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Magnetic and Electric Field Testing of the Massachusetts Bay Transportation Authority (MBTA) Urban Transit System

Volume I: Analysis

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13. ABSTRACT (Maximum 200 words)

The safety of magnetically levitated (maglev) and high speed rail (HSR) trains proposed for application in the United States is the responsibility of the Federal Railroad Administration (FRA). Plans for near future US applications include maglev projects (e.g. in Orlando, FL and Pittsburgh, PA) and high speed rail (the French Train a Grande Vitesse (TGV) in the Texas Triangle).

Concerns exist regarding the potential safety, environmental and health effects on the public and on transportation workers due to electrification along new or existing rail corridors, and to maglev and high speed rail operations. Therefore, the characterization of electric and magnetic fields (EMF) produced by both steady (dc) and alternating currents (ac) at power frequency (50 Hz in Europe and 60 Hz in the U.S.) and above, in the Extreme Low Frequency (ELF) range (3-3000 Hz) is of interest.

An EMF survey of the MBTA transit system was performed, as part of a comprehensive comparative EMF assessment of the German Transrapid (TR-07) maglev system with other existing and advanced rail systems. This report provides the Analysis (Vol. I) of results, and detailed data and statistical summaries (Vol. II, Appendices) of representative EMF profiles on vehicles and facilities typical of electrotechnologies used in this transit system (3rd rail dc, catenary with pantograph, trolley bus). Each electrotechnology has specific EMF frequency signatures. EMF data represent a range of system operating conditions and locations (in vehicles, stations and waysides), as well as traffic control and electrical power supply facilities.

A portable magnetic field monitoring system (augmented to include an electric fields probe) was used to sample, record and store 3 axis static and ac magnetic fields waveforms simultaneously, at multiple locations. A real time Digital Audio Tape (DAT) recorder able to capture EMF transients, and two personal power-frequency magnetic field monitors were used to collect complementary data. Both dc magnetic fields and EMF ELF field levels for the MBTA system are comparable to those produced by common environmental sources at home, work, and under power lines, but they are more variable in time.

14. SUBJECT TERMS Electric and Magnetic Fields (EMF); Static (dc) Magnetic Field; Alternating (ac) Field; Extreme Low Frequency (ELF); MBTA; Transit System; Rapid Rail Transit System; Trolley; Bus; Third Rail; Catenary; Traffic Control Center; Transit Stations; Power Substations; Power Frequency (PF); Harmonics; Transients; Fourier Analysis; EMDEX Personal Magnetic Field Exposure Monitor; Digital Audio Tape (DAT) Recorder; MultiWave Magnetic Field Recording System.

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SYSTÈME INTERNATIONAL (SI) UNIT DEFINITIONS AND CONVERSIONS USED IN THIS REPORT

DISTANCE (ENGLISH-TO-SI CONVERSION):

1 inch (in)	= 2.54 centimeters (cm)	= 0.025 meters (m)
1 foot (ft)	= 30.5 centimeters (cm)	= 0.305 meters (m)
1 yard (yd)	= 91.4 centimeters (cm)	= 0.914 meters (m)
1 mile (mi)	= 1.61 kilometers (km)	= 1,610 meters (m)

ELECTRICAL QUANTITIES:

Electric Fields

1 Volt/meter (V/m)	= 0.01 Volts/centimeter (V/cm)
1 kiloVolt/meter (kV/m)	= 1000 Volts/meter (V/m)
1 kiloVolt/meter (kV/m)	= 10 Volts/centimeter (V/cm)

Magnetic Flux Densities (English-to-SI Conversion)

10,000 Gauss (G)	= 1 Tesla (T)
10 milliGauss (mG)	= 1 microTesla (μT)
1 milliGauss (mG)	= .1 microTesla (μT)
0.01 milliGauss (mG)	= 1 nanoTesla (nT)

Electromagnetic Frequency Bands

1 cycle per second	= 1 Hertz (Hz)
1,000 cycles per second	= 1 kiloHertz (kHz)

Ultra Low Frequency (ULF) Band	= 0 Hz to 3 Hz
Extreme Low Frequency (ELF) Band	= 3 Hz to 3 kHz
Very Low Frequency (VLF) Band	= 3 kHz to 30 kHz
Low Frequency (LF) Band	= 30 kHz to 300 kHz

PREFACE

The Federal Railroad Administration (FRA) has undertaken a series of studies to facilitate the introduction of advanced high speed guided ground transportation (HSGGT) technology to the U.S., including both magnetic levitation (maglev) and steel wheel on rail high speed alternatives, such as the French Train a Grande Vitesse (TGV), the Swedish Tilt Train (X2000), or the German Intercity Express (ICE). HSGGT technology options can be expected to undergo detailed public scrutiny and environmental assessment in order to convincingly establish their safety.

Timely development of technical information required for rulemaking initiatives is needed to ensure the public safety. An emerging concern related to environmental, workers', and to public health and safety is that of potentially adverse health effects of extremely low frequency (ELF) electric and magnetic fields (EMF) commonly associated with power transmission and distribution lines. Magnetic fields are of greater concern than electric fields, because they are pervasive, penetrate biological tissues without attenuation, and are more difficult to shield. Although no federal standards and guidelines on EMF/ELF exposure of workers and the public exist at present, international, state and professional associations have issued interim guidelines.

To enable informed assessments and comparisons to be made amongst emerging and existing technologies, a thorough EMF characterization (frequency, intensity, spatial and temporal variability, source analysis) of all representative existing and advanced electrical transportation systems is needed. This report is one of a comprehensive series of studies and reports addressing the ELF EMF emgineering and related safety issues for candidate HSGGT technologies and systems.

Electric Research and Management, Inc. (ERM) was engaged to measure, characterize and analyze the EMF for representative existing and advanced rail and transit systems.

This report presents data on both static (dc) and alternating (ac) magnetic fields and on ac electric fields obtained on the Massachusetts Bay Transportation Authority (MBTA), or Boston "T" system. Volume I, Analysis presents a summary of representative EMF data on various types of transit system vehicles and facilities, over a full range of operating conditions, as well as their variability in time, space and frequency. A comparison of transit system magnetic fields strengths with power frequency EMF produced by home appliances and common electric power distribution and transmission lines is also provided. Volume II, Appendices contains detailed EMF data files by location, time, and frequency range, as well as statistics.

This report was prepared by a team of Electric Research and Management, Inc. (ERM) personnel designated as authors for each volume, led by Fred M. Dietrich, Program Manager and William E. Feero, President. The technical monitor for this task and for the

entire series of reports characterizing Extreme Low Frequency (ELF) Electric and Magnetic Fields (EMF) for rail technologies was Dr. Aviva Brecher of the DOT/RSPA John A. Volpe National Transportation Systems Center (VNTSC), who manages the FRA's EMF Research Program. Guidance and program support was provided by Robert Dorer, the HSGGT Safety Program Manager at VNTSC. Professor Ross Holmstrom of University of Masachussetts and VNTSC, assisted both in planning the measurements and review of the results. Arne Bang, Senior Manager of Special Programs and the FRA sponsor for this work is thanked for overall direction and oversight.

Mr. Ronald D. Kangas and Mr. Jeffrey G. Mora from the Federal Transit Administration's Office of Technical Assistance and Safety provided technical advice and review comments. Valuable assistance with the measurements and logistics, as well as review comments on the draft report were provided by Mr. John Lewis, Manager, and Ms. Rachel Durkee, Signal Engineer, Mr. George Dennison, Power System and Equipment, and several other MBTA engineering staff members.

VOLUME I

TABLE OF CONTENTS

VOLUME I

TABLE OF CONTENTS (CONT'D)

VOLUME I

TABLE OF CONTENTS (CONT'D)

VOLUME I

TABLE OF CONTENTS (CONT'D)

VOLUME I

TABLE OF CONTENTS (CONT'D)

VOLUME I

LIST OF FIGURES

VOLUME I

LIST OF FIGURES (CONT'D)

VOLUME I

LIST OF FIGURES (CONT'D)

VOLUME I

LIST OF FIGURES (CONT'D)

LIST OF FIGURES (CONT'D)

VOLUME I

LIST OF FIGURES (CONT'D)

LIST OF FIGURES (CONT'D)

LIST OF FIGURES (CONT'D)

LIST OF FIGURES (CONT'D)

VOLUME I

LIST OF FIGURES (CONT'D)

VOLUME I

LIST OF TABLES

VOLUME I

LIST OF TABLES (CONT'D)

VOLUME I

LIST OF TABLES (CONT'D)

LIST OF TABLES (CONT'D)

VOLUME II

TABLE OF CONTENTS

VOLUME II

TABLE OF CONTENTS (CONT'D)

VOLUME II

TABLE OF CONTENTS (CONT'D)

VOLUME II

TABLE OF CONTENTS (CONT'D)

VOLUME II

LIST OF FIGURES

VOLUME II

LIST OF TABLES

1. EXECUTIVE SUMMARY

This report documents the static magnetic fields and extreme low frequency electric and magnetic fields associated with the operation of the Massachusetts Bay Transportation Authority's (MBTA) urban transit system in the Boston area. With excellent cooperation and assistance of MBTA system personnel, comprehensive measurements were made on and along the MBTA system lines and at select facilities.

1.1 BACKGROUND

Extensive measurements have previously been made and reported for four other electrified rail transportation systems[1,2,3,4,5]. These include the Transrapid TR07 magnetic levitation (maglev) system at the test track in Emsland, Germany, AMTRAK trains operating on the Northeast Corridor (NEC), New Jersey Transit trains on the North Jersey Coast Line, the *Train à Grande Vitesse Atlantique* (TGV-A) System in France and the Washington, D.C. Metropolitan Area Transit Authority (WMATA) Metrorail urban transit system.

The motivation for these extensive measurements was the creation of a comprehensive database of the electric and magnetic field characteristics of conventional existing electrified rail transportation systems against which the field characteristics of new systems such as the maglev can be evaluated. While maglev magnetic field magnitudes were within the range of fields produced by other well documented field sources such as electric power lines and substations, the frequency and temporal characteristics differed from those relatively constant sources of power frequency fields. Magnitude comparisons alone for such temporally different sources are not appropriate for the multi-frequency and complex time characteristics associated with the maglev and other rail electrotechnologies.

To have the necessary data to fairly assess the electric and magnetic fields for any new electrified transportation system to be installed in the United States, the FRA research program sponsored a measurement program to fully characterize the ULF and ELF fields of four existing electrified rail systems. These include the AMTRAK Northeast Corridor, the French TGV, the Washington, D.C. WMATA Metrorail, and the MBTA system. With such a dataset, more appropriate comparisons can be made since the service functions are comparable.

1.2 MEASUREMENT APPROACH

All of these measurements have been made using the portable *MultiWave*™ System (hereinafter referred to as the waveform capture system) originally developed under sponsorship of the Electric Power Research Institute (EPRI). This system quantifies both the spatial and temporal characteristics of the magnetic field. By recording the actual waveform of the magnetic field with sensors having frequency responses from 0 to 3 kHz, the waveform capture system makes it possible to examine the frequency characteristic as well throughout the ULF and ELF bands. (The reader who is unfamiliar with terms like "Hz" and "ELF" is encouraged to review the conversion table in the front of this report.) The waveform capture system also recorded the electric field nominally at standing head height. The waveform capture system data was complemented by continuous field recordings at one sensor location made on a digital audio tape (DAT) recorder to capture transient events and with data from two EMDEX-II (hereinafter referred to as rms recorders) which recorded the root mean square (rms) value of the magnetic field encountered by the wearers throughout the day.

The magnetic field and electric field measurements made on or near the Boston MBTA system facilities were grouped into six areas:

- within vehicle passenger compartments;
- within the operator's position;
- in the passenger stations;
- along the track rights-of-way (wayside);
- inside and outside the traction power supply stations; and
- in a dispatcher's control room.

The results from measurements in each of these areas are presented in detail in a separate section of this report.

Measurements onboard the train were made in each of the four different types of subway cars and a High Speed Trolley and a Trolley Bus operating on the MBTA system. The subway cars' traction power came from a 600 V dc third rail, and the trolley traction power came from a 600 V dc catenary. The fields in each type of vehicle were characterized in the center and rear of the passenger compartment and in the operator's area.

At the stations, electric and magnetic field measurements were made at the arriving and departing ends of the platforms at the yellow safety line, that is, points nearest the track where a person could reasonably stand.

Wayside measurements were made to quantify the field environment in areas along the line route accessible to the general public. Measurements were taken at both subway car and Trolley Bus waysides.

Traction power supply station measurements were made inside three different stations at various locations near ac and dc equipment and near control panels within the facilities. Measurements were also made at two locations outside one of the stations.

Finally, field measurements were in the vicinity of a dispatcher's work-area to characterize fields within control facilities.

Figure 1-1 is a map of the entire Boston MBTA system (the Trolley Bus lines are not shown). The onboard magnetic and electric field measurements were made on the Green Line between Lechmere and Government Center Stations, on the Blue line between Aquarium and Wonderland Stations, on the Orange Line between Malden Center and Downtown Crossing Stations, on the Red Line between Downtown Crossing and Shawmut Stations, and at different locations along the Mattapan High Speed Trolley Line. The passenger station measurements were taken at the Wood Island Blue Line outdoor platform, and the Government Center and Downtown Crossing underground subway stations. The wayside measurements were taken near the Wood Island Station (Blue Line) and on Beacon Street (Green Line). The dispatcher's room, and traction power supply station measurements were taken at sites not shown on the map.

1.3 SUMMARY OF BOSTON MBTA SYSTEM FIELD LEVELS

The following is a concise description of the magnetic field characteristics at each of the areas examined. Three types of electrification technology were analyzed: third rail electrification operation with cam (camshafts which switch resistors to control the dc traction motors) type cars; catenary operation with cam cars; and catenary operation with chopper cars. It should be noted that all measured electric fields were less than 10 volts per meter (V/m) and are not discussed in this summary.

1.3.1 Vehicles

The magnetic fields in the passenger areas of the MBTA system vehicles arise mainly from the traction power control equipment beneath the floor of the cars and also possibly the current in the loop created by the third rail (or catenary) and track return circuit. These fields are predominantly static with low frequency time varying components resulting from fluctuations in the static field level, as well as some rectifier ripple even harmonics.

The static magnetic field at seat level (60 cm above the floor) in these dc powered MBTA system subway cars averaged 507 mG. The maximum static field encountered at seat height for the same samples was 1446 mG. The corresponding average and maximum time varying magnetic fields for the High Speed Trolley and Trolley Bus were 312 mG and 775 mG, respectively.

The total time varying magnetic field levels for the subway cars averaged 5.7 mG over all samples and all sensor locations. The maximum time varying field encountered during the same periods was 68 mG. For the High Speed Trolley and Trolley Bus, over all samples and all sensor locations, the corresponding average and maximum time varying magnetic fields were 2.5 mG and 26 mG, respectively.

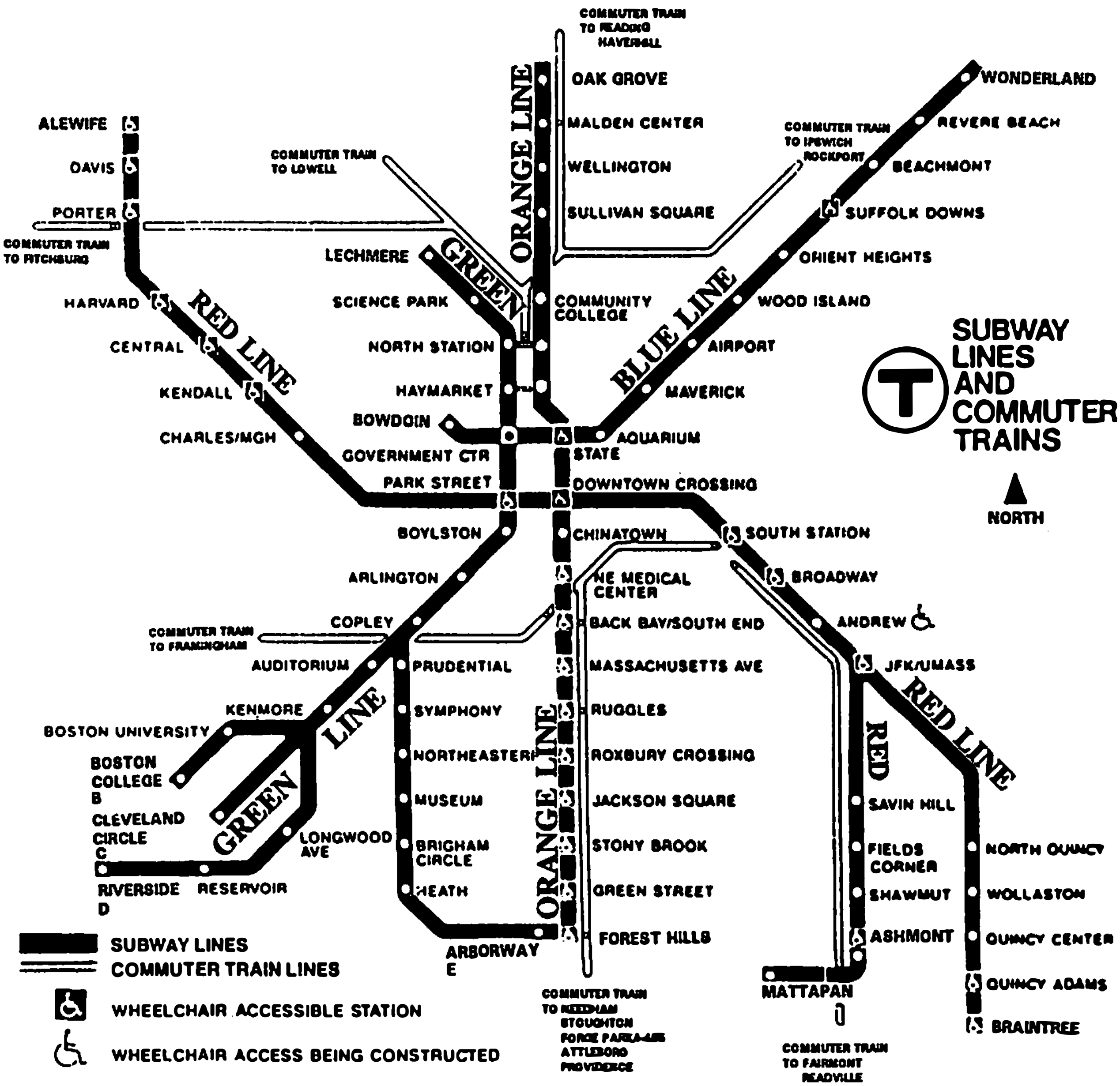


FIGURE 1-1. MBTA SYSTEM MAP SHOWING THE SUBWAY LINES, MATTAPAN HIGH SPEED TROLLEY LINE, AND PASSENGER STATIONS

1.3.2 Operator's Area

The principal sources of magnetic field in the operator's area are the same as in the passenger areas, that is, the traction power equipment beneath the floor and the current in the loop created by the third rail (or catenary) and the track return circuit. There appeared to be no additional source unique to the operator's position. As described in Section 1.3.1, these fields are predominantly static with low frequency time varying components resulting from fluctuations in the static field level. The measurements made onboard the four different types of cars are comparable to one another. Thus, an overall set of statistics is possible, termed the subway operator's position. The same holds true for combining the High Speed Trolley and Trolley Bus data. The following summary values were obtained close to the operator's seat.

The static magnetic field, as measured by the repetitive waveform recorder, averaged 699 mG at seat level (60 cm height). The maximum static field encountered for the same 60 cm height was 2220 mG. The corresponding average and maximum static magnetic fields for the High Speed Trolley and Trolley Bus were 387 mG and 651 mG, respectively.

The total time varying magnetic field levels for the subway cars operator's seat averaged 4.8 mG at the 60 cm height level and the maximum field encountered was 53 mG. The corresponding average and maximum time varying magnetic fields for the High Speed Trolley and Trolley Bus were 1.8 mG and 11.5 mG, respectively.

1.3.3 MBTA System Waysides

The static magnetic field at the wayside of the MBTA system lines arises from a combination of the earth's magnetic field (approximately 550 mG in Boston) and the static magnetic field due to the dc traction current in the rails (or catenary). At locations outside the right-of-way exclusion fence, the static field from traction current in the third rail (or catenary) and tracks does not add appreciably to the natural static field environment. At locations along the Trolley Bus route, there are no right-of-way exclusion fences. However, the static field from traction current in the dual overhead catenary does not add appreciably to the natural static field environment at the sidewalk, where the measurements were taken.

The time varying field at the wayside has components from three sources: changes in the dc traction current produce low frequency components whose magnitude depends on the rate of change of the dc current; second, from the rectifier ripple currents in the rails, and third, from the 60 Hz current in any nearby commercial power lines. Since the magnetic field at the railroad wayside due to the current in the rails (or catenary) attenuates rapidly with distance from the tracks, at distances comparable to the exclusion fence location, the time varying field from common sources such as distribution lines equals or exceeds the components from the MBTA system.

The average value of the dc field measured at the wayside was 492 mG, which compares with the published value of 548 mG (Geophysical Investigations Map GP-987-F, Department of the Interior, U.S. Geological Survey) for Boston. The largest dc value measured at the wayside was 823 mG. The average and maximum ac magnetic fields measured at the right-of-way exclusion fence, an equivalent distance of 4.6 m (15 ft), were 4.4 mG and 11.5 mG, respectively, but those values are dominated by fields from nearby powerlines. The average and maximum fields actually arising from the MBTA system are estimated to be 0.8 mG and 3.5 mG, respectively.

Measurements along the MBTA system Trolley Bus route found the average and maximum static field levels to be 505 mG and 522 mG with buses passing by. The measured average and maximum time varying field levels were 2.2 mG and 3.2 mG, but those values included fields apparently arising from nearby powerlines.

The electric fields measured along the waysides were under 1 V/m.

1.3.4 Passenger Station Platforms

The magnetic field environment on a passenger station platform is similar to the wayside except that the passenger is closer to the rails. Static fields from traction power current in the third rail (or catenary) and track return circuit add to the naturally occurring geomagnetic field. The earth's magnetic field is also distorted in an underground platform due to ferromagnetic material in the structure. The time varying magnetic field at the platforms arises from changes in the static (dc) component due to changing dc traction power in the rails (or catenaries), the rectifier harmonics and fields from the passing cars themselves. Moreover, there are 60 Hz fields from nearby electric equipment, such as station wiring, lights and ventilating motors.

The average values of the static field measured at body/torso height (110 cm above the floor) near the edge of the passenger platforms were fairly close for the three electrification types, namely 444 mG for cam-third rail, 485 mG for cam-catenary, and 494 mG for chopper-catenary, respectively. The corresponding maximum static field levels were 892 mG, 971 mG and 765 mG, respectively.

The average time varying magnetic fields measured 110 cm above the edge of the platform for the same three cases were 3.4 mG, 9.5 mG and 3.9 mG, respectively. The corresponding maximum values were 12.7 mG, 82 mG and 15 mG.

The electric fields measured on any of the platforms were under 4 V/m.

1.3.5 Traction Power Supply Stations

Data was recorded both outside and inside the traction power supply stations. Only modest strength magnetic fields were observed outside the stations. The largest measured static magnetic field value was 976 mG and the average value was 483 mG. The average and maximum time varying magnetic field levels were 3.0 mG and 15.2 mG for the same outside measurements.

Substantially higher magnetic fields were observed inside the traction power supply stations. The largest measured static magnetic field value was 2750 mG and the average value was 841 mG. The corresponding average and maximum time varying magnetic field levels were 12.3 mG and 133 mG.

The highest electric field measured inside the stations was under 3 V/m and on the outside was less than 1 V/m.

1.3.6 Control Facilities

The major sources of magnetic fields in the dispatcher's area are currents in the building wiring which supplies power to the equipment and lights, and the equipment itself, such as video display terminals (VDT). The measured average and maximum ac magnetic fields in the dispatcher's room were 4.9 mG and 6.6 mG. The higher values were found closer to equipment. The static field in the dispatcher's room was fairly constant over time but varied spatially from a high value of 1106 mG at 160 cm above the floor near the operator's seat, to a low value of 208 mG near the VDT.

The highest electric fields measured inside the dispatcher's room was 1.2 V/m.

1.4 COMPARISON OF MBTA SYSTEM FIELDS TO OTHER ELECTRO-TECHNOLOGIES

Much of the concern about ELF magnetic field levels is driven by uncertainty as to whether such fields exert an adverse effect on human health. Existing scientific knowledge provides no sound insight as to what aspects of ELF magnetic exposure, if any, are of biological concern[6]. Consequently, public acceptance of magnetic field exposures is presently based more on equity and comparability to other exposures than to quantifiable characteristics of the field itself. Therefore, this section compares and contrasts the magnetic fields produced by the MBTA system operation to other sources of magnetic fields.

1.4.1 Static Fields

Static magnetic fields beyond normal range due to passive perturbation of the earth's geomagnetic field exist inside the vehicles, the operator's position, at the wayside, on the platforms, inside and outside the traction power supply stations, and inside control rooms because of the dc nature of the MBTA system electrification. The largest measured static field of 3 gauss was encountered in subway cars and trolleys, near the floor. For comparison, the maximum magnetic field reading at 60 cm above the floor was 2.2 gauss. Total static fields in excess of one gauss also existed on platforms (2.4 G) and inside the traction power supply stations (2.8 G).

1.4.2 Frequency Spectrum

The frequency characteristics of the magnetic fields onboard or near the MBTA system vehicles is different from those reported near many ac-powered electrical appliances[7]. The dc electrification gives rise to low frequency components which are the result of temporal changes in the dc traction current drawn by operating cars. Also, there are harmonics of 60 Hz present that arise from the rectification ripple currents in the traction current. Moreover, the Green Line cars contain semiconductor choppers and filtering reactor coils, located beneath the cars, which produce fields in the higher end of the ELF band.

1.4.3 Time Characteristics

The magnetic fields onboard the MBTA system vehicles, both subway and trolley, or near the rails have pronounced temporal variability similar to the variability of magnetic fields near appliances with varying load or intermittent use. These fields have much greater variability than the fields found near most commercial electric power lines.

1.4.4 Amplitude Characteristics

This subsection compares the measured time varying magnetic field levels onboard the MBTA system vehicles or near the MBTA system lines and its facilities to the reported environmental field levels from various power frequency sources. This comparison is based on total ELF magnetic field and does not take into consideration the significant differences in frequency spectra. For considerations where frequency is an important factor, this comparison is invalid because the MBTA system fields which contain little or no 60 Hz component are compared to fields which are primarily 60 Hz.

1.4.4.1 Vehicles - Figure 1-2 shows the general range of total time varying magnetic fields measured in both the subway and trolley vehicles on the MBTA system lines as a function of distance from the source, which for purposes of this graph is presumed to be the vehicle floor. The range is plotted over the graph of a typical transmission line, distribution line and appliance field levels[6] discussed earlier. As the graph illustrates, the intensity of the ELF magnetic field inside the vehicles diminishes away from the floor.

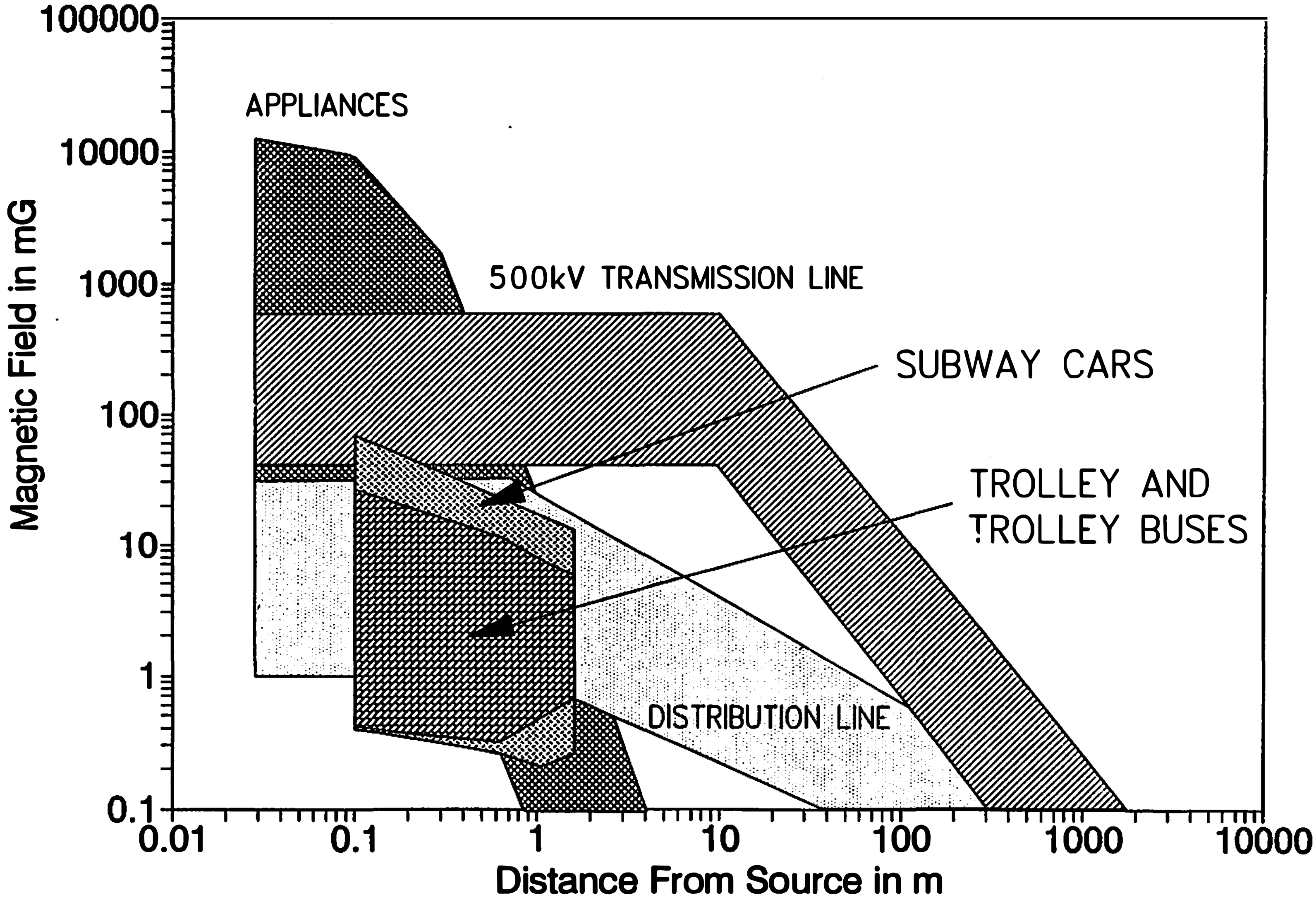


FIGURE 1-2. THE RANGE OF TOTAL TIME VARYING MAGNETIC FIELD LEVELS IN THE MBTA SYSTEM SUBWAY, TROLLEY, AND TROLLEY BUS VEHICLES COMPARED TO TYPICAL LEVELS OF POWER FREQUENCY MAGNETIC FIELDS PRODUCED BY COMMON SOURCES

The range of magnetic field intensities spans about two orders of magnitude, including the range of magnetic fields found under all distribution lines and some transmission lines. However some higher intensities are found near transmission lines and close to appliances. There is essentially little difference between the subway cars and the High Speed Trolleys or Trolley Buses.

1.4.4.2 Operator's Position - Figure 1-3 shows the range of total time varying magnetic fields recorded in the MBTA system operator's position as a function of distance from the floor. The data are plotted over the same typical power frequency magnetic field levels. The magnetic field levels in the operator's compartment are similar to those found in other parts of the cars (see Figure 1-2) and are within the range of field levels found beneath electric distribution lines or near appliances.

1.4.4.3 Along the Wayside - Figure 1-4 shows the plot of the ranges corresponding to the two types of measurement locations, namely the subway waysides of the Green and Blue Lines and the sidewalk wayside along the Trolley Bus route. The distance to the source for the subway waysides is measured to the centerline of the nearest set of tracks. The distance to the source for the Trolley Bus wayside is measured to the nearest overhead double catenary centerline. As described in Section 6, these measured field levels included fields from both the MBTA system and background fields from other sources. Consequently, the measured values overstate the magnitude of the field actually produced by the MBTA system. The figure shows that these conservative measures of magnetic field levels at both locations are within the general range of magnetic fields near distribution lines. The actual contribution to the magnetic fields from the MBTA system facilities is actually lower.

1.4.4.4 Passenger Stations - The ranges of time varying magnetic fields measured on the passenger platforms, both indoor and outdoor, on third rail with cam cars and on catenaries with and without chopper-type cars were sufficiently similar to combine into one dataset for purposes of this graph. These time varying magnetic fields are shown in relation to other sources in Figure 1-5. The distance to the source is the distance to the floor of the platform. The range of magnetic field levels at the platforms are about the same as the general range of magnetic fields near distribution lines.

1.4.4.5 Power Supply Station Measurements - The ranges of total time varying magnetic fields recorded at the three traction power supply stations are shown in Figures 1-6 and 1-7. Figure 1-6 shows the magnetic field levels measured outside traction power supply station, where distance is height above the sidewalk. It can be seen that these field levels are in the range of fields found under distribution lines. Figure 1-7 shows the magnetic field levels inside traction power supply station, where the distance is the

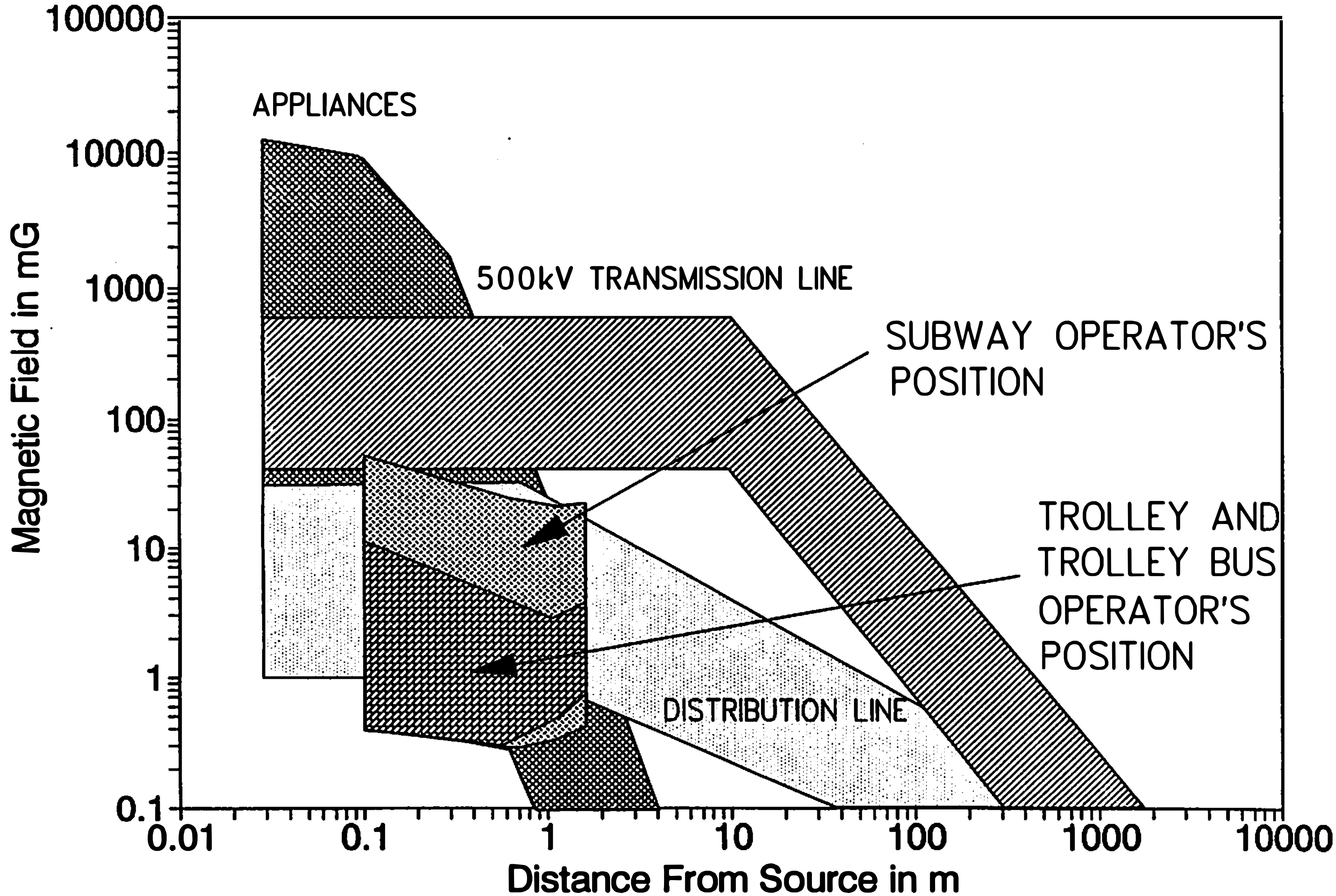


FIGURE 1-3. **THE RANGE OF TOTAL TIME VARYING MAGNETIC FIELD LEVELS IN THE OPERATOR'S POSITION OF THE MBTA SYSTEM SUBWAY, TROLLEY, AND TROLLEY BUS VEHICLES COMPARED TO TYPICAL LEVELS OF POWER FREQUENCY MAGNETIC FIELDS PRODUCED BY COMMON SOURCES**

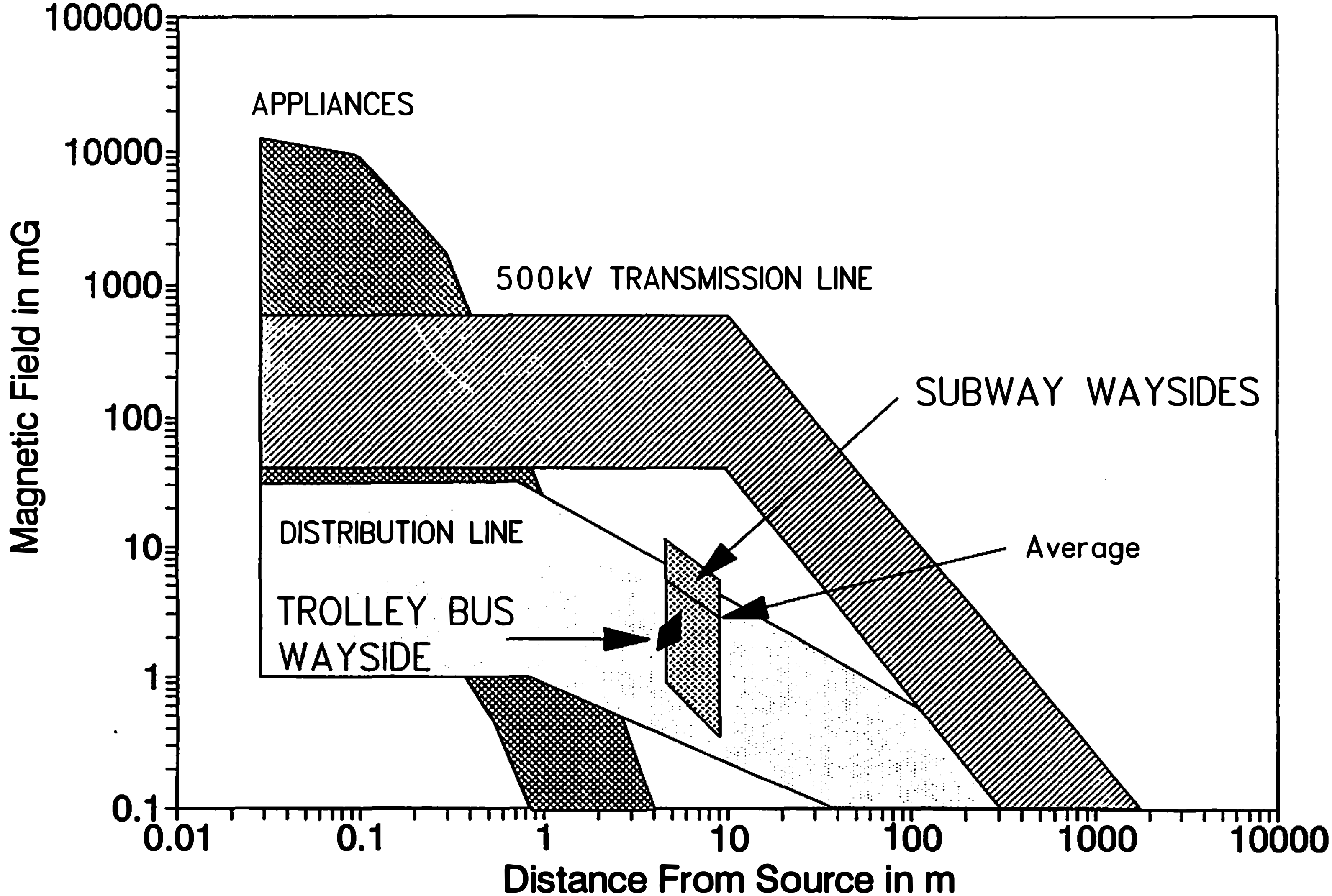


FIGURE 1-4. **THE RANGE OF TOTAL TIME VARYING MAGNETIC FIELD LEVELS AT SUBWAY WAYSIDES AND TROLLEY BUS WAYSIDE, AT VARIOUS DISTANCES FROM THE NEAREST TRACK OR CATENARY, COMPARED TO TYPICAL LEVELS OF POWER FREQUENCY MAGNETIC FIELDS PRODUCED BY COMMON SOURCES**

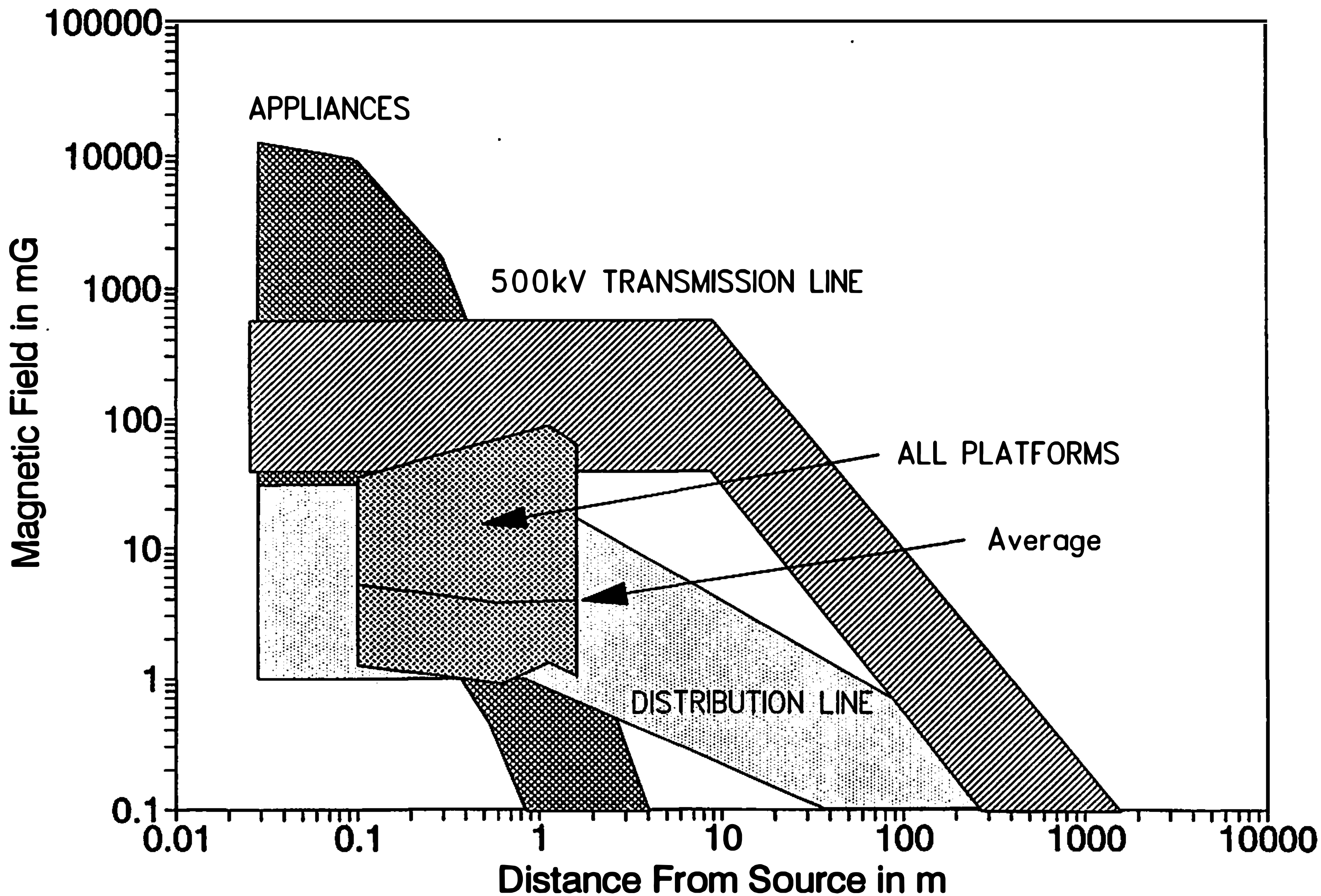


FIGURE 1-5. **THE RANGE OF TOTAL TIME VARYING MAGNETIC FIELD LEVELS ON THE PLATFORMS, AT VARIOUS DISTANCES FROM THE FLOOR, COMPARED TO TYPICAL LEVELS OF POWER FREQUENCY MAGNETIC FIELDS PRODUCED BY COMMON SOURCES**

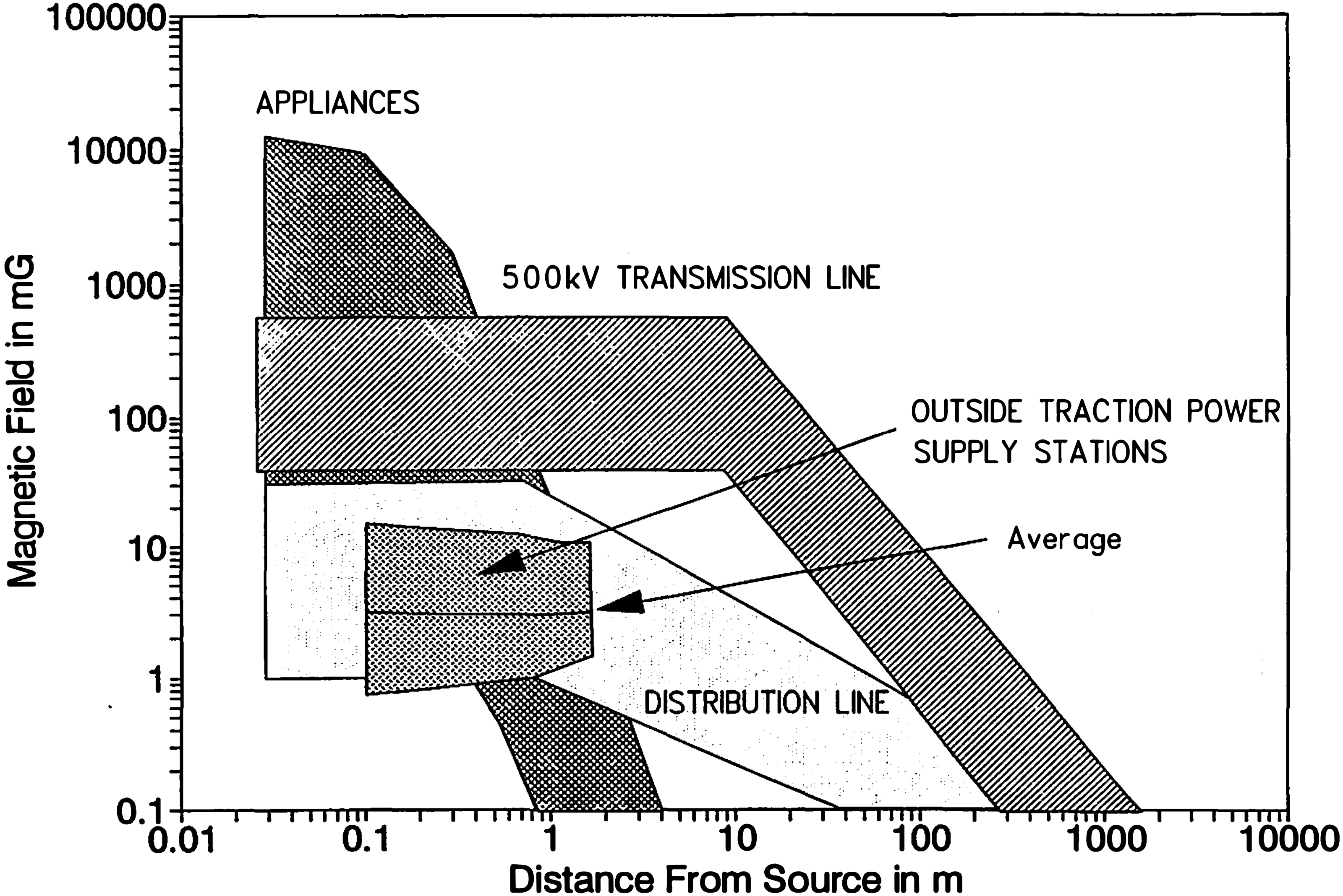


FIGURE 1-6. **THE RANGE OF TOTAL TIME VARYING MAGNETIC FIELD LEVELS OUTSIDE TRACTION POWER SUPPLY STATIONS, AT VARIOUS DISTANCES FROM THE GROUND, COMPARED TO TYPICAL LEVELS OF POWER FREQUENCY MAGNETIC FIELDS PRODUCED BY COMMON SOURCES**

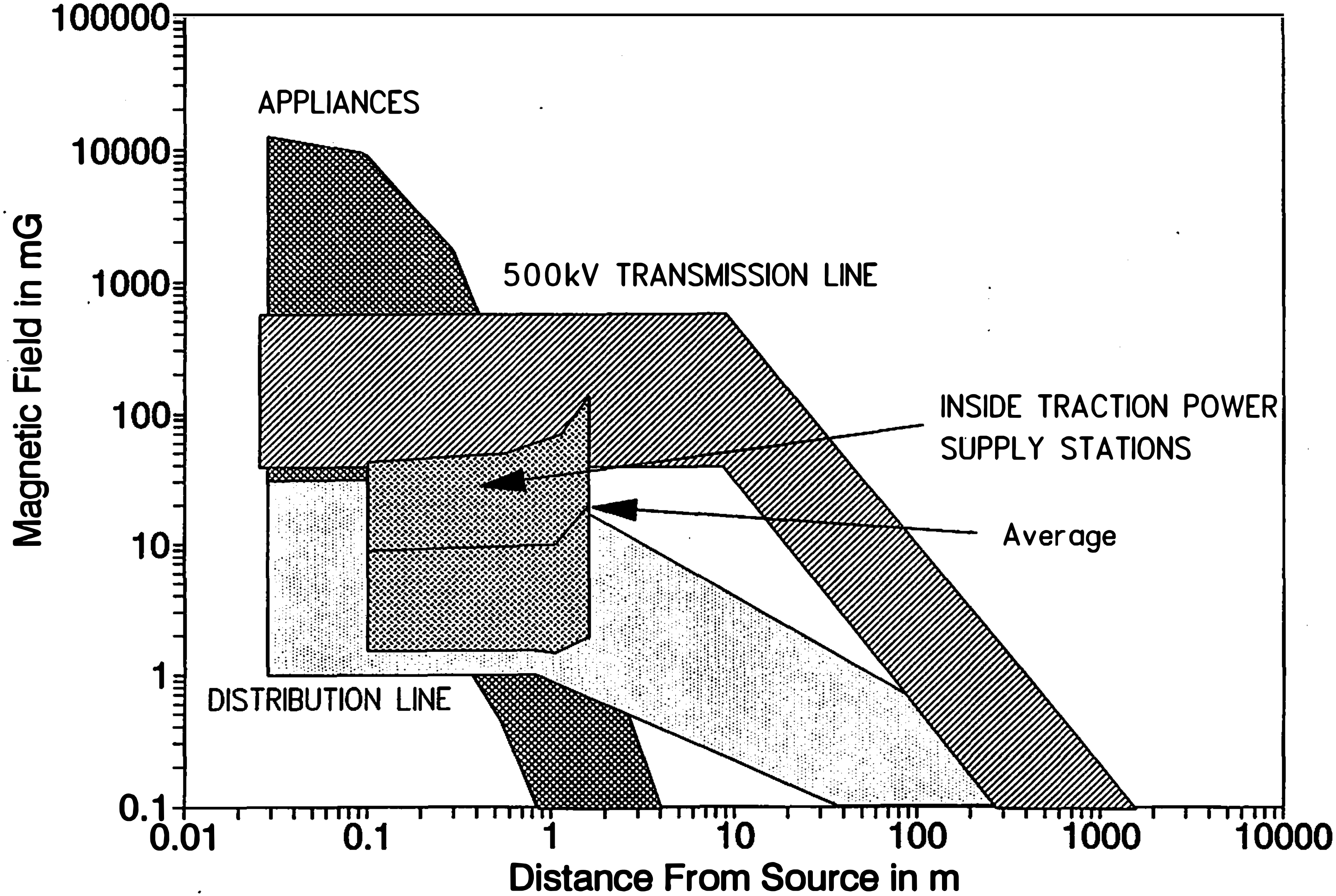


FIGURE 1-7. THE RANGE OF TOTAL TIME VARYING MAGNETIC FIELD LEVELS INSIDE TRACTION POWER SUPPLY STATIONS, AT VARIOUS DISTANCES FROM THE FLOOR, COMPARED TO TYPICAL LEVELS OF POWER FREQUENCY MAGNETIC FIELDS PRODUCED BY COMMON SOURCES

height above the floor of the station. The range of magnetic field levels inside the stations are at the low side of the range of magnetic fields near transmission lines.

1.4.4.6 Traffic Control Areas - Figure 1-8 shows the plot of the range of time varying magnetic fields in front of the dispatcher's VDT in the dispatcher's room. The distance to the source is the distance to the VDT screen. As one would expect, the figure shows that the range of magnetic field levels from the VDT is well within the range of magnetic fields near appliances. The sharp change of the VDT field curve beyond 1 m (3.3 ft) from the source represents the point where the general background field level within the dispatcher's room is predominant. That background level is very modest compared to the range of field levels found near the three common field sources depicted in the figure.

1.5 CONCLUSIONS

1.5.1 Magnetic Fields

The magnetic fields associated with the Boston MBTA system contain both static and time varying components. The dc traction current in the third rail or catenary, in the track return, in the power control equipment beneath the vehicles, and in the traction power supply station creates static fields in the vicinity of those facilities. The time varying magnetic fields associated with the MBTA system are of two distinct types. First, changes in the "static" field level brought about by changes in the dc traction current in the aforesaid circuits produces low frequency time varying components that vary in intensity depending on the time rate of change of the static field. Secondly, there are periodic time varying components of the field arising from rectifier ripple in the dc traction current and from chopper current in the Green Line cars.

Both static and time varying magnetic fields onboard the vehicles arise predominantly from the traction power control equipment beneath the floor and secondarily from the current loop formed by the third rail (or catenary) and the tracks. Because power needs of the cars vehicles set by terrain and speed control, these fields are highly variable over time.

On station platforms, especially near the edge of the platform close to the rails (or catenary), static and time varying magnetic fields arise both from the traction power (dc and rectification harmonics) and equipment onboard the passing trains. At the wayside locations, the time varying magnetic fields also arise from rectification harmonics on the traction power. However, they were smaller than the 60 Hz and harmonic fields from nearby power lines. Magnetic fields from equipment onboard the passing train were not found at the wayside location.

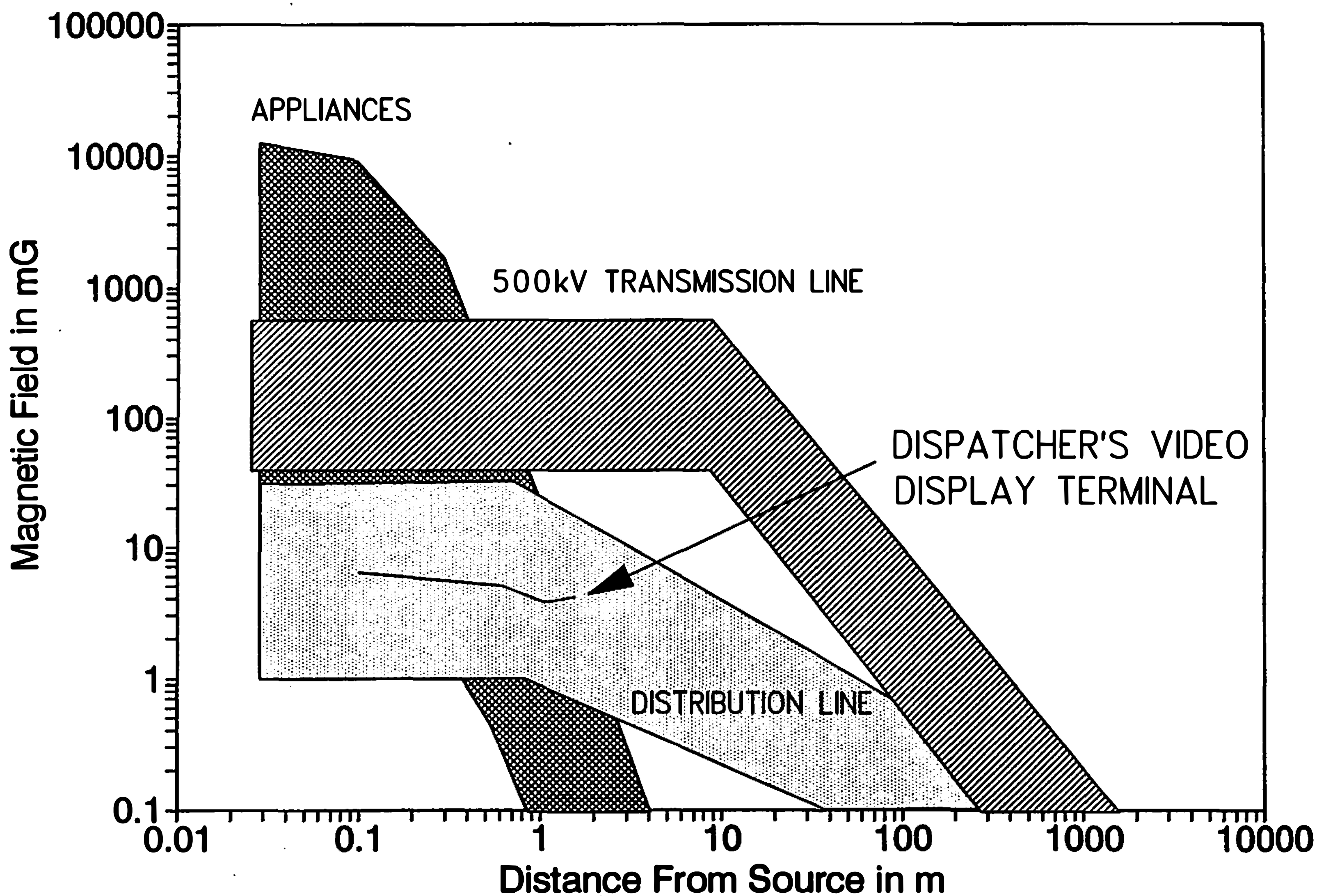


FIGURE 1-8. THE RANGE OF TOTAL TIME VARYING MAGNETIC FIELD LEVELS IN FRONT OF A DISPATCHER'S VIDEO DISPLAY TERMINAL, AT VARIOUS DISTANCES FROM THE VDT, COMPARED TO TYPICAL LEVELS OF POWER FREQUEMCY MAGNETIC FIELDS PRODUCED BY COMMON SOURCES

Inside traction power supply stations, measurements at the sides close to the ac electric equipment such as transformers and switchgear, yield 60 Hz and odd harmonic (mainly third harmonic) fields. At the dc side equipment inside the station such as rectifiers, magnetic fields have a time varying static component and the ripple-frequency (even harmonics) components.

1.5.2 Electric Fields

No significant electric fields were detected anywhere in the system. On the average the electric fields inside the vehicles, including the operator's position, measured less than 0.5 V/m, with an occasional reading higher, up to 5 V/m. In the traction power supply stations and passenger stations all readings were below 4 V/m. Along the wayside and outside the traction power supply stations, the fields measured less than 1 V/m. Electric field of 1.2 V/m was detected in the dispatcher's office. The predominant frequency of all these fields was 60 Hz.

2. OVERVIEW

This report presents quantitative and qualitative data on the electric and magnetic fields associated with the Massachusetts Bay Transportation Authority (MBTA) urban transit system, commonly known as the Boston "T". It is one of a series of related reports by Electric Research & Management, Inc. (ERM) for the Federal Railroad Administration (FRA) on the general characteristics of magnetic and electric fields associated with existing or advanced rail systems. The previous reports have covered a number of different technologies. Specifically, measurements have been made and reported onboard the German Transrapid TR07 magnetic levitation (maglev) system, AMTRAK diesel and electrified trains on the Northeast Corridor, electrified trains on the New Jersey Transit's North Jersey Coast Line from Matawan to Long Branch, the French *Train à Grande Vitesse* (TGV) and the Washington, D.C. Metropolitan Area Transit Authority (WMATA) Metrorail system. Electric and magnetic fields have, in each case, been measured and reported at the stations, along the wayside, at power supply facilities, and in control facilities for each of these transportation systems for a range of operating conditions.

2.1 REPORT ORGANIZATION

This report is organized into two volumes. The body of the report contained in Volume I focuses on representative data analysis and summarizes statistical data for the reader who is interested in overall system characteristics. The representative data demonstrate the general characteristics of the magnetic and electric fields on or in the vicinity of the MBTA transit system.

The extensive appendices of Volume II detail the magnetic and electric fields at specific locations on or near the Boston MBTA transit system for the reader looking for specific details of field characteristics.

The first section of this report is an executive summary intended for less technical readers. It describes the magnetic fields produced by the Boston transit system and the conclusions reached by these measurements in language which avoids engineering jargon to the greatest extent practical. In spite of its non-technical nature, it is recommended to all readers as an orientation to the report contents and will assist the technical reader in critically examining the contents of the report.

This section is an overview describing the report structure in more detail and directing the reader to other sources of relevant information not contained herein. It also provides some background information about the measurement program, describes instrumentation, explains the significance of the repetitive waveform data, the method of analysis, the format of presentation, and certain other items relevant to the report as a whole.

Sections 3 through 8 focus on the characteristics of the magnetic fields measured at representative locations: onboard the vehicles, within the operator's area, along the wayside, at passenger stations, near power supply facilities, and inside control facilities, respectively. Within each section, there is a further subdivision that covers separately each one of the different technologies and transit lines.

Section 9 of the report both summarizes the magnetic and electric field characteristics of the Boston MBTA transit system and compares these characteristics to magnetic fields produced by other common sources.

2.2 BACKGROUND

The increasing public awareness of the controversy over possible health implications due to exposure to magnetic fields makes it desirable to quantify the magnetic fields associated with use or operation of all electrical apparatus. Previous measurements have characterized the magnetic fields associated with state-of-the-art transportation systems like the Transrapid TR07 maglev vehicle and the French TGV electrified railroad system. Similar measurements have been made onboard AMTRAK electrified trains and near the facilities of the Northeast Corridor (NEC) to provide baseline magnetic field data on a conventional, historically well accepted transportation technology against which the magnetic field environment of emerging technologies may be compared. Additional magnetic field measurements have been made onboard trains and adjacent to facilities of the New Jersey Transit's North Jersey Coast Line from Matawan to Long Branch. That section of the railroad is electrified using somewhat newer technology. Measurements have also been made onboard trains and adjacent to facilities of the WMATA Metrorail system which is typical of a modern urban mass transit system using 750 volts dc third rail technology. This report is on the measurements associated with the MBTA system which is characterized by a combination of technologies spanning the last 60 years. The system uses both 600 volts dc third rail and catenary technology.

To achieve the goal of fully quantifying the electromagnetic environment of the Boston transit system, an exhaustive set of measurements was made onboard trains, in the operator's area, at passenger stations, along the wayside, in control facilities, and near power supply facilities. These measurements were made for a sampling of operating conditions. However, before the amplitude, time, and frequency characteristics of the fields are analyzed and presented, it is necessary to discuss some general background information on magnetic fields.

2.2.1 Natural Magnetic Field Characteristics

The earth's naturally-occurring geomagnetic field is generally considered to be static, i.e., not variable over time (in some literature, static fields are referred to as dc fields). The earth's field is normally static at levels between 240 milligauss in Southern Brazil to 670 milligauss at the magnetic South Pole. In any region of the earth's surface, fluctuations will occur during solar magnetic disturbances. These fluctuations normally have frequencies that are less than one hundredth of a cycle per second to as high as 1000 cycles per second. The magnitude of these fluctuations is normally largest at the lowest frequencies and in the polar regions. Mid-latitude variations of 2 to 4 milligauss are common during strong solar storms. In polar regions, solar magnetic disturbances can cause greater than ± 20 milligauss fluctuations. Therefore, the natural environment is made up of magnetic fields with both spatial and temporal characteristics.

2.2.2 Technological Magnetic Field Perturbations

Man-made ferromagnetic structures and electro-technologies perturb these natural fields. In close proximity to building and vehicle steel, increases or decreases to the earth's unperturbed geomagnetic field (approximately 550 mG in Boston) of 2 to 1 are readily observed. Any electrical device that draws significant current for operation or uses magnetic material will create magnetic field intensities close to the device that are on the order of the naturally occurring magnetic fields. Most electrical devices in common usage are powered by alternating current (ac) sources. The magnetic fields produced have the frequency of the power source and weaker harmonics (sub or super) which result from the device's operating characteristics. On the North American continent, the dominant power source frequency is 60 cycles per second (the engineering and scientific communities have agreed to refer to cycles per second as hertz and to further shorten the reference by using the abbreviation Hz). In Europe most power systems are 50 Hz. Therefore, most electro-technology magnetic fields produced are primarily at these power frequencies. The magnitudes of the magnetic fields at the power frequencies range from fractions of milligauss in rural residences to tens of gauss near high current carrying conductors found in many commercial and industrial facilities. Many commonly used household appliances, such as high speed hair dryers and handheld drills, exhibit power frequency magnetic fields well above one gauss (one thousand mG) in close proximity to the appliance. In some appliances power control devices also produced harmonic and transient magnetic fields.

2.2.3 Electric and Magnetic Fields and Biological Effects

Since the late 1800s, electro-technologies have been perturbing the natural electromagnetic environment. In the early 1970s, the subject of electric fields surfaced as a possible health concern when electric utilities tried to gain rights-of-way for power transmission lines. Transmission lines were one of a small number of electro-technologies that produced strong power frequency electric fields where there was public access. The transmission lines at the center of the controversy were a new technology in that the operating voltage was 60 percent higher than previous design. The frequency characteristics were unchanged. While magnetic fields were raised as an issue in the 1970s because of a Navy submarine communications project, it was not until 1979 that magnetic fields appeared as a possible health concern. It was suggested that there was a weak correlation with an increased risk of childhood leukemia for populations living near distribution lines. While the first such study was considered to be technically flawed, two subsequent, improved epidemiological studies continued to find a consistent pattern when a surrogate for magnetic fields, power lines with large conductors and proximity to the cases, were documented. In 1992 Swedish researchers reported on finding a somewhat stronger association for childhood leukemia among children living in close proximity to transmission lines in Sweden[8]. Starting with the assertion of biological effects from electric fields and renewed with the emergence of the magnetic field effect hypothesis, laboratory scientists have reported many electric and magnetic field effects found by *in vitro* (tissue culture preparations) and *in vivo* (whole animal studies) experiments.

Many of the laboratory studies and a concurrent body of clinical studies have reported effects which appear to result from exposure to fields with a wide range of magnitudes and frequencies. To explain these observations, hypotheses such as "cyclotron resonance" which links the co-existence of static (dc) and ac fields have been offered. Because much of the political controversy has been focused on determining if transmission lines can be sited, most of the laboratory effort has been directed at the very selective power frequencies, 50 and 60 Hz. Yet many reported results have little to do with the power frequencies. Many studies report findings in the few hertz to tens of hertz frequency band. There are reports of findings when the exposure repetition rate was above the power frequencies. Other studies suggest the duration of exposure is important, or that both intensity (magnitude) and frequency windows exist, i.e., above or below a certain region no effect is observed. Some studies suggest that the transition from one field level to another is important, others debate whether magnetic fields act directly on the body or via induced currents. Few of these studies have been replicated and no accepted mechanism of interaction of environmentally relevant electric or magnetic field exists.

In the absence of an accepted mechanism, many have chosen to relegate the reported effect of electric and magnetic fields to the category of "pathological science" (a term coined by the late Irving Langmuir). However, the persistence of public concern necessitates that any serious attempt at magnetic field quantification which claims to serve as a basis for evaluating possible health effects must not be an inadvertently selective measure of magnitude at a single or narrow band of frequencies. In the extreme, if health effects are found, the continuum of electromagnetic exposure may be required to establish relative risk. It has only recently become possible to record and store all of the discrete segments of frequency bands which biological reports suggest may be important. Based on the biological studies reported to 1992, the electrified railroad measurements focused on the 0 to 2500 Hz portion of the electromagnetic spectrum.

2.3 THE MBTA SYSTEM

This study concentrates on the characteristics of the MBTA system that provide urban mass transit to the greater Boston metropolitan area. The measurements were taken on portions of all four subway lines (the Red, Orange, Blue and Green lines), as well as the Mattapan High Speed Trolley and the Trolley Bus lines.

As mentioned, there is a variety of technologies present in the system. The differences can be associated with and are easily distinguishable among the different transit lines. Thus, the Boston transit system can be best described by discussing each one of the lines separately.

The electrical power supply system of the train is 600 volts dc through either a third rail or a catenary. This supply is produced by converting 60 Hz ac power from commercial utility sources to dc power through rectification at a series of traction power supply stations distributed along the Boston transit lines. These traction power supply stations contain transformers, rectifiers, switchgear, and filter capacitors which convert the incoming three-phase 60 Hz power supplied at distribution voltages (typically 13.8 kV) into the 600 volts dc that is applied to the third rail (or catenary) to supply power to the train or trolley. On most of the subway systems, the dc current is then collected from the third rail through contactor shoes on the front and back trucks of the cars. The Green and Blue Line cars when above ground, and the trolley or trolley buses collect power from overhead catenaries with pantographs or trolley poles. The dc current flows through under-car wiring to the under-car power control equipment (either cam or electronic chopper) and to the dc traction motors on the trucks before returning to traction power station ground via the wheels and track. In the case of the trolley buses, the dc current is returned to the traction power station ground via a second trolley pole and second overhead catenary.

Although all cars on all four lines on the Boston transit system have dc propulsion systems, two different traction power control technologies are used to regulate the amount of electrical power provided to the traction motors. The Red, Orange and Blue Line cars have cam controlled traction control systems built by Westinghouse (Red Line) or General Electric (Blue and Orange Lines). Semiconductor chopper control is used in the Green Line cars. Cam control means that resistors are mechanically switched in and out of either the armature or field of the motors in order to control their speed and torque. Similarly, resistors are switched in to provide dynamic braking. All of the resistors and associated switches are located beneath the cars between the two trucks.

