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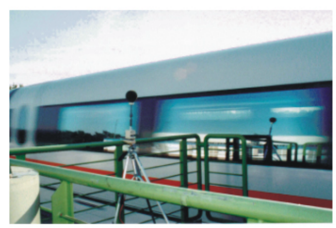
Washington, DC 20590

Electromagnetic Field Characteristics of the Transrapid TR08 Maglev System



U.S. Department of Transportation
Research and Special Programs Administration
John A. Volpe National Transportation Systems Center
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13. ABSTRACT (Maximum 200 words)
As part of the Federal Railroad Administration's (FRA) Magnetic Levitation Transportation Technology Deployment Program, this technical report has been prepared to characterize the temporal, spatial, and frequency-dependent variability of electromagnetic fields (EMF) associated with the operation of the Transrapid International (TRI) TR08 Maglev System. The TRI TR08 Maglev System is an advanced transportation technology in which magnetic forces levitate, propel, and guide a vehicle over a specially-designed guideway. The TR08 Maglev System is the technology that is being considered for deployment in the U.S., and potential EMF impacts were not known. This document presents EMF data collected during measurements of the TRI TR08 Maglev System in August 2001 at the TRI Test Facility in the Emsland region of Germany. *MultiWave*® digital data recorders were used to characterize static and extremely low frequency (ELF; 3-3,000 Hz) magnetic fields; these data were augmented with measurements of very low frequency (3-30 kHz) and low frequency (30-300 kHz) magnetic fields, ELF electric fields, and radiofrequency electric fields. EMF personal exposure data were collected using EMDEX and Nardalert probes. Measured EMF levels and characteristics are similar to those of existing electric transportation and comply with all current applicable human exposure safety standards.

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PREFACE

As part of the Federal Railroad Administration's (FRA) Magnetic Levitation Transportation Technology Deployment Program, this technical report characterizes the electromagnetic fields (EMF) and radiation (EMR) associated with the operation of the Transrapid International TR08 Maglev System, a transportation system employing magnetic levitation (maglev). This report presents measurements of EMF/EMR associated with the TR08 Maglev System; these measurements were taken at the Transrapid Test Facility (TVE) in the Emsland region of Germany, in August, 2001. The data presented and analyzed herein can be utilized to support the required environmental planning and deployment activities for any Transrapid Maglev project in the U.S.

This report is the product of a combined international effort. The authors wish to thank the many individuals and organizations whose contributions were instrumental in the coordination, test plan development, field measurements, analysis, documentation, and supporting functions for this report. Foremost among these is Mr. Fred Dietrich of Electric Research who provided essential leadership and contributions to all aspects of this measurement effort. The participation, cooperation, and forbearance of the operators and staff of TVE during the measurement campaign were especially appreciated. Without their gracious hosting of the measurements, this work would not have been possible. The valuable assistance of Mr. Robert Budell, Mr. Christian Rausch, and Mr. Frank Litzmann of Transrapid International, and Mr. Laurence Blow and Mr. Reed Tanger of Transrapid USA, are also acknowledged, as their contributions were critical to the success of this effort. The staff of IABG (Industrieanlagen Betriebsgesellschaft), including Mr. Gerold Snieders and Mr. Hans-Gert Runde, provided important information to the measurement team; special thanks is extended to Dr. Klaus-Peter Schmitz (IABG), for his thorough explanations of TR08 technology and equipment placement, and his daily assistance in coordinating that day's tests.

Mr. Arnold Kupferman, Dr. John Harding, and Mr. David Valenstein of FRA provided programmatic guidance and leadership; additionally, Mr. Valenstein's participation in the EMF survey was appreciated.

In the coordination of the measurement campaign and in the production of this report, we also acknowledge the support of staff at Electric Research, MAGLEV, Inc., and the John A. Volpe National Transportation Systems Center. Particularly, the assistance of Mr. Edd Manges from MAGLEV, Inc., was useful.

EXECUTIVE SUMMARY

OBJECTIVE

A measurement campaign for the Transrapid TR08 magnetically levitated transportation system was undertaken in August 2001 at the Transrapid Test Facility (TVE), in the Emsland region of Germany, to characterize and quantify the static and extreme low frequency (ELF) (3 Hertz [Hz] to 3000 Hz [3 kilohertz (kHz)]) magnetic fields to which passengers may be exposed while traveling in that transportation system. Very low frequency (VLF) (3 kHz to 30 kHz) and low frequency (LF) (30 kHz to 300 kHz) magnetic fields, ELF electric fields, and radiofrequency (RF) electric fields were also characterized, but in less detail, because significant emissions were not anticipated in those frequency ranges. This report also characterizes and quantifies magnetic fields in areas of public access on the station platform, beneath or near the guideway, and near electrical switching cabinets along the guideway.

PROCEDURES

Because of past measurements on the TR07 system (FRA 1992), it was anticipated that the ELF and static magnetic field conditions on board the TR08 vehicle would be extremely dynamic, changing in amplitude, direction, and frequency distribution over time, vehicle speed, location, and other less well defined parameters. To appropriately characterize the short-term temporal characteristics of the field, static and ELF fields were measured with three-axis fluxgate magnetometers and recorded in the *MultiWave®* digital data recorders using a waveform sampling technique compatible with Fourier spectral analysis. At each sensor location, the instantaneous field was sampled at a high rate for a period of 300 milliseconds (ms). The resulting field 'snapshot' could resolve the frequency and intensity of all field components from 0 to 3000 Hz with a resolution of 3.3 Hz. Longer-term temporal variations in field conditions associated with system operating conditions were characterized by taking repeated field snapshots throughout an entire trip, consisting usually of two laps around the test track.

Spatial variability of the static and ELF magnetic field over the dimensions of a passenger's body was documented by performing simultaneous measurements at locations representing the head, waist, and ankle of a seated or standing passenger. These measurements were accomplished with sensors securely clamped in an articulated plastic mannequin which could be stood upright or seated in any seat while maintaining the anatomically relevant placement of the sensors. Other sensors were attached to the mannequin or placed near the mannequin to measure ELF electric fields, VLF magnetic fields, LF magnetic fields, and RF electric fields concurrent with the static and ELF magnetic field measurements. Spatial variability of the fields within each car and among the three cars of the consist were characterized by moving the sensor-equipped mannequin from one location to another and repeating the tests during another two-lap trip around the test track. Ultimately, detailed measurements were completed with the sensor mannequin at 14 locations within the passenger compartment and one location in the attendant's forward compartment.

To characterize and quantify the magnetic and electric fields on the station platform, the instrumented mannequin was placed in a standing position on the platform. Data were collected as the TR08 made multiple passes by the station and while it pulled into the station and stopped. This characterization was repeated twice, once with the sensors 1 m from the TR08 (the nearest permissible under safety constraints) and during a different trip with the sensors 1.9 m from the passing vehicle (the most distant position possible given the narrow width of the platform).

Using techniques similar to those employed on board the vehicle, electric and magnetic fields were measured near five different kinds of guideway beams. Rather than being mounted on the mannequin, the sensors were placed at incremental distances from the guideway, so that the rate of field attenuation away from the guideway could be determined. At each of these locations, field characteristics were recorded during at least two vehicle passes.

Electric and magnetic fields were also measured around two of the electrical switching cabinets along the guideway. As for the guideway measurements, sensors were placed at incremental distances from the cabinets to document the field attenuation.

For validation and verification purposes, additional EMF personal exposure measurements were made using an EMDEX-II system (Enertech Consultants) most sensitive at power frequency and harmonics (60-300 Hz). Data were collected adjacent to and simultaneous with *MultiWave*® recordings. These data also served to expand the overall dataset for this study.

Magnetic field data were collected using protocols and instrumentation compatible with those previously employed for similar measurements in the prior Transrapid prototype vehicle, the TR07 (FRA 1992), and in a variety of conventional transportation systems (FRA 1993b, 1993c, 1993d, 1993e). Therefore, valid comparisons can be made of EMF emissions and exposure conditions across frequencies and operational conditions.

RESULTS

ELF and static magnetic field conditions on board the TR08 vehicle were extremely dynamic, changing in amplitude, direction, and frequency distribution over time, vehicle speed, location, and other less well defined parameters. Those fields arose principally from sources below the floor and were uniformly distributed along the length of the vehicle. Because these fields are principally static and low frequency fields with often non-periodic waveforms, they appear to arise from the levitation and/or guidance magnets in the magnetic bogies or the control circuitry for those devices. These magnetic field sources produce the highest field levels near the floor of the vehicle, and the lowest near the ceilings. Secondary magnetic field sources throughout the vehicle produce periodic magnetic fields having a frequency proportional to the vehicle speed. These sources are often beneath the floor, but sometimes also in the bulkheads or overhead.

ELF electric fields were measurable on board the TR08, but were of negligible amplitude below a few volts per meter (V/m). VLF and LF magnetic fields were too small to be measured. Small RF electric fields, near the minimum sensitivity of the instrument, were barely detected. It is not clear whether those measurements represent a valid quantification of RF electric fields produced by the vehicle or associated infrastructure, or if they represent noise and spurious signals from other communications devices not related to the TR08 system.

At the station platform and along the guideway, the principal static and ELF magnetic field sources are clearly the three-section train consist as it passes by, or starts or stops adjacent to the point of interest. ELF magnetic fields from the energized guideway are insignificant if the vehicle is not immediately present. Electric fields and magnetic fields in higher frequency bands are of insignificant intensity, near or below the sensitivity of the instruments, or below the background fields from sources not part of the TR08 system.

ELF magnetic fields arise from the electrical switching cabinets, of which there are two designs. ELF magnetic fields arise principally from the cabinet of newer design whenever the vehicle is operating on one of the guideway sections powered from that cabinet. The magnitude of these fields is proportional to the magnitude of the guideway current and attenuates rapidly with increased distance from the cabinets. No significant fields were observed in any of the higher frequency bands.

Personal EMF exposure time-series confirm the high variability, but overall low average levels, of broadband EMF at power frequency and harmonics.

COMPARISON OF THE TR08 TO CONVENTIONAL ELECTRIFIED RAIL SYSTEMS

A summary of static and ELF average and maximum magnetic field levels measured in a variety of other transportation systems using similar instrumentation and protocols has been previously published (FRA 1993f). Figure ES-1 shows static and ELF magnetic field levels measured on board the TR08 compared to levels measured on board a variety of conventional rail systems and the earlier TR07 prototype. As the figure illustrates, the average magnetic field on board the TR08 is similar in amplitude and frequency distribution to those seen in the conventional electrified rail systems.

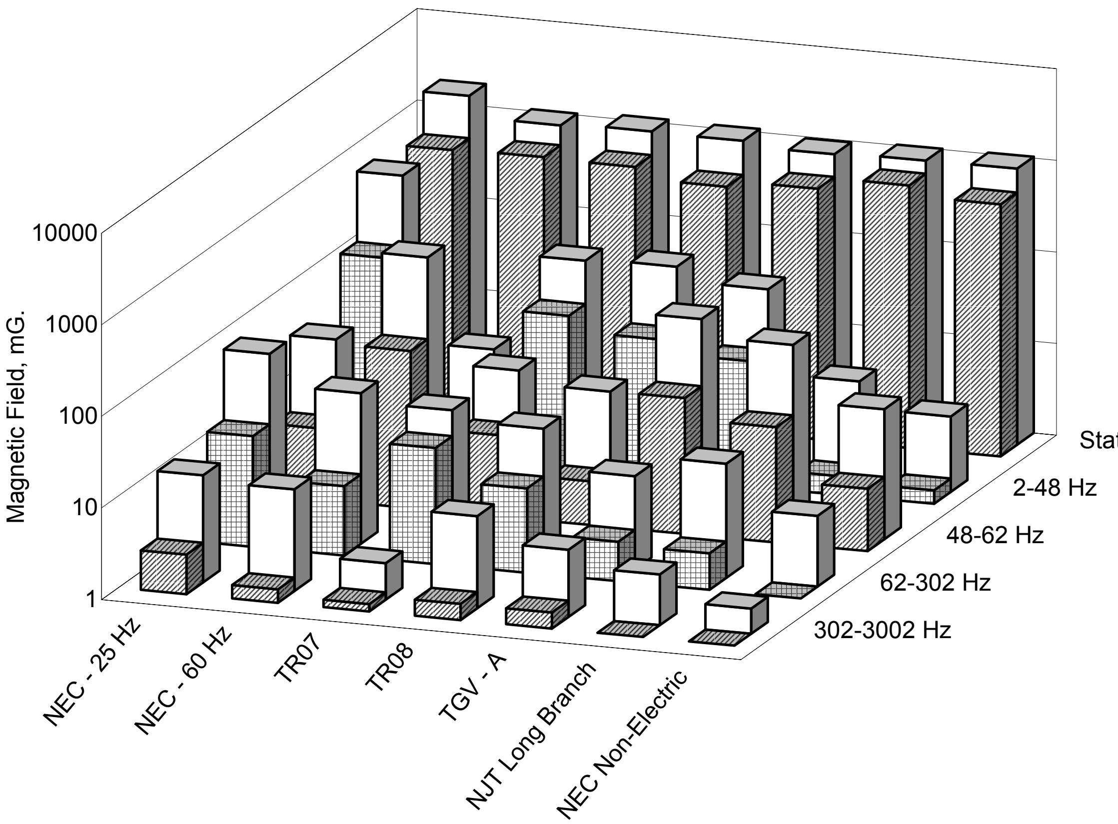


Figure ES-1. Average (shaded bar) and maximum (light bar) magnetic field levels (in milligauss) in passenger compartments of magnetically levitated and conventional intercity trains[1] (logarithmic scale)

COMPARISON WITH STANDARDS AND GUIDELINES

There are currently no national standards for static or ELF magnetic field exposure limits in the United States. However, there are voluntary ACGIH (American Conference of Governmental Industrial Hygienists) guidelines for occupational threshold limit values (ACGIH 2001). The International Commission on Non-Ionizing Radiation Protection (ICNIRP) published guidelines recommending maximum permissible exposures to the general public for both static (1994) and time-varying (1998) magnetic fields up to 300 GHz (gigahertz). The ICNIRP public exposure limits at 60 Hz correspond to 800 milligauss (mG) for magnetic fields and 8.3 kV/m for electric fields, but vary with frequency. The

[1] Rail systems shown in Figure ES-1 include: Amtrak Northeast Corridor (NEC) 25 Hz electrification, 60 Hz electrification, and non-electrified; the Transrapid TR07 and TR08 Maglev Systems; the TGV-Atlantique (TGV-A) 50 Hz electrification; and the New Jersey Transit (NJT) Long Branch 60 Hz electrification.

FCC published guidelines for human exposures to RF fields in 1997 (FCC 1997a, 1997b).

Figure ES-2 compares the absolute maximum magnetic field levels measured on board the TR08, on the station platform, near the guideway, or near the electrical switching (vertical bars) to the ICNIRP recommended ELF exposure safety levels. It is clear that those maximum fields are at all times less than the ELF exposure levels permitted by the ICNIRP guidelines. The ICNIRP guidelines provide recommendations for both public and occupational exposure; relative to the public limits, the occupational limits are about five times higher for magnetic fields and two times higher for electric fields. Since the occupational limits are higher than those recommended for the general public, compliance with the more stringent public exposure criteria ensures compliance with the limits recommended for workers.

The American Conference of Governmental Industrial Hygienists (ACGIH) also publishes static and ELF electric and magnetic field exposure guidelines for workers (ACGIH 2001). As with the ICNIRP occupational limits, the ACGIH occupational limits are equal to or larger than the ICNIRP guidelines for the general public.

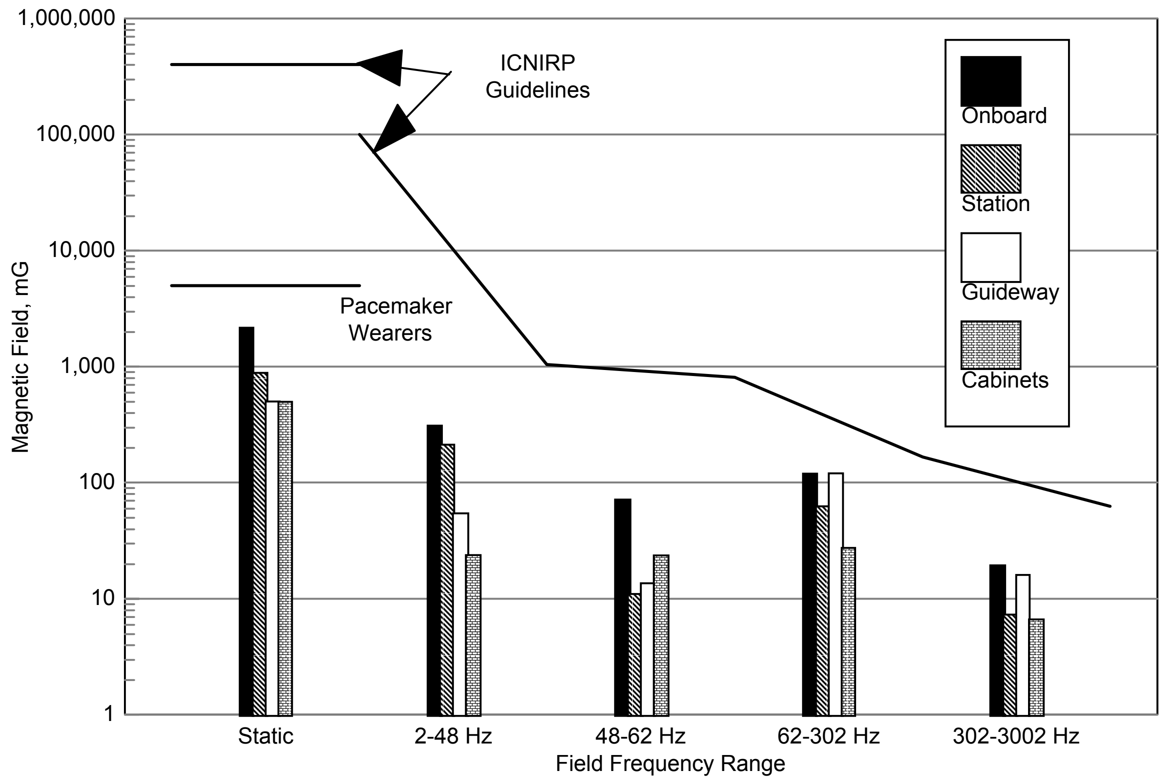


Figure ES-2. Maximum static and time-varying magnetic fields recorded on board the TR08, at the station platform, and near the guideway or electrical switching cabinets, compared to ICNIRP recommended guidelines for permissible magnetic field exposure to the general public.

Similar analyses for compliance with RF and ELF electric field standards and guidelines are contained in the report. The conclusions of those analyses are similar: the highest magnetic and electric field levels measured on board the TR08, on the station platform, near the guideway, and near the switching cabinets are well within the most recent ICNIRP recommended human exposure safety limits endorsed by the World Health Organization.

CHAPTER 1 INTRODUCTION

1.1 PURPOSE

As part of the Federal Railroad Administration's Magnetic Levitation Transportation Technology Deployment Program (Maglev Deployment Program), this technical report characterizes the electromagnetic fields (EMF) and electromagnetic radiation (EMR) associated with the operation of the Transrapid International TR08 Maglev System, a transportation system employing magnetic levitation (maglev). The TR08 Maglev System is the technology that is being considered for deployment in the U.S. (FRA 2001) by maglev programs in Pennsylvania and Maryland. Under the National Environmental Policy Act, potential environmental impacts, including EMF and EMR impacts, of a maglev transportation system must be assessed.

The environmental measurements described in this report took place at the Transrapid Test Facility in the Emsland region of Germany, in August, 2001. The data presented and analyzed herein can be utilized to support the required environmental planning and deployment activities for any Transrapid maglev project in the U.S. This report also includes a limited comparison of the data to similar data from other modes of transportation as well as to current EMF/EMR guidelines.

1.2 BACKGROUND

In the Transportation Equity Act for the 21st Century (TEA-21), Congress authorized the Magnetic Levitation Transportation Technology Deployment Program (Maglev Deployment Program) to evaluate the transportation, economic, environmental, energy, and other benefits of an operating transportation system employing magnetic levitation (maglev). Maglev is an advanced transportation technology in which magnetic forces lift, propel, and safely guide a vehicle over a specially designed guideway at variable speeds, including those in excess of 386 kilometers per hour (km/h) (240 miles per hour (mph)). Congress directed the Maglev Deployment Program to the Federal Railroad Administration (FRA) for implementation.

In order to comply with the TEA-21, FRA conducted a competitive award and selection process to demonstrate maglev in a U.S. transportation application. In May 1999, the Secretary of Transportation selected, from a pool of eleven applicants, seven states (or state-designated authorities) to receive grants for pre-construction planning of their maglev programs. To satisfy the requirements of the National Environmental Policy Act (NEPA), FRA, as the lead agency, determined that the Maglev Deployment Program constituted a major Federal action with the potential to have a significant effect on the environment, and accordingly published a Programmatic Environmental Impact Statement (PEIS) (FRA 2001). The purpose of the PEIS was to describe the Maglev Deployment

Program and the potential environmental impacts associated with its possible implementation, as well as to encourage public involvement and to address agency and public concerns (FRA 2001). In developing the PEIS, FRA required each of the seven state participants to prepare environmental assessments, which became the source of baseline data in the Draft PEIS (DPEIS), approved in June 2000. After collecting and incorporating appropriate public and agency comments on the DPEIS, the John A. Volpe National Transportations Systems Center (Volpe Center), on behalf of the FRA, refined the document and prepared the Final PEIS (PEIS), approved in March 2001 (see text at http://www.fra.dot.gov/rdv/maglev/mag_peis.htm). A Record Of Decision (ROD) was executed with the PEIS (FRA 2001).

The PEIS (FRA 2001) analyzed the potential environmental and related impacts associated with the Maglev Deployment Program using the maglev technology available at the time the environmental impacts were being analyzed, and at a level of detail commensurate with the program-level decisions being made at the time of PEIS publication (April 2001). The PEIS included available EMF data on existing and advanced transportation systems, including maglev, as well as a discussion of applicable standards and guidelines for EMF and EMR human exposure safety. A selection process administered by FRA led to the authorization of further funding for two project-specific environmental impact statements (EIS) for the Maryland and Pennsylvania Maglev Alternatives. Operational parameters of the Transrapid International TR07 Maglev System were used for the PEIS analysis of these two Alternatives, since no direct technical information was available on the proposed vehicle, the TRO8 Maglev System. The information about TR07 was based on electromagnetic field measurements made in 1990 and published in 1992 (FRA 1992), and on noise measurements presented in a 1993 publication (FRA 1993a). However, the ROD executed with the PEIS (FRA 2001) specified that in order to fully address environmental impacts of the maglev technology, the (1) electromagnetic fields (EMF) and electromagnetic radiation (EMR), (2) noise impacts, and (3) vibration impacts associated with the proposed vehicle, the Transrapid International TR08 Maglev System (see Section 1.4), needed to be identified.

To fulfill the directives of the ROD and its requirements in its grant agreement with FRA, the Port Authority of Allegheny County (the project sponsor of the Pennsylvania Maglev Alternative) contracted with MAGLEV, Inc., to measure and report the EMF/EMR characteristics of the TR08 Maglev System and co-author this report. The research on EMF/EMR impacts associated with the TR08 vehicle reported in this technical characterization report will be included by reference in the project-specific EISs, which tier from the PEIS (FRA 2001).

1.3 ROLES AND RESPONSIBILITIES

The Maglev Deployment Program constitutes a major Federal action with the potential to have a significant effect on the environment, and therefore requires compliance with NEPA. The FRA is the lead agency for the Maglev Deployment Program and is responsible for the NEPA compliance process and for documenting the technical support information identified in this report.

The sponsor of the Pennsylvania Project (the Pennsylvania Maglev Alternative) is the Port Authority of Allegheny County. The Port Authority of Allegheny County's private partner, MAGLEV, Inc., coordinated, managed, and had technical oversight of the characterization of the electromagnetic fields associated with the TR08 Maglev System. The actual EMF/EMR data were collected, analyzed, and reported by Electric Research (ERM, also known as Electric Research & Management, Inc.) and are presented in Chapters two through seven.

The Volpe Center's National Expert in Safety, Health, and Environment provided active oversight by viewing a significant portion of the ERM measurement effort, by conducting limited measurements as an order of magnitude check, and by critically reviewing the test protocol, the measurement results, the analyses methods, and the conclusions.

Assistance to the measurement team, both prior to testing (during development, review, and approval of test plans) and at the test facility in Emsland, Germany, was also provided by technical staff of the FRA, the Volpe Center, MAGLEV, Inc., Transrapid International, and IABG (Industrieanlagen Betriebsgesellschaft, a European scientific/technical services company). The Test Plan (Appendix A) was also reviewed and the tests were observed by representatives of the Baltimore-Washington Maglev Project (the Maryland Maglev Alternative), including an environmental planning staff person from the Maryland Transit Administration and a representative from Parsons-Engineering Science, a consultant for the Baltimore-Washington Maglev Project.

The Volpe Center has, on behalf of the FRA and the Port Authority of Allegheny County, assembled and co-authored this EMF/EMR Characterization Report along with MAGLEV, Inc., and ERM.

1.4 TR08 MAGLEV SYSTEM TECHNOLOGY INFORMATION

Maglev is a transportation technology that uses non-contact electromagnetic systems to lift, guide, and propel the vehicle over a specially-designed guideway. Without wheels or other mechanical parts to cause resistance, cruising speeds of 320 to 480 km/h (200-300 mph) can be reached (TRI 2001).

Maglev technology has been researched since the 1960s, and development programs have been conducted by several countries, most notably Japan and Germany. Both these countries have test tracks on which they have conducted extensive testing and refinement of their maglev concepts and of different prototype vehicles. The German technology, the Transrapid International (TRI)

Maglev System, has a design based on a long stator linear synchronous motor with conventional electromagnets in an attractive magnetic force configuration. The Japanese technology, the Railway Technical Research Institute's (RTRI) MLU-series system, has a design based on superconducting magnets in an electrodynamic repulsive system (RTRI 2001). The German TRI TR08 Maglev System is the technology that has been selected for deployment in both the Pennsylvania and Maryland maglev projects (FRA 2001).

TRI has been investigating high-speed rail systems utilizing electromagnetic levitation systems since 1969, commissioning the TR02 in 1971. The eighth generation vehicle, the TR08 (Figure 1-1), and some of its precursor prototype vehicles, the TR07 and TR06, have been demonstrated and tested at the Transrapid Versuchsanlage Emsland (TVE), in the Emsland region of Germany, for more than 15 years (TRI 2001). A significant number of tests and simulated revenue-service operations were conducted with the TR07 from 1989-1999. The TR08 was delivered to the TVE in August 1999. Although significant differences in measured information/data between the TR07 and TR08 are not expected, some design upgrades and changes (e.g., power rail DC segments near stations for battery charging) necessitated new measurements so that the most recent technical and operational environmental performance data may be used for site-specific EIS work for the planned U.S. projects.

Source: Transrapid International (TRI)

Figure 1-1. The TRI TR08 Maglev System

According to the manufacturer, the TR08 is more aerodynamic, quieter, and more economical than its predecessor, the TR07 (TRI 2001). A hybrid design, using aluminum hollow profiles and aluminum-clad foam sandwich panels, provides a light and stiff structure for the carriage body; these changes in vehicle design and materials may account for differences between TR07 and TR08 EMF levels reported herein. A TR08 train consist is made up of two end sections and zero to eight middle sections (Table 1-1). The consist would not be separated in normal operations. The TR08 used at the TVE is a three-section, pre-production consist that is 79.70 m (261.5 ft) long, weighs 188.50 metric tons (t) (415,571 lbs), has seating for 190+ passengers (Figure 1-2), and is designed for peak 550 km/h (342 mph) operation. The TR08 at TVE is operated as a shuttle on a single track with one station. (TRI 2001)

Table 1-1. Specifications of the Transrapid TR08 Maglev System

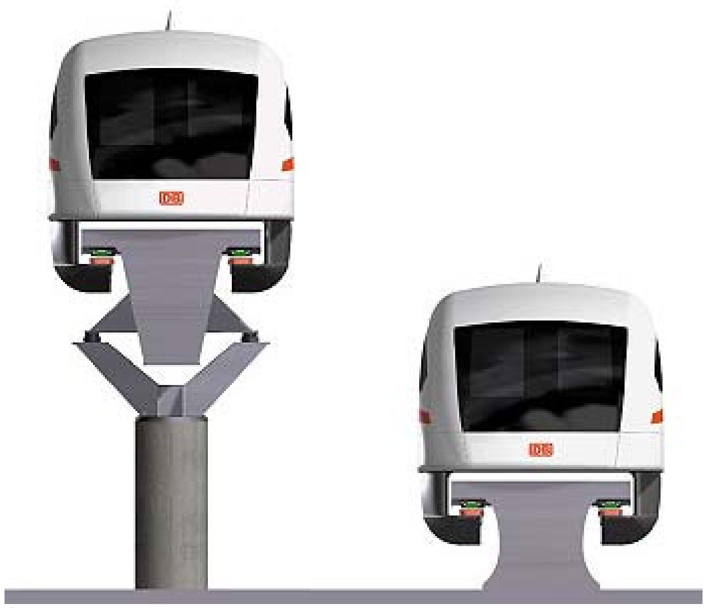
System Features	End Section	Middle Section
Train Size:	2	0-8
Section Length	26.99 m (88.6 ft)	24.77 m (81.27 ft)
Section Width	3.70 m (12.14 ft)	3.70 m (12.14 ft)
Section Height	4.16 m (13.65 ft)	4.16 m (13.65 ft)
Payload per Section:		
Passenger Vehicle	10.3 t (22,708 lbs)	13.9 t (30,644 lbs)
Cargo Vehicle	14.0 t (30,865 lbs)	17.5 t (38,581 lbs)
Seats per Section	62-92	84-126
Floor Space per Section	70 m^2 (754 ft^2)	77 m^2 (818 ft^2)

Source: Transrapid International (TRI)
*TRI offers clients multiple configuration options, thus certain specifications may vary slightly among trains.

Source: Adapted from image provided by Transrapid International (TRI)

Figure 1-2. Typical TRI TR08 Interior Plans for (a) medium-density intercity seating, (b) high-density commuter type seating, and (c) first-class intercity seating

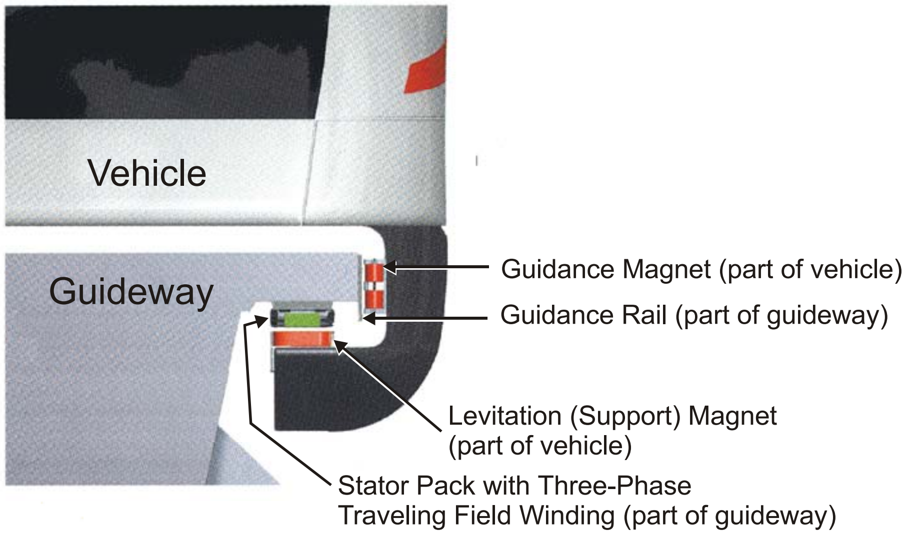
The guideway is the physical structure along which the maglev vehicles are levitated, guided, and propelled. The guideway can be elevated on bridge-style columns, be mounted at grade on a continuous foundation, or can use other configurations (Figure 1-3). The guideway beam structure can be fabricated from steel, concrete, or in a hybrid of steel and concrete; a flexible steel guideway crossover switch section is used for switching.



Source: Transrapid International (TRI)

Figure 1-3. TRI TR08 Guideway (can be either elevated on columns or mounted at grade)

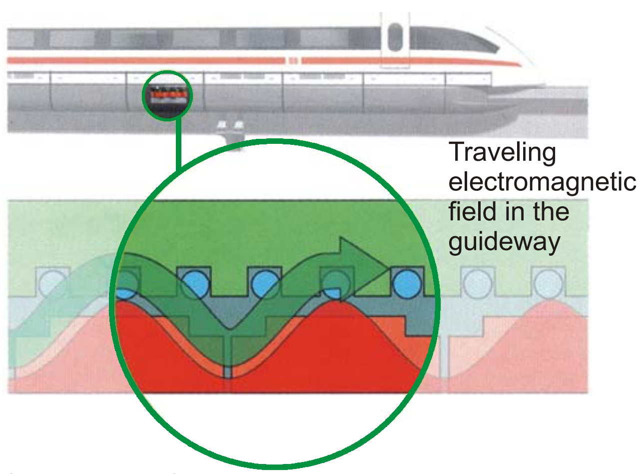
The TRI Maglev vehicle levitation frame wraps around the "T-shaped" guideway to securely hold and guide the vehicle. Attractive forces between the electromagnets located in the vehicle levitation frame that surrounds the guideway and the stator packs installed on the underside of the guideway allow the vehicle to levitate. The guidance magnets located on the interior sides of the vehicle frame hold the vehicle laterally in place (Figure 1-4). The levitation and guidance magnets are separated from the guideway by a gap of about 1 cm (0.4 in) to allow for levitation and minor vertical and lateral movement.



Source: Adapted from image provided by Transrapid International (TRI)

Figure 1-4. TRI TR08 Support and Guidance Systems

The power to propel maglev vehicles is provided via the powered guideway (Figure 1-5). An electric current through the guideway windings generates a traveling electromagnetic field along the guideway. The interaction between the traveling electromagnetic field in the guideway and electromagnetic fields in the vehicle pulls the vehicle along. Adjusting the frequency (0 Hz to approximately 300 Hz) of the alternating electric current can accelerate or decelerate the vehicle – the higher the frequency of the current, the higher the vehicle's speed.



Source: Adapted from image provided by Transrapid International (TRI)

Figure 1-5. TRI TR08 Propulsion

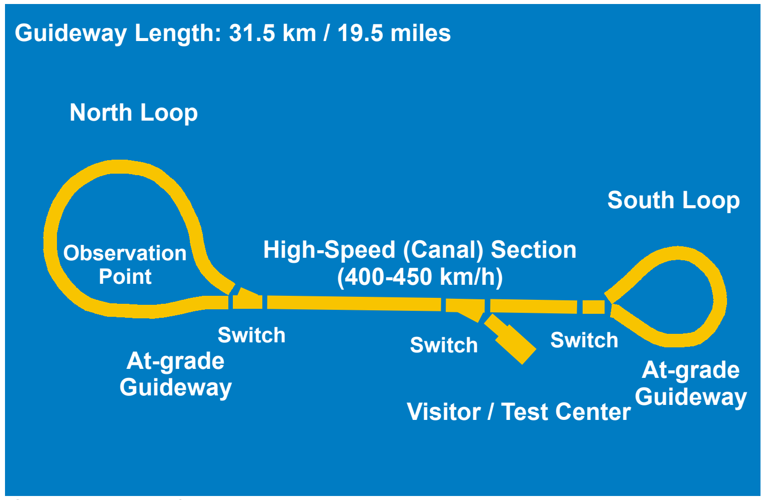
Maglev trains are controlled and monitored from a central operations center and the system runs in automatic mode with pre-programmed speed profiles for revenue operations. Communication between the vehicle and control center is via directional radio data transmission (to date, 38 to 40 gigahertz (GHz) line-of-sight data radio links have been used for the data transmission line).

Power to the maglev system is supplied by electrical power substations that, in turn, supply several individual switching sections. The substations are located at various points along the track and are configured to receive their power from the commercial power grid. For reliability, current is fed separately and redundantly into each side of the guideway motor. The long-stator linear synchronous motor installed in the guideway is divided into individual segments (“blocks”); only those segments in which the vehicle is located at that moment are switched on and supplied with current.

1.5 TEST FACILITY

The TVE was completed in 1984 with the purpose of simulating long-term operation of vehicles under conditions similar to actual applications. The Versuchs- und Planungsgesellschaft für Magnetbahnsysteme (MVP), a consortium of German companies, is the owner and operator of the TVE, with management sub-contracted to IABG. Revenue operations began at the TVE in 1995, and more than 70,000 visitors have ridden in the Transrapid maglev vehicles (TRI 2001).

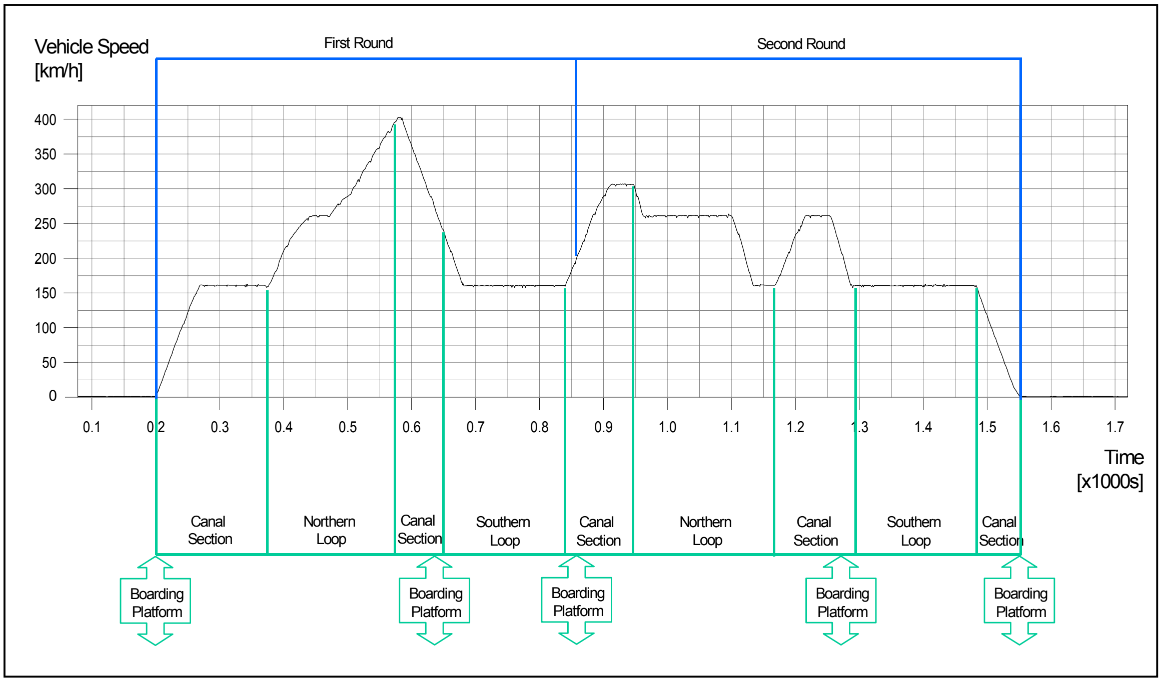
The TVE test facility, located in a generally flat, agricultural, lowland landscape in the Emsland region of Germany, consists of a 31.5 km (19.5 mile) guideway, with two loops (one with constant radius and one without a constant radius) at either end of a straight section (Figure 1-6). Various guideway types (steel, concrete, hybrid) and configurations (at-grade, elevated) exist at the test track. The concrete, steel, and hybrid beam sections are elevated on concrete columns. A flexible steel high-speed switch diverts the northbound maglev vehicle on a turnout to the north loop, then moves back to accommodate the through movement onto the high speed straight section. The switch consists of a continuous steel beam, anchored at the end adjoining the straight section and moveable at the other end with an electro-mechanical actuated drive system. The at-grade section is an embankment of soil built up to the level of the guideway in the high-speed section of the north loop. Two different at-grade guideway types are placed on the embankment, steel beams and concrete beams. Each type is represented by four 6.2 meter (20.3 feet) beams for a total of 25 meters (82 feet) of concrete at-grade beams and 25 meters of steel at-grade beams.



Source: Adapted from image provided by Transrapid International (TRI)

Figure 1-6. Transrapid Test Facility (TVE)

EMF/EMR measurements were taken for representative guideway types. The test facility typically operates 3-5 days a week and undergoes maintenance at least 1-2 days a week. Normally, the vehicle runs 5-7 times a day depending on weather and track conditions. Each trip consists of two complete runs of the entire test track length. The normal operating sequence provides speeds of 150 km/h, 400 km/h, 200 km/h, and 300 km/h on the straight section (Figure1-7).



Source: Transrapid International (TRI)

Figure 1-7. Typical speed profile of TR08 at the Transrapid Test Facility

1.6 EMF/EMR MEASUREMENTS

1.6.1 General

Concerns that magnetic fields associated with maglev transportation vehicles may be excessive and possibly result in adverse health consequences led the FRA to fund a comprehensive set of magnetic field measurements in and around the TRI TR07 Maglev vehicles, stations, guideway, power supply equipment, and operator locations. These measurements were taken in August 1990 as part of the National Maglev Initiative (NMI) (FRA 1992). Customized, portable EMF survey instrumentation and a standardized protocol were developed by ERM to Volpe Center/FRA specifications for maglev, as well as for other existing and advanced rail transportation systems, in order to enable a complete characterization of EMF and their relative EMF signature comparisons (USDOT 1999). These EMF measurements were made over the past decade in a consistent manner by ERM, under contract to the Volpe Center, to assemble a comprehensive EMF database on transportation systems and facilities (see USDOT 2001 and the references therein).

Earlier measurements on the TR07 vehicle had demonstrated that the extremely low frequency (ELF) range of the electromagnetic spectrum (0-3 kilohertz (kHz)) was adequate in encompassing the principal magnetic field components and any significant harmonics. Because the TR08 vehicle operates on the same guideway and with the same drive frequencies as did the TR07 prototype (albeit with some improvements, such as larger stator pack magnets and direct current (dc) power rails near stations replacing some on-board batteries for TR07 back-up power), it is likely to have similar EMF emissions. Additionally, the database of field measurements for conventional vehicles, against which the field performance of the TR08 was evaluated, is limited to this frequency range. Finally, potentially adverse health responses to fields in this power frequency and harmonics range have been and remain a key environmental concern (NAS 1996, NIEHS 1998, WHO 2000) and the focus of continuing research on cells, humans, and other animals. Because of this previous research on Transrapid and conventional vehicles as well as the aforementioned potential impact of ELF magnetic fields, this measurement campaign focused on characterizing ELF magnetic fields in greatest detail.

The TRI TR08 Maglev System is the technology selected for deployment by the Maryland and Pennsylvania maglev projects. In order to assure that technical concerns are addressed accurately, in 2001 the FRA sponsored an EMF/EMR measurement program carried out at the TVE on the TR08 Maglev System as part of pre-construction, site-specific environmental impact analysis. Test plans are presented in Appendix A and are briefly summarized below. Although the test plan was essentially adhered to, on-site conditions and events at the time of the tests forced numerous deviations from the original plan. However, these deviations are anticipated in all field measurement programs and the resulting changes did not adversely affect the results obtained. Chapter 2 describes the actual measurement equipment, protocol, and analytical procedures in detail.

EMF/EMR measurements on the TR08 Maglev System concentrated on those locations accessible to passengers or the general public, where environmental magnetic fields produced by the TR08 system and operations may be encountered. Magnetic fields were characterized and quantified in passenger compartments of the vehicle, within the station, in areas of public access on the station platform, beneath the different types of elevated guideway segments or near the at-grade guideway segments, and near electrical power switching cabinets along the guideway. In addition, a complete set of measurements indicative of occupational EMF exposures were also performed in the attendant’s cab located in the forward compartment of the lead vehicle. In the original TR07 study, additional measurements were recorded in or near facilities associated with the test track (such as electric power conditioning and transfer substations and the TVE Control Center) in order to establish typical occupational exposure levels. Because these facilities have not changed significantly and because the maglev system facility designs, as implemented in the U.S., are likely to be different from those at the TVE test track, such measurements were not repeated with the TR08.

The TR08 magnetic field data in the ELF range were collected with third generation *MultiWave*® portable instrumentation (see Chapter 2), using both survey and statistics protocols, and proprietary data analysis software for tabulation and display (see Ch.3-7). The protocol and instrumentation are fully consistent with those previously employed for similar EMF measurements in the TR07 vehicle (FRA 1992), with the addition of higher frequency probes for EMR. Although the focus was on ELF fields, a significant measurement effort focused on other frequencies. Broadband measurements of the root-mean-square (rms) magnetic field strength in the very low frequency (VLF) (3 kHz - 30 kHz) and the low frequency (LF) (30 kHz - 300 kHz) bands were made concurrent with the detailed ELF field measurements to ensure that significant higher frequency magnetic fields were not overlooked. Although significant electric fields were not anticipated in or near the TR08 vehicle because of the metallic construction of the vehicle and guideway pole pieces, single-axis ELF electric fields were measured concurrent with the magnetic field measurements. Limited radiofrequency (RF) measurements were made with a broadband (80 MHz to 40 GHz) isotropic electric field sensor to ensure that no potentially hazardous RF emissions were present, but more extensive measurements in the RF range were outside the scope of this effort.

Magnetic field waveform-capture measurement technology and digital Fast Fourier Transform (FFT) spectral analysis were used to characterize magnetic fields in or near the TR08 Maglev System. Such technology permits the identification of individual field components from multiple sources which, when combined, produce the total resultant broadband magnetic field environment. Thus, magnetic field "signatures" in frequency, time, and spatial domains, attributable to sources on board the vehicle can be distinguished from those attributable to the guideway and guideway subsystems.

In addition, the Volpe Center performed measurements of personal EMF and RF exposure (see Ch.8) complementary to ERM's measurements, as previously done for all other rail and transit systems documented in the EMF database. These environmental exposure data provide independent verification and validation (V&V) of ERM results in the power frequency and harmonics (3-300 Hz) portion of the ELF spectrum at all TR08 Maglev System locations surveyed.

1.6.2 Applicability of Data

The measurements, data analyses, and conclusions presented in this report are representative of the TR08 Maglev System as constructed and operated in Germany at the TVE in August 2001 for the specific operational speed profile described. Any specific operational applications based on the German TR08 maglev technology, such as the construction of a maglev system elsewhere outside of TVE, will probably have project-specific modifications of the design and operating parameters of the power supply, communications and control, guideway, and/or vehicle consist and operation concept. Such modifications may produce somewhat different EMF and EMR emissions, which would therefore require further analysis during the site-specific EIS process, and possibly also require characterization during acceptance and safety qualification testing of the TR08 Maglev System. Nevertheless, the accumulated transportation-related EMF database, together with the results presented here, offer a sufficient and credible basis for comparing and projecting public, occupational, and environmental levels of EMF from a maglev system based on the German TR08 technology currently being planned for deployment in the U.S.

1.7 REPORT ORGANIZATION

This report is organized into an Executive Summary and nine chapters. The Executive Summary is aimed toward the reader interested in merely an overview of the effort and the salient conclusions. Chapter 1 provides background information on the Maglev Deployment Program, states the objectives and approach of the field measurement effort, describes the TR08 technology, and presents the roles and responsibilities of the various co-authors as well as other people involved in the measurement effort. Chapters 2-6 contain the technical details of the measurement procedures and results. Particularly, Chapters 3-6 provide detailed descriptions of magnetic and electric field characteristics on board the vehicle, at the station platform, along the guideway, and near the electrical switching cabinets, respectively. Chapter 7 summarizes field levels as a function of frequency, speed, and location in a more concise way, and comments briefly on apparent sources. It also compares the measured field levels to those found on board or near other transportation facilities and to exposure safety levels permitted by various applicable standards and guidelines. Chapter 8 describes the validation and verification process and results; measurements of personal EMF and RF exposure are presented here. References are listed in Chapter 9.

CHAPTER 2 PROCEDURES

A formal test plan (Appendix A) was submitted and approved prior to the magnetic and electric field measurements described in this report. Although that test plan was specific and essentially complete, conditions and events at the time of the tests forced numerous deviations from that plan; however, these deviations did not adversely affect the results obtained. The following material describes the measurement and analysis procedures actually employed to generate and analyze the magnetic and electric field data for the TR08.

2.1 SPECIFIC GOALS

The measurements described herein were designed to:

- characterize and quantify the static and extreme low frequency (ELF) magnetic fields to which passengers may be exposed while traveling in the Transrapid TR08 magnetically levitated transportation system;
- characterize and quantify the static and ELF magnetic fields in areas of public access in stations and on the station platforms;
- characterize and quantify the static and extreme low frequency (ELF) magnetic fields in areas of public access beneath or near the guideway;
- obtain summary data on the ELF electric field within the TR08 vehicle, station, station platform, and near the guideway;
- obtain summary data on the very low frequency (VLF) magnetic field within the TR08 vehicle, station, station platform, and near the guideway;
- obtain summary data on the low frequency (LF) magnetic field within the TR08 vehicle, station, station platform, and near the guideway; and
- obtain summary data on the radiofrequency (RF) power density within the TR08 vehicle, station, station platform, and near the guideway at frequencies arising from the system's communications and control transmitters.

2.2 INSTRUMENTATION

The following instrumentation was used for the measurements described in this report.

Data Logging: *MultiWave*® System II four-channel digital data acquisition systems, model MW2SYS02 (Electric Research). These recorders are optimized for recording three-axis static and ELF magnetic field waveforms, but are also useful for recording any analog waveforms over the frequency range from 0 to 3000 Hz.

Static and ELF Magnetic Fields: Three-axis magnetic field sensor, model MAG-03MC1000 (Bartington). These triaxial fluxgate magnetometers simultaneously sense magnetic fields over the range of 0 to 3000 Hz in three orthogonal directions and produce analog waveforms for recording by the *MultiWave*® data recorders. The effective dynamic range of these sensors with the *MultiWave*® recorders is from much less than 0.01 mG to 10,000 mG across the entire frequency range from 0 to 3000 Hz.

ELF Electric Fields: *MultiWave*® ELF electric field sensor, model MW2ELF01 (Electric Research). When used with the *MultiWave*® recorder, this single-axis optically isolated electric field sensor records ELF (3 to 3000 Hz) electric field waveforms over a dynamic range from less than 1 V/m to 70 kV/m.

Magnetic Field: *MultiWave*® wideband triaxial magnetic field sensor, model MW2HBA01 (Electric Research). This triaxial magnetic field sensor simultaneously converts 3 orthogonal measurements of magnetic field to three analog waveforms. The bandwidth extends from 20 Hz to 300 kHz.

VLF Magnetic Field: *MultiWave*® VLF band filter, model MW2VLF01 (Electric Research). This accessory is used with the *MultiWave*® recorder and wideband triaxial magnetic field sensor to obtain isotropic rms measurements of magnetic field levels over the VLF range (3 to 30 kHz). The dynamic range of the system is from less than 0.5 mG to several thousand mG.

LF Magnetic Field: *MultiWave*® LF band filter, model MW2LF01 (Electric Research). This accessory is used between the wideband triaxial magnetic field sensor and the *MultiWave*® recorder to obtain isotropic rms measurements of magnetic field levels over the LF range (30 to 300 kHz). The dynamic range of the system is from less than 0.5 mG to several thousand mG.

RF Electric Field: Broadband RF electric field sensor (Holaday Instruments model 9455) used with graphic readout (Holaday Instruments model 4460). This system is a fiber-optically isolated isotropic RF electric probe and digital data acquisition system intended for survey measurements of broadband (80 MHz to 40 GHz) radio electric field levels. Because its purpose is to quantify RF field levels that represent a possible threat to health and safety, it is not designed for detection and resolution of low RF electric field levels below a few volts per meter. The manufacturer specifies the dynamic range of the system from 1 to 300 V/m. Because the design incorporated internal systems to compensate for internal noise, the authors have no firsthand experience with either the actual noise floor or whether that noise floor shifts depending on environmental parameters such as temperature.

2.3 MEASUREMENT SITE

All measurements on the TR08 reported herein were conducted at the Transrapid Test Facility (TVE) in the Emsland region of Germany (see Section 1.5 for more detail). The TR08 vehicle configuration was a three-car consist.

2.4 PERSONNEL

EMF/EMR data were collected, analyzed, and reported by Electric Research (ERM; also known as Electric Research & Management, Inc.).

2.5 TEST DATES

The tests reported herein were conducted between August 14 and August 21, 2001.

2.6 MEASUREMENT PROCEDURES

The procedures used to collect electric and magnetic field data on board the TR08, at the station, along the guideway, and near electrical switching cabinets are described in the following subsections.

2.6.1 Onboard Measurements

ELF and static magnetic field conditions on board the TR08 vehicle are dynamic, changing in amplitude, direction, and frequency distribution over time, vehicle speed, location; additional sources of variability exist which were not well understood. To appropriately characterize the short-term temporal characteristics of the field, static and ELF fields were measured with three-axis fluxgate magnetometers and recorded in the *MultiWave*® digital data recorders using a waveform sampling technique compatible with Fourier spectral analysis. At each sensor location, the instantaneous field was sampled at a high rate for a period of 300 ms. The resulting field 'snapshot' could resolve the frequency and intensity of all field components from 0 to 3000 Hz with a resolution of 3.3 Hz.

Longer-term temporal variations in field conditions associated with system operating conditions were characterized by taking repeated field snapshots every 15 seconds. That rate was intended to produce a sample of approximately 100 snapshots over a standard trip of two laps around the test track plus a few samples while the vehicle was at the station. Unfortunately, system operation difficulties prevented the operators from running identical trips with the intended speed profiles. As a result, sample sizes varied markedly.

Spatial variability of the static and ELF magnetic field over the dimensions of a passenger's body were documented by performing simultaneous measurements at locations representing the head, waist, and ankle of a seated or standing passenger. These measurements were accomplished with three fluxgate magnetometers securely clamped in an articulated plastic mannequin which can be stood upright or seated in any seat while maintaining the anatomically relevant placement of the sensors. A photograph of the mannequin on board the TR08 showing the placement of the sensors is provided in Figure 2-1. Unless indicated otherwise, the RF electric field sensor was placed at head level, but in a direct contralateral position to avoid interference between measurements.

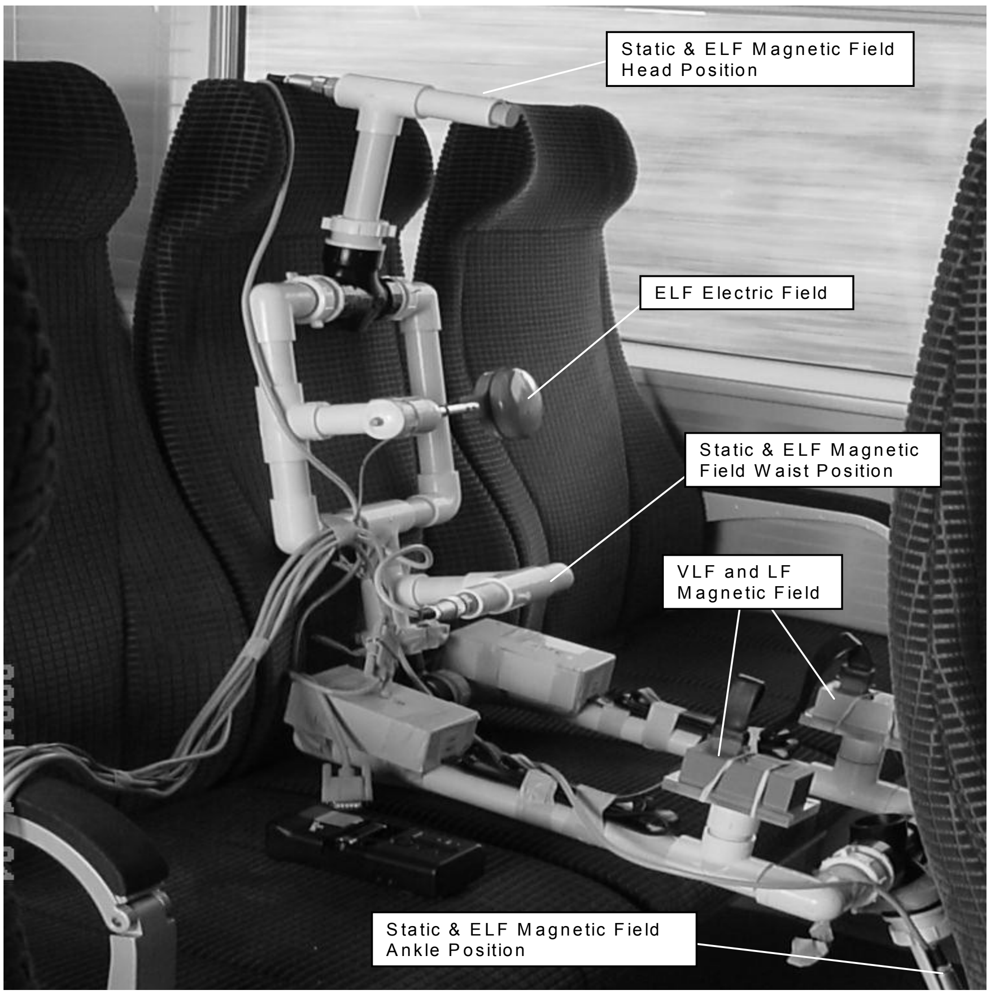


Figure 2-1. Photograph of the sensor support mannequin seated on the TR08 vehicle indicating the positions of various sensors

Spatial variability within each car and among the three cars of the consist was characterized by moving the sensor-equipped mannequin from one location to another and repeating the tests during another two-lap trip around the test track.

In consultation with Transrapid and the test track personnel, specific measurement locations were selected in the TR08 three-car consist. Those locations are indicated in Figures 2-2, 2-3, and 2-4 with bold numbers.

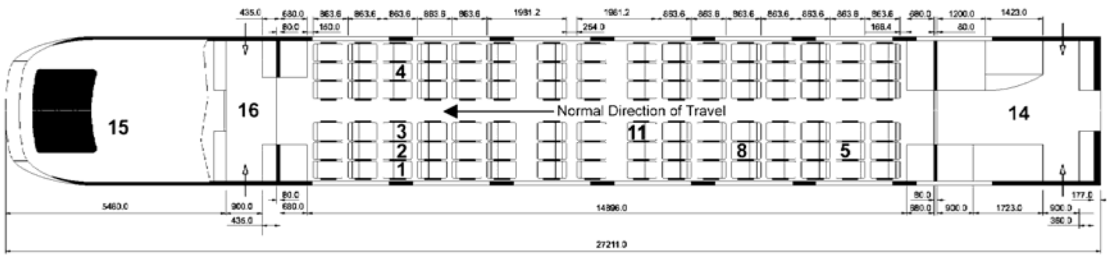


Figure 2-2. Location of magnetic and electric field measurements in the lead car of the TR08 3-car consist

Magnetic bogies, the power electronic modules which control the bogies, and the battery charger modules are distributed approximately evenly along the length of all three vehicles. The first five measurement locations were selected to characterize the spatial variability of fields from those devices. Measurement locations 1 through 3 were selected to identify the lateral variability of field conditions above the bogies and power modules. The specific row indicated was above the air duct, hence expected to have the least influence from other onboard systems. Measurements were conducted in location 4 to verify the symmetry of the field conditions across centerline. Location 5 is above an air duct toward the rear of the car. Measurements were made there to examine the uniformity of field characteristics of the bogies' control equipment and battery chargers along the length of the vehicle.

There are some onboard electrical or electronic systems which are more localized and could be sources of fields in their vicinity. Location 3 is near an air compressor beneath the center aisle. Measurements were made at location 8 because it was above a battery pack. The major voltage distribution bus is at the center of the car adjacent to measurement location 12. At location 14, the sensor mannequin was stood erect to simulate a standing passenger near the ventilation air-handler and other systems in the compartments on either side of the aisle. The RF electric field sensor was also at head level at the center of the aisle but about 15 m further aft. RF electric fields were measured at the head level of a standing passenger at location 16, because the 40 GHz communications and telemetry transceiver is in the overhead compartment above that point and the antenna is on the vehicle roof above that.

