnetic and Electric Field Statistics for Southbound Acela Express Train

Pass 4-Acela Southbound

Band	Position	Minimum	Maximum
Static (mG)	A - 5 m	609	619
	B - 10 m	528	531
	C - 15 m	539	540
2-48 Hz (mG)	A - 5 m	0.1	7.3
	B - 10 m	0.0	1.0
	C - 15 m	0.0	0.2
48-62 Hz (mG)	A - 5 m	12.4	60.4
	B - 10 m	2.5	10.3
	C - 15 m	0.9	4.6
62-302 Hz (mG)	A - 5 m	2.0	5.9
	B - 10 m	0.4	1.1
	C - 15 m	0.2	0.5
302-3000 Hz (mG)	A - 5 m	0.4	1.6
	B - 10 m	0.1	0.2
	C - 15 m	0.1	0.5
2-3000 Hz (mG)	A - 5 m	12.7	60.7
	B - 10 m	2.6	10.4
	C - 15 m	1.0	4.7
E Field (V/m)	A - 5 m	42.1	395.2

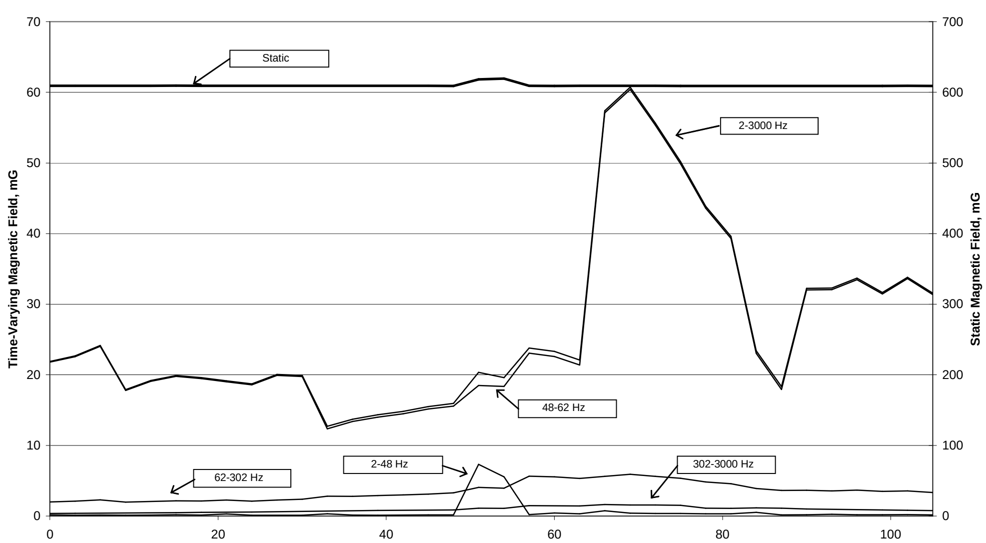


Figure K12. Short-Term Variation of Static and Time-Varying Magnetic Field Levels Measured at the Closest Position (5 Meters) for a Passing Southbound Acela Express. The Dip in the Static Field Indicates the Time at Which the Train Passed the Sensors

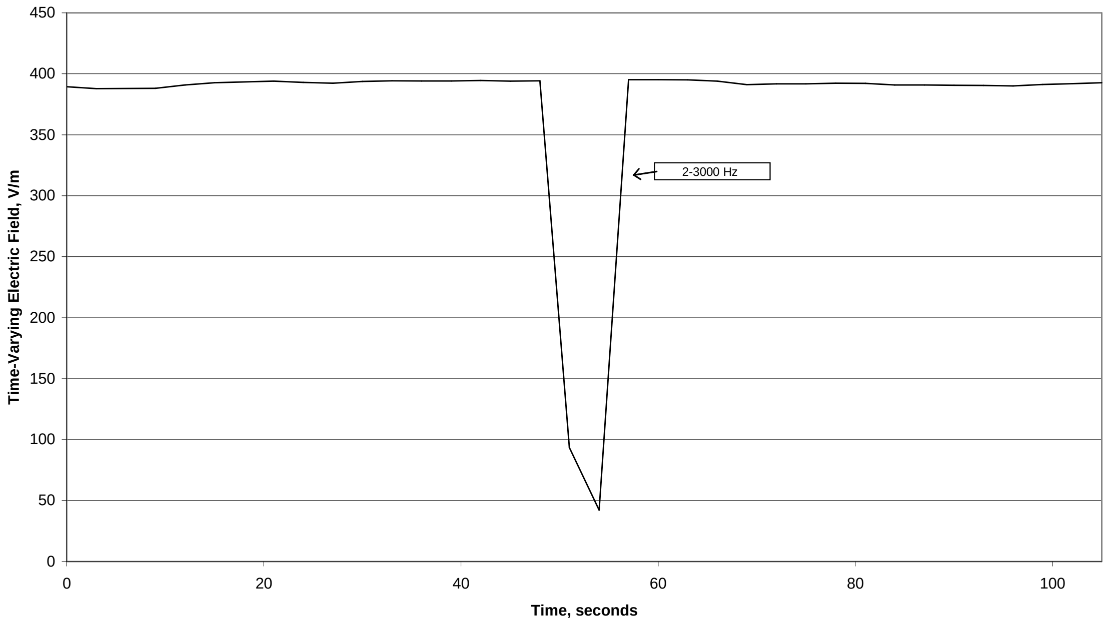


Figure K13. Short-Term Variation of ELF Electric Field Levels Measured at 5 Meters from the Southbound Rail Centerline Due to a Passing Southbound Acela Express. The Relatively Constant Electric Field is Due to the 25 kV Overhead Conductor and the Dip is Due to Shading of the Electric Field as the Train Passes

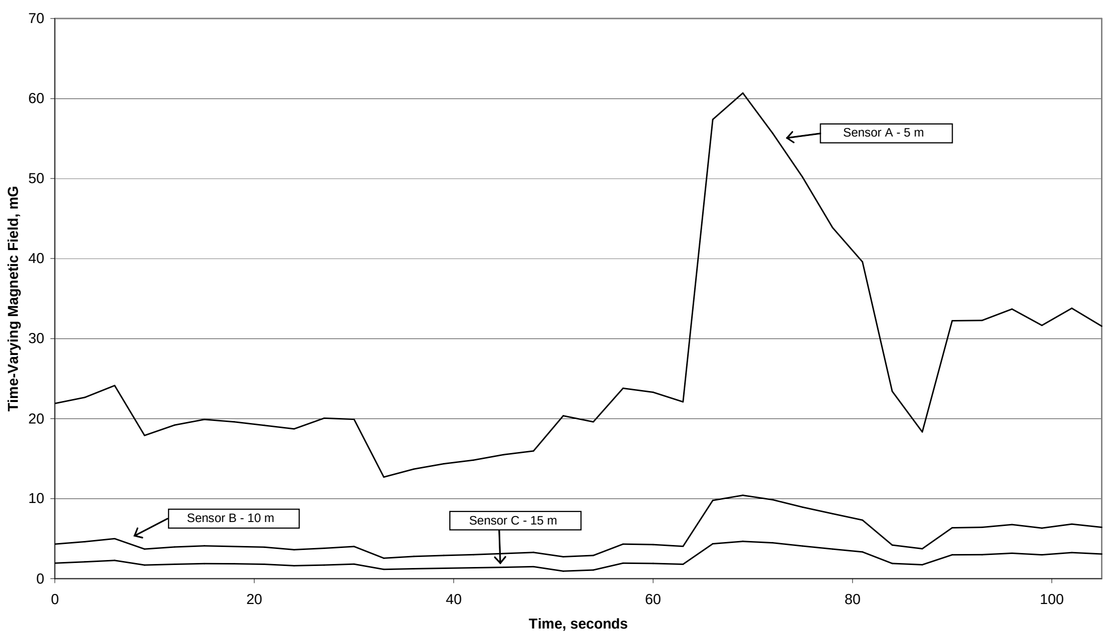


Figure K14. Time-Varying Magnetic Field Levels at 5, 10, and 15 Meters from the Southbound Track Centerline Due to Passing of a Southbound Acela Express. This Plot Shows the Rapid Attenuation of the Magnetic Fields with Increasing Distance from the Track