The majority of the fleet of Red Line cars were built by either Pullman Standard or UTD.C. of Canada. These sister cars are approximately 21.4 m (70 ft) long, have aluminum bodies, and are equipped with Westinghouse cam controlled propulsion systems. Tests were made on this kind of car.

Cars on the Blue and Orange Lines were built by Hawker-Sidley and equipped with General Electric cam controlled propulsion systems. The major difference between these steel cars is their length. Orange Line cars are 19.8 m (65 ft) long while the Blue Line cars are only 15.3 m (50 ft) long. Blue Line cars are also equipped with pantographs so that they can operate from either third rail in tunnels or from overhead catenaries on the surface section of the line east of Maverick Square.

The Green Line cars are articulated cars approximately 22.9 m (75 ft) long and supported on three trucks. The center truck beneath the articulation is not powered. There are two distinct series of cars, one built by Boeing and the other built by Kinki-Sharyou. They both use semiconductor choppers to accomplish traction power control via voltage control. This is functionally like the Washington, D.C. Metrorail's 3000 series cars. Reactors are provided before and after the chopper to filter or "smooth out" some of the chopper ripple in the line and motor currents, respectively. Neither series of cars has a reactor as big as the D.C. Metrorail's 3000 series cars. The choppers, reactors, and other traction power control equipment are located beneath the cars in the central areas in front of and behind the center truck. Other auxiliary equipment such as the motor-alternator for hotel power and air compressor are also located beneath the car but more toward the front or rear truck. Traction motors are on the front and rear trucks only. Dynamic braking resistors are on the roof of the cars along with the air conditioners. The chopper frequencies were not readily available from MBTA system personnel to whom we spoke, but the frequency signatures of the magnetic fields on both cars indicated a frequency of approximately 218 Hz.

The Mattapan High Speed Trolley is a classic urban "streetcar" of the President's Car Commission (PCC) design. The Trolley receives current from a single trolley pole which travels along one catenary with current return through the tracks. Its propulsion is dc motors that are cam controlled.

The Trolley Bus is a rubber tire vehicle that has two trolley arms at the rear which travel on two overhead catenaries. These catenaries are approximately .45 m (18 in) apart and are the supply and return portions of the circuit. Its cam controlled dc motor propulsion system is manufactured by General Electric.

2.4 AN APPROACH TO ORGANIZING ELECTROMAGNETIC DATA

The magnetic field environment over the frequency range from 0 to 2500 Hz can be efficiently recorded with excellent resolution using the waveform capture system described in the following subsection. Unlike most systems which merely report the total magnetic field over their frequency range, the waveform capture system was operated during the railroad tests in a manner which detects the magnetic field in very narrow frequency bands across the spectrum from 0 to 2500 Hz. The effective frequency resolution of these data is 1 Hz increments from 0 to 100 Hz and 5 Hz increments from 5 to 2500 Hz.

The data collected in this manner brackets most of the frequency bandwidths implicated by the biological effects findings discussed briefly above. Both temporal and spatial quantification of the magnetic field in and around the Boston Transit System are available. Because each of these measurements was repeated every few seconds to gain a measure of the long-term temporal characteristics of the magnetic fields, a large, as well as comprehensive, dataset exists. The challenge of this report, as in the other reports of the FRA-sponsored series, has been to reduce this data without losing the uniqueness of the information. Also, to maximize the utility of the data, it must be presented so that it can be compared to data collected on the magnetic field characteristics of other electro-technologies.

To this end, the following aggregation was chosen for this evaluation. It is also being followed in an ongoing project to establish a rigorous protocol for quantifying the magnetic fields associated with appliances. Shown in pictorial form in Figure 2-1, this system allows for the grouping of data into frequency bands where effects have been reported and/or other datasets have been collected. The two large boxes depict the frequency regions defined by IEEE Std 100-1988[9] as Ultra Low Frequency (ULF), which covers the frequency range from 3 Hz down to static, and Extreme Low Frequency (ELF), which covers the frequency band from 3 Hz to 3000 Hz. Other organizations and agencies sometimes define these bands differently, but the IEEE definitions will be used throughout this report. The boxes within the large boxes depict the partitioning which was chosen to present clearly, but succinctly, the findings of these Boston MBTA system measurements.

The partitioning in Figure 2-1 also allows for comparison with data collected by less sophisticated instruments. In particular, the rms recorder which has come into wide use in the utility industry has a 3 dB bandwidth between 40 Hz and 800 Hz, mainly the power frequency and some harmonics. Other survey meters only respond to the power frequency band.

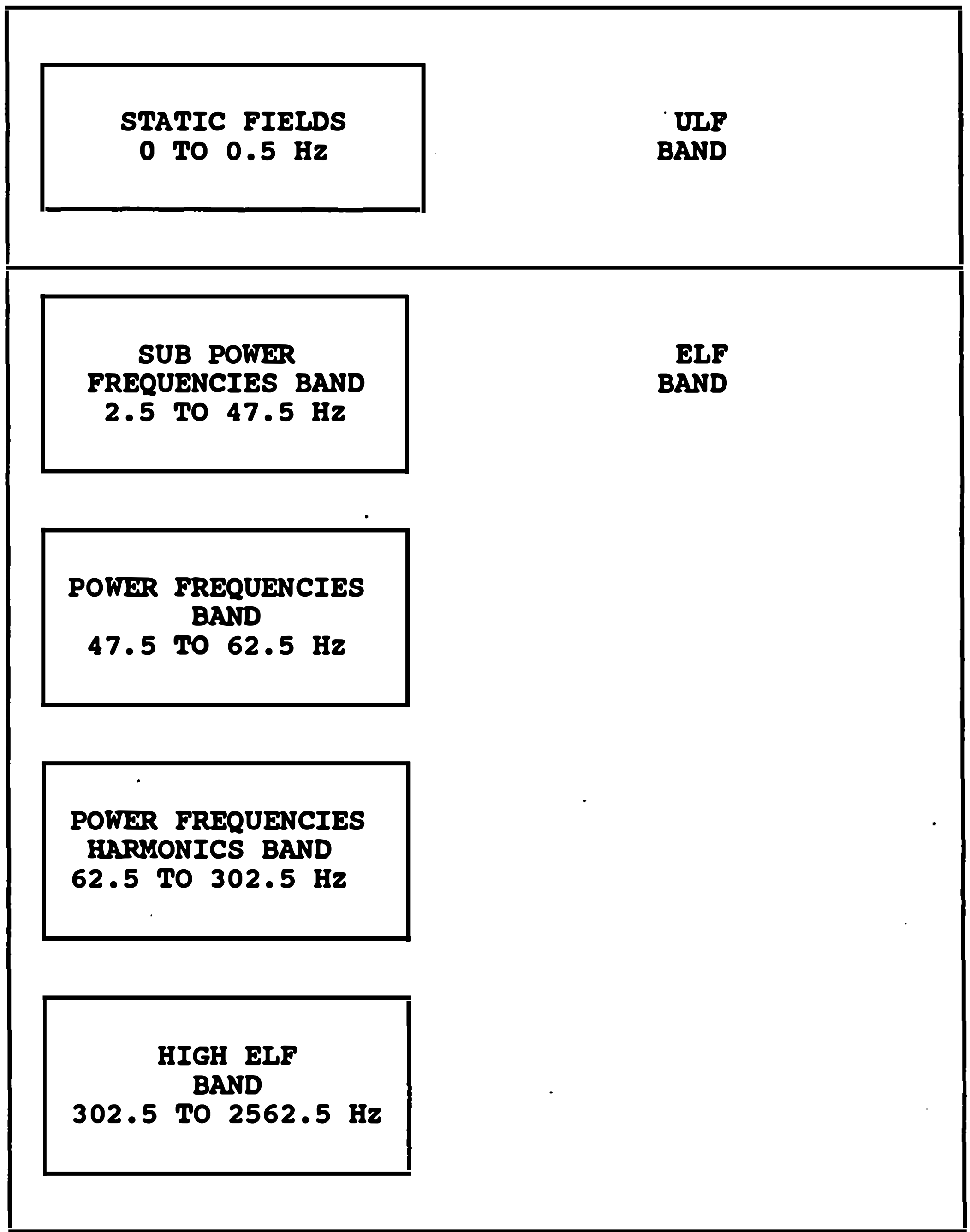


FIGURE 2-1. MAGNETIC FIELD FLUX DENSITIES GROUPED BY FREQUENCY PARTITIONS WITHIN THE ELF BAND AND ULF BAND

2.5 INSTRUMENTATION

The principal instrumentation system used for magnetic field measurements on the electrified railroads was a system which repetitively records the waveform of the electric and magnetic field. The repetitive waveform system was augmented with a digital audio tape (DAT) recorder to obtain a continuous record of magnetic field levels at one location. Personal magnetic field exposure monitors were also used to document the significance of personnel movement throughout the train. Additionally, an electric field meter was used for some of the tests.

2.5.1 Repetitive Waveform System

The repetitive field waveform recording system used in the tests reported herein is a portable version of the *MultiWave*™ waveform capture system used for the Transrapid TR07 measurements, as optimized for measurements on transportation systems. The magnetic field waveform recording approach utilized by the waveform capture system has already been reported[1]. It was originally developed for the Electric Power Research Institute (EPRI) to conduct in-depth measurements of residential and commercial facilities where it was expected that complex temporal and spacial magnetic field characteristics exist. The portable version configured for transportation system measurements employs the same measurement philosophy (four sensors in a staff located at distances of .1, .6, 1.1, and 1.6 m (.3, 2, 3.6 and 5.3 ft) along its length and a remote stationary sensor) and uses software nearly identical to the standard waveform capture system software but has a number of enhancements[3].

The repetitive waveform recording system was operated throughout the MBTA system tests in modes which produce data directly comparable to the data obtained for the Transrapid TR07 maglev system, the NEC, the French TGV and the Washington Metrorail systems. Hence the results reported previously for the TR07 system[1,2], the NEC[3], the TGV[4] and the Metrorail[5] can be compared directly to the results reported herein for the MBTA system.

2.5.2 Digital Audio Tape Recorder

The waveform capture system is a sampling-type recording system in the sense that it records the magnetic field environment in great detail for a brief period of time (0.2 to 1.0 seconds) then pauses for a period of time (5 to 60 seconds) before initiating another detailed sample. Hence, there is a possibility that the repetitive waveform recording system could miss capturing brief events such as rapid field transients if they are very rare. In order to determine whether the sampling recording system was failing to capture rare short-term events, a TEAC Model RD 130T DAT recorder was connected to the analog output port of the waveform capture system's reference probe. This permitted the DAT to make continuous recordings of the three-axis field (0-2500 Hz, 6 gauss full scale) at the reference probe. Three additional channels of the DAT made continuous recordings of the ac field (3-2500 Hz) amplified by a factor of ten or more to ensure enough resolution for accurate recording of the higher frequency components.

2.5.3 Personal Magnetic Field Exposure Monitors

The rms recorders (EMDEX-II) developed for Electric Power Research Institute are convenient and useful instruments for monitoring personal exposure to ELF magnetic fields from power systems. Their broadband response is nominally 40 to 800 Hz, which is adequate to capture the fundamental and low order harmonic components of the magnetic fields from 50 Hz or 60 Hz power systems. Unfortunately, the pass band of the rms recorder is not sufficient to capture either the static or the low frequency time varying fields found near dc-powered transportation systems. Furthermore, the upper frequency limit of the rms recorder is not sufficient to capture many of the harmonics of the chopper frequency encountered in the Boston MBTA system. Nevertheless, the rms recorders have been used throughout the measurement programs as personal exposure monitors to determine the extent to which stationary field measurements correlate with exposure of a passenger moving throughout the train or in a surrounding area.

2.6 REPETITIVE WAVEFORM DATA

As described in the preceding reports[2,3,4,5], the waveform capture system records the actual waveform of the three orthogonal components of the magnetic field at multiple measurement locations by sampling those waveforms at a high rate and storing the values digitally on computer disk or computer tape. These digital waveform recordings are saved one after another in rapid succession. Any one of these waveform recordings can be viewed individually in either the time or frequency domain to get a "snapshot view" of the waveform or frequency spectrum of the magnetic field at the particular instant in time when the waveform sample was recorded. These "snapshots", when viewed individually, have little statistical validity and tell nothing about the evolution of magnetic field characteristics over time as the train speeds up, slows down, makes use of its dynamic braking, passes the station, and so on. In order to examine these questions of statistical and temporal variability of the magnetic field, many of these "snapshots" must be played back in rapid succession to produce a "moving picture" of the magnetic field at each measurement location.

As described in later sections of the report, the measurement protocol applied for the electrified railroad measurements generally involved the use of five fluxgate magnetic field (B) sensors arrayed in such a way that spatial variability of the magnetic field could be characterized. Since magnetic fields onboard or near the train can arise from numerous sources, each with different temporal characteristics, the spatial pattern of the magnetic field is a dynamic characteristic which must be assessed from the "moving picture" of the magnetic field obtained from analysis of the repetitive waveform samples.

A list of the repetitive waveform datasets collected during the measurements on the Boston MBTA transit system is given in Table 2-1. The table also identifies the nature of the measurement, the measurement time, and the sample time for each of the 52 datasets. Table 2-1 also gives numerical codes for sensor locations (indicating also the figure which illustrates staff and reference probe locations) which are described in more detail later in the report. The analysis method applied to these repetitive waveform datasets is described in detail in a previous report[2]. The information contained in each of the 52 datasets has been processed using that procedure and is presented in detail in Appendices B through AZ in Volume II of this report.

2.7 DAT WAVEFORM DATA

Three-axis magnetic field waveforms from the reference sensor of the repetitive waveform recording system were also recorded using the digital audio tape recorder. Two recordings were made of each orthogonal component (axis) of the field: one of the signal directly from the magnetometer; and a second of the signal with the static component filtered out and the time varying components amplified (usually by a factor of ten) to provide better resolution of higher frequency components. Approximately 2.5 hours of recordings were produced for the test conditions reported in Table 2-2.

The continuous recordings of magnetic field waveform were reviewed for any transient magnetic field conditions which might exist. The type of analysis conducted on the DAT data was to construct time course plots of the magnetic field over the time of the recordings. These results were compared to the corresponding data from the portable waveform capture system to determine whether the data sampling procedure of the waveform capture system lost any significant data which is obtainable by continuous monitoring.

2.8 PERSONAL MAGNETIC FIELD EXPOSURE DATA

Several recordings of personal magnetic field exposure were made by members of the measurement crew while traveling on the MBTA system or working at the stations, wayside, or power supply facilities. These data are compared and contrasted with the repetitive waveform system and DAT data.

TABLE 2-1.

INDEX OF REPETITIVE WAVEFORM DATA MBTA SYSTEM
JUNE 9-11, 1992

DATA FILE NUMBER	APPENDIX CONTAINING DATA	DATE/ TIME	PROBE LOCATION FIG.	STAFF	REF.	SAMPLE INTERVAL, SECONDS	NUMBER OF SAMPLES	LOCATION AND TYPE OF MEASUREMENT
		JUN 9						
BOS001	B	09:58-09:59	7-1	46	47	5	13	NEAR RECTIFIER IN HIGH STREET TRACTION POWER SUPPLY STATION. STAFF IN VERTICAL POSITION
BOS002	C	10:00-10:03	7-1	46	47	5	37	SAME AS BOS001
BOS003	D	10:16-10:18	7-1	48	49	5	25	NEAR DC SWITCHGEAR IN HIGH STREET TRACTION POWER SUPPLY STATION. STAFF IN VERTICAL POSITION
BOS004	E	10:45-10:46	8-1	63	65	5	14	IN ORANGE LINE DISPATCHER'S ROOM, AT DISPATCHER'S SEAT. STAFF IN VERTICAL POSITION
BOS005	F	10:52-10:54	8-1	64	65	5	13	IN ORANGE LINE DISPATCHER'S ROOM WITH STAFF IN HORIZONTAL POSITION FROM COMPUTER MONITORS, 1 m (3.3 ft) ABOVE FLOOR
BOS006	G	11:24-11:26	7-2	50	51	5	25	NEAR MAIN CONTROL BOARD IN SOUTH BOSTON TRACTION POWER SUPPLY STATION. STAFF IN VERTICAL POSITION

TABLE 2-1.

INDEX OF REPETITIVE WAVEFORM DATA MBTA SYSTEM JUNE 9-11, 1992 (CONT'D)

DATA FILE NUMBER	APPENDIX CONTAINING DATA	DATE/ TIME	PROBE LOCATION FIG.	STAFF	REF.	SAMPLE INTERVAL, SECONDS	NUMBER OF SAMPLES	LOCATION AND TYPE OF MEASUREMENT
BOS007	H	11:35-11:37	7-2	52	53	5	25	IN BUS ROOM B IN SOUTH BOSTON TRACTION POWER SUPPLY STATION. STAFF IN VERTICAL POSITION
BOS008	I	13:32-13:35	7-3	54	56	5	25	BETWEEN AC SWITCHGEAR AND RECTIFIERS IN BENNETT STREET TRACTION POWER SUPPLY STATION. STAFF IN VERTICAL POSITION
BOS009	J	13:36-13:38	7-3	55	56	5	25	BETWEEN AC SWITCHGEAR AND RECTIFIERS IN BENNETT STREET TRACTION POWER SUPPLY STATION. STAFF IN HORIZONTAL POSITION, 1 m (3.3 ft) ABOVE GROUND, FROM RECTIFIER CABINET
BOS010	K	13:43-13:45	7-3	57	58	5	25	IN FRONT OF DC SWITCHGEAR IN BENNETT STREET TRACTION POWER SUPPLY STATION. STAFF IN VERTICAL POSITION
BOS011	L	13:59-14:01	7-3	59	60	5	25	ON BENNETT ALLEY SIDEWALK OUTSIDE BENNETT STREET TRACTION POWER SUPPLY STATION. STAFF IN VERTICAL POSITION
BOS012	M	14:08-14:10	7-3	61	62	5	26	ON BENNETT STREET SIDEWALK OUTSIDE BENNETT STREET TRACTION POWER SUPPLY STATION. STAFF IN VERTICAL POSITION

TABLE 2-1.

INDEX OF REPETITIVE WAVEFORM DATA MBTA SYSTEM
JUNE 9-11, 1992 (CONT'D)

DATA FILE NUMBER	APPENDIX CONTAINING DATA	DATE/ TIME	PROBE LOCATION FIG.	STAFF	REF.	SAMPLE INTERVAL, SECONDS	NUMBER OF SAMPLES	LOCATION AND TYPE OF MEASUREMENT
BOS013	N	14:31-14:33	5-1	30	31	5	25	TROLLEY BUS WAYSIDE ON CONCORD AVENUE IN FRONT OF HARVARD ASTROPHYSICAL LAB. STAFF IN VERTICAL POSITION
BOS014	O	14:48-14:49	5-1	30	31	5	15	SAME AS BOS013
		JUN 10						
BOS015	P	11:23-11:25	3-1	1	2	5	25	AT OPERATOR'S LEFT SHOULDER IN BLUE LINE CAR. STAFF IN VERTICAL POSITION
BOS016	Q	11:28-11:30	3-1	1	2	5	19	SAME AS BOS015
BOS017	R	11:31-11:32	3-1	3	2	5	10	AT CENTERLINE OF BLUE LINE CAR, BETWEEN REAR DOORS. STAFF IN VERTICAL POSITION
BOS018	S	11:34-11:35	3-1	4	2	5	14	IN FRONT OF OPERATOR'S SEAT OF BLUE LINE CAR. STAFF IN VERTICAL POSITION
BOS019	T	11:40-11:45	3-1	1	2	5	51	AT LEFT SHOULDER OF OPERATOR IN BLUE LINE CAR. STAFF IN VERTICAL POSITION. CHANGE FROM CATENARY TO THIRD RAIL
BOS020	U	12:23-12:25	3-1	4	5	5	26	IN FRONT OF OPERATOR'S SEAT IN ORANGE LINE CAR. STAFF IN VERTICAL POSITION

TABLE 2-1.

INDEX OF REPETITIVE WAVEFORM DATA MBTA SYSTEM JUNE 9-11, 1992 (CONT'D)

DATA FILE NUMBER	APPENDIX CONTAINING DATA	DATE/ TIME	PROBE LOCATION FIG.	STAFF	REF.	SAMPLE INTERVAL, SECONDS	NUMBER OF SAMPLES	LOCATION AND TYPE OF MEASUREMENT
BOS021	V	12:26- 12:29	3-1	3	5	5	40	IN PASSENGER AREA OF ORANGE LINE CAR. STAFF IN VERTICAL POSITION IN CENTER OF CAR ABOVE TRUCK
BOS022	W	13:00- 13:02	6-1	36	37	5	25	ORANGE LINE STATION AT DOWNTOWN CROSSING. ON THE DEPARTING END OF THE SOUTH BOUND SIDE OF PLATFORM. STAFF IN VERTICAL POSITION
BOS023	X	13:09- 13:12	6-1	66	67	5	25	ORANGE LINE STATION AT DOWNTOWN CROSSING. ON THE ARRIVING END OF THE SOUTH BOUND SIDE OF PLATFORM. STAFF IN VERTICAL POSITION
BOS024	Y	14:10- 14:10	6-1	32	33	5	3	RED LINE STATION AT DOWNTOWN CROSSING. ON THE ARRIVING END OF THE SOUTH BOUND SIDE OF PLATFORM. STAFF IN VERTICAL POSITION
BOS025	Z	14:10- 14:11	6-1	32	33	5	8	SAME AS BOS024.
BOS026	AA	14:19- 14:23	6-1	34	35	5	27	RED LINE STATION AT DOWNTOWN CROSSING. ON THE DEPARTING END OF THE SOUTH BOUND SIDE OF PLATFORM. STAFF IN VERTICAL POSITION
BOS027	AB	14:43- 14:45	3-1	6	7	5	15	IN FRONT OF OPERATOR'S SEAT IN RED LINE CAR. STAFF IN VERTICAL POSITION

TABLE 2-1.

INDEX OF REPETITIVE WAVEFORM DATA MBTA SYSTEM
JUNE 9-11, 1992 (CONT'D)

DATA FILE NUMBER	APPENDIX CONTAINING DATA	DATE/ TIME	PROBE LOCATION FIG.	STAFF	REF.	SAMPLE INTERVAL, SECONDS	NUMBER OF SAMPLES	LOCATION AND TYPE OF MEASUREMENT
BOS028	AC	14:46-14:48	3-1	8	7	5	20	IN PASSENGER AREA OF RED LINE CAR. STAFF IN VERTICAL POSITION IN CENTER OF CAR, MIDDLE OF FRONT DOORS OVER TRUCK
BOS029	AD	14:50-14:53	3-1	9	7	5	19	IN PASSENGER AREA OF RED LINE CAR. STAFF IN VERTICAL POSITION AT CENTERLINE OF CAR, FOUR FEED BEHIND MIDDLE OF THE FRONT DOORS
BOS030	AE	15:11-15:14	3-2	15	16	5	29	ON HIGH SPEED TROLLEY AT MATTAPAN STATION. STAFF IN VERTICAL POSITION NEAR OPERATOR'S RIGHT SHOULDER. TROLLEY IS STATIONARY
BOS031	AF	15:15-15:16	3-2	15	16	5	12	ON HIGH SPEED TROLLEY. STAFF IN VERTICAL POSITION NEAR OPERATOR'S RIGHT SHOULDER. TROLLEY IS MOVING
BOS032	AG	15:18-15:20	3-2	17	16	5	14	ON HIGH SPEED TROLLEY. STAFF IN VERTICAL POSITION IN CENTER OF CAR
		JUN 11						
BOS033	AH	09:18-09:21	3-1	10	-	5	20	ON KINKI-SHARYOU GREEN LINE CAR. STAFF IN VERTICAL POSITION ON CENTERLINE OF CAR JUST FORWARD OF REAR DOORS

TABLE 2-1.

INDEX OF REPETITIVE WAVEFORM DATA MBTA SYSTEM
JUNE 9-11, 1992 (CONT'D)

DATA FILE NUMBER	APPENDIX CONTAINING DATA	DATE/ TIME	PROBE LOCATION FIG.	STAFF	REF.	SAMPLE INTERVAL, SECONDS	NUMBER OF SAMPLES	LOCATION AND TYPE OF MEASUREMENT
BOS034	AI	09:21-09:23	3-1	11	-	5	15	ON KINKI-SHARYOU GREEN LINE CAR. STAFF IN VERTICAL POSITION IN CENTER OF CAR
BOS035	AJ	09:24-09:25	3-1	12	-	5	7	ON KINKI-SHARYOU GREEN LINE CAR. STAFF IN VERTICAL POSITION AT REAR OF CAR, NOT ON THE CENTERLINE
BOS036	AK	09:26-09:27	3-1	13	-	5	13	ON KINKI-SHARYOU GREEN LINE CAR. STAFF IN VERTICAL POSITION ON THE CENTERLINE AT REAR OF CAR
BOS037	AL	09:32-09:35	6-3	45	-	5	26	GREEN LINE STATION AT GOVERNMENT CENTER. ON ARRIVING END OF WEST BOUND SIDE OF PLATFORM. STAFF IN VERTICAL POSITION
BOS038	AM	09:37-09:43	6-3	44	-	5	60	GREEN LINE STATION AT GOVERNMENT CENTER. ON DEPARTING END OF WEST BOUND SIDE OF PLATFORM. STAFF IN VERTICAL POSITION
BOS039	AN	09:46-09:47	6-2	43	-	5	10	BLUE LINE STATION AT GOVERNMENT CENTER. ON DEPARTING END OF EAST BOUND SIDE OF PLATFORM. STAFF IN VERTICAL POSITION

TABLE 2-1.

INDEX OF REPETITIVE WAVEFORM DATA MBTA SYSTEM JUNE 9-11, 1992 (CONT'D)

DATA FILE NUMBER	APPENDIX CONTAINING DATA	DATE/ TIME	PROBE LOCATION FIG.	STAFF	REF.	SAMPLE INTERVAL, SECONDS	NUMBER OF SAMPLES	LOCATION AND TYPE OF MEASUREMENT
BOS040	AO	09:51-09:52	6-2	42	-	5	8	BLUE LINE STATION AT GOVERNMENT CENTER. ON ARRIVING END OF EAST BOUND SIDE OF PLATFORM. STAFF IN VERTICAL POSITION
BOS041	AP	10:27-10:29	3-1	14	-	5	18	ON BOEING GREEN LINE CAR. STAFF IN VERTICAL POSITION IN FRONT OF OPERATOR'S SEAT
BOS042	AQ	10:29-10:31	3-1	14	-	5	17	SAME AS BOS041
BOS043	AR	11:24-11:29	3-2	18	19	5	31	IN CENTER AT REAR OF A TROLLEY BUS, 1.2 m (4 ft) BEHIND REAR AXLE. STAFF IN VERTICAL POSITION
BOS044	AS	11:29-11:32	3-2	20	19	5	25	IN CENTER OF A TROLLEY BUS IN LINE WITH REAR DOORS. STAFF IN VERTICAL POSITION
BOS045	AT	11:33-11:34	3-2	21	19	5	13	1.2 m (4 ft) BEHIND REAR AXLE OF TROLLEY BUS. STAFF IN HORIZONTAL POSITION 1 m (3.3 ft) ABOVE FLOOR WITH LEFT WINDOW AS REFERENCE
BOS046	AU	11:42-11:44	3-2	22	23	5	25	ON TROLLEY BUS. STAFF IN VERTICAL POSITION AT OPERATOR'S RIGHT SHOULDER

TABLE 2-1.

INDEX OF REPETITIVE WAVEFORM DATA MBTA SYSTEM
JUNE 9-11, 1992 (CONT'D)

DATA FILE NUMBER	APPENDIX CONTAINING DATA	DATE/ TIME	PROBE LOCATION FIG.	STAFF	REF.	SAMPLE INTERVAL, SECONDS	NUMBER OF SAMPLES	LOCATION AND TYPE OF MEASUREMENT
BOS047	AV	13:21-13:22	5-1	28	29	5	14	GREEN LINE WAYSIDE AT BEACON STREET. STAFF IN VERTICAL POSITION 4.6 m (15 ft) FROM NEAR TRACK
BOS048	AW	13:45-13:47	5-1	26	27	5	16	BLUE LINE WAYSIDE 30.5 m (100 ft) FROM WOOD ISLAND STATION. STAFF IN VERTICAL POSITION 4.6 m (15 ft) FROM NEAR TRACK
BOS049	AX	14:01-14:02	6-2	40	41	5	7	WOOD ISLAND STATION ON BLUE LINE. DEPARTING END OF EAST BOUND SIDE OF PLATFORM. STAFF IN VERTICAL POSITION AT YELLOW SAFETY LINE
BOS050	AY	14:09-14:10	6-2	38	39	5	5	WOOD ISLAND STATION ON BLUE LINE. ARRIVING END OF EAST BOUND SIDE OF PLATFORM. STAFF IN VERTICAL POSITION AT YELLOW SAFETY LINE

TABLE 2-2.

INDEX OF CONTINUOUS WAVEFORM (DAT) DATA MBTA SYSTEM MEASUREMENTS
JUNE 9-11, 1992

TAPE/GROUP/ RECORD #	DATE/TIME	PROBE LOCATION	FIGURE NUMBER	RECORD LENGTH MIN:SEC	LOCATION AND TYPE OF MEASUREMENT
	JUNE 9				
1/1/1	9:50:16 - 10:01:22	47	7-1	11:07	HIGH STREET TRACTION POWER SUPPLY STATION BETWEEN AC SWITCHGEAR AND RECTIFIER CABINET
1/1/2	10:01:23 - 10:05:26	47	7-1	4:03	SAME AS 1/1/1
1/1/3	10:14:26 - 10:20:54	49	7-1	6:29	HIGH STREET TRACTION POWER SUPPLY STATION, .9 m (3 ft) FROM FRONT OF DC SWITCHGEAR
1/1/4	10:44:18 - 10:46:26	45	8-1	2:07	CENTRAL OPERATIONS, ORANGE LINE DISPATCHER'S AREA, IN CHAIR AT CONSOLE
1/1/5	10:49:34 - 10:53:38	45	8-1	4:04	SAME AS 1/1/4
1/1/6	11:24:09 - 11:26:32	51	7-2	2:23	SOUTH BOSTON TRACTION POWER SUPPLY STATION, .6 m (2 ft) IN FRONT OF THE MAIN CONTROL BOARD
1/1/7	11:34:14 - 11:37:52	53	7-2	3:38	SOUTH BOSTON TRACTION POWER SUPPLY STATION, CHAIR AT DESK IN BUS ROOM B

TABLE 2-2.

INDEX OF CONTINUOUS WAVEFORM (DAT) DATA MBTA SYSTEM MEASUREMENTS JUNE 9-11, (CONT'D)

TAPE/GROUP/ RECORD #	DATE/TIME	PROBE LOCATION	FIGURE NUMBER	RECORD LENGTH MIN:SEC	LOCATION AND TYPE OF MEASUREMENT
1/1/8	13:32:25 - 13:34:46	56	7-3	2:20	BENNETT STREET TRACTION POWER SUPPLY STATION BETWEEN AC SWITCHGEAR AND RECTIFIER CABINET
1/1/9	13:35:34 - 13:38:36	56	7-3	3:02	SAME AS 1/1/9
1/1/11	13:43:12 - 13:44:57	58	7-3	1:45	BENNETT STREET TRACTION POWER SUPPLY STATION IN FRONT OF DC SWITCHGEAR
1/2/1	13:58:58 - 14:01:25	60	7-3	2:27	BENNETT STREET TRACTION POWER SUPPLY STATION ON SIDEWALK OUTSIDE FRONT DOOR
1/2/2	14:07:33 - 14:10:52	62	7-3	3:19	BENNETT STREET TRACTION POWER SUPPLY STATION ON SIDEWALK OUTSIDE TRANSFORMER BAY
1/2/3	14:30:58 - 14:32:39	31	5-1	1:42	TROLLEY BUS WAYSIDE ON CONCORD AVENUE
1/2/4	14:47:59 - 14:49:31	31	5-1	1:32	SAME AS 1/2/3
	JUNE 10				
1/2/6	11:23:03 - 11:25:38	2	3-1	2:35	BLUE LINE CAR WINDOW LEDGE ACROSS FROM OPERATOR'S SEAT
1/2/7	11:28:22 - 11:31:00	2	3-1	2:38	SAME AS 1/2/6

TABLE 2-2.

INDEX OF CONTINUOUS WAVEFORM (DAT) DATA MBTA SYSTEM MEASUREMENTS JUNE 9-11, (CONT'D)

TAPE/GROUP/ RECORD #	DATE/TIME	PROBE LOCATION	FIGURE NUMBER	RECORD LENGTH MIN:SEC	LOCATION AND TYPE OF MEASUREMENT
1/2/8	11:40:49 - 11:45:25	2	3-1	4:36	SAME AS 1/2/6
1/2/9	12:20:35 - 12:30:46	5	3-1	10:11	ORANGE LINE CAR ON TOP OF A METAL CABINET ACROSS FROM THE OPERATOR'S SEAT
1/2/10	13:01:10 - 13:03:23	37	6-1	2:13	ORANGE LINE STATION AT DOWNTOWN CROSSING AT THE SOUTH (DEPARTING) END OF THE SOUTHBOUND PLATFORM
1/2/11	13:10:13 - 13:12:34	67	6-1	2:21	ORANGE LINE STATION AT DOWNTOWN CROSSING AT THE NORTH (ARRIVING) END OF THE SOUTHBOUND PLATFORM
1/2/12	14:03:15 - 14:05:15	33	6-1	2:00	RED LINE STATION AT DOWNTOWN CROSSING AT THE NORTH (ARRIVING) END OF THE SOUTHBOUND PLATFORM (NO TRAINS PASSING)
1/2/13	14:10:26 - 14:14:21	33	6-1	3:55	SAME AS 1/2/12 BUT TRAIN PASSES
1/2/14	14:20:15 - 14:23:30	35	6-1	3:15	RED LINE STATION AT DOWNTOWN CROSSING AT SOUTH (DEPARTING) END OF THE SOUTHBOUND PLATFORM
1/2/15	14:42:16 - 14:45:45	7	3-1	3:29	RED LINE CAR ON TOP OF A METAL CABINET ACROSS FROM THE OPERATOR'S SEAT

TABLE 2-2.

INDEX OF CONTINUOUS WAVEFORM (DAT) DATA MBTA SYSTEM MEASUREMENTS JUNE 9-11, (CONT'D)

TAPE/GROUP/ RECORD #	DATE/TIME	PROBE LOCATION	FIGURE NUMBER	RECORD LENGTH MIN:SEC	LOCATION AND TYPE OF MEASUREMENT
1/3/1	14:52:22 - 14:54:12	7	3-1	1:50	SAME AS 1/2/15
1/3/2	15:12:16 - 15:20:38 *	16	3-2	7:15	HIGH SPEED TROLLEY IN A PASSENGER'S WINDOW SEAT 2.1 m (7 ft) FEET BEHIND THE OPERATOR
	JUNE 11				
2/1/1	11:23:45 - 11:31:22 *	19	3-2	7:04	TROLLEY BUS ON RIGHT REAR PASSENGER SEAT
2/1/2	11:32:25 - 11:34:06	19	3-2	1:41	SAME AS 2/1/1
2/1/3	11:41:37 - 11:44:37	23	3-2	3:00	TROLLEY BUS ON PASSENGER'S WINDOW SEAT 2.7 m (9 ft) BEHIND OPERATOR'S SEAT
2/1/4	13:14:43 - 13:16:25	29	5-1	1:41	GREEN LINE WAYSIDE LOCATION 9.2 m (30 ft) FROM TRACK (NO TRAIN PASSING)
2/1/5	13:18:51 - 13:19:48	29	5-1	0:57	SAME AS 2/2/4 EXCEPT WITH TRAIN PASSING
2/1/6	13:20:29 - 13:21:40	29	5-1	1:11	SAME AS 2/2/4 EXCEPT WITH TRAIN PASSING
2/1/7	13:45:16 - 13:46:59	27	5-1	1:43	BLUE LINE WAYSIDE LOCATION 9.2 m (30 ft) FROM TRACK
2/1/8	13:58:09 - 13:59:05	41	6-2	0:56	BLUE LINE STATION AT WOOD ISLAND AT THE EAST (DEPARTING) END OF THE EASTBOUND PLATFORM

TABLE 2-2.

INDEX OF CONTINUOUS WAVEFORM (DAT) DATA MBTA SYSTEM MEASUREMENTS JUNE 9-11, (CONT'D)

TAPE/GROUP/ RECORD #	DATE/TIME	PROBE LOCATION	FIGURE NUMBER	RECORD LENGTH MIN:SEC	LOCATION AND TYPE OF MEASUREMENT
2/1/9	14:00:56 - 14:02:02	41	6-2	1:06	SAME AS 2/2/8
2/1/10	14:08:47 - 14:09:46	39	6-2	0:59	BLUE LINE STATION AT WOOD ISLAND AT THE WEST (ARRIVING) END OF THE EASTBOUND PLATFORM

* Indicates a brief pause of approximately 30 seconds in the recording.

3. MEASUREMENTS ONBOARD VEHICLE

When developing the measurement plan for these tests, it was apparent that magnetic fields within the vehicle could arise from various sources:

- Track/third rail or catenary power circuit;
- Traction motors on the trucks;
- Traction power control equipment (switches, resistors, choppers and reactors) and the associated wiring beneath the vehicles;
- Heating, lighting, air conditioning and other equipment, including power converters, on or beneath the vehicles; and
- External sources, such as other trains and nearby transmission lines.

Consideration was also given to the fact that four different subway lines and two surface trolley lines, each with unique technical characteristics, are incorporated in the MBTA system. In order to best evaluate the significance of the magnetic field contribution from the above-mentioned sources and their variabilities, field measurements were made at a minimum of two general locations inside each of the six types of vehicles: near the operator's position and near the front or rear of the vehicle above the rear axle or truck mounted traction motors, third-rail contact shoes and associated wiring. Additional measurements were made in certain vehicles to characterize fields from specific sources such as motor control units containing choppers and reactors. At all locations, measurements were made with the sensor staff oriented vertically so that the measurements obtained by the four sensors distributed along the staff characterized the spatial variation in magnetic field conditions in a vertical direction. This type of measurement is referred to as a vertical profile measurement. In some cases, magnetic field measurements were also made with the probe in a horizontal position perpendicular to the long axis of the vehicle (lateral), to quantify the spatial variability of the field in the horizontal plane. These horizontal profiles were usually measured at a height of 1 m (3.3 ft) above the floor. The results of measurements near the operator's seat are described in Section 4.

3.1 MEASUREMENT LOCATIONS

The general layout of MBTA system subway cars is shown in Figure 3-1. The numbered measurement locations are keyed to datasets in Tables 2-1, 2-2, and 3-1 and to the data in the corresponding appendices. Measurements are seen to be clustered in three major locations:

1) End of car, between the front or rear doors - This point is above the traction motors and other truck-mounted equipment and is easily identifiable from car to car.

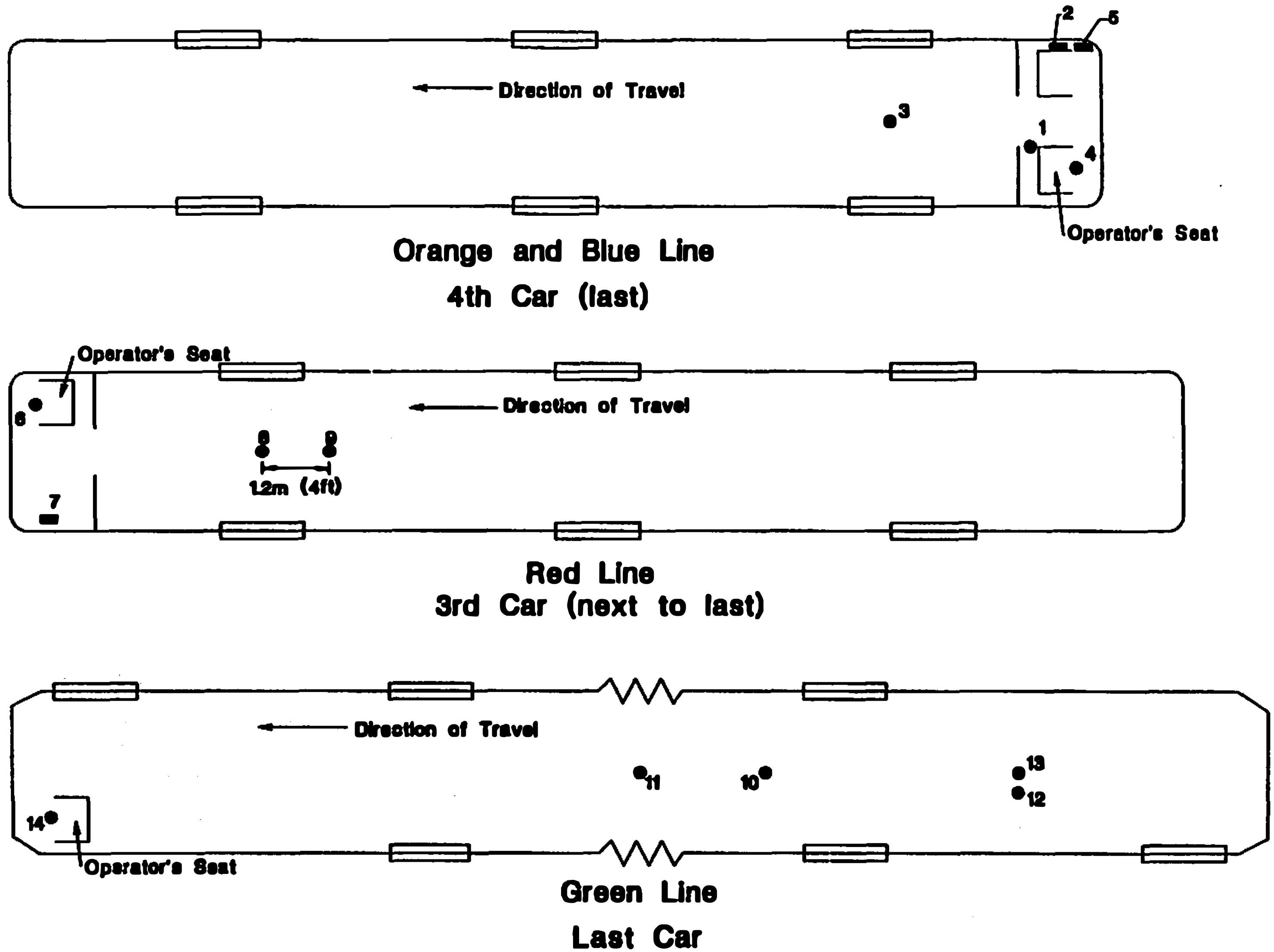


FIGURE 3-1. REPETITIVE FIELD WAVEFORM AND DAT MEASUREMENT LOCATIONS WITHIN THE ORANGE, BLUE, RED AND GREEN LINE CARS

TABLE 3-1.

REPETITIVE MAGNETIC FIELD WAVEFORM DATASETS MEASURED ONBOARD MASS TRANSIT VEHICLES CLASSIFIED BY VEHICLE TYPE AND MEASUREMENT LOCATION

Location numbers given in () are keyed to Figures 3-1 and 3-2.

TRANSIT VEHICLE	ABOVE MOTOR	POWER SUPPLY POINT	POWER CONTROL	OPERATOR POSITION
BLUE LINE-CATENARY	BOS017(3)	BOS017(3)		BOS015(1) BOS016(1) BOS018(4) BOS019(1)
BLUE LINE-THIRD RAIL				BOS019(1)
ORANGE LINE	BOS021(3)	BOS021(3)		BOS020(4)
RED LINE	BOS028(8) BOS029(9)	BOS028(8) BOS029(9)		BOS027(6)
GREEN LINE	BOS035(12) BOS036(13)	BOS033(10) BOS034(11)	BOS033(10) BOS034(11)	BOS041(14) BOS042(14)
MATTAPAN TROLLEY	BOS030(15) BOS031(15)	BOS032(17)		BOS030(15) BOS031(15)
TROLLEY BUS	BOS043(18) BOS045*(21)	BOS044(20)		BOS046(22)

*** Horizontal Profile**

2) Operator's compartment - These measurements are described in Section 4.

3) Near center of car - This is above the traction power control equipment which is installed beneath the Green Line car floor just forward and aft of the center truck. This is directly above the filter reactors and semiconductor choppers, equipment which were found to be significant field sources in chopper-controlled cars on the Washington Metropolitan Area Transit Authority (WMATA) Metrorail System[5]. Measurements were made between the center doors at the center of the aisle.

Whenever possible, measurements were made at the same locations for all four types of cars.

Figure 3-2 gives a sketch of the measurement locations in the Mattapan Trolley and the Trolley Bus. The same philosophy used to choose sensor locations in the subway car was applied to these

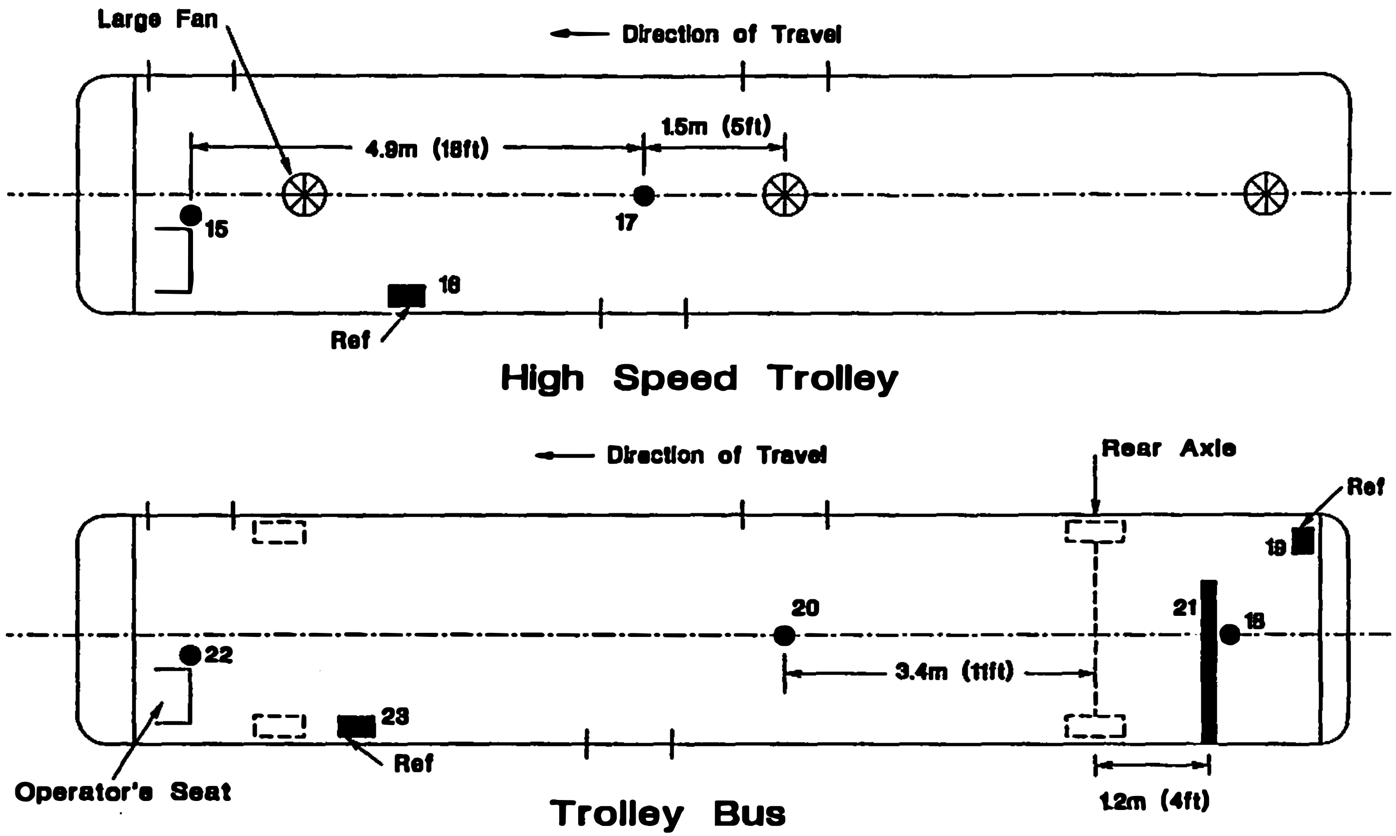


FIGURE 3-2. REPETITIVE FIELD WAVEFORM AND DAT MEASUREMENT LOCATIONS WITHIN THE MATTAPAN HIGH SPEED TROLLEY AND THE TROLLEY BUS

vehicles. Measurements near the operator in the High Speed Trolley served two functions because they were both near the operator's control equipment and above the front truck of the Trolley. Measurements at the center of the car were intended to identify magnetic fields from current between the trolley pole at the rear of the car and the controls and motors at the front. On the Trolley Bus shown in the lower frame of Figure 3-2, measurements were made above the motor which was reportedly behind the rear axle and near the operator's seat. Additional measurements were made at a point below the roof-mounted trolley poles.

Onboard measurements were taken on both June 10 and June 11, 1992. Figure 1-1 shows a map of the MBTA system. Blue Line measurements were made between Aquarium and Wonderland Stations which included sections with overhead power catenary and sections with third rail. The Orange Line tests were between Downtown Crossing and Malden Center Stations. Measurements in Red Line cars were made between Downtown Crossing and Shawmut Stations. Both Orange and Red Line tests were made entirely on third-rail powered cars. Tests on the Green Line, which is powered from overhead catenaries, were made between Lechmere and Government Center Stations. Tests on the Mattapan High Speed Trolley and the Trolley Bus were taken throughout their routes.

3.2 REPETITIVE WAVEFORM DATASETS

There are 23 repetitive waveform datasets quantifying magnetic field characteristics within the MBTA system vehicles, as recorded with the waveform capture system. Table 3-1 is a summary of these datasets classified by type of car and measurement position within the car. All of these datasets represent profile measurements, usually vertical, at distances of 10, 60, 110, and 160 cm above the floor. One horizontal profile was measured across the rear of the trolley bus. In that case, the profile is in terms of distance from the left window. Figure 3-2 shows the direction of the staff when used in a horizontal orientation.

Complete plots of field versus frequency over time, and field versus distance over time are found in the appendices as indicated in Table 2-1. The appendices also contain notes about train operating conditions, locations, and, where pertinent, the presence of external field sources such as power lines or substations.

3.3 MAGNETIC FIELD CHARACTERISTICS

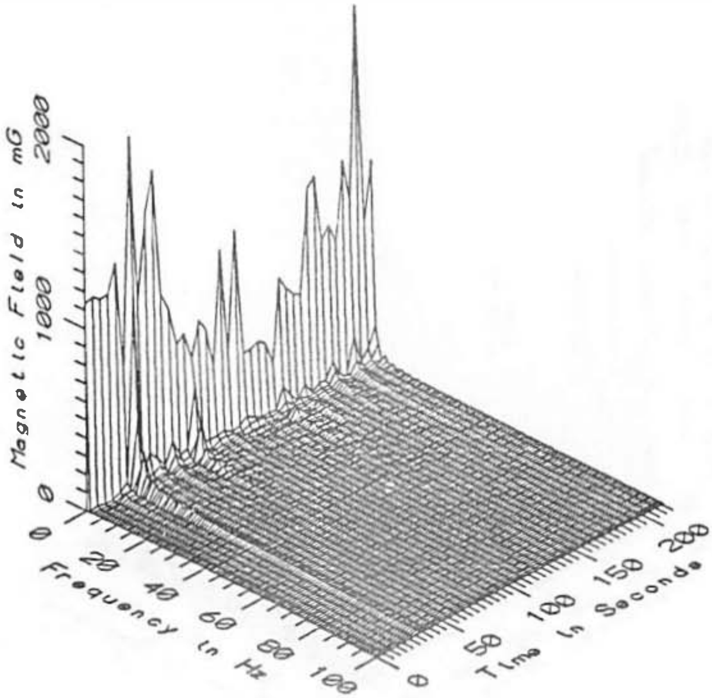
Magnetic field measurements onboard the vehicles provided the opportunity to measure the extent to which various operating conditions contribute to the total magnetic field environment. That information, together with other temporal, frequency and spatial characteristics of the magnetic field, offers insight to the probable sources of the magnetic field within the passenger compartment of the various MBTA system vehicles.

3.3.1 Orange Line

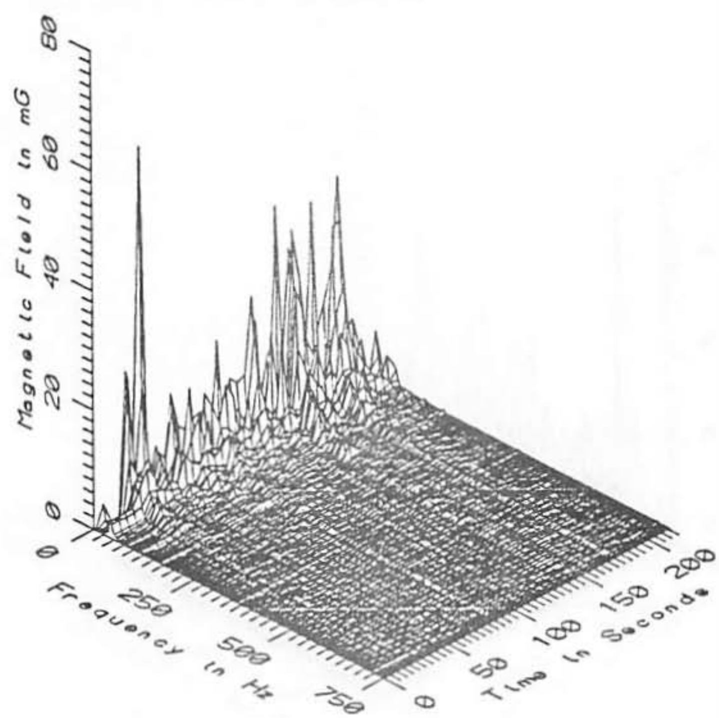
The top frame of Figure 3-3 shows a plot of magnetic field strength near the floor above the rear truck of an Orange Line car as a function of frequency and time. Two significant characteristics of the magnetic field are immediately obvious. First, the magnitude of the field is highly variable over the time of the recording. This measurement started shortly before the car left the Wellington Station and ended after the car stopped at the Malden Center Station. It appears from the temporal characteristics of Figure 3-3 that the static (zero frequency) magnetic field at the measurement location is elevated well above the normal geomagnetic field level of 500 mG when the train is accelerating out of a station (30 to 50 seconds into the record) or decelerating (200 second point) as it approaches the next station. The temporal correlation between field level and vehicle acceleration or deceleration indicates that the source of the field involves the propulsion system. Current in the third rail and track circuit is not a likely source because the elevated field exists during both acceleration and deceleration. Since the Orange Line cars do not have regenerative braking, there is no increase in third rail current during deceleration, but since these cars have dynamic braking, there is elevated current in the traction motors, resistors, contactor switches, and other components and associated wiring of the traction power and control circuitry beneath the floor of the car during both acceleration and braking. Therefore, that system appears to be a likely field source based on the temporal characteristics of the magnetic field near the floor of the Orange Line car.

The second important characteristic of the magnetic field in the Orange Line car depicted in Figure 3-3 is that the only time varying components of the magnetic field are those related to changes in the static field level. This point is most clearly illustrated by the bottom frame of the figure, in which the static component of the magnetic field has been removed and the time varying components are replotted on a more appropriate scale of magnetic field intensity. The pattern of field intensity decreasing exponentially with increasing frequency seen in these data is indicative of shifts in static field level which have no stable periodic frequency. This absence of discrete-frequency time varying components in the magnetic field frequency spectrum is consistent with the suggestion that, from the characteristics of the field, the primary source is the dc traction power and control equipment installed beneath the floor of the car.

Figure 3-4 is similar to Figure 3-3 except that it shows the magnetic field levels measured 160 cm above the floor at the center of the aisle above the rear truck in the Orange Line Car. Since the data in these two figures were measured simultaneously, they can be compared point by point. Although the temporal characteristics of the static fields are similar at both measurement locations, the intensity levels are quite different. The magnitude of the static field during periods of train

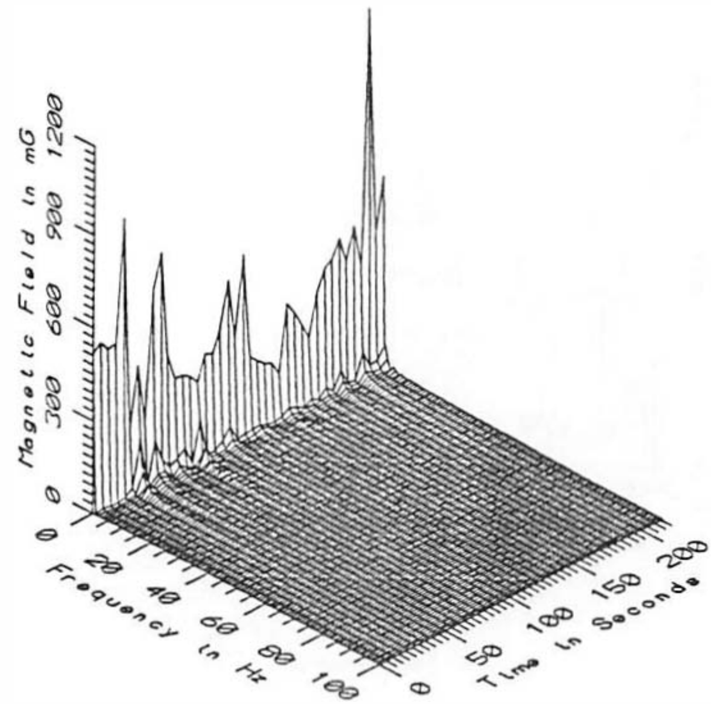


BOS021 - 10cm ABOVE FLOOR IN CENTER OF ORANGE LINE CAR, ABOVE TRUCK

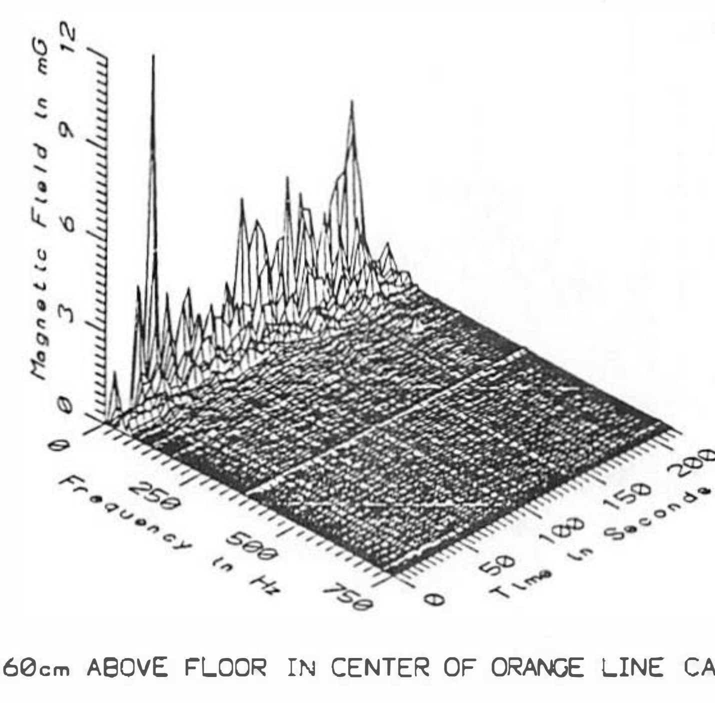


BOS021 - 10cm ABOVE FLOOR IN CENTER OF ORANGE LINE CAR, ABOVE TRUCK

FIGURE 3-3. **MAGNETIC FIELD 10 cm ABOVE THE FLOOR AT THE MIDDLE OF THE AISLE ABOVE THE REAR TRUCK IN AN ORANGE LINE CAR AS A FUNCTION OF FREQUENCY AND TIME. THE STATIC FIELD COMPONENT IS SUPPRESSED IN THE LOWER FRAME TO SHOW THE TIME VARYING COMPONENTS**



BOS021 - 160cm ABOVE FLOOR IN CENTER OF ORANGE LINE CAR, ABOVE TRUCK



BOS021 - 160cm ABOVE FLOOR IN CENTER OF ORANGE LINE CAR, ABOVE TRUCK

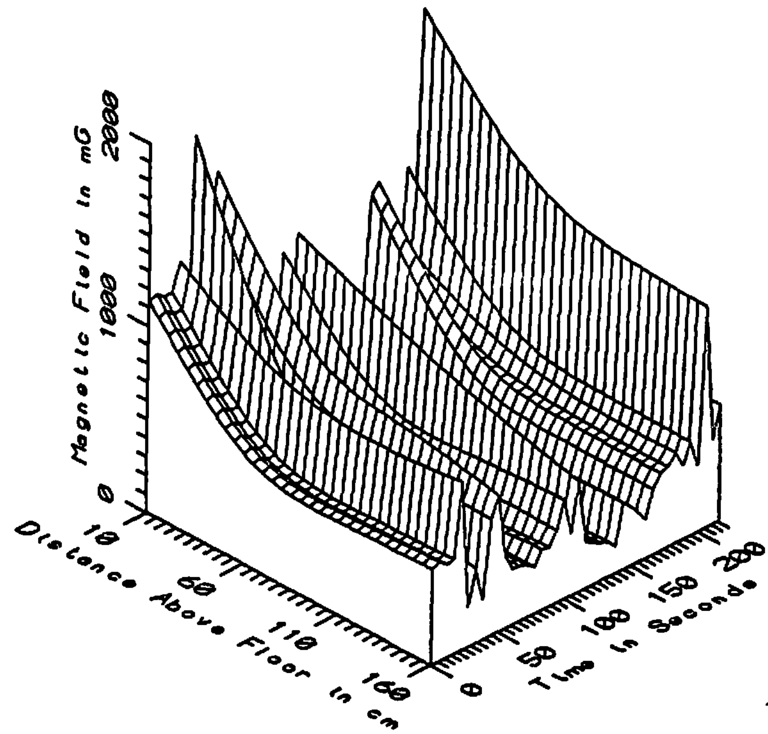
FIGURE 3-4. MAGNETIC FIELD 160 cm ABOVE THE FLOOR IN THE CENTER OF THE AISLE ABOVE THE REAR TRUCK IN AN ORANGE LINE CAR AS A FUNCTION OF FREQUENCY AND TIME. THE STATIC COMPONENT IS SUPPRESSED IN THE LOWER FRAME TO SHOW THE TIME VARYING COMPONENTS

acceleration and deceleration are much smaller at the point 160 cm above the floor (Figure 3-4) than at the point much nearer the floor (Figure 3-3). Similar data for intermediate measurement heights above the floor, provided in Appendix V, fall in between the extremes illustrated here. By comparing the static magnetic field levels measured at the four heights above the floor for each time point throughout the measurement record, the vertical profile of field attenuation over time shown in the top frame of Figure 3-5 is obtained. The orderly attenuation of magnetic field level with increasing height above the floor during periods of train acceleration and deceleration further supports the other indications that the principal static field source in the Orange Line car at this location is the traction power and control system beneath the floor. When the train is stopped, such as at the first 15 seconds of the record, the static magnetic field no longer shows attenuation with increasing height above the floor at heights of 60 cm or more, but shows a relatively constant field strength at all heights. Of course, that is the situation one would expect if the principal static field source at those times is the natural geomagnetic field.

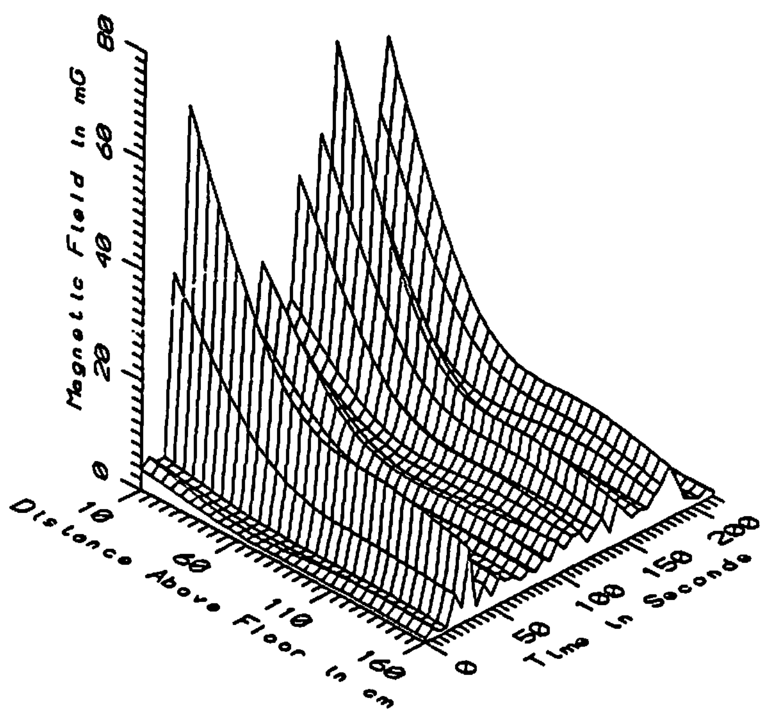
The time varying magnetic fields at the measurement point 160 cm above the floor (lower frame of Figure 3-4) show the same exponential decay with increasing frequency seen at the measurement point near the floor, but the fields are smaller at the higher location. Those attenuation features are shown more graphically in the lower frame of Figure 3-5, where the magnitude of the low frequency components of the time varying magnetic fields at the four measurement heights are plotted to produce vertical attenuation profiles over the time period of the record. The very low level of the low frequency time varying magnetic field in the first 15 seconds of the record shown in the lower frame of Figure 3-5 reflects the inactivity of the traction power and control circuitry while the car is stopped at the Wellington Station.