The attendant's position in the forward cabin was of interest, but it was impossible to measure there without displacing the attendant. Hence, the sensor mannequin was seated in a chair contralateral to the attendant's seat and the RF electric field sensor was placed behind his seat.

As indicated in Figure 2-3, three sets of measurements were made in the middle car to determine whether fields varied materially from one car to another. Location 6 is over an air duct and adjacent to a compressor, similar to location 3 in the lead car. Locations 9 and 12 are above the battery pack and adjacent to the voltage distribution bus, respectively, for comparison to locations 8 and 11 in the lead car.

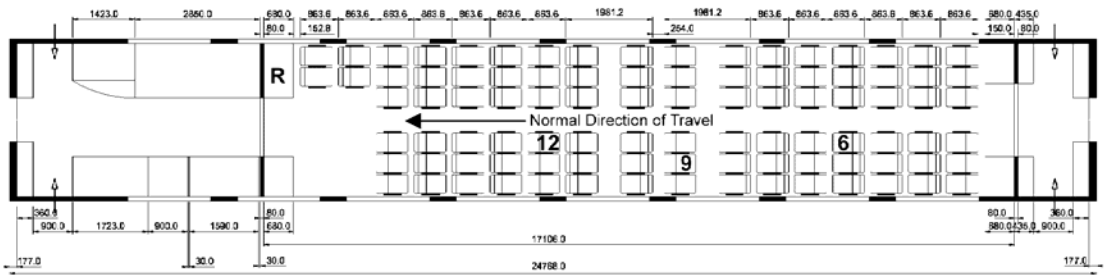


Figure 2-3. Location of magnetic and electric field measurements in the middle car of the TR08 3-car consist

The trailing car of the consist is the test and instrumentation car. It is not equipped with six-across seating as were the forward and middle cars. The aft half of the trailing car contains instruments, but the forward portion of that car has four-across seating. Because of the difference in seating, it was not possible to duplicate measurement locations in the other cars. Nevertheless, measurements were made in three aisle seats with approximate locations (indicated in Figure 2-4) that best approximated measurements in the other cars. Location 7 is above the air duct adjacent to a compressor, as are locations 3 and 6. Like locations 8 and 9, location 10 is above the battery pack. Location 13 is near the voltage distribution bus, similar to locations 11 and 12 in the lead and middle cars, respectively.

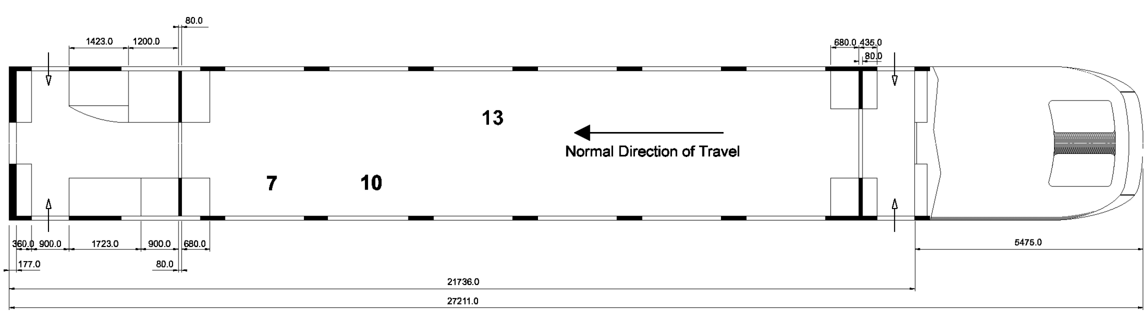


Figure 2-4. Location of magnetic and electric field measurements in the trailing car of the TR08 3-car consist

The technique of performing non-simultaneous measurements in a number of locations to determine spatial variability of magnetic and electric fields is most effective when the fields are stable over time. That is clearly not possible in the magnetically levitated vehicle when in motion around a test track. A suitable alternative in such a situation is to collect a statistically representative number of measurements at each location while the vehicle operates over a repeatable schedule. The latter is the approach attempted in this set of measurements. A standardized trip of two laps around the test track having the speed profile shown in Figure 2-5 was intended. That speed profile provided a full range of operating conditions including high and low speed, acceleration, deceleration, running at a fixed speed and station stops. To verify that the standardized trip with fixed speed profile was producing repeatable static and ELF magnetic field conditions within the TR08 vehicle, magnetic field measurements were made at a fixed location in the middle car concurrently with the measurements at the test locations identified above. The reference location was 1 m above the floor in a luggage area identified by "R" in Figure 2-3.

As it turns out, it was very fortunate that these concurrent fixed-location reference measurements were made, because system operational difficulties prevented the TR08 from achieving the standardized trip speed profile during most trips.

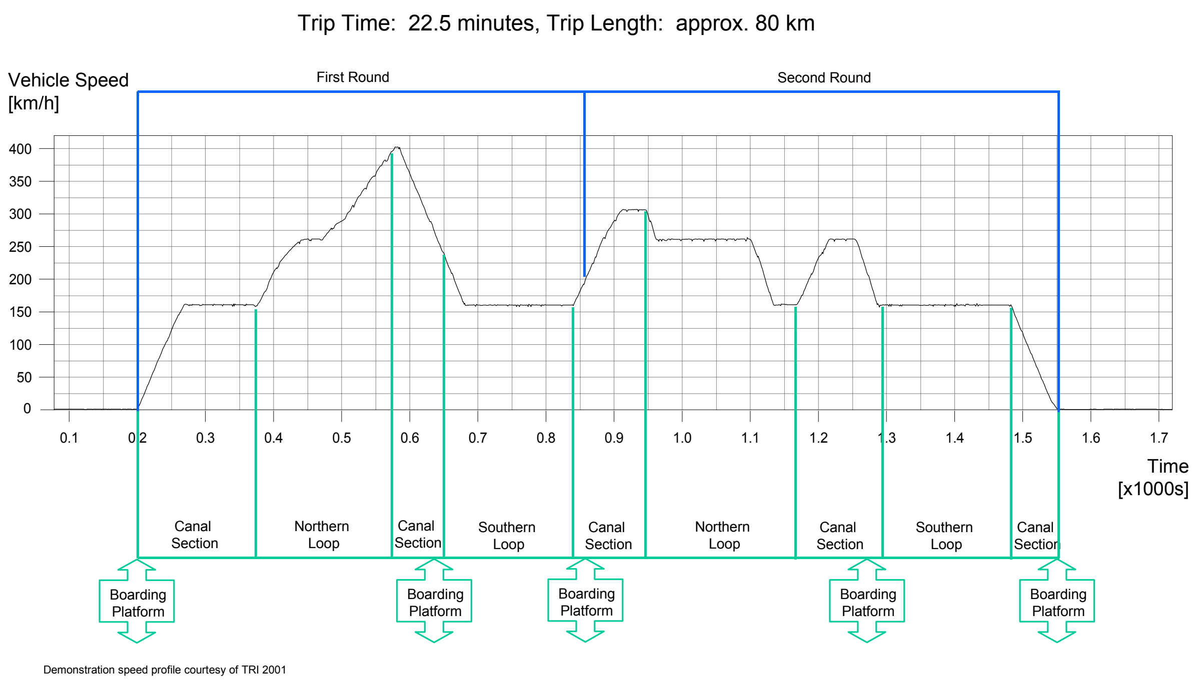


Figure 2-5. Standardized speed profile during the intended 22.5 minute trip if two laps were completed around the test track during which field measurements were made in the TR08

ELF electric field normal to the chest of a seated or standing passenger was measured using the same waveform sampling technique discussed above for static and ELF magnetic field measurements. The free-body dipole sensor was attached to the sensor mannequin as shown in Figure 2-1 and moved from seat to seat concurrently with the magnetic field measurements, thereby recording the spatial variability of electric field within a car and from car to car.

RMS values of the VLF and LF magnetic fields were recorded concurrently with the static and ELF magnetic field measurements by placing broadband omni-directional sensors (band-limited to the VLF and LF frequency ranges) at the knees of the sensor mannequin as shown in Figure 2-1.

RF electric fields were measured concurrently with the magnetic field measurements by placing a wideband electric field sensor at head level in the seat contralateral to the seated sensor mannequin. As stated earlier in this chapter, the RF electric field sensor was, in some circumstances, placed elsewhere. The bandwidth of the RF electric field sensor was sufficiently broad to include the frequency of the onboard and wayside guideway control and communications transmitters operating near 40 GHz.

2.6.2 Station Platform Measurements

The equipment and procedures described above for onboard measurements were used with small adaptations for measurements on the station platform. The instrumented mannequin was placed in a standing position as shown in Figure 2-6 and the RF electric field sensor was placed in an adjacent position the same distance from the edge of the platform. RF electric field measurements were measured at two-second intervals as the TR08 made multiple passes by the station and while it pulled into the station and stopped. The other electric and magnetic field parameters recorded with the waveform sampling technique had waveform snapshots gathered every three seconds during the passbys and station stop. These measurements described above were repeated twice on the station platform, once with the sensors 1 m from the TR08 (the nearest permissible under safety constraints) and during a different trip with the sensors 1.9 m from the passing vehicle (the most distant position possible given the narrow width of the platform).

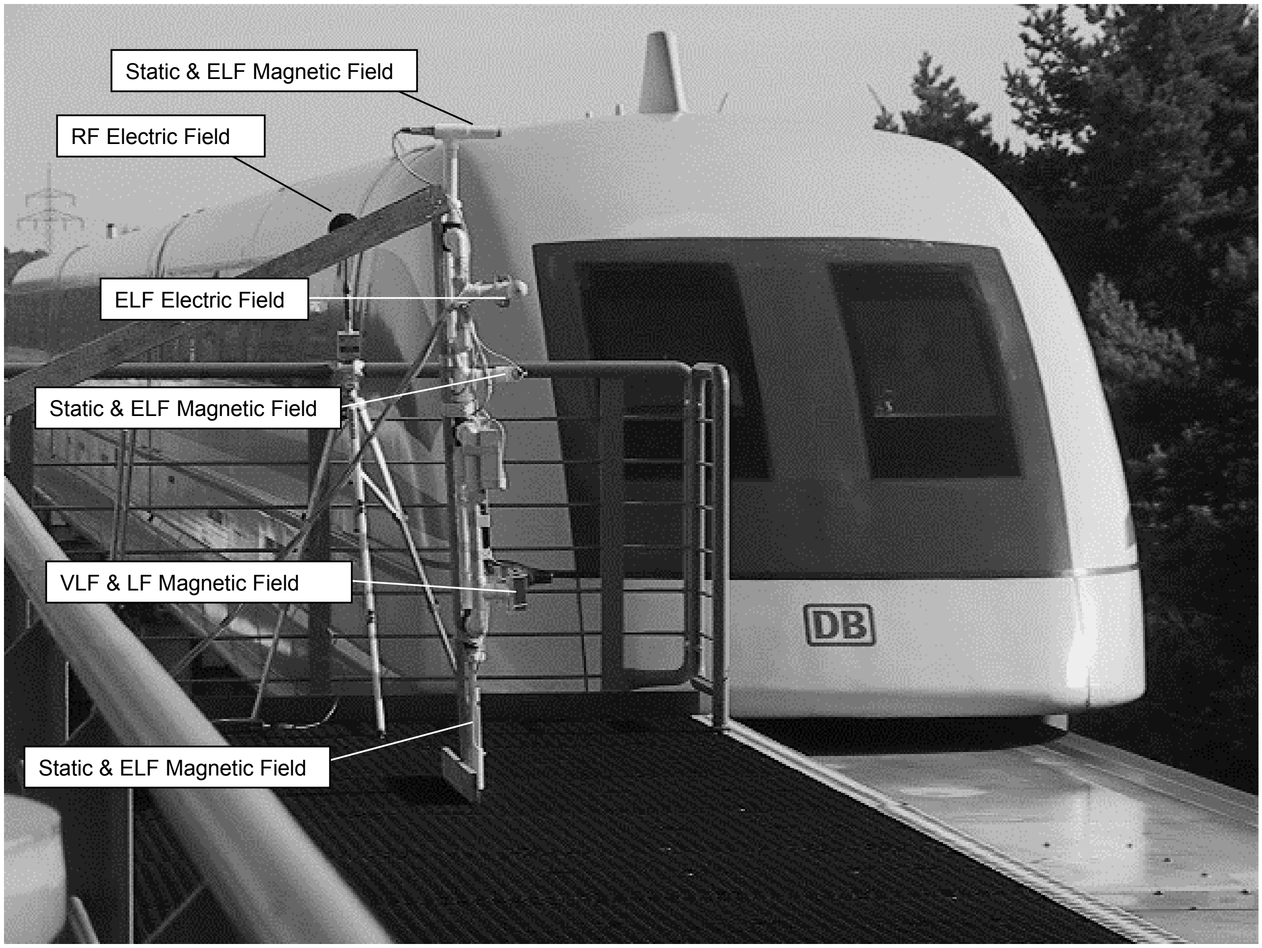


Figure 2-6. Photograph of the sensor support mannequin standing on the station platform with the RF electric sensor beside it

2.6.3 Near or Beneath the Guideway

Electric and magnetic field measurements were made at the five locations around the guideway indicated in Figure 2-7 (an enlarged version of Figure 2-7 is reproduced in Appendix A, page A-47). These locations were selected to represent a broad range of guideway designs:

1. 50 m elevated concrete beam (beam #213-214);
2. 50 m elevated steel beam (beam #215-216);
3. 62 m elevated hybrid beam (beam #267-268);
4. 25 m at-grade concrete plate (beam #341a-d); and
5. 25 m at-grade steel plate (beam #340 a-d).

At each of these locations, field characteristics were recorded during at least two vehicle passes. All static and ELF magnetic field measurements and the ELF electric field measurements were made with the waveform sampling technique, with waveforms recorded for 0.3 seconds every 3 seconds. VLF and LF magnetic fields were also sampled and recorded every 3 seconds. The RF electric field levels were recorded every 2 seconds.

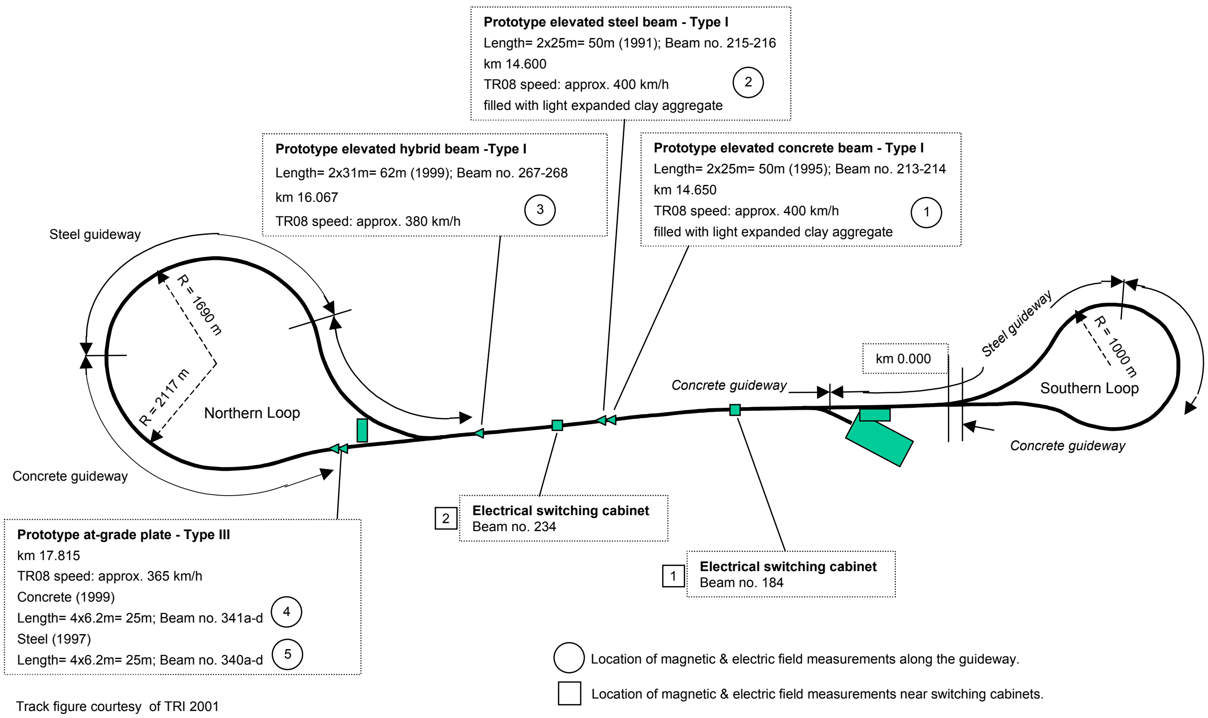


Figure 2-7. Locations of five sets of measurements near and beneath the guideway and at two sets of measurements around electrical switching cabinets

At the elevated guideway test locations, the field sensors were deployed as illustrated in Figure 2-8. All sensors, except the RF electric field sensor, were positioned 1 m above ground. The RF electric field sensor was 1.7 m above ground to simulate head height. The four fluxgate magnetometers used to measure static and ELF magnetic fields were placed at incremental distances from centerline of the guideway to record the rate at which those magnetic fields attenuate moving away from the guideway. All of the remaining sensors were placed beneath the guideway because that position represents the nearest that one can approach the guideway. The ELF electric field sensor is the only single-axis sensor. It was placed with its sensitive axis in the vertical direction, the standard orientation for ELF measurements near the horizontal Earth surface.

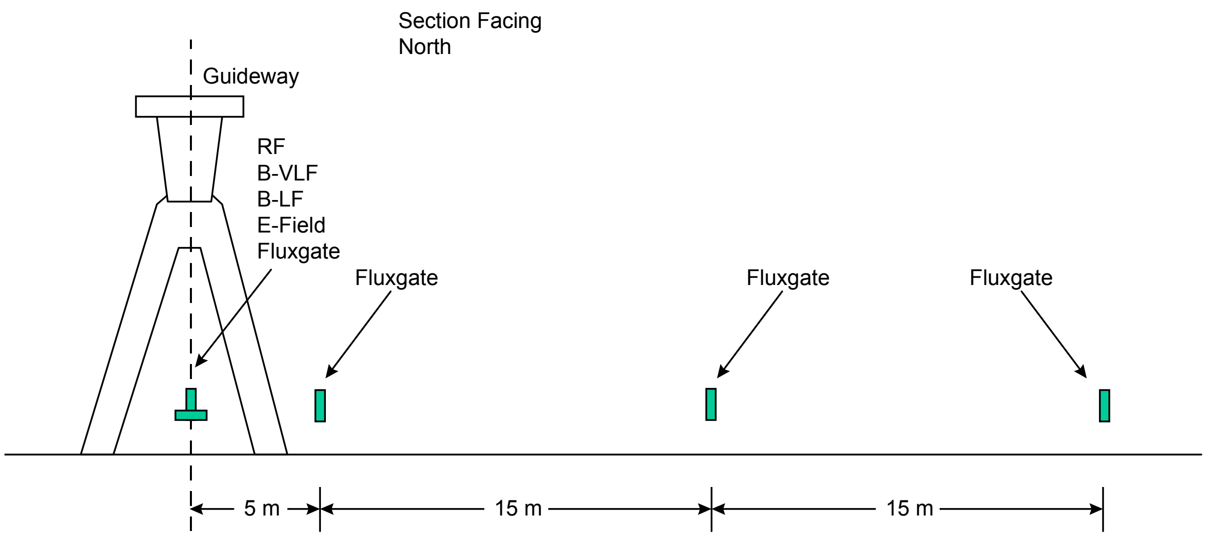


Figure 2-8. Sensor placement beneath and near the elevated guideway for wayside measurements

Near the at-grade guideway sections, it was not possible to gain access beneath the guideway. Hence, the sensors placed beneath the elevated guideway were placed 1.7 m outside the guideway exclusion fence, the nearest point accessible to the general public. Sensors for the static and ELF magnetic field profile were kept at 5, 20, and 35 m from centerline of the guideway. Figure 2-9 shows this placement graphically. Since access to the fenced area along the at-grade guideway was prohibited during the day when the TR08 was operating, fluxgate magnetometers had to be placed adjacent to both the steel and concrete guideway sections. To accommodate this, a tri-axis wideband magnetic field sensor was used in place of the fluxgate at the 11.5 m position. This substitution prohibited measuring static magnetic fields and time-varying fields below 30 Hz at that location.

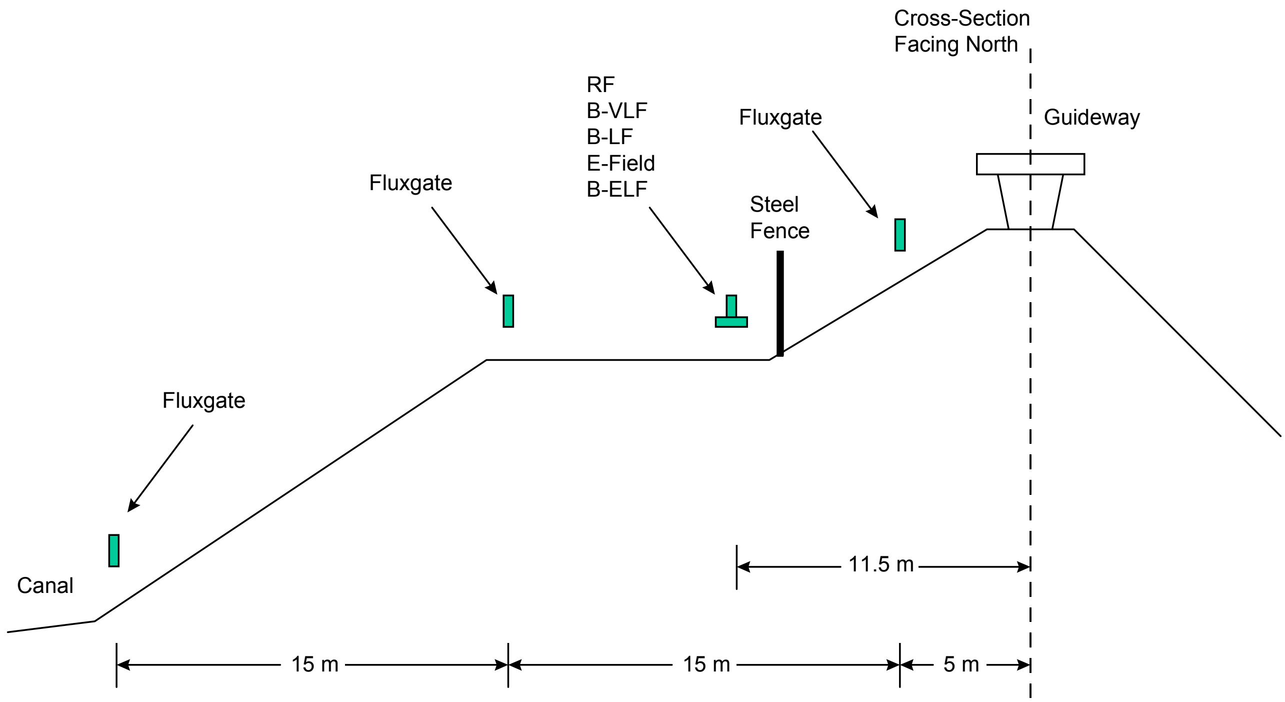


Figure 2-9. Sensor placement near the at-grade guideway for wayside measurements

2.6.4 Near Electrical Switching Cabinets

Electrical switching cabinets are located periodically along the guideway to route power from the inverter stations to successive sections of the guideway longstator. These cabinets are active for a brief period of time while the vehicle is operating in the section of guideway controlled by a particular cabinet. Because these cabinets represent a potential field source in areas accessible to the public, magnetic and electric field measurements were made in the vicinity of the two cabinets indicated on Figure 2-7. The cabinet at beam number 234 is of an older design and is representative of many around the test track. The cabinet at beam 184 is of a newer design and perhaps more representative of current technology. Because the switching cabinets are located beneath the guideway, a sensor placement similar to that used for measurements near the overhead guideway was used. The sensor arrangement is shown in Figure 2-10. Fluxgate magnetometers are kept at 5, 20, and 35 m from centerline of the cabinet to measure the attenuation of fields from the cabinet. The magnetometer formerly located directly beneath the guideway is kept beneath the guideway, but placed

3.5 m north of the north wall of the switching cabinet. This measurement position is the same distance from the face of the cabinet as the nearest sensor along the lateral profile, enabling an evaluation of the field differences from the sides and ends of the cabinet.

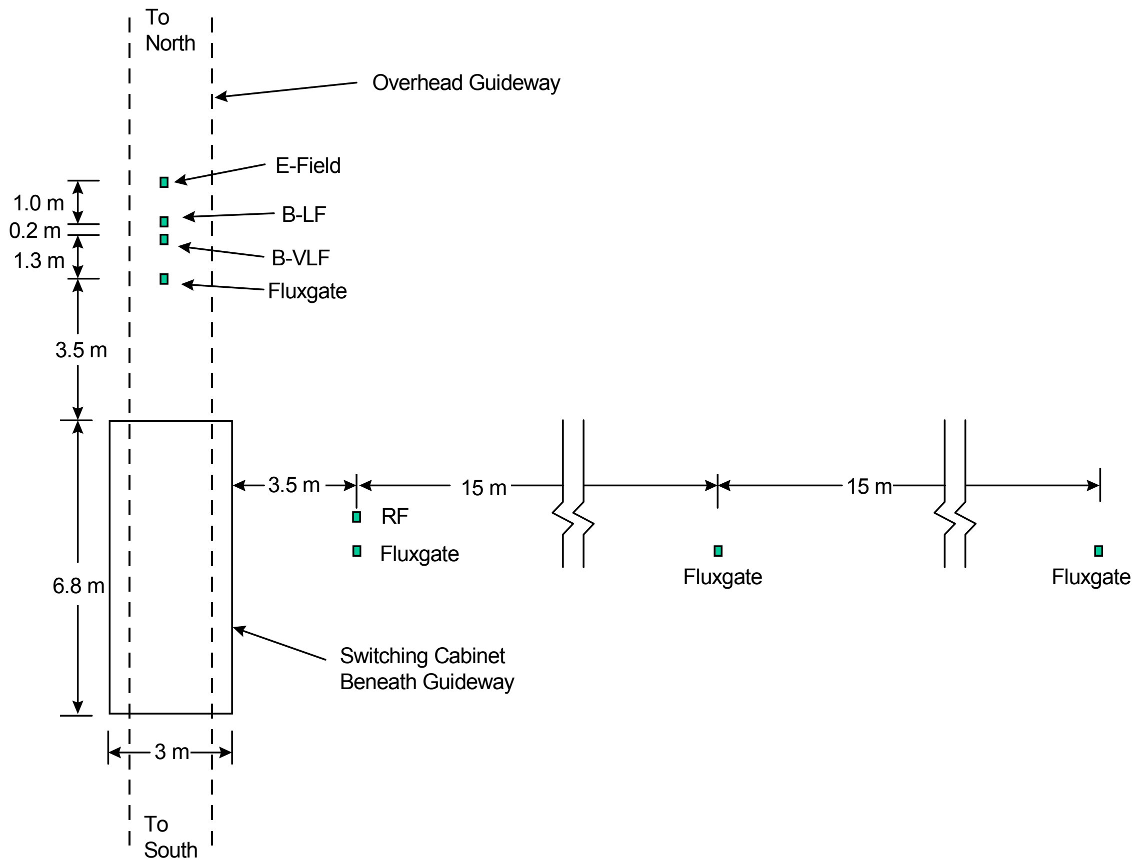


Figure 2-10. Sensor placement near the electrical switching cabinets

All of these sensors are the same horizontal distance from centerline of the guideway as the regular guideway measurements, thereby facilitating any necessary correction for fields from the guideway. VLF and LF magnetic field sensors and the ELF electric field sensor were kept beneath the centerline of the guideway and as close to the cabinet as possible without interfering with one another. The RF electric field sensor was placed in front of the cabinet 5 m from centerline as shown in Figure 2-10. All sensor heights were the same as those used for measurements near the elevated guideway and reported in the preceding subsection. Measurement procedures were also similar except that the duration of the measurement interval was extended before and after every pass of the TR08 to characterize fields for the whole time the switching cabinet was active.

2.7 DATA FROM THE TEST FACILITY

Before these tests, it was not known whether magnetic fields on board or near the TR08 were highly dependent on the magnitude of the guideway longstator current. Because the magnitude of that current is dependant on the motive thrust requirements of the vehicle and that need may vary from one deployment to another, there was a possibility that field levels measured on or near the TR08 at TVE may not be representative of those which would exist elsewhere (e.g. in the U.S.) if the other deployment required greater or less guideway longstator current and different power, control, and communications frequencies. To facilitate an analysis of the influences of guideway current, the staff of the TVE provided measurements of guideway current, vehicle speed, and vehicle position at 0.1 second intervals throughout the duration of all vehicle trips during these tests. The data were provided in digital form to facilitate automated analysis.

All of the data logging equipment used in these tests was digital and contained internal clocks to time stamp all recorded data. Prior to the first tests, the internal clocks of all of the recording instruments were synchronized with the clock of the test facility data-logging computer. This was necessary to correlate the guideway current, vehicle speed, and vehicle position data with the various field measurements. At the conclusion of the tests, the internal clocks of all of the recording instruments were again compared to the clock of the test facility data logger to identify and correct for any drifts in the various instrument clocks.

2.8 ANALYSIS PROCEDURES

Some level of preprocessing was required for most of the data prior to the final analysis described in the following subsections.

2.8.1 Guideway Longstator Current

Current data supplied by the test facility included the magnitude of the component of current in phase with the voltage (thrust current) and the magnitude of the reactive current in quadrature to the thrust current. These numbers were provided for both power supplies. (In this discussion, ‘power supply’ means the inverter, transformers, resistors, and related equipment at a substation required to provide power to a section of guideway longstator.) The total current was computed for each power supply by taking root-sum-square of the quadrature components (phasor sum). Because the power supplies energize successive portions of the guideway in a leap-frog fashion, most of the time there is significant thrust current from only one supply. While the vehicle is crossing from one section to the next, there can be current in both supplies. The guideway current was taken to be the larger of the currents from the two power supplies, reasoning that the majority of the vehicle is on the portion of the guideway energized by the power supply with the greatest current. The sum of the current from the two power supplies was considered inappropriate, because there is no location along the guideway where the currents add.

2.8.2 Field Waveform Data

All of the static and ELF magnetic and electric field waveform data were saved as digitized waveforms. The collected data was first consolidated and audited for quality.

Following verification of the data integrity, the digitized waveforms were run through a Fast Fourier Transform (FFT) algorithm to generate frequency spectra files. Those files contain the field magnitude in 3.33 Hz increments from 0 to 3000 Hz. Resultant field levels were computed from the three orthogonal components by computing the root-sum-square at each 3.33 Hz frequency interval component, resulting in a frequency spectrum of the resultant field for the waveform snapshot. Successive snapshots are compiled into a master grid file of the field at a specific location during an entire trip, or an entire passby at the station or along the guideway. These grid files can be plotted to show field level as a function of frequency and time or used for further statistical analysis. The plots of field level as a function of time and frequency are especially useful for gaining an understanding of the complex field dynamics in the TR08.

The frequency spectra in the grid files contain nearly 1000 field levels at 3.33 Hz increments from 0 to 3000 Hz. This frequency detail is too fine for statistical analysis. Consequently, these magnetic field components are aggregated into the following frequency sub-bands:

Static – 0 Hz component
Low Frequency – 3.3 Hz to 46.7 Hz inclusive
Power Frequency – 50 Hz to 60 Hz inclusive
Power Harmonic Frequencies – 63.3 to 300 Hz inclusive
High Frequencies – 303.3 to 3000 Hz inclusive

Note, however, that because the frequency spectra were determined with a 3.33 Hz bandwidth, the actual range of frequencies contained within each sub-band is:

Static – 0 to 1.7 Hz
Low Frequency – 1.7 to 48.3 Hz
Power Frequency – 48.3 to 61.7
Power Harmonic Frequencies – 61.7 to 301.7 Hz
High Frequencies – 301.7 to 3001.7 Hz

The choice of frequency ranges was chosen to facilitate comparisons of complex field environments near electronic systems like the TR08 with those far more common environmental fields at power frequency (60 Hz in North America, 50 Hz in Europe and many other locations) and harmonics. Much of the statistical analysis in the following sections focused on the total ELF field and field in the sub-bands of frequencies. Analyses using similar frequency sub-bands were the standard procedure in many past studies of fields associated with transportation systems (FRA 1992, 1993b, 1993c, 1993d, 1993e, 1993f). While there was sometimes a 1 Hz or 2 Hz difference in sub-band frequency ranges resulting from differences in instrumentation, the frequency sub-bands were essentially the same in all FRA-sponsored ERM studies of EMF levels in rail and transit systems.

2.8.3 Time Matching

Time stamps on electric and magnetic field sample data sometimes drifted slightly from the time stamps of the guideway current, vehicle speed and vehicle position data provided by the TVE. Time stamps were adjusted using linear interpolation of the drift in instrument clocks over the eight day period of the tests. Because of the criticality of timing at the station, wayside, and switching cabinets, further fine adjustment of the sample times was carried out manually based on the vehicle position data.

2.8.4 Current Correlations

Once the time-matching was completed, correlation analyses were run to quantify the relationship between magnetic fields in the static, ELF, low frequency, power frequency, harmonic frequency, and high-frequency bands and guideway current. Vehicle speed was often included in these correlation analyses.

2.8.5 Final Analysis

After the various steps listed above, the field data was subjected to statistical, graphical, or regression analysis as described in the following chapters.

2.8.6 Units of Electric and Magnetic Field Strength

For the sake of simplicity, the magnitudes of magnetic fields reported throughout this document are stated in terms of the magnetic flux density, rather than the actual magnetic field strength (if desired, the reader can convert magnetic flux density values to magnetic field strength values by dividing by the permeability of air, the medium in which all of the measurements were made).

Unless otherwise indicated, all of the magnetic field levels are stated in milligauss (mG) rather than the international standard unit, teslas. For those who wish to convert magnetic field levels to teslas:

1 milligauss (mG) = 0.1 microteslas (μT); or, 10,000 Gauss (G) = 1 Tesla (T)

Electric field levels are reported in international standard units of volts or kilovolts per meter (V/m or kV/m).

CHAPTER 3 FIELD CHARACTERISTICS ON BOARD THE TR08

3.1 VEHICLE OPERATING CHARACTERISTICS

Magnetic and electric field characteristics were measured on board the TR08 at 14 locations in the passenger spaces and at one location in the attendant's space using procedures described in Chapter 2. These locations are reported in Figures 2-2 through 2-4. Although it was intended that the measurements be made in successive trips having identical speed profiles, a variety of unforeseen technical difficulties prevented that from happening. On several occasions, the vehicle had difficulties departing the station. In other cases, it overshot the station at the end of the trip or stopped unexpectedly along the guideway. Because of these operational difficulties, midway through the test program a routine trip was reduced from two laps around the guideway loop to a single lap.

The measurement protocol was designed around a pre-planned, two-lap trip of just over twenty minutes. Therefore, the principal recording equipment was programmed to collect a sample every 15 seconds and reach its maximum capacity of data storage in just over 26 minutes. Unsuccessful starts of the vehicle, other delays in leaving the station, or unexpected stops along the guideway sometimes extended the trip time, and the storage capacity of the instruments were exceeded before the trip was complete. In other cases, the data set was only half the planned size because the trip consisted of only one lap instead of two. Other trip anomalies, which affected data set sample size and trip-to-trip comparability, included over-running the station, which resulted in the need to back up, and unexpected stops along the guideway.

The number of field snapshots obtained at each measurement location while the TR08 was levitating or in motion is given in Table 3-1, along with a summary of the vehicle speed and guideway current at the time of those measurements. Table 3-1 also shows the mean, standard deviation, and range of ELF magnetic field levels recorded at the fixed reference location in the middle vehicle during each trip. It is reassuring to note that, although the standard speed profile planned for all trips was seldom achieved and that many of the trips deviated dramatically from that planned profile, the mean vehicle speeds were similar on most trips.

Anticipating that there may be uncertainty about the comparability of field measurements at different locations measured on successive trips rather than simultaneously, the measurement protocol included reference measurements of ELF magnetic fields at a single fixed location in the middle vehicle during all trips. The mean, standard deviation, and range of ELF field levels measured at the reference locations for each trip are also tabulated in Table 3-1. Those values are remarkably similar from trip to trip, considering the dramatic differences in speed profiles, trip durations, and unscheduled interruptions. Because of this consistency in ELF magnetic field conditions at the reference locations from one trip to the next, any material differences in field conditions measured at the 15 locations onboard the TR08 can be objectively attributed to spatial effects without significant confounding trip-to-trip variability in operating characteristics.

Table 3-1. Summary of Guideway Current, Vehicle Speed, and ELF Magnetic Field at the Fixed Reference Location During Measurement On Board the TR08

Measurement Location	Number of Samples	Guideway Current (Amperes)		Vehicle Speed (km/hr)		ELF Field at Reference Location (mG)	
		Mean ± Std Dev	Range	Mean ± Std Dev	Range	Mean ± Std Dev	Range
Passenger Locations							
1	100	661 ± 703	2 - 1745	190 ± 84	0 - 401	24.9 ± 12.1	2.4 - 64.7
1 Repeat	100	721 ± 616	2 - 1701	189 ± 70	1 - 401	23.9 ± 10.9	1.4 - 54.1
2	83	624 ± 620	2 - 1700	189 ± 73	9 - 398	22.0 ± 10.2	10.4 - 61.7
3	100	520 ± 629	1 - 1703	181 ± 74	20 - 397	24.1 ± 13.4	5.0 - 76.2
4	104	711 ± 617	36 - 1738	180 ± 65	1 - 384	23.1 ± 10.8	3.4 - 58.0
5	98	652 ± 584	4 - 1747	193 ± 67	52 - 397	23.6 ± 11.1	1.2 - 62.4
6	54	586 ± 496	29 - 1697	175 ± 55	8 - 230	23.3 ± 12.6	1.7 - 59.2
7	100	687 ± 604	82 - 1701	189 ± 68	22 - 398	24.0 ± 10.8	2.2 - 60.1
8	105	555 ± 523	2 - 1698	179 ± 59	1 - 300	23.1 ± 12.3	1.2 - 57.2
9	51	860 ± 611	2 - 1733	187 ± 92	1 - 401	23.1 ± 11.9	1.2 - 50.6
10	61	789 ± 644	3 - 1715	157 ± 100	1 - 394	24.7 ± 14.8	1.3 - 70.7
11	51	622 ± 694	2 - 1706	182 ± 87	1 - 398	26.8 ± 13.6	2.0 - 70.9
12	52	774 ± 616	103 - 1719	191 ± 85	1 - 397	24.8 ± 12.2	2.8 - 53.9
13	52	848 ± 645	50 - 1698	182 ± 87	3 - 401	24.6 ± 13.3	3.9 - 75.9
14	50	806 ± 644	2 - 1713	189 ± 86	1 - 398	23.1 ± 13.2	1.2 - 59.0
Summary of 14 Passenger Locations							
Average	77	694 ± 616	22 - 1714	184 ± 77	8 - 380	23.9 ± 12.2	2.7 - 62.3
Extremes			1 - 1747		0 - 401		1.2 - 76.2
Attendant Location							
15	103	718 ± 603	1 - 1708	162 ± 77	0 - 401	23.0 ± 16.7	0.8 - 119.3
Summary of All On Board Locations							
Average	79	696 ± 615	20 - 1714	182 ± 77	7 - 381	23.9 ± 12.5	2.6 - 65.9
Extremes			1 - 1747		0 - 401		0.8 - 119.3

3.2 STATIC AND ELF MAGNETIC FIELDS

The central focus of this measurement program was to characterize the static and extreme low frequency (ELF) magnetic fields associated with the TR08. This focus was due to the utilization of magnetic fields in those frequency ranges for the levitation, propulsion, and guidance of the vehicle.

3.2.1 Qualitative Characteristics

Because of the complexity of the magnetic levitation, propulsion, and guidance systems incorporated in the TR08, the magnetic field environment has a complex frequency spectrum that varies over time and operating conditions. Graphs such as the one shown in Figure 3-1 are helpful for documenting the complex characteristics of those magnetic fields. Figure 3-1 shows magnetic field conditions at the waist height of a seated passenger at measurement location 2 before and during a trip along the guideway. The speed profile for this trip is shown again in Figure 3-7 later in this chapter. The intensity of the magnetic flux density vector (hereafter referred to as the magnetic field) is shown on the vertical axis as a function of frequency and time. The TR08 is stationary for the first 250 seconds as it levitates a few times, but is unsuccessful at achieving motion.

While the vehicle is stationary, the dominant magnetic field component is Earth's natural magnetic field at the site, also called the static (0 Hz) or direct current (DC) field, of just over 400 mG. This intensity is typical of Earth's normal geomagnetic field intensity and direction (inclination, declination) at mid-latitudes. Deviations from Earth's ambient field can be caused by the type, amount, and geometry of any nearby magnetizable steel or iron structures (in the station, vehicle or guideway). In this case the DC field decreases when the vehicle levitates. There is also evidence of a small power frequency (50 Hz) magnetic field while the TR08 is stationary, probably due to powered up heat, ventilation and air conditioning (HVAC), as well as nearby power supply cables and transformers.

At approximately 250 seconds, the vehicle levitates and begins movement along the guideway. While in motion, significant variations in Earth's natural static field are observed and a variety of low-frequency magnetic field components appear.

To observe the characteristics of the ELF (3 Hz to 3 kHz) magnetic field components better, the data from Figure 3-1 are replotted in Figure 3-2 with the large natural static field component removed. This allows the vertical axis to be expanded to provide better resolution of the smaller ELF magnetic fields. This expanded graph shows that there are no material field components present at frequencies above a few hundred Hz.

To better view the characteristics of the principal low-frequency magnetic field components, the same data are again replotted in Figure 3-3 with an expanded frequency scale to show details below 300 Hz. In this expanded graph, the small, 50 Hz power frequency field is clearly evident when the train is stationary. Small, low-frequency fields associated with three failed attempts to depart the station are also apparent in the first 400 seconds when the TR08 is stationary. Once the vehicle begins moving, a more complex and dynamic magnetic field environment develops. ELF components of just a few Hz usually have the largest amplitude; however, other frequency components are also present. At least two frequency components are related to vehicle speed, reaching maximum frequencies of approximately 110 Hz and 220 Hz at 700 seconds when the TR08 achieves its maximum speed of approximately 400 km/hr. The TR08 made its second lap around the north loop of the guideway without accelerating to its maximum speed (e.g., at 1300 seconds), hence the speed-related magnetic field components were constrained to lower frequencies (approximately 70 Hz and

140 Hz). The speed profile for this trip is shown in Figure 3-7 later in this chapter.

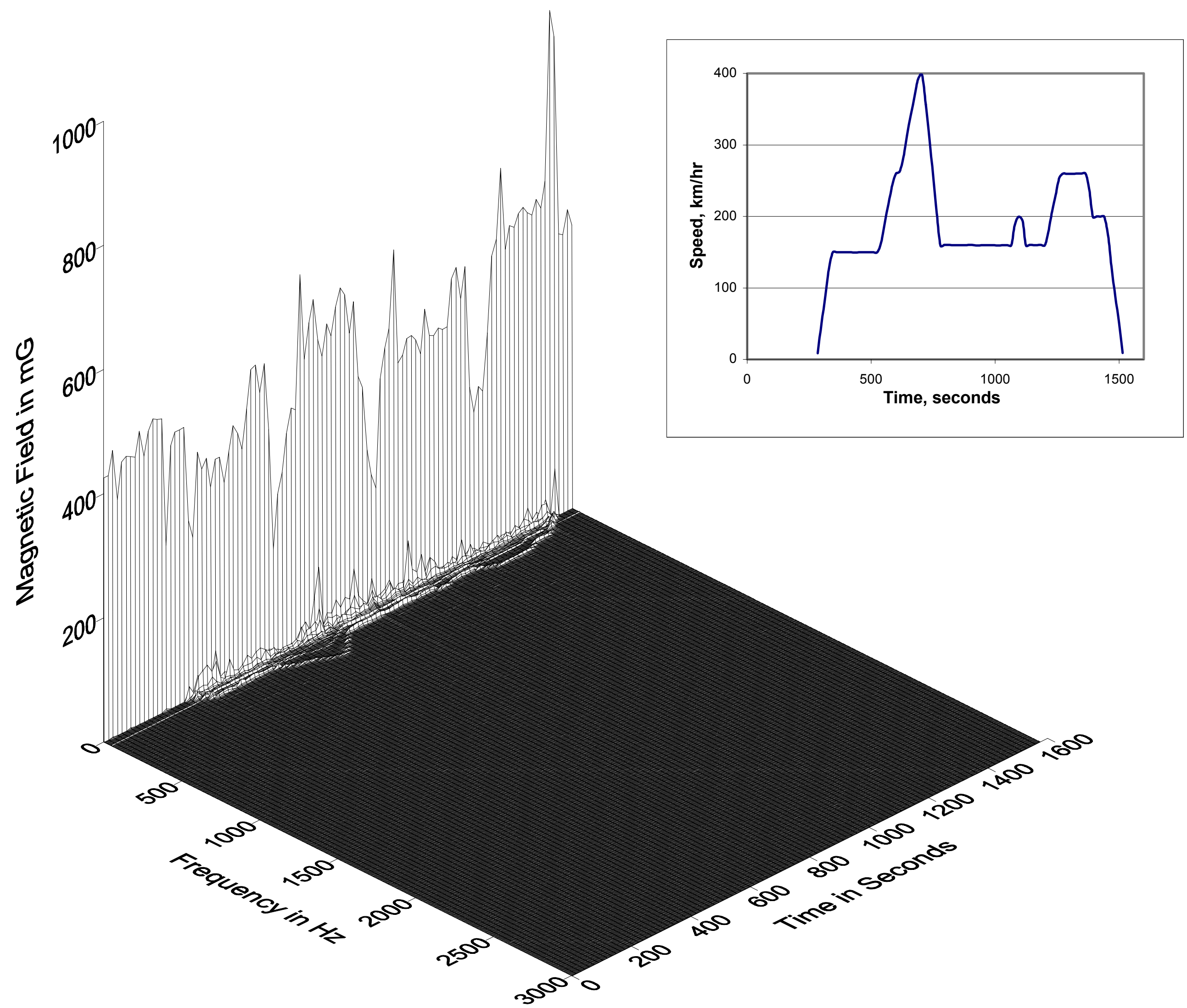


Figure 3-1. Static and ELF magnetic field levels at waist height of a seated passenger at measurement location 2 as a function of frequency and time

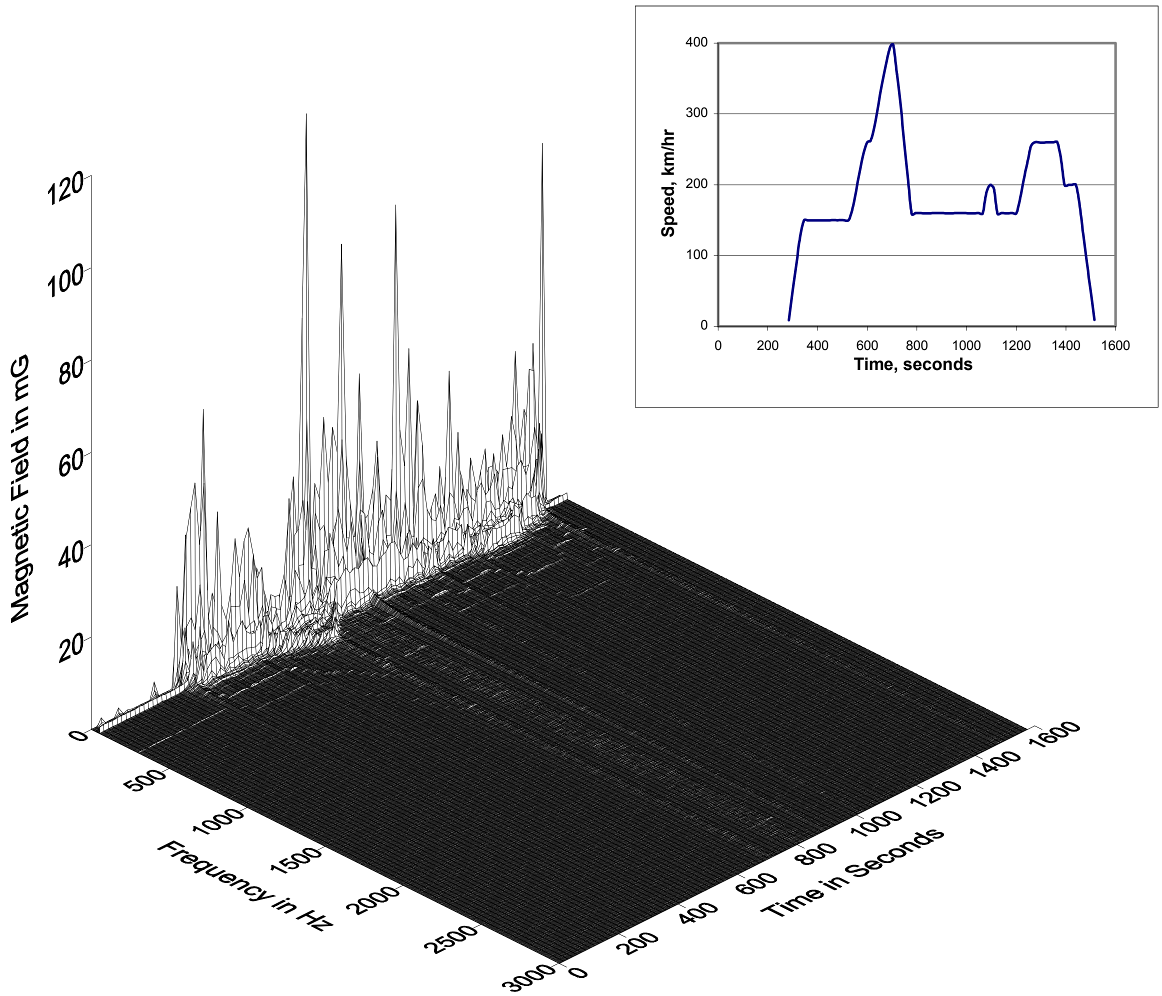


Figure 3-2. ELF magnetic field levels at waist height of a seated passenger at measurement location 2 as a function of frequency and time (the static field is not shown)

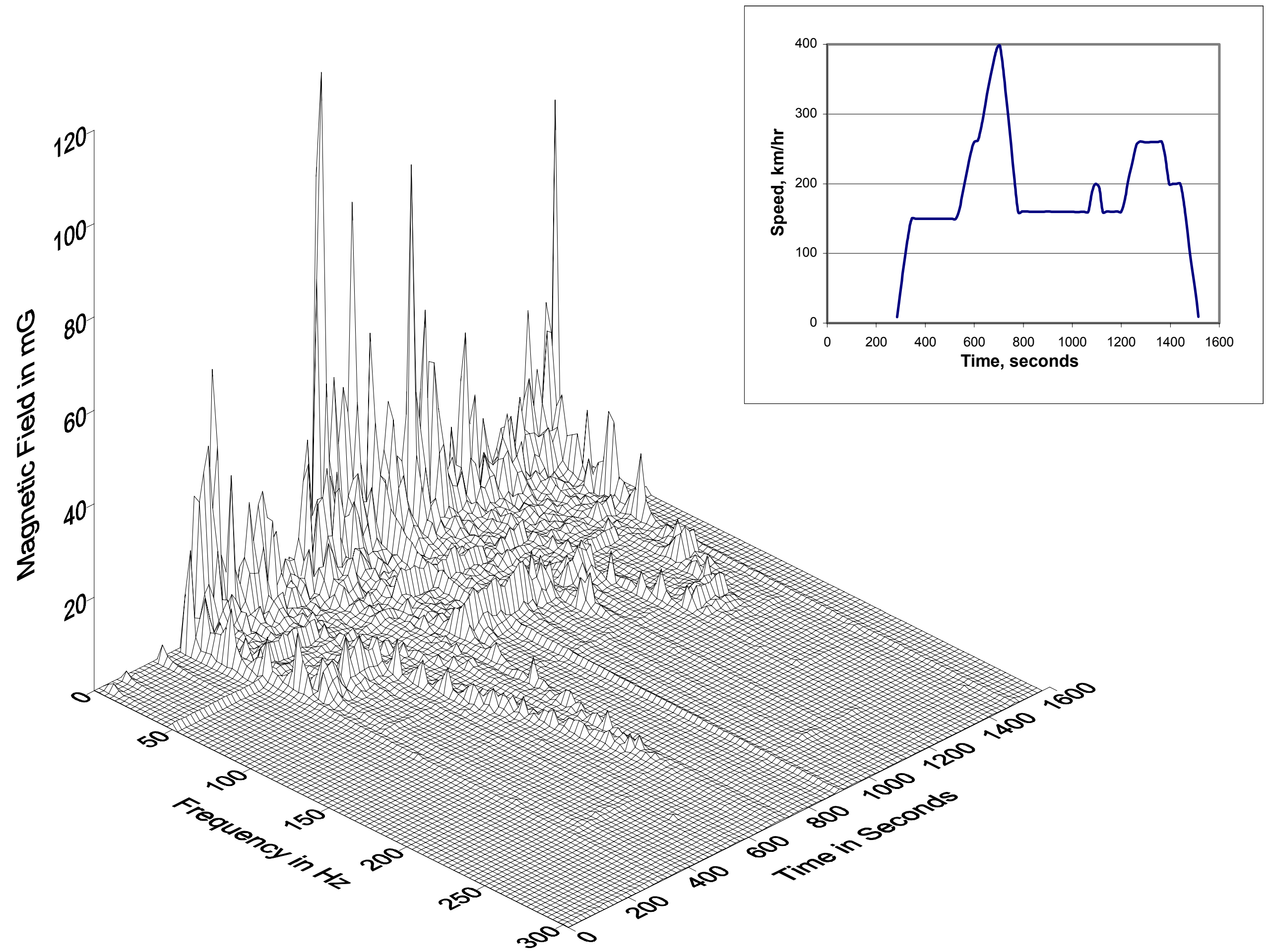


Figure 3-3. 3 to 300 Hz magnetic field levels at waist height of a seated passenger at measurement location 2 as a function of frequency and time (static field is not shown and the frequency scale is expanded to show detail below 300 Hz)

Data such as those shown in Figures 3-1 through 3-3 were collected at head, waist, and ankle height at all 15 magnetic field measurement locations within the TR08. Because the qualitative similarities in the magnetic fields measured at most locations were similar to those shown in the three preceding figures, the magnetic field levels at other locations are reported in tabular form (Tables 3-2 through 3-4) rather than graphically. The magnetic field components are grouped into the following frequency ranges:

- Static - Less than 2 Hz
- Low Frequency - 2 Hz to 48 Hz
- Power Frequency - 48 Hz to 62 Hz
- Harmonic Frequency - 62 Hz to 302 Hz
- High ELF Frequency - 302 Hz to 3002 Hz

- All ELF Frequencies - 2 Hz to 3002 Hz

The selection of these frequency ranges is based on providing the ability to compare and contrast magnetic fields having complex frequency spectra such as those within the TR08. The more common ELF magnetic fields from power lines and appliances have very limited frequency spectra in the power frequency and harmonic frequency ranges as defined above. These frequency ranges are consistent with those used previously when reporting magnetic fields from transportation systems such as the TR07 (FRA 1992).

3.2.2 Fields in Stationary Vehicle

Table 3-2 gives the mean magnetic field level (and the standard deviation) in each of the above six frequency ranges obtained at head, waist, and ankle height at the 14 measurement locations within the passenger compartments of the TR08. These values were computed from measurements taken when the vehicle was stationary and not levitating. Data at the bottom of Table 3-2 show summary mean field strength and a standard deviation over the 14 measurement locations in the passenger compartments. These values are the averages of the reported means and standard deviations reported for the 14 individual locations rather than the mean and standard deviation of the complete pooled data set. Summary statistics on the pooled data were considered possibly misleading because of the large differences in the number of samples at the various locations.

