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16. Abstract

The safety of various magnetically levitated (maglev) and high speed rail (HSR) trains proposed for application in the United States is of direct concern to the Federal Railroad Administration (FRA). The characterization of electric and magnetic fields (EMF) emissions, both steady (dc) and produced by alternating currents (ac) at power frequency (50 Hz in Europe and 60 Hz in the U.S.) and other frequencies in the Extreme Low Frequency (ELF) range (3-3000 Hz), and associated public and worker exposures to EMF, are a growing health and safety concern worldwide. As part of a comprehensive safety assessment of the German TransRapid (TR-07) maglev system undertaken by the FRA, with technical support from the DOT/RSPA Volpe National Transportation System Center (VNTSC), magnetic field measurements were performed by Electric Research and Management, Inc. (ERM) at the Transrapid Test Facility (TVE) in Emsland, Germany in August, 1990. The *MultiWave*™ magnetic field monitoring system was used to sample, record and store 3 axis dc and ac magnetic fields waveforms simultaneously, at multiple locations: in the TR-07 vehicle (both passenger compartment and operator cab), near the guideway, in the passenger station, and in the vicinity of power supply equipment (inverter building, transformers yard, feeder cables). Volume I-Analysis summarizes the experimental findings and compares results to common home, work, and power lines emissions for selected spectral bands. Volume II-Appendices catalogs and documents detailed magnetic field data files and their specifics (static fields, spectral waveforms, temporal and spatial information) by location.

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PREFACE

The use of high speed guided ground transportation systems for both urban and intercity travel, including magnetically levitated (maglev) trains, might become a reality within the decade. The first such system in the United States will probably be the Florida Maglev Demonstration Project in Orlando, which is based on the German electromagnetic attraction (EMS) technology represented by the TransRapid (TR-07) prototype. The Federal Railroad Administration (FRA) has the legislative responsibility for the safety of maglev systems in the United States, under the provisions of the Rail Safety Improvement Act of 1988.

One of the emerging environmental health and safety concerns relates to potentially adverse health effects of extreme low frequency (ELF) electric and magnetic fields (EMF) associated with power lines and electrified transportation systems. Magnetic fields at power and harmonics frequencies are of greater public concern, because, unlike electric fields, they are pervasive, penetrate biological tissue, and are more difficult to shield. In addition, maglev and high speed rail (HSR) systems, like most novel and unproven technologies, will undergo more public scrutiny in order to convincingly demonstrate their safety. However, no systematic data on EMF characteristics for existing and advanced electrified transportation systems exists on which to base an assessment of relative emissions profile and associated potential health impacts.

The FRA, with technical and administrative support from the Research and Special Programs Administration (RSPA) Volpe National Transportation Systems Center (VNTSC), has sponsored a comprehensive series of studies and reports addressing the safety issues for candidate high speed rail technologies and systems. The FRA, through VNTSC, has contracted with Electric Research and Management, Inc. (ERM) to measure, characterize, and analyze EMF emissions for both established and advanced rail systems, in order to compile a database on their common and specific EMF signatures, as the basis for comparing them with typical home, work and power line EMF environments. This report on measured levels, spatial, and frequency characteristics of both static (dc) and alternating (ac) magnetic fields associated with the TR-07 maglev, is the first of a series: future reports will describe and discuss EMF characteristics for representative electrical rail systems, existing or proposed for U.S. applications.

This report was prepared by ERM personnel, including Fred Dietrich, Program Manager, William E. Feero, George Steiner, and David Robertson. We acknowledge technical guidance from the FRA sponsor, Mr. Arne Bang, and close interaction with the Technical Monitor, Dr. Aviva Brecher of VNTSC. We also acknowledge experimental design assistance from Dr. Ross Holmstrom, and support from Mr. Robert M. Dorer, Project Leader of the VNTSC Safety Analysis team.

METRIC / ENGLISH CONVERSION FACTORS

ENGLISH TO METRIC

LENGTH (APPROXIMATE)

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

AREA (APPROXIMATE)

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

MASS - WEIGHT (APPROXIMATE)

1 ounce (oz) = 28 grams (gr)
1 pound (lb) = .45 kilogram (kg)
1 short ton = 2,000 pounds (lb) = 0.9 tonne (t)

VOLUME (APPROXIMATE)

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

TEMPERATURE (EXACT)

$[(x - 32)(5/9)]$ °F = y °C

METRIC TO ENGLISH

LENGTH (APPROXIMATE)

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

AREA (APPROXIMATE)

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

MASS - WEIGHT (APPROXIMATE)

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

VOLUME (APPROXIMATE)

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

TEMPERATURE (EXACT)

$[(9/5)y + 32]$ °C = x °F

QUICK INCH-CENTIMETER LENGTH CONVERSION

INCHES: 0 1 2 3 4 5 6 7 8 9 10

CENTIMETERS: 0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 25.40

QUICK FAHRENHEIT-CELSIUS TEMPERATURE CONVERSION

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

For more exact and/or other conversion factors, see NBS Miscellaneous Publication 286, Units of Weights and Measures. Price $2.50. SD Catalog No. C13 10 286.

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1.0 EXECUTIVE SUMMARY

This document is the final of two reports describing the magnetic field measurements conducted onboard the Transrapid TR07 Maglev Vehicle and in the vicinity of the vehicle, guideway, passenger station, control center, and power supply facilities at the Transrapid Test Facility in Emsland, Germany in August 1990. The earlier report[2] described the nature of the tests and the test equipment, cataloged the collected data, and provided an interim analysis of approximately 20% of the data consisting of time domain and frequency domain "snapshots" of the magnetic field. The bulk of the data collected on the TR07 System consisted of magnetic field waveform recordings collected in rapid succession to document the temporal fluctuations of magnetic field conditions over periods of time considerably longer than the short term "snapshot" recordings. These data have now been analyzed and, to a considerable extent, form the basis of the material contained in this report. The conclusions presented in this document are comprehensive in the sense that they are drawn from material in the first report, material in this report, as well as data on the Transrapid System from other sources.

1.1 Background

At the outset of the TR07 test it was recognized that the simple magnetic field survey instruments used for transmission and distribution line surveys would be inappropriate for quantifying the fields associated with the TR07. Many of the laboratory studies and a concurrent body of clinical studies have reported effects which appear to result from exposure to fields over a wide range of magnitudes and frequencies. Most of the existing field survey meters were sensitive only to a relatively narrow band of frequencies, centered on the power frequencies of 50 and 60 Hz. Any serious attempt at magnetic field quantification which would claim to serve as a basis for evaluating public health effects must not inadvertently be a selective measure of the magnitude at a single or narrow band of frequencies. In the extreme, if health effects are found, the continuum of electromagnetic exposure may be required to establish relative risk. Practically, it has only recently been possible to record and store all of the discrete segments of the frequency bands which biological reports suggest may be important.

Based on the biological studies reported through 1990, the TR07 measurements focused on the frequency bands from dc, or zero frequency, to 2000 Hz ("Hz" is defined as "cycles per second"). The study also only measured the magnetic field, because the electric field was not expected to differ from that found in most building environments. Onboard the train, since the metallic structure of the train is between the electrical system and the passenger compartment, it is reasonable to assume that the electric fields interior to the train would be minimal. It is also the experience of researchers that making measurements of electric fields in anything but a very precisely defined environment is of little value. Since human bodies are extremely good shields relative to electric fields, data collected by positioning sensors in an environment in close proximity to occupied space is difficult to interpret.

Magnetic fields are not shielded by biological systems. Metallic, non-ferromagnetic materials only mildly affect low frequency magnetic fields. Ferromagnetic materials do provide some shielding of magnetic fields, but complete shielding is rarely practical.

The magnetic field data collected from TR07 was significantly more complicated than that which is found in the vicinity of power lines. The most significant complications arise from the following characteristics of the TR07 magnetic fields.

<u>Multiple Sources</u>: The magnetic fields onboard or in the vicinity of the TR07 Maglev System arise from multiple sources, hence spatial distributions cannot be expressed as simple attenuation curves which are temporally stable.

<u>Continuous Frequency Distribution</u>: The time-varying component of the guidance and levitation magnetic fields have a distributed rather than discrete frequency distribution. Consequently, one must address field intensities in various bands of finite width rather than fields at specific frequencies.

<u>Variable Frequency Components</u>: The magnetic field from the longstator of the linear synchronous motor (or from the power equipment driving that field) is a discrete frequency component which varies over time. Consequently, simple averaging of repetitive frequency spectra will obliterate this component of the field as a discrete component.

1.2 <u>Organizing Electromagnetic Data</u>

To measure the magnetic field environment of the TR07, a new magnetic field monitoring system developed under the sponsorship of the Electric Power Research Institute was used. The system, marketed under the brand name *MultiWave*™, has the capability to record and store 3-axis magnetic fields in up to 40 different physical locations nearly simultaneously. The 3-axis feature, combined with waveforms captured in each axis (vertical and both transverse and longitudinal), preserves the direction, magnitude, polarization, and frequency spectrum of the magnetic field at each point in space which was measured. To gain temporal information on the nature of the magnetic field, the field is sampled repetitively at intervals set by the test requirements. Using this system generates excellent but extensive data. Before undertaking the evaluation of the magnetic field characteristics of the TR07, it was necessary to develop subsets of the data which partitioned it into frequency bands which would facilitate understanding its significance relative to previous research. Aggregating the data within the subsets allowed the authors to draw general conclusions as to the character and expected impact of the fields produced by the TR07.

While the exact procedure for developing subsets can only be explained by carefully reading the body of the report, in essence the data was decomposed into frequency bands of only 5 Hz. Using Fourier transform techniques it was possible to evaluate the frequency spectra from approximately 2.5 Hz to 2562.5 Hz. The data can be shown graphically over such a wide bandwidth, but to have data to relate to reported health concerns, it seemed appropriate to segregate the data into groupings. These groupings were chosen to be: the static field, or dc field; the sub-power frequencies from 2.5 Hz to 47.5 Hz; power frequencies from 47.5 Hz to 62.5 Hz; low super power frequencies from 62.5 Hz to 302.5 Hz; and high super power frequencies from 302.5 Hz to 2562.5 Hz. Aggregation of the data from all the sample intervals into these subsets provided magnitude and frequency summaries that might be important in determining the possibility of the various biological effects that have been reported. It also provided for a means of evaluating previously measured data on other electro-technologies taken with simpler instrumentation systems.

1.3 Findings

The body of this report presents the results of the analysis of this extensive measurement of magnetic fields within the TR07 vehicle along the guideway, at the passenger station, and in the vicinity of the power supply equipment used to operate the system. A general finding is that the magnetic fields at all of these locations have complex frequency spectra that are highly variable over time. These characteristics of the magnetic fields in the TR07 vehicle and near associated equipment differ from those of magnetic fields produced by electric power lines, where the fields are predominantly 50 Hz or 60 Hz and somewhat more temporally stable. Specifically, we found the following:

> Passenger Compartments: The time-varying magnetic fields in the passenger compartments of the TR07 vehicle covered the frequency range from 2.5 Hz to over 2 kHz and were highly variable over time. The average field levels ranged from approximately 100 mG near the floor of the vehicle to approximately 20 mG at standing head level. Aside from the strong height dependence, the magnetic field levels were not strongly dependent on location within the passenger compartment. The standard deviation of the magnetic field intensity over time was typically 40% of the mean value, but maximum values at any height above the floor were often 2-1/2

times the average values. Typically, 70 to 80 percent of the time-varying magnetic fields were at frequencies below 47.5 Hz. The static magnetic field level within the passenger compartments was dominated by the geomagnetic fields at standing head level. Higher static fields resulted mainly from vehicle-generated fields near the floor. Fields in between were a varying mixture of the fields from these two sources. Average static magnetic field levels near the floor were 835 mG (as compared to the earth's magnetic field in that vicinity of 500 mG) and reduced to approximately 500 mG at standing level. Static fields were more spatially variable but slightly more stable over time than the alternating or time-varying fields. The fields measured in the engineer's compartment were similar to that of the passengers' compartment except that there was less reduction of the field intensity with an increasing height above the floor.

Near the Guideway: Elevated magnetic field levels only exist near the guideway for very brief periods of time when the guideway is energized and a vehicle is passing. The maximum time-varying magnetic field levels within 3 meters of the center line of the guideway are comparable to average field levels onboard the vehicle, 65 mG to 95 mG, but occur only for a brief period of time. At 10 meters from the center line of the guideway, the guideway height is not a significant factor in determining field level and the maximum time-varying magnetic field levels are approximately 20 mG. Like the fields onboard the vehicle, the magnetic fields along the guideway have a complex frequency spectrum, with the largest fields at frequencies below 47.5 Hz. Unless the TR07 vehicle stops and levitates, the system does not produce a static field near the guideway significantly different from the earth's magnetic field.

Passenger Station: Magnetic field levels at the passenger station are similar in nature to those along the guideway. Time-varying field levels near the edge of the loading platform approach 300 mG as the vehicle passes by, but this is in a vicinity where people will not be permitted while the vehicle is moving. Within the waiting area at the station the time-varying magnetic fields produced by the passing vehicle on the energized guideway is approximately 20 mG. As in other locations along the guideway the magnetic field is predominantly low frequency components below 47.5 Hz and occurs only for brief instances when the vehicle passes on the energized guideway.

Power Equipment: The magnetic fields near power equipment have different frequency and time characteristics from those onboard the TR07 vehicle or along the guideway. The magnetic field characteristics near one piece or group of equipment differ from those near another. Although time-varying magnetic fields near the principal pieces of equipment have very complex frequencies and temporal characteristics, the average field intensities are generally low, approximately 2 mG. The significant exception to that trend is the field levels near the inverter building, approximately 20 mG at 5 meters' distance from the building. Since this entire area is fenced, with limited personnel access, frequent human exposure to magnetic fields from the power supply equipment is unlikely.

Feeder Cables: Feeder cables are the only major component of the power supply system outside controlled areas. All the attempts to measure magnetic fields from these cables were difficult. The fields from the cable were small in comparison to the fields from nearby sources. Although the situation made measurement of the cable field somewhat imprecise, the data shows the time-varying magnetic fields of all the cables are less than 2 mG and attenuate quickly with distance from the cables. The cables and the power site supply equipment had no measurable effect on the earth's static magnetic field other than the passive perturbation of the field due to the ferromagnetic material used in construction of structures and equipment.

1.4 Comparison of TR07 Fields to Other Environmental Magnetic Fields

Existing scientific knowledge provides no sound insight as to what aspects of low frequency magnetic field exposure, if any, are of biological concern. Consequently, public acceptance of magnetic field exposures is presently more on an equitable and comparable basis to other exposures than it is to quantifiable characteristics of the field itself. It is in that light that this comparison and contrast of magnetic fields produced by the TR07 to other environments is presented.

Static Fields: The static fields encountered onboard the TR07 vehicle, mean values from 500 mG to 1000 mG, are generally within the range of static fields encountered daily in the perturbated geomagnetic fields (250 mG to 1000 mG). The peak values encountered near the floor of the vehicle are comparable to those near a refrigerator which is equipped with a magnetic door seal. The magnitude of the static field onboard the TR07 vehicle has substantial temporal variability. Sizeable changes in static field intensity occur more frequently and more rapidly than do most changes in the geomagnetic field which result from walking past a perturbing object such as a steel column or beam. Static field conditions at the station, along the guideway, or near power supply equipment are essentially all geomagnetic fields, with no significant contribution from active operation of the TR07 system.

Field Frequency: The frequency characteristic of the time-varying magnetic fields onboard the TR07 vehicle at the station, near the guideway, or near the power supply equipment are unique from those that have been measured to date anywhere else in the environment. There are no compelling scientific data available which demonstrate that field frequency is a significant parameter in adverse effects of low frequency magnetic field exposure on human health, or that that parameter should be evaluated. However, there are a number of proposed mechanisms for interaction and a variety of experimental studies which suggest that frequency characteristics of the magnetic field are equally important as the intensity parameter for eliciting a biological response. Consequently, a comparison of the fields at the various sources should include a comparison of the frequency characteristics.

The magnetic fields onboard the TR07 system generally have their highest components at frequencies below the power frequency, a frequency range where other common field sources produce little or no magnetic fields. Undoubtedly, there are industrial or scientific facilities which produce magnetic fields in the sub-power frequency range, but there are no data currently available for comparison.

The magnetic fields produced by the TR07 at the power frequency range are generally a small portion of the overall fields; the converse is true for most environmental fields. A notable exception is near the transformer yard where the power frequency predominates. Onboard the TR07 vehicle and along the guideway the field varies with frequency within the power frequency band of 47.5 Hz to 62.5 Hz, while for other common frequency sources the frequency is stable at 50 Hz or 60 Hz.

The magnetic fields produced by the TR07 propulsion system in the frequency band of 62.5 Hz to 302.5 Hz are, in terms of frequency, comparable to environmental magnetic fields produced by harmonic distortion of the power frequency electric currents in wiring and appliances. There is a difference in that the frequency of the TR07 is more continuously variable throughout this frequency range than the discrete harmonic steps which characterize most other environmental fields. For purposes of comparison to other environmental fields, little data is available from other electro-technologies in the frequency range between 300 Hz and 2560 Hz.

Time Characteristics: The time characteristics of the magnetic fields produced by the TR07 are highly variable over time, especially at the station and along the guideway. Most other sources of environmental magnetic fields tend to be more stable in frequency and intensity over time. To date, the characterization of intermittent fields near appliances and industrial equipment is very limited, consequently there does not exist a database against which to match the temporal fluctuations that characterize TR07 fields. Although intermittency of magnetic fields has been suggested as a factor of biological significance, experimental data supporting that suggestion is limited.

<u>Amplitude Characteristics</u>: Notwithstanding the aforementioned need to compare the temporal and frequency characteristics for various low frequency magnetic fields, this subsection will compare the measured magnetic field levels onboard and near the TR07 facility to reported magnetic field levels near various power frequency sources. The lack of comparable environmental field data in several of the frequency bands makes any other approach unworkable. The reader must be aware that the comparison of the total magnetic field bandwidth between 2.5 Hz and 2562.5 Hz of the TR07 to the predominantly power frequency environment field levels concurrently reported in the literature is an apples-to-oranges comparison. With that important caveat, generalizations are offered.

The magnetic fields of magnitudes found in the passenger compartment of the TR07 can be shown to fall well within the intensity levels that characterize magnetic fields found near appliances and at the edge of transmission line rights-of-way. The magnetic field intensities found in the engineer's compartment are similar in intensity to those found at the edge of transmission line rights-of-way and in close proximity to standard household appliances. The magnetic field intensities found near the guideways exhibit a highly temporal characteristic. When a train passes by, the magnetic field magnitudes close to the guideway are typical of those found at the edge of transmission line rights-of-way and near household appliances. The magnetic field levels remote from the guideway are similar to fields found near distribution line rights-of-way. The fields found at the passenger station platform have intensities that range, while the train is passing, from those found at the edge of transmission line rights-of-way and near household appliances to field levels below those near distribution lines. The magnetic field intensities found near the power equipment are at or below those typically found around utility power equipment, and at or below those found near distribution line rights-of-way. The magnetic field intensities found in the immediate vicinity of the underground feeder cables are similar to those found immediately adjacent to distribution line rights-of-way and decay very rapidly to background fields with distance from the cables.

1.5 Comparison of TR07 Fields to Existing Standards

There are only a few existing standards worldwide that could be used to evaluate the fields produced by the TR07. They are

The World Health Organization's (WHO) "Criteria 69." TR07 magnetic fields onboard the vehicle are at least two orders of magnitude below the level set as the maximum for continuous exposure by the WHO.

International Radiation Protection Agency (IRPA). The maximum magnetic field intensities found on the TR07 are one order of magnitude below the 1 Gauss continuous public exposure criteria set by IRPA.

German standard DIN VDE 0848. Magnetic field intensities onboard the TR07 vehicle are at least 2 orders of magnitude below the criteria set by DIN VDE 0848.

American Conference of Governmental Industrial Hygienists (ACGIH). The magnetic fields onboard the TR07 are 3 orders of magnitude below the criteria set by this standard.

State Power Line Limits. These are not standards; they are status quo rulings handed down by the State of Florida and the State of New York, pertinent only to edge of right-of-way fields. However, the magnetic field intensity levels found on TR07 are generally less than 100 mG, which under the most stringent application of these rulings is less than two-thirds of the magnetic field value permitted.

2.0 OVERVIEW

2.1 Background

The increasing public awareness of the controversy over possible health implications due to exposure to magnetic fields makes it desirable to quantify the magnetic fields associated with use or operation of all electrical apparatus. Whether justified or not, new electrical technologies find that their possible environmental impact is questioned more than existing technologies. Any technology whose successful introduction requires rapid acceptance by the general public and/or the gaining of rights-of-way from segments of the public who might not directly benefit from the technology must be prepared with indepth answers to any question that may arise about the characteristics of the technology. Therefore, the introduction of magnetically levitated mass transportation systems can logically expect that its electromagnetic characteristics will be carefully evaluated.

To augment the process of fully quantifying the electromagnetic characteristics of magnetic levitation systems, an extensive set of measurements were made on and around the Transrapid TR07 Maglev Vehicle. The magnetic fields onboard the TR07 vehicle, under and near the guideway, in the station, and near the control and power supply facilities were recorded for a variety of operating conditions. These measurements were taken in early August 1990 at the Transrapid Test Facility in Emsland, Germany. The data gathered consisted of extensive information on the magnitude and time characteristics of the magnetic field attributable to the TR07 operation. Before this data can be summarized, it is necessary to discuss why magnetic field magnitude and time characteristics may be important.

Natural Magnetic Field Characteristics. The earth's naturally occurring geomagnetic field is generally considered to be static, i.e., not variable over time (in some literature, static fields are referred to as dc fields). The earth's field is normally static at levels between 240 to 620 milligauss, depending on locations between the magnetic equator and the magnetic polar regions respectively. In any of these regions, fluctuation will occur during solar magnetic disturbances. These fluctuations normally have frequencies that are less than one hundredth of a cycle per second to as high as 1000 cycles per second. The magnitude of these fluctuations is normally largest at the lowest frequencies and in the polar regions. However, mid-latitude variations of 2 to 4 milligauss are common during strong solar storms. In polar regions, solar magnetic disturbances will exceed ± 20 milligauss fluctuations. Therefore, the natural environment is made up of magnetic fields with both spatial and temporal characteristics.

Technological Magnetic Field Perturbations. Manmade ferromagnetic structures and electro-technologies perturb these natural fields.

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

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

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

Absent an accepted mechanism, many have chosen to relegate the reported effect of electric and magnetic fields to the category of "pathological science" (coined by the late Irving Langmuir). However, the persistence of public concern necessitates that any serious attempt at magnetic field quantification which claims to serve as a basis for evaluating possible health effects must not be an inadvertently selective measure of magnitude at a single or narrow band of frequencies. In the extreme, if health effects are found, the continuum of electromagnetic exposure may be required to establish relative risk. Practically, it has only recently become possible to record and store all of the discrete segments of frequency bands which biological reports suggest may be important. Based on the biological studies reported to 1990, the TR07 measurements focused on the dc to 2000 Hz portion of the electromagnetic spectrum.

2.2 An Approach to Organizing Electromagnetic Data

At the outset of the TR07 test, it was recognized that the simple magnetic field survey instruments used for transmission and distribution line surveys would be inappropriate for quantifying the field associated with the TR07. A new magnetic field instrumentation system had just been developed by Electric Research and Management, Inc. under sponsorship of the Electric Power Research Institute. Sold under the brand name *MultiWave*™, it has the capability to record and store 3-axis magnetic fields at up to 40 different physical locations nearly simultaneously. The 3-axis feature combined with waveform capture in each axis (vertical and both the transverse and longitudinal) preserves the direction, magnitude, polarization, and frequency spectrum of the magnetic field at each point in space measured.

For the TR07, measurement waveform periods were recorded through two different sensor types. To gather data on the static or dc magnetic field, a sensor technology known as fluxgate was used. Waveforms over periods between 1 to 5 seconds were recorded from this sensor group. The waveform data from each axis of each probe was stored in the memory of the control computer of the *MultiWave*™ System. The digitization rate of the waveform from the fluxgate probes gave frequency information from 0 to 200 Hz. A second set of probes which sensed the rate of change of the magnetic field, sometimes referred to as coil type sensors, was sampled for periods of .2 seconds. These waveforms were digitized at a rate which gave frequency information in the 5 to 2500 Hz band.

The data collected in this manner brackets most of the frequency bandwidth implicated by the biological findings briefly discussed above. Both temporal and spatial quantification in and around the TR07 are available. Because each of these measurements were repeated every few seconds to gain a measure of the long term temporal characteristic of the magnetic fields, an extremely large as well as comprehensive data set exists. The challenge of this report has been to reduce this data without losing the uniqueness of the information. Also to maximize the utility of the data, it must be presented so that it can be compared to data collected on the magnetic field characteristics of other electro-technologies.

To this end, the following aggregation was chosen for this evaluation. It also is being followed in an ongoing project to establish a rigorous protocol for quantifying the magnetic fields associated with appliances. Shown in pictorial form in Figure 2-1, this system allows for the grouping of data into frequency bands where effects have been reported and/or other data sets have been collected. The two large boxes depict the frequency regions defined by IEEE Std 100-1988[1] as Ultra Low Frequency (ULF) which covers the frequency range from 3 Hz down to static, and Extreme Low Frequency (ELF) which covers the frequency band from 3 Hz to 3000 Hz. Other organizations and agencies sometimes define these bands differently but the IEEE definitions will be used throughout this report. The boxes within the large boxes depict the partitioning which was chosen to clearly but succinctly present the findings of the TR07 measurements. Future investigation may expand the number of major boxes to include the Very Low Frequency (VLF) band which covers the frequency range between 3 kHz to 30 kHz. In the future it may also be desirable to further partition the ULF band to better examine motion effects and ultradian and circadian rhythm effects. While the TR07 data set contains some additional ULF information beyond static fields, its usefulness at this juncture is not clear and therefore has not been analyzed.

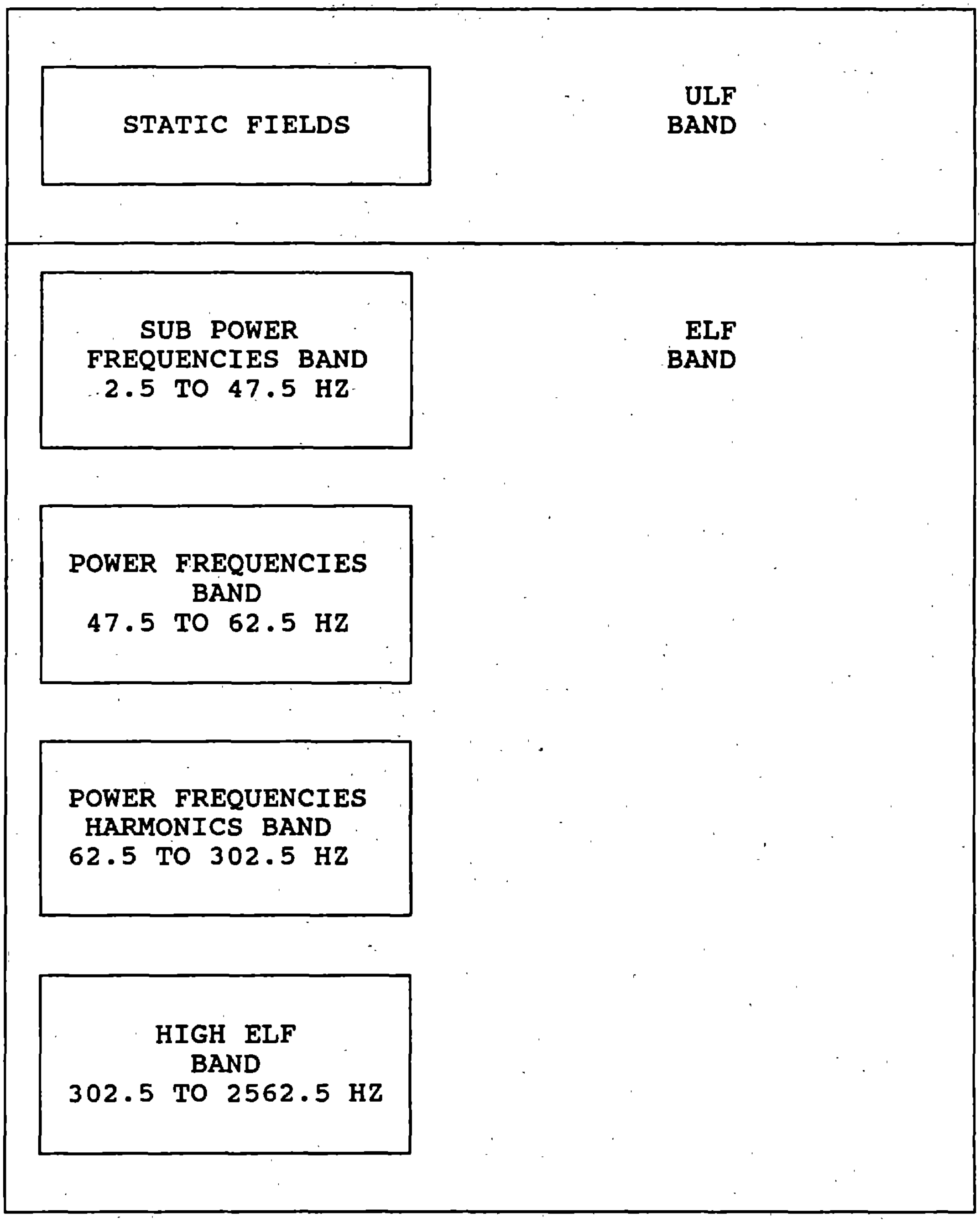


Figure 2-1 Magnetic field flux densities grouped by frequency partitions within the ELF band and ULF band.

The partitioning in Figure 2-1 allows for comparison with data collected by less sophisticated instruments. In particular, one instrument which has come into wide use in the utility industry has a bandwidth between 40 Hz and 1000 Hz. Other survey meters only respond to the power frequency band.

2.3 Report Organization

This report is organized into seven sections (Volume I) and 26 appendices (Volume II). The extensive appendices of Volume II contain a full reporting of the frequency, time, and space dependencies of the magnetic fields on or near the TR07 System for the reader looking for specific details of field characteristics. The body of the report contained in Volume I focuses on representative data which demonstrates the general characteristics of the magnetic fields on or in the vicinity of the TR07 Maglev transportation system and summary statistical data which present the "big picture" to the reader less concerned with the multitude of details in the data of the appendices. Details of the instrumentation, test locations, conditions, dates, etcetera have been reported previously and are not repeated in detail in this document.

The first section of this report is an Executive Summary intended for the semi-technically based reader. It describes the magnetic fields produced by the TR07 System and the conclusions reached by these measurements in language which avoids engineering jargon to the greatest extent practical. In spite of the non-technical nature, it is recommended to all readers as an orientation to the report contents which will assist the technical reader in critically examining the contents of the report.

This section is an overview which seeks to describe the report structure in more detail and direct the reader to other sources of relevant information not contained herein. It also seeks to explain the significance of the repetitive waveform data, the method of analysis, the format of presentation, and certain other items relevant to the report as a whole.

Sections 3 through 6 focus on the characteristics of the magnetic fields measured onboard the TR07 vehicle, along the guideway, at the station, and near the control and power supply facilities respectively. The results of the measurements made during the August 1990 tests are compared to magnetic field data measured or reported by others where such data are available.

The final section of the report attempts to both summarize the magnetic field characteristics of the TR07 System and compare the characteristics of those fields to magnetic fields produced by other common sources.

2.4 Repetitive Waveform Data

As described in the preceding report, the *MultiWave*™ Magnetic Field Recording System used of the August 1990 measurements on the TR07 System records the actual waveform of the three orthogonal components of the magnetic field at multiple measurement locations by sampling those waveforms at a high rate and storing the values digitally on computer disk or computer tape. These digital waveform recordings are saved one after another in rapid succession. Any one of these waveform recordings can be viewed individually in either the time or frequency domain as was done in the Interim Report to get a "snapshot view" of the waveform or frequency spectrum of the magnetic field at the particular instant in time when the waveform sample was recorded. Unfortunately, these "snapshots" when viewed individually have little statistical validity and tell nothing about the evolution of magnetic field characteristics over time as the TR07 vehicle speeds up, slows down, makes use of its dynamic braking, passes the station, and so on. In order to examine these questions of statistical and temporal variability of the magnetic field, many of these "snapshots" must be played back in rapid succession to produce a "moving picture" of the magnetic field at each measurement location.

As described in the Interim Report, the measurement protocol applied for the TR07 measurements generally involved the use of five fluxgate magnetic field (B) sensors and five coil-type magnetic field derivative (B dot) sensors arrayed in such a way that spatial variability of the magnetic field could be characterized. Since magnetic fields onboard or near the system arise from numerous sources, each with different temporal characteristics, the spatial pattern of the magnetic field is a dynamic characteristic which must be assessed from the "moving picture" of the magnetic field obtained from analysis of the repetitive waveform samples.

A list of the repetitive waveform data sets collected during the measurements on the TR07 System is given in Table 2-1. The table also identifies the nature of the measurement, the measurement locations, the number of repetitive waveform samples, the date and time, and the sample time for each of the twenty five data sets. The range of speed of the vehicle at the time of the measurement is also tabulated for those data sets where the information was known. The information contained in each of the 25 data sets has been processed using the procedure described in the following subsection and is presented in detail in Appendices B through Z in Volume II of the report.

TABLE 2-1

INDEX OF REPETITIVE WAVEFORM DATA
TR07 MEASUREMENTS, AUGUST 1990

DATA FILE # [SIZE,KB]	DATE/ HHMM	VEL.* KM/HR	PROBE LOC.♦ AC	DC	t_{S-DC} **, s	REMARKS
	AUG.7					ON TR07, ON TEST TRACK
TR7001## [1,330]	1020-1030	308/171	4	3	1.0	21 SAMPLES, 30 s APART MID CAR #2, WINDOWS
TR7002## [1,330]	1038-1048	396/162	2	1	1.0	21 SAMPLES, 30 s APART LOC. MID CAR #2, AISLE
TR7003## [1,079]	1332-1340	302/168	2	1	5.0	17 SAMPLES, 30 s APART LOC MID CAR #2, AISLE
	AUG.7					TR07 STARTUP AND RUN
TR7008## [1,206]	1735-1744	300/168	12	11	5.0	19 SAMPLES, 30 s APART LOC PASSENGER BULKHEAD (REAR)
	AUG.7					TR07 ON TRACK, CONTINUOUS
TR7009## [1,079]	1752 1800	320/170	14	13	5.0	17 SAMPLES LOC VIP SECTION
TR7010## [1,270]	1802-1812	340/170	16	15	5.0	20 SAMPLES LOC REAR ENGR. AREA
TR7011## [381]	1817-1822	180/0	17	17	5.0	6 SAMPLES, 30 s APART PROBES ON FLOOR, DECEL., STOP
	AUG.8					HIGH STEEL G/W NEAR CTL CTR †
TR7012## [1,333]	1042-1047		18	18	2.0	21 SAMPLES, ≈ 12 s APART AUTORANGE ON
TR7013## [14,029]	1050-1112		18	18	2.0	221 SAMPLES, ≈ 6 s APART AUTORANGE ON
TR7014## [2,539]	1226-1237		18	18	2.0	116 SAMPLES, ≈ 6 s APART AUTORANGE ON
TR7015## [825]	1239-1240		18	18	2.0	13 SAMPLES, < 6 s APART
TR7017## [1,016]	1246-1254		18	18	2.0	16 SAMPLES, < 6 s APART

TABLE 2-1 CONTINUED

DATA FILE # [SIZE,KB]	DATE/ HHMM	VEL.* KM/HR	PROBE LOC.♦ AC	DC	t_{S-DC} **,s	REMARKS
TR7018## [3,303]	1256- 1301		19	19	2.0	52 SAMPLES, < 6 s APART REF PROBE NEAR TRANSFORMER YARD
	AUG.8					LOW CONCRETE GUIDEWAY, S. LOOP †
TR7019## [12,316]	1600- 1620		20	20	2.0	194 SAMPLES, ≈ 6 s APART
	AUG.9					PASSENGER STATION,HIGH CONC.G/W†
TR7020## [14,539]	1026- 1046	300/ 170	21	21	2.0	229 SAMPLES, 4 s APART LOC:STATION, HIGH CONCRETE G/W
TR7021## [14,539]	1051- 1110	250/ 173	21	21	2.0	229 SAMPLES, 5 s APART LOC:STATION, HIGH CONCRETE G/W
	AUG.9					TRANSFORMER YARD AT CTL CTR † ‡
TR7022## [14,602]	1508- 1528		22	22	2.0	230 SAMPLES, 4 s APART TRANSFORMER YARD PROFILE
	AUG.9					BRAKING RESISTOR BANK † ‡
TR7023## [16,189]	1618- 1638		23	23	2.0	255 TIME SAMPLES, 4 s INT. BRAKING RES. BANK PROFILE
TR7024## [4,317]	1649- 1655		23	23	2.0	68 TIME SAMPLES, 4 s INT. ATTEMPT TO CATCH BRAKING
	AUG.9					ENTRANCE TO MAINTENANCE FACILITY
TR7025## [635]	1731- 1732		24	24	2.0	10 TIME SAMPLES, 4 s APART TR07 LEVITATING, LOW CONC. G/W
TR7026## [2,476]	1806- 1810		24	24	2.0	39 TIME SAMPLES, 4 s APART TR07 LEVITATING AT SERVICE ENT.
	AUG10					INVERTER BLDG,4m N. OF 1st LOC†‡
TR7028## [381]	1005- 1006		26	26	2.0	6 TIME SAMPLES, 4 s APART TR07 ON TRACK

TABLE 2-1 CONTINUED

DATA FILE # [SIZE,KB]	DATE/ HHMM	VEL.* KM/HR	PROBE LOC.♦ AC	DC	t_{S-DC} **,s	REMARKS
TR7030## [13,904]	1207-1227		26	26	2.0	219 TIME SAMPLES, 4 s APART TR07 ON TRACK
	AUG10					SOUTH FEEDER NEAR CTL CTR † ‡ ◊
TR7031## [381]	1304-1305		27	27	2.0	6 TIME SAMPLES, 4 s APART H=0m AT SOUTH FEEDER
TR7032## [13,903]	1620-1640		28	28	2.0	219 TIME SAMPLES, 4 s APART H=1m, TR07 ON TRACK

* VELOCITY CODE: + = SPEED INCREASING; - = SPEED DECREASING; / INDICATES RANGE OF VALUES, MAX/MIN; NO POSTFIX INDICATES CONSTANT SPEED.

** SAMPLE TIME FOR DC PROBE IS TABULATED (ALL AC PROBES, t_{S-AC} = 0.2 s).

† A_m = AC_m = MAXIMUM AC RMS B (FLUX DENSITY) FROM B-DOT PROBES, mG.
D_m = DC/AC_m = MAXIMUM AC RMS VALUE FROM FLUXGATES, mG.

‡ NUMBER PAIR IN PARENTHESIS INDICATES (AC_m, DC/AC_m).

◊ H = PROBE HEIGHT ABOVE LOCAL GROUND SURFACE.

♦ SEE INTERIM REPORT[2] FOR PROBE LOCATIONS.

2.5 Analysis Method for Repetitive Field Waveforms

Four potentially important parameters of the magnetic field onboard or near the TR07 Maglev System are field intensity, frequency spatial distribution, and temporal variability. Since the extreme low frequency (ELF) magnetic fields produced by most other environmentally relevant sources lack the complexity of the magnetic fields produced by the TR07 System, appropriate methods for analyzing and displaying ELF field data without obliterating the information on one or more of the above mentioned parameters did not exist at the outset of the project, much of the prior work with ELF magnetic field characterization has focused on electric power systems; most notably, on transmission lines. The magnetic fields produced by transmission lines consist primarily of a 60 Hz (in North America, 50 Hz elsewhere) frequency component and to a lesser extent, components at harmonics of 60 Hz. These discrete frequencies are small in number and have essentially no temporal variability. Furthermore, the relative intensity of the field components at these frequencies are not highly spatially dependant and the relative spatial distribution is not time dependant. Consequently, rather simplistic two-dimensional analysis is sufficient to document most interactions between time, frequency, intensity, and spatial factors for powerline magnetic fields.

The complexity of the TR07 magnetic field data makes the analysis and presentation methods used for powerline magnetic fields inappropriate. The most significant complications arise from the following characteristics of the TR07 magnetic fields.

Multiple Sources: The magnetic fields onboard or in the vicinity of the TR07 Maglev System arise from multiple sources, hence spatial distributions can not be expressed as simple attenuation curves which are temporally stable.

Continuous Frequency Distribution: The time-varying component of the guidance and levitation magnetic fields have a distributed rather than discrete frequency distribution. Consequently, one must address field intensities in various bands of finite width rather than fields at specific frequencies.

Variable Frequency Components: The magnetic field from the longstator of the linear synchronous motor (or from the power equipment driving that field) is a discrete frequency component which varies over time. Consequently, simple averaging of repetitive frequency spectra will obliterate this component of the field as a discrete component.

In order to accommodate these characteristics, a data analysis and reporting procedure was developed specifically for the TR07 magnetic field data. However, to ensure the compatibility with magnetic field data from future measurements, the procedure was kept entirely general.

The Interim Report contained numerous graphs showing the amplitude of the magnetic field as a function of frequency at a specific point in time and at a specific location. Those graphs demonstrated that the frequency characteristics of the ELF magnetic fields produced by the TR07 System are quite different than the frequency characteristics the ELF magnetic fields from most other environmentally relevant sources. Hence, it is important that the data analysis and presentation method applied to the data not obscure this potentially important frequency information. Therefore it was decided that the most comprehensive presentation of the repetitive waveform data collected at each measurement location would be a pseudo-three-dimensional plot of the magnetic flux density as a function of frequency and time.

This was accomplished by converting each time domain waveform sample(each of the orthogonal components separately) to the frequency domain by computing the fourier transform using the Fast Fourier Transform (FFT) capability of the *MultiWave*™ analysis software package. The total rms value of the flux density at each frequency was then computed by the root-sum-square of the three orthogonal rms values at the same frequency. Functionally, this is the same procedure used to produce the frequency spectra in the Interim Report except that the FFTs were executed at the time of measurement and the transformed data were stored. Three dimensional graphs showing the effect of time on the flux density and frequency were constructed by placing frequency spectra information derived from successive repetitive waveform samples behind one another to generate a time dimension. Figure 2-2 shows and example of one such three-dimensional graph for one set of measurements using the ac coil sensors onboard the TR07 vehicle. The inherent derivative response of the ac field derivative probes was compensated for with software integration as described in the Interim Report.