K.5 Southbound Regional, Train Pass 5

Table K6. ELF Magnetic and Electric Field Statistics for Southbound Regional Train

Pass 5-Regional Southbound

Band	Position	Minimum	Maximum
Static (mG)	A - 5 m	602	609
	B - 10 m	528	529
	C - 15 m	-	-
2-48 Hz (mG)	A - 5 m	0.1	5.6
	B - 10 m	0.0	1.1
	C - 15 m	-	-
48-62 Hz (mG)	A - 5 m	3.0	35.3
	B - 10 m	0.7	6.9
	C - 15 m	-	-
62-302 Hz (mG)	A - 5 m	0.3	3.2
	B - 10 m	0.1	2.8
	C - 15 m	-	-
302-3000 Hz (mG)	A - 5 m	0.2	0.6
	B - 10 m	0.0	0.4
	C - 15 m	-	-
2-3000 Hz (mG)	A - 5 m	3.1	35.3
	B - 10 m	0.7	6.9
	C - 15 m	-	-
E Field (V/m)	A - 5 m	59.1	429.8

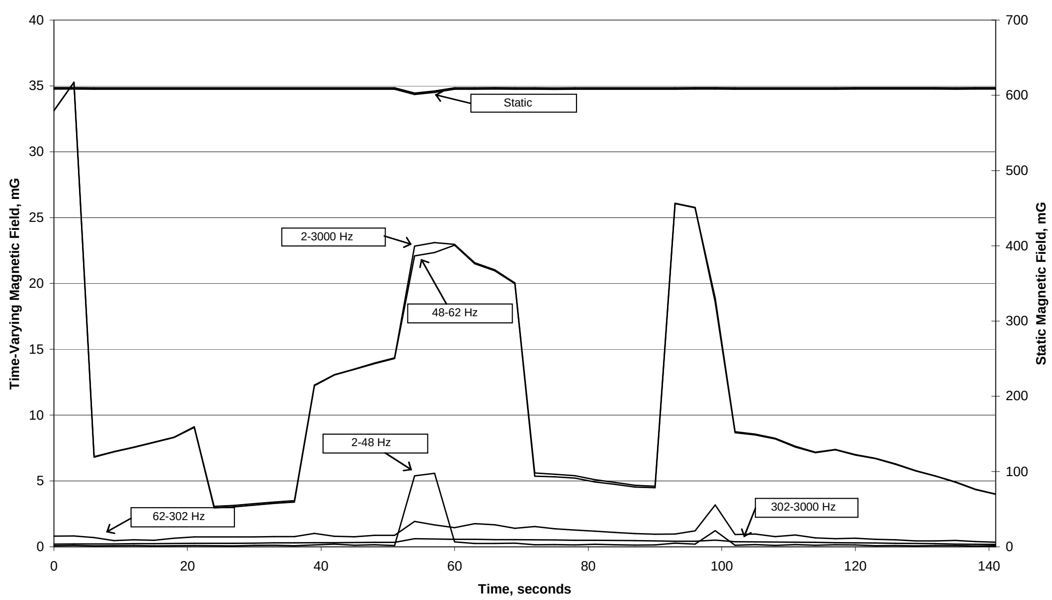


Figure K15. Short-Term Variation of Static and Time-Varying Magnetic Field Levels Measured at the Closest Position (5 Meters) for a Passing Southbound Regional Train. The Dip in the Static Field Indicates the Time at Which the Train Passed the Sensors

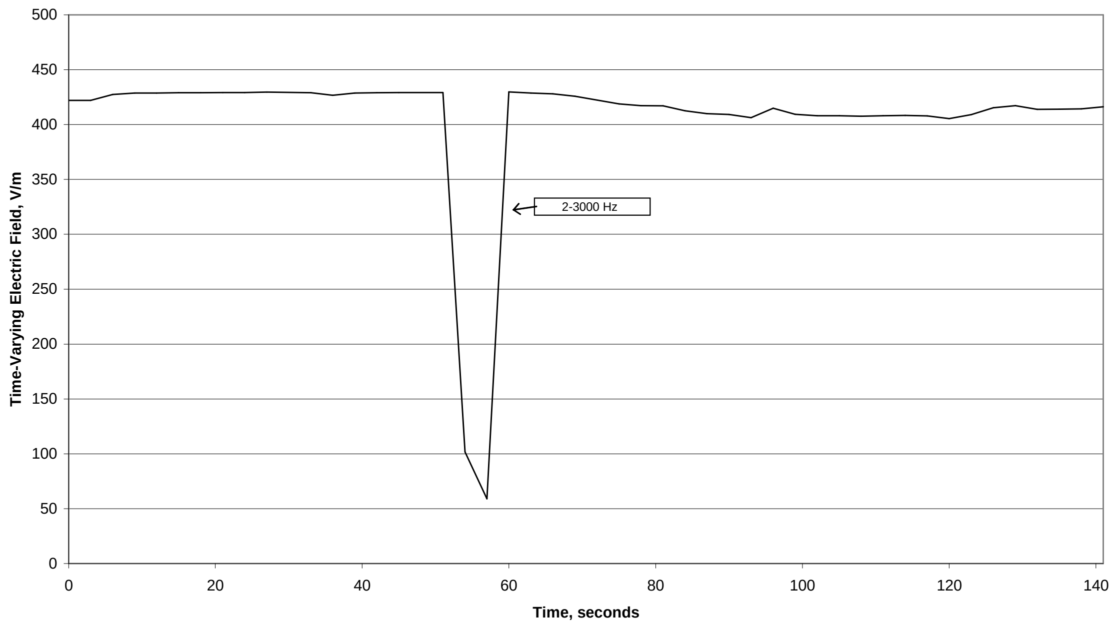


Figure K16. Short-Term Variation of ELF Electric Field Levels Measured at 5 Meters from the Southbound Rail Centerline Due to a Passing Southbound Regional Train. The Relatively Constant Electric Field is Due to the 25 kV Overhead Conductor, and the Dip is Due to Shading of the Electric Field as the Train Passes

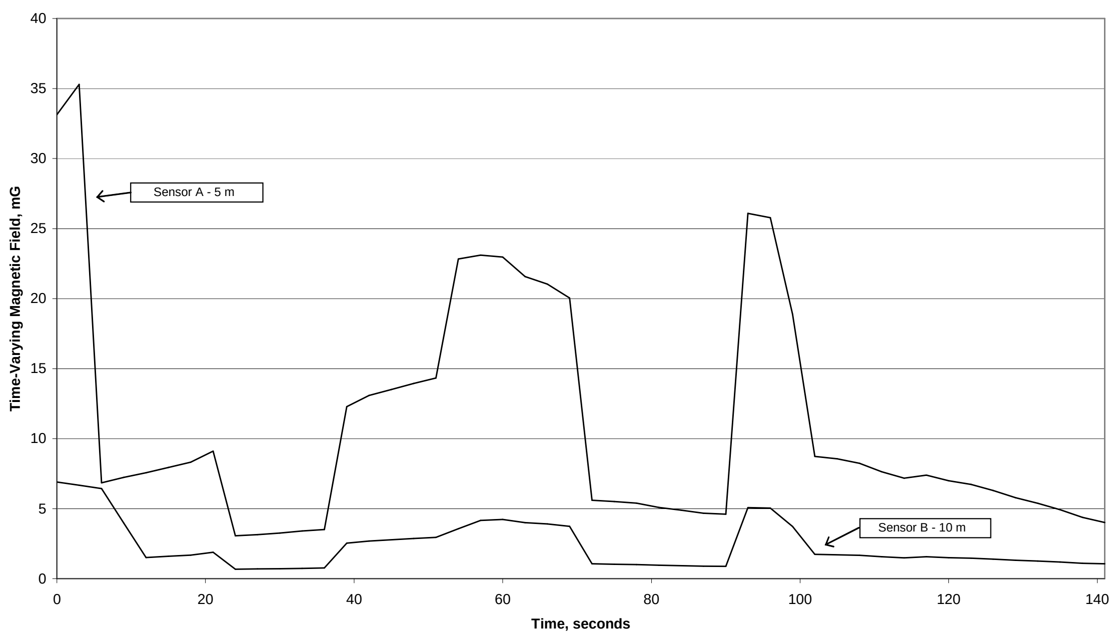


Figure K17. Time-Varying Magnetic Field Levels at 5 and 10 Meters from the Southbound Track Centerline Due to Passing of a Southbound Regional Train

Appendix L
Underpass/Overpass Measurements

L.1 Underpass Results

Milepost 127+1625

Location Type: Underpass on road out to Bluff Point State Park beside Poquonock River in Connecticut.