Table 3-2. Static and ELF Magnetic Field Levels in Milligauss at Passenger Locations within the TR08 While Stationary

Measure-Ment Location	Number Of Samples	Static Field 0 Hz Mean ± Std Dev	Low Freq. 2 - 48 Hz Mean ± Std Dev	Power Freq. 48 - 62 Hz Mean ± Std Dev	Harmonic Freq. 62 – 302 Hz Mean ± Std Dev	High Freq. 302 - 3002 Hz Mean ± Std Dev	All ELF Freq. 2 - 3002 Hz Mean ± Std Dev
Head Level							
1	6	501 ± 0.1	0.09 ± 0.01	0.80 ± 0.04	0.87 ± 0.01	0.10 ± 0.00	1.19 ± 0.02
1 Repeat	2	592 ± 0.4	0.06 ± 0.02	0.80 ± 0.03	0.75 ± 0.01	0.10 ± 0.00	1.10 ± 0.01
2	20	569 ± 45.4	0.15 ± 0.10	0.92 ± 0.06	0.20 ± 0.08	0.10 ± 0.01	0.97 ± 0.06
3	5	648 ± 5.6	0.10 ± 0.02	1.14 ± 0.03	0.07 ± 0.00	0.09 ± 0.00	1.15 ± 0.03
4	2	400 ± 31.5	0.22 ± 0.11	1.30 ± 0.02	0.12 ± 0.01	0.09 ± 0.00	1.33 ± 0.03
5	7	673 ± 33.8	0.10 ± 0.05	0.38 ± 0.04	0.42 ± 0.09	0.10 ± 0.00	0.59 ± 0.06
6	1	391	0.25	0.28	0.15	0.09	0.41
7	3	482 ± 8.8	0.10 ± 0.00	0.39 ± 0.10	0.16 ± 0.01	0.09 ± 0.00	0.44 ± 0.09
8	2	333 ± 0.1	0.04 ± 0.00	0.10 ± 0.02	0.16 ± 0.00	0.10 ± 0.00	0.22 ± 0.01
9	3	417 ± 0.1	0.05 ± 0.00	0.12 ± 0.00	0.34 ± 0.01	0.09 ± 0.00	0.37 ± 0.01
10	7	541 ± 9.4	0.10 ± 0.05	0.08 ± 0.02	0.22 ± 0.07	0.09 ± 0.00	0.28 ± 0.07
11	1	613	0.05	0.03	0.16	0.09	0.19
12	7	522 ± 1.7	0.06 ± 0.02	0.04 ± 0.01	0.33 ± 0.00	0.09 ± 0.00	0.35 ± 0.01
13	8	556 ± 15.5	0.08 ± 0.01	0.08 ± 0.01	0.36 ± 0.01	0.10 ± 0.01	0.39 ± 0.01
14	10	579 ± 61.5	0.23 ± 0.05	0.21 ± 0.05	0.17 ± 0.04	0.09 ± 0.00	0.37 ± 0.03
Waist Level							
1	5	334 ± 0.9	0.10 ± 0.01	0.95 ± 0.04	0.48 ± 0.01	0.06 ± 0.00	1.07 ± 0.04
1 Repeat	2	377 ± 0.7	0.09 ± 0.04	0.91 ± 0.00	0.41 ± 0.01	0.06 ± 0.00	1.00 ± 0.01
2	20	447 ± 24.4	0.20 ± 0.10	1.39 ± 0.05	0.16 ± 0.07	0.06 ± 0.01	1.42 ± 0.05
3	5	478 ± 5.9	0.21 ± 0.08	2.34 ± 0.03	0.06 ± 0.00	0.06 ± 0.00	2.36 ± 0.03
4	2	310 ± 31.2	0.37 ± 0.16	2.47 ± 0.01	0.14 ± 0.01	0.06 ± 0.01	2.50 ± 0.04
5	7	738 ± 53.5	0.12 ± 0.05	0.89 ± 0.07	0.35 ± 0.07	0.06 ± 0.00	0.97 ± 0.06
6	1	541	0.39	0.77	0.13	0.06	0.87
7	3	374 ± 8.4	0.18 ± 0.00	1.01 ± 0.21	0.24 ± 0.02	0.06 ± 0.00	1.06 ± 0.20
8	2	223 ± 0.4	0.04 ± 0.00	0.11 ± 0.00	0.16 ± 0.00	0.06 ± 0.00	0.20 ± 0.00
9	3	291 ± 1.6	0.05 ± 0.00	0.14 ± 0.01	0.50 ± 0.01	0.06 ± 0.00	0.53 ± 0.01
10	7	390 ± 9.4	0.15 ± 0.04	0.08 ± 0.01	0.32 ± 0.11	0.06 ± 0.00	0.37 ± 0.10
11	1	510	0.04	0.03	0.30	0.06	0.31
12	7	476 ± 16.1	0.04 ± 0.01	0.05 ± 0.01	0.36 ± 0.00	0.06 ± 0.00	0.37 ± 0.00
13	4	398 ± 16.9	0.12 ± 0.01	0.07 ± 0.01	0.62 ± 0.01	0.07 ± 0.00	0.64 ± 0.01
14	10	599 ± 99.9	0.23 ± 0.05	0.11 ± 0.05	0.24 ± 0.09	0.06 ± 0.00	0.36 ± 0.06
Ankle Level							
1	6	612 ± 0.2	0.10 ± 0.01	0.67 ± 0.05	0.20 ± 0.00	0.05 ± 0.00	0.71 ± 0.05
1 Repeat	2	668 ± 1.3	0.10 ± 0.02	0.66 ± 0.00	0.18 ± 0.00	0.05 ± 0.00	0.70 ± 0.00
2	20	823 ± 62.7	0.26 ± 0.18	1.19 ± 0.04	0.15 ± 0.05	0.06 ± 0.02	1.24 ± 0.07
3	5	1012 ± 11.1	0.27 ± 0.09	2.51 ± 0.02	0.24 ± 0.00	0.07 ± 0.00	2.54 ± 0.01
4	2	438 ± 70.2	0.68 ± 0.41	3.41 ± 0.02	0.29 ± 0.01	0.07 ± 0.02	3.52 ± 0.06
5	7	946 ± 104.8	0.34 ± 0.06	4.15 ± 0.05	0.41 ± 0.08	0.06 ± 0.00	4.18 ± 0.05
6	1	620	1.13	9.40	0.43	0.08	9.48
7	3	455 ± 15.6	0.38 ± 0.01	6.93 ± 0.63	0.42 ± 0.01	0.06 ± 0.00	6.95 ± 0.63
8	2	239 ± 0.1	0.05 ± 0.00	0.09 ± 0.02	0.31 ± 0.00	0.07 ± 0.00	0.33 ± 0.01
9	3	337 ± 3.5	0.16 ± 0.02	0.27 ± 0.00	0.67 ± 0.02	0.06 ± 0.00	0.74 ± 0.02

10	7	406 ± 22.0	0.48 ± 0.15	0.15 ± 0.02	0.95 ± 0.32	0.08 ± 0.01	1.08 ± 0.33
11	1	542	0.12	0.06	1.91	0.23	1.93
12	7	502 ± 16.9	0.14 ± 0.01	0.07 ± 0.01	1.37 ± 0.02	0.16 ± 0.00	1.39 ± 0.02
13	4	515 ± 16.5	0.31 ± 0.01	0.07 ± 0.00	1.55 ± 0.01	0.14 ± 0.00	1.59 ± 0.01
14	10	694 ± 121.0	0.19 ± 0.06	0.18 ± 0.08	0.62 ± 0.17	0.07 ± 0.01	0.69 ± 0.13
Summary of 14 Passenger Locations							
Head Level	5.6	521 ± 16.4	0.11 ± 0.03	0.44 ± 0.03	0.30 ± 0.03	0.09 ± 0.00	0.62 ± 0.03
Waist Level	5.3	432 ± 20.7	0.15 ± 0.04	0.75 ± 0.04	0.30 ± 0.03	0.06 ± 0.00	0.94 ± 0.05
Ankle Level	5.3	587 ± 34.3	0.32 ± 0.08	1.99 ± 0.07	0.65 ± 0.05	0.09 ± 0.01	2.47 ± 0.11

Examination of Table 3-2 reveals that the principal ELF fields are in the range of frequencies used for power distribution or harmonics thereof. This is consistent with expectations because active field sources on the stationary vehicle are those associated with lighting, air conditioning, and other passenger comfort functions rather than levitation, propulsion, or guidance. Since nearly all of the stationary measurements were made at the station, one can not say with certainty that the ELF fields measured in the stationary TR08 arise from the vehicle and not the station. However, the concentration of fields near the floor of the vehicle at most measurement locations indicates a below-floor source too close to the vehicle to be a magnetic field source in the station.

A dc ‘third rail’ was installed along the guideway at and near the station to charge the onboard batteries when the vehicle was stationary or moving too slowly for the linear induction charging to be effective. Current in the third rail did not appear to be a significant field source in the stationary vehicle.

Although very few measurements were made in the stationary vehicle, at most locations the small standard deviation indicated little temporal variability in those fields. This finding was consistent with observations of qualitative field characteristics derived from Figures 3-1 through 3-3.

With the exception of location 1, ELF magnetic fields in the stationary vehicle were concentrated near the floor, suggesting the presence of sources beneath the floor. At location 1, there was a magnetic field source in the overhead area that contributed to the ELF magnetic field environment in that area.

Ankle-level power frequency and harmonic frequency magnetic fields in the stationary vehicle varied over time from location to location, with limited apparent pattern. They tended to be highest at measurement locations 2, 4, 5, 6, and 7 which were selected to have the same relative proximity to various kinds of under-floor equipment. Nevertheless, the ankle-level field levels varied from 1.2 to 9.5 mG. They did share the common feature of being predominantly 50 Hz fields with little harmonic content. Locations 8, 9, and 10 also had similar proximity to under-floor equipment and were selected because of their proximity to the battery compartments. Among these locations, field levels at ankle height varied, but had the common feature that the largest component was in the harmonic frequency range. The greatest similarity in ankle-high field conditions in the stationary vehicle occurred between locations 11, 12, and 13, chosen to be near the onboard dc voltage distribution systems of the three TR08 cars. At these locations, the ELF fields varied from 1.4 to 1.9 mG in the stationary vehicle and were concentrated in the harmonic frequency range.

Static fields at various locations in the stationary TR08 varied by as much as a factor of five, from 223 mG to over 1000 mG. The expected level from the ambient geomagnetic field was between 400 and 500 mG. The deviation from the expected ambient static field is greatest near the floor, suggesting either field enhancement from ferromagnetic structures of the vehicle or guideway, or from various dc currents in circuits beneath the floor.

Typically, the standard deviation of the static field measurements was small, suggesting little temporal variability in the stationary vehicle. However, for selected locations (2, 4, 5, 14), the variability in static field levels was markedly higher in the measurements reported in Table 3-2. In these data sets, measurements were made both before the TR08 departed the station and when it returned, or at the station and at an unplanned stop along the guideway. The increased variability in static field levels in those data sets appeared to result from differences in train position rather than sample-to-sample variability. Magnetic field measurements were made two times at location 1 on different days. ELF fields in the stationary vehicle were very similar in both sets of measurements, but the static field levels were not (even though there was negligible temporal variability in both measurements). These observations suggest that the ankle-level deviation of the static field level in the stationary TR08 from the ambient geomagnetic field level was in part due to field perturbation by ferromagnetic structures in the guideway, or residual magnetic flux in guideway or vehicle components.

3.2.3 Moving Vehicle

Static and ELF magnetic field data measured while the TR08 was in motion were extracted from data sets measured at the 14 on-board measurement locations in the passenger compartments of the TR08 and are summarized as means and standard deviations in Table 3-3. Data showing the range of magnetic field levels (minimum to maximum) are reported in Table 3-4. Summary data reported at the bottom of this table include average ranges (average minimum field to average maximum field) as well as extreme ranges (overall minimum to overall maximum without regard to location). The average range indicates the range of field levels one might encounter when seated in any random seat in the passenger compartments. The extreme range indicates the highest and lowest fields on board the vehicle without regard to any particular seat.

As illustrated graphically in Figures 3-1 through 3-3, these tables show that the ELF fields were much larger when the guideway longstator and magnetic bogies beneath the vehicle were active and the TR08 was in motion. The temporal variability of the static and ELF fields was also greater in the moving vehicle than the stationary vehicle. Furthermore, as discussed in the above qualitative description of fields in the moving vehicle, the largest ELF magnetic fields are in the low frequencies below the normal European 50 Hz power frequency.

Table 3-3. Static and ELF Magnetic Field Levels in Milligauss at Passenger Locations within the TR08 While in Motion

Measure-Ment	Static Field 0 Hz	Low Freq. 2 - 48 Hz	Power Freq. 48 - 62 Hz	Harmonic Freq. 62 - 302 Hz	High Freq. 302 - 3002 Hz	All ELF Freq. 2 - 3002 Hz
Location	Mean ± Std Dev	Mean ± Std Dev	Mean ± Std Dev	Mean ± Std Dev	Mean ± Std Dev	Mean ± Std Dev
Head Level						
1	539 ± 75	28.7 ± 15.1	3.8 ± 3.3	18.1 ± 5.7	2.1 ± 1.0	35.2 ± 14.2
1 Repeat	552 ± 77	27.5 ± 16.3	3.3 ± 2.4	17.5 ± 5.3	1.9 ± 0.8	33.9 ± 15.0
2	499 ± 75	23.8 ± 13.2	2.6 ± 1.4	9.9 ± 3.2	1.1 ± 0.5	26.5 ± 12.6
3	553 ± 134	24.2 ± 14.8	2.8 ± 2.6	8.7 ± 3.5	1.1 ± 0.6	26.4 ± 14.5
4	506 ± 66	24.4 ± 13.5	3.2 ± 2.4	9.4 ± 3.1	1.2 ± 0.8	26.8 ± 13.2
5	567 ± 72	22.9 ± 12.7	1.8 ± 0.8	6.7 ± 2.5	1.1 ± 0.5	24.3 ± 12.4
6	619 ± 105	21.0 ± 12.1	1.9 ± 1.1	5.7 ± 2.7	1.0 ± 0.4	22.1 ± 11.9
7	586 ± 54	21.3 ± 10.8	1.9 ± 0.9	6.7 ± 2.6	1.0 ± 0.5	22.8 ± 10.4
8	539 ± 68	20.1 ± 10.6	1.7 ± 0.6	6.6 ± 2.5	1.1 ± 0.5	21.5 ± 10.3
9	525 ± 58	20.5 ± 12.1	1.9 ± 1.7	5.2 ± 2.4	0.9 ± 0.4	21.5 ± 11.8
10	610 ± 134	22.8 ± 17.7	2.4 ± 2.5	6.4 ± 4.2	1.0 ± 0.9	24.4 ± 17.6
11	580 ± 102	19.3 ± 11.8	2.0 ± 2.0	5.2 ± 2.1	0.9 ± 0.5	20.4 ± 11.5
12	535 ± 83	19.6 ± 13.2	2.1 ± 2.5	6.0 ± 2.8	1.0 ± 0.6	21.2 ± 12.9
13	580 ± 65	16.6 ± 13.0	1.9 ± 1.0	7.6 ± 4.0	0.9 ± 0.7	19.1 ± 12.6
14	534 ± 46	15.5 ± 9.8	1.9 ± 1.3	5.4 ± 2.2	0.9 ± 0.5	16.8 ± 9.6
Waist Level						
1	429 ± 107	43.3 ± 23.5	3.8 ± 2.9	11.7 ± 4.2	2.1 ± 1.6	45.4 ± 23.3
1 Repeat	424 ± 109	43.5 ± 27.0	3.5 ± 2.0	11.2 ± 3.7	2.0 ± 1.2	45.5 ± 26.6
2	423 ± 111	35.8 ± 21.2	3.3 ± 1.6	9.7 ± 3.2	1.5 ± 1.0	37.6 ± 20.9
3	376 ± 183	35.7 ± 24.0	3.9 ± 2.6	9.4 ± 3.8	1.6 ± 1.0	37.6 ± 23.7
4	522 ± 127	35.3 ± 19.2	4.3 ± 2.3	9.4 ± 3.1	1.7 ± 1.2	37.1 ± 19.0
5	521 ± 95	37.6 ± 21.1	2.6 ± 1.2	7.3 ± 2.8	1.6 ± 1.0	38.7 ± 20.9
6	565 ± 99	31.3 ± 16.8	2.5 ± 1.2	6.4 ± 2.8	1.3 ± 0.8	32.3 ± 16.6
7	515 ± 77	31.3 ± 16.2	2.7 ± 1.1	8.2 ± 3.3	1.4 ± 0.9	32.9 ± 15.9
8	451 ± 71	32.1 ± 17.8	2.2 ± 1.0	6.8 ± 2.5	1.4 ± 0.9	33.1 ± 17.7
9	443 ± 100	31.6 ± 19.8	2.4 ± 1.9	5.8 ± 2.6	1.3 ± 0.9	32.5 ± 19.7
10	504 ± 165	35.4 ± 26.2	3.1 ± 2.9	7.7 ± 4.9	1.6 ± 1.5	36.8 ± 26.3
11	444 ± 64	25.5 ± 16.6	2.2 ± 2.2	5.7 ± 2.4	1.1 ± 0.8	26.6 ± 16.3
12	392 ± 79	26.5 ± 19.9	2.8 ± 3.1	7.2 ± 3.5	1.4 ± 1.3	28.2 ± 19.8
13	382 ± 75	22.8 ± 19.3	2.5 ± 1.6	10.2 ± 5.8	1.2 ± 1.1	26.1 ± 19.0
14	540 ± 62	21.5 ± 14.0	2.7 ± 2.3	8.1 ± 3.4	1.3 ± 0.7	23.8 ± 13.6
Ankle Level						
1	1105 ± 229	91.4 ± 46.4	7.4 ± 4.6	16.7 ± 6.3	4.3 ± 3.3	93.6 ± 46.5
1 Repeat	1067 ± 237	97.0 ± 57.9	7.7 ± 3.9	17.3 ± 6.3	4.4 ± 2.9	99.3 ± 57.8
2	885 ± 165	63.6 ± 36.7	5.5 ± 2.9	11.7 ± 3.5	2.6 ± 1.6	65.2 ± 36.5
3	905 ± 375	56.7 ± 40.0	5.4 ± 2.6	11.2 ± 4.8	2.4 ± 1.3	58.5 ± 39.9

4	919 ± 290	65.7 ± 34.6	7.3 ± 3.1	12.5 ± 3.9	3.1 ± 2.0	67.6 ± 34.4
5	696 ± 135	71.9 ± 40.5	5.8 ± 2.0	10.4 ± 4.4	2.6 ± 1.8	73.2 ± 40.4
6	797 ± 211	61.7 ± 35.6	10.6 ± 2.0	14.7 ± 7.2	3.0 ± 1.6	65.3 ± 34.7
7	699 ± 145	63.0 ± 38.0	7.8 ± 1.8	12.9 ± 5.7	2.7 ± 2.0	65.4 ± 37.4
8	845 ± 128	67.4 ± 40.0	4.0 ± 1.9	10.0 ± 4.2	2.7 ± 1.7	68.5 ± 39.9
9	579 ± 129	79.2 ± 43.2	5.1 ± 3.2	10.2 ± 4.5	3.2 ± 2.4	80.3 ± 43.3
10	692 ± 208	58.5 ± 40.5	5.0 ± 4.5	10.7 ± 6.4	2.7 ± 2.4	60.2 ± 40.8
11	467 ± 65	55.7 ± 44.7	5.4 ± 6.2	18.8 ± 9.1	2.6 ± 1.8	61.2 ± 43.1
12	452 ± 94	49.2 ± 39.3	5.9 ± 7.2	16.8 ± 8.9	2.6 ± 1.9	54.0 ± 38.8
13	452 ± 98	29.8 ± 15.5	3.4 ± 2.3	15.4 ± 8.9	1.5 ± 0.7	34.9 ± 15.6
14	532 ± 108	56.6 ± 42.8	6.0 ± 3.9	17.7 ± 8.7	3.0 ± 2.3	61.0 ± 42.0
Summary of 14 Passenger Locations						
Head Level	555 ± 81	21.9 ± 13.1	2.4 ± 1.8	8.3 ± 3.2	1.1 ± 0.6	24.2 ± 12.7
Waist Level	462 ± 102	32.6 ± 20.2	3.0 ± 2.0	8.3 ± 3.5	1.5 ± 1.1	34.3 ± 20.0
Ankle Level	739 ± 174	64.5 ± 39.7	6.2 ± 3.5	13.8 ± 6.2	2.9 ± 2.0	67.2 ± 39.4

Table 3-4. Range of Static and ELF Magnetic Field Levels in Milligauss at Passenger Locations within the TR08 While in Motion

Measure-ment Location	Static Field 0 Hz	Low Freq. 2 - 48 Hz	Power Freq. 48 - 62 Hz	Harmonic Freq. 62 - 302 Hz	High Freq. 302 - 3002 Hz	All ELF Freq. 2 – 3002 Hz
	Range	Range	Range	Range	Range	Range
Head Level						
1	325 - 852	6.9 - 101.5	0.9 - 21.9	1.2 - 33.7	0.6 - 9.0	7.1 - 108.1
1 Repeat	367 - 696	1.5 - 81.3	0.8 - 22.5	1.1 - 27.9	0.2 - 5.2	2.0 - 84.0
2	306 - 862	10.5 - 95.3	0.8 - 10.7	1.2 - 17.7	0.3 - 3.0	13.6 - 95.8
3	369 - 1158	3.5 - 87.4	1.1 - 19.8	0.5 - 20.2	0.2 - 3.7	3.7 - 87.4
4	157 - 611	1.7 - 79.5	1.1 - 16.3	0.3 - 14.5	0.2 - 4.3	2.1 - 80.3
5	417 - 786	0.1 - 56.6	0.5 - 6.7	0.4 - 15.3	0.1 - 2.5	0.6 - 57.3
6	395 - 826	2.1 - 55.4	0.5 - 8.5	0.3 - 11.6	0.2 - 2.0	2.2 - 56.6
7	366 - 792	1.1 - 54.0	0.3 - 8.3	0.3 - 13.5	0.1 - 2.5	1.2 - 54.8
8	183 - 821	0.1 - 54.4	0.1 - 3.4	0.6 - 15.8	0.1 - 2.5	0.6 - 55.1
9	306 - 648	0.0 - 48.2	0.1 - 11.2	0.2 - 10.8	0.1 - 2.1	0.4 - 48.8
10	201 - 1003	0.2 - 91.7	0.0 - 15.2	0.1 - 22.2	0.1 - 5.0	0.2 - 92.5
11	123 - 714	6.4 - 51.6	0.4 - 12.4	0.7 - 9.1	0.2 - 3.0	6.6 - 52.2
12	139 - 699	2.7 - 65.5	0.2 - 17.0	0.6 - 13.0	0.2 - 2.9	2.8 - 66.1
13	486 - 874	2.2 - 64.8	0.2 - 5.8	0.5 - 15.5	0.2 - 3.9	2.2 - 65.5
14	336 - 612	1.5 - 39.7	0.2 - 8.5	0.1 - 9.4	0.1 - 3.1	1.7 - 40.4
Waist Level						
1	150 - 845	8.1 - 119.3	1.2 - 19.5	1.7 - 27.8	0.5 - 10.1	8.4 - 123.5
1 Repeat	111 - 683	1.7 - 136.7	0.9 - 17.4	0.7 - 20.8	0.2 - 6.5	2.1 - 137.7
2	175 - 820	15.0 - 151.4	1.2 - 10.6	1.1 - 17.5	0.4 - 6.7	17.0 - 151.9
3	124 - 1084	4.5 - 122.7	2.3 - 21.5	0.6 - 19.7	0.3 - 4.8	5.1 - 123.8
4	219 - 817	2.4 - 134.2	2.4 - 17.4	0.4 - 16.5	0.2 - 6.5	3.4 - 135.3
5	373 - 802	0.1 - 102.7	1.0 - 7.7	0.3 - 14.9	0.1 - 6.4	1.1 - 104.1
6	394 - 823	3.1 - 71.9	1.0 - 8.8	0.5 - 12.5	0.2 - 4.5	3.4 - 72.4
7	226 - 783	1.4 - 90.8	0.9 - 8.2	0.4 - 17.0	0.1 - 5.4	1.7 - 91.6

8	88 - 726	0.1 - 107.6	0.1 - 6.7	0.6 - 15.9	0.1 - 5.3	0.6 - 108.6
9	131 - 627	0.0 - 105.8	0.1 - 12.1	0.2 - 11.9	0.1 - 5.5	0.5 - 106.7
10	50 - 927	0.3 - 120.7	0.1 - 17.1	0.1 - 24.9	0.1 - 7.4	0.3 - 122.0
11	213 - 560	8.8 - 81.2	0.4 - 13.2	0.8 - 10.2	0.2 - 4.4	10.0 - 81.6
12	214 - 602	4.3 - 85.0	0.4 - 20.4	0.8 - 15.1	0.2 - 6.2	4.4 - 86.3
13	281 - 782	3.1 - 110.5	0.2 - 8.1	0.9 - 21.9	0.1 - 6.8	3.2 - 111.7
14	282 - 664	1.7 - 58.9	0.1 - 16.4	0.1 - 15.9	0.1 - 4.1	1.7 - 59.4
Ankle Level						
1	575 - 2168	26.6 - 229.5	1.6 - 31.2	3.3 - 45.9	0.6 - 19.4	27.0 - 236.1
1 Repeat	494 - 1726	1.9 - 309.7	0.7 - 23.5	0.4 - 41.0	0.2 - 19.3	2.0 - 311.6
2	495 - 1546	24.2 - 257.8	1.4 - 19.4	0.9 - 20.0	0.4 - 8.1	24.3 - 258.3
3	512 - 2035	6.8 - 190.4	2.5 - 19.1	1.0 - 18.2	0.4 - 6.6	7.3 - 190.6
4	273 - 1520	5.5 - 244.2	3.3 - 21.2	0.9 - 20.7	0.4 - 10.4	6.6 - 245.7
5	374 - 1106	0.3 - 181.4	3.0 - 16.8	0.4 - 23.2	0.1 - 10.8	4.2 - 182.7
6	412 - 1324	5.9 - 145.7	7.8 - 19.8	0.9 - 31.1	0.3 - 8.4	10.2 - 147.0
7	298 - 1279	1.6 - 168.0	5.2 - 17.7	0.6 - 27.4	0.1 - 10.6	7.5 - 169.2
8	126 - 1170	0.1 - 268.7	0.1 - 14.7	0.9 - 24.3	0.1 - 11.7	1.0 - 270.4
9	218 - 917	0.2 - 212.8	0.2 - 16.9	0.5 - 18.9	0.1 - 8.9	0.8 - 213.7
10	206 - 1195	0.4 - 202.4	0.1 - 20.3	0.2 - 33.0	0.1 - 10.6	0.4 - 203.8
11	339 - 589	15.8 - 180.7	1.1 - 38.4	2.6 - 38.8	0.5 - 7.6	19.8 - 181.7
12	185 - 840	7.8 - 211.1	0.7 - 49.6	2.4 - 38.9	0.4 - 9.2	8.2 - 212.2
13	315 - 967	4.8 - 83.3	0.4 - 16.0	2.0 - 33.9	0.3 - 3.7	5.2 - 84.9
14	283 - 843	2.6 - 177.6	0.2 - 24.3	0.1 - 38.1	0.1 - 9.9	2.6 - 178.7
Summary of 14 Passenger Locations						
Average Range						
Head Level	298 - 797	2.7 - 68.4	0.5 - 12.6	0.5 - 16.7	0.2 - 3.6	3.1 - 69.7
Waist Level	202 - 770	3.6 - 106.6	0.8 - 13.7	0.6 - 17.5	0.2 - 6.0	4.2 - 107.8
Ankle Level	340 - 1282	7.0 - 204.2	1.9 - 23.3	1.1 - 30.2	0.3 - 10.4	8.5 - 205.8
Extreme Range						
Head Level	123 - 1158	0.0 - 101.5	0.0 - 22.5	0.1 - 33.7	0.1 - 9.0	0.2 - 108.1
Waist Level	50 - 1084	0.0 - 151.4	0.1 - 21.5	0.1 - 27.8	0.1 - 10.1	0.3 - 151.9
Ankle Level	126 - 2168	0.1 - 309.7	0.1 - 49.6	0.1 - 45.9	0.1 - 19.4	0.4 - 311.6

Examination of Tables 3-3 and 3-4 reveals substantial similarities in magnetic field levels and frequency distribution from one measurement location to another. In most cases, the variability in the ELF field level among head, waist, and ankle height at one location was larger than the variability among the field levels at similar heights from one location to another.

Perhaps the most atypical field condition was at location 1, at which the magnetic field levels in the harmonic frequency range were larger at head level than at foot level. That result indicated the presence of a magnetic field source in the overhead area above the window seat in addition to the sources beneath the floor throughout the entire vehicle.

Because of that atypical characteristic, together with the fact that the first set of measurements at location 1 were made during a trip with a markedly aberrant speed profile, the measurements were repeated at the same location three days later. The repeat measurements at location 1 confirmed the initial results demonstrating the existence of an apparent magnetic field source in the overhead area, and also demonstrating the minimal effect of trip speed profile on the central tendency of magnetic field levels measured during the trip.

The ELF magnetic field levels measured at head level at location 1 during the repeat measurements are plotted as a function of frequency and time in Figure 3-4. The frequency scale was again expanded to show detail below 300 Hz because there were no material field components at higher frequencies. Comparing this figure to Figure 3-3, showing waist-level fields in the adjacent seat (qualitatively typical of magnetic field characteristics in most passenger locations), reveals that the speed-dependent frequency components of the magnetic field were disproportionately high at head level near the bulkhead (location 1). This would imply that the source in the bulkhead or overhead at location 1 emitted the speed-dependent frequency components.

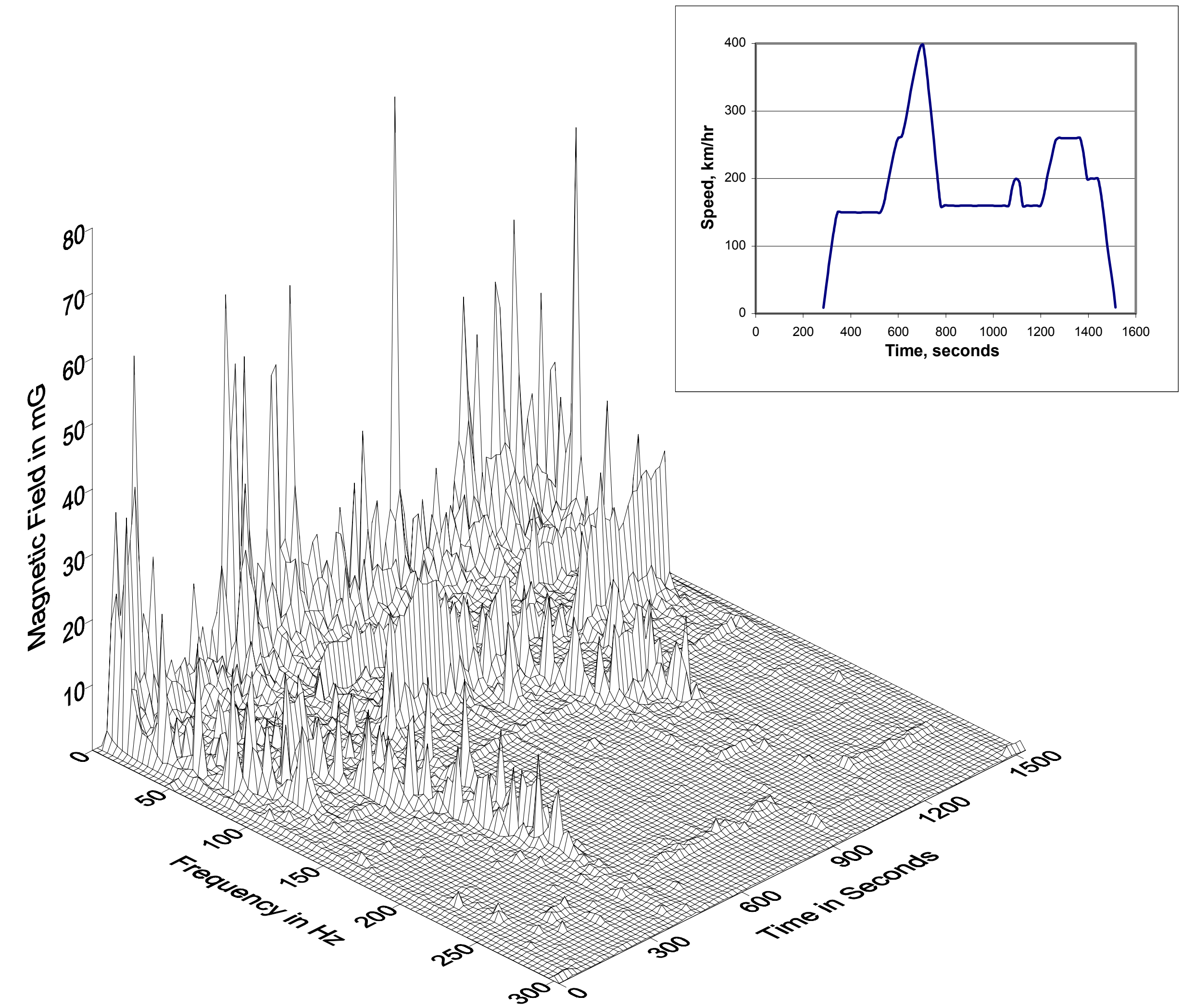


Figure 3-4. 3 to 300 Hz magnetic field levels at head height of a seated passenger at measurement location 1 as a function of frequency and time (static field is not shown and the frequency scale is expanded to show detail below 300 Hz)

Measurements were made at an insufficient number of locations on board the TR08 to completely map the spatial variability of the static and ELF magnetic fields. Rather, the test plan sought to provide a statistical description of field levels and a coarse evaluation of the influence of major electrical systems.

Data from measurement locations 1, 2, and 3 demonstrate the variability in field conditions laterally from centerline to bulkhead. It was anticipated that the largest fields would be in the second seat from the bulkhead (middle seat, location 2) because it was approximately centered above the levitation, propulsion, and guidance equipment beneath the floor. The data in Table 3-3 indicate otherwise. For most frequency ranges and heights, the largest magnetic fields were at the seat near the bulkhead (window seat, location 1). Furthermore, the presence of the magnetic field source high in the bulkhead or in the overhead near the window seat was unexpected. There was little difference between field characteristics in the middle seat (location 2) and the aisle seat (location 3).

Location 4 was chosen contralateral to location 2 to examine field symmetry about the vehicle and guideway centerlines. While field characteristics were not identical from side to side, they were similar in mean magnetic field level and frequency distribution.

Location 5 was chosen above an air duct in the rear part of the lead car to have similar proximity to under-floor equipment as that in locations 2 and 4. The general similarity in field characteristics among those locations revealed no gross front-to-back variations in field characteristics within the lead car. The head-level magnetic fields in the power frequency and harmonic frequency ranges were smaller near the rear of the car (location 5) than at either side near the front of the car (locations 2 and 4). That suggests that the field source in the side bulkhead or overhead above the window seats was less prominent or absent toward the rear of the vehicle.

Car-to-car variability in magnetic field characteristics was assessed by comparing data from locations 2, 4, and 5 in the lead car to data from location 6 in the middle car and location 7 in the trailing car. Although the frequency characteristics were generally similar at all locations, the mean ELF magnetic field levels at head and waist levels tended to be slightly smaller in the middle and rear car. Ankle-level fields were similar in all three cars. Like the location in the rear of the lead car (location 3), measurements in the middle and trailing cars did not demonstrate the presence of a significant field source in the side bulkhead or overhead above the adjacent window seat. Data from location 6 revealed higher power-frequency magnetic fields at ankle height in the middle car than in the other cars. There was a weak tendency for elevated harmonic-frequency fields at that location, as well.

Measurement locations 8, 9, and 10 were middle seats above battery compartments in the lead, middle, and trailing cars, respectively. The magnetic field characteristics at those locations did not materially differ from field characteristics at the locations above the air ducts (locations 5, 6, and 7), indicating that the batteries and nearby related components were not significant contributors to the magnetic field environment in the moving TR08.

Measurement locations 11, 12, and 13 were aisle seats near the voltage distribution circuits in the lead, middle, and trailing cars, respectively. At these locations, low-frequency ELF fields tended to be smaller than at other locations. That was probably a result of position near the centerline of the vehicle (aisle seats) rather than proximity to the voltage distribution cables. Ankle-level harmonic fields were elevated at all three locations near the voltage distribution cables (locations 11, 12, and 13) relative to other locations in the passenger compartment of the TR08.

Only one set of measurements was made simulating a passenger standing in the aisle along the centerline of the TR08. At this location (location 14), ankle-level fields were similar to those elsewhere in the vehicle, but head-level and waist-level fields were lower than head-level and waist-level measurements for seated passengers. This difference was apparently due to the fact that, when standing, a passenger's waist and head are more distant from under-floor field sources than when seated.

3.2.4 Attendant's Position

Although the TR08 was driven from the land-based central control room, there was an onboard attendant on duty in the front cabin of the lead vehicle. Magnetic fields could not be measured in the attendant's seat because the attendant must have complete access to the seat and instrument panel. To collect data in the vicinity of the attendant, a chair was placed in the contralateral position in the front compartment, and measurements were conducted in that seat (location 15).

Mean static and ELF magnetic field levels in this simulated attendant's location were measured while the TR08 was stationary and not levitating, and their standard deviations are reported in Table 3-5. The ELF fields were somewhat larger than in the passenger compartments while the vehicle was stationary and, like in the passenger compartment, consisted principally of power-frequency and power-harmonic-frequency fields. Static fields in the attendant's location were similar to those in passenger locations while the TR08 was stationary.

Table 3-5. Static and ELF Magnetic Field Levels in Milligauss at the Attendant Location within the Front Cabin of the TR08 While Stationary

Measure-Ment Location	Number Of Samples	Static Field 0 Hz Mean ± Std Dev	Low Freq. 2 - 48 Hz Mean ± Std Dev	Power Freq. 48 – 62 Hz Mean ± Std Dev	Harmonic Freq. 62 - 302 Hz Mean ± Std Dev	High Freq. 302 - 3002 Hz Mean ± Std Dev	All ELF Freq. 2 - 3002 Hz Mean ± Std Dev
Head Level	0						
Waist Level	2	387 ± 60.8	0.07 ± 0.03	2.29 ± 1.60	0.48 ± 0.39	0.08 ± 0.01	2.51 ± 1.39
Ankle Level	2	448 ± 84.4	0.10 ± 0.05	2.87 ± 0.87	1.03 ± 0.34	0.11 ± 0.02	3.12 ± 0.69

Static and ELF magnetic field characteristics at the simulated attendant's location (location 15, contralateral to the real attendant's seat) are reported in Tables 3-6 and 3-7. Static field levels at the attendant's location were, on average, smaller than in the passenger locations but tended to have more temporal variation at the ankle and waist heights. ELF magnetic fields were larger at the attendant's location than in passenger seats in all frequency ranges, with the most pronounced differences in the harmonic frequency range. Mean field levels in the harmonic frequency range were 4 to 6 times higher at the attendant's location than at the passenger's location. Because these fields were larger at head level and ankle level than at waist level, it would appear that multiple sources are involved, some of which appear to be in the overhead.

Table 3-6. Static and ELF Magnetic Field Levels in Milligauss at the Attendant Location within the Front Cabin of the TR08 While in Motion

Measure-Ment Location	Static Field 0 Hz	Low Freq. 2 - 48 Hz	Power Freq. 48 - 62 Hz	Harmonic Freq. 62 - 302 Hz	High Freq. 302 - 3002 Hz	All ELF Freq. 2 - 3002 Hz
	Mean ± Std Dev	Mean ± Std Dev	Mean ± Std Dev	Mean ± Std Dev	Mean ± Std Dev	Mean ± Std Dev
Head Level	473 ± 46	31.0 ± 21.5	5.6 ± 3.1	56.9 ± 14.0	4.3 ± 1.4	66.7 ± 21.5
Waist Level	384 ± 147	42.4 ± 35.2	8.3 ± 9.3	40.6 ± 19.9	3.8 ± 1.8	65.8 ± 30.4
Ankle Level	308 ± 191	63.3 ± 53.8	11.3 ± 13.0	50.3 ± 24.1	4.8 ± 2.4	90.5 ± 46.0

Table 3-7. Range of Static and ELF Magnetic Field Levels in Milligauss at the Attendant Location within the Front Cabin of the TR08 While in Motion

Measure-Ment Location	Static Field 0 Hz	Low Freq. 2 - 48 Hz	Power Freq. 48 - 62 Hz	Harmonic Freq. 62 - 302 Hz	High Freq. 302 - 3002 Hz	All ELF Freq. 2 - 3002 Hz
	Range	Range	Range	Range	Range	Range
Head Level	384 - 594	8.7 - 95.3	2.1 - 17.5	35.9 - 88.5	2.0 - 7.7	38.1 - 109.7
Waist Level	95 - 946	0.9 - 184.0	1.1 - 57.4	0.2 - 92.9	0.1 - 8.4	4.1 - 185.0
Ankle Level	35 - 1253	1.2 - 257.8	2.4 - 71.7	0.7 - 119	0.1 - 14.0	4.6 - 259.7

Figure 3-5 shows a plot of magnetic field levels at waist height as a function of frequency and time in the simulated attendant's seat (contralateral to the actual attendant's seat). As in many of the similar figures in this report, the static field has been removed and the frequency range restricted to 300 Hz to best show the characteristics of the ELF magnetic field components. Comparing this figure to Figure 3-3, which shows typical waist-high fields in a passenger seat, one immediately sees the enhancement of all field components greater than 10 Hz at the attendant's position. In general, these frequency components were the same as those found in the passenger compartments, but had higher levels by a factor of two for all ELF, but by factors of 3-5 at power frequency and harmonics.

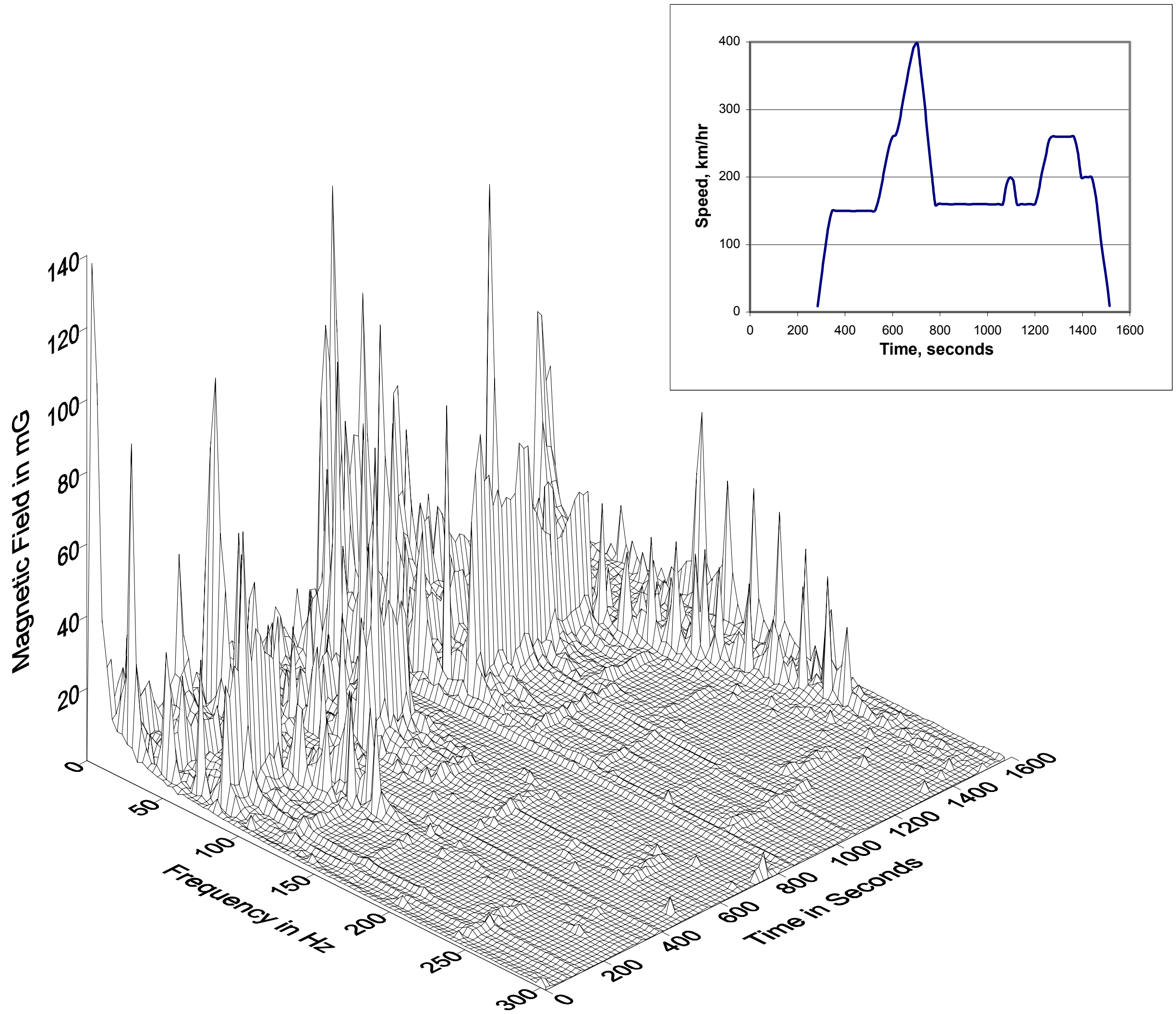


Figure 3-5. 3 to 300 Hz magnetic field levels at waist height of a seated attendant in the front compartment (location 15) as a function of frequency and time (static field is not shown and the frequency scale is expanded to show detail below 300 Hz)

Figure 3-5 also shows the presence of ELF fields at frequencies greater than 250 Hz which were not seen in the passenger compartments. Magnetic field conditions for the same location are replotted in Figure 3-6 over a wider frequency range to show the small, but detectable, field components that reached frequencies as high as 1000 Hz.

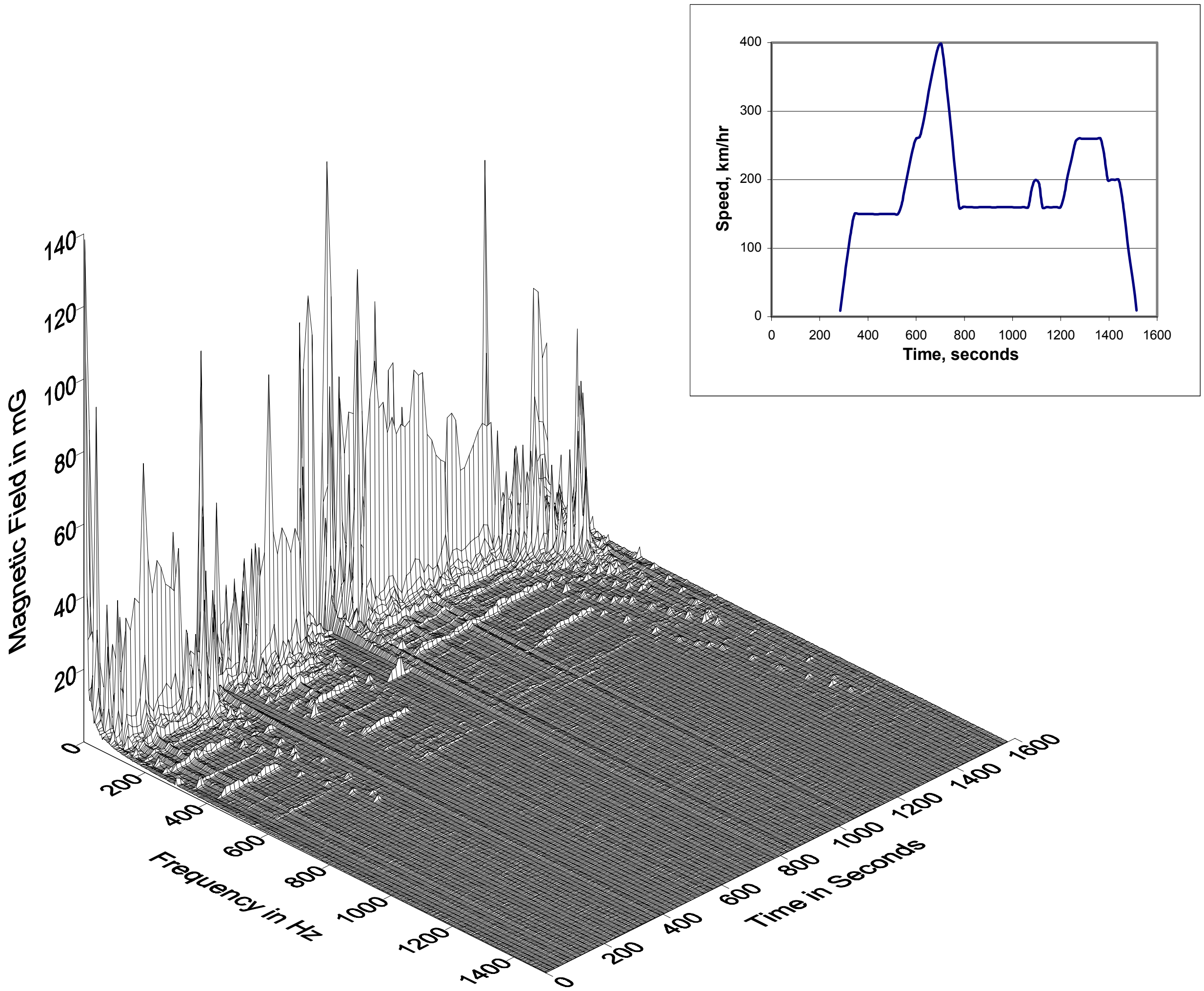


Figure 3-6. 3 to 1500 Hz magnetic field levels at waist height of a seated attendant.

3.2.5 Correlation with Speed or Guideway Current

Figure 3-7 shows a graph of ELF magnetic field levels at a passenger's waist at location 2 as a function of time. This is the same data shown in Figures 3-1 through 3-3, but plotted for individual frequency bands. At stated previously, this data is representative of magnetic field conditions throughout the passenger areas of the TR08 vehicle. The vehicle speed is also plotted on the same graph as a heavy line. While this figure again shows that the magnetic fields in the vehicle were small when the vehicle was stationary and larger when moving, there is no clear indication of a correlation between vehicle speed and the field level in any of the frequency bands.

Figure 3-8 shows the same magnetic field data but is compared to guideway current, rather than to vehicle speed. Visual inspection of that graph shows no apparent correlation between guideway current and ELF magnetic field level or the level of the magnetic field in any of the smaller frequency ranges, but there does seems to be a correlation with acceleration or deceleration rate.

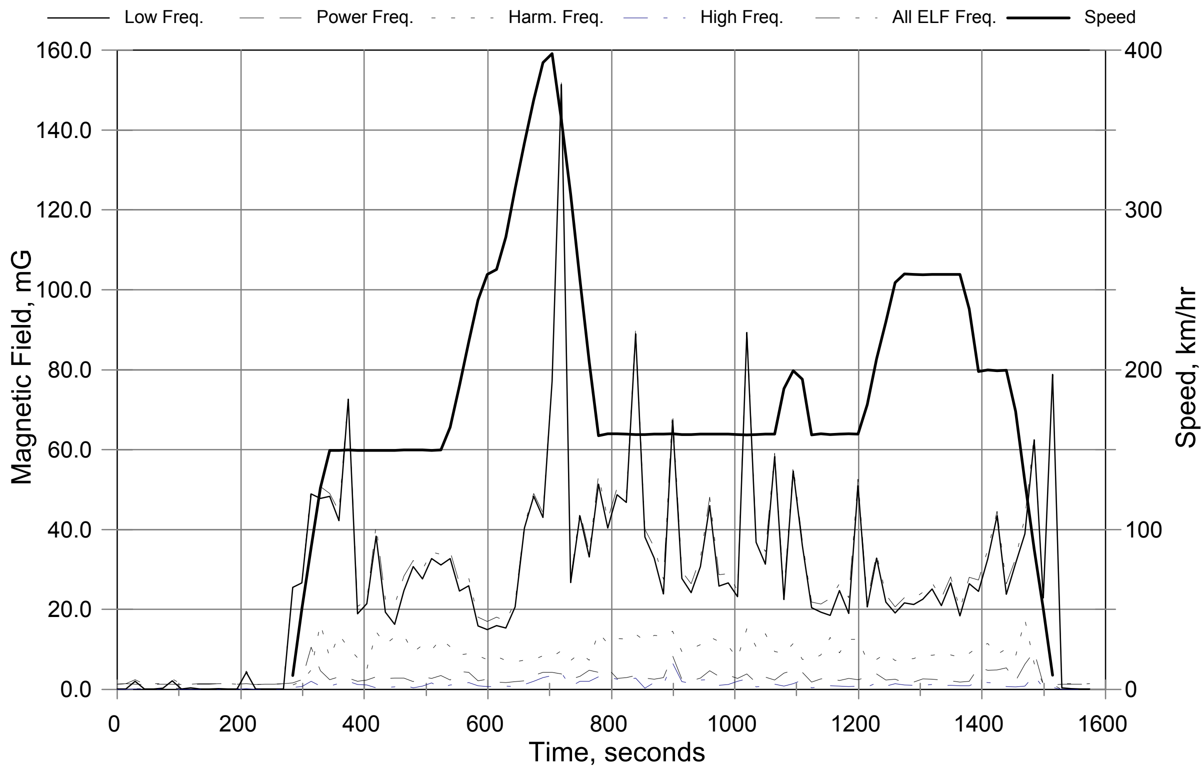


Figure 3-7. ELF magnetic field levels at the waist of a seated passenger at measurement location 2 and vehicle speed as a function of time

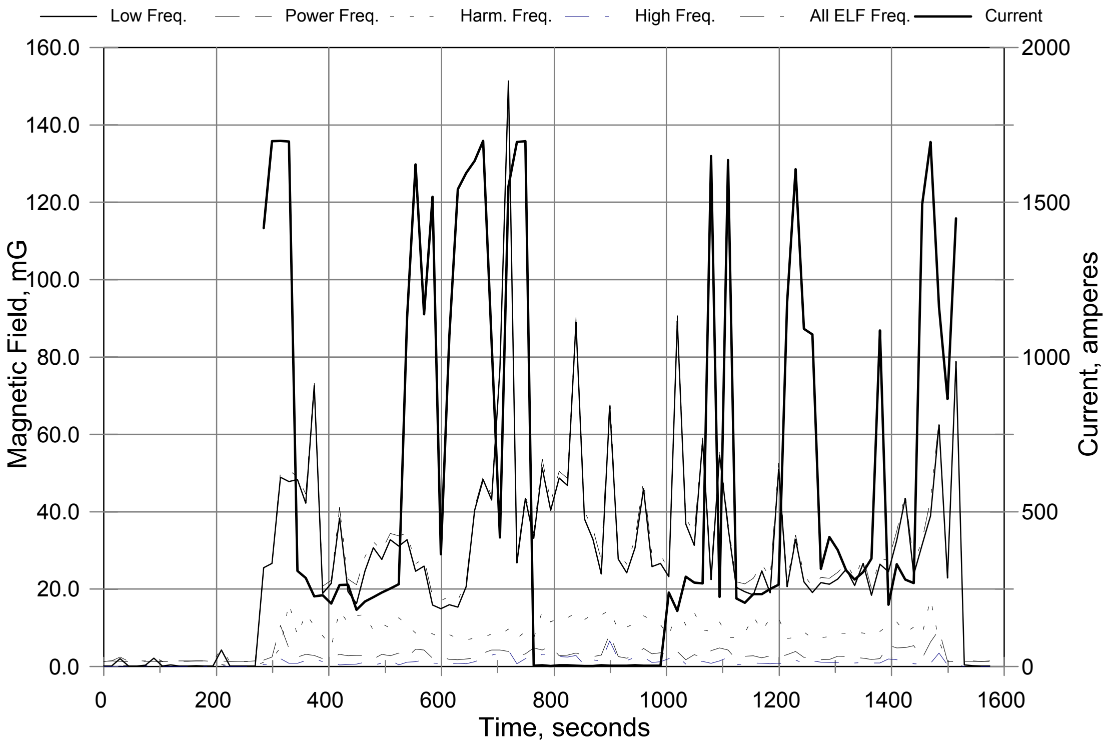


Figure 3-8. ELF magnetic field levels at the waist of a seated passenger at measurement location 2 and guideway current as a function of time.

To determine if there was any subtle correlation between magnetic field levels and speed or current, a formal mathematical correlation analysis was conducted between speed or current and magnetic field levels. This analysis was restricted to data collected while the TR08 was in motion in order to avoid confusing the results with the trivial dichotomy in field levels between the stationary and moving vehicle conditions. Correlation coefficients computed for data measured at waist height at location 2 are shown in Table 3-8 as a representative example of the correlations seen at all onboard locations. Correlation coefficients can range from -1.0 to +1.0, with -1.0 being a perfect negative correlation and +1.0 being a perfect positive correlation. A correlation coefficient of 0.0 indicates no correlation. The square of the correlation coefficient is a rough indicator of the amount of variability in one parameter accounted for by the variability in the other.

Table 3-8. Correlation Coefficients for the Relationship Between Vehicle Speed or Guideway Current and Magnetic Field at Waist Height at Measurement Location 2 in the Moving TR08

	Static Field	Low Freq	Power Freq	Harmonic Freq	High Freq	All ELF Freq
Speed	-0.01	0.05	-0.10	-0.03	0.18	0.05
Current	0.02	0.05	0.09	-0.44	-0.13	0.03

As illustrated in Table 3-8, there was no strong correlation between either speed or current and the magnetic field level. At several locations, there was a weak correlation (typically 0.15 to 0.20) between vehicle speed and magnetic field level in the high-frequency range from 300 Hz to 3 kHz. Given that a Variable Voltage-Variable Frequency (VVVF) controller enables higher speeds for higher frequency power to the electromagnets, that relationship was not unexpected.

At some locations, including location 2 for which the data in Table 3-8 apply, a weak negative correlation was observed between guideway current and field level in the power frequency harmonic band from 60 Hz to 300 Hz. The negative correlation coefficient indicates that those magnetic fields were larger when the guideway current was small, and smaller when the guideway current was large. This relationship is just the opposite of what would be expected if the guideway current was a significant magnetic field source.

The small correlation coefficients for magnetic field relationships with either vehicle speed or guideway current indicated no strong relationship. Nonetheless, the small positive correlation coefficients seen in the data from many of the measurement locations did not completely rule out a very weak correlation. As a final test to examine a possible relationship between guideway current and magnetic field levels, the magnetic field level measured in each of the frequency sub-bands was divided by the guideway current which existed at the exact time of each field sample. Field levels were normalized to current by dividing the magnitude of each field measurement sample by the corresponding current. The coefficient of variation of the resulting normalized field levels obtained at each measurement location was then compared to the coefficient of variation of the unnormalized data. In all cases, there was less relative variance in the unnormalized data indicating that guideway current was not a direct factor in static or ELF magnetic field levels or in any of the frequency sub-bands.

3.2.6 Effect of Passenger Load

During the five days of magnetic field tests on the TR08, passengers were on board the vehicle for three of the days. Typical passenger load on those days is estimated to have ranged from one-third to one-half the maximum that could be seated in a three-car consist. To determine if passenger load had a detectable effect on magnetic field levels on board the TR08, field levels measured in the empty vehicle (measurements at locations 1—initial measurement, 2, 5, 8, and 11) were compared to those measured in the vehicle carrying passengers (measurements at locations 1—repeat 3, 4, 6, 7, 9, 10, 12, 13, and 14). The average mean magnetic field levels and the average standard deviations of the measurement data, thus separated, are shown in Table 3-9. There is no evidence of increased magnetic field levels in the TR08 associated with increased passenger load. In fact, the data suggest a non-significant trend toward lower fields in the vehicle carrying passengers. This conclusion is consistent with that drawn from an examination of the measurement results for location 1 where replicate measurements were made with (repeat measurement) and without (initial measurement) passengers (see Tables 3-3 and 3-4).

Table 3-9. Static and ELF Magnetic Field Levels in Milligauss at Passenger Locations within the TR08 While in Motion With and Without Passengers Present

Measurement Height	Static Field 0 Hz	Low Freq. 2 - 48 Hz	Power Freq. 48 - 62 Hz	Harmonic Freq. 62 - 302 Hz	High Freq. 302 - 3002 Hz	All ELF Freq. 2 - 3002 Hz
	Mean ± Std Dev	Mean ± Std Dev	Mean ± Std Dev	Mean ± Std Dev	Mean ± Std Dev	Mean ± Std Dev
Summary of 5 Passenger Locations While Passengers Were Not On board						
Head Level	545 ± 78	23.0 ± 12.7	2.4 ± 1.6	9.3 ± 3.2	1.2 ± 0.6	25.6 ± 12.2
Waist Level	453 ± 90	34.9 ± 20.0	2.8 ± 1.8	8.3 ± 3.0	1.5 ± 1.0	36.3 ± 19.8
Ankle Level	800 ± 144	70.0 ± 41.6	5.6 ± 3.5	13.5 ± 5.5	3.0 ± 2.0	72.4 ± 41.3
All Levels	599 ± 104	42.6 ± 24.8	3.6 ± 2.3	10.4 ± 3.9	1.9 ± 1.2	44.7 ± 24.4
Summary of 10 Passenger Locations While Passengers Were On board						
Head Level	560 ± 82	21.3 ± 13.3	2.3 ± 1.8	7.9 ± 3.3	1.1 ± 0.6	23.5 ± 13.0
Waist Level	466 ± 108	31.5 ± 20.2	3.0 ± 2.1	8.4 ± 3.7	1.5 ± 1.1	33.3 ± 20.0
Ankle Level	709 ± 190	61.7 ± 38.7	6.4 ± 3.5	14.0 ± 6.5	2.9 ± 1.9	64.7 ± 38.5
All Levels	579 ± 126	38.2 ± 24.1	3.9 ± 2.5	10.1 ± 4.5	1.8 ± 1.2	40.5 ± 23.8

3.3 ELF ELECTRIC FIELDS

Single-axis, ELF electric field measurements were made at chest level (sensitive axis normal to the chest) at the 15 on-board measurement locations discussed above for the static and ELF magnetic field measurements. Because each electric field measurement was synchronized with a static and ELF magnetic field measurement, the system operating conditions summarized in Table 3-1 apply to the electric field measurements, as well.

The mean, standard deviation, and range of electric field levels measured at the 15 locations on board the TR08 are reported in Table 3-10. Data are presented for both stationary and moving vehicle conditions for the passenger locations, but only for the moving condition at the attendant's location.