3.3.2 <u>Blue Line</u>

Dataset BOS017 consists of magnetic field data similar to those just discussed from dataset BOS021, except that they were measured in the rear of a Blue Line car above the rear truck while traveling between Beachmont and Suffolk Downs Stations. The complete data are provided in Appendix C, but graphs of the magnetic field as a function of frequency and time at the low sensor location (10 cm above the floor) and the high sensor location (160 cm above the floor are included here as Figures 3-6 and 3-7, respectively. Visual comparison of those graphs to the corresponding graphs of data measured in the Orange Line (Figures 3-3 and 3-4) shows that the magnetic fields in the Blue Line car operating from overhead catenary are similar in character to those in the Orange Line car except for the high static field at the 160 cm measurement height at the 34-second sample point (Figure 3-7). Figure 3-8 shows the vertical attenuation profiles of the static and low frequency time varying magnetic field levels over the rear truck in the Blue Line

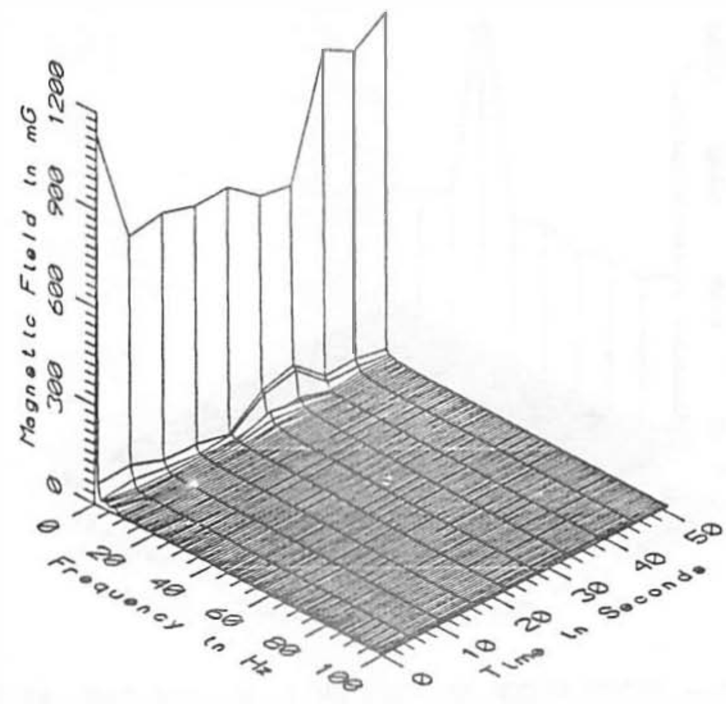


BOS021 - CENTER OF ORANGE LINE CAR, ABOVE TRUCK - STATIC

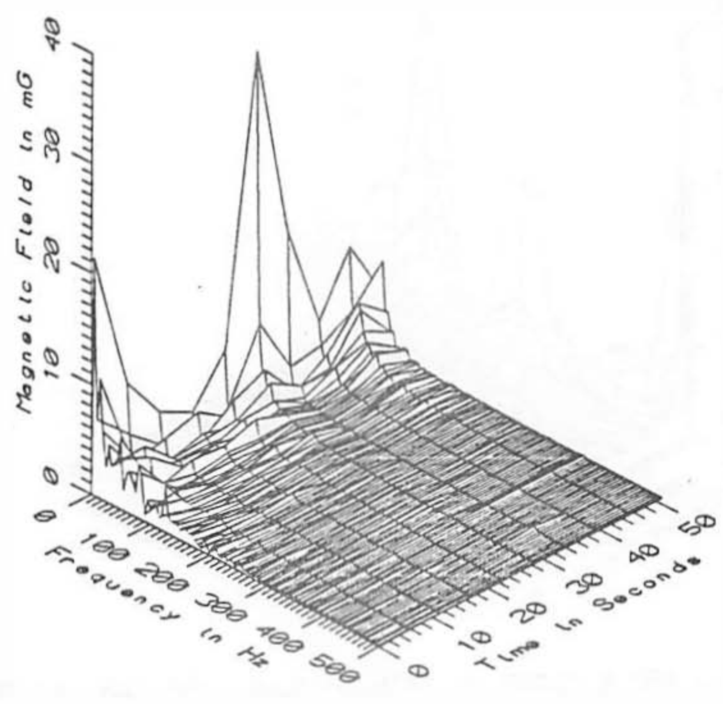


BOS021 - CENTER OF ORANGE LINE CAR, ABOVE TRUCK - LOW FREQ. 5-45Hz

FIGURE 3-5. STATIC (TOP FRAME) AND LOW FREQUENCY TIME VARYING (BOTTOM FRAME) MAGNETIC FIELD ABOVE THE REAR TRUCK IN AN ORANGE LINE CAR AS A FUNCTION OF HEIGHT ABOVE THE FLOOR AND TIME

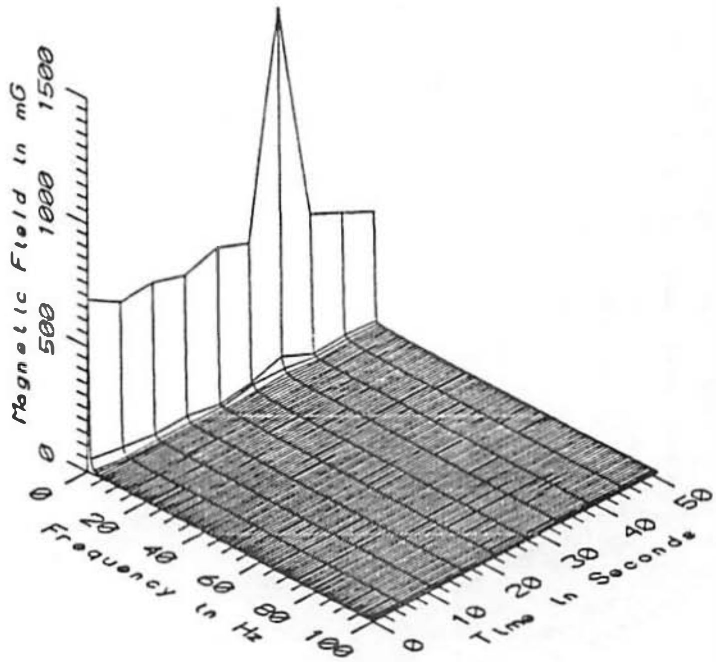


BOS017 - 10cm ABOVE FLOOR ON AXIS OF BLUE LINE CAR, AT REAR DOORS

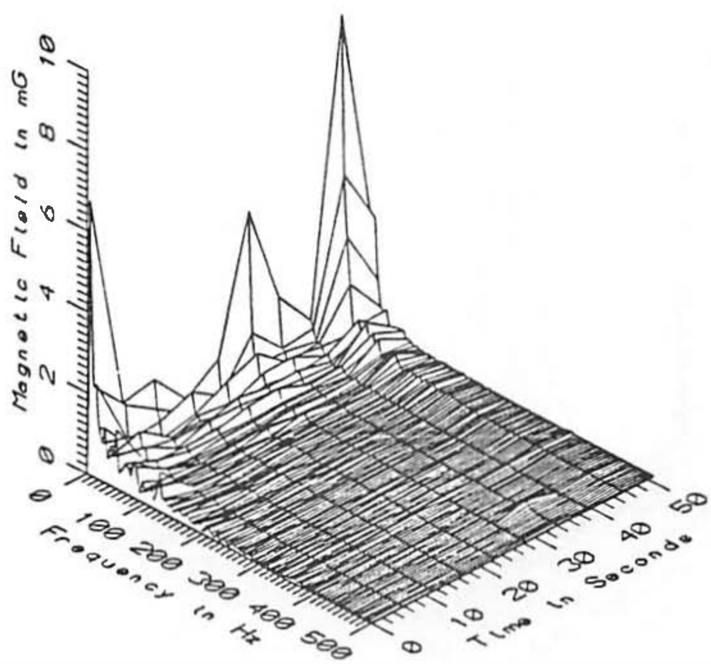


BOS017 - 10cm ABOVE FLOOR ON AXIS OF BLUE LINE CAR, AT REAR DOORS

FIGURE 3-6. MAGNETIC FIELD 10 cm ABOVE THE FLOOR AT THE MIDDLE OF THE AISLE ABOVE THE REAR TRUCK IN A BLUE LINE CAR AS A FUNCTION OF FREQUENCY AND TIME WHILE OPERATING FROM AN OVERHEAD CATENARY

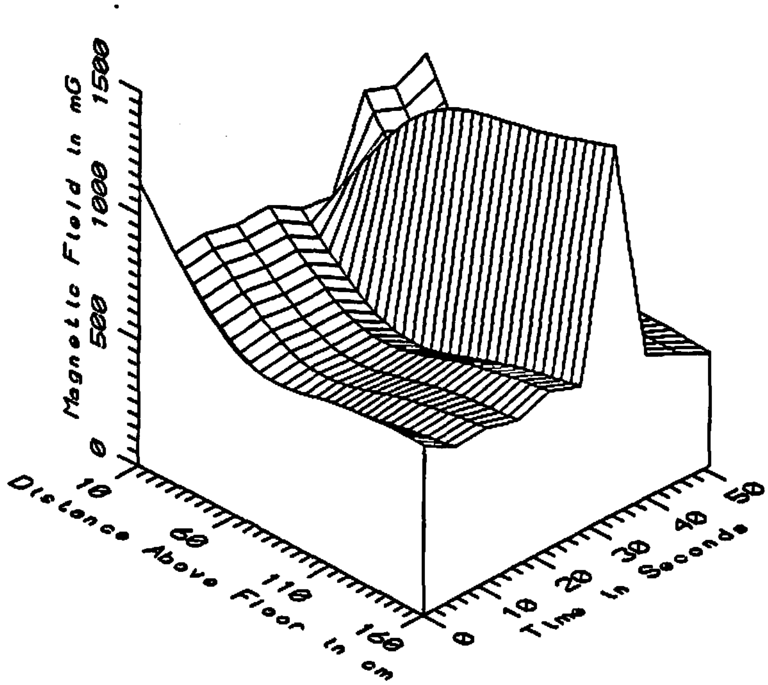


BOS017 - 160cm ABOVE FLOOR ON AXIS OF BLUE LINE CAR. AT REAR DOORS

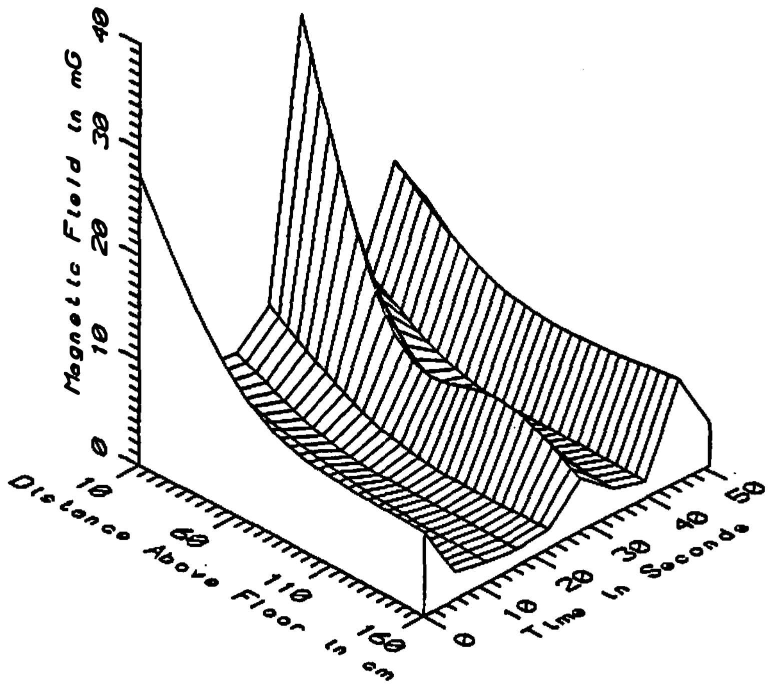


BOS017 - 160cm ABOVE FLOOR ON AXIS OF BLUE LINE CAR. AT REAR DOORS

FIGURE 3-7. **MAGNETIC FIELD 160 cm ABOVE THE FLOOR AT THE MIDDLE OF THE AISLE ABOVE THE REAR TRUCK IN A BLUE LINE CAR AS A FUNCTION OF FREQUENCY AND TIME WHILE OPERATING FROM AN OVERHEAD CATENARY**



BOS017 - ON AXIS OF BLUE LINE CAR, AT REAR DOORS - STATIC



BOS017 - ON AXIS OF BLUE LINE CAR, AT REAR DOORS - LOW FREQ. 5-45Hz

FIGURE 3-8. STATIC FIELD (TOP FRAME) AND LOW FREQUENCY TIME VARYING (BOTTOM FRAME) MAGNETIC FIELD ABOVE THE REAR TRUCK OF A BLUE LINE CAR AS A FUNCTION OF HEIGHT ABOVE THE FLOOR AND TIME WHILE OPERATING FROM AN OVERHEAD CATENARY

car. The static component shown in the top frame of the figure shows a clear attenuation with height at all time samples except at 34 seconds, confirming that a principal field source is again below the floor. At the 34-second time point, however, the static field is approximately uniform at the 60 cm, 110 cm and 160 cm measurement heights. That pattern of uniformity could be produced by dc current in the loop consisting of the overhead catenary and track return circuit. The low frequency time varying field attenuation curve measured in the Blue Line car (lower frame of Figure 3-8) is similar in attenuation pattern to that seen in the Orange Line car (Figure 3-5) showing a source beneath the floor of the car. There are apparently no significant time varying fields produced by current in the catenary/track circuit.

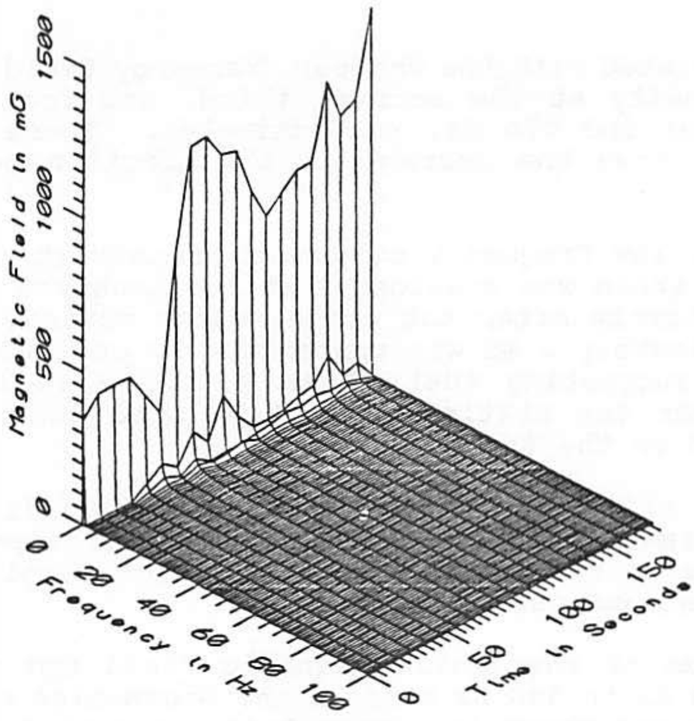
3.3.3 Red Line

Magnetic field data were measured at two locations, roughly over the front truck of the third Red Line car in a four car train rather than over the rear truck of the rear car, as was done on the other three lines. The resulting data comprise datasets BOS028 and BOS029 in Appendices AC and AD. The static and the time varying magnetic fields measured in the Red Line cars had frequency and spatial attenuation characteristics similar to those seen in the Orange Line cars, but they were lower in magnitude in the Red Line car.

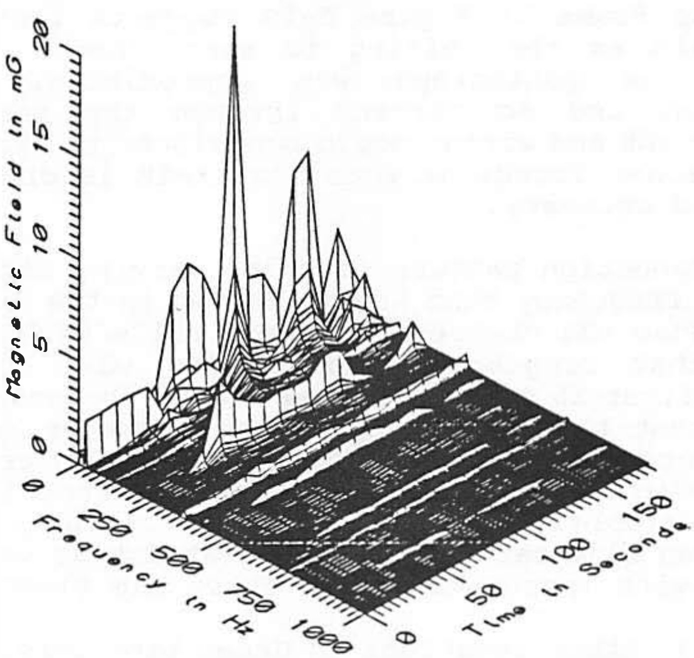
3.3.4 Green Line

Magnetic fields were measured at several locations in the Green Line car as illustrated in Figure 3-1 in attempts to detect any localized areas of unusually high magnetic fields which might result from smoothing reactors associated with the semiconductor chopper traction power control circuits. No significant highly localized sources were found. Measurements contained in dataset BOS033 (Appendix AH) were measured at a point in a Kinki-Sharyou Green Line car which was reportedly over the equipment module containing the semiconductor choppers (Location 10 in Figure 3-1). A graph of the magnetic field as a function of frequency and time near the floor at this location is shown in Figure 3-9. The top frame shows the static field in the car when it is stationary the first 25 seconds) and as it departs the Lechmere Station enroute to downtown Boston. These static and low frequency field components have temporal, spatial, frequency and intensity characteristics similar to those measured on the Red, Blue, and Green Line cars and described in detail above.

However, as shown in the lower frame of the figure, there are several discrete frequency time varying magnetic field components present in the frequency spectrum. Perhaps the most obvious of these is a field component at approximately 218 Hz which appears in the spectrum when the car is moving (from 25 seconds and beyond). This field is apparently due to the action of the 218 Hz semiconductor choppers. Other, smaller time varying components



BOS033 - 10cm ABOVE FLOOR ON AXIS AT REAR DOORS, KINKI GREEN LINE CAR



BOS033 - 10cm ABOVE FLOOR ON AXIS AT REAR DOORS, KINKI GREEN LINE CAR

FIGURE 3-9. MAGNETIC FIELD 10 cm ABOVE THE FLOOR IN A GREEN LINE CAR AT A POINT ABOVE THE CHOPPER CABINET AS A FUNCTION OF FREQUENCY AND TIME. THE STATIC FIELD COMPONENT IS SUPPRESSED IN THE LOWER FRAME TO SHOW THE TIME VARYING COMPONENTS

temporally correlated with the chopper frequency field are found at decreasing intensity at the second, third, and fourth harmonics (435 Hz, 652.5 Hz and 870 Hz, respectively). These fields also appear to arise from the current in the traction power control circuitry.

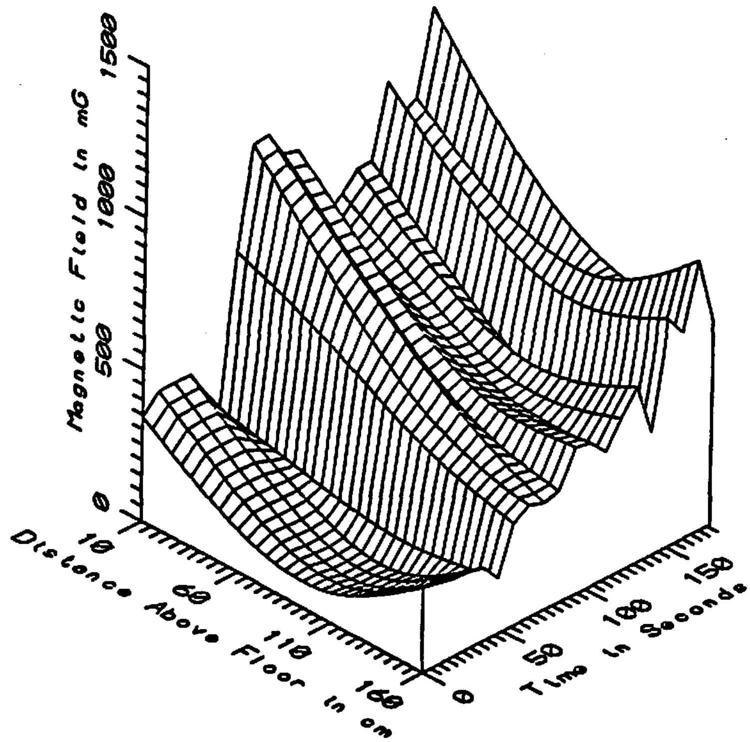
There is another low frequency component present at approximately 25 Hz, when the train was stationary at the Lechmere Station, but it disappears shortly after the train begins moving. That small field of approximately 2 mG was approximately uniform at all four sensor heights suggesting that it is either a field from some source in or near the station or perhaps some source at a more distant location on the train.

The other small time varying harmonics are at 60 Hz and certain even harmonics (second, sixth, and twelfth) and appear to arise from power lines in the vicinity and rectifier ripple current in the catenary/track current, respectively.

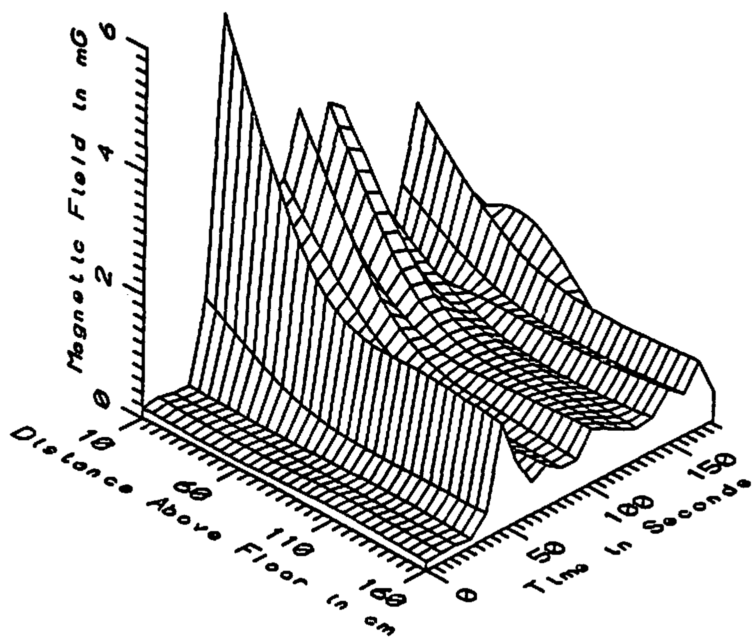
Vertical profiles of the static magnetic field and the magnetic field within the 65 to 300 Hz band in the Green Line car above the chopper cabinets are shown in Figure 3-10. The static field (top frame) is seen to be relatively low and uniform when the train is stationary (because it is due primarily to the earth's magnetism) but increases in intensity and shows an attenuation pattern indicative of a source beneath the floor as the train begins moving. The top frame of Figure 3-10 suggests that the static field rises again as the ceiling is approached. That is not surprising as the pantograph was approximately above the measurement point and dc current through the pantograph and associated equipment and wiring could contribute to elevated static fields at the higher locations when the train is drawing current from the overhead catenary.

The vertical attenuation pattern for time varying magnetic fields in the 65-300 Hz frequency band are displayed in the lower frame of Figure 3-10 because the chopper frequency falls within that band. The field in that frequency band is low when the train is stationary (the first 25 seconds of the record) because there is no significant current through the choppers. However, as the train begins to draw current through the choppers for its traction power needs, the magnetic fields from the chopper current itself or the chopper current ripple on current in other circuits beneath the floor of the Green Line car producing elevated time varying fields which attenuate with increased height above the floor.

Magnetic fields at other locations in Green Line cars, reported in Appendices AI, AJ, and AK, have characteristics similar to those just discussed, however, the magnetic field components at the chopper frequency tend to be smaller at points further away from the chopper cabinet.



BOS033 - ON AXIS AT REAR DOORS, KINKI GREEN LINE - STATIC



BOS033 - ON AXIS AT REAR DOORS, KINKI GREEN LINE - POWER HARM, 65-300Hz

FIGURE 3-10. STATIC (TOP FRAME) AND CHOPPER RIPPLE FREQUENCY (BOTTOM FRAME) MAGNETIC FIELD ABOVE THE CHOPPER CABINET IN A GREEN LINE CAR AS A FUNCTION OF HEIGHT ABOVE THE FLOOR AND TIME

3.3.5 Mattapan High Speed Trolley

The magnetic fields above the front truck of the Mattapan High Speed Trolley stationary and in motion are documented in datasets BOS030 (Appendix AE) and BOS031 (Appendix AF), respectively. Additional magnetic field data measured further back in the car approximately beneath the trolley arm are contained in dataset BOS032 (Appendix AG).

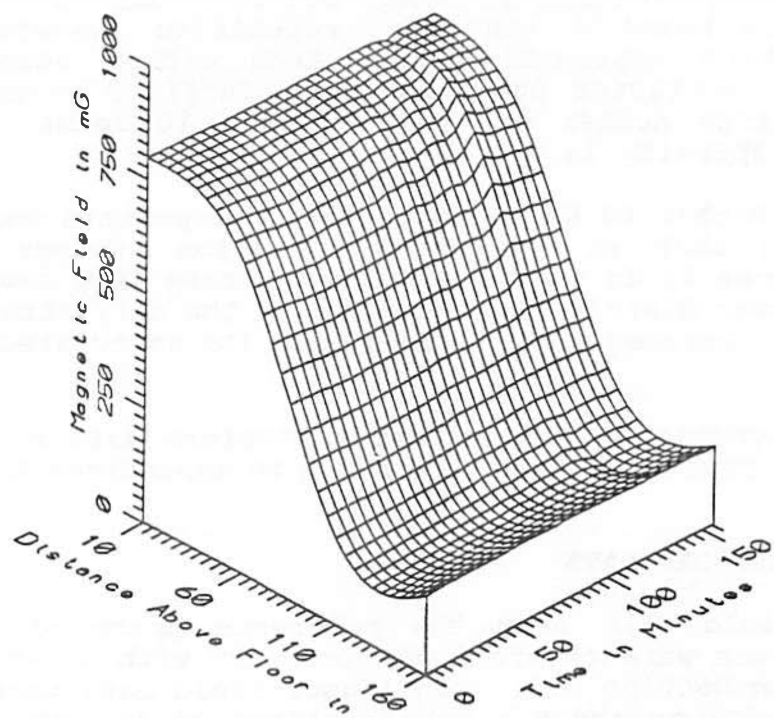
Static magnetic fields in the stationary Trolley are severely perturbed, apparently due to magnetization of the car body or static fields from the overhead ventilation fan. The upper frame of Figure 3-11 shows a variation in static field level as a function of height near the front of the standing Trolley Static field levels range from approximately 800 mG near the floor to approximately 170 mG at 160 cm above the floor. The expected geomagnetic field is approximately 500 mG. Since this pattern does not change, current in the overhead trolley wire supplying other cars on the line can be ruled out as a potential cause.

There is also a pattern of small, random time varying components in the magnetic field in the front of the stationary Trolley as shown in the lower frame of Figure 3-11. These are most pronounced at the highest measurement height, suggesting an overhead source. The spatial orientation and random nature of these time varying field components suggest that they may arise from commutator sparking in a dc ventilator fan motor. There are also small time varying field components present at 60 Hz, 360 Hz and 720 Hz in the stationary Trolley, as shown in the bottom frame of Figure 3-11. The 60 Hz fields appear to arise from a 60 Hz power circuit in or near the station, while the other two components appear to be caused by rectifier ripple in the dc current running lights and ventilation equipment in the car.

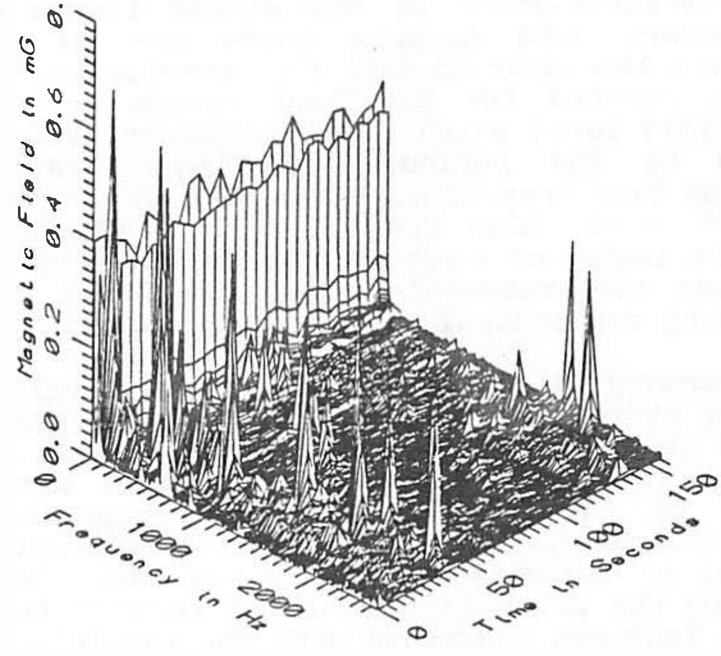
When the Trolley is moving, it exhibits all of the field characteristics discussed above for cam controlled subway cars. Static fields fluctuate over time due to fluctuating power needs by the car. The principal time varying components are low frequency components which arise from changes in dc traction current. The static and low frequency field components show clear attenuation with increased height above the floor indicating that they arise from sources beneath the floor. Frequency spectra and vertical attenuation graphs for these fields are found in Appendices AF and AG.

3.3.6 Trolley Bus

Magnetic fields in the Trolley Bus are similar in magnitude, frequency spectra and temporal variability to those in the High Speed Trolley. The differences in spatial variability result from the differences in equipment placement. Although the fields are relatively small on the trolley bus, they are largest close to the floor a few feet behind the rear axle of the bus. This is



BOS030 - OPERATOR'S RIGHT SHOULDER, TROLLEY - STATIC



BOS030 - 160cm ABOVE FLOOR AT OPERATOR'S RIGHT SHOULDER, TROLLEY

FIGURE 3-11. VERTICAL PROFILE OF STATIC MAGNETIC FIELD (TOP FRAME) AND FREQUENCY SPECTRUM OF THE TIME VARYING MAGNETIC FIELD 160 cm ABOVE THE FLOOR (BOTTOM FRAME) IN A STATIONARY TROLLEY BUS

presumably the location of the motor. Random time varying fields were found at that the repetitive waveform sampling location which apparently arise from either motor commutator sparking or contactor operation in underfloor control circuits. From the large number of these events, it seems unlikely that commutator sparking is the case.

There were higher 60 Hz magnetic field components measured in the Trolley Bus than in other transportation systems of the MBTA system. Those 60 Hz fields apparently arose from commercial 60 Hz electric power distribution lines along the city streets where the trolley bus operated and not the bus or its associated power supply system.

Complete magnetic field repetitive waveform data measured in the Trolley Bus passenger areas are found in Appendices AR, AS, and AT.

3.4 DAT WAVEFORM DATA

Magnetic field data from the reference probe of the waveform capture system were recorded continuously with a DAT recorder, as described in Section 2.5. Continuous field data were measured at a window ledge or above a metal cabinet at the end of the Blue, Orange, and Red Line cars. Additional measurements were made at different locations in Trolley and Trolley Bus vehicles as identified in Table 2-2. Those recordings provide better detail of the temporal characteristics of the static fields than do the repetitive waveform data because there are no interruptions necessary to store the incoming data from the single sensor. Those recordings were scanned for transient fields or sudden, brief excursions in field level which were fundamentally different from those recorded by the periodic sampling. Fast transients (occurring in the time span of milliseconds) in the magnetic field were only found in the High Speed Trolley. Slower "transient" (occurring in the tenths of a second time span) changes in magnetic field with modest time-rates-of-change were found in all of the vehicles employing cam control of traction power.

A statistical summary of static magnetic field levels measured by the DAT recorder system in the passenger compartments of the MBTA system vehicles is presented in Table 3-2. However, in the Red, Blue and Orange Line cars, these measurements were made in a distant corner of the car to avoid interruption of revenue passengers and the resulting data may not be typical of magnetic field conditions in the central area of the car. DAT recordings were not made in the Green Line vehicles because the operations manager of that line was concerned with the possible interference with revenue passengers.

3.4.1 Blue, Orange and Red Lines

Continuous recordings of the magnetic field were made in the Blue, Red, and Orange Line cars at the reference sensor location opposite

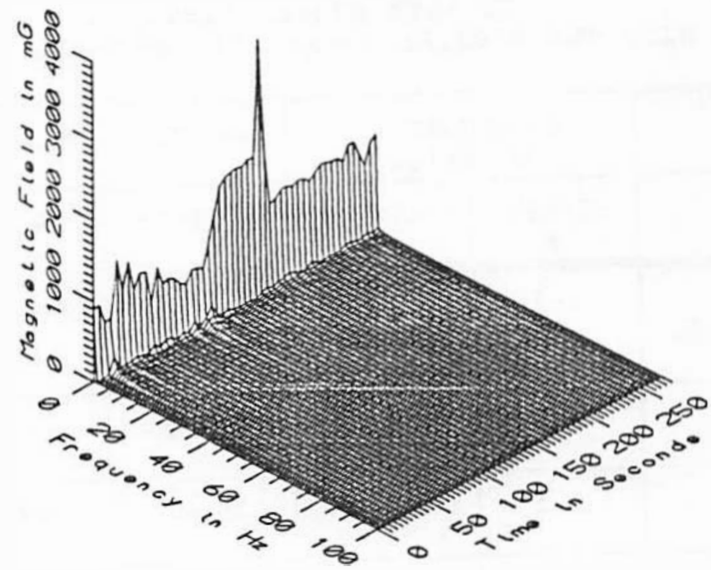
TABLE 3-2.

SUMMARY OF STATIC MAGNETIC FIELD LEVELS RECORDED
IN MBTA SYSTEM VEHICLES
WITH THE DIGITAL AUDIO TAPE RECORDER (DAT)

TYPE OF CAR	MEASUREMENT LOCATION		STATIC MAGNETIC FIELD (mG)		
(TAPE/GROUP RECORD)	FIGURE #	LOCATION	MINIMUM	AVERAGE	MAXIMUM
BLUE LINE (1/2/6, 1/2/7 AND 1/2/8)	3-1	2	495 mG	1009 mG	3217 mG
ORANGE LINE (1/2/9)	3-1	5	136 mG	342 mG	1211 mG
RED LINE (1/2/5, 1/3/1)	3-1	7	79 mG	340 mG	1103 mG
TROLLEY (1/3/2)	3-2	16	63 mG	385 mG	1068 mG
TROLLEY BUS, REAR (2/1/1, 2/1/2)	3-2	19	64 mG	179 mG	591 mG
TROLLEY BUS, CENTER (2/1/3)	3-2	23	247 mG	277 mG	314 mG

the operator's seat. These recordings show the temporal characteristics of the field with greater temporal resolution than data which takes only periodic samples of the magnetic field characteristics. The continuous field measurements in all three lines showed a number of common characteristics. Consequently those features are discussed just once in this subsection and apply to all three lines using cam controlled traction power systems unless otherwise indicated.

Figure 3-12 shows a comparison of simultaneous static field measurements over a 4-1/2 minute period in a Blue Line car made with the waveform capture system (top frame) and the DAT (bottom frame). Examination of the figure reveals that the data from both systems indicate the same gross temporal characteristics and intensities of the fields, but the DAT system provides finer detail of the temporal pattern over time periods of just a few seconds. For purposes of statistical analysis, the two recordings provide comparable data and are therefore somewhat redundant. However, for the detection of specific rare or infrequent events which occur for only brief periods of time, the DAT data are preferable. For example, the brief episode of high magnetic field which occurred 155 seconds (2.6 minutes) into the record lasted approximately 6 seconds. That was sufficiently long to assure detection by the



BOS019 - REFERENCE PROBE - ON WINDOW LEDGE, FRONT OF BLUE LINE CAR

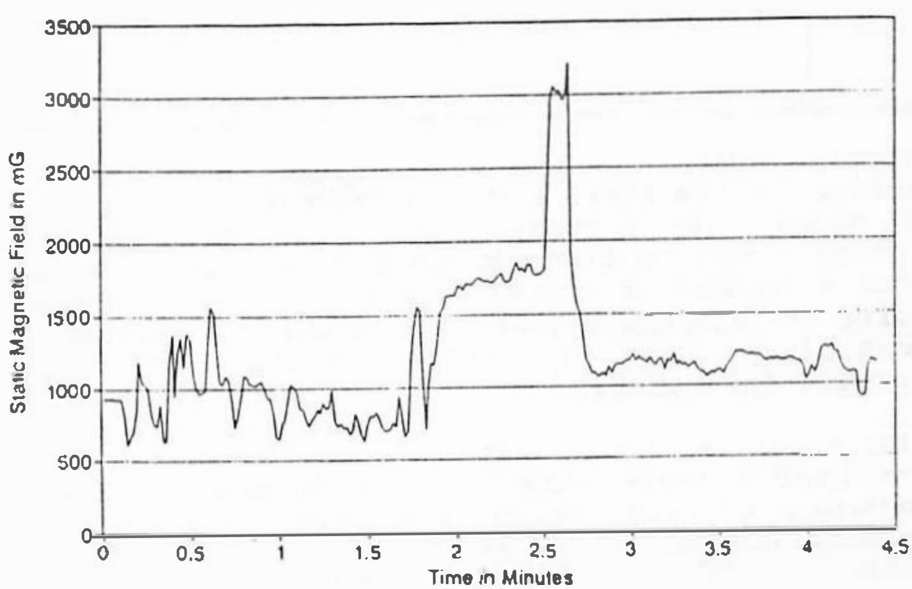


FIGURE 3-12. COMPARISON OF STATIC FIELD RECORDINGS OVER TIME AT THE REFERENCE SENSOR IN THE BLUE LINE CAR MEASURED WITH THE REPETITIVE WAVEFORM RECORDER (TOP FRAME) AND WITH THE DIGITAL AUDIO TAPE RECORDER (BOTTOM FRAME)

waveform capture system, but the exact duration of the episode was missed. The DAT data were compared to the waveform capture system data to determine if any significant episodes of large field excursions were missed in the repetitive waveform data collected in the Blue, Orange, or Red Line cars, and no such undetected episodes were found.

The reason for selecting the specific DAT record in Figure 3-12 for discussion rather than one of the others which show similar correlation with repetitive waveform data is that this specific record was measured while the Blue Line train traveled between the Airport and Aquarium Stations with an intermediate stop at Maverick Square. Just prior to arriving at Maverick Square, the Blue Line train enters the underground portion of its route and at or near Maverick Square, shifts from catenary to third rail operation. The episode of high magnetic field from approximately 115 seconds (1.9 minutes) to 160 seconds (2.7 minutes) into the record is unique to this dataset and its cause is not fully understood. The train was stopped in the Maverick Square Station from approximately the 130 second (2.2 minutes) time point to the 160 second (2.7 minute) time point. Consequently, the elevated field appears to be due to a specific feature of the station, or the portion of the tunnel from the portal into the station. It does not appear to reflect field conditions produced by the Blue Line car because the train was stationary for a considerable portion of the time that elevated fields were present.

The fine temporal detail of the magnetic field data measured with the DAT and shown in the bottom frame of Figure 3-12 appears to suggest that the static component of the magnetic field has considerably more temporal variability on sections of the Blue Line using catenary power delivery (0 - 1.8 minutes) than on third rail powered sections (2.7 - 4.4 minutes). That, too, appears to be a site-specific observation because the temporal variability of static fields in other third rail powered cars on the Orange and Red Lines was comparable to that seen on the catenary powered sections of the Blue Line.

All of the DAT recordings on the Red, Blue, and Orange lines were scanned for very fast transient fields, but none were found. Numerous incidents of relatively slow transient field conditions exist when the level of power to the traction motors is changed by switching in or switching out resistors. Figure 3-13 shows a particularly interesting example which was measured in the Blue Line car as it entered the Aquarium Station. This point corresponds to the 255 second (4.3 minute) time point in Figure 3-12. The rising static field has a transient rate of rise of approximately 8 gauss per second, and although the magnitude of this particular transient is not as great as those associated with passage through the typical field conditions found near the Maverick Square Station, it has a similar rate of rise (approximately 8 G/second) and is more representative of the "typical" magnitude (200 mG) of field transients on the cam controlled cars of the Red, Blue, and Orange lines. The feature which drew initial attention to this particular transient was the

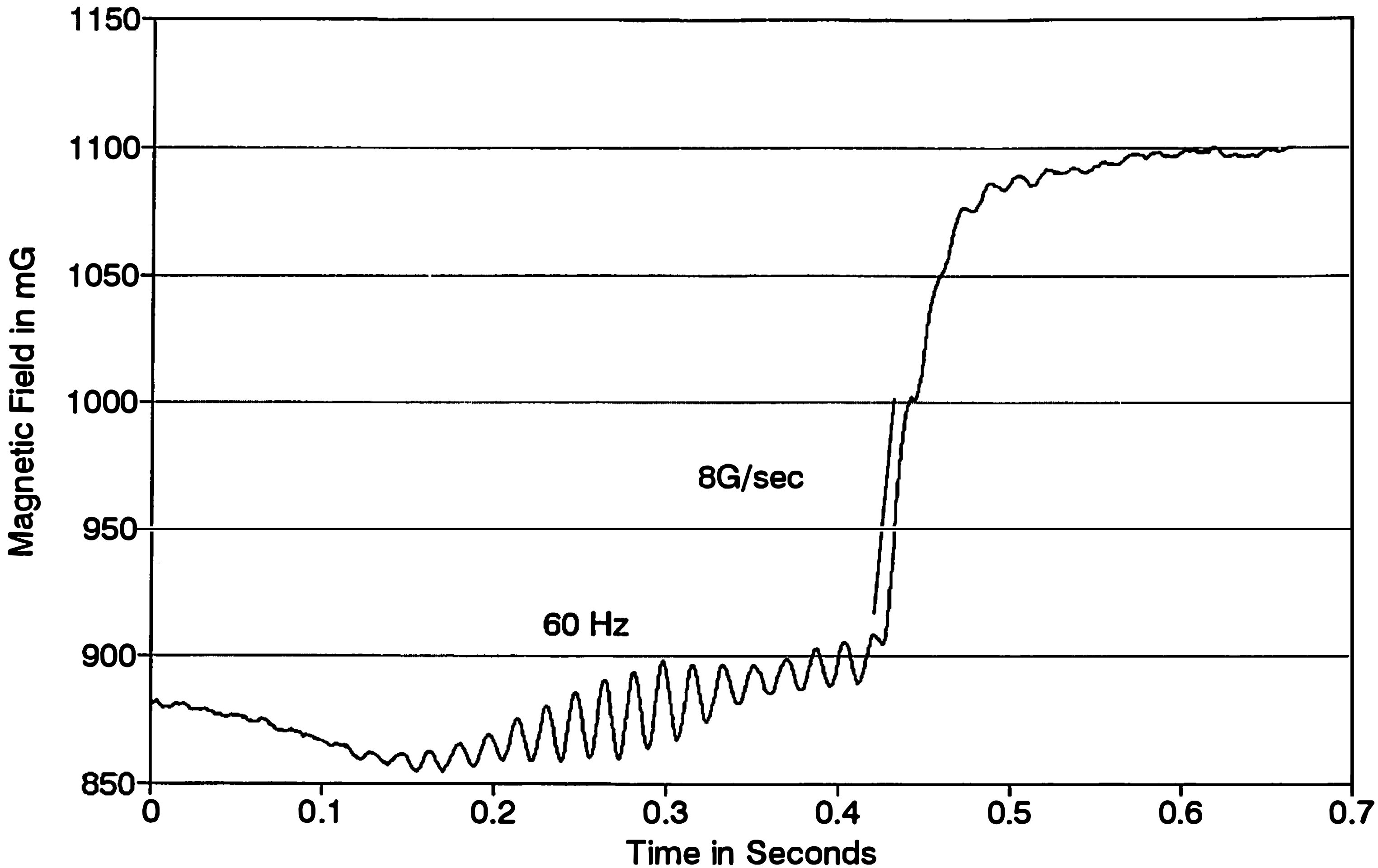


FIGURE 3-13. DETAIL OF A TRANSIENT CHANGE IN MAGNETIC FIELD LEVEL DETECTED IN A BLUE LINE CAR OPERATING FROM THIRD RAIL POWER

burst of periodic time varying magnetic field which immediately precedes the transient. However, after further analysis, the transient field and the periodic field appear unrelated. The transient field is just a typical response to change in cam control setting while the burst of 60 Hz periodic field coincidentally preceding the transient reflects the influence of a power frequency magnetic field source at the end of the station which is passed by the train as it enters the station.

3.4.2 Mattapan High Speed Trolley

Examination of the DAT records of continuous magnetic field levels measured on the Mattapan High Speed Trolley and presented in Figure 3-14 revealed good agreement with the repetitive waveform data (Appendices AE, AF, and AG) over the broad time scale, but contains the continuous record, a wealth of detailed temporal information about fields in the Trolley only suggested by the other measurements. The time record in Figure 3-14 shows field levels in a passenger's seat approximately 2.1 m (7 ft) behind the back of the driver's seat (Location 16 of Figure 3-2). For the first three minutes, the Trolley is stationary at the Mattapan Station. As the Trolley accelerates between the 3 and 3.5 minute points on the record, static fields at the measurement point produced by the system are oppositely aligned to the geomagnetic field and the two partially cancel one another. But as the trolley employs its dynamic braking, the direction of field produced by the Trolley changes and adds to the geomagnetic field. After the Trolley makes a brief station stop at the 4 minute point (evidenced by the constant field level and other time varying field data in the appendices), the Trolley again accelerates, brakes and stops at a second station at the five minute point. That process repeats as the Trolley accelerates and slows through two more cycles without actually stopping at the stations.

Figure 3-14 shows that there is considerably more short term variability in static fields in the Trolley than on the subway cars. Figure 3-15 shows an expanded detail of the transient magnetic field condition which occurred as the Trolley left its first station stop just after the 4 minute point in Figure 3-14. The fast and slow transients present in this figure are typical of those seen frequently throughout the DAT data measured in the Trolley. The slow transient associated with changes in dc traction current has an initial rate of rise of approximately 11 G/second. That portion of the transient is very similar in both rate of rise and magnitude (200 mG) to those seen in the subway cars on the Red, Blue, and Orange lines. What is unique, however, is the fast field transients which accompany the slow transient. These appear to be due to contact bounce and arcing of cam or contactor switches in the old traction power control system of this vintage trolley system rather than the traction motors because they also occur while the Trolley is stationary but preparing to depart a station.

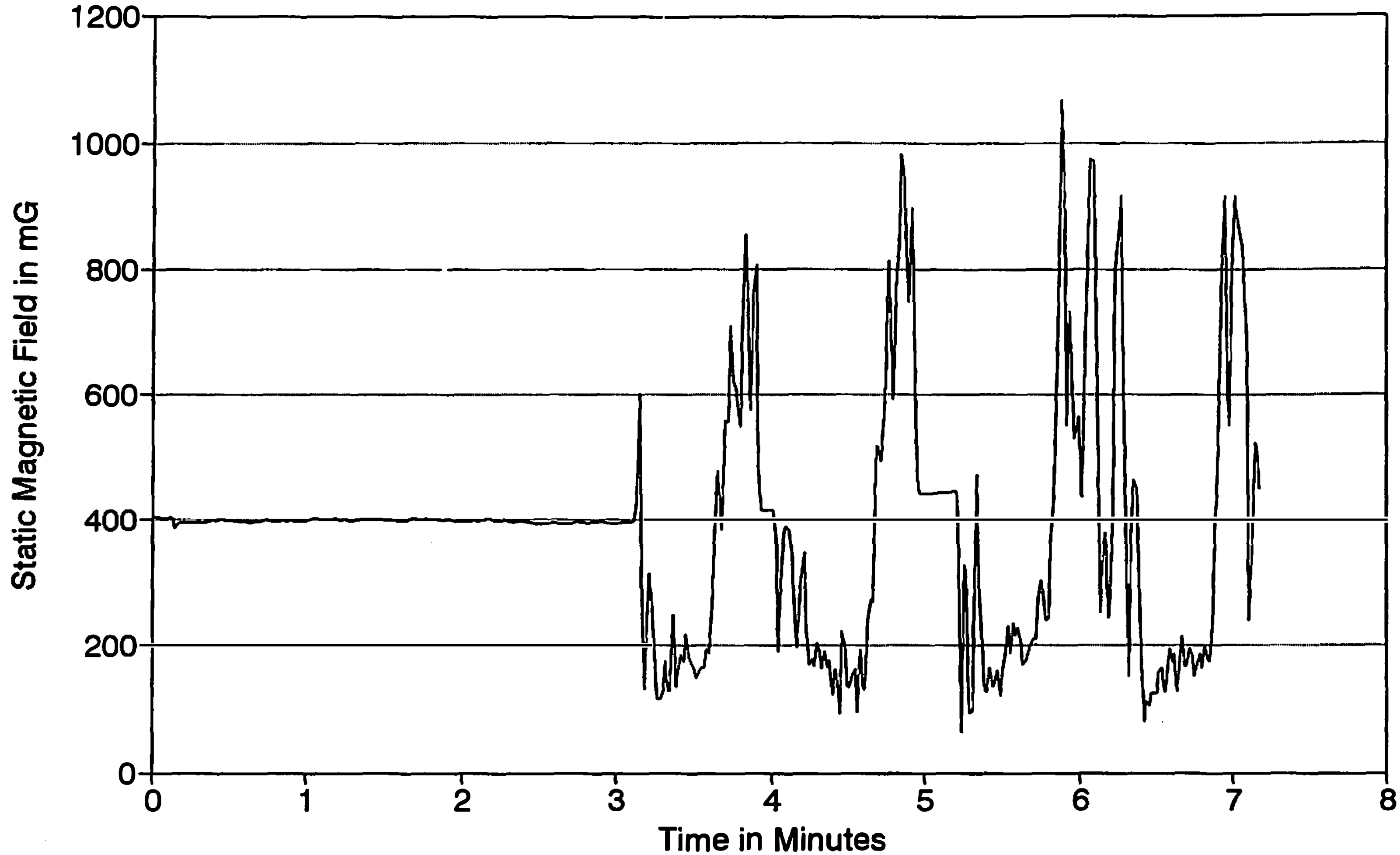


FIGURE 3-14. CONTINUOUS RECORDING OF STATIC FIELD LEVELS IN A PASSENGER SEAT OF THE MATTAPAN HIGH SPEED TROLLEY

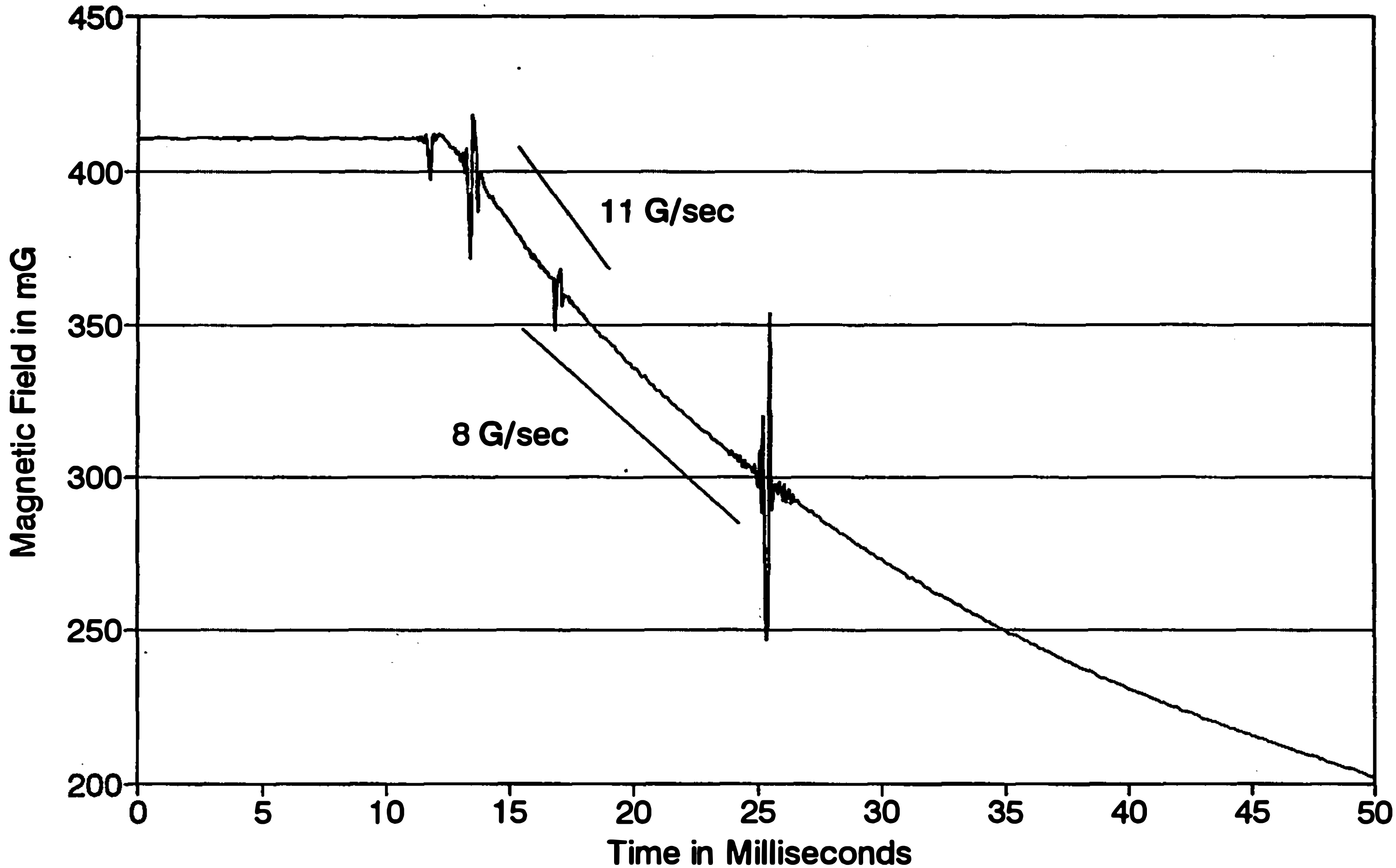


FIGURE 3-15. DETAIL OF THE TRANSIENT MAGNETIC FIELD MEASURED IN A PASSENGER'S SEAT OF THE MATTAPAN HIGH SPEED TROLLEY AS IT APPLIED POWER TO ITS TRACTION MOTORS TO LEAVE A STATION

Figure 3-16 shows a detail of the fast transient which preceded the energization of the traction motors detailed in Figure 3-15 by a few tenths of a second. It may have been due to energization of the motor field coils. The rates of rise of these transient magnetic fields are quite high, approximately 8000 G/second in the example given in Figure 3-16. They are unique to the Mattapan High Speed Trolley system in that they were not seen on any of the other MBTA vehicles examined. These fast magnetic field transients were not isolated to conditions of leaving a station but occurred throughout a variety of operating conditions.

3.4.3 Trolley Bus

The continuous magnetic field recordings in the Trolley Bus indicated frequent slow transients in the static magnetic field due apparently to its many stops for loading or discharging passengers as well as accommodating the normal start and stop movement of city traffic. Figure 3-17 shows a typical detail of the transient magnetic fields in the back of the Trolley Bus. The magnitude of the transients is generally smaller than on the other systems and of similar or slower risetimes.

3.5 RMS RECORDER DATA

Magnetic field levels measured by the waveform capture system or DAT recorders provide detailed documentation of magnetic field levels at a few discrete locations within the coaches but do not factor in the possibility that passengers moving about the coaches may encounter high fields from specific, localized sources. To examine the extent to which spot measurements of magnetic fields can be generalized to passenger exposure, two members of the measurement team wore personal rms recorders.

For these tests, the instruments were used in the "broadband" mode which yielded the widest frequency response (nominally a 3 dB bandwidth between 40 Hz and 800 Hz) and therefore provided the instrument's most complete measurement of ELF magnetic fields. The rms recorders lack the ability to measure static magnetic fields or the low frequency components produced by changes in the static field. Since those low frequency components are the predominant components of the ELF magnetic field in the MBTA system vehicles, they are of limited value and not directly comparable to ELF magnetic field levels measured with instruments having bandwidths which cover the majority of the ELF band. Nonetheless, the data are reported here for completeness.

The rms recorders were mostly worn waist high, while wandering about the approximate vicinity of the car where the other measurements were being made, or while seated in a passenger seat while traveling between measurement sites. Figures 3-18 through 3-21 show the correlation of field levels recorded by the exposure monitors on two different people over time on the Blue, Orange and Red subway lines and on the High Speed Trolley line, respectively.

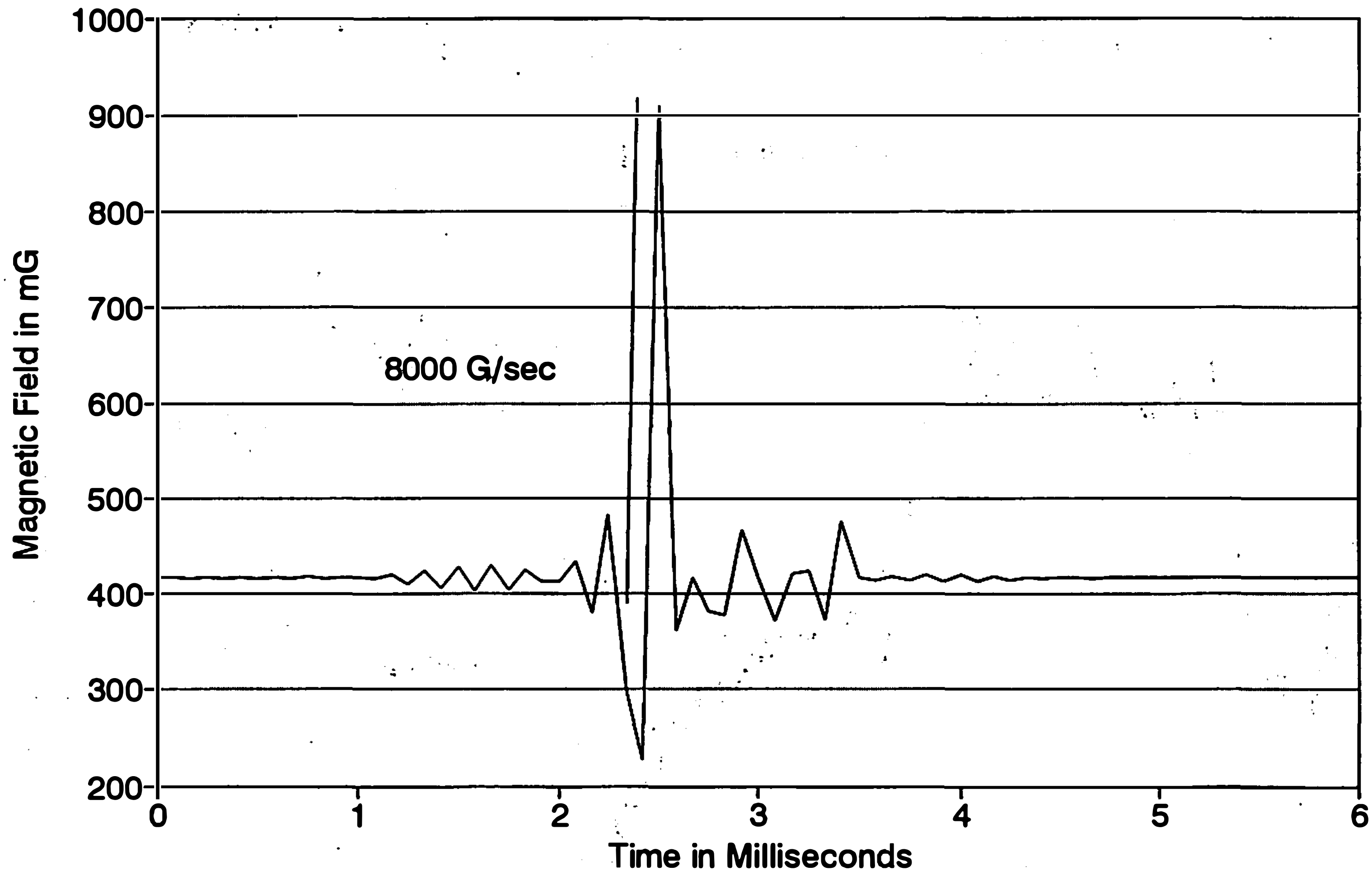


FIGURE 3-16. DETAIL OF THE TRANSIENT MAGNETIC FIELDS IN A PASSENGER SEAT OF THE MATTAPAN HIGH SPEED TROLLEY JUST PRIOR TO DEPARTING A STATION

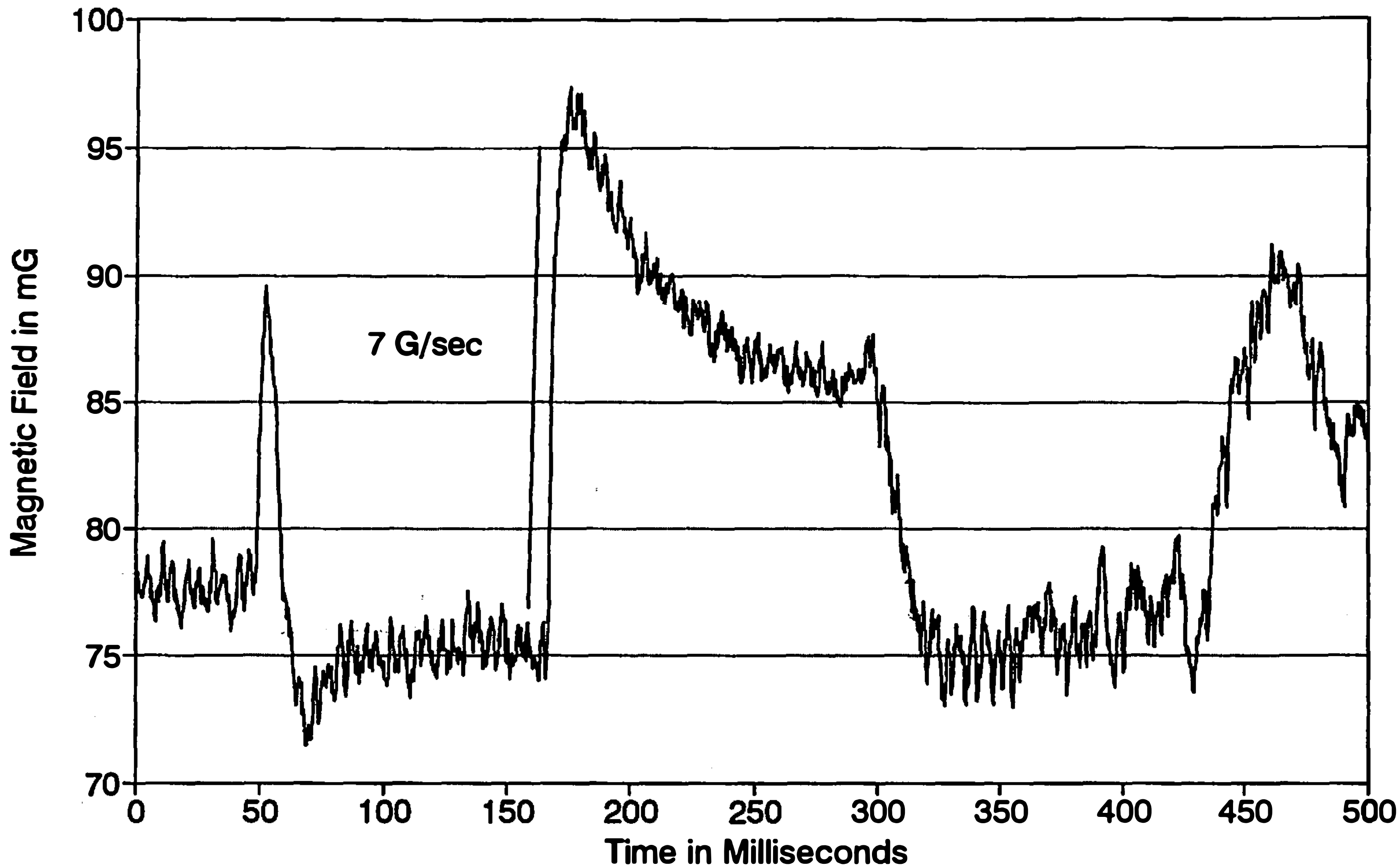


FIGURE 3-17. TRANSIENT MAGNETIC FIELD ON THE REAR SEAT OF A TROLLEY BUS AS IT DEPARTS FROM A ROADSIDE STOP

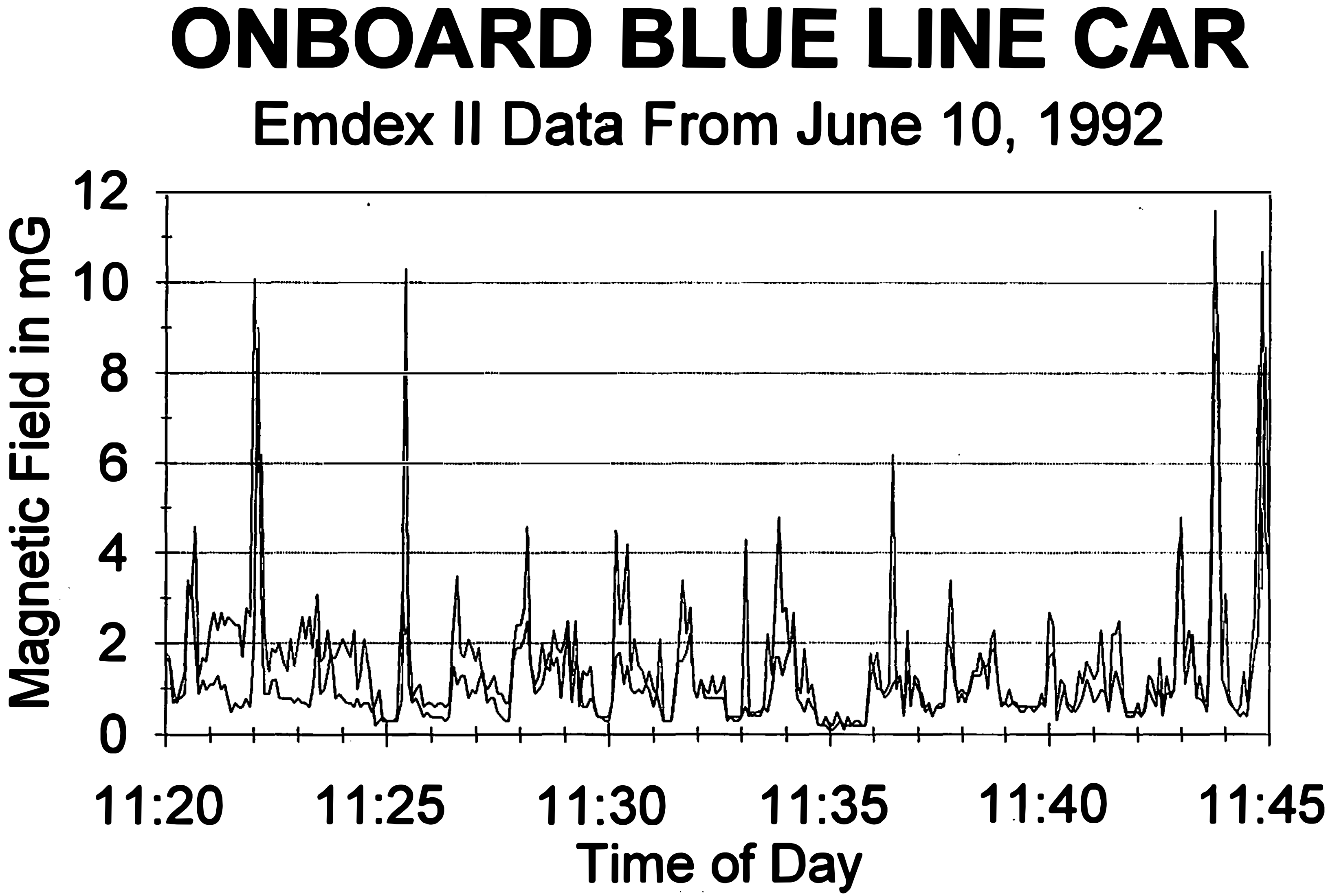


FIGURE 3-18. MAGNETIC FIELD LEVELS MEASURED BY TWO PEOPLE WEARING PERSONAL EXPOSURE MONITORS IN A BLUE LINE CAR

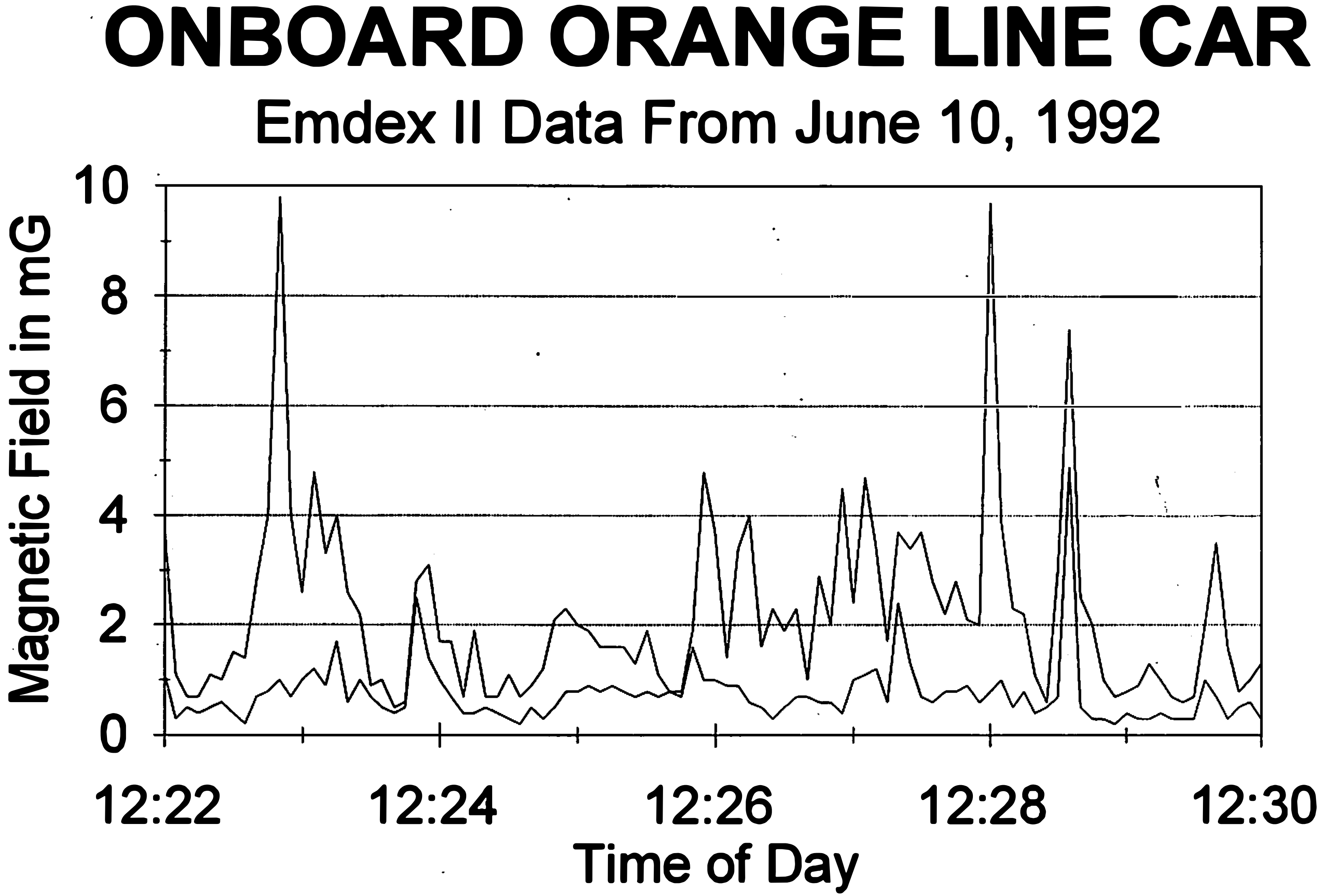


FIGURE 3-19. MAGNETIC FIELD LEVELS MEASURED BY TWO PEOPLE WEARING PERSONAL EXPOSURE MONITORS IN AN ORANGE LINE CAR

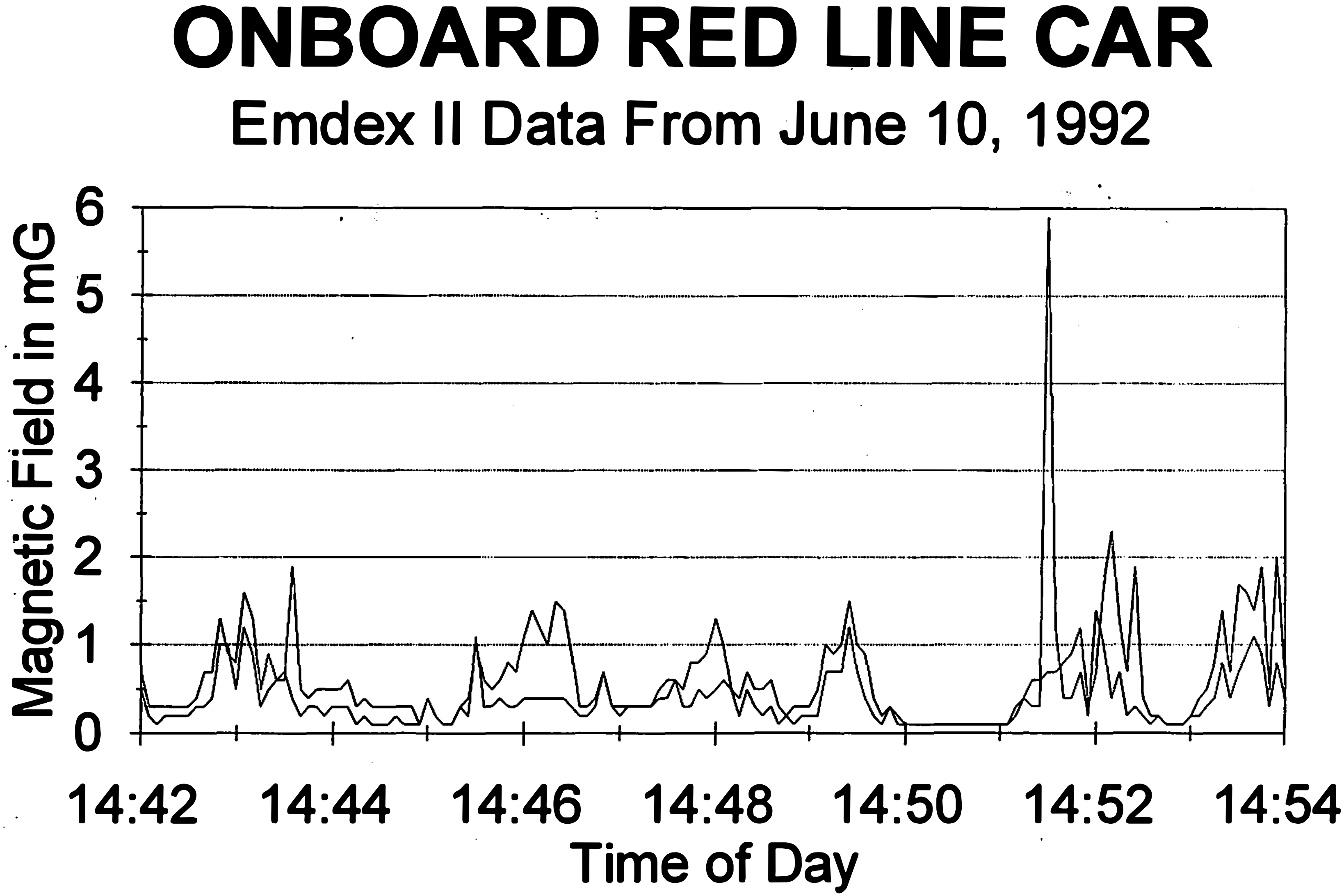


FIGURE 3-20. MAGNETIC FIELD LEVELS MEASURED BY TWO PEOPLE WEARING PERSONAL EXPOSURE MONITORS IN A RED LINE CAR

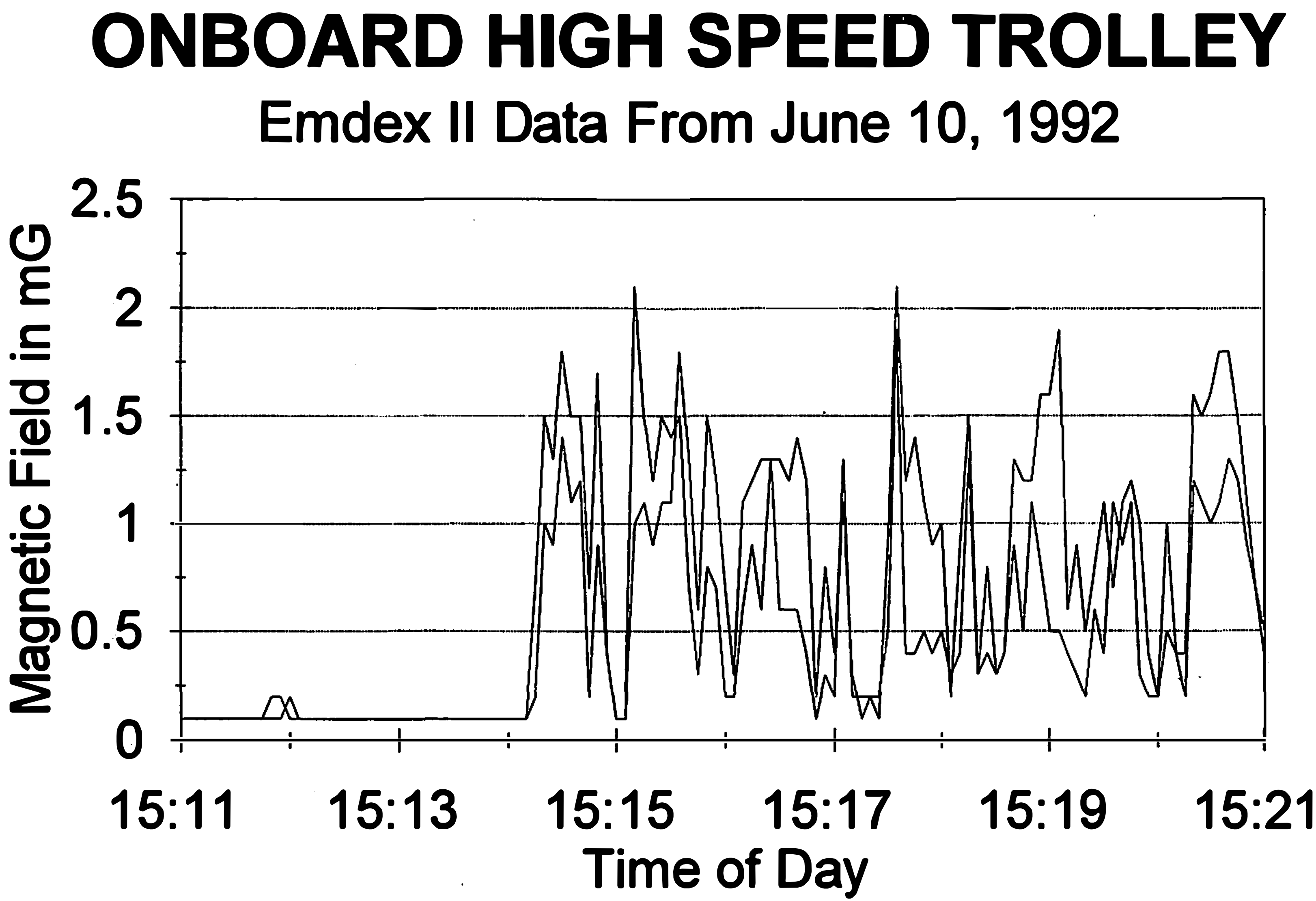


FIGURE 3-21. MAGNETIC FIELD LEVELS MEASURED BY TWO PEOPLE WEARING PERSONAL EXPOSURE MONITORS IN A MATTAPAN HIGH SPEED TROLLEY

Table 3-3 shows the statistical minimum, average and maximum values obtained by the rms recorders in the passenger area of four MBTA system vehicles. Data are presented for each recorder individually and as pooled data for the two recorders.