Table L1. Train Passes Measured at Underpass near the Midway Maintenance Facility

Pass	Train Type	Direction	Start Time	End Time	Samples
1	Regional	South	9:08:07	9:09:13	38
2	Acela	North	9:22:07	9:26:33	145
3	Regional	North	9:36:33	9:38:16	56
4	Freight	North	10:08:33	10:10:51	76

Figure L1. Diesel Engine Stopped in Front of the Underpass Where RF Measurements were Recorded near the Midway Maintenance Facility. This Underpass is on the Road Leading out to Bluff Point State Park in Connecticut

Sensor Arrangement: The Narda broadband electric field probe A8722D and one three-axis fluxgate sensor were situated beneath the underpass at the east curb of the underpass. Measurements were recorded as four trains passed.

Field Characteristics: RF results were essentially zero, well below the noise floor of the electric field probe. No large values or spikes were recorded with the RF broadband probe. The ELF magnetic fields did show significant increases with the passing of trains due to the catenary currents. The increases depended on the operation profile of the train in the vicinity of the underpass. Table L2 summarizes the ELF magnetic field results from the single fluxgate sensor beneath the underpass for all four train passes. Graphs in Figures L2 to L5 show the measured magnetic fields in each of the frequency bands for each pass per Table L1 above.

Table L2. Summary of Underpass ELF Magnetic Field Measurements by Frequency Bands

Band	Pass	Minimum (mG)	Maximum (mG)
Static	1	507	513
	2	505	515
	3	500	561
	4	503	513
2-48 Hz	1	0.0	2.9
	2	0.0	6.4
	3	0.0	3.6
	4	0.0	0.9
48-62 Hz	1	0.6	4.6
	2	0.3	104.7
	3	0.5	55.3
	4	0.2	7.6
62-302 Hz	1	0.1	0.6
	2	0.1	4.9
	3	0.2	9.7
	4	0.0	0.4
302-3000 Hz	1	0.0	0.2
	2	0.0	1.1
	3	0.1	4.8
	4	0.0	0.1
2-3000 Hz	1	0.7	5.2
	2	0.3	104.7
	3	0.7	56.4
	4	0.3	7.6

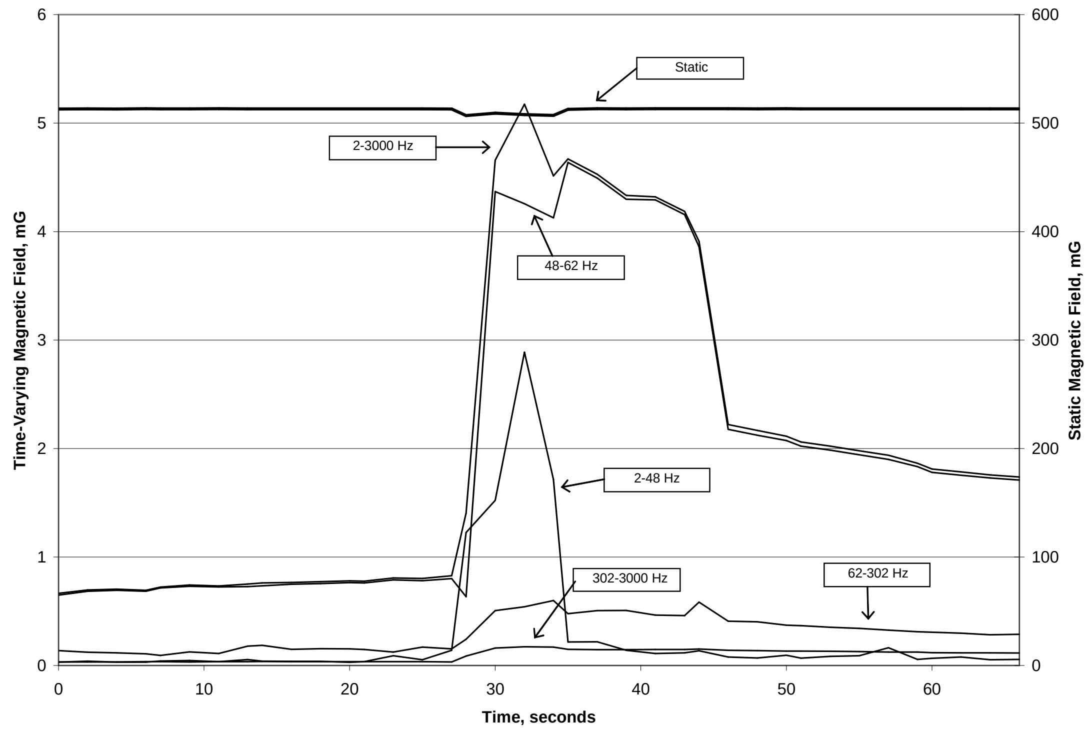


Figure L2. ELF Magnetic Fields Measured at the Underpass Location as a Southbound Region Electric Train Passed (Train Pass Number 1 for the Underpass)

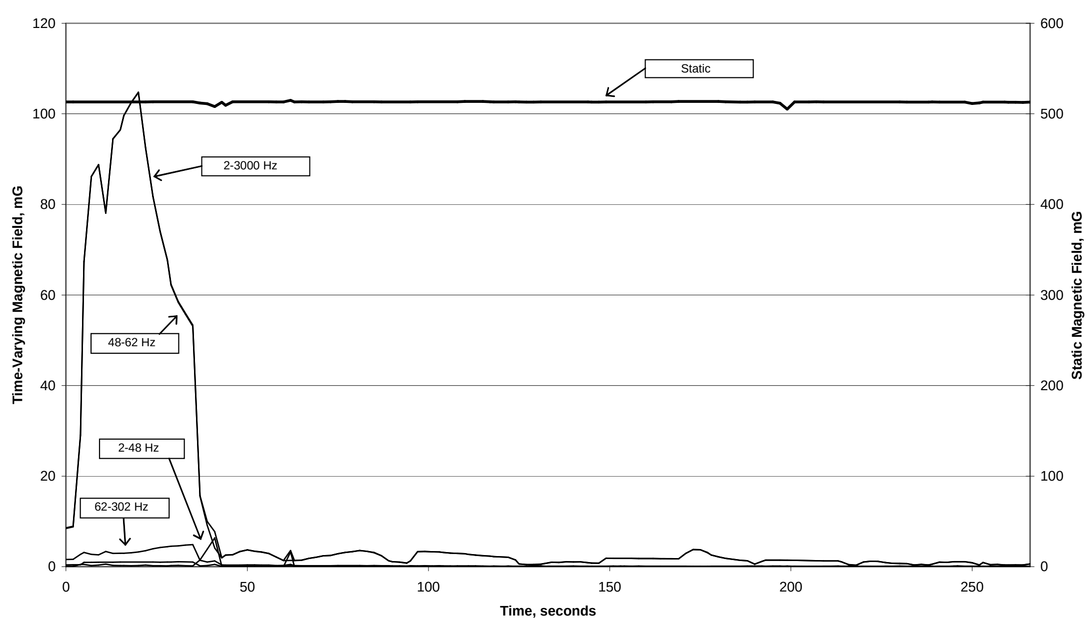


Figure L3. ELF Magnetic Fields Measured at the Underpass Location as a Northbound Acela Passed (Train Pass Number 2 for the Underpass)