Table 3-10. ELF Electric Field Levels Measured On Board the TR08 Vehicle (All Data)

Measurement Location	Electric Field while Stationary (V/m) # Samples	Mean ± Std Dev	Range	Electric Field while Moving (V/m) # Samples	Mean ± Std Dev	Range
Passenger Locations						
1	6	1.8 ± 0.0	1.8 - 1.8	100	2.3 ± 0.3	1.6 - 2.6
1 Repeat	2	1.9 ± 0.1	1.9 - 2.2	100	2.0 ± 0.1	1.9 - 2.5
2	20	3.1 ± 1.2	2.6 - 8.2	83	3.1 ± 0.3	2.6 - 3.5
3	5	3.7 ± 0.5	3.3 - 4.7	100	3.3 ± 0.4	2.2 - 4.1
4	2	1.9 ± 0.0	1.9 - 2.0	104	2.2 ± 1.4	1.8 - 15.9
5	7	2.8 ± 0.3	2.2 - 3.3	98	3.8 ± 8.1	2.1 - 82.5
6	1	3.2 ± 0.0	3.2 - 3.2	54	2.9 ± 0.3	2.5 - 4.9
7	3	2.0 ± 0.0	2.0 - 2.0	100	2.3 ± 0.3	1.9 - 4.7
8	2	1.9 ± 0.1	1.8 - 2.0	105	2.5 ± 4.0	1.8 - 42.9
9	3	1.8 ± 0.1	1.7 - 1.8	51	2.9 ± 5.6	1.7 - 41.3
10	7	3.8 ± 4.1	1.9 - 13.9	61	2.5 ± 1.4	1.9 - 11.1
11	1	2.6 ± 0.0	2.6 - 2.6	51	3.0 ± 1.8	2.3 - 10.6
12	7	2.7 ± 0.1	2.6 - 2.9	52	3.0 ± 0.7	2.6 - 5.7
13	8	2.7 ± 0.2	2.3 - 3.0	52	3.2 ± 1.0	2.4 - 7.6
14	10	2.1 ± 0.1	2.0 - 2.4	50	2.4 ± 0.7	1.9 - 5.5
Summary of 14 Passenger Locations						
Average	5.6	2.5 ± 0.5	2.3 - 3.7	77.4	2.8 ± 1.8	2.1 - 16.4
Extremes	1 - 20		1.7 - 13.9	50 - 105		1.6 - 82.5
Attendant Location						
15*	0			45	19.7 ± 9.6	5.7 - 41.7
Summary of All On board Locations						
Average	5.3	2.5 ± 0.5	2.3 - 3.7	75.4	3.8 ± 2.3	2.3 - 18.0
Extremes	0 - 20		1.7 - 13.9	50 - 105		1.6 - 82.5

*A data file containing data at location 15 while the TR08 was stationary was corrupted and the data were irretrievable.

As Table 3-10 indicates, electric field levels were generally very low, averaging less than 4 volts per meter in the passenger areas. Because these fields were almost always 50 Hz power-frequency fields, neither frequency spectra plots nor division of the electric field levels into frequency bands was required.

At some locations, measurement samples infrequently yielded electric field levels in the tens of volts per meter. An examination of the electric field waveforms for those atypical measurements revealed a consistent but unexpected pattern (e.g., the waveform shown in Figure 3-9. The 50 Hz sinusoidal electric field waveform is very small, not much greater than the internal noise of the electric field sensor. That part of the waveform is representative of most other measurement samples. The unexpected feature is the two clusters of four large spikes on the 50 Hz waveform. The clusters of four spikes are seen in about half of the atypical electric field waveforms. In the others, the numbers of spikes per cluster increases or the clusters become so frequent that they are almost continuous throughout the sample period. These atypical electric field waveforms occurred in small numbers (1 through 6) at 9 of the 14 passenger locations (an average of 1.8 atypical samples per measurement location). There was no spatial pattern within the vehicle to suggest that they are associated with a specific piece of equipment. Furthermore, they occurred both while the vehicle was stationary and while it was moving. At the attendants' location, these atypical electric field waveforms had the same qualitative characteristics, but occurred far more frequently. The unexplained spikes were found in half of the samples.

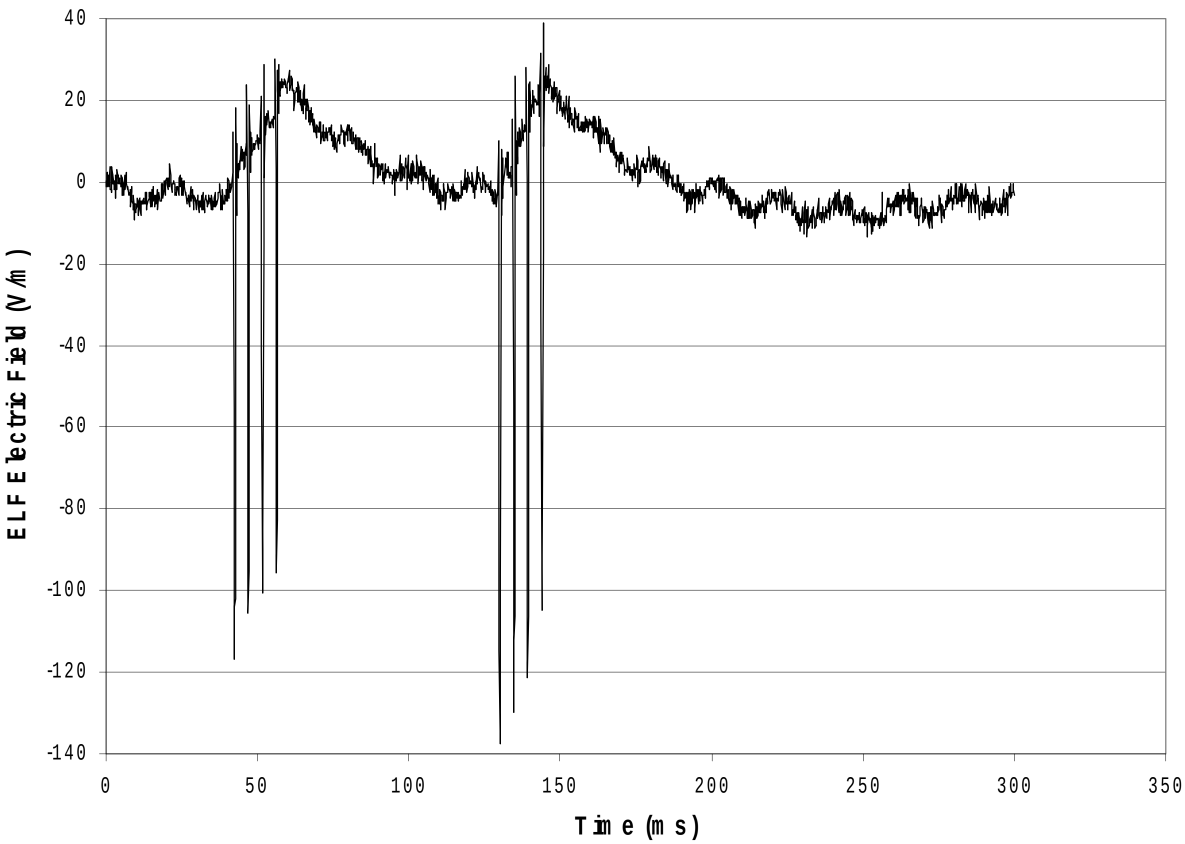


Figure 3-9. Atypical ELF electric field waveform at chest height of a seated passenger at measurement location 5

Because of the characteristics of these infrequent electric field spikes (their appearance is most often late in each measurement set, near the time the TR08 is entering the station), the high frequency of their occurrence near the attendant, and the lack of other likely sources, the authors suspect that they may represent out-of-bound interference from the two-way radios or cellular telephones used frequently by the vehicle crew. The ELF electric field sensor is known to be sensitive to interference from strong radiofrequency field sources. Table 3-11 represents the ELF electric field level summary that would result if the aberrant samples were deleted from the data set. The number of aberrant samples removed from the data at each location is also tabulated.

Table 3-11. ELF Electric Field Levels Measured On Board the TR08 Vehicle (Questionable Samples Removed)

Measurement Location	Electric Field while Stationary (V/m) # Removed	Mean ± Std Dev			Range			Electric Field while Moving (V/m) # Removed	Mean ± Std Dev			Range		
Passenger Locations														
1	0	1.8	±	0.0	1.8	-	1.8	0	2.3	±	0.3	1.6	-	2.6
1 Repeat	0	1.9	±	0.1	1.9	-	2.2	0	2.0	±	0.1	1.9	-	2.5
2	1	2.8	±	0.1	2.6	-	3.2	0	3.1	±	0.3	2.6	-	3.5
3	0	3.7	±	0.5	3.3	-	4.7	0	3.3	±	0.4	2.2	-	4.1
4	0	1.9	±	0.0	1.9	-	2.0	2	2.0	±	0.2	1.8	-	3.8
5	0	2.8	±	0.3	2.2	-	3.3	3	2.8	±	0.4	2.1	-	4.3
6	0	3.2	±	0.0	3.2	-	3.2	0	2.9	±	0.3	2.5	-	4.9
7	0	2.0	±	0.0	2.0	-	2.0	0	2.3	±	0.3	1.9	-	4.7
8	0	1.9	±	0.1	1.8	-	2.0	2	2.1	±	0.3	1.8	-	3.5
9	0	1.8	±	0.1	1.7	-	1.8	3	1.9	±	0.3	1.7	-	3.0
10	2	1.8	±	0.8	1.9	-	2.5	1	2.3	±	0.3	1.9	-	3.4
11	0	2.6	±	0.0	2.6	-	2.6	5	2.5	±	0.1	2.3	-	2.9
12	0	2.7	±	0.1	2.6	-	2.9	2	2.9	±	0.4	2.6	-	4.5
13	0	2.7	±	0.2	2.3	-	3.0	6	2.9	±	0.6	2.4	-	5.0
14	0	2.1	±	0.1	2.0	-	2.4	0	2.4	±	0.7	1.9	-	5.5
Summary of 14 Passenger Locations														
Average	0.2	2.4	±	0.2	2.3	-	2.6	1.6	2.5	±	0.3	2.1	-	3.9
Extremes	2				1.7	-	4.7	6				1.6	-	5.5
Attendant Location														
15								23	11.2	±	3.6	5.7	-	16.5
Summary of All On board Locations														
Average	0.2	2.4	±	0.2	2.3	-	2.6	2.9	3.1	±	0.5	2.3	-	4.7
Extremes	2				1.7	-	4.7	23				1.6	-	16.5

Though it is the authors' professional opinion that data in Table 3-11 more accurately represent ELF electric field levels on board the TR08 than do those in Table 3-10, this cannot be proven. Actual measured data in Table 3-10 represent an indisputable upper bound on ELF electric field levels. However, the field levels are so low in either case, there is little need to pursue the issue further.

3.4 VLF AND LF MAGNETIC FIELDS

Three-axis very low frequency (VLF, 3 kHz to 30 kHz) and low frequency (LF, 30 kHz to 300 kHz) magnetic field measurements were made at knee height at the 15 locations on board the TR08 where static and ELF magnetic fields were measured. Because each of these measurements was synchronized with a static and ELF magnetic field measurement, the system operating conditions summarized in Table 3-1 apply to the VLF and LF magnetic field measurements as well.

At none of the measurement locations did the VLF or LF magnetic field level exceed the noise threshold of those sensors (0.25 mG and 0.15 mG, respectively). This finding is consistent with the spectral analysis of the ELF magnetic field measurements, which indicated only very small and rapidly diminishing magnetic field levels at frequencies greater than 300 Hz (1000 Hz in the attendant's area).

3.5 RADIOFREQUENCY ELECTRIC FIELDS

Three-axis, radiofrequency (RF) electric fields within the TR08 were measured at head height at passenger seats contralateral to the 13 seats in which the other electric and magnetic field measurements were made. In addition, RF electric fields were also measured at three additional locations:

- Head height of a standing passenger in the rear of the lead car (location 14)
- Head height directly behind the attendant's seat in the front cabin of the lead car (location 15)
- Head height of a standing passenger in the front of the lead car just outside the door to the attendant's compartment (location 16)

The last location was selected to be as close as possible to the microwave telemetry transceiver located in the overhead above that location and the antenna located on top of the vehicle just above the transceiver.

RF electric field measurements were made with a broadband (80 MHz to 40 GHz) survey instrument that responds to the electric field component in all RF fields within its frequency range, regardless of whether they arise from the TR08 or other communications devices on board or in the area, such as, but not limited to, broadcast radio and televisions stations, walkie-talkies, cellular phones, and wireless microphones.

Table 3-12 shows the RF electric field levels on board the TR08 when the vehicle was stationary and while it was in motion. Measurements at location 10 were inadvertently recorded with the instrument in a data storage mode having limited resolution. Hence, differences between RF field levels at that location and other on board locations should be interpreted with caution.

Replicate RF field measurements were made at locations 1 and 12. The agreement between the replicate measurements was not especially good. In fact, the disparity between replicate measurements at the same location was similar to the differences in measured levels from one passenger location to another. Hence, one can not conclude that there were position-dependent differences in RF electric field levels among measurement locations 1 through 14, regardless of whether the TR08 was stationary or in motion. Furthermore, there did not appear to be a consistent difference in RF electric field levels at those 14 locations when the vehicle was moving compared to when it was stationary.

Table 3-12. Radiofrequency Electric Field Levels Measured On Board the TR08 Vehicle

Measurement Location	RF Electric Field while Stationary (V/m)							RF Electric Field while Moving (V/m)						
	# Samples	Mean ± Std Dev			Range			# Samples	Mean ± Std Dev			Range		
Passenger Locations														
1	90	1.16	±	0.22	0	-	1.54	748	1.24	±	0.56	0	-	4.64
1 Repeat	135	0.94	±	0.24	0	-	1.44	748	0.96	±	0.42	0	-	2.36
2	768	1.35	±	0.20	0	-	2.93	629	1.33	±	0.45	0	-	4.17
3	117	1.15	±	0.19	0.52	-	1.63	352	1.11	±	0.19	0	-	1.61
4	776	1.02	±	0.21	0	-	1.48	751	0.96	±	0.26	0	-	2.31
5	330	1.35	±	0.19	0	-	1.82	710	1.38	±	0.25	0	-	2.36
6	156	1.07	±	0.38	0	-	2.30	358	1.19	±	0.86	0	-	3.49
7	413	1.33	±	0.30	0	-	4.25	458	1.31	±	0.38	0	-	4.25
8	358	1.35	±	0.19	0.52	-	2.84	671	1.40	±	0.18	0.57	-	2.05
9	106	1.22	±	0.66	0	-	4.76	377	1.16	±	0.55	0	-	2.84
10	216	0.34	±	0.74	0	-	2.75	381	0.85	±	1.01	0	-	3.88
11	39	1.05	±	0.20	0.44	-	1.34	383	1.05	±	0.39	0	-	2.32
12	329	1.15	±	0.36	0	-	4.23	829	1.13	±	0.56	0	-	5.01
12 Repeat	492	1.17	±	0.95	0	-	7.45	365	1.26	±	0.78	0	-	3.86
13	157	1.24	±	0.61	0	-	6.20	368	1.16	±	0.80	0	-	4.10
14	171	1.12	±	0.43	0	-	4.52	375	1.14	±	0.86	0	-	3.84
16	83	1.37	±	0.18	1.00	-	1.76	40	1.46	±	0.34	0.67	-	2.26
Summary of 15 Passenger Locations														
Average	279	1.14	±	0.37	0.15	-	3.13	503	1.18	±	0.52	0.07	-	3.26
Extremes	39 - 776				0	-	7.45	40 – 748				0	-	5.01
Attendant Location														
15	380	1.96	±	0.23	1.44	-	2.84	877	1.98	±	0.56	0.00	-	3.63
Summary of All On board Locations														
Average	284	1.19	±	0.36	0.22	-	2.96	523	1.23	±	0.52	0.07	-	3.28
Extremes	39 - 776				0	-	7.45	40 – 877				0	-	5.01

Average RF electric field levels tended to be 20% larger at the standing head level at location 16 (directly under the telemetry transceiver) than the average of the other passenger locations. That difference might have arisen purely from chance, since fields of nearly similar amplitude were seen at location 8. There was no dramatic elevation in RF field levels close to the telemetry transceiver and antenna, locations at which elevation would be expected if those devices were the principal RF field sources.

RF electric field levels showed a statistically significant elevation in the attendant's compartment relative to the passengers' areas, but the fields were still quite small. It is not known whether the RF field elevation in this area resulted from the operator's use of his walkie-talkie and cellular telephone or whether it was an indication of RF emissions from electronic equipment within that compartment (equipment cabinet doors were open due to the failure of a cabinet cooling fan).

CHAPTER 4 FIELD CHARACTERISTICS AT THE STATION

Although safety precautions prohibit passengers and test personnel on the open, unprotected station platform at the test facility, commercial stations may have walls with closed doors protecting the waiting passengers from the moving vehicle. In that case, passengers could be in close proximity to the levitating or moving vehicle. While the walls and doors would likely provide significant shielding to electric fields, they may have only modest impact on the magnetic fields, especially if constructed with non-ferromagnetic material such as aluminum, stainless steel, glass, composites, or plastic. In order to collect worst-case data on field levels close to a moving vehicle, electric and magnetic field measurements were made on the station platform both while the TR08 passed by at high speed and while it entered the station and stopped.

4.1 MEASUREMENT CONDITIONS

As described in Chapter 2, static, extremely low frequency (ELF), very low frequency (VLF), and low frequency (LF) magnetic fields and ELF and radiofrequency (RF) electric fields were measured at two locations on the station platform. Measurements were made 1.0 m from the vehicle (the nearest location permitted) and 1.9 m from the vehicle (the most distant location possible without interference from an iron fence). Measurements were made at the distant location during four “fast” passes (two at 176 km/hr and two at 160 km/hr) and while the vehicle pulled into the station and stopped. During the measurements at the nearest location, the TR08 made only three fast passes (two at 176 km/h (110 mph) and one at 160 km/h (100 mph). During this test, the vehicle failed to stop at the station. It coasted through at 21 km/h (13 mph) and stopped a short distance down the guideway. It then reversed direction and traveled slowly back to the station. Measurements were made at the nearest (1 m (3.3 ft)) location during both the low-speed pass and the low-speed return to the station.

4.2 STATIC MAGNETIC FIELDS

The current in the guideway longstator was time-varying with little or no direct current (dc) component. Hence, the guideway should have produced no static magnetic field other than that of residual magnetism in its ferromagnetic components. There was, however, a dc “third rail” along the guideway in the vicinity of the station, used for charging the vehicle batteries when stationary or traveling at a low speed. As demonstrated in the preceding chapter, sources within the TR08 vehicle (magnetic bogies, circuits with dc current, etc.) produced static magnetic fields while the vehicle was in motion. However, when the vehicle passed the stationary measurement location at high speed, the static field of the vehicle appeared to be time-varying from the frame of reference of a person on the platform. Hence, one would have expected to see the largest effects on static magnetic fields as the vehicle slowly entered the station or perhaps while it was levitating or parked there.

The results of static magnetic field measurements on the station platform are shown in Table 4-1. Simultaneous measurements were made at heights representing the head, waist, and ankle of a standing passenger at two distances from the passing vehicle. The measurements at the two distances were not simultaneous. They were made on separate trips.

Table 4-1. Static Magnetic Field Levels Measured at the Station

Measurement	Magnetic Field 1 m From TR08 (mG)			Magnetic Field 1.9 m From TR08 (mG)		
Location	# Samples	Mean ± Std Dev	Range	# Samples	Mean ± Std Dev	Range
Head Level						
Ambient Field Levels						
TR08 Not Running	5	519 ± 0	518 - 519			
TR08 Stopped at Station				2	679 ± 3	677 - 682
TR08 Running Elsewhere	14	517 ± 2	515 - 519	10	581 ± 1	577 - 582
TR08 Passing Station						
1st Pass at 176 km/hr	4	517 ± 2	515 - 518	4	574 ± 9	561 - 581
2nd Pass at 176 km/hr	5	518 ± 2	515 - 519	4	575 ± 11	558 - 582
1st Pass at 160 km/hr	5	517 ± 2	515 - 519	4	569 ± 18	542 - 580
2nd Pass at 160 km/hr				4	580 ± 1	578 - 581
All Fast Passes	14	517 ± 2	515 - 519	16	574 ± 11	542 - 582
Pass at 21 km/hr	18	549 ± 38	484 - 606			
Stopping at the Station	16	533 ± 34	477 - 619	15	593 ± 22	559 - 633
Summary of Passes and Stop						
Average	16.0	533 ± 25	492 - 542	15.5	584 ± 16	551 - 607
Extremes	14 – 18		477 - 619	15 – 16		542 - 633
Waist Level						
Ambient Field Levels						
TR08 Not Running	5	503 ± 0	502 - 503			
TR08 Stopped at Station				1	617	617 - 617
TR08 Running Elsewhere	14	502 ± 1	501 - 504	10	556 ± 1	553 - 558
TR08 Passing Station						
1st Pass at 176 km/hr	4	502 ± 1	501 - 503	4	543 ± 17	517 - 553
2nd Pass at 176 km/hr	5	502 ± 2	501 - 504	4	546 ± 19	517 - 557
1st Pass at 160 km/hr	5	502 ± 2	500 - 504	4	541 ± 19	515 - 556
2nd Pass at 160 km/hr				4	556 ± 1	555 - 558
All Fast Passes	14	502 ± 1	500 - 504	16	546 ± 16	515 - 558

Pass at 21 km/hr	18	565	±	78	448	-	718							
Stopping at the Station	16	519	±	26	472	-	559	15	577	±	36	517	-	637
Summary of Passes and Stop														
Average	16.0	529	±	35	473	-	537	15.5	562	±	26	516	-	597
Extremes	14 – 18				448	-	718	15 - 16				515	-	637
Ankle Level														
Ambient Field Levels														
TR08 Not Running	5	452	±	0	451	-	452							
TR08 Stopped at Station								1	1065			1065	-	1065
TR08 Running Elsewhere	14	456	±	1	453	-	457	10	433	±	1	431	-	434
TR08 Passing Station														
1st Pass at 176 km/hr	4	455	±	2	453	-	456	4	421	±	17	396	-	431
2nd Pass at 176 km/hr	5	456	±	0	455	-	456	4	425	±	17	400	-	434
1st Pass at 160 km/hr	5	457	±	1	456	-	457	4	421	±	16	401	-	434
2nd Pass at 160 km/hr								4	434	±	1	433	-	435
All Fast Passes	14	456	±	1	453	-	457	16	425	±	14	396	-	435
Pass at 21 km/hr	18	612	±	186	413	-	879							
Stopping at the Station	15	519	±	79	411	-	642	15	468	±	47	406	-	539
Summary of Passes and Stop														
Average	15.7	529	±	89	426	-	532	15.5	447	±	30	401	-	487
Extremes	14 – 18				411	-	879	15 - 16				396	-	539

For each measurement height and distance, Table 4-1 contains ambient static magnetic field data for conditions when the TR08 was not operating, or when it was far from the station and had no impact on magnetic field conditions at the station. It also contains static magnetic field data for fast passes, a low-speed pass, and stopping at the station.

Ambient static field conditions were different when the TR08 was parked at the station from when it was absent. This difference was greatest at ankle height. That static field did not appear to arise from dc current in the third rail mounted on the opposite side of the guideway. At that distance, the influence would have been more similar at the three measurement heights. The field pattern suggested the source was something associated with the vehicle's magnetic bogie or under-floor equipment. Because the authors have no knowledge of which systems were active while the vehicle was parked, they are unable to suggest whether this static magnetic field arose from an active source (dc current) or from residual magnetism in a ferromagnetic component of the vehicle guidance or levitation system.

Data in Table 4-1 confirm expectations that fast passes had little impact on the ambient static magnetic field environment. Low-speed passes or pulling into the station and stopping had a modest effect on the ambient static magnetic field. This effect was small compared to the change which arose within two minutes after the vehicle was parked (the ambient condition with the train stopped).

4.3 ELF MAGNETIC FIELDS

Extreme low frequency (ELF) magnetic fields were produced by both current in the guideway longstator and the vehicle itself. The dynamics of the ELF magnetic field are well demonstrated in Figure 4-1. Plots of the guideway current and ELF magnetic field levels for the same time period are shown in Figure 4-2. From the zero time point on the figure to the three-second point, the vehicle was still in the distance, and the section of guideway longstator at the station was not energized. The only ELF magnetic field was the low ambient 50 Hz field. By 6 seconds, the section of longstator through the station was energized with a 43 Hz current. From 6 seconds until about 20 seconds, the dominant ELF magnetic field source was the longstator. As the vehicle slowed through that time period, the longstator current decreased in both amplitude and frequency, which caused the magnetic field also to decrease in magnitude and frequency. By 25 seconds into the plots, the vehicle was in the station and the magnetic field was dominated by the levitation and guidance fields of the vehicle. At this point, a new field component at approximately 300 Hz appeared from a source in the vehicle. Around 40 seconds, the vehicle stopped moving and levitating, but the onboard system producing the 300 Hz field continued to produce small fields. Beyond 50 seconds, the vehicle was parked and the ELF magnetic fields returned to ambient conditions.

The following qualitative description of the ELF magnetic fields helps interpret the quantitative data shown in Table 4-2. As shown graphically, ambient ELF magnetic field levels at the station were low and predominantly 50 Hz regardless of whether the entire system was deactivated, the vehicle was parked at the station, or the vehicle was running on a distant part of the guideway. Data in Tables 4-2 through 4-6 confirm the qualitative evaluation showing the ambient power-frequency fields to be 0.4 to 0.8 mG and the ambient field in other frequency sub-bands to be 0.1 mG or less.

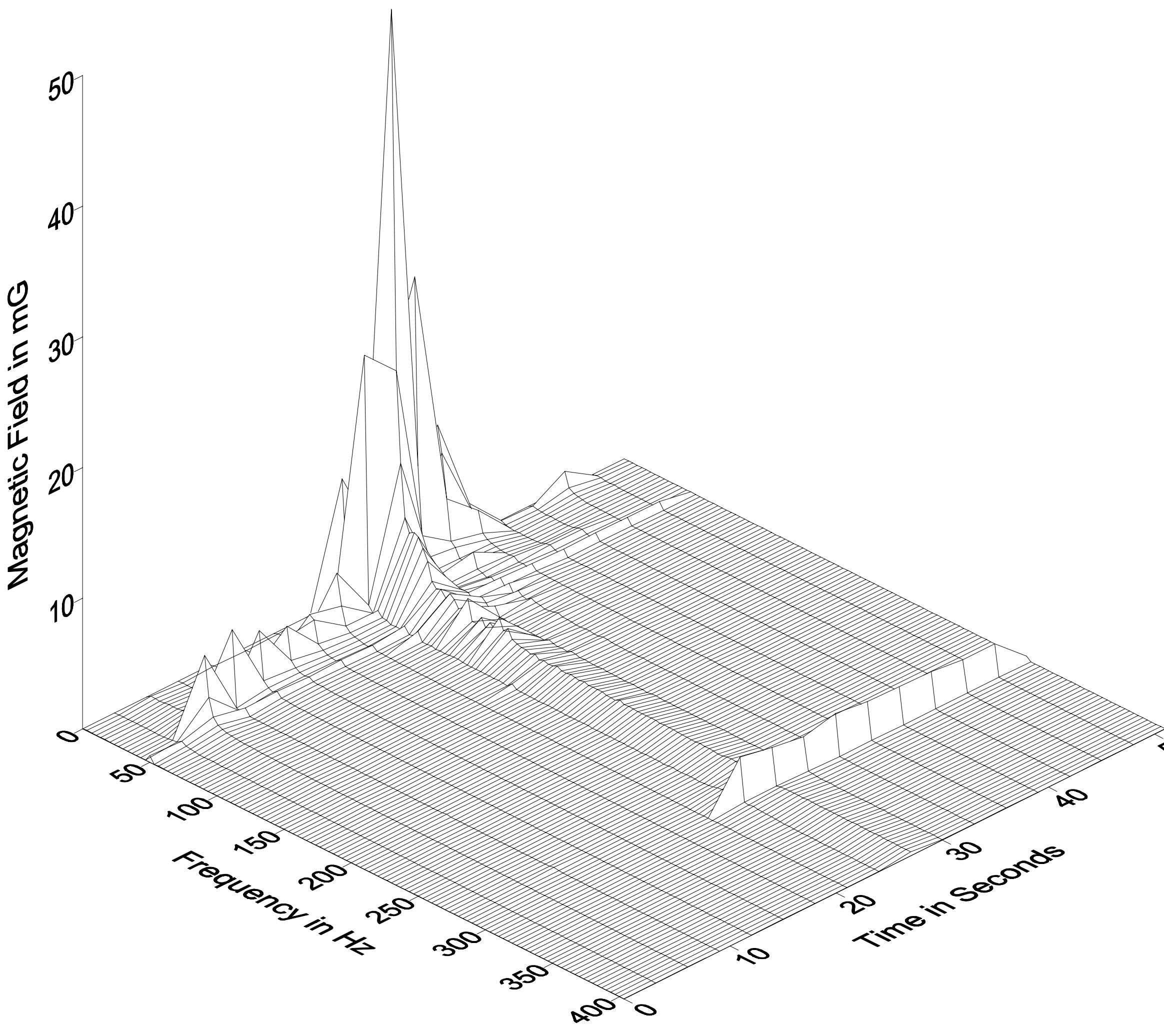


Figure 4-1. ELF magnetic field levels at waist height of a passenger standing on the station platform 1.9 m from the edge of the platform as a function of frequency and time as the vehicle entered the station (static magnetic field is not shown and the frequency scale is expanded to show detail below 400 Hz)

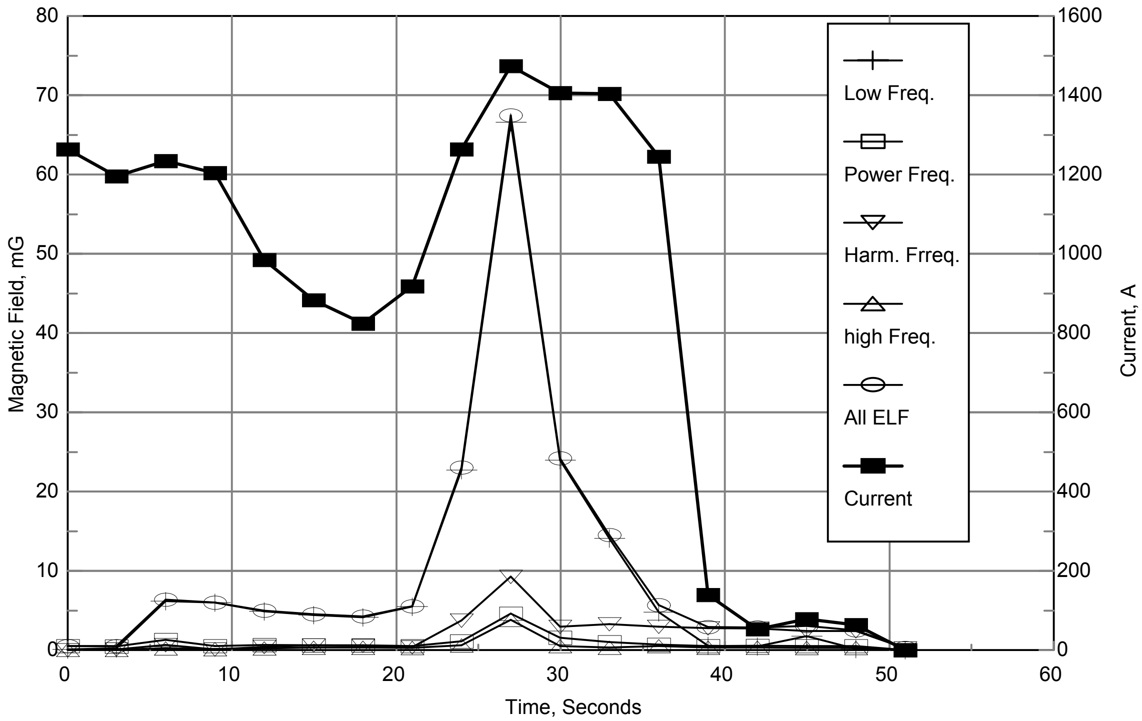


Figure 4-2. Guideway current and ELF magnetic field level and magnetic field levels by frequency band at the waist height of a standing passenger, 1.9 m from the edge of the platform, as a function of time as the vehicle entered the station; there is only a rough correlation of the guideway longstator current levels and bystander ELF/EMF exposure levels (except at peak levels)

Table 4-2. ELF (2 to 3002 Hz) Magnetic Field Levels Measured at the Station

Measurement Location	Magnetic Field 1 m From TR08 (mG)			Magnetic Field 1.9 m From TR08 (mG)		
	# Samples	Mean ± Std Dev	Range	# Samples	Mean ± Std Dev	Range
Head Level						
Ambient Field Levels						
TR08 Not Running	5	0.6 ± 0.0	0.6 - 0.6			
TR08 Stopped at Station				2	0.3 ± 0.0	0.3 - 0.3
TR08 Running Elsewhere	14	0.6 ± 0.0	0.6 - 0.6	10	0.5 ± 0.0	0.5 - 0.5
TR08 Passing Station						
1st Pass at 176 km/hr	4	2.7 ± 1.0	1.8 - 3.8	4	14.6 ± 26.3	1.2 - 54.1
2nd Pass at 176 km/hr	5	2.2 ± 1.6	1.0 - 5.0	4	13.6 ± 25.1	0.9 - 51.2
1st Pass at 160 km/hr	5	3.1 ± 2.0	1.6 - 6.5	4	9.3 ± 15.5	1.3 - 32.6
2nd Pass at 160 km/hr				4	3.4 ± 4.2	0.7 - 9.6
All Fast Passes	14	2.7 ± 1.6	1.0 - 6.5	16	10.2 ± 18.3	0.7 - 54.1
Pass at 21 km/hr	18	20.9 ± 29.3	0.6 - 116.3			
Stopping at the Station	16	24.4 ± 26.6	3.1 - 108.3	15	10.3 ± 14.5	2.1 - 57.4
Summary of Passes and Stop						
Average	16.0	16.0 ± 19.1	1.6 - 31.0	15.5	10.2 ± 16.4	1.4 - 55.7
Extremes	14 - 18		0.6 - 116.3	15 - 16		0.7 - 57.4
Waist Level						
Ambient Field Levels						
TR08 Not Running	5	0.6 ± 0.0	0.6 - 0.7			
TR08 Stopped at Station				1	0.3	0.3 - 0.3
TR08 Running Elsewhere	14	0.7 ± 0.0	0.6 - 0.7	10	0.5 ± 0.0	0.5 - 0.6
TR08 Passing Station						
1st Pass at 176 km/hr	4	3.0 ± 0.9	2.2 - 4.0	4	17.3 ± 31.0	1.6 - 63.7
2nd Pass at 176 km/hr	5	2.4 ± 1.6	1.2 - 5.1	4	16.6 ± 31.3	0.6 - 63.6
1st Pass at 160 km/hr	5	3.5 ± 1.9	1.9 - 6.8	4	15.6 ± 18.3	1.4 - 40.0
2nd Pass at 160 km/hr				4	3.5 ± 4.3	0.7 - 9.9
All Fast Passes	14	3.0 ± 1.5	1.2 - 6.8	16	13.3 ± 22.2	0.6 - 63.7
Pass at 21 km/hr	18	26.3 ± 37.7	0.6 - 148.8			
Stopping at the Station	16	30.5 ± 34.1	3.8 - 140.1	15	11.9 ± 16.9	2.5 - 67.5
Summary of Passes and Stop						
Average	16.0	19.9 ± 24.4	1.9 - 39.1	15.5	12.6 ± 19.6	1.5 - 65.6
Extremes	14 - 18		0.6 - 148.8	15 - 16		0.6 - 67.5

Ankle Level														
Ambient Field Levels														
TR08 Not Running	5	0.7	±	0.0	0.7	-	0.8							
TR08 Stopped at Station								1	4.1			4.1	-	4.1
TR08 Running Elsewhere	14	0.8	±	0.0	0.7	-	0.8	10	0.6	±	0.0	0.6	-	0.6
TR08 Passing Station														
1st Pass at 176 km/hr	4	3.8	±	0.7	3.0	-	4.5	4	22.4	±	40.4	2.0	-	82.9
2nd Pass at 176 km/hr	5	2.9	±	1.6	1.7	-	5.5	4	21.1	±	39.8	0.6	-	80.8
1st Pass at 160 km/hr	5	4.2	±	1.8	2.6	-	7.3	4	21.3	±	23.8	1.8	-	50.7
2nd Pass at 160 km/hr								4	3.9	±	4.6	0.8	-	10.8
All Fast Passes	14	3.6	±	1.5	1.7	-	7.3	16	17.2	±	28.7	0.6	-	82.9
Pass at 21 km/hr	18	40.2	±	57.1	0.7	-	211.5							
Stopping at the Station	15	43.7	±	49.2	6.4	-	204.1	15	15.6	±	23.2	4.2	-	94.1
Summary of Passes and Stop														
Average	15.7	29.2	±	35.9	2.9	-	55.2	15.5	16.4	±	26.0	2.4	-	88.5
Extremes	14 - 18				0.7	-	211.5	15 - 16				0.6	-	94.1

During fast passes, only a few (typically four) samples were collected while the section of the guideway through the station was activated. Data reported for fast passes represent the means, standard deviations, and ranges of ELF field levels during the 12 to 15 seconds that fields were above ambient levels. Because the vehicle was adjacent to the measurement instruments for only a very brief period of time during the fast passes, it became a matter of chance whether a sample was taken at the instant that the vehicle was passing the sensor. For that reason, some passes produced a sample in which the field contributions from the passing vehicle were present, and others did not. To help account for that variability, all of the data from the three or four fast passes were pooled to obtain what was hoped to be a more objective estimate of mean field level and range of field levels during fast passes. However, that goal was not achieved. None of the ELF magnetic field samples at the 1.0 m location captured the passing vehicle, while the passing vehicle was captured in three of the four passes at the 1.9 m location. For that reason, the fast pass data did not provide a reliable estimate of the rate at which fields attenuate horizontally away from the edge of the platform.

During the low-speed pass or while the vehicle was pulling into the station, several field samples were collected with the vehicle adjacent to the instruments. As a result, the mean and maximum field levels were higher than during fast passes, and the data provided a reliable indication of field attenuation rates. For example, at ankle height, doubling the distance from the edge of the platform reduced the field more than twofold. At head height, the attenuation was less steep because the change in radial distance from the source (longstator and magnetic bogie) was less. As a first order approximation, based on approximate distances to the magnetic bogie, the field attenuation rate was at least as rapid as it was inversely proportional to the distance squared. This implies that, while ELF magnetic fields might have been high for brief periods of time at the portion of the station platform very near the guideway, the field attenuated very rapidly with distance and would have been much smaller a few meters away.

Magnetic field levels in the narrower frequency bands discussed earlier are shown in Tables 4-3 through 4-6. Comparing those tables with Table 4-2 reveals that, for low-speed passes and entering and stopping at the station, most of the ELF magnetic field was in the low frequency band below 48 Hz. That was expected because, to move the vehicle at low speeds, the guideway longstator current (and field) must be of low frequency. Furthermore, the fields from the vehicle, which dominated when nearby, were concentrated in that low frequency band. During fast passes, however, the guideway longstator current must have had a higher frequency, predominantly in the power harmonic frequency band from 62 Hz to 302 Hz, but spilling over to the lower and higher frequency bands as well.

Table 4-3. Low Frequency (2 to 48 Hz) Magnetic Field Levels Measured at the Station

Measurement Location	Magnetic Field 1 m From TR08 (mG)							Magnetic Field 1.9 m From TR08 (mG)						
	# Samples	Mean ± Std Dev			Range			# Samples	Mean ± Std Dev			Range		
Head Level														
Ambient Field Levels														
TR08 Not Running	5	0.0	±	0.0	0.0	-	0.1							
TR08 Stopped at Station								2	0.0	±	0.0	0.0	-	0.1
TR08 Running Elsewhere	14	0.1	±	0.0	0.0	-	0.1	10	0.1	±	0.0	0.1	-	0.1
TR08 Passing Station														
1st Pass at 176 km/hr	4	0.4	±	0.3	0.1	-	0.7	4	6.4	±	12.5	0.1	-	25.2
2nd Pass at 176 km/hr	5	0.2	±	0.2	0.1	-	0.7	4	5.8	±	11.5	0.1	-	23.0
1st Pass at 160 km/hr	5	0.3	±	0.4	0.1	-	0.9	4	5.5	±	10.8	0.1	-	21.8
2nd Pass at 160 km/hr								4	0.5	±	0.7	0.1	-	1.5
All Fast Passes	14	0.3	±	0.3	0.1	-	0.9	16	4.6	±	9.3	0.1	-	25.2
Pass at 21 km/hr	18	20.1	±	29.5	0.2	-	116.1							
Stopping at the Station	16	23.3	±	27.2	0.1	-	107.9	15	9.6	±	14.6	0.1	-	56.6
Summary of Passes and Stop														
Average	16.0	14.6	±	19.0	0.1	-	28.4	15.5	7.1	±	12.0	0.1	-	40.9
Extremes	14 - 18				0.1	-	116.1	15 - 16				0.1	-	56.6
Waist Level														
Ambient Field Levels														
TR08 Not Running	5	0.0	±	0.0	0.0	-	0.1							
TR08 Stopped at Station								1	0.0			0.0	-	0.0
TR08 Running Elsewhere	14	0.1	±	0.0	0.0	-	0.1	10	0.1	±	0.1	0.1	-	0.3
TR08 Passing Station														
1st Pass at 176 km/hr	4	0.4	±	0.3	0.1	-	0.7	4	8.0	±	15.6	0.2	-	31.4
2nd Pass at 176 km/hr	5	0.3	±	0.2	0.1	-	0.7	4	8.2	±	16.1	0.1	-	32.4
1st Pass at 160 km/hr	5	0.3	±	0.4	0.1	-	1.0	4	12.1	±	14.8	0.1	-	30.7
2nd Pass at 160 km/hr								4	0.5	±	0.7	0.1	-	1.5
All Fast Passes	14	0.3	±	0.3	0.1	-	1.0	16	7.2	±	12.8	0.1	-	32.4
Pass at 21 km/hr	18	25.4	±	38.0	0.2	-	148.5							
Stopping at the Station	16	29.1	±	34.8	0.1	-	139.4	15	11.1	±	17.1	0.2	-	66.6
Summary of Passes and Stop														

Average	16.0	18.3	±	24.3	0.1	-	36.4	15.5	9.2	±	14.9	0.1	-	49.5
Extremes	14 - 18				0.1	-	148.5	15 - 16				0.1	-	66.6
Ankle Level														
Ambient Field Levels														
TR08 Not Running	5	0.1	±	0.0	0.0	-	0.1							
TR08 Stopped at Station								1	0.1			0.1	-	0.1
TR08 Running Elsewhere	14	0.1	±	0.0	0.0	-	0.1	10	0.1	±	0.1	0.1	-	0.3
TR08 Passing Station														
1st Pass at 176 km/hr	4	0.4	±	0.3	0.2	-	0.8	4	13.7	±	26.9	0.3	-	54.0
2nd Pass at 176 km/hr	5	0.3	±	0.2	0.1	-	0.7	4	13.2	±	26.1	0.1	-	52.3
1st Pass at 160 km/hr	5	0.4	±	0.4	0.1	-	1.0	4	19.7	±	24.0	0.1	-	49.2
2nd Pass at 160 km/hr								4	0.5	±	0.7	0.1	-	1.6
All Fast Passes	14	0.4	±	0.3	0.1	-	1.0	16	11.8	±	21.2	0.1	-	54.0
Pass at 21 km/hr	18	39.0	±	57.4	0.2	-	211.1							
Stopping at the Station	15	41.9	±	50.2	0.2	-	203.4	15	14.2	±	23.3	0.1	-	92.1
Summary of Passes and Stop														
Average	15.7	27.1	±	36.0	0.1	-	52.3	15.5	13.0	±	22.2	0.1	-	73.0
Extremes	14 - 18				0.1	-	211.1	15 - 16				0.1	-	92.1

Table 4-4. Power Frequency (48 to 62 Hz) Magnetic Field Levels Measured at the Station

Measurement Location	Magnetic Field 1 m From TR08 (mG) # Samples	Mean ± Std Dev	Range	Magnetic Field 1.9 m From TR08 (mG) # Samples	Mean ± Std Dev	Range
Head Level						
Ambient Field Levels						
TR08 Not Running	5	0.6 ± 0.0	0.6 - 0.6			
TR08 Stopped at Station				2	0.0 ± 0.0	0.0 - 0.0
TR08 Running Elsewhere	14	0.6 ± 0.0	0.6 - 0.6	10	0.5 ± 0.0	0.5 - 0.5
TR08 Passing Station						
1st Pass at 176 km/hr	4	0.6 ± 0.0	0.6 - 0.7	4	1.2 ± 1.4	0.5 - 3.2
2nd Pass at 176 km/hr	5	0.7 ± 0.1	0.6 - 0.8	4	2.1 ± 3.2	0.5 - 6.9
1st Pass at 160 km/hr	5	0.6 ± 0.0	0.6 - 0.7	4	1.6 ± 2.3	0.5 - 5.1
2nd Pass at 160 km/hr				4	0.5 ± 0.1	0.5 - 0.7
All Fast Passes	14	0.6 ± 0.1	0.6 - 0.8	16	1.4 ± 2.0	0.5 - 6.9
Pass at 21 km/hr	18	1.1 ± 0.7	0.6 - 2.9			
Stopping at the Station	16	1.3 ± 0.8	0.7 - 3.7	15	0.9 ± 0.9	0.5 - 4.0
Summary of Passes and Stop						
Average	16.0	1.0 ± 0.5	0.6 - 1.4	15.5	1.1 ± 1.4	0.5 - 5.5
Extremes	14 - 18		0.6 - 3.7	15 - 16		0.5 - 6.9
Waist Level						
Ambient Field Levels						
TR08 Not Running	5	0.6 ± 0.0	0.6 - 0.7			
TR08 Stopped at Station				1	0.0	0.0 - 0.0
TR08 Running Elsewhere	14	0.6 ± 0.0	0.6 - 0.7	10	0.5 ± 0.0	0.4 - 0.5
TR08 Passing Station						
1st Pass at 176 km/hr	4	0.7 ± 0.0	0.6 - 0.7	4	1.6 ± 2.2	0.5 - 5.0
2nd Pass at 176 km/hr	5	0.7 ± 0.1	0.6 - 0.9	4	2.5 ± 4.1	0.5 - 8.6
1st Pass at 160 km/hr	5	0.6 ± 0.0	0.6 - 0.7	4	2.5 ± 2.7	0.5 - 6.1
2nd Pass at 160 km/hr				4	0.5 ± 0.1	0.5 - 0.7
All Fast Passes	14	0.7 ± 0.1	0.6 - 0.9	16	1.8 ± 2.5	0.5 - 8.6
Pass at 21 km/hr	18	1.3 ± 1.0	0.6 - 4.1			
Stopping at the Station	16	1.6 ± 1.1	0.7 - 4.9	15	1.0 ± 1.1	0.5 - 4.6
Summary of Passes and Stop						
Average	16.0	1.2 ± 0.7	0.6 - 1.7	15.5	1.4 ± 1.8	0.5 - 6.6
Extremes	14 - 18		0.6 - 4.9	15 - 16		0.5 - 8.6
Ankle Level						
Ambient Field						

Levels														
TR08 Not Running	5	0.7	±	0.0	0.7	-	0.8							
TR08 Stopped at Station								1	0.1			0.1	-	0.1
TR08 Running Elsewhere	14	0.7	±	0.0	0.7	-	0.8	10	0.6	±	0.0	0.5	-	0.6
TR08 Passing Station														
1st Pass at 176 km/hr	4	0.8	±	0.1	0.7	-	0.9	4	1.9	±	2.5	0.5	-	5.6
2nd Pass at 176 km/hr	5	0.8	±	0.1	0.7	-	1.0	4	3.2	±	5.2	0.5	-	11.0
1st Pass at 160 km/hr	5	0.7	±	0.0	0.7	-	0.8	4	3.1	±	3.4	0.6	-	7.7
2nd Pass at 160 km/hr								4	0.6	±	0.1	0.6	-	0.8
All Fast Passes	14	0.8	±	0.1	0.7	-	1.0	16	2.2	±	3.2	0.5	-	11.0
Pass at 21 km/hr	18	2.0	±	1.7	0.7	-	5.7							
Stopping at the Station	15	2.1	±	1.6	0.7	-	7.2	15	1.4	±	2.0	0.5	-	8.5
Summary of Passes and Stop														
Average	15.7	1.6	±	1.1	0.7	-	2.3	15.5	1.8	±	2.6	0.5	-	9.8
Extremes	14 - 18				0.7	-	7.2	15 - 16				0.5	-	11.0

Table 4-5. Power Harmonic Frequency (62 to 302 Hz) Magnetic Field Levels Measured at the Station

Measurement Location	Magnetic Field 1 m From TR08 (mG)			Magnetic Field 1.9 m From TR08 (mG)		
	# Samples	Mean ± Std Dev	Range	# Samples	Mean ± Std Dev	Range
Head Level						
Ambient Field Levels						
TR08 Not Running	5	0.0 ± 0.0	0.0 - 0.0			
TR08 Stopped at Station				2	0.3 ± 0.0	0.2 - 0.3
TR08 Running Elsewhere	14	0.1 ± 0.0	0.0 - 0.2	10	0.1 ± 0.0	0.0 - 0.1
TR08 Passing Station						
1st Pass at 176 km/hr	4	2.5 ± 1.0	1.6 - 3.6	4	12.8 ± 23.2	1.0 - 47.6
2nd Pass at 176 km/hr	5	1.9 ± 1.7	0.7 - 4.8	4	11.8 ± 22.3	0.4 - 45.1
1st Pass at 160 km/hr	5	2.9 ± 2.0	1.3 - 6.3	4	6.9 ± 11.1	1.0 - 23.5
2nd Pass at 160 km/hr				4	3.1 ± 4.3	0.3 - 9.5
All Fast Passes	14	2.4 ± 1.6	0.7 - 6.3	16	8.6 ± 15.9	0.3 - 47.6
Pass at 21 km/hr	18	3.5 ± 2.5	0.0 - 8.7			
Stopping at the Station	16	3.9 ± 1.4	1.9 - 7.6	15	2.0 ± 2.0	0.1 - 8.1
Summary of Passes and Stop						
Average	16.0	3.3 ± 1.9	0.9 - 4.7	15.5	5.3 ± 8.9	0.2 - 27.9
Extremes	14 - 18		0.0 - 8.7	15 - 16		0.1 - 47.6
Waist Level						
Ambient Field Levels						
TR08 Not Running	5	0.0 ± 0.0	0.0 - 0.0			
TR08 Stopped at Station				1	0.3	0.3 - 0.3
TR08 Running Elsewhere	14	0.1 ± 0.0	0.0 - 0.2	10	0.1 ± 0.1	0.0 - 0.2
TR08 Passing Station						
1st Pass at 176 km/hr	4	2.8 ± 0.9	2.0 - 3.8	4	14.9 ± 26.8	1.3 - 55.1
2nd Pass at 176 km/hr	5	2.0 ± 1.7	0.8 - 4.9	4	13.9 ± 26.6	0.2 - 53.9
1st Pass at 160 km/hr	5	3.2 ± 2.0	1.6 - 6.6	4	9.6 ± 12.6	1.1 - 27.9
2nd Pass at 160 km/hr				4	3.2 ± 4.4	0.3 - 9.7
All Fast Passes	14	2.7 ± 1.6	0.8 - 6.6	16	10.4 ± 18.5	0.2 - 55.1
Pass at 21 km/hr	18	4.4 ± 3.3	0.0 - 11.6			
Stopping at the Station	16	4.9 ± 1.7	2.3 - 9.6	15	2.4 ± 2.3	0.1 - 9.3
Summary of Passes and Stop						

Average	16.0	4.0 ± 2.2	1.1 - 5.4	15.5	6.4 ± 10.4	0.2 - 32.2
Extremes	14 - 18		0.0 - 11.6	15 - 16		0.1 - 55.1
Ankle Level						
Ambient Field Levels						
TR08 Not Running	5	0.0 ± 0.0	0.0 - 0.0			
TR08 Stopped at Station				1	4.1	4.1 - 4.1
TR08 Running Elsewhere	14	0.1 ± 0.0	0.1 - 0.2	10	0.1 ± 0.1	0.0 - 0.2
TR08 Passing Station						
1st Pass at 176 km/hr	4	3.6 ± 0.7	2.8 - 4.2	4	16.9 ± 30.4	1.4 - 62.6
2nd Pass at 176 km/hr	5	2.5 ± 1.7	1.2 - 5.2	4	15.7 ± 29.8	0.2 - 60.4
1st Pass at 160 km/hr	5	4.0 ± 1.8	2.2 - 7.1	4	10.9 ± 14.1	1.4 - 31.4
2nd Pass at 160 km/hr				4	3.5 ± 4.8	0.4 - 10.6
All Fast Passes	14	3.3 ± 1.6	1.2 - 7.1	16	11.7 ± 20.9	0.2 - 62.6
Pass at 21 km/hr	18	6.2 ± 4.7	0.0 - 17.1			
Stopping at the Station	15	6.9 ± 2.6	3.3 - 13.7	15	3.6 ± 3.9	0.2 - 15.9
Summary of Passes and Stop						
Average	15.7	5.5 ± 3.0	1.5 - 6.8	15.5	7.7 ± 12.4	0.2 - 39.2
Extremes	14 - 18		0.0 - 17.1	15 - 16		0.2 - 62.6

Table 4-6. High Frequency (302 to 3002 Hz) Magnetic Field Levels Measured at the Station

Measurement Location	Magnetic Field 1 m From TR08 (mG)			Magnetic Field 1.9 m From TR08 (mG)		
	# Samples	Mean ± Std Dev	Range	# Samples	Mean ± Std Dev	Range
Head Level						
Ambient Field Levels						
TR08 Not Running	5	0.1 ± 0.0	0.1 - 0.1			
TR08 Stopped at Station				2	0.1 ± 0.0	0.1 - 0.1
TR08 Running Elsewhere	14	0.1 ± 0.0	0.1 - 0.1	10	0.1 ± 0.0	0.1 - 0.1
TR08 Passing Station						
1st Pass at 176 km/hr	4	0.6 ± 0.1	0.4 - 0.7	4	1.0 ± 0.8	0.6 - 2.2
2nd Pass at 176 km/hr	5	0.7 ± 0.3	0.3 - 0.9	4	1.1 ± 0.9	0.5 - 2.4
1st Pass at 160 km/hr	5	0.7 ± 0.1	0.6 - 0.8	4	1.1 ± 0.9	0.7 - 2.5
2nd Pass at 160 km/hr				4	0.7 ± 0.2	0.4 - 0.9
All Fast Passes	14	0.7 ± 0.2	0.3 - 0.9	16	1.0 ± 0.7	0.4 - 2.5
Pass at 21 km/hr	18	0.7 ± 0.7	0.1 - 2.4			
Stopping at the Station	16	0.9 ± 0.8	0.2 - 3.5	15	0.5 ± 0.8	0.2 - 3.4
Summary of Passes and Stop						
Average	16.0	0.8 ± 0.6	0.2 - 1.2	15.5	0.7 ± 0.8	0.3 - 3.0
Extremes	14 - 18		0.1 - 3.5	15 - 16		0.2 - 3.4
Waist Level						
Ambient Field Levels						
TR08 Not Running	5	0.1 ± 0.0	0.1 - 0.1			
TR08 Stopped at Station				1	0.1	0.1 - 0.1
TR08 Running Elsewhere	14	0.1 ± 0.0	0.1 - 0.1	10	0.1 ± 0.0	0.1 - 0.1
TR08 Passing Station						
1st Pass at 176 km/hr	4	0.7 ± 0.1	0.5 - 0.8	4	1.5 ± 1.7	0.6 - 4.0
2nd Pass at 176 km/hr	5	0.8 ± 0.3	0.3 - 1.1	4	1.3 ± 1.6	0.2 - 3.6
1st Pass at 160 km/hr	5	0.9 ± 0.1	0.7 - 1.0	4	1.5 ± 1.1	0.7 - 3.1
2nd Pass at 160 km/hr				4	0.7 ± 0.3	0.4 - 1.0
All Fast Passes	14	0.8 ± 0.2	0.3 - 1.1	16	1.3 ± 1.2	0.2 - 4.0
Pass at 21 km/hr	18	0.9 ± 0.9	0.1 - 3.5			
Stopping at the Station	16	1.2 ± 1.0	0.3 - 4.5	15	0.6 ± 0.9	0.2 - 3.9
Summary of Passes and Stop						
Average	16.0	1.0 ± 0.7	0.2 - 1.5	15.5	0.9 ± 1.0	0.2 - 3.9
Extremes	14 - 18		0.1 - 4.5	15 - 16		0.2 - 4.0
Ankle Level						
Ambient Field Levels						

TR08 Not Running	5	0.0	±	0.0	0.0	-	0.0							
TR08 Stopped at Station								1	0.2			0.2	-	0.2
TR08 Running Elsewhere	14	0.1	±	0.0	0.0	-	0.1	10	0.1	±	0.0	0.1	-	0.1
TR08 Passing Station														
1st Pass at 176 km/hr	4	1.0	±	0.2	0.7	-	1.1	4	1.5	±	1.4	0.8	-	3.7
2nd Pass at 176 km/hr	5	1.1	±	0.4	0.4	-	1.3	4	1.6	±	1.8	0.2	-	4.3
1st Pass at 160 km/hr	5	1.1	±	0.2	0.9	-	1.2	4	1.9	±	1.3	0.9	-	3.7
2nd Pass at 160 km/hr								4	0.9	±	0.3	0.5	-	1.1
All Fast Passes	14	1.1	±	0.3	0.4	-	1.3	16	1.5	±	1.3	0.2	-	4.3
Pass at 21 km/hr	18	1.4	±	1.5	0.0	-	4.0							
Stopping at the Station	15	1.7	±	1.5	0.5	-	6.4	15	0.9	±	1.8	0.2	-	7.3
Summary of Passes and Stop														
Average	15.7	1.4	±	1.1	0.3	-	1.9	15.5	1.2	±	1.5	0.2	-	5.8
Extremes	14 – 18				0.0	-	6.4	15 - 16				0.2	-	7.3

4.4 ELF ELECTRIC FIELDS

Any commercial station would be likely to have a physical barrier between the station platform and a moving vehicle, and any barrier would dramatically attenuate ELF electric fields. However, for completeness, ELF electric fields were measured during these tests. The single-axis sensor was mounted at chest height of a standing passenger, with the sensitive axis horizontal and pointed toward the guideway. The ELF electric field levels measured during ambient conditions, fast passes, low-speed passes, and entering the station to stop are shown on Table 4-7. Most samples indicated levels similar to the 2 V/m ambient; however, levels were measured during fast passes if a sample occurred as the vehicle passed the sensor. Those few samples never exceeded 33 V/m and, based on the recorded waveforms, resulted from rapidly-moving static charge on the passing vehicle or, more likely, the air displaced by the leading edge of the vehicle.

Table 4-7. ELF Electric Field Levels Measured at the Station

Measurement Location	Electric Field 1 m From TR08 (V/m) # Samples	Mean ± Std Dev	Range	Electric Field 1.9 m From TR08 (V/m) # Samples	Mean ± Std Dev	Range
Chest Level						
Ambient Field Levels						
TR08 Not Running	2	2.1 ± 0.3	1.9 - 2.3			
TR08 Stopped at Station				2	1.8 ± 0.1	1.7 - 1.9
TR08 Running Elsewhere	14	2.0 ± 0.2	1.9 - 2.8	10	2.5 ± 0.6	2.1 - 4.0
TR08 Passing Station						
1st Pass at 176 km/hr	4	2.2 ± 0.4	2.0 - 2.9	4	4.9 ± 5.1	2.1 - 12.6
2nd Pass at 176 km/hr	5	2.1 ± 0.1	2.0 - 2.2	4	6.8 ± 9.2	2.0 - 20.6
1st Pass at 160 km/hr	5	2.1 ± 0.2	1.9 - 2.5	4	2.6 ± 0.7	2.0 - 3.5
2nd Pass at 160 km/hr				4	2.2 ± 0.3	2.0 - 2.5
All Fast Passes	14	2.1 ± 0.3	1.9 - 2.9	16	4.1 ± 5.1	2.0 - 20.6
Pass at 21 km/hr	18	2.1 ± 0.3	1.8 - 2.9			
Stopping at the Station	16	4.4 ± 7.9	1.8 - 32.9	15	2.3 ± 0.4	1.8 - 3.2
Summary of Passes and Stop						
Average	16.0	2.9 ± 2.8	1.9 - 6.4	15.5	3.2 ± 2.7	1.9 - 11.9
Extremes	14 - 18		1.8 - 32.9	15 - 16		1.8 - 20.6

4.5 VLF AND LF MAGNETIC FIELDS

Very low frequency (VLF) and low frequency (LF) magnetic fields were measured on the station platform at knee height of a standing passenger. These measurements were made 1.0 m and 1.9 m from the edge of the platform during ambient conditions, fast passes, low-speed passes, and while the TR08 pulled into the station and stopped. In no cases were VLF or LF magnetic field levels found to exceed the internal noise floor of the sensors (0.25 and 0.15 mG, respectively).