Throughout this report, magnetic flux densities are reported in gauss or milligauss. Although the Tesla is the international standard unit for magnetic flux density, the unit gauss is more commonly used in the United States. For purposes of conversion,

$$1\ \mathrm{T} = 10{,}000\ \mathrm{G}$$

in those portions of the report where the measured field data are compared to field data reported in Tesla, converted values are provided.

Note in Figure 2-2 that the flux density is represented as a surface above the plane of the time and frequency variables. For data from the ac coils, the frequency range spans from 5 Hz to 2560

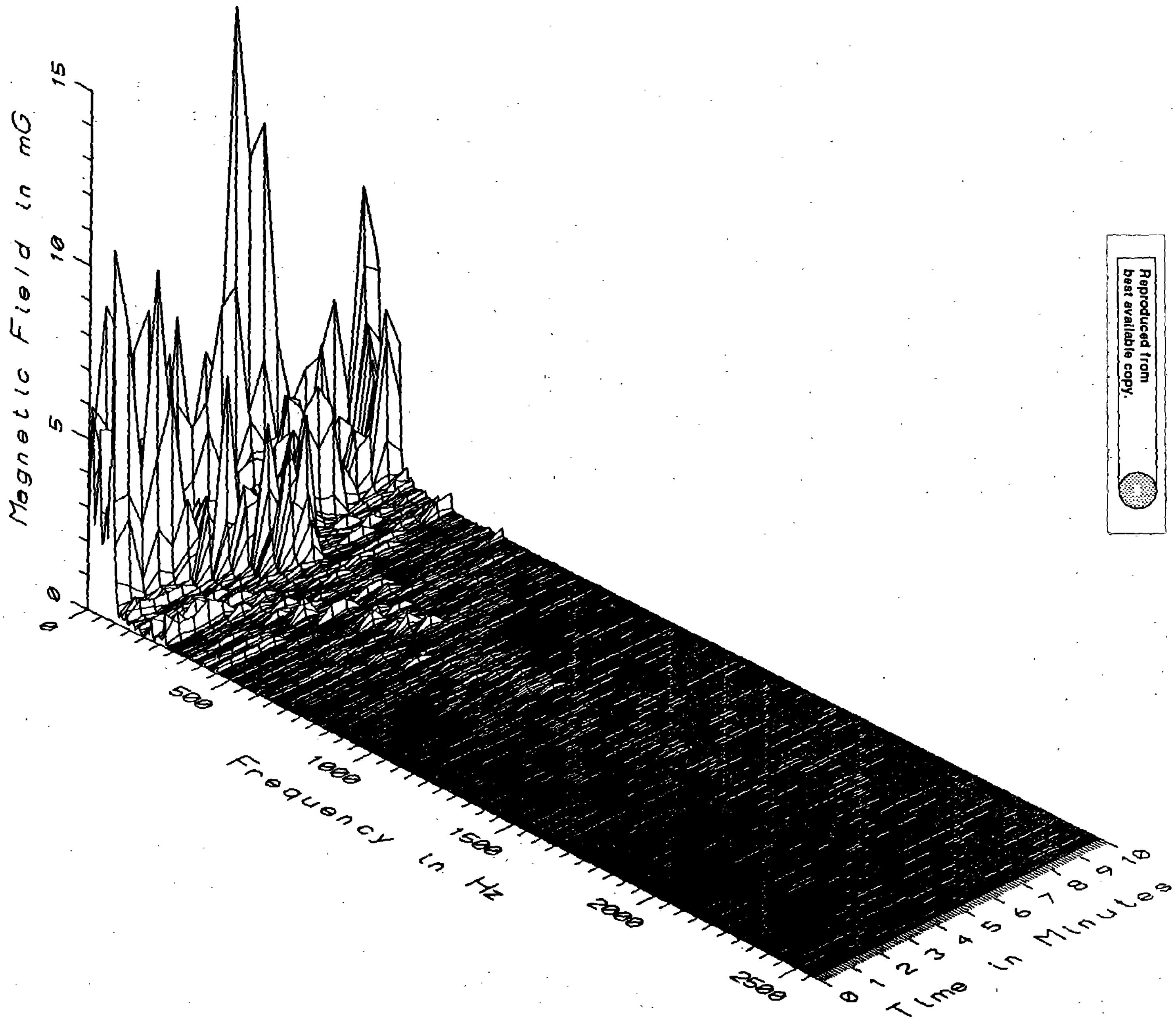


Figure 2-2 Typical pseudo-three-dimensional plot of magnetic flux density versus time and frequency.

Hz and the time spans the duration of the measurement. Since there are no field components with significant magnitude at frequencies above approximately 750 Hz, the three dimensional graph can be redrawn focusing on the lower frequencies and showing the major field components in more detail as illustrated in Figure 2-3. Three dimensional graphs of magnetic flux density as a function of time and frequency are provided for all of the repetitive waveform data listed in Table 2-1. In most cases, the graphs of magnetic field data from the ac coil-type sensors only cover a frequency range from 5 Hz to 500 Hz because there were no significant field components at higher frequencies. In those cases where higher frequency components of the magnetic field were present, additional three-dimensional graphs are provided to show those components. Absence of such supplemental graphs indicates that the data were examined and no higher frequency fields of significant amplitude were found.

The pseudo-three-dimensional graphs of flux density versus time and frequency can be used in several ways. Frequency spectra at any time can be determined by visualizing a "cut" through the three dimensional graph parallel to the frequency axis at the time in question. Figure 2-4 illustrates this approach by graphically "cutting" the surface at the five minute time point. The cut surface reveals the magnetic flux density as a function of frequency which existed at that time. Since these figures are pseudo-three-dimensional drawings and not true three dimensional solids, one can not literally cut the surface, but a network of grid lines parallel to the time and frequency axes are plotted on the surface to assist in visualizing such cuts.

Similarly, one can visualize the time fluctuation in magnetic flux density at any particular frequency by visualizing a "cut" through the surface at the frequency of concern. Figure 2-5 illustrates this concept.

Perhaps the most powerful use of the three dimensional graphs is to examine the topography of the magnetic flux density contour across frequency and time. This view of the data provides a "moving picture" of the magnetic field frequency spectrum as it shifts and adjusts in response to different operating conditions of the TR07 System. To demonstrate this concept, the portion of the data in Figure 2-3 below 250 Hz is replotted on Figure 2-6. This is merely one example of a ten-minute recording of the magnetic field at a point within the TR07 vehicle as it travels around the Emsland Test Facility guideway. Plotted in the upper right corner of the figure is a graph of the vehicle speed during the ten-minute recording. Examination of the magnetic flux density contour reveals the way in which the magnetic field changes in amplitude and frequency distribution over time as the vehicle accelerates and decelerates. This dynamic view of the shifting magnetic field characteristics is lost in either the two-dimensional analysis of frequency spectrum plots or time course plots.

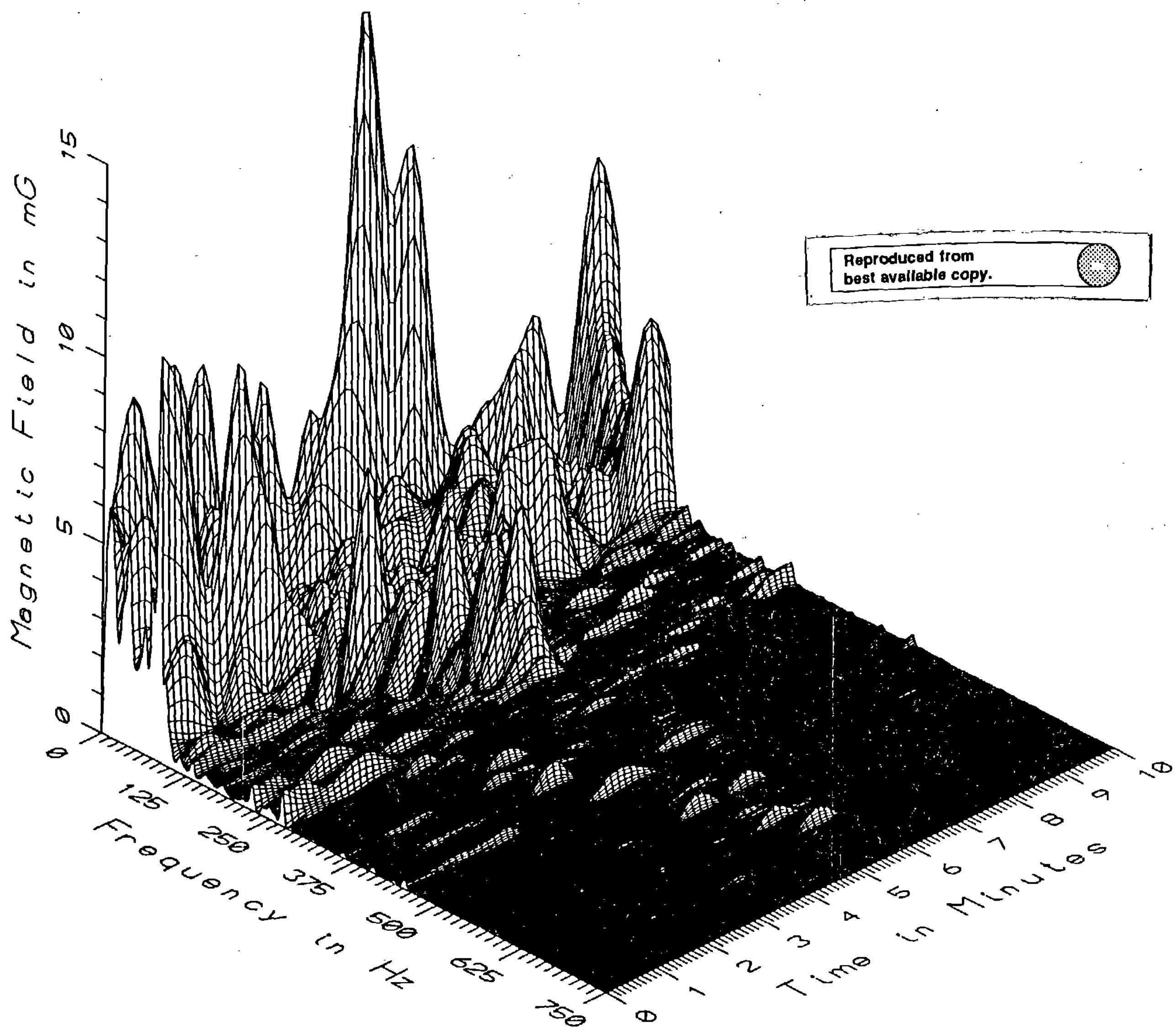


Figure 2-3 Enlargement of the low frequency portion of Figure 2-2.

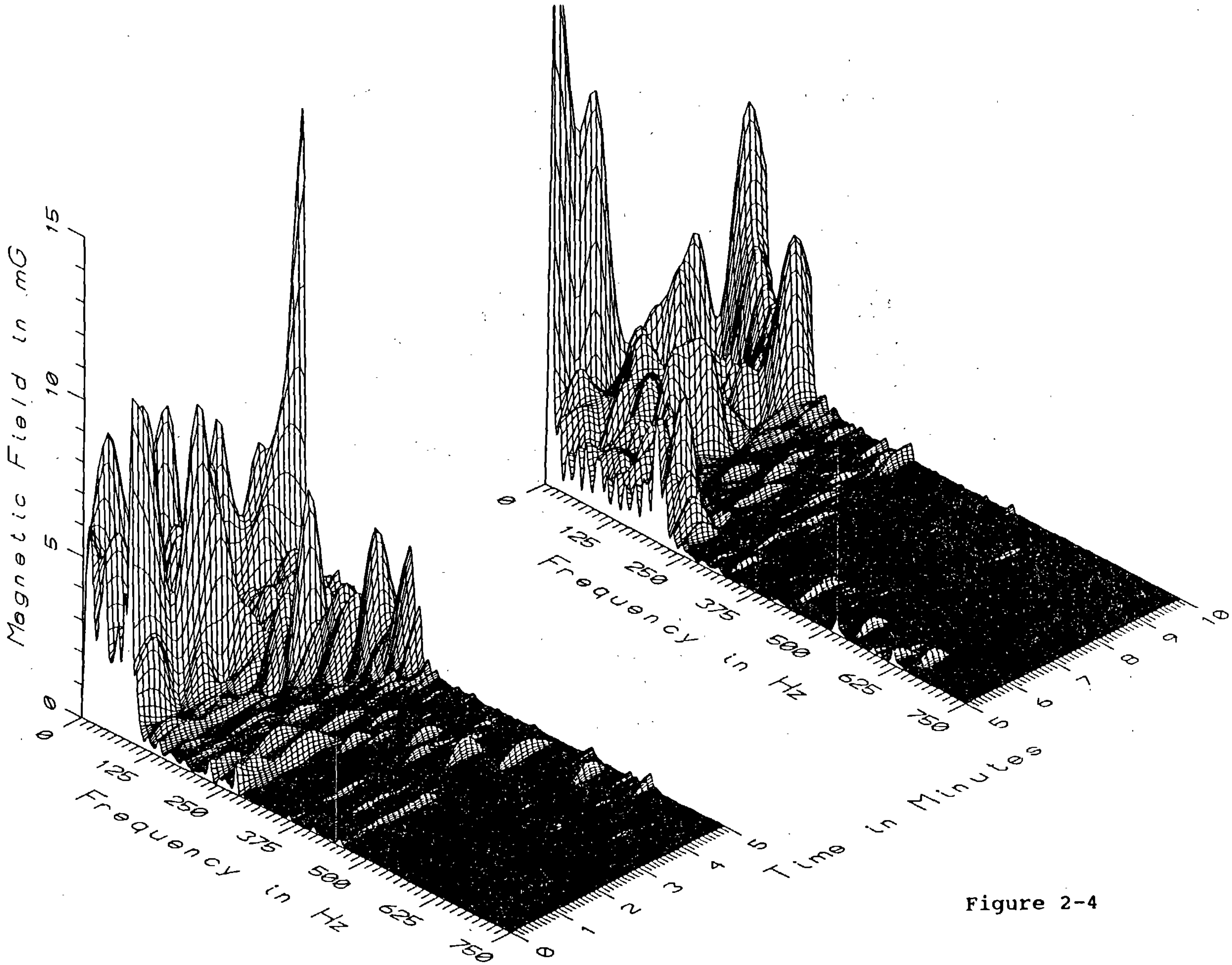
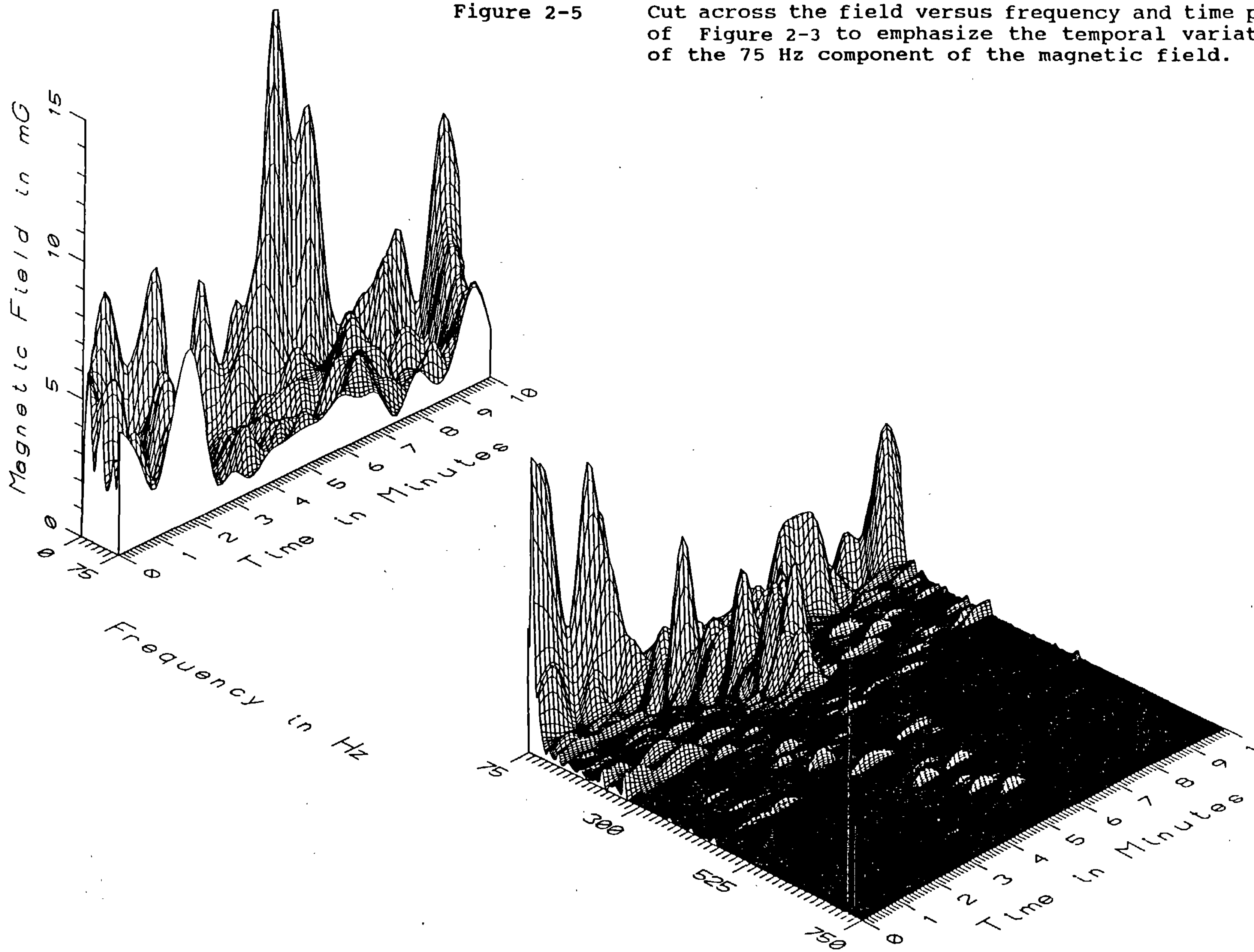


Figure 2-4

Cut across the field versus frequency and time plot of Figure 2-3 to emphasize the frequency spectrum of the magnetic field at the 5 minute point of the data.

Figure 2-5 Cut across the field versus frequency and time plot of Figure 2-3 to emphasize the temporal variation of the 75 Hz component of the magnetic field.



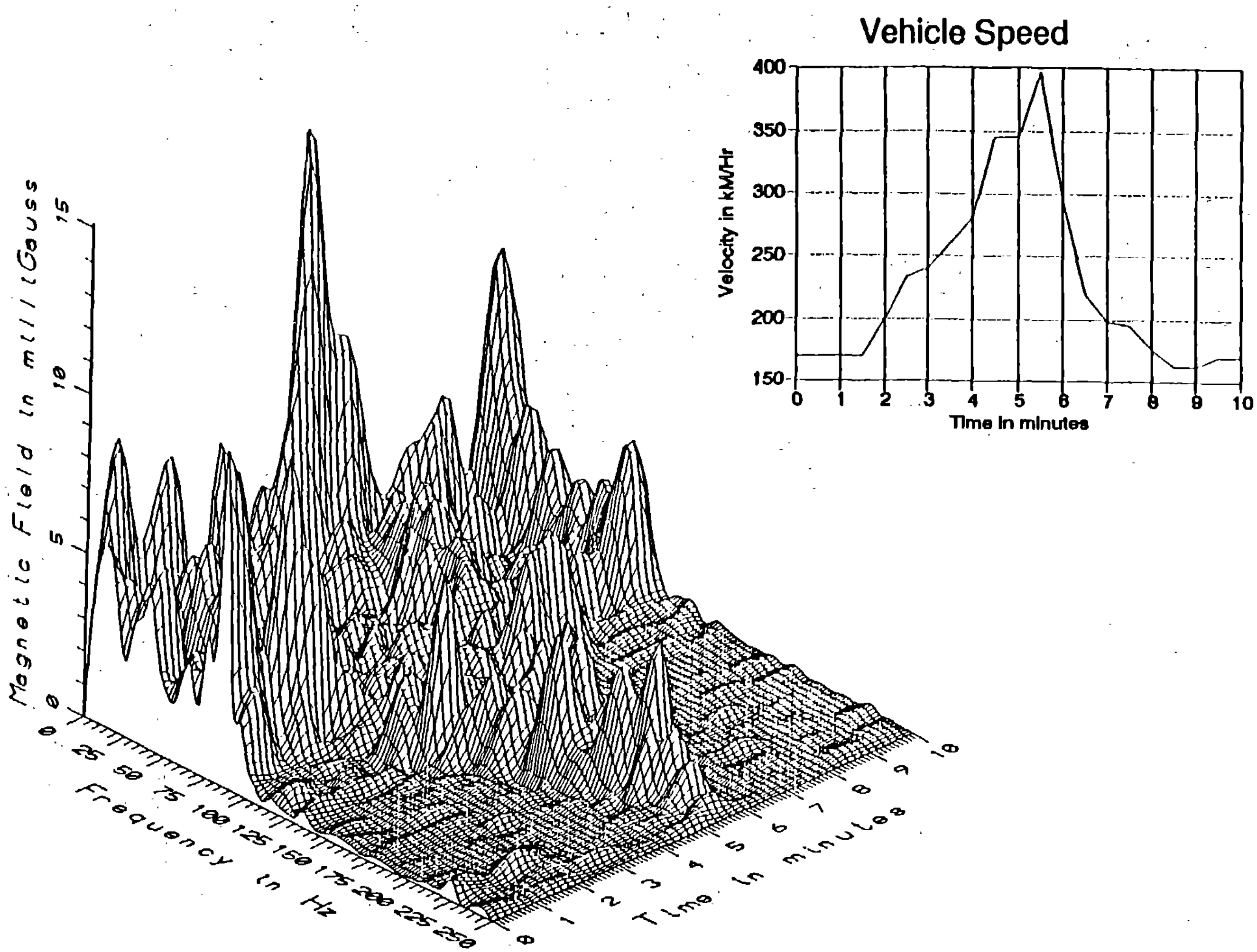


Figure 2-6 Typical magnetic flux density versus time and frequency plot showing the dynamics of the field characteristics within the TR07 vehicle in response to different vehicle operating conditions.

Repetitive waveform data were also collected with fluxgate sensors to quantify the static component of the magnetic field and provide better resolution of the very low frequency components of the time-varying magnetic fields. Pseudo-three-dimensional plots of magnetic flux density were also prepared for these data and are found in the appendices at the end of this report.

The three dimensional analysis of field dependency upon frequency and time presents the available data in the most comprehensive yet concise form available. However, further reductions in the complexity of the data are necessary in order to progress with the spatial, temporal and statistical analysis of the repetitive waveform data. One obvious approach is to collapse the data across frequency domain and do an analysis of "total magnetic field". However, in doing so, one completely obliterates the frequency information. Another approach is to collapse the data across the time axis by computing mean values in each frequency band. That approach not only sacrifices the information on temporal variability, but is also adulterates the frequency by washing out the various peaks in the individual frequency spectra which vary from frequency to frequency over time. It was concluded that the essential features of these data could be best preserved by collapsing the data across the frequency domain but rather than producing just one value for total field strength, six values are produced indicative of the total field within specific ranges of frequency. In this way, some measure of the frequency characteristics are preserved and numerical values are produced which can be compared to magnetic field levels from other sources having similar ranges of frequency.

The six frequency ranges selected for the further analysis are as follows:

<u>Static Field:</u> this is the non-time-varying magnetic field measured by the fluxgate sensor.

<u>Total AC Field:</u> This is the total time-varying fields measured with the ac coil-type sensors. For digital frequency analysis purposes, the bandwidth is 2.5 Hz to 2562.5 Hz. However, physical performance of the ac field sensors limits their maximum frequency to 2 kHz for ±5% accuracy although the 3 dB point is above 3 kHz.

For purposes of simplicity throughout the remainder of the report, this band is defined in terms of the FFT components combined to produce the data. Since each FFT component of the data from the ac probes represents the energy within a 5 Hz bandwidth, the band center frequencies for the total ac field band are from 5 Hz to 2560 Hz.

<u>Low Frequency Field:</u> This quantity represents the total ac field in frequencies below the customary frequencies used for

electric power systems. The range of FFT components included is from 5 Hz to 45 Hz but the actual bandwidth is from 2.5 Hz to 47.5 Hz.

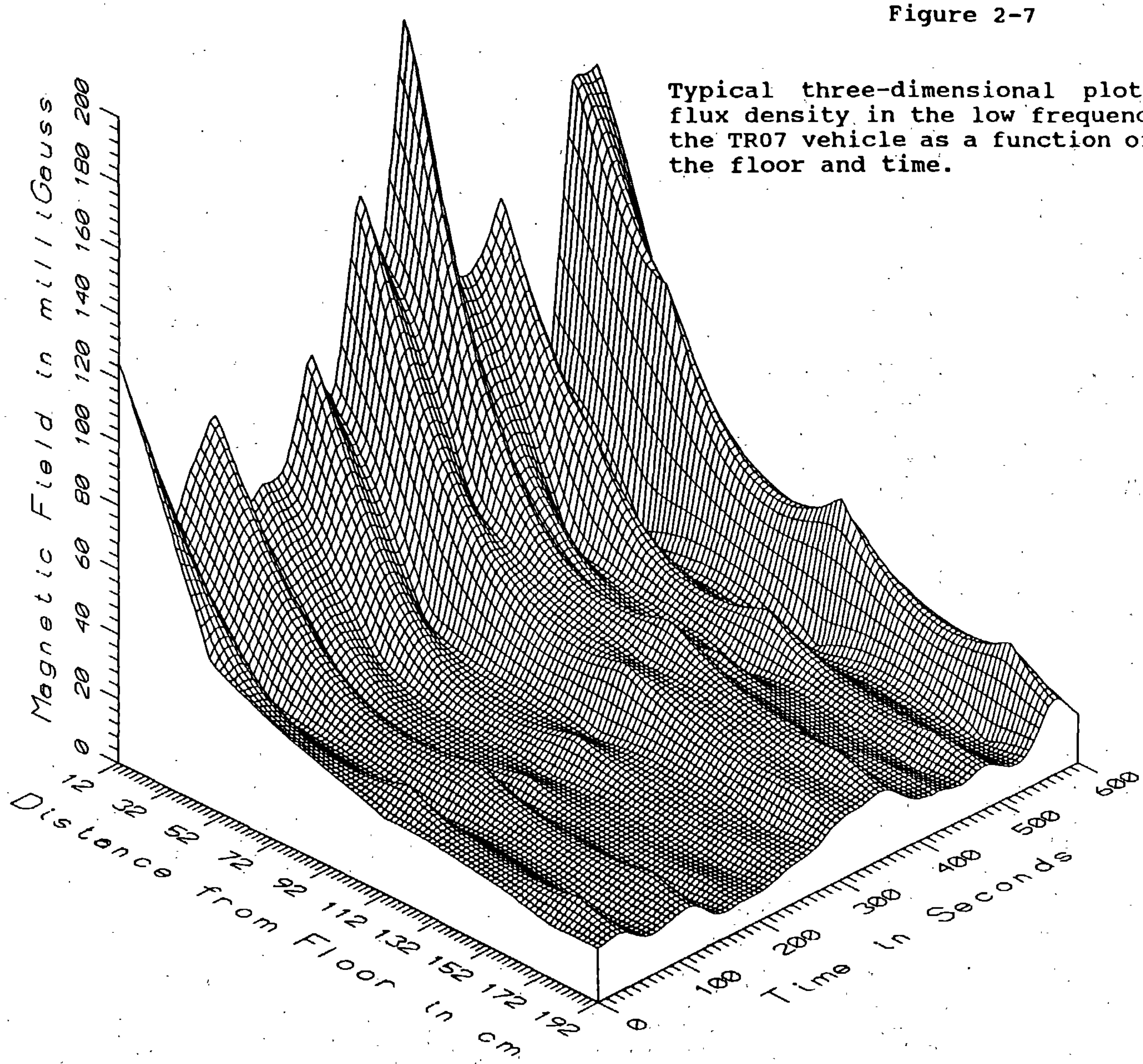
Power Frequency Field: This is the strength of those components of the magnetic field in the range of frequencies used for electric power systems (50 Hz in Europe, 60 Hz in North America). In order to have the analysis uniformly applicable to North America and Europe, the FFT components at 50 Hz, 55 Hz, and 60 Hz were included in the band. The actual bandwidth is from 47.5 Hz to 62.5 Hz.

Power Frequency Harmonic Field: This band which extends from 62.5 Hz to 302.5 Hz includes the first few harmonics above the power frequency, as well as much of the frequency range used for propulsion of the TR07 vehicle. The range of FFT components combined to obtain this quantity is from 65 Hz to 300 Hz.

High Frequency Field: This quantity represents the magnetic field components in the upper part of the frequency range measured (302.5 Hz to 2562.5 Hz). This is a range of frequencies where neither power systems nor the TR07 System would normally produce significant magnetic fields. By examining the FFT components from 305 Hz to 2560 Hz, those small fields can be quantified accurately without being obscured by the larger fields present at lower frequencies.

Once the repetitive waveform magnetic field data had been collapsed along the frequency domain into the above described bands, the spatial distribution of the field could be examined for each band. For most of the tests, multiple sensors were placed colinearly in either a vertical or horizontal line directed away from the presumed major magnetic field source. The magnetic flux density measured by each at identical times can be plotted to show the variability in magnetic field along that line as a function of distance along the line. Such profile plots are often helpful for confirming the source of the magnetic field and documenting attenuation rates for predicting field strengths at other locations away from the source. Since the *MultiWave*™ Monitoring System measures the magnetic field at each sensor every time it scans, the repetitive waveform data contains repetitive spatial profile measurements of the magnetic flux density. These repetitive profiles can be plotted as pseudo-three-dimensional graphs of magnetic flux density as a function of distance along the profile and time in a way analogous to the way the field versus frequency and time plots were produced. Figure 2-7 shows a typical plot of the magnetic flux density in the above described low-frequency band in the TR07 vehicle plotted as a function of height above the floor and time. As with the time by frequency plots, one can "cut" this

Figure 2-7



Typical three-dimensional plot of magnetic flux density in the low frequency band within the TR07 vehicle as a function of height above the floor and time.

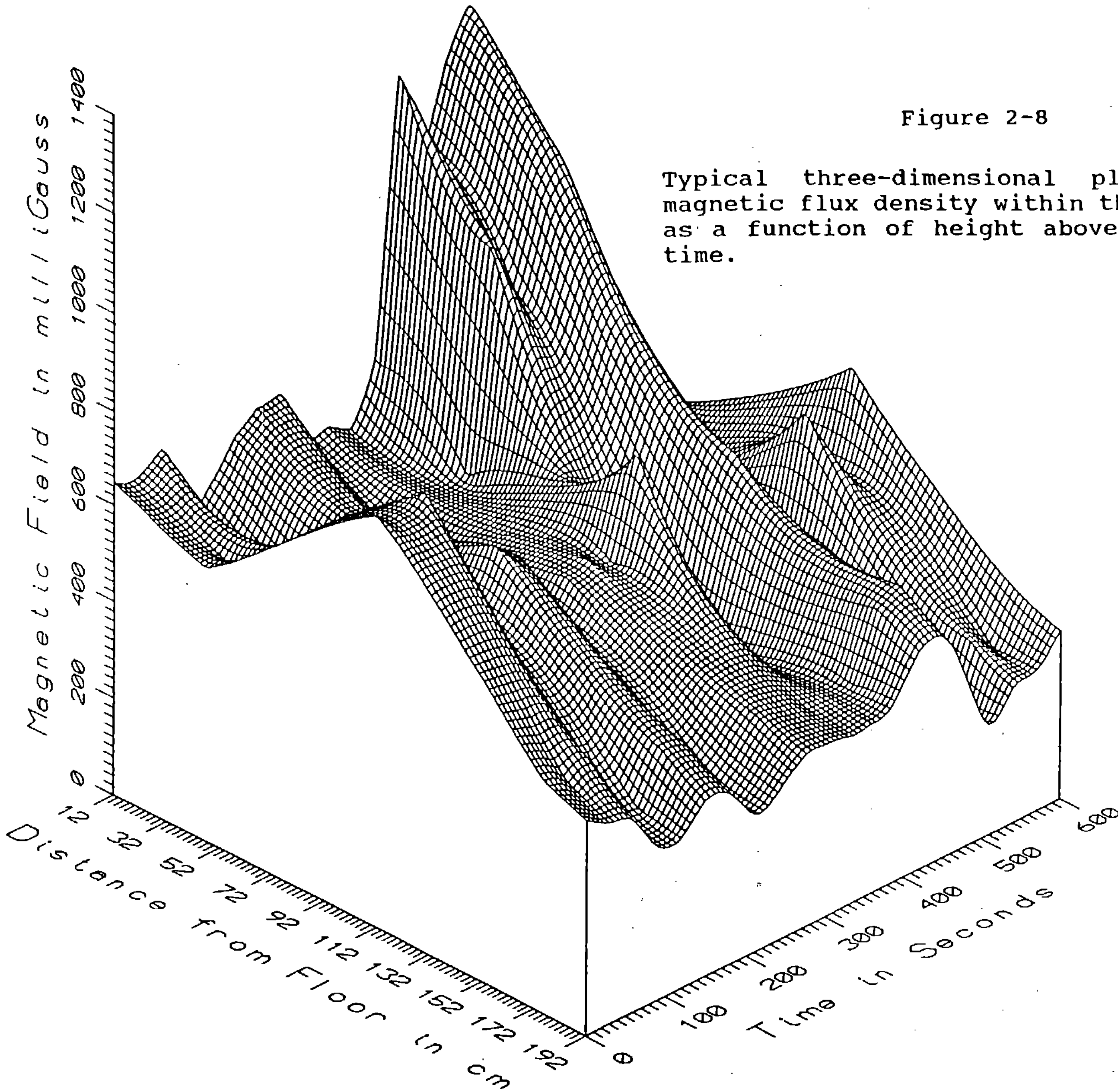
surface various ways to determine the field attenuation characteristics at any time for the temporal variation of the field at any height above the floor. Furthermore, one can view the profile as a whole and conclude that the attenuation rates are consistent over time and that there is one principal source of magnetic field which is located below the floor of the vehicle. Figure 2-8 shows a similar plot of the static magnetic flux density for the same test reported in Figure 2-7. Note that there is no longer a well behaved attenuation pattern which is stable over time because there are two significant sources of static magnetic field (the magnet structures below the vehicle floor and the earth's geomagnetic field).

Similar plots of magnetic flux density in each of the six frequency bands as functions of time and distance are found in the appendices of this report for each of the data sets listed in Table 2-1.

The final step of the analysis and compression of the repetitive waveform data involved computing mean values of the magnetic flux density in each frequency band at each measurement location. Standard deviations and coefficients of variation for the flux density were also computed. This process produces "single number" measures of the strength of the magnetic field at the cost of losing virtually all of the time and frequency characteristics of the magnetic field.

Figure 2-8

Typical three-dimensional plot of static magnetic flux density within the TR07 vehicle as a function of height above the floor and time.



3.0 ONBOARD VEHICLE MEASUREMENTS

The instrumentation and procedures used for magnetic field measurements onboard the TR07 vehicle in August 1990 are described in detail in the previous Interim Report[2]. That report also presented and discussed characteristic point-in-time frequency spectra and time domain waveform data collected during the measurement program. Extensive repetitive waveform data were also collected and have now been analyzed using the procedures outlined in Section 2 above. This section will describe the results of that analysis and compare the results of the repetitive waveform measurements with the interim results in the earlier report and with magnetic field measurements made in Transrapid vehicles by others.

3.1 Measurement Locations

Seven sets of repetitive waveform measurements were made onboard the TR07 vehicle. Pertinent information on these measurements are found in Table 3-1.

More detailed information on the specific locations of the measurements were reported in Section 4.1 and Appendix B of the Interim Report.

3.2 Field Levels in the Passenger Areas

Of the seven data sets, five are vertical profiles at various locations within the regular and VIP passenger compartments of the second (trailing) TR07 vehicle. Each vertical profile consisted of simultaneous repetitive waveform measurements at heights of 13, 47, 112, and 175 cm above the floor. A fifth set of simultaneous repetitive waveform measurements was made at a reference location which did not vary throughout all of the onboard measurements. Pseudo-three-dimensional graphs showing the magnetic flux density at each measurement location as a function of frequency and time are found in Appendices B through F at the end of this report. A graph of the vehicle speed over the measurement period is also provided in each appendix. The range of vehicle speeds is similar during each of the five sets of vertical profile measurements in the TR07 passenger compartments as indicated on Table 3-1. Therefore, comparisons of field conditions between those sets provides insight into the spatial variability of the magnetic field in the vehicle and analysis of the five data sets as a whole is indicative of average field conditions within the passenger compartments.

3.2.1 Time-Varying Fields

Figures 3-1 through 3-4 show the field versus time and frequency plots at increasing heights above the floor for

TABLE 3-1

SUMMARY OF REPETITIVE WAVEFORM MEASUREMENTS
ONBOARD THE TRANSRAPID TR07 VEHICLE

DATA SET NUMBER, LOCATION, AND TYPE OF MEASUREMENT	APPENDIX CONTAINING DATA	DATE AND TIME	VEHICLE VELOCITY KM/HR	NUMBER OF SAMPLES	INTERVAL BETWEEN SAMPLES
TR7001 MIDDLE OF SECOND CAR AT WINDOW SEAT - VERTICAL PROFILE AT 13, 47, 112, AND 175 CM ABOVE FLOOR	B	AUG 7 10:20- 10:30	320 TO 170	21	30 SEC
TR7002 MIDDLE OF SECOND CAR AT SIDE OF AISLE - VERTICAL PROFILE AT 13, 47, 112, AND 175 CM ABOVE FLOOR	C	AUG 7 10:38- 10:48	396 TO 162	21	30 SEC
TR7003 MIDDLE OF SECOND CAR AT SIDE OF AISLE - VERTICAL PROFILE AT 13, 47, 112, AND 175 CM ABOVE FLOOR	D	AUG 7 13:32- 13:40	302 TO 168	17	30 SEC
TR7008 REAR WINDOW SEAT OF SECOND CAR MAIN PASSENGER SECTION VERTICAL PROFILE AT 13, 47, 112, AND 175 CM ABOVE FLOOR	E	AUG 7 17:35- 17:44	300 TO 168	19	30 SEC

TABLE 3-1 CONTINUED

SUMMARY OF REPETITIVE WAVEFORM MEASUREMENTS ONBOARD THE TRANSRAPID TR07 VEHICLE

DATA SET NUMBER, LOCATION, AND TYPE OF MEASUREMENT	APPENDIX CONTAINING DATA	DATE AND TIME	VEHICLE VELOCITY KM/HR	NUMBER OF SAMPLES	INTERVAL BETWEEN SAMPLES
TR7009 BEHIND SEATS IN THE VIP SECTION OF SECOND CAR VERTICAL PROFILE AT 13, 47, 112, AND 175 CM ABOVE FLOOR	F	AUG 7 17:52-18:00	320 TO 170	17	30 SEC
TR7010 AT SEATS IN THE ENGINEERS COMPARTMENT OF SECOND CAR VERTICAL PROFILE AT 13, 47, 112, AND 175 CM ABOVE FLOOR	G	AUG 7 18:02-18:12	340 TO 170	20	30 SEC
TR7011 MIDDLE OF SECOND CAR ≈5 CM ABOVE FLOOR - LATERAL PROFILE AT 10, 75, 140, AND 175 CM FROM THE SIDE OF THE VEHICLE (WINDOW SEAT, AISLE SEAT, AISLE, AND AISLE)	H	AUG 7 18:17-18:22	180 TO 0	6	30 SEC

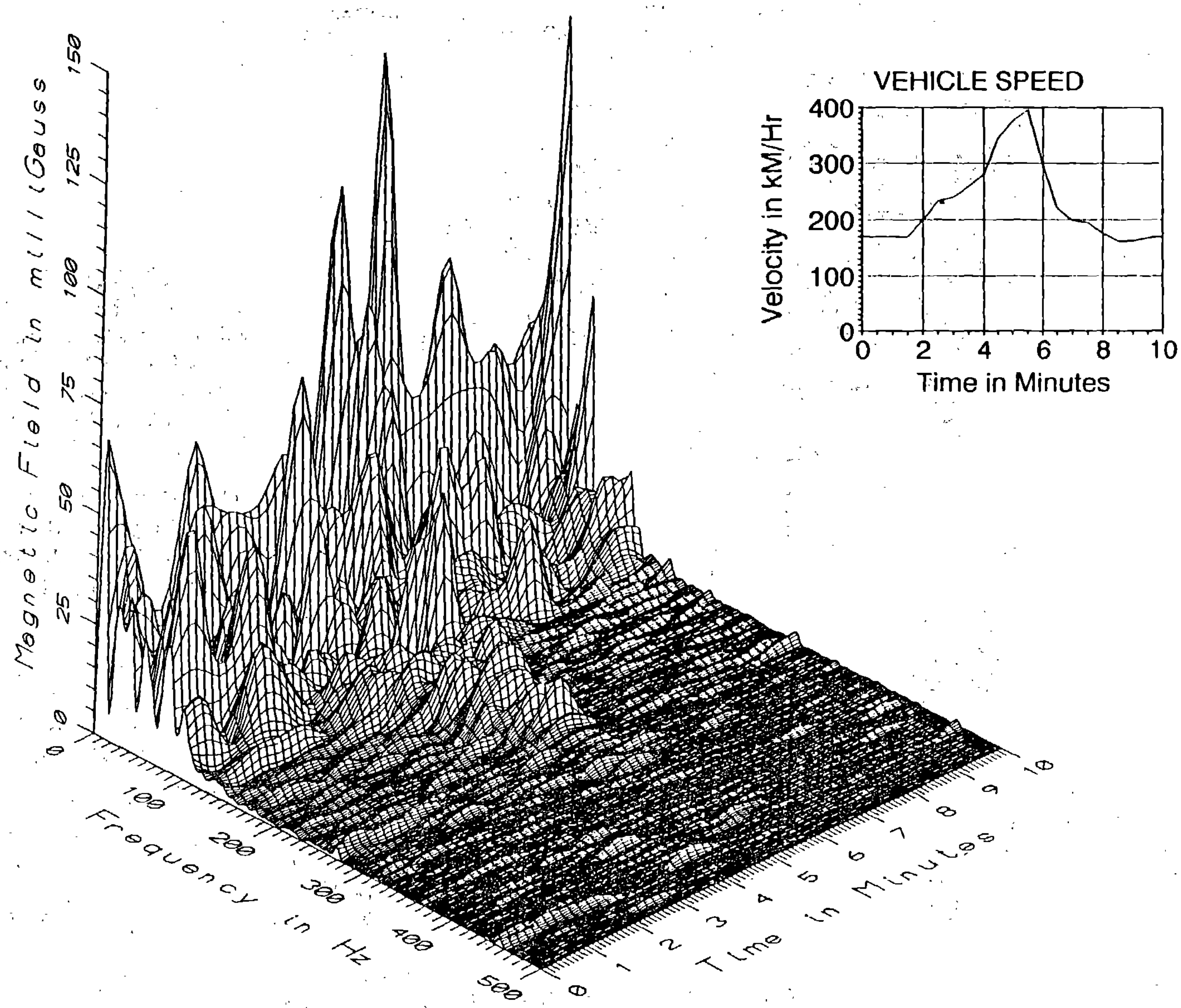


Figure 3-1 Magnetic flux density versus frequency and time at 13 cm above the floor at the side of the aisle in the center of Car 2.