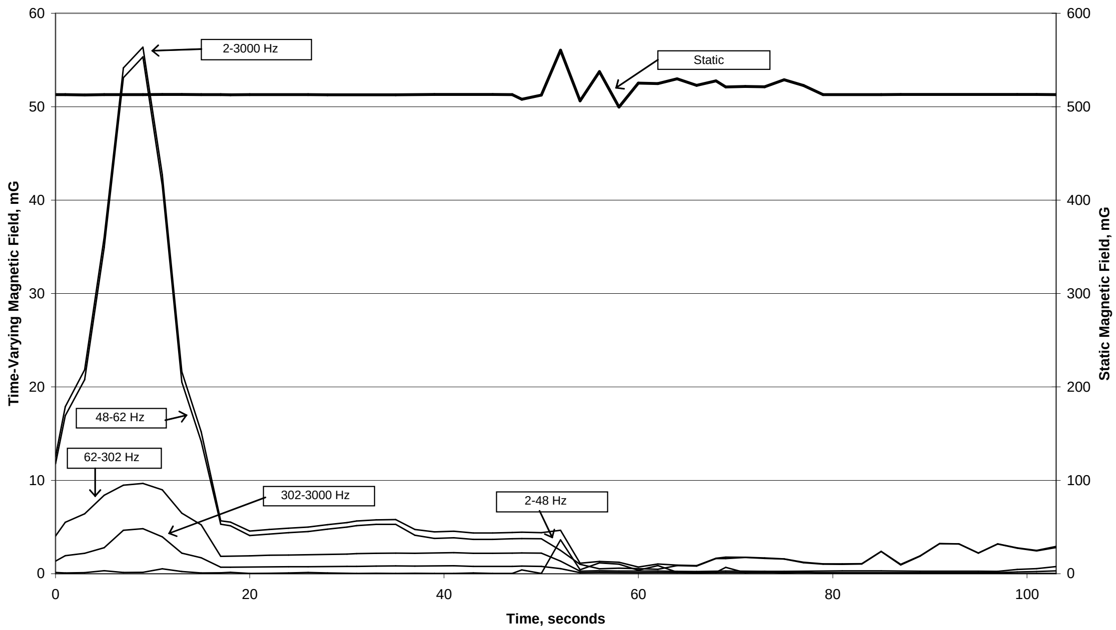


Figure L4. ELF Magnetic Fields Measured at the Underpass Location as a Northbound Regional Train Passed (Train Pass Number 3 for the Underpass)

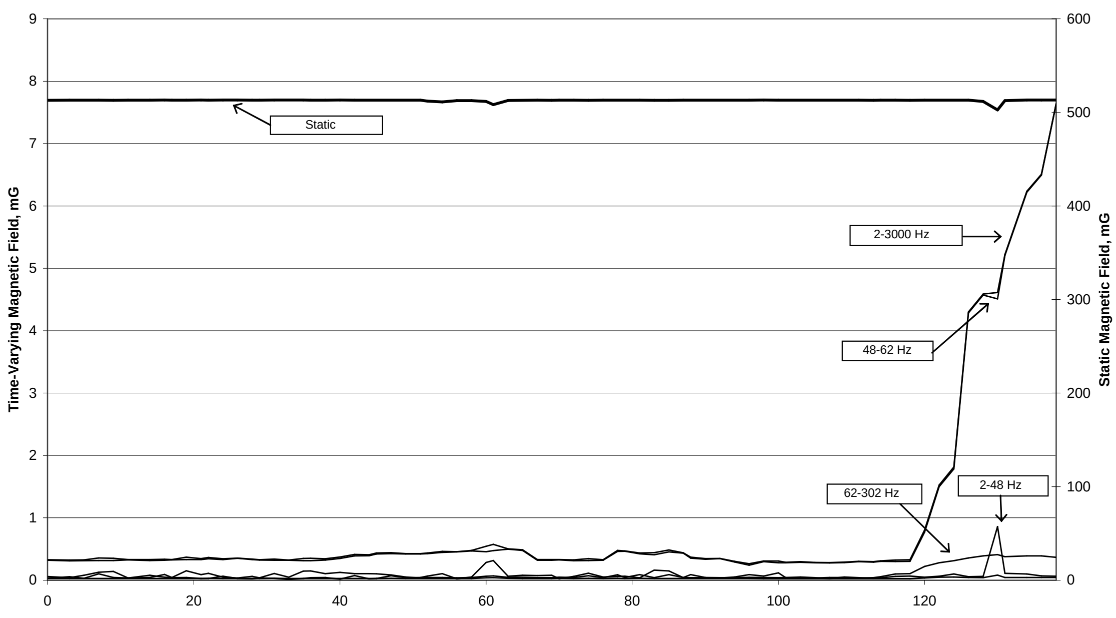


Figure L5. ELF Magnetic Fields Measured at the Underpass Location as a Northbound Regional Train Passed (Train Pass Number 4 for the Underpass). A Freight Train Stopped and then Cleared the Track just before the Regional Approached. Only a Portion of this Pass was Recorded

L.2 Overpass Results

Milepost 176+2730

Location Type: Overpass on Coronado Road Extension just off of Jefferson Boulevard in Warwick, RI. This overpass is just south of the Warwick SS.

Sensor Arrangement: The Narda broadband electric field probe A8722D and one three-axis fluxgate sensor were situated on the south curb of the overpass. Significant aluminum shields were present along the walkways to prevent contact with the 25 kV lines. Measurements were recorded as two trains passed per Table L3.

Table L3. Two Train Passes at the Overpass Location in Warwick, RI

Train Type	Direction	Start Time	End Time	Samples
Regional	Northbound	15:43:34	15:44:26	30
Regional	Southbound	16:03:41	16:05:32	60

Table L4. Summary of Underpass ELF Magnetic Field Measurements by Frequency Bands

Band	Pass	Minimum (mG)	Maximum (mG)
Static	1	927	940
	2	929	938
2-48 Hz	1	0.0	4.2
	2	0.0	1.0
48-62 Hz	1	1.2	22.0
	2	0.8	29.3
62-302 Hz	1	0.5	2.9
	2	0.5	1.5
302-3000 Hz	1	0.1	0.2
	2	0.1	0.2
2-3000 Hz	1	1.3	22.0
	2	1.1	29.4

Field Characteristics: As with the underpass, the measured RF levels were essentially zero, well below the noise floor of the electric field probe. No large values or spikes were recorded with the RF broadband probe. The ELF magnetic fields increased with the passing of trains because of the catenary currents. Due to the proximity of the Warwick SS, it was expected that when the train is south of the underpass, a large amount of current flows south to the train (causing significant ELF magnetic fields at the overpass). Conversely, when the train is north of the overpass, magnetic fields should be relatively low, since most current will travel from the Warwick SS directly to the train, and very little will run to the train from the East Greenwich PS due to the distance. Table L4 above summarizes the ELF magnetic field results from the single fluxgate sensor on the overpass for the two train passes. Graphs in Figures L6 and L7 show the measured magnetic fields in each of the frequency bands for the northbound and southbound passes, respectively.

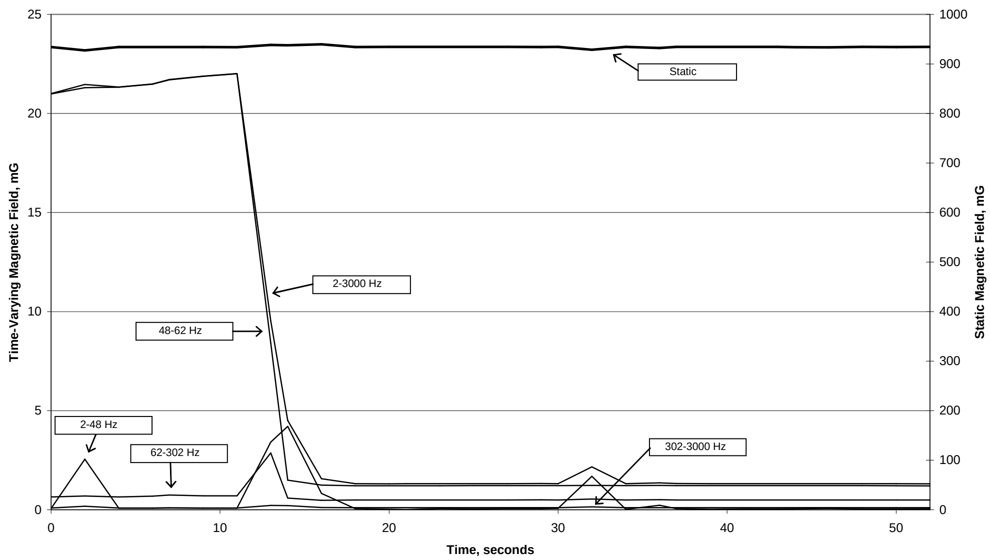


Figure L6. ELF Magnetic Fields Measured at the Overpass Location in Warwick as a Northbound Regional Train Passed. Once North of the Overpass, Magnetic Fields Drop off Because Very Little Current is Provided from the East Greenwich PS (Due to the Distance)