4.6 RADIOFREQUENCY ELECTRIC FIELDS

Radiofrequency (RF) electric fields were measured at head height on the station platform using a three-axis broadband sensor covering the range from 80 MHz to 40 GHz. Measurements were made 1.0 m and 1.9 m from the edge of the platform during high and low-speed passes, while the TR08 entered the station and parked, and during ambient conditions. The vast majority of the samples indicated no measurable presence of a RF electric field. Several spikes (individual samples above the threshold of the instrument while the preceding and succeeding samples were not) occurred early during the ambient measurements, while the vehicle was still in the maintenance building. These are believed to have arisen from the fields produced by walkie-talkies or cellular phones used by observers to check the status of the system. Once that activity subsided, a very small number of spikes were recorded. Some, but certainly not all, of those spikes correlated with vehicle passes. One single sample indicating 3.0 V/m occurred during one of seven fast passes, and one single sample of 2.45 V/m occurred during the two entries into the station. No spikes were recorded during the low-speed passes. Spikes of similar magnitude (1.74 to 3.5 V/m) were recorded between passes when the vehicle was not near the station.

Based on the predominantly zero readings and the inconsistent pattern of the very small number of RF electric field readings above the instrument's threshold of sensitivity, the authors conclude that the RF electric fields on the station platform produced by the TR08's microwave telemetry system or other RF sources associated with the system were less than the sensitivity of the instrument.

CHAPTER 5 FIELD CHARACTERISTICS NEAR THE GUIDEWAY

Electric and magnetic field measurements were made near both the elevated and at-grade guideway while the TR08 passed by at high speed. Samples were taken near both the steel and concrete at-grade plates (at-grade guideway sections) as well as beneath and near steel, concrete, and hybrid elevated guideway beams. The details of measurement locations and procedures are contained in Chapter 2.

5.1 MEASUREMENT CONDITIONS

Because there was a desire to measure electric and magnetic field characteristics near a variety of guideway beam, pillar, and plate types (steel, concrete, or hybrids), the measurements were carried out at a number of locations along the guideway. As a result, identical vehicle speeds were not possible at all measurement locations. Furthermore, a variety of system operation problems resulted in atypical runs with fewer passes than planned, or passes at speeds other than planned. Furthermore, guideway current varied dramatically at several locations or among passes at the same location. All told, data were collected for 11 fast passes (295 to 399 km/hr) and two lower-speed passes (150 km/hr). The actual speed and guideway current are reported below with the ELF measurement results.

5.2 STATIC MAGNETIC FIELDS

The passing TR08 had a negligible effect on the magnitude of the static magnetic field beneath or near the guideway. At measurement locations directly beneath the elevated guideway or at 5 m from centerline of the at-grade guideway, the static magnetic field deviated 2% or less from the ambient geomagnetic field level (approximately 500 mG) that existed at that same location when the TR08 was not operating. At measurement locations more distant from the guideway, deviations from the normal static geomagnetic field level were well less than 1%.

5.3 ELF MAGNETIC FIELDS

Because of the high speed of the TR08, it was not possible to ensure that a field waveform sample was recorded exactly when the vehicle passed the sensor. Instead, the recording equipment was set to sample at three-second intervals as the vehicle approached, passed, and departed the measurement location. Inspection of the measurement data revealed that ELF magnetic fields were usually elevated above ambient during only one of the samples. During the sample three seconds earlier or the sample three seconds later, ELF magnetic field levels were insignificant compared to the peak measured while the vehicle was close to the sensors. During only three of the 13 passes were the ELF magnetic fields elevated for two successive samples. The temporal characteristic of the ELF magnetic fields indicated that the ELF magnetic fields arose from the vehicle, not the guideway. The following analysis focused on the characteristics of the one sample ELF field burst that occurred as the vehicle passed the sensors. ELF magnetic fields were so low during the samples preceding or succeeding that burst that they did not warrant analysis and reporting. Stated another way, there was no reason to average magnetic field levels over several samples because doing so would only obscure the characteristics of the single burst.

Figure 5-1 shows ELF magnetic field levels measured adjacent to the steel and concrete at-grade guideway plates as the TR08 passed by. Magnetic field samples were recorded exactly as the vehicle was passing during four of the five passes. The fifth measurement missed the exact instant of the vehicle pass by approximately one second. Magnetic field levels were similar for both the steel and concrete guideway plates.

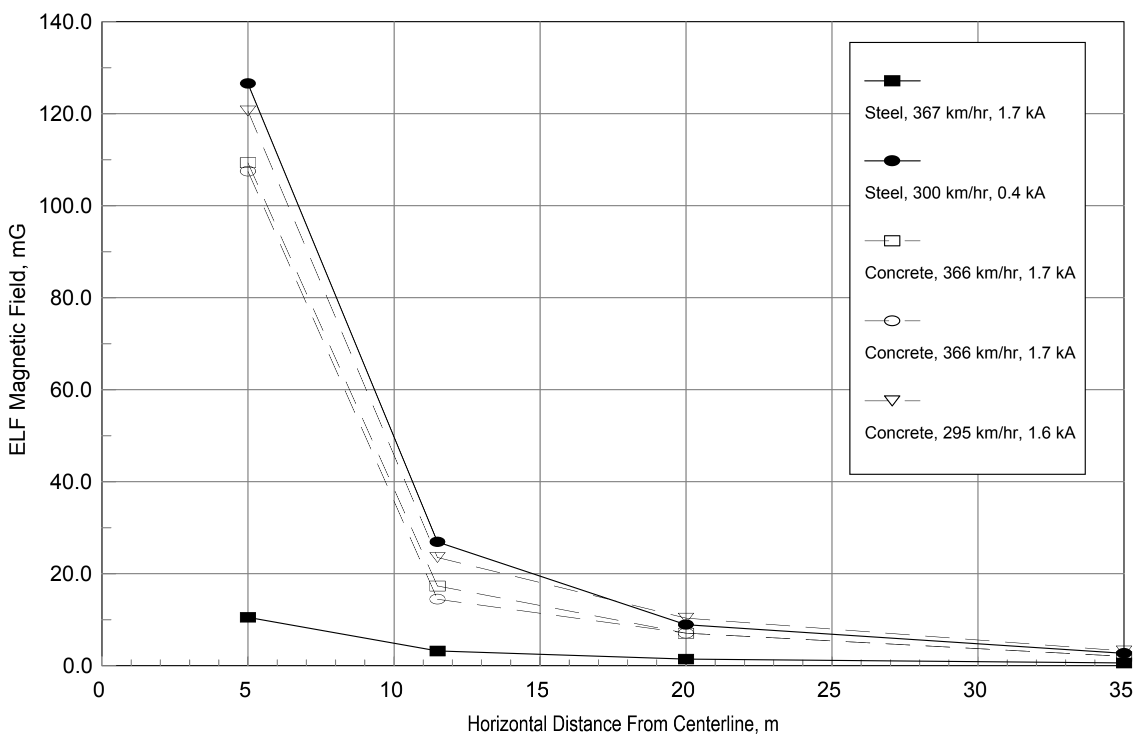


Figure 5-1. ELF magnetic field levels at incremental distances from centerline of the at-grade guideway during vehicle passes

To better illustrate the attenuation characteristics of the ELF magnetic field with distance from the guideway, the data contained in Figure 5-1 are replotted using logarithmic scales in Figure 5-2. Plotting magnetic field data in such a way tends to make the curves linear on the graph and helps quantify the rate of attenuation. Inspection of the figure indicates that the curves are indeed straight lines on the logarithmic graph. To help assess the attenuation rates of the measured fields, two straight lines with different slopes are also plotted on Figure 5-2. The steeper line represents an attenuation rate inversely proportional to the distance squared ($1/d^2$). The flatter curve represents a fall-off rate inversely proportional to the distance from the guideway (1/d). Note that the four sets of data gathered while the vehicle was directly abreast of the sensor indicate an attenuation rate of $1/d^2$. For the fifth set of data, the apparent attenuation rate is not as great. That was expected because, in this case, the distance to the guideway was not the same as the distance to the vehicle. With the vehicle further down the guideway, the relative difference in distance from the source (the vehicle) to the near or far measurement locations was not as great as if the vehicle was abreast of the sensors.

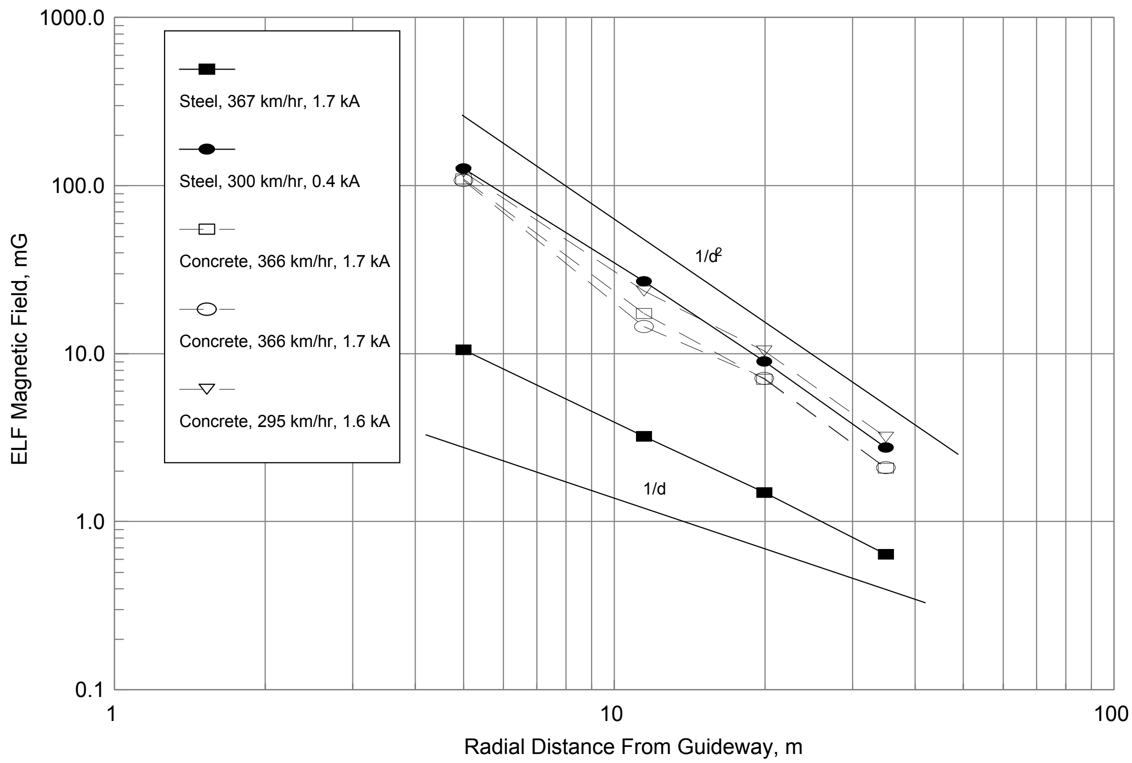


Figure 5-2. ELF magnetic field levels at incremental distances from centerline of the at-grade guideway (logarithmic scales)

The frequency spectrum of the ELF magnetic field burst caused by the passing vehicle was complex, but most of the energy was in the component associated with guideway longstator current. That field component fell within the 62 to 302 Hz frequency range, which is identified in this report as the power harmonics band. ELF magnetic field levels in that frequency range are plotted in Figure 5-3.

Because these field components are the dominant magnetic fields in the entire ELF band, Figure 5-3 closely resembles Figure 5-2.

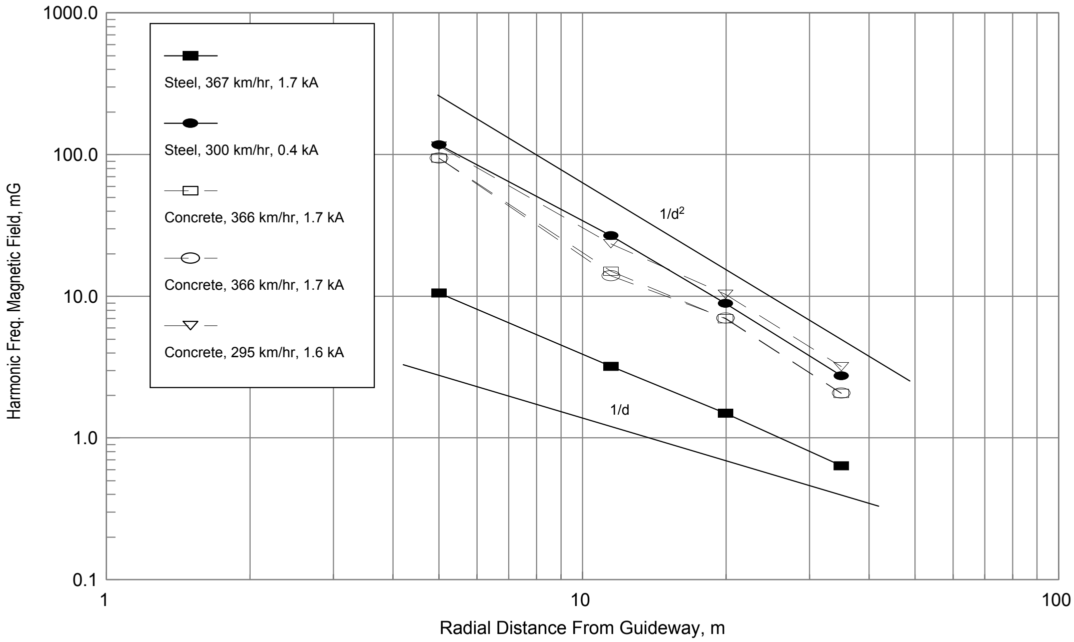


Figure 5-3. Magnetic field levels in the power harmonic frequency band (62 Hz to 302 Hz) at incremental distances from centerline of the at-grade guideway (logarithmic scales)

Magnetic fields in the low frequency band (2-48 Hz) were smaller than those in the harmonic frequency band, but not negligible. They are plotted in Figure 5-4. Note that when the TR08 was directly abreast of the field sensors, the low frequency field data demonstrated a more rapid attenuation pattern inversely proportional to the cube of the distance ($1/d^3$), typical of “magnetic dipole,” or compact, sources, and indicative of a localized source (probably the nearest electromagnets).

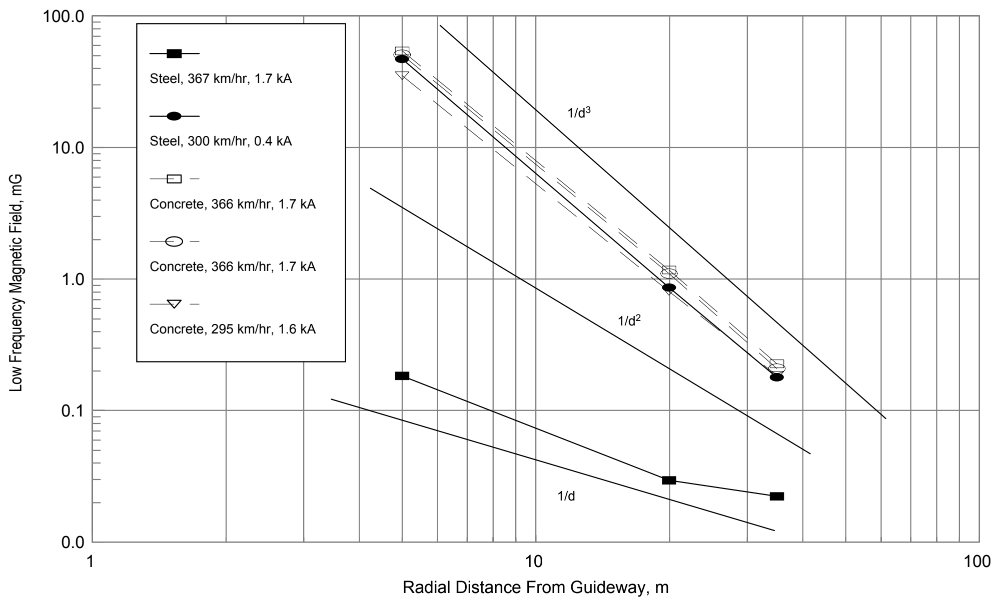


Figure 5-4. Magnetic field levels in the low-frequency band (2 Hz to 48 Hz) at incremental distances from centerline of the at-grade guideway (logarithmic scales)

The legends on Figures 5-1 through 5-4 contain information about the vehicle speed and guideway current at the time of the passby. It is important to note that all of the magnetic field levels and attenuation rates measured when the vehicle was abreast of the sensors cluster into a tight pattern, even though one guideway plate was steel and the other was concrete. Vehicle speeds ranged from 295 to 367 km/hr and guideway current ranged from 0.4 to 1.7 kA. These observations further support the conclusion that the vehicle was the dominant magnetic field source, and the guideway itself produced little magnetic field at the distances involved. (The guideway magnetic field should theoretically attenuate extremely rapidly).

Because of the tight clustering of the data from four sets of measurements near the at-grade guideway, they are averaged in Figure 5-1 to produce a summary of field levels near the at-grade guideway the instant the TR08 passed. Both average and maximum field levels are given at all four distances for fields in the total ELF frequency band (2 to 3002 Hz) and each of its smaller sub-bands. For completeness, data are given for the one passby where the vehicle was not adjacent to the sensor at the time of the sample.

From the quantitative information in Table 5-1 and the preceding discussion of attenuation rates, one can generate generalized equations to estimate the expected magnetic field levels at various distances from the TR08.

For the entire ELF frequency range, the field falls off rapidly with the inverse square of distance. Thus:

$$B \cong 2900/d^2$$

where: B is the magnetic field in mG and
d is the distance to the center of the guideway in meters.

For the fields in the harmonic frequency range:

$$B \cong 2600/d^2$$

For the fields in the low frequency range:

$$B \cong 5900/d^3$$

Table 5-1. Summary of Maximum ELF Magnetic Field Levels in Milligauss at Various Distances from Centerline of the At-Grade Guideway During Fast Passes of the TR08

Frequency Range	Number Of Passes	5 m From Centerline		11.5 m From Centerline		20 m From Centerline		35 m From Centerline	
		Average	Maximum	Average	Maximum	Average	Maximum	Average	Maximum
TR08 Adjacent to Sensors									
All ELF	4	116.02	126.61	20.59	26.92	8.38	10.36	2.53	3.19
Low	4	46.81	54.35			0.98	1.17	0.20	0.23
Power	4	2.81	3.75	0.94	1.99	0.19	0.25	0.07	0.08
Harmonic	4	105.24	117.16	19.82	26.83	8.29	10.31	2.52	3.18
High	4	8.90	9.46	1.64	1.86	0.60	0.63	0.16	0.19
Speed, km/hr		331.95	366.43						
Current, kA		1.35	1.70						
TR08 Not Adjacent to Sensors									
All ELF	1	10.56		3.22		1.49		0.64	
Low	1	0.18				0.03		0.02	
Power	1	0.14		0.06		0.03		0.02	
Harmonic	1	10.55		3.21		1.49		0.64	
High	1	0.50		0.15		0.08		0.05	
Speed, km/hr		366.51							
Current, kA		1.70							

ELF magnetic field measurements beneath the elevated guideway were not as successful as those near the at-grade guideway. Data were collected while the vehicle was abreast of the sensors during only one of the eight passbys. During a second passby, the vehicle was present part, but not all, of the time (0.3 seconds) required to collect the waveform sample. Consequently, the data in Figure 5-5 and in Table 5-2 show high ELF magnetic field levels beneath and near the elevated guideway for only one passby on the steel guideway. Data from the passby where the TR08 was abreast of the sensors for only half of the sample duration are not included on the table because they do not fit properly in either category.

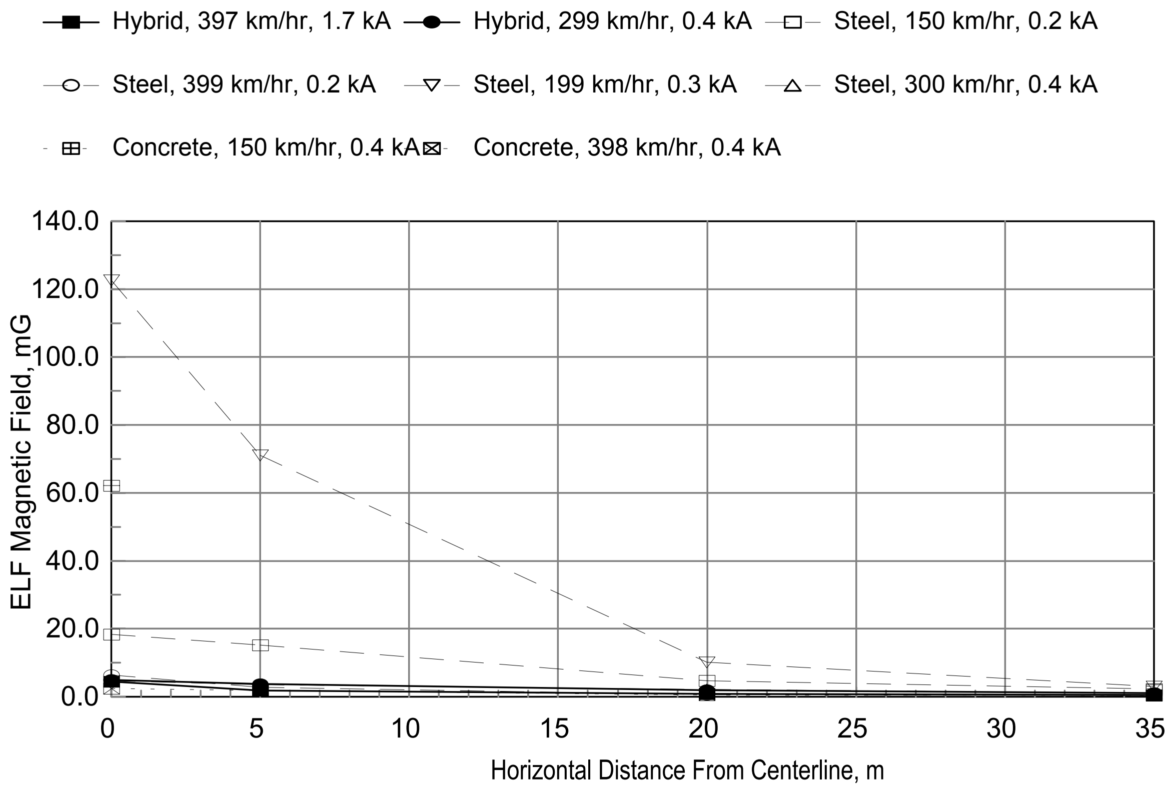


Figure 5-5. ELF magnetic field levels at incremental distances from centerline of the elevated guideway during vehicle passes

Table 5-2. Summary of Maximum ELF Magnetic Field Levels in Milligauss at Various Distances from Centerline of the Elevated Guideway During Fast Passes of the TR08

Frequency Range	Number of Passes	At Centerline		5 m From Centerline		20 m From Centerline		35 m From Centerline	
		Average	Maximum	Average	Maximum	Average	Maximum	Average	Maximum
TR08 Adjacent to Sensors									
All ELF	1	122.66		71.12		10.17		3.07	
Low	1	9.46		4.83		0.32		0.12	
Power	1	13.54		8.04		1.72		0.59	
Harmonic	1	120.49		69.93		9.98		3.00	
High	1	16.01		8.90		0.87		0.19	
Speed, km/hr		199.31							
Current, kA		0.34							
TR08 Not Adjacent to Sensors									
All ELF	6	6.94	18.43	4.94	15.22	1.88	4.79	0.99	2.36
Low	6	0.85	2.97	0.74	2.59	0.28	1.01	0.16	0.63
Power	6	0.33	1.06	0.34	0.79	0.16	0.39	0.10	0.20
Harmonic	6	6.80	17.93	4.81	14.84	1.83	4.65	0.96	2.27
High	6	0.97	2.85	0.67	2.02	0.18	0.47	0.08	0.13
Speed, km/hr		323.91	399.21						
Current, kA		0.56	1.75						

Because the guideway was elevated, one can not simply replot the data from Figure 5-5 on logarithmic scales to examine the field attenuation as a function of distance from the field source. The slope distance from the measurement points to the magnetic field source (approximated by the center of the guideway at the elevation of the longstator packs) must first be calculated and used as the horizontal axis. Doing so yields Figure 5-6. As at the at-grade guideway, the data collected when the vehicle was adjacent to the sensors show a $1/d^2$ attenuation rate when the distance was the radial (slope) distance from the center of the actual guideway to the measurement sensor. Furthermore, the magnitude of the ELF fields beneath the elevated steel guideway fell within the cluster of data from measurements near the at-grade guideway when compared at similar radial distances from the guideway center.

ELF magnetic fields measured beneath the elevated concrete guideway had a similar attenuation pattern, but at lower levels, because the vehicle was abreast of the sensors for only part of the measurement. Data from other passes showed varying attenuation rates, depending upon the actual position of the vehicle at the exact time of the measurement.

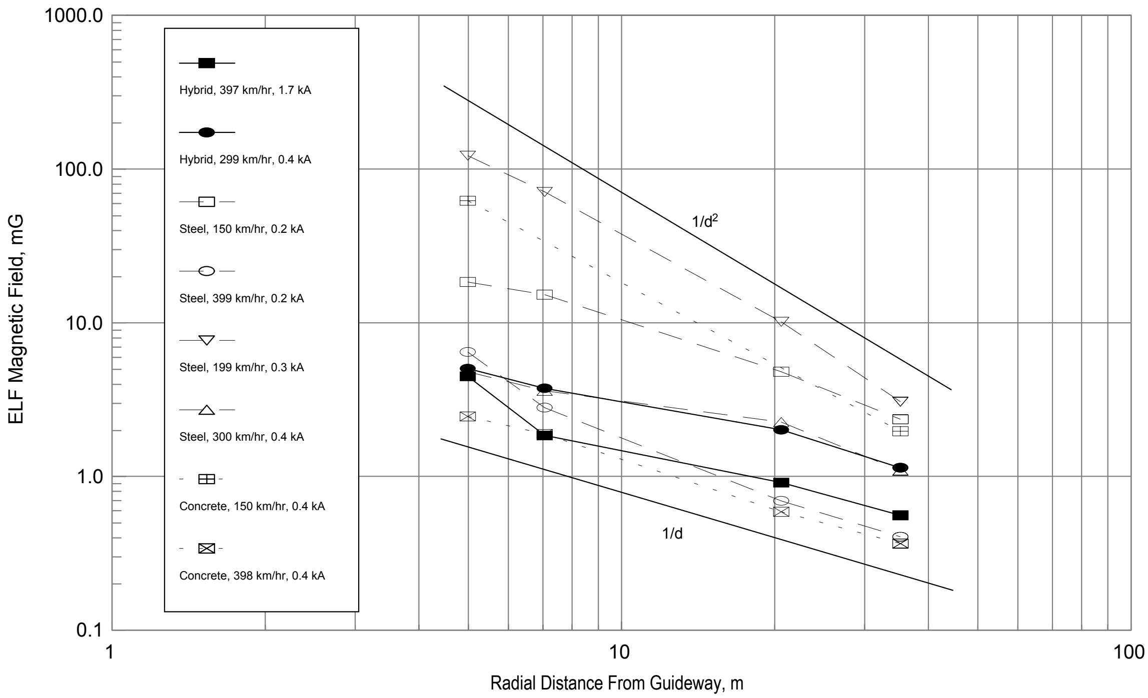


Figure 5-6. ELF magnetic field levels at incremental distances from centerline of the elevated guideway (logarithmic scales)

Figures 5-7 and 5-8 show magnetic field levels in the harmonic frequency and low-frequency portions of the ELF band, respectively. The harmonic frequency data on Figure 5-7 for the one pass where the TR08 was directly abreast of the sensors at the time of the sample is also consistent with the harmonic frequency band data measured at the at-grade plates when the vehicle was similarly placed. The low-frequency fields, however, do not match those seen at the at-grade guideway.

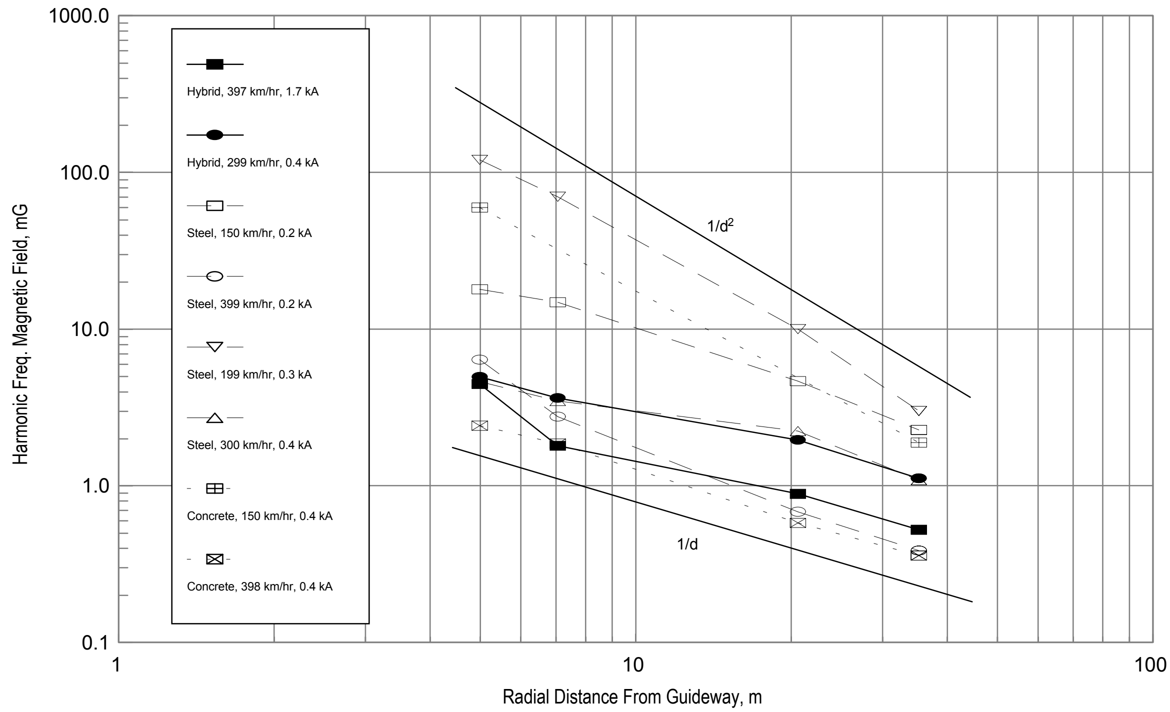


Figure 5-7. Magnetic field levels in the power harmonic frequency band (62 Hz to 302 Hz) at incremental distances from centerline of the elevated guideway (logarithmic scales)

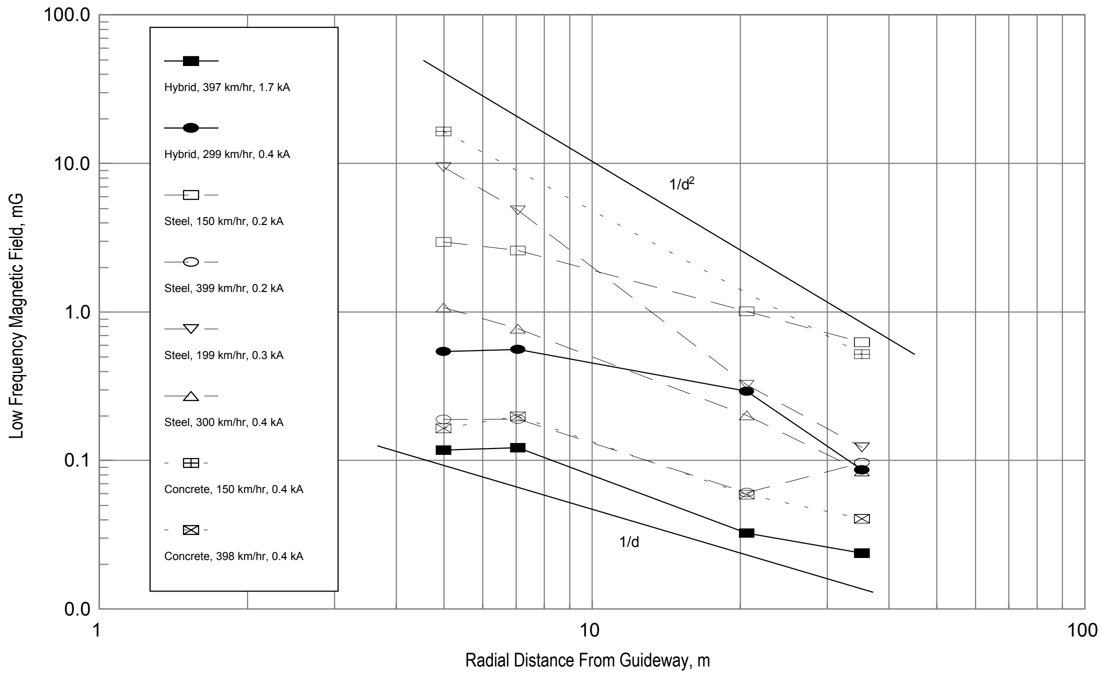


Figure 5-8. Magnetic field levels in the low-frequency band (2 Hz to 48 Hz) at incremental distances from centerline of the elevated guideway (logarithmic scales)

Data collected when the TR08 was not abreast of the magnetic field sensors were flawed and of little value because it missed the peak of the magnetic field burst of the passing vehicle. A regression analysis was run between these reduced fields and current to see if any correlation existed. Such a correlation would indicate that longstator current was a detectable field source when the vehicle was not immediately present. No positive correlation was found between current and ELF field or fields in any sub-bands.

Unfortunately, the failure to obtain magnetic field samples beneath or near the elevated guideway at the instant the TR08 passed prevented a systematic evaluation of any possible effect of guideway construction on nearby magnetic field levels. However, the measurements near the guideway provided persuasive evidence that it was the passing vehicle, not the guideway itself, that was the important ELF magnetic field source. Thus, the guideway construction or material should not be expected to significantly change the ELF magnetic fields.

The consistency between ELF and harmonic frequency magnetic field levels and attenuation rates seen in the one measurement near the elevated steel guideway and the cluster of data measured near the at-grade guideway indicated that those field components were independent of guideway type. Hence, the equations given above for estimating approximate ELF and harmonic frequency magnetic fields near the guideway are universal, provided that the distance parameter is the radial distance from the center of the guideway to the measurement location.

The above equation for low-frequency field levels was not consistent with measurements near the elevated steel guideway, even though it was consistent with four measurements on at-grade steel and concrete guideway plates. This anomaly may be simple random variability, the result of different guidance field requirements on a curve (at-grade locations) versus a straightaway (elevated steel guideway location), or some other unknown factor.

5.4 ELF ELECTRIC FIELDS

Concurrent with the ELF magnetic field measurements near the guideway, vertical ELF electric fields were measured 11.5 m from centerline of the at-grade guideway (outside the exclusion fence) or beneath the elevated guideway. During ten passes, electric field levels did not deviate from their small background levels (less than 2 V/m). During two other passes, the sensor was inoperable due to rain. In only one instance beneath the elevated steel guideway was there a small rise in ELF electric field levels from 1.7 V/m to 3.3 V/m as the TR08 passed overhead. This electric field was trivial, and, based on the waveform characteristics, probably unrelated to the passing of the TR08.

5.5 VLF AND LF MAGNETIC FIELDS

VLF and LF magnetic fields were measured 11.5 m from the at-grade guideway (outside the exclusion fence) or beneath the elevated guideway concurrent with the ELF magnetic field measurements. No field levels were detected in either the VLF or LF bands above the noise floor of the instruments (0.25 and 0.15 mG, respectively) during vehicle passes.

5.6 RADIOFREQUENCY ELECTRIC FIELDS

Radiofrequency (RF) electric field measurements were attempted near the at-grade guideway and beneath the elevated guideway. Unfortunately, rain during the setup for the first measurements saturated the sensor and resulted in spurious, inaccurate measurements throughout the day until the sensor could be thoroughly dried overnight. As a result, credible RF electric field data were only collected under the elevated concrete guideway beam where measurements were made on another day. No RF electric fields above the sensitivity of the instrument were detected during two passes of the TR08.

CHAPTER 6 FIELD CHARACTERISTICS NEAR THE SWITCHING CABINETS

Aside from the vehicle, guideway, and station, the only other TR08 Maglev System components accessible to the general public and that represented potential magnetic or electric field sources were the electrical switching cabinets along the guideway. At the test facility, those cabinets were installed at periodic locations directly beneath the elevated guideway. Electric power from the inverter stations was fed by cable to these cabinets, and from there routed to the various sections of the guideway longstator to power the vehicle as it passed by. Because power was routed to longstator sections in a leapfrog manner to energize only the section of the guideway where the vehicle was traveling, plus the section it had just left or the one that it was about to enter, each switching cabinet functioned primarily when the vehicle was in the vicinity of that cabinet. Electric and magnetic field measurements were made in the vicinity of the switching cabinets while the TR08 vehicle operated in the area controlled by the cabinet.

6.1 MEASUREMENT CONDITIONS

Two types of electric switching cabinets existed along the guideway. Most were of a type designed and installed with the guideway, referred to herein as standard switching cabinets. Electric and magnetic fields measurements were made around a standard switching cabinet beneath guideway beam 234. A newer cabinet was designed for the previously proposed Berlin to Hamburg line and a cabinet of that new design was installed beneath guideway beam 184. That cabinet represented a design more typical of what would be built today for a commercial installation. Hence, measurements were also made around this new cabinet.

Because the switching cabinets were located beneath the guideway, it was necessary to separate the field emissions of the vehicle and guideway from those of the switching cabinet. To facilitate that process, field sensor placement was similar to that used to measure fields at other locations near the guideway. Static and extremely low frequency (ELF) magnetic field sensors were placed at 5, 20, and 35 m from centerline of the guideway and cabinet along a line perpendicular to the guideway and passed through the center of the switching cabinet. Those sensors duplicated the position of three of the four sensors used to measure field attenuation away from the guideway. Since the cabinets were 3 m wide, the first sensor was 3.5 m from the face of the cabinet. For the guideway measurements, the fourth sensor was placed at centerline of the guideway and in line with the other three sensors. For these measurements around the switching cabinets, that sensor was placed along the guideway centerline at a point 3.5 m from the end of the switching cabinet.

Very low frequency (VLF) and low frequency (LF) magnetic field sensors and ELF electric field sensors were placed along the centerline of the guideway just beyond the static and ELF magnetic field sensor. The radiofrequency (RF) electric field sensor was placed 5 m east of centerline (3.5 m from the face of the cabinet) near the first static and ELF magnetic field profile sensor. Position of all sensors is shown in more detail in Chapter 2 of this report.

Five sets of measurements were collected near the switching cabinets. They consisted of two sets during vehicle passes at the standard switching cabinet and three passes at the new cabinet. Although the test plan called for standard repeatable vehicle speed profiles during all trips, operational problems at the test site prevented them. That problem, together with the differences in at-speed profiles at the two sites resulting from their differing locations, and missed passes due to equipment setup times, caused the vehicle speed and guideway current conditions to be quite different during the five sets of measurements. Actual speed and current conditions for the five data sets are reported along with the ELF magnetic field data in Section 7.3.

6.2 STATIC MAGNETIC FIELDS

The electrical switching cabinets had no material effect on the static magnetic field environment in their vicinity other than the perturbations to the static geomagnetic fields caused by the iron and steel components of the cabinets and their contents. At none of the measurement locations did the static magnetic field of the operating cabinets deviate more than 1% from ambient levels existing when the cabinets were not energized.

6.3 ELF MAGNETIC FIELD

ELF magnetic field levels as a function of time at various distances from the new switching cabinet during the second measurement sequence at that site are shown in Figure 6-1. Field levels collected at the instant the TR08 passed the field sensors were deleted from the figure because they were believed to have resulted, in part, from the passing vehicle. The first data point at the left of the graph shows ambient ELF magnetic field levels that existed 1.5 minutes earlier, when the guideway was not energized. Guideway current is also plotted on this graph. Over the time period indicated, the vehicle accelerated from 45 km/hr to 150 km/hr.

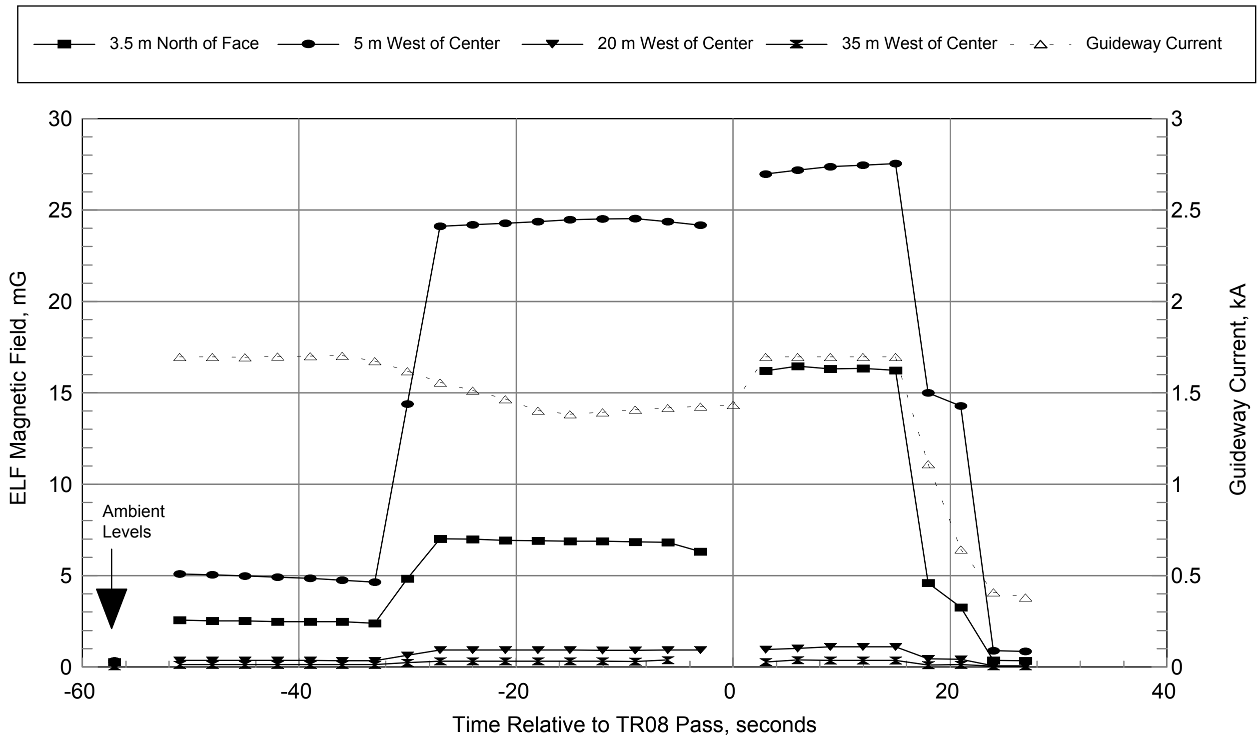


Figure 6-1. ELF magnetic field levels at four locations near the new switching cabinet while it is active before and after the TR08 passes by at 120 km/hr (linear scale)

Examination of Figure 6-1 demonstrates that magnetic field levels change abruptly at times not accounted for by changes in current. This represents changes in magnetic field characteristics associated with operation of the switches within the cabinet. To better demonstrate the characteristics of the field levels, especially at the more distant measurement locations where the fields are smaller, data from Figure 6-1 are replotted in Figure 6-2 using logarithmic vertical scales. The benefit of doing so is that curves that differ by a fixed proportion (e.g., one is always a constant factor larger or smaller than the other) appear on a logarithmic scale as similar curves displaced up or down from one another. Figure 6-2 shows that similar displacement to be the case for the three measurements made at incremental distances to the east of the switching cabinet. Hence, at all three locations, the fields came from the same configuration of sources within the cabinet. The ELF magnetic fields were lower 3.5 m to the north of the cabiner than they were at a similar distance to the east of the face of the cabinet, and had a somewhat different temporal pattern. That was not surprising because equipment and buswork sources such as those likely to exist in the cabinet were generally not omnidirectional. This observation confirms that the magnetic fields reported in the figure arose from the switching cabinet.

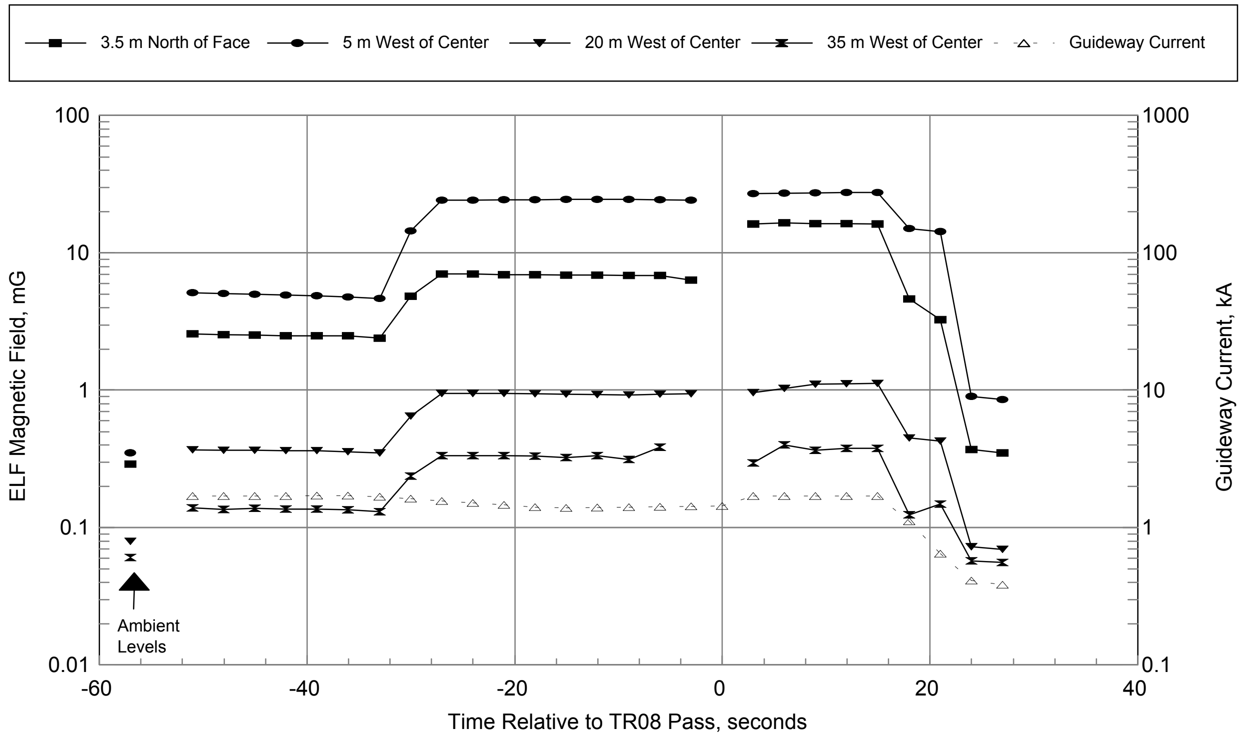


Figure 6-2. ELF magnetic field levels at four locations near the new switching cabinet while it is active before and after the TR08 passes by at 120 km/hr (logarithmic scale)

The similar general decline in the magnitude of the current and the magnetic fields seen in Figure 6-2 between 15 and 25 seconds after the vehicle passed suggests a strong correlation between magnetic field level and guideway current, as long as the switches within the cabinet remain in the same position.

Figure 6-3 shows ELF magnetic field data measured around the new cabinet before and after the third pass of the TR08. The vehicle was running at a constant 300 km/hr until it passed the measurement location, then decelerated to 233 km/hr over the next 30 seconds. As indicated in the graph, the guideway current was low while the TR08 was running at a constant speed, but increased during deceleration to provide the braking thrust. Again, strong correlation between ELF magnetic field and guideway current was indicated in the three samples before the TR08 passed. Although the speed profile for this pass was very different from the pass for which data is reported in Figure 6-2, there was significant similarity in the qualitative characteristics of the field spatial and temporal characteristics. Field magnitudes also matched during corresponding time periods if the current levels were similar. In those time periods where current levels differed, the field levels normalized to current level (field divided by current) also matched. The differences in time duration of each switch mode in

Figure 6-2 as compared to Figure 6-3 is explained by the differences in vehicle speed and resulting time required to travel the length of one section of longstator.

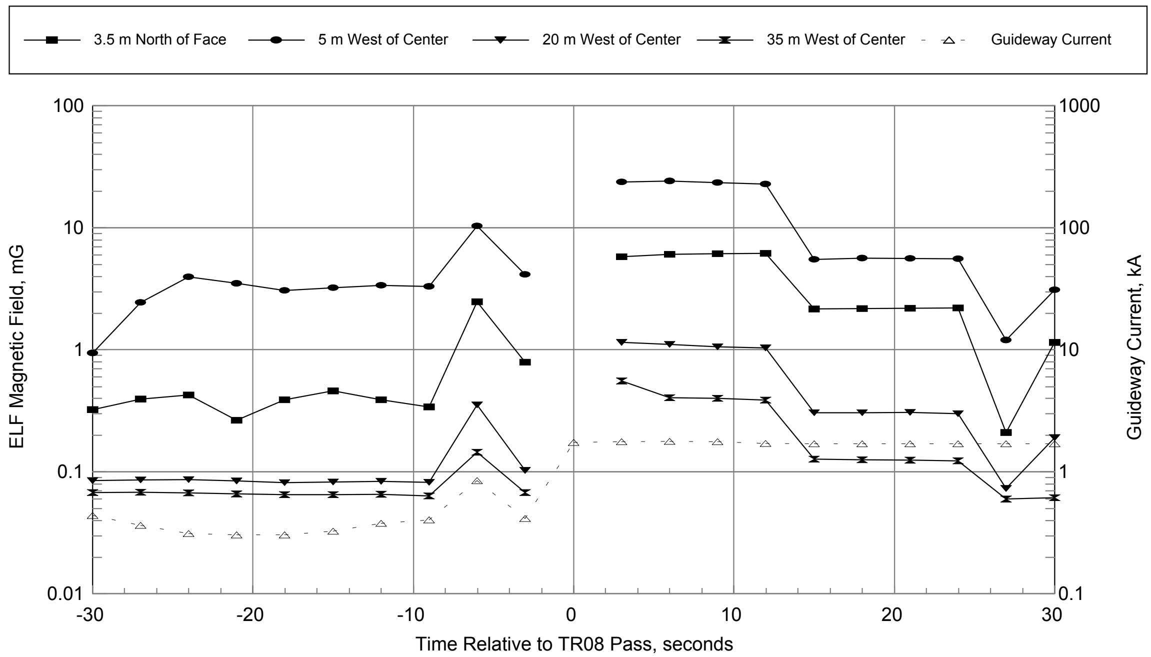


Figure 6-3. ELF magnetic field levels at four locations near the new switching cabinet while it is active before and after the TR08 passes by at 294 km/hr (logarithmic scale)

ELF magnetic field data measured around the standard switch cabinet during a 200 km/hr pass followed by deceleration to 160 km/hr are shown in Figure 6-4. The field characteristics shown in Figure 6-4 differ markedly from those shown in Figures 6-2 and 6-3. First of all, the magnetic field levels were three times lower around the standard cabinet during corresponding times and when current levels were similar. Adjusted for current level, magnetic fields were two and a half to three times lower around the standard cabinet during times that current levels were different. The duration of elevated magnetic field was much shorter around the standard cabinet, and that difference was not explained by differences in vehicle speed.

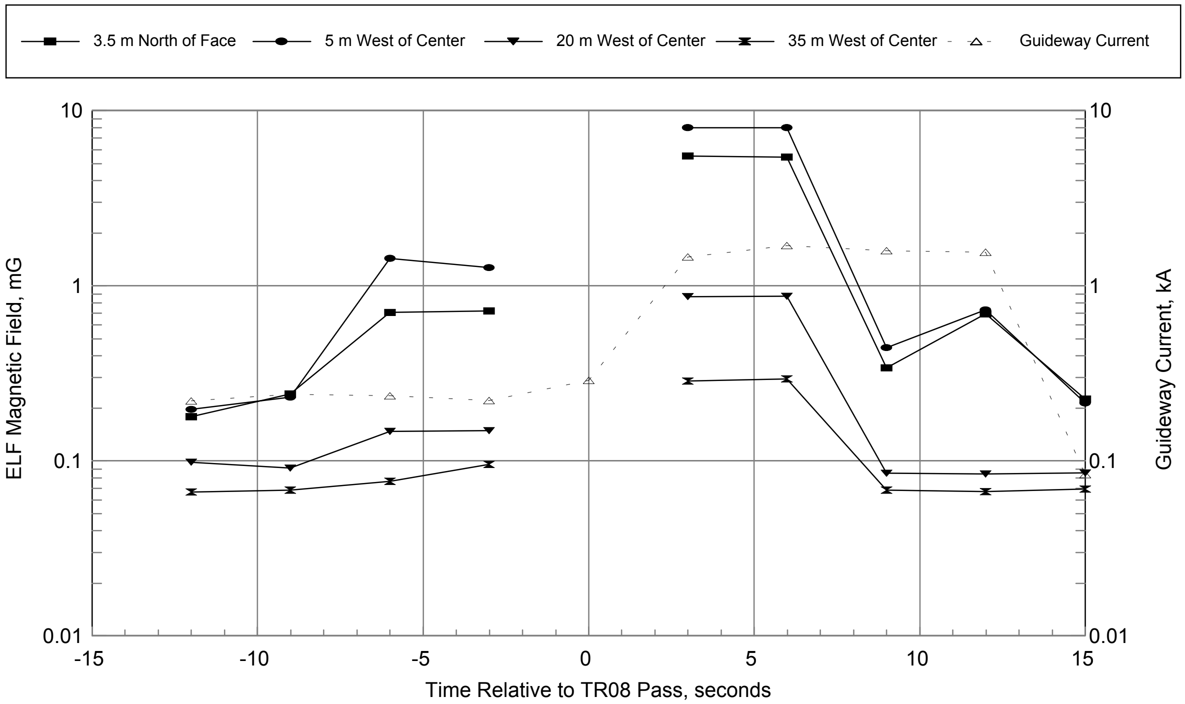


Figure 6-4. ELF magnetic field levels at four locations near the standard switching cabinet while it is active before and after the TR08 passes by at 200 km/hr (logarithmic scale)

The ELF magnetic fields around the switching cabinets were nearly sinusoidal and at a frequency proportional to vehicle speed. For the longstator pitch (distance along the longstator at which the three-phase pole windings repeat) at the test center, the field frequency in Hz was approximately 0.55 times the vehicle speed in km/hr. Because of the uncomplicated spectral characteristics of the ELF magnetic fields around the switch cabinet, no frequency sub-band analysis is warranted. It was sufficient to recognize that the field frequency was known if the vehicle speed was known.

Because of the persuasive evidence of strong correlation between magnetic field levels produced by the switching cabinets and guideway current, the magnetic field levels measured near both switching cabinets were normalized to 1 kiloampere (kA) of current by dividing each field measurement greater than ambient by the current (in kA) at the time of the measurement. For the measurement location 5 m east of centerline at the new switching cabinet, the average and maximum normalized ELF magnetic field levels were 10.1 mG/kA and 22.2 mG/kA, respectively. Five meters east of centerline at the standard switching cabinet, the average and maximum normalized magnetic field levels were 4.0 mG/kA and 6.1 mG/kA, respectively.

Using the magnetic field data measured 5, 20, and 35 m east of the new switching cabinet, attenuation rates were calculated for the magnetic field from the switching cabinets using the same procedure described in Chapter 6 for guideway fields. The attenuation rates for the various data samples and the mean values of all measurements at each distance were found to be inversely proportional to the square of the distance from the center of the cabinet. Combining that attenuation rate with the normalized field levels at 5 meters from the new type cabinet, one can produce generalized empirical equations for magnetic field levels at any distance from the new style switching cabinet. The equation for average ELF magnetic field level is as follows:

$$B_{avg} = 253 * I / d^2$$

where: B_{avg} is the average magnetic field level in mG,
I is guideway current in kA, and
d is radial distance to the center of the switching cabinet in m.

The maximum magnetic field level is calculated by the equation:

$$B_{max} = 555 * I / d^2$$

where: B_{max} is the maximum magnetic field level in mG,
I is guideway current in kA, and
d is radial distance to the center of the switching cabinet in m.

ELF magnetic field levels around the standard switching cabinet were so low that an attenuation rate could not be reliably determined. If one assumes that the rate is similar to that near the new style cabinet (there is good theoretical basis for believing that it is at least as rapid as $1/d^2$), the empirical equations for calculating ELF magnetic fields around a standard cabinet are as follows:

$$B_{avg} = 100 * I / d^2$$

$$B_{max} = 153 * I / d^2$$

where: B_{avg} is the average magnetic field level in mG,
B_{max} is the maximum magnetic field level in mG,
I is guideway current in kA, and
d is radial distance to the center of the switching cabinet in m.

6.4 ELF ELECTRIC FIELDS

ELF electric fields were measured concurrently with the ELF magnetic fields. No electric fields above background (less than 2 V/m) could be detected from either type of switching cabinet at the sensor locations approximately 6 m north of the cabinets. This was expected, because both types of switching cabinets were totally enclosed and constructed of materials sufficiently conductive to shield ELF magnetic fields.

6.5 VLF AND LF MAGNETIC FIELDS

VLF and LF magnetic fields were measured 5 m north of both types of electrical switching cabinet before, during, and after multiple passes of the TR08. No magnetic field levels attributable to the switching cabinets were detected in either the VLF or LF bands above the internal noise of the broadband sensors (0.25 and 0.15 mG, respectively).

6.6 RADIOFREQUENCY ELECTRIC FIELDS

Radiofrequency (RF) electric field measurements were made 5 m east of both the standard type electrical switching cabinet and the newer style cabinet. Near the standard cabinet, no RF field levels above the sensitivity of the instrument were detected. North of the newer style cabinet, low levels of RF electric field were recorded both when the TR08 was active and when it was not active. When the system was not running, the ambient RF electric fields averaged 0.592 V/m and had a maximum of 1.02 V/m. Throughout the time before, during, and after each pass when the switching cabinet was active, the RF electric fields averaged 0.535 V/m with a maximum of 1.04 V/m. Since those values were not different from the ambient levels measured a short time earlier, no detectable RF electric fields emanated from the switching cabinet.

CHAPTER 7 SUMMARY AND INTERPRETATION OF FIELD LEVELS

Magnetic and electric field characteristics measured on board the TR08, on the station platform, near the guideway, and near the electrical switching cabinets were described in detail. Extremely low frequency (ELF) magnetic fields were found to be complex, containing a variety of frequency components. Those fields were also dynamic, changing in both intensity and frequency distribution depending on the vehicle operating conditions.

In this chapter, focus is shifted from the complexity of the field structures to rather simplistic summaries focusing primarily on field intensity. This is not intended to imply that temporal, spatial, and frequency characteristics of the fields are unimportant, but is merely an accommodation to the more common public interest in average field intensity. For that reason, a certain level of generalization is required to focus on the more typical features of the fields. Various exceptions to these generalizations exist; hence, the technical reader is encouraged to look at the whole report, not just at this summary chapter.

7.1 SUMMARY OF FIELD INTENSITIES

Magnetic and electric field levels measured on board the TR08 or near the associated facilities are summarized in this subsection.

7.1.1 Static Magnetic Fields

The ambient static geomagnetic field in the vicinity of the test facility was nearly 500 mG. That ambient field has not been removed from the static field levels reported in Table 7-1. As that summary table indicates, the static magnetic fields on board the vehicle were, on average, within 25% of the normal ambient level and never deviated by more than 120%. Deviations of the static magnetic field were much smaller at the station (6% average, 45% maximum) and negligible along the guideway or near the electrical switching cabinets.