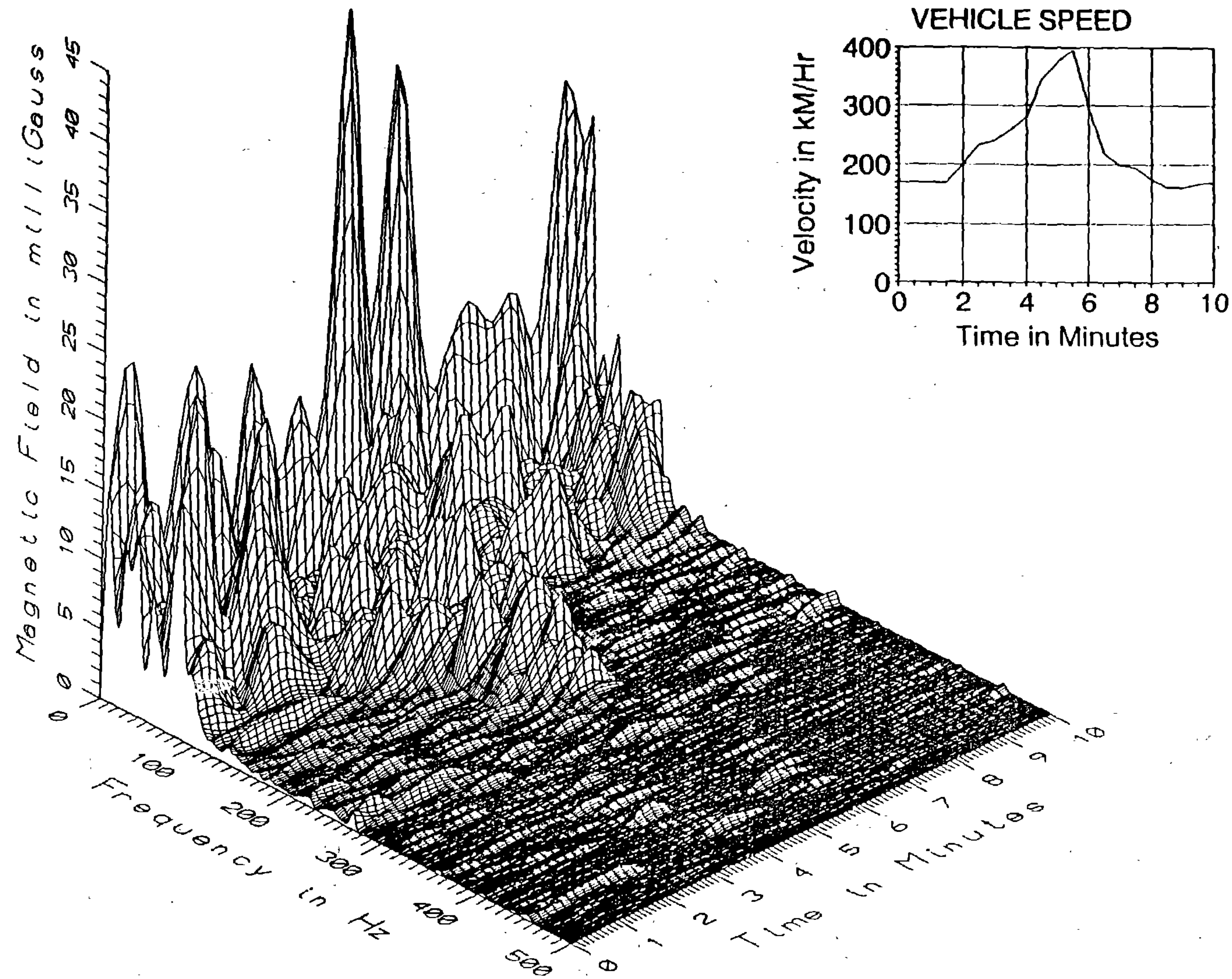


Figure 3-2 Magnetic flux density versus frequency and time at 47 cm above the floor at the side of the aisle in the center of Car 2.

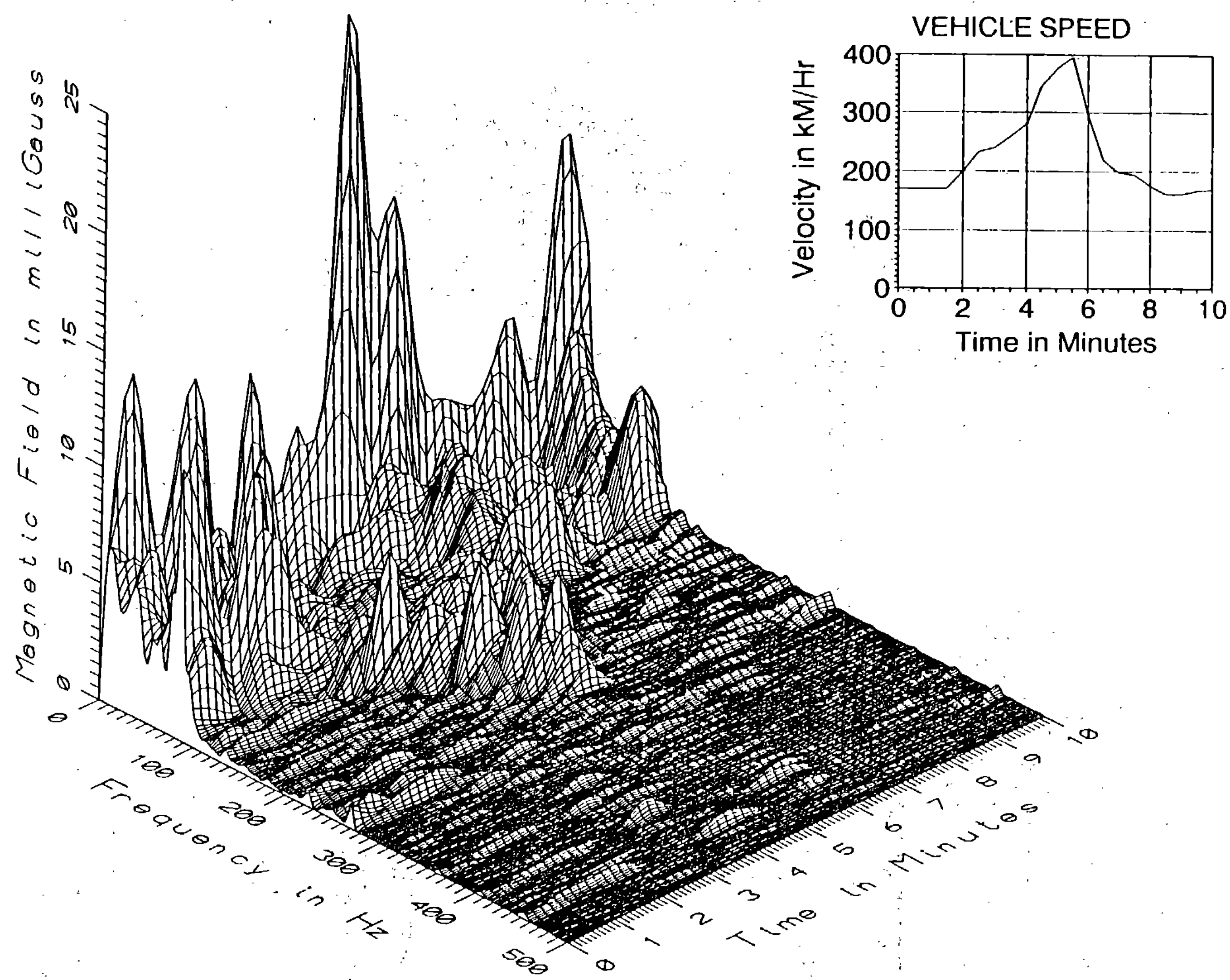


Figure 3-3 Magnetic flux density versus frequency and time at 112 cm above the floor at the side of the aisle in the center of Car 2.

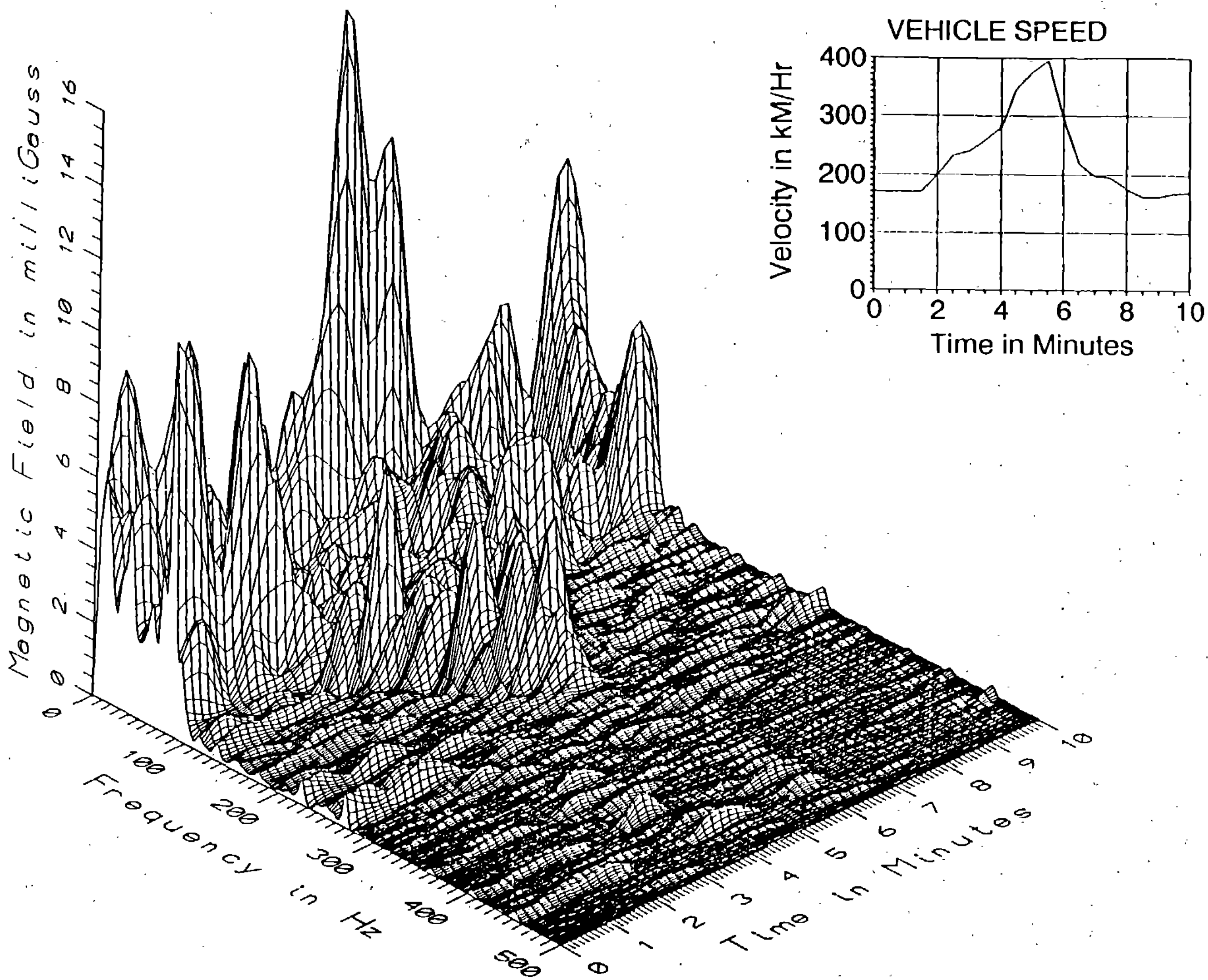


Figure 3-4 Magnetic flux density versus frequency and time at 175 cm above the floor at the side of the aisle in the center of Car 2.

repetitive waveform measurements made with the ac probes at the edge of the aisle in the center of the second TR07 car.

Figure 3-5 shows the low frequency (5-45 Hz) field as a function of height above the floor and time. These are taken from Appendix C but are typical of the data obtained at other locations within the vehicle. For convenience, graphs of vehicle speed versus time have also been placed on the figures. The most noticeable difference is that fields tend to be somewhat higher and perhaps less height dependant toward the rear of the main passenger compartment and in the VIP compartment. The data for each measurement location are found in Appendices B through F. A number of important observations can be made from these data.

- The frequency spectrum of the magnetic field varies considerably over time due to various factors. Vehicle speed accounts for much of the variability in spectral components above approximately 50 Hz but other factors presumably related to dynamic control of the levitation and guidance magnets affect the frequency and amplitude characteristics of the lower frequency components.

- Field intensity is highly variable over time with little correlation between the intensity of higher and lower frequency components. Intensity does not correlate well with vehicle speed but may be related to both forward and lateral acceleration or deceleration.

- Field intensity is strongly affected by measurement height but the time and frequency dependence of the magnetic field is very similar at all heights. This observation is consistent with the expectation that the magnet structures, their associated wiring, and guideway longstator beneath the vehicle are the principal magnetic field sources.

Figure 3-6 shows the field by time and frequency curve measured at the reference probe location concurrent with the measurements reported in Figures 3-1 through 3-4. Since the reference probe is located at seat level, its data should be most closely related to that in Figure 3-2. Comparison of Figures 3-2 and 3-6 shows that the magnetic field is typically higher at the reference probe location than at the center of the car. While there is considerable similarity in the topography of the two graphs, the frequency and time characteristics of the magnetic field at the reference location differ more from those in Figure 3-2 than do those for measurements in Figures 3-1, 3-3, or 3-4. That result suggests that the differences in field characteristics from one location to another are moderately affected by location but height above the floor is a stronger determinant of field

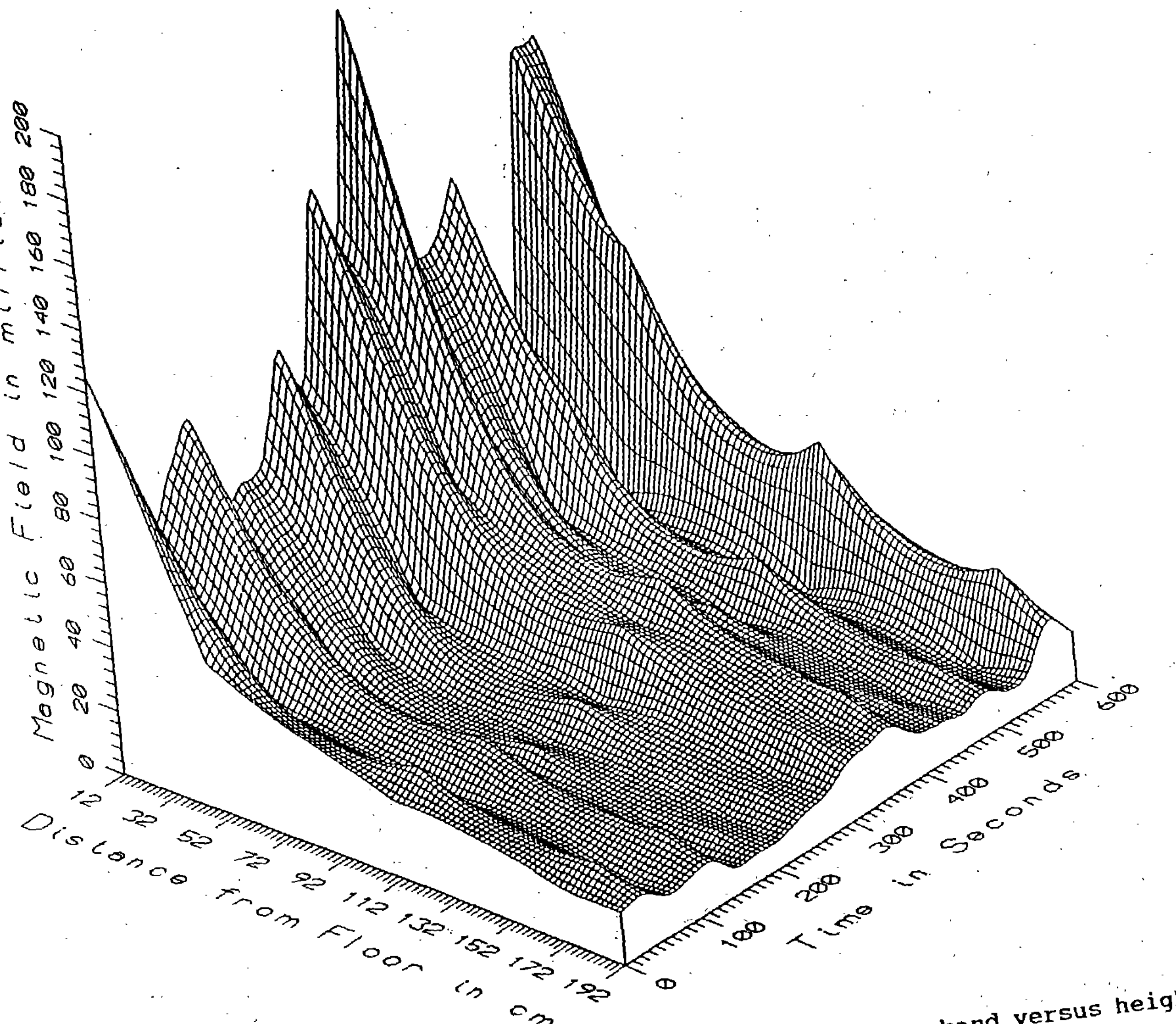


Figure 3-5 Magnetic flux density in the low (5-45 Hz) frequency band versus height above floor and time at the side of the aisle in the center of Car 2.

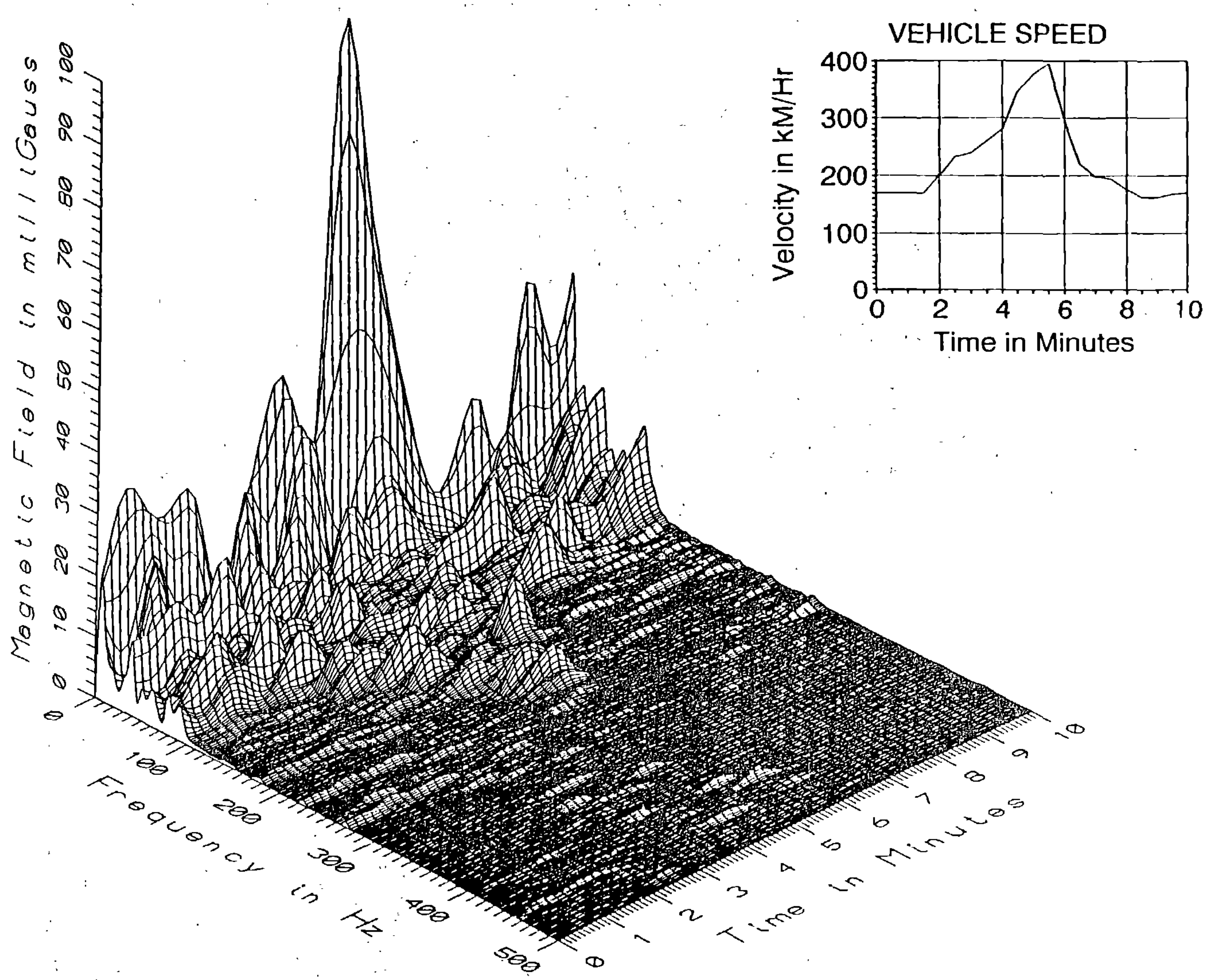


Figure 3-6 Magnetic flux density versus frequency and time at the reference probe location at the rear of the passenger section of Car 2.

strength. Review of the other data in Appendices B through F confirms this observation.

3.2.2 Static Fields

Figures 3-7 and 3-8 show magnetic flux density as a function of frequency and time for measurements with the fluxgate sensors at standing head level and near the floor at the edge of the aisle in the center of the second vehicle. They are from Appendix C but are representative of comparable measurements elsewhere on the vehicle. On average, the static fields tend to be somewhat higher in magnitude at the measurement locations to the rear of the passenger compartment and in the VIP passenger compartment. Like the ac fields the static field levels are higher and more variable over time near the floor of the vehicle. Static field levels do not correlate with vehicle speed. The data suggest that there are at least two principal sources of static magnetic field; the geomagnetic field of the earth and one or more sources beneath the floor of the vehicle, such as magnet structures and interconnecting wiring. The increased fields toward the rear engineering area of the vehicle is consistent with the possibility that power wiring routed beneath the floor to the magnets is a significant source of fields onboard the vehicle.

The total static magnetic field onboard the vehicle is the vector sum of the magnetic field from the earth and from onboard sources. From the frame of reference of the moving vehicle, the orientation of the field from onboard sources would remain reasonably stationary over time but the orientation of the horizontal component of the geomagnetic field varies depending on the position of the vehicle on the test track. Consequently, the horizontal component of the total static magnetic field fluctuates depending on whether the horizontal components from the two principal sources add or cancel at any particular instant.

The geomagnetic field of the earth is in the range of 485 or 490 mG in the vicinity of the Emsland Test Site (see Section 4 below). However, near objects having large pieces of iron, steel, or other ferromagnetic material, the magnetic field of the earth tends to concentrate in the ferromagnetic material due to its high magnetic permeability. This results in a disruption or perturbation of the normal geomagnetic field often producing enhanced fields above or below the structure and reduced fields along side the structure. Aside from the perturbing effects of ferromagnetic material onboard the vehicle or in the guideway, one would expect to find a static field of approximately 490 mG throughout the interior of the TR07 vehicle arising from the earth's magnetism. Figure 3-7 shows that the average static magnetic field at head level is

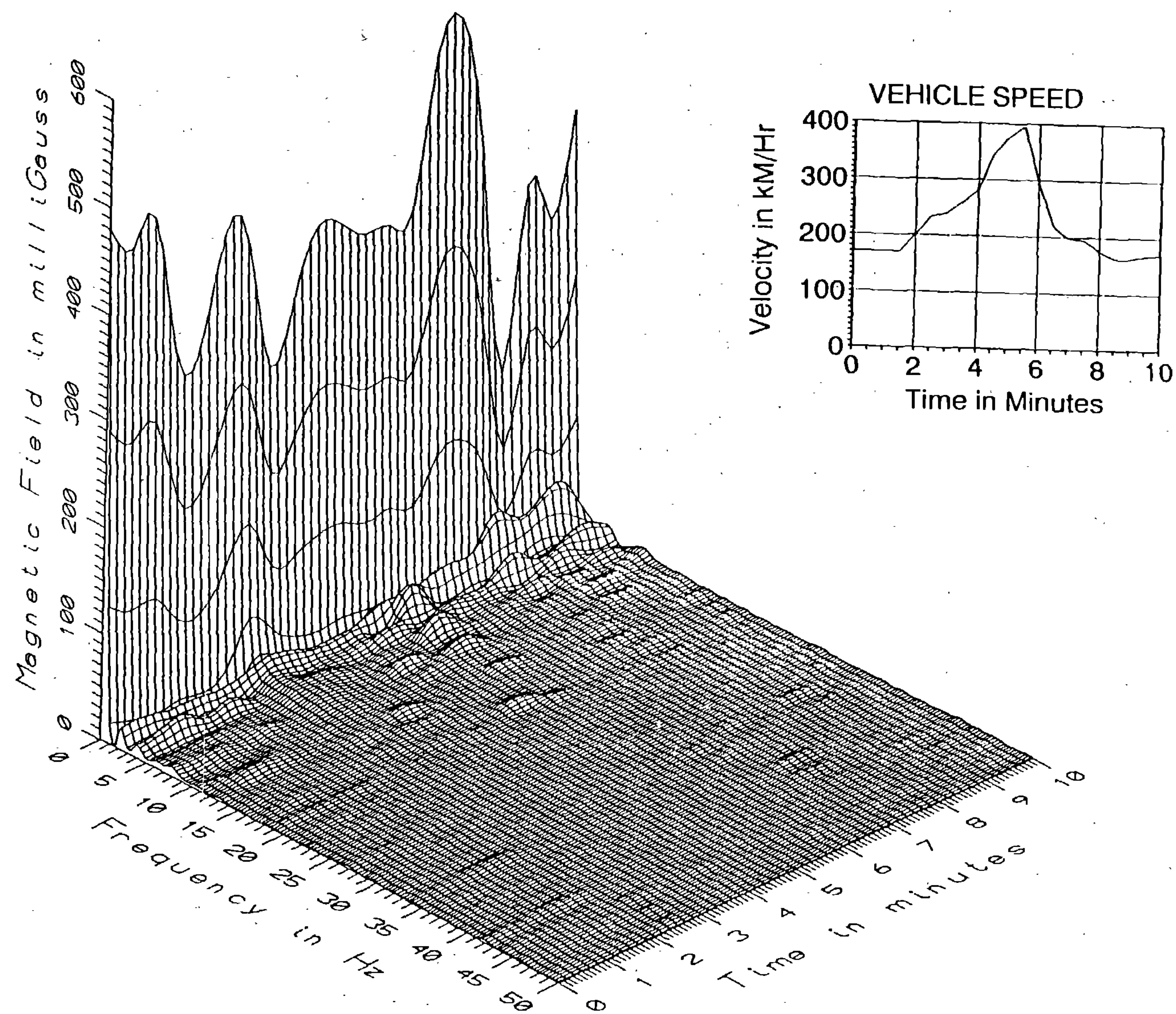


Figure 3-7 Magnetic flux density versus frequency and time at 175 cm above the floor at the reference probe location at the rear of the passenger section of Car 2.

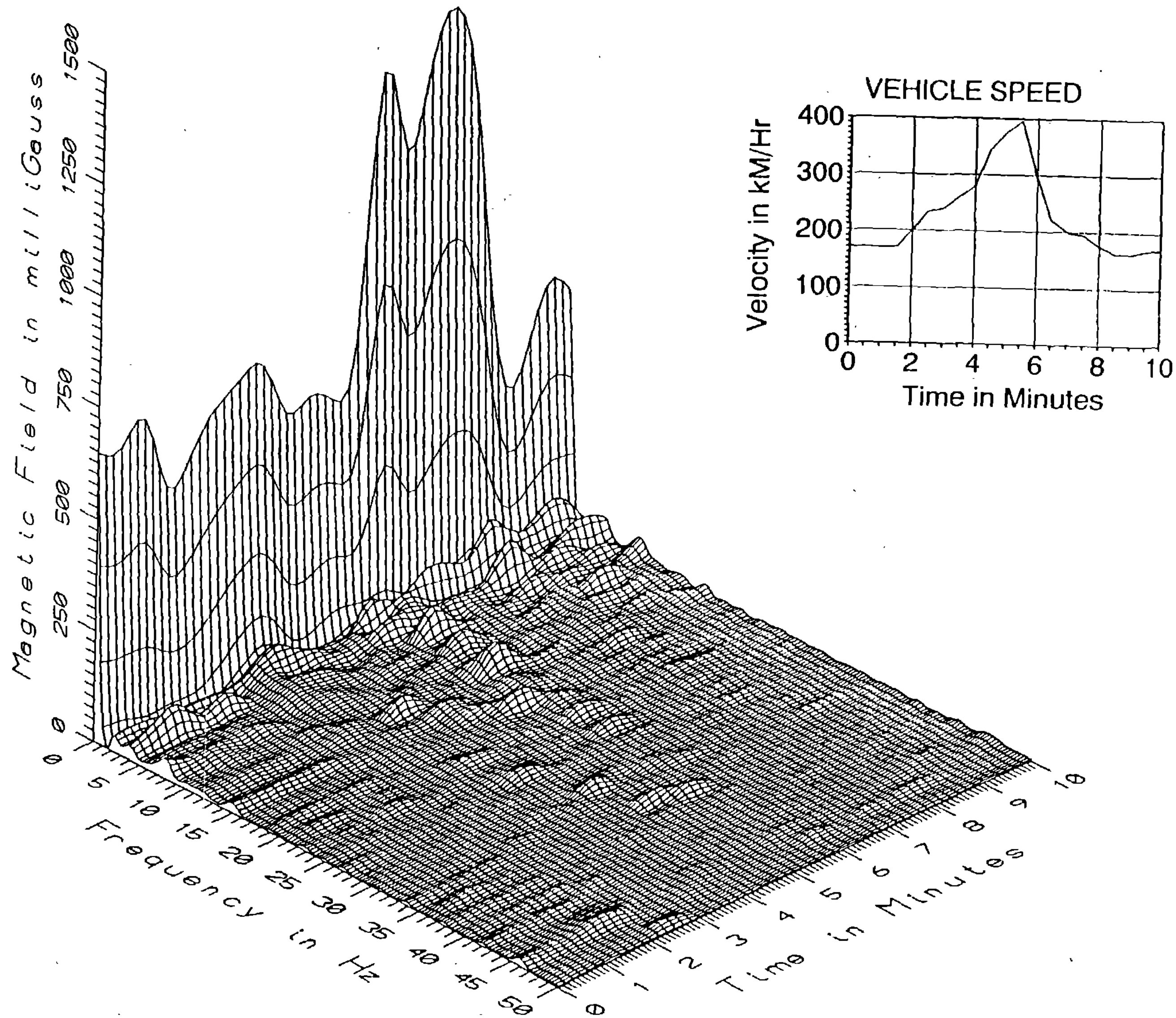


Figure 3-8 Magnetic flux density versus frequency and time measured with the fluxgate sensor 13 cm above the floor at the side of the aisle in the center of Car 2.

approximately 400 mG but varies above or below the average value by about 150 mG.

Those results would suggest that the vertical component of the static field produced by the vehicle at the measurement location is opposite the direction of the vertical component of the earth's field (yielding a reduced average value) and that the degree of fluctuation as the vehicle circumvents the track is to some extent indicative of the field produced by the vehicle.

The static magnetic field measurement data near the floor presented in Figure 3-8 show a somewhat different situation. Here, the static magnetic field produced by the vehicle clearly dominates the static field environment as evidenced by the higher average static field and the increased variability. This is consistent with nearer proximity to the source.

The graph of static field strength as a function of measurement height and time for the various onboard measurements provide further insight to the interaction of the geomagnetic and vehicle-generated field. Figure 3-9 from Appendix C represents measurements at the side of the aisle in the middle of the second car but is representative of similar plots for the other data sets. Under some conditions, such as in the time interval from 400 to 500 seconds, the TR07 vehicle is oriented in such a way that the geomagnetic and vehicle generated static fields are aligned and add resulting in higher total fields and a well defined attenuation pattern with increased height above the floor. At other times, relative orientation of the static field components is more random and constructive or destructive vector addition occurs depending on both the relative intensities of the fields (which in turn depends to some extent on height above the floor) and relative field orientation (which is time dependant in the moving vehicle).

3.2.3 Summary Data

After collapsing the field by time and frequency data into frequency bands for spatial analysis, the mean, standard deviation, and coefficient of variation of the magnetic field was calculated at each height above the floor and within each frequency band for all of the measurements within the passenger compartments. The results are presented along with the maximum and minimum values of the field at each height and in each frequency band in Table 3-2. As described above, the magnetic fields are highly variable (large coefficients of variation and wide minimum to maximum range) are strongly height dependent and are larger in magnitude at the lower frequencies (the 50-60 Hz band values are numerically low due to the fact that this band is considerably narrower than the

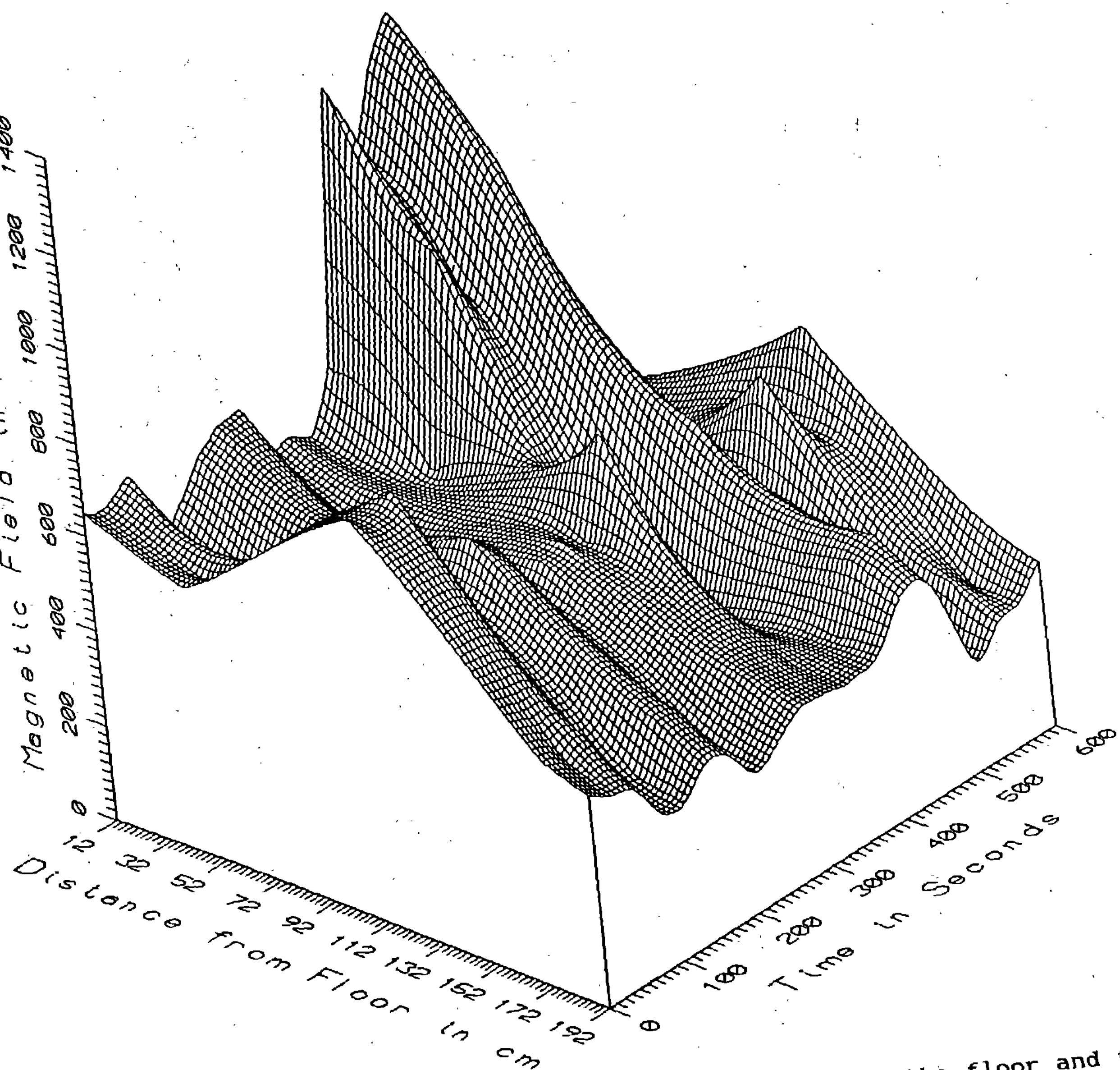


Figure 3-9 Static magnetic flux density versus height above the floor and time at the side of the aisle in the center of Car 2.

TABLE 3-2

SUMMARY DATA FOR MAGNETIC FIELD MEASUREMENTS WITHIN THE PASSENGER COMPARTMENTS OF THE TR07 VEHICLE

PASSENGER SECTION, CAR#2		TOTAL OF 95 SAMPLES				
FREQUENCY BAND	HEIGHT ABOVE FLOOR (cm)	MINIMUM MAGNETIC FIELD (mG)	MAXIMUM MAGNETIC FIELD (mG)	AVERAGE MAGNETIC FIELD (mG)	STANDARD DEVIATION (mG)	COEFFICIENT OF VARIATION (%)
STATIC	175.26	169.20	981.62	497.48	170.59	34.29
STATIC	111.76	225.96	1036.18 *	633.55 *	220.54 *	34.81 *
STATIC	46.99	69.84	1110.38 **	611.14 **	226.79 **	37.11 **
STATIC	12.70	166.81	1501.63 ***	834.42 ***	304.13 ***	36.45 ***
5-45 Hz	175.26	5.00	53.46	16.98	7.41	43.66
5-45 Hz	111.76	7.44	76.76	26.06	11.33	43.47
5-45 Hz	46.99	17.46	141.44	47.58	22.01	46.25
5-45 Hz	12.70	31.37	235.53	89.77	39.83	44.37
50-60 Hz	175.26	0.85	18.93	3.83	2.72	71.15
50-60 Hz	111.76	1.22	27.17	5.18	3.30	63.78
50-60 Hz	46.99	2.60	29.42	7.74	3.87	50.02
50-60 Hz	12.70	3.76	42.60	14.80	8.36	56.49
65-300 Hz	175.26	2.70	25.02	10.95	5.44	49.66
65-300 Hz	111.76	3.11	29.55	13.72	6.01	43.79
65-300 Hz	46.99	5.63	35.46	18.45	7.13	38.64
65-300 Hz	12.70	10.65	88.22	32.48	17.11	52.69
305-2560 Hz	175.26	0.20	1.97	0.78	0.48	61.63
305-2560 Hz	111.76	0.23	2.29	1.00	0.56	56.13
305-2560 Hz	46.99	0.43	2.46	1.15	0.48	41.33
305-2560 Hz	12.70	0.45	4.57	1.93	0.96	49.95
5-2560 Hz	175.26	7.58	53.62	21.13	8.32	39.37
5-2560 Hz	111.76	9.92	76.92	30.55	11.69	38.27
5-2560 Hz	46.99	21.13	143.19	52.42	21.62	41.24
5-2560 Hz	12.70	34.84	253.50	98.37	40.06	40.73

NOTES:

- * The fluxgate sensor was saturated on one of the three axes for four of the 95 measurements.
- ** The fluxgate sensor was saturated on one of the three axes for two of the 95 measurements.
- *** The fluxgate sensor was saturated on one of the three axes for 20 of the 95 measurements.

others). Graphs showing the effect of height above the floor on mean, minimum, and maximum field levels in the passenger areas for each frequency band are given in Figures 3-10 through 3-15.

The fluxgate sensors used for the static magnetic field measurements have a maximum field measurement capability of 1000 mG per axis. Depending on the orientation of the sensor relative to the static field to be measured, one or more axis of the sensor will saturate when the incident field exceeds a value of 1000 to 1730 mG. Sensor saturation was encountered in 26 of the 380 measurements within the passenger compartment. Because of that limitation in instrumentation, actual static magnetic field levels are greater than reported values in those measurements where saturation occurred.

Twenty-three of the 26 incidents of sensor saturation occurred in the measurements in the VIP compartment because field orientation was such that it favored saturation at a lower level. No valid static field data was obtained at floor level in that compartment. However, it is known that the actual average floor level static field was greater than the 1043 mG reported. The frequency of sensor saturation and estimated extent of saturation were sufficiently small in other data sets to have only minimal impact on the validity of the summary data.

In all cases, data corrupted by sensor saturation are clearly noted.

Throughout all of the onboard vehicle measurements, one coil-type sensor and one fluxgate sensor were located near the rear bulkhead of the main passenger compartment at heights of approximately 47 cm and 112 cm above the floor, respectively. Summary data from those sensors are shown in Table 3-3. Although the mean field values at the reference probe location tends to be somewhat higher than the mean values at comparable heights throughout the passenger area given in Table 3-3, the coefficients of variation for the ac fields are similar. That result suggests that most of the variation in ac field levels reported in Table 3-3 is variation with time rather than location. Static fields, on the other hand, appear to be more dependent on measurement location within the vehicle as indicated by the differences in mean values between reference probe measurements and measurements elsewhere in the vehicle and the smaller coefficient of variation in the stationary reference probe measurement.