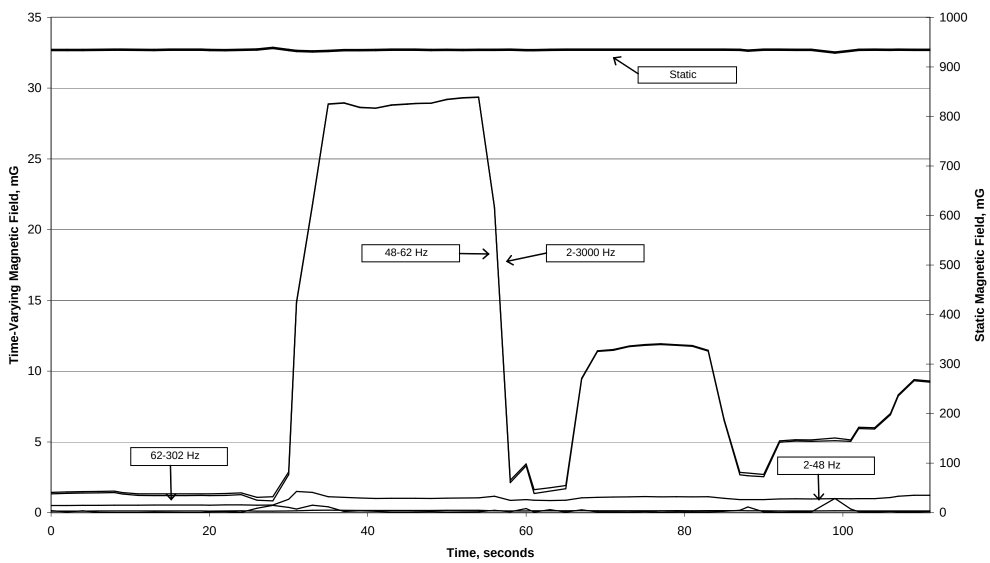


Figure L7. ELF Magnetic Fields Measured at the Overpass Location in Warwick as a Southbound Regional Train Passed. Once South of the Overpass, the Magnetic Field Increase as nearly All Currents Pass by the Overpass on the Catenary since the Warwick SS is so Close

Appendix M
Onboard Acela Measurements

ELF magnetic and electric fields and RF electric fields were measured on board an Acela Express train. Both ELF magnetic and electric fields and RF electric fields were recorded in a coach passenger compartment at various times while traveling from Boston to New Haven. ELF magnetic fields and RF electric fields were also recorded in the engineer's cab of the trailing locomotive on the return trip from New Haven to Boston.

M.1 Passenger Compartment

Measurements were recorded in a coach passenger compartment in an aisle seat facing backward (opposite to direction of travel).

Sensor Arrangement: Three-axis fluxgate magnetometers were set at head, waist, and ankle positions. One ELF electric field sensor was at the chest position, and VLF and low frequency (LF) magnetic field sensors were located near the knees. A broadband electric field RF probe, A8722D, was mounted on a tripod in the aisle beside the seat, and readings were logged at 1-second intervals with a Narda 8718B meter.

Field Characteristics: All RF readings in the passenger compartment were at or below the noise floor of the A8722D probe, which is calibrated to read from 0.3 percent to 300 percent of the occupational 1997 FCC standard for electric field exposure. Thus, the passenger compartment results indicated very low RF electric fields over the bandwidth of the probe, from 500 kHz to 50 GHz.

For the ELF, VLF, and LF sensors, three data sets were recorded, with 235 measurements in each data set. Measurements were recorded at 3-second intervals. Thus, the total measurement period for each data set was just under 12 minutes. Table M1 summarizes the ELF magnetic field results for all three data sets combined—705 total measurements over a period of 35 minutes—for the three sensor positions (head, waist, ankle).

The measured static magnetic fields showed a large amount of variation and generally increased moving towards the floor, with relatively large values on the order of 1000 mG measured at the ankle position. The largest time-varying fields, 100 to 200 mG, occurred in the 2 to 48 Hz range due to the transients associated with catenary currents. However, the largest average magnetic fields occurred at the power frequency of 60 Hz as would be expected. Time-varying magnetic fields were similar at all three positions, though slightly decreasing from head to ankle as shown by the statistics.

ELF electric fields were relatively low, on the order of 2 to 6 V/m, with a few spikes ranging from 10 to 50 V/m. Passengers moving along the aisle and passing close to the electric field sensor may have caused the spikes.

Table M1. Summary of Static and Time-Varying Magnetic and Electric Fields Measured in the Passenger Compartment of an Operating Acela Express

Band	Sensor Position	Minimum	Maximum	Average	Standard Deviation	Coefficient of Variation
Static (mG)	Head	343	1055	685	104	15
	Waist	408	1183	771	114	15
	Ankle	738	1429	1048	112	11
2-48 Hz (mG)	Head	0.1	217.5	7.4	15.9	214
	Waist	0.1	173.7	8.6	16.0	186
	Ankle	0.1	122.6	10.9	18.0	165
48-62 Hz (mG)	Head	0.5	119.4	15.9	19.4	122
	Waist	0.5	106.5	14.0	16.0	115
	Ankle	0.4	101.4	12.8	14.1	110
62-302 Hz (mG)	Head	0.1	25.0	1.2	2.0	161
	Waist	0.1	20.2	1.2	1.9	159
	Ankle	0.1	17.7	1.3	2.0	147
302-3000 Hz (mG)	Head	0.0	12.3	0.5	1.0	209
	Waist	0.0	10.1	0.5	1.0	195
	Ankle	0.0	8.8	0.6	1.0	174
2-3000 Hz (mG)	Head	1.4	237.6	19.2	23.9	124
	Waist	1.5	190.5	18.4	21.3	116
	Ankle	1.3	138.5	19.1	21.2	111
E Field (V/m)	Chest	1.8	52.2	3.9	3.4	87

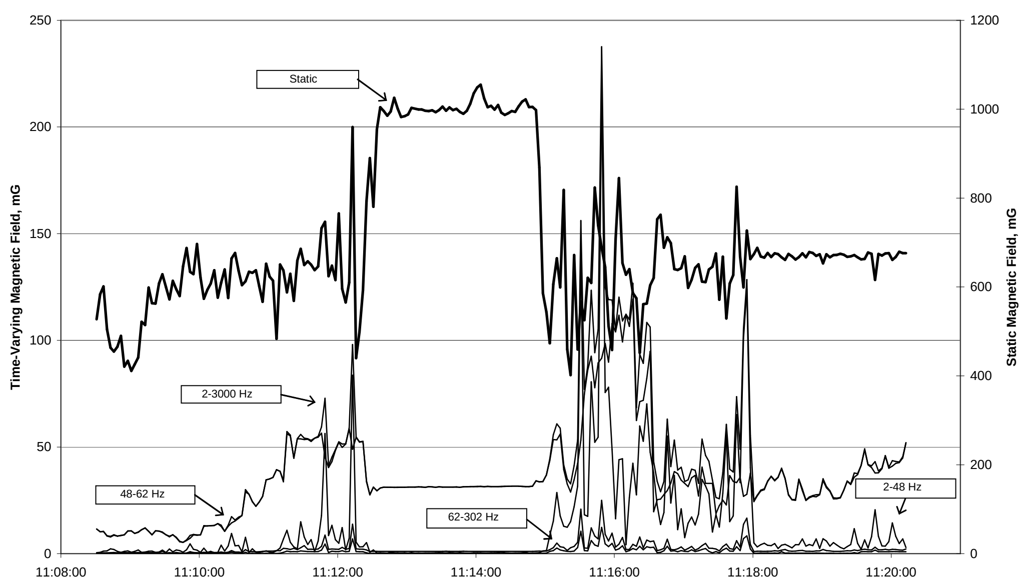


Figure M1. Static and Time-Varying Magnetic Fields from First Data Set on Board the Acela Express Leaving Boston, Headed toward New Haven, as Measured in the Passenger Compartment. These Measurements are from the Head Position on the Sensor Mannequin