Table 7-1. Static Magnetic Field Levels in Milligauss at Waist Height at Various Locations On Board or Near the TR08

Location	Average	Minimum	Maximum
On board			
Passenger Locations	462	50	1084
Attendant's Location	384	95	948
Station Platform			
1 m from TR08	529	448	718
Guideway			
Beneath Elevated	*	*	*
5 m from At-Ground	*	*	*
Switching Cabinets			
5 m from Centerline	*	*	*
* Denotes less than 2% from ambient.			

7.1.2 ELF Magnetic Fields

ELF magnetic field levels measured on board the TR08, on the station platform, near the guideway, and near the electrical switching cabinets are summarized in Table 7-2.

Table 7-2. Average (and Maximum) ELF Magnetic Field Levels in Milligauss at Waist Height at Various Locations On Board or Near the TR08

Location	All ELF 2-3002	Low Freq 2-48	Power Freq 48-62	Harmonic Freq 62-3002	High Freq 302-3002
On board					
Passenger Locations	34.3 (151.9)	32.6 (151.4)	3.0 (21.5)	8.3 (27.8)	1.5 (10.1)
Attendant's Location	65.8 (185.0)	42.4 (184.0)	8.3 (57.4)	40.6 (92.9)	3.8 (8.4)
Station					
1 m from TR08	19.9 (148.8)	18.3 (148.5)	1.2 (4.9)	4.0 (11.6)	1.0 4.5
Guideway					
Beneath Elevated	122.7 -	9.5 -	13.5 -	120.5 -	16.0 -
5 m from At-Grade	116.0 (126.6)	46.8 (54.4)	2.8 (3.8)	105.2 (117.2)	8.9 (9.5)
Switching Cabinets					
Standard 5 m	4.0* (6.1)*	** **	** **	** **	** **
New Design 5 m	10.1* (22.2)*	** **	** **	** **	** **
* Depends on guideway current. Values are mG per kA of guideway current. ** Depends on the speed of the vehicle.					

The natural ambient ELF magnetic field was insignificant, so virtually all of the magnetic fields measured arose from the transportation facilities or other nearby human-made sources. Electric power transmission lines crossed the test guideway at a few locations and were nearby at others. Any magnetic fields from those power lines would have been predominantly 50 Hz and would have appeared in the power frequency sub-band. As the table indicates, fields in that frequency range were not a significant component of the total ELF magnetic field levels. Thus, human-made magnetic field sources unrelated to the TR08 system were, at most, a negligible contributor to the reported ELF magnetic field levels.

The ELF magnetic field levels tabulated for passenger locations on board the vehicle represented the average and maximum field level measured at waist height at 14 locations within the passenger compartments of the TR08. Between 51 and 105 individual field measurements were made at each location to ensure that the measured field levels represented the range of field levels present during all routine operating conditions. Magnetic field levels given for the attendant's location represented field levels at waist height during 103 individual measurements.

ELF magnetic fields at the station and along the guideway arose primarily from the vehicle. Therefore, they were of brief duration as the vehicle passed. The levels given in Table 7-2 correspond to the time when the vehicle passed the measurement point. Three seconds earlier or three seconds later, the ELF magnetic fields vanished. Hence, field values were not averaged over time. The average value indicated the average of field levels measured on different vehicle passes and at different guideway positions. The maximum value was the highest magnetic field measured during all passes. During the elevated guideway tests, measurements captured the ELF magnetic field characteristics at the instant that the vehicle passed during only one pass. Hence, the average field levels were also the maximum levels recorded.

The magnetic fields provided by the electrical switching cabinets were nearly sinusoidal, at the frequency of the guideway current, and had a magnitude linearly proportional to the guideway current. Hence, the reported ELF magnetic field level was normalized to 1 kA of guideway current. Actual ELF magnetic field level will depend on the average and maximum guideway current. Actual field levels as reported measured at the two specific switching cabinets are shown in Chapter 6, but may not be representative of other cabinets at the facility or cabinets on a commercial system where guideway currents are different.

Table 7-2 does not show the field distribution among sub-bands of frequency for measurements near the switching cabinets. That is because the field frequency depends on vehicle speed, a site-specific parameter not universal to all electrical switching cabinets. The magnetic field frequency in Hz was 0.55 times the vehicle speed expressed in km/hr. The magnetic field level was negligible in frequency bands other than the one containing the field component related to vehicle speed.

7.1.3 VLF and LF Magnetic Fields

At no locations on board the TR08, at the station platform, near the guideway, or near the switching cabinets were very low frequency (VLF) or low frequency (LF) magnetic fields detected above the sensitivity threshold of the instruments (0.25 and 0.15 mG, respectively).

7.1.4 ELF Electric Fields

Small, but detectable, ELF electric fields were measured at chest height on board the vehicle and at the station. These fields were predominantly 50 Hz magnitudes as shown in Table 7-3. The slightly elevated ELF electric field levels in the attendant's compartment may not be representative. The metal doors of the electrical equipment cabinets within the compartment were open during the tests to facilitate cooling of the interior. The cooling fan within the cabinet had failed. Electric fields produced by equipment in those cabinets would be essentially eliminated if the doors were closed.

Table 7-3. ELF and RF Electric Field Levels in Volts per Meter at Various Locations On Board or Near the TR08

Location	ELF		RF	
	Average	Maximum	Average	Maximum
On board				
Passenger Locations	2.5	5.5	1.2	5.0
Attendant's Location	11.2	16.5	2.0	3.6
Station Platform				
1 m from TR08	2.9	32.9	0.1	3.0
Guideway				
Beneath Elevated	*	*	*	*
5 m from At-Ground	*	*	*	*
Switching Cabinets				
5 m from Centerline	*	*	*	*
* Negligible deviation from ambient.				

7.1.5 RF Electric Fields

Small radiofrequency (RF) electric fields were measured on board the TR08, as indicated in Table 7-3. The source of these fields was not determined with certainty. They were approximately similar throughout the vehicle and not any larger in close proximity to the 40 GHz communications and telemetry transmitter or antenna. On the station platform, 19 RF electric field measurements were taken while the TR08 was passing by the station or entering the station and stopping. All but two of the measurements indicated no RF electric field. The average RF field level indicated in Table 7-3 at the station is the average across all samples, including the ones that indicated zero RF electric fields. This computed average was an order of magnitude less than the lower end of the instrument's specified dynamic range.

7.2 SUMMARY OF FIELD SOURCES

The principal magnetic field sources on board the TR08 vehicle were below the floor and uniformly distributed along the length of the vehicle. Because they were principally static and low-frequency fields with often non-periodic waveforms, they appeared to arise from the levitation and/or guidance magnets in the magnetic bogies or the control circuitry for those devices. These magnetic field sources produced the highest field levels near the floor of the vehicle and the lowest near the ceilings.

Secondary field sources throughout the vehicle produced periodic magnetic fields having a frequency proportional to the vehicle speed. These sources were often beneath the floor, but sometimes also in the bulkheads or overhead spaces. Although speed dependent, they appeared not to arise directly from guideway currents for two reasons. First, their spatial distribution suggested numerous sources, not all of which were beneath the floor. Second, from the point of view of an observer in the vehicle, the magnetic field from the longstator did not appear to have the same frequency as it did from the ground. Because the vehicle and observer were being pulled along with the longstator field as it moved along the guideway, the field appeared nearly stationary from the observer's point of view.

At the station platform and along the guideway, the principal static and time-varying magnetic field sources were clearly the vehicle as it passed by, or started or stopped adjacent to the point of interest. ELF magnetic fields from the energized guideway were insignificant if the vehicle was not immediately present. This observation probably arose from the fact that, while guideway currents were high and resulting fields were very high at the longstator pole faces, those fields attenuated very quickly due to cancellation by out-of-phase fields from adjacent poles. Because of the short pitch of the longstator poles and their precise uniformity, significant fields should not have been expected at longer distances from the guideway.

Guideway current appeared to be a significant magnetic field source only near the switching cabinets. Although the measurements showed quite clearly that the ELF magnetic fields arose from the cabinets, most principally the cabinet of newer design, the attenuation rate of those fields away from the cabinets was less rapid than one might expect if the fields arose from discrete sources within the cabinets. Large loops in the buswork within the cabinets or cables connecting to the cabinets could explain this observation.

Significant ELF electric fields were not observed on board the TR08, at the station, near the guideway, or near the switching cabinets. Very small, 50 Hz fields were observed on board, possibly from the vehicle lighting or from other sources, including power cables to the instruments used in these tests. Small, 50 Hz electric fields were also seen at the station platform and some wayside measurement sites. Those fields apparently came from 50 Hz power circuits near the station and more distant overhead electric power transmission lines unrelated to the transportation facility. Infrequent elevations were observed in the ELF electric field, producing the peak values listed in Table 7-3. In those measurements, the ELF electric field was almost entirely in the lowest frequencies, suggesting that the field arose from moving static electric charge in the vicinity of the sensor. On board, the source was probably electric charge on clothing of people walking past the sensor. At the station, it appeared to be static charge on the vehicle or in the air displaced by the vehicle as it passed by the electric field sensor.

The source of RF electric fields on board the TR08 was unclear. Although the RF electric fields were small and very near the threshold of the instrument's sensitivity, they appeared consistently higher on board than off of the vehicle. Spatial distributions indicated that they did not arise from the 40 GHz communications and telemetry transceiver or antenna. Possible sources were signals from walkie-talkies used by the vehicle crew, wireless microphones used by the onboard tour guides, cellular phones frequently in use by crew and observers, and electrical noise from the electrical systems on board the vehicle.

7.3 COMPARISON TO OTHER TRANSPORTATION SYSTEMS

Static and ELF magnetic field levels have been measured in a variety of other transportation systems using similar instrumentation and protocols (FRA 1992, 1993b, 1993c, 1993d, 1993e). A summary and comparison of those results have been previously published (FRA 1993f). In the following paragraphs, tables, and figures, static and magnetic field levels measured on board or near the TR08 will be compared to levels measured on board and near the following:

- Amtrak Northeast Corridor (NEC) 25 Hz electrification;
- Amtrak Northeast Corridor (NEC) 60 Hz electrification;
- Amtrak Northeast Corridor (NEC) non-electrified;
- New Jersey Transit Long Branch 60 Hz electrification;
- TGV-Atlantique (TGV-A) 50 Hz electrification; and
- Transrapid TR07 Maglev System.

No comparisons are made of VLF or LF magnetic field levels or ELF and RF electric fields because no significant field levels were detected.

Table 7-4 lists average and maximum static and ELF magnetic field levels in passenger compartments of various intercity rail systems, as well as the TR07 and TR08. Within the rail system coaches, magnetic field levels were more uniform from floor to ceiling than in either the TR07 or TR08. Hence, field levels from all measurement heights were included in the average. In the TR07 and TR08, magnetic fields were materially larger near the floor, an area of limited interest when evaluating hazard concerns. Therefore, the average and maximum field levels in those vehicles were computed from data measured at waist level. As the table indicates, static and ELF magnetic field levels in the passenger compartments of the magnetically levitated systems were not out of the range of field levels found in conventional rail system coaches. Furthermore, the distribution of field levels in the various frequency sub-bands was not dramatically different in the magnetically levitated systems from that seen in conventional rail coaches, when considered collectively.

Table 7-4. Comparison of Average (and Maximum) Magnetic Field Levels in Milligauss in Passenger's Compartments of Various Transportation Vehicles by Frequency Range

Transportation System	Static 0 Hz	All ELF 2-3002 Hz	Low Frequency 2-48 Hz	Power Frequency 48-62 Hz	Harmonic Frequency 62-303 Hz	High Frequency 302-3002 Hz
NEC 25 Hz	606 (1763)	133.8 (782.1)	132.0 (776.0)	6.0 (41.4)	16.2 (95.2)	2.7 (14.7)
NEC 60 Hz	630 (1039)	52.5 (408.4)	1.4 (12.2)	52.0 (407.0)	5.7 (43.9)	1.4 (12.8)
NEC Non-Electrified	569 (1033)	5.2 (26.5)	1.4 (6.7)	4.8 (26.3)	0.7 (5.9)	0.2 (1.9)
NJT Long Branch	734 (1016)	18.6 (108.8)	1.6 (13.0)	18.2 (107.1)	2.5 (17.7)	0.7 (3.6)
TGV-A	545 (962)	43.2 (165.0)	23.3 (106.2)	30.5 (164.7)	2.7 (10.4)	1.5 (5.4)
TR07	611 (1110)	52.4 (143.2)	47.6 (141.4)	7.7 (29.4)	18.5 (35.5)	1.2 (2.5)
TR08	462 (1084)	34.3 (151.9)	32.6 (151.4)	3.0 (21.5)	8.3 (27.8)	1.5 (10.1)

To aid in the visualization of these trends, the data from Table 7-4 are plotted in Figure 7-1. The height of the light portion of the bar indicates the maximum field value and the shaded portion of the bar indicates the average field value. To better view the wide range of field values at different frequencies, the data in Figure 7-1 are replotted in Figure 7-2 using a logarithmic scale for the field levels.

Table 7-5 shows the static and ELF magnetic field levels at waist height near the attendant's seat in the TR08, as compared to average and maximum field levels at several heights in the operator's compartments of intercity rail locomotives. These data are presented graphically in Figure 7-3. With the exception of the fields in the harmonic frequency sub-band, the levels at waist level at the attendant's position in the TR08 were in the range of field levels seen in the operator's compartments of other rail systems. The average time-varying fields in the harmonic frequency range (62-302 Hz) were higher in both the TR07 and the TR08 than in other intercity rail locomotives (except for the NEC, 25 Hz electrification), although maximal levels are comparable for all electrotechnologies.

Static and ELF field levels on station platforms are compared in Table 7-6 and Figure 7-4. Again, the waist level fields are shown for the TR08. As with the previous comparisons, magnetic field levels measured on the station platform near the TR08 were in the range of field levels measured on the platforms of the TR07 and conventional intercity rail systems.

Static magnetic field levels at accessible locations near the guideway were not affected by the passing TR08. This was similar to observations at similar distances from conventional intercity trains. Comparison of ELF magnetic field levels was complicated by the fact that measurements were made at different distances from the passing vehicle in different systems. For the purpose of comparison, field levels or ranges and attenuation rates reported for different systems were used to compute the expected ELF field level 10 m from the track or guideway at the time that the vehicle passed. At that distance, the field level is approximately 39 mG near the TR08. The value reported for the TR07 was 41 mG. A wide range of ELF field levels from 7.7 mG to 9.5 mG was reported for various intercity railroad trains at various locations. Unlike the TR08, magnetic fields near a conventional electrified railroad varied dramatically depending upon the traction power requirements at the time of the measurement. Furthermore, these fields remain present (but often at a somewhat reduced level) the entire time the locomotive was in that power block. This was unlike fields near the TR08 guideway, which were only elevated for a very brief time (less than a few seconds) as the vehicle passed.

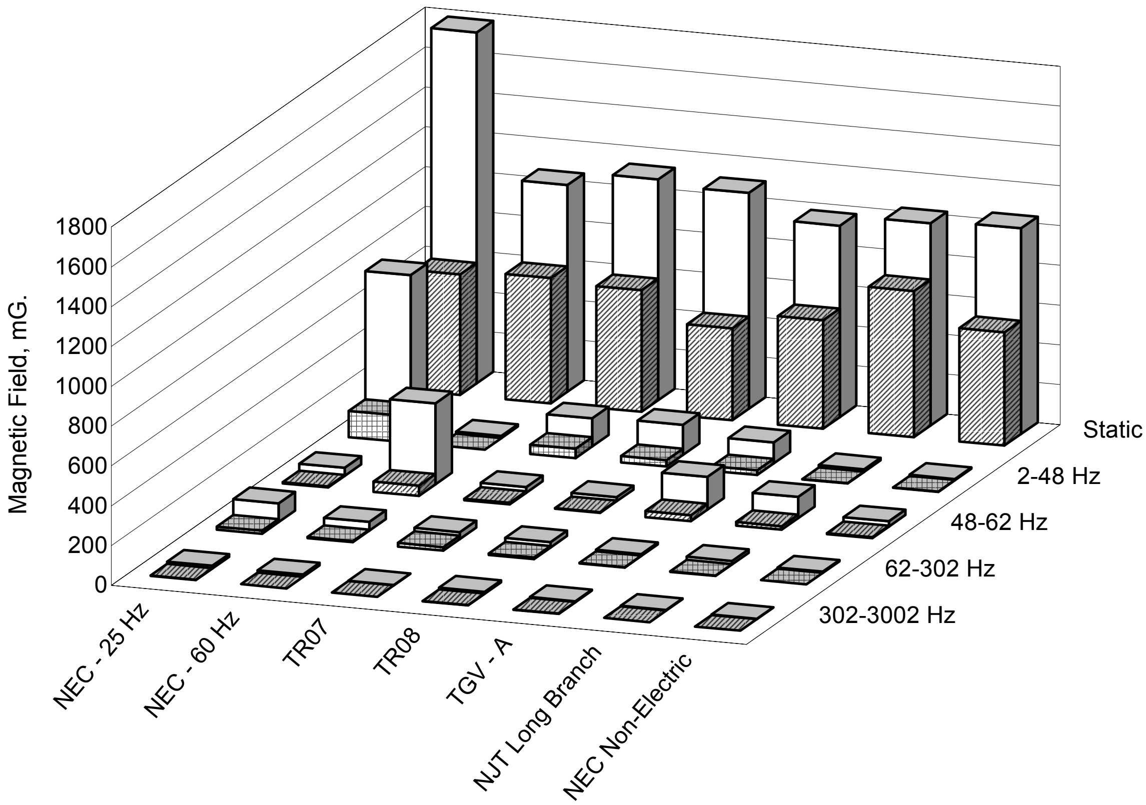


Figure 7-1. Average (shaded bar) and maximum (light bar) magnetic field levels in passenger compartments of magnetically levitated and conventional intercity trains (linear scale)

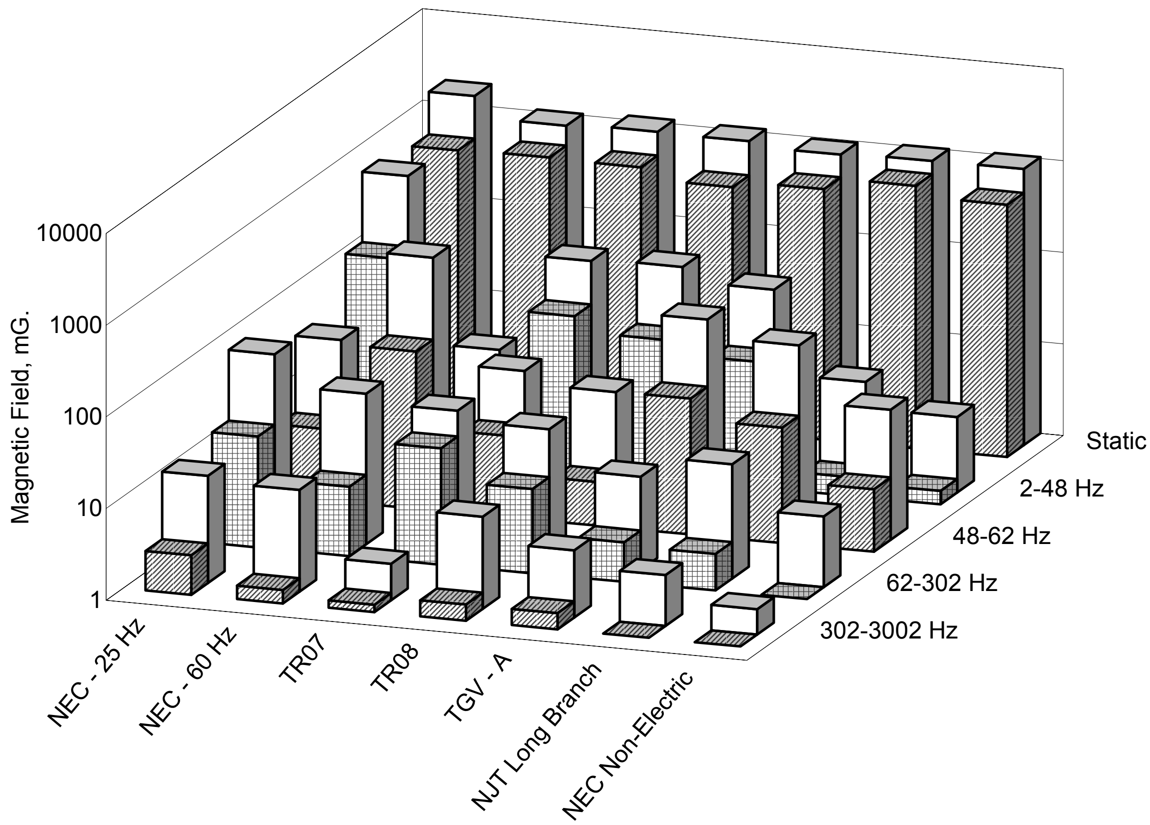


Figure 7-2. Average (shaded bar) and maximum (light bar) magnetic field levels in passenger compartments of magnetically levitated and conventional intercity trains (logarithmic scale)

Table 7-5. Comparison of Average (and Maximum) Magnetic Field Levels in Milligauss in Operator's or Attendant's Compartments of Various Transportation Vehicles by Frequency Range

Transportation System	Static 0 Hz	All ELF 2-3002 Hz	Low Frequency 2-48 Hz	Power Frequency 48-62 Hz	Harmonic Frequency 62-303 Hz	High Frequency 302-3002 Hz
NEC 25 Hz	648 (1555)	46.0 (250.9)	41.2 (247.4)	11.7 (52.8)	5.5 (26.7)	1.4 (5.9)
NEC 60 Hz	435 (992)	27.4 (174.7)	2.1 (19.0)	26.8 (174.3)	3.9 (19.5)	1.2 (7.1)
NEC Non-Electrified	330 (767)	1.9 (12.7)	1.0 (12.1)	0.4 (2.2)	1.0 (3.9)	1.0 (5.3)
NJT Long Branch	319 (445)	31.5 (123.7)	1.3 (12.5)	31.1 (122.6)	3.8 (17.2)	1.2 (3.8)
TGV-A	795 (1149)	94.2 (367.7)	18.0 (50.2)	87.3 (366.6)	16.6 (68.3)	4.4 (11.9)
TR07	791 (1108)	60.5 (98.4)	37.3 (80.8)	11.5 (24.7)	45.2 (62.0)	2 (4.2)
TR08	384 (946)	65.8 (185.0)	42.4 (184.0)	8.3 (57.4)	40.6 (92.9)	3.8 (8.4)

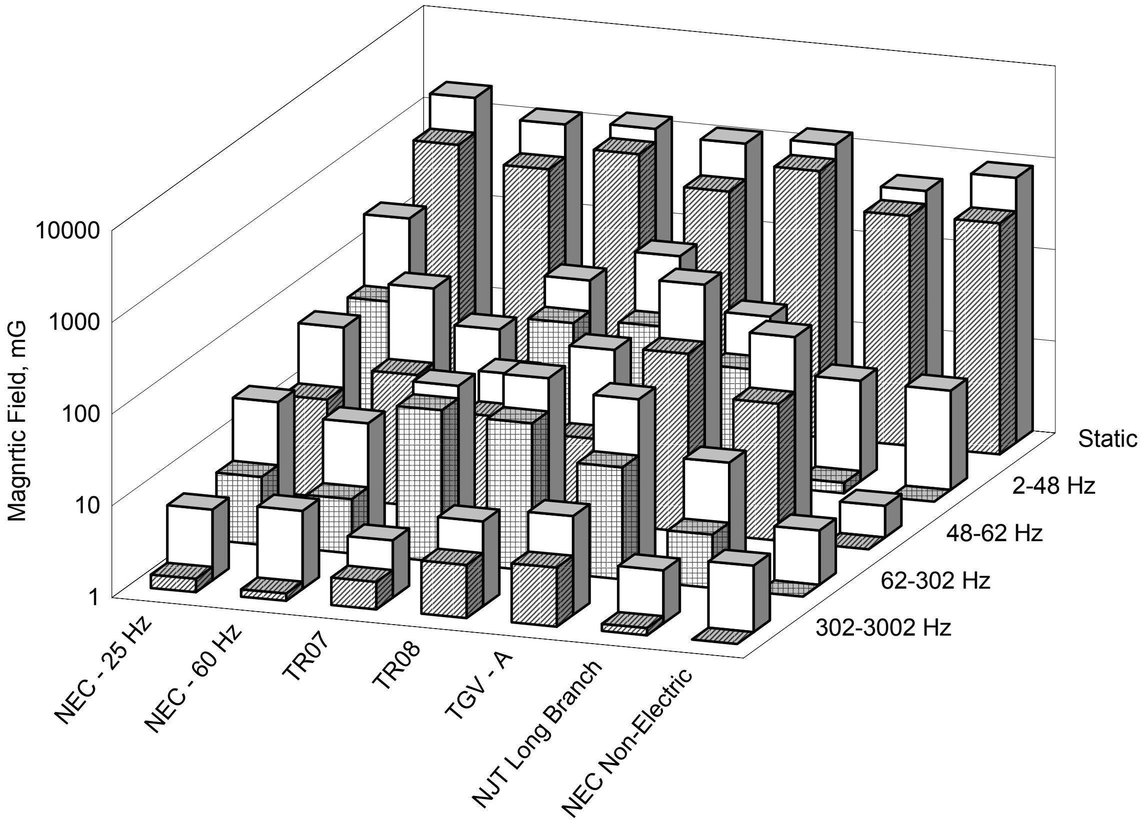


Figure 7-3. Average (shaded bar) and maximum (light bar) magnetic field levels in the operator's or attendant's compartments of magnetically levitated and conventional intercity trains (logarithmic scale)

Table 7-6. Comparison of Average (and Maximum) Magnetic Field Levels in Milligauss on Station Platforms of Various Transportation Systems as a Function of Frequency Range

Transportation System	Static 0 Hz	All ELF 2-3002 Hz	Low Frequency 2-48 Hz	Power Frequency 48-62 Hz	Harmonic Frequency 62-303 Hz	High Frequency 302-3002 Hz
NEC 25 Hz	422 (970)	39.6 (550.8)	38.1 (537.0)	1.1 (13.8)	8.8 (121.2)	1.6 (17.1)
NEC 60 Hz	650 (1629)	62.6 (417.6)	0.9 (51.5)	59.8 (407.2)	15.6 (101.6)	4.9 (26.6)
NJT Long Branch	525 (615)	28.8 (213.2)	0.6 (4.8)	28.0 (209.4)	8.0 (50.6)	2.6 (15.7)
TGV-A	460 (485)	9.0 (43.9)	0.3 (0.9)	7.0 (43.8)	0.6 (1.6)	0.7 (1.5)
TR07*(2.5 m from gdwy. centerline)	357.7 (370.5)	1.74 (297.4)	1.5 (287.3)	0.2 (20.5)	0.6 (75.1)	0.1 (8.0)
TR08 (1.0 m from vehicle)	529 (718)	19.9 (148.8)	14.6 (116.1)	1.2 (4.9)	4.0 (11.6)	1.0 (4.5)

*During the TR07 measurements, the only measurements permitted on the station platform were with the sensor instruments attached directly to the station platform rather than at a level comparable with the other measurements reported in this table and in Figure 7.4. Because of the close proximity of the magnetic field sensors to the perturbing ferromagnetic station platform and because of the proximity to the vehicle magnetic bogies, the resulting measurements are unlikely to be representative of field levels at waist level.

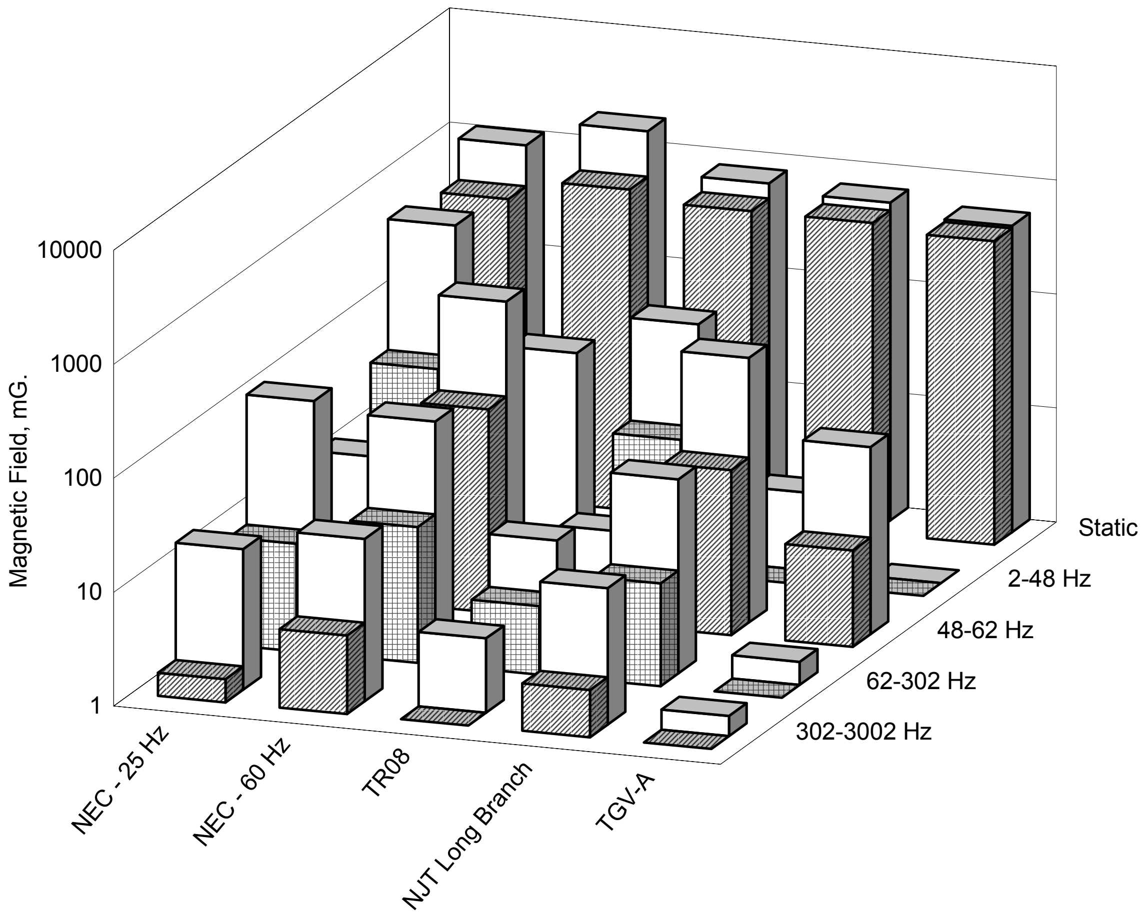


Figure 7-4. Average (shaded bar) and maximum (light bar) magnetic field levels on the station platform while magnetically levitated and conventional trains pass by or stop (logarithmic scale)

7.4 REGULATORY CONTEXT

There are currently no national standards in the United States for static or ELF magnetic field exposure limits. The American Conference of Governmental Industrial Hygienists (ACGIH) annually publishes voluntary compliance guidelines for workplace threshold limit values (TLV) of exposure to static, ELF, and RF magnetic fields. However, that guideline is not intended for uncontrolled public exposure.

The International Commission on Non-Ionizing Radiation Protection (ICNIRP) also published guidelines on occupational and general public exposure to static (ICNIRP 1994) and time-varying (ICNIRP 1998) magnetic fields (Table 7-7).

Table 7-7. Electromagnetic Field Standards

Organization	Time-Varying (AC) Magnetic Field
German Radiation Protection Commission (BUNR) (1997 EMF Ordinance)	1 G at 50 Hz 3 G at 16 Hz
International Commission on Non-Ionizing Radiation Protection (ICNIRP) (50/60 Hz)	5 G at 50 Hz (occupational) 1 G at 50 Hz (public)
American Conference of Governmental Industrial Hygienists (ACGIH)	1 G (medical device wearers) 600/frequency (f) at f=1-300 Hz 2 G at f=300 Hz-3 kHz 10 G at 60 Hz

Sources: BUNR 1997, ICNIRP 1998, ACGIH 2002

The ICNIRP recommendations for permissible exposures to the general public are lower than their occupational guidelines, or the ACGIH recommendations; hence, they are the basis of the analysis shown in Figure 7-5. The ICNIRP and ACGIH guidelines are frequency-dependent, as indicated in the graph. The maximum magnetic field levels measured at any time or any place on board the vehicle, on the station platform, near the guideway, or near the electrical switching cabinets are plotted as vertical bars. The attendant's compartment is included in the on board field data. It is clear that those maximum fields are at all times below the exposure limits recommended by the ICNIRP guideline. Because typical, whole-body exposures are usually much less than the maximum values plotted in the figure, the safety margin between field levels and exposure guidelines is larger than indicated.

As with ELF magnetic fields, there are no national standards limiting exposure to ELF electric fields. Both the ACGIH (2002) and the ICNIRP (1998) guidelines cover ELF electric fields, but the ICNIRP recommendation for the general public is the most stringent. Like the magnetic field standard, the electric field exposure guideline is also dependent upon frequency. At 50 Hz (the frequency most often dominant in the electric field frequency spectra), the permissible exposure level is 4167 V/m, which is three orders of magnitude greater than the 50 Hz electric field usually seen on board the vehicle or at the station. The maximum ELF electric field seen anywhere during these tests was 32.9 V/m on the station platform as the vehicle passed by. That maximum reading is insignificant compared to field levels permitted under the ICNIRP guideline.

In 1996, the Federal Communications Commission (FCC) amended its rules to adopt a standard for public radiofrequency field exposure safety. The FCC standard is based upon recommendations in the National Council on Radiation Protection and Measurements (NCRP) Guideline (1996) and is in good agreement with both the American National Standards Institute (ANSI) limits (ANSI 1999) and the ICNIRP Guideline (ICNIRP 1998). In all four of those guidelines, RF electric field limits are frequency-dependent, but all have the most stringent constraint of 27.5 V/m between the frequencies of 10 MHz and 300 MHz for exposure to the general public. These standards say that RF field levels should be averaged over a time period ranging from 6 minutes to 30 minutes and the average must not exceed the 27.5 V/m threshold.

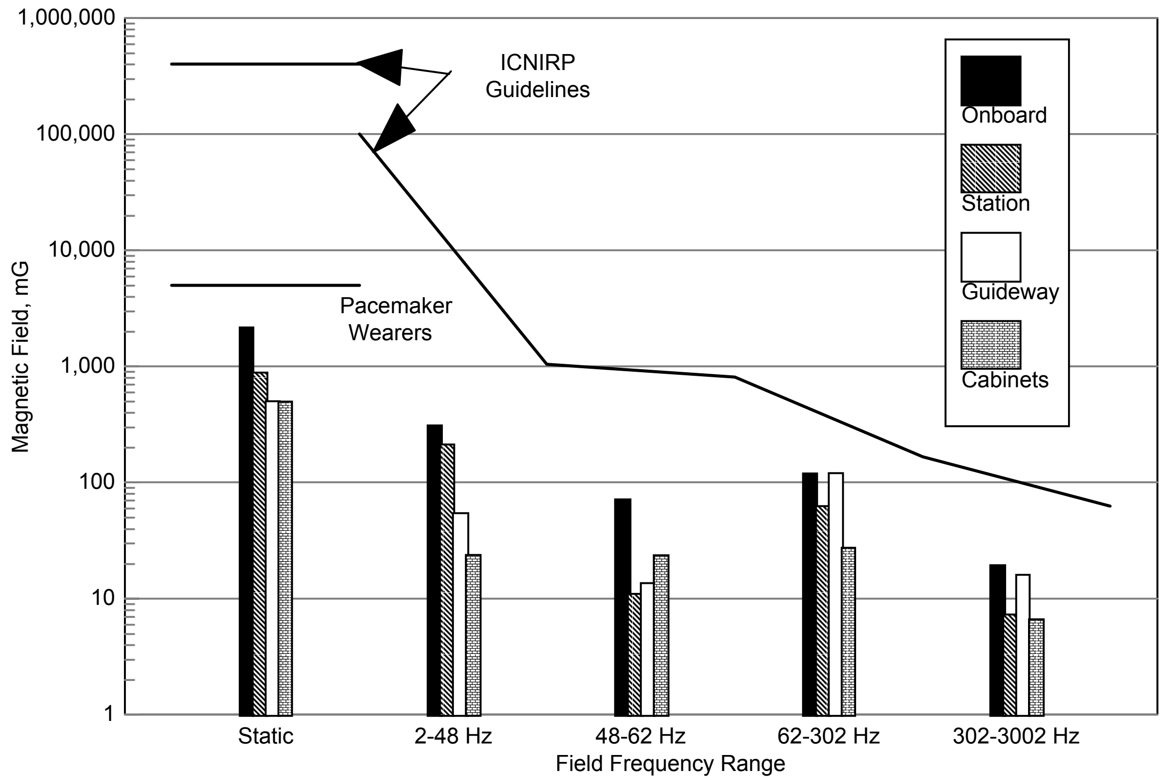


Figure 7-5. Maximum static and time-varying magnetic fields recorded on board the TR08, at the station platform, or near the guideway or electrical switching cabinets compared to ICNIRP recommended guidelines for permissible magnetic field exposure to the general public

RF electric field measurements were made in this study using a broadband instrument covering the range of 80 MHz to 40 GHz. Since there was no way of knowing the actual frequency or frequency distribution of the RF electric fields detected on board the TR08 or at the station, one must assume that they fell between 80 MHz and 300 MHz and were, therefore, subject to the 27.5 V/m imposed by the FCC standards and the other three guidelines. Comparing that threshold to the average RF electric field levels tabulated in Table 7-3, one observes that compliance is achieved within a wide margin of safety.

CHAPTER 8 VOLPE CENTER'S INDEPENDENT VERIFICATION AND VALIDATION OF EMF AND EMR MEASURMENTS: PROCESS AND RESULTS

8.1 DESCRIPTION OF PROCESS

An independent verification and validation (V&V) effort was undertaken by the Volpe Center on behalf of the FRA. In addition to providing input to the Test Plan (Appendix A) and overseeing a significant portion of the Electric Research (ERM) measurement effort, the Volpe Center's National Expert in Safety, Health, and Environment used an EMDEX recorder to make supplemental electromagnetic field (EMF) and electromagnetic radiation (EMR) measurements of the TR08 Maglev System at the Transrapid Test Center (TVE). The EMDEX EMF personal exposure data were obtained at power frequency and harmonics to complement and verify portions of the *MultiWave®* dataset collected by ERM (see Section 1.3 for more detail on roles and responsibilities).

The V&V process and activities consisted of:

- observing and verifying that ERM's survey techniques, protocol, measurement locations, and level of sample replication closely matched the established FRA practices for desired completeness and statistical power of EMF characterization;
- reviewing ERM data analyses and interpretation of TR08 results to ensure their consistency and comparability with previous EMF reports for TR07, TGV, Amtrak and other electrified rail and transit systems. This EMF transportation database was compiled and obtained by ERM over the past decade, with Volpe Center management and technical guidance, for the FRA National Maglev Initiative and the Department of Energy's (DOE) Electric and Magnetic Fields Research and Public Information Dissemination (EMF RAPID) Program;
- conducting simultaneous onboard TR08 measurements with the EMDEX meter and a Nardalert radiofrequency (RF) meter on the seat near or adjacent to the ERM sensor mannequin for a portion of the test runs;
- independently performing additional in-vehicle and near-guideway magnetic field and RF measurements using the EMDEX meter and the Nardalert 8861 unit;
- independently analyzing the Volpe Center EMF and RF results;
- comparing EMDEX results for broadband (BB) resultant fields and its components at power frequency and harmonics with the average magnetic field levels in corresponding *MultiWave®* frequency bands;
- assessing the compliance of TR08 measured EMF levels with the applicable current EMF and RF human exposure safety standards, as part of an overall environmental compatibility assessment.

8.1.1 Instrumentation Used for Validation and Verification

The EMDEX II, a compact battery-powered body-worn magnetic measurement system and its associated data analysis software (EMCALC), were developed by Etc. Enertech Consultants for the Electric Power Research Institute (EPRI). It was designed for EMF measurements in the power frequency and harmonics spectral range (40–800 Hz), although sensor response is optimized for 60 Hz-300 Hz. The EMDEX II is a programmable data acquisition system, requiring the EMCALC 2000 software to analyze, tabulate and plot the EMF levels vs. time in the power frequency and harmonic bands from 40 Hz to 300 Hz. Root mean square (RMS) field levels can be characterized in the BB (40-300 Hz), harmonic frequency (HF, 100- 300 Hz), or power frequency (PF, 50-60 Hz) ranges. The EMDEX measures three orthogonal magnetic field vector components and calculates the resultant magnetic field.

The EMDEX II was used to collect independent EMF personal exposure data for TR08 to complement and verify portions of the dataset collected by ERM using *MultiWave*® instrumentation (specifically, those sub-bands of the ERM dataset labeled as “Power Frequency” (48.3-61.7 Hz) and “Power Harmonic Frequencies” (61.7-301.7 Hz); see Section 2.8.2) (Figure 8-1).

Figure 8.1. EMDEX II magnetic measurement instrument (highlighted by arrow) that was used for validation of ERM’s measurements, on seat adjacent to ERM mannequin outfitted with *MultiWave*® instrumentation

The EMDEX personal EMF monitor is widely used in the utility industry to assess workplace time-weighted-averaged (TWA) eight hours or time integrated (milliGauss multiplied by hour, mG-hr) EMF exposures, to identify EMF hotspots and exposure levels, and to verify compliance with exposure safety standards. It is used as a personal EMF exposure meter, and worn at the waist or anywhere on the body; it can also be placed on the seat or other in-vehicle and power substation locations to sample and record up to 24 hrs of EMF. An EMDEX II was also used by the Volpe Center and ERM to provide supplemental magnetic field measurements in the PF and HF range in other surveys of transportation vehicles and facilities studied to-date, as documented in the referenced reports and the EMF RAPID database.

EMF levels are read on the LCD display and recorded in the computer chip memory. EMCALC produces plots of time against the PF, HF, and their RMS BB resultant strength (in mG), as well as performing statistical analyses (calculations of mean, mode, maximum, minimum, and RMS average values). The magnetic field readings for PF, HF, and BB are measured in mG, with a dynamic range from 1 mG to 5.5 Gauss (G). For simplicity, figures 8-2 through 8-5 show only BB magnetic field levels, at selected locations, plotted against time.

Readings are made after averaging over pre-selected time intervals, from 3 seconds to 5 minutes. To capture the EMF variability with time and to provide a higher number of data records for improved statistics, ten-second-sampling and averaging intervals were used at TVE. Event markers were flagged in the original data sets to denote changes in speed, location and time. Detailed field notes concerning the precise measurement location for each event (e.g. the guideway pillar number; guideway segment-type (steel, hybrid or concrete)), and any noticed change in conditions (e.g. vehicle movement, acceleration, or braking) assisted in interpreting observed EMF levels.

Since the instrument's data storage capacity is limited, the EMDEX data files were downloaded to a computer at regular intervals during continuous measurements. The EMCALC-2000 data analysis graphic displays (Figures 8-2 through 8-5) and Table 8-1 provide some statistical parameters (mean, standard deviation, etc.) and the range (maximum, minimum) for EMF values.

For RF personal exposure measurements, a Nardalert (Model 8861 ELF immune version) demonstrator (made available on loan by the L-3 Communication, Microwave NardaEast Division[*]) and the associated interface kit and analysis software were used. This radiofrequency-radiation (RFR) personal exposure system is an ultra-BB antenna detector (BB: 10 MHz to 100 GHz), that brackets expected transceiver communication and TR08 control frequencies at TVE. It is programmed to compare RFR levels to the current Federal Communications Commission (FCC) human-exposure safety standard of about five milliwatt/cm^2,

[*] The RF data was retrieved by a representative of L-3 NardaEast.

and to sound an alarm when EMR levels exceed 50% of the public-exposure safety limit in the standard (FCC 1997a, 1997b).

A digital camera was used to document EMF/EMR measurement locations.

8.2 VALIDATION AND VERIFICATION OF EMF MEASUREMENT PROTOCOL

Adherence to the EMF test protocol developed and used for the TR07 EMF survey (FRA 1992) was observed throughout, as stated in the original Test Plan (Appendix A). Such adherence was essential to ensure both the completeness of the TR08 dataset (capturing the full dynamic range of operational conditions at representative locations), and its comparability to public and occupational exposure levels in the comprehensive EMF database, collected over the past decade for various existing and advanced transportation systems and technologies (FRA 1993b, 1993c, 1993d, 1993e, 1993f).

The Volpe Center representative witnessed most EMF and EMR survey activities carried out by ERM and the measurement team. By accompanying the ERM team on two separate days to perform in-vehicle, station, and wayside survey measurements, it was confirmed that procedures and locations conformed to the established FRA/DOT protocol for characterization of EMF in transportation sources. The protocol was followed to the extent feasible, unless actual field conditions required deviations from the plan.

To verify data quality and correct equipment operation, the first day on site was devoted by ERM and Volpe Center to instrument calibration, checkout, data downloading, and analysis software testing. This ensured the practical feasibility of the test plan, subject to real time constraints (e.g., allowance of only 30 minutes to return to the lab from the field, and of about one hour to recharge the *MultiWave*® power supply after each two to three hour interval of field measurements).

Thorough wayside EMF and EMR measurements were made for all public access areas, both for background conditions (prior to TR08 power-up) and for the full dynamic range of TR08 operating conditions. Some ad-hoc changes in testing schedules and locations were forced by unforeseen problems with the planned run-schedule and speed profiles for TR08 operation; thus, ERM extended the duration of the on-site survey by several days. Changes in the Test Plan did not significantly affect, either in substance or quality, the statistical power and completeness of EMF and EMR data collected at various locations.

8.3 INDEPENDENT EMF PERSONAL EXPOSURE MEASUREMENTS FOR VALIDATION OF MULTIWAVE 3-300 HZ DATASET

For V&V purposes, portions of the EMF exposure data were recorded jointly with ERM, at the same conditions, locations, and times, while others were collected independently. EMF and RF personal exposure measurements were made at TVE over a three day period (August 14-16, 2001) as discrete ‘runs’ (i.e., datasets representing all publicly accessible locations, under a full range of operational conditions):

- stationary (powered-up and levitated) and at scheduled speeds and acceleration/deceleration cycles;
- within vehicles (at passengers and in attendant’s cab) for empty and passenger-loaded consist;
- in the passenger station and next to the power conditioning and supply facilities;
- at wayside locations along the guideway, under and near concrete, steel, and hybrid segments, for both background and TR08 pass-by conditions.

Numbered event markers were documented for each EMDEX dataset to denote time, speed, and other potentially significant changes in TR08 speed, state (empty or loaded with passengers), or location in the run. To assist in the interpretation and analysis of EMF levels, the following details about each measurement location were noted: spatial location (e.g. on seat, on floor, at cab attendant’s location); whether the vehicle was stationary or in power-up levitated mode at the station; whether the vehicle was operating at low speed or in a high-speed run; and whether the vehicle was accelerating or braking.

Although magnetic fields were plotted and analyzed against time for PF (60Hz), HF (60-300 Hz) and the BB total (root-sum-square over 40-800 Hz), for simplicity and clarity only the BB EMF levels at representative locations and conditions are shown in Figures 8-2 through 8-5. These data correspond to a subset of the ERM *MultiWave*® measurements in extremely low frequency (ELF, 3-300 Hz) sub-bands “Power Frequency” (48-62 Hz) and “Power Harmonic Frequencies” (62-302 Hz).

Due to differences in measurement times and locations (only a subset of measurements were made simultaneously) and differences in instrumentation, a direct comparison of the data is not possible. However, comparison of statistics from the measurement data provides an order of magnitude validation. The EMDEX statistics are based on the four data sets shown in Figures 8-2 through 8-5 and the ERM statistics are from all passenger compartment *MultiWave*® data recorded at the waist level ELF magnetic field sensor position per the protocol in Appendix A.

EMDEX data were compared with the *MultiWave*® data (averages at waist-level) from the summary tables listed below:

- Stationary TR08, Table 3-2: The *MultiWave*® PF and HF means are 0.75 and 0.3 mG, respectively, while comparable EMDEX data inside the unloaded vehicle are 0.6-0.9 mG and 0.11-0.3 mG for in-station samples. The *MultiWave*® and EMDEX measurements are in general agreement.
- Moving TR08, Table 3-3: For the unloaded TR08 vehicle, *MultiWave*® data are 3.0 (+/- 2.0) and 8.3 (+/- 3.5) mG for PF and HF means, while the corresponding EMDEX results are 4.9 and 2.8 mG, with a BB resultant of 6.2 (+/- 9.0) mG. These datasets agree only approximately, in view of the fact that *MultiWave*® data produce more powerful statistics, were collected over a much broader frequency range, and represent more frequent sampling.
- Attendant's cab, Tables 3-6 and 3-7 for waist level: *MultiWave*® EMF levels are 8.3 (+/- 9.0) at PF, and 40.6 (+- 20.0) at HF, with maxima of 57.0 mG at PF and 93.0 mG at HF; whereas the EMDEX record in the cab was 77.0 for the BB resultant of PF and HF, and 54.0 at HF. The *MultiWave*® and EMDEX measurements are in general agreement.
- Passenger locations at waist level, Table 3-9: *MultiWave*® EMF levels are identical for loaded and unloaded moving vehicles: respectively, PF of 2.8 and 3.0 and HF of 8.3. These levels are in good agreement with the in-vehicle EMDEX mean values of 6.0 mG and 8.2 mG, for unloaded and loaded TR08 (Table 8-1), respectively.
- In stations: Table 4-4 (PF) shows levels of 0.6 mG while the TR08 is stationary, and Table 4-5 (HF) shows non-detectable levels of <0.1 mG, which agree well with the EMDEX measurements recorded for the stationary TR08 shown (Table 8-2).
- EMF maxima near the guideway, for fast TR08 passes (> 300 km/h (188 mph)), from Figures 5-1 and 5-2: At the nearest point (about 5 m) from the guideway centerline, ERM recorded transient maximum EMF levels of 110-130 mG. As Table 8-1 and Figure 8-4 show, no levels this high were recorded with the EMDEX along the wayside, except inside the TR08, because of time averaging and slow instrument response. The wave capture technique, utilized by *MultiWave*® instrumentation, is better in recording EMF maxima and minima, and in determining the fall-off with distance from the guideway.

Representative EMF profiles for the TR08, shown in Figures 8-2 through 8-4, illustrate the highly variable exposure in time and space for typical in-vehicle and wayside locations, over a full range of operating conditions ,and agree with the key conclusion from the *MultiWave*® 3-D data displays and analyses.

The results for environmental ELF EMF exposure levels for magnetic fields resulting from PF and HF components (60-300 Hz) are summarized in Table 8-1.

The BB resultant, expressed as a mean value +/- standard deviation, is the root-sum-squared of the fundamental PF field and of the HF content.

Table 8-1. EMDEX Broadband (BB) EMF Summary for the TR08 Maglev System

Date-dataset	Location/ loading state	Mean (mG)	Std. deviation. (mG)	Max./Min. (mG)	90% data < X (mG)	Integrated time exposure (mG-hr)
8.14.01-1	In-vehicle/ empty	6	9.6	89/0.1	17	15.7
8.14.01-2	Wayside	0.2	0.7	17.5/0.01	0.3	0.25
8.15.01-1	In-vehicle/ loaded	8.2	14.5	123.5/0.1	18	18.3
8.15.01-2	Wayside	0.9	3.3	51.5/0.1	1.3	0.9
8.16.01	Guideway Switches	0.25	1.6	47.3/0.01	0.2	0.8

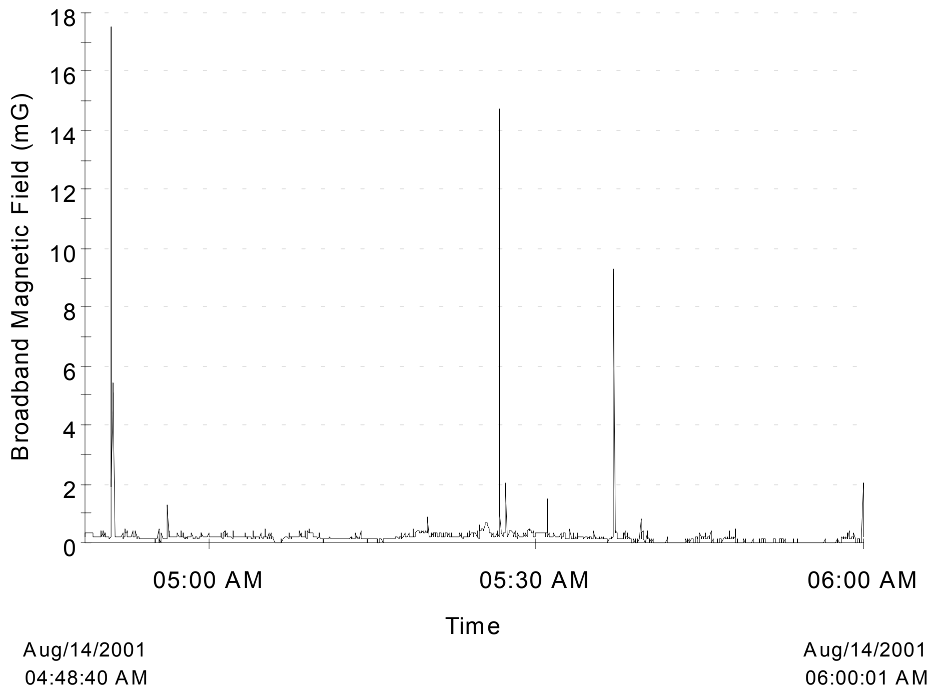


Figure 8-2. Background levels of broadband EMF recorded every three seconds from an automobile driving along the South loop of the guideway, as well as from a person walking along the guideway and crossing under the high-speed switch segment; EMF peaks were recorded when the TR08 passed by or passed overhead, and under the high voltage power line next to the radio control-tower*

* The EMDEX system was calibrated and the internal clock was set for Eastern Standard Time (EST) in the U.S.; this feature could not be changed. Local time during these measurements is six hours later than the times shown in the Figure.

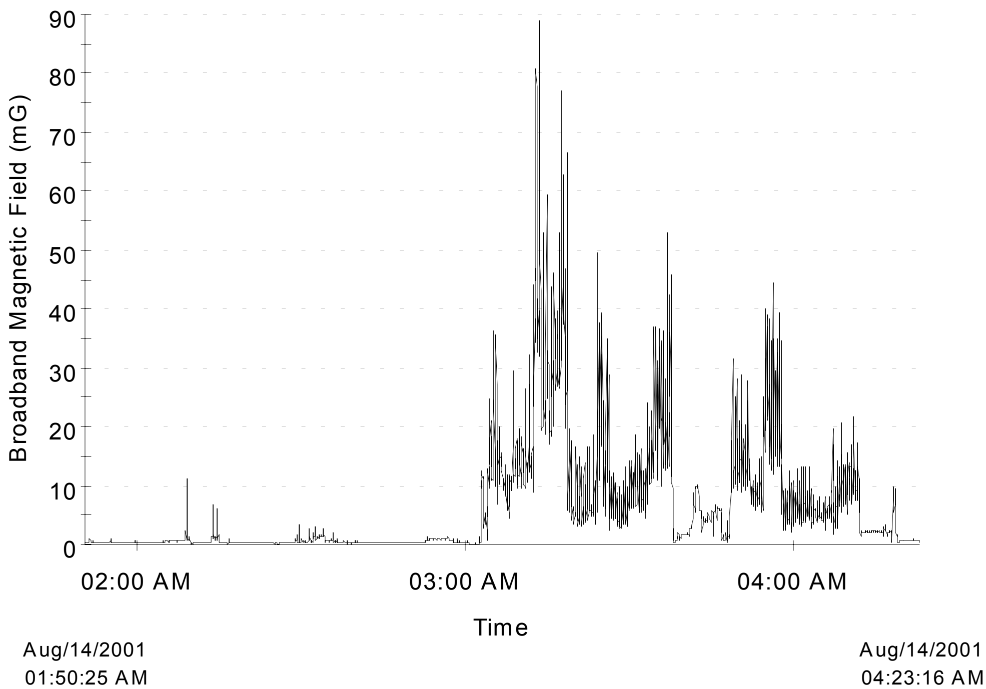


Figure 8-3. Broadband EMF personal exposure profiles inside the unloaded TR08 three-vehicle consist; low exposures correspond to TR08 standing in stations, while the peaks are indicative of acceleration or deceleration during two consecutive runs with peak speeds of 270 and 400 km/h (169 and 250 mph), respectively*

* The EMDEX system was calibrated and the internal clock was set for EST in the U.S.; this feature could not be changed. Local time during these measurements is six hours later than the times shown in the Figure.

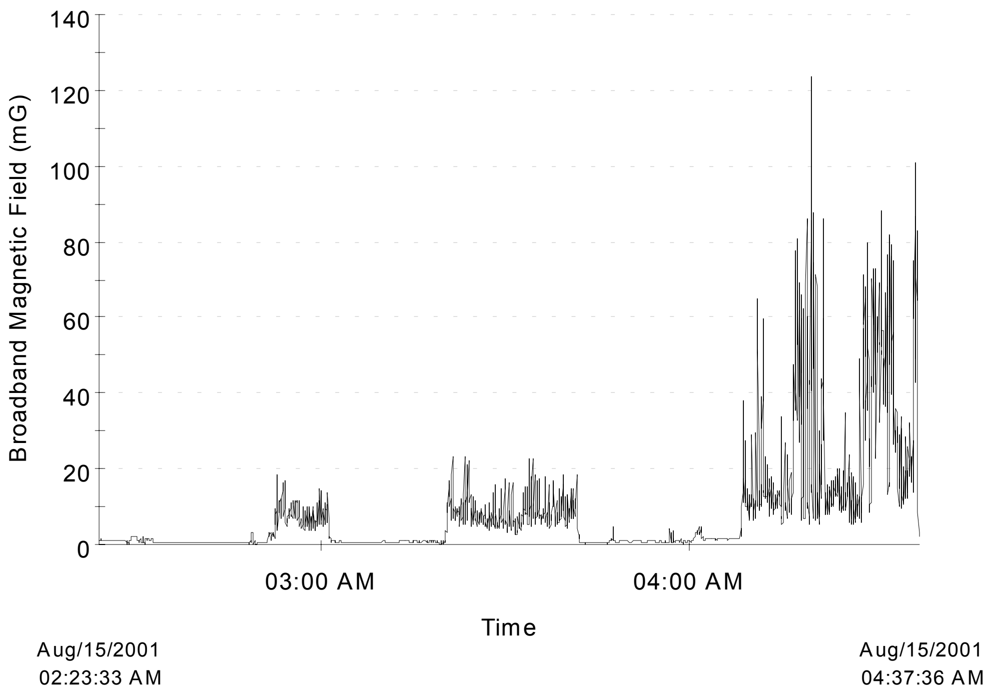


Figure 8-4. TR 08 EMF broadband resultant for three TR08 runs, the first in an unloaded vehicle, the last two in fully loaded cars; low EMF intervals correspond to the TR08 waiting in stations*

* The EMDEX system was calibrated and the internal clock was set for EST in the U.S.; this feature could not be changed. Local time during these measurements is six hours later than the times shown in the Figure.