To further explore the significance of measurement location within the passenger area, mean values of the magnetic field were computed for each of the five measurement data sets

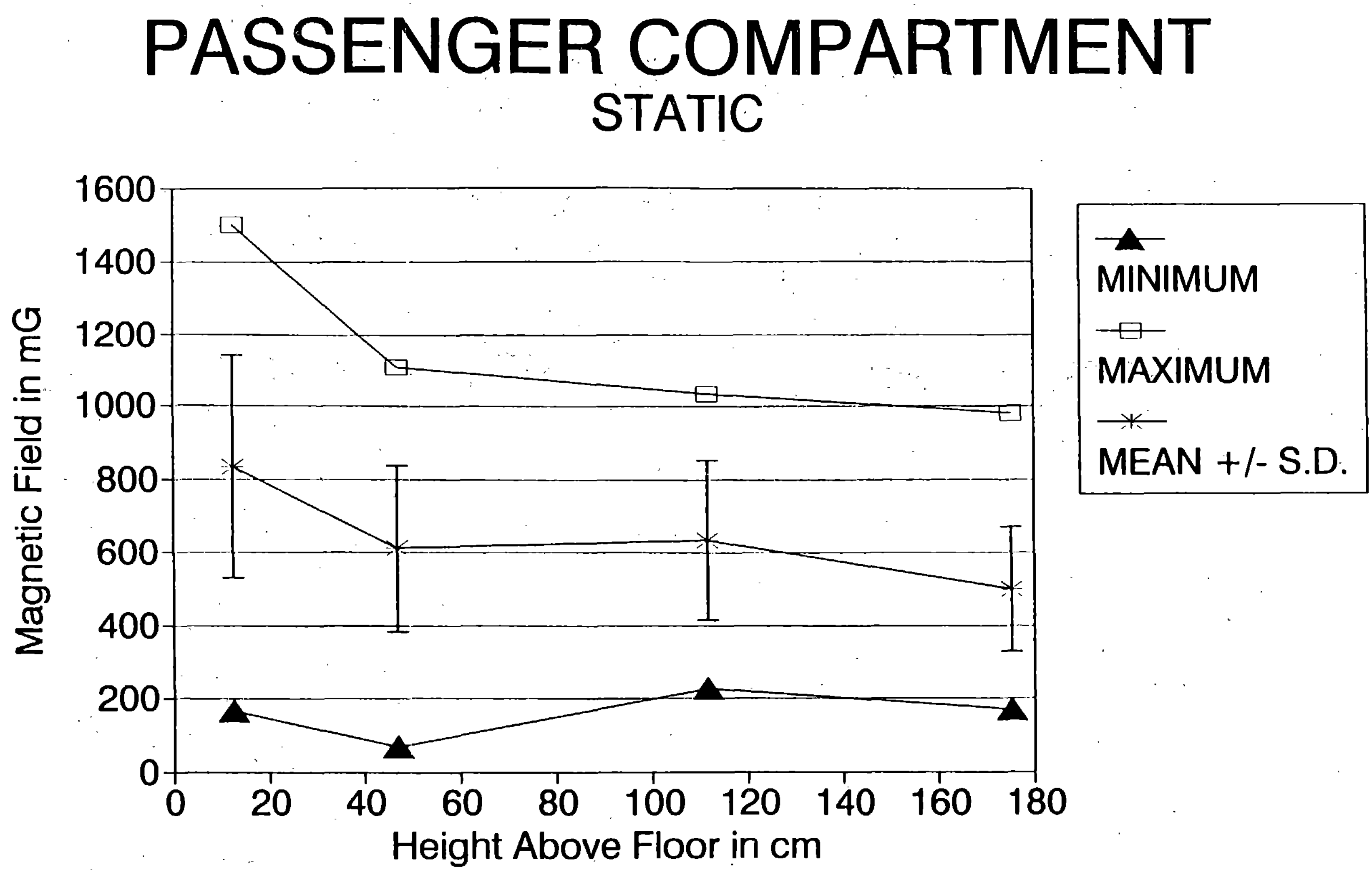


Figure 3-10 Minimum, average, and maximum values of static magnetic fields measured in the passenger compartments of the TR07 vehicle for various heights above the floor.

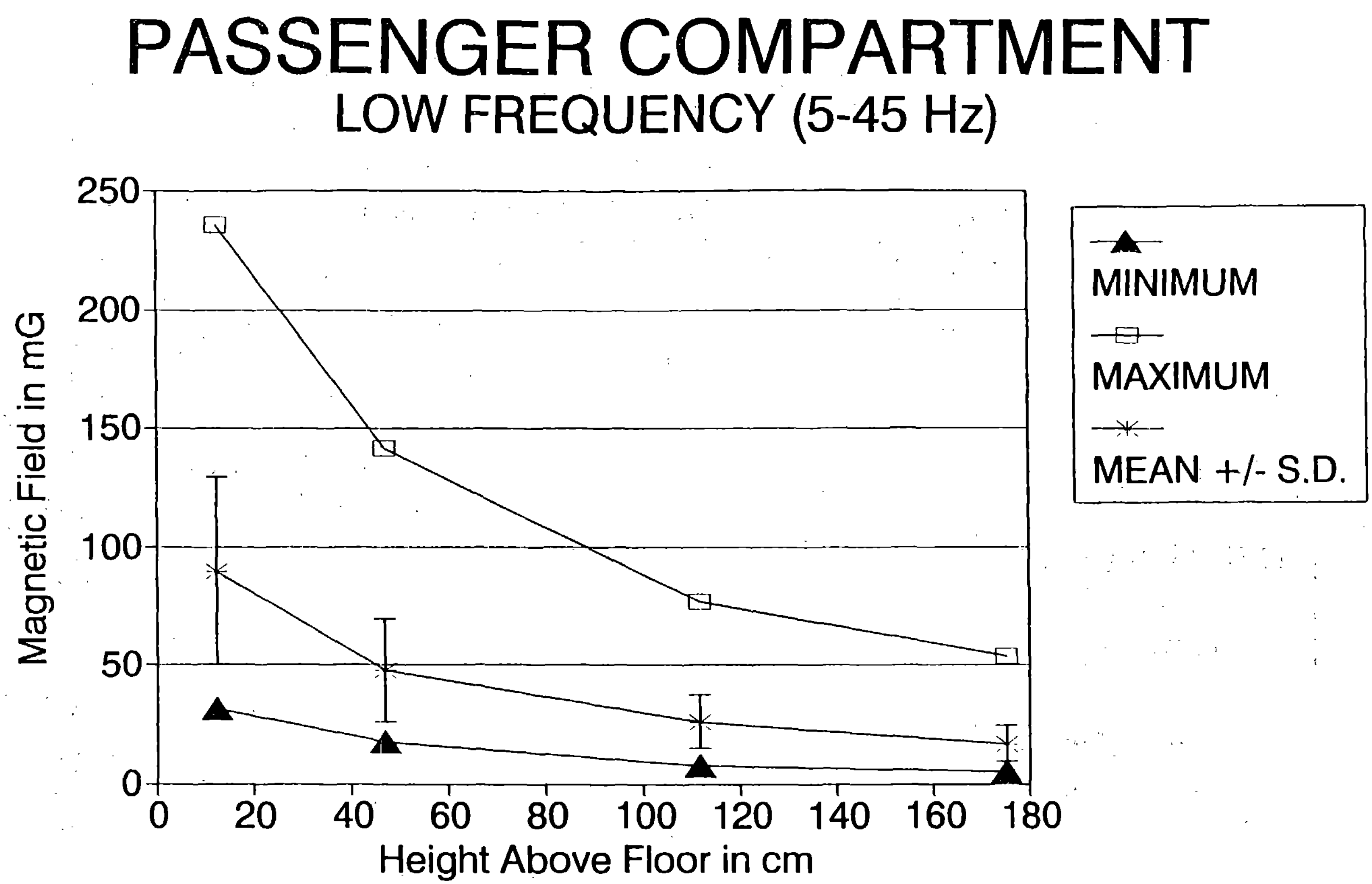


Figure 3-11 Minimum, average, and maximum time varying magnetic field in the low frequency (5-45 Hz) band measured in the passenger compartments of the TR07 vehicle for various heights above the floor.

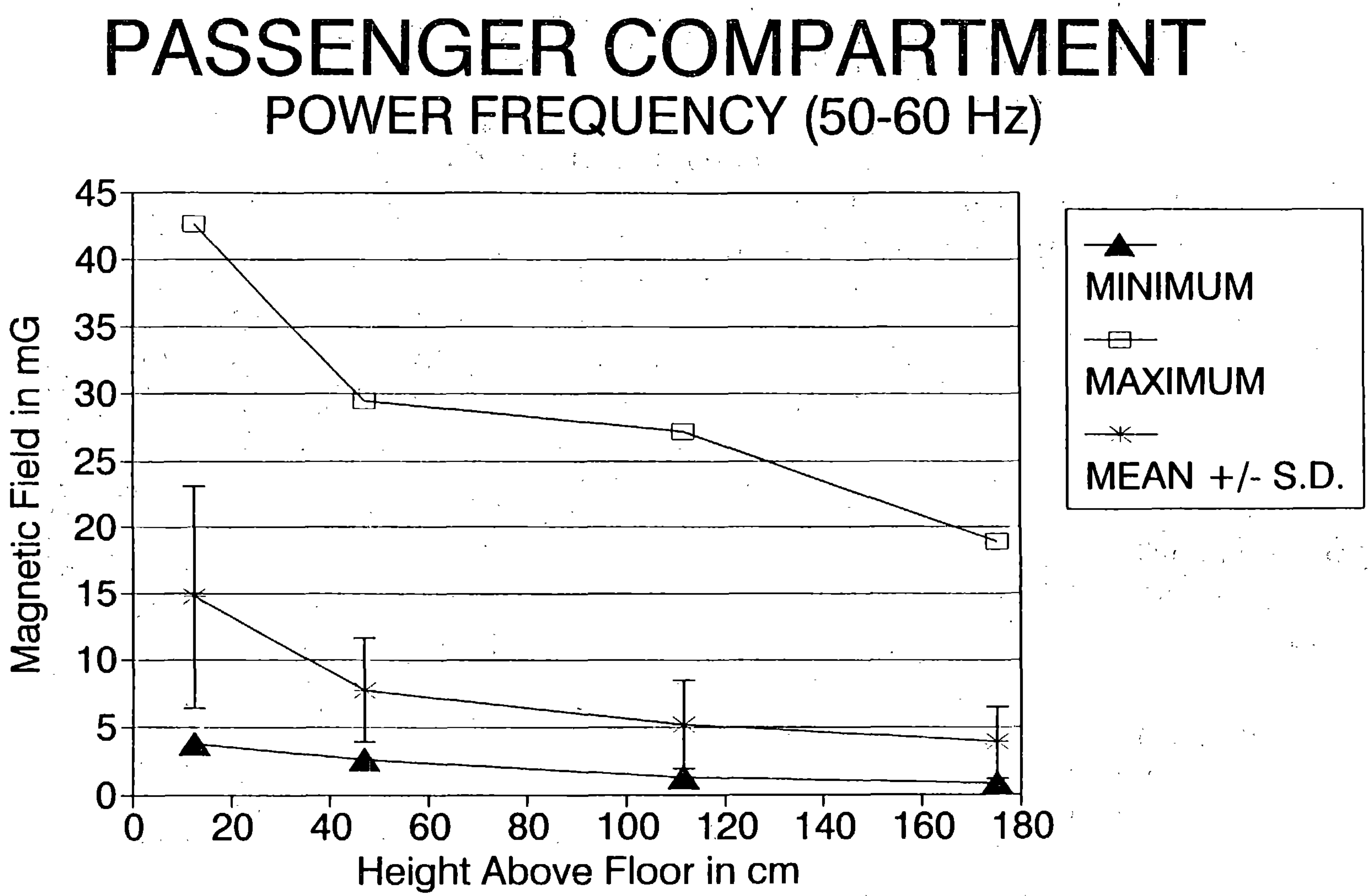


Figure 3-12 Minimum, average, and maximum time varying magnetic field in the power frequency (50-60 Hz) band measured in the passenger compartments of the TR07 vehicle for various heights above the floor.

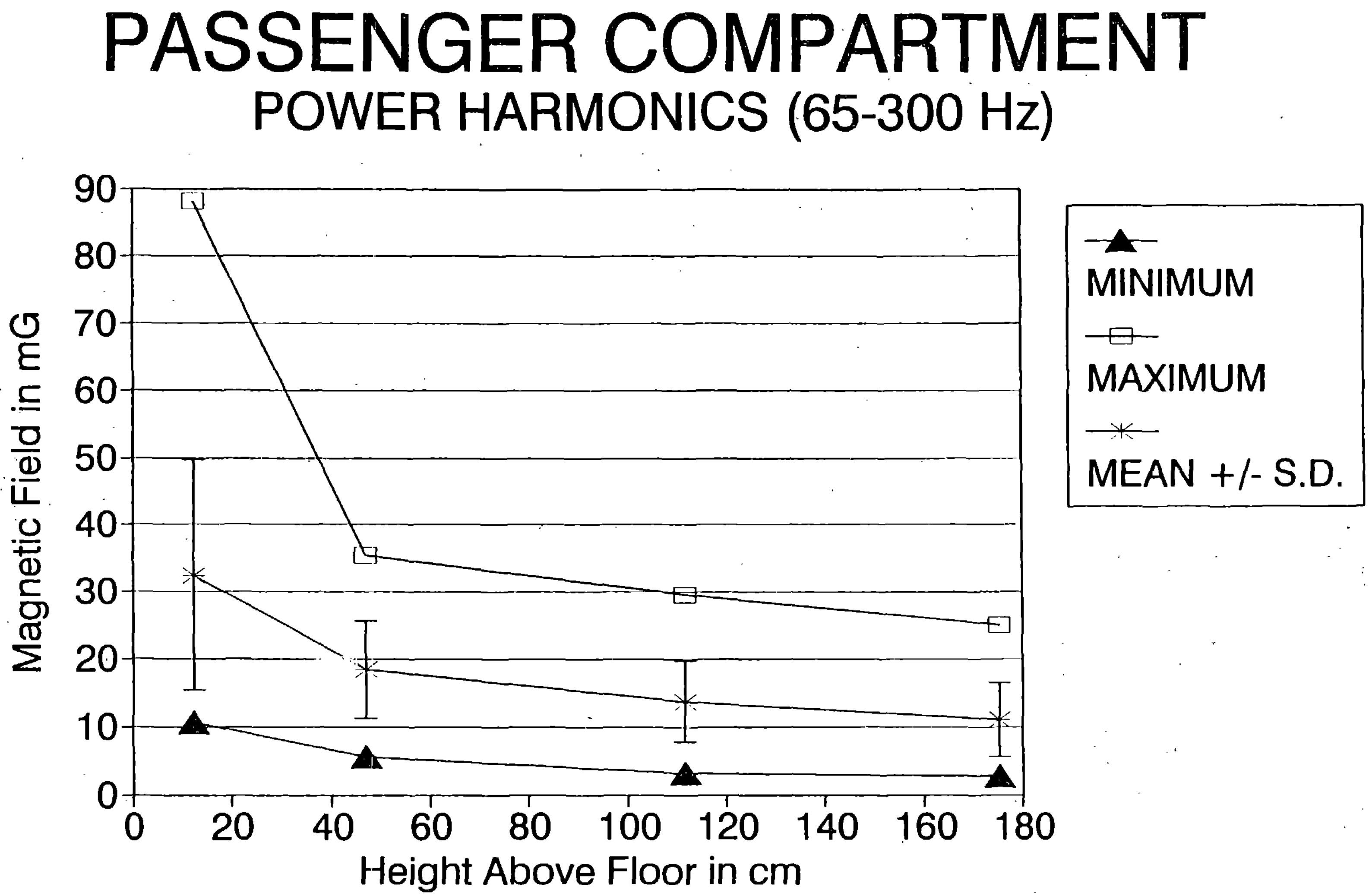


Figure 3-13 Minimum, average, and maximum time varying magnetic field in the power harmonics (65-300 Hz) band measured in the passenger compartments of the TR07 vehicle for various heights above the floor.

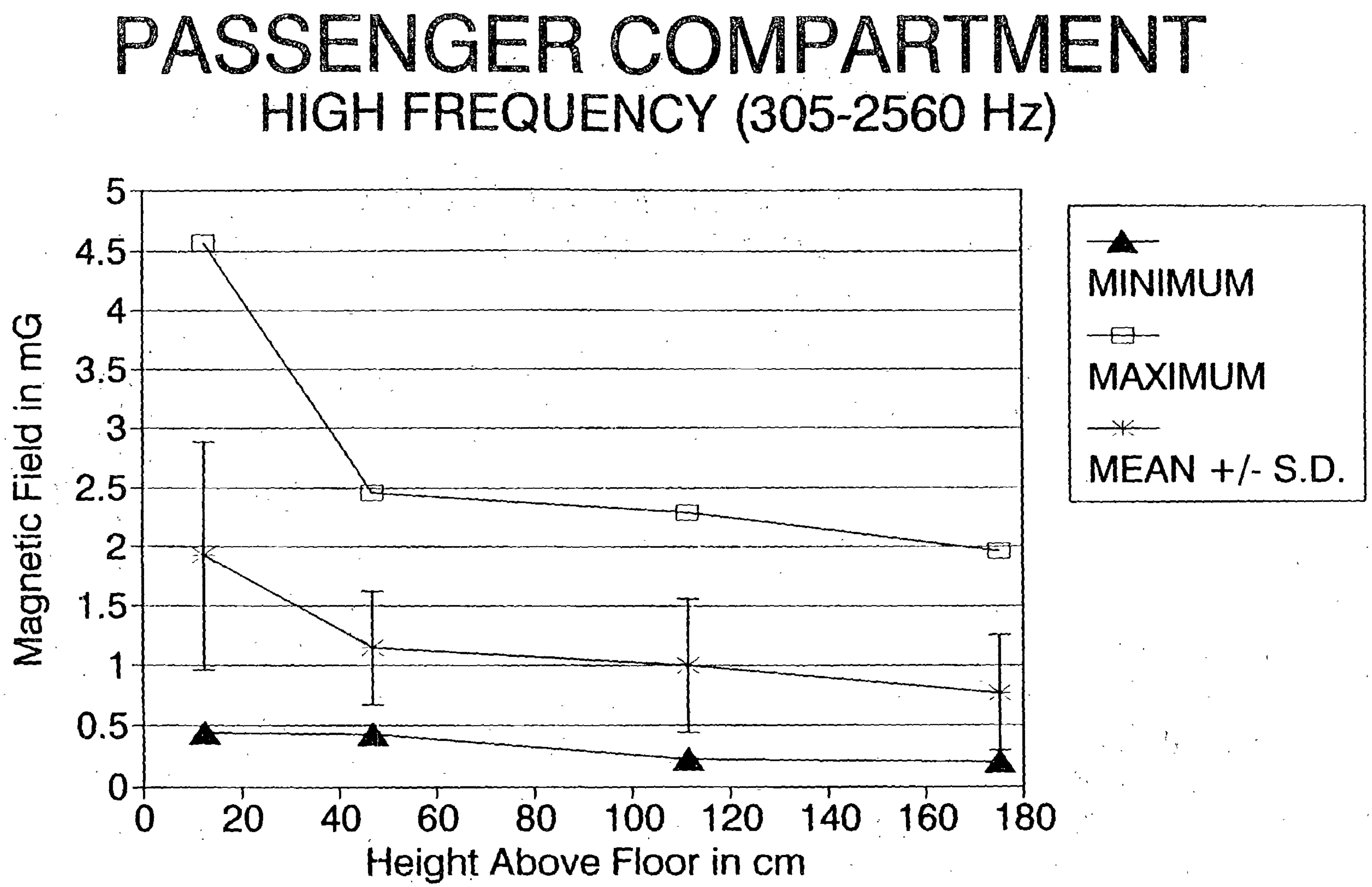


Figure 3-14 Minimum, average, and maximum time varying magnetic field in the high frequency (305-2560 Hz) band measured in the passenger compartments of the TR07 vehicle for various heights above the floor.

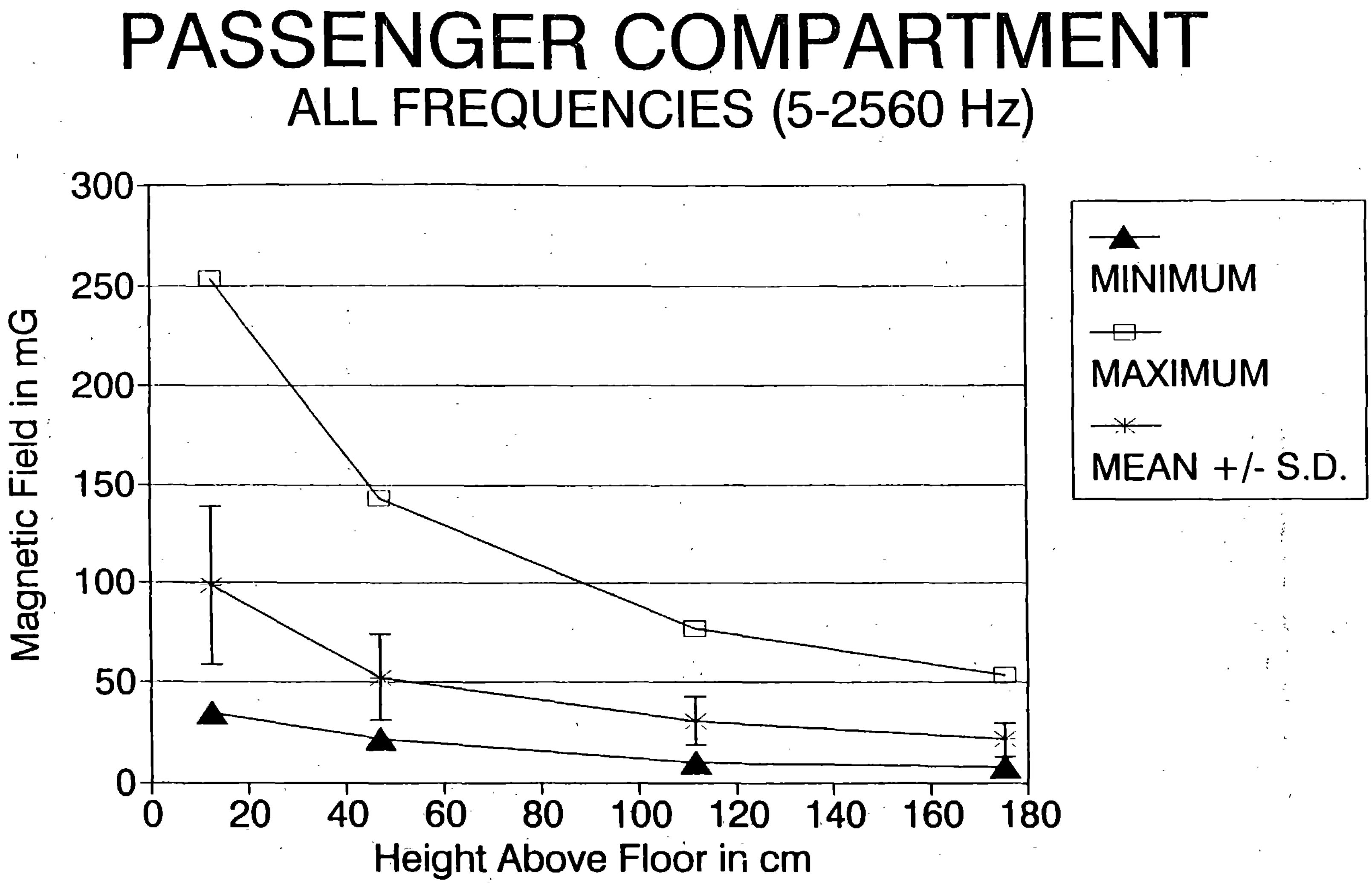


Figure 3-15 Minimum, average, and maximum time varying magnetic field in the frequency range from 5 to 2560 Hz measured in the passenger compartments of the TR07 vehicle for various heights above the floor.

TABLE 3-3

SUMMARY DATA FOR THE STATIONARY REFERENCE PROBES AT THE REAR BULKHEAD OF THE MAIN PASSENGER COMPARTMENT OF THE TR07 VEHICLE

PASSENGER SECTION CAR#2 - REFERENCE PROBES - LOCATED AT REAR BULKHEAD						95 SAMPLES
FREQUENCY BAND	VERTICAL HEIGHT	MINIMUM MAGNETIC FIELD (mG)	MAXIMUM MAGNETIC FIELD (mG)	AVERAGE MAGNETIC FIELD (mG)	STANDARD DEVIATION (mG)	COEFFICIENT OF VARIATION (%)
STATIC	SEATED HEAD LEVEL	447.03	981.29	745.51	116.66	15.65
5-45 Hz	SEAT LEVEL	21.34	259.07	63.15	33.79	53.51
50-60 Hz	SEAT LEVEL	1.93	27.57	8.60	4.79	55.63
65-300 Hz	SEAT LEVEL	4.85	27.09	17.37	5.48	31.55
305-2560 Hz	SEAT LEVEL	0.27	2.31	1.14	0.53	46.90
5-2560 Hz	SEAT LEVEL	26.98	259.46	66.80	33.13	49.60

collected in the passenger areas. As indicated in Table 3-1, these represent four areas:

- window seat mid-vehicle;
- edge of aisle mid-vehicle (2 data sets);
- window seat rear of vehicle; and
- seat in the VIP compartment.

These values are contained in Table 3-4. The data from repetitive measurements at the aisle seat in the center of the car provide an example of the difference in mean values obtainable from two successive 8 to 10 minute samples at the same location within the car. Comparison of the data across measurement locations indicate that the tendency toward higher fields toward the rear of the vehicle, especially at the greater heights above the floor. There is little consistent difference between field levels near the window versus near the aisle (see Appendix H for more detailed data). Finally, the differences in field level from one location to another are generally less than the differences produced by a half meter increase in height above the floor.

3.3 Field Levels in the Engineer's Area

The data set contained in Appendix G was obtained from repetitive waveform measurements in the rear engineer's compartment of the second car. The time-varying field measurements were made at various heights immediately behind the engineer's seat while the static field measurements were made behind the seat on the opposite side of the compartment. Photographs and diagrams of the measurement locations are in Section 4.1 and Appendix B of the Interim report.

The field versus time and frequency plots for measurement within the engineering area are similar in character to those seen elsewhere on the vehicle. However, the intensity of the time-varying fields does not decrease as rapidly with increasing height above the floor in the engineer's compartment as it does in the passenger areas. Consequently, the ac magnetic field tends to be higher at seat level, seated head level, and standing head level in the engineer's compartment than in the passenger compartments.

Figure 3-16 shows the field by time and height above the floor plot for the low frequency (5-45 Hz) magnetic fields measured in the engineer's compartment. It is typical of the corresponding curves for the other frequency bands which are contained in Appendix G. Comparison of this figure to Figure 3-5, which shows the corresponding graph for measurements in the center of the passenger compartment, illustrates the less rapid attenuation of field strength with increasing measurement height and the higher field levels at seat level and above mentioned in the preceding paragraph.

TABLE 3-4

SUMMARY DATA FOR MAGNETIC FIELD MEASUREMENTS WITHIN THE PASSENGER COMPARTMENTS OF THE TR07 BY LOCATION

PASSENGER SECTION CAR #2 - AVERAGE MAGNETIC FIELD BY LOCATION							
FREQUENCY BAND	HEIGHT ABOVE FLOOR (cm)	WINDOW SEAT CENTER OF CAR (mG)	AISLE SEAT CENTER OF CAR (mG)	AISLE SEAT CENTER OF CAR (mG)	REAR WINDOW SEAT (mG)	VIP SEAT (mG)	REFERENCE LOCATION (mG)
STATIC	175.26	425.11	377.65	375.83	580.66	763.57	
STATIC	111.76	462.76	579.92	598.29	621.35	959.67 *	745.51
STATIC	46.99	447.01	576.34	553.00	686.01	831.35 **	
STATIC	12.70	698.34	702.81	703.41	1060.80 ***	>1043.08 ****	
5-45 Hz	175.26	16.01	15.32	17.40	17.07	19.71	
5-45 Hz	111.76	26.41	23.04	25.83	28.74	26.59	
5-45 Hz	46.99	52.32	40.96	44.05	59.16	40.46	63.15
5-45 Hz	12.70	96.20	98.78	97.98	94.67	56.98	
50-60 Hz	175.26	2.82	2.99	2.83	4.59	6.24	
50-60 Hz	111.76	4.71	4.00	3.62	6.78	6.98	
50-60 Hz	46.99	6.75	7.78	6.61	9.32	8.29	8.60
50-60 Hz	12.70	11.40	21.04	17.97	11.95	11.28	
65-300 Hz	175.26	7.66	8.09	7.89	12.85	19.51	
65-300 Hz	111.76	12.74	9.88	9.61	15.74	21.50	
65-300 Hz	46.99	16.98	17.44	17.23	19.94	21.09	17.37
65-300 Hz	12.70	24.46	42.48	43.98	25.46	26.37	
305-2560 Hz	175.26	0.60	0.52	0.58	1.10	1.14	
305-2560 Hz	111.76	1.19	0.60	0.64	1.34	1.22	
305-2560 Hz	46.99	1.20	0.96	1.00	1.50	1.07	1.14
305-2560 Hz	12.70	1.32	2.57	2.87	1.70	1.18	
5-2560 Hz	175.26	18.19	17.90	19.83	22.33	28.71	
5-2560 Hz	111.76	30.01	25.82	28.41	34.12	35.23	
5-2560 Hz	46.99	55.87	46.11	48.83	63.88	46.72	66.80
5-2560 Hz	12.70	100.66	112.09	111.30	99.66	64.25	

NOTES:

* The fluxgate sensor was saturated on one of three axes for 4 of the 17 measurements.

** The fluxgate sensor was saturated on one of three axes for 2 of the 17 measurements.

*** The fluxgate sensor was saturated on two of three axes for 3 of the 19 measurements.

**** The fluxgate sensor was saturated on one of three axes for all of the 17 measurements.

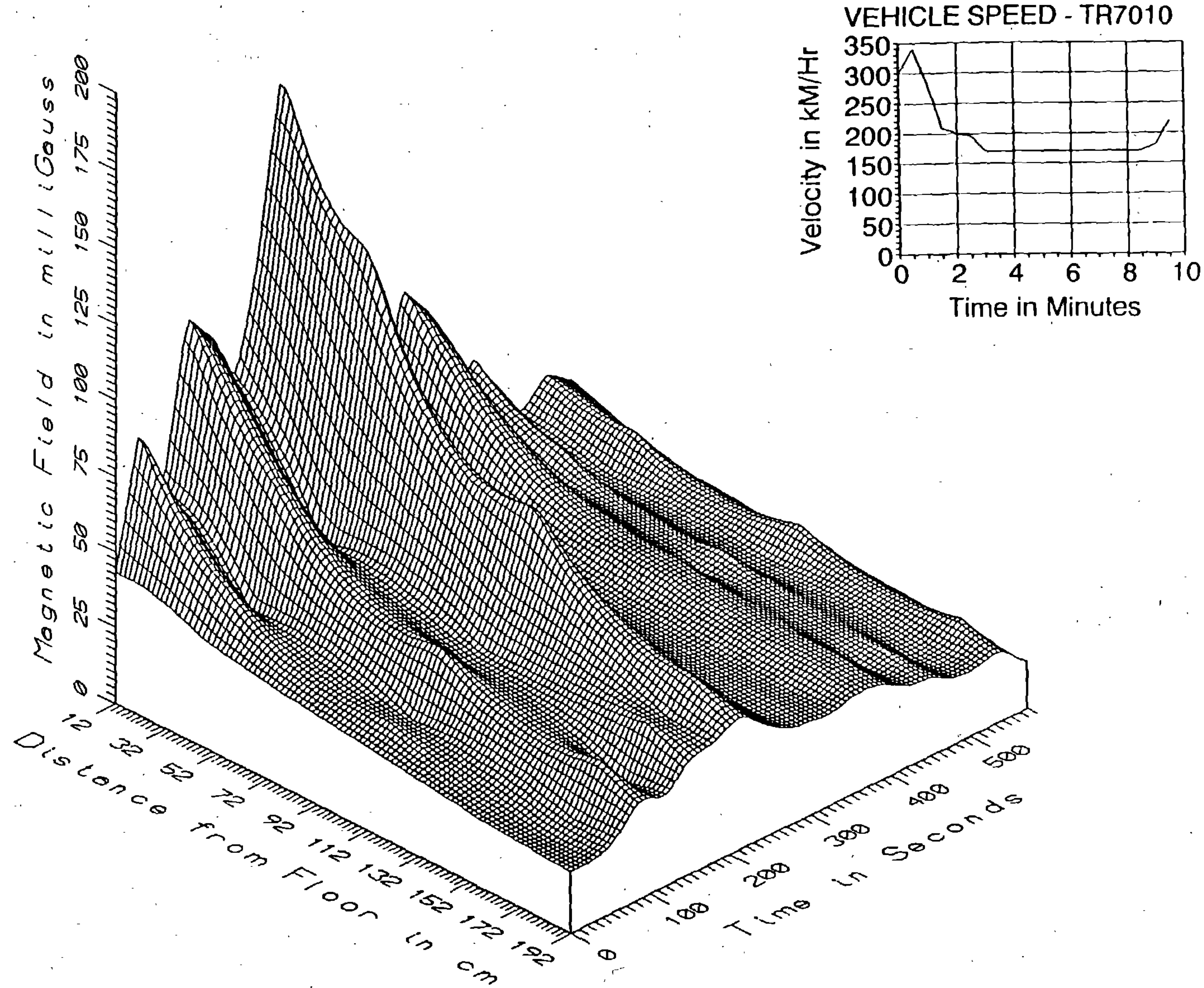


Figure 3-16 Field versus time and height above the floor for low frequency (5-45 Hz) magnetic fields in the rear engineer's compartment.

Summary data for the measurements within the engineer's compartment are continued in Table 3-5. Saturation of the static field sensors occurred a significant number of times in the floor level and seat level measurements. The validity of the floor level data is doubtful but the seat level data appear only minimally affected. When compared to passenger compartment data in Table 3-2, the summary data also reveal the above mentioned trend. Figures 3-17 through 3-22 show the summary data graphically.

The reduced attenuation rate and increased field indicate that there are sources of magnetic field in the engineer's compartment or the immediate vicinity which are located well above the floor level. These sources may well be equipment or instrumentation within the compartment, or the associated wiring. These field sources appear to have frequency and temporal characteristics similar to those of the primary field sources below the vehicle floor.

3.4 Other Onboard Measurements

The last onboard measurement data set contained in Appendix H represents a profile of repetitive waveform measurements made perpendicular to the long axis of the TR07 vehicle at a height of approximately 5 cm above the floor at a point midway through the main passenger compartment of the second car. Details on, and a photograph of, the measurement location are found in Section 4.1 and Appendix B of the Interim Report. These measurements were taken to address the question of whether small changes in position might produce large changes in field level such as those which might occur if strong localized field sources were located immediately below the floor. These data should not be directly compared to other data sets collected onboard the TR07 vehicle because the vehicle was operating at low speed and stopped during this test. Nevertheless, the relative field levels between field sensors could be compared to show that time varying magnetic field conditions are relatively uniform laterally across the floor of the vehicle. Figure 3-23 shows the field by time and distance from the center of the aisle for the total time varying field. There is little variability along the distance axis at any time indicating that the field is spatially uniform (the reader is reminded that measurements were taken at only 4 locations marked by the cusps in the graph along the time = 0 and time = 150 seconds borders to the graph. The curved profile between these sparse measurement locations is an artifact of the surface fitting algorithm used to prepare the pseudo-three-dimensional graphs. Figure 3-24 presents the corresponding graph for static field measurements. Lateral position within the vehicle has a somewhat larger effect on static field level than the time varying field level, but the influence of lateral position is small compared to the effects of vertical position or time.

TABLE 3-5

SUMMARY DATA FOR THE MAGNETIC FIELD MEASUREMENTS WITHIN THE REAR ENGINEER'S COMPARTMENT OF THE TR07 VEHICLE

REAR ENGINEER SECTION, CAR#2		TOTAL OF 20 SAMPLES				
FREQUENCY BAND	HEIGHT ABOVE FLOOR (cm)	MINIMUM MAGNETIC FIELD (mG)	MAXIMUM MAGNETIC FIELD (mG)	AVERAGE MAGNETIC FIELD (mG)	STANDARD DEVIATION (mG)	COEFFICIENT OF VARIATION (%)
STATIC	175.26	656.31	839.18	729.84	56.73	7.77
STATIC	111.76	655.67	954.96	791.35	94.75	11.97
STATIC	46.99	730.83	1108.22 *	926.43 *	106.84 *	11.53 *
STATIC	12.70	792.03	1098.48 **	986.02 **	76.13 **	7.72 **
5-45 Hz	175.26	13.57	49.19	29.64	8.89	29.98
5-45 Hz	111.76	16.83	80.83	37.29	13.69	36.73
5-45 Hz	46.99	22.41	138.84	52.00	26.60	51.16
5-45 Hz	12.70	31.11	180.31	75.53	37.69	49.90
50-60 Hz	175.26	2.16	24.17	11.30	7.37	65.22
50-60 Hz	111.76	2.17	24.65	11.53	7.09	61.51
50-60 Hz	46.99	1.92	22.35	11.59	5.98	51.54
50-60 Hz	12.70	3.08	29.41	16.28	6.88	42.29
65-300 Hz	175.26	27.42	55.76	42.46	7.01	16.50
65-300 Hz	111.76	28.58	61.99	45.21	7.95	17.58
65-300 Hz	46.99	24.36	66.93	45.72	10.94	23.92
65-300 Hz	12.70	24.60	85.48	55.28	15.96	28.87
305-2560 Hz	175.26	0.93	4.20	1.92	1.01	52.87
305-2560 Hz	111.76	0.91	4.17	1.96	0.98	50.09
305-2560 Hz	46.99	0.80	3.83	1.84	0.86	46.55
305-2560 Hz	12.70	0.94	4.28	2.09	0.89	42.66
5-2560 Hz	175.26	35.02	73.30	53.62	10.91	20.35
5-2560 Hz	111.76	37.13	98.37	60.47	14.59	24.13
5-2560 Hz	46.99	35.32	149.50	71.44	26.15	36.60
5-2560 Hz	12.70	39.80	190.89	96.59	37.55	38.87

NOTES: * Fluxgate sensor was saturated on one of the three axes for 5 of the 20 measurements.

** Fluxgate sensor was saturated on one of the three axes for 9 of the 20 measurements.

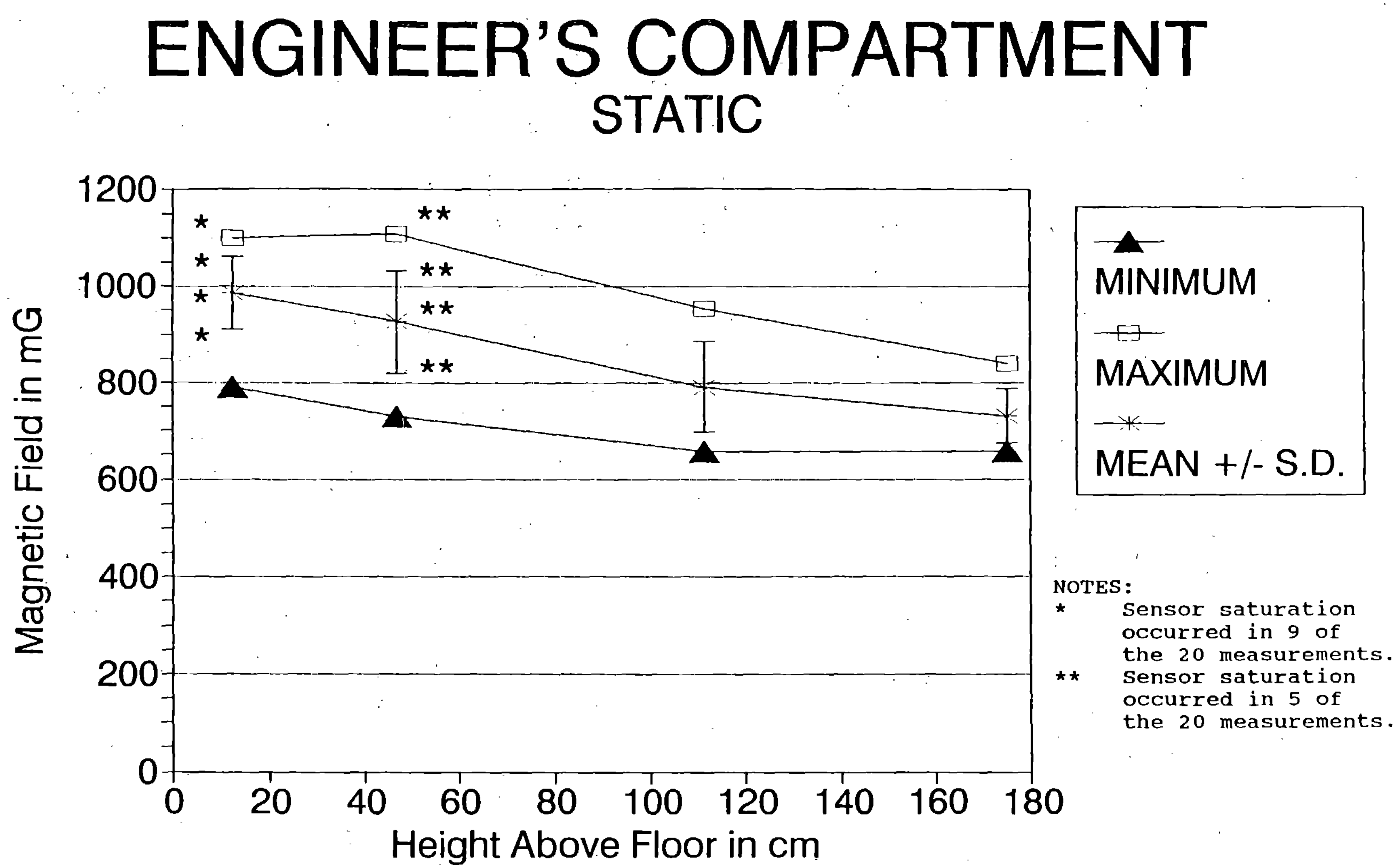


Figure 3-17 Minimum, average, and maximum values of static magnetic field measured in the engineer's compartment of the TR07 vehicle for various heights above the floor.