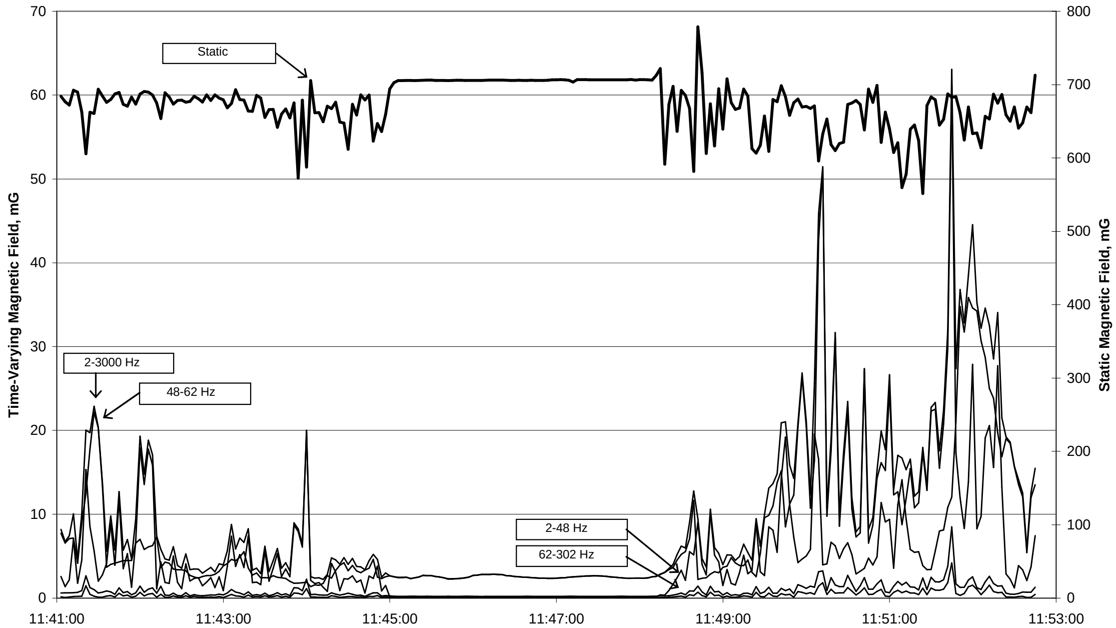


Figure M2. Static and Time-Varying Magnetic Fields from Second Data Set on Board the Acela Express, Headed Toward New Haven, as Measured in the Passenger Compartment. These Measurements are from the Head Position on the Sensor Mannequin

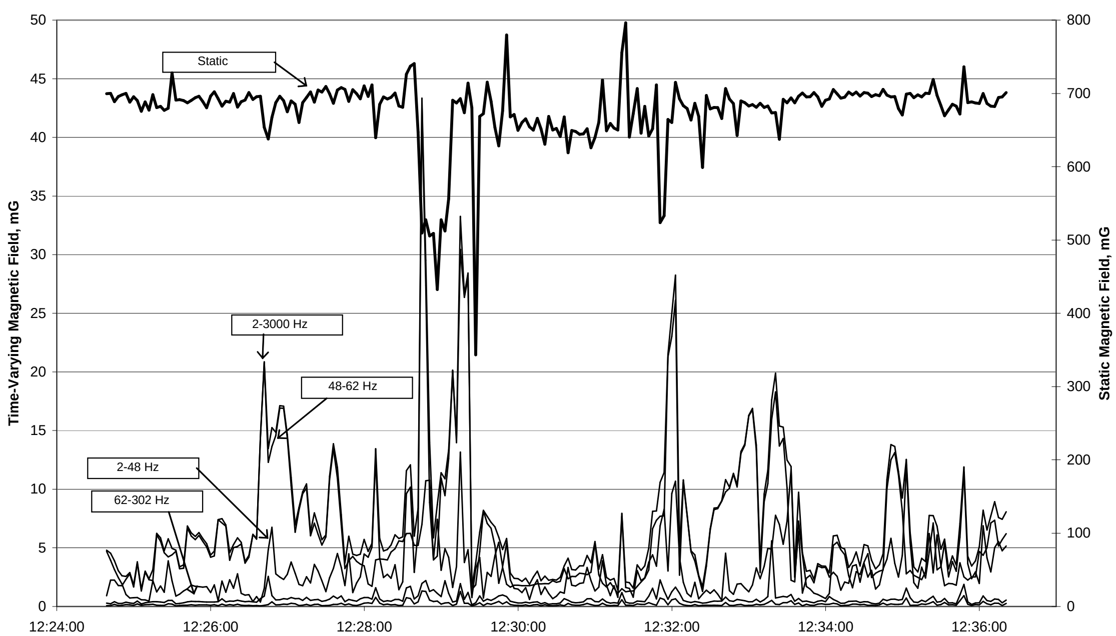


Figure M3. Static and Time-Varying Magnetic Fields from Third Data Set on Board the Acela Express, Headed Toward New Haven, as Measured in the Passenger Compartment. These Measurements are from the Head Position on the Sensor Mannequin

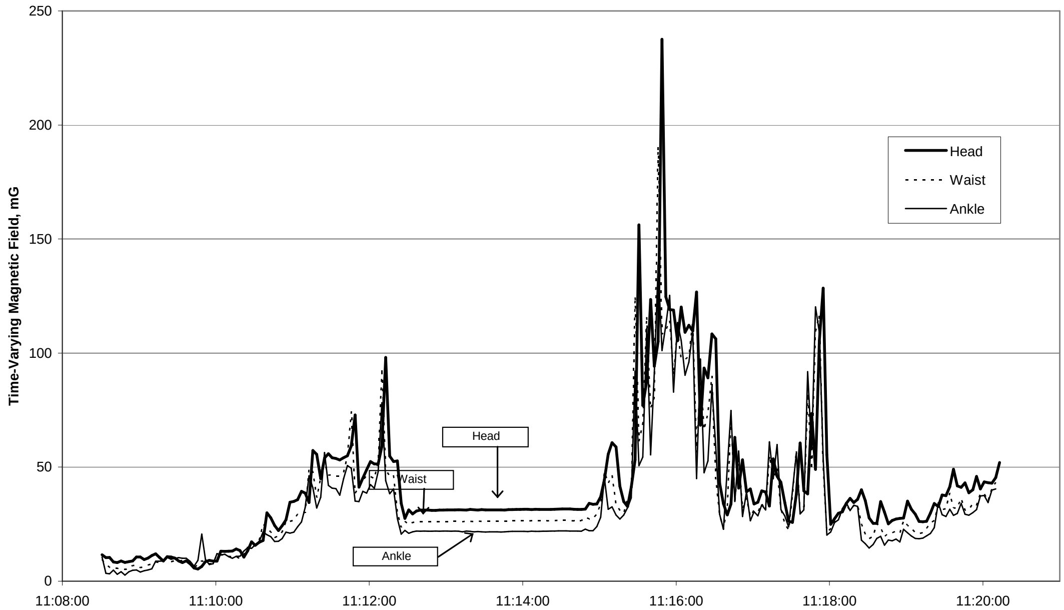


Figure M4. ELF Time-Varying Magnetic Fields from the First Data Set (Heading out of Boston) Showing that the Head, Waist, and Ankle Positions All Recorded Similar Magnetic Fields, with Slight Decreases from Head to Ankle, in General