TABLE 3-3.

STATISTICAL SUMMARY OF MAGNETIC FIELD LEVELS RECORDED IN MBTA SYSTEM VEHICLES USING RMS RECORDERS

VEHICLE	RMS RECORDER #	AVERAGE	MAXIMUM
BLUE LINE	PERSON 1	1.14 mG	10.7 mG
(REAR)	PERSON 2	1.57 mG	11.6 mG
	COMBINED	1.36 mG	11.6 mG
ORANGE LINE	PERSON 1	0.75 mG	4.9 mG
(REAR)	PERSON 2	2.22 mG	9.8 mG
	COMBINED	1.49 mG	9.8 mG
RED LINE	PERSON 1	0.40 mG	5.0 mG
(FRONT)	PERSON 2	0.62 mG	2.3 mG
	COMBINED	0.51 mG	5.9 mG
HIGH SPEED	PERSON 1	0.65 mG	2.1 mG
TROLLEY	PERSON 2	0.55 mG	2.1 mG
(THROUGHOUT)	COMBINED	0.60 mG	2.1 mG

3.6 SUMMARY OF MAGNETIC FIELD LEVELS

As discussed in the preceding subsections, the predominant magnetic field sources in the passenger areas of the MBTA system subway cars appear to be traction power and control equipment beneath the floor of the cars and possible current in the loop created by the catenary or third rail track return circuit. Consequently, tabulations of magnetic field level provided in this subsection give field values at various heights above the floor. These fields are predominantly static with low frequency time varying components resulting from fluctuations in the static field level. However, time varying fields are found in the higher frequency bands in the Green Line cars which use 218 Hz semiconductor choppers to control the amount of electric power supplied to the traction motors.

The magnetic fields measured on the Mattapan High Speed Trolley and the North Cambridge Trolley Bus are also predominantly static with low frequency time varying components resulting from fluctuations in the static field level. Higher frequency ELF magnetic fields are also present, especially in the trolley bus where magnetic fields from 60 Hz current in nearby commercial power distribution lines contribute to the field environment in the bus.

3.6.1 Orange, Blue and Red Lines

A summary of the magnetic field levels measured at various heights above the floor over the rear truck of an Orange Line car is presented in Table 3-4. Static fields and time varying fields are highest near the floor and become weaker with increased height, indicating that the predominant source is beneath the floor. Time varying fields are predominantly at the low end of the ELF band resulting from changes in static field level. Maximum field levels are typically two to three times larger than the average field level.

Corresponding data measured in a Blue Line car operating from an overhead catenary are show in Table 3-5. Time varying magnetic fields in the Blue Line car show similar distribution over frequency bands and similar differences between average and peak field levels seen as in the Orange Line car, but are on average 20 percent smaller in the Blue Line car. That is perhaps not unexpected because both cars are built by the same company and have traction equipment built by the same company, but the Blue Line cars are about 23 percent shorter. They would therefore require somewhat less traction power and therefore produce correspondingly lower magnetic fields.

The static magnetic fields measured near the floor are also lower in the Blue Line cars than those at the corresponding location in the larger Orange Line cars. But at greater heights above the floor, that relationship is reversed. The higher average static magnetic field levels in the Blue Line cars and the tendency for increase in static field levels with height points to the significance of catenary rather than third rail power supply to the train. DC current in the catenary represents an important source of static magnetic field at locations above the floor of the Blue Line car, but sources beneath the floor appear to dominate static field levels near floor level and perhaps ELF fields at all measurement heights.

Vertical profiles of magnetic field strength were measured at two locations in the front of a Red Line car at positions generally above the front truck. These measurement locations are identified as Locations 8 and 9 in Figure 3-1 and summaries of the field levels measured at those two locations are reported in Appendices AC and AD, respectively. The data from both datasets were similar, they were pooled and are summarized statistically in Table 3-6. A comparison of field levels in the Red Line car to those in either the Blue or Orange Line cars reveals that both static and ELF

TABLE 3-4.

SUMMARY STATISTICS FOR MAGNETIC FIELD LEVELS MEASURED IN AN ORANGE LINE CAR

BOS021 - IN CENTER OF ORANGE LINE CAR, ABOVE TRUCK					TOTAL OF 40 SAMPLES	
FREQUENCY BAND	HEIGHT ABOVE FLOOR (cm)	MINIMUM MAGNETIC FIELD (mG)	MAXIMUM MAGNETIC FIELD (mG)	AVERAGE MAGNETIC FIELD (mG)	STANDARD DEVIATION (mG)	COEFFICIENT OF VARIATION (%)
STATIC	10	278.12	1981.24	893.99	399.31	44.67
	60	134.11	1446.00	478.55	268.27	56.06
	110	123.19	1233.66	406.24	220.20	54.21
	160	146.95	1189.42	415.77	203.84	49.03
5-45Hz LOW FREQ	10	3.79	66.00	24.72	16.64	67.34
	60	1.14	24.36	7.42	5.24	70.56
	110	0.81	16.65	5.17	3.44	66.55
	160	0.73	13.06	4.09	2.55	62.26
50-60Hz PWR FREQ	10	1.08	14.65	4.35	2.86	65.80
	60	0.45	3.56	1.12	0.68	60.45
	110	0.23	2.18	0.78	0.42	54.13
	160	0.18	1.85	0.68	0.32	47.33
65-300Hz PWR HARM	10	1.22	18.34	5.36	3.66	68.24
	60	0.40	4.67	1.42	0.92	65.04
	110	0.21	2.31	0.91	0.52	56.65
	160	0.26	1.78	0.78	0.39	50.65
305-2560Hz HIGH FREQ	10	0.44	4.70	1.61	1.00	62.21
	60	0.19	1.23	0.52	0.28	52.79
	110	0.11	0.86	0.34	0.20	58.16
	160	0.12	0.69	0.31	0.15	47.95
5-2560Hz ALL FREQ	10	4.17	68.36	25.84	17.12	66.28
	60	1.33	24.41	7.69	5.31	69.03
	110	0.98	16.71	5.34	3.48	65.05
	160	0.92	13.14	4.25	2.56	60.33

TABLE 3-5.

SUMMARY STATISTICS FOR MAGNETIC FIELD LEVELS
MEASURED IN A BLUE LINE CAR

BOS017 - ON AXIS AT REAR DOORS OF BLUE LINE CAR					TOTAL OF 10 SAMPLES	
FREQUENCY BAND	HEIGHT ABOVE FLOOR (cm)	MINIMUM MAGNETIC FIELD (mG)	MAXIMUM MAGNETIC FIELD (mG)	AVERAGE MAGNETIC FIELD (mG)	STANDARD DEVIATION (mG)	COEFFICIENT OF VARIATION (%)
STATIC	10	674.47	1128.48	867.86	167.40	19.29
	60	408.24	1217.46	565.36	237.96	42.09
	110	449.22	1360.97	615.37	267.79	43.52
	160	450.93	1473.08	674.66	287.93	42.68
5-45Hz LOW FREQ	10	5.96	34.95	14.65	9.56	65.24
	60	2.15	12.51	5.75	3.59	62.56
	110	1.58	8.94	4.24	3.07	72.36
	160	1.55	9.80	3.90	2.88	73.81
50-60Hz PWR FREQ	10	0.77	7.70	2.69	1.93	71.88
	60	0.43	1.90	1.15	0.51	44.02
	110	0.39	1.38	0.81	0.33	41.39
	160	0.30	1.62	0.67	0.41	61.28
65-300Hz PWR HARM	10	1.05	11.48	3.64	2.94	80.79
	60	0.53	3.62	1.32	0.90	68.72
	110	0.43	2.73	1.01	0.69	68.69
	160	0.44	2.45	0.93	0.63	67.32
305-2560Hz HIGH FREQ	10	0.63	1.58	1.00	0.33	32.65
	60	0.28	0.84	0.47	0.18	37.93
	110	0.21	0.69	0.37	0.15	39.68
	160	0.18	0.74	0.35	0.17	47.06
5-2560Hz ALL FREQ	10	7.05	35.32	15.55	9.86	63.38
	60	2.93	13.18	6.10	3.61	59.12
	110	1.95	9.21	4.49	3.11	69.13
	160	1.79	10.01	4.11	2.94	71.60

TABLE 3-6.

SUMMARY STATISTICS FOR MAGNETIC FIELD LEVELS
MEASURED IN A RED LINE CAR

RED LINE CAR ABOVE TRUCK					TOTAL OF 39 SAMPLES	
FREQUENCY BAND	HEIGHT ABOVE FLOOR (cm)	MINIMUM MAGNETIC FIELD (mG)	MAXIMUM MAGNETIC FIELD (mG)	AVERAGE MAGNETIC FIELD (mG)	STANDARD DEVIATION (mG)	COEFFICIENT OF VARIATION (%)
STATIC	10	235.74	1091.21	569.90	170.29	29.88
	60	62.33	1002.23	425.01	154.73	36.40
	110	11.82	864.75	364.13	133.12	36.56
	160	71.55	737.33	336.24	109.82	32.66
5-45Hz LOW FREQ	10	0.31	10.26	3.94	3.18	80.67
	60	0.16	6.43	2.17	1.98	91.33
	110	0.07	4.88	1.72	1.55	90.10
	160	0.18	5.89	1.52	1.35	89.15
50-60Hz PWR FREQ	10	0.17	2.59	0.69	0.54	77.65
	60	0.07	0.96	0.35	0.23	66.15
	110	0.18	1.18	0.39	0.20	50.21
	160	0.09	1.22	0.30	0.20	69.09
65-300Hz PWR HARM	10	0.07	5.31	1.44	1.41	98.14
	60	0.14	1.61	0.53	0.40	74.37
	110	0.09	1.07	0.49	0.27	56.57
	160	0.14	0.89	0.39	0.23	58.65
305-2560Hz HIGH FREQ	10	0.08	2.05	0.66	0.59	89.55
	60	0.04	0.57	0.20	0.13	64.22
	110	0.04	0.37	0.16	0.10	61.80
	160	0.03	0.42	0.14	0.09	66.67
5-2560Hz ALL FREQ	10	0.44	11.34	4.37	3.48	79.68
	60	0.26	6.55	2.31	2.00	86.59
	110	0.22	4.99	1.91	1.51	79.00
	160	0.26	5.98	1.63	1.36	83.58

magnetic field levels are lower in the Red Line car. The difference is possibly due to the fact that the measurements in the Red Line car were near the center of the train (the front of the third of four cars) while the Orange and Blue Line measurements were at the end of the train (the rear of fourth of four cars). One might argue that there is less current in the third rail and track circuit at the point midway through the train, however, available evidence indicates that onboard traction power and control equipment is a more important field source than is current in the third rail and track. The argument is further supported by the measurements made with the personal exposure monitors reported in Table 3-3. Even though the rms recorders are measuring no static fields and only the limited portion of the ELF band from 40 Hz to 800 Hz, they show the same trend of markedly lower magnetic fields in the Red Line car. From the available data, the difference in field levels between those in cars on the Red Line and those on the Blue or Orange Lines appears to result in differences in design of the under-floor traction power and control equipment supplied by Westinghouse and General Electric, respectively.

Since the Orange, Blue and Red line cars are all cam controlled cars having basically similar magnetic field characteristics, the measurements made on all three lines have been pooled to provide the summary table presented in Table 3-7.

3.6.2 Green Line

Vertical profiles of magnetic field were measured at four locations in the passenger areas of a Green Line car to determine if there were localized areas of high magnetic field above the semiconductor choppers, above the smoothing reactors, above the trucks, or beneath the pantograph. Although variations in field level from one location to another were found (and statistics on field levels for each location are found in Appendices AH through AK) the differences were not large compared to the temporal variability at any one location. Furthermore, the frequency and spatial characteristics of the magnetic field were similar at all four locations. Therefore, the magnetic field data from datasets BOS033 through BOS036 were pooled and a statistical summary of the resulting field levels is presented in Table 3-8. Comparing the data in the summary table for the Green Line chopper controlled cars to those in Table 3-7 for cam controlled cars shows that the Green Line cars tend to have slightly smaller time varying magnetic fields. The time varying magnetic fields from the chopper controlled current contains detectable components at the chopper frequency (218 Hz) and harmonics thereof, but the magnitude of those time varying field components are comparable to or lower than the time varying magnetic fields in similar frequency bands within the cam controlled cars. The static magnetic fields within the chopper controlled Green Line cars is comparable in magnitude to that in the cam controlled Orange, Blue, and Red Line cars. In both cases, the average static field in the car only departs markedly from the normal geomagnetic field level near the floor of

TABLE 3-7.

SUMMARY STATISTICS FOR MAGNETIC FIELD LEVELS MEASURED IN ORANGE, BLUE AND RED LINE CARS (CAM CONTROL)

PASSENGER AREAS IN CAM CONTROL CARS					TOTAL OF 89 SAMPLES	
FREQUENCY BAND	HEIGHT ABOVE FLOOR (cm)	MINIMUM MAGNETIC FIELD (mG)	MAXIMUM MAGNETIC FIELD (mG)	AVERAGE MAGNETIC FIELD (mG)	STANDARD DEVIATION (mG)	COEFFICIENT OF VARIATION (%)
STATIC	10	235.74	1981.24	749.04	333.81	44.57
	60	62.33	1446.00	464.85	223.52	48.08
	110	11.82	1360.97	411.28	205.44	49.95
	160	71.55	1473.08	410.01	206.12	50.27
5-45Hz LOW FREQ	10	0.31	66.00	14.48	15.28	105.50
	60	0.16	24.36	4.93	4.63	93.91
	110	0.07	16.65	3.56	3.16	88.87
	160	0.18	13.06	2.94	2.47	84.06
50-60Hz PWR FREQ	10	0.17	14.65	2.56	2.67	104.45
	60	0.07	3.56	0.79	0.64	80.59
	110	0.18	2.18	0.61	0.38	62.22
	160	0.09	1.85	0.51	0.34	67.16
65-300Hz PWR HARM	10	0.07	18.34	3.45	3.34	96.74
	60	0.14	4.67	1.02	0.85	83.07
	110	0.09	2.73	0.74	0.50	67.91
	160	0.14	2.45	0.62	0.42	67.36
305-2560Hz HIGH FREQ	10	0.08	4.70	1.13	0.90	79.92
	60	0.04	1.23	0.38	0.26	69.21
	110	0.04	0.86	0.27	0.18	68.47
	160	0.03	0.74	0.24	0.16	65.72
5-2560Hz ALL FREQ	10	0.44	68.36	15.27	15.77	103.22
	60	0.26	24.41	5.15	4.71	91.39
	110	0.22	16.71	3.74	3.17	84.70
	160	0.26	13.14	3.08	2.50	81.21

TABLE 3-8.

SUMMARY STATISTICS FOR MAGNETIC FIELD LEVELS
MEASURED IN A GREEN LINE CAR (CHOPPER CONTROL)

PASSENGER AREAS IN CHOPPER CONTROL CARS					TOTAL OF 55 SAMPLES	
FREQUENCY BAND	HEIGHT ABOVE FLOOR (cm)	MINIMUM MAGNETIC FIELD (mG)	MAXIMUM MAGNETIC FIELD (mG)	AVERAGE MAGNETIC FIELD (mG)	STANDARD DEVIATION (mG)	COEFFICIENT OF VARIATION (%)
STATIC	10	239.56	1571.43	792.80	301.10	37.98
	60	138.52	1180.30	576.21	227.04	39.40
	110	74.73	1090.78	459.74	233.79	50.85
	160	145.45	1190.86	470.22	253.55	53.92
5-45Hz LOW FREQ	10	0.99	19.62	4.82	3.28	68.06
	60	0.78	7.19	2.95	1.33	45.13
	110	0.75	6.86	2.42	1.17	48.15
	160	0.84	7.00	2.57	1.38	53.52
50-60Hz PWR FREQ	10	0.23	2.92	1.36	0.59	43.15
	60	0.28	2.40	0.93	0.42	44.72
	110	0.26	1.52	0.68	0.27	39.69
	160	0.26	2.25	0.79	0.43	54.29
65-300Hz PWR HARM	10	0.14	5.95	2.13	1.31	61.32
	60	0.11	2.93	1.15	0.68	58.77
	110	0.13	2.64	0.96	0.65	67.56
	160	0.13	3.26	1.18	0.88	74.51
305-2560Hz HIGH FREQ	10	0.24	2.64	1.18	0.71	60.17
	60	0.21	2.58	0.91	0.82	90.90
	110	0.15	2.27	0.76	0.75	97.87
	160	0.12	2.49	0.86	0.84	97.29
5-2560Hz ALL FREQ	10	1.68	20.16	5.84	3.18	54.49
	60	1.20	7.79	3.57	1.41	39.57
	110	1.00	6.95	2.93	1.27	43.35
	160	1.12	7.42	3.24	1.56	48.25

the car. However, all of the cars produce occasional static fields twice or more the normal earth field level of 550 mG.

3.6.3 Subway Cars Collectively

A statistical summary of the magnetic field levels found in the passenger areas of MBTA system subway cars without regard to type (pooled data from all four lines) is provided in Table 3-9.

3.6.4 Mattapan High Speed Trolley

The magnitudes of the static and time varying magnetic fields in the center of a Mattapan High Speed Trolley are summarized in Table 3-10. Even though this measurement location was in the vicinity of the point where the trolley arm attached to the top of the car, the largest static and time varying magnetic fields are found near the floor. This again points to the importance of field sources such as various traction and power control circuits and the associated wiring beneath the car. With the exception of the high static field near the floor of the Trolley at this measurement location, the average magnetic field levels in the Trolley have the same general characteristics and range of intensities as those seen in the subway cars.

3.6.5 Trolley Bus

The Trolley Bus is a dc powered, cam controlled transportation vehicle, as are all of the other MBTA system vehicles investigated, but it has a number of unique characteristics which might be important from a magnetic field point of view. Principal among these are that the 600 volt dc supply and the return conductors are located side by side as overhead catenaries. Their close proximity causes the opposing currents in the two wires to produce magnetic fields which to a large extent cancel one another. Similarly, the twin trolley arms and presumably parallel wiring of the supply and return power cables in the bus reduce the effectiveness of those components to produce magnetic fields. Furthermore, since there is only one traction motor driving the rear axle of the bus, power cabling need not run the length of the vehicle to accommodate motors on front and rear trucks. Although these features combined to produce low magnetic fields throughout the Trolley bus, somewhat higher fields were found at a measurement point approximately four feet behind the back axle of the bus. That was reportedly the approximate location of the motor. Magnetic field levels measured at four heights above the floor at that location are summarized in Table 3-11.

It is interesting to note a few characteristics of the magnetic fields within the trolley bus from Figure 3-11 other than their low magnitudes. First of all, the average static magnetic field is well below the normal geomagnetic field level of 500 mG. Since

TABLE 3-9.

SUMMARY STATISTICS FOR MAGNETIC FIELD LEVELS MEASURED IN ORANGE, BLUE, RED AND GREEN LINE CARS

PASSENGER AREAS IN SUBWAY CARS					TOTAL OF 144 SAMPLES	
FREQUENCY BAND	HEIGHT ABOVE FLOOR (cm)	MINIMUM MAGNETIC FIELD (mG)	MAXIMUM MAGNETIC FIELD (mG)	AVERAGE MAGNETIC FIELD (mG)	STANDARD DEVIATION (mG)	COEFFICIENT OF VARIATION (%)
STATIC	10	235.74	1981.24	765.75	321.35	41.97
	60	62.33	1446.00	507.38	230.56	45.44
	110	11.82	1360.97	429.79	217.19	50.53
	160	71.55	1473.08	433.00	226.46	52.30
5-45Hz LOW FREQ	10	0.31	66.00	10.79	13.03	120.78
	60	0.16	24.36	4.17	3.85	92.19
	110	0.07	16.65	3.12	2.64	84.53
	160	0.18	13.06	2.80	2.12	75.82
50-60Hz PWR FREQ	10	0.17	14.65	2.10	2.21	105.10
	60	0.07	3.56	0.84	0.57	67.00
	110	0.18	2.18	0.64	0.34	53.80
	160	0.09	2.25	0.62	0.40	64.99
65-300Hz PWR HARM	10	0.07	18.34	2.95	2.81	95.44
	60	0.11	4.67	1.07	0.79	73.52
	110	0.09	2.73	0.82	0.57	69.35
	160	0.13	3.26	0.83	0.69	82.23
305-2560Hz HIGH FREQ	10	0.08	4.70	1.15	0.83	72.44
	60	0.04	2.58	0.58	0.60	104.25
	110	0.04	2.27	0.46	0.54	118.19
	160	0.03	2.49	0.48	0.61	128.59
5-2560Hz ALL FREQ	10	0.44	68.36	11.67	13.34	114.28
	60	0.26	24.41	4.55	3.87	85.15
	110	0.22	16.71	3.43	2.64	76.77
	160	0.26	13.14	3.14	2.19	69.62

TABLE 3-10.

SUMMARY STATISTICS FOR MAGNETIC FIELD LEVELS MEASURED IN THE MATTAPAN HIGH SPEED TROLLEY

BOS032 - IN CENTER OF HIGH SPEED TROLLEY					TOTAL OF 14 SAMPLES	
FREQUENCY BAND	HEIGHT ABOVE FLOOR (cm)	MINIMUM MAGNETIC FIELD (mG)	MAXIMUM MAGNETIC FIELD (mG)	AVERAGE MAGNETIC FIELD (mG)	STANDARD DEVIATION (mG)	COEFFICIENT OF VARIATION (%)
STATIC	10	620.25	3074.28	1501.55	760.32	50.64
	60	412.95	774.53	516.87	93.79	18.15
	110	339.73	555.80	411.93	55.20	13.40
	160	331.12	563.78	446.00	70.29	15.76
5-45Hz LOW FREQ	10	2.56	25.61	9.67	7.34	75.94
	60	0.83	11.32	3.06	2.83	92.53
	110	0.60	7.17	2.13	1.71	80.15
	160	0.60	4.59	1.68	1.11	66.00
50-60Hz PWR FREQ	10	0.30	4.75	1.29	1.17	90.74
	60	0.14	3.93	0.64	0.99	155.75
	110	0.14	4.10	0.62	1.03	166.87
	160	0.08	3.66	0.53	0.95	178.35
65-300Hz PWR HARM	10	0.33	3.68	1.63	1.02	62.55
	60	0.14	1.93	0.50	0.47	92.83
	110	0.13	1.18	0.39	0.26	67.25
	160	0.17	0.87	0.35	0.18	51.36
305-2560Hz HIGH FREQ	10	0.29	1.84	0.70	0.47	67.17
	60	0.07	1.02	0.25	0.25	98.75
	110	0.06	0.63	0.17	0.15	83.95
	160	0.05	0.43	0.14	0.10	67.29
5-2560Hz ALL FREQ	10	3.32	26.03	10.09	7.25	71.85
	60	1.04	11.60	3.37	2.82	83.86
	110	1.00	7.33	2.48	1.72	69.50
	160	0.67	4.72	2.00	1.16	57.98

TABLE 3-11.

SUMMARY STATISTICS FOR MAGNETIC FIELD LEVELS MEASURED
IN THE AISLE OF A TROLLEY BUS AT A POINT
APPROXIMATELY 1.2 m (4 ft) BEHIND THE BACK AXLE

BOS043 - ON AXIS AT REAR OF TROLLEY BUS					TOTAL OF 31 SAMPLES	
FREQUENCY BAND	HEIGHT ABOVE FLOOR (cm)	MINIMUM MAGNETIC FIELD (mG)	MAXIMUM MAGNETIC FIELD (mG)	AVERAGE MAGNETIC FIELD (mG)	STANDARD DEVIATION (mG)	COEFFICIENT OF VARIATION (%)
STATIC	10	289.60	467.28	365.81	58.81	16.08
	60	191.70	338.98	247.53	51.31	20.73
	110	210.39	323.55	252.01	41.86	16.61
	160	182.22	304.48	227.33	44.54	19.59
5-45Hz LOW FREQ	10	0.30	12.85	3.54	2.89	81.63
	60	0.32	6.64	1.70	1.57	92.67
	110	0.10	4.54	0.77	0.82	107.09
	160	0.28	3.22	0.68	0.55	80.73
50-60Hz PWR FREQ	10	0.48	2.84	1.40	0.68	48.84
	60	0.44	6.47	1.77	1.32	74.51
	110	0.57	2.98	1.52	0.74	48.86
	160	0.57	3.82	1.83	0.96	52.54
65-300Hz PWR HARM	10	0.34	3.37	1.64	1.12	68.12
	60	0.33	2.05	0.72	0.50	68.74
	110	0.16	0.83	0.56	0.16	29.06
	160	0.28	0.45	0.35	0.04	12.79
305-2560Hz HIGH FREQ	10	0.44	9.25	3.41	3.25	95.05
	60	0.33	4.72	1.13	1.07	95.30
	110	0.19	0.73	0.39	0.17	42.41
	160	0.19	0.47	0.29	0.07	25.60
5-2560Hz ALL FREQ	10	0.96	13.24	5.88	3.83	65.14
	60	0.93	7.59	3.03	2.05	67.76
	110	0.88	4.64	1.97	0.88	44.83
	160	0.82	3.86	2.08	0.93	44.56

there is relatively little temporal variability of the static field as evidenced by its low coefficient of variability, one would conclude that the reduced static field is the result of passive shielding by what is apparently a ferromagnetic body on the bus.

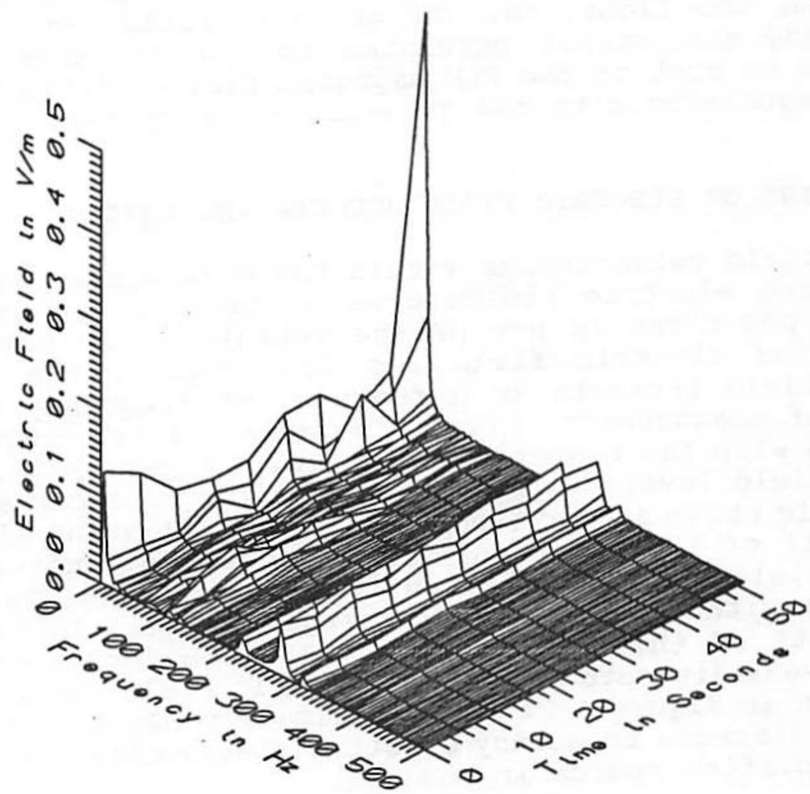
Secondly, the time varying magnetic field at all frequencies except the power frequency band attenuates with increasing height above the floor, consistent with the earlier observation that either the motor or the associated wiring at this location was the principal field source. But the power frequency field shows a moderate increase in strength with increasing height above the floor. The frequency and attenuation pattern strongly indicates that this power frequency component of the magnetic field in the trolley bus comes from commercial electric power distribution lines on poles along the street, not from the trolley bus itself. Referring again to Table 3-11, one recognizes that except at the 10 cm measurement height near the floor, the ELF magnetic fields from distribution lines along the street unrelated to the transportation system contribute as much to the ELF magnetic fields within the bus as do sources associated with the transportation system.

3.7 SUMMARY OF ELECTRIC FIELD SOURCES AND LEVELS

Electric field measurements within the MBTA system did not detect time varying electric fields greater than 10 V/m in any of the measuring positions in any of the vehicles. In most cases, the time varying electric field was less than 1 V/m. Graphs of electric field strength as a function of frequency and time for each set of measurements listed in Table 3-1 are contained in the appendices with the magnetic field data. Figure 3-22, which shows electric field levels in the rear of a Blue Line car at the center of the aisle above a rear truck is representative of electric field data in all of the vehicles. The largest components of the ELF electric field are the very low frequency components which arise from people with static electric charge on their clothing moving in the vicinity of the field sensor. At some locations, there are also very weak discrete frequency electric field components such as those shown in Figure 3-22 at approximately 220 Hz, 280 Hz and 315 Hz. These discrete frequency electric fields apparently arise from some unidentified source in the car.

Extremely small electric fields such as those measured within the transit vehicles are expected because ULF and ELF electric fields are effectively attenuated by conductive barriers such as the metallic bodies of the vehicles. Consequently, significant electric fields from external sources such as the commercial power system were not expected to be present inside the vehicles.

The displacement current measurement approach employed for the electric field measurements within the vehicles does not respond to static fields such as those produced by the static voltage on the catenary or third rail. Nevertheless, electric fields produced by the voltage on those objects will not penetrate the conductive vehicles bodies. Therefore, even though static electric field levels could not be measured, it is highly unlikely that any exist within the cars aside from those produced by static charges on passengers and their clothing.



BOS017 - ELECTRIC FIELD 170cm ABOVE AXIS OF BLUE LINE CAR, AT REAR DOORS

FIGURE 3-22. TIME VARYING ELECTRIC FIELD IN A BLUE LINE CAR AS A FUNCTION OF FREQUENCY AND TIME MEASURED AT THE CENTER OF THE AISLE OVER THE REAR TRUCK

4. OPERATOR'S COMPARTMENT MEASUREMENTS

The operator's compartment in the MBTA system Orange, Blue and Red Line cars is a small compartment at the end of each car. In the Green Line cars, the High Speed Trolley and the Trolley Bus, the operator does not have a compartment separate from the passenger area. Consequently, all of the possible sources of magnetic field discussed in Section 3 for the passenger section of the vehicle are also possible sources of field for the operator's compartment. In addition, the various control equipment within the compartment or near the operator's seat represent a unique potential source applying to the operator's area only. Therefore, magnetic field measurements were made in the operator's compartment or at the operator's seat to determine if the field environment was different in that area and to quantify the field environment at the operator's workplace.

4.1 MEASUREMENT LOCATIONS

The general layout of the MBTA system vehicles is shown in Figures 3-1 and 3-2. The numbered measurement locations are keyed to datasets in Tables 2-1 and 2-2 and to the data in the corresponding appendices. Measurements in the passenger sections of the vehicles were reported in the preceding section. This section reports the results of measurements made in the operator's areas.

Magnetic fields were measured along a vertical profile at the operator's workplace by positioning the sensor staff vertically at either the center of the front edge of the operator's seat or against a rear corner of the seat. As indicated in Figure 3-1, these measurements were made in unoccupied operator's positions at or near the end of multi-car trains in order to avoid interruption of the operator. The magnetic field measurements were made in front of the operator's seat in the Orange, Blue, Red and Green line cars (Locations 4, 6, and 14 on Figure 3-1). Additional measurements were made at the operator's left shoulder position in the Blue Line car (Position 3 of Figure 3-1).

The Mattapan High Speed Trolley and the Trolley Bus are single-car vehicles with no vacant operator's positions. Consequently, magnetic field measurements were made at the right rear corner of the operator's seat next to his shoulder (Positions 15 and 22 on Figure 3-2). This position was as close to the operator's equipment and controls as possible, where measurements could be made without interfering with the operator's duties.

All of the measurements in the operator's areas were made on June 10 and 11, 1992 along with the field measurements in the passenger areas. Neither DAT nor personal exposure monitor measurements were made in the operator's areas. In most cases, DAT measurements were made concurrently in an area of the passenger compartment at the reference sensor location nearest the operator's area.

Furthermore, personal magnetic field exposure monitors were worn by test personnel working in the adjacent passenger areas while measurements were underway in the operator's area. The DAT and rms recorder data collected during these times have been reported in Section 3 above.

4.2 REPETITIVE WAVEFORM DATASETS

There are twelve repetitive waveform datasets quantifying magnetic field characteristics within the operator's areas of the six types of MBTA system vehicles examined in this measurement program. They are identified in Table 3-1 by dataset number and sensor location number keyed to Figures 3-1 and 3-2. All of these datasets represent vertical profile measurements at distances of 10, 60, 110, and 160 cm above the floor. Complete plots of field versus frequency over time, and field versus distance over time, are found in the appendices as indicated in Table 2-1. The appendices also contain notes about train, trolley or bus operating conditions, locations and, where pertinent, the presence of external field sources such as power lines or substations.

4.3 MAGNETIC FIELD CHARACTERISTICS

Magnetic field measurements in the operator's areas demonstrated that the fields within those areas were similar in all characteristics to those measured at the rear of the passenger compartments of the vehicles. Neither the frequency, spatial, nor temporal characteristics of the measured fields suggested significant contributions from sources unique to the operator's compartment. Therefore, the description of magnetic field characteristics in the passenger areas of the vehicles, provided in Section 3 above, applies to the operator's area as well. Graphs of magnetic field versus frequency and time, and graphs of magnetic field versus height above the floor and time for the operator's compartment are found in Appendices P, Q, S, T, U, AB, AE, AF, AP, AQ and AU.

4.4 DAT WAVEFORM DATA

Magnetic field data from the reference probe of the repetitive waveform recording system located in the passenger area of the transit vehicle near the operator's area was recorded continuously with a DAT recorder, as described in Section 2.5. Pertinent information about the time and duration of these measurements is contained in Table 2-2. Those recordings were analyzed and reported in Section 3.4 above.

4.5 RMS RECORDER DATA

Because of the small size of the operator's compartment of the subway cars, it was impractical to have a rms recorder-wearer in the compartment with the other measurement sensors. Therefore, they stood in the general vicinity of the compartment door while the operator's area measurements were in progress. Similarly, the rms recorder wearers stood near the operators of the High Speed Trolley and Trolley Bus. The data recorded with the rms recorders during the operator's compartment tests are included with other passenger compartment data in Table 3-3.

4.6 SUMMARY OF MAGNETIC FIELD LEVELS

As discussed in the preceding subsections, the predominant magnetic field sources in the passenger areas of the Boston MBTA transit system vehicles appear to be traction power control equipment beneath the floor of the vehicles and also possibly current in the loop created by the third rail or catenary and track return circuit. Consequently, tabulations of magnetic field level provided in the operator's area give field values at various heights above the floor. These fields are predominantly static with low frequency time varying components resulting from fluctuations in the static field level.

4.6.1 Orange, Blue and Green Line Cars

Tables 4-1 through 4-3 summarize the magnetic field levels measured with the repetitive waveform technique in front of the operator's seat of the Orange, Blue and Red Line cars, respectively. Each table shows the minimum, maximum and average field levels, as well as the standard deviation and the coefficient of variation for the repetitive waveform datasets listed in the title heading. Each table provides the statistics at four heights above the floor for the static field, the total time varying field in the frequency range from 5 Hz to 2560 Hz, and the time varying field in various smaller frequency bands. Table 4-2 shows higher static field levels at the front of the Blue Line car operator's seat than was seen in the passenger's compartment, but that anomaly is believed to result from the relatively small dataset, not a specific characteristic of the measurement location. Similarly high static field levels were not found in front of the Orange Line operator's seat. Table 4-4 shows a summary of more extensive measurements made at the left rear corner of the operator's seat in the Blue Line car. It demonstrates magnetic field intensities and field spatial and frequency distributions more nearly similar to those seen in the passenger's compartment supporting the conclusion that the atypically high field levels measured in front of the Blue Line car's operator's seat reported in Table 4-2 are not a representative characteristic of that operator's compartment.

4.6.2 Green Line

The magnetic field levels measured at the front edge of the operator's seat in a Boeing Green Line car, pooled from datasets BOS041 and BOS042, are summarized in Table 4-5.

TABLE 4-1.

SUMMARY STATISTICS FOR MAGNETIC FIELD LEVELS MEASURED IN FRONT OF THE OPERATOR'S SEAT OF AN ORANGE LINE CAR

BOS020 - IN FRONT OF OPERATOR'S SEAT, ORANGE LINE					TOTAL OF 26 SAMPLES	
FREQUENCY BAND	HEIGHT ABOVE FLOOR (cm)	MINIMUM MAGNETIC FIELD (mG)	MAXIMUM MAGNETIC FIELD (mG)	AVERAGE MAGNETIC FIELD (mG)	STANDARD DEVIATION (mG)	COEFFICIENT OF VARIATION (%)
STATIC	10	357.57	1585.74	671.86	241.36	35.92
	60	257.48	1141.57	465.01	184.53	39.68
	110	205.39	902.34	393.60	163.04	41.42
	160	109.55	752.56	321.91	169.15	52.55
5-45Hz LOW FREQ	10	1.21	34.00	9.14	7.24	79.25
	60	0.56	23.84	4.46	4.70	105.36
	110	0.61	15.94	3.71	3.25	87.54
	160	0.65	17.89	3.54	3.47	98.08
50-60Hz PWR FREQ	10	0.51	4.21	1.46	1.07	73.19
	60	0.20	1.67	0.59	0.34	58.42
	110	0.28	1.23	0.55	0.22	40.25
	160	0.31	1.07	0.59	0.25	43.10
65-300Hz PWR HARM	10	0.28	8.52	2.44	2.18	89.42
	60	0.14	2.46	0.77	0.60	78.63
	110	0.23	2.23	0.70	0.52	73.90
	160	0.33	1.73	0.68	0.38	56.04
305-2560Hz HIGH FREQ	10	0.26	2.71	0.96	0.61	63.57
	60	0.17	1.16	0.37	0.21	56.49
	110	0.14	0.88	0.32	0.19	59.26
	160	0.14	0.75	0.31	0.17	53.93
5-2560Hz ALL FREQ	10	1.39	35.06	9.73	7.52	77.29
	60	0.72	24.06	4.62	4.71	101.83
	110	0.90	16.07	3.87	3.25	84.09
	160	1.07	18.00	3.72	3.44	92.48

TABLE 4-2.

SUMMARY STATISTICS FOR MAGNETIC FIELD LEVELS MEASURED IN FRONT OF THE OPERATOR'S SEAT OF A BLUE LINE CAR

BOS018 - IN FRONT OF OPERATOR'S SEAT, BLUE LINE CAR					TOTAL OF 14 SAMPLES	
FREQUENCY BAND	HEIGHT ABOVE FLOOR (cm)	MINIMUM MAGNETIC FIELD (mG)	MAXIMUM MAGNETIC FIELD (mG)	AVERAGE MAGNETIC FIELD (mG)	STANDARD DEVIATION (mG)	COEFFICIENT OF VARIATION (%)
STATIC	10	454.46	1837.45	1080.00	320.95	29.72
	60	557.65	2056.81	1187.23	342.82	28.88
	110	597.69	2066.26	1158.68	340.75	29.41
	160	808.08	2211.41	1358.53	338.04	24.88
5-45Hz LOW FREQ	10	0.45	19.06	8.73	6.48	74.25
	60	0.36	11.06	4.84	3.78	78.21
	110	0.23	21.07	4.86	5.52	113.56
	160	0.33	21.90	4.92	5.67	115.44
50-60Hz PWR FREQ	10	0.22	4.08	1.56	1.13	72.14
	60	0.14	2.15	0.86	0.62	71.80
	110	0.28	1.16	0.69	0.30	43.01
	160	0.10	1.42	0.60	0.41	68.12
65-300Hz PWR HARM	10	0.18	6.23	2.48	1.89	76.16
	60	0.25	2.65	1.20	0.76	63.54
	110	0.19	1.88	0.91	0.52	56.79
	160	0.24	1.69	0.86	0.52	60.56
305-2560Hz HIGH FREQ	10	0.24	2.59	1.10	0.83	74.81
	60	0.32	1.15	0.66	0.32	48.60
	110	0.25	1.24	0.56	0.29	51.37
	160	0.17	1.40	0.52	0.38	74.23
5-2560Hz ALL FREQ	10	0.60	19.32	9.35	6.79	72.60
	60	0.56	11.21	5.19	3.80	73.35
	110	0.48	21.11	5.11	5.47	107.04
	160	0.47	21.97	5.10	5.68	111.35

TABLE 4-3.

SUMMARY STATISTICS FOR MAGNETIC FIELD LEVELS MEASURED IN FRONT OF THE OPERATOR'S SEAT OF A RED LINE CAR

BOS027 - IN FRONT OF OPERATOR'S SEAT, RED LINE CAR					TOTAL OF 15 SAMPLES	
FREQUENCY BAND	HEIGHT ABOVE FLOOR (cm)	MINIMUM MAGNETIC FIELD (mG)	MAXIMUM MAGNETIC FIELD (mG)	AVERAGE MAGNETIC FIELD (mG)	STANDARD DEVIATION (mG)	COEFFICIENT OF VARIATION (%)
STATIC	10	174.80	640.39	418.71	131.06	31.30
	60	172.59	604.31	342.66	135.30	39.48
	110	133.10	520.89	378.19	99.18	26.22
	160	207.57	589.94	452.18	105.85	23.41
5-45Hz LOW FREQ	10	0.26	13.62	4.82	3.52	73.08
	60	0.17	6.57	2.12	1.97	92.59
	110	0.12	6.90	2.29	2.03	88.58
	160	0.28	5.05	1.91	1.55	81.28
50-60Hz PWR FREQ	10	0.23	1.61	0.85	0.39	45.48
	60	0.08	0.97	0.34	0.31	90.51
	110	0.19	1.06	0.46	0.31	68.16
	160	0.14	0.88	0.35	0.26	72.23
65-300Hz PWR HARM	10	0.11	2.82	1.26	0.69	54.74
	60	0.14	1.68	0.45	0.41	90.66
	110	0.23	1.55	0.56	0.35	62.93
	160	0.27	1.28	0.48	0.27	56.22
305-2560Hz HIGH FREQ	10	0.20	1.28	0.53	0.27	50.04
	60	0.09	0.81	0.24	0.19	77.29
	110	0.22	0.79	0.36	0.16	43.27
	160	0.29	0.69	0.40	0.11	26.78
5-2560Hz ALL FREQ	10	0.44	14.06	5.12	3.57	69.85
	60	0.28	6.71	2.22	2.03	91.21
	110	0.42	7.07	2.45	2.05	83.76
	160	0.56	5.25	2.07	1.56	75.68

TABLE 4-4.

SUMMARY STATISTICS FOR MAGNETIC FIELD LEVELS MEASURED AT THE LEFT REAR CORNER OF THE OPERATOR'S SEAT IN A BLUE LINE CAR

OPERATOR'S SHOULDER, BLUE LINE					TOTAL OF 95 SAMPLES	
FREQUENCY BAND	HEIGHT ABOVE FLOOR (cm)	MINIMUM MAGNETIC FIELD (mG)	MAXIMUM MAGNETIC FIELD (mG)	AVERAGE MAGNETIC FIELD (mG)	STANDARD DEVIATION (mG)	COEFFICIENT OF VARIATION (%)
STATIC	10	161.18	3078.42	977.62	491.59	50.28
	60	226.73	2220.04	775.90	340.39	43.87
	110	196.40	2029.19	799.08	297.51	37.23
	160	114.44	1939.80	845.43	330.50	39.09
5-45Hz LOW FREQ	10	0.45	45.38	9.16	8.18	89.27
	60	0.36	17.26	4.15	3.50	84.21
	110	0.22	17.42	2.80	2.89	103.33
	160	0.38	13.94	2.84	2.70	94.94
50-60Hz PWR FREQ	10	0.27	9.50	2.07	1.90	91.73
	60	0.25	3.92	0.98	0.83	84.41
	110	0.19	3.07	0.75	0.53	70.85
	160	0.15	2.71	0.80	0.51	63.15
65-300Hz PWR HARM	10	0.16	25.18	2.76	3.52	127.58
	60	0.19	8.01	1.05	1.14	108.24
	110	0.09	7.92	0.82	1.02	124.54
	160	0.19	6.35	0.77	0.83	108.89
305-2560Hz HIGH FREQ	10	0.21	5.27	0.96	0.88	91.70
	60	0.17	1.54	0.54	0.34	63.02
	110	0.14	2.08	0.66	0.40	60.31
	160	0.12	1.45	0.43	0.26	60.72
5-2560Hz ALL FREQ	10	0.66	52.86	9.98	9.00	90.21
	60	0.76	17.92	4.50	3.70	82.35
	110	0.37	19.49	3.18	3.03	95.41
	160	0.70	15.62	3.16	2.80	88.47

TABLE 4-5.

SUMMARY STATISTICS FOR MAGNETIC FIELD LEVELS MEASURED IN THE OPERATOR'S AREA IN A BOEING GREEN LINE CAR

OPERATOR'S AREA IN BOEING GREEN LINE CAR					TOTAL OF 35 SAMPLES	
FREQUENCY BAND	HEIGHT ABOVE FLOOR (cm)	MINIMUM MAGNETIC FIELD (mG)	MAXIMUM MAGNETIC FIELD (mG)	AVERAGE MAGNETIC FIELD (mG)	STANDARD DEVIATION (mG)	COEFFICIENT OF VARIATION (%)
STATIC	10	283.42	1515.55	679.71	212.92	31.33
	60	328.47	1553.20	621.46	192.00	30.89
	110	313.56	1709.49	599.03	224.29	37.44
	160	428.26	2067.94	698.39	265.14	37.96
5-45Hz LOW FREQ	10	0.24	7.29	2.55	1.73	67.71
	60	0.26	5.16	1.82	1.19	65.27
	110	0.30	6.20	1.81	1.28	70.95
	160	0.38	7.78	1.95	1.52	77.75
50-60Hz PWR FREQ	10	0.91	2.17	1.29	0.33	25.74
	60	0.60	2.02	1.11	0.29	25.77
	110	0.33	2.61	1.23	0.57	46.26
	160	1.13	9.28	3.28	2.49	75.84
65-300Hz PWR HARM	10	0.19	1.54	0.88	0.33	37.52
	60	0.13	1.61	0.79	0.29	36.80
	110	0.19	2.15	0.99	0.40	39.78
	160	0.62	3.22	1.64	0.76	46.30
305-2560Hz HIGH FREQ	10	0.28	1.72	1.20	0.49	40.75
	60	0.14	1.46	0.70	0.35	49.52
	110	0.10	1.94	0.99	0.52	52.55
	160	0.15	2.73	0.99	0.58	58.19
5-2560Hz ALL FREQ	10	1.90	7.52	3.43	1.41	41.04
	60	0.89	5.49	2.51	1.04	41.41
	110	0.64	6.57	2.77	1.19	42.86
	160	1.40	10.16	4.57	2.57	56.25

Although this car has semiconductor chopper control of its traction power, the time varying magnetic field level at the chopper frequency (218 Hz) is very small, due apparently to the effective smoothing reactors within the chopper control unit and the distance from the control unit to the operator's position. Aside from the power frequency (60 Hz) fields present at this measurement location, the frequency distribution of the magnetic field is similar to that seen in the cam controlled cars of the Orange, Blue and Red lines. The modestly elevated 60 Hz field level at the highest measurement location appears due to an onboard source, possibly a light above the operator's seat.

The static and time varying magnetic field levels show less vertical spatial variability at the Green Line operator's seat than was seen in most other onboard measurements. That is because the distance between the operator's seat and traction power and control equipment is large enough that the fields from that source are modest and come from a direction more toward the rear of the car than directly beneath the floor. Because of that distance and the relatively small fields from that source, the current in the catenary and track return circuit is a much more important contributor to the overall field environment than in most other datasets. Since the current in that circuit effectively produces a loop encircling the interior of the car, the resulting fields should be approximately uniform, but slightly higher nearest the catenary (160 cm location) and nearest the track (10 cm location). The average static field values reported in Table 4-5 reflect that pattern. A similar pattern is reflected in the time varying field levels in the high frequency band from 305 to 2560 Hz which arise primarily from 360 Hz and 720 Hz rectifier ripple in the dc current of the catenary and track circuit.

4.6.3 All Subway Cars

Since there were no fundamental differences in the frequency distributions or temporal patterns of the magnetic fields measured at the operator's seats in the Orange, Blue, Red and Green line cars, the data from measurements on all four lines were pooled to provide a summary of the characteristics of the subway system as a whole. The field values for the pooled data are summarized in Table 4-6.

4.6.4 Mattapan High Speed Trolley

The magnetic field levels measured at the right rear corner of the driver's seat in the Mattapan High Speed Trolley are summarized in Table 4-7. They have essentially the same characteristics as the magnetic fields elsewhere in the trolley which were described in detail in Section 3.

TABLE 4-6.

SUMMARY STATISTICS FOR MAGNETIC FIELD LEVELS MEASURED IN THE OPERATOR'S AREA OF MBTA SUBWAY CARS

OPERATOR'S POSITION IN SUBWAY CARS					TOTAL OF 185 SAMPLES	
FREQUENCY BAND	HEIGHT ABOVE FLOOR (cm)	MINIMUM MAGNETIC FIELD (mG)	MAXIMUM MAGNETIC FIELD (mG)	AVERAGE MAGNETIC FIELD (mG)	STANDARD DEVIATION (mG)	COEFFICIENT OF VARIATION (%)
STATIC	10	161.18	3078.42	840.72	431.10	51.28
	60	172.59	2220.04	698.99	347.49	49.71
	110	133.10	2066.26	697.33	334.35	47.95
	160	109.55	2211.41	750.98	384.86	51.25
5-45Hz LOW FREQ	10	0.24	45.38	7.52	7.28	96.71
	60	0.17	23.84	3.64	3.46	95.00
	110	0.12	21.07	2.85	3.02	105.84
	160	0.28	21.90	2.85	2.98	104.33
50-60Hz PWR FREQ	10	0.22	9.50	1.70	1.51	89.02
	60	0.08	3.92	0.89	0.68	76.82
	110	0.19	3.07	0.78	0.53	67.44
	160	0.10	9.28	1.19	1.53	128.75
65-300Hz PWR HARM	10	0.11	25.18	2.22	2.81	126.63
	60	0.13	8.01	0.92	0.91	98.00
	110	0.09	7.92	0.82	0.80	97.20
	160	0.19	6.35	0.90	0.80	88.51
305-2560Hz HIGH FREQ	10	0.20	5.27	0.98	0.76	76.98
	60	0.09	1.54	0.53	0.34	63.61
	110	0.10	2.08	0.64	0.43	67.43
	160	0.12	2.73	0.52	0.41	77.83
5-2560Hz ALL FREQ	10	0.44	52.86	8.26	7.80	94.38
	60	0.28	24.06	4.01	3.54	88.35
	110	0.37	21.11	3.29	3.04	92.55
	160	0.47	21.97	3.56	3.15	88.42

TABLE 4-7.

SUMMARY STATISTICS FOR MAGNETIC FIELD LEVELS MEASURED AT THE RIGHT REAR CORNER OF THE OPERATOR'S SEAT IN THE MATTAPAN HIGH SPEED TROLLEY

BOS031 - AT OPERATOR'S RIGHT SHOULDER, TROLLEY					TOTAL OF 12 SAMPLES	
FREQUENCY BAND	HEIGHT ABOVE FLOOR (cm)	MINIMUM MAGNETIC FIELD (mG)	MAXIMUM MAGNETIC FIELD (mG)	AVERAGE MAGNETIC FIELD (mG)	STANDARD DEVIATION (mG)	COEFFICIENT OF VARIATION (%)
STATIC	10	542.67	737.57	631.44	54.68	8.66
	60	197.33	651.35	457.33	128.72	28.15
	110	70.08	385.45	147.19	90.10	61.22
	160	75.69	411.39	173.87	85.59	49.23
5-45Hz LOW FREQ	10	0.31	11.29	4.96	3.05	61.41
	60	0.26	3.69	2.02	1.09	53.94
	110	0.16	2.66	1.58	0.78	49.23
	160	0.48	2.27	1.29	0.49	38.04
50-60Hz PWR FREQ	10	0.22	1.06	0.55	0.23	42.31
	60	0.10	0.32	0.22	0.07	30.72
	110	0.27	0.51	0.40	0.07	16.83
	160	0.23	0.37	0.31	0.04	11.96
65-300Hz PWR HARM	10	0.04	1.77	0.78	0.44	56.46
	60	0.14	0.58	0.39	0.12	31.90
	110	0.35	0.67	0.48	0.09	19.17
	160	0.39	0.64	0.48	0.07	15.14
305-2560Hz HIGH FREQ	10	0.08	0.89	0.38	0.21	55.97
	60	0.08	0.30	0.20	0.06	31.65
	110	0.11	0.35	0.22	0.07	32.86
	160	0.11	0.69	0.44	0.19	42.64
5-2560Hz ALL FREQ	10	0.39	11.52	5.08	3.07	60.44
	60	0.32	3.73	2.09	1.08	51.71
	110	0.48	2.77	1.74	0.72	41.07
	160	0.73	2.38	1.50	0.45	30.13

4.6.5 Trolley Bus

The magnetic fields at the operator's seat in the Trolley Bus are very low, consisting almost entirely of the earth's geomagnetic field and a small 60 Hz field from power lines along the streets on which the Trolley Bus runs. The field values are summarized in Table 4-8.

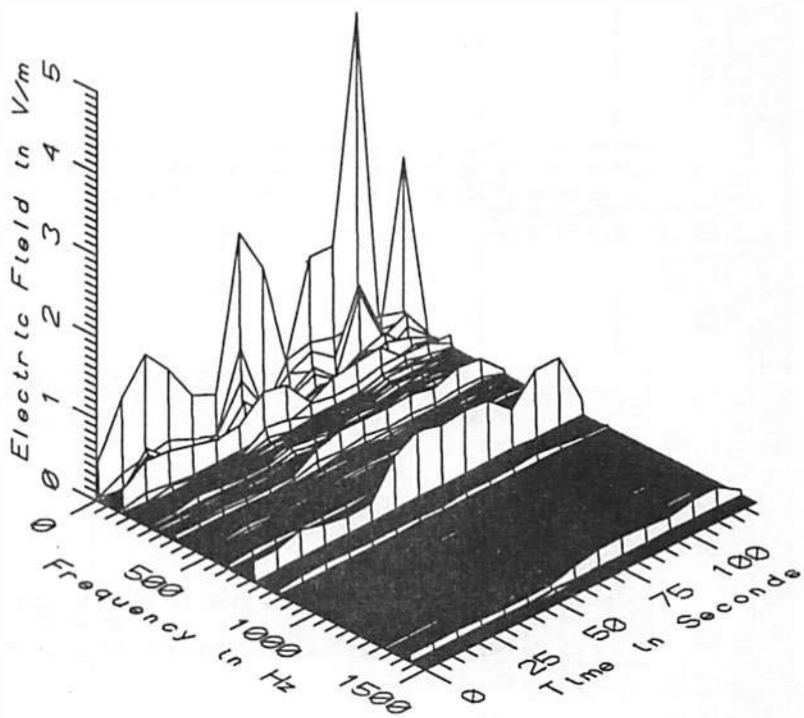
4.7 SUMMARY OF ELECTRIC FIELD SOURCES AND LEVELS

Significant levels of time varying electric fields (greater than 10 V/m) were not present within the operator's compartment of the Boston MBTA system vehicles. That is expected because electric fields are effectively attenuated by conductive barriers such as the metallic bodies of the vehicles and the fact that all of the electrical apparatus in the compartment was housed in metal enclosures. The largest electric fields were found in front of the operator's seat where, as shown in Figure 4-1, the low frequency field presumably from the nearby movement of people with static electric charge on their clothing or external field penetration through the windshield reached 4 V/m for one sample point. It is interesting to note, also in Figure 4-1, that small electric field levels of a volt per meter or less were also detected at 120 Hz, 360 Hz, 720 Hz and 1440 Hz, the ripple frequencies on the dc voltage of the third rail. Since the electric field was measured at only one location, it can not be determined if this small electric field arises from an unshielded source within the operator's compartment or represents a small amount of penetration through the windshield of the external electric field produced by the energized third rail.

TABLE 4-8.

SUMMARY STATISTICS FOR MAGNETIC FIELD LEVELS MEASURED AT THE RIGHT REAR CORNER OF THE OPERATOR'S SEAT ON THE TROLLEY BUS

BOS046 - AT OPERATOR'S RIGHT SHOULDER, TROLLEY BUS					TOTAL OF 25 SAMPLES	
FREQUENCY BAND	HEIGHT ABOVE FLOOR (cm)	MINIMUM MAGNETIC FIELD (mG)	MAXIMUM MAGNETIC FIELD (mG)	AVERAGE MAGNETIC FIELD (mG)	STANDARD DEVIATION (mG)	COEFFICIENT OF VARIATION (%)
STATIC	10	293.83	407.60	384.36	22.54	5.87
	60	320.46	441.97	352.55	21.16	6.00
	110	452.35	654.01	491.74	36.38	7.40
	160	502.31	705.51	540.82	38.11	7.05
5-45Hz LOW FREQ	10	0.11	1.35	0.63	0.34	54.31
	60	0.22	1.19	0.57	0.25	44.42
	110	0.10	1.22	0.45	0.27	60.47
	160	0.23	1.15	0.54	0.27	51.10
50-60Hz PWR FREQ	10	0.46	2.33	1.12	0.49	43.43
	60	0.33	2.66	1.16	0.57	49.21
	110	0.29	2.72	1.07	0.54	50.38
	160	0.23	3.49	1.25	0.69	55.29
65-300Hz PWR HARM	10	0.06	0.25	0.13	0.06	45.83
	60	0.17	0.28	0.20	0.03	17.01
	110	0.10	0.35	0.26	0.07	26.70
	160	0.16	0.31	0.21	0.04	17.07
305-2560Hz HIGH FREQ	10	0.06	0.16	0.09	0.03	31.27
	60	0.06	0.19	0.09	0.03	37.38
	110	0.06	0.20	0.09	0.04	46.32
	160	0.06	0.26	0.11	0.06	48.33
5-2560Hz ALL FREQ	10	0.55	2.48	1.34	0.46	34.42
	60	0.65	2.70	1.35	0.52	38.78
	110	0.60	2.74	1.24	0.50	39.90
	160	0.78	3.52	1.44	0.62	43.23



BOS027 - ELECTRIC FIELD IN FRONT OF OPERATOR'S SEAT, RED LINE CAR

FIGURE 4-1. ELECTRIC FIELD LEVEL AS A FUNCTION OF FREQUENCY AND TIME AT THE FRONT EDGE OF THE OPERATOR'S SEAT OF A RED LINE CAR

5. MEASUREMENTS ALONG THE WAYSIDE

Measurements along the wayside were conducted to determine the magnetic field in the vicinity of the Boston MBTA lines. The data in this section shows the contribution to the environmental field made by the Boston "T" System and the attenuation of the field with distance away from the tracks.

5.1 MEASUREMENT LOCATIONS

Measurements were made at three different wayside locations, exemplifying two distinctly different types of electrification. The wayside locations along the Blue and Green Lines are powered from a catenary with the rail tracks for the return current circuit. The wayside location along the Trolley Bus route is powered by supply and return catenaries, both overhead. Data was collected using the waveform data recording sensor staff and reference probe, and both rms and DAT recordings. The DAT recorder used magnetic field data from the reference probe as input and was physically located near the probe. As previously mentioned, the repetitive waveform recording staff has four probes located at distances of 10, 60, 110 and 160 cm along its length.

Figure 5-1 shows the layout and probe locations for all three sites. Measurements were made on the Blue Line outside a fence approximately 30.5 m (100 ft) from the Wood Island Station. This site was chosen so as to capture data from a catenary electrification section, and it is the Blue Line that runs on both types of electrification schemes. (Measurements were not taken along the Blue Line third rail sections because the third rail is used only in tunnels.) The staff was in a vertical position 4.6 m (15 ft) from the nearest track, with the reference probe located 4.6 m (15 ft) further away, 10 cm above the ground. Dataset BOS048, in Appendix AW, is the record of these measurements that were taken on June 11, 1992 from 13:45 to 13:47.

The same figure shows the schematic of the measurement location in the open space along the track of the Green Line, close to Beacon Street. This line is also powered by a catenary. The wayside was at a point just before an uphill grade on the track. The staff was placed vertically 4.6 m (15 ft) from the track. The reference probe was located at a distance of approximately 4.6 m (15 ft) from the staff, or 9.2 m (30 ft) from the track. Measurements were taken on June 11, 1992 from 13:21 to 13:22 and the results are included in Appendix AV, dataset BOS047.

The figure also shows the schematic of the measurement location on the sidewalk along the path of the Trolley Bus on Concord Avenue, in front of the Harvard Astrophysical Lab. Outbound Trolley Buses are closest to the measurement and are also going uphill. The staff was placed vertically on the sidewalk, 3.1 m (10 ft)

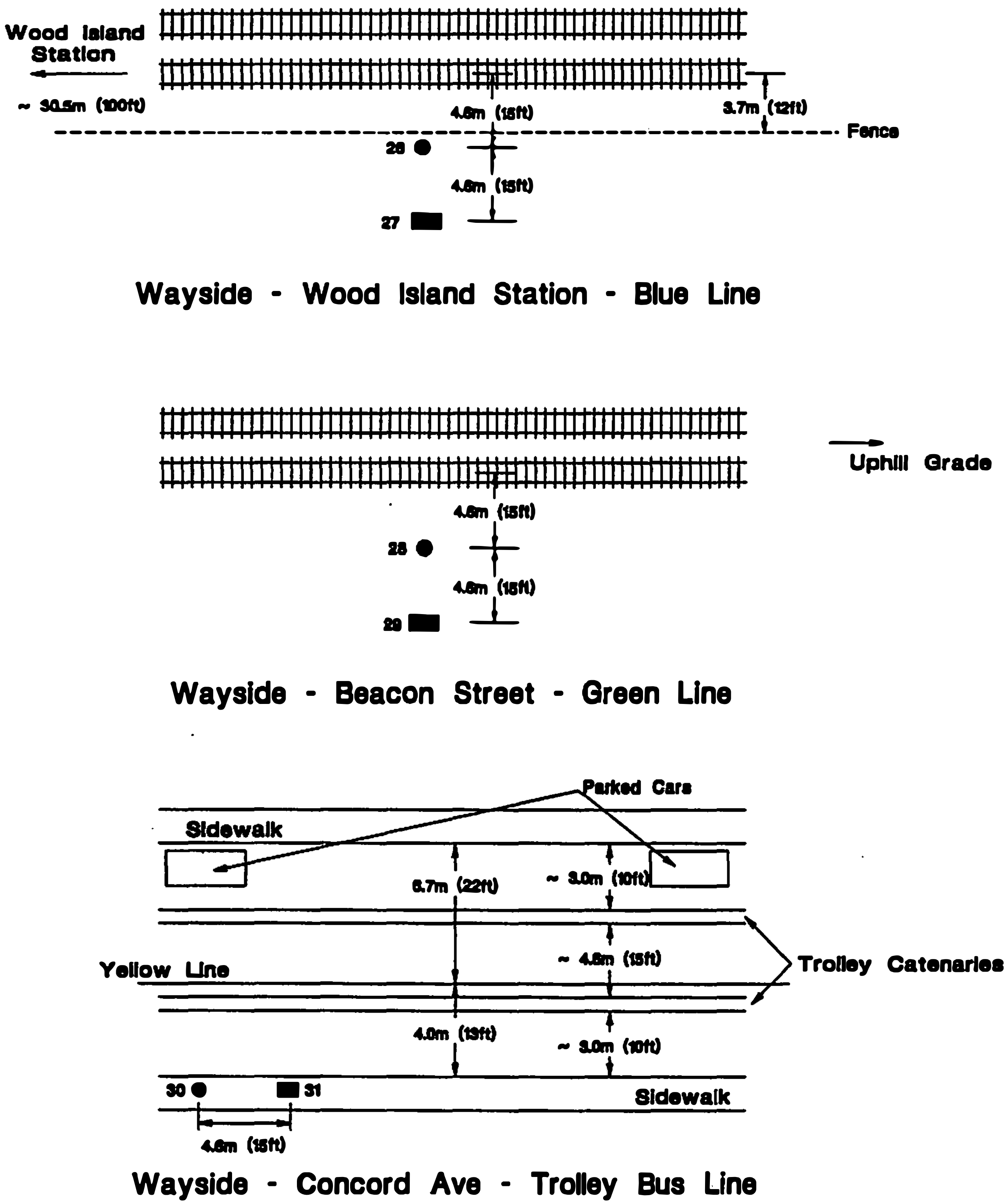


FIGURE 5-1. REPETITIVE WAVEFORM MEASUREMENT LOCATIONS AT WAYSIDE ON THE BLUE LINE (WOOD ISLAND STATION), THE GREEN LINE (BEACON STREET), AND THE TROLLEY BUS (CONCORD AVENUE)

horizontal distance from the trolley catenary overhead. The reference probe was located at a distance of approximately 4.6 m (15 ft) from the staff on the same sidewalk. Measurements were taken on June 9, 1992 from 14:31 to 14:49. The results are included in Appendices N and O, datasets BOS013 and BOS014, respectively.

5.2 REPETITIVE WAVEFORM DATASETS

The datasets that contain the information from the three locations described in Section 5.1 are BOS048, BOS047, BOS013 and BOS014 and correspond to the Blue Line, Green Line and Trolley Bus route. Table 5-1 repeats the pertinent summary information about these datasets, also shown in Table 2-1, including the number of samples and the appendix which contains the complete set of collected data. All datasets were taken at sample intervals of 5 seconds (12 per minute).

A train passed on the near side of the Blue Line tracks during the recording of dataset BOS048 next to the Wood Island Station. The train passed 25 seconds into the recording. The second listed dataset BOS047, at Beacon Street of the Green Line, began 43 seconds before a two car train passed on the near side. Two Trolley Buses passed while recording on the sidewalk on Concord Avenue; the first one, downhill on the far side (BOS013), and the second, uphill on the near side (dataset BOS014).

TABLE 5-1.

REPETITIVE MAGNETIC FIELD WAVEFORM DATASETS MEASURED ALONG THE WAYSIDE

DATA FILE NUMBER	DATE/TIME	FIG. # LOCAT'N	# OF SAMPLES & RATE	APPENDIX	REMARKS
BOS048	JUNE 11 13:45-13:47	5-1 26	16 5 SEC	AW	BLUE LINE TRAIN PASSED NEAR SIDE
BOS047	JUNE 11 13:21-13:22	5-1 28	14 5 SEC	AV	GREEN LINE TRAIN PASSED NEAR SIDE
BOS013	JUNE 9 14:31-14:33	5-1 30	25 5 SEC	N	TROLLEY BUS DESCENDING
BOS014	JUNE 9 14:48-14:49	5-1 30	15 5 SEC	O	TROLLEY BUS ASCENDING

5.3 MAGNETIC FIELD CHARACTERISTICS

The magnetic field at wayside locations includes contributions from natural sources (the geomagnetic field), the Boston MBTA System, and other man-made sources (primarily the electric power distribution system). The extent to which these sources contribute to the total field at the wayside is examined separately for the three measurement locations.