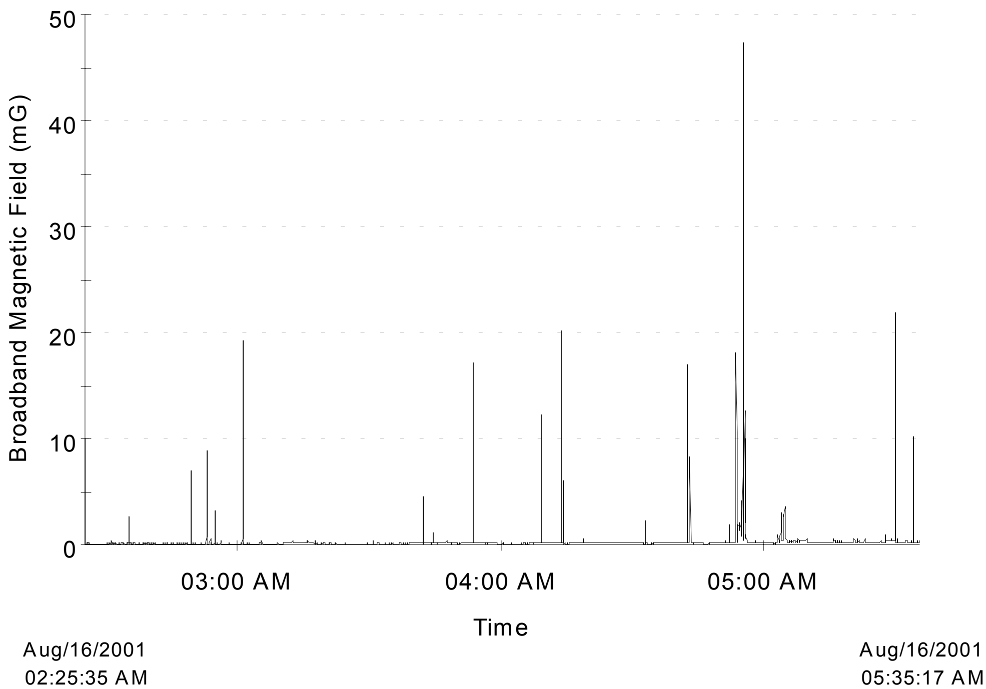


Figure 8-5. Typical wayside EMF broadband resultant exposures (starting at same at-grade location as the ERM team, and walking to locations just under the guideway, from steel to concrete and hybrid sections and to a switching substation next to the RF transceiver; the EMF peaks correspond to an overhead passby of the TR08 at speeds from 180 to 400 km/h (113 to 250 mph)*

8.4 FINDINGS AND CONCLUSIONS

8.4.1 Validation and Verification

The following observations are based on the EMDEX measurements, summarized in Table 8-1, and shown graphically in Figures 8-2 through 8-5.

The wayside background levels of EMF (within the EMDEX measurement bandwidth) are very low (typically below one mG), even when accounting for short-duration peak exposures of 50 mG when the TR08 passes overhead or next to at-grade guideway segments. Such low EMF levels were encountered for other railway right-of-way (ROW) conditions in rural areas (in the U.S. and France), but are below EMF environmental levels in typical urban environments.

* The EMDEX system was calibrated and the internal clock was set for EST in the U.S.; this feature could not be changed. Local time during these measurements is six hours later than the times shown in the Figure.

In-vehicle mean EMF personal exposure levels for seated passengers are 6.0-8.0 mG, even for a fully loaded consist. Short-duration peak EMF values of 90.0-125.0 mG occur, as seen in Figures 8-2 and 8-3, corresponding to rapid acceleration or deceleration and reflect higher current levels in the guideway magnets.

The EMF data in Table 8-1 indicate that 90% of measurements are below 18.0 mG inside the TR08 vehicle, and below 0.5-1.5 mG for outdoor wayside locations in the rural setting of the TVE test-site, no matter what the guideway material (steel, hybrid, or concrete).

The time-integrated EMF exposure (in mG-hr, Table 8-1) was assumed by some researchers (NIEHS 1998) to be a relevant "exposure dose." In this case, the data in Table 8-1 reflect those measurements collected over the duration of two-hour runs, though it should be noted that the TR08 was not operating continuously during the entire two hour period. Such data represent an occupational exposure (2-8 hrs) rather than a commuting passenger's integrated exposure (15 min-30 min). The current occupational EMF exposure safety standards (ICNIRP, ACGIH 2001) refer to limits considered safe and harmless for eight regular hours of continuous daily repeated work exposure. In-vehicle EMF passenger and worker "exposures" for 2-hr. measurement runs were found to be generally below 20.0 mG-hr.

The EMDEX personal EMF exposure data presented in this chapter are considered to be representative of all TR08 locations and operational conditions, as both worker (attendant's cab and power substation proximity) and passenger areas (in all three sections and on station platforms) were sampled. Datasets were recorded for up to two-hour intervals, which include several round trips, and involve the full range of TR08 speeds.

The ultra-wideband (10 MHz-100 GHz) RF EMR levels, monitored with a Nardalert Model 8718 personal exposure meter in the vicinity of the TVE during TR08 operations and next to power and control facilities, were, at all times, not distinguishable from background noise levels, with the exception of a small measurable signal right under the wayside transponder tower. However, the RF data never exceeded 10% of the FCC limit— even under the transceiver wayside tower at TVE . Therefore EMR levels from any TR08 transmitter fully comply and are well below the FCC's 5 mW/cm^2 public exposure safety limit when integrated over the spectrum. This finding also agrees with ERM's reported results, and independently verifies their conclusion.

8.4.2 Overall EMF/EMR Survey

The overall conclusion from the environmental EMF/EMR site survey of system-related potential exposures of workers, passengers, and the public living or working along the guideway, is that there are no unusual or higher levels of exposure from the TR08 Maglev System than there are from well-accepted operational electrified rail and transit systems (see Section 7.4). Although the EMF intensity and variability of the TR08 are comparable to other electric transportation systems, its frequency domain is unique to the Transrapid Maglev System. All measured magnetic and electric fields, even at maximum levels for very short durations, are below currently applicable national and international EMF/EMR occupational and public human exposure safety standards and guidelines (see Section 7.5).

Therefore, this report documents that the EMF/EMR aspects of the TR08 Maglev System (facilities, vehicles, guideway) and operations are fully compatible with environmental performance goals and with current human exposure safety limits.

However, were any modifications to power and propulsion systems and to the elevated guideway design necessary for U.S. or other outside applications, it is recommended that an EMF/EMR survey be conducted prior to start-up of service operation. Such a survey is necessary to check that environmental EMF/EMR levels are not excessive, to verify compliance with any state limits on electric and magnetic fields for power lines along the ROW, and to ensure that electromagnetic compatibility and interference will not pose safety hazards from any U.S. maglev system and operations to wayside communication facilities, airports, hospitals, etc.

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APPENDIX A TEST PLAN

This appendix contains the original text of the Final Test Plans for measurement of electromagnetic fields and radiation (EMF/EMR) as well as noise and vibration associated with the Transrapid TR08 Maglev System. Details of the noise and vibration measurements have been omitted, as they are not relevant to this report.

The Final Test Plans were completed in June 2001. MAGLEV, Inc., and Electric Research (ERM; also known as Electric Research & Management, Inc.) authored these plans, with input and additional material from technical staff of the Federal Railroad Administration (FRA), the John A. Volpe National Transportation Systems Center (Volpe Center), Harris Miller Miller & Hanson (HMMH), Transrapid International (TRI), and IABG (Industrieanlagen Betriebsgesellschaft, a European scientific/technical services company). The Test Plans were also reviewed by representatives of the Baltimore-Washington Maglev Project, including an environmental planning staff person from the Maryland Transit Administration and a representative from Parsons-Engineering Science, a consultant for the Baltimore-Washington Maglev Project.

Magnetic Levitation Transportation Technology Deployment Program

Section XIV, Pre-Environmental Impact Statement (EIS) Activities

Field Measurement of the EMF, Noise and Vibration Characteristics of the TR08

Final Test Plans

SECTION XIV
Pre-Environmental Impact Statement (EIS) Activities
Part B and C Final Test Plans

Field Measurement of the EMF, Noise and Vibration Characteristics of the TR08

Disclaimer

Section 1: Introduction

This report documents the final test plans for conducting the field measurements of the electromagnetic fields (EMF), noise and vibration characteristics of the TR08. This document is being submitted to the FRA for approval of the test plans prior to implementation.

The purpose of these tests in part is to repeat previous EMF and noise measurements that were made on the TR07 in the early 1990's. The test plans are also supplemented to include vibration measurements that were not part of the original 1990 FRA test program. The completion of the test plans, data evaluation, and data analysis will result in detailed documentation of the electrical emissions, noise emissions and vibration characteristics of the Transrapid Maglev System and TR08 vehicle. This measurement data will be utilized to support the required environmental planning and deployment activities for any Transrapid Maglev Project in the United States. This work is being accomplished as part of the Federal Railroad Administration's (FRA) Scope of Work Amendment No. 2, Section XIV Pre-Environmental Impact Statement (EIS) Activities, part B and Part C.

Section XIV part B and C is restated here for reference.

B. Field Measurement EMI, EMF and EMR Characteristics of TR08

In cooperation with assigned staff from the Volpe National Transportation Systems Center (VNTSC), the Grantee shall develop a plan to measure and analyze the electromagnetic interference (EMI), electromagnetic fields (EMF), and the electromagnetic radiation (EMR) caused by the operation of the TR08 vehicle in service at the Transrapid Maglev Test Track in Emsland, Germany. With the approval of the FRA, the plan will be implemented.

C. Field Measurement of Noise and Vibration Characteristics of TR08

In cooperation with assigned staff from the Volpe National Transportation Systems Center (VNTSC), the Grantee shall develop a plan to measure and analyze the noise and vibration caused by the operation of the TR08 vehicle in service at the Transrapid Maglev Test Track in Emsland, Germany. With the approval of the FRA, the plan will be implemented.

MAGLEV, Inc. is performing the role of coordinating the diverse technical requirements and logistics associated with the planned test campaign as it relates to US maglev projects.

Section 2: Test Plan Development and Finalization

Under the direction of the FRA, MAGLEV, Inc. contracted the vendor Electric Research Management (ERM) for the electrical emissions testing and the vendor Harris, Miller, Miller and Hanson (HMM&H) for the noise and vibration testing of the TR08. The test plans contained in appendix A and B of this report are the collective efforts of the vendors, staff at Volpe and MAGLEV, Inc. These plans were developed in cooperation with and with the approval of Transrapid International and the TVE test center staff.

Numerous technical interchanges and discussions were held with Volpe personnel, Electric Research Management (EMF test vendor), Harris, Miller, Miller and Hanson (noise and vibration test vendor) and Transrapid in finalizing the plans for the environmental testing of the TR08. As part of this effort, Transrapid recommended and supported a pre-meeting with the vendors and MAGLEV, Inc at the test facility. The purpose of this meeting was to discuss and finalize the details of the draft test plans, familiarize the vendors with the test facility and to select the actual guideway and vehicle locations for measurements.

On February 15-16, 2001, the vendors and MAGLEV, Inc. traveled to the test facility in Emsland, Germany for a meeting with Transrapid and the TVE test facility personnel. As a result of this meeting, agreement was reached on a consolidated test matrix for the noise, vibration and EMF testing. The consolidated test matrix and the measurement locations are documented in appendix C of this report. The noise testing requires the most preparation and time to conduct and therefore drives the test matrix activities. The EMF and vibration measurement activities have been developed to permit all work to be done concurrently with the noise measurements.

Pending approval of the test plans by the FRA, the actual field measurements are scheduled to begin during the week of April 2, 2001 at the test facility.

Section 3: TVE Test Facility Layout and Operational Considerations

The TVE test facility layout and daily operating parameters were considered in developing the final plans. The TVE test facility consists of a 31.5 km track as shown in Illustration 1 below. Various guideway types and configurations (steel, concrete, hybrid, at grade and elevated) exist at the test track. The final plan includes measurements at each representative guideway type.

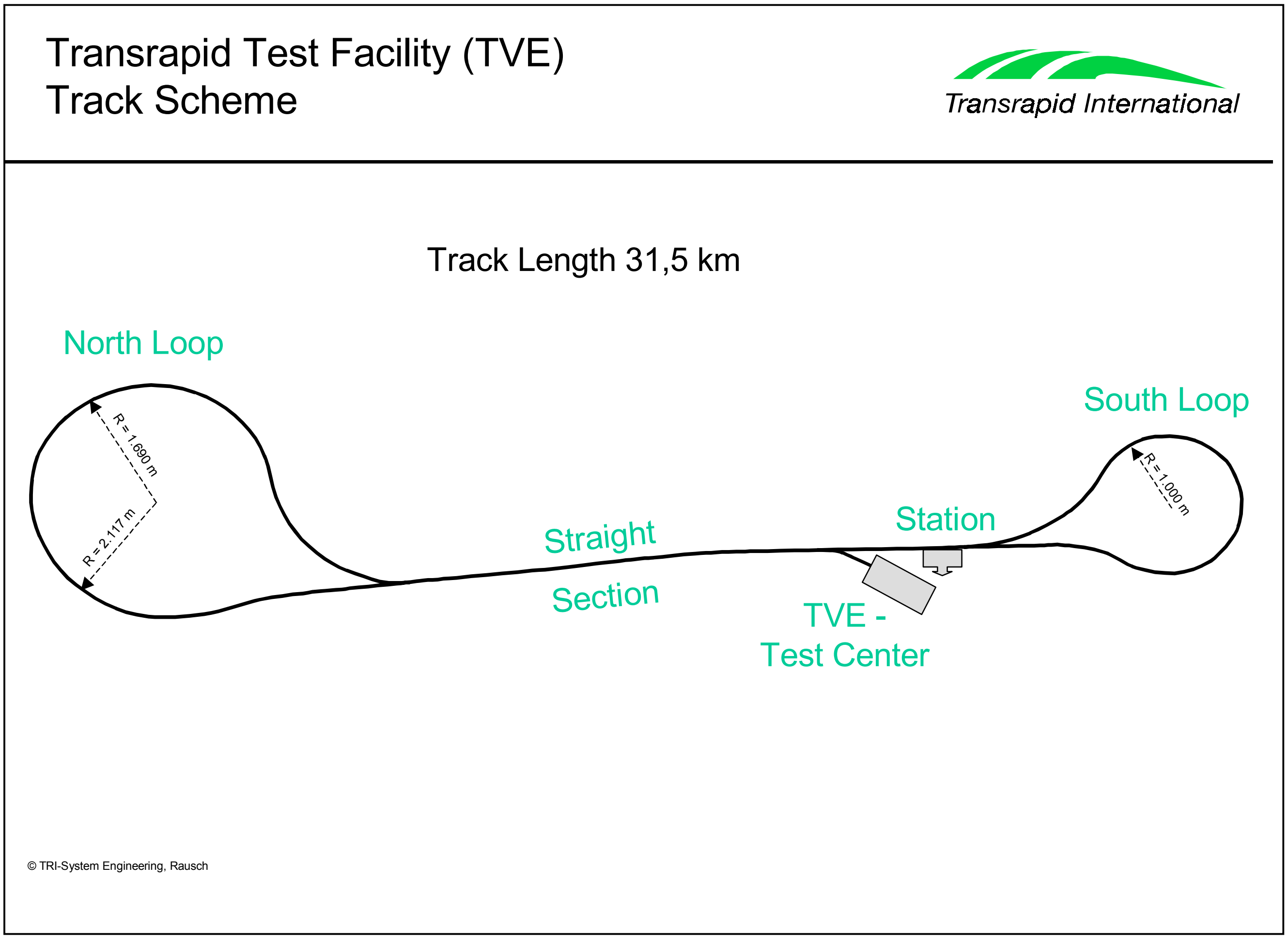

Illustration 1 Transrapid TVE Test Facility Track Scheme

The test facility normally operates from approximately 8:30 AM until 2:30 PM on Tuesday through Friday of each week. The train operates approximately every 30 minutes in the morning hours and every 45 minutes during the afternoon hours. Monday is reserved for facility maintenance and other test activities therefore no measurements requiring vehicle movements have been scheduled on Mondays. Based on the required measurements to fully characterize the noise, vibration and EMF of the system, a period of six days is required to conduct the field measurements.

Table 1: TVE Normal Operating Schedule

Trip Number[1)]	Time of Departure [2)]	Speed Profile [3)]
N1	08:30 am	First Trip of the day, guideway inspection with low speed
N2	09:30 am	Demonstration speed profile
N3	10:00 am	Demonstration speed profile
N4	10:30 am	Demonstration speed profile
N5	11:00 am	Demonstration speed profile
N6	00:15 pm	Demonstration speed profile
N7	01:00 pm	Demonstration speed profile
N8	01:45 pm	Demonstration speed profile
	02:30 pm	Transfer into the Test Center

1) Each trip encompasses two rounds with a total trip length of 80 km
2) Departing at the TVE-Station
3) Speed profile can be adjusted according to the test requirements

Excluding the first inspection trip of the day, each trip consists of two complete runs of the entire test track length. This provides for a total of twenty-eight pass-bys (2 rounds x 2 pass-bys x 7 trips per day = 28 pass-bys) at each of the guideway locations in the straight sections of the track. Table 2 provides a summary of the trips and number of pass-bys.

Table 2, Pass-by Events along the Straight Section of the Guideway

Trip Number	Time of Departure At Station	No. Of Event Pass-by	Direction Towards	Vehicle Speed [1)]
N2	09:30 am	1.	North, 1. Round	up to local max. Speed [2)]
		2.	South, 1. Round	up to local max. Speed [2)]
		3.	North, 2. Round	up to local max. Speed [2)]
		4.	South, 2. Round	up to local max. Speed [2)]
N3	10:00 am	5.	North, 1. Round	up to local max. Speed [2)]
		6.	South, 1. Round	up to local max. Speed [2)]
		7.	North, 2. Round	up to local max. Speed [2)]
		8.	South, 2. Round	up to local max. Speed [2)]
...	...	.		
...	...	.		
N8	01:45 pm	25.	North, 1. Round	up to local max. Speed [2)]
		26.	South, 1. Round	up to local max. Speed [2)]
		27.	North, 2. Round	up to local max. Speed [2)]
		28.	South, 2. Round	up to local max. Speed [2)]

1) Speed can be adjusted according to the test requirements
2) Local maximum speed depends on location

The speed profile for the normal operating sequence permits runs of up to 400 km/h in the straight section of the test track. Referring to Illustration 2, the normal operating sequence will provide a run of 150 km/h, 400 km/h, 200 km/h and 300 km/h in the straight section of the test track for each complete trip (two rounds). Trip time to complete the two rounds is approximately 22.5 minutes. Accounting for time necessary to download measurement data, approximately two trips will be made each hour. Additional trips can be added to the daily schedule in the event of delays in completing the measurements. The normal daily operating speed profile is shown in Illustration 2.

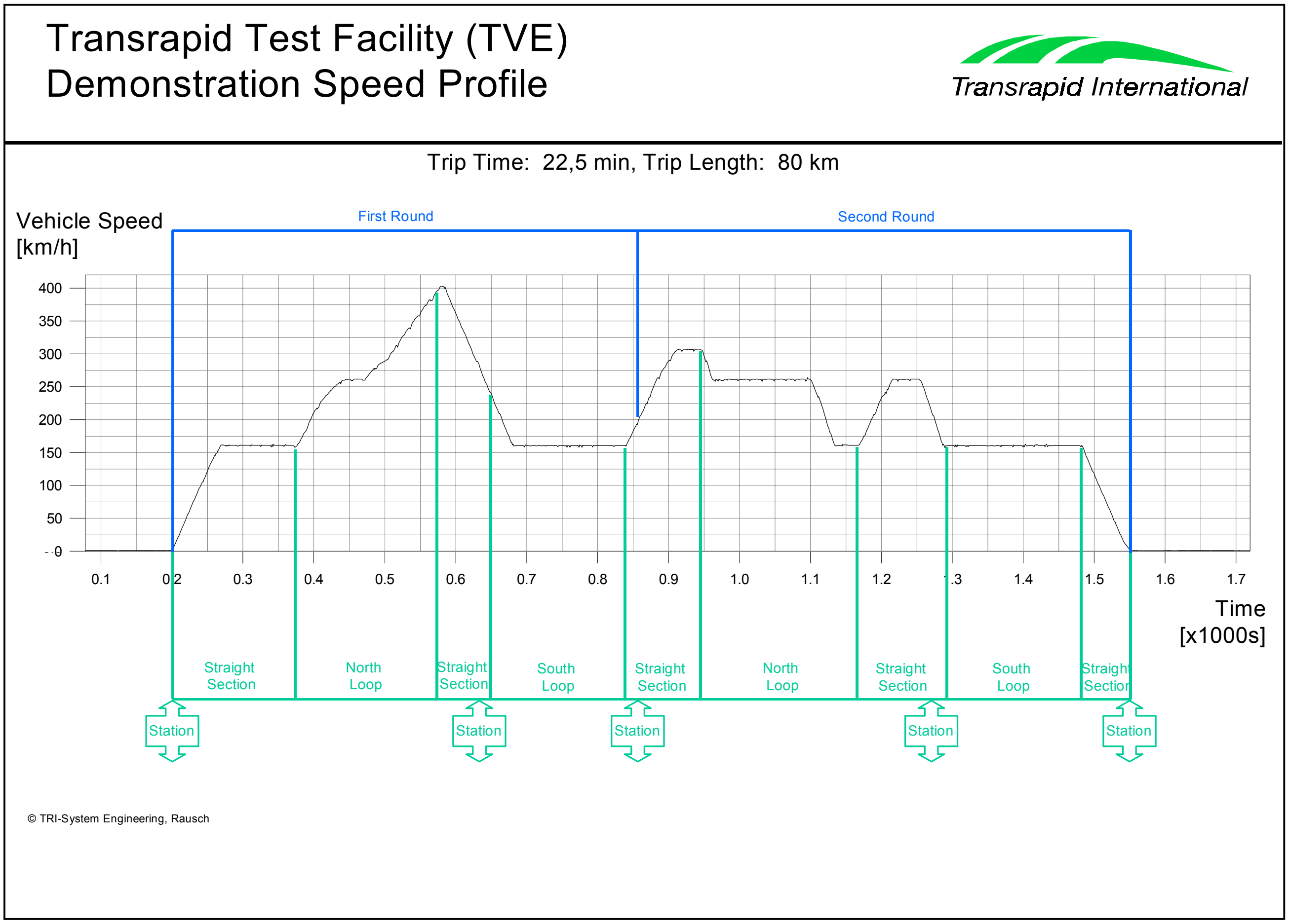

Illustration 2, Transrapid Test Facility (TVE) Demonstration Speed Profile

Guideway Measurement Locations and Local Speeds.
As part of the pre-meeting with Transrapid and the TVE facility personnel, the vendors conducted a survey of the facility and guideway locations. The purpose of this survey was to finalize the test locations for measuring the various guideway types (steel, concrete, hybrid, at grade and elevated) for guideway design and installations that represent the configurations that could be utilized for

a US application. The survey also included a review of the local terrain conditions to determine the suitability of the site for measurement purposes. Based on the survey and Transrapid's description of the various guideway types and configurations, specific measurement sites were selected as shown in Illustration 3. The associated maximum speeds at each location are also identified in this Illustration.

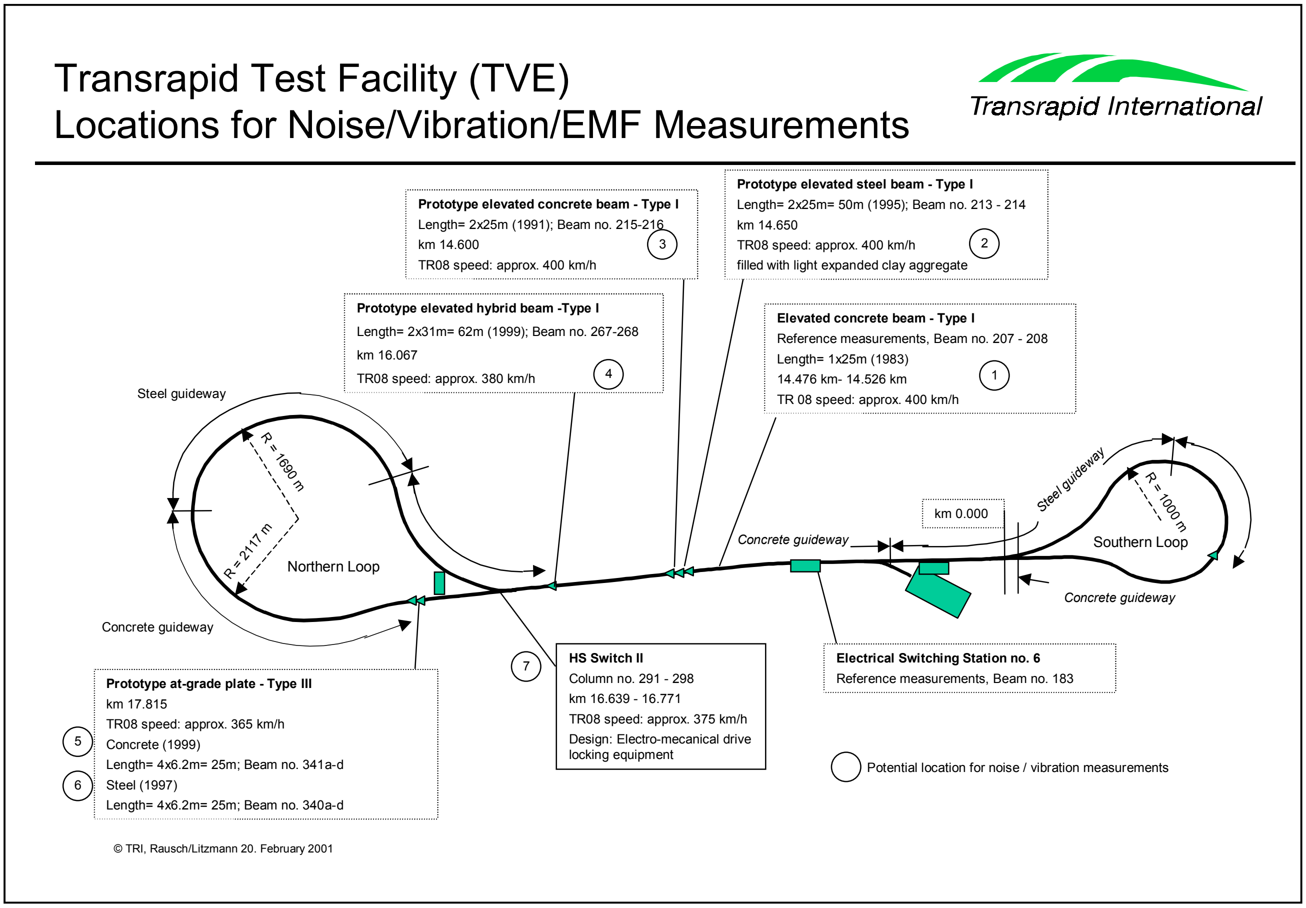

Illustration 3, Location of Measurement Sites and Associated Maximum Speeds

The numbered circles on Illustration 3 identify the basic order that the noise measurements will be conducted. As previously identified, the vibration and wayside EMF measurement teams will coordinate their activities with the noise measurement team. This way each vendor will have unrestricted access to each measurement location during the testing time.

Vehicle Measurement Locations. EMF measurements begin at several locations on the vehicles. These vehicle measurements will be made concurrently with the runs for the noise and vibration testing. Specific locations for measurements on the vehicle will be identified based on the location of propulsion, HVAC, communications and other onboard equipment. Measurements will be made at sixteen locations within the vehicle plus the attendant's compartment. This will result in a complete mapping of the spatial distribution of the electrical fields on board the vehicle.

Section 4: Summary

MAGLEV, Inc. has worked with Electric Research Management, Harris, Miller, Miller and Hanson, Volpe, Transrapid International and the TVE test facility personnel to develop the final test plan presented in this document. The plan incorporates all comments from the participants and represents a well-structured methodology to obtain, analyze and document the EMF, noise and vibration characteristics of the Transrapid Maglev System and TR08 vehicle.

The measurement location diagram and corresponding consolidated test matrix in Appendix C of this report summarizes each of the daily testing activities. The type of measurement (EMF, noise or vibration), trip number (N2 – N8), guideway measurement location, measurement equipment configurations and pass-by speeds for each series of measurements is identified in the matrix.

The testing is scheduled to commence during the week of April 2, 2001 and will be completed the following week. An additional day for making measurements has also been built into the plan to account for potential equipment failures or weather related delays.

Following completion of the testing in April, all data will be reduced, cataloged and evaluated by the vendors. The vendors are scheduled to complete the data evaluation and analysis and document the testing in a final report approximately two months following completion of the field measurements.

Section 5: Reporting of Results

Subsequent to preparation of Appendices A and B of this document, it was agreed that a collaborative effort as outlined in this Section will be used to prepare and publish final reports that provide documentation and results of the environmental tests.

Background. It is anticipated that the measurement results will be used in the development of maglev project environmental impact statements required under the National Environmental Policy Act (NEPA). The results should be presented in a manner that is acceptable from a technical and objective standpoint, and will minimize questioning of their validity. This information will also become a part of the permanent public record and will be posted by the FRA on a website for general access.

Report Format. The information will be documented in two separate FRA/Volpe Center official reports, one for EMF/EMR and the other for noise and vibration. These reports will be produced as a collaborative effort among the contractors, MAGLEV, Inc. and the federal staff of the Volpe Center. The "Authors" Box # 6 of the Report Documentation Page will list contributing staff members from contractors, MAGLEV, Inc. and the Volpe Center. The "Performing Organization" Box # 7 will identify their respective organizations. Box # 9 will show the FRA and the Port Authority as "Sponsors".

The Volpe Center staff will write an introductory chapter that describes the maglev deployment program, addresses the administrative process under which the tests were done, describes the MAGLEV Inc. and FRA/Volpe Center validation, verification and quality assurance efforts, and gives a general summary, interpretation, and perspective of the results. The contractors will prepare the remainder of each report including appendices. Descriptive summary statistics of the EMF/EMR, noise (including spectral time histories), and vibration levels measured on or near the TR08 will be reported in tabular form and summarized graphically. These data will be event-based, i.e., provided for the specific locations and speeds of the vehicle at the time of the measurements. All documentation will be provided in hardcopy and electronic form. Electronic information will use Microsoft office products (WORD for text/ tables, Excel for spreadsheet and graphs) as well as portable document format (.pdf).

Test Plan for EMF Testing of the TR08

(Appendix A in original Test Plans)

Test Plan Addendum

Measurements to Characterize the Static and ELF Magnetic Fields and Obtain Summary Data on ELF Electric fields, VLF and LF Magnetic Fields, and RF Power Density in Areas of Public Exposure Within and Near the Transrapid TR-08 Magnetically Levitated Transportation Vehicle

February 28, 2001

Objective
This document provides minor modifications to the attached Draft #2A test plan of the same title previously submitted on November 22, 2000, for measurements to be conducted in or near the Transrapid TR08 magnetically levitated transportation system. This addendum provides greater clarification of certain issues resolved during an on-site pretest meeting at the Transrapid Test Facility (TVE) on February 16, 2001. It also describes two additional tests not covered in the subject test plan.

All planned testing and schedules are identified in the consolidated test matrix.

This addendum does not change any of the objectives of the original test plan nor does it reduce its scope.

Modifications
This addendum provides the following modifications to the test plan.

1. The measurement team need not collect Guideway current measurements. The TVE data acquisition system provides the necessary data with better resolution than could be obtained by procedure outlined in the test plan. TVE personnel have agreed to provide their logged data of real and reactive current during all test runs in a digital format demonstrated to be suitable for required analysis.

2. Onboard measurements will be made during a standardized trip consisting of two laps around the test track rather than the one lap stated in the test plan. This change is required to accommodate the operational schedules of the TVE and achieve compatibility with the noise measurement test plan. The data “snapshot” sample rate will be reduced to accommodate the longer time of the two-lap trip. The resulting data sets will be as large or larger than those anticipated from the original test plan and produce equal or better statistical description of the temporal variability in field levels within the vehicle.

3. Measurements along the guideway will be collected during two passes (different speeds) of the vehicle at five different locations rather than the single pass described in the test plan. Magnetic field data at two levels of guideway current will facilitate more accurate normalization of field levels to current.

Additions
This addendum provides the following additions to the test plan.

1. A complete set of measurements of the type proposed for onboard measurements in passenger seats will be preformed in the operator’s seat in

the nose of the lead vehicle. This addition is in response to the VTSC request for data in the onboard worker's compartment.

2. Measurements will be made near the wayside switching cabinets (2 types) used to distribute power to individual guideway sections. These lateral profile measurements will be similar to those described in the test plan for other guideway locations. In that way, an analysis can be conducted to determine if those cabinets materially contribute to wayside field levels. Two tests are scheduled to assess the standard cabinets and a newer design of switching enclosures developed for the anticipated Hamburg-Berlin line. This addition is to address a wayside infrastructure component not previously addressed.

Clarifications

This addendum provides the following clarifications to the test plan.

1. The specific locations for onboard measurements in the passenger compartments have been identified by characteristic in the test matrix. Specific seat numbers will be chosen upon receipt of drawings showing the placement of under-floor equipment. If satisfactory drawings are not received prior to the tests, those seat assignments will be made the day before the tests in consultation with TRI personnel and inspection of the vehicle. The locations are chosen as follows to assess various potential field sources:

Lead Vehicle		
	Reference location to verify trip-to-trip Consistency	1 location
	Side-to-side guideway fields	4 locations
	Front-to-back guideway fields	2 additional locations
	Proximity to onboard sources	4 locations
Middle Vehicle		
	Vehicle-to-vehicle fields	3 locations
Trailing Vehicle		
	Vehicle-to-vehicle fields	3 locations

2. Specific locations for guideway measurements have been selected based upon the full range of beam types that would likely be used in a US installation. They are:

Beam 213	Prototype elevated steel beam, 2x25m
Beam 215	Prototype elevated concrete beam, 2x25m
Beam 267-268	Prototype elevated hybrid beam, 2x31m
Beam 340 a-d	Prototype at-grade steel plate, 4x6.2m
Beam 341 a-d	Prototype at-grade concrete plate, 4x6.2m

DRAFT #2A

Test Plan

Measurements to Characterize the Static and ELF Magnetic Fields and Obtain Summary Data on ELF Electric Fields, VLF and LF Magnetic Fields, and RF Power Density in Areas of Public Exposure Within and Near the Transrapid TR-08 Magnetically Levitated Transportation Vehicle

November 22, 2000

Objective

This document provides a concise description of measurements to be conducted in or near the Transrapid TR08 magnetically levitated transportation system. The purpose of these measurements is to repeat previous ELF magnetic field testing of the TR07 vehicle using similar protocols and instrumentation. These measurements will focus on passenger exposure onboard the vehicle, at the station platform, and near guideways. The Federal Railroad Administration (FRA) has requested this testing program as part of the Pre-Environmental Impact Statement (EIS) Activities.[1]

Along with the original TR07 onboard and guideway measurements, additional measurements were recorded in or near facilities associated with the test track in order to establish typical occupational exposure levels. Because these facilities have not changed significantly and because the facility designs, as implemented in the US, are likely to be substantially different from the test track, this test plan does not include a repeat of the facility testing.

The measurements described herein were outlined in Electric Research & Management, Inc. (ERM) Proposal dated September 11, 2000, which is included as attachment #1 of this plan. The measurements will:

- characterize and quantify the static and extreme low frequency (ELF) magnetic fields to which passengers may be exposed while traveling in the Transrapid TR08 magnetically levitated transportation system
- characterize and quantify the static and ELF magnetic fields in areas of public access within the station and on the station platform
- characterize and quantify the static and extreme low frequency ELF magnetic fields in areas of public access beneath or near the guideway
- collect concurrent data on the amplitude and characteristics of the electric current in the guideway to facilitate reliable extrapolation of the field conditions measured at Transrapid's Emsland test facility to those which will exist will exist within and near systems deployed within the United States even though those future systems may differ in route conditions, speed profiles, and consist configurations
- obtain summary data on the ELF electric field within the TR08 vehicle, station, station platform, and near the guideway
- obtain summary data on the very low frequency (VLF) magnetic field within the TR08 vehicle, station, station platform, and near the guideway

- obtain summary data on the low frequency (LF) magnetic field within the TR08 vehicle, station, station platform, and near the guideway

[1] **FRA Scope of Work Amendment No. 2. Section XIV. Pre-Environmental Impact Statement (EIS) Activities, Part B, Field Measurement EMI, EMF, and ERM Characteristics of TR 08 (12/31/2000)** "In cooperation with assigned staff from the Volpe National Transportation Systems Center (VNTSC), the Grantee shall develop a plan to measure and analyze the electromagnetic interference (EMI), electromagnetic fields (EMF), and the electromagnetic radiation (EMR) caused by the operation of the TR 08 vehicle in service at the Transrapid Maglev Test Track in Emsland, Germany. With the approval of the FRA, the plan will be implemented."

- obtain summary data on the radio frequency (RF) power density within the TR-08 vehicle, station, station platform, and near the guideway arising from the system's communications and control transmitters

The data obtained will be compatible with or exceed data obtained at the corresponding locations in or near the TR07 vehicle. The measurement protocol incorporates the relevant portions of the protocols implemented in previous measurements on several transportation systems sponsored by the US Department of Transportation.

Principal Equipment

Data logging:
5 MultiWave System II 4 channel digital data acquisition systems (Electric Research)

Static and ELF magnetic field Measurements:
4 1mT three-axis fluxgate magnetometers (Bartington)
1 articulated sensor-mounting mannequin

ELF electric field
1 MultiWave single-axis optically-isolated electric field sensor (Electric Research)

VLF magnetic field
1 MultiWave three-axis RMS VLF magnetic field sensor (Electric Research)

LF magnetic field
1 MultiWave three-axis RMS LF magnetic field sensor (Electric Research)

RF power density
1 broadband isotropic RF electric field sensor, model 4455 (Holaday)
1 graphic readout, model 4460 (Holaday)

Guideway current:
(Current transformers and potential device to be specified depending upon need)

Personnel and Support
A two-member measurement team from Electric Research will set up virtually all of the equipment and perform all of the field measurements described in this test plan. Personnel from TRI or the test facility will be required to operate the system and vehicle, attach any current transformers or potential devices required, and record vehicle speed and guideway current (if possible). Support from TRI or facility personnel equipped with two-way radios will also be helpful during measurements near the guideway to notify the measurement team of the approaching vehicle. Support from TRI or the test facility personnel will also be required to obtain general information about the facility and

vehicle to assist in selection of optimum measurement locations within the vehicle and along the guideway.

Procedures
Guideway Current Measurements

To facilitate extrapolation of the magnetic field conditions and intensities measured on the TR-08 system configuration at the Emsland test facility to that of somewhat different configurations proposed for various locations in the United States, data regarding the real and reactive components of guideway current are required at the time of each magnetic field measurement. If the Emsland test facility has the capability of recording those parameters (or other parameters from which they can be extracted) on a continuous basis (or sampled basis with a sample rate of at least once every few seconds) their cooperation in providing those data will be extremely helpful.

If the test facility lacks that capability, the measurement team will, with the permission of TRI and the test facility, measure the guideway current. To accomplish this measurement, calibrated current transformers will be placed around cables feeding the guideway or around the secondary leads of existing current transformers measuring that current. CT placement on the secondaries of existing current transformers is the preferred approach because it does not require close proximity to high power equipment. In order identify real and reactive components of the guideway current, a concurrent measurement is required on one of the phase voltages. The preferred approach is to attach a small potential divider to the secondary leads of an existing potential device. If that is not practical, a high-voltage (30 kV) potential divider will be connected at an appropriate location.

Signals derived from the three current transformers and the one potential divider will be recorded with one of the MultiWave recorders. One test engineer from Electric Research will operate this equipment making measurements concurrent with the magnetic field measurements carried out by the other member of the team.

Because of uncertainty regarding the capabilities of the test facility, their willingness to permit attachment of current and potential devices to their system, and the ratings of the required current and potential devices, this task requires verbal coordination before traveling to Europe as well as at the test facility.

Onboard Measurements

It is anticipated that the magnetic fields within the TR08 are highly variable over space, time, and operating condition. To appropriately characterize the short-term temporal characteristics of the field, static and ELF fields will be measured with three-axis fluxgate magnetometers and recorded in the MultiWave digital data recorders using a waveform sampling technique compatible with Fourier spectral analysis. At each sensor location, the instantaneous field will be sampled at a high rate for a period of 200 ms. The resulting field ‘snapshot’ will resolve the frequency and intensity of all field components from 0 to 3000 Hz with a resolution of 5 Hz.

Longer-term temporal variations in field conditions associated with system operating condition will be characterized by taking repeated field ‘snapshots’ at approximately 10 per minute. The actual rate will be selected to permit uniform sampling over the period of time required to levitate briefly at the station, accelerate to a speed of at least 386 km/h, circumnavigate the test course, and return to the station without exceeding the storage capacity of the recording devices.

Spatial variability of the static and ELF magnetic field over the dimensions of a passenger’s body will be documented by performing simultaneous measurements at locations representing the head, waist, and feet of a seated or standing passenger. These measurements are accomplished with three fluxgate magnetometers securely clamped in an articulated plastic mannequin which can be stood upright or seated in any seat while maintaining the anatomically relevant placement of the sensors.

Spatial variability within each car and among the three cars of the consist will be characterized by moving the sensor-equipped mannequin from one location to another and repeating the tests during another circumnavigation of the test track. Measurements on the TR07 vehicle were recorded at nine locations (with one being the reference location). Based on the spatial variation seen in the TR07 measurements, we believe that a minimum of nine passenger locations and the operator location should be measured in one car to assess the field variability arising from both the guideway and onboard sources. These ten locations will be selected after examination of the vehicle and consultation with TRI personnel to identify principal magnetic or high-current components. Additional measurement locations will be recorded in the same car as time permits to improve the detail of our spatial mapping. Measurements will be made at three locations in each of the other two cars of the consist to identify the variability in magnetic field conditions from one car to another. These three locations will be a subset of the nine monitored in the first car chosen based on onboard equipment placement to best identify the similarities and differences between vehicles.

For this technique to be effective, the operating profile during each lap of the test track and station stop (a minimum of 16 such trips) must be as repeatable as possible. Each operational profile should consist of a nearly complete regime of typical operation. A proposed operational regime is described below in the section “System Operating Profiles”. Approximately 10 to 15 minutes are required to set the mannequin and sensors at a new location and download the data to diskette for transfer to a laptop computer hard drive. To verify the repeatability of magnetic field conditions during the repeated trips, static and ELF magnetic field will be measured at one fixed location in the center car of the consist during every trip.

ELF electric field normal to the chest of a seated or standing passenger will be measured using the same waveform sampling technique discussed above for static and ELF magnetic field measurements. The free-body dipole sensor will be attached to the sensor mannequin and moved from seat to seat concurrent with the magnetic field measurements thereby recording the spatial variability of electric field within a car and from car to car.

RMS values of the VLF and LF magnetic fields will be recorded concurrent with the static and ELF magnetic field measurements by placing broadband omni-directional sensors (band-limited to the VLF and LF frequency ranges) at the hip of the sensor mannequin.

RF power density will be measured concurrently with the magnetic field measurements by placing a wideband electric field sensor at a suitable location on or near the sensor mannequin. The RF sensor head will be selected to include the frequency of the onboard and guideway control and communications transmitters (approximately 40 GHz).

Station and platform measurements

The equipment and procedures described above for onboard measurements will be used with small adaptations for measurements in the station waiting area and on the station platform. Using the instrumented mannequin, all of the parameters described above will be measured at two locations (one as near the guideway as practical and one as distant as practical) within the passenger waiting area during two operational conditions:

- while the vehicle approaches the station, stops, levitates, and departs, and
- while the vehicle passes the station without stopping.

Additional measurements will be made at numerous location on the station platform with the mannequin in the standing position while the vehicle is at the station (simulating conditions when passengers enter the vehicle). Since the vehicle operating condition is unchanging, only one waveform sample will be obtained at each position permitting rapid mapping of field conditions on the platform.

Guideway Measurements

Static and ELF magnetic field measurements will be made using the waveform sampling technique described above at a height of 1 m above ground at 4 incremental distances from the guideway (0m, 5m, 20m, and 35m for the high guideway, 5m, 10m, 25m, and 40m for the low guideway) while the vehicle passes. This test will be repeated at 4 to 8 locations as required to assess conditions near all available combinations of guideway material (steel or concrete), guideway elevation (high or low) and presence or absence of the power contact rail. Specific measurement locations will be selected in areas where high vehicle thrust is expected. During the guideway measurements, sufficient separation between the ERM equipment and the noise and vibration measurement equipment will be maintained to eliminate the possibility of interference.

At each location, static and ELF magnetic field ‘snapshots’ will be acquired at the maximum rate of the recorders during the brief period that the adjacent section of the guideway is active and the vehicle passes. Data will be collected during two passes with the vehicle exhibiting maximum thrust. At one location, data will be collected during two additional passes with the vehicle exhibiting moderate thrust.

During the above described static and ELF magnetic field measurements, the following additional parameters will be measured 1m above ground beneath the high guideway or 5m from the low guideway.

- vertical ELF electric field
- VLF magnetic field
- LF magnetic field
- RF electric field

Speed Measurements

Information about the vehicle speed will enhance interpretation of the magnetic field conditions and intensities measured on the TR-08 system configuration at the Emsland test facility. If the Emsland test facility has the capability of recording vehicle speed on a continuous basis (or sampled basis with a sample rate of at least once every few seconds) their cooperation in providing those data will be extremely helpful.

System Operating Profiles

To most efficiently achieve the objectives of this measurement effort, the following system operational profiles are required.

Onboard Measurements

15 or more repeats of the following profile:

> Levitate briefly at the station, accelerate at the standard rate to a speed of at least 386 km/h, circumnavigate the test course, return to the station decelerating at the standard rate, and remain at the station in a condition representing passenger boarding.

Approximately 10 to 15 minutes are required between profile repeats to download data from the recorders and reposition the sensor mannequin.

Station Measurements

2 repeats of the following profile:

> Pass the station at high speed. On the next lap, return to the station decelerating at the standard rate, remain at the station in a condition representing passenger boarding, and leave the station accelerating at the standard rate.

Approximately 10 to 15 minutes are required after each profile to download data from the recorders and reposition the sensor mannequin.

1 repeat of the following profile:

> Vehicle at rest at the station in the typical mode while passengers board or depart the vehicle.

No time is required after this profile.

Guideway Measurements

4 to 8 repeats of the following profile:

> Two high speed passes on successive laps with the vehicle at maximum thrust. At one location, repeat with two additional passes at moderate thrust.

Time required between repeats of the above profile is twenty minutes plus the travel time to the next guideway location.

Setup Times and Contingency

Guideway Current Measurements:

> If current and voltage transducers must be attached to the system electrical system, as much as 4 hours of setup time may be required.

Onboard Measurements:

> Approximately 1 hour setup time. Ten minutes setup time if done immediately after the station and platform measurements.

Station and Platform Measurements:

> Approximately 1 hour setup time. Ten minutes setup time if done immediately after the onboard measurements.

Guideway Measurements:

> Approximately ½ hour setup time.

As with any test plan, adjustments may be required based on actual field conditions and requirements. In addition, a contingency of approximately two days should be allotted in the event of operational problems or unforeseen delays during the test period.

Preliminary Schedule

The main requirement for the onboard TR08 measurements is a minimum of 16 identical trips around the track with time between runs to download data and reposition sensors. Additional vehicle passes and stationary operation are required for the guideway and station measurements. There are two options for scheduling this testing. The first option is to coordinate our schedule with the noise and vibration testing by taking measurements during their setup times and by utilizing several of their vehicle runs if the TR08 follows the standard trip profile that we have requested while meeting the noise and vibration pass by requirements. The table below shows a tentative schedule in which we attempt to interleave our testing with the noise and vibration setup times. If the power data is already available from the test track in sufficient detail, then on-board testing can start on Day 1.

The second option is to block out three solid days for our measurements at a time when no noise and vibration measurements are being performed. This option can be utilized as a backup if necessary.

Day 1 Monday

Task	**Approx. Time**	**TR08 Operation Requirement**
Unpack equipment, set-up, and check.	0800 to 1200	
Power monitoring ct and pt installation and testing	1300 to 1700	Single run of vehicle to check that power monitoring equipment is operating

Day 2 Tuesday

Task	**Approx. Time**	**TR08 Operation Requirement**
Set-up for onboard measurements.	0730 to 0830	
Onboard measurements (time required between runs to download data)	0830 to 1000	3-4 identical repeats of "Onboard meas. operating profile" with max. speed of 400 km/hour
Check and review onboard measurement data	1000 to 1200	
Onboard measurements (time required between runs to download data)	1200 to 1400	4-6 identical repeats of "Onboard meas. operating profile" with max. speed of 400 km/hour
Check and review onboard measurement data	1400 to 1600	
Onboard measurements (time required between runs to download data)	1600 to 1800	4-6 identical repeats of "Onboard meas. operating profile" with max. speed of 400 km/hour

Day 3 Wednesday

Task	**Approx. Time**	**TR08 Operation Requirement**
Set-up for onboard measurements.	0730 to 0800	
Onboard measurements (time required between runs to download data)	0830 to 0900	2-3 identical repeats of "Onboard meas. operating profile" with max. speed of 400 km/hour
Check and review onboard measurement data	0900 to 1100	
Complete onboard measurements with required number of runs	1100 to 1400	Required repeats of "Onboard meas. operating profile" with max. speed of 400 km/hour

Setup for station and platform measurements	1400 to 1530	
Station and platform measurements (10-15 minutes required between runs to download data)	1530 to 1630	2 repeats of profile: Pass the station at high speed. On the next lap, return to the station decelerating at the standard rate, remain at the station in a condition representing passenger boarding, and leave the station accelerating at the standard rate.
Mapping measurements on station platform	1630 to 1800	Vehicle at rest in the station simulating passengers boarding or leaving the vehicle.

Day 4 Thursday

Task	**Approx. Time**	**TR08 Operation Requirement**
Set-up for guideway measurements	0730 to 0830	
Guideway measurements at 4 to 8 locations (time required to download data between runs and to move to next location)	0830 to 1500	At each location: 2 high speed passes with vehicle at max. thrust and 2 passes at moderate thrust.
Pack equipment for Friday departure if all measurements complete	1500 to 1900	

ATTACHMENT #1 (as Referenced in the test plan)

PROPOSAL FOR

CHARACTERIZATION OF THE STATIC AND ELF MAGNETIC FIELDS IN AREAS OF PUBLIC EXPOSURE WITHIN AND NEAR THE TRANSRAPID TR08 MAGNETICALLY LEVITATED TRANSPORTATION VEHICLE

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OBJECTIVE

The effort proposed herein will characterize and quantify the static and extreme low frequency (ELF) magnetic fields to which passengers may be exposed while traveling in the Transrapid TR08 magnetically levitated transportation system. It will also characterize and quantify magnetic fields in areas of public access within the station, on the station platform, and beneath or near the guideway. Magnetic field data will be collected using protocols and instrumentation compatible with those previously employed for similar measurements in the older Transrapid TR07 vehicle1 and in a variety of conventional transportation systems2,3,4,5 to permit valid comparisons of exposure conditions across frequencies and operational conditions. If possible, this effort will also collect concurrent data on the amplitude and characteristics of the electric current in the guideway. This additional data will facilitate reliable extrapolation of the field conditions measured at Transrapid's Emsland test facility to those which will exist within and near systems deployed within the United States even though those future systems may differ in route conditions, speed profiles, and consist configurations.

BACKGROUND

Concerns that magnetic fields associated with magnetically levitated transportation vehicles (maglev) may be excessive and possibly result in adverse health consequences lead the U.S. Federal Railroad Administration (FRA) to fund a comprehensive set of magnetic field measurements in and around the Transrapid TR07 maglev vehicles, stations, guideway, power supply equipment, and operator locations1 . In areas routinely accessible to passengers, workers, and the general public, magnetic fields were found to be of moderate intensity and highly variable in both time and space. The magnetic field varied in frequency and was rich in harmonics with the significant components between zero and a few hundred hertz.

The 1990 TR07 measurements, performed over a four-day period from August 7-10, were in the frequency bands from dc to 2000 Hz. The study focused on magnetic fields because the electric field was not expected to differ significantly from that found in typical building environments. Because there is a metallic structure between the electric system and the passenger compartment on board the maglev vehicle, it is reasonable to assume that the interior electric fields will be minimal. Also, because electric fields are influenced quite strongly by people and by nearly all objects, most researchers agree that, except for extremely well-controlled environments, electric field measurements are of minimal value and very difficult to interpret.

The magnetic field measurements were made using three-axis coil and fluxgate sensors (at multiple heights above the vehicle floor) that fed their signals to a waveform capture system. This system recorded the actual waveform of all three sensor axes by rapidly sampling the analog signal on each channel and digitally storing the values. Thus, the measured waveforms could be viewed in either the time domain or frequency domain using the Fast Fourier Transform (FFT). The ability to view the measurement data in the frequency domain allowed us to characterize frequency spectra and the time variation of these spectra through different maglev operational regimes. Multiple measurements at fixed locations as the vehicle changed operating parameters provided a view of the temporal variation in field levels based on the operation of the train. Measurements at multiple locations within the vehicle provided information about the spatial variation of the field levels inside the train.

Specifically, measurements were recorded on board the TR07 vehicle at the following locations:

- the vehicle passenger section at the middle of a car in a window seat and an aisle seat,
- the last row of the passenger section in a window seat,
- a seat located in the VIP passenger section,
- the engineer's seat in the rear car, and
- along a lateral profile in the passenger section at floor level.

Off the vehicle, measurements were recorded at the following locations:

- along lateral profiles beneath the high steel guideway (multiple data sets),
- along lateral profile beneath a low concrete guideway with a passing train, parked train, and levitating train,
- along lateral profiles at a passenger station (two sets),
- near a transformer yard,
- near braking resistor banks (two sets),
- near an inverter building and feeder cables, and
- along lateral profiles above the feeder cables (two sets).

The final report1 provides detailed descriptions of the wave-capture measurement system and measurement locations, as well as the full analysis of the results.

Lacking definitive guidelines regarding magnetic field thresholds which may be unacceptable, the FRA undertook comparable measurements in conventional electrified steel-wheeled rail and transit systems to establish magnetic field levels and characteristics in existing transportation systems2,3,4,5 . While the magnetic fields associated with the TR07 varied in frequency, they were not significantly larger than the fixed-frequency magnetic fields of conventional electrified rail systems6 . Furthermore, the fixed-frequency magnetic fields of the conventional rail systems that varied from system to system spanned the range of the variable frequency fields produced by the TR07.

Transrapid has superceded the TR07 vehicle with a new vehicle designated as the TR08. The TR08 has improved aerodynamics, improved crash-withstand, less active dynamic control of levitation and guidance magnets, fewer on-board batteries, a contact-rail system for charging batteries when the vehicle is at low speed, and various other improvements. The TR08 operates on the same guideway as the TR07, the guideway longstator assembly is unchanged, and the power supply system is fundamentally unchanged.

The TR08 system is the preferred technology for several proposed maglev systems in the United States. It is unlikely, however, that the system configuration installed in America will be identical to the system on test in Emsland, Germany. A system ultimately installed here will likely have different route conditions, speed profiles, and consist configurations. These differences will cause the system ultimately deployed to have different thrust requirements than the system at the Emsland test facility. To accommodate the differences in thrust, there will be proportional differences in electric current in the longstator of the guideway. Those components of the magnetic field resulting from on-board sources are likely to be unaffected by these differences in system configuration. The components of the magnetic field resulting from current in the guideway longstator will differ in proportion to the difference in longstator current between the test facility configuration and the configuration ultimately deployed in the United States.

APPROACH

Electric Research proposes to collect a set of static and ELF magnetic field measurements on the Transrapid TR08 system using instrumentation and methodologies functionally similar to those used in the earlier measurements on the TR07 system. In that way, the accumulated data set can be used directly to compare the magnetic field environment of the TR08 to that of the earlier TR07 or to the database of magnetic field conditions associated with conventional electrified rail systems. Because there are no material changes in the guideway or power supply system, many of the measurements made near those components of the TR07 need not be repeated. The measurements on the TR08 will concentrate on those locations accessible to passengers or the general public where magnetic fields from the TR08 vehicle will be encountered. Specifically, measurements are proposed in the passenger compartments of the vehicle, in the station, on the station platform, and beneath and along the guideway as the vehicle passes.

The measurements proposed herein will focus on magnetic fields in the frequency range from zero to 3 kHz. The reason for this focus is threefold. First, the earlier measurements on the TR07 demonstrated that the principal magnetic field components were less than a few hundred hertz. Significant harmonics were generally no higher than a kilohertz. The TR08 vehicle operates on the same guideway as the TR07 with the same drive frequencies. Furthermore, the TR08 reportedly has less active dynamic control of the levitation and guidance magnets suggesting that it will have fewer high-frequency field components from those sources. The second reason for concentrating on fields below 3 kHz is that the database of field data for conventional vehicles against which the field performance of the TR08 will likely be evaluated is limited to that frequency range. The third motivation for focus on the ELF frequency range is the suggestion by some that there may be adverse health responses to such fields.

Limited measurements of the rms magnetic field strength in the VLF (3 kHz - 30 kHz) and the LF (30 kHz - 300 kHz) bands will be made concurrent with the detailed ELF field measurements to ensure that significant higher frequency magnetic fields are not overlooked. Although significant electric fields are not anticipated in or near the TR08 vehicle owing to the metallic construction of the vehicle and guideway pole pieces, single-axis ELF electric fields will be measured concurrent with the magnetic field measurements. More extensive EMI/EMC measurements are outside the scope of this proposed effort.

To facilitate extrapolation of the magnetic field conditions and intensities measured on the TR08 system configuration at the Emsland test facility to that of somewhat different configurations proposed for various locations in the United States, Electric Research proposes to measure the three phase currents in the guideway longstator and one phase voltage concurrent with the magnetic field measurements. The resulting data will provide a record of the real and reactive power being delivered to the guideway. The magnitude of the real power delivered to the guideway is primarily dependant upon the motive thrust required by the entire consist. Larger consists, consists traveling at higher speeds, and consists operating on steeper inclines will require larger thrusts and concomitantly larger real power in the guideway. With this data and a knowledge of which magnetic field components arise from the current in the longstator, magnetic field data from the TR08 at Emsland can be reliably extrapolated to other installations operating larger or smaller consists, running at higher or lower speeds, or operating on routes with steeper or flatter inclines by scaling the intensity of the field components from the guideway in proportion to the guideway current.

Magnetic fields in or near the TR08 vehicle are likely to arise from many sources. The magnetic field waveform capture measurement technology proposed for these measurements, together with digital spectral analysis, permits the identification of individual field components from multiple sources which combine to produce the total magnetic field environment. Once the unique frequency, temporal, and spatial field signatures of the individual sources are identified, the extent to which each contributes to the total field can be evaluated. Electric Research believes it can achieve a first-order estimation of the magnetic field components attributable to the vehicle and those attributable to the guideway longstator by carefully examining the spatial characteristics of various field components. Fields that are concentrated around the magnetic bogies or other vehicle components and are consistent from one car to the next will be assigned to the vehicle. Field components spatially oriented with the longstator, consistent the length of the vehicle, and having frequency signatures similar to those of the longstator current will be attributed to the longstator. These later field components may vary from one installation to another and should be intensity scaled for the longstator current computations for proposed future installations.

INSTRUMENTATION

For the measurements on the Maglev TR08 vehicle and system, Electric Research proposes to use the *MultiWave*® System II field measurement apparatus. These instruments are updated portable 4-channel versions of the wave-capture recording system used for the TR07 measurements a decade ago. Each System II unit can record the three signals from a three-axis Bartington fluxgate magnetometer (leaving a 4th channel free for an auxiliary sensor). They will measure the ELF magnetic fields (three-axis) in the frequency range from dc to 3 kHz, saving digitized waveforms of each axis of the magnetic field within the digital memory of the instrument. These waveforms provide a precise "snapshot" of the magnetic field environment detailing the intensity, frequency, short-term temporal variability, and spatial orientation of the field at the time of the measurement. These snapshot measurements are repeated in rapid succession to document the longer-term temporal characteristics of the field analogous to the way that a video camera repeatedly scans an image to capture the essence of movement. Spatial variability is documented by making simultaneous measurements at multiple locations with multiple "slave" *MultiWave*® instruments synchronized to a master unit. For measurements in transportation vehicles or the station waiting area, the spatial measurements are proposed at positions representing the head, waist, and ankle of seated or standing passengers. In this way, field conditions spanning the passenger's body are documented. A PVC "mannequin" frame (built to hold sensors for a series of DOT measurement studies on various transportation systems) will hold the fluxgate magnetometers at the desired positions thereby facilitating rapid setup and repeatable sensor positioning. At locations more distant from the field source where field conditions change less rapidly with distance, simultaneous measurements are made at greater distances from one another. For example, beneath the guideway, magnetometers may be placed 5 to 10 meters apart to document the field attenuation pattern away from the guideway.