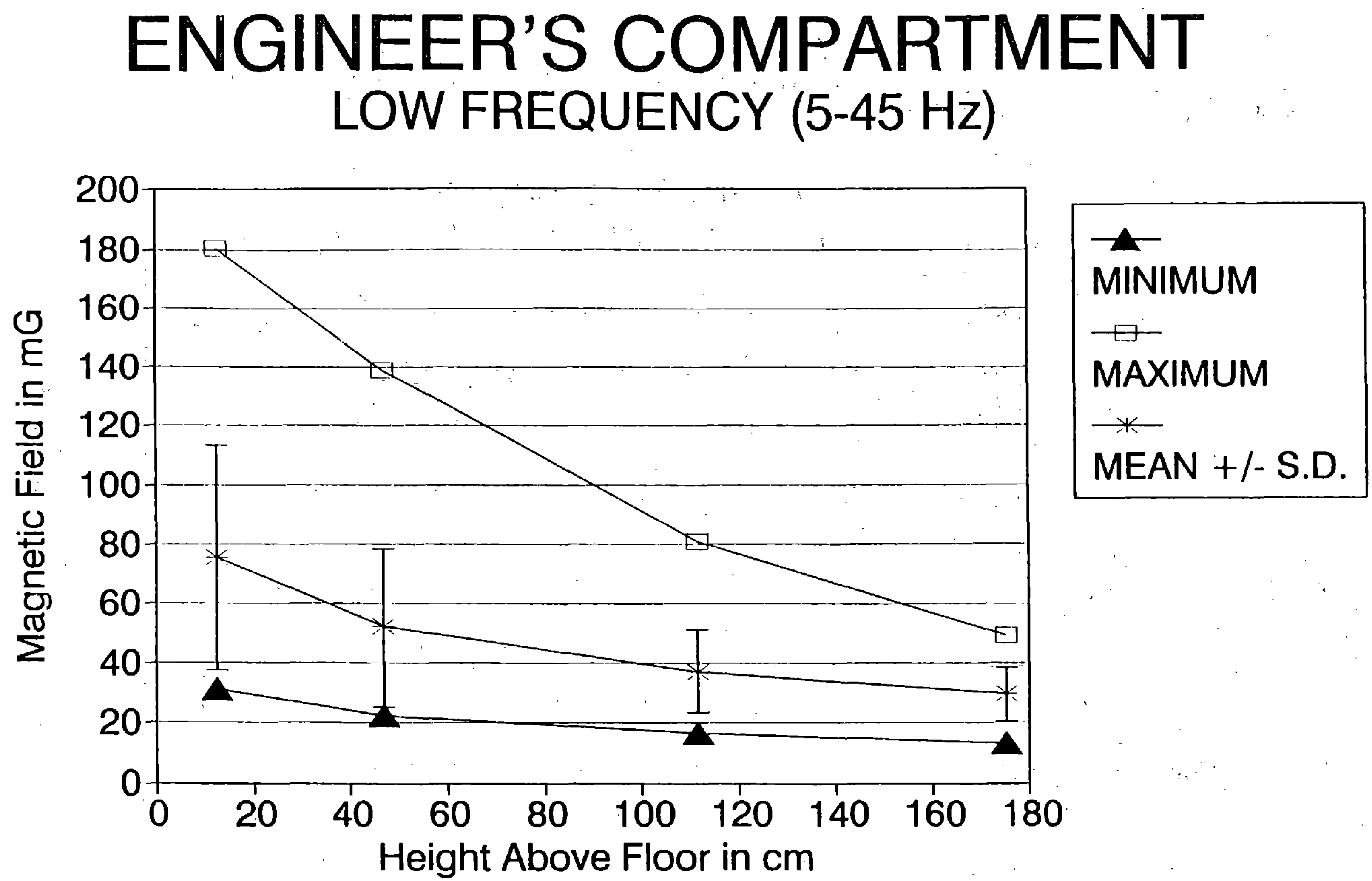


Figure 3-18 Minimum, average, and maximum time varying magnetic field in the low frequency (5-45 Hz) band measured in the engineer's compartment of the TR07 vehicle for various heights above the floor.

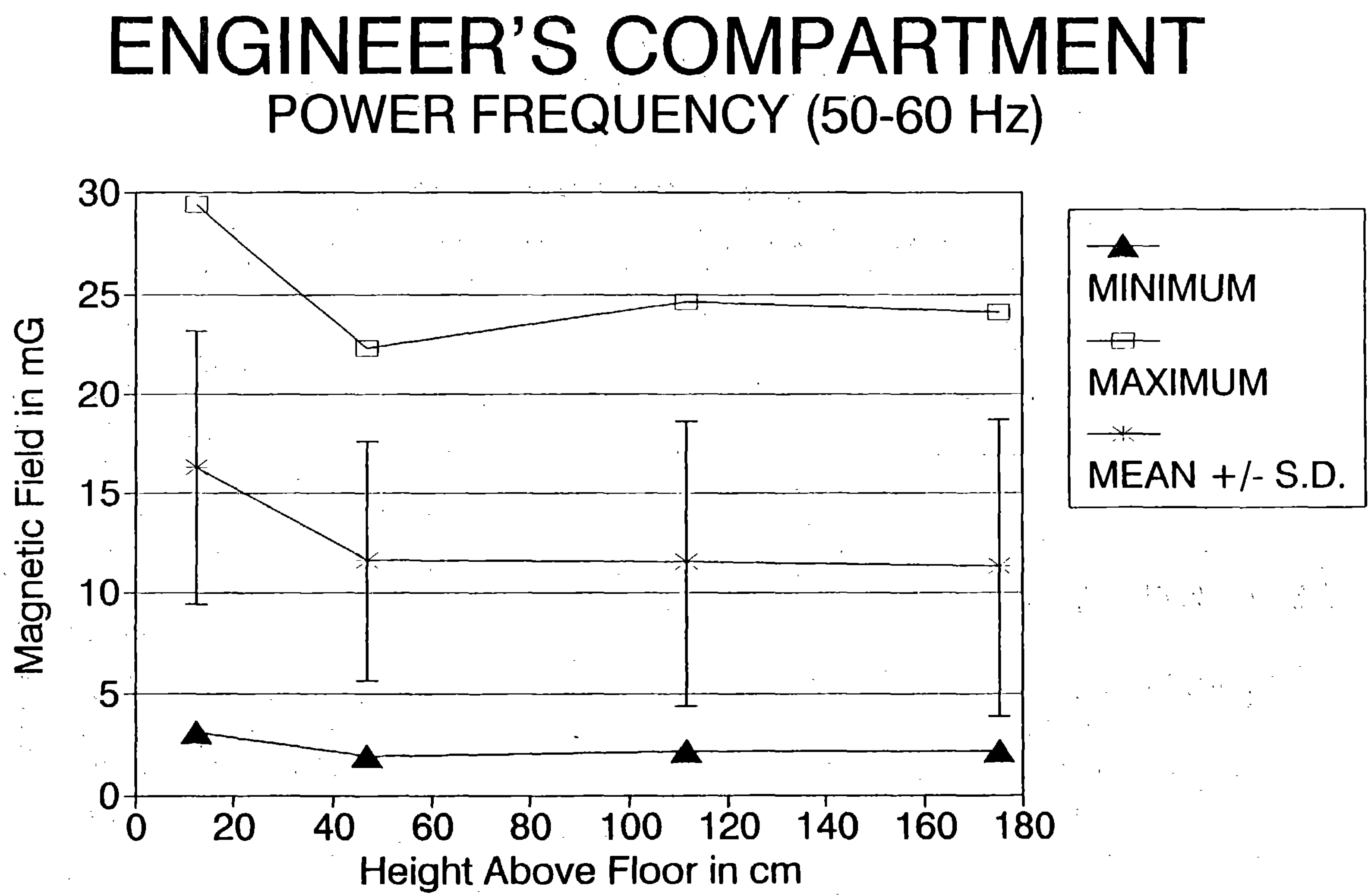


Figure 3-19 Minimum, average, and maximum time varying magnetic field in the power frequency (50-60 Hz) band measured in the engineer's compartment of the TR07 vehicle for various heights above the floor.

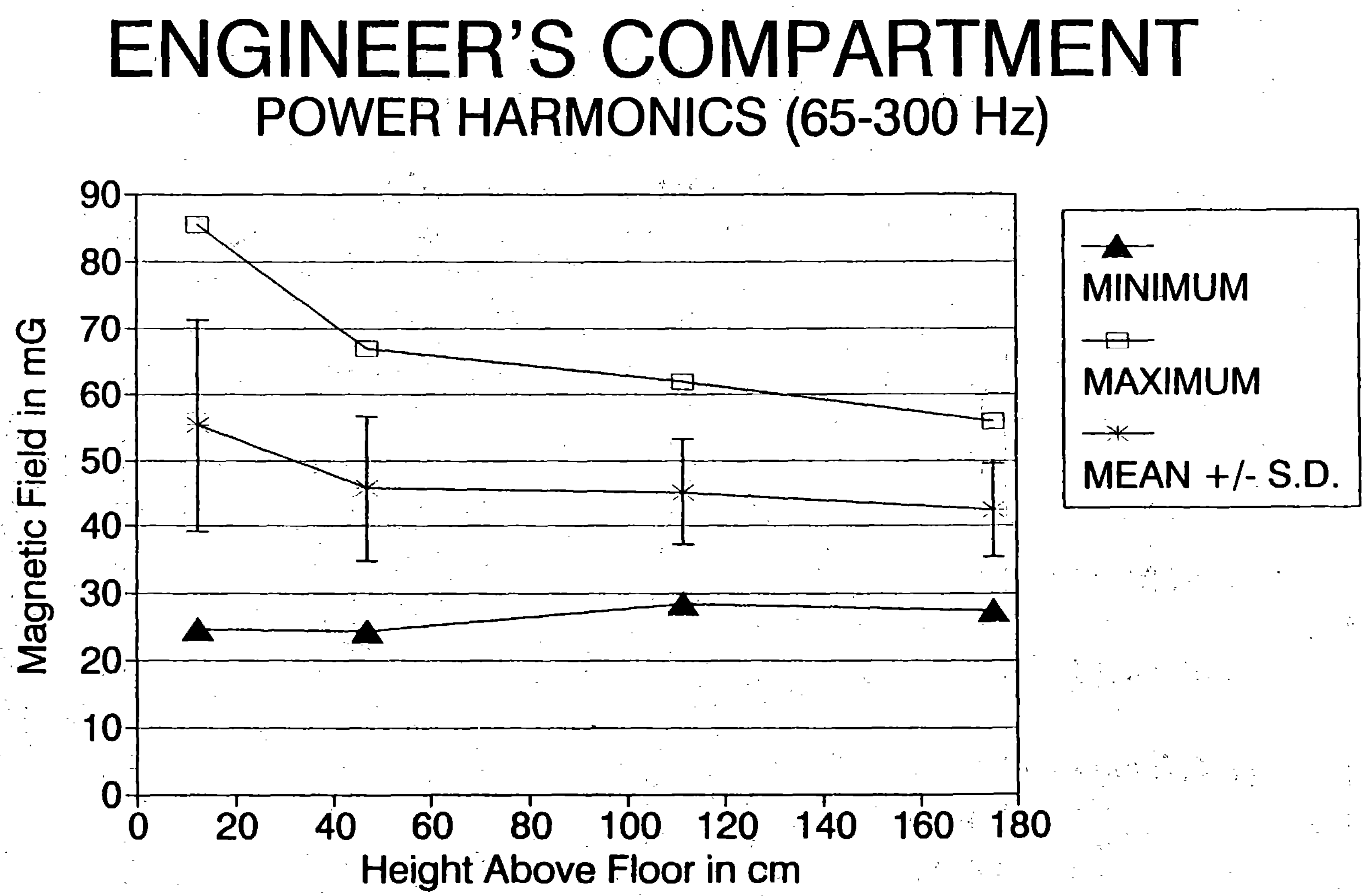


Figure 3-20 Minimum, average, and maximum time varying magnetic field in the power harmonics (65-300 Hz) band measured in the engineer's compartment of the TR07 vehicle for various heights above the floor.

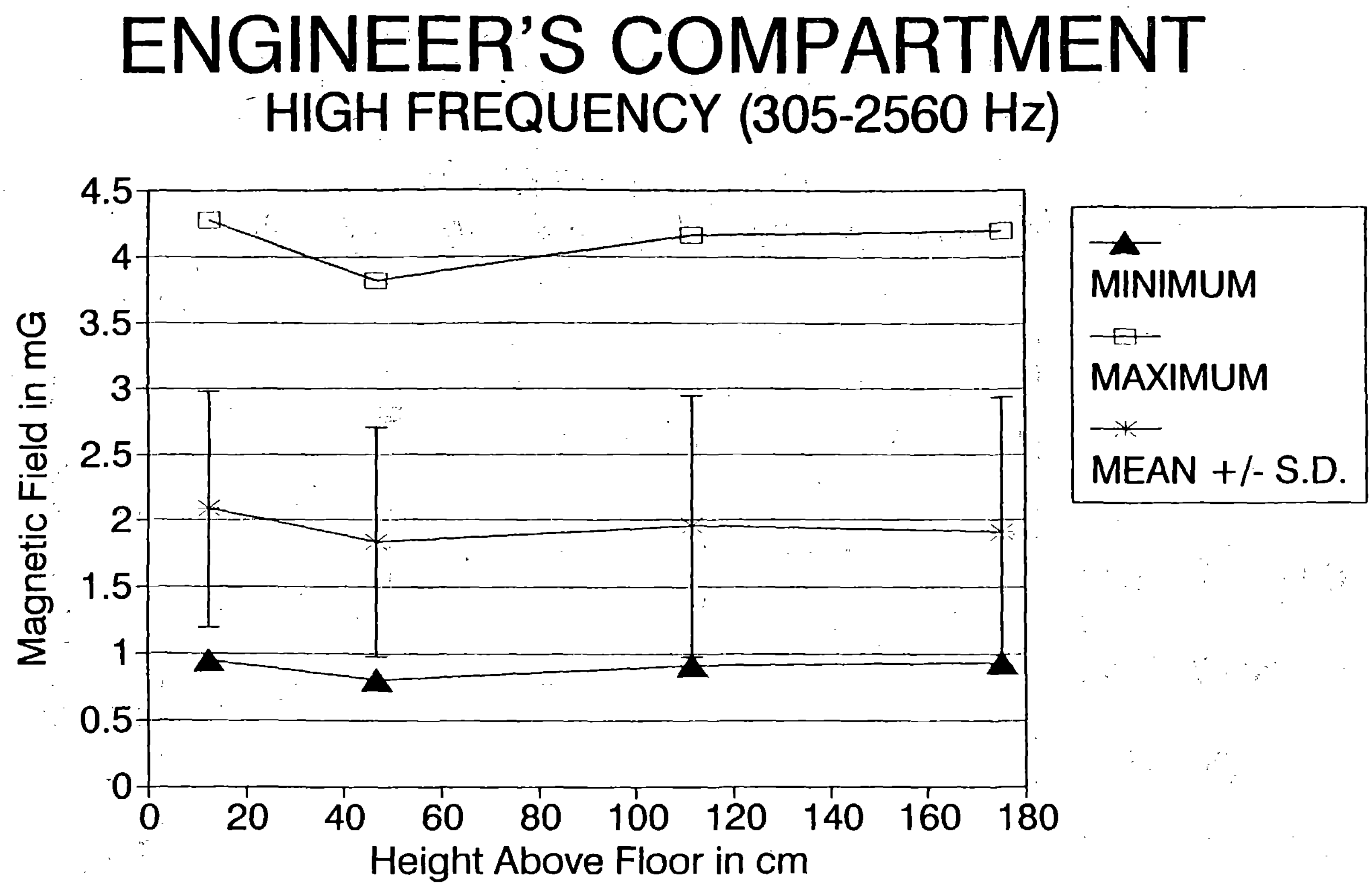


Figure 3-21 Minimum, average, and maximum time varying magnetic field in the high frequency (305-2560 Hz) band measured in the engineer's compartment of the TR07 vehicle for various heights above the floor.

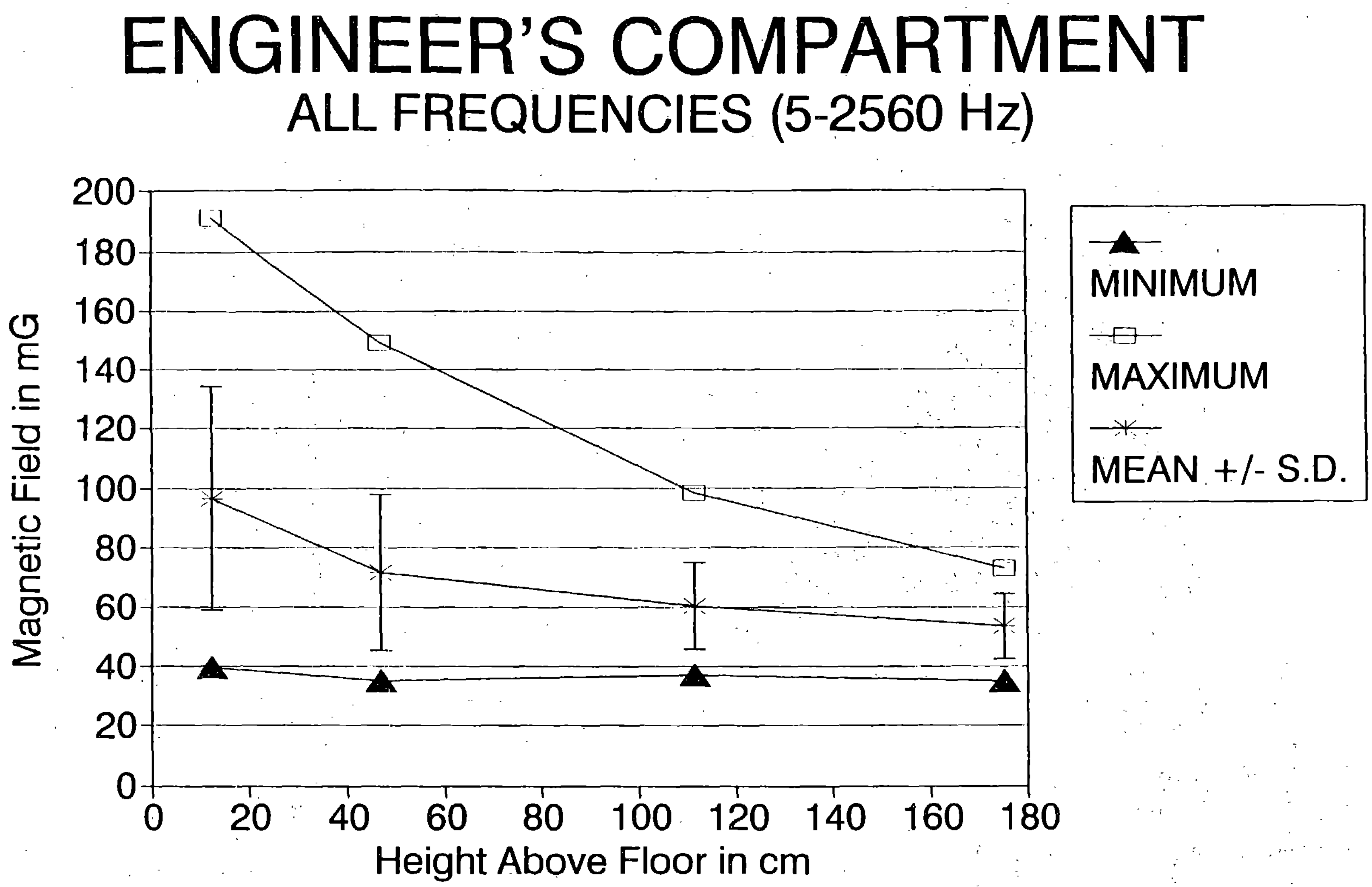


Figure 3-22 Minimum, average, and maximum time varying magnetic field in the frequency range from 5 to 2560 Hz measured in the engineer's compartment of the TR07 vehicle for various heights above the floor.

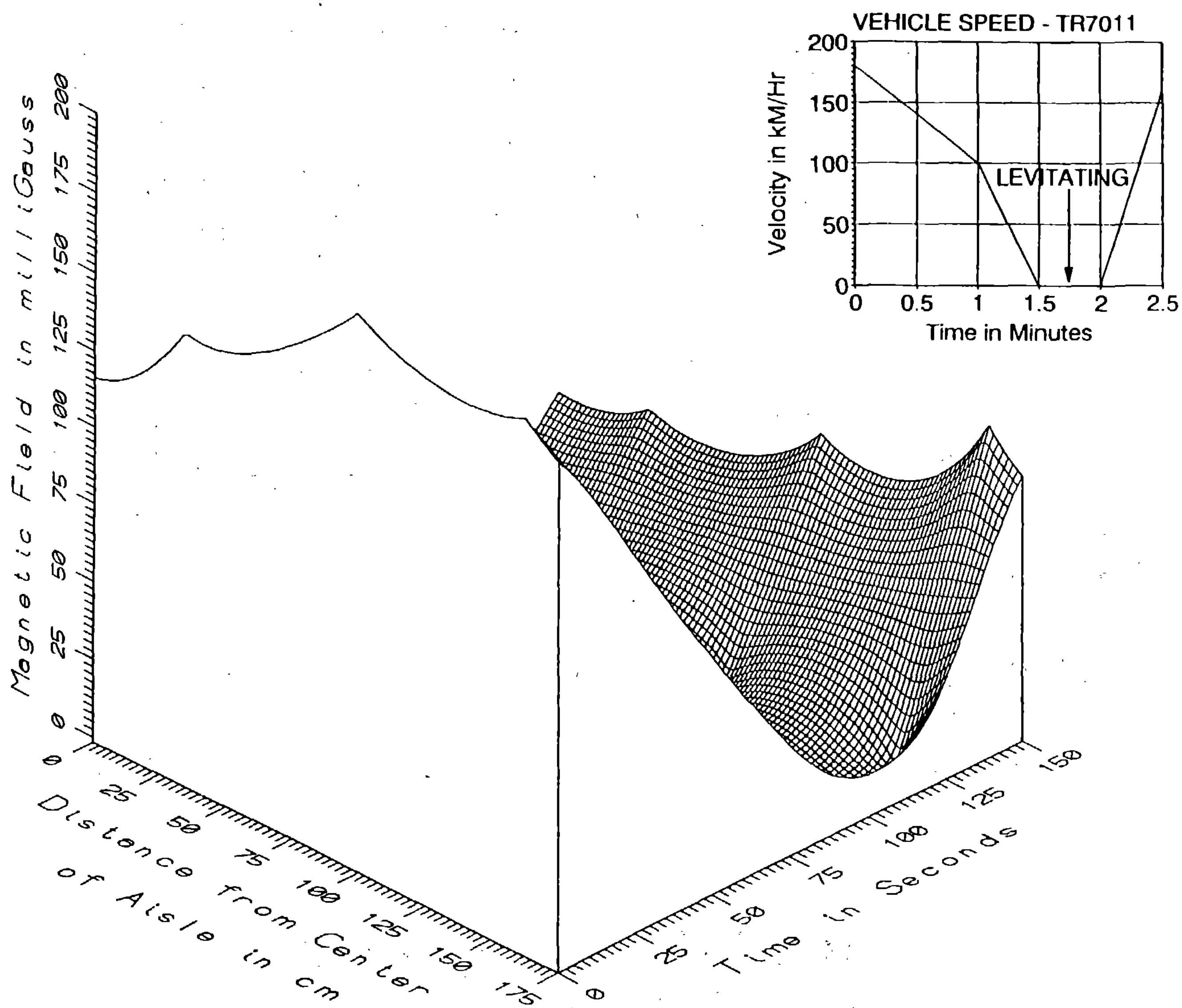


Figure 3-23 Field versus time and distance from center of aisle for AC field lateral profile measurements 5 cm above the floor at the center of the second car.

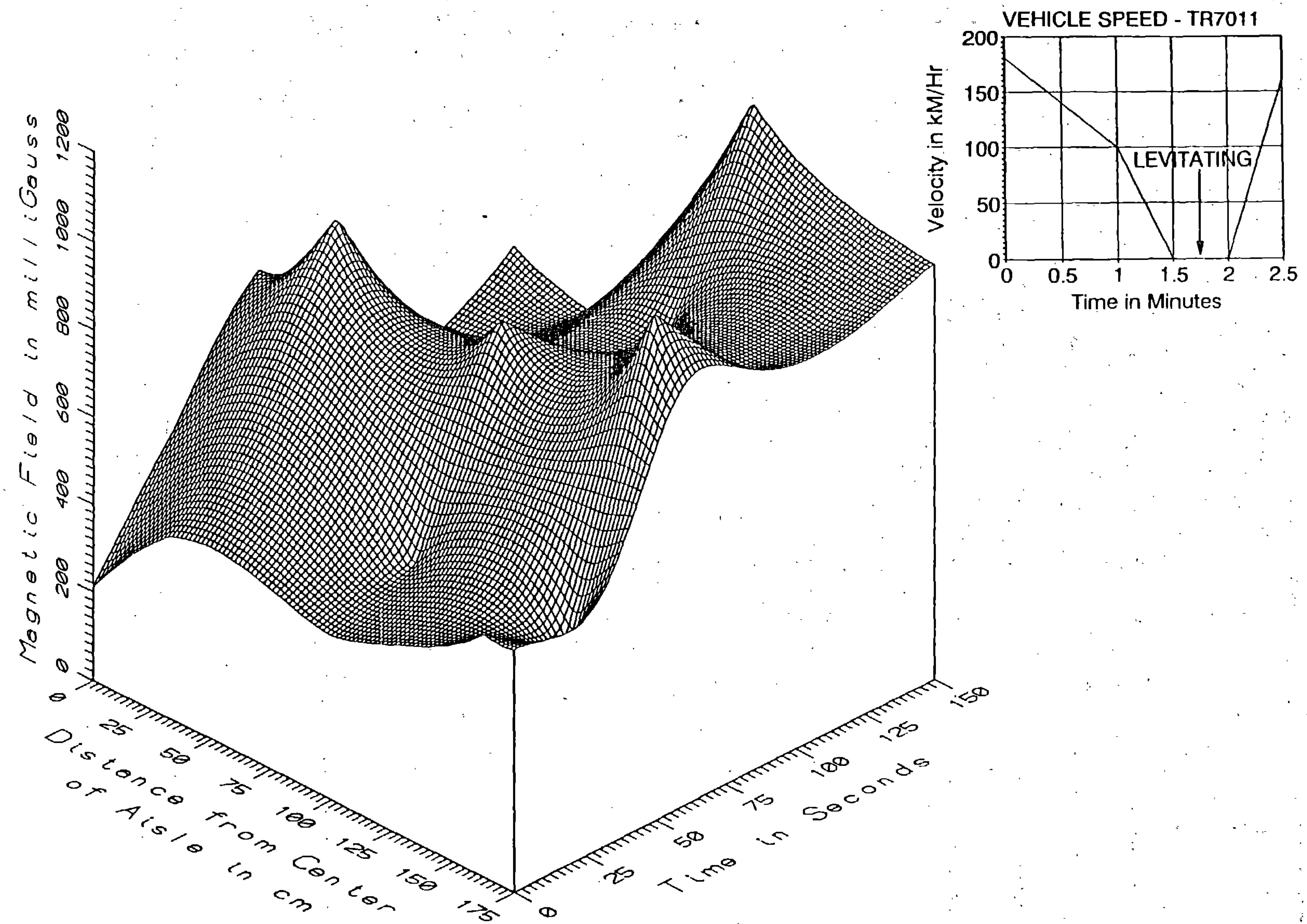


Figure 3-24 Field versus time and distance from the center of the aisle for static field lateral profile measurements 5 cm above the floor at the center of the second car.

During the lateral profile measurement, the TR07 vehicle came to a stop, levitated for a short period of time, then began moving again. Figures 3-25 and 3-26 show field versus frequency and time graphs of field data measured with coil-type and fluxgate-type sensors at a point approximately 5 cm above the floor at the edge of the aisle midway through the passenger compartment of the second car. These graphs show that almost all of the time-varying magnetic fields disappear during the interval from 1.5 to 2.0 minutes when the vehicle is stopped but levitating. Only a small 25 Hz component remains. The total static field during levitation at this point is just slightly less than the earth's geomagnetic field indicating some cancellation between earth's field and the static field produced by the vehicle. If the vehicle was stopped at a different location, or at different locations within the vehicle, mutual orientation of the locally produced static field and the geomagnetic field would likely be different and the total field produced by the two sources could be different than that indicated in Figure 3-26. Similar graphs for data taken at other locations within the vehicle are located in Appendix H. They show similar characteristics of disappearing time-varying fields when the vehicle levitates.

3.5 Comparison with Other Data

The report focuses on the analysis of the repetitive waveform data which was not included in the Interim Report. The field intensity values reported herein have more statistical validity than those contained in the Interim Report by virtue of the large number of repetitive measurements within the data sets described in this report. Nonetheless, this report neither detracts from nor supersedes analyses of specific field waveforms and frequency spectra contained in the Interim Report. On the contrary, it broadens and reaffirms the qualitative interpretations of the data presented earlier.

Personnel at Industrienanlagan-Betriebsgeseuschaft mbH (IABG) have conducted various measurements of magnetic field and electromagnetic interference (EMI) onboard and adjacent to the TR07 system and earlier magnetically levitated transportation systems. Unfortunately, most of these reports are confidential with restricted distribution. MVP was kind enough to provide copies of several pertinent reports of measurements onboard the TR06 and TR07 vehicles to the U.S. Federal Railroad Administration to assist in their assessment of the safety aspects of the Transrapid technology. Two of those reports [3,4] contain magnetic field measurement data related to the data collected in the measurement program reported herein. Since the authors wish to honor the confidentiality of the IABG data, none will be presented here. Rather, the authors will comment on the consistencies and inconsistencies of the two data sets.

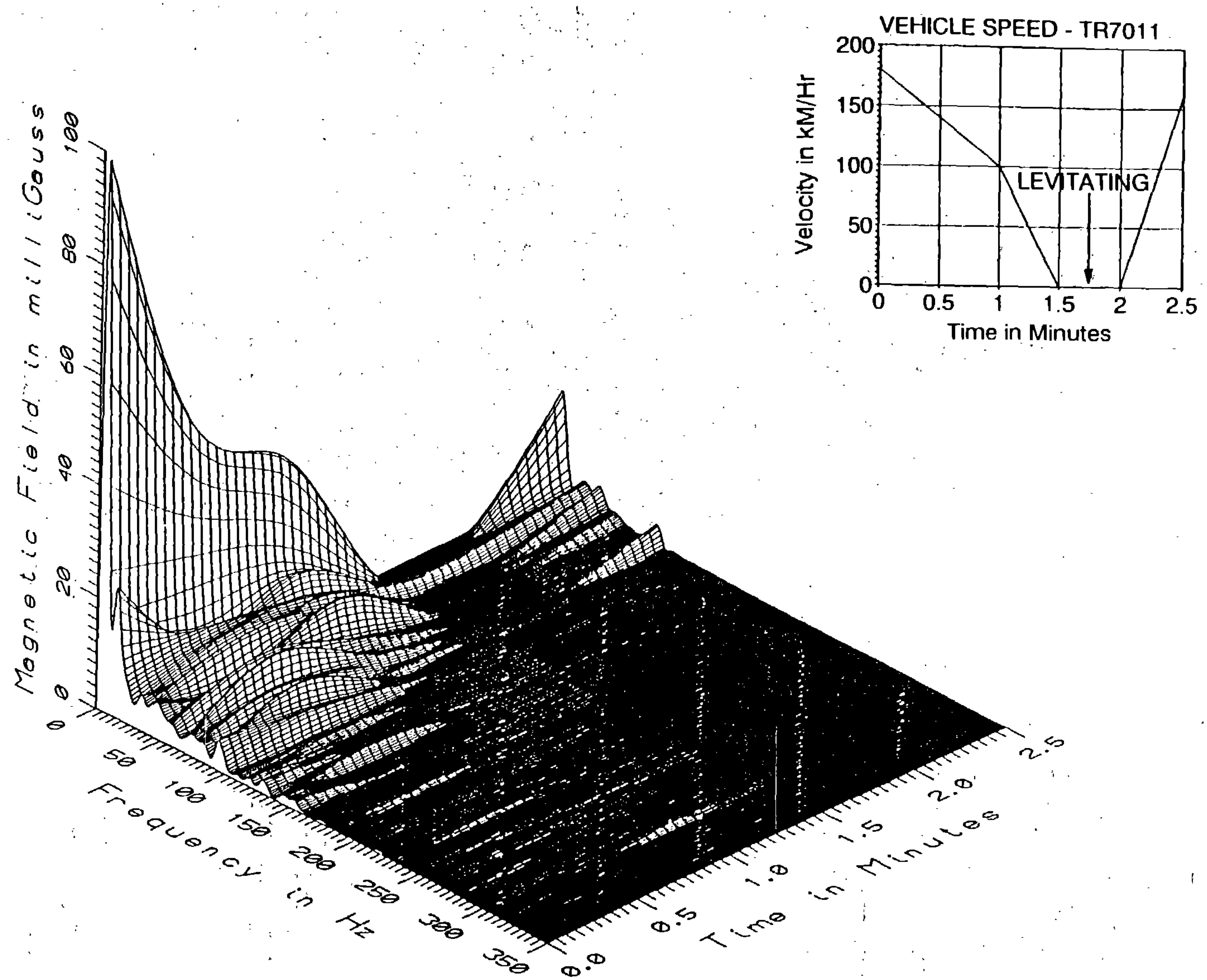


Figure 3-25 Time varying magnetic field as a function of time and frequency 5 cm above the floor at the edge of the aisle in the middle of Car 2.

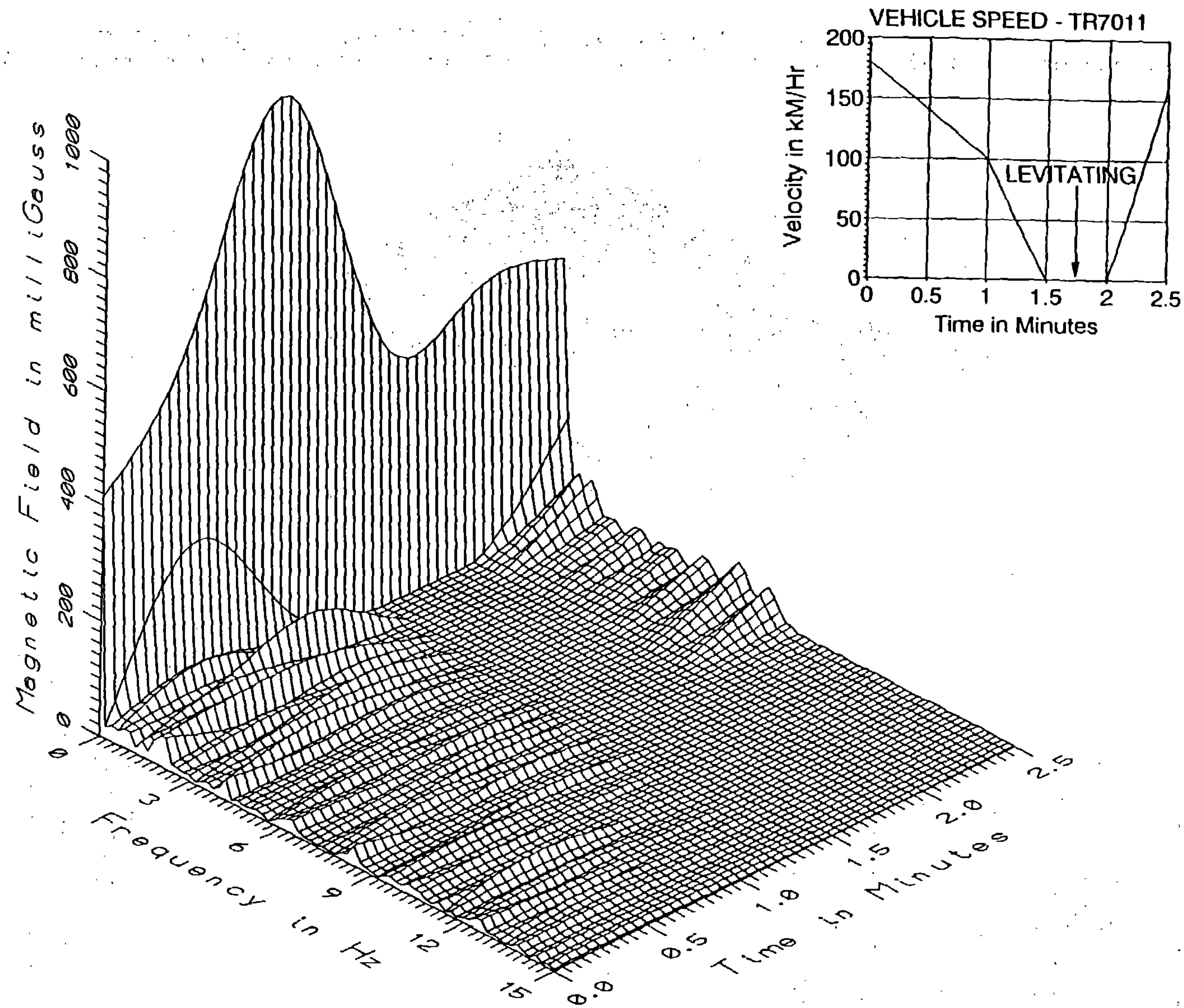


Figure 3-26 Static and low frequency magnetic field as a function of time and frequency 5 cm above the floor at the edge of the aisle in Car 2.

Available IABG data on the TR07 vehicle[3] consists of magnetic field measurements in the vehicle and EMI measurements outside the vehicle. The EMI measurements focus on frequencies above 10 kHz commonly used for communications and are therefore not relevant to the measurements reported herein. The reported static component magnetic field at floor level within the vehicle shows good agreement with the magnitudes reported here. This IABG report does not provide a spectral analysis of the time-varying components of the magnetic field in the vehicle. Furthermore, the waveform recordings (due to their slow time scale) do not provide sufficient detail for these authors to approximate frequency characteristics or compare time domain waveform information to their measurements.

IABG magnetic field measurements onboard the TR06 vehicle were apparently more comprehensive than their measurements on the TR07. The TR07 vehicle is of somewhat different construction than the earlier TR06 and there are differences in the magnet structures. Nevertheless, the levitation, guidance, and propulsion technology are basically the same. Hence there is valid reason to compare measurements on the two vehicles. Frequency spectra are reported[4] for a variety of operating conditions. Most spectra have the general characteristics indicated in Figure 3-27 which came from a document with uncontrolled circulation[5]. Figure 3-27 also contains an insert showing field levels at floor, seat, and seat back levels but there is no indication if these are static fields, time-varying fields, or total fields. The measurements reported for the TR06 compare to those measured by Electric Research and Management, Inc. in August 1990 in the following ways:

- Static fields at floor, seat, and seated head levels measured by Electric Research and Management, Inc. averaged 834 mG, 611 mG, and 634 mG, respectively (83 μT, 61 μT, and 63 μT). These include the geomagnetic field. The floor level measurement is comparable to that indicated in the insert within Figure 3-27, but the seat and seated head level fields are substantially higher than indicated in the figure insert. Correction for the geomagnetic field ($\approx$ 49 μT) would not account for the difference. Either the values indicated in the insert in Figure 3-27 are not static field values or static field levels were different for the TR06. Static field values reported for the TR07 measurements[3] are in good agreement with the values measured by Electric Research and Management, Inc.

- Total time-varying fields in the frequency range from 2.5 Hz to approximately 2 kHz measured by Electric Research and Management, Inc. in the passenger section of the TR07 were 96 mG, 52 mG, and 31 mG (9.8 μT, 5.2 μT, and 3.1 μT) at floor level, seat level and seated head level, respectively. The time-varying field level measured at floor level is substantially less than the value given in the insert in Figure 3-27, but the measured time-varying fields at the seat and head level are slightly larger.

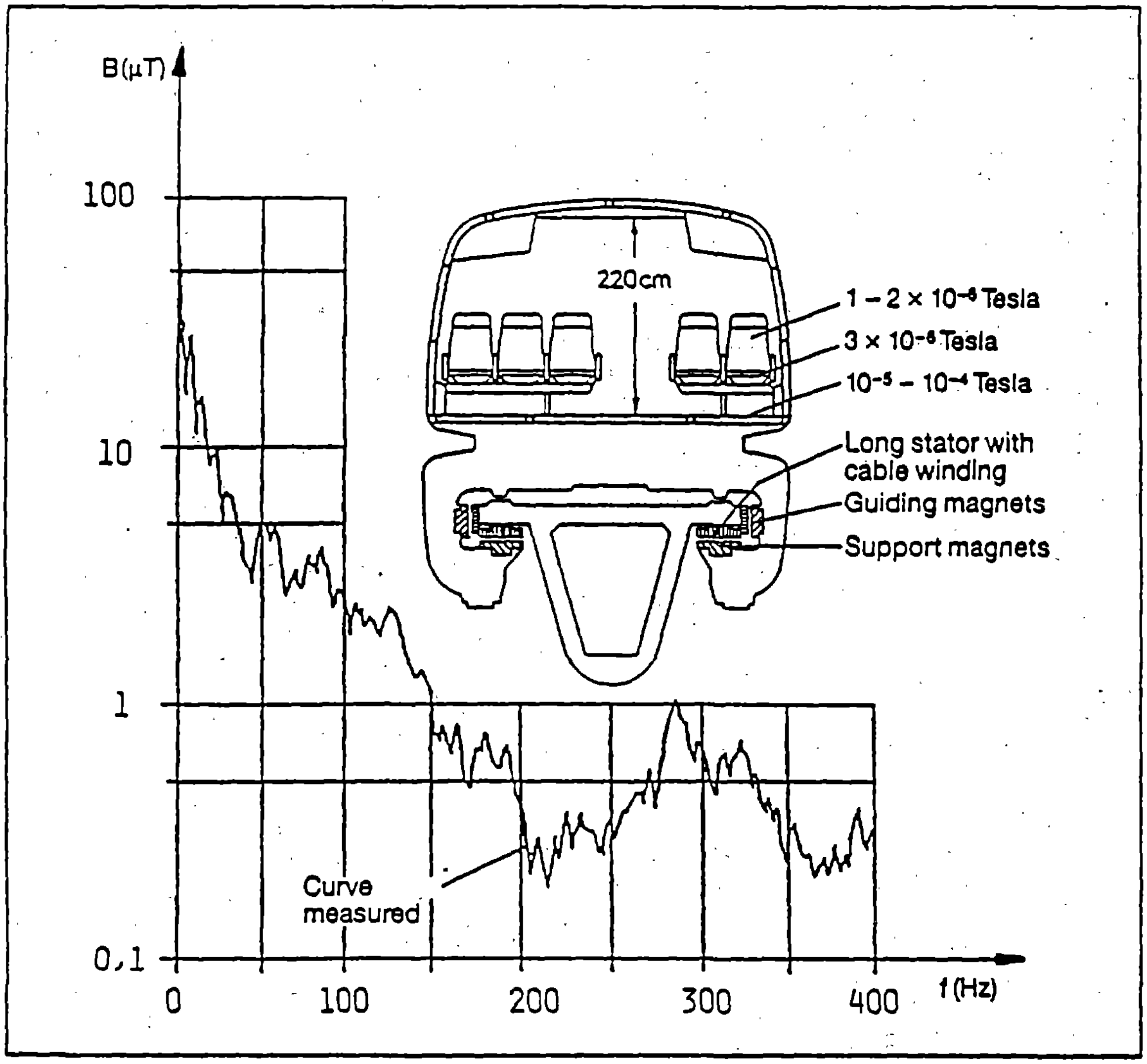


Figure 3-27 Magnetic flux density for a measuring point on the floor of the TR06 vehicle as a function of the frequency and its magnitude in the seating area of the passenger accommodation. - The Earth's magnetic field in comparison: about 5 x 10^{-5} Tesla.