5.3.1 At Blue Line Wayside

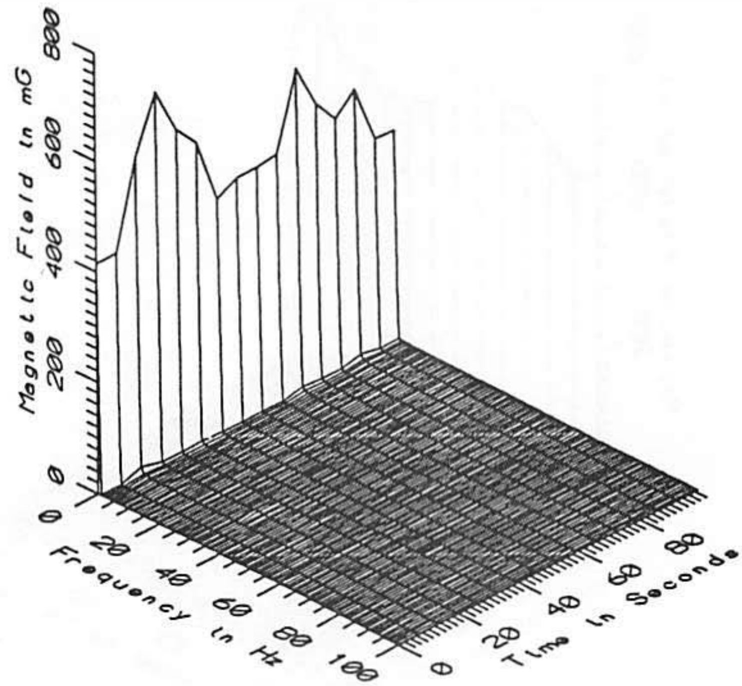
Figure 5-2 is the three-dimensional field plot from dataset BOS048 for the 110 cm height probe. The plot shows the rms magnetic flux density in mG versus frequency in Hz and time in seconds. The upper curve exhibits the static component and the lower plot suppresses it. The 60 Hz component and its even harmonics are clearly distinguishable for the entire time period. The even harmonics have a temporal variation in concert with the static component variation, but substantially different from the 60 Hz fundamental. These plots indicate that there are two principal sources of the time varying magnetic field. Current in the catenary-tracks loop gives rise to time varying field components, primarily rectifier ripple frequencies such as 120, 360 and 720 Hz. On the other hand, the 60 Hz fundamental shows little variation with time which indicates that the field source is current in a nearby commercial electric power distribution system. Magnetic fields from power systems are predominantly 60 Hz and the odd harmonics of 60 Hz.

Neither the static nor the time varying magnetic field components show any significant variation in field strength as a function of height above the ground.

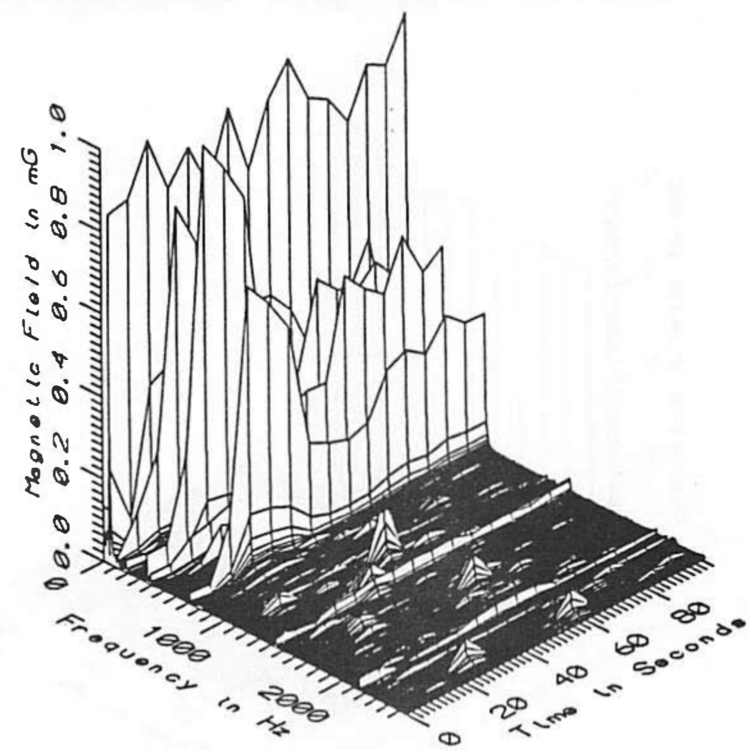
5.3.2 At Green Line Wayside

Figure 5-3 is the three-dimensional plot of the magnetic field versus frequency and time for dataset BOS047 at the probe location 110 cm above ground. The most prominent component present is the 60 Hz fundamental. The even harmonics are also present, as in the case of the Blue Line, however at smaller magnitudes. There appears to be a field at approximately 220 Hz that has a different temporal variation pattern from the rest and the frequency does not match any multiple of 60. The frequency corresponds closely to the "K" cars 218 Hz chopper frequency. The static and time varying fields do not exhibit any related temporal variation, indicating that there are probably two sources for the field, current in the catenary-tracks loop and current in a nearby commercial electric power distribution system.

Neither the static nor the time varying magnetic field components show any significant variation in field strength as a function of height above the ground.

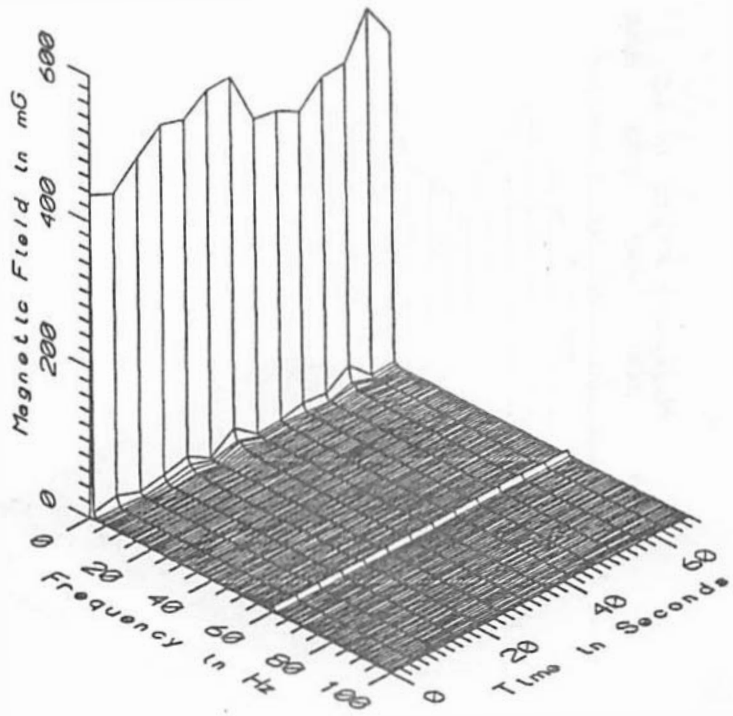


BOS048 - 110cm ABOVE GROUND. BLUE LINE WAYSIDE NEAR WOOD ISLAND STATION

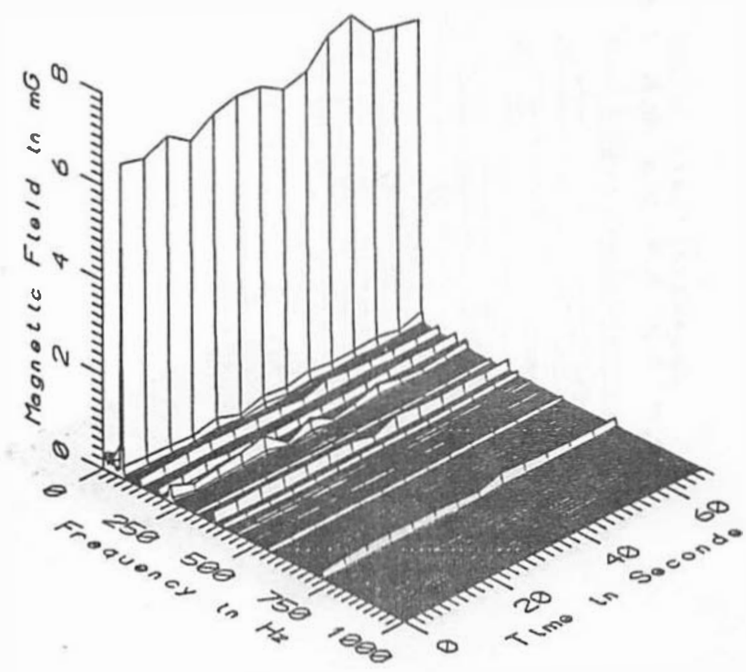


BOS048 - 110cm ABOVE GROUND. BLUE LINE WAYSIDE NEAR WOOD ISLAND STATION

FIGURE 5-2. MAGNETIC FIELD LEVEL, WITH AND WITHOUT THE STATIC COMPONENT, AT 110 cm HEIGHT ABOVE GROUND AT THE BLUE LINE WAYSIDE NEAR WOOD ISLAND STATION, AS A FUNCTION OF FREQUENCY AND TIME



BOS047 - 110cm ABOVE GROUND. GREEN LINE WAYSIDE AT BEACON STREET



BOS047 - 110cm ABOVE GROUND. GREEN LINE WAYSIDE AT BEACON STREET

FIGURE 5-3. MAGNETIC FIELD LEVEL, WITH AND WITHOUT THE STATIC COMPONENT, AT 110 cm HEIGHT ABOVE GROUND AT THE GREEN LINE WAYSIDE NEAR BEACON STREET, AS A FUNCTION OF FREQUENCY AND TIME

5.3.3 At Trolley Bus Wayside

Figure 5-4 is the three-dimensional plot of the magnetic field versus frequency and time for dataset BOS013 at the 110 cm height probe location on the sidewalk on Concord Avenue. The most prominent frequency is the 60 Hz fundamental. Its variation over time does not appear to correlate with the static variation, indicating that the main source is probably nearby power circuits. There are also even harmonics present that are very small, which are part of the rectification process of the Boston MBTA power supply. A 390 Hz component, not a 60 Hz harmonic, is also visible. Its origin is not known. Dataset BOS014 exhibits the same characteristics (see Appendix N). There appears to be very little effect on the field from any of the passing Trolley Buses.

Figure 5-5 is the plot of the power frequency components (50-60 Hz) as a function of height from the sidewalk over time. The power frequencies show a definite strengthening of the field closer to the sidewalk, which indicates a possible power underground cable.

5.4 DAT WAVEFORM DATA

Magnetic field data from the reference probe of the magnetic field repetitive waveform measuring system was recorded continuously with a digital audio tape recorder (as described in Section 2.5) at all three wayside locations. These recordings are identified with Tape, Group and Record numbers in Table 2-2 as follows:

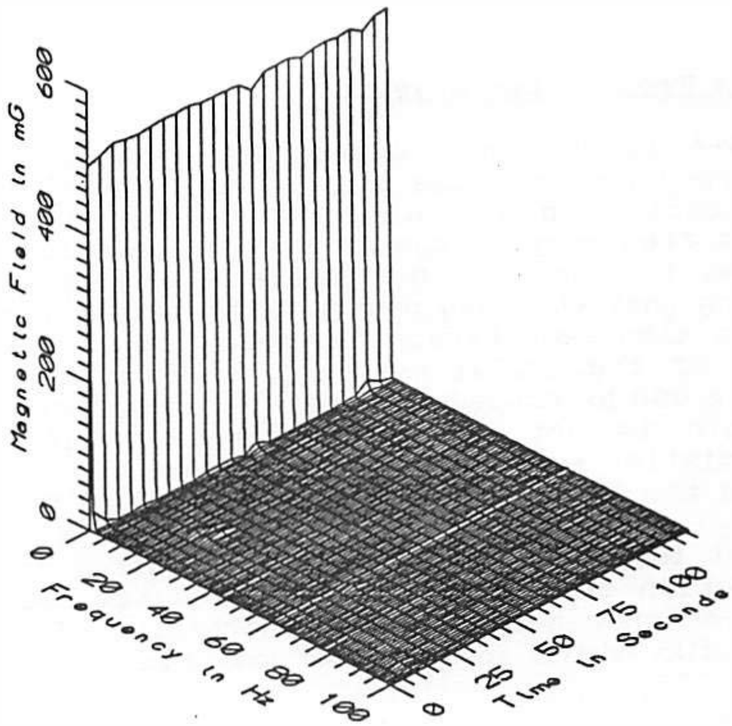
Trolley Bus Wayside:	Tape 1, Group 2, Records 3 and 4
Green Line Wayside:	Tape 2, Group 1, Records 4, 5 and 6
Blue Line Wayside:	Tape 2, Group 1, Record 7

The analysis of total rms time varying magnetic field in the DAT recording provided no useful information about time varying fields from the Boston MBTA System because background time varying field from apparent power systems sources obscured the weaker fields from the Boston MBTA System.

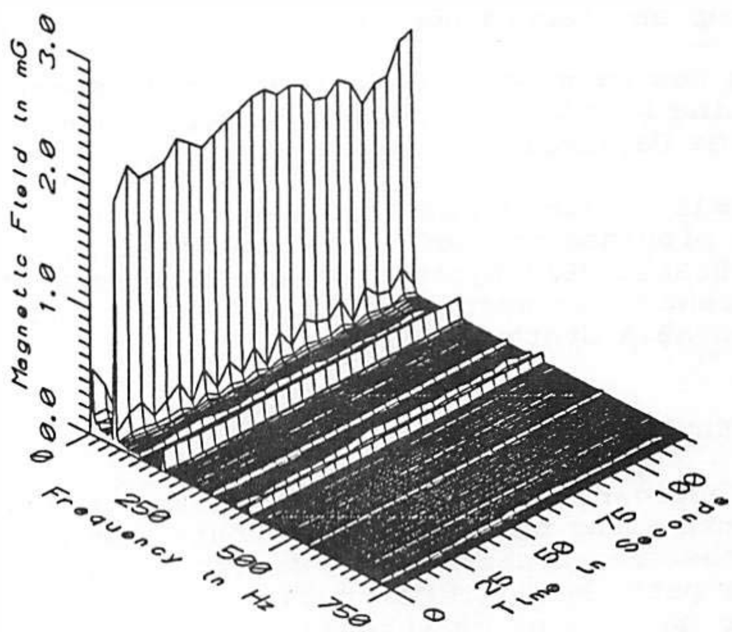
5.5 RMS RECORDER DATA

The rms recorders were carried by of two researchers during the measurements along the Trolley Bus route. As mentioned previously, one of the researchers did wander about not following any particular path, hence having recorded data that does not correlate with other methods of measurements.

Figure 5-6 shows the time course plots for the two rms recordings on the sidewalk on Concord Avenue. It spans the time period from 14:30 to 14:50 on June 9, 1992. The field levels recorded by the two rms recorders are in general agreement with each other and the waveform records, except for a brief period starting at time 14:42.

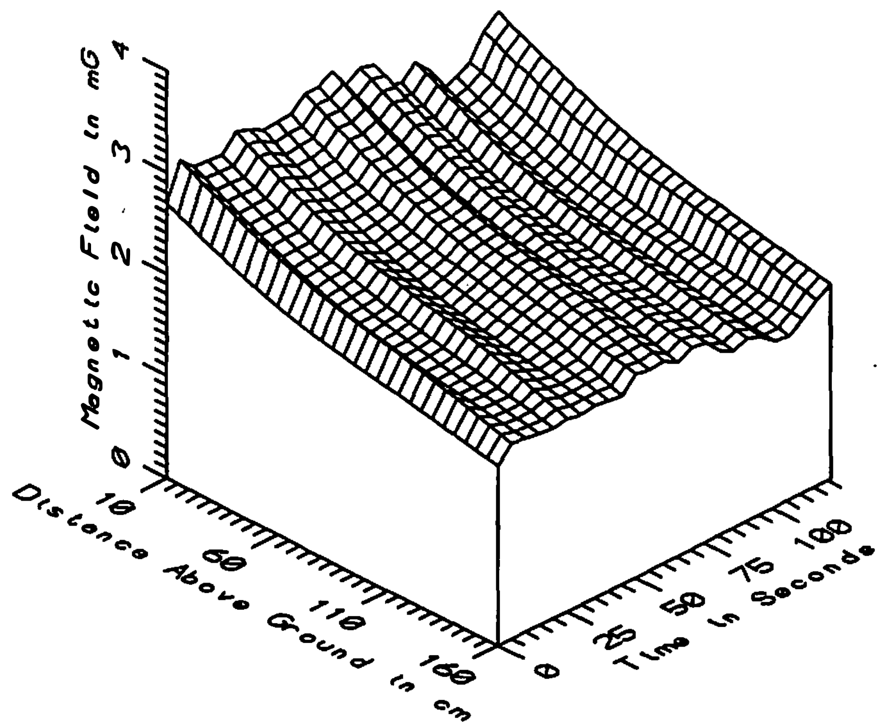


BOS013 - 110cm ABOVE GROUND, TROLLEY BUS WAYSIDE ON CONCORD AVE.



BOS013 - 110cm ABOVE GROUND, TROLLEY BUS WAYSIDE ON CONCORD AVE.

FIGURE 5-4. MAGNETIC FIELD LEVEL, WITH AND WITHOUT THE STATIC COMPONENT, AT 110 cm HEIGHT ABOVE GROUND AT THE SIDEWALK ON CONCORD AVENUE ALONG THE TROLLEY BUS ROUTE, AS A FUNCTION OF FREQUENCY AND TIME



BOS013 - TROLLEY BUS WAYSIDE ON CONCORD AVE. - POWER FREQ, 50-60Hz

FIGURE 5-5. MAGNETIC FIELD LEVEL VERSUS DISTANCE FROM THE SIDEWALK FOR THE POWER FREQUENCY (50-60 Hz) COMPONENT AT THE SIDEWALK ON CONCORD AVENUE ALONG THE TROLLEY BUS ROUTE, AS A FUNCTION OF TIME

Table 5-2 shows the statistics for Concord Avenue Trolley Bus route wayside records.

TABLE 5-2.

STATISTICAL SUMMARY OF MAGNETIC FIELDS IN mG RECORDED AT THE TROLLEY BUS WAYSIDE USING RMS RECORDERS

	AVERAGE	MAXIMUM
RMS RECORDER #1	3.52	13.6
RMS RECORDER #2	1.71	2.6
BOTH	2.61	13.6

TROLLEY BUS WAYSIDE

Emdex II Data From June 9, 1992

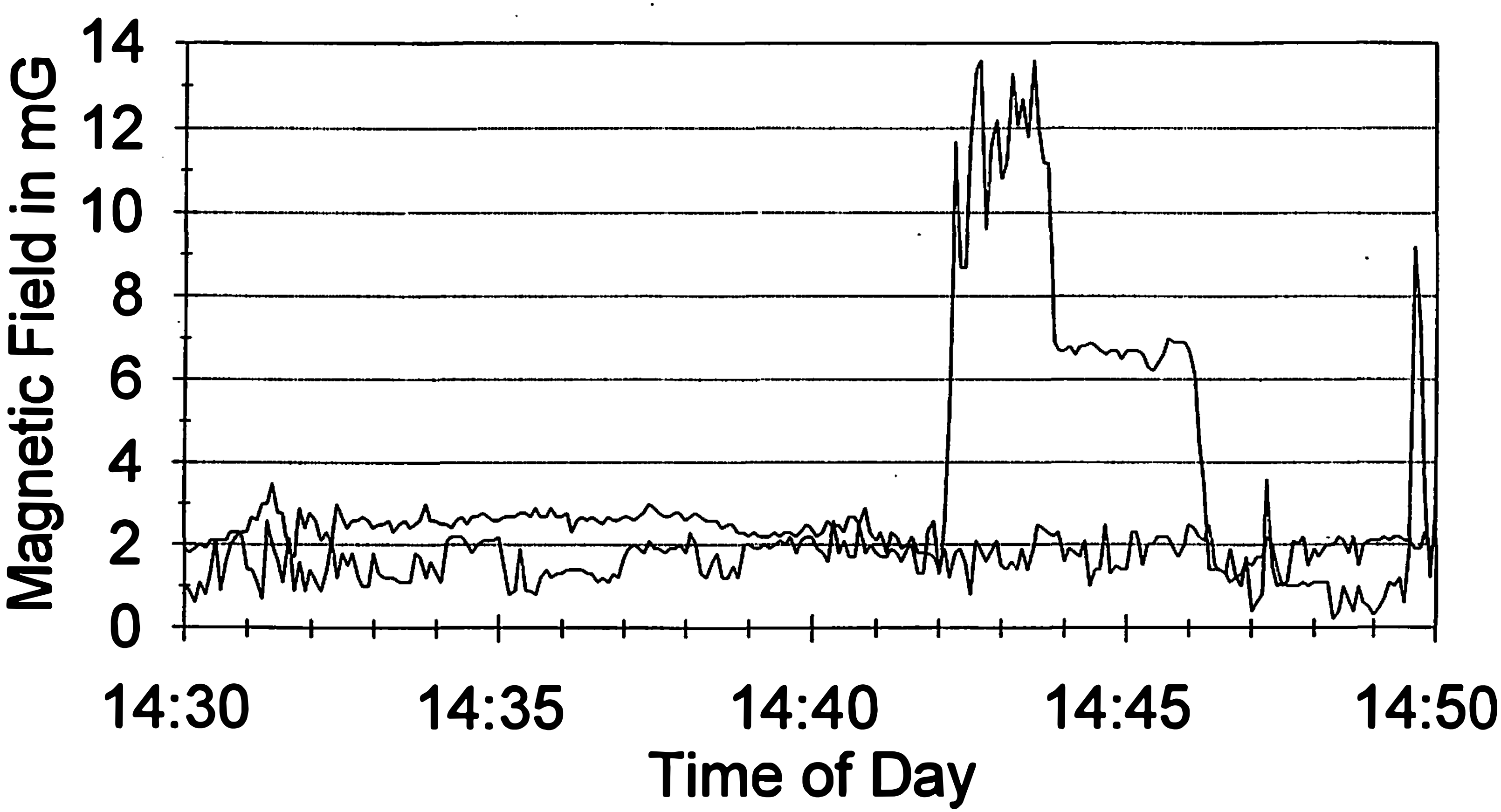


FIGURE 5-6. MAGNETIC FIELD LEVELS RECORDED OUTSIDE AT THE SIDEWALK ON CONCORD AVENUE ALONG THE TROLLEY BUS ROUTE USING THE RMS RECORDERS, AS A FUNCTION OF TIME

5.6 SUMMARY OF MAGNETIC FIELD LEVELS

Appendices AW and AV contain the figures of the magnetic field plots for the wayside measurements on the Blue and Green Lines, respectively. Appendices N and O contain the figures of the magnetic field plots for the wayside records along the Trolley Bus route on Concord Avenue. The main sources of magnetic fields at these locations were apparently the nearby commercial electric power lines or cables and the geomagnetic field of the earth. The MBTA transit line produced detectable static and time varying magnetic fields but they were typically smaller than the fields which existed from other sources.

Table 5-3 summarizes the statistics of the vertical measurements made at the Blue Line wayside near the Wood Island Station. This table, like the others, shows the minimum, maximum and average field levels, as well as standard deviation and coefficient of variation. The results are summarized by the set of five frequency ranges discussed in Section 2.4 (Figure 2-1) and are used throughout this report. The maximum time varying field reading of 1.35 mG occurred in the high frequency range, at the 160 cm probe level. The low frequency maximum of 1.21 mG is not substantially different. The high frequency is due to the rectifier harmonics and the low frequency band variation reflects the static field perturbations as the cars pass by. The magnetic field levels reported in the static band are dominated by the earth's field while values reported in the other time varying bands are dominated by background field levels from nearby power lines.

Table 5-4 summarizes the statistics of the vertical measurements made at the Green Line wayside near Beacon Street. This table again shows the minimum, maximum and average field levels, as well as standard deviation and coefficient of variation. The maximum time varying field reading of 11.20 mG occurred in the power frequency range, at the 10 cm probe level. This field is believed to originate from a nearby underground power line for the reasons described above. This conclusion is further supported by the very low standard deviation of less than 4 percent for the power frequency indicating little variation during the recording even though a train passed the measurement point. The time varying magnetic field levels produced by the Boston MBTA System are considerably smaller than the background levels from other sources reported in Table 5-4.

Table 5-5 summarizes the statistics of both vertical measurements (datasets BOS013 and BOS014) made at the Trolley Bus wayside on the sidewalk on Concord Avenue. This table, like the others, shows the statistics for the five frequency bands. The maximum time varying field reading of 3.17 mG occurred in the power frequency range, at the 10 cm probe level. This field is believed to originate from a nearby underground power line for the reasons described above. The time varying magnetic field levels produced by the Boston MBTA System are considerably smaller than the background levels from other sources as seen in Table 5-5.

TABLE 5-3.

STATISTICAL SUMMARY OF THE MAGNETIC FIELD LEVEL AT VARIOUS HEIGHTS ABOVE THE GROUND AT THE BLUE LINE WAYSIDE NEAR WOOD ISLAND STATION (DATASET BOS048)

BOS048 - BLUE LINE WAYSIDE NEAR WOOD ISLAND STATION					TOTAL OF 16 SAMPLES	
FREQUENCY BAND	HEIGHT ABOVE FLOOR (cm)	MINIMUM MAGNETIC FIELD (mG)	MAXIMUM MAGNETIC FIELD (mG)	AVERAGE MAGNETIC FIELD (mG)	STANDARD DEVIATION (mG)	COEFFICIENT OF VARIATION (%)
STATIC	10	289.39	646.00	413.35	80.96	19.59
	60	362.39	823.32	679.64	154.31	22.70
	110	378.64	673.07	483.62	85.07	17.59
	160	446.96	768.91	545.90	97.22	17.81
5-45Hz LOW FREQ	10	0.19	1.07	0.55	0.27	49.85
	60	0.36	1.12	0.56	0.27	49.05
	110	0.12	1.12	0.43	0.34	78.98
	160	0.23	1.21	0.48	0.33	68.33
50-60Hz PWR FREQ	10	0.87	0.99	0.92	0.03	3.57
	60	0.84	0.97	0.91	0.05	5.12
	110	0.84	1.07	0.95	0.07	7.67
	160	0.66	0.98	0.79	0.09	11.16
65-300Hz PWR HARM	10	0.07	0.76	0.35	0.19	54.81
	60	0.27	0.84	0.47	0.16	34.60
	110	0.15	0.94	0.53	0.18	34.27
	160	0.20	0.87	0.44	0.19	44.18
305-2560Hz HIGH FREQ	10	0.12	1.20	0.56	0.31	56.30
	60	0.14	1.21	0.59	0.32	54.20
	110	0.11	1.30	0.60	0.34	56.02
	160	0.11	1.35	0.62	0.35	57.09
5-2560Hz ALL FREQ	10	0.93	1.81	1.32	0.25	18.89
	60	0.97	1.83	1.36	0.26	19.44
	110	0.98	1.87	1.38	0.28	20.03
	160	0.80	1.93	1.26	0.33	25.73

TABLE 5-4.

STATISTICAL SUMMARY OF THE MAGNETIC FIELD LEVEL AT VARIOUS HEIGHTS ABOVE THE GROUND AT THE GREEN LINE WAYSIDE NEAR BEACON STREET (DATASET BOS047)

BOS047 - GREEN LINE WAYSIDE AT BEACON STREET					TOTAL OF 14 SAMPLES	
FREQUENCY BAND	HEIGHT ABOVE GROUND (cm)	MINIMUM MAGNETIC FIELD (mG)	MAXIMUM MAGNETIC FIELD (mG)	AVERAGE MAGNETIC FIELD (mG)	STANDARD DEVIATION (mG)	COEFFICIENT OF VARIATION (%)
STATIC	10	351.39	539.44	417.09	51.63	12.38
	60	388.47	510.53	435.09	37.68	8.66
	110	406.63	502.76	455.13	32.31	7.10
	160	437.11	538.46	487.14	30.73	6.31
5-45Hz LOW FREQ	10	0.49	3.53	1.66	0.85	51.00
	60	0.35	2.60	1.17	0.61	52.14
	110	0.26	2.15	0.94	0.51	54.11
	160	0.25	1.80	0.79	0.41	52.36
50-60Hz PWR FREQ	10	9.74	11.20	10.28	0.40	3.86
	60	7.69	8.86	8.12	0.32	3.90
	110	6.39	7.36	6.74	0.26	3.87
	160	5.76	6.49	6.00	0.22	3.61
65-300Hz PWR HARM	10	0.67	1.35	1.01	0.25	24.61
	60	0.45	0.95	0.67	0.16	24.20
	110	0.35	0.83	0.54	0.14	25.94
	160	0.28	0.66	0.42	0.10	24.96
305-2560Hz HIGH FREQ	10	0.59	1.19	0.93	0.20	21.47
	60	0.42	0.65	0.55	0.08	14.42
	110	0.22	0.47	0.36	0.06	15.30
	160	0.14	0.36	0.25	0.06	23.13
5-2560Hz ALL FREQ	10	9.94	11.49	10.54	0.45	4.26
	60	7.78	9.05	8.27	0.35	4.25
	110	6.45	7.52	6.86	0.30	4.32
	160	5.79	6.62	6.09	0.25	4.08

TABLE 5-5.

STATISTICAL SUMMARY OF THE MAGNETIC FIELD LEVEL AT VARIOUS HEIGHTS ABOVE THE SIDEWALK AT THE TROLLEY BUS WAYSIDE ON CONCORD AVENUE (DATASETS BOS013 AND BOS014)

BOS013, 014 - TROLLEY BUS WAYSIDE ON CONCORD AVENUE					TOTAL OF 40 SAMPLES	
FREQUENCY BAND	HEIGHT ABOVE GROUND (cm)	MINIMUM MAGNETIC FIELD (mG)	MAXIMUM MAGNETIC FIELD (mG)	AVERAGE MAGNETIC FIELD (mG)	STANDARD DEVIATION (mG)	COEFFICIENT OF VARIATION (%)
STATIC	10	486.45	511.48	503.65	4.76	0.95
	60	479.40	501.57	495.34	4.73	0.96
	110	488.01	510.10	504.60	4.74	0.94
	160	500.56	522.35	516.54	4.61	0.89
5-45Hz LOW FREQ	10	0.07	0.53	0.28	0.12	42.01
	60	0.15	0.71	0.25	0.13	54.14
	110	0.03	1.11	0.19	0.21	107.48
	160	0.16	1.68	0.27	0.26	94.18
50-60Hz PWR FREQ	10	2.01	3.17	2.70	0.32	11.83
	60	1.74	2.58	2.25	0.23	10.14
	110	1.64	2.26	2.00	0.17	8.53
	160	1.50	1.97	1.77	0.14	7.65
65-300Hz PWR HARM	10	0.25	0.31	0.28	0.02	5.82
	60	0.24	0.30	0.26	0.01	5.23
	110	0.18	0.37	0.27	0.06	21.70
	160	0.19	0.39	0.23	0.03	13.37
305-2560Hz HIGH FREQ	10	0.15	0.20	0.16	0.01	7.90
	60	0.11	0.20	0.15	0.02	15.78
	110	0.08	0.15	0.10	0.02	17.24
	160	0.05	0.18	0.08	0.02	31.57
5-2560Hz ALL FREQ	10	2.04	3.20	2.74	0.32	11.52
	60	1.78	2.62	2.29	0.22	9.83
	110	1.67	2.40	2.04	0.18	8.71
	160	1.55	2.48	1.82	0.17	9.35

5.7 ATTENUATION OF MAGNETIC FIELDS

The fall-off or attenuation takes effect as the distance from the tracks is increased, if the source of the field is the catenary-tracks combination (double catenary for the Trolley Bus). In this study, the attenuation is described as the point where the maximum or average values of the recorded data diminish to 1 mG. The source of the even harmonics can be shown to be the train electrification and attenuation can be calculated. The difficulty arises in not being able to separate the 60 Hz portion that comes from the tracks. Thus, the calculations are based on the attenuation of the power frequency harmonics only, namely the even.

The calculations proceed as follows. First, the statistics for the power harmonic frequencies are obtained for the two measurement points, the 10 cm probe and the reference probe. Next, the values are curve fitted to a $1/d^2$ curve for the 4.6 m (15 ft) and 9.2 m (30 ft) respective distances. This second order curve appears to be the best fit to the data and is also the theoretically expected fit. The curve fitted equations are then used to calculate the point at which the value of the power harmonics field drops off to 1 mG.

Table 5-6 shows the point at which the value of the harmonics field attenuates to a 1 mG value. This is given as a distance from the track, in m (ft). Table 5-6 shows the attenuation of both the maximum and average fields, for the Blue and Green Lines. The maximum values are obtained by considering the maximum points recorded and their time coincident maximum points at the reference location. The average values are, in reality, averages of all the magnetic field values while a train was in that portion of the circuit.

TABLE 5-6.

CALCULATED DISTANCES FROM TRACK TO REACH A 1 mG POWER HARMONICS MAGNETIC FIELD MAXIMUM OR AVERAGE LEVEL BASED ON CURVE FIT OF DATA FOR THE BLUE AND GREEN LINES ALONG THEIR WAYSIDE

	BLUE LINE	GREEN LINE
MAXIMUM	3.6 m (11.9 ft)	5.7 m (18.6 ft)
AVERAGE	1.4 m (4.5 ft)	4.6 m (15.1 ft)

Reliable empirical estimates of the attenuation rate of magnetic fields away for the Trolley Bus route cannot be made from the available data because the weak fields from the transit system are obscured by background fields from other sources.

5.8 SUMMARY OF ELECTRIC FIELD LEVELS

Time varying electric field levels were measured at all three locations along the wayside, the Blue Line, Green Line and Trolley Bus route. The electric field was measured at 1.7 m (5.6 ft) above ground at the same location as the staff, namely Locations 26 (Blue Line), 28 (Green Line) and 30 (Trolley Bus) shown in Figure 5-1. The field measured less than 1 V/m in all locations and for the duration of the measurements. Appendices AW, AV, N and O contain the plots of the results.

6. PASSENGER STATION MEASUREMENTS

Readings on the passenger platform were taken at five locations covering all four lines. The Red and Orange Line platform measurements were made at the Downtown Crossing Station. Two Blue Line platform measurements were made at the Wood Island Station and the Government Center. The Green Line platform measurements were also made at the Government Center.

6.1 MEASUREMENT LOCATIONS

All measurements were taken with the staff with the four probes in a vertical position placed at the yellow safety line near the edge of the platforms. That position, which is approximately .45 m (18 in) from the edge of the platform, was chosen because it represents an easily identifiable position as near the edge of the platform as a passenger could safely and reasonably stand while waiting for a train. The reference probe was placed inward from the edge, on a line directly behind the staff, 1.5 to 3.1 m (5 to 10 ft) away.

Figure 6-1 shows the schematic layout of the Downtown Crossing platforms of the Red and Orange Lines. The Red Line platform is a center track platform. Readings were taken at the edge of the platform and at the end of the platform in order to record fields for trains leaving from and arriving at the station. Datasets BOS024 and BOS025 were recorded at the arriving end with the reference probe set 1.5 m (5 ft) behind because of an obstruction of the steps and also the proximity to a large fan. Dataset BOS026 was recorded at the departing end of this platform with the reference probe set at 3.1 m (10 ft) behind. The data was collected on June 10, 1992 from 14:10 to 14:23.

The Orange Line platform is in the same location as the Red Line platform and within walking distance, but not in close proximity to it. Measurements were also taken near the edge of the platform on the southbound side. Dataset BOS023 was recorded at the arriving end, whereas BOS022 was recorded at the departing end of this platform. The reference probe was set 3.1 m (10 ft) behind the staff in both cases. The data was collected on June 10, 1992 from 13:00 to 13:12.

Figure 6-2 shows the schematic layout of the Blue Line platforms at Wood Island Station and Government Center. The Wood Island Station is a center track outdoor station with power fed from a catenary, whereas the Government Center is an underground center-type platform station powered by a third rail. At the Wood Island Station measurements were taken on the eastbound (outbound) side of the platform at both ends. The arriving end dataset is BOS050 and the departing end is dataset BOS049. The reference probes were placed 3.1 m (10 ft) behind in both cases. The recordings were taken on June 11, 1992 from 14:01 to 14:10.

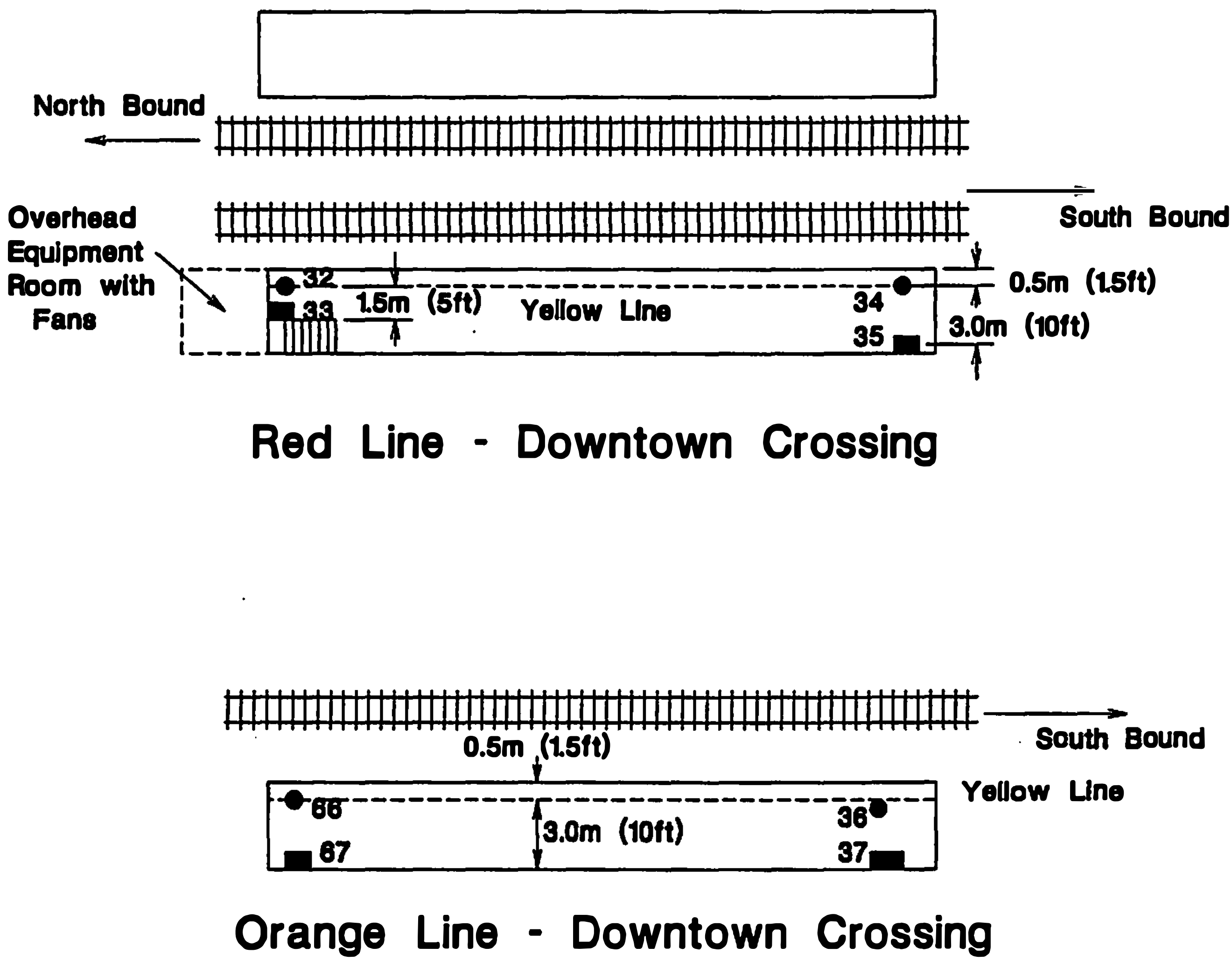
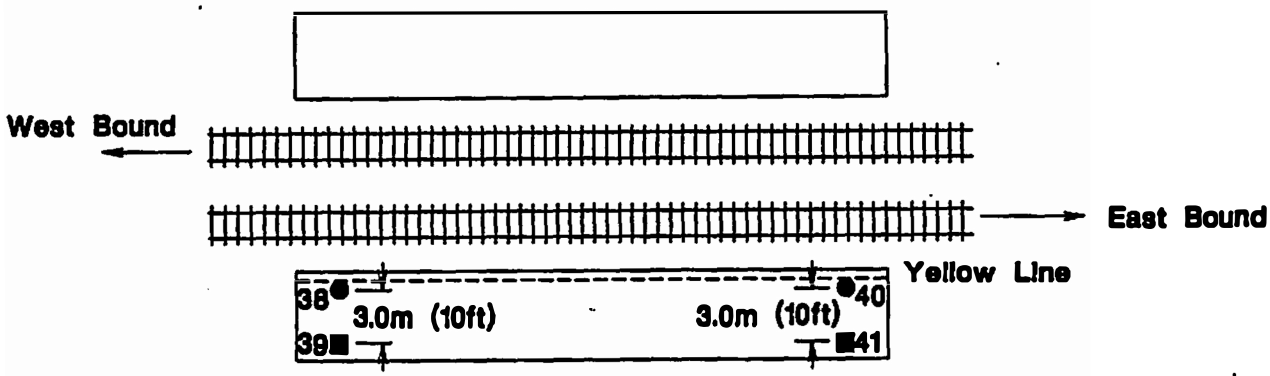
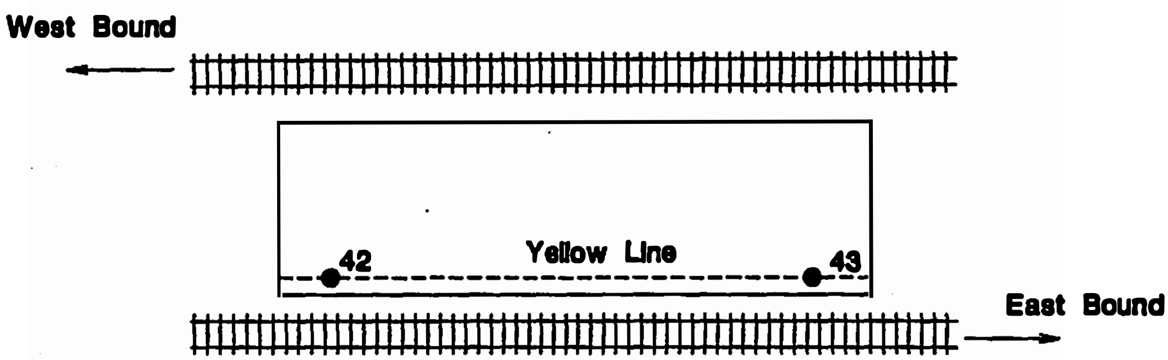


FIGURE 6-1. REPETITIVE WAVEFORM MEASUREMENT LOCATIONS ON THE RED LINE AND ORANGE LINE PASSENGER PLATFORMS AT DOWNTOWN CROSSING



Blue Line - Wood Island Station



Blue Line - Government Center

FIGURE 6-2. REPETITIVE WAVEFORM MEASUREMENT LOCATIONS ON THE BLUE LINE PASSENGER PLATFORMS AT WOOD ISLAND STATION AND GOVERNMENT CENTER

The Blue Line Government Center measurements were taken on the eastbound side. The arriving end dataset is BOS040 and the departing end is dataset BOS039. No reference probes were deployed. The recordings were taken on June 11, 1992 from 09:46 to 09:52.

Figure 6-3 shows the schematic layout of the Green Line platform at Government Center. Measurements were taken near the edge of the platform on the westbound side (to Riverside). The Green Line platform is near the Blue Line platform of the same name and within walking distance, but not in close proximity to it. Dataset BOS037 was recorded at the arriving end and dataset BOS038 was recorded at the departing end of this platform. No reference probes were deployed. The data was collected on June 11, 1992 from 09:32 to 09:35.

Data was also collected using the DAT and rms recorders. DAT recordings were made from the sensor in the reference probe, whose locations have already been described. The rms recorders were worn by two members of the measurement team. While their exact locations during the recordings are not known, they were in the general area where the other measurements were in progress.

6.2 REPETITIVE WAVEFORM DATASETS

The eleven datasets just described were recorded at the five passenger stations of the four MBTA transit lines. Table 2-1 summarizes the pertinent information contained in these eleven datasets, including the appendix where the corresponding data are located, the number of samples and the location of probes. The appendices contain figures that are three-dimensional plots of magnetic field versus frequency over time and horizontal or vertical profile plots of field versus distance over time.

6.3 MAGNETIC FIELD CHARACTERISTICS

The measurements discussed in this section of the report are intended to characterize the magnetic fields that a passenger might encounter at a station. Consequently, many measurements were made near the edge of the platform where the magnetic field from passing trains or from current in the third rail and tracks, or catenaries would likely be the largest.

Table 6-1 summarizes some salient characteristics of the eleven magnetic field waveform datasets that were taken on passenger platforms. The table shows the specific dataset associated with each line and each platform. The table further shows which end of the platform the data was collected and what type of electrification technology is used. Not summarized is the type of platform, in that only the Blue Line at Wood Island was an outdoor platform, the rest being underground. With respect to the electrification technology, the measurements can be classified into three broad categories:

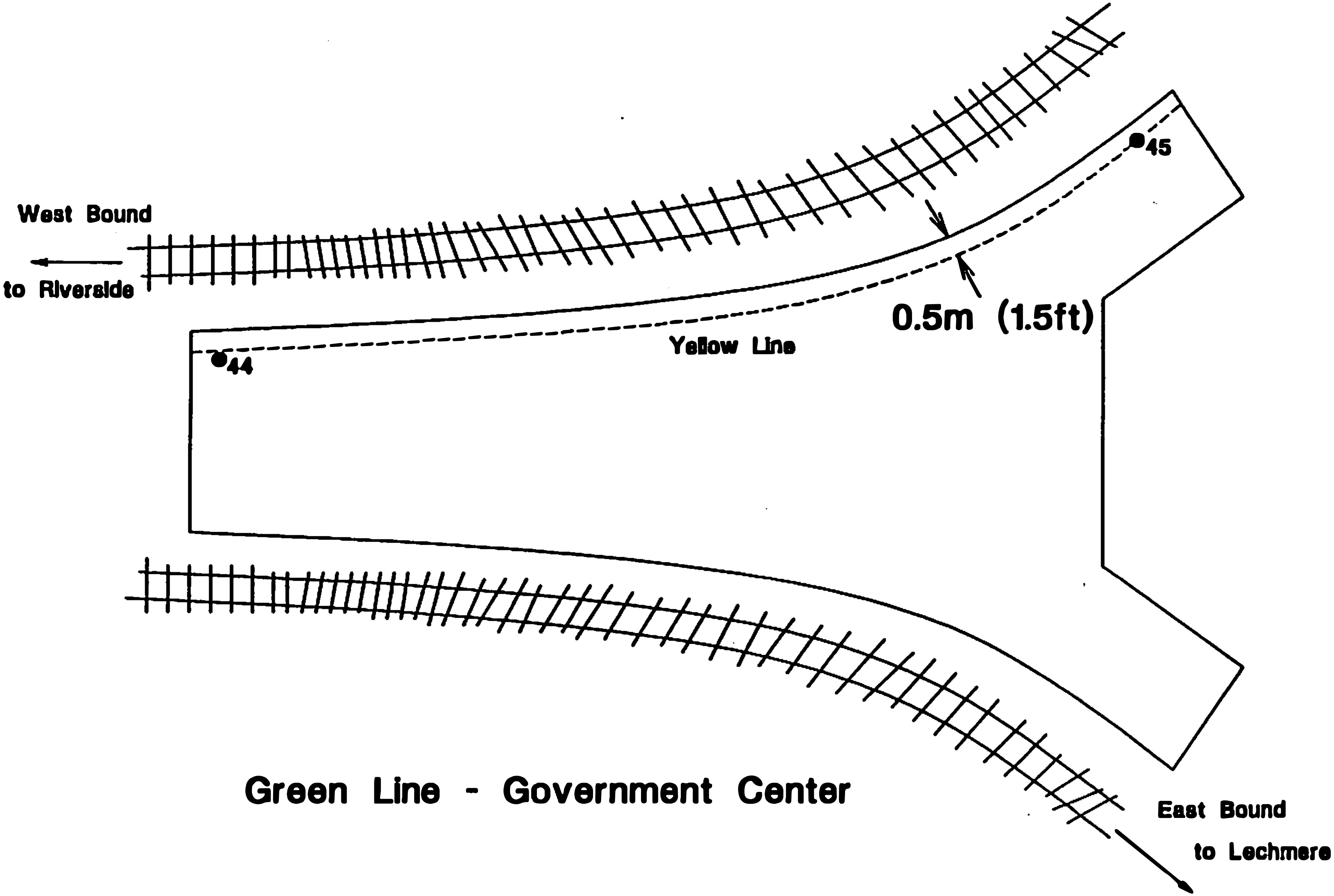


FIGURE 6-3. REPETITIVE WAVEFORM MEASUREMENT LOCATIONS ON THE GREEN LINE PASSENGER PLATFORM AT GOVERNMENT CENTER

1) Third rail supplied power with cam operated cars. These include all of the Red and Orange Lines and the Blue Line at Government Center.

2) Catenary supplied power with cam operated cars. These include datasets BOS049 and 50 of the Blue Line at Wood Island.

3) Catenary supplied power with chopper operated cars. These are the Green Line measurements.

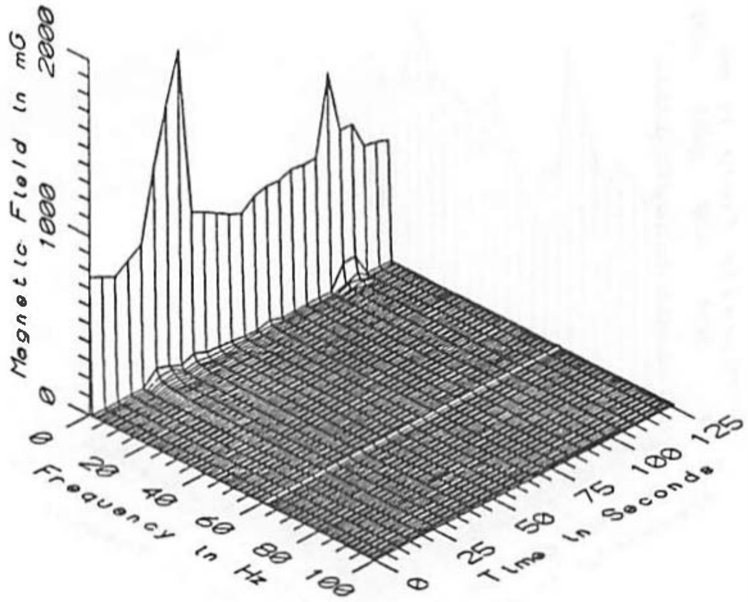
TABLE 6-1.

SUMMARY OF MAGNETIC FIELD WAVEFORM DATASETS MEASURED ON PASSENGER PLATFORMS

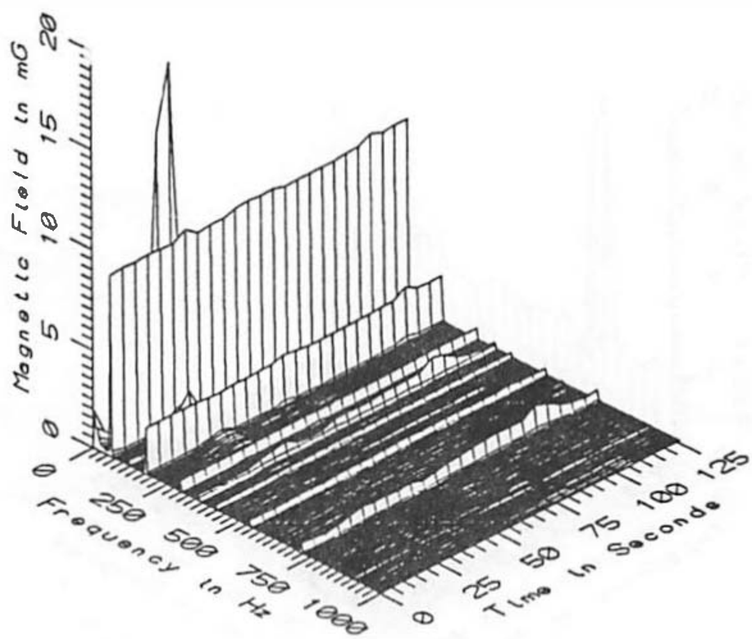
LINE / DESCRIPTION	DATASET NUMBER	PLATFORM LOCATION	ELECTRIFICATION TECHNOLOGY
RED LINE / DOWNTOWN CROSSING	BOS024	ARRIVING END	3RD RAIL / CAM
RED LINE / DOWNTOWN CROSSING	BOS025	ARRIVING END	3RD RAIL / CAM
RED LINE / DOWNTOWN CROSSING	BOS026	DEPARTING END	3RD RAIL / CAM
ORANGE LINE / DOWNTOWN CROSSING	BOS022	DEPARTING END	3RD RAIL / CAM
ORANGE LINE / DOWNTOWN CROSSING	BOS023	ARRIVING END	3RD RAIL / CAM
BLUE LINE / WOOD ISLAND	BOS049	DEPARTING END	CATENARY / CAM
BLUE LINE / WOOD ISLAND	BOS050	ARRIVING END	CATENARY / CAM
BLUE LINE / GOVERNMENT CENTER	BOS039	DEPARTING END	3RD RAIL / CAM
BLUE LINE / GOVERNMENT CENTER	BOS040	ARRIVING END	3RD RAIL / CAM
GREEN LINE / GOVERNMENT CENTER	BOS037	ARRIVING END	CATENARY / CHOPPER
GREEN LINE / GOVERNMENT CENTER	BOS038	DEPARTING END	CATENARY / CHOPPER

6.3.1 The Red and Orange Lines

Figures 6-4 and 6-5 are plots of the magnetic flux density in mG versus frequency in Hz and time in seconds measured 10 cm and

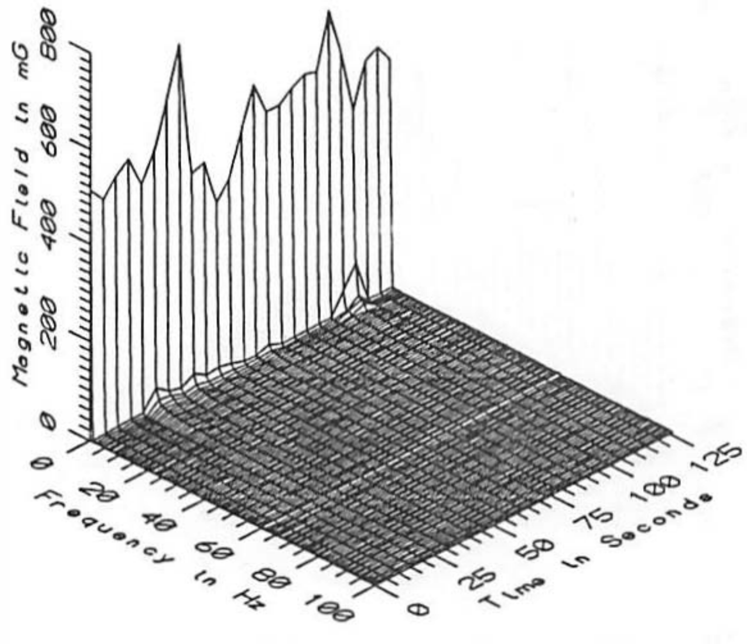


BOS022 - 10cm ABOVE PLATFORM AT DOWNTOWN CROSSING, ORANGE LINE

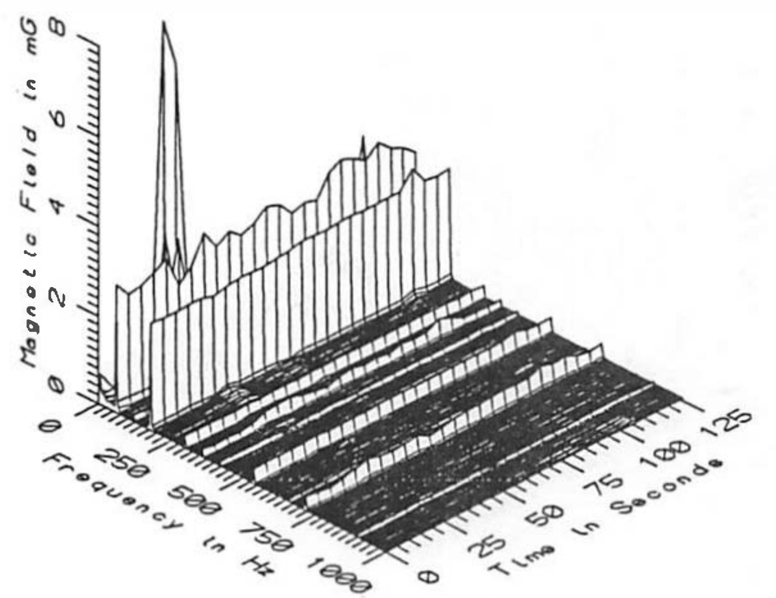


BOS022 - 10cm ABOVE PLATFORM AT DOWNTOWN CROSSING, ORANGE LINE

FIGURE 6-4. MAGNETIC FIELD LEVEL 10 cm ABOVE THE FLOOR AT THE EDGE OF THE ORANGE LINE PLATFORM AT DOWNTOWN CROSSING. THE STATIC FIELD IS SUPPRESSED IN THE LOWER FRAME TO SHOW THE TIME VARYING COMPONENTS



BOS022 - 160cm ABOVE PLATFORM AT DOWNTOWN CROSSING, ORANGE LINE



BOS022 - 160cm ABOVE PLATFORM AT DOWNTOWN CROSSING, ORANGE LINE

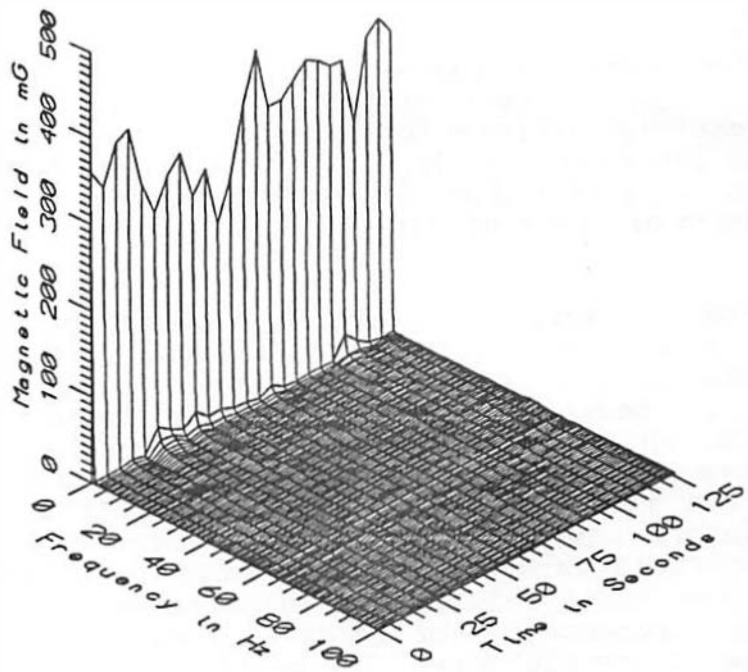
FIGURE 6-5. MAGNETIC FIELD LEVEL 160 cm ABOVE THE FLOOR AT THE EDGE OF THE ORANGE LINE PLATFORM AT DOWNTOWN CROSSING. THE STATIC FIELD IS SUPPRESSED IN THE LOWER FRAME TO SHOW THE TIME VARYING COMPONENTS

160 cm above the floor at the edge of the Orange Line Downtown Crossing platform at the southbound departing end. The measurement location is identified as Location 36 on Figure 6-1. Figure 6-6 is the plot of the magnetic flux density in mG versus frequency in Hz and time in seconds measured at the reference probe, Location 37 on Figure 6-1. These are part of dataset BOS022 contained in Appendix W.

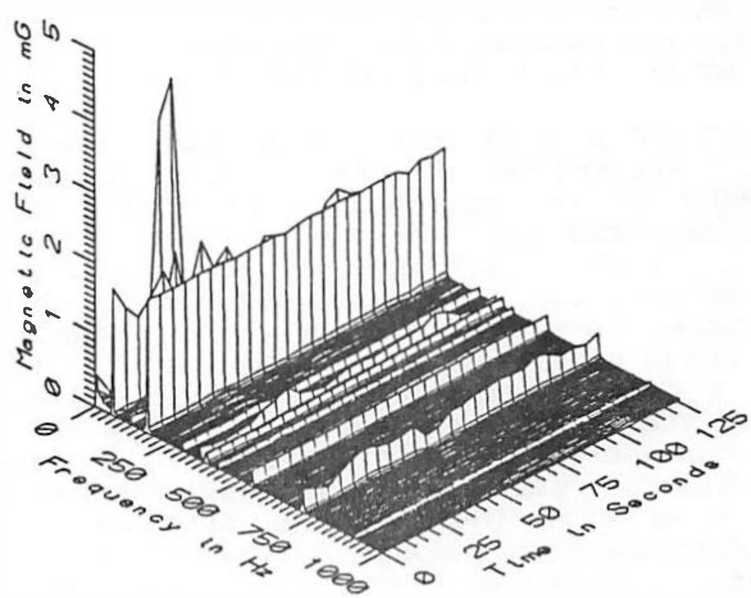
The repetitive waveform sampling technique of field characterization was not developed to reliably capture infrequent transient events such as passage of a train very close to the sensors. That is because those events can occur between the waveform samples which occur every 5 seconds. As described in Section 2.5 above, a continuous recording of the magnetic field was made with the DAT recorder at one location to "fill in" between repetitive waveform samples. Figure 6-7 shows a plot of total static magnetic field versus time for Record 10 of the first DAT tape, Group 2 (see Table 2-2 for pertinent information) which was recorded at the reference sensor location (Location #37 on Figure 6-1) at the edge of the platform. The portion of this record, from approximately the 0.4 minute point to the 1.7 minute point, was recorded concurrently with the repetitive waveform system shown in Figures 6-4 through 6-6. Figure 6-6 is most comparable to Figure 6-7, since the data is commonly obtained from the reference sensor. Comparison of the relevant portion of the continuous static field recording of Figure 6-7 to the static field recording in the top frame of Figure 6-6, which originated from successive 5 second samples, shows that in this case, the repetitive waveform samples captured not only the general time characteristic of the magnetic field but some of the finer temporal variations.

From the temporal and spatial characteristics of the static field, it appears that there are two principal sources of static magnetic field at the edge of the platform. The first is the earth's magnetism which produces the background level of approximately 500 mG, more or less, depending on the location within the platform. In other words, the earth's field is changed by the platform structures themselves. The second source is the dc current in the third rail and track return circuit which produces static fields with less spatial variability, but which are temporally correlated with train activities such as acceleration which requires considerable electric current. An examination of the 10 cm probe and the reference probe plots (Figures 6-4 and 6-6, respectively) shows that there is an attenuation of the dc component with distance from the end, indicating the third rail and tracks as the source of the variability. However, the time course of these two figures is not similar, indicating that trains on the northbound side also influence the reference probe.

Examination of the bottom frame of Figures 6-3 through 6-6 shows that the most prominent frequency components are the 60 Hz and the 180 Hz (third harmonic) indicative of an electric power source, such as lights or heating/air conditioning or fans. There are relatively small even harmonics present, such as 360 Hz and 720 Hz, which appear to follow the variations of the static field,



BOS022 - REFERENCE PROBE - ON DOWNTOWN CROSSING PLATFORM, ORANGE LINE



BOS022 - REFERENCE PROBE - ON DOWNTOWN CROSSING PLATFORM, ORANGE LINE

FIGURE 6-6. MAGNETIC FIELD LEVEL AT THE REFERENCE PROBE 3.1 m (10 ft) FROM THE EDGE OF THE ORANGE LINE PLATFORM AT DOWNTOWN CROSSING. THE STATIC FIELD IS SUPPRESSED IN THE LOWER FRAME TO SHOW THE TIME VARYING COMPONENTS

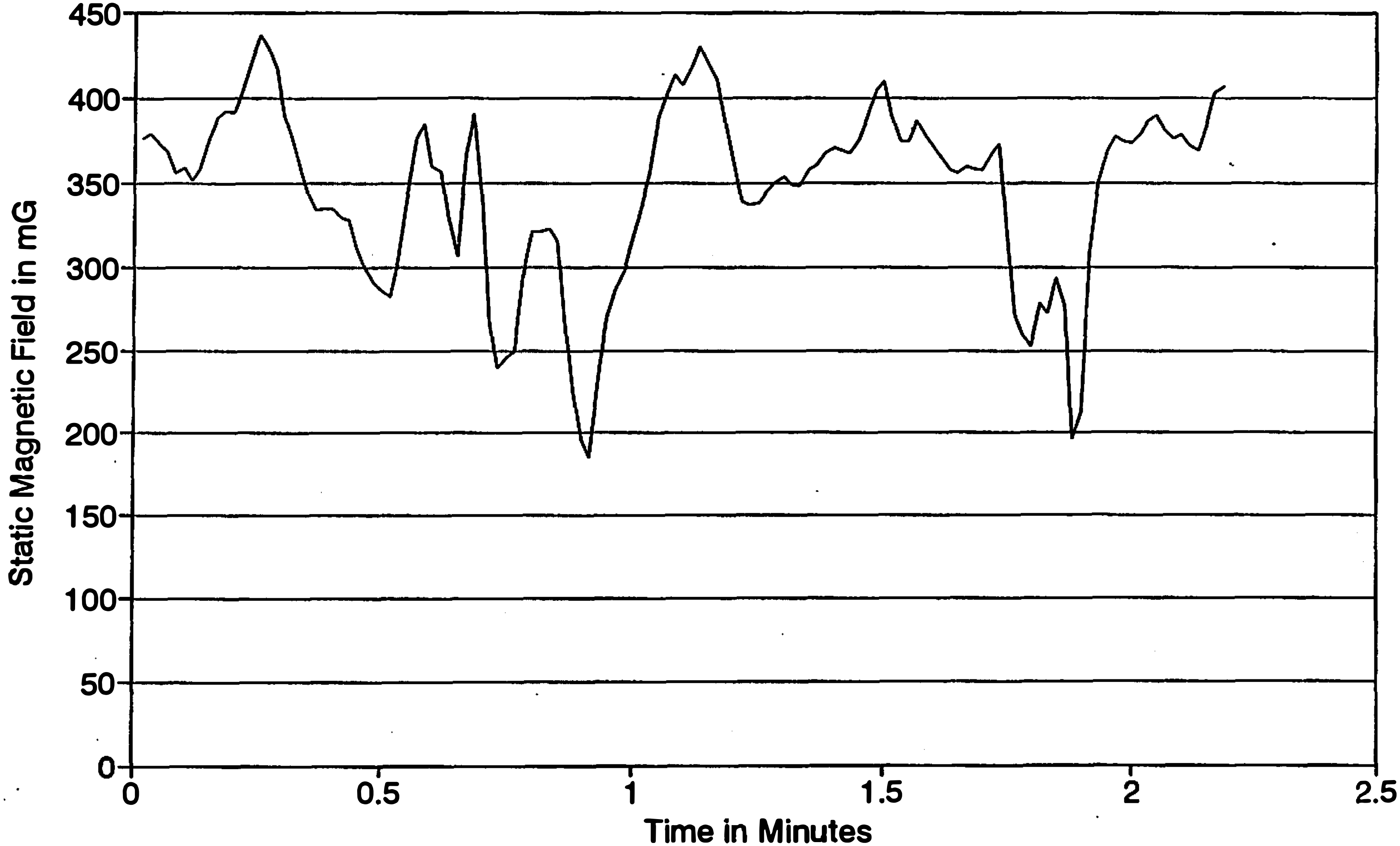


FIGURE 6-7. CONTINUOUS MAGNETIC FIELD RECORDING 3.1 m (10 ft) FROM THE EDGE OF THE ORANGE LINE PLATFORM AT DOWNTOWN CROSSING AT THE DEPARTING END

indicating the traction power is the source. The 180 Hz appears to be fairly constant, whereas the 60 Hz varies in a unique pattern not matching any of the others. This indicates that the 60 Hz component is the result of multiple sources. Comparison of Figures 6-4 and 6-5 shows that the magnetic field is larger at the top of the staff than the bottom for all frequency components (Appendix W has all the profiles).

Datasets BOS024 through BOS026, the Red Line, show similar characteristics to the Orange Line which was just discussed.

6.3.2 The Blue Line

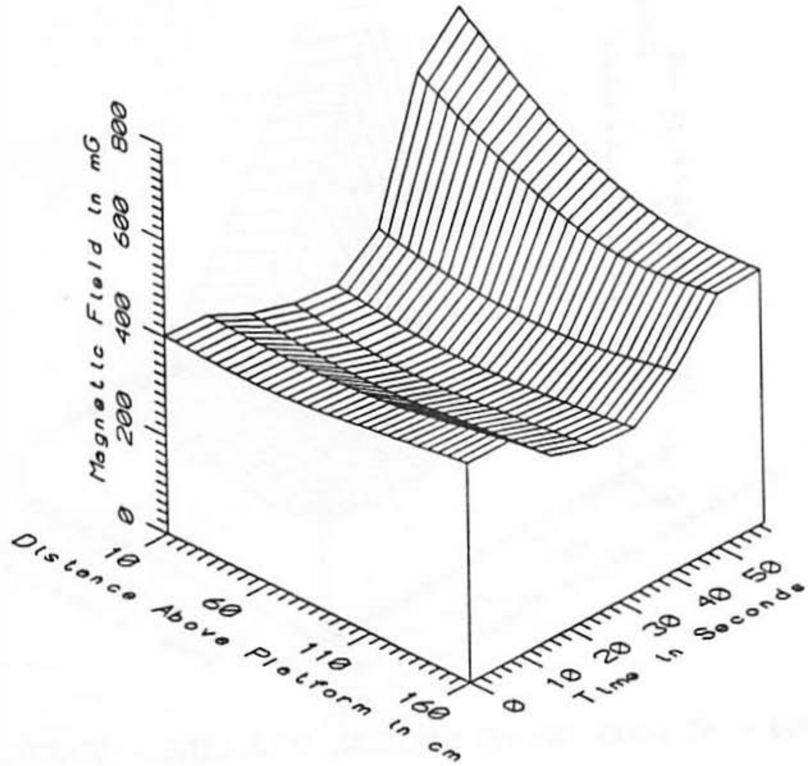
The Blue Line operates on both a catenary and a third rail, depending on the location. The catenary is used almost everywhere as the main choice, with the third rail used in tunnels and underground stations. Datasets BOS049 and BOS050 are from an outdoor platform and hence a catenary operated portion of the line, whereas datasets BOS039 and BOS040 are from an indoor platform and a third rail portion of the line.

Analysis of the data of the third rail operation is expected to yield similar results to those discussed for the Red and Orange Lines. This is indeed the case, as can be seen in Appendices AN and AO. In other words, there are multiple sources for 60 Hz and the odd harmonics; there are even, rectification harmonics that vary with the static component, the source being the third rail and the tracks.