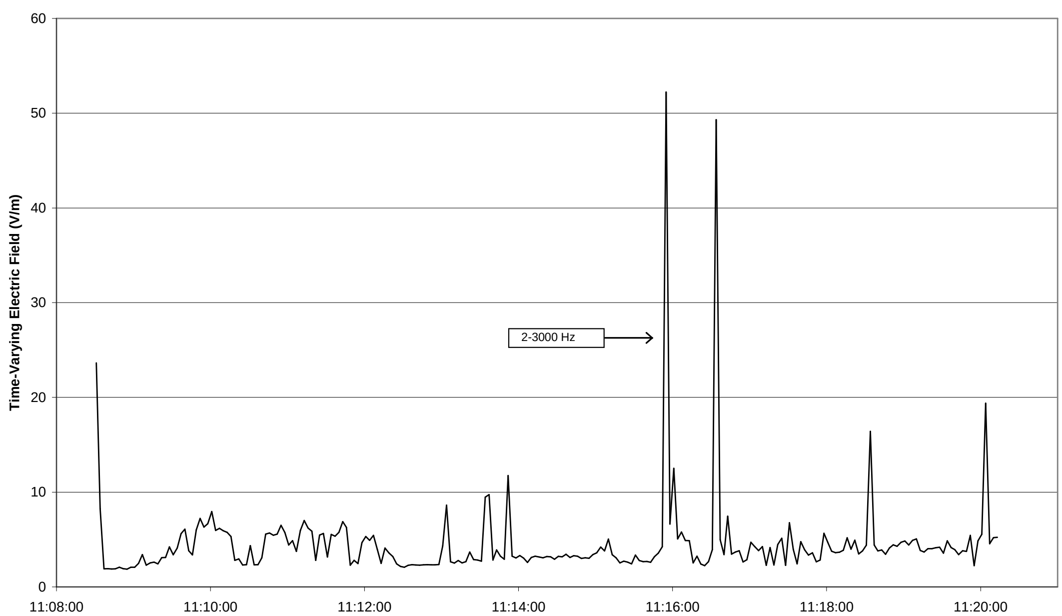


Figure M5. Time-Varying Electric Fields from the First Data Set on Board the Acela Express Heading out of Boston toward New Haven, as Measured in the Passenger Compartment. The Electric Field Sensor is Located at Chest Height, Measuring Magnetic Fields Perpendicular to the Chest

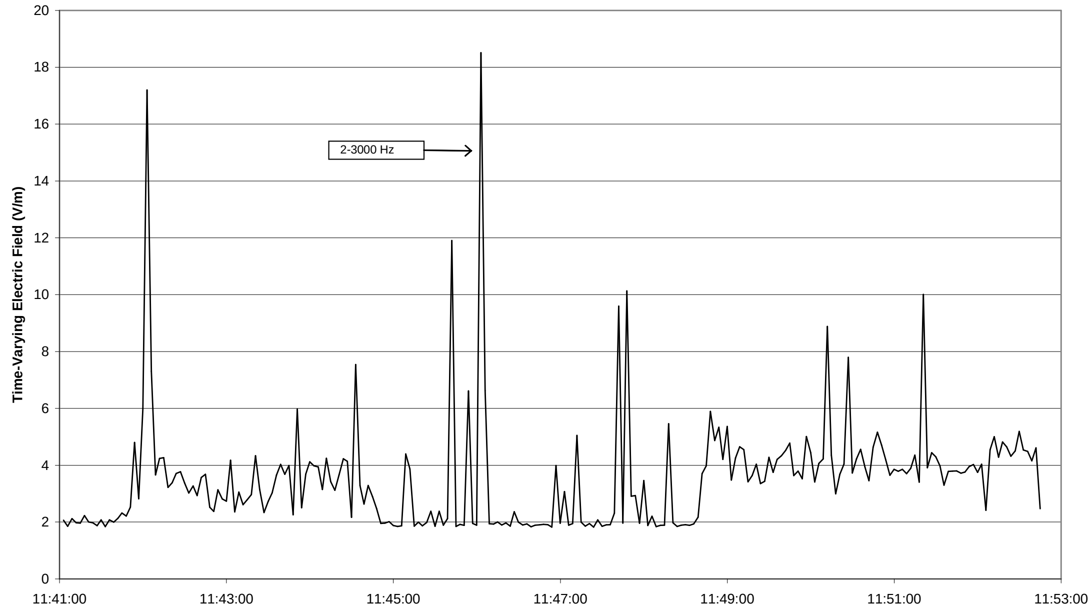


Figure M6. Time-Varying Electric Fields from the First Data Set on Board the Acela Express Heading out of Boston toward New Haven, as Measured in the Passenger Compartment. The Electric Field Sensor is Located at Chest Height, Measuring Magnetic Fields Perpendicular to the Chest

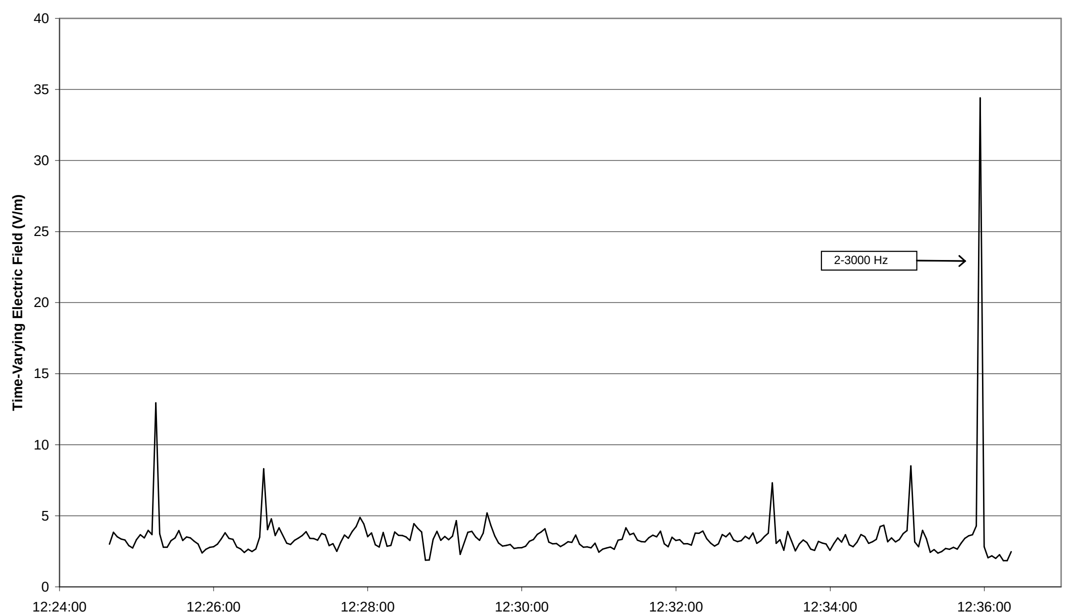


Figure M7. Time-Varying Electric Fields from the Third Data Set on Board the Acela, Express Heading toward New Haven, as Measured in the Passenger Compartment. The Electric Field Sensor is Located at Chest Height, Measuring Magnetic Fields Perpendicular to the Chest

M.2 Measurements in Engineer's Cab of Trailing Locomotive

Measurements were recorded in the left seat of the engineer's cab in the trailing Acela Express locomotive during a portion of the trip from New Haven to Old Saybrook. Data was recorded over a period of approximately 12 minutes.

Sensor Arrangement: Because one MultiWave System II unit did not operate properly, ELF magnetic fields were recorded at two positions instead of three, specifically the head and ankle positions. RF readings were logged using the electric field RF probe, A8722D, mounted on a tripod set in the middle of the cab, and readings were again logged at 1-second intervals with a Narda 8718B meter.

Field Characteristics: The RF readings were higher than in the passenger compartment, with a maximum reading of 2.6 percent of the occupational FCC standard, and an average of 1 percent. The static magnetic fields were also much lower than the passenger compartment, possibly due to the large amount of steel in the Acela Express locomotive provide a shielding effect. Static fields were lower at the ankle position near the cab floor. The highest time-varying fields were similar in magnitude in the 2-48 Hz band and the 48-62 Hz band, with the largest average time-varying fields occurring at the power frequency of 60 Hz.