- Frequency spectra reported by IABG did not include a statement about the measurement bandwidth and therefore cannot be interpreted quantitatively.

- The magnetic field frequency spectra reported by IABG are qualitatively similar to those measured by Electric Research and Management, Inc. except the IABG spectra tend to be smoother. That difference may have arisen from use of a wider bandwidth or averaging over time. Neither parameter (bandwidth or sample time) are explicitly stated in the IABG report[4].

- The IABG report indicates that the major source of magnetic fields within the TR06 vehicle is not the magnets but the power cables to the magnets. The Electric Research and Management, Inc. measurements neither confirm nor contradict that conclusion since they indicate only that the fields come predominantly from a source beneath the floor.

Data from the Electric Research and Management, Inc. measurements on the TR07 are generally consistent with IABG measurement data from the TR06 to the extent that the IABG report the specific information needed for the comparison. It is impossible to determine if the apparent inconsistencies result from differences between the TR06 and TR07 technology or differences in measurement approach which are not completely reported. None of the comparisons are conclusively contradictory hence the IABG data should be accepted at face value.

During a visit by Volpe National Transportation Systems Center and Federal Railroad Administration to the Emsland test facility on October 17, 1991, magnetic field measurements were also made to provide comparison data to the measurements described in this report. Measurements were made with a model EMDEX-II Electric and Magnetic Field Digital Exposure Meter (EMDEX) manufactured by ENERTECH Consultants of Santa Clara County, Inc. The instrument was worn at belt level within the TR07 vehicle. Those data were provided to Electric Research and Management, Inc. for comparison with their measurements. Figure 3-28 presents the data indicating magnetic field strength as a function of time. Also plotted on Figure 3-28 is a profile of the approximate vehicle speed. It is immediately obvious that the temporal variability of the magnetic field intensity recorded by the EMDEX is large and apparently not correlated with vehicle speed. These observations are consistent with the more extensive data collected in August 1990.

Since the EMDEX does not measure the frequency characteristics of the field, these data can confirm neither the above reported frequency spectra nor the variability of those spectra in response to vehicle speed. Taken at face value, these EMDEX appear to contradict the earlier measurements of time-varying field intensity

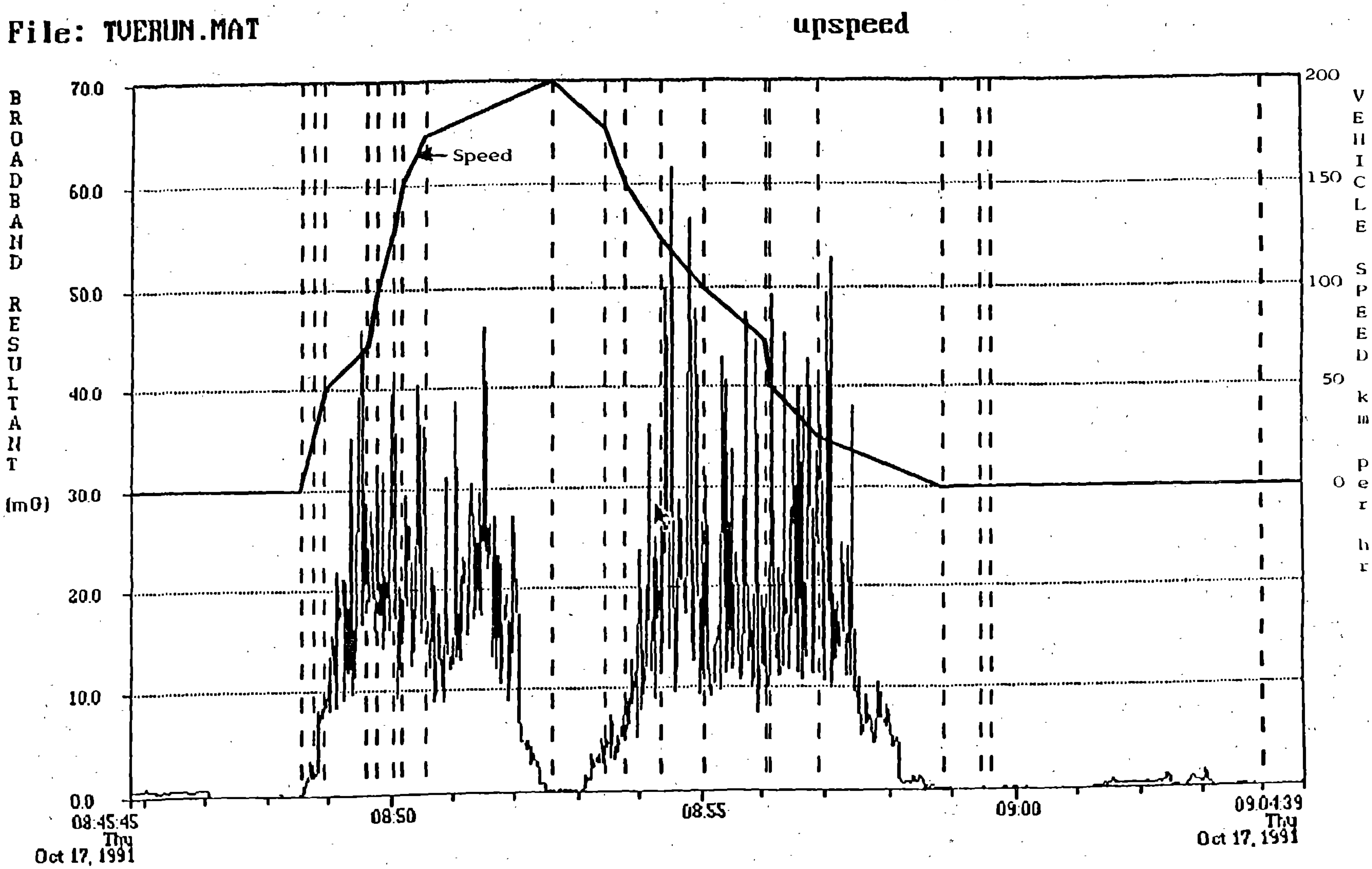


Figure 3-28 Magnetic field on the TR07 vehicle measured with an EMDEX meter worn at waist level and approximate vehicle speed during the measurements.

summarized in Table 3-2, but that is not the case. The EMDEX meter has a 3 dB bandwidth from approximately 40 Hz to approximately 1000 Hz. It is insensitive to magnetic fields at frequencies outside that band.. Consequently, it fails to record the strongest components of the time-varying magnetic field onboard the TR07 vehicle which occur at frequencies below 40 Hz. One can determine the average magnetic field measured during the August 1990 tests which falls within the limited bandwidth of the EMDEX meter by computing the root-sum-square of the average fields in the 45-60, 65-300, and 300-2560 bands given in Table 3-2. That calculation yields a seat level mean field level of 20.0 mG. Examining Figure 3-28, one finds that when corrected for instrument bandwidth, the EMDEX data and the Electric Research and Management, Inc. data agree well. Unfortunately, the EMDEX data can neither confirm nor contradict the August 1990 measurements of fields below 40 Hz since the EMDEX meter is unresponsive at those frequencies.

4.0 MEASUREMENTS ALONG THE GUIDEWAY

Measurements of magnetic fields produced by the operating TR07 System were made beneath and at increasing distances from the guideway at three locations as described in detail in Sections 4.2 through 4.4 of the Interim Report[2]. Those measurements included repetitive waveform measurements which have been analyzed as described in Section 2 above. Those results are presented here and compared to the interim results presented in the earlier report. Additional special measurements of the magnetic fields near the guideway for a stationary but levitating TR07 vehicle were made at one location outside the maintenance building.

4.1 Measurement Locations

Nine sets of repetitive waveform measurements were made at three locations where the guideway construction differed. Six data sets were measured beneath and near the high steel guideway in the vicinity of the control center as described in Section 4.2 and Appendix C of the Interim Report. All sensors were mounted 1 meter above the ground. Three sensors were placed along a line perpendicular to the guideway at distances of 0, 3, and 10 meters from centerline to record the rate at which the field attenuates at increasing distances from the right-of-way. Three sensors were located at 25 meter increments along the guideway at 3 meters from centerline to quantify the variation in field conditions along the guideway and increase the probability of obtaining a measurement with the vehicle passing directly past a sensor.

One set of repetitive waveform data was collected beneath and adjacent to the low concrete guideway in the south loop. The layout of sensors is detailed in Section 4.3 and Appendix D of the Interim Report. This is similar to the array pattern used at the high steel guideway measurement location except that the longitudinal profile is measured 4 meters from centerline.

The third group of guideway measurements is two data sets obtained beneath the high concrete guideway at the passenger station. Three sensors were located 1 meter above ground at distances of 0, 3, and 9 meters from centerline of the guideway as described in Section 3.4 and Appendix E of the Interim Report.

The pertinent information about the data obtained in these nine sets of repetitive waveform recordings is provided in Table 4-1. Pseudo-three-dimensional graphs of the magnetic flux density versus frequency and time and the graphs of flux density versus distance from centerline of the guideway and time are provided in Appendices I through Q of this report as specified in Table 4-1.

A special set of measurements were conducted to quantify the magnetic field conditions near a stationary but levitating TR07 vehicle. These measurements, which were made on the low guideway

TABLE 4-1

SUMMARY OF REPETITIVE WAVEFORM MEASUREMENTS
NEAR THE TRANSRAPID TR07 GUIDEWAY

DATA SET NUMBER AND LOCATION	APPENDIX CONTAINING DATA	DATE AND TIME	NUMBER OF VEHICLE PASSES	NUMBER OF SAMPLES	INTERVAL BETWEEN SAMPLES
TR7012 HIGH STEEL GUIDEWAY SETUP #18	I	AUG 8 10:42- 10:47	1	6	≈6 SEC
TR7013 HIGH STEEL GUIDEWAY SETUP #18	J	AUG 8 10:50- 11:12	4	221	≈6 SEC
TR7014 HIGH STEEL GUIDEWAY SETUP #18	K	AUG 8 12:26- 12:37	2	116	≈6 SEC
TR7015 HIGH STEEL GUIDEWAY SETUP #18	L	AUG 8 12:39- 12:40	1	13	≈6 SEC
TR7017 HIGH STEEL GUIDEWAY SETUP #18	M	AUG 8 12:46- 12:54	1	16	≈6 SEC
TR7018 HIGH STEEL GUIDEWAY SETUP #19	N	AUG 8 12:56- 13:01	0	52	≈6 SEC

TABLE 4-1 CONTINUED

SUMMARY OF REPETITIVE WAVEFORM MEASUREMENTS NEAR THE TRANSRAPID TR07 GUIDEWAY

DATA SET NUMBER AND LOCATION	APPENDIX CONTAINING DATA	DATE AND TIME	NUMBER OF VEHICLE PASSES	NUMBER OF SAMPLES	INTERVAL BETWEEN SAMPLES
TR7019 LOW CONCRETE GUIDEWAY IN SOUTH LOOP, SETUP #20	O	AUG 8 16:00- 16:20	2	194	≈6 SEC
TR7020 HIGH CONCRETE GUIDEWAY AT THE STATION, SETUP #21	P	AUG 9 10:26- 10:46	4	229	≈6 SEC
TR7021 HIGH CONCRETE GUIDEWAY AT THE STATION, SETUP #21	Q	AUG 9 10:51- 11:10	4	229	≈6 SEC
TR7025 LOW CONCRETE GUIDEWAY AT THE MAINTENANCE BUILDING, SETUP #24, VEHICLE PARKED	U	AUG 9 17:31- 17:32	N/A	10	≈6 SEC
TR7026 LOW CONCRETE GUIDEWAY AT MAINTENANCE BUILDING, SETUP #24, VEHICLE LEVITATING	V	AUG 9 18:06- 18:10	N/A	39	≈6 SEC

just outside the maintenance building, consisted of two sets of repetitive waveform measurements, one with the vehicle parked on the guideway to determine ambient background conditions; and the other with the vehicle levitating. Detailed information regarding this test and sensor locations can be found in Section 4.5.3 and Appendix H of the Interim Report. Pertinent data on sample rate, number of samples, etc. are given in Table 4-1.

4.2 AC Field Measurements

The various data sets obtained near the three sections of guideway are similar. Figures 4-1 through 4-3 show the ac magnetic flux density versus frequency and time for measurements under the high steel guideway at increasing distances from centerline from Appendix J. They are typical of other measurements along the guideway. They clearly illustrate that there is no significant field from the guideway except for those brief intervals when that section is energized to power a passing vehicle. The background fields (a 50 Hz component from the nearby power system and a 380 Hz component frequently encountered of unknown origin) are approximately of equal intensity at all distances from the guideway, indicating that the guideway is not the source.

When the guideway is energized and a vehicle is passing, a magnetic field appears. The field decreases with amplitude as the distance from the guideway increases, confirming that the guideway is the source. Figure 4-4 is a field versus time and distance plot emphasizing this fact. Note that the frequency spectrum differs from one train pass to the next in Figures 4-1 through 4-3, but that for each pass the spectrum is essentially identical at all distances from the guideway.

Figures 4-2, 4-5, and 4-6 show plots of field strength versus time and frequency at three locations, each three meters from the guideway, but at 25 meter increments along the guideway. The measurements were made simultaneously yet both the intensity and frequency distribution characteristics of the field vary by location. This difference is apparently due to the specific location of the vehicle during the 0.2 second interval that the discrete waveforms were recorded. Since repetitive waveform samples can be recorded no more frequently than about every 5 to 6 seconds with the version of the *MultiWave*™ recorder used for these tests, and since the speed of the TR07 vehicle is very large, performing a measurement while the vehicle is centered above the probe is unlikely. From Figures 4-2, 4-5, and 4-6, it appears as though at the first pass, the vehicle was near or just south of the southern-most probe; during the second pass, was between the southern-most and center probe; and for the third and fourth passes, was near or slightly north of the northern-most probe at the exact instant that one of the repetitive waveform samples was taken.

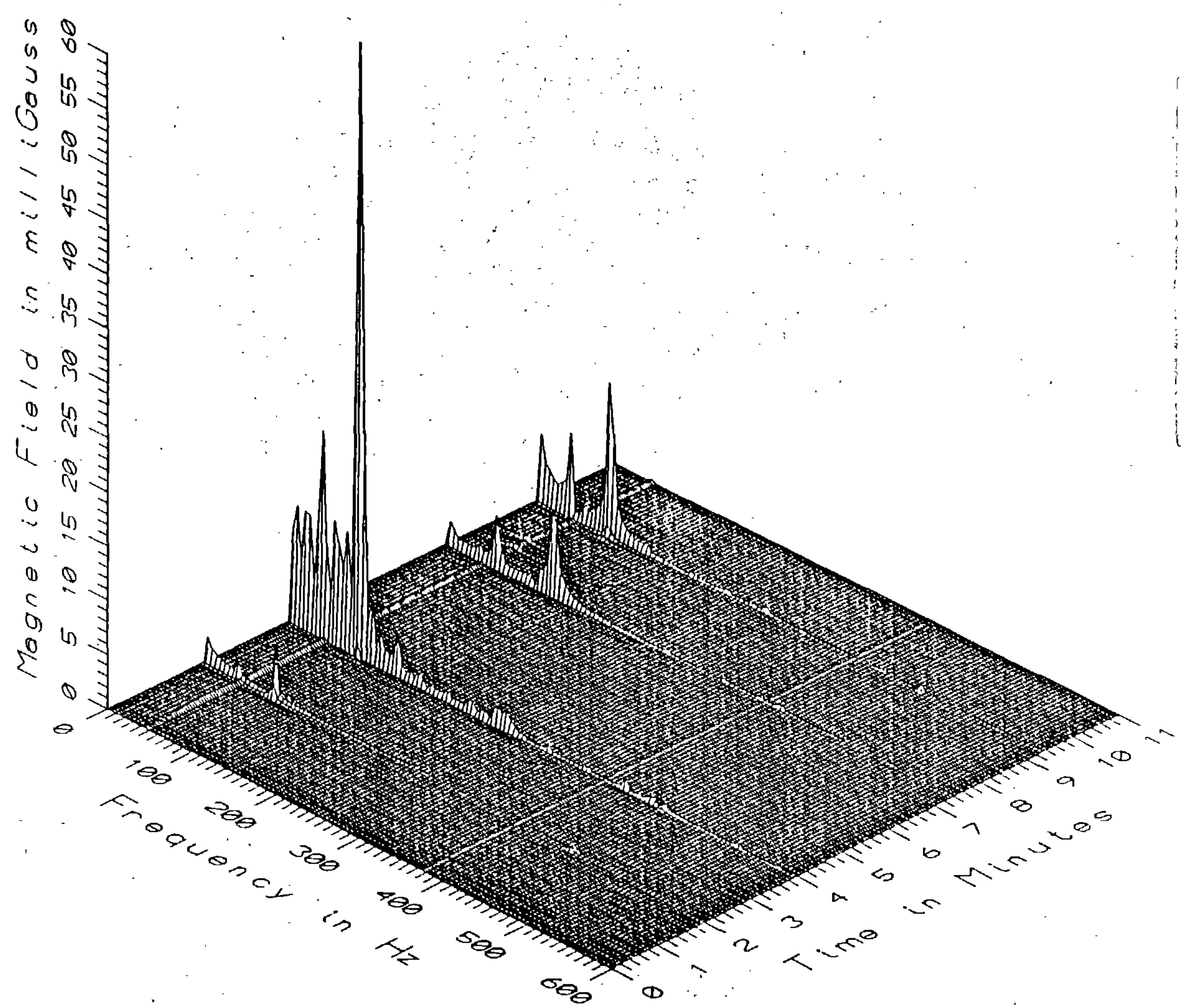


Figure 4-1 Typical field versus time and frequency plot for measurements beneath the guideway.

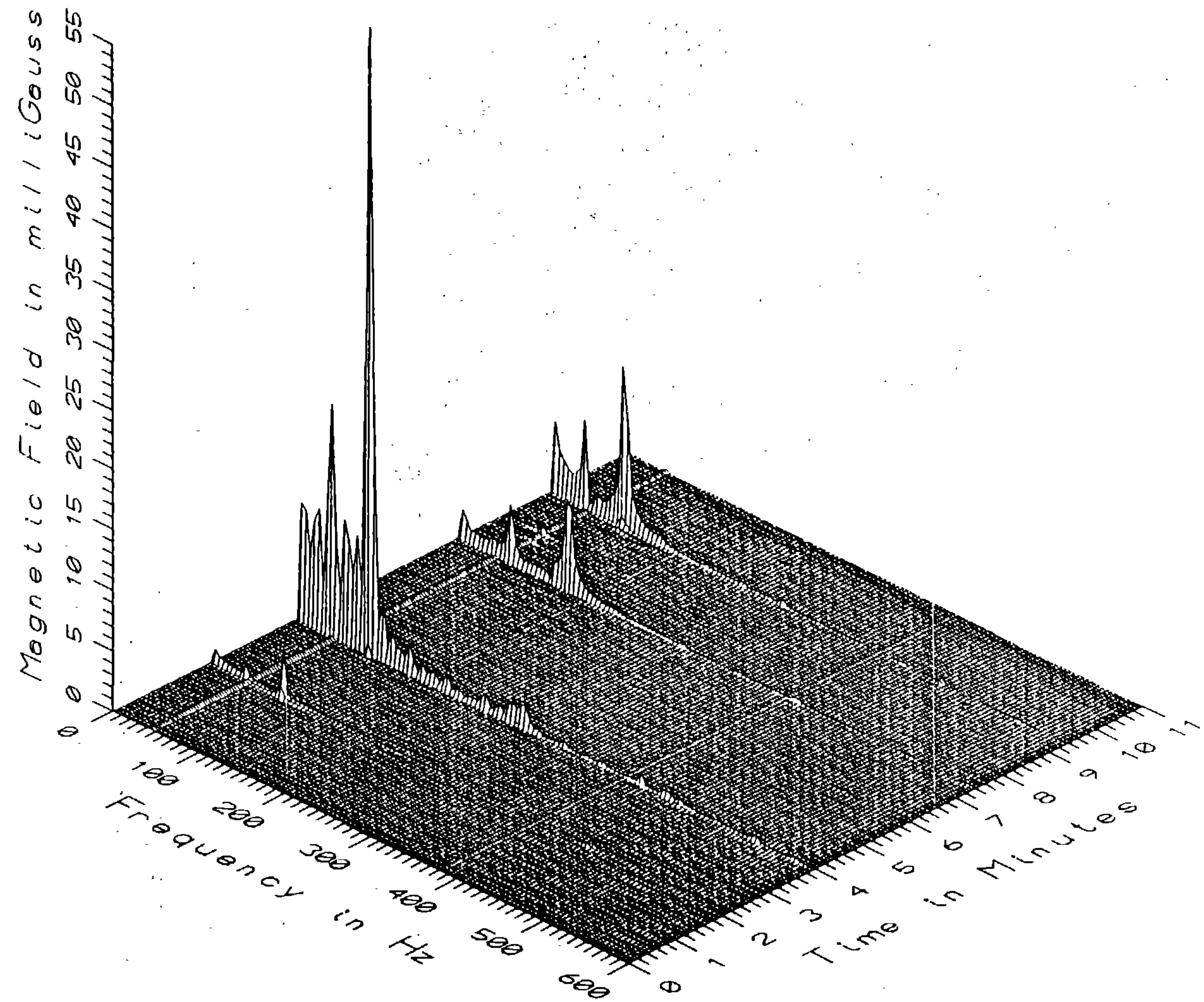


Figure 4-2 Typical field versus time and frequency plot for measurements 3 m from centerline of the guideway.

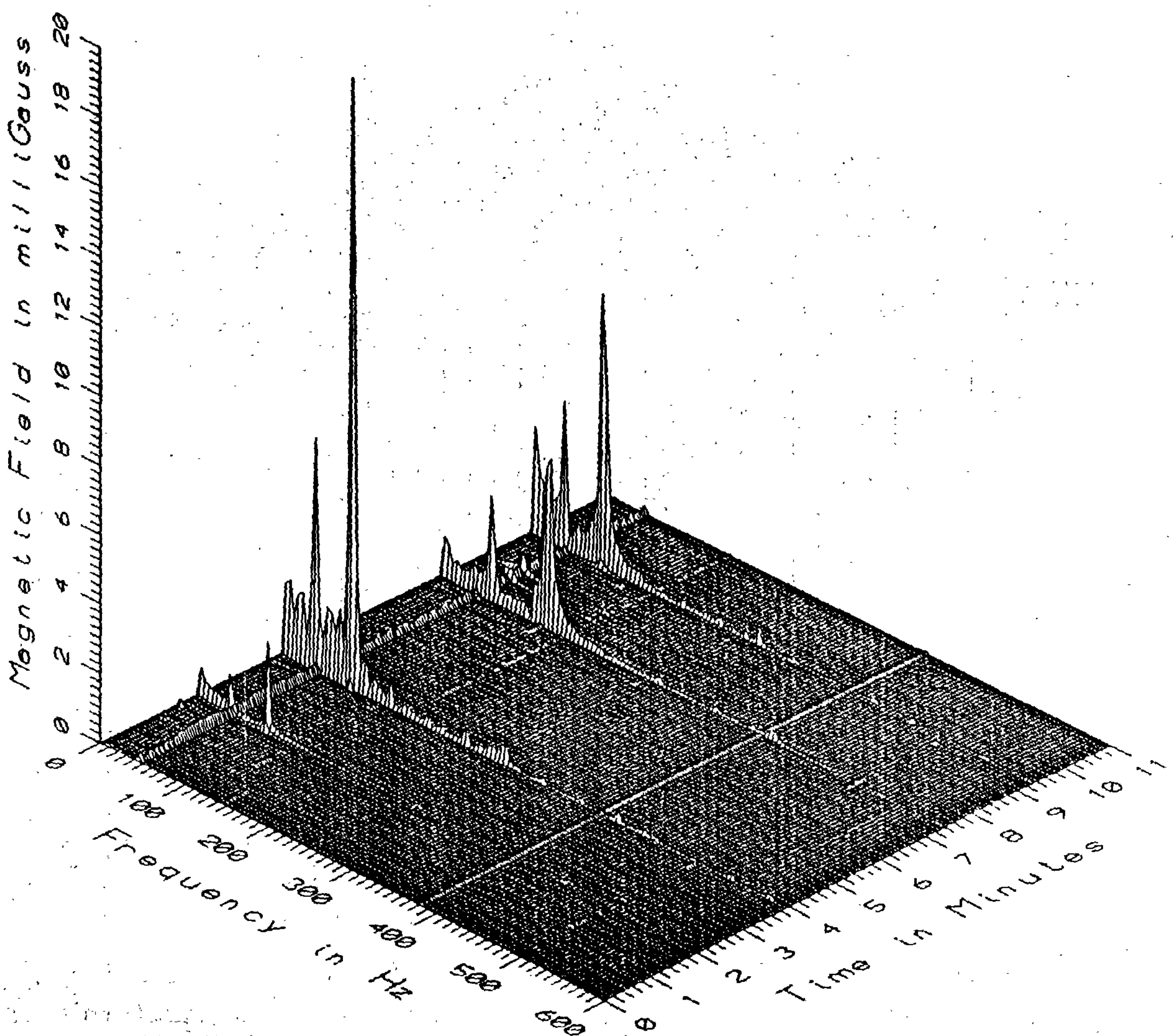


Figure 4-3 Typical field versus time and frequency plot for measurements 10 m from centerline of the guideway.

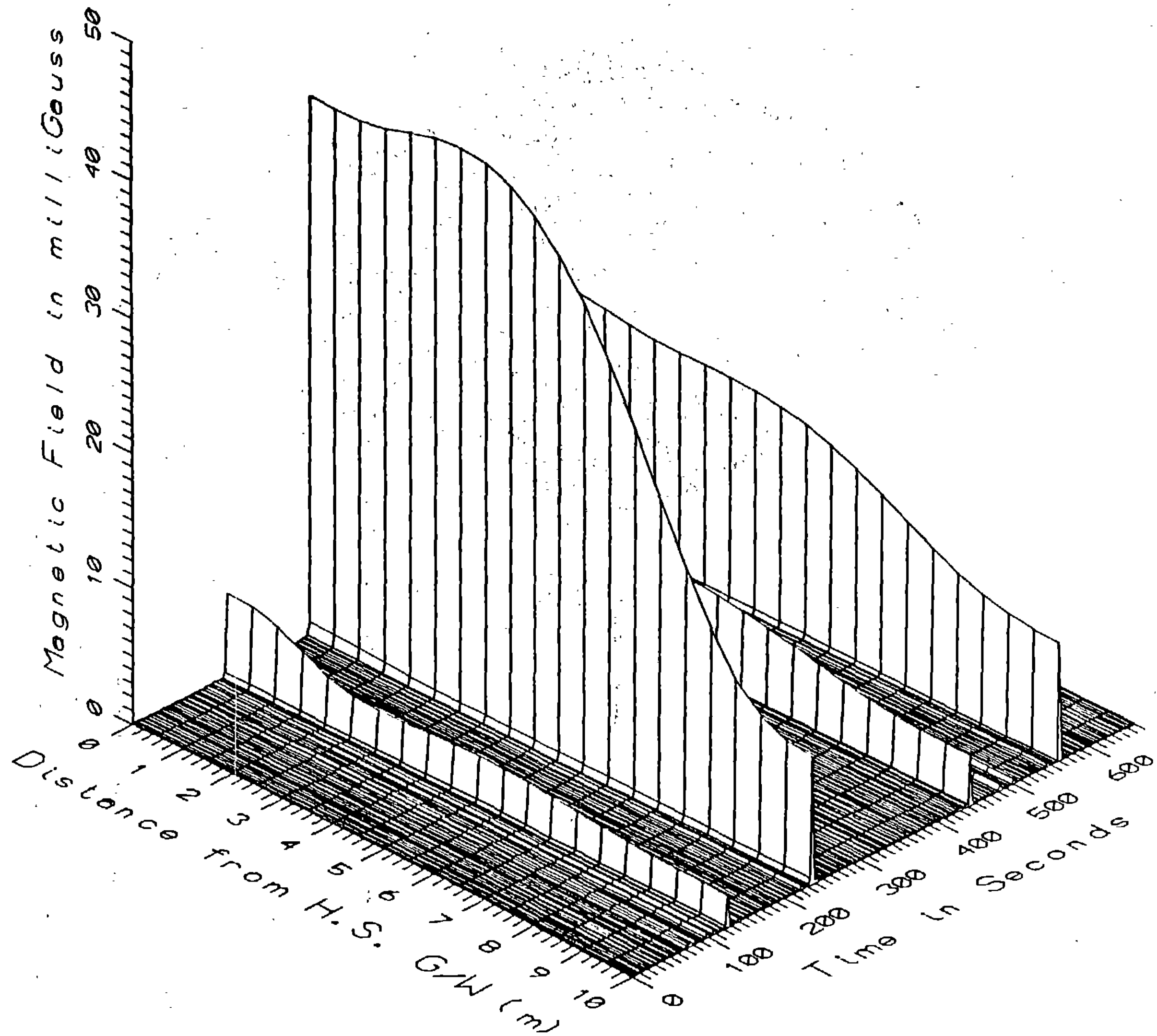


Figure 4-4 Typical field versus time and distance from the guideway plot for the low frequency (5-45 Hz) band showing field attenuation away from the guideway and lack of significant field when the guideway is not energized.

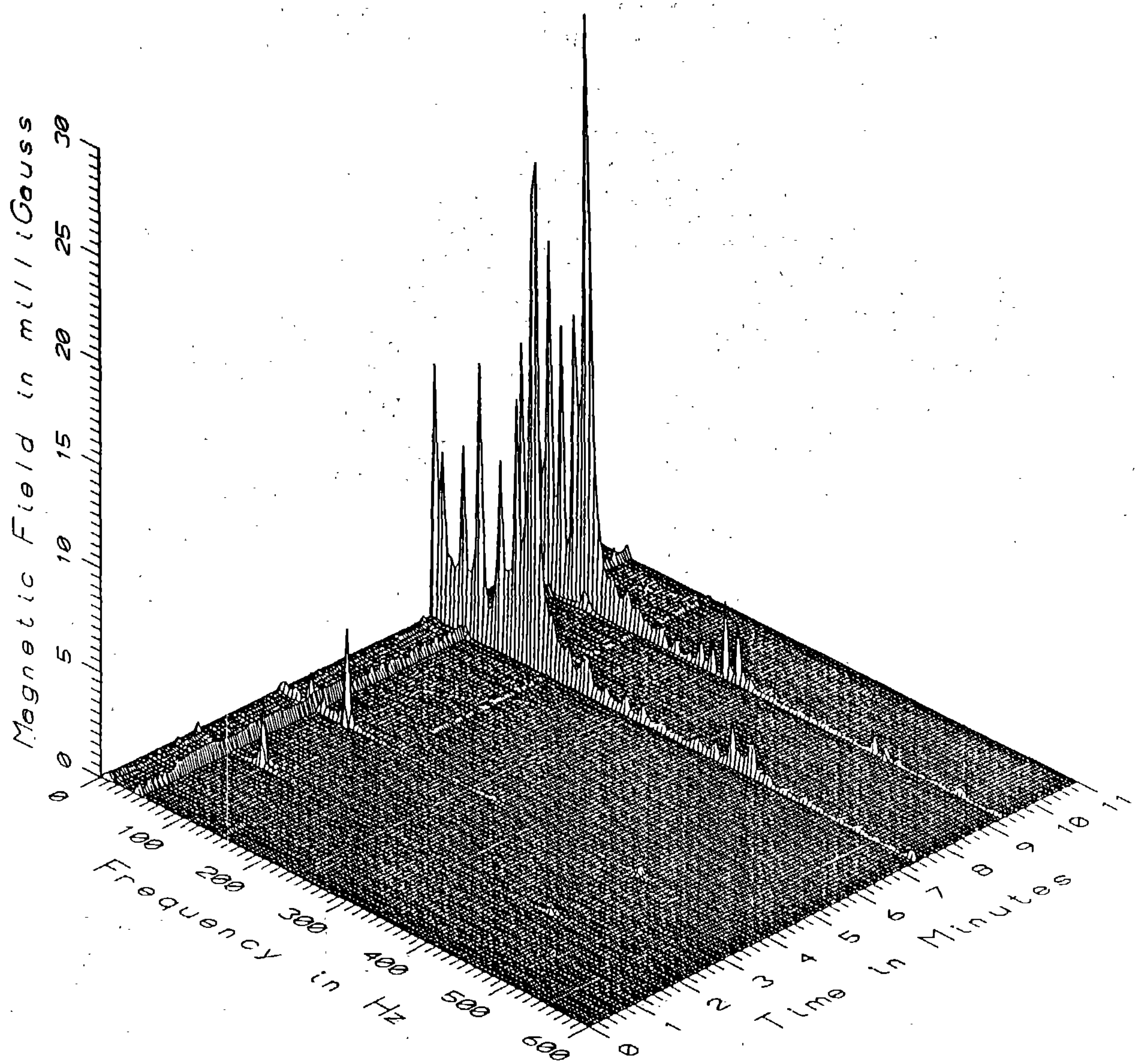


Figure 4-5 Typical field versus time and frequency plot three meters from centerline of the guideway at a point 25 meters north of the point for which the data in Figure 4-2 was recorded.

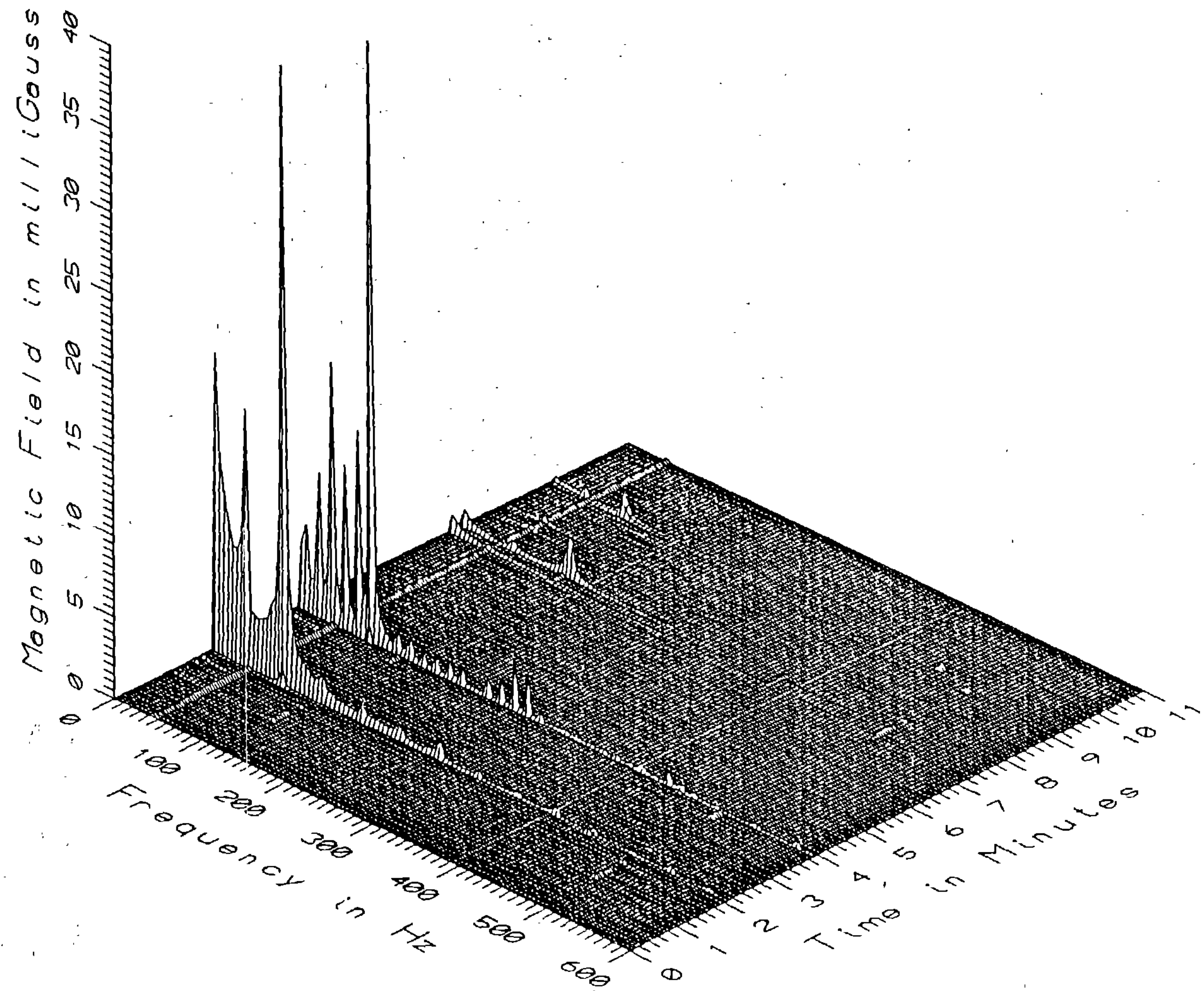


Figure 4-6 Typical field versus time and frequency plot three meters from centerline of the guideway at a point 25 meters south of the point for which the data in Figure 4-2 was recorded.

4.3 Static Field Measurements

The static field measurements revealed no significant effect of the passing TR07 vehicle, nor should they have been expected to show such an effect. The vehicle passes the measurement point so rapidly that any field which is static with regard to the vehicle's frame of reference is dynamic with regard to stationary measurements along the guideway. Figure 4-7 shows a field versus time and frequency plot of data collected beneath the high steel guideway using a fluxgate sensor. This data, like the ac field data described above comes from Appendix J. It is typical of similar plots of repetitive waveform data from fluxgate sensors at all locations near all three types of guideway. This figure confirms that the static field is essentially unchanged by the four passes of the TR07 vehicle that occurred during this measurement. Some low frequency time-varying fields were recorded for the second and third pass of the vehicle. Looking closely at the magnitude of the static field over time, one can detect a very slight lowering of the field at the first and third passes of the vehicle and increase in the field after the second and fourth passes. This is apparently due to a small residual magnetism remaining in the guideway after the vehicle passes. Presumably, the residual magnetism adds to the geomagnetic field after the vehicle passes in one direction but subtracts from the geomagnetic field after the vehicle passes headed the other direction. This phenomena will be more apparent in some of the data collected at the passenger station reported in the next section.

Spatial distribution of the static field beneath the high steel guideway is shown in Figure 4-8. It too was taken from Appendix J for consistency. The lack of temporal variability indicates that active operation of the guideway has no significant effect on the static magnetic field in the vicinity. However, the static field directly beneath the guideway is higher than the geomagnetic field further removed. This suggests that the presence of the iron in the guideway enhances the geomagnetic field beneath it. Geomagnetic field enhancement was also seen beneath the high and low concrete guideways but to a lesser extent as demonstrated by the data in Appendices O, P, and Q.

4.4 Summary Data

After collapsing the field by time and frequency data into frequency bands for spatial analysis, the mean and standard deviation and coefficient of variation of the field was calculated at each location and within each frequency band. Those results along with the minimum values of the field are presented in Tables 4-2, 4-3, and 4-4 for the high steel guideway, low concrete guideway and high concrete guideway respectively. Data from set number TR7018 are not included in the summary because that set contains only background field data when no trains are passing.

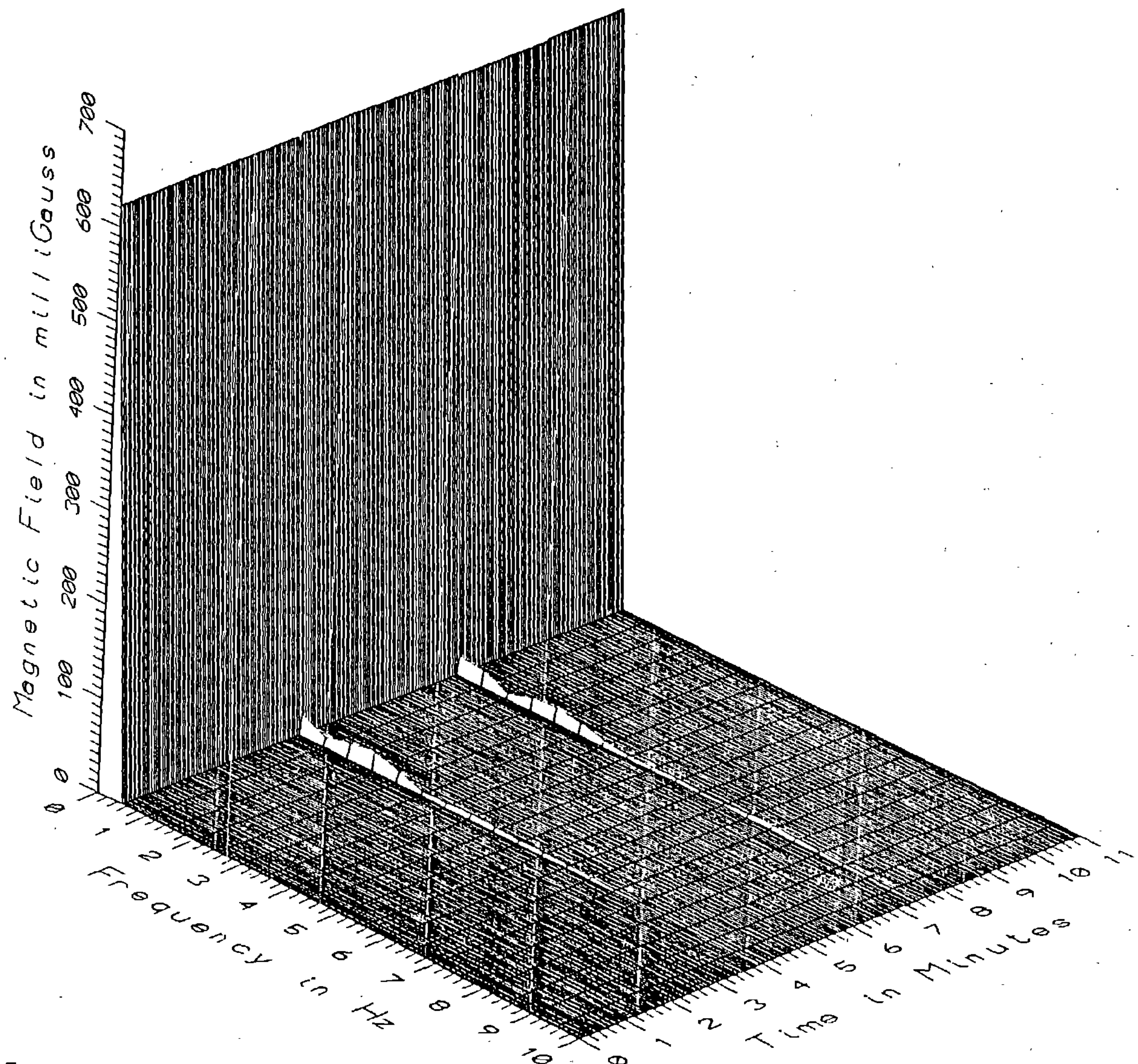


Figure 4-7 Typical field versus time and frequency plot for static and low frequency measurements beneath or near the guideway.

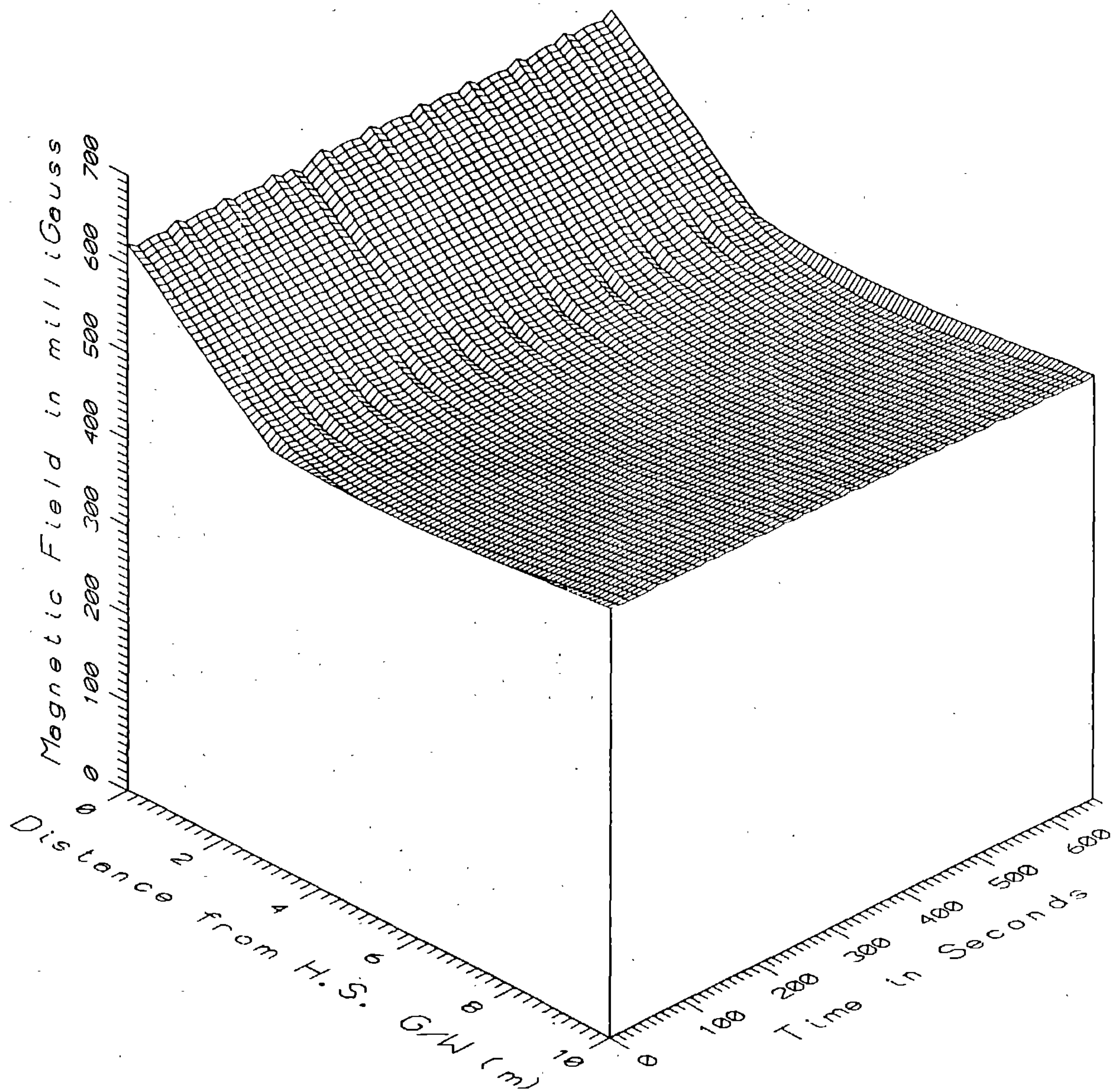


Figure 4-8 Typical plot of static field versus time and distance from the high steel guideway showing no effect of passing vehicles on static field but a passive field enhancement by the guideway structure.

TABLE 4-2

SUMMARY DATA FOR MAGNETIC FIELD MEASUREMENTS BENEATH THE HIGH STEEL GUIDEWAY NEAR THE CONTROL BUILDING

HIGH STEEL GUIDEWAY NEAR CONTROL CENTER (PILLAR 2423)					TOTAL OF 372 SAMPLES	
FREQUENCY BAND	DISTANCE WEST OF H.S. G/W (m)	MINIMUM MAGNETIC FIELD (mG)	MAXIMUM MAGNETIC FIELD (mG)	AVERAGE MAGNETIC FIELD (mG)	STANDARD DEVIATION (mG)	COEFFICIENT OF VARIATION (%)
STATIC	0.00	609.91	623.44	622.04	1.49	0.24
STATIC	3.00	465.88	472.04	471.32	0.59	0.13
STATIC	10.00	483.57	486.45	484.58	0.39	0.08
5-45 Hz	0.00	0.04	39.68	0.54	3.55	662.61
5-45 Hz	3.00	0.03	41.50	0.46	3.27	710.06
5-45 Hz	10.00	0.04	12.39	0.23	1.07	468.85
50-60 Hz	0.00	0.06	15.05	0.35	1.20	338.94
50-60 Hz	3.00	0.05	13.48	0.30	1.02	341.17
50-60 Hz	10.00	0.06	2.73	0.23	0.22	96.04
65-300 Hz	0.00	0.01	68.80	0.69	5.17	749.67
65-300 Hz	3.00	0.01	62.56	0.59	4.55	765.21
65-300 Hz	10.00	0.01	19.05	0.25	1.61	646.05
305-2560 Hz	0.00	0.08	2.23	0.12	0.20	165.12
305-2560 Hz	3.00	0.07	2.16	0.10	0.19	187.39
305-2560 Hz	10.00	0.07	0.56	0.09	0.05	56.96
5-2560 Hz	0.00	0.14	80.86	1.07	6.37	595.28
5-2560 Hz	3.00	0.12	76.30	0.92	5.68	620.87
5-2560 Hz	10.00	0.13	21.35	0.50	1.93	388.65

TABLE 4-3

SUMMARY DATA FOR MAGNETIC FIELD MEASUREMENTS
BENEATH THE LOW CONCRETE GUIDEWAY IN THE SOUTH LOOP

LOW CONCRETE GUIDEWAY IN SOUTH LOOP		TOTAL OF 194 SAMPLES				
FREQUENCY BAND	DISTANCE EAST OF G/W (m)	MINIMUM MAGNETIC FIELD (mG)	MAXIMUM MAGNETIC FIELD (mG)	AVERAGE MAGNETIC FIELD (mG)	STANDARD DEVIATION (mG)	COEFFICIENT OF VARIATION (%)
STATIC	0.00	501.89	552.55	548.54	5.26	0.96
STATIC	4.00	443.03	448.87	447.02	2.08	0.46
STATIC	10.00	487.89	490.48	488.81	0.41	0.08
5-45 Hz	0.00	0.06	69.00	1.04	5.34	511.02
5-45 Hz	4.00	0.04	87.03	0.74	6.25	842.76
5-45 Hz	10.00	0.03	12.49	0.16	0.89	544.25
50-60 Hz	0.00	0.07	21.75	0.45	2.11	467.26
50-60 Hz	4.00	0.11	15.77	0.27	1.16	423.89
50-60 Hz	10.00	0.11	2.92	0.16	0.20	131.33
65-300 Hz	0.00	0.03	40.47	1.95	7.01	358.60
65-300 Hz	4.00	0.01	37.62	0.67	3.26	485.84
65-300 Hz	10.00	0.01	18.77	0.17	1.36	809.93
305-2560 Hz	0.00	0.08	2.96	0.21	0.43	205.46
305-2560 Hz	4.00	0.07	1.70	0.11	0.16	146.53
305-2560 Hz	10.00	0.05	0.60	0.06	0.04	64.91
5-2560 Hz	0.00	0.14	81.50	2.53	9.00	355.17
5-2560 Hz	4.00	0.16	96.13	1.21	7.13	590.82
5-2560 Hz	10.00	0.15	22.74	0.34	1.63	478.89

TABLE 4-4

SUMMARY DATA FOR MAGNETIC FIELD MEASUREMENTS BENEATH THE HIGH CONCRETE GUIDEWAY AT THE LOADING PLATFORM

GUIDEWAY AT LOADING PLATFORM, WEST PROFILE				TOTAL OF 458 SAMPLES		
FREQUENCY BAND	DISTANCE WEST OF G/W (m)	MINIMUM MAGNETIC FIELD (mG)	MAXIMUM MAGNETIC FIELD (mG)	AVERAGE MAGNETIC FIELD (mG)	STANDARD DEVIATION (mG)	COEFFICIENT OF VARIATION (%)
STATIC	0.00	488.73	502.25	494.97	2.30	0.46
STATIC	3.00	463.23	476.02	468.05	2.50	0.54
STATIC	9.00	485.10	491.14	486.82	0.85	0.17
5-45 Hz	0.00	0.03	60.37	0.40	3.68	921.59
5-45 Hz	3.00	0.04	60.19	0.44	4.18	956.64
5-45 Hz	9.00	0.07	15.55	0.27	1.04	384.06
50-60 Hz	0.00	0.02	14.95	0.22	0.87	386.54
50-60 Hz	3.00	0.18	11.30	0.27	0.70	254.07
50-60 Hz	9.00	0.04	6.63	0.11	0.38	363.16
65-300 Hz	0.00	0.04	40.59	0.38	3.20	844.58
65-300 Hz	3.00	0.06	31.51	0.33	2.45	750.09
65-300 Hz	9.00	0.04	19.13	0.20	1.45	719.44
305-2560 Hz	0.00	0.05	6.30	0.10	0.38	398.97
305-2560 Hz	3.00	0.19	5.17	0.23	0.30	131.94
305-2560 Hz	9.00	0.34	2.06	0.35	0.10	29.77
5-2560 Hz	0.00	0.09	72.46	0.67	4.96	741.82
5-2560 Hz	3.00	0.28	67.48	0.77	4.89	632.02
5-2560 Hz	9.00	0.35	24.01	0.58	1.81	313.00

The static field data in the summary tables have very low coefficients of variation consistent with the above observation that these are geomagnetic fields. For all three types of guideway, the static field is higher under the guideway. Figure 4-9 shows the lateral profiles of the mean static field at increasing distances from the guideway. The steel guideway has the greatest enhancement effect due to its large quantity of iron. The low concrete guideway has less iron than the steel guideway but is closer to the measurement probe and therefore causes significant enhancement beneath the guideway and reduction a few meters out to the side. The high concrete guideway appears to have the least effect on the uniformity of the geomagnetic field.

Since the ac fields of interest are those that exist when the overhead guideway is energized and the vehicle is nearby, the mean value of the ac field has little significance. Its value is greatly diluted by the extended periods of time that the guideway is de-energized relative to the time it is energized. The mean value would therefore be directly proportional to the frequency of vehicle passes and highly dependant on background field levels. A better indicator of field conditions present while a vehicle passes is the maximum value of the recorded field. The maximum field in each frequency band is plotted as a function of distance from the guideway for each type of construction in Figures 4-10 through 4-14.

Figures 4-10 and 4-11 show that the magnetic fields in the lower frequency ranges tend to be higher near the low concrete guideway but similar for all three types of construction at the 10 meter distance. This appears to be the result of near proximity to the low guideway. The disappearance of that effect at the higher frequencies may be an artifact of the lower speed of the vehicle in the south loop where the low concrete guideway measurements were made.

The elevated 65 to 300 Hz magnetic fields beneath the high steel guideway and elevated 305 to 2560 Hz fields beneath the high concrete guideway indicated in Figures 4-12 and 4-13, respectively, appear to result from differences in excitation frequency of the guideway resulting from differences in vehicle speed at the two locations and do not appear to be influenced by guideway construction. Please refer to the field by time and frequency plots in Appendices J and P.

4.5 Special Test of Levitating Vehicle

As mentioned above, the amount of time required for the TR07 vehicle to pass by a measurement site along the guideway is very short. As a result, there is no static field from the vehicle in the frame of reference of the stationary measurement. In order to better characterize and understand the magnetic field environment outside the TR07 vehicle and along the guideway, a special set of

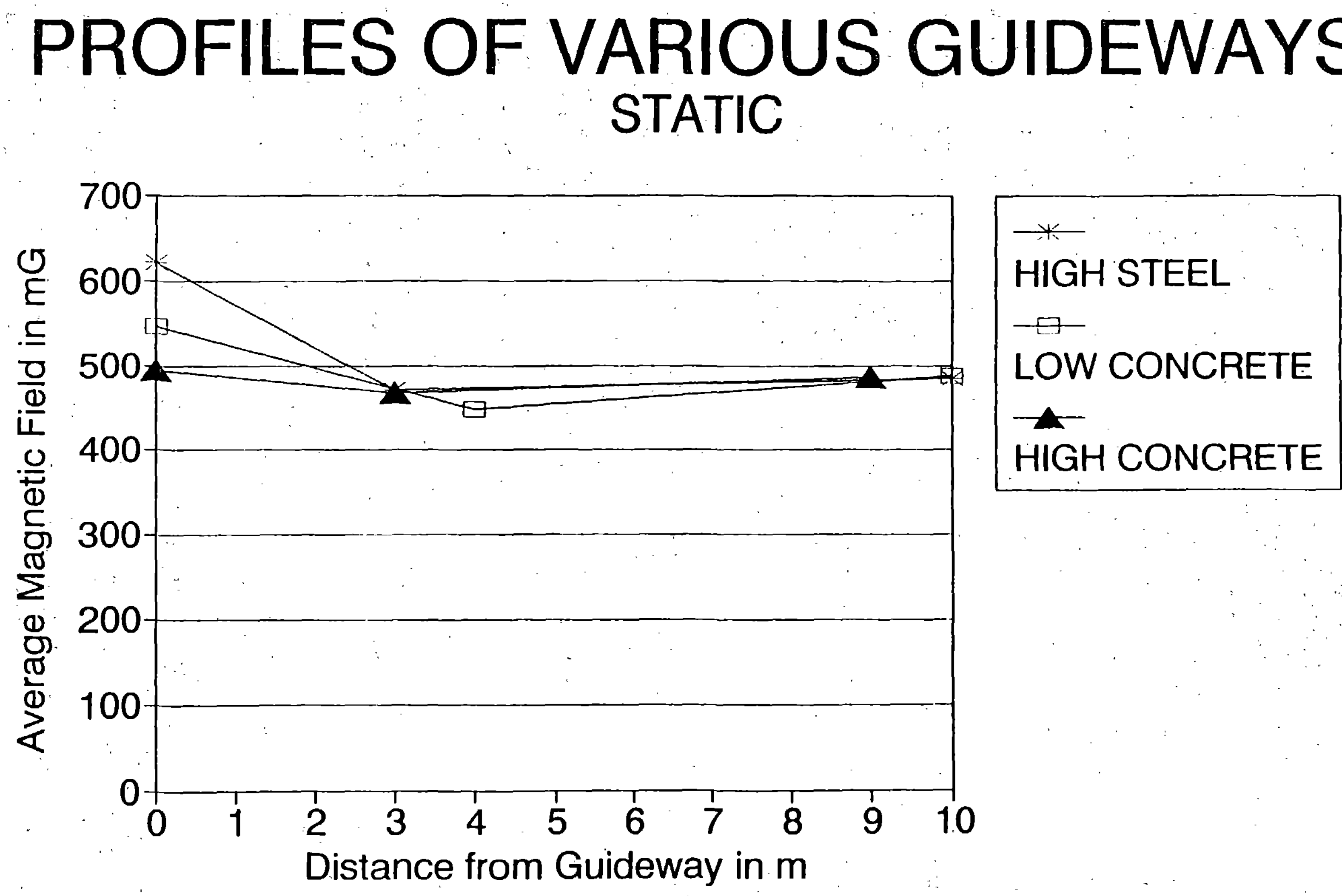


Figure 4-9 Lateral profile of mean static field level one meter above ground as a function of distance from centerline of the guideway.

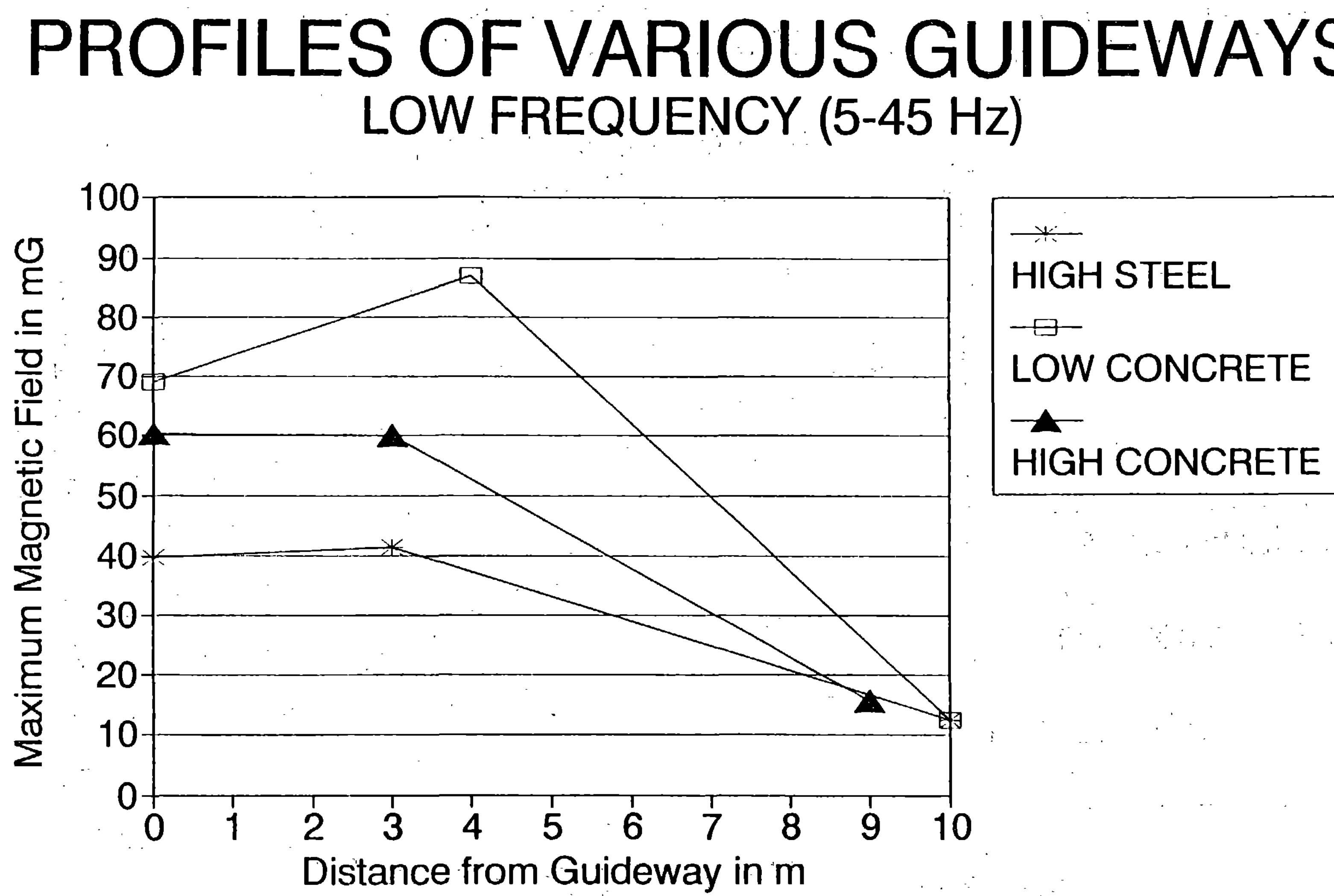


Figure 4-10 Lateral profile of maximum time varying magnetic field in the 5 to 45 Hz frequency band one meter above ground as a function of distance from centerline of the guideway.

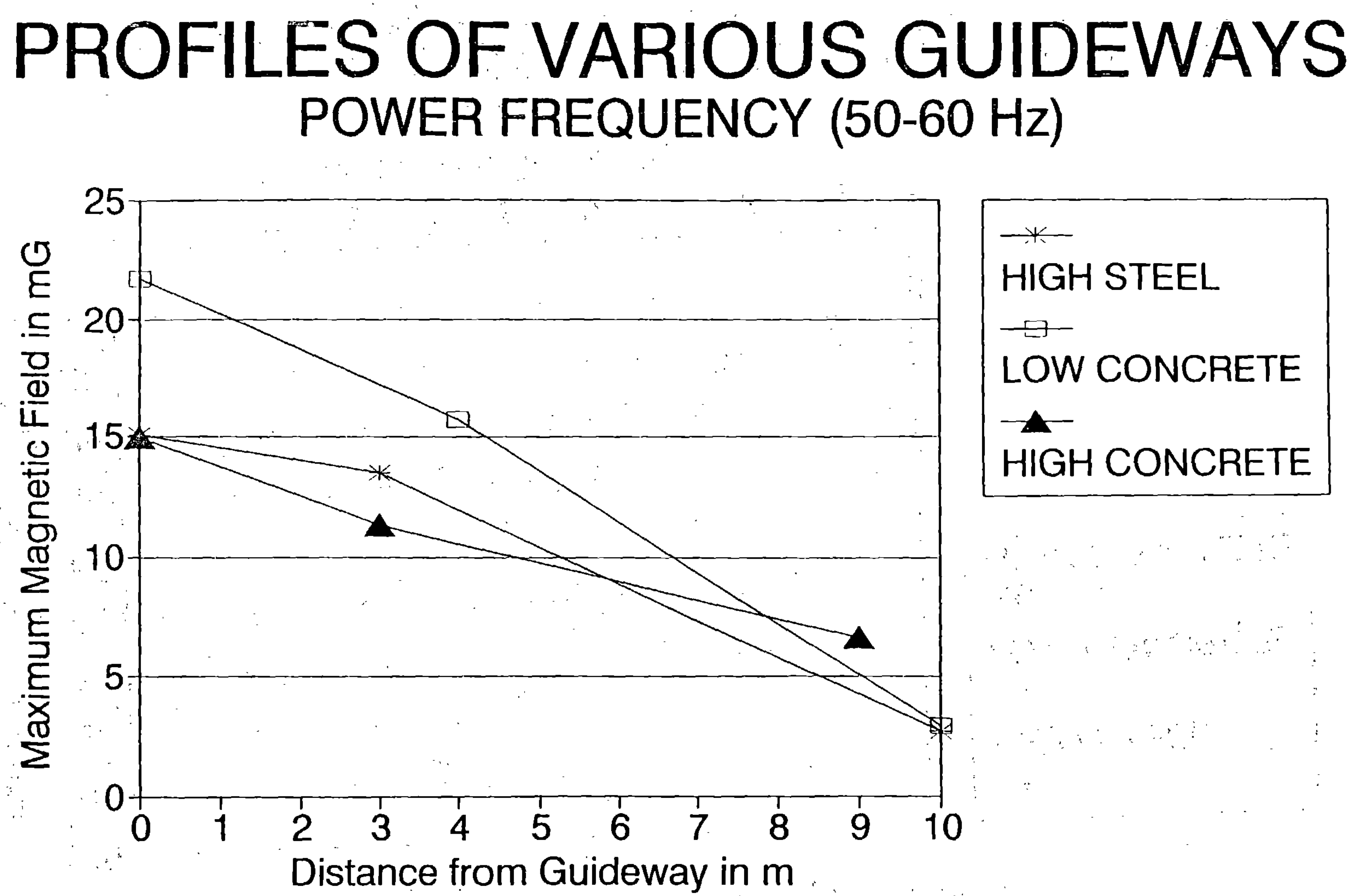


Figure 4-11 Lateral profile of maximum time varying magnetic field in the 50 to 60 Hz frequency band one meter above ground as a function of distance from centerline of the guideway.

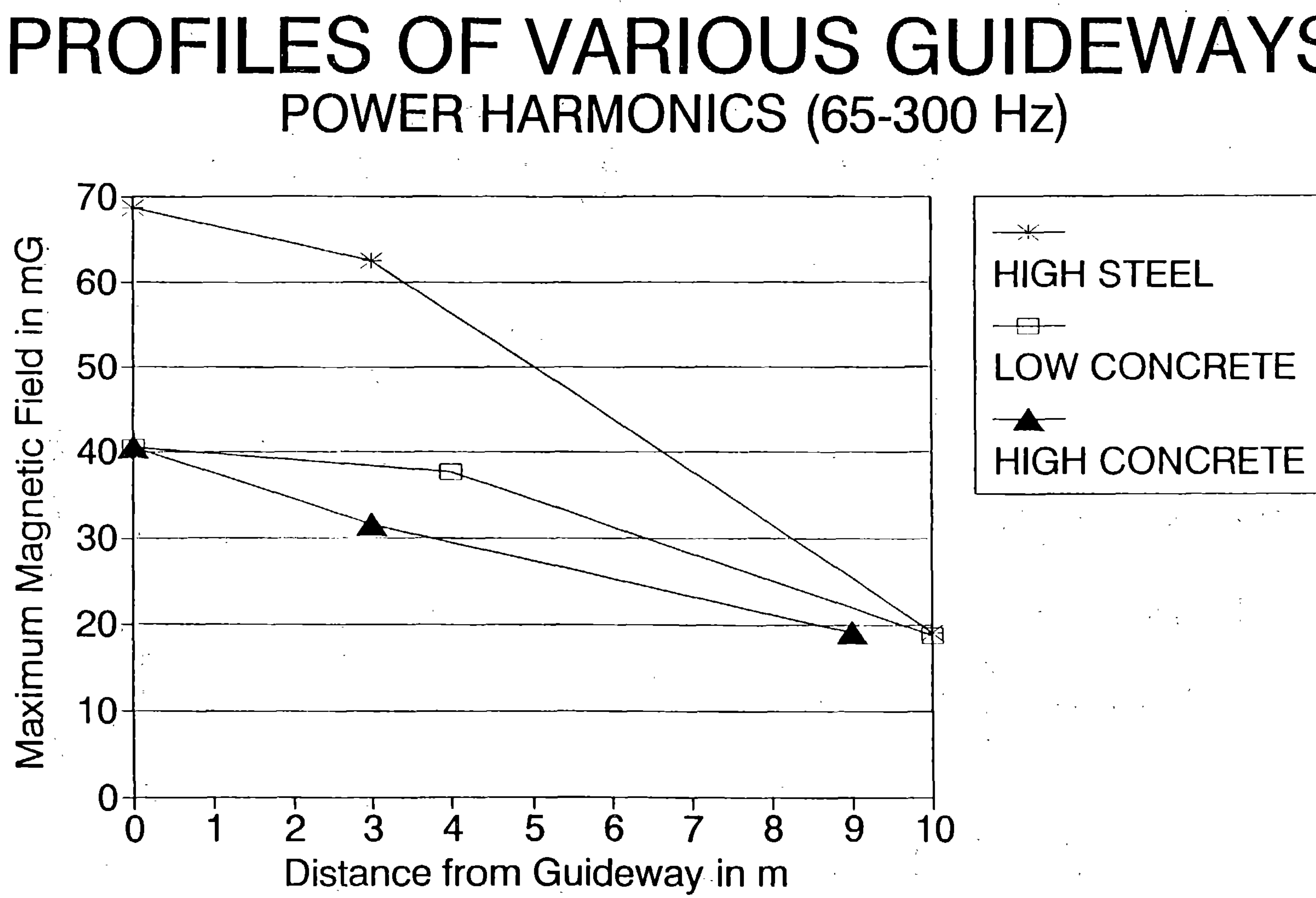


Figure 4-12 Lateral profile of maximum time varying magnetic field in the 65 to 300 Hz frequency band one meter above ground as a function of distance from centerline of the guideway.

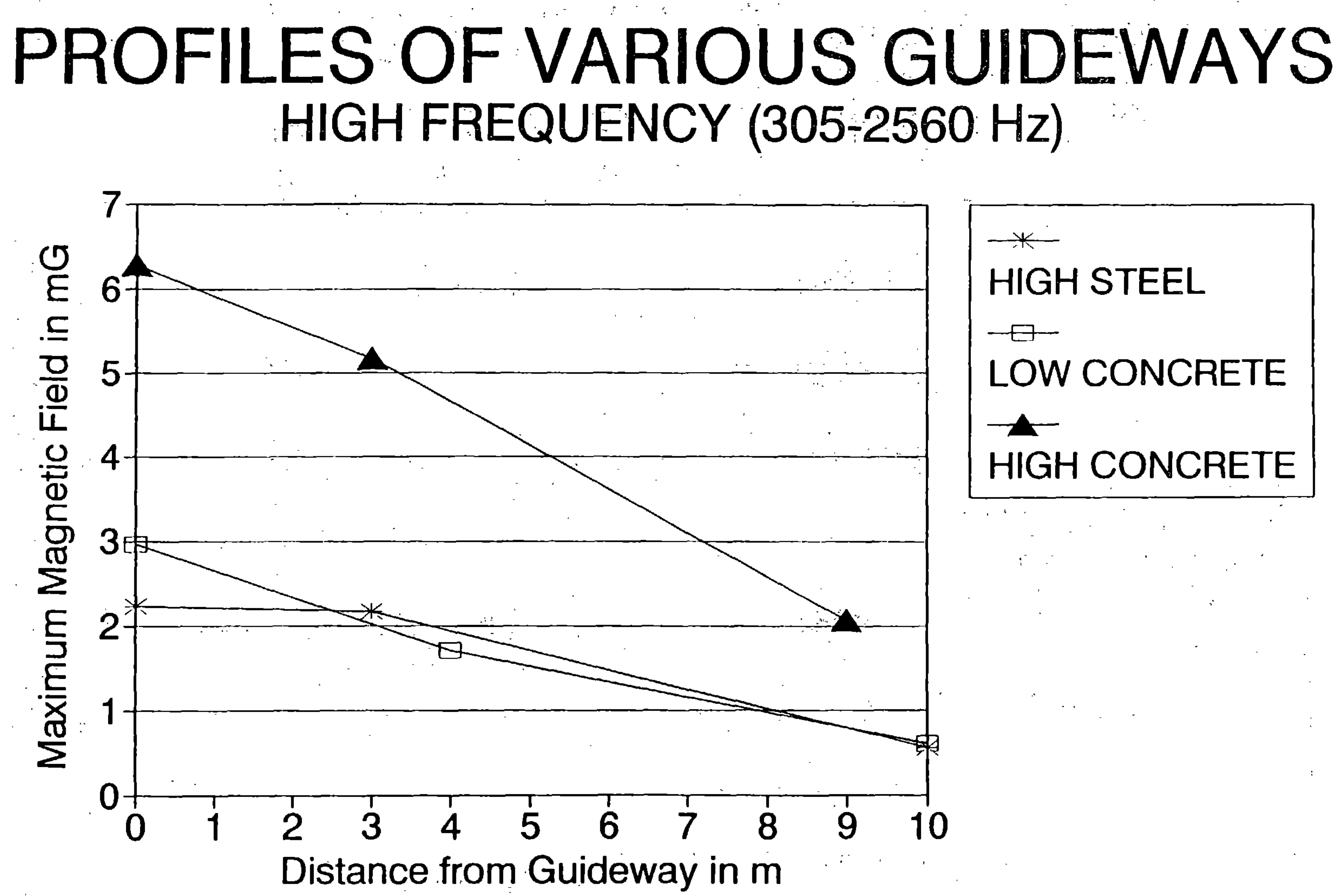


Figure 4-13 Lateral profile of maximum time varying magnetic field in the 305 to 2560 Hz frequency band one meter above ground as a function of distance from centerline of the guideway.

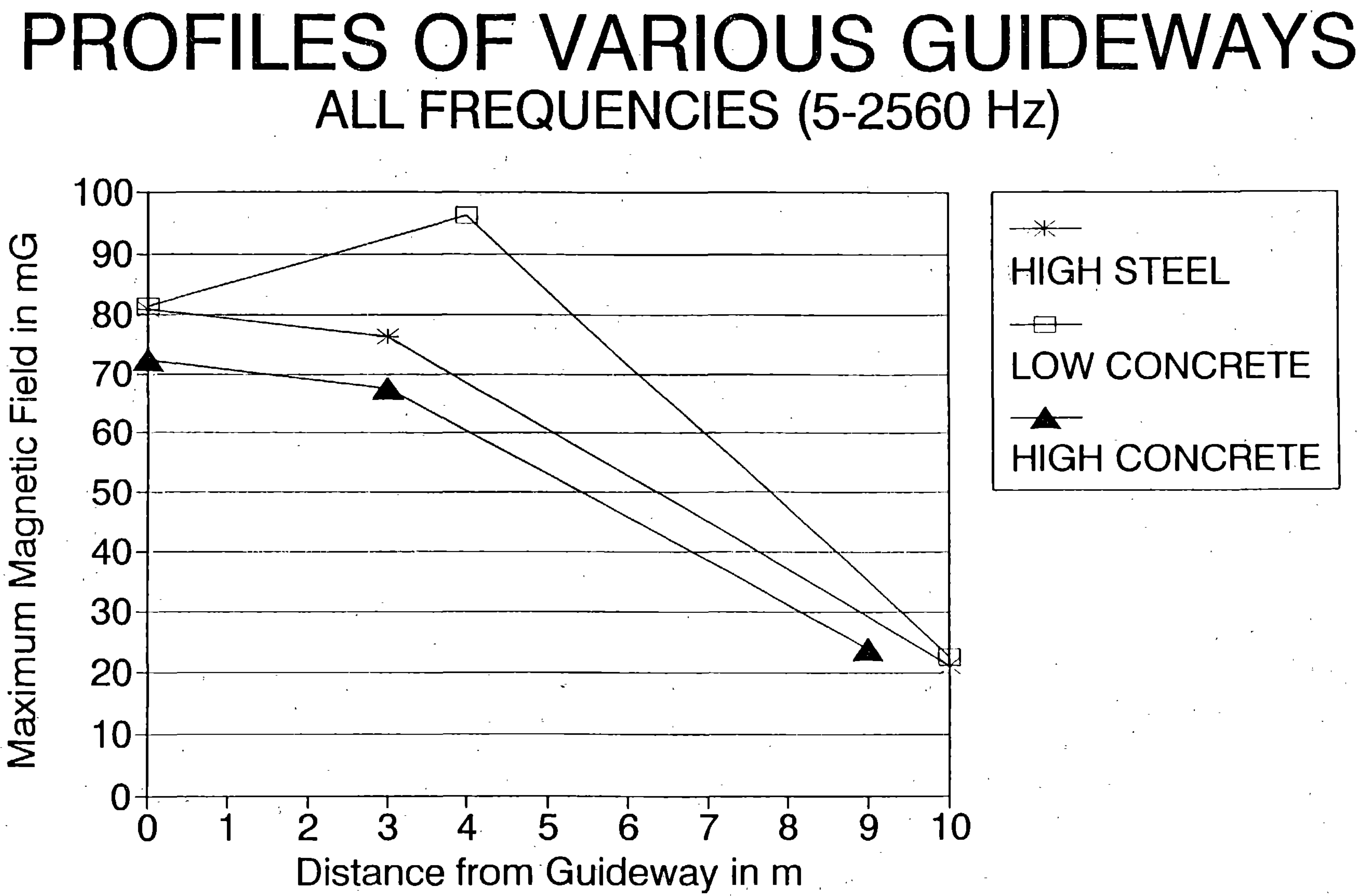


Figure 4-14 Lateral profile of maximum time varying magnetic field in the 5 to 2560 Hz frequency band one meter above ground as a function of distance from centerline of the guideway.

measurements were made for the stationary vehicle alternatively levitating then settling on its skids. The data from these measurements are provided in Appendix V. Another set of repetitive waveform measurements were made at the same location but with the vehicle parked to quantify the background fields in the area just outside the maintenance area which do not come from the TR07 vehicle. The background field data are in Appendix U.

The background static field varies from approximately 450 mG to 600 mG depending on the degree of perturbation of the geomagnetic field caused by ferromagnetic structures in the vicinity. The time-varying background magnetic field is primarily a 50 Hz field of about one quarter to one third milligauss. Harmonics of the power frequency field and fields at other discrete frequencies are also present in amounts that vary by time and location.

When the vehicle levitates, the time-varying fields increase markedly. The largest fields are near the guideway, attenuating as the distance from the guideway increases. There are also considerable differences in the intensities of the field at different points longitudinally along the guideway. The principal discrete frequencies in these fields appear to be the power frequency (50 Hz) and its 5th harmonic (250 Hz). Low frequency fields below the power frequency are also present in varying degrees. Since no one field by time and frequency plot is representative, the reader is referred to Appendix V for these details. Summary data are found in Table 4-5.

Static field levels near the guideway are significantly affected by levitation of the vehicle at locations near the guideway. The static field increases or decreases during levitation depending on the relative orientation of the static field from the vehicle and the geomagnetic field of the earth. Figures 4-15 and 4-16 both represent data taken at the edge of the guideway but at different locations along the guideway. The additive effect of the vehicle fields in Figure 4-15 and cancellation effect in Figure 4-16 are clearly evident. At increasing distances from the guideway, the perturbation of the geomagnetic field diminishes to only about ±1% at 10 meters from the guideway. Specific information on static field characteristics are in Appendix V. The summary information in Table 4-5 reflects this trend as decreased coefficient of variation in the static field values at increased distance from the guideway.

4.6 Comparison with Other Data

The data in the summary tables and graphs are very consistent with preliminary data presented in the Interim Report[2], as well they should be because the interim data were to a large extent a selected subset of the data presented here. The available IABG Reports[3,4] of magnetic field measurements on the TR06 and TR07 Systems do not report measurements of the magnetic field along the

TABLE 4-5

SUMMARY DATA FOR MAGNETIC FIELD MEASUREMENTS BENEATH THE LOW CONCRETE GUIDEWAY WITH THE STATIONARY TR07 VEHICLE LEVITATING OVERHEAD

LOW CONCRETE GUIDEWAY OUTSIDE MAINTENANCE FACILITY					TOTAL OF 39 SAMPLES	
FREQUENCY BAND	DISTANCE WEST OF G/W (m)	MINIMUM MAGNETIC FIELD (mG)	MAXIMUM MAGNETIC FIELD (mG)	AVERAGE MAGNETIC FIELD (mG)	STANDARD DEVIATION (mG)	COEFFICIENT OF VARIATION (%)
STATIC	0.00	140.71	668.62	505.77	164.17	32.46
STATIC	3.00	*	*	*	*	*
STATIC	10.00	551.53	566.34	556.58	3.69	0.66
6-45 Hz	0.00	15.51	95.92	34.10	18.91	55.47
6-45 Hz	3.00	3.82	22.19	9.42	4.43	47.01
6-45 Hz	10.00	0.80	2.49	1.24	0.45	36.41
48-60 Hz	0.00	4.88	51.79	16.86	14.32	84.97
48-60 Hz	3.00	2.09	26.26	7.95	7.13	89.78
48-60 Hz	10.00	0.26	3.15	0.98	0.84	85.65
63-300 Hz	0.00	5.77	27.64	11.66	6.42	55.04
63-300 Hz	3.00	1.91	7.59	3.31	1.52	45.90
63-300 Hz	10.00	0.27	1.25	0.49	0.26	53.29
303-1536 Hz	0.00	3.55	10.66	5.83	1.80	30.80
303-1536 Hz	3.00	1.16	3.69	1.82	0.59	32.63
303-1536 Hz	10.00	0.16	0.54	0.25	0.09	36.27
6-1536 Hz	0.00	19.07	110.04	40.72	23.76	58.36
6-1536 Hz	3.00	5.96	34.11	13.27	7.94	59.81
6-1536 Hz	10.00	0.99	4.18	1.72	0.90	52.10

NOTE: * Data lost due to probe failure.

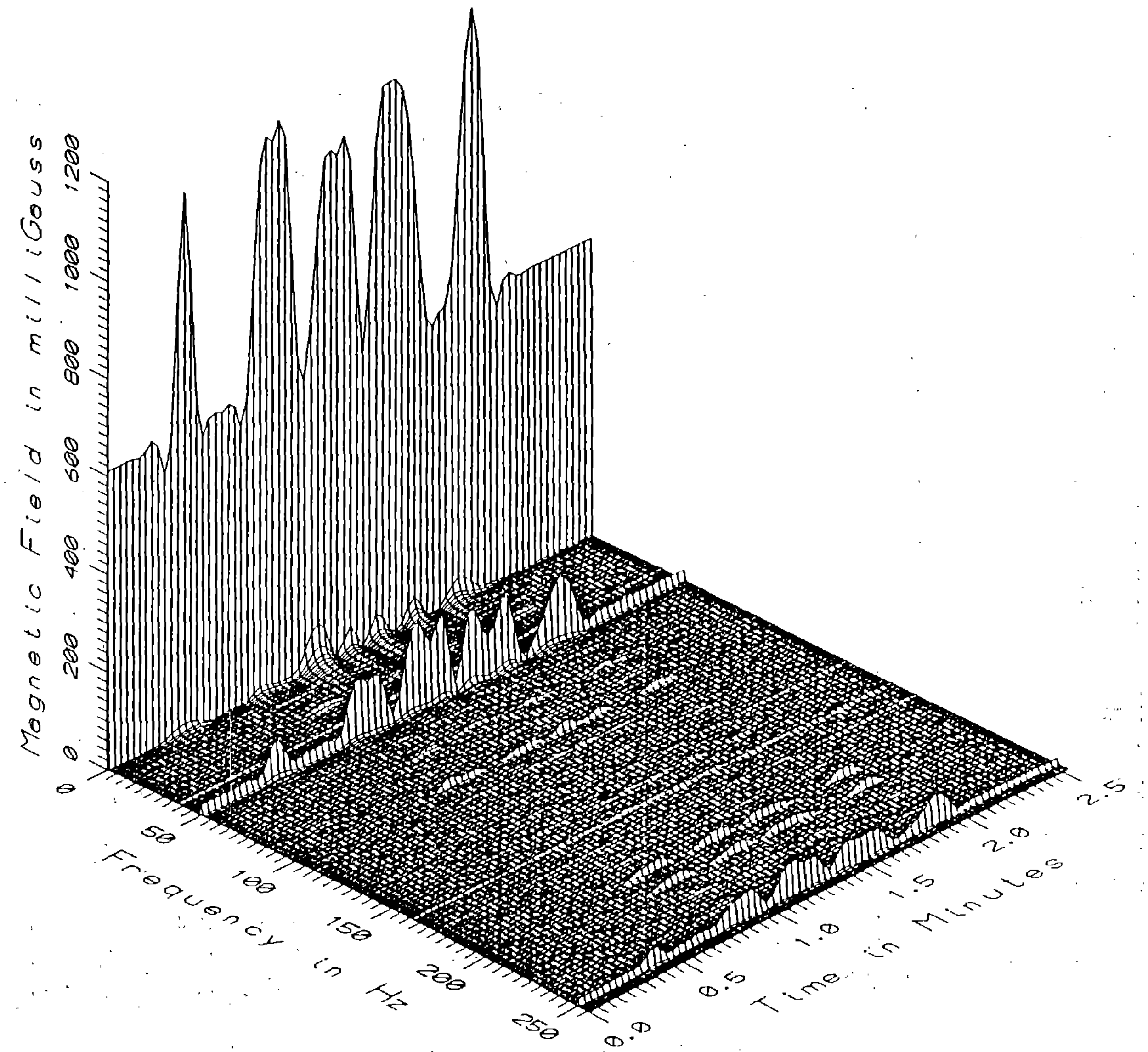


Figure 4-15 Magnetic flux density versus frequency and time measured with a fluxgate sensor beneath the low concrete guideway 6 meters from the lateral profile with the TR07 vehicle levitating overhead.