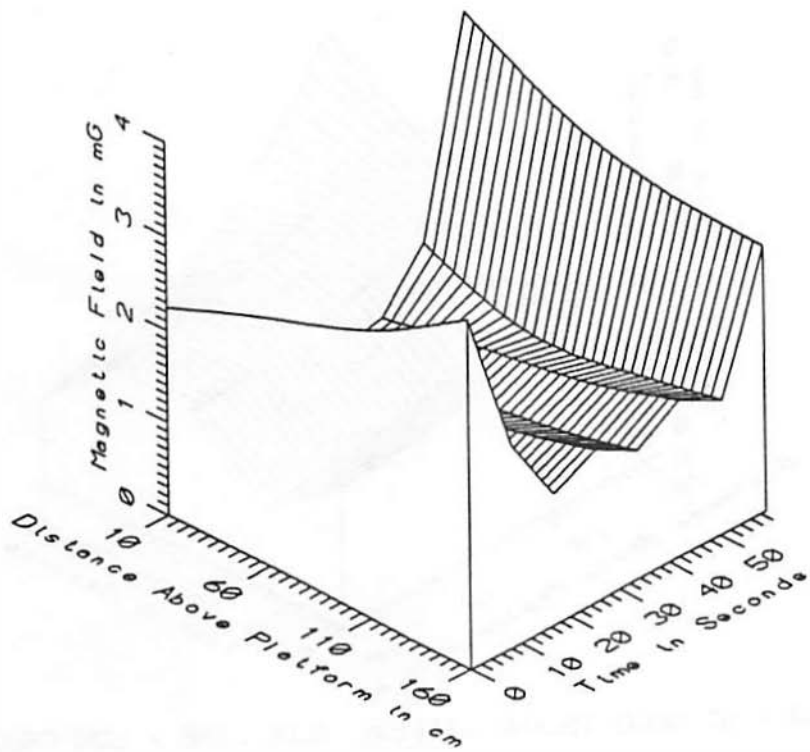
The next question is whether or not there is substantial difference in the field characteristics of the two different types of operation of the Blue Line. Figures 6-8 and 6-9 are the plots of the rms magnetic flux density in mG versus distance from the platform in cm and time in seconds of the static and low frequency components. Figure 6-8 (BOS040) is for the Government Center Station, the third rail operation, measurement Location #42 on Figure 6-2. Figure 6-9 (BOS050) is for the Wood Island Station, the catenary operation, measurement Location # 38. Both locations are at the arriving ends of the platforms. Examination of these figures, as well as others in the corresponding Appendices AO and AY, shows no substantial difference in the field characteristics of the two different types of operation of the Blue Line. The only characteristic is that the quiescent static field of the outdoor platform appears to be very close to the earth's undisturbed field value.

6.3.3 The Green Line

The Green Line field characteristics (Appendices AL and AM) appear to match the characteristics of the other platforms as discussed in Sections 6.3.1 and 6.3.2. There were two slight exceptions, the first being the detection of a very small chopper frequency signature that was tied to the passage of trains. The other

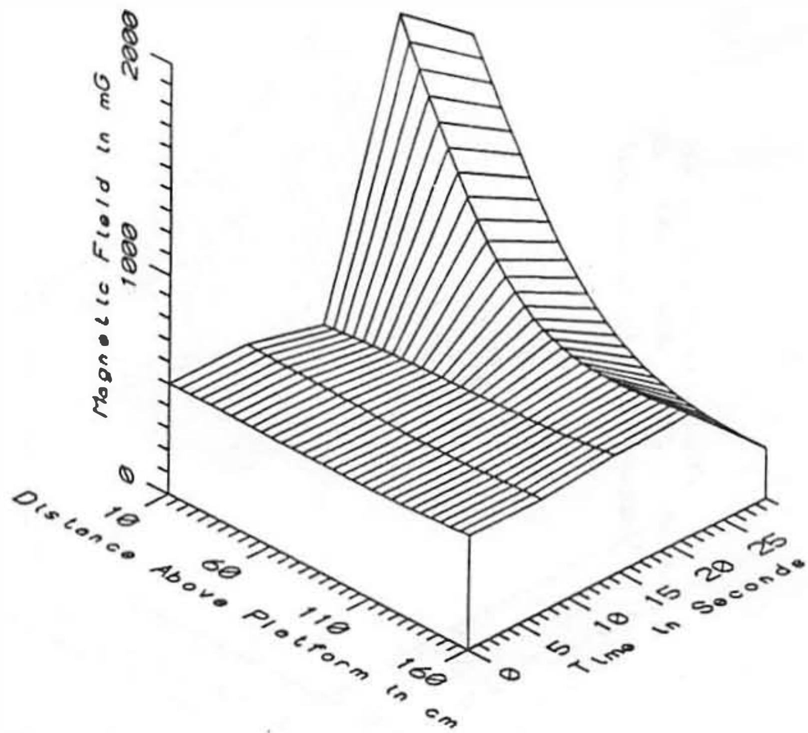


BOS040 - AT GOVERNMENT CENTER, BLUE LINE - STATIC

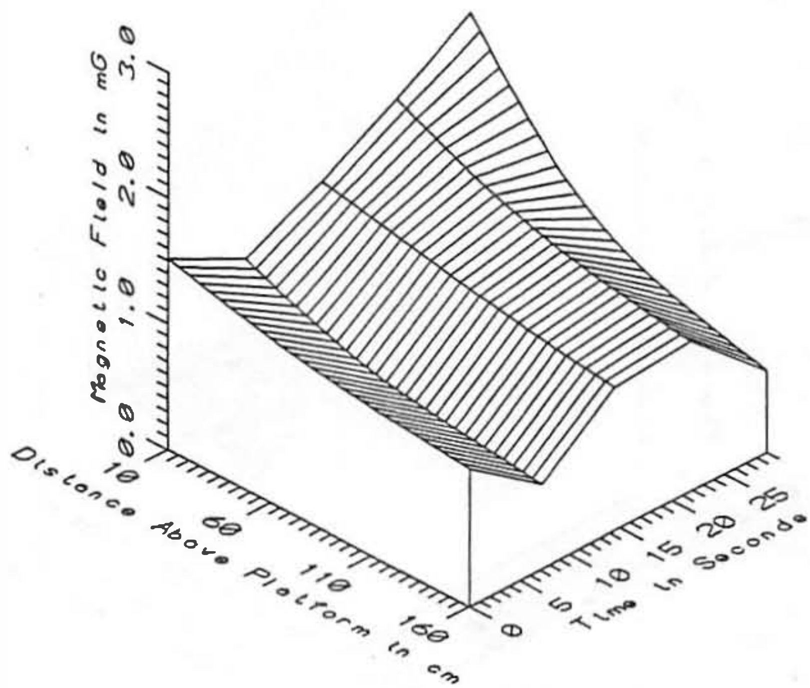


BOS040 - AT GOVERNMENT CENTER, BLUE LINE - LOW FREQ, 5-45Hz

FIGURE 6-8. MAGNETIC FIELD LEVEL VERSUS DISTANCE FROM THE FLOOR, FOR THE STATIC AND THE LOW FREQUENCY HARMONICS (5-45 Hz) COMPONENTS, AT THE BLUE LINE GOVERNMENT CENTER PLATFORM, AS A FUNCTION OF TIME



BOS050 - AT WOOD ISLAND STATION, BLUE LINE - STATIC



BOS050 - AT WOOD ISLAND STATION, BLUE LINE - LOW FREQ. 5-45Hz

FIGURE 6-9. MAGNETIC FIELD LEVEL VERSUS DISTANCE FROM THE FLOOR, FOR THE STATIC AND THE LOW FREQUENCY HARMONICS (5-45 Hz) COMPONENTS, AT THE BLUE LINE WOOD ISLAND STATION PLATFORM, AS A FUNCTION OF TIME

exception is the absence of any vertical attenuation, as shown in Figure 6-10. This figure shows the plots of the power frequency and power harmonic components as a function of the distance from the platform surface and time.

In summary, the magnetic field data of the passenger platforms indicate temporal variations in both static and time varying field levels. The variability is due to both nearby electric power supply circuits, such as lights, and the changing current in the third rail and track circuit, which depends on the power needs of the Boston MBTA transit cars. Both static and time varying fields are also produced for a short duration as trains pass by. The fields from current in the rails and the passing trains have large spatial variability, especially at the edge of the platform. Moreover, there are background fields present from the earth's magnetism and from 60 Hz electric power circuits in and around the station. However, no statistical significant variability was detected between the arriving and departing ends of the platform or among the various electrification types.

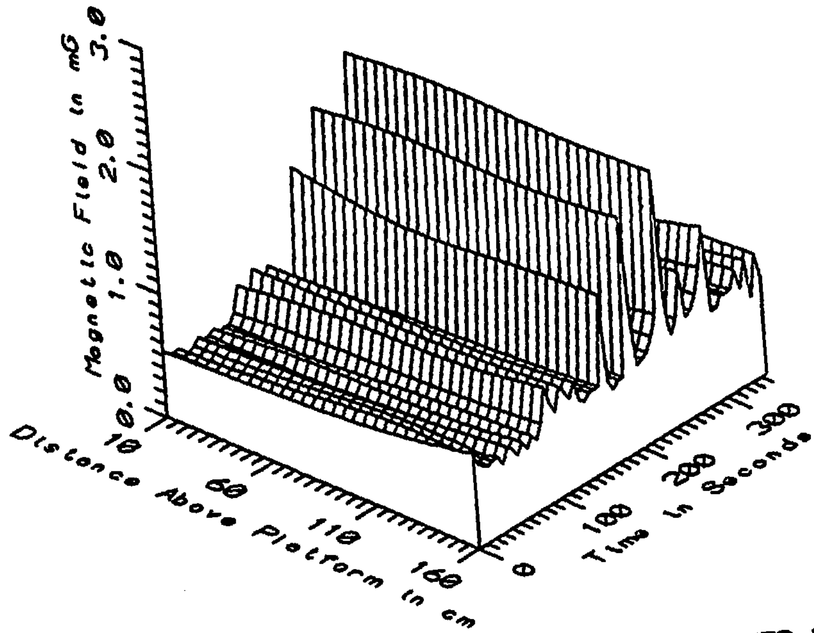
6.4 DAT WAVEFORM DATA

Magnetic field data from the reference probe of the repetitive waveform measuring system was recorded continuously with a DAT recorder, as described in Section 2.5. These measurements were made at various places along the edge of the platform at the Downtown Crossing (Red and Orange Lines) and Wood Island (Blue Line) passenger platform stations. The reference probe was placed on the platform floor inward from the edge, on a line directly behind the staff at the approximate locations designated with small rectangles in Figures 6-1, 6-2 and 6-3. The continuous field recordings made on these platforms are identified as Tape 1/Group 2, Records 10 through 14 and Tape 2/Group 1, Records 8 through 10 in Table 2-2. Pertinent data concerning the time and duration of these measurements and the key to the specific sensor location are found in that table. These recordings contain better detail of the temporal characteristics of the static fields than do the repetitive waveform data because there are no interruptions necessary to store the incoming data from the single sensor. These recordings were scanned for rapid transients then converted into total (resultant) magnetic field and plotted to show the fine temporal characteristics of the static field. One of these time plots was presented in the preceding subsection (Figure 6-7).

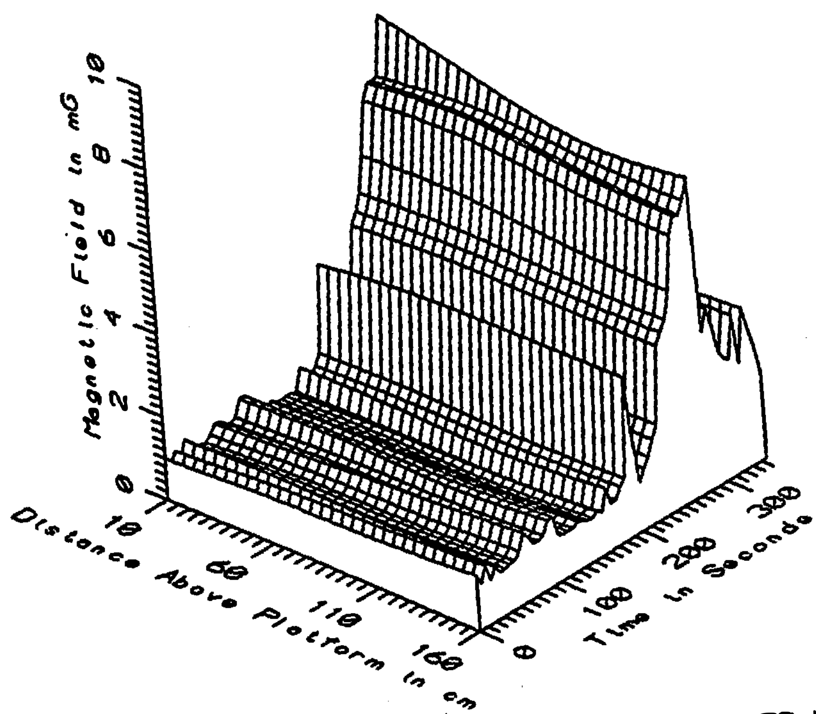
Statistical summaries of static magnetic field levels measured by the DAT Recording System on the station platforms are presented in Table 6-2.

6.5 RMS RECORDER DATA

As stated previously, there are two major difficulties in analyzing and interpreting rms recorder data collected near the Boston MBTA



BOS038 - AT GOVERNMENT CENTER, GREEN LINE - POWER FREQ, 50-60Hz



BOS038 - AT GOVERNMENT CENTER, GREEN LINE - POWER HARM, 65-300Hz

FIGURE 6-10. MAGNETIC FIELD LEVEL VERSUS DISTANCE FROM THE FLOOR, FOR THE POWER FREQUENCY (50-60 Hz) AND THE POWER FREQUENCY HARMONICS (65-300 Hz) COMPONENTS, AT THE GREEN LINE GOVERNMENT CENTER PLATFORM, AS A FUNCTION OF TIME

TABLE 6-2.

SUMMARY OF STATIC MAGNETIC FIELD LEVELS RECORDED ON THE STATION PLATFORMS WITH THE DIGITAL AUDIO TAPE RECORDER (DAT) AS TRAINS PASS

STATION/ LOCATION	MEASUREMENT LOCATION CODE		STATIC MAGNETIC FIELD MILLIGAUSS		
(TAPE/GROUP /RECORD)	FIG. #	LOCATION	MINIMUM	AVERAGE	MAXIMUM
ORANGE LINE DOWNTOWN CROSSING					
DEPART. END (1/2/10)	6-1	37	186 mG	346 mG	437 mG
ARRIV. END (1/2/11)	6-1	67	177 mG	464 mG	741 mG
RED LINE DOWNTOWN CROSSING					
ARRIV. END (1/2/12)	6-1	33	327 mG	434 mG	591 mG
ARRIV. END (1/2/13)	6-1	33	200 mG	463 mG	836 mG
DEPART. END (1/2/14)	6-1	35	356 mG	590 mG	1729 mG
BLUE LINE WOOD ISLAND					
DEPART. END (2/1/8)	6-2	41	164 mG	224 mG	288 mG
DEPART. END (2/1/9)	6-2	41	212 mG	399 mG	781 mG
ARRIV. END (2/1/10)	6-2	39	268 mG	384 mG	600 mG
ALL STATIONS	---	---	164 mG	457 mG	1729 mG

transit system. First of all, researchers carrying the recorders neither follow a particular path nor keep an exact log of their location. In areas where there is a large spatial gradient in the field, such as near the edge of the station platform, the field value recorded is highly dependent on the position of the wearer. The second difficulty arises because much of the time varying field near the dc-powered MBTA System is in the low frequencies below the response band of the rms recorders. However, the rms recordings on the Red and Orange Lines at the Downtown Crossing platform are appropriate because the significant time varying magnetic fields are 60 Hz, 180 Hz and some even harmonics, within the frequency bandwidth of the rms recorder monitor.

Table 6-3 shows the statistics for these rms records at the Downtown Crossing passenger station platforms. The average and maximum values are more indicative of the background time varying field levels at the station from common 60 Hz electric power circuits unrelated to the transportation system and even rectification harmonics.

TABLE 6-3.

SUMMARY OF MAGNETIC FIELD LEVELS RECORDED ON THE RED AND ORANGE LINE PASSENGER PLATFORMS AT DOWNTOWN CROSSING USING RMS RECORDERS

	AVERAGE	MAXIMUM
RED LINE / DOWNTOWN CROSSING		
RMS RECORDER #1	1.26 mG	4.8 mG
RMS RECORDER #2	1.67 mG	5.5 mG
BOTH	1.46 mG	5.5 mG
ORANGE LINE / DOWNTOWN CROSSING		
RMS RECORDER #1	4.18 mG	7.8 mG
RMS RECORDER #2	5.99 mG	11.9 mG
BOTH	5.09 mG	11.9 mG

NOTE: RMS recorder data was not collected on the other platforms.

6.6 SUMMARY OF MAGNETIC FIELD LEVELS

The major sources of magnetic fields associated with the MBTA transit system are the currents in the rails as MBTA transit cars travel, brake or accelerate and the current in the traction power control circuits beneath the cars. These add to the background fields in the stations which arise primarily from the earth's magnetism and 60 Hz electric power circuits in or near the stations and produce the total field environment of the stations. Appendices W through AA, AL through AO, and AX and AY contain the data from measurements of the total ULF and ELF magnetic field environment at all the MBTA platforms. Due to the large temporal variability of the fields at the edge of the station platforms, they must be quantified statistically.

In order to produce general and reliable descriptions of field intensity, datasets found to have similar characteristics are pooled. Positions along the edge of the platform influenced the temporal characteristics of the field, but did not influence frequency, intensity, nor spatial variability to any large extent. Hence, all of the datasets at the platform edge at each station are pooled. The classification of Subsection 6.3 is also used in the overall statistical summaries.

Table 6-4 has the overall statistics of the combined datasets BOS022 through BOS026, BOS039 and BOS040. These are all vertical profile datasets taken at the safety line near the edge of the Red Line and Orange Line at Downtown Crossing, and Blue Line at Government Center platforms. These datasets are all associated with cam type cars and third rail operation. All data were taken while some train activity was present. The combined datasets give a good indication as to the field levels that can be expected at the safety line. The maximum readings presented in Table 6-4 are associated with train passes, such as the one shown in Figure 6-4. Attenuation of the maximum fields with increased heights is evident in all frequency bands except the power frequency band. That is because the MBTA Transit System does not produce significant fields in the power frequency band. Average field levels are to a large extent dominated by fields from sources other than the MBTA transit system, therefore there is much less evidence of field attenuation with height in the average field strength data.

Table 6-5 has the overall statistics of the combined datasets BOS049 and BOS050. These are all vertical profile datasets taken at the safety line near the edge of the Blue Line Wood Island platform. These two datasets are associated with cam type cars but operating with a catenary. The combined datasets give a good indication as to the field levels that can be expected at the safety line. The maximum reading of 7.9 mG presented in Table 6-5 is associated with the power harmonics which are predominantly rectifier ripple.

Table 6-6 has the overall statistics of datasets BOS037 and BOS038. These are vertical profile datasets taken on the Green Line platform at Government Center, at the yellow line safety edge. They are indicative of the field levels that can be expected at times of train activity on a platform associated with a third rail operation and chopper type cars. The maximum reading of 16.2 mG occurred in the power harmonics range, again indicative of rectifier ripple.

TABLE 6-4.

STATISTICAL SUMMARY OF THE MAGNETIC FIELD LEVEL OF COMBINED VERTICAL DATASETS AT THE SAFETY LINE AT MBTA PLATFORM FOR CAM CARS AND THIRD RAIL OPERATION (DATASETS BOS022 THROUGH BOS026, BOS039 AND BOS040)

BOS022 - 026, 039, 040 - ORANGE, RED, AND BLUE LINE PLATFORMS					TOTAL OF 106 SAMPLES	
FREQUENCY BAND	HEIGHT ABOVE FLOOR (cm)	MINIMUM MAGNETIC FIELD (mG)	MAXIMUM MAGNETIC FIELD (mG)	AVERAGE MAGNETIC FIELD (mG)	STANDARD DEVIATION (mG)	COEFFICIENT OF VARIATION (%)
STATIC	10	185.02	2411.25	791.27	506.07	63.96
	60	187.94	1265.73	504.50	224.72	44.54
	110	182.56	892.05	444.40	156.39	35.19
	160	197.53	771.46	434.52	127.58	29.36
5-45Hz LOW FREQ	10	0.30	20.52	2.71	3.94	145.63
	60	0.32	11.30	1.51	2.05	135.73
	110	0.22	12.46	1.72	2.44	141.68
	160	0.30	10.58	1.62	2.12	130.74
50-60Hz PWR FREQ	10	0.42	9.51	3.80	3.10	81.61
	60	0.39	4.28	2.02	1.19	59.16
	110	0.37	3.11	1.93	0.81	41.75
	160	0.34	4.65	2.28	1.37	59.80
65-300Hz PWR HARM	10	0.21	4.08	1.76	1.00	57.11
	60	0.24	2.78	1.05	0.50	47.96
	110	0.25	2.55	1.36	0.74	54.20
	160	0.28	3.04	1.45	0.93	64.37
305-2560Hz HIGH FREQ	10	0.20	2.23	1.05	0.41	38.46
	60	0.18	1.42	0.54	0.20	37.02
	110	0.21	1.26	0.69	0.20	29.22
	160	0.24	1.13	0.63	0.17	27.31
5-2560Hz ALL FREQ	10	1.34	23.02	5.79	4.31	74.42
	60	0.89	11.72	3.09	2.01	65.12
	110	1.25	12.68	3.35	2.22	66.20
	160	1.07	11.75	3.56	2.21	62.03

TABLE 6-5.

STATISTICAL SUMMARY OF THE MAGNETIC FIELD LEVEL OF COMBINED VERTICAL DATASETS AT THE SAFETY LINE ON THE WOOD ISLAND STATION PLATFORM OF THE BLUE LINE FOR CAM CARS AND CATENARY OPERATION (DATASETS BOS049 AND BOS050)

BOS049, 050 - ON WOOD ISLAND STATION PLATFORM, BLUE LINE					TOTAL OF 12 SAMPLES	
FREQUENCY BAND	HEIGHT ABOVE FLOOR (cm)	MINIMUM MAGNETIC FIELD (mG)	MAXIMUM MAGNETIC FIELD (mG)	AVERAGE MAGNETIC FIELD (mG)	STANDARD DEVIATION (mG)	COEFFICIENT OF VARIATION (%)
STATIC	10	420.65	1718.22	912.59	406.07	44.50
	60	264.65	1105.57	610.77	201.33	32.96
	110	169.25	970.47	484.56	186.28	38.44
	160	164.84	808.29	444.32	166.84	37.55
5-45Hz LOW FREQ	10	0.57	33.92	3.92	9.46	241.15
	60	0.50	68.77	6.55	19.60	299.14
	110	0.30	81.41	7.43	23.30	313.73
	160	0.34	65.04	6.02	18.59	308.67
50-60Hz PWR FREQ	10	1.35	6.42	3.76	1.75	46.45
	60	1.38	4.48	2.96	1.13	38.26
	110	1.39	4.92	2.65	0.99	37.30
	160	1.26	4.26	2.32	0.82	35.12
65-300Hz PWR HARM	10	0.71	6.07	1.52	1.50	98.59
	60	0.57	6.36	1.31	1.60	122.67
	110	0.46	7.92	1.41	2.06	146.01
	160	0.37	5.86	1.14	1.50	132.25
305-2560Hz HIGH FREQ	10	0.67	3.71	1.73	1.00	57.70
	60	0.76	3.30	1.33	0.67	50.40
	110	0.77	3.88	1.27	0.85	67.31
	160	0.46	3.06	1.20	0.66	55.47
5-2560Hz ALL FREQ	10	2.78	34.96	7.14	8.85	123.97
	60	2.06	69.29	8.88	19.04	214.41
	110	1.88	82.03	9.51	22.85	240.33
	160	1.54	65.51	7.85	18.17	231.30

TABLE 6-6.

STATISTICAL SUMMARY OF THE MAGNETIC FIELD LEVEL OF COMBINED VERTICAL DATASETS AT THE SAFETY LINE ON THE GOVERNMENT CENTER PLATFORM OF THE GREEN LINE FOR CHOPPER CARS AND THIRD RAIL OPERATION (DATASETS BOS049 AND BOS050)

BOS037, 038 - ON GOVERNMENT CENTER PLATFORM, GREEN LINE TOTAL OF 86 SAMPLES						
FREQUENCY BAND	HEIGHT ABOVE FLOOR (cm)	MINIMUM MAGNETIC FIELD (mG)	MAXIMUM MAGNETIC FIELD (mG)	AVERAGE MAGNETIC FIELD (mG)	STANDARD DEVIATION (mG)	COEFFICIENT OF VARIATION (%)
STATIC	10	124.50	841.36	499.87	153.84	30.78
	60	159.25	795.62	496.07	145.76	29.38
	110	147.11	764.83	493.68	154.80	31.36
	160	168.75	911.91	558.46	187.42	33.56
5-45Hz LOW FREQ	10	0.49	7.28	2.11	1.63	77.64
	60	0.54	7.46	2.11	1.57	74.68
	110	0.51	7.98	2.04	1.53	75.23
	160	0.50	7.67	1.95	1.44	73.74
50-60Hz PWR FREQ	10	0.40	3.76	0.82	0.53	65.04
	60	0.41	3.83	0.83	0.51	62.07
	110	0.43	3.73	0.85	0.48	57.03
	160	0.54	3.68	0.92	0.46	50.11
65-300Hz PWR HARM	10	0.71	15.13	2.67	2.28	85.39
	60	0.71	16.23	2.70	2.31	85.69
	110	0.69	14.15	2.63	2.12	80.53
	160	0.64	10.56	2.65	1.86	70.01
305-2560Hz HIGH FREQ	10	0.40	7.84	1.17	1.07	91.49
	60	0.40	7.30	1.16	1.02	88.14
	110	0.41	6.21	1.10	0.87	78.85
	160	0.39	5.47	1.10	0.75	68.50
5-2560Hz ALL FREQ	10	1.26	16.60	4.00	2.63	65.74
	60	1.37	17.57	4.02	2.60	64.75
	110	1.39	15.15	3.89	2.38	61.15
	160	1.55	11.28	3.85	2.09	54.33

6.7 SUMMARY OF ELECTRIC FIELD LEVELS

No significant levels of time varying electric field were present on MBTA transit system station platforms. The average levels were typically in the range of 0.5 V/m, with peak levels of about less than 4 V/m. The plots of the electric field as a function of frequency and time for the electric field measurements are contained in the corresponding appendices.

7. POWER SUPPLY SYSTEM MEASUREMENTS

The power supply system for the Boston MBTA transit system is comprised of a few large traction power supply stations spaced along the various lines and trolleys. These stations are combined transformer and rectifier facilities which convert commercial three-phase 60 Hz ac electric power distributed at 13.8 kV to 600 V dc to feed the third rail. This section of the report covers the fields recorded in the vicinity of three different traction power stations.

7.1 MEASUREMENT LOCATIONS

The three representative TPSS locations surveyed are:

1. The Boston South Station located on High Street close to the downtown area.

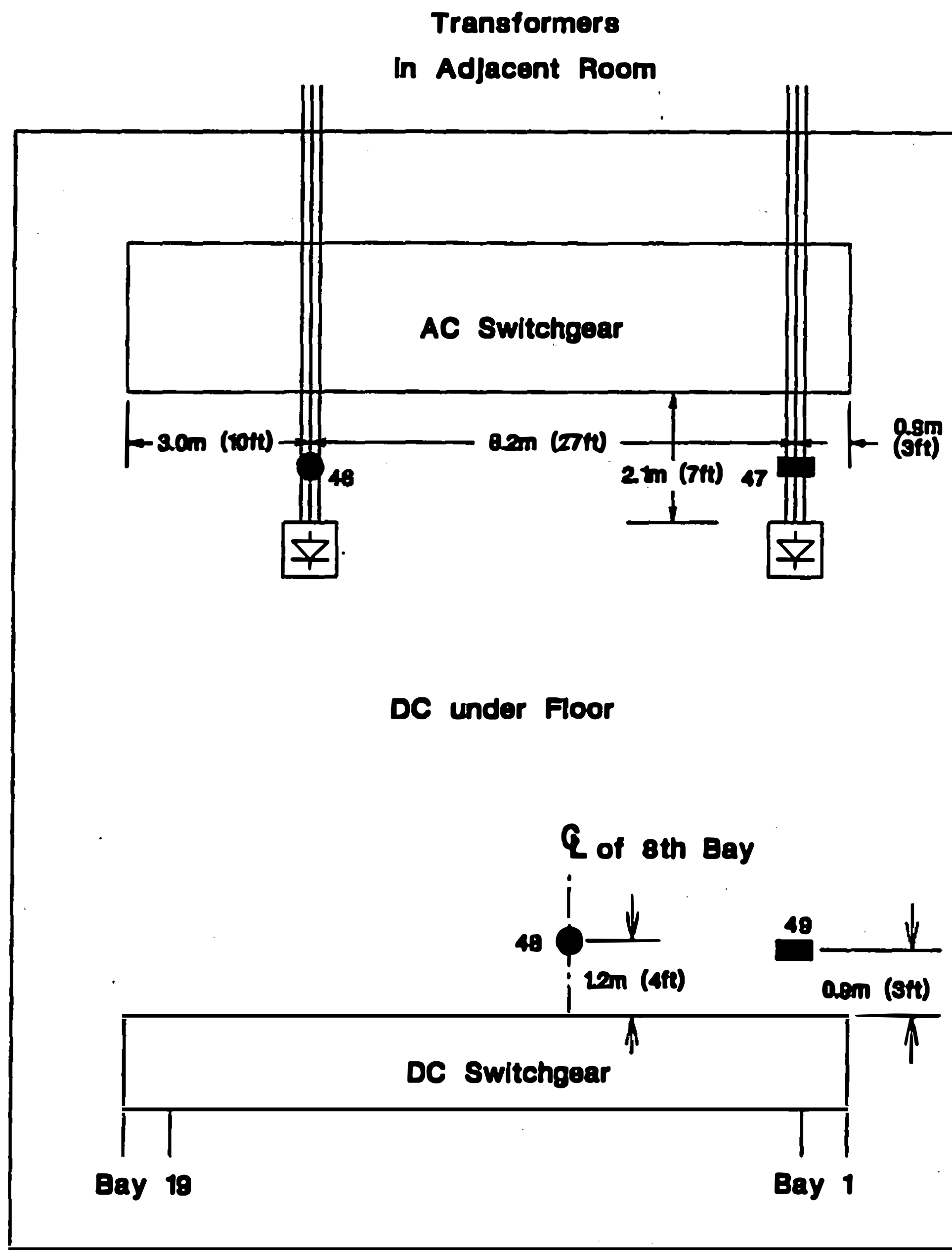
2. The South Boston TPSS, also called the South Boston switching station, located in the south of downtown.

3. The Bennett Street TPSS located northwest of downtown.

Figure 7-1 shows a plan view of the TPSS located on High Street. The room measures approximately 12.2 m (40 ft) by 15.3 m (50 ft) and it contains ac switchgear, rectifiers and dc switchgear. Transformers are said to be behind the wall. Power comes in at 13.8 kV, 60 Hz under the floor to the ac switchgear and then, still under the floor, to the transformers. From the transformers, it travels 2.7 m (9 ft) overhead to the rectifiers in the middle of the room. The 600 V dc from the rectifiers goes under the floor to the dc switchgear and in turn is used to supply the third rail (or catenary) along the MBTA transit lines.

As shown in the figure, measurements at fixed positions over extended time were made close to both the ac and dc switchgear cabinets. The first measurements were made with the staff in a vertical position at a location underneath the six phase ac lines going into one of the two rectifiers, Location #46. The reference probe was under the other six phase line, 8.2 m (27 ft) from the staff. The next measurements were taken with the staff again in vertical position in front of the dc switchgear, in the middle of the 8th Bay. The reference probe was located on the floor near Bay 1. These measurements are recorded in datasets BOS001 through BOS003. The plots of the recorded data are given in Appendices B through D, respectively. The data was collected between 09:58 and 10:18 on June 9, 1992.

Figure 7-2 shows the traction power supply station at South Boston. The main switchgear room is surrounded by four bus rooms, which



High Street Traction Power Supply Station

FIGURE 7-1. REPETITIVE WAVEFORM MEASUREMENT LOCATIONS AT THE HIGH STREET TRACTION POWER SUPPLY STATION

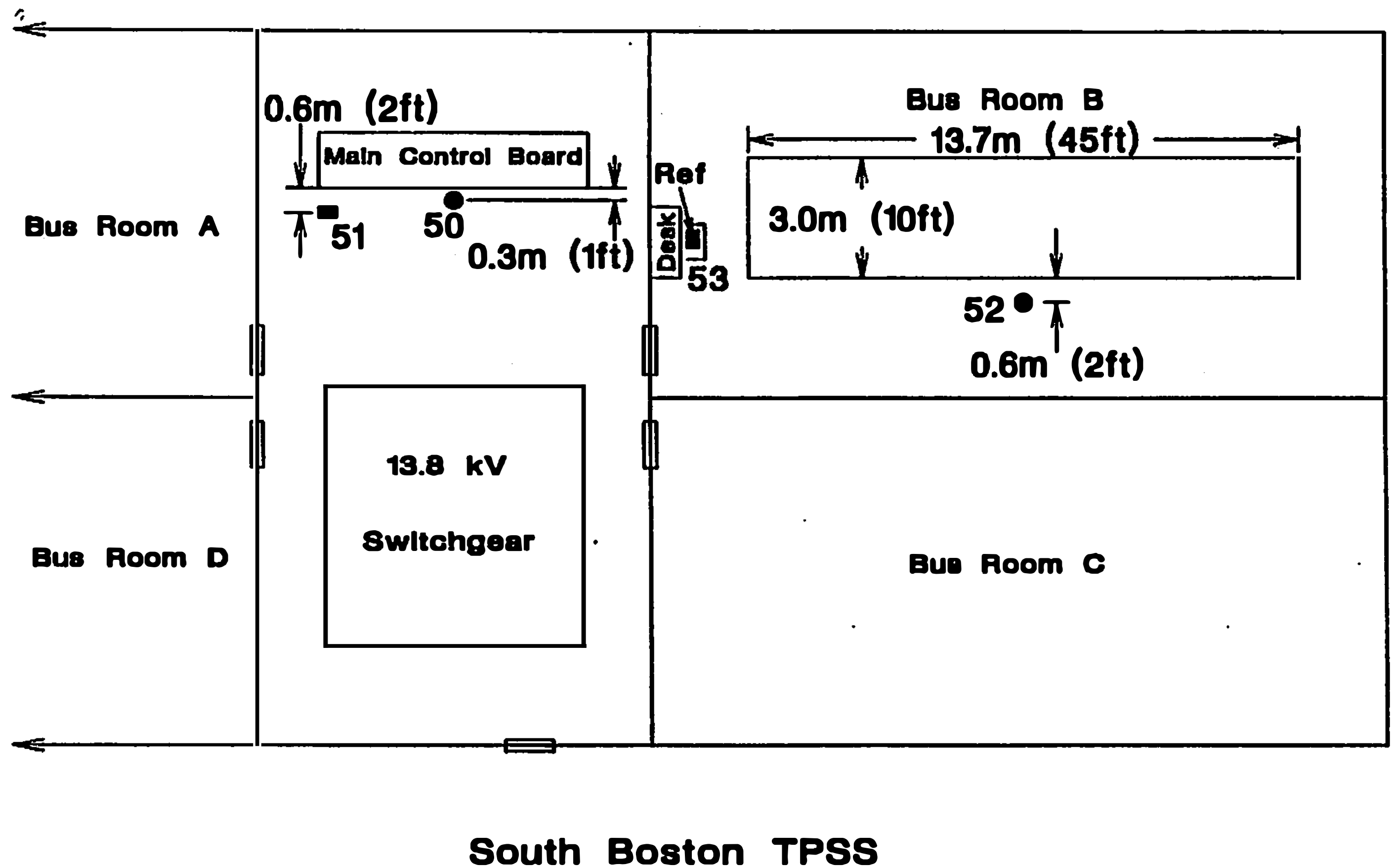


FIGURE 7-2. REPETITIVE WAVEFORM MEASUREMENT LOCATIONS AT THE SOUTH BOSTON TRACTION POWER SUPPLY STATION

contain electric equipment, possibly rectifiers. The ac is distributed to the four bus rooms via a ring bus overhead at a height of 3.1 m (10 ft). All other electrical cabling is done under the floor. The staff was placed vertically at the center of the main control board and .3 m (1 ft) away from it (Location #50). The reference probe was located at one end of the control board and .6 m (2 ft) from it (Location #51). Further measurements were taken inside one of the bus rooms, with the staff in a vertical position .6 m (2 ft) in front of the cabinets (Location #52), with the reference probe located on a chair by a desk on the side wall of the room (Location #53). Measurements were taken on June 9, 1992 from 11:24 to 11:37 and the records are datasets BOS006 and BOS007. Appendices G and H contain the plots of the data contained in these datasets.

Figure 7-3 shows a plan view of the TPSS located on Bennett Street. The room measures approximately 15.3 m (50 ft) by 19.8 m (65 ft) and contains ac switchgear, rectifiers and dc switchgear. Three transformers are located outside the wall on the Bennett Street side in an outdoor structure that is enclosed by louvers. The overhead bus structure that connects the transformers, switchgear and rectifiers travels at a 3.1 m (10 ft) height inside the room. The 600 V dc from the rectifiers goes under the floor to the dc switchgear and in turn is used to supply the third rail (or catenary) along the Boston "T" lines.

As shown in this figure, extended time measurements at fixed positions were made close to both the ac and dc switchgear cabinets and also outside the station. The ac switchgear measurements were made with the staff in a vertical position at a location underneath the middle ac line going into the middle rectifier, Location #54, resulting in dataset BOS008. Then, measurements were taken with the staff in a horizontal position at 1 m (3.3 ft) height in front of the middle rectifier, Location #55, resulting in dataset BOS009. The reference probe was under the other six phase line, 4.6 m (15 ft) from the staff, for both of these measurements. The next measurements were taken with the staff again in vertical position .9 m (3 ft) in front and in the middle of the dc switchgear, Location #57, resulting in dataset BOS010. The reference probe was located on the floor near the end of the cabinet and .9 m (3 ft) away from it, Location #58. The distance between the reference probe and the staff was approximately 3.7 m (12 ft).

The outside measurements were recorded on the sidewalks as dataset BOS011 in the alley (Location #59) and dataset BOS012 on the street side (Location #61). The street side measurements were positioned so as to have the staff and the reference probe in line with the axes of two of the transformers, approximately 4.6 m (15 ft) apart. The plots of the recorded data for all these datasets are given in Appendices I through M, respectively. The data was collected between 13:32 and 14:10 on June 9, 1992.

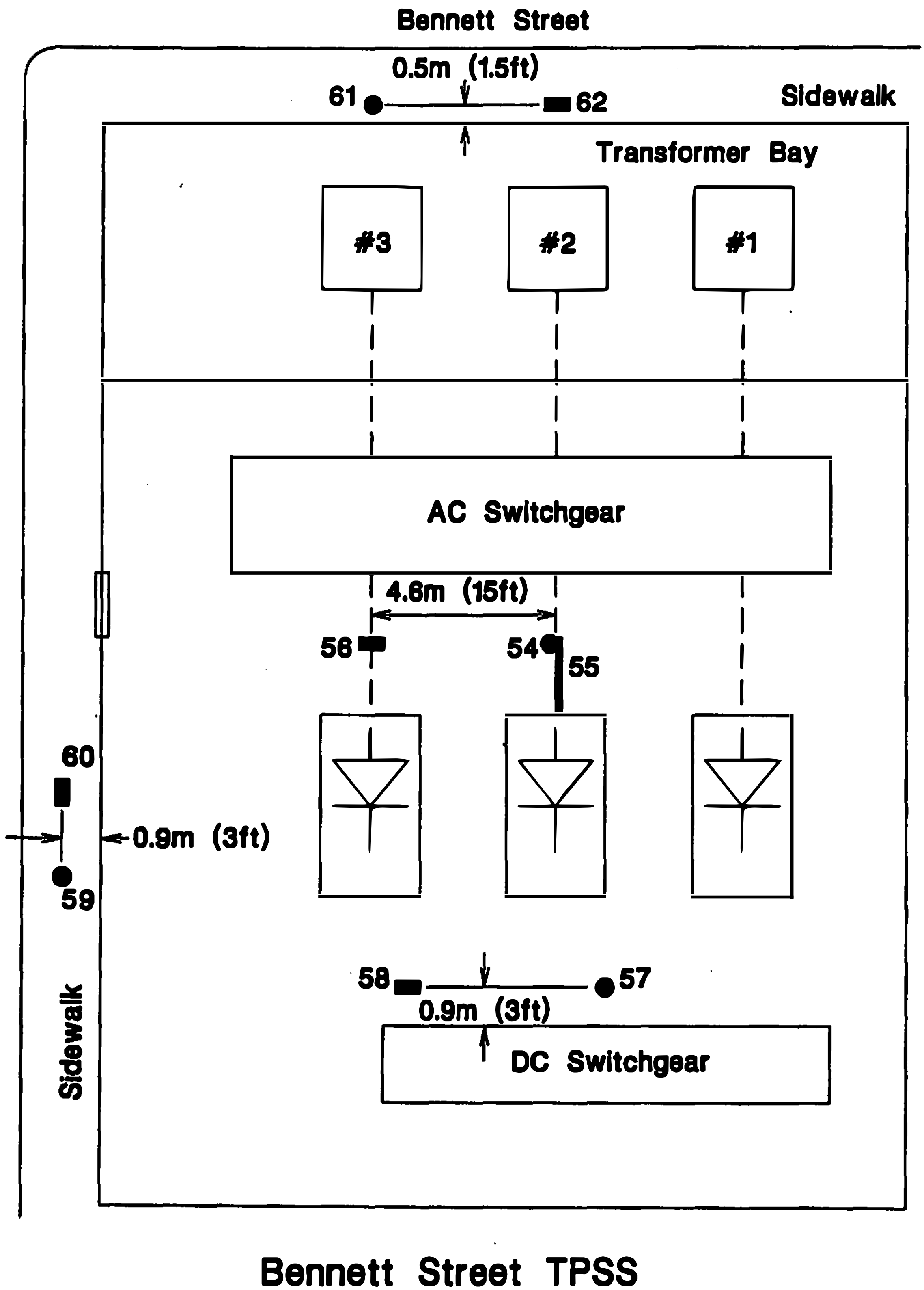


FIGURE 7-3. REPETITIVE WAVEFORM MEASUREMENT LOCATIONS AT THE BENNETT STREET TRACTION POWER SUPPLY STATION

7.2 REPETITIVE WAVEFORM DATASETS

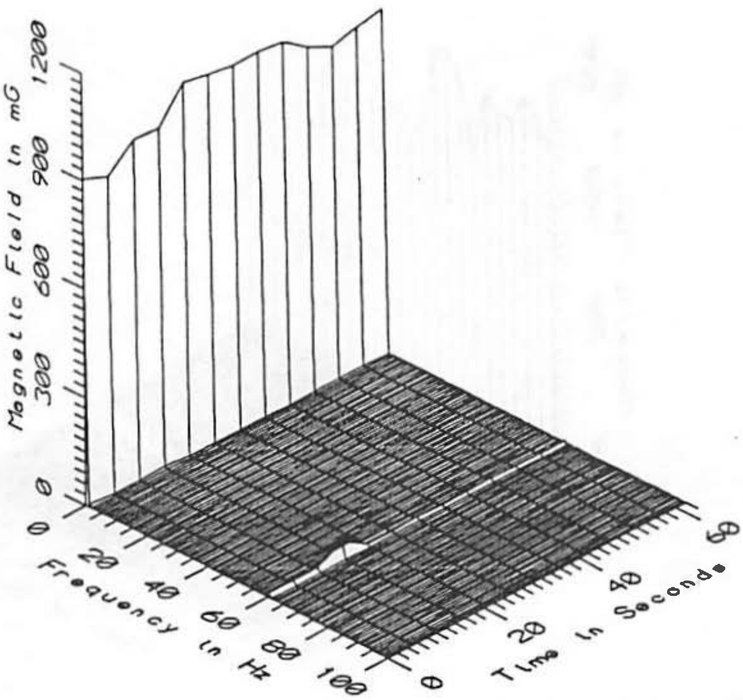
The ten repetitive waveform datasets that are associated with the TPSS measurements are shown in Table 2-1. The data was recorded with the waveform capture system. The table summarizes the pertinent information about these datasets, including the corresponding appendix number, number of samples, associated figure number and location of the probes. The appendices contain figures that are three-dimensional graphs of the magnetic field versus frequency over time, horizontal profiles of the magnetic field versus distance from the station over time, and electric field graphs, where applicable.

7.3 MAGNETIC FIELD CHARACTERISTICS

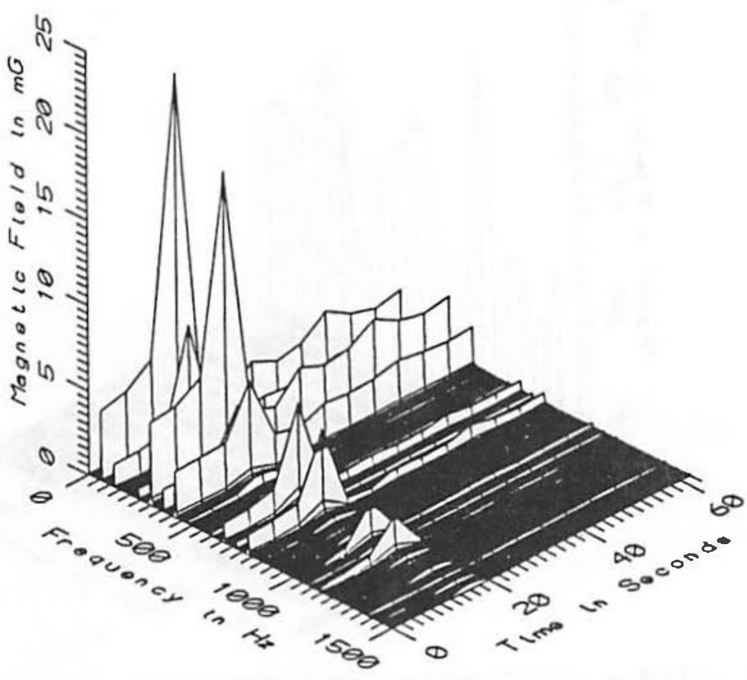
The magnetic fields inside TPSSs arise from several sources. These include the transformers, rectifiers, switchgear equipment cabinets, cabling or feeders and house wiring within the station. Outside the TPSS, the potential magnetic field sources include the previous list of equipment in the building and any nearby third rail or catenary and track circuit, or other nearby power lines or equipment unrelated to the MBTA facilities.

The magnetic field data in these TPSS datasets, for all stations, show several different patterns, amenable to classification by location within the station, i.e., proximity to different equipment. The patterns are not always pure, which indicates multiplicity of sources in that vicinity. The classification is in three parts: proximity to ac switchgear and ac cabling; proximity to dc switchgear, rectifiers and dc cabling; and other miscellaneous locations, such as near a control panel or at a desk. The outside measurements are analyzed separately and are compared to the wayside measurements discussed in Section 5.

The first pattern associated with the ac circuitry shows mostly the 60 Hz fundamental and its odd harmonics. Figure 7-4 is the 110 cm probe of dataset BOS001 and is illustrative of this pattern. The staff was placed near the ac switchgear and under the overhead six phase lines in the High Street Station. The lower frame indicates that the odd harmonics follow the temporal pattern of the fundamental. Figure 7-5 is the 110 cm probe of dataset BOS008, measured in front of the ac switchgear in the Bennett Street Station and it also illustrates this pattern, although the harmonics are low in magnitude. The temporal variation of the ac components is what might be expected from changes in electric load on the station which is reflected in the currents. Although, the dc variation of dataset BOS008 indicates that there is a dc side source nearby as well, which will be discussed later. These two datasets are representative of this first pattern.

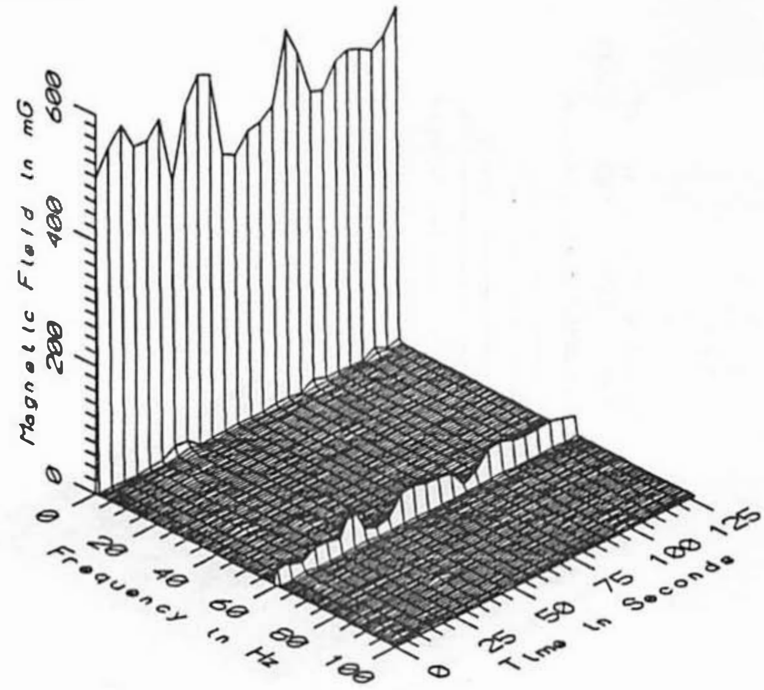


BOS001 - 110cm ABOVE GROUND NEAR RECTIFIER IN HIGH STREET T.P.S.S.

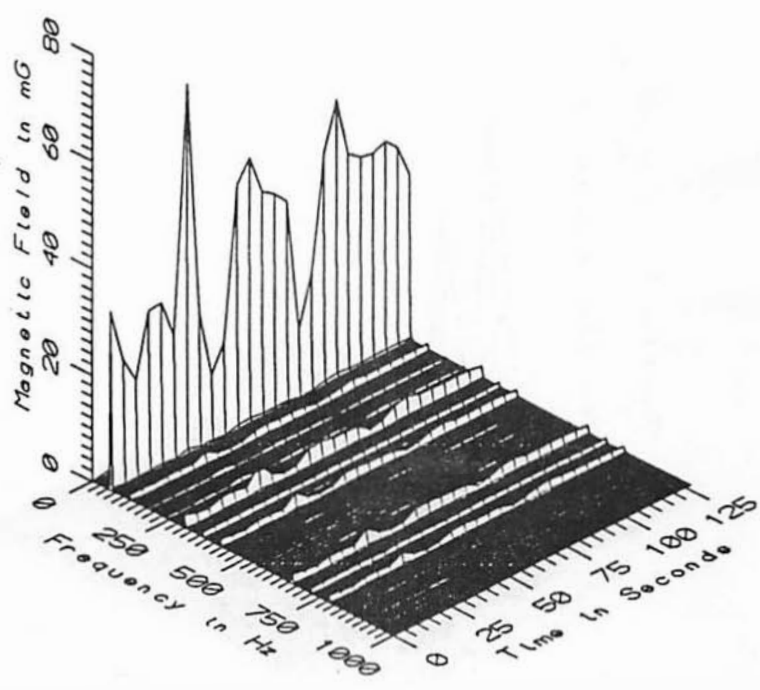


BOS001 - 110cm ABOVE GROUND NEAR RECTIFIER IN HIGH STREET T.P.S.S.

FIGURE 7-4. MAGNETIC FIELD LEVEL, WITH AND WITHOUT THE STATIC COMPONENT, AT 110 cm DISTANCE FROM THE FLOOR INSIDE THE HIGH STREET TRACTION POWER SUPPLY STATION BETWEEN THE RECTIFIER AND THE AC SWITCHGEAR, AS A FUNCTION OF FREQUENCY AND TIME



BOS008 - 110cm ABOVE GROUND NEAR RECTIFIER IN BENNETT ST. T.P.S.S.



BOS008 - 110cm ABOVE GROUND NEAR RECTIFIER IN BENNETT ST. T.P.S.S.

FIGURE 7-5. MAGNETIC FIELD LEVEL, WITH AND WITHOUT THE STATIC COMPONENT, AT 110 cm DISTANCE FROM THE FLOOR INSIDE THE BENNETT STREET TRACTION POWER SUPPLY STATION BETWEEN THE RECTIFIER AND THE AC SWITCHGEAR, AS A FUNCTION OF FREQUENCY AND TIME

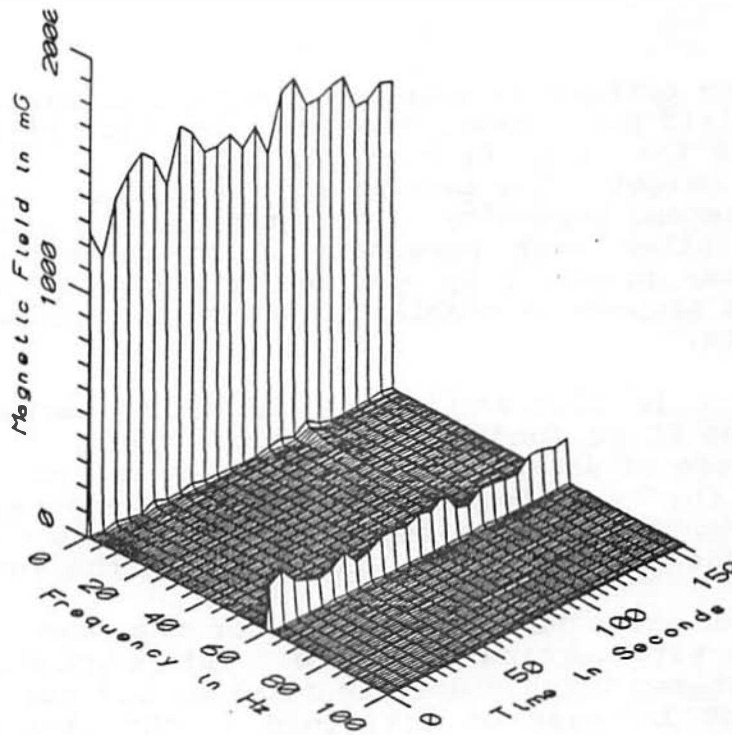
The second pattern is associated with even harmonics. Figure 7-6 is the field plot versus frequency and time of the 10 cm probe in front of the rectifier at the Bennett Street Station at a 1 m (3.3 ft) height. The most prominent frequencies are 60 Hz and 120 Hz (the second harmonic). Their temporal variations in tandem, as are the other even harmonics which correspond to the ripple frequencies produced by the rectification process. The static component temporal variability appears to be unrelated to the other components.

Figure 7-7 is illustrative of the third pattern which contains mostly the 60 Hz fundamental. This figure is the plot of the 110 cm probe of dataset BOS006, near the center of the main control board of the South Boston Station. The temporal variation of the ac components is what might be expected from changes in electric load on the station or the wiring within the room.

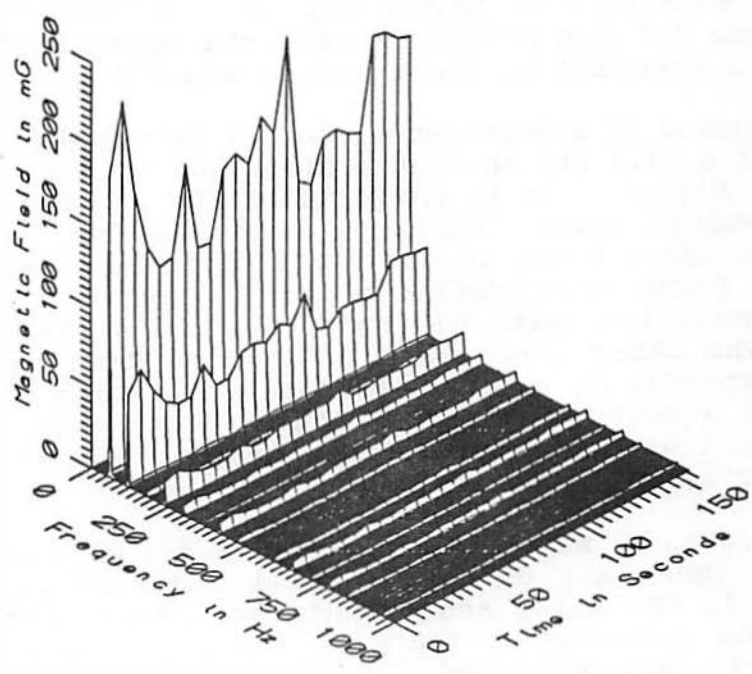
Figure 7-8 shows the attenuation for the power frequency and its harmonics with vertical distance. This figure is the plot of the BOS001 dataset taken under the overhead six phase cables and shows a distinct increase of the field as the ceiling is approached, indicating that the source is overhead. On the other hand, Figure 7-9 shows both fundamental and harmonics increasing both ways: towards the floor and towards the ceiling. This indicates that there are sources both in the ceiling and under the floor. Figure 7-9 is from dataset BOS008, inside the Bennett Station, and there are indeed overhead ac lines and dc under the floor.

Dataset BOS009 is a measurement made with the staff in a horizontal position 1 m (3.3 ft) above the floor and set against the rectifier cabinet. Figure 7-10 is the plot of the magnetic field levels of dataset BOS009 versus distance from the rectifier cabinet over time. The upper frame is the profile of the power frequencies and the lower frame is a profile of the harmonics. Both plots show a sharp attenuation with distance, reaching ambient levels around 60 cm. The other components follow the same pattern, as can be seen in Appendix J. This is a clear indication that the rectifier cabinet is a source of even harmonic fields (see also Figure 7-6). The temporal variation of the components is indicative of changes in the rectifier electric load.

The two outside measurements were made at the Bennett Street Station. These are datasets BOS011 and BOS012, measured on the sidewalks in the alley and the street, respectively. The Bennett Street side measurement (dataset BOS012, Locations 61 and 62 in Figure 7-3) was expected to show a 180 Hz component, third harmonic, because of the proximity to the transformers. This third harmonic is normally present in transformer currents because of the non-linear magnetization curve of the core material. Figure 7-11 is the 110 cm height magnetic field plot of dataset BOS012 as a function of frequency and time. The plot shows only the fundamental and no third harmonic, indicating that the transformer

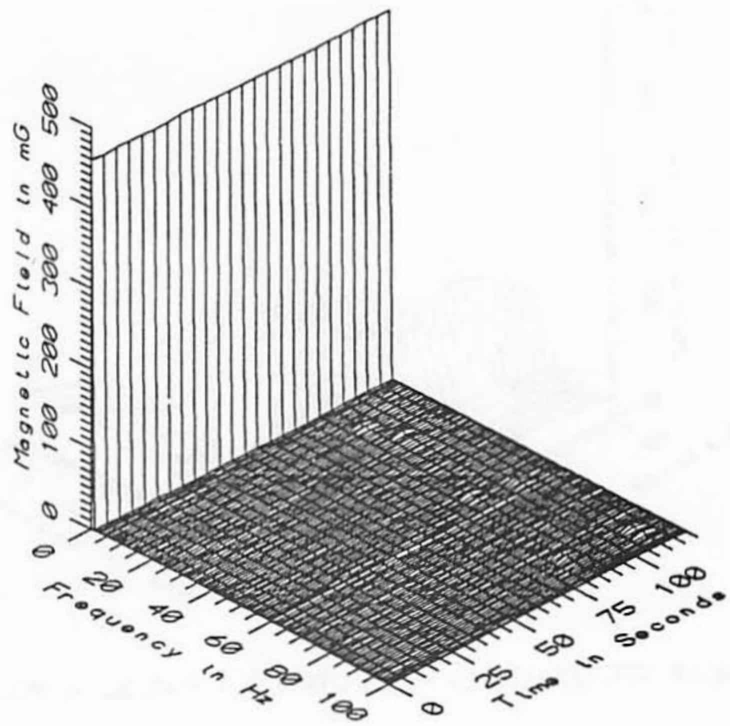


BOS009 - 10cm FROM RECTIFIER, 1M ABOVE GROUND IN BENNETT ST. T.P.S.S.

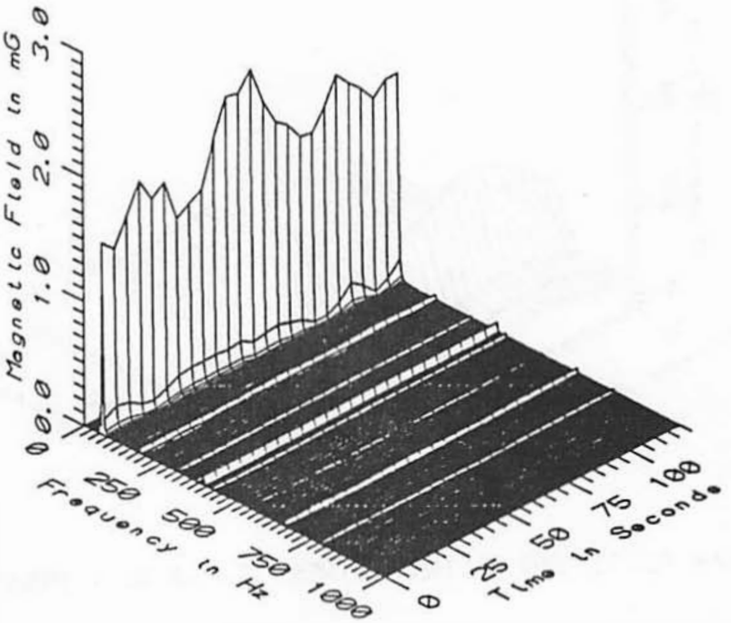


BOS009 - 10cm FROM RECTIFIER, 1M ABOVE GROUND IN BENNETT ST. T.P.S.S.

FIGURE 7-6. MAGNETIC FIELD LEVEL, WITH AND WITHOUT THE STATIC COMPONENT, AT 10 cm DISTANCE FROM THE RECTIFIER CABINET INSIDE THE BENNETT STREET TRACTION POWER SUPPLY STATION, AS A FUNCTION OF FREQUENCY AND TIME

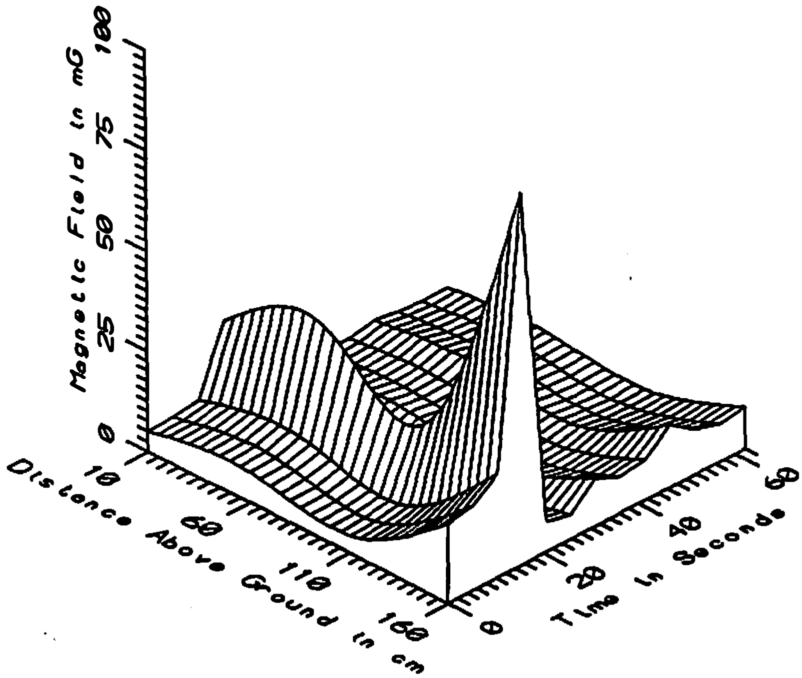


BOS006 - 110cm ABOVE GROUND NEAR MAIN CONTROL BOARD, S. BOSTON T.P.S.S.

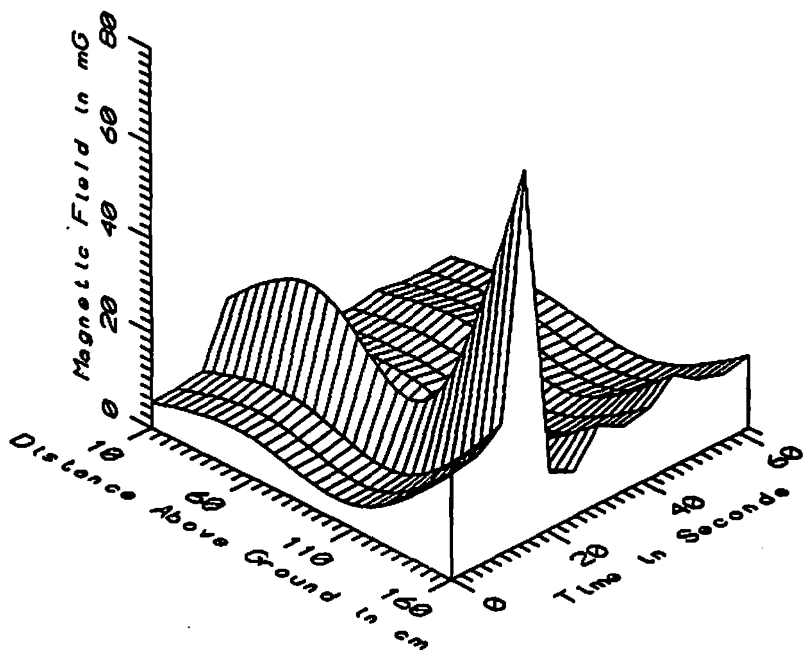


BOS006 - 110cm ABOVE GROUND NEAR MAIN CONTROL BOARD, S. BOSTON T.P.S.S.