Table M2. Summary Table of ELF Magnetic Fields in the Operator's Cab of the Trailing Acela Express Locomotive at the Head and Ankle Positions

Band	Sensor Position	Minimum	Maximum	Average	Standard Deviation	Coefficient Of Variation
Static (mG)	Head	253	594	546	38	6.9
	Ankle	45	412	299	58	19.4
2-48 Hz (mG)	Head	0.5	60.2	4.3	4.5	104.2
	Ankle	1.8	22.7	7.8	3.7	46.8
48-62 Hz (mG)	Head	1.4	57.8	19.1	12.6	65.8
	Ankle	0.9	48.4	13.6	8.2	60.6
62-302 Hz (mG)	Head	0.3	8.4	1.3	0.7	54.8
	Ankle	0.5	11.1	2.2	1.4	64.5
302-3000 Hz (mG)	Head	0.1	4.2	0.4	0.3	84.7
	Ankle	0.2	3.8	0.7	0.7	96.6
2-3000 Hz (mG)	Head	2.2	61.5	20.2	12.5	62.1
	Ankle	4.0	49.1	16.7	7.6	45.8

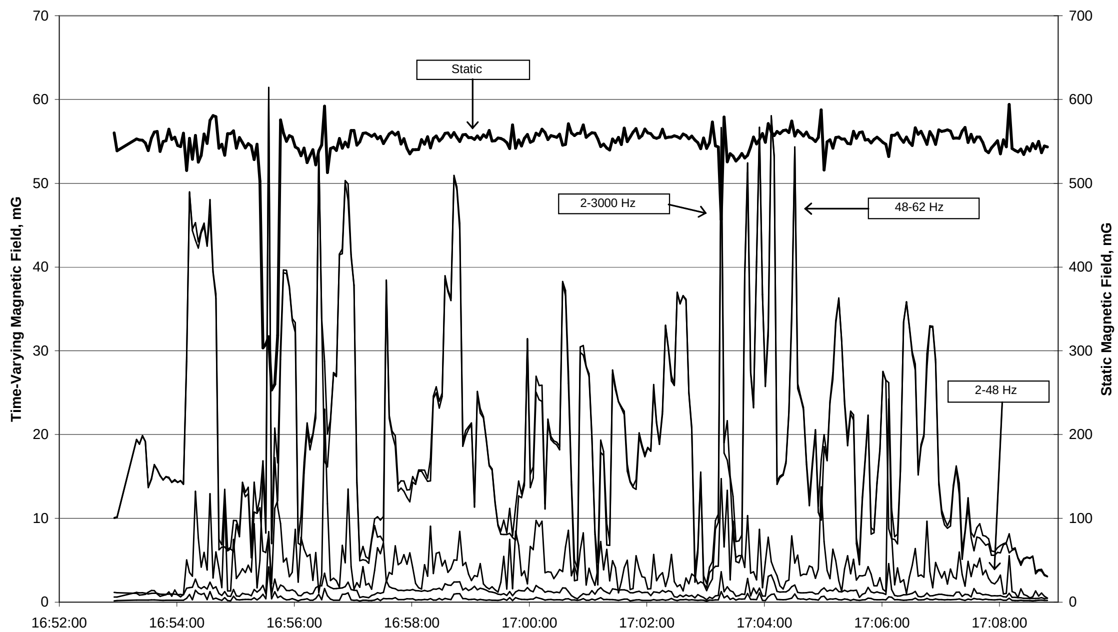


Figure M8. Static and Time-Varying Magnetic Fields at the Head Position in the Left Seat of the Engineer's Cab in the Trailing Acela Express Locomotive

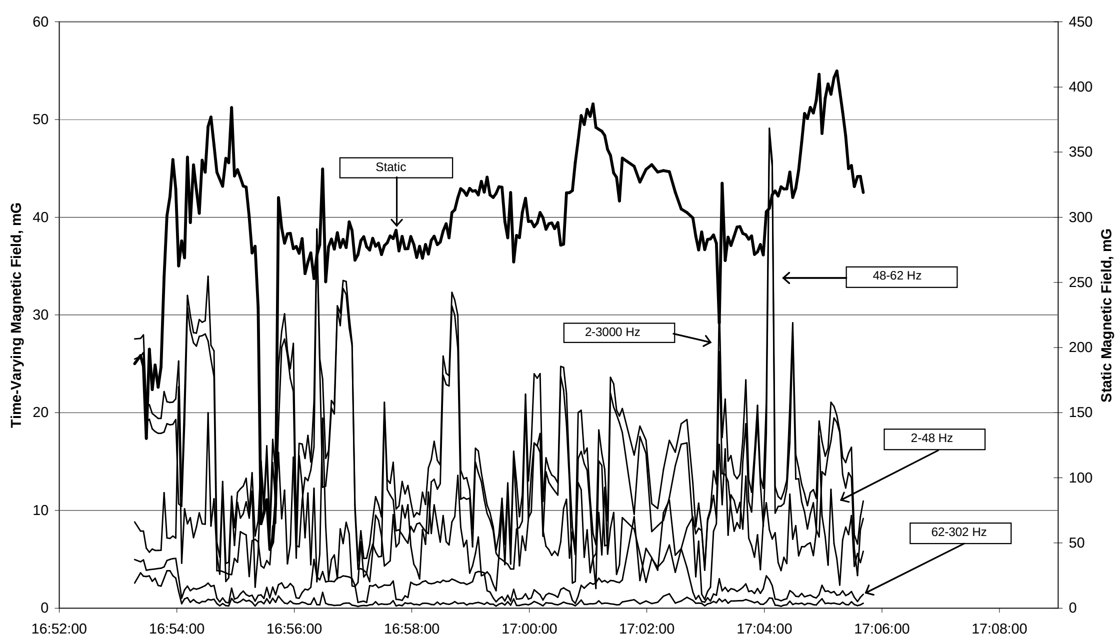


Figure M9. Static and Time-Varying Magnetic Fields at the Ankle Position in the Left Seat of the Engineer's Cab in the Trailing Acela Express Locomotive

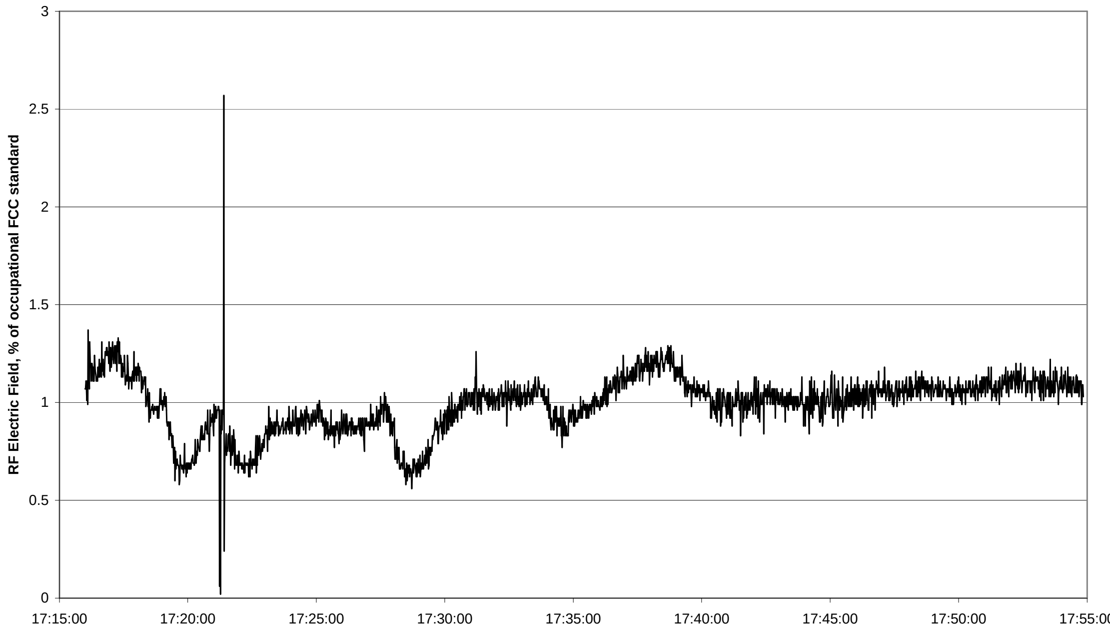


Figure M10. RF Electric Fields as a Percentage of the FCC Standard for Electromagnetic Exposure Measured in the Middle of the Engineer's Cab in the Trailing Acela Express Locomotive

Acronyms

AC	alternating current
ACGIH	American Conference of Industrial Hygienists
ACSES	Advanced Civil Speed Enforcement System
BECO	Boston Edison Company
DC	direct current
DOT	Department of Transportation
EIS	Environmental Impact Statement
ELF	extreme low frequency
EMF	electric and magnetic fields
ERM	Electric Research & Management, Inc.
FCC	Federal Communications Commission
FFT	Fast Fourier Transform
FRA	Federal Railroad Administration
IEEE	Institute of Electrical and Electronic Engineers
MBTA	Massachusetts Bay Transportation Authority
MPE	maximum permissible exposure
NEC	Northeast Corridor
OCS	overhead catenary system
PS	paralleling station
PVC	polyvinyl chloride
RF	radio frequency
ROD	Record of Decision
ROW	Right-of-Way
SS	substation
SwS	switching station
TL	tie-line
VLF	very low frequency