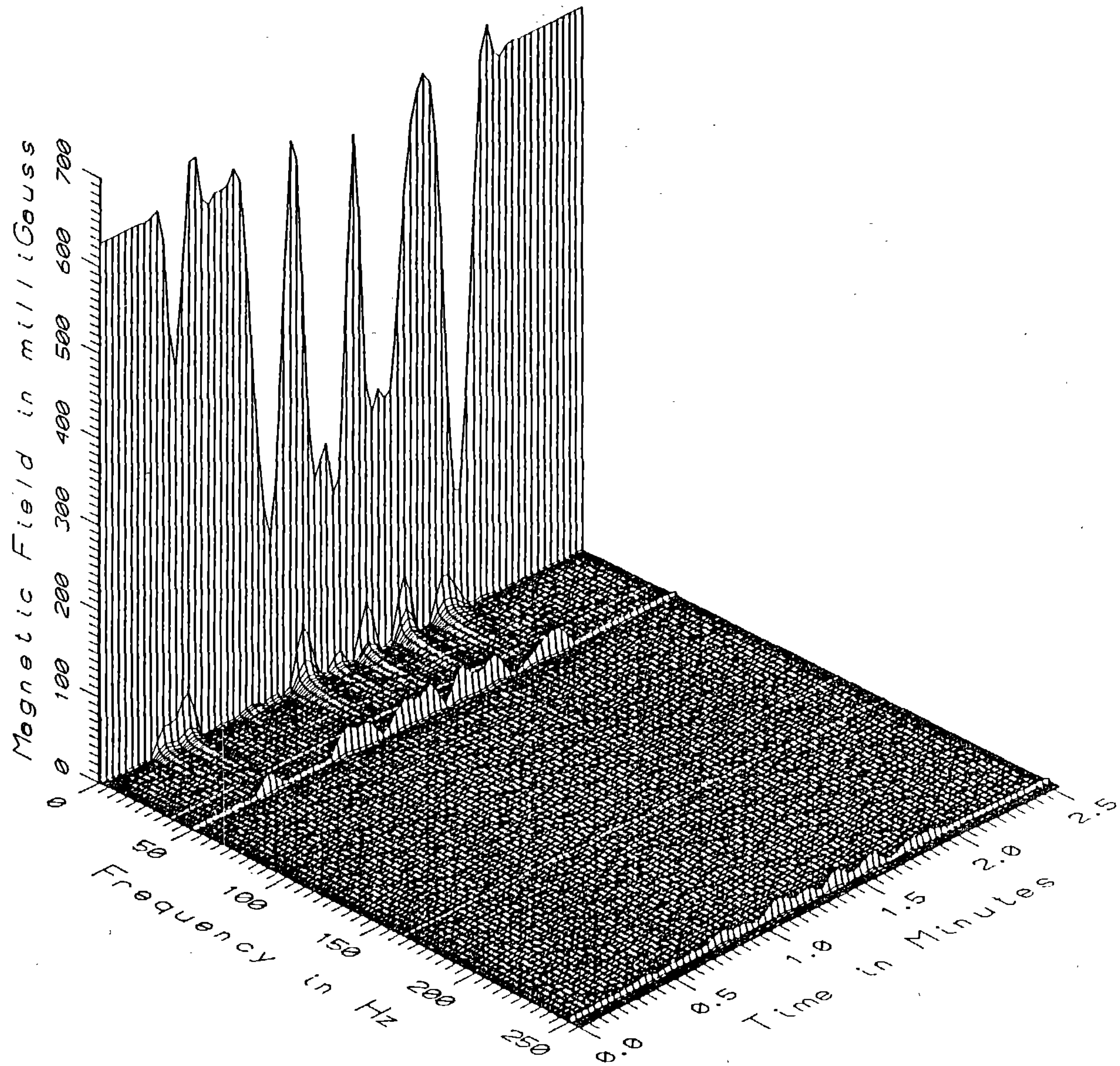


Figure 4-16 Magnetic flux density versus frequency and time measured with a fluxgate sensor beneath the low concrete guideway at the lateral profile point with the TR07 vehicle levitating overhead.

guideway in the frequency range addressed here. Those reports focus on frequencies above 10 kHz where emitted electromagnetic fields might affect radio frequency communication.

5.0 MEASUREMENTS AT THE PASSENGER STATION

5.1 Measurement Locations

Measurements of the magnetic field were made at two locations at the passenger station. The first was approximately 5 cm above the loading platform deck at a point 2.5 m from centerline of the guideway. This location was just inside the railing which surrounds the outdoor platform. The second measurement point was one meter above the floor just inside the passenger waiting area. This point was 5.5 m from centerline of the guideway. More detailed information concerning the placement of the sensors can be found in Section 4.4 and Appendix E of the Interim Report[2].

Two sets of repetitive waveform data were collected at these measurement locations as the TR07 vehicle passed at high speed without stopping. As indicated in Table 2-1, these are part of data sets TR7020 and 7021 and are found in Appendices P and Q.

5.2 Time-Varying Magnetic Fields

The magnetic field characteristics at the station are very similar in nature to those near the guideway as discussed in Section 4 above. Table 5-1 shows the summary data on field strength for these measurements. As was the case for the measurements along the right-of-way, the actual time is very short when the guideway in front of the platform is energized and the vehicle is in the vicinity. Consequently, the average fields are very low. The increased field levels produced by the energized guideway and nearby vehicle are diluted in the average by the long periods of low background field levels between train passes. The average value of the magnetic field at the station is a poor indicator of performance since it is dependant on the frequency of train passes and background field levels; parameters which would certainly be application specific. The maximum magnetic field which occurs as the vehicle passes is more objective characterization of the technology. Average field levels for a specific application could be computed from the maximum value and site specific information on background field levels and frequency of vehicle passes.

Comparing the maximum magnetic fields at the station shown in Table 5-1 to those along the guideway (Figures 4-2 through 4-4), one sees that the time-varying fields on the loading platform (25 m from the guideway) are substantially larger than those along the guideway. That appears to be due entirely to proximity. The temporal characteristics of the field at this point are similar to those of magnetic fields at locations along the guideway. Frequency spectra are also similar except there is proportionately more low frequency fields present at the platform measurement location. This difference appears both in the summary data and the field by time and frequency plots of Appendices P and Q.

TABLE 5-1

SUMMARY DATA FOR MAGNETIC FIELD MEASUREMENTS AT THE PASSENGER STATION

GUIDEWAY AT LOADING PLATFORM, EAST PROFILE		TOTAL OF 358 SAMPLES				
FREQUENCY BAND	DISTANCE EAST OF G/W (m)	MINIMUM MAGNETIC FIELD (mG)	MAXIMUM MAGNETIC FIELD (mG)	AVERAGE MAGNETIC FIELD (mG)	STANDARD DEVIATION (mG)	COEFFICIENT OF VARIATION (%)
STATIC	2.50	320.01	370.49	357.71	6.68	1.87
STATIC	5.50	545.79	549.15	547.37	0.68	0.12
5-45 Hz	2.50	0.03	287.27	1.52	17.55	1154.81
5-45 Hz	5.50	0.01	12.35	0.13	0.94	707.58
50-60 Hz	2.50	0.04	20.52	0.21	1.55	722.28
50-60 Hz	5.50	0.02	6.27	0.09	0.35	385.09
65-300 Hz	2.50	0.01	75.16	0.60	5.59	925.92
65-300 Hz	5.50	0.01	14.89	0.13	1.11	859.31
305-2560 Hz	2.50	0.05	7.95	0.12	0.59	474.04
305-2560 Hz	5.50	0.00	1.27	0.01	0.08	527.40
5-2560 Hz	2.50	0.08	297.44	1.74	18.49	1062.47
5-2560 Hz	5.50	0.04	19.48	0.23	1.49	659.95

The time-varying magnetic field characteristics including intensity at the measurement location within the passenger waiting area (5.5 m from the guideway centerline) are typical of those along the guideway at comparable distances from centerline.

5.3 Static Magnetic Fields

Static field levels at both station measurement locations appear to be predominantly due to the geomagnetic field. Deviation from the typical geomagnetic field strength in the Emsland appears due to the "perturbing" effect of iron and steel components in the station and platform structure. Table 5-1 shows that both maximum and minimum values of the static field are close to the average value indicating that the passing vehicle produces neither marked increases nor decreases in the static field. This same conclusion can be drawn from inspection of the field by time and frequency plots for the fluxgate measurement sensor in Appendices P and Q. Figure 5-1 shows one such field by time and frequency plot for the measurement location 5 cm above the deck of the outdoor platform taken from Appendix P. Note that there is a step shift in static field intensity at this location each time the TR07 vehicle passes and the direction of the step is dependant on the direction of travel of the vehicle. That phenomena apparently results from residual magnetism in the ferromagnetic components of the guideway and/or loading platform. The effect is most noticeable at this location because the sensor is only a few centimeters above the platform, because the probe is close to the guideway, or both. This phenomena is still visible at the measurement location within the passenger waiting area.

5.4 Comparison with Other Data

The station data has already been compared to data obtained along the guideway in the preceding discussion. The Interim Report described the time domain waveforms of selected subsets of the data described herein and is consistent with the data presented above. The authors are not aware of other data on magnetic field strength or characteristics within the passenger station waiting area or on the platform.

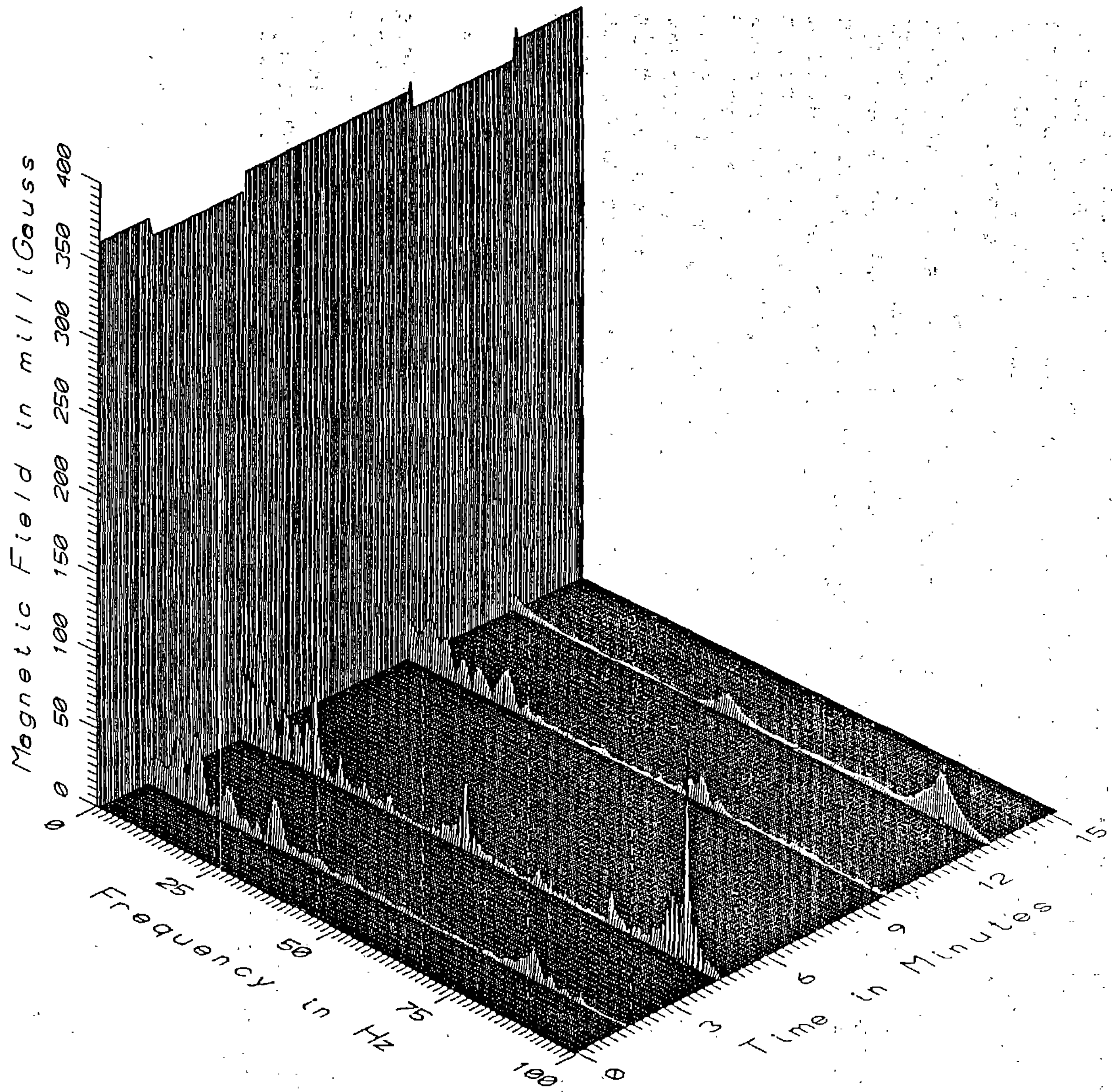


Figure 5-1 Magnetic flux density versus frequency and time measured with a fluxgate sensor located 5 cm above the deck of the loading platform 2.5 m from centerline of the guideway.

6.0 MEASUREMENTS NEAR POWER SUPPLY EQUIPMENT

Variable frequency electric power for the Transrapid TR07's linear synchronous motor propulsion system is obtained from the 50 Hz electric power grid via two banks of 50 Hz stepdown transformers, two rectifier banks and two inverter banks. The variable frequency output power from the inverters is then fed through banks of output transformers, through underground feeder cables, to the appropriate sections of longstator in the guideway. During dynamic braking of the vehicle, electrical energy generated in the longstator is backfed through the cables, output transformers, and inverters to the dc bus where it is dissipated in chopper controlled resistor banks. The rectifiers, inverters, and much of the control equipment is housed indoors in the inverter building. The transformers and braking resistors are housed outdoors. The approximate locations of the indoor rectifier and inverter area, and the outdoor transformer and resistor yards are shown in Figure 6-1 along with the general route of feeder cables to the guideway.

Since all of these power supply components are potential sources of magnetic field, four specific sets of measurements were made near these components to characterize their fields. Additional nearby measurements under the high steel guideway provide additional information about magnetic fields from the power supply equipment, but at one more distant location.

6.1 Measurement Locations

Magnetic fields were measured in five areas around the power supply equipment. These general areas are indicated on Figure 6-1, unless otherwise noted. The sensors were 1 m above ground and measurements were made with the TR07 vehicle running continuously. The measurement set indicated "A" on the figure primarily addressed the magnetic fields produced by the TR07 vehicle operating on the overhead guideway. However, during the intervals between vehicle passes, these data provide information about the magnetic fields at greater distances from the power supply equipment. During one of the high steel guideway measurements reported in Appendix N, a probe was located between the transformer yard and the inverter building to quantify the magnetic fields at that location. Specific information about the placement of these probes is in Section 4.2 and Appendix C of the Interim Report[2].

Field measurements were made at the south side of the transformer yard in the shaded area marked "B" in Figure 6-1. The five sensors were arrayed in a cross pattern as indicated to better quantify spatial variation in the field parallel to and perpendicular to the transformer yard boundary. Section 4.5.1 and Appendix F of the Interim Report detail sensor locations.

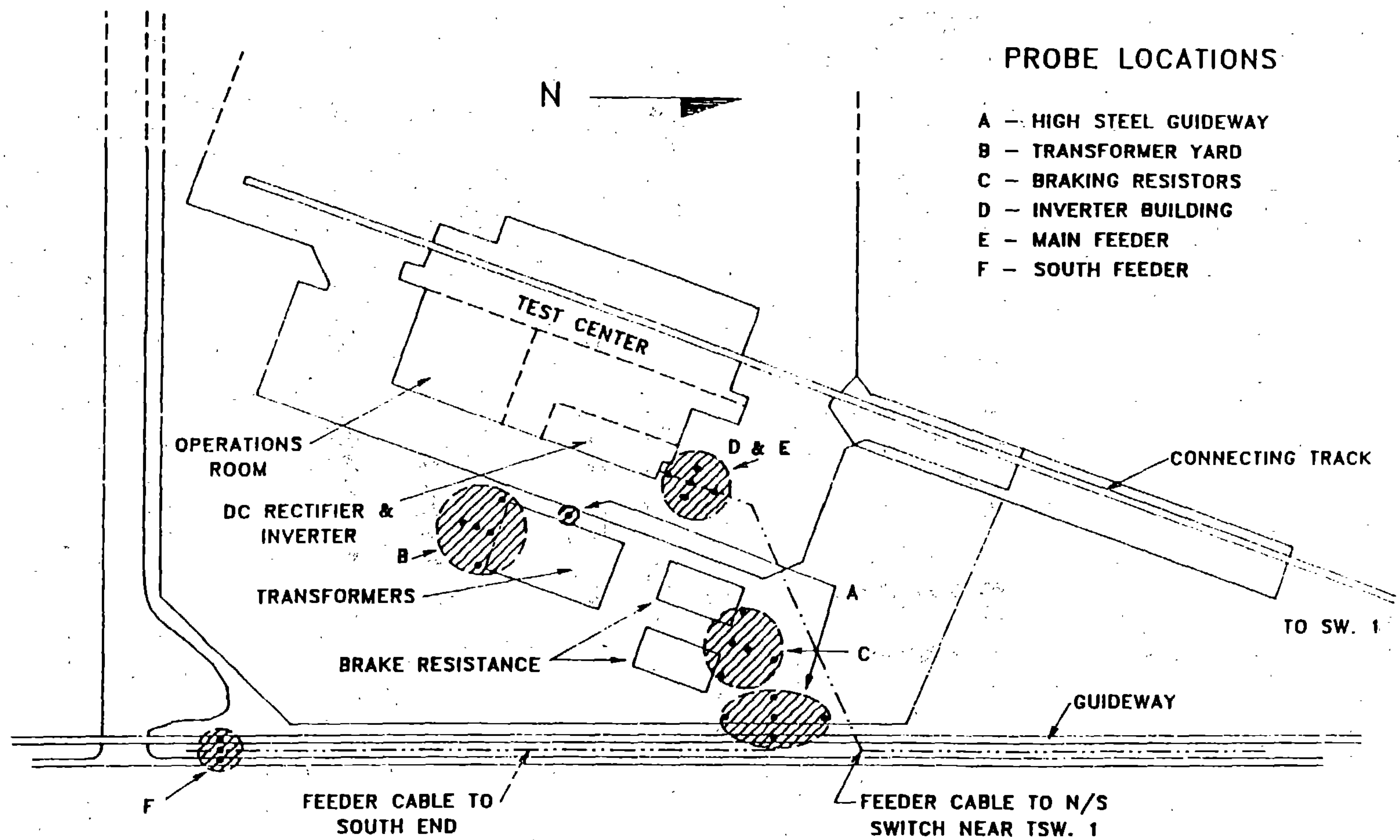


Figure 6-1 Location of power supply equipment and related magnetic field measurements.

Magnetic fields in the vicinity of the braking resistor banks were measured in the area labelled "C" on Figure 6-1, again using a cross shaped array of sensors. Specific sensor locations are indicated in detail in Section 4.5.2 and Appendix G of the Interim Report.

The next set of measurements were at the area marked "D and E" on Figure 6-1. The goal of these measurements was to quantify the magnetic fields from the inverter building and the fields from the main feeder cable. Section 4.5.4 and Appendix I of the Interim Report document the locations of the sensors.

The final set of field measurements were above the feeder cable at location "F" on Figure 6-1. For one set of measurements, the sensors were on the ground at this location and 1 m above the ground for the other measurements. Section 4.5.5 and Appendix J of the Interim Report show exact sensor locations.

Table 6-1 provides a listing of the repetitive waveform data sets collected during this series of tests, the test locations, the appendices where the field data are found and other pertinent measurement parameters.

6.2 Transformer Yard

Graphs of magnetic flux density versus time and frequency and magnetic flux density versus time and distance from the yard edge are presented in Appendix R and summarized in Table 6-2. Figure 6-2 shows the field by frequency and time graph from Appendix R for the time-varying magnetic field measurements at the center of the south edge of the yard. This figure is similar in character to all of the measurements near the yard except those 7 m east of that point which is somewhat more variable in time and frequency. That difference is apparently due to the proximity of this probe to the inverter output transformers which are at the east side of the yard. The principal field components of the magnetic field are the 50 Hz power frequency and the fifth and seventh harmonics thereof (250 Hz and 350 Hz) which are relatively constant over time. In addition to those relatively stable components, there are intermittent fields at 50 Hz approaching three times the steady state value and intermittent fields at other frequencies. These intermittent fields extend well up into the kilohertz range but at lower intensities as indicated in Figure 6-3.

The time-varying magnetic fields from the transformer yard generally attenuate in a well behaved consistent pattern as indicated in the field by time and distance plots of Appendix R. Figure 6-4 is an example of one such plot of field attenuation over time. A similar attenuation pattern can be seen in the summary data of Table 6-2. However, at specific times and at specific frequencies, the attenuation pattern is not maintained.

TABLE 6-1

SUMMARY OF REPETITIVE WAVEFORM MEASUREMENTS NEAR VARIOUS COMPONENTS OF THE TR07 POWER SUPPLY EQUIPMENT

DATA SET, MEASUREMENT LOCATION, AND MEASUREMENT CONDITIONS	APPENDIX CONTAINING DATA	DATE AND TIME	NUMBER OF SAMPLES	INTERVAL BETWEEN SAMPLES
TR7018, UNDER HIGH STEEL GUIDEWAY AND BETWEEN THE TRANSFORMER YARD AND INVERTER BUILDING, VEHICLE RUNNING	N	AUG 8 12:56-13:01	52	≈6 SEC
TR7022, SOUTH END OF THE TRANSFORMER YARD, VEHICLE RUNNING	R	AUG 9 15:08-15:28	230	≈6 SEC
TR7023, NORTH END OF RESISTOR BANK YARD, VEHICLE RUNNING	S	AUG 9 16:18-16:38	255	≈6 SEC
TR7024, NORTH END OF RESISTOR BANK YARD, ATTEMPT TO CATCH BRAKING OPERATION	T	AUG 9 16:49-16:55	68	≈6 SEC
TR7028, NEAR INVERTER BUILDING AND OVER FEEDER CABLE, VEHICLE RUNNING	W	AUG 10 10:05-10:06	6	≈6 SEC
TR7030, NEAR INVERTER BUILDING AND OVER FEEDER CABLES, VEHICLE RUNNING	X	AUG 10 12:07-12:27	219	≈6 SEC

TABLE 6-1 CONTINUED

SUMMARY OF REPETITIVE WAVEFORM MEASUREMENTS NEAR VARIOUS COMPONENTS OF THE TR07 POWER SUPPLY EQUIPMENT

DATA SET, MEASUREMENT LOCATION, AND MEASUREMENT CONDITIONS	APPENDIX CONTAINING DATA	DATE AND TIME	NUMBER OF SAMPLES	INTERVAL BETWEEN SAMPLES
TR7031, ABOVE SOUTH FEEDER CABLE, SENSORS AT GROUND LEVEL, VEHICLE PARKED IN MAINTENANCE FACILITY	Y	AUG 10 13:04-13:05	6	≈6 SEC
TR7032, ABOVE SOUTH FEEDER CABLE, SENSORS 1 M ABOVE GROUND, VEHICLE RUNNING	Z	AUG 10 16:20-16:40	219	≈6 SEC

6-5

TABLE 6-2

SUMMARY DATA FOR THE MAGNETIC FIELD MEASUREMENTS AT THE SOUTH EDGE OF THE OUTPUT TRANSFORMER YARD

OUTPUT TRANSFORMER YARD, SOUTH EDGE			TOTAL OF 230 SAMPLES			
FREQUENCY BAND	DISTANCE SOUTH OF YARD (m)	MINIMUM MAGNETIC FIELD (mG)	MAXIMUM MAGNETIC FIELD (mG)	AVERAGE MAGNETIC FIELD (mG)	STANDARD DEVIATION (mG)	COEFFICIENT OF VARIATION (%)
STATIC	0.00	493.09	506.27	499.15	2.42	0.49
STATIC	3.00	*	*	*	*	*
STATIC	10.00	*	*	*	*	*
5-45 Hz	0.00	0.06	2.00	0.32	0.23	72.80
5-45 Hz	3.00	0.02	1.69	0.16	0.17	105.64
5-45 Hz	10.00	0.02	1.79	0.09	0.15	162.54
50-60 Hz	0.00	1.14	4.49	1.66	0.69	41.54
50-60 Hz	3.00	0.54	2.03	0.77	0.31	40.38
50-60 Hz	10.00	0.19	0.69	0.26	0.11	41.03
65-300 Hz	0.00	0.30	3.13	0.44	0.25	56.84
65-300 Hz	3.00	0.16	2.73	0.23	0.24	104.68
65-300 Hz	10.00	0.05	2.61	0.10	0.21	205.70
305-2560 Hz	0.00	0.18	0.75	0.25	0.12	48.36
305-2560 Hz	3.00	0.08	0.40	0.12	0.06	53.34
305-2560 Hz	10.00	0.02	0.17	0.04	0.03	63.11
5-2560 Hz	0.00	1.24	4.59	1.80	0.71	39.35
5-2560 Hz	3.00	0.57	3.50	0.85	0.38	45.28
5-2560 Hz	10.00	0.20	2.84	0.32	0.25	80.06

NOTE: * Data lost due to probe failure.

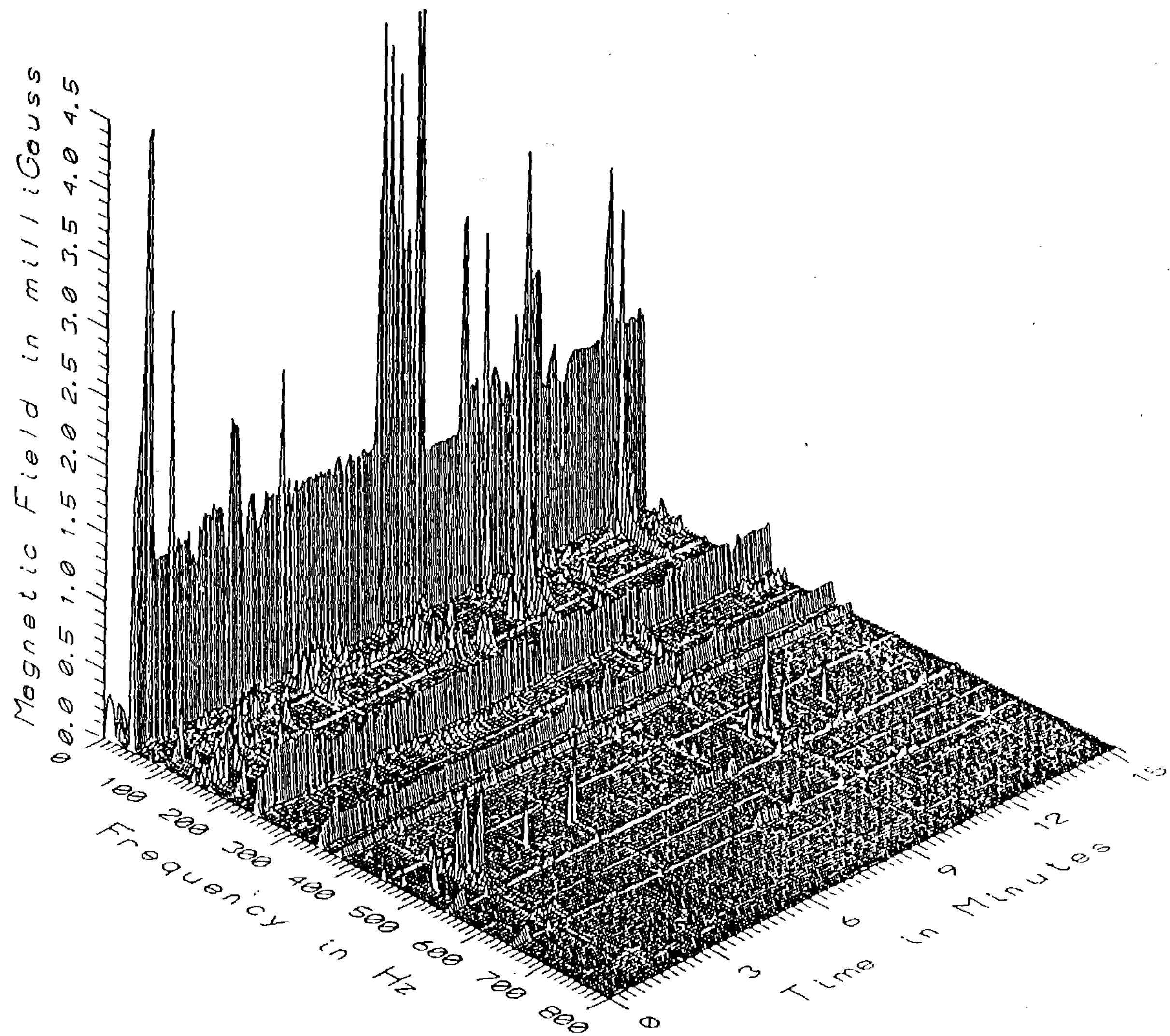


Figure 6-2 Flux density versus frequency and time for measurements with a coil-type field probe at the center of the south edge of the transformer yard.

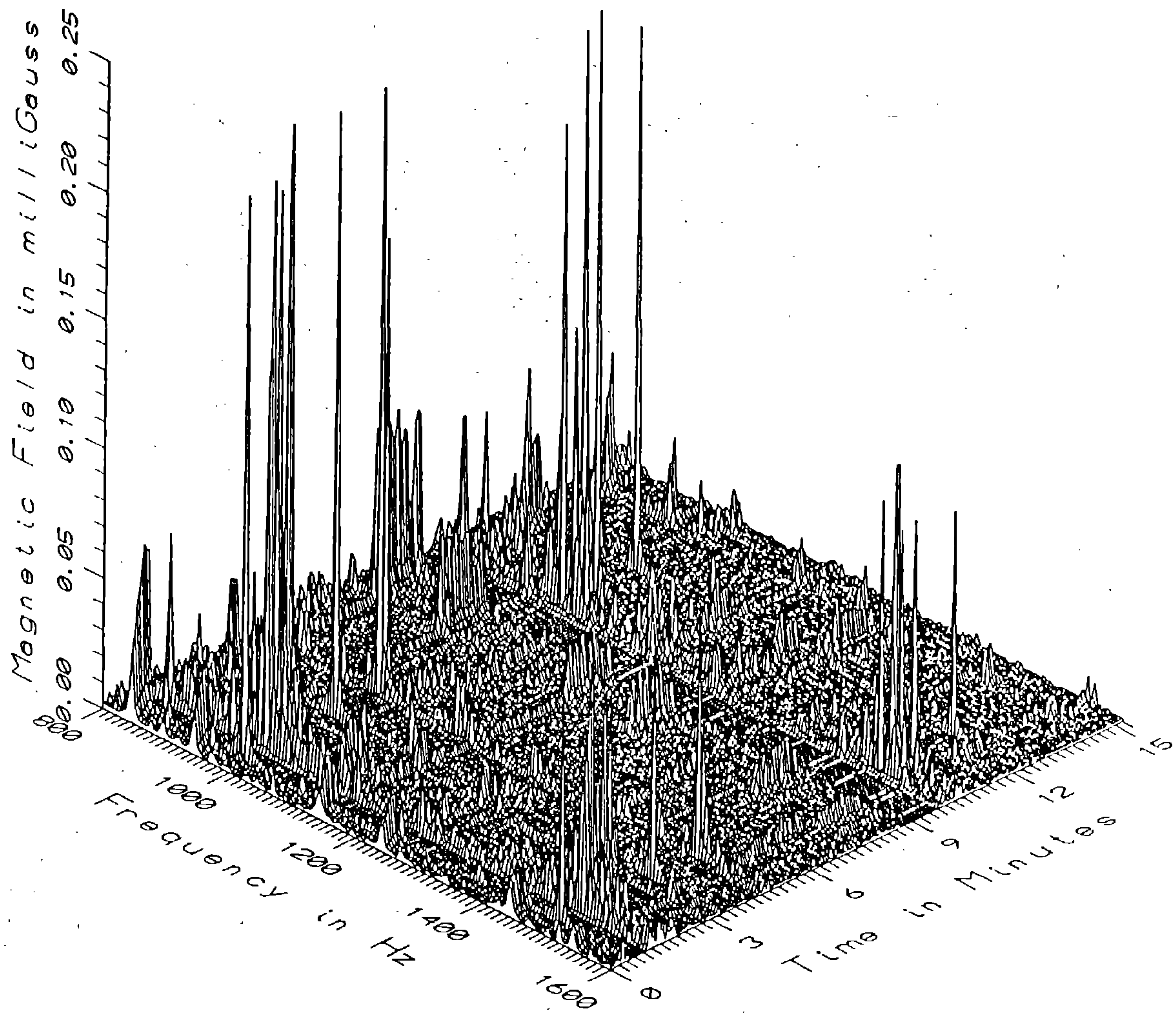


Figure 6-3 Flux density by frequency and time plot for the same conditions in Figure 6-2 but at higher frequencies.

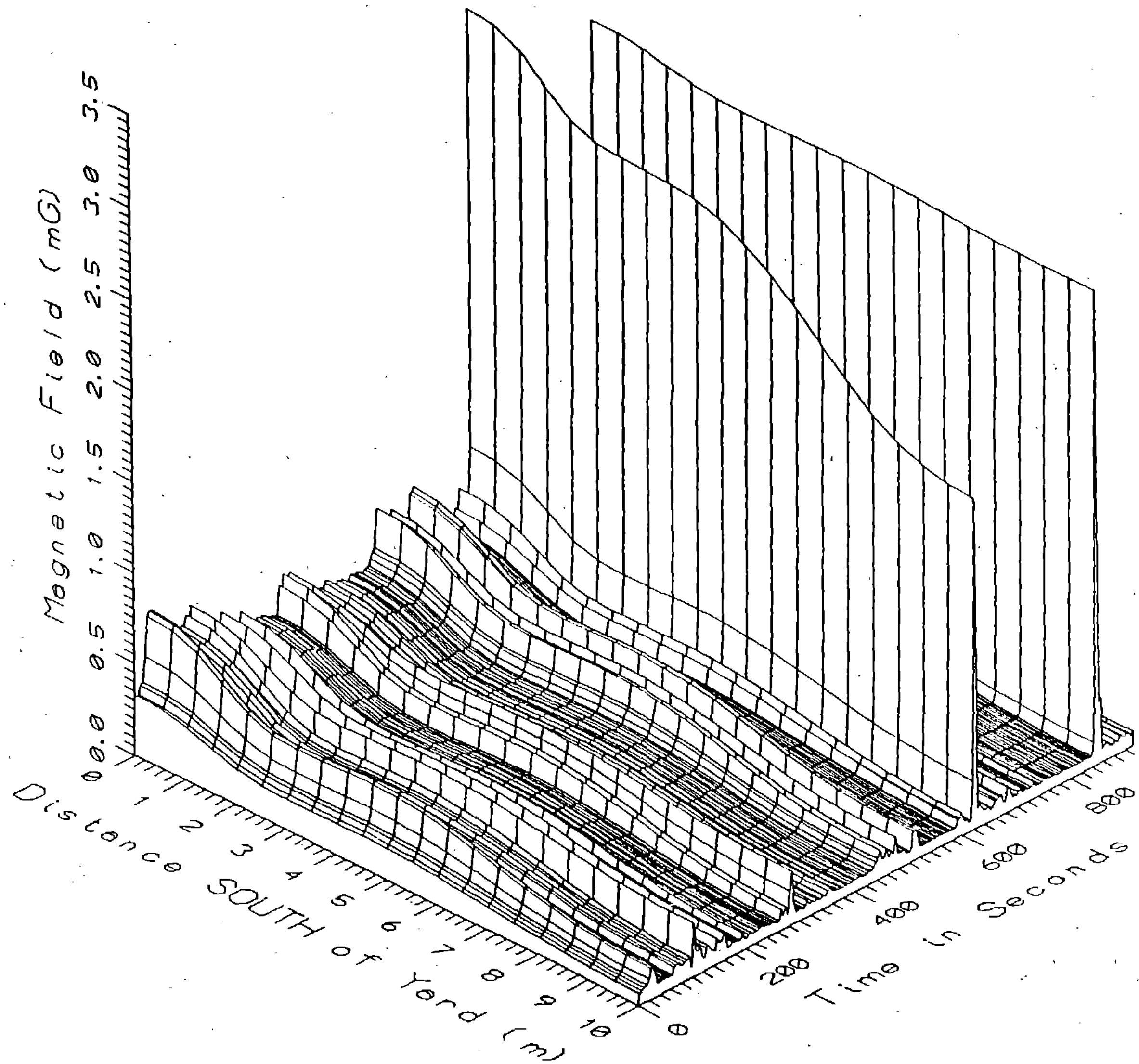


Figure 6-4 Field versus time and distance from the transformer yard for time varying AC field measurements in the 65 to 300 Hz range.

The intermittent field conditions at time 620 s and 860 s are good examples of this phenomena. This lack of attenuation suggests that these field components arise from a source other than the transformer yard. The pattern in levels at all probes suggests that some of these intermittent fields come from the direction of the inverter building.

Static field levels near the transformer yard show essentially no variability over time which can be related to TR07 operation. the static field level at the three measurement locations along the south edge of the yard is relatively uniform at a level representative of the geomagnetic field level in the Emsland area. The static field sensors at the 3 meter point and 10 meter point each had one inoperative channel during this test. As a result, magnetic field attenuation away from the transformer yard was not measured. The lack of measurable static field influences at the transformer yard boundary indicated no need to measure attenuation characteristics.

The time-varying fields near the transformer yard have low average and low peak values which in general attenuate with increased distance from the yard. Some of the intermittent components which fail to show attenuation away from the yard appear to arise from a source west of the yard, possibly the inverter building.

6.3 Braking Resistor Bank

Two sets of repetitive waveform measurements were made at the north edge of the braking resistor yard at the location indicated on Figure 6-1. The field versus frequency and time and field versus distance from yard and time plots for these measurements are in Appendices S and T. Those data are summarized in Table 6-3.

The general time and frequency characteristics of the measured time-varying magnetic fields at the five probe locations are similar to those of the field at the center of the north edge of the resistor yard as shown in Figures 6-5 and 6-6. The field which is highly intermittent (only while the vehicle is braking) has both low frequency components primarily below 50 Hz and higher frequency components centered around 125 Hz and its harmonics up through at least 1500 Hz. The intensity of the field decreases at the higher harmonics. Small but continuous fields are observed at 50 Hz and approximately 375 Hz but they appear to be background fields from other sources.

The general pattern of field intensities measured at the five probe locations indicates that most of the measured time-varying fields come from the resistor banks, and most predominantly, the west bank. This is also evident from the reduction in average field level with increased distance from the bank apparent in the data of Table 6-3 for most frequency ranges. The notable exception is the power frequency field which is neither strongly distance or time

TABLE 6-3

SUMMARY DATA FOR THE MAGNETIC FIELD MEASUREMENTS AT THE NORTH EDGE OF THE BRAKING RESISTOR YARD

BRAKING RESISTOR BANK YARD, NORTH EDGE				TOTAL OF 323 SAMPLES		
FREQUENCY BAND	DISTANCE NORTH OF YARD (m)	MINIMUM MAGNETIC FIELD (mG)	MAXIMUM MAGNETIC FIELD (mG)	AVERAGE MAGNETIC FIELD (mG)	STANDARD DEVIATION (mG)	COEFFICIENT OF VARIATION (%)
STATIC	1.00	476.54	482.54	479.38	0.88	0.18
STATIC	4.00	*	*	*	*	*
STATIC	11.00	*	*	*	*	*
5-45 Hz	1.00	0.03	30.96	1.21	3.70	304.69
5-45 Hz	4.00	0.02	3.78	0.36	0.69	192.28
5-45 Hz	11.00	0.02	8.61	0.18	0.52	286.06
50-60 Hz	1.00	0.13	0.78	0.18	0.07	38.46
50-60 Hz	4.00	0.12	0.67	0.16	0.05	31.57
50-60 Hz	11.00	0.11	0.87	0.14	0.05	32.89
65-300 Hz	1.00	0.01	6.95	0.30	0.74	243.77
65-300 Hz	4.00	0.01	8.76	0.21	0.61	289.30
65-300 Hz	11.00	0.01	13.04	0.11	0.74	681.38
305-2560 Hz	1.00	0.07	2.98	0.35	0.67	191.37
305-2560 Hz	4.00	0.04	1.22	0.19	0.35	180.97
305-2560 Hz	11.00	0.01	0.74	0.05	0.09	181.04
5-2560 Hz	1.00	0.16	30.99	1.44	3.78	263.45
5-2560 Hz	4.00	0.13	9.39	0.55	0.96	173.10
5-2560 Hz	11.00	0.12	15.67	0.31	0.89	291.84

NOTE: * Data lost due to probe failure.