FIGURE 7-7. MAGNETIC FIELD LEVEL, WITH AND WITHOUT THE STATIC COMPONENT, AT 110 cm DISTANCE FROM THE FLOOR INSIDE THE SOUTH BOSTON TRACTION POWER SUPPLY STATION NEAR THE MAIN CONTROL BOARD, AS A FUNCTION OF FREQUENCY AND TIME

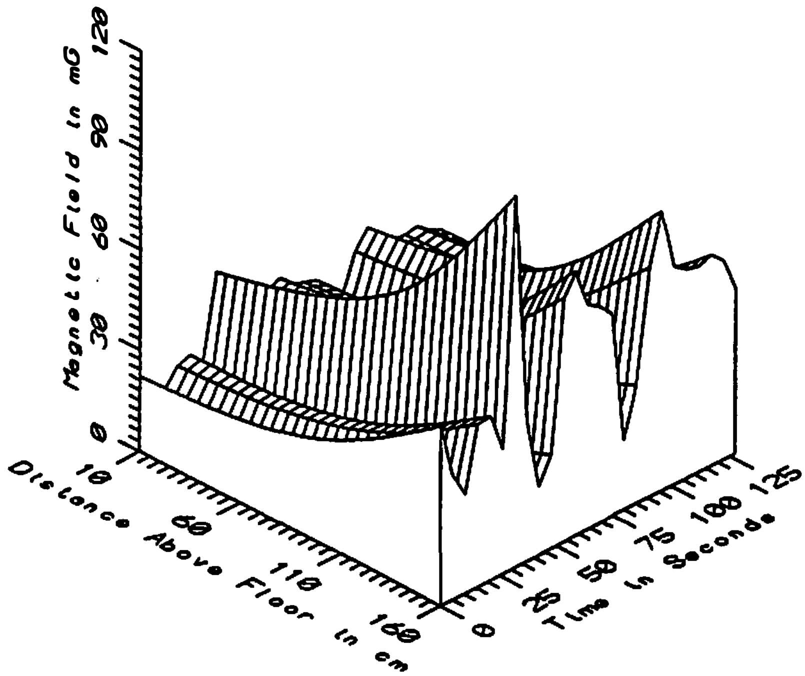


BOS001 - NEAR RECTIFIER IN HIGH STREET T.P.S.S. - POWER FREQ. 50-60Hz

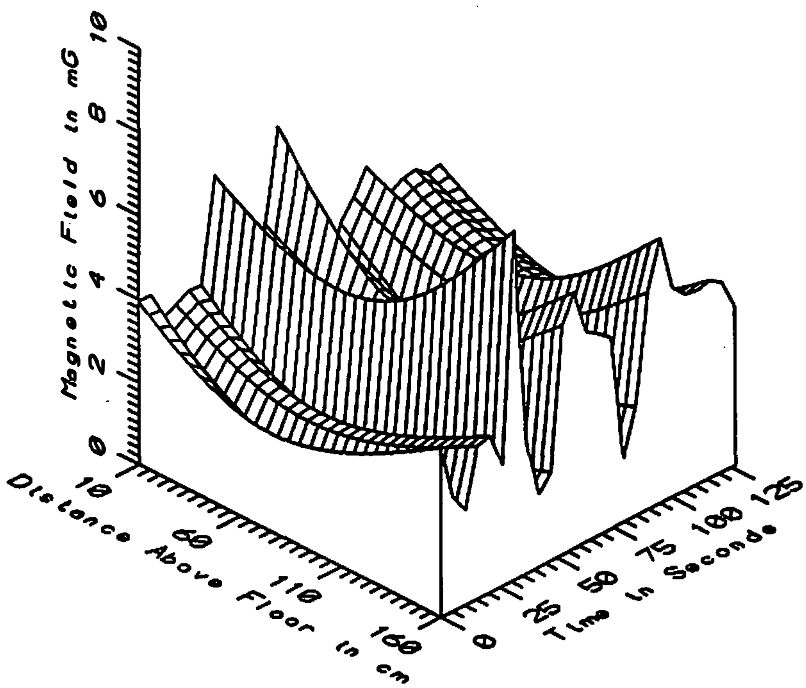


BOS001 - NEAR RECTIFIER IN HIGH STREET T.P.S.S. - POWER HARM. 65-300Hz

FIGURE 7-8. MAGNETIC FIELD LEVEL VERSUS DISTANCE FROM THE FLOOR, FOR THE POWER FREQUENCY (50-60 Hz) AND THE POWER FREQUENCY HARMONICS (65-300 Hz) COMPONENTS, AT THE HIGH STREET TRACTION POWER SUPPLY STATION BETWEEN THE RECTIFIER AND THE AC SWITCHGEAR, AS A FUNCTION OF TIME

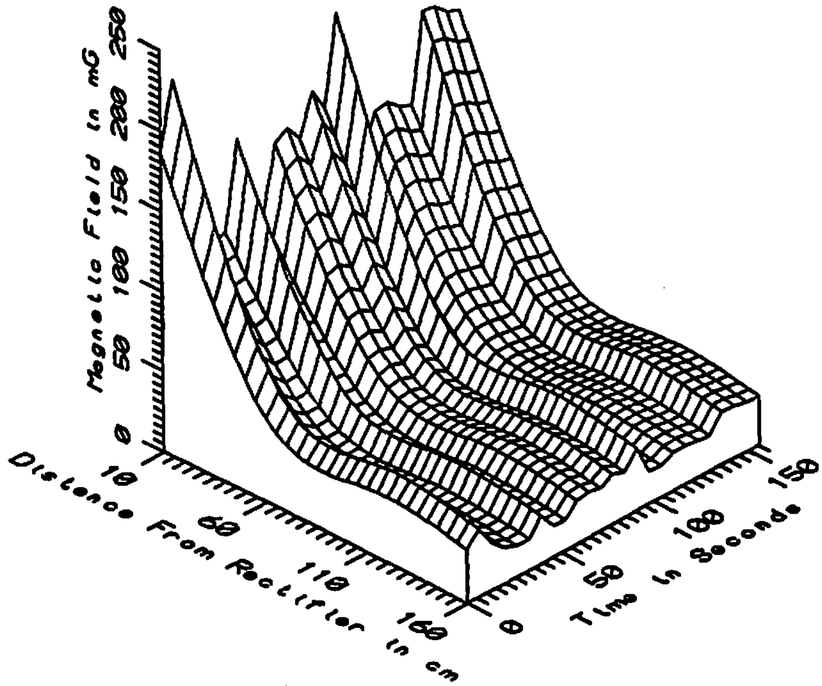


BOS008 - NEAR RECTIFIER IN BENNETT ST. T.P.S.S. - POWER FREQ. 50-60Hz

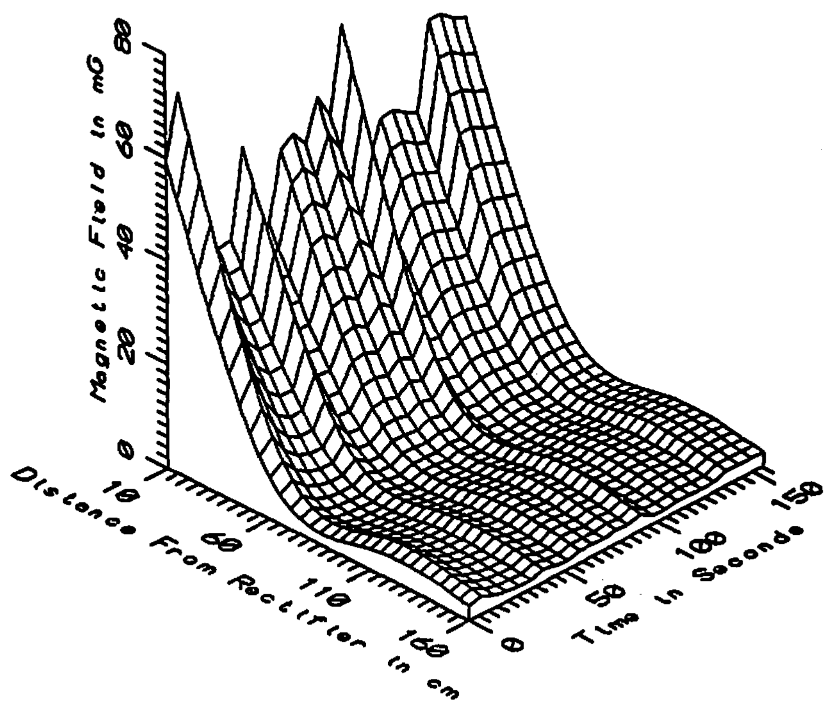


BOS008 - NEAR RECTIFIER IN BENNETT ST. T.P.S.S. - POWER HARM. 65-300Hz

FIGURE 7-9. MAGNETIC FIELD LEVEL VERSUS DISTANCE FROM THE FLOOR, FOR THE POWER FREQUENCY (50-60 Hz) AND THE POWER FREQUENCY HARMONICS (65-300 Hz) COMPONENTS, AT THE BENNETT STREET TRACTION POWER SUPPLY STATION BETWEEN THE RECTIFIER AND THE AC SWITCHGEAR, AS A FUNCTION OF TIME

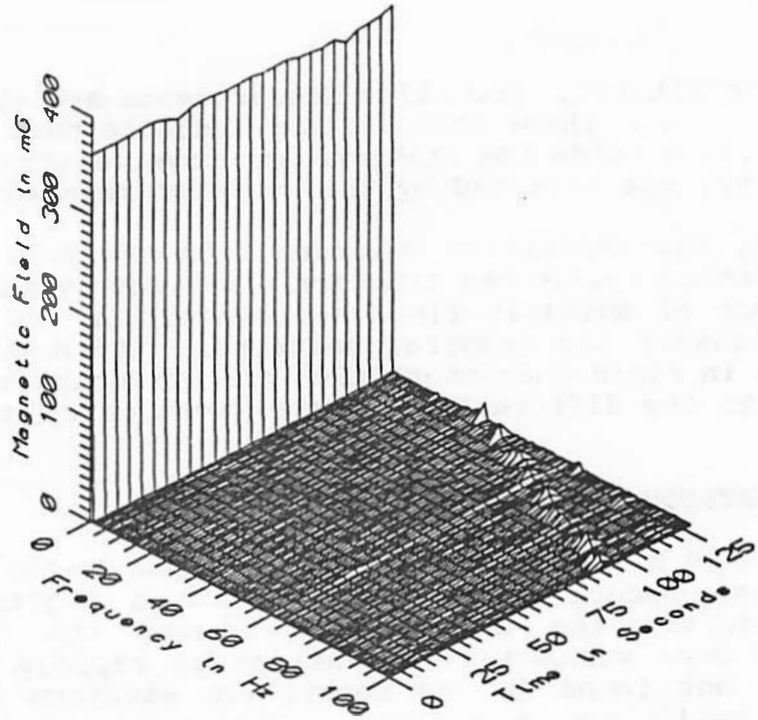


BOS009 - IN BENNETT ST. T.P,S.S., 1M ABOVE GROUND - POWER FREQ. 50-60Hz

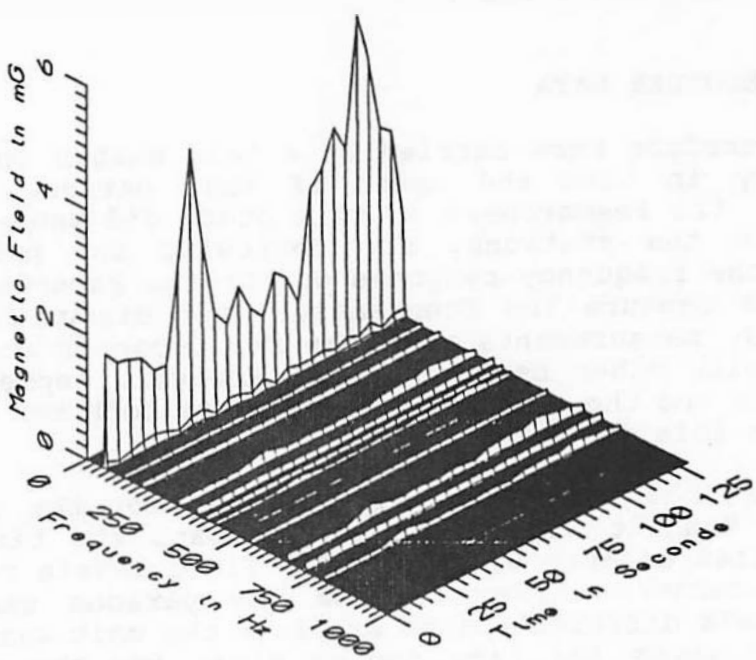


BOS009 - IN BENNETT ST. T.P.S.S., 1M ABOVE GROUND - POWER HARM. 65-300Hz

FIGURE 7-10. MAGNETIC FIELD LEVEL VERSUS DISTANCE FROM THE RECTIFIER CABINET, FOR THE POWER FREQUENCY (50-60 Hz) AND THE POWER FREQUENCY HARMONICS (65-300 Hz) COMPONENTS, AT THE BENNETT STREET TRACTION POWER SUPPLY STATION, AS A FUNCTION OF TIME



BOS012 - 110cm ABOVE SIDEWALK ON BENNETT STREET, BENNETT ST. T.P.S.S.



BOS012 - 110cm ABOVE SIDEWALK ON BENNETT STREET, BENNETT ST. T.P.S.S.

FIGURE 7-11. MAGNETIC FIELD LEVEL, WITH AND WITHOUT THE STATIC COMPONENT, AT 110 cm DISTANCE FROM THE SIDEWALK SURFACE OUTSIDE THE BENNETT STREET TRACTION POWER SUPPLY STATION ON THE STREET SIDE, AS A FUNCTION OF FREQUENCY AND TIME

is not a contributor. The alley measurements are similar in nature (see Appendix L). These observations indicate that the main source of the fields outside the stations are power distribution lines in the vicinity, not affected by the stations themselves.

In summary, the repetitive waveform data analysis magnetic field characteristics inside the traction power supply stations indicate the presence of multiple field sources within the station having unique frequency and temporal patterns. There are also spatial variations in field characteristics and strength, depending on the proximity to the different type of current carrying apparatus.

7.4 DAT WAVEFORM DATA

Magnetic field data from the reference probe of the field waveform recorder was recorded continuously with a digital, audio tape recorder during the measurements around the TSPPs. Those recordings were scanned for transient or rapidly changing field conditions not found in the repetitive waveform data. No such transient conditions were found. Table 2-2 has the information regarding these TPSS DAT tapes. The TPSS records are in Tape 1, Group 1, Records 1 through 3 and Records 6 through 11; and on Tape 1, Group 2, Records 1 and 2.

7.5 RMS RECORDER DATA

The rms recorders were carried by a team member and thus reflect the history in time and space of that person. As mentioned previously, the researchers in this study did wander about inside and outside the stations, not following any particular path. Moreover, the frequency response of the rms recorder is such that it does not capture low frequencies (for discussion see Section 2.8). Thus, measurements with the rms recorder are difficult to correlate with other measurements. However, representative time course plots and the summary statistics of both rms recordings are included in this report.

Figure 7-12 shows the time course plots for the rms recordings inside the Bennett Street TPSS. It spans the time period from 13:30 to 13:45 on June 9, 1992. The field levels recorded by the two rms recorders differ because the persons wearing the rms recorders walk different paths or place the unit against cabinets. Figure 7-13 shows the time course plots for the rms recordings outside the Bennett Street TPSS facility. It spans the time period from 13:58 to 14:10 on June 9, 1992.

Table 7-1 shows the statistics for all of the recordings inside and outside all three TPSSs.

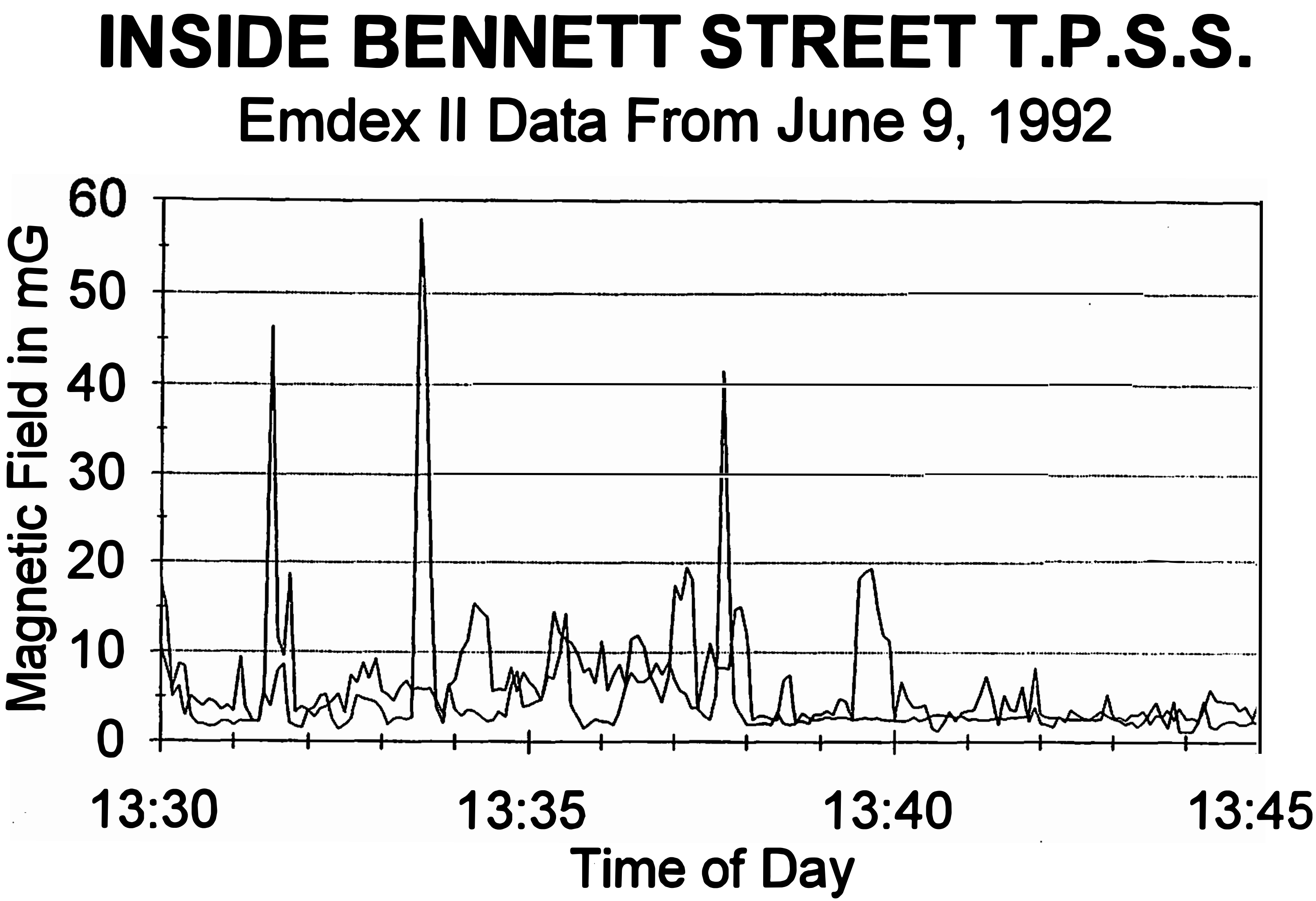


FIGURE 7-12. MAGNETIC FIELD LEVELS RECORDED INSIDE THE BENNETT STREET TRACTION POWER SUPPLY STATION USING THE RMS RECORDERS, AS A FUNCTION OF TIME

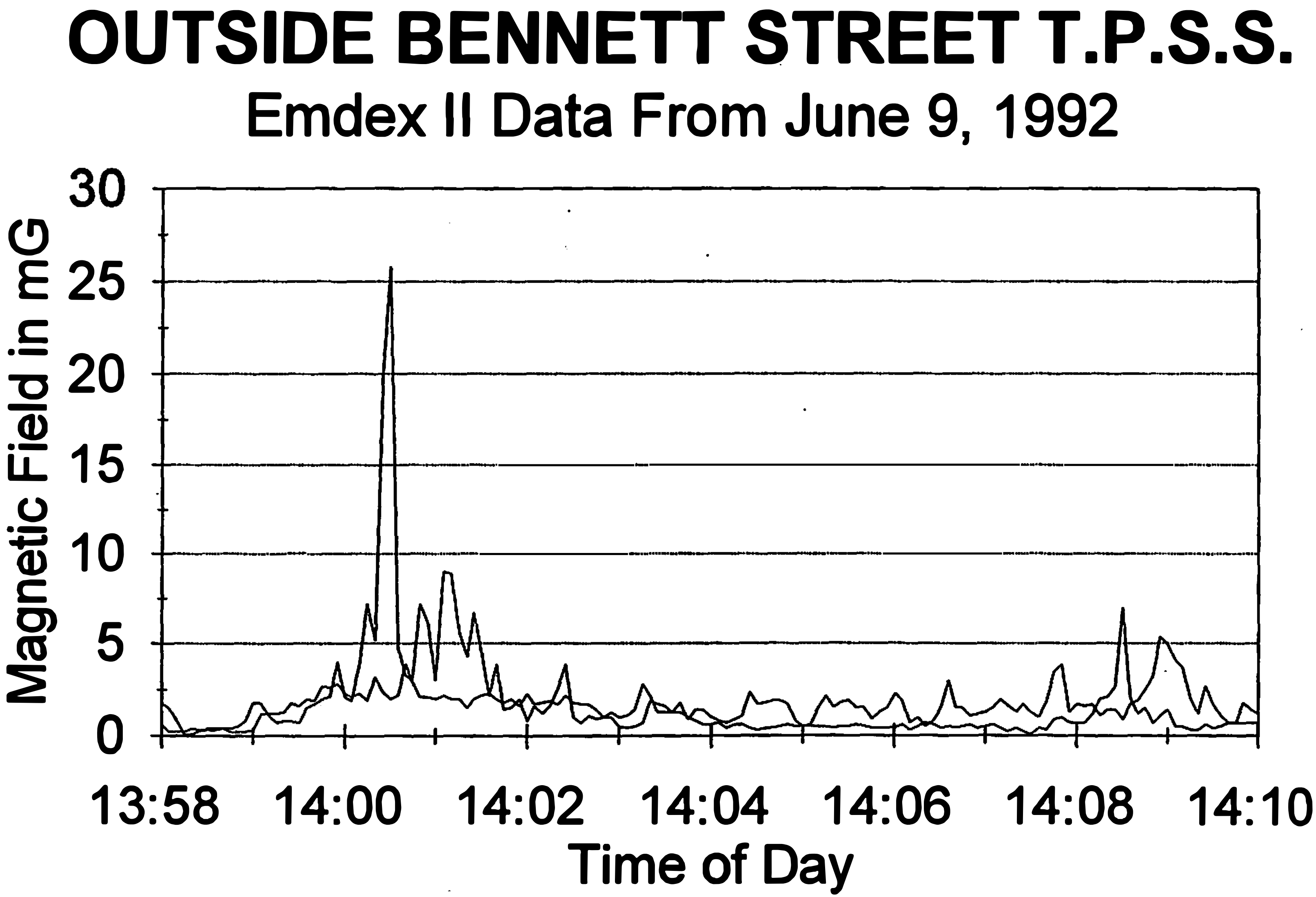


FIGURE 7-13. MAGNETIC FIELD LEVELS RECORDED OUTSIDE THE BENNETT STREET TRACTION POWER SUPPLY STATION USING THE RMS RECORDERS, AS A FUNCTION OF TIME

TABLE 7-1.

STATISTICAL SUMMARY OF MAGNETIC FIELDS IN mG RECORDED INSIDE AND OUTSIDE TRACTION POWER SUPPLY STATIONS USING RMS RECORDERS

	AVERAGE	MAXIMUM
INSIDE HIGH STREET TPSS		
RMS RECORDER #1	6.32	74.8
RMS RECORDER #2	7.33	126.6
BOTH	6.82	126.6
INSIDE SOUTH BOSTON TPSS		
RMS RECORDER #1	2.50	16.6
RMS RECORDER #2	9.87	214.2
BOTH	6.18	214.2
INSIDE BENNETT STREET TPSS		
RMS RECORDER #1	6.37	46.4
RMS RECORDER #2	4.59	58.0
BOTH	5.48	58.0
OUTSIDE BENNETT STREET TPSS		
RMS RECORDER #1	1.75	25.8
RMS RECORDER #2	1.65	5.4
BOTH	1.70	25.8

7.6 SUMMARY OF MAGNETIC FIELD LEVELS

Appendices B, C and D contain the figures of the magnetic and electric field plots for the three datasets inside the High Street TPSS. Appendices G and H contain the figures of the field plots for the two datasets inside the South Boston TPSS. Appendices I through M contain the figures of the magnetic and electric field plots for the five datasets inside and outside the Bennett Street TPSS. As previously mentioned, the major source of ac magnetic fields is the current carried by the equipment and structures inside the station. There are two sets of frequencies, one set associated with the main power supply and the other associated with the rectifiers. Also, there are some low frequency components that are associated with the perturbation of the static field.

Tables 7-2 through 7-5 summarize the statistics of the pertinent data of the three sites. Each table shows the minimum, maximum and average field levels, as well as the standard deviation and coefficient of variation. The results are summarized by the same set of five frequency ranges used throughout this report, and by the distance from the floor or ground at the station, as given by the four sensor locations mounted on the staff.

Table 7-2 has the overall statistics of the ac side records, datasets BOS001, 2 and 8.

Table 7-3 has the overall statistics of the dc side records, datasets BOS003 and 10.

Table 7-4 has the overall statistics for all vertical datasets measured inside the three TPSS, datasets BOS001, 2, 3, 6, 7, 8 and 10. It provides a summary of the magnetic field levels that can be expected inside such a facility. The maximum time varying field which existed inside the building was 111 mG in the power frequency band at the 160 cm point of BOS008 of the Bennett Street TPSS.

Table 7-5 has the overall statistics for all vertical datasets measured outside the Bennett Street TPSS, datasets BOS011 and BOS012. It provides a summary of the magnetic field levels that can be expected outside such a facility. The maximum time varying field which existed outside the building was 14.6 mG in the low frequency range at the 10 cm point on the alley side of the Bennett Street TPSS.

For all the cases reported in this section, the largest coefficient of variation of 152 percent is in the low frequency range for the 60 cm probe for dataset BOS002. That is because the low frequency fields are associated with the fluctuations of the dc (static) field which result from changes in the power demand of trains.

7.7 SUMMARY OF ELECTRIC FIELD LEVELS

The TPSS are indoor facilities containing transformer, rectifier, switchgear and associated cables. Any electric fields produced outside the buildings are effectively shielded by the buildings. Similarly, any electric fields produced by energized apparatus within the buildings are effectively contained within the building due to the electric field shielding effectiveness of the buildings. No substantial electric fields were detected outside the Bennett Street TPSS but small electric fields were measured inside the South Boston TPSS. Figure 7-14 shows a plot of the electric field as a function of frequency and time which was measured approximately 1.7 m (5.6 ft) above the floor inside the South Boston TPSS near the main control board, Location 50 in Figure 7-2. The field consists mainly of a varying 60 Hz component of less than 2 V/m accompanied by odd harmonics of values less than 0.5 V/m.

TABLE 7-2.

STATISTICAL SUMMARY OF THE MAGNETIC FIELD LEVEL AT VARIOUS DISTANCES FROM THE FLOOR, INSIDE THE TRACTION POWER SUPPLY STATIONS ON THE AC SIDE (DATASETS BOS001, 2 AND 8)

BOS001, 002, 008 - AC SIDE INSIDE T.P.S.S.					TOTAL OF 75 SAMPLES	
FREQUENCY BAND	HEIGHT ABOVE GROUND (cm)	MINIMUM MAGNETIC FIELD (mG)	MAXIMUM MAGNETIC FIELD (mG)	AVERAGE MAGNETIC FIELD (mG)	STANDARD DEVIATION (mG)	COEFFICIENT OF VARIATION (%)
STATIC	10	580.83	917.65	749.75	84.54	11.28
	60	497.11	1004.75	793.89	156.76	19.75
	110	426.19	1052.41	808.26	220.28	27.25
	160	405.23	1105.60	840.68	260.37	30.97
5-45Hz LOW FREQ	10	0.24	12.60	1.37	2.09	152.16
	60	0.19	6.49	0.83	1.15	138.71
	110	0.07	3.19	0.50	0.59	119.08
	160	0.19	3.85	0.73	0.69	94.14
50-60Hz PWR FREQ	10	1.74	42.33	10.71	10.01	93.50
	60	2.46	50.19	13.03	11.28	86.56
	110	1.16	69.13	14.10	16.48	116.84
	160	6.02	110.67	30.45	25.11	82.47
65-300Hz PWR HARM	10	1.90	19.21	4.66	2.79	59.87
	60	1.07	30.06	6.27	4.96	79.00
	110	1.08	19.15	4.27	2.93	68.45
	160	1.54	78.41	15.77	13.60	86.25
305-2560Hz HIGH FREQ	10	2.97	12.29	4.64	1.69	36.30
	60	1.66	20.48	5.14	3.13	61.00
	110	1.55	12.30	3.44	1.70	49.38
	160	1.86	55.76	12.50	9.36	74.85
5-2560Hz ALL FREQ	10	4.20	43.19	13.52	9.58	70.88
	60	5.79	50.61	16.86	10.68	63.35
	110	3.20	69.57	16.46	15.52	94.28
	160	14.72	133.13	40.35	24.58	60.91

TABLE 7-3.

STATISTICAL SUMMARY OF THE MAGNETIC FIELD LEVEL AT VARIOUS DISTANCES FROM THE FLOOR, INSIDE THE TRACTION POWER SUPPLY STATIONS ON THE DC SIDE (DATASETS BOS003 AND 10)

BOS003, 010 - DC SIDE INSIDE T.P.S.S.					TOTAL OF 50 SAMPLES	
FREQUENCY BAND	HEIGHT ABOVE GROUND (cm)	MINIMUM MAGNETIC FIELD (mG)	MAXIMUM MAGNETIC FIELD (mG)	AVERAGE MAGNETIC FIELD (mG)	STANDARD DEVIATION (mG)	COEFFICIENT OF VARIATION (%)
STATIC	10	1697.05	2750.43	1915.94	186.12	9.71
	60	890.08	2419.79	1302.11	302.78	23.25
	110	604.80	2230.59	1045.28	328.13	31.39
	160	472.10	2023.73	870.50	318.73	36.61
5-45Hz LOW FREQ	10	0.42	18.39	3.01	4.06	134.91
	60	0.36	15.32	2.56	3.37	132.00
	110	0.34	14.02	2.33	3.02	129.62
	160	0.41	12.26	2.13	2.57	120.67
50-60Hz PWR FREQ	10	0.63	9.00	3.10	2.71	87.45
	60	0.39	7.16	2.17	2.04	94.13
	110	0.31	6.63	1.92	1.85	96.61
	160	0.32	6.64	1.88	1.82	97.03
65-300Hz PWR HARM	10	0.55	5.64	2.02	1.58	77.87
	60	0.54	4.49	1.59	1.15	72.24
	110	0.54	3.99	1.39	0.94	68.10
	160	0.56	3.73	1.27	0.80	62.96
305-2560Hz HIGH FREQ	10	1.75	3.69	2.48	0.59	23.69
	60	1.35	2.62	1.86	0.31	16.42
	110	0.99	2.11	1.61	0.25	15.82
	160	0.90	1.90	1.57	0.28	18.01
5-2560Hz ALL FREQ	10	2.14	20.89	5.86	4.60	78.46
	60	1.88	16.98	4.58	3.62	79.12
	110	1.80	15.46	4.10	3.20	77.90
	160	1.90	13.58	3.90	2.74	70.41

TABLE 7-4.

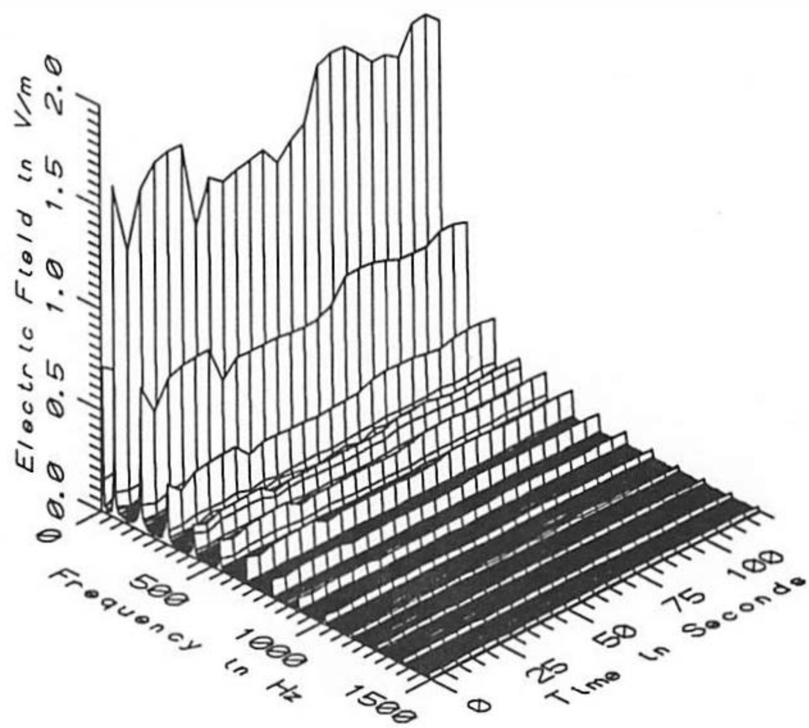
STATISTICAL SUMMARY OF THE MAGNETIC FIELD LEVEL AT VARIOUS DISTANCES FROM THE FLOOR OF COMBINED DATASETS INSIDE ALL THE TRACTION POWER SUPPLY STATIONS (DATASETS BOS001, 2, 3, 6, 7, 8 AND 10)

BOS001, 2, 3, 6, 7, 8, 10 - VERTICAL DATASETS INSIDE T.P.S.S.					TOTAL OF 175 SAMPLES	
FREQUENCY BAND	HEIGHT ABOVE GROUND (cm)	MINIMUM MAGNETIC FIELD (mG)	MAXIMUM MAGNETIC FIELD (mG)	AVERAGE MAGNETIC FIELD (mG)	STANDARD DEVIATION (mG)	COEFFICIENT OF VARIATION (%)
STATIC	10	487.76	2750.43	1048.63	568.87	54.25
	60	249.39	2419.79	822.85	403.25	49.01
	110	365.12	2230.59	763.08	332.50	43.57
	160	405.23	2023.73	730.32	308.54	42.25
5-45Hz LOW FREQ	10	0.09	18.39	1.51	2.76	182.23
	60	0.15	15.32	1.13	2.16	190.10
	110	0.02	14.02	0.90	1.89	208.89
	160	0.15	12.26	0.98	1.63	166.87
50-60Hz PWR FREQ	10	0.63	42.33	6.66	7.68	115.32
	60	0.39	50.19	7.65	9.03	118.10
	110	0.31	69.13	8.31	12.22	147.10
	160	0.32	110.67	15.80	21.09	133.48
65-300Hz PWR HARM	10	0.08	19.21	2.62	2.77	105.90
	60	0.12	30.06	3.20	4.27	133.21
	110	0.06	19.15	2.29	2.65	115.76
	160	0.08	78.41	7.19	11.60	161.25
305-2560Hz HIGH FREQ	10	0.14	12.29	2.75	2.19	79.58
	60	0.13	20.48	2.78	2.96	106.44
	110	0.09	12.30	1.98	1.77	89.51
	160	0.10	55.76	5.87	8.41	143.42
5-2560Hz ALL FREQ	10	1.53	43.19	8.66	8.06	93.14
	60	1.51	50.61	9.98	9.55	95.67
	110	1.46	69.57	9.95	11.96	120.25
	160	1.90	133.13	20.62	23.74	115.11

TABLE 7-5.

STATISTICAL SUMMARY OF THE MAGNETIC FIELD LEVEL AT VARIOUS DISTANCES FROM THE SIDEWALK SURFACE OF COMBINED DATASETS OUTSIDE THE BENNETT STREET TRACTION POWER SUPPLY STATION (DATASETS BOS011 AND BOS012)

BOS011, 012 - VERTICAL DATASETS OUTSIDE T.P.S.S.					TOTAL OF 51 SAMPLES	
FREQUENCY BAND	HEIGHT ABOVE GROUND (cm)	MINIMUM MAGNETIC FIELD (mG)	MAXIMUM MAGNETIC FIELD (mG)	AVERAGE MAGNETIC FIELD (mG)	STANDARD DEVIATION (mG)	COEFFICIENT OF VARIATION (%)
STATIC	10	377.37	975.63	529.48	160.51	30.31
	60	348.46	884.90	470.13	131.08	27.88
	110	350.84	871.63	455.60	118.39	25.99
	160	387.89	932.14	476.91	114.49	24.01
5-45Hz LOW FREQ	10	0.06	14.57	1.49	2.62	175.52
	60	0.11	11.61	1.18	2.08	175.47
	110	0.03	9.93	1.00	1.79	179.44
	160	0.11	9.92	1.02	1.77	172.67
50-60Hz PWR FREQ	10	0.70	4.29	1.87	0.96	51.20
	60	0.93	4.47	1.95	0.88	45.14
	110	1.03	5.24	2.08	0.97	46.35
	160	1.11	6.14	2.28	1.14	50.06
65-300Hz PWR HARM	10	0.11	2.15	0.63	0.58	91.97
	60	0.15	1.79	0.56	0.45	80.14
	110	0.13	1.53	0.52	0.37	71.05
	160	0.15	1.52	0.50	0.36	73.02
305-2560Hz HIGH FREQ	10	0.20	2.24	1.02	0.80	77.60
	60	0.20	1.98	0.95	0.67	70.63
	110	0.20	1.71	0.83	0.57	69.10
	160	0.21	1.53	0.77	0.51	65.35
5-2560Hz ALL FREQ	10	0.76	15.16	3.05	2.56	84.09
	60	0.97	12.22	2.91	1.92	65.93
	110	1.15	10.58	2.86	1.63	56.75
	160	1.36	10.58	3.03	1.65	54.30



BOS006 - ELECTRIC FIELD NEAR MAIN CONTROL BOARD, S. BOSTON T.P.S.S.

FIGURE 7-14. **ELECTRIC TIME VARYING FIELD LEVEL 1.7 m (5.6 ft) ABOVE THE FLOOR, INSIDE THE SOUTH BOSTON TRACTION POWER SUPPLY STATION NEAR THE MAIN CONTROL BOARD, AS A FUNCTION OF FREQUENCY AND TIME**

8. MEASUREMENTS IN CONTROL FACILITIES

Electric and magnetic field measurements were taken in the Orange Line dispatcher's room on the third floor at the Boston South traction power supply station on High Street as part of an effort to characterize the field environment in locations where transit workers may encounter magnetic fields from sources other than the transit electrical traction system.

8.1 MEASUREMENT LOCATIONS

Figure 8-1 shows the layout of the Orange Line dispatcher's room on High Street. As shown in the figure, there were two sets of fixed position, extended time measurements at the dispatcher's work station. One was a vertical profile measurement at the dispatcher's seat (Location #63 in the figure). Those data constitute dataset BOS004. The second measurement in the dispatcher's area (Location #64) was a horizontal profile 1 m (3.3 ft) from the floor with one end of the staff placed between the two video display terminal (VDT) monitors close to the screen. These data are recorded as dataset BOS005. Both sets of data were collected between 10:45 and 10:54 on June 9, 1992. The reference probe was placed on the second dispatcher's chair (Location #65 in Figure 8-1) during both the horizontal and vertical profile measurements.

8.2 REPETITIVE WAVEFORM DATASETS

The two repetitive waveform datasets that are associated with the dispatcher's room measurements are BOS004 and BOS005. The corresponding Appendices are E and F. The data were recorded with the repetitive waveform meter. Table 2-1 summarizes the pertinent information about these datasets, including the number of samples, sampling interval and the appendix containing the data measured in each test. Each appendix contains plots of the magnetic field as a function of frequency and time, as well as profiles showing field strength as a function of height above the floor or distance from the VDT screen over time.

8.3 MAGNETIC FIELD CHARACTERISTICS

This study measured the magnetic fields inside the Orange Line dispatcher's room at High Street near the computer monitors. Control room ELF magnetic fields appear to arise mainly from two sources: the video display monitors of the dispatcher's console and the electrical wiring and equipment within the room or beneath the floor and in the building.

Figure 8-2 shows the characteristics of the magnetic field near the seat level at the dispatcher's seat. This is a plot from the

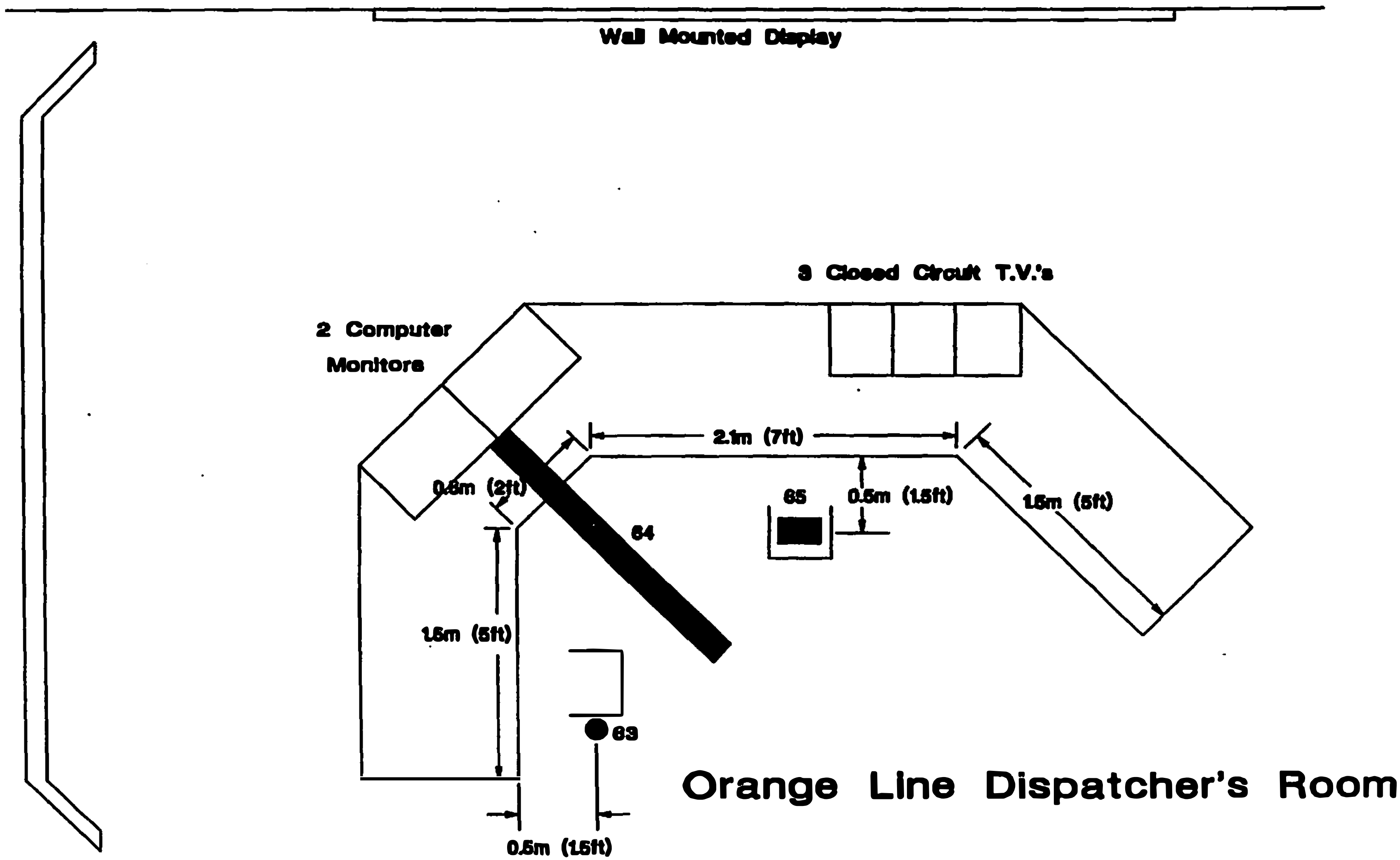
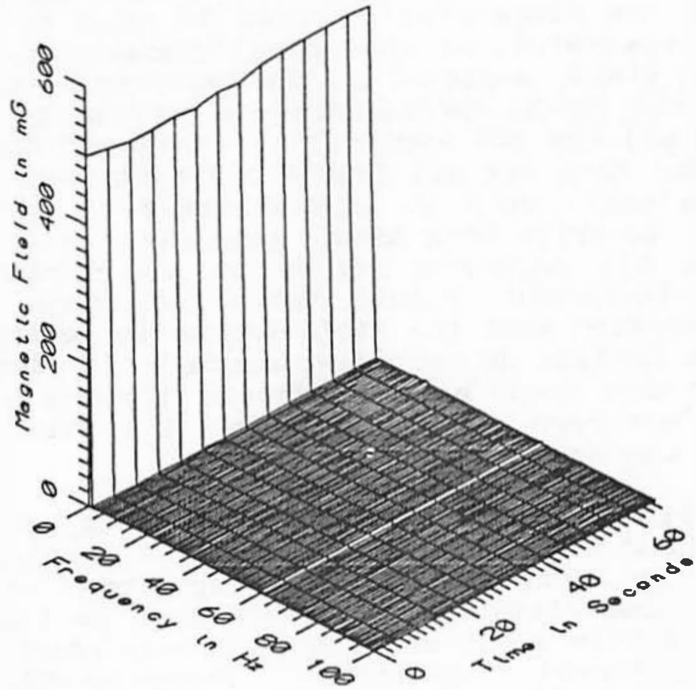
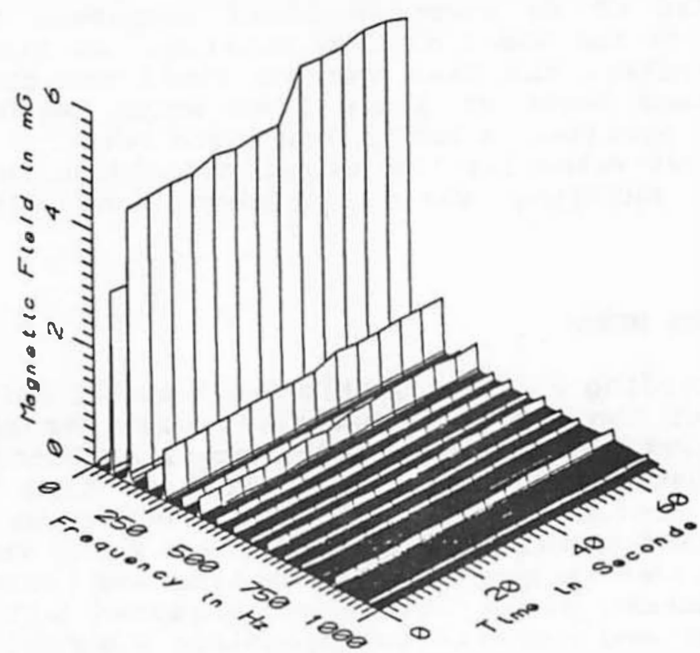


FIGURE 8-1. REPETITIVE WAVEFORM MEASUREMENT LOCATIONS INSIDE THE ORANGE LINE DISPATCHER'S ROOM AT BOSTON SOUTH STATION ON HIGH STREET



BOS004 - 60cm ABOVE FLOOR AT ORANGE LINE DISPATCHER'S SEAT



BOS004 - 60cm ABOVE FLOOR AT ORANGE LINE DISPATCHER'S SEAT

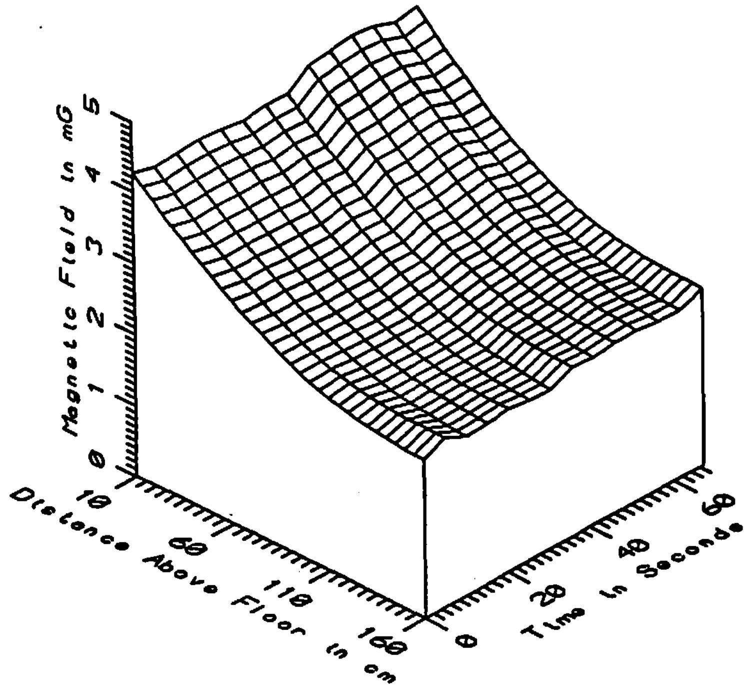
FIGURE 8-2. MAGNETIC FIELD LEVEL, WITH AND WITHOUT THE STATIC COMPONENT, AT 60 cm HEIGHT ABOVE THE FLOOR BY THE DISPATCHER'S SEAT INSIDE THE ORANGE LINE DISPATCHER'S ROOM ON HIGH STREET, AS A FUNCTION OF FREQUENCY AND TIME

vertical profile dataset BOS004 contained in Appendix E. The static field at the dispatcher's seat is seen to be constant overtime and approximately at the normal geomagnetic field level. The time varying field, depicted in the lower frame of the figure, is dominated by the 120 Hz second harmonic component, but the 60 Hz fundamental and all the odd and even harmonics of the fundamental are also present. They are all fairly constant over time, varying in concert as a small step at approximately 35 seconds. Those harmonics appear to arise from single phase rectifier ripple. The fundamental and all harmonic fields at the dispatcher's seat decrease with increasing height above the floor, as shown in Figure 8-3, indicating that the field source is beneath the floor. Possible sources include dc rectifier currents in circuits beneath this third floor that could be in conductor channels in the ceiling of the second floor room below. Figure 7-1 is the layout of the ground floor in the same building.

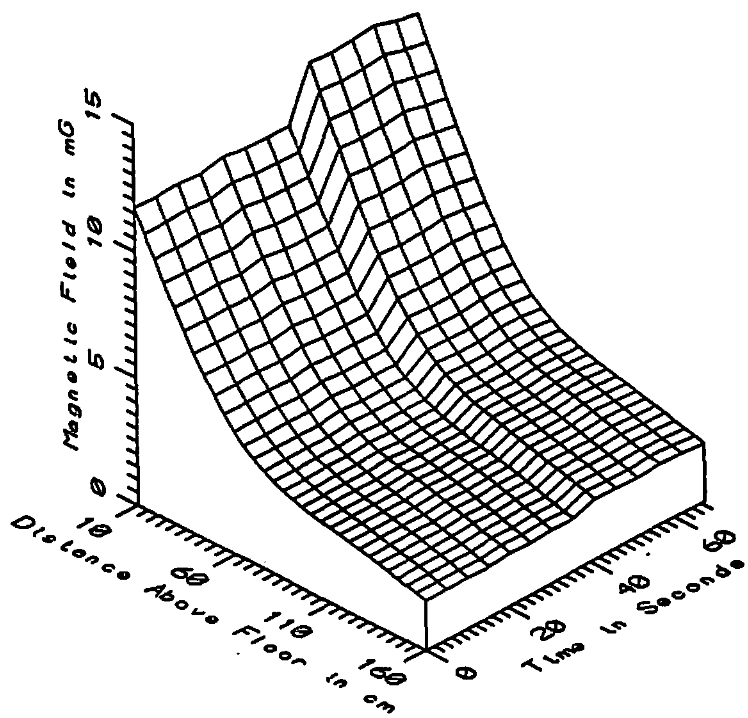
The characteristics of the magnetic field 10 cm in front of the video display monitor are shown in Figure 8-4 which comes from dataset BOS005 in Appendix F. The top frame of the figure indicates an reduced static field level which is fairly constant over time. The bottom frame shows a frequency spectrum dominated by a 60 Hz fundamental component. There is also a 1250 Hz component of unknown local origin that did not appear in the reference probe in another part of the room. Attenuation profiles of the fundamental and power harmonics ELF magnetic fields at increasing distances from the video display monitor are shown in Figure 8-5. The 60 Hz magnetic field decreases rapidly with distance away from the video display monitor. At 110 cm from the front of the monitor, the time varying field has decreased to a relatively uniform level of about 1 mG which persists for the remainder of the profile. A background field level of 1 milligauss or so is a typical value for the magnetic fields within buildings resulting from building wiring, lights, and other general equipment.

8.4 DAT WAVEFORM DATA

A continuous recording of the magnetic field at the reference probe located on top of the second dispatcher's seat was made with the DAT while the vertical and horizontal profile measurements were being made. That recording is identified as Tape 1, Group 1, Records 4 and 5 listed in Table 2-2. The record was scanned for transients or brief excursions in field level which were missed by the repetitive waveform sampling but nothing was found except for essentially constant field levels as measured with the field waveform recorder and reported in Appendices E and F.

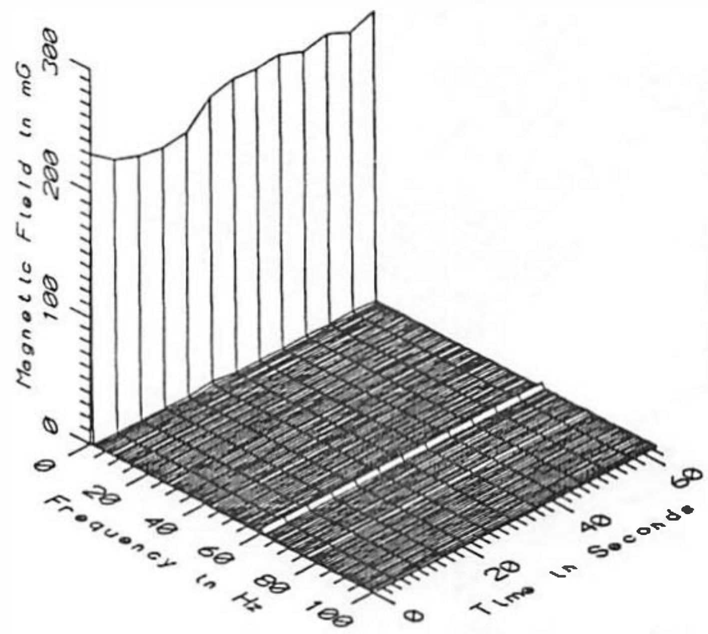


BOS004 - AT ORANGE LINE DISPATCHER'S SEAT - POWER FREQ, 50-60Hz

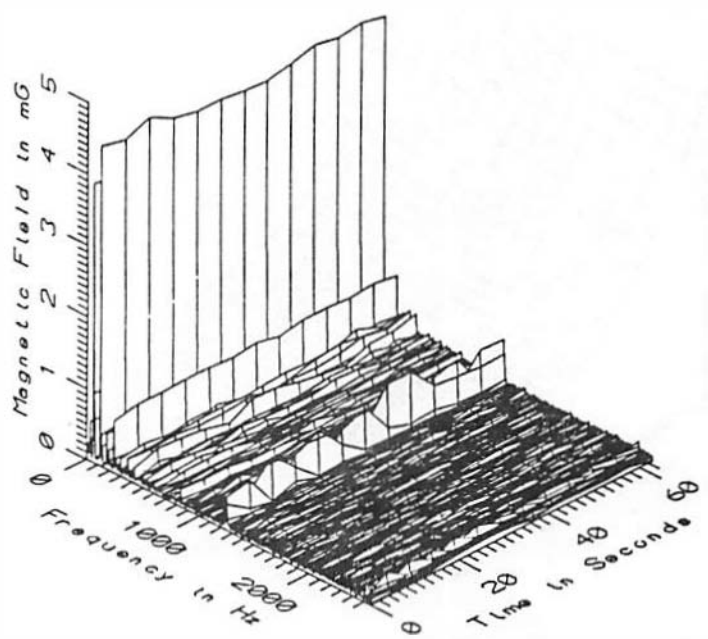


BOS004 - AT ORANGE LINE DISPATCHER'S SEAT - POWER HARM, 65-300Hz

FIGURE 8-3. MAGNETIC FIELD LEVEL VERSUS DISTANCE FROM THE FLOOR AT THE DISPATCHER'S SEAT, FOR THE POWER FREQUENCY (50-60 Hz) AND THE POWER FREQUENCY HARMONICS (65-300 Hz) COMPONENTS, AT THE ORANGE LINE DISPATCHER'S ROOM, AS A FUNCTION OF TIME

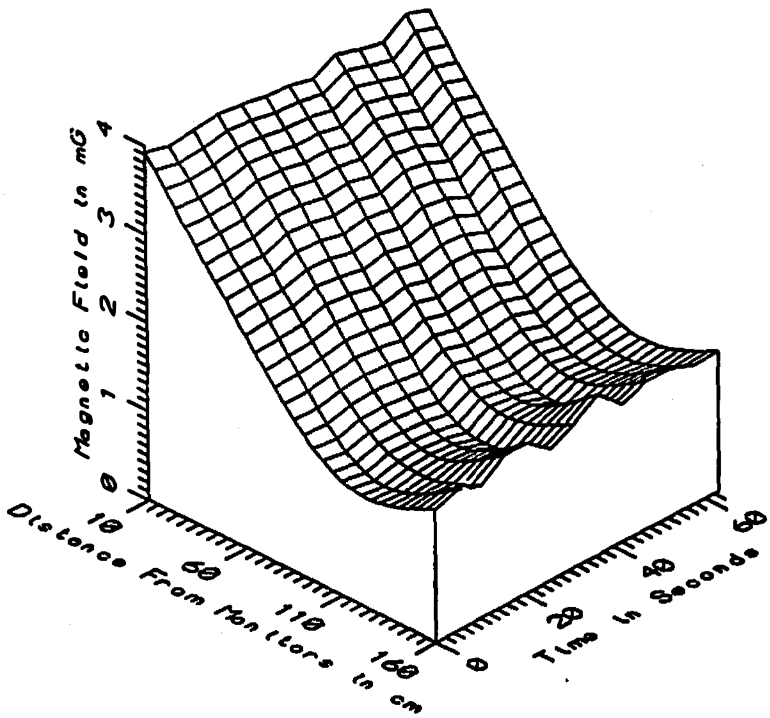


BOS005 - 10cm FROM MONITORS IN ORANGE LINE DISPATCHER'S ROOM

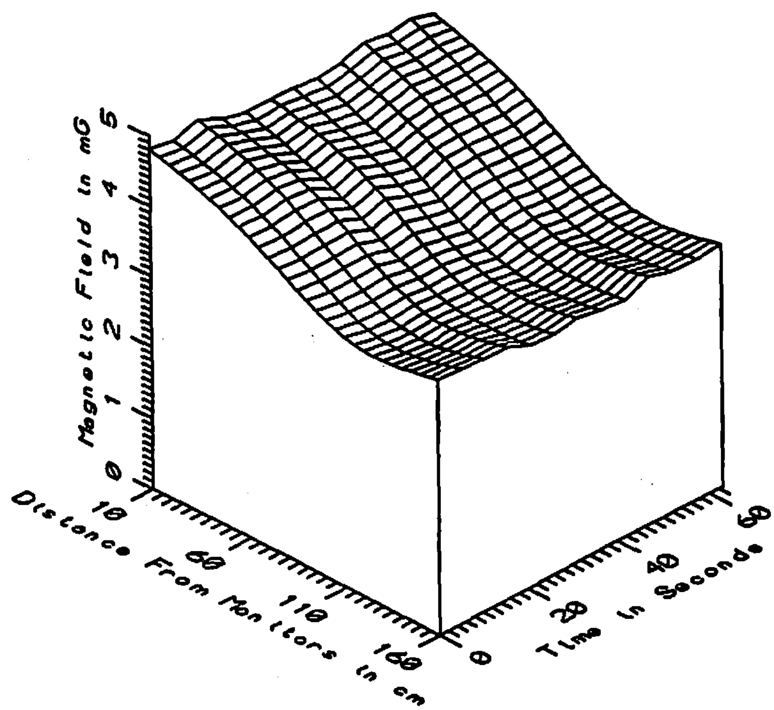


BOS005 - 10cm FROM MONITORS IN ORANGE LINE DISPATCHER'S ROOM

FIGURE 8-4. MAGNETIC FIELD LEVEL, WITH AND WITHOUT THE STATIC COMPONENT, AT 10 cm FROM THE VDT MONITOR BY THE DISPATCHER'S SEAT INSIDE THE ORANGE LINE DISPATCHER'S ROOM ON HIGH STREET, AS A FUNCTION OF FREQUENCY AND TIME



BOS005 - IN ORANGE LINE DISPATCHER'S ROOM - POWER FREQ. 50-60Hz



BOS005 - IN ORANGE LINE DISPATCHER'S ROOM - POWER HARM. 65-300Hz

FIGURE 8-5. MAGNETIC FIELD LEVEL VERSUS DISTANCE FROM THE VDT MONITOR BY THE DISPATCHER'S SEAT, FOR THE POWER FREQUENCY (50-60 Hz) AND THE POWER FREQUENCY HARMONICS (65-300 Hz) COMPONENTS, AT THE ORANGE LINE DISPATCHER'S ROOM, AS A FUNCTION OF TIME

8.5 RMS RECORDER DATA

Both rms recorder data time course recordings, while inside the dispatcher's room, are presented here as Figure 8-6. These time course plots are from 10:44 to 10:54 on June 9, 1992. Table 8-1 shows the statistics for these recordings. As mentioned before, the researchers did wander about and placed the rms recorders against different equipment where high localized fields were found.

TABLE 8-1.

STATISTICAL SUMMARY OF MAGNETIC FIELDS IN mG RECORDED INSIDE THE DISPATCHER'S ROOM USING RMS RECORDERS

	AVERAGE	MAXIMUM
RMS RECORDER #1	4.60 mG	7.80 mG
RMS RECORDER #2	3.81 mG	14.00 mG
BOTH	4.20 mG	14.00 mG

8.6 SUMMARY OF MAGNETIC FIELD LEVELS

The major sources of ELF time varying magnetic fields in the vicinity of the dispatcher's seat are apparently the current in the building wiring, vertical deflection coils in the video display terminals, and rectifier power supplies beneath the floor. Appendices E and F contain the figures of the magnetic field plots for the Orange Line dispatcher's room at High Street Station as well as the summary statistics. Table 8-2, taken from Appendix E, summarizes the field levels measured along a vertical profile at the dispatcher's seat. The table presents the minimum, maximum and average field levels, as well as the standard deviation and coefficient of variation. The results are summarized by the same set of five frequency ranges used throughout this report, and by the height above the floor, given by the four sensor locations mounted on the staff. The overall time varying maximum field level is 14.8 mG, measured at 10 cm above the floor. The corresponding average value in the same place is 13.4 mG, not substantially different.

Table 8-3, taken from Appendix F dataset BOS005, summarizes the field levels measured on a horizontal profile along the distance from the monitor screens. The overall time varying maximum field level is 6.6 mG, measured at 10 cm from the VDT. The corresponding average value in the same place is 6.4 mG, not substantially different.

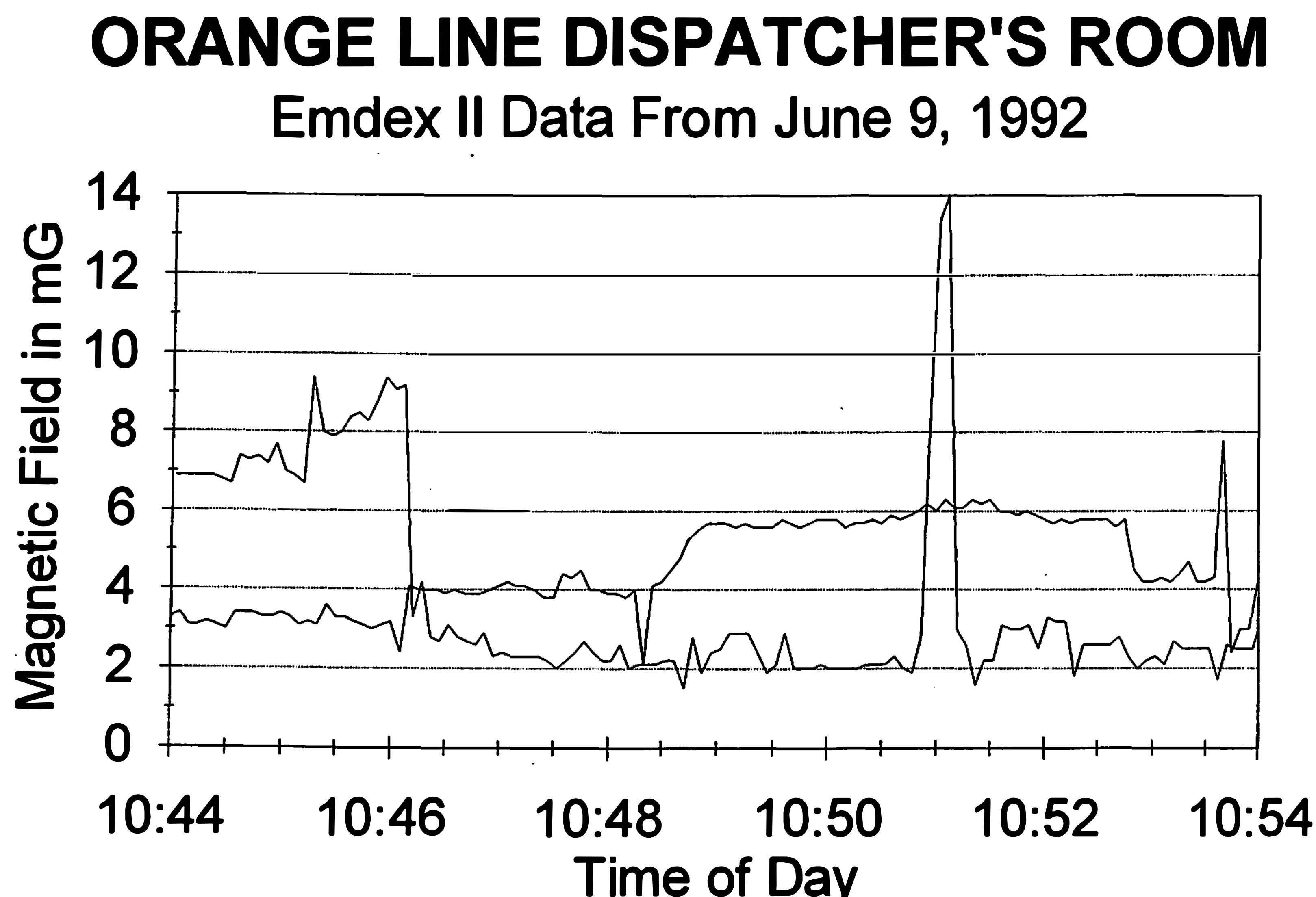


FIGURE 8-6. MAGNETIC FIELD LEVELS RECORDED INSIDE THE ORANGE LINE DISPATCHER'S ROOM ON HIGH STREET USING THE RMS RECORDERS, AS A FUNCTION OF TIME

TABLE 8-2.

STATISTICAL SUMMARY OF THE MAGNETIC FIELD LEVEL AT VARIOUS HEIGHTS ABOVE THE FLOOR INSIDE THE ORANGE LINE DISPATCHER'S ROOM ON HIGH STREET (DATASET BOS004)

BOS004 - AT ORANGE LINE DISPATCHER'S SEAT					TOTAL OF 14 SAMPLES	
FREQUENCY BAND	HEIGHT ABOVE FLOOR (cm)	MINIMUM MAGNETIC FIELD (mG)	MAXIMUM MAGNETIC FIELD (mG)	AVERAGE MAGNETIC FIELD (mG)	STANDARD DEVIATION (mG)	COEFFICIENT OF VARIATION (%)
STATIC	10	315.34	349.77	331.94	12.42	3.74
	60	486.40	507.33	496.99	7.63	1.54
	110	354.75	387.86	371.17	12.01	3.24
	160	383.47	418.19	400.73	12.58	3.14
5-45Hz LOW FREQ	10	0.15	0.44	0.32	0.08	26.37
	60	0.15	0.32	0.23	0.06	24.46
	110	0.05	0.25	0.14	0.07	49.97
	160	0.17	0.40	0.25	0.08	32.31
50-60Hz PWR FREQ	10	4.19	4.60	4.36	0.16	3.61
	60	3.06	3.36	3.18	0.11	3.39
	110	2.40	2.63	2.49	0.09	3.53
	160	2.20	2.48	2.30	0.08	3.61
65-300Hz PWR HARM	10	11.69	13.97	12.63	1.04	8.26
	60	4.78	5.70	5.17	0.41	7.90
	110	2.89	3.35	3.08	0.19	6.32
	160	1.97	2.32	2.12	0.15	6.90
305-2560Hz HIGH FREQ	10	1.17	1.46	1.30	0.12	9.20
	60	0.47	0.67	0.57	0.07	12.97
	110	0.32	0.40	0.35	0.03	7.55
	160	0.26	0.33	0.29	0.02	8.06
5-2560Hz ALL FREQ	10	12.48	14.78	13.43	1.04	7.77
	60	5.71	6.65	6.10	0.41	6.68
	110	3.78	4.27	3.98	0.20	5.12
	160	2.97	3.37	3.16	0.15	4.70

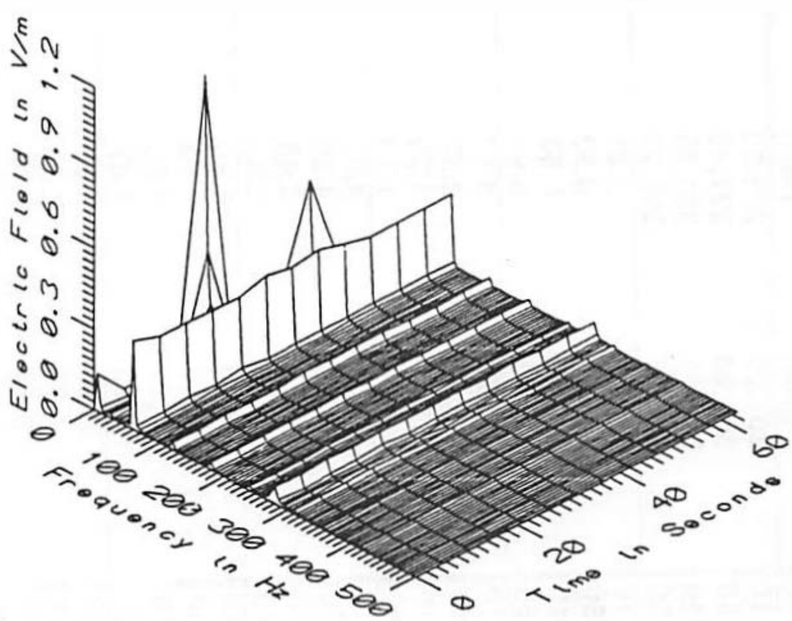
TABLE 8-3.

STATISTICAL SUMMARY OF THE MAGNETIC FIELD LEVEL AT VARIOUS DISTANCES FROM THE VDT MONITOR INSIDE THE ORANGE LINE DISPATCHER'S ROOM ON HIGH STREET (DATASET BOS005)

BOS005 - FROM MONITOR'S IN ORANGE LINE DISPATCH ROOM					TOTAL OF 13 SAMPLES	
FREQUENCY BAND	DIST. FROM VDT (cm)	MINIMUM MAGNETIC FIELD (mG)	MAXIMUM MAGNETIC FIELD (mG)	AVERAGE MAGNETIC FIELD (mG)	STANDARD DEVIATION (mG)	COEFFICIENT OF VARIATION (%)
STATIC	10	207.63	236.20	225.57	10.44	4.63
	60	306.94	337.46	326.54	11.40	3.49
	110	301.01	331.75	320.36	11.39	3.56
	160	276.27	307.23	296.29	11.93	4.03
5-45Hz LOW FREQ	10	0.58	1.21	0.68	0.16	23.48
	60	0.23	0.93	0.34	0.18	54.43
	110	0.20	0.63	0.27	0.11	42.62
	160	0.23	0.92	0.36	0.18	50.21
50-60Hz PWR FREQ	10	3.79	3.97	3.88	0.06	1.43
	60	2.35	2.52	2.45	0.05	2.09
	110	1.21	1.35	1.28	0.04	3.30
	160	1.45	1.78	1.58	0.09	5.89
65-300Hz PWR HARM	10	4.59	4.89	4.71	0.09	1.83
	60	3.99	4.28	4.14	0.09	2.12
	110	3.29	3.48	3.37	0.05	1.58
	160	3.29	3.56	3.41	0.09	2.57
305-2560Hz HIGH FREQ	10	1.80	1.90	1.85	0.04	1.99
	60	1.56	1.72	1.65	0.04	2.48
	110	1.51	1.65	1.59	0.04	2.30
	160	1.52	1.67	1.61	0.05	2.91
5-2560Hz ALL FREQ	10	6.28	6.57	6.42	0.08	1.24
	60	4.97	5.23	5.10	0.07	1.37
	110	3.88	4.05	3.95	0.05	1.17
	160	3.97	4.22	4.11	0.08	1.88

8.7 SUMMARY OF ELECTRIC FIELD LEVELS

The graphs of electric field level as a function of frequency and time appear in the appendices. Figure 8-7 shows the electric field, as a function of frequency and time, as it was measured at 1 m (3.3 ft) above the floor and 1.7 m (5.7 ft) from the VDT screen, near the dispatcher's seat, Location #64 in Figure 8-1. The field is very low, not exceeding 1.2 Volts/meter, fairly constant over time and consisting mainly of 60 Hz and some harmonics. The highly variable low-frequency components are indicative of changes in static field level usually caused by the movement of nearby people who have some static charge on their clothing or a slight movement of the recording staff.



BOS005 - ELECTRIC FIELD 170cm FROM ORANGE LINE DISPATCHER'S MONITORS

FIGURE 8-7. **ELECTRIC TIME VARYING FIELD LEVEL 1.7 m (5.6 ft) ABOVE THE FLOOR, AT THE ORANGE LINE DISPATCHER'S SEAT ON HIGH STREET, AS A FUNCTION OF FREQUENCY AND TIME**

9. CONCLUSIONS

Sections 3 through 8 of this report presented the results and analysis of extensive measurements taken on magnetic and electric fields within the cars and operator's area, along the wayside, at passenger stations, inside and outside electric traction power supply stations and inside control facilities of the Boston MBTA urban transit system and vicinity.

As described in these sections, the magnetic fields associated with the MBTA system have both static and time varying components. The dc traction current in the third rail or catenary, in the track return, in the power control equipment beneath the cars, and in the TPSS creates static fields in the vicinity of those facilities. The time varying magnetic fields associated with the MBTA system are of two distinct types. First, changes in the "static" field level brought about by changes in the dc traction current in the aforesaid circuits produces low frequency time varying components that vary in intensity depending on the time rate of change of the static field. Secondly, there are periodic time varying components of the field arising from rectifier ripple in the dc traction current and from chopper current in the Green Line cars.

Both static and time varying magnetic fields onboard the cars arise predominantly from the traction power control equipment beneath the floor and secondarily from the current loop formed by the third rail (or catenary) and the tracks. Because power needs of the cars are set by terrain and speed control, these fields are highly variable over time.

On station platforms, especially near the edge of the platform close to the rails (or catenary), static and time varying magnetic fields arise both from the traction power (dc and rectification harmonics) and equipment onboard the passing trains. At the wayside locations the time varying magnetic fields also arise from rectification harmonics on the traction power, however, they were smaller than 60 Hz and harmonic fields from nearby power lines. Magnetic fields from equipment onboard the passing train were not found at the wayside locations.

Inside TPSSs, measurements at the sides close to the ac electric equipment such as transformers and switchgear, yield 60 Hz and odd harmonic (mainly third harmonic) fields. At the dc side equipment inside the station, such as rectifiers, magnetic fields have a time varying static component and the ripple-frequency (even harmonics) components.

No significant electric fields were detected anywhere in the system. On the average the electric fields inside the cars, including the operator's position, measured less than 0.5 V/m, with an occasional reading higher, up to 5 V/m. It appears that some of the higher readings might be caused by a sudden movement of the recording staff. In the passenger stations, all readings were below 4 V/m. Along the wayside and outside the TPSS the fields measured less than 1 V/m. An electric field of 1.2 V/m was detected in the dispatcher's office. The electric fields inside the TPSSs were of the order of 3 V/m. The predominant frequency of all these fields was 60 Hz.