ELF electric field (3 Hz to 3 kHz) will be measured at a location and orientation so as to document the field normal to the passenger's chest. Beneath the guideway, the sensor will be oriented to measure the vertical component of the electric field. The sensor is a fiber-optically isolated dipole probe which connects to one of the *MultiWave*® instruments. The rms magnetic fields in the 3 kHz to 30 kHz and 30 kHz to 300 kHz ranges will be measured using three-axis Faraday induction sensors coupled to electronic modules which appropriately band-limit the signals, compute the root-mean-square magnitude of the signal from each of the orthogonal sensors, and then computes the root-sum-square of the three orthogonal rms components. The outputs of these modules are fed to the *MultiWave*® instruments where they are recorded digitally.

PERSONNEL

The principal investigator for these measurements will be Mr. Fred Dietrich. His biography is included at the end of this document. Mr. Dietrich has three decades of experience in electromagnetic measurements including several studies of transportation systems. Mr. Robert Kulp will be the co-investigator. Mr. Kulp has recently conducted electric and magnetic field measurements on the New Jersey Transit rail system.

TASKS

The proposed effort is divided into six tasks to facilitate planning, scheduling, and cost estimation.

Task 1 Test Plan Development and Coordination

Successful completion of this effort will require coordination between Electric Research, Maglev, Inc., the Volpe Transportation Systems Center, Transrapid, and the operators of the Emsland test facility. At the time of this writing, the required coordination is not in place. Since we are unaware of the operating schedule at Emsland, the extent to which Transrapid and the test facility operators can and will modify their operating schedule to accommodate magnetic field testing, and the practicality of making current measurements, we can not advance a test plan at this time. The purpose of this first task will be to establish communication between the involved parties, obtain details of the TR08 operating schedule, investigate the practicality of making current measurements, and develop a firm test plan.

For purposes of planning, the following test plan outline is suggested:

I Current Measurements (These measurements will run concurrently with all of the other following measurements.)

Select one System II recorder for current measurements and configure it appropriately. Ensure that its real time clock is synchronized to the clocks of the other units.

If current transformers are already in place on the three-phase output cables from the inverters to the guideway, install Sentran clamp-on current transformers on the secondary leads of those current transformers. Connect the secondaries of the Sentrans to the main input of a System II. If no suitable current transformers are present or if applying clamp-on current transformers to their secondary leads is not permitted, attach Fluke or other suitable clamp-on current transformers to the output cables. Connect the current transformers with suitable burden resistors to the main input of the System II.

If potential transformers are present at the output of the inverter, connect a MultiWaveâ voltage probe to the secondary of the potential transformer and connect the probe's output to the auxiliary input of the System II. If no suitable potential transformer is present or connections to its secondary leads is not permitted, connect a Ross high voltage divider to one phase of the inverter and connect the output to the auxiliary input of the System II.

Initiate data collection when starting magnetic field measurements and terminate when field measurements are complete. Download data to floppy disk as required. Verify integrity of files on floppy disks with notebook computer.

II Onboard Measurements (This assumes many scheduled trips of short duration.)

If the vehicle is carrying passengers, attempt to reserve one car or a portion of one car for measurements.

Stack three System II units on a small, two-wheeled luggage cart. Install three 10 gauss fluxgate magnetometers in a PVC mannequin frame at positions corresponding to the ankles, waist, and head of a seated or standing person, depending on the mannequin position. Run sensor cables from the System II units on the cart to the sensors on the mannequin. Install the ELF electric field sensor at a position normal to the chest of the person represented by the mannequin. Attach the VLF and LF rms magnetic field sensors at the midsection of the mannequin. Connect the cables from these sensors to the auxiliary inputs of the three System II units on the cart.

Select one seat central to the vehicle as a reference location and place the fluxgate magnetometer for the fourth System II unit in that seat away from the metal frame. Secure with masking tape. Place the System II unit in the adjacent seat and connect it to its sensor. Run a trigger cable from this reference System II to the three units on the cart.

Configure all System II units for identical appropriate sample conditions ensuring that the recording time will be sufficient to accommodate the entire trip from station stop to station stop but still collect a minimum of twenty samples over the duration of the trip. Configure the top unit on the cart as master and the remaining units as slaves.

Select a seat for the first magnetic field measurement. Place the mannequin in the seat. Initiate recording on the master unit just before the vehicle departs the station and terminate recording after the vehicle returns to the station. Watch for over-range conditions while recording data.

Quickly move the mannequin to another seat and repeat the process. Systematically sample field conditions in as many seats as practical in the allotted time depending on the frequency and duration of trips. Select a sampling pattern that will thoroughly cover the car obtaining data above the magnetic bogies, batteries, charger, etc. and away from those devices. Conduct more limited measurements in the other cars. Download data as required onto floppy disks. Verify integrity of files on floppy disks with notebook computer.

If the vehicle is making few but longer trips, conduct measurements from station to station at a minimum of two locations. Record for one or more full laps in all other seats selected for the sample to obtain data under comparable operating conditions.

III Station

Select a seat as a reference seat. Install the reference fluxgate magnetometer and associated System II unit as described above for onboard measurements.

Select a seat for the first magnetic field measurement as near as practical to the guideway. Install the System II units on the cart and the sensors on the mannequin as described above for onboard measurements. Place the mannequin in the seat. Configure all four System II units for rapid sampling in the master/slave mode. Initiate recording on the master unit just before the vehicle arrives at the station and terminate recording after the vehicle leaves the station. If there is considerable standing time at the station, suspend sampling after ten samples are recorded in the standing condition and reinitiate sampling just before the vehicle departs the station. If possible, repeat the measurement as the vehicle passes the station without stopping. Watch for over-range conditions while recording data.

Move the mannequin to a seat at the opposite side of the station and repeat the measurement. Download data as required onto floppy disks. Verify integrity of files on floppy disks with notebook computer. Measure in additional seats or standing near the platform door as time permits.

IV Platform measurements (It is anticipated that passengers are not permitted on the platform when the vehicle passes at high speed.)

Place the reference sensor and associated System II unit in the reference position used for the station measurements

Install three System II units on the cart and the sensors on the mannequin as described above for station measurements. Place the mannequin in a standing position. Configure all four System II units for sampling at a rate to collect at least twenty samples during the time that passengers will be permitted on the platform. Place the units in the master/slave mode. While sampling data, walk the mannequin from the station to the vehicle door and back to the station.

If standing is permitted on the platform as the vehicle arrives and departs, stand the mannequin at reasonable locations and sample as the vehicle arrives and departs.

V Beneath the elevated guideway

Select a location beneath the elevated guideway where the vehicle will pass at a high speed drawing significant power from the guideway. Install four fluxgate magnetometers 1 m above ground on nonmagnetic stands at centerline of the guideway and at 5 m, 15 m, and 30 m from centerline. Place a System II unit on the ground near each magnetometer and connect it to the sensor. Install the electric field probe 1 m above ground beneath the center of the guideway and orient it to measure the vertical component of the electric field. Connect it to the adjacent System II unit. Install the VLF and LF magnetic field sensors 1 m above ground at the 5 m and 15 m locations, respectively. Connect these sensors to the nearby System II units.

Configure all four System II units for rapid sampling in the master/slave mode. Initiate recording on the master as the vehicle approaches the measurement location and terminate recording after the vehicle leaves the location. Sample data during three passes of the vehicle. Download data as required onto floppy disks. Verify integrity of files on floppy disks with notebook computer.

Repeat the measurements at another elevated guideway position if time permits.

VI Adjacent to an at-grade or low guideway

Select a location near an at-grade or low guideway where the vehicle will pass at a high speed drawing significant power from the guideway. Install four fluxgate magnetometers 1 m above ground on nonmagnetic stands at the guideway exclusion fence and at 5 m, 15 m, and 30 m from the fence. If the only sections of low or at grade guideway are in a controlled area, define a fence location based on reasonable protection clearances required for safety. Place a System II unit on the ground near each magnetometer and connect it to the sensor. Install the electric field probe 1 m above ground near the fence and orient it to measure the vertical component of the electric field. Connect it to the adjacent System II unit. Install the VLF and LF magnetic field sensors 1 m above ground at the 5 m and 15 m locations, respectively. Connect these sensors to the nearby System II units.

Configure all four System II units for rapid sampling in the master/slave mode. Initiate recording on the master as the vehicle approaches the measurement location and terminate recording after the vehicle leaves the location. Sample data during three passes of the vehicle. Download data as required onto floppy disks. Verify integrity of files on floppy disks with notebook computer.

Repeat the measurements at another elevated guideway position if time permits.

Task 2 Equipment Preparation

All of the electric and magnetic field equipment will be carefully checked and calibrated according to the provisions of IEEE Standard 644. European power cords will be obtained for all universal voltage battery chargers. Battery chargers having only 120 V input voltages will be replaced or a suitable step-down transformer will be obtained. Current transformers, voltage probes, or voltage dividers required for current measurements will be obtained, fitted with appropriate connections to the System II, and calibrated. A carnet will be obtained for international transportation of the equipment. Equipment will be packed for shipment.

Task 3 Travel and Setup

This task includes the time for travel to and from Emsland Germany, unpacking of equipment, verifying its performance, and repacking it after completion of the tests.

Task 4 On-Site Measurements

This task is self-explanatory. It will involve the execution of the test plan developed under Task 1.

Task 5 Data Analysis

The extensive volume of digital data collected during the on-site measurements will be loaded onto a computer having a large hard drive, organized, files grouped, and audited for integrity. Data sets containing inconsistent numbers of records, inappropriate time stamps, or other signs of possibly corrupted data will be flagged for closer examination. Data that are flawed will be purged.

Following the data audit, the data sets will be run through a number proprietary programs which extract user-specified field parameters for each data sample. Parameters extracted from the electric and magnetic field records will include the date and time of the sample, sample number, static field, total ELF field, total VLF field, total LF field, and total field in the various frequency sub-bands analyzed in the previous transportation field study reports.

Summary statistics (mean, maximum, minimum, standard deviation, coefficient of variation, etc.) will be computed for each parameter at each location across each data set. For those conditions where multiple data sets were collected, the data will be tested for similarity and pooled if similar. Inconsistent data sets obtained under apparently similar conditions will be examined manually to understand the differences.

Time-course plots will be generated for many of the field parameters to examine the relationship of the field parameter to vehicle speed, position on the guideway and other potentially relevant parameters.

Selected data sets will be subjected to Fourier analysis to examine the frequency spectra of the fields. Frequency, spatial, and temporal characteristics of the fields measured onboard the vehicle will be examined to identify field signatures indicative of specific field sources.
The current data will be processed to extract the sample number, time stamp, three-phase currents, the components of those currents in phase with the voltage (real currents), and the components in quadrature with the voltage (reactive currents). Time course plots of various current parameters will be matched up with field parameters measured at various locations to seek correlations useful for normalizing certain field components to guideway current. Fourier transforms will be computed for selected sets of the current data and the resulting frequency spectra compared to spectra of the magnetic fields at various locations to help confirm apparent sources. For those field components that appear to correlate with guideway current and have similar frequency signatures, a simple correlation model will be developed which can be useful for normalizing field levels to guideway current.

Task 6 Reporting

A report will be prepared to document the test procedures and summarize the findings. Measurement procedures, measurement locations, and vehicle operating conditions will be thoroughly documented. Descriptive summary statistics of the field levels measured on or near the TR08 will be reported in tabular form and summarized graphically. Graphs will show the spatial variations of field level within the vehicle in relation to major equipment representing potential field sources (magnetic bogies, batteries and chargers, control equipment, etc.). Temporal variations in field strength as the vehicle accelerates and decelerates will be graphed for fields in various frequency sub-bands. Outside the vehicle, time course plots will show the time that fields are present at the station or along the guideway as the vehicle passes. If significant field components are found to originate from current in the guideway longstator, a procedure will be reported for extrapolating the measured data to proposed installations that may have different guideway current profiles. Finally, the magnetic field levels and frequencies in or near the TR08 vehicle will be compared graphically to the field conditions in the TR07 and conventional electrified rail systems using graphs similar to those used previously6 to compare the magnetic field environments of transportation systems.

ESTIMATED TIME LINE FOR TESTING

Day 1 Arrive in Germany in the morning.
Claim baggage and equipment, travel to the hotel.
Rest for several hours.
Travel to the Transrapid facility.
Begin equipment set-up and test (approx. 5 hours).

Day 2 Complete equipment set-up and test (approx. 2 hours).
Begin measurements on-board TR08 vehicle (approx. 7 hours).

Day 3 Complete TR08 on-board measurements (approx. 6 hours).
Start guideway and station measurements (approx. 4 hours)

Day 4 Complete guideway and passenger waiting area measurements (approx. 7 hours).
Pack equipment and prepare for departure (approx. 3 hours)

REFERENCES

1. Safety of High Speed Magnetic Levitation Transportation Systems: Magnetic Field Testing of theTR07 Maglev Vehicle and System, Volume I - Analysis, Volume II - Appendices. Electric Research and Management, Inc. Prepared for U.S. Department of Transportation, Federal Railroad Administration (USDOT/FRA). Report No. DOT/FRA/ORD-92/09.I and DOT/FRA/ORD-92/09.II. Available from NTIS, Springfield, VA. April 1993.

2. Safety of High Speed Guided Ground Transportation Systems: Magnetic and Electric Field Testing of the Amtrak Northeast Corridor and New Jersey Transit North Jersey

Coast Line Rail Systems, Volume I - Analysis, Volume II - Appendices. Electric Research and Management, Inc. Prepared for USDOT/FRA. Report No. DOT/FRA/ORD-93/01.I and DOT/FRA/ORD-93/01.II. Available from NTIS, Springfield, VA. April 1993.

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4. Safety of High Speed Guided Ground Transportation Systems: Magnetic and Electric Field Testing of the Washington Metropolitan Area Transit Authority (WMATA) Metrorail System, Volume I - Analysis, Volume II - Appendices. Electric Research and Management, Inc. Prepared for USDOT/FRA. Report No. DOT/FRA/ORD-93/04.I and DOT/FRA/ORD-93/04.II. Available from NTIS, Springfield, VA. June 1993.

5. Safety of High Speed Guided Ground Transportation Systems: Magnetic and Electric Field Testing of the Massachusetts Bay Transportation Authority (MBTA) Urban Transit System, Volume I - Analysis, Volume II - Appendices. Electric Research and Management, Inc. Prepared for USDOT/FRA. Report No. DOT/FRA/ORD-93/05.I and DOT/FRA/ORD-93/05.II. Available from NTIS, Springfield, VA. June 1993.

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7. Survey and Assessment of Electric and Magnetic Field (EMF) Public Exposure in the Transportation Environment. Electric Research and Management, Inc. Prepared for USDOT/FRA. Contract No. DTRS-57-96-C-00073. March 1999.

INTRODUCTION TO ELECTRIC RESEARCH

Electric Research was organized in the early 1980's with the personal commitment of its founders for providing clients with the highest quality service and products. Often this commitment is manifested in the management of multi-disciplinary research and development projects with solution teams composed of experts drawn from both within and external to Electric Research. On any project we undertake, our solution teams always possess the in-depth expertise in science and engineering required to find a cost effective and innovative solution to the electrical system or equipment problem facing the client.

Magnetic Field Management

Magnetic field management involves a comprehensive understanding of magnetic field sources and the range of options available for reducing the magnetic fields in various situations. Electric Research has a thorough understanding of magnetic field management principles as well as the corresponding physics of magnetic field shielding. Capabilities include magnetic source identification and characterization using advanced measurement systems, reconfiguration design of conductor, cable, and bus layouts for minimum magnetic fields, and magnetic shielding analysis and design, including ferromagnetic/conductive shields as well as passive and active cancellation systems.

Geomagnetic Storm Monitoring

Electric Research has developed a system that provides warnings of geomagnetic storms and near-real-time data to customers via the Internet. This system, operated in conjunction with EPRI, is known as the SUNBURST System. Information available includes near-real-time plots and tables for specific sites and a severity index for all sites. Information from this System allows users to take precautions to lessen the impact from the geomagnetic storm on their system. Actions taken may include closing a contact to desensitize a relay, initiating a SCADA-controlled change in VAR loading, etc. depending on the implementation selected for a particular site.

Specialty Product Development

Electric Research utilizes the newest technologies for developing data acquisition, monitoring, and analysis hardware. All logic circuits utilize programmable FPGA technology. This technology provides a versatile and powerful platform in the development of special purpose products to satisfy a clients need. Specialty products also include the incorporation of a digital signal processor (DSP) to provide the speed necessary to perform calculations and analysis of collected data. Examples of these technologies at work include the sampling and calculations for magnetic field data, 3-phase power system data, and relay control.

Near-Real-Time Internet Based Data Acquisition System

Electric Research has developed a flexible data acquisition system that utilizes the Internet for data communication. All data is transported to a centrally located server via the Internet. Likewise, customers access to the data is via the Internet using a standard web browser. The user interface provides access to plots of both the near-real-time and historical data. Users can select periods of historical data to download in a format that is suitable for importing into a standard spreadsheet program. Users can also receive e-mail notification when data values exceed predefined trigger levels.

Specialty Testing

Electric Research has developed a versatile and high energy output three-phase terminal simulator. It is used to simulate any desired system dynamic conditions and to monitor the response of the device under test. Combinations of dynamic power frequency and concurrent harmonic conditions can be simulated to test for the effects of power quality on the test devices operating characteristics. True transient responses without any artifactual transition transients can be simulated. Also, field test data and recorder data can be replayed through the simulator with both time and magnitude fidelity being maintained.

Excitation System Analysis

Electric Research's staff has extensive experience in the adjustment of excitation systems and related power system stabilizers for high-initial response excitation or for the older Amplidyne, Magastat and other similar systems. Excitation system analysis may include field tests of existing systems, recommendations for modification of alignment, assistance in alignment, development of stability study constants from field measurements, and a study of special problems. Electric Research's GETS System can be used to completely check out the dynamic performance of generator excitation systems.

Automatic Generation Control Analysis

Electric Research's staff has in depth experience in the theoretical and operational requirements of automatic generation control. Electric Research also has the capability to test, align, design and model existing and proposed systems. Electric Research can adjust filters, power plant allocators, generator allocators, and constraint limiters. Special controller problems can be analyzed, algorithm modifications suggested, and recommendations made for alignment of governing systems to work effectively with automatic generation control.

Independent Power Producer/Utility Interface

Electric Research has the capability to conduct extensive model studies of IPP (Independent Power Producers) or DSG (Distribution System Generation or Dispersed Storage and Generation) interconnections using both analog and digital system simulators. If necessary, Electric Research has the specialized field test equipment to monitor the dynamic performance of IPP installations. In addition, Electric Research has developed a simple technique to assess the choice of transformer and power factor correction options to minimize possible adverse interaction with the power system. Electric Research offers a tutorial, "Non-Utility Generation Interconnection", to utilities with IPP or DSG installations.

Transportation Studies

Electric Research has used the MultiWaveâ System to characterize the magnetic fields inside and around public and private transportation systems, from magnetically levitated trains to private automobiles. The MultiWaveâ System hardware gives our engineers the ability to capture any dc magnetic fields by using Hall-effect or fluxgate devices connected to dc voltage probes. The software allows our engineers to set the base frequency for the ac magnetic field probes anywhere from 1 Hz to 1 kHz so that waveforms that are not at power frequencies can be captured.

Following is a partial list of transportation studies performed by Electric Research:

- Maglev TR07
- Massachusetts Bay Area Transit Authority
- TGV
- Washington, DC Metro
- AMTRAK NE Corridor
- NJ Transit
- Electric Highway Vehicle Measurements
- Conventional Highway Vehicle Measurements
- AMTRAK Pre-Electrification Measurement Study, Northeast Corridor from New Haven to Boston

BIOGRAPHY OF FRED DIETRICH

In 1980, Mr. Dietrich was one of the founders of Electric Research. His responsibilities at Electric Research include analysis and measurement of power frequency fields, electromagnetic interference, audible noise and other corona phenomena from electric power systems, the development of power system transient measurement systems, and the design of special instruments for power system related measurements. He has also been active in the review and analysis of exposure systems and exposure conditions used by biomedical researchers to study the possible health effects of exposure to power frequency electric and magnetic fields. He has recently been involved in analytical studies, field measurements, and expert testimony dealing with corona and field effects of transmission lines and substations, the design and development of small animal electric field exposure systems, the design and development of a sophisticated computer-based instrument package for characterizing magnetic fields around power system facilities, homes, and workplaces, and the characterization of the complex magnetic field environments of industrial facilities and electrified transportation systems.

In 1979, Mr. Dietrich was a co-incorporator of Systems Engineering for Power, Incorporated which dealt with both power systems and control systems.

In 1978, he operated a sole proprietorship engineering company offering consulting services in the area of power transmission and designing and manufacturing specialized electronic instrumentation for power systems applications.

Earlier in 1978, he had been with the Development Projects Group of Westinghouse Electric Corporation, Advanced Systems Technology Division. Here he was responsible for the design and specification of the electrical supply system, high-voltage test equipment, instrumentation and building shielding and ground systems for a large indoor high-voltage laboratory.

From 1976 to 1977, Mr. Dietrich was a member of the staff of the Westinghouse-operated EPRI Waltz Mill Underground Transmission Test Facility. Here he was responsible for coordinating the installation of prototype cable systems supplied by the industry, specifying and installing the appropriate instrumentation, conducting the applicable test program, and analyzing and reporting the resulting data.

From 1972 to 1976, Mr. Dietrich was with the Advanced Systems Technology Division of Westinghouse. His primary responsibility was for client studies relating to corona effects and field effects of EHV transmission lines. He was lead engineer for the Westinghouse involvement in the Apple Grove 765 kV Project for several years prior to its closing in 1976.

Prior to joining Westinghouse, Mr. Dietrich served as a captain in the U.S. Army Signal Corps.

EDUCATION

Carnegie□Mellon University	B.S.E.E. 1969 M.S.E.E. 1978

REGISTRATION

Professional Engineer in Pennsylvania

PROFESSIONAL SOCIETIES

Fellow, IEEE - Power Engineering Society
Member IEEE/PES Corona and Field Effects Subcommittee
Member of the AC and DC Fields Working Group
Member of the Corona Effects Working Group

SIGNIFICANT PUBLICATIONS

1974 Experimental Oxidant Projection Rates for EHV Transmission Lines and Theoretical Estimates of Ozone Concentrations Near Operating Lines (with J.F. Roach and V.L. Chartier). TRANSACTIONS IEEE, PAS Vol. 93, No.2, 1974, pp. 647-57.

1974 The Apple Grove 750 kV Project □ Statistical Analysis of Audible Noise Performance of Conductors at 775 kV (with N. Kolcio, B.J. Ware, R.L. Zagier and V.L. Chartier). TRANSACTIONS IEEE, PAS Vol. 93, No.3, pp. 831-40.

1976 Corona and Electric Field Effects at the Apple Grove Project and an 800 kV Line in the USA (with N. Kolcio). CIGRE PROCEEDINGS, Paper 31-08.

1977 Apple Grove 750 kV Project □ Two Year Statistical Analysis of Audible Noise from Conductors at 775 kV and Ambient Noise Data (with N. Kolcio and J. DePlacido). TRANSACTIONS IEEE, PAS vol. 96, No.2, 1977, pp. 560-70.

1978 Mechanical Effects of Load Cycling on Pipe□Type Cable (with E.E. McIlveen, R.C. Waldron, J.W. Bankoske, H.G. Matthews and J.F. Shimshock). TRANSACTIONS IEEE, PAS Vol. 97, No.3, 1978, pp. 903-13.

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1987 Shielding Effects in Small Animal Exposure Systems (with R.C. Patterson). IEEE TRANSACTIONS ON POWER DELIVERY, Vol. PWRD-2, No. 4, October 1987, pp. 1303-09.

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1993 A Critical Review of the Genotoxic Potential of Electric and Magnetic Fields (with J. McCann, C. Rafferty, and A.O. Martin). Mutation Research, Vol. 297, 1993, pp. 61-95.

1994 Magnetic Field Quantification of Electrified Transportation Systems (with W.E. Feero), IEEE T&D Conference, EMF Management Techniques Training Session, April 1994.

1995 "Electric and Magnetic Field Mitigation Strategies", with D.W. Fugate and W.E. Feero. Chapter 13 of Electromagnetic Fields: Biological Interactions and Mechanisms (Advances in Chemistry #250) Book Edited by Dr. Martin Blank. Published by American Chemical Society, Washington, DC. November 1995.

Test Plan for Noise and Vibration Testing of the TR08

(Appendix B in original Test Plans)

APPENDIX B NOT INCLUDED IN THIS REPORT

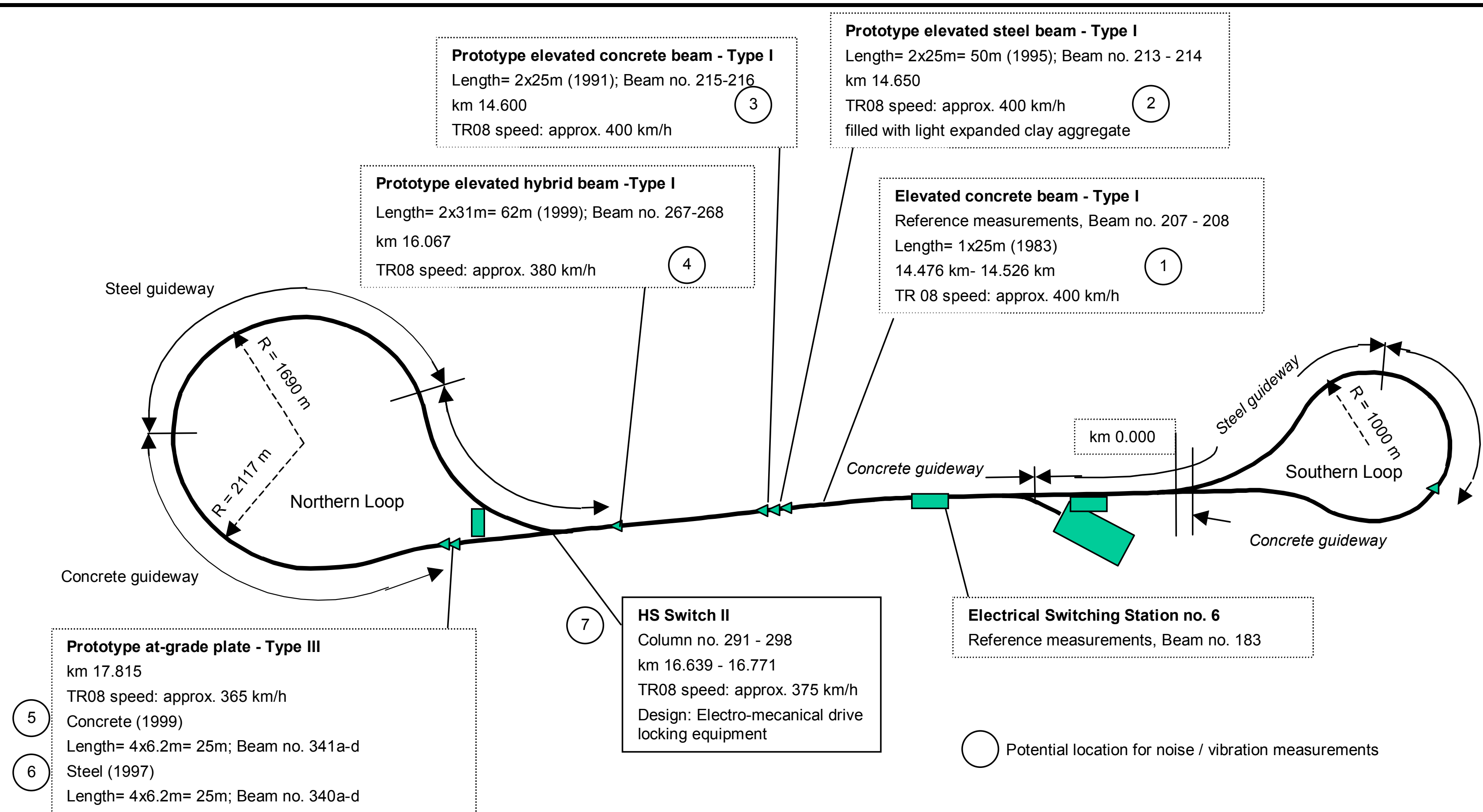
Locations for Noise/Vibration/EMF Measurements and Consolidated Test Matrix

Revised May 24, 2001 To Include Noise Measurements Under the Guideway and Vibration Measurements at the Station Platform

(Appendix C in the original test plans)

Transrapid Test Facility (TVE)
Locations for Noise/Vibration/EMF Measurements

Transrapid International



Consolidated Test Matrix Schedule of Environmental Noise, Vibration, and EMF Tests at TVE

Date: Monday, 2001-08-13

Noise Measurement Activities	Trip	Time frame	Measuring location	Beam no.	Array configuration	Single microphones	Pass-by vehicle speed [km/h]	Measuring series	Pass-by ID
Inspect equipment, assembly of electronic equipment in measuring van, installation of WX32 microphone array, mount array on IABG telescopic tower.		9:00-18:00							

Date: Monday, 2001-08-13

Vibration Measurement Activities	Trip	Time frame	Measuring location	Beam no.			Pass-by vehicle speed [km/h]	Measuring series	Pass-by ID
Arrive in Amsterdam; clear equipment through customs.		6:00 – 10:00							
Drive to Emsland; orientation at TVE.		10:00-18:00							

Date: Monday, 2001-08-13

EMF Measurement Activities	Trip	Time frame	Measuring location	Beam no.	Sensor array configuration		Vehicle operating speed profile	Measuring series	
Inspect equipment, standardise MultiWave instruments to the time reference of the TVE data acquisition system, select on-board measurement location seat numbers, install sensors on the mannequin, place instruments on charge, and stake sensor locations near the guideway to facilitate rapid relocation of the equipment between tests.		9:00-18:00							

Date: Tuesday, 2001-08-14

Noise Measurement Activities	Trip	Time frame	Measuring location	Beam no.	Array configuration	Single microphones	Pass-by vehicle speed [km/h]	Measuring series	Pass-by ID
Install microphones on WX32 array, calibrate, elevate array to “mid” position, set up single microphones.		7:00-9:30	concrete guideway (reference type) ①	208	setup/ reconstruction	setup/ reconstruction			
Make noise measurements with WX32 array in "mid" position, make noise measurements with single microphones.	N2	09:30-10:00	concrete guideway (reference type) ①	208	WX32	6.5 m (high)	standardized speed profile (150, 200, 300, 400 km/h)	A	A-150-1 A-400-1 A-200-1 A-300-1
	N3	10:00-10:30							A-150-2 A-400-2 A-200-2 A-300-2
	N4	10:30-11:00							A-150-3 A-400-3 A-200-3 A-300-3
Reconfigure array to WX16, elevate array to “mid” position, make noise measurements with single microphones.	N5	11:00-11:30	concrete guideway (reference type) ①	208	setup/ reconstruction	6.5 m (high), 25 m, 50 ft, 100 ft, under guideway	100 km/h	A	A-100-1 A-100-2
						6.5 m (low), 25 m, 50 ft, 100 ft, under guideway	100 km/h	B	B-100-1 B-100-2
Make noise measurements with WX16 array in "mid" position, make noise measurements with single microphones.	N7	13:00-13:30	concrete guideway (reference type) ①	208	WX16	6.5 m (low), 25 m, 50 ft, 100 ft, under guideway	standardized speed profile (150, 200, 300, 400 km/h)	B	B-150-1 B-400-1 B-200-1 B-300-1
	N8	13:45-14:15							B-150-2 B-400-2 B-200-2 B-300-2
	N9 (instead of N6)	14:30-15:00							B-150-3 B-400-3 B-200-3 B-300-3

Retrieve single microphones and reconstruct array to WV08/16/32.		15:00-18:00			setup/ reconstruction	setup/ reconstruction			

Date: Tuesday, 2001-08-14

Vibration Measurement Activities	Trip	Time frame	Measuring location	Beam no.	Activity		Pass-by vehicle speed [km/h]	Measuring series	Pass-by ID
Unpack and check out equipment.		7:00-9:30			setup/ reconstruction				
Set up accelerometer, recording instruments. Calibrate.	N2	09:30-10:00	steel guideway ②	213	setup/ reconstruction		standardized speed profile (150, 200, 300, 400 km/h)	A	A-150-1 A-400-1 A-200-1 A-300-1
	N3	10:00-10:30							A-150-2 A-400-2 A-200-2 A-300-2
	N4	10:30-11:00							A-150-3 A-400-3 A-200-3 A-300-3
Record ground vibrations from TR08 at site.	N5	11:00-11:30	steel guideway ②	213	Measure		100 km/h	A	A-100-1 A-100-2
							100 km/h	B	B-100-1 B-100-2
	N7	13:00-13:30	steel guideway ②	213	Measure		standardized speed profile (150, 200, 300, 400 km/h)	B	B-150-1 B-400-1 B-200-1 B-300-1
	N8	13:45-14:15							B-150-2 B-400-2 B-200-2 B-300-2
	N9	14:30-15:00							B-150-3 B-400-3 B-200-3 B-300-3

Set up ground impacter and conduct transfer mobility test.		15:00-18:00			setup/ reconstructi on/ measure				

Date: Tuesday, 2001-08-14

EMF Measurement Activities	Trip	Time frame	Measuring location	Beam no.	Sensor array configuration		Vehicle operating speed profile	Measuring series	
Transport equipment to the lead vehicle, place sensors in the first measurement location, and verify instrument performance.		8:00-9:30	Onboard lead vehicle		Mannequin positions and fixed reference				
Onboard lead vehicle. EMF and RF measurements in three adjacent seats toward the front of the vehicle and away from major on-board equipment to identify center-to-side variation in field levels.	N2	09:30-10:00	Onboard lead vehicle Aisle seat.		„		Standardized speed profile	Onboard	
	N3	10:00-10:30	Onboard lead vehicle Middle seat.		„		Standardized speed profile	Onboard	
	N4	10:30-11:00	Onboard lead vehicle Window seat.		„		Standardized speed profile	Onboard	
Station measurements. EMF and RF measurements in the station as the vehicle departs, passes, and re-enters.	N5	11:00-11:30	Location nearest the vehicle where a passenger might wait.		„		Nonstandard speed profile required for low speed noise measurements	Station	
Onboard lead vehicle. EMF and RF measurements away from major on-board equipment to identify side-to-side variation in field levels.	N7 [1]	13:00-13:30	Onboard lead vehicle Middle seat contra-lateral to seat measured on Trip N3 above.		„		Standardized speed profile	Onboard	
Onboard lead vehicle. EMF and RF measurements away from major on-board equipment to identify front-to-back variation in field levels.	N8 [1]	13:45-14:15	Onboard lead vehicle Middle seat far behind seat measured on Trip N3 above but having similar proximity to onboard equipment.		„		Standardized speed profile	Onboard	
Onboard lead vehicle. EMF and RF measurements away from major on-board equipment to confirm side-to-side and front-to-back variation in field levels.	N9 [1] (instead of N6)	14:30-15:00	Onboard lead vehicle Middle seat contra-lateral to seat measured on Trip N8 above.		„		Standardized speed profile	Onboard	

EMF Measurement Activities	Trip	Time frame	Measuring location	Beam no.	Sensor array configuration		Vehicle operating speed profile	Measuring series	
Remove instruments from the vehicle and place them on charge. Inspect data for integrity and back up.		15:00-16:30			Instruments removed from vehicle				

Note: [1] All trips conforming to the standardized speed profile regardless of their trip number will be used for onboard measurements which will be conducted in the order given in this test plan. If additional trips are made during any given day, they will be used to accelerate the test schedule.

Date: Wednesday, 2001-08-15

Noise Measurement Activities	Trip	Time frame	Measuring location	Beam no.	Array configuration	Single microphones	Pass-by vehicle speed [km/h]	Measuring series	Pass-by ID
Install microphones on WV08/16/32 wayside vertical array, calibrate, elevate array to "high" position.		7:00-9:30	concrete guideway (reference type) ①	208	setup/ reconstruction				
Set up single microphones at at-grade guideway.		7:30-9:30	at-grade guideway (concrete and steel) ⑤⑥	341a-d 340a-d		setup/ reconstruction			
Make noise measurements with WV08/16/32 array in "high" position.	N2	09:30-10:00	concrete guideway (reference type) ①	208	WV08/16/32 (high)	no	standardized speed profile (150, 200, 300, 400 km/h)	C	C-150-1 C-400-1 C-200-1 C-300-1
	N3	10:00-10:30							C-150-2 C-400-2 C-200-2 C-300-2
	N4	10:30-11:00							C-150-3 C-400-3 C-200-3 C-300-3
Make noise measurements with single microphones at at-grade guideway.	N2	09:30-10:00	at-grade guideway (concrete and steel) ⑤⑥	341a-d 340a-d	no	6.5 m (high and low)	standardized speed profile (300, 400 km/h)	Y	Y-400-1 Y-300-1
	N3	10:00-10:30							Y-400-2 Y-300-2
	N4	10:30-11:00							Y-400-3 Y-300-3
Lower array to "low" position.		11:00	concrete guideway (reference type) ①	208	setup/ reconstruction				
Make noise measurements with WV08/16/32 array in "low" position.	N5	11:00-11:30	concrete guideway (reference type) ①	208	WV08/16/32 (low)	no	standardized speed profile (150, 200, 300, 400 km/h)	D	D-150-1 D-400-1 D-200-1 D-300-1
	N6	12:15-12:45							D-150-2 D-400-2 D-200-2 D-300-2

<table>
<tr><th>Noise Measurement Activities</th><th>Trip</th><th>Time frame</th><th>Measuring location</th><th>Beam no.</th><th>Array configuration</th><th>Single microphones</th><th>Pass-by vehicle speed [km/h]</th><th>Measuring series</th><th>Pass-by ID</th></tr>
<tr><td></td><td>N7</td><td>13:00-13:30</td><td></td><td></td><td></td><td></td><td></td><td></td><td>D-150-3
D-400-3
D-200-3
D-300-3</td></tr>
<tr><td rowspan="3">Make noise measurements with single microphones at at-grade guideway.</td><td>N5</td><td>11:00-11:30</td><td rowspan="3">at-grade guideway (concrete and steel)
⑤⑥</td><td rowspan="3">341 a-d
340 a-d</td><td rowspan="3">no</td><td rowspan="3">6.5 m
(high and low)</td><td rowspan="3">standardized speed profile
(300, 400 km/h)</td><td rowspan="3">Y</td><td>Y-400-4
Y-300-4</td></tr>
<tr><td>N6</td><td>12:15-12:45</td><td>Y-400-5
Y-300-5</td></tr>
<tr><td>N7</td><td>13:00-13:30</td><td>Y-400-6
Y-300-6</td></tr>
<tr><td>Make noise measurements with WV08/16/32 array in "low" position.</td><td>N8</td><td>13:45-14:15</td><td>at-grade guideway (concrete and steel)
⑤⑥</td><td>341 a-d
340 a-d</td><td>WV08/16/32
(low)</td><td>no</td><td>100 km/h</td><td>D</td><td>D-100-1
D-100-2
D-100-3
D-100-4</td></tr>
<tr><td>Make noise measurements with single microphones at at-grade guideway.</td><td>N8</td><td>13:45-14:15</td><td>at-grade guideway (concrete and steel)
⑤⑥</td><td>341 a-d
340 a-d</td><td>no</td><td>6.5 m
(high and low)</td><td>100 km/h</td><td>Y</td><td>Y-100-1
Y-100-2</td></tr>
<tr><td>Retrieve single microphones and reconstruct array to wayside horizontal configuration.</td><td></td><td>14:30-18:00</td><td></td><td></td><td>setup/
reconstruction</td><td>setup/
reconstruction</td><td></td><td></td><td></td></tr>
</table>

Date: Wednesday, 2001-08-15

Vibration Measurement Activities	Trip	Time frame	Measuring location	Beam no.	Pass-by vehicle speed [km/h]	Measuring series	Pass-by ID
Set up accelerometers, recording instrumentation, and ground impacter at site near hybrid guideway and conduct transfer mobility test.		7:00-9:30	hybrid guideway ④	267			
Record ground vibrations from TR08 at site. .	N2	09:30-10:00	hybrid guideway ④	267	standardized speed profile (150, 200, 300, 400 km/h)	C	C-150-1 C-400-1 C-200-1 C-300-1
	N3	10:00-10:30					C-150-2 C-400-2 C-200-2 C-300-2
	N4	10:30-11:00					C-150-3 C-400-3 C-200-3 C-300-3
	N5	11:00-11:30			standardized speed profile (150, 200, 300, 400 km/h)	D	D-150-1 D-400-1 D-200-1 D-300-1
Move accelerometer mounts to high speed switch. Set up accelerometers, recording instrumentation at site near switch		11:30 – 13:00	HS switch II ⑦	291-298			
Record ground vibrations from TR08 at site.	N7	13:00 – 13:30			standardized speed profile (150, 200, 300, 400 km/h)	V	V-150-1 V-400-1 V-200-1 V-300-1
	N8	13:45 – 14:15					V-150-2 V-400-2 V-200-2 V-300-2
	N9	14:30 – 15:00					V-150-3 V-400-3 V-200-3 V-300-3
Set up ground impacter at site near switch and conduct transfer mobility test.		15:00 – 18:00					

Date: Wednesday, 2001-08-15

EMF Measurement Activities	Trip	Time frame	Measuring location	Beam no.	Sensor array configuration		Vehicle operating speed profile	Measuring series	
Transport equipment to the lead vehicle, place sensors in the seventh onboard measurement location, and verify instrument performance.		8:00-9:30	Onboard lead vehicle		Mannequin positions and fixed reference				
Onboard lead vehicle. EMF and RF measurements near onboard equipment.	N2	09:30-10:00	Onboard lead vehicle Middle seat above a battery compartment.		,,		Standardized speed profile	Onboard	
	N3	10:00-10:30	Onboard lead vehicle Middle seat above battery charger and control equipment.		,,		Standardized speed profile	Onboard	
	N4	10:30-11:00	Onboard lead vehicle Middle seat above an air conditioning compressor.		,,		Standardized speed profile	Onboard	
Onboard middle vehicle. EMF and RF measurements at a locations corresponding to the to test locations in the lead car to identify variation in field levels among cars. The measurement locations will correspond to three locations where measurements were made in the lead vehicle.	N5	11:00-11:30	Onboard middle vehicle. Middle seat away from onboard equipment.		,,		Standardized speed profile	Onboard	
	N6	12:15-12:45	Onboard middle vehicle . Middle seat above a battery compartment.[2]		,,		Standardized speed profile	Onboard	
	N7	13:00-13:30	Onboard middle vehicle. Middle seat above a battery charger and control equipment.[2]		,,		Standardized speed profile	Onboard	
Station measurements. EMF and RF measurements in the station as the vehicle departs, passes, and re-enters.	N8	13:45-14:15	Location distant from the vehicle where a passenger might wait.		,,		Nonstandard speed profile required for low speed noise measurements	Station	
Remove instruments from the station and place them on charge. Inspect data for integrity and back up.		14:30-16:00			Instruments removed from station				

Note: [2] One of these locations may be changed to above the air conditioning compressor if measurements in the lead vehicle show that piece of equipment to be a significant field source.

Date: Wednesday, 2001-08-15

EMF Measurement Activities	Trip	Time frame	Measuring location	Beam no.	Sensor array configuration		Vehicle operating speed profile	Measuring series	
Transport equipment to the lead vehicle, place sensors in the seventh onboard measurement location, and verify instrument performance.		8:00-9:30	Onboard lead vehicle		Mannequin positions and fixed reference				
Onboard lead vehicle. EMF and RF measurements near onboard equipment.	N2	09:30-10:00	Onboard lead vehicle Middle seat above a battery compartment.		,,		Standardized speed profile	Onboard	
	N3	10:00-10:30	Onboard lead vehicle Middle seat above battery charger and control equipment.		,,		Standardized speed profile	Onboard	
	N4	10:30-11:00	Onboard lead vehicle Middle seat above an air conditioning compressor.		,,		Standardized speed profile	Onboard	
Onboard middle vehicle. EMF and RF measurements at a locations corresponding to the to test locations in the lead car to identify variation in field levels among cars. The measurement locations will correspond to three locations where measurements were made in the lead vehicle.	N5	11:00-11:30	Onboard middle vehicle. Middle seat away from onboard equipment.		,,		Standardized speed profile	Onboard	
	N6	12:15-12:45	Onboard middle vehicle . Middle seat above a battery compartment.[2]		,,		Standardized speed profile	Onboard	
	N7	13:00-13:30	Onboard middle vehicle. Middle seat above a battery charger and control equipment.[2]		,,		Standardized speed profile	Onboard	
Station measurements. EMF and RF measurements in the station as the vehicle departs, passes, and re-enters.	N8	13:45-14:15	Location distant from the vehicle where a passenger might wait.		,,		Nonstandard speed profile required for low speed noise measurements	Station	
Remove instruments from the station and place them on charge. Inspect data for integrity and back up.		14:30-16:00			Instruments removed from station				

Note: [2] One of these locations may be changed to above the air conditioning compressor if measurements in the lead vehicle show that piece of equipment to be a significant field source.

Date: Thursday, 2001-08-16

Noise Measurement Activities	Trip	Time frame	Measuring location	Beam no.	Array configuration	Single microphones	Pass-by vehicle speed [km/h]	Measuring series	Pass-by ID
Install microphones on WH08/16/32 wayside horizontal array, calibrate, elevate array to “low” position.		7:00-9:30	concrete guideway (reference type) ①	208	setup/ reconstruction				
Install single microphones at northern switch.		9:00-13:00	HS switch II ⑦	291-298		setup/ reconstruction			
Make noise measurements with WH08/16/32 array in "low" position.	N2	09:30-10:00	concrete guideway (reference type) ①	208	WH08/16/32	no	standardized speed profile (150, 200, 300, 400 km/h)	E	E-150-1 E-400-1 E-200-1 E-300-1
	N3	10:00-10:30							E-150-2 E-400-2 E-200-2 E-300-2
	N4	10:30-11:00							E-150-3 E-400-3 E-200-3 E-300-3
Make measurements with single microphones at switch.	N7	13:00-13:30	HS switch II ⑦	291-298	No	6.5 m (high and low), 25 m, 50 ft, 100 ft, under guideway	standardized speed profile (150, 200, 300, 400 km/h)	Z	Z-150-1 Z-400-1 Z-200-1 Z-300-1
	N8	13:45-14:15					standardized speed profile (150, 200, 300, 400 km/h)		Z-150-2 Z-400-2 Z-200-2 Z-300-2
	N9 (instead of N5/N6)	14:30-15:00					100 km/h		Z-100-1 Z-100-2 Z-100-3 Z-100-4
Retrieve single microphones and detach array from tower.		15:00-16:00			setup/ reconstruction	setup/ reconstruction			
Move tower and equipment to measuring		16:00-18:00			setup/ reconstruction				

Noise Measurement Activities	Trip	Time frame	Measuring location	Beam no.	Array configuration	Single microphones	Pass-by vehicle speed [km/h]	Measuring series	Pass-by ID
site at steel guideway.									

Date: Thursday, 2001-08-16

Vibration Measurement Activities	Trip	Time frame	Measuring location	Beam no.	Pass-by vehicle speed [km/h]	Measuring series	Pass-by ID
Set up accelerometers, recording instrumentation, and ground impacter at site near concrete guideway and conduct transfer mobility test.		7:00-9:30	concrete guideway (reference type) ①	208			
Record ground vibrations from TR08 at site	N2	09:30-10:00	concrete guideway (reference type) ①		standardized speed profile (150, 200, 300, 400 km/h)	E	E-150-1 E-400-1 E-200-1 E-300-1
	N3	10:00-10:30					E-150-2 E-400-2 E-200-2 E-300-2
	N4	10:30-11:00					E-150-3 E-400-3 E-200-3 E-300-3
Move accelerometer mounts to at-grade guideway. Set up accelerometers, recording instrumentation at site.		11:00 – 13:00	at-grade guideway (concrete and steel) ⑤⑥	341a-d 340a-d			
Record ground vibrations from TR08 at site	N7	13:00-13:30	at-grade guideway (concrete and steel) ⑤⑥	341a-d 340a-d	standardized speed profile (150, 200, 300, 400 km/h)	Z	Z-150-1 Z-400-1 Z-200-1 Z-300-1
	N8	13:45-14:15			standardized speed profile (150, 200, 300, 400 km/h)		Z-150-2 Z-400-2 Z-200-2 Z-300-2
	N9 (instead of N5/N6)	14:30-15:00			100 km/h		Z-100-1 Z-100-2 Z-100-3 Z-100-4
Set up ground impacter at site near at-grade guideway and conduct transfer mobility test.		15:00-17:00					
Move accelerometers to station platform site.		17:00-18:00					

Date: Thursday, 2001-08-16 [3]

EMF Measurement Activities	Trip	Time frame	Measuring location	Beam no.	Sensor array configuration		Pass-by vehicle speed [km/h]	Measuring series	
Transport equipment to beam 213 of the elevated guideway, place sensors beneath the guideway and at distances of 5, 20, and 35m from centerline, and verify instrument performance.		8:00-9:30	Elevated steel guideway	213	Lateral profile 1m above ground.				
Wayside. EMF and RF measurements beneath and near elevated guideway.	N2	09:30-10:00	Elevated steel guideway	213	„		Standardized speed profile (300 and 400 km/h passes recorded)	Guideway	
	N3	10:00-10:30	Elevated concrete guideway	215	„			Guideway	
	N4	10:30-11:00	Elevated hybred guideway	267-268	„			Guideway	
Wayside. EMF and RF measurements near at-grade guideway.	N7[4]	13:00-13:30	Steel at-grade plate	340 a-d	„		Standardized speed profile (200 and 400 km/h passes recorded)	Guideway	
	N8[4]	13:45-14:15	Concrete at-grade plate	341 a-d	„			Guideway	
Wayside. EMF and RF measurements near wayside electrical switching cabinets.	N9[4] (instead of N5)	14:30-15:00	Standard switch cabinets	183	„		Standardized speed profile (300 and 400 km/h passes recorded)	Wayside equipment	
	N10[4] (instead of N6)	15:00-15:30	Swirch building designed for Berlin/Hamberg		„			Wayside equipment	
Remove instruments from the wayside and place them on charge. Inspect data for integrity and back up.		15:30-17:30			Instruments removed from wayside				

Notes: [3] Outdoor measurements described for this day may be moved a day earlier or a day later depending on weather conditions.
[4] All trips conforming to the standardized speed profile regardless of their trip number will be used for guideway measurements. Non-standard trips will be used for the switching cabinet measurements if required

Date: Friday, 2001-08-17

Noise Measurement Activities	Trip	Time frame	Measuring location	Beam no.	Array configuration	Single microphones	Pass-by vehicle speed [km/h]	Measuring series	Pass-by ID
Install microphones on WV08/16/32 wayside vertical array, calibrate, elevate array to "high" position, set up single microphones.		7:00-9:30	steel guideway ②	213	setup/ reconstruction	setup/ reconstruction			
Make noise measurements with WV08/16/32 array in "high" position, make measurements with single microphones.	N2	09:30-10:00	steel guideway ②	213	WV08/16/32 (high)	6.5 m (high)	standardized speed profile (150, 200, 300, 400 km/h)	G	G-150-1 G-400-1 G-200-1 G-300-1
	N3	10:00-10:30							G-150-2 G-400-2 G-200-2 G-300-2
	N4	10:30-11:00							G-150-3 G-400-3 G-200-3 G-300-3
Lower microphone array and 6.5 m single microphone to "low" position.		11:00			setup/ reconstruction	setup/ reconstruction			
Make noise measurements with WV08/16/32 array in "low" position, make noise measurements with single microphones.	N5	11:00-11:30	steel guideway ②	213	WV08/16/32 (low)	6.5 m (low), 25 m, 50 ft, 100 ft, under guideway	standardized speed profile (150, 200, 300, 400 km/h)	H	H-150-1 H-400-1 H-200-1 H-300-1
	N6	12:15-12:45							H-150-2 H-400-2 H-200-2 H-300-2
	N7	13:00-13:30							H-150-3 H-400-3 H-200-3 H-300-3
	N8	13:45-14:15				6.5 m (low), 25 m, 50 ft, 100 ft, under guideway	100 km/h		H-100-1 H-100-2
						6.5 m (high), 25 m, 50 ft, 100 ft, under guideway	100 km/h		H-100-3 H-100-4

Retrieve single microphones and detach array from tower.		14:30-16:30							
Move tower to measuring site at hybrid guideway.		15:30-16:30							
Reconstruct array to WV08/16/32.		16:30-17:30			setup/ reconstruction				
Pack equipment for weekend storage.		17:30-18:00							

Date: Friday, 2001-08-17

Vibration Measurement Activities	Trip	Time frame	Measuring location	Beam no.	Pass-by vehicle speed [km/h]	Measuring series	Pass-by ID
Set up accelerometers, recording instrumentation, and ground impacter at site near station platform and conduct transfer mobility test.		7:00-9:30	Station Platform				
Record ground vibrations from TR08 at site	N2	09:30-10:00	Station Platform		Low	G	G-1
	N3	10:00 –10:30					G-2
	N4	10:30-11:00					G-3
Pack equipment and depart TVE		11:00 – 15:00					

Date: Friday, 2001-08-17

EMF Measurement Activities	Trip	Time frame	Measuring location	Beam no.	Sensor array configuration		Vehicle operating speed profile	Measuring series	
Transport equipment to the trailing vehicle, place sensors in the seventh onboard measurement location, and verify instrument performance.		8:00-9:30	Onboard trailing vehicle		Mannequin positions and fixed reference				
Onboard trailing vehicle. EMF and RF measurements at a locations corresponding to the to test locations in the lead car to identify variation in field levels among cars. The measurement locations will correspond to three locations where measurements were made in the lead vehicle.	N2	09:30-10:00	Onboard trailing vehicle. Middle seat away from onboard equipment.		„		Standardized speed profile	Onboard	
	N3	10:00-10:30	Onboard middle vehicle . Middle seat above a battery compartment.[2]		„		Standardized speed profile	Onboard	
	N4	10:30-11:00	Onboard middle vehicle. Middle seat above a battery charger and control equipment.[2]		„		Standardized speed profile	Onboard	
Onboard leading vehicle. EMF and RF measurements at the attendant's position in the nose of the vehicle.	N5	11:00-11:30	Onboard leading vehicle. Attendant's position in the nose of the vehicle.		„		Standardized speed profile	Onboard	
Onboard leading vehicle. EMF and RF measurements near onboard equipment.	N6	12:15-12:45	Onboard leading vehicle. Standing near the air handlers at the rear of the vehicle.		„		Standardized speed profile	Onboard	
Contingency This trip will be used to repeat any defective onboard measurement or conduct an additional onboard measurement suggested by a review of data collected in the first two measurement days.	N7	13:00-13:30	As required.		„		Standardized speed profile	Onboard	
Contingency This trip will be used to repeat any defective station measurement or conduct an additional station measurement suggested by a review of data collected in the first two measurement days.	N8	13:45-14:15	As Required.		„		Nonstandard speed profile required for low speed noise measurements	Station	
Remove instruments from the station and pack for shipment. Inspect data for integrity and back up.		14:15-18:00			Instruments removed from station				

Date: Tuesday, 2001-08-21

Noise Measurement Activities	Trip	Time frame	Measuring location	Beam no.	Array configuration	Single microphones	Pass-by vehicle speed [km/h]	Measurin g series	Pass-by ID
Install microphones on WV08/16/32 wayside vertical array, calibrate, elevate array to "high" position, set up single microphones.		7:00-9:30	hybrid guideway ④	267	setup/ reconstruction	setup/ reconstruction			
Make noise measurements with WV08/16/32 array in "high" position, make noise measurements with single microphones.	N2	09:30-10:00	hybrid guideway ④	267	WV08/16/32 (high)	6.5 m (high)	standardized speed profile (150, 200, 300, 400 km/h)	I	I-150-1 I-400-1 I-200-1 I-300-1
	N3	10:00-10:30							I-150-2 I-400-2 I-200-2 I-300-2
	N4	10:30-11:00							I-150-3 I-400-3 I-200-3 I-300-3
Lower array and 6.5 m single microphone to "low" position.		11:00			setup/ reconstruction	setup/ reconstruction			
Make noise measurements with WV08/16/32 array in "low" position, make noise measurements with single microphones.	N5	11:00-11:30	hybrid guideway ④	267	WV08/16/32 (low)	6.5 m (low), 25 m, 50 ft, 100 ft, under guideway	standardized speed profile (150, 200, 300, 400 km/h)	J	J-150-1 J-400-1 J-200-1 J-300-1
	N6	12:15-12:45							J-150-2 J-400-2 J-200-2 J-300-2
	N7	13:00-13:30							J-150-3 J-400-3 J-200-3 J-300-3
	N8	13:45-14:15				6.5 m (low), 25 m, 50 ft, 100 ft, under guideway	100 km/h		J-100-1 J-100-2
						6.5 m (high), 25 m, 50 ft, 100 ft, under guideway	100 km/h		J-100-3 J-100-4
Retrieve single microphones and detach		14:30-15:30							

array from tower.									
Move tower and equipment to measuring site at concrete guideway.		15:30-16:30							
Reconstruct array to WV08/16/32.		16:30-18:00			setup/ reconstruction				

Date: Tuesday, 2001-08-21

Vibration Measurement Activities	Trip	Time frame	Measuring location	Beam no.	Array configuration	Single microphones	Pass-by vehicle speed [km/h]	Measuring series	Pass-by ID
Contingency day for tests if delays.									

Date: Wednesday, 2001-08-22

Noise Measurement Activities	Trip	Time frame	Measuring location	Beam no.	Array configuration	Single microphones	Pass-by vehicle speed [km/h]	Measuring series	Pass-by ID
Install microphones on WV08/16/32 wayside vertical array, calibrate, elevate array to “high” position, set up single microphones.		7:00-9:30	prototype concrete guideway ③	215	setup/ reconstruction	setup/ reconstruction			
Make noise measurements with WV08/16/32 array in "high" position, make noise measurements with single microphones.	N2	09:30-10:00	prototype concrete guideway ③	215	WV08/16/32 (high)	6.5 m (high)	standardized speed profile (150, 200, 300, 400 km/h)	K	K-150-1 K-400-1 K-200-1 K-300-1
	N3	10:00-10:30							K-150-2 K-400-2 K-200-2 K-300-2
	N4	10:30-11:00							K-150-3 K-400-3 K-200-3 K-300-3
Lower array and 6.5 m single microphone to "low" position.		11:00			setup/ reconstruction	setup/ reconstruction			
Make noise measurements with WV08/16/32 array in "low" position, make noise measurements with single microphones.	N5	11:00-11:30	prototype concrete guideway ③	215	WV08/16/32 (low)	6.5 m (low), 25 m, 50 ft, 100 ft, under guideway	standardized speed profile (150, 200, 300, 400 km/h)	L	L-150-1 L-400-1 L-200-1 L-300-1
	N6	12:15-12:45							L-150-2 L-400-2 L-200-2 L-300-2
	N7	13:00-13:30							L-150-3 L-400-3 L-200-3 L-300-3
	N8	13:45-14:15				6.5 m (low), 25 m, 50 ft, 100 ft, under guideway	100 km/h		L-100-1 L-100-2

						6.5 m (high), 25 m, 50 ft, 100 ft, under guideway	100 km/h		L-100-3 L-100-4
Retrieve single microphones and detach array from tower. Pack equipment.		14:30-18:00							

Date: Wednesday, 2001-08-22

Vibration Measurement Activities	Trip	Time frame	Measuring location	Beam no.	Array configuration	Single microphones	Pass-by vehicle speed [km/h]	Measuring series	Pass-by ID
Contingency day for tests if delays encountered..									

Date: Thursday, 2001-08-22

Noise Measurement Activities	Trip	Time frame	Measuring location	Beam no.	Array configuration	Single microphones	Pass-by vehicle speed [km/h]	Measuring series	Pass-by ID
Additional contingency day due to weather problems or other unforeseen events.									