9.1 SUMMARY OF MBTA SYSTEM FIELD LEVELS

This section provides a concise description of the magnetic field characteristics at each of the areas examined. As noted above, all measured electric fields were less than 10 volts per meter (10 V/m) and are not discussed in detail.

9.1.1 Vehicles

The magnetic fields in the passenger areas of the MBTA vehicles arise mainly from the traction power control equipment beneath the floor of the vehicles and also possibly the current in the loop created by the third rail (or catenary) and track return circuit. These fields are predominantly static with low frequency time varying components resulting from fluctuations in the static field level, as well as some rectifier ripple even harmonics.

The static magnetic field at seat level (60 cm above the floor) in these dc-powered MBTA subway cars averaged 507 mG. The maximum static field encountered at seat height for the same samples was 1446 mG. The corresponding average and maximum time varying magnetic fields for the Trolley and Trolley Bus were 312 mG and 775 mG, respectively.

The total time varying magnetic field levels for the subway cars averaged 5.7 mG over all samples and all sensor locations. The maximum time varying field encountered during the same periods was 68 mG. For the Trolley and Trolley Bus, over all samples and all sensor locations, the corresponding average and maximum time varying magnetic fields were 2.5 mG and 26 mG, respectively.

9.1.2 Operator's Area

The principal sources of magnetic field in the operator's area are the same as in the passenger areas, that is, the traction power equipment beneath the floor and possibly the current in the loop created by the third rail (or catenary) and the track return circuit. There appeared to be no additional sources unique to the operator's position. As described in Section 9.1.1, these fields are predominantly static with low frequency time varying components resulting from fluctuations in the static field level. The measurements made onboard the four different types of subway cars are comparable to one another. Thus, an overall set of statistics is possible, termed the subway operator's position. The same holds true for combining the Trolley and Trolley Bus data. The following summary values were obtained close to the operator's seat.

The static magnetic field, as measured by the repetitive waveform recorder, averaged 699 mG at seat level (60 cm height). The maximum static field encountered for the same 60 cm height was 2220 mG. The corresponding average and maximum time varying magnetic fields for the Trolley and Trolley Bus were 387 mG and 651 mG, respectively.

The total time varying magnetic field levels for the subway cars operator's seat averaged 4.8 mG at the 60 cm height level, and the maximum field encountered was 53 mG. The corresponding average and maximum time varying magnetic fields for the Trolley and Trolley Bus were 1.8 mG and 11.5 mG, respectively.

9.1.3 MBTA System Waysides

The static magnetic field at the wayside of the MBTA transit lines arises from a combination of the earth's magnetic field and the static magnetic field due to the dc traction current in the rails (or catenary). At locations outside the right-of-way exclusion fence, the static field from traction current in the third rail (or catenary) and tracks does not add appreciably to the natural static field environment. At locations on the Trolley Bus route there are no right-of-way exclusion fences. However, the static field from traction current in the dual overhead catenary does not add appreciably to the natural static field environment at the sidewalk, where the measurements were taken.

The time varying field at the wayside has components from three sources: changes in the dc traction current produce low frequency components whose magnitude depends on the rate of change of the dc current; second, from the rectifier ripple currents in the rails; and third, from the 60 Hz current in any nearby commercial power lines. Since the magnetic field at the railroad wayside due to the current in the rails (or catenary) attenuates rapidly with distance from the tracks, at distances comparable to the exclusion fence location, the time varying field from common sources such as distribution lines equal or exceed the components from the MBTA System.

The average value of the dc field measured at the wayside was 492 mG, which compares with the published value of 548 mG for Boston. The largest dc value measured at the wayside was 823 mG. The average and maximum ac magnetic fields measured at the right-of-way exclusion fence or equivalent distance of 4.6 m (15 ft) were 4.4 mG and 11.5 mG, respectively, but those values are dominated by fields from nearby powerlines. The average and maximum fields actually arising from the MBTA System are estimated to be 0.8 mG and 3.5 mG, respectively.

Measurements along the MBTA Trolley Bus route found the average and maximum static field levels to be 505 mG and 522 mG with buses passing by. The measured average and maximum time varying field levels were 2.2 mG and 3.2 mG, but those values included fields apparently arising from nearby powerlines. The estimated average field from the MBTA system was 0.2 mG with a maximum value of 1.6 mG.

The electric fields measured along the waysides were under 1 V/m.

9.1.4 Passenger Station Platforms

The magnetic field environment on a passenger station platform is similar to the wayside except that the passenger is closer to the power supply. Static fields from traction power current in the third rail (or catenary) and track return circuit add to the naturally occurring geomagnetic field. The earth's magnetic field is also distorted at an underground platform due to ferromagnetic material in the structure. The time varying magnetic field at the platforms arises from changes in the static (dc) component due to changing dc traction power in the rails (or catenaries), the rectifier harmonics, and fields from the passing cars themselves. Moreover, there are 60 Hz fields from nearby electric equipment, such as station wiring, lights and ventilating motors.

Three types of electrification technology were analyzed, as delineated in Section 6.3: third rail electrification operation with cam type cars; catenary operation with cam cars; and catenary operation with chopper cars. The average values of the static field measured at body/torso height (110 cm above the floor) near the edge of the passenger platforms were fairly close for these three electrification types, namely 444 mG, 485 mG and 494 mG, respectively. The corresponding maximum static field levels were 892 mG, 971 mG and 765 mG, respectively. The variation of the maximum values may be due to the time window of the measurement and may not be indicative of any differences between the three types.

The average and maximum time varying magnetic fields measured 110 cm above the edge of the platform for the same three cases were 3.4 mG, 9.5 mG and 3.9 mG, respectively. The corresponding maximum values were 12.7 mG, 82 mG and 15 mG. As mentioned above, the difference in measured field levels was probably due to the difference in the time window of the measurement.

The electric fields measured on any of the platforms were under 4 V/m.

9.1.5 Traction Power Supply Stations

Data was recorded both outside and inside the traction power supply stations. Only modest strength magnetic fields were observed outside the stations. The largest measured static value was 976 mG and the average value was 483 mG. The coefficient of variation was less than 30 percent. The average and maximum time varying magnetic field levels were 3.0 mG and 15.2 mG for the same outside measurements.

Substantially higher magnetic fields were observed inside the traction power supply stations. The largest measured static value was 2750 mG and the average value was 841 mG. The corresponding average and maximum time varying magnetic field levels were 12.3 mG and 133 mG. The largest coefficient of variation was 209 percent and it occurred in the low frequency range which is indicative of the load variations of the dc currents.

The highest electric field measured inside the stations was under 3 V/m and on the outside was less than 1 V/m.

9.1.6 Control Facilities

The major sources of magnetic fields in the dispatcher's area are the current in the building wiring which supplies power to the equipment and lights, and the equipment itself, such as VDTs. The measured average and maximum ac magnetic fields in the dispatcher's room were 4.9 mG and 6.6 mG. The higher values were found closer to equipment. The static field in the dispatcher's room was fairly constant over time, having a coefficient of variation no larger than 7 percent for any of the measurements, but varied spatially from a high value of 1106 mG at 160 cm above the floor near the operator's seat, to a low value of 208 mG near the VDT.

The highest electric field measured inside the dispatcher's room was 1.2 V/m.

9.2 ENVIRONMENTAL MAGNETIC FIELD LEVELS

The predominant source of static field in the environment is the earth's geomagnetic field. The unperturbed geomagnetic field intensity varies over the surface of the earth from roughly 240 mG to 670 mG. The geomagnetic field level in the vicinity of Boston is approximately 548 mG. The presence of iron and steel components in buildings, vehicles, and structures perturbs the geomagnetic field in the vicinity of those objects making the geomagnetic field intensities routinely encountered by people somewhat more variable. Static field levels ranging from 200 mG to 1000 mG are frequently found in such areas.

Permanent magnets also represent localized sources of high intensity static magnetic fields. A child's toy magnet may have a flux density of several hundred to a few thousand gauss at its pole. Ferrite permanent magnets imbedded in seals and weatherstrips around refrigerator doors and home or office doors and windows are frequently encountered, providing static fields of a few gauss at the portal.

The overwhelmingly predominant source of ELF magnetic fields in the environment is the 50 or 60 Hz magnetic field produced by virtually all equipment or facilities which generate, distribute, or utilize electric power. Due to the electrification of our modern society, power frequency (60 Hz in North America, 50 Hz in Europe) magnetic fields are ubiquitous. Numerous authors have reported environmental levels of power frequency magnetic fields for specific situations. Nair, *et al.*,[6] provides a summary of that information as well as useful insight into the parameters which affect power frequency magnetic fields. Figure 9-1 shows the range of power frequency magnetic field levels which may be found at various distances from three important sources of magnetic field.

Power frequency magnetic fields in American homes arise primarily from three sources: outdoor power distribution lines; house wiring; and household appliances. Field levels for power lines and appliances are summarized in Figure 9-1. Field levels from house wiring differ greatly from home to home. The total power frequency magnetic fields in homes is typically about 0.7 mG[6,10] at the center of each room but can vary substantially from room to room or home to home. Magnetic field levels in excess of 10 mG at the center of a room are atypical but not uncommon.

Power frequency magnetic field levels in the workplace are highly variable. In offices and most commercial establishments, the power frequency magnetic field environment is similar to or somewhat higher than that in homes. But in certain industrial settings, considerably higher ELF magnetic field levels are encountered[11]. Unfortunately, field characterization in the workplace is limited to a small number of measurements which lack validity as indicators of "typical" or "overall" estimators of workplace magnetic field levels.

These common environmental sources of ELF magnetic field are predominantly power frequency field sources. Magnetic fields near power lines and substations may have low order harmonic components, but these are generally only a small percentage of the fundamental power frequency component[10]. The harmonic content of residential and most workplace magnetic fields is also generally quite low, but on occasion can become a significant part of the total field. High harmonic content appears most frequently in magnetic fields near appliances containing non-linear electrical load control devices. Figure 9-2 shows a field by frequency and time plot for the magnetic field produced by a triac-controlled vacuum cleaner. Although the harmonic content is relatively large, only the lower order harmonics have significant amplitude. Essentially, no energy is present at frequencies below the power frequency. This is characteristic of the magnetic fields produced by many appliances with electronic controls.

Televisions and computer video display units which make use of magnetic deflection are the most commonly encountered source of ELF magnetic fields at frequencies other than the power frequency. Vertical deflection frequencies for these devices are generally in the 55 to 75 Hz range; however, the magnetic fields are rich in harmonics. Horizontal deflection frequencies and their associated fields are well above the ELF range. Certain pieces of industrial and medical equipment also produce relatively large ELF magnetic

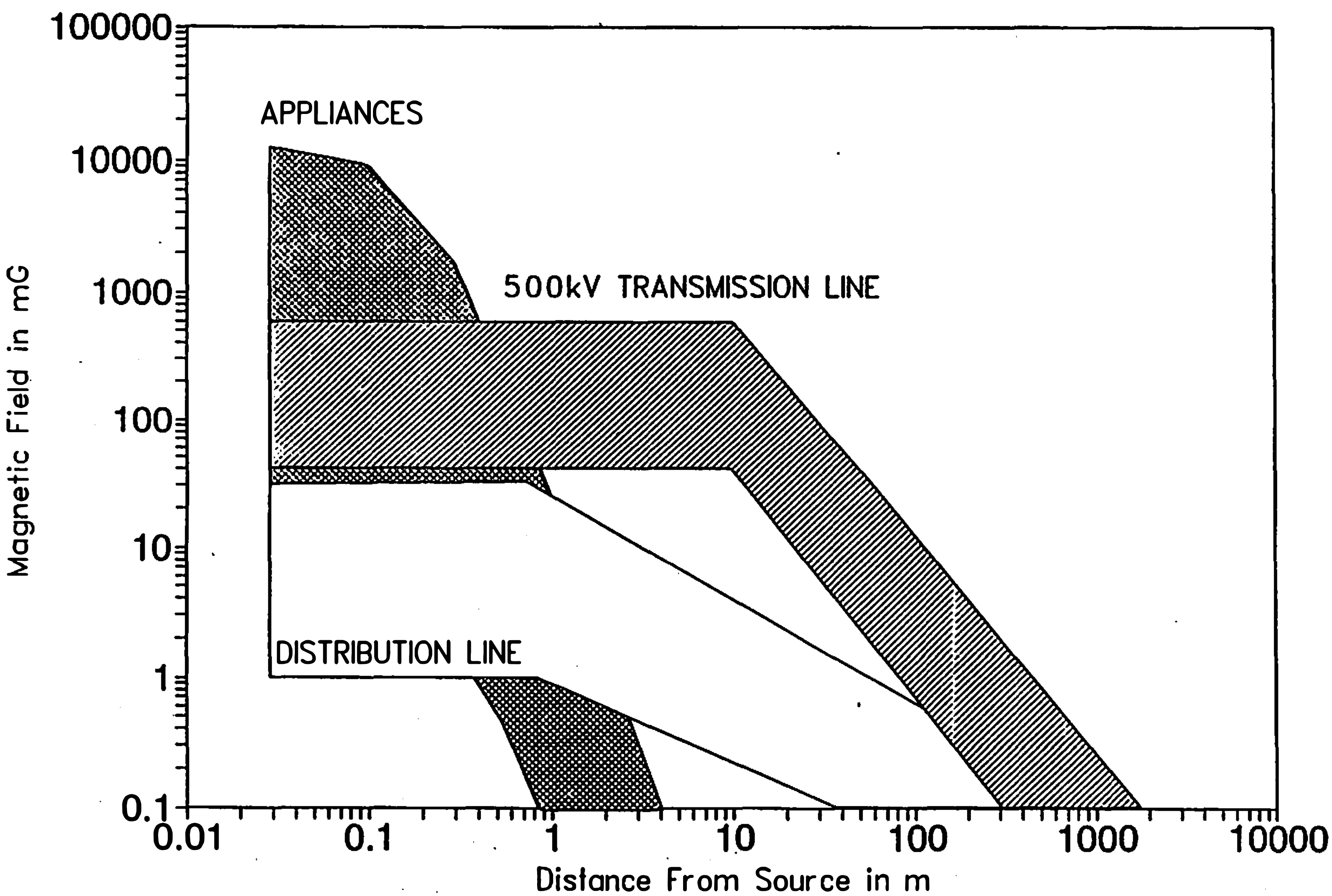


FIGURE 9-1. ILLUSTRATION OF HOW THE MAGNETIC FIELD INTENSITY AT GROUND LEVEL CHANGES WITH HORIZONTAL DISTANCE FROM THREE COMMON SOURCES OF POWER-FREQUENCY MAGNETIC FIELDS. THE BANDS REPRESENT VARIATION ACROSS INDIVIDUAL SOURCES IN EACH GROUP. ADAPTED FROM NAIR, ET AL[6]

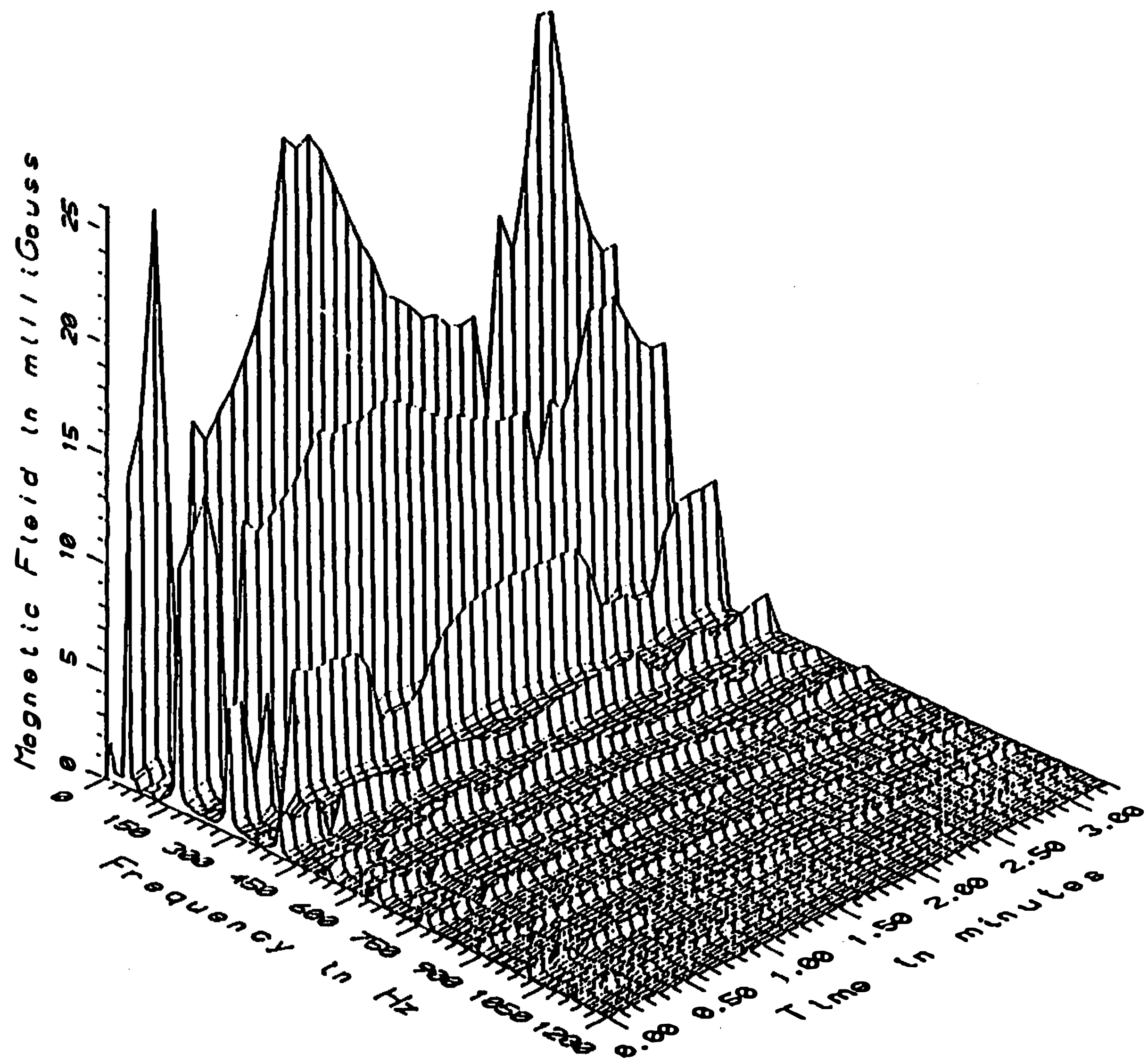


FIGURE 9-2. MAGNETIC FIELD 30 cm FROM A SHOP VAC

fields at frequencies other than 50 or 60 Hz, but they are rarely encountered by the general public.

ELF electric fields in the environment arise most frequently from unshielded equipment or facilities used to generate, distribute, or utilize electric power. Like ELF magnetic fields, these electric fields have the frequency of the electric power system: 60 Hz in North America and 50 Hz in Europe. Since ELF electric fields are easily shielded by materials with even modest electrical conductivity, the predominant sources encountered by the general public are overhead electric power transmission and distribution lines, home or office electrical appliances and some electric lights. Nair, *et al.*,[6] provide a discussion of environmental electric fields well summarized by Figure 9-3, which is extracted from their report.

9.3 COMPARISON OF MBTA SYSTEM FIELDS TO OTHER ELECTRO-TECHNOLOGIES

Much of the concern about ELF magnetic field levels is driven by uncertainty as to whether such fields exert an adverse effect on human health. Existing scientific knowledge provides no sound insight as to what aspects of ELF magnetic exposure, if any, are of biological concern[6]. Consequently, public acceptance of magnetic field exposures is presently based more on equity and comparability to other exposures than it is to quantifiable characteristics of the field itself. Therefore, this section compares and contrasts the magnetic fields produced by the MBTA operation to other sources of magnetic fields.

9.3.1 Static Fields

Static magnetic fields beyond normal range normally due to passive perturbation of the earth's geomagnetic field exist inside the cars, the operator's position, at the wayside, on the platforms, inside and outside the traction power supply stations and inside control rooms because of the dc nature of the MBTA electrification. The largest measured static fields of 3 gauss were encountered in subway cars and trolleys, near the floor. For comparison, the maximum magnetic field reading at 60 cm above the floor was 2.2 gauss. Total static fields in excess of 1 gauss also existed on platforms (2.4 G) and inside the TPSS (2.8 G).

9.3.2 Frequency Spectrum

The frequency characteristics of the magnetic fields onboard or near the MBTA transit vehicles is substantially different from those near many electrical appliances. The dc electrification gives rise to low frequency components which are the result of temporal changes in the dc traction current drawn by operating cars. Also, there are even harmonics of 60 Hz present that arise from the rectification ripple currents in the traction current.

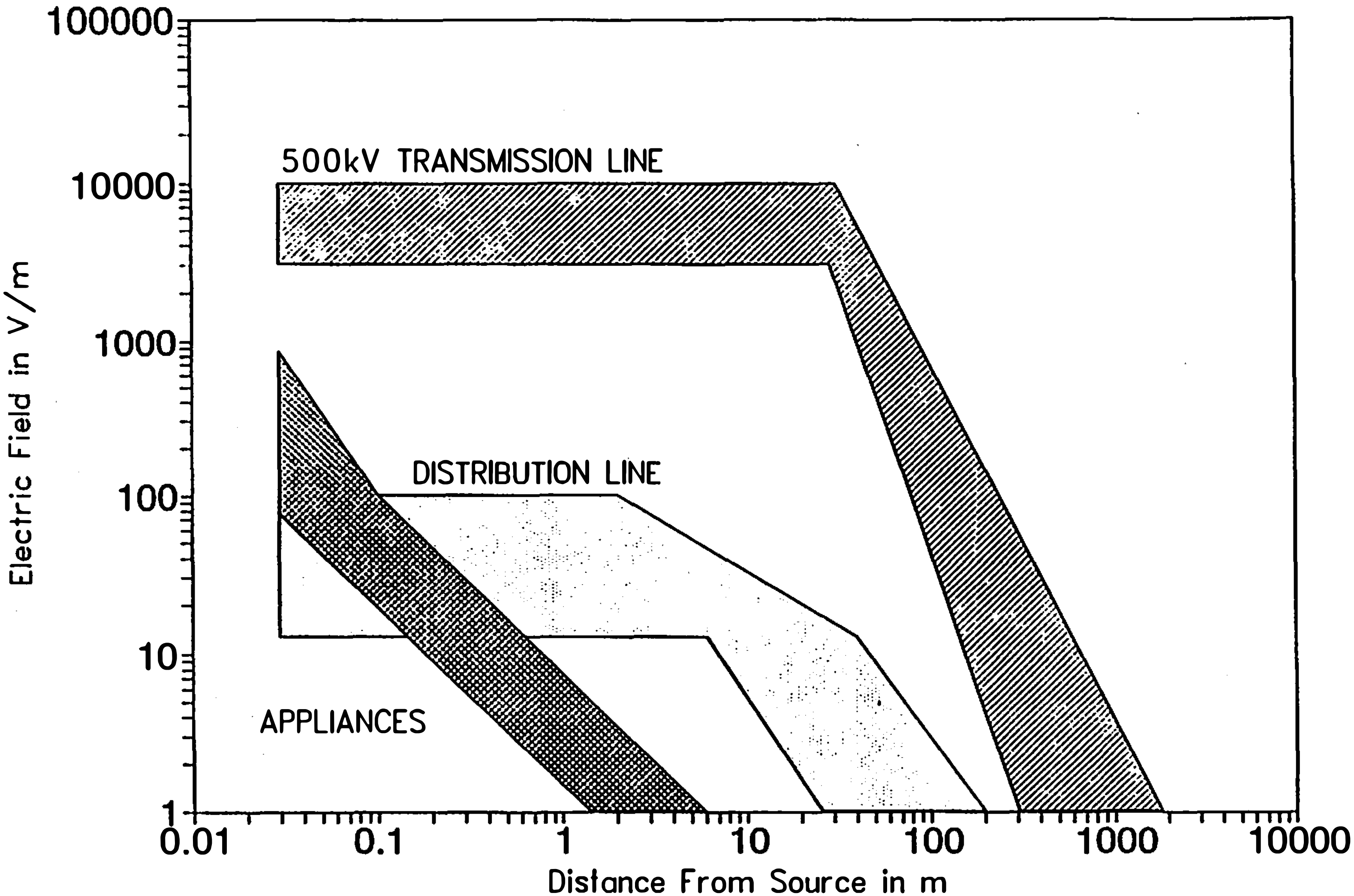


FIGURE 9-3. ILLUSTRATION OF HOW ELECTRIC FIELD INTENSITY NEAR GROUND LEVEL WILL CHANGE WITH HORIZONTAL DISTANCE FROM THREE COMMON SOURCES OF POWER-FREQUENCY ELECTRIC FIELDS. THE BANDS REPRESENT VARIATION ACROSS INDIVIDUAL SOURCES IN EACH GROUP. ADAPTED FROM NAIR, ET AL[6]

Moreover, the Green Line cars contain semiconductor choppers and filtering reactor coils, located beneath the cars, which produce fields in the higher end of the ELF band.

9.3.3 Time Characteristics

The magnetic fields onboard the MBTA vehicles, both subway, Trolley, and Trolley Bus or near the rails have pronounced temporal variability similar to the variability of magnetic fields near appliances with varying load or intermittent use. These fields have much greater variability than the fields found near most commercial electric power lines.

9.3.4 Amplitude Characteristics

This section compares the measured time varying magnetic field levels onboard the MBTA vehicles or near the MBTA lines and its facilities to the reported environmental field levels from various power frequency sources. This comparison is based on total ELF magnetic field (rms of total bandwidth) and does not take into consideration the significant differences in frequency spectra. For considerations where frequency is an important factor, this comparison is invalid because the MBTA System fields which contain little or no 60 Hz component are compared to fields which are essentially entirely 60 Hz.

9.3.4.1 Vehicles - Figure 9-4 shows the general range of total time varying magnetic fields measured in the subway, Trolley, and Trolley Buses on the MBTA transit lines as a function of distance from the source, which for purposes of this graph is presumed to be the car floor. The range is plotted over the graph of a typical transmission line, distribution line and appliance field levels[6] discussed earlier. As the graph illustrates, the intensity of the ELF magnetic field inside the vehicles diminishes away from the floor. The range of magnetic field intensities spans about two orders of magnitude, including the range of magnetic fields found under all distribution lines and some transmission lines. However some higher intensities are found in transmission lines and close to appliances. There is essentially little difference between the subway cars and the Trolley or Trolley Buses.

9.3.4.2 Operator's Position - Figure 9-5 shows the range of total time varying magnetic fields recorded in the MBTA operator's position as a function of distance from the floor. The data are plotted over the same typical power frequency magnetic field levels. The magnetic field levels in the operator's compartment are similar to those found in other parts of the vehicle (see Figure 9-4) and are within the range of field levels found beneath electric distribution lines or near appliances.

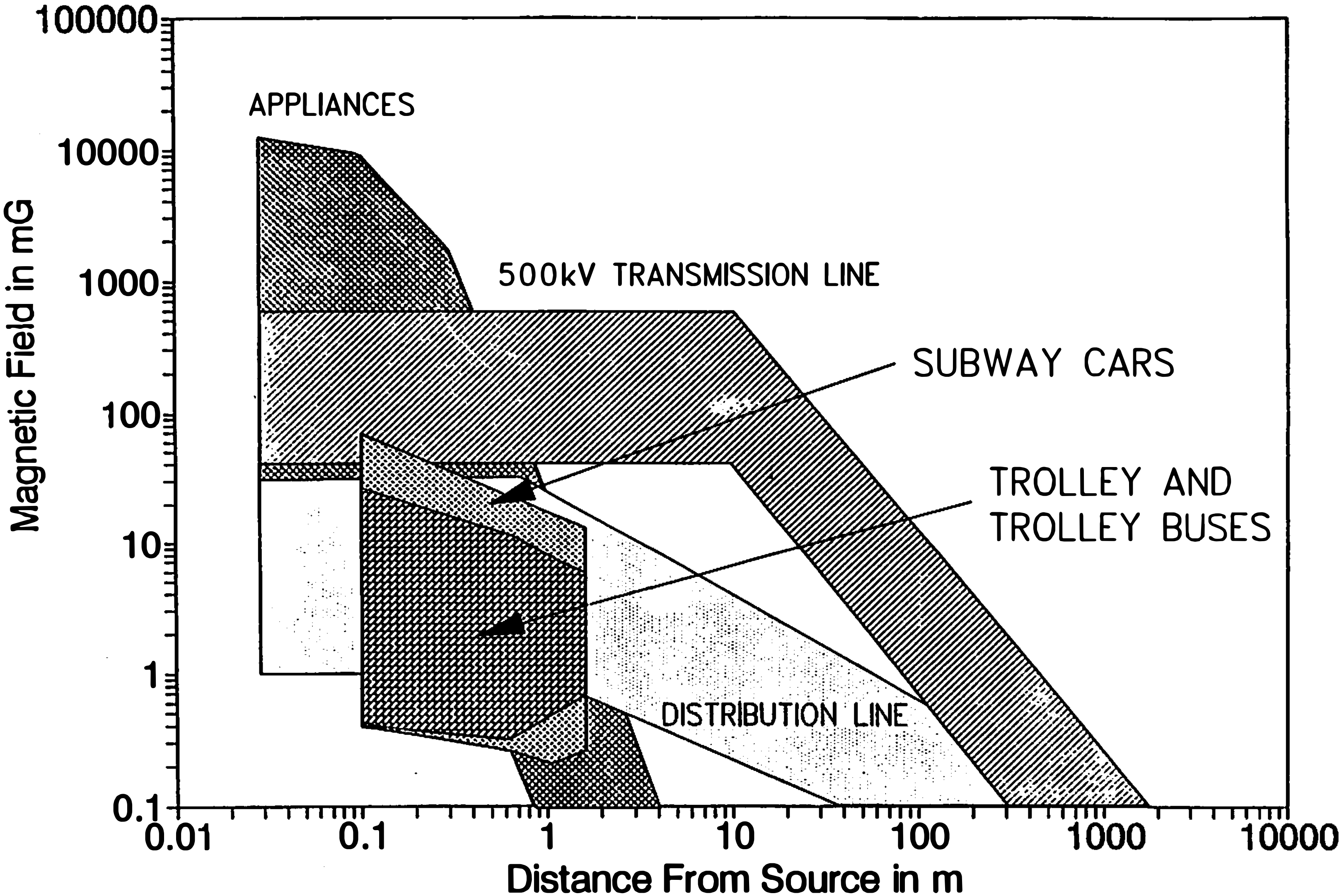


FIGURE 9-4. **THE RANGE OF TOTAL TIME VARYING MAGNETIC FIELD LEVELS IN THE MBTA SYSTEM SUBWAY, TROLLEY, AND TROLLEY BUS VEHICLES COMPARED TO TYPICAL LEVELS OF POWER FREQUENCY MAGNETIC FIELDS PRODUCED BY COMMON SOURCES**

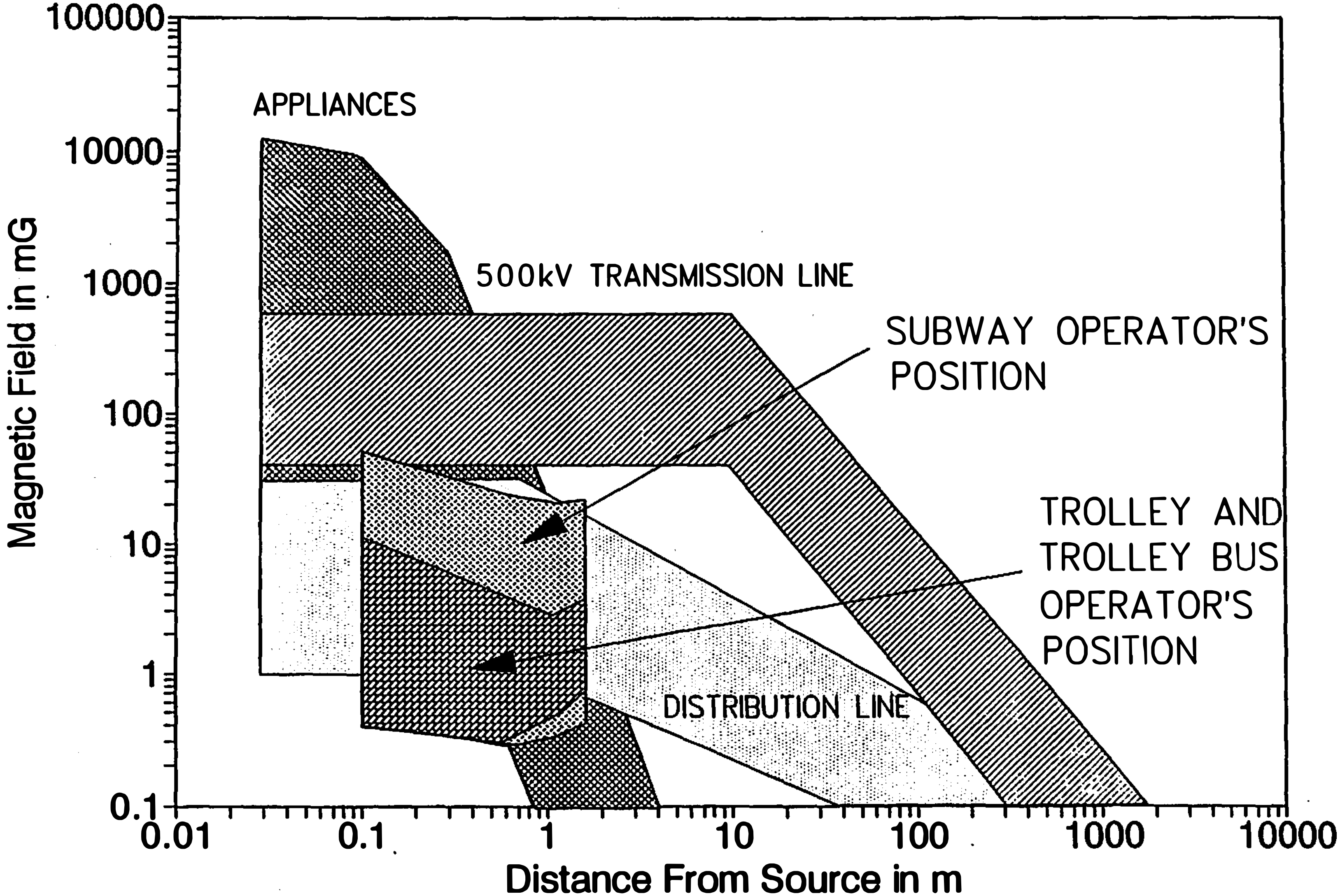


FIGURE 9-5. **THE RANGE OF TOTAL TIME VARYING MAGNETIC FIELD LEVELS IN THE OPERATOR'S POSITION OF THE MBTA SYSTEM SUBWAY, TROLLEY, AND TROLLEY BUS VEHICLES COMPARED TO TYPICAL LEVELS OF POWER FREQUENCY MAGNETIC FIELDS PRODUCED BY COMMON SOURCES**

9.3.4.3 Along the Wayside - Figure 9-6 shows the plot of the ranges corresponding to the two types of measurement locations, namely the subway waysides of the Green and Blue Lines and the sidewalk wayside along the Trolley Bus route. The distance to the source for the subway waysides is measured to the centerline of the nearest set of tracks. The distance to the source for the Trolley Bus wayside is measured to the nearest overhead double catenary centerline. As described in Section 6, these measured field levels included fields from both the MBTA system and background fields from other sources. Consequently, the measured values overstate the magnitude of the field actually produced by the MBTA System. The figure shows that these conservative measures of magnetic field levels at both locations are within the general range of magnetic fields near distribution lines. The actual contribution to the magnetic fields from the MBTA facilities is lower.

9.3.4.4 Passenger Stations - The ranges of time varying magnetic fields measured on the passenger platforms, both indoor and outdoor, on third rail with cam cars and on catenaries with and without chopper-type cars were sufficiently the same that they have been combined into one set for purposes of this graph. These time varying magnetic fields are shown in relation to other sources in Figure 9-7. The distance to the source is the distance to the floor of the platform. The range of magnetic field levels at the platforms are about the same as the general range of magnetic fields near distribution lines.

9.3.4.5 Power Supply System Measurements - The ranges of total time varying magnetic fields recorded at the three traction power supply stations are shown in Figures 9-8 and 9-9. Figure 9-8 shows the outside TPSS measurements, where the distance is measured to the sidewalk floor. It can be seen that these field levels are in the range of fields found under distribution lines. Figure 9-9 shows the inside TPSS measurements, where the distance to the source is the distance to the floor of the station. The range of magnetic field levels inside the stations are at the low side of the range of magnetic fields near transmission lines.

9.3.4.6 Control Areas - Figure 9-10 shows the plot of the range of time varying magnetic fields in front of the dispatcher's VDT in the dispatcher's room. The distance to the source is the distance to the VDT screen. As one would expect, the figure shows that the range of magnetic field levels from the VDT is well within the range of magnetic fields near appliances. The sharp change of the VDT field curve beyond 1 m (3.3 ft) from the source represents the point where the general background field level within the dispatcher's room is predominant. That background level is very modest compared to the range of field levels found near the three common field sources depicted in the figure.

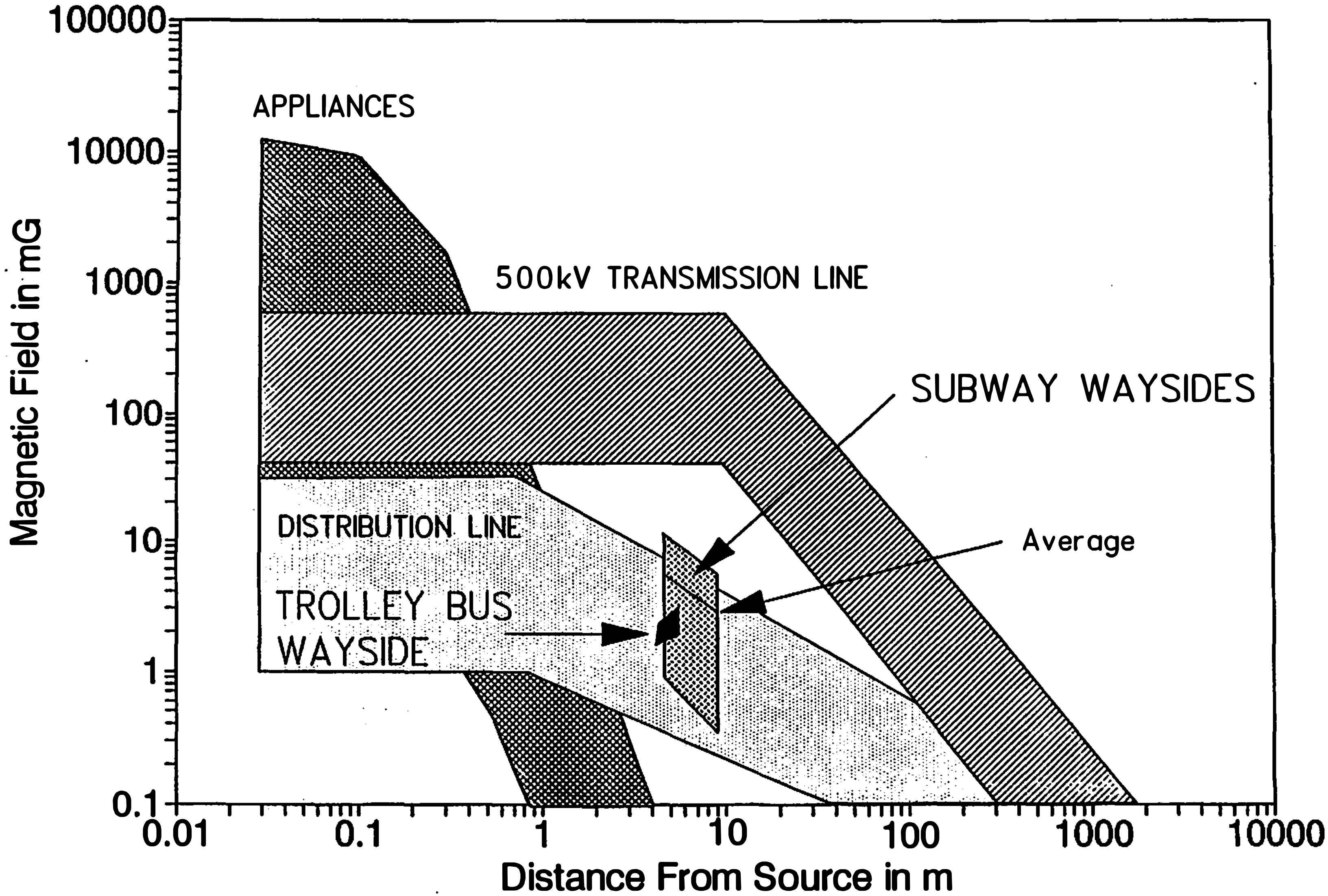


FIGURE 9-6. **THE RANGE OF TOTAL TIME VARYING MAGNETIC FIELD LEVELS AT SUBWAY WAYSIDES AND TROLLEY BUS WAYSIDE, AT VARIOUS DISTANCES FROM THE NEAREST TRACK OR CATENARY, COMPARED TO TYPICAL LEVELS OF POWER FREQUENCY MAGNETIC FIELDS PRODUCED BY COMMON SOURCES**

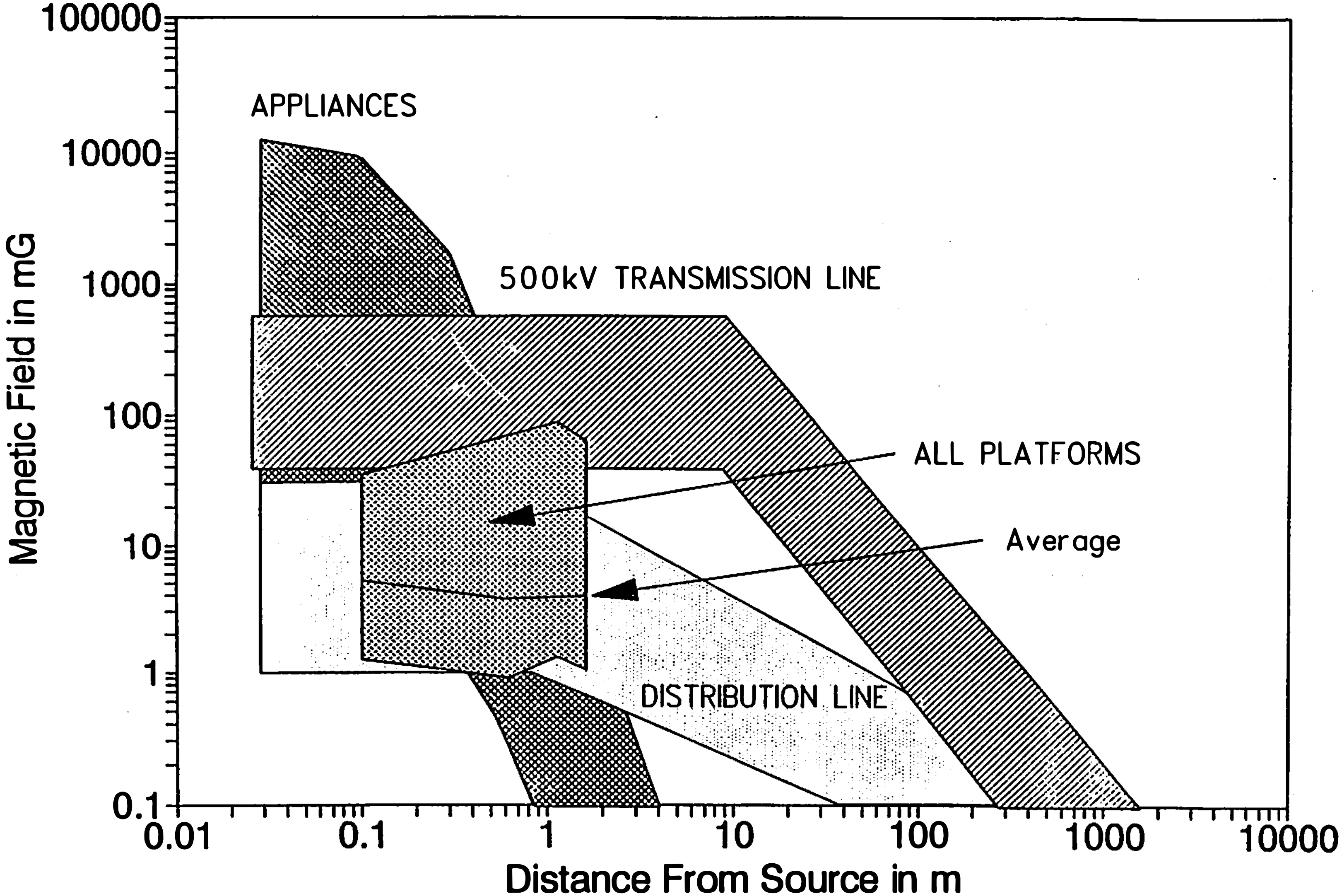


FIGURE 9-7. THE RANGE OF TOTAL TIME VARYING MAGNETIC FIELD LEVELS ON THE PLATFORMS, AT VARIOUS DISTANCES FROM THE FLOOR, COMPARED TO TYPICAL LEVELS OF POWER FREQUENCY MAGNETIC FIELDS PRODUCED BY COMMON SOURCES

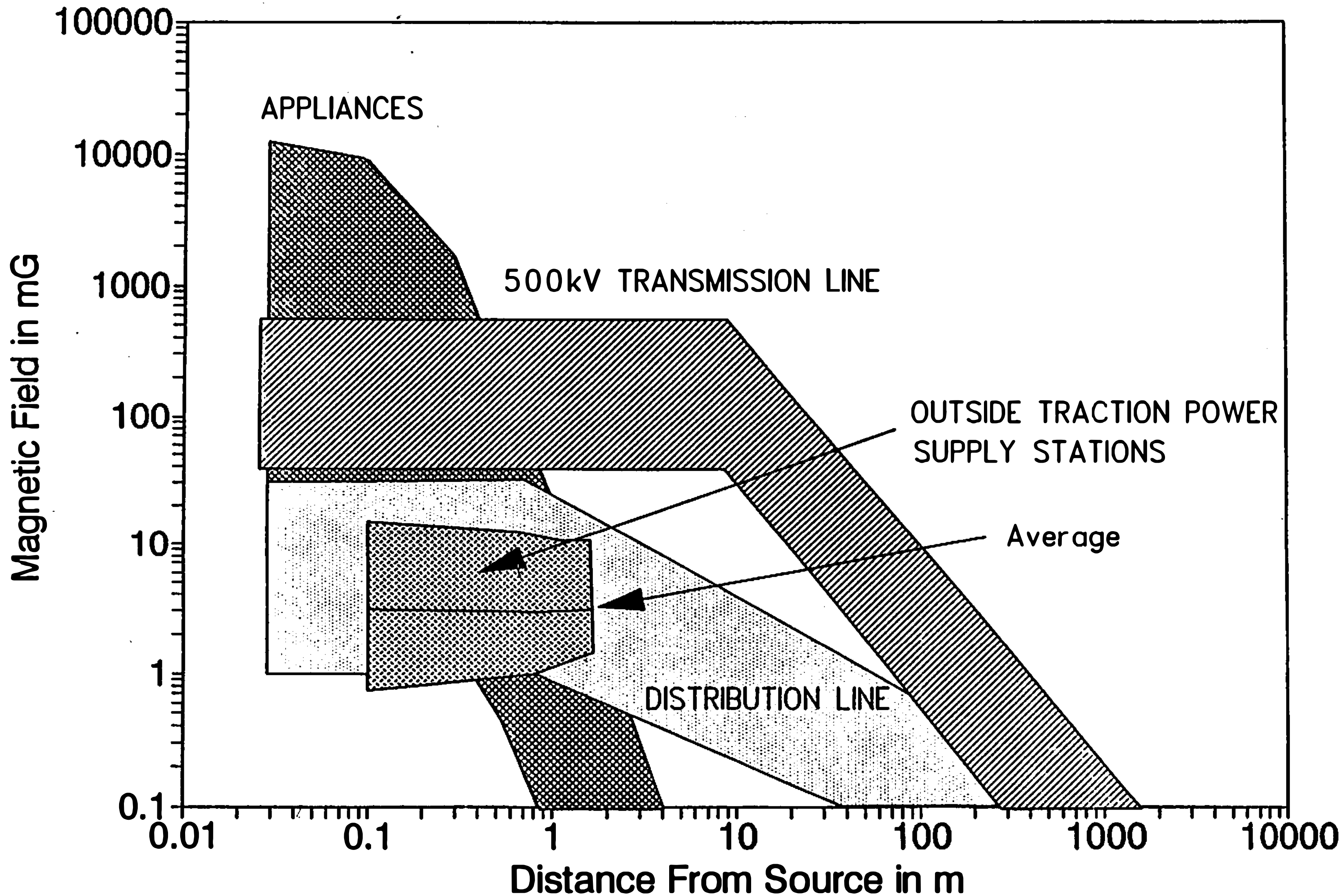


FIGURE 9-8. THE RANGE OF TOTAL TIME VARYING MAGNETIC FIELD LEVELS OUTSIDE TRACTION POWER SUPPLY STATIONS, AT VARIOUS DISTANCES FROM THE GROUND, COMPARED TO TYPICAL LEVELS OF POWER FREQUENCY MAGNETIC FIELDS PRODUCED BY COMMON SOURCES

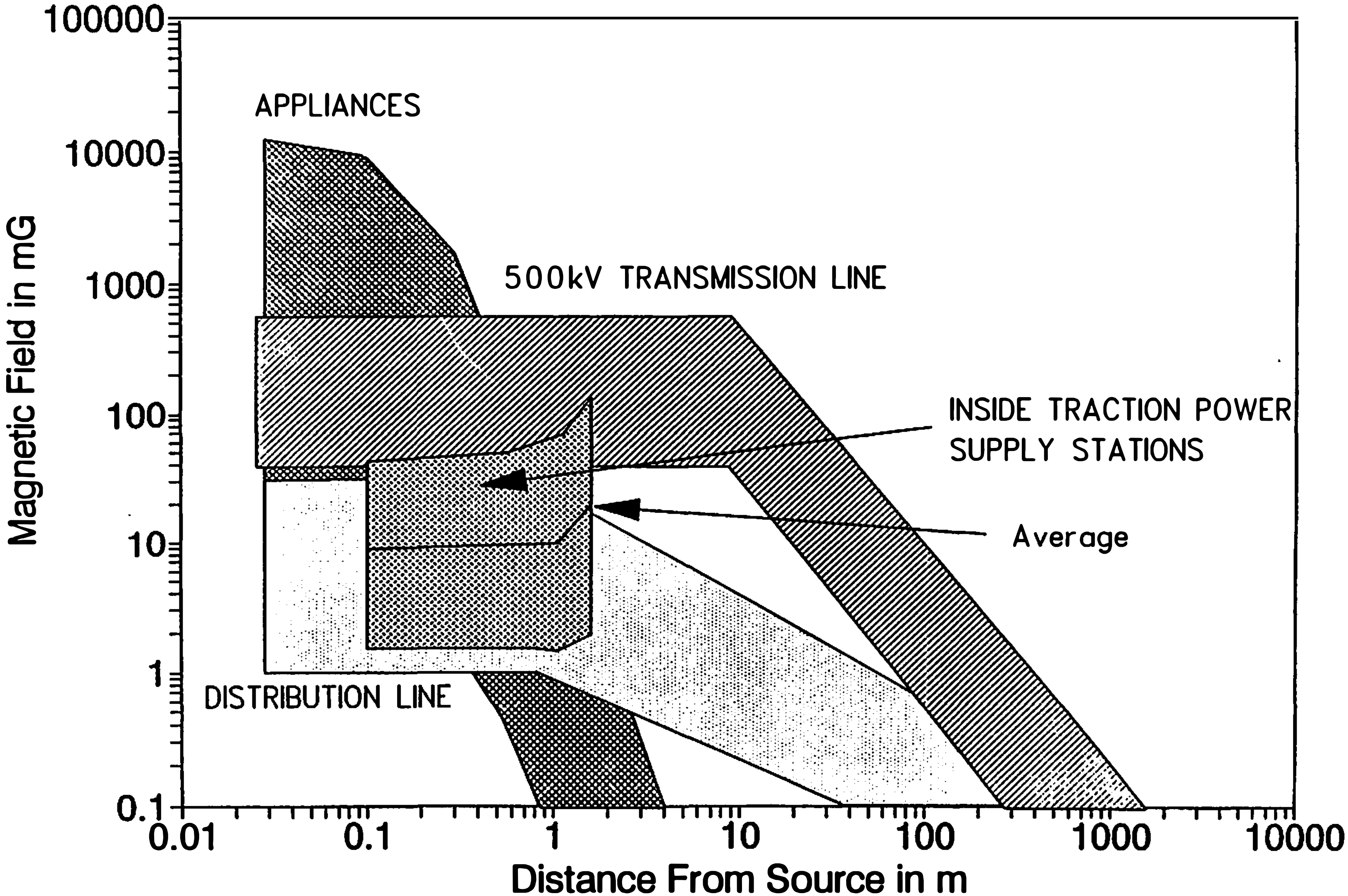


FIGURE 9-9. THE RANGE OF TOTAL TIME VARYING MAGNETIC FIELD LEVELS INSIDE TRACTION POWER SUPPLY STATIONS, AT VARIOUS DISTANCES FROM THE FLOOR, COMPARED TO TYPICAL LEVELS OF POWER FREQUENCY MAGNETIC FIELDS PRODUCED BY COMMON SOURCES

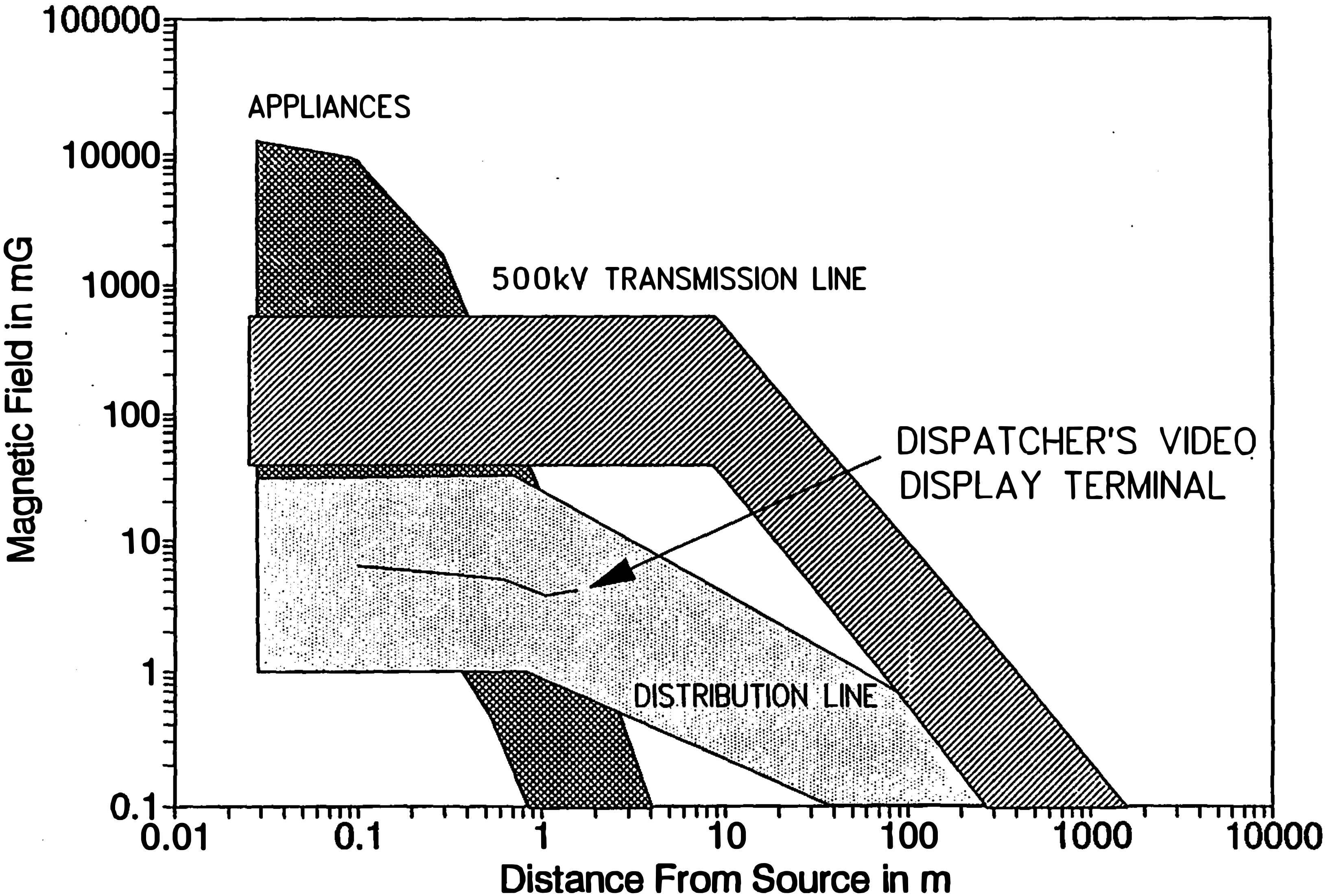


FIGURE 9-10. THE RANGE OF TOTAL TIME VARYING MAGNETIC FIELD LEVELS IN FRONT OF A DISPATCHER'S VIDEO DISPLAY TERMINAL, AT VARIOUS DISTANCES FROM THE VDT, COMPARED TO TYPICAL LEVELS OF POWER FREQUENCY MAGNETIC FIELDS PRODUCED BY COMMON SOURCES

9.4 COMPARISON OF MBTA SYSTEM FIELDS TO EXISTING STANDARDS

The United States has no national standards which establish limits on the intensity of ULF and ELF electric magnetic fields. There are two interim guidelines established by international organizations and one established by a domestic professional trade organization. Furthermore, while over 24 states are actively reviewing the need for standards, presently there are two state level standards limiting ELF magnetic fields and several others limiting ELF electric fields. These state standards presently apply only to electric power lines and substations. This subsection of the report will compare the magnetic field levels onboard the MBTA vehicles and inside or near related facilities to the field levels permitted under the above-mentioned standards. Figures 9-11 and 9-12 summarize the overall comparison of the magnetic field levels in the passenger compartments of various vehicles to existing standards. Figure 9-11 shows the comparison for Red, Blue, Green and Orange Line vehicles while Figure 9-12 shows a similar comparison for fields in the Mattapan High Speed Trolley and the North Cambridge Trolley Bus. Field levels 60 cm above the floor were chosen for purposes of this comparison as that height is the approximate body center of a person in a seated position.

9.4.1 World Health Organization

The World Health Organization's (WHO) *Environmental Health Criteria 35: Extremely Low Frequency (ELF) Fields*[12] addresses both electric and magnetic fields but focuses more heavily on electric fields. Although it concludes that "adverse human health effects from exposure to ELF electric field levels normally encountered in the environment or the workplace have not been established" and sets no numerical limits for general or occupational exposure, it recommends limiting long-term exposures to 50/60 Hz electric fields to levels between 1 and 10 kV/m as "levels as low as can be reasonably achieved." By comparison, the highest electric field levels encountered in these measurements were 5 V/m, 200 times less than the lower end of this recommended limit.

WHO's *Environmental Health Criteria 69*[13] addresses ELF magnetic fields. The document concludes that available scientific knowledge does not permit establishment of a definitive limit for static or time varying magnetic fields. The document indicates that adverse human health effects are unlikely at static field levels less than 2 T (20,000 gauss) or with time varying magnetic fields which induce current densities of less than 10 mA/m^2 within tissue or extracellular fluids. Based on available scaling data for magnetically induced currents in the human body, the 10 mA/m^2 threshold is reached at 60 Hz field levels of approximately 10 gauss. The corresponding level at another ELF frequency would be adjusted from the 10 G value by the reciprocal of the ratio of the frequencies.

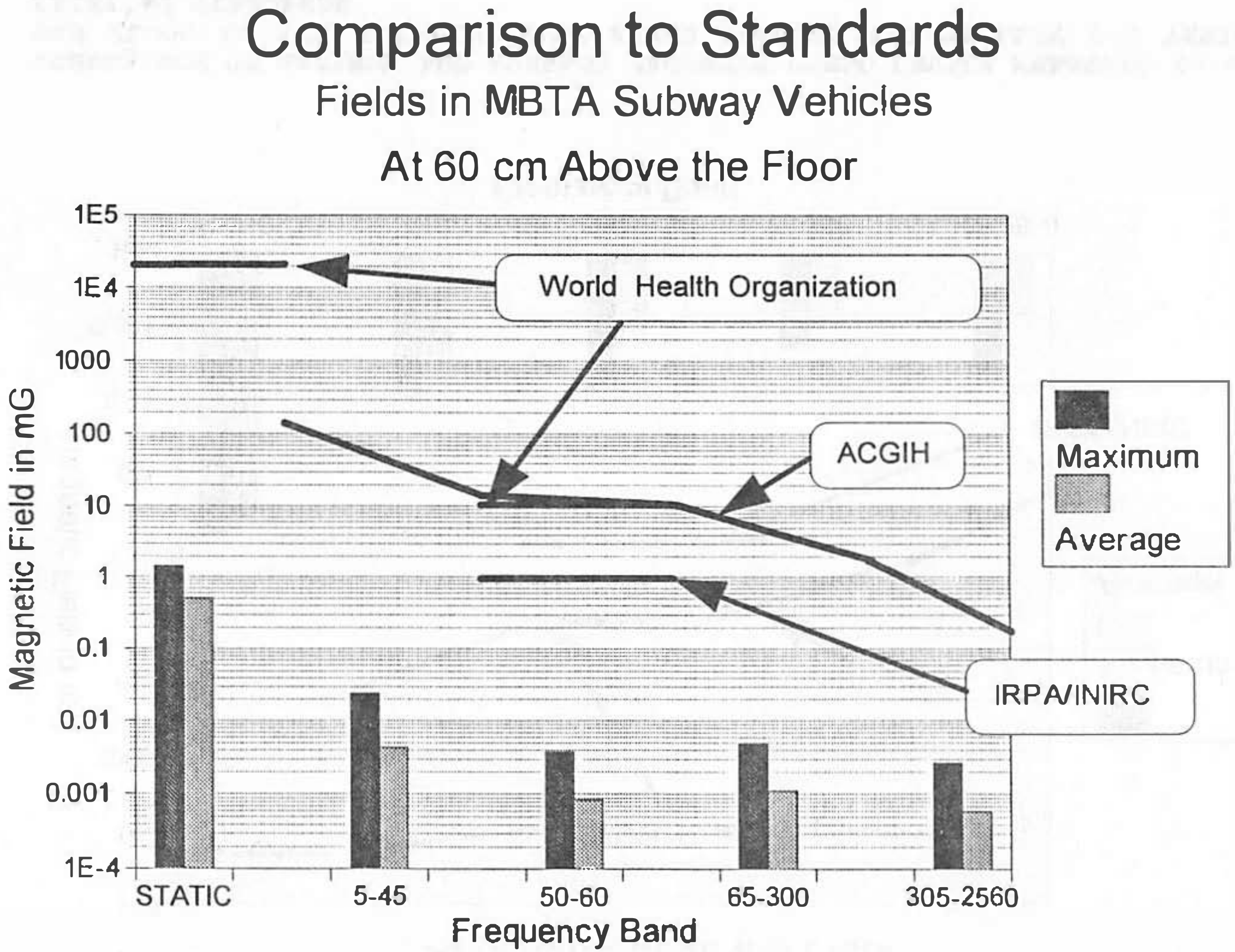


FIGURE 9-11. **COMPARISON OF MAXIMUM AND AVERAGE MAGNETIC FIELD LEVELS MEASURED 60 cm ABOVE THE FLOOR IN RED, ORANGE, BLUE AND GREEN LINE SUBWAY VEHICLES TO EXISTING STANDARDS**

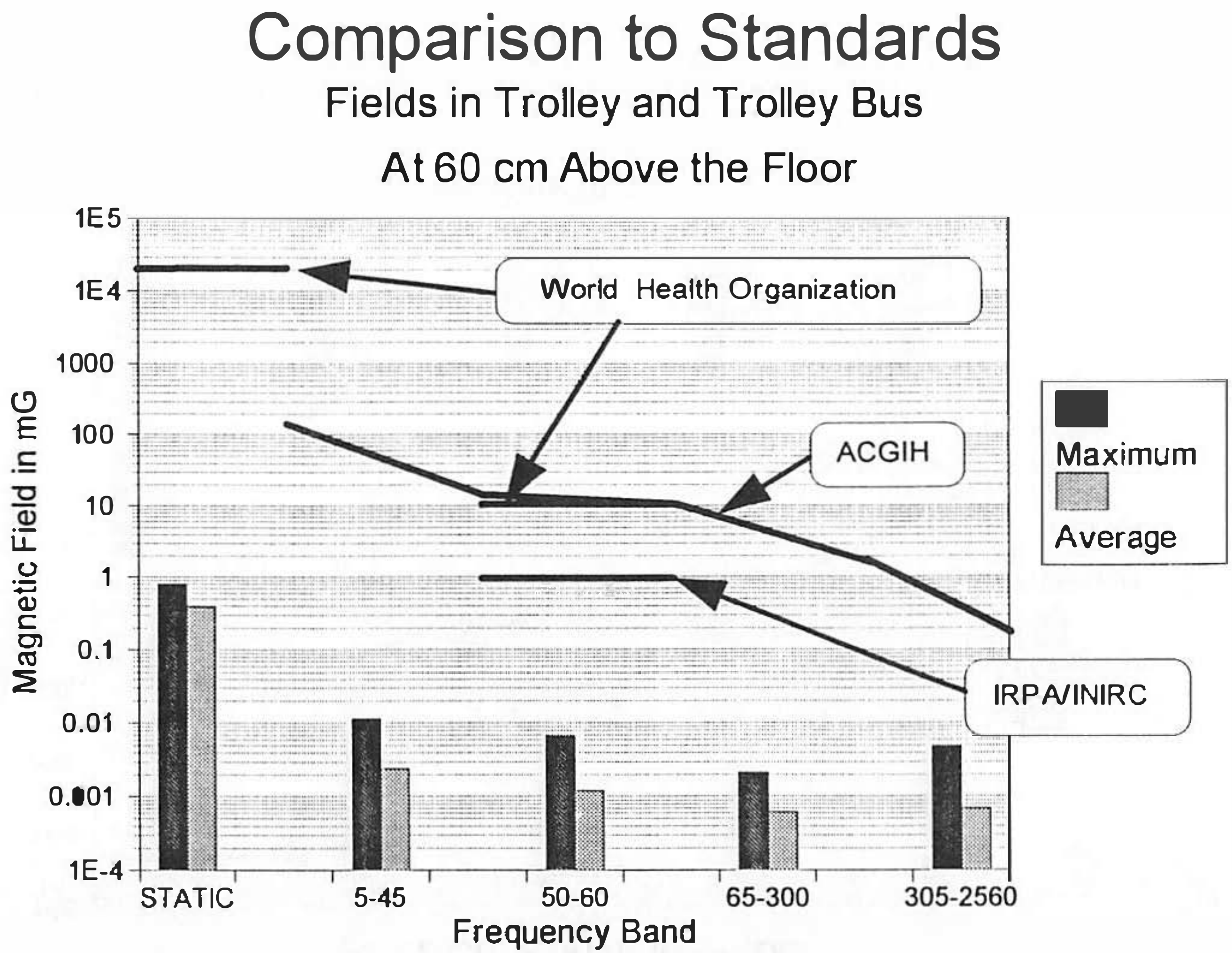


FIGURE 9-12. COMPARISON OF MAXIMUM AND AVERAGE MAGNETIC FIELD LEVELS MEASURED 60 cm ABOVE THE FLOOR IN THE MATTAPAN HIGH SPEED TROLLEY AND TROLLEY BUS VEHICLES TO EXISTING STANDARDS

The measured time varying magnetic fields in various frequency bands are two orders of magnitude below the WHO criterion in each frequency band. Even greater margins of compliance are found for static magnetic fields (3000 mG, as discussed in Section 9.3.1) where the WHO criterion is 20,000,000 mG.

9.4.2 International Radiation Protection Association

The International Non-Ionizing Radiation Committee (INIRC) of the International Radiation Protection Association (IRPA) has developed an interim standard[14] limiting human exposure to power frequency (50/60 Hz) electric and magnetic fields. The established magnetic field limit for 24 hours per day to the general public is 1 gauss. Short-term exposures of up to a few hours per day are permitted to 10 gauss. Permitted occupational exposure levels are five times that permitted for the general public. The highest average time varying power frequency magnetic field level associated with the MBTA system was 111 mG recorded inside the TPSS. This level is 2.2 percent of the 5 gauss, 24-hour occupational limit. The highest non-occupational corresponding average is 1.5 percent, recorded at the 10 cm level inside the subway cars. The highest of the total ELF magnetic field level is 133 mG, recorded inside the TPSS, and is below the IRPA recommended limit.

The numerical field limits in the IRPA standard apply explicitly to power frequency magnetic fields. However, the text of the standard clearly demonstrates that the standard is based on induced current concerns. Hence, acceptable field limits at frequencies other than 50 or 60 Hz would be related to the 50/60 Hz threshold by the ratio of the power frequency to the frequency of the magnetic field.

9.4.3 American Conference of Governmental Industrial Hygienists

The American Conference of Governmental Industrial Hygienists (ACGIH) has established a "threshold limit value" (TLV) for 60 Hz magnetic fields at 10 gauss and a static magnetic threshold limit of 600 gauss[15]. The document recommends that routine occupational exposures should not exceed the 10 gauss at 60 Hz, but states that the value is to be used as a guideline, not as a strict determination of safe and unsafe levels. For example, values ten times less than the above TLVs are recommended for persons with implanted pacemakers. These TLV values are comparable to the guidelines recommended by the World Health Organization and the tenfold lower level suggested for pacemaker wearers is comparable to the IRPA guideline. As discussed above, these limits are above the IRPA/INIRC time varying limits and the measured magnetic fields on or near the MBTA System meet those criteria.

The TLV for electric fields at frequencies of 100 Hz or less is 25 kV/m[15]. The highest electric field levels found in or around the existing MBTA electrified transit facilities was 5 V/m, well within the TLV guidelines.

9.4.4 State Power Line Limits

The states of Florida[16] and New York[17] have adopted standards specifically limiting the intensity of the power frequency electric and magnetic fields at the boundaries of transmission lines' rights-of-way or substation property lines to values from 1.6 to 2.0 kV/m and 150 mG to 250 mG, depending on the type of transmission line. Both standards are established on a "status quo" basis rather than a health or safety basis. Although neither applies to transportation systems, they do provide some guidance as to the levels of magnetic fields which have been judged tolerable at the boundaries of linear facilities which are in that respect similar to the MBTA transit lines corridor. The maximum electric field found, at 170 cm above the floor/ground, was less than 5 V/m and the total time varying magnetic field was 82 mG, at the platforms made up of mostly low frequency components; both below the transmission line limits.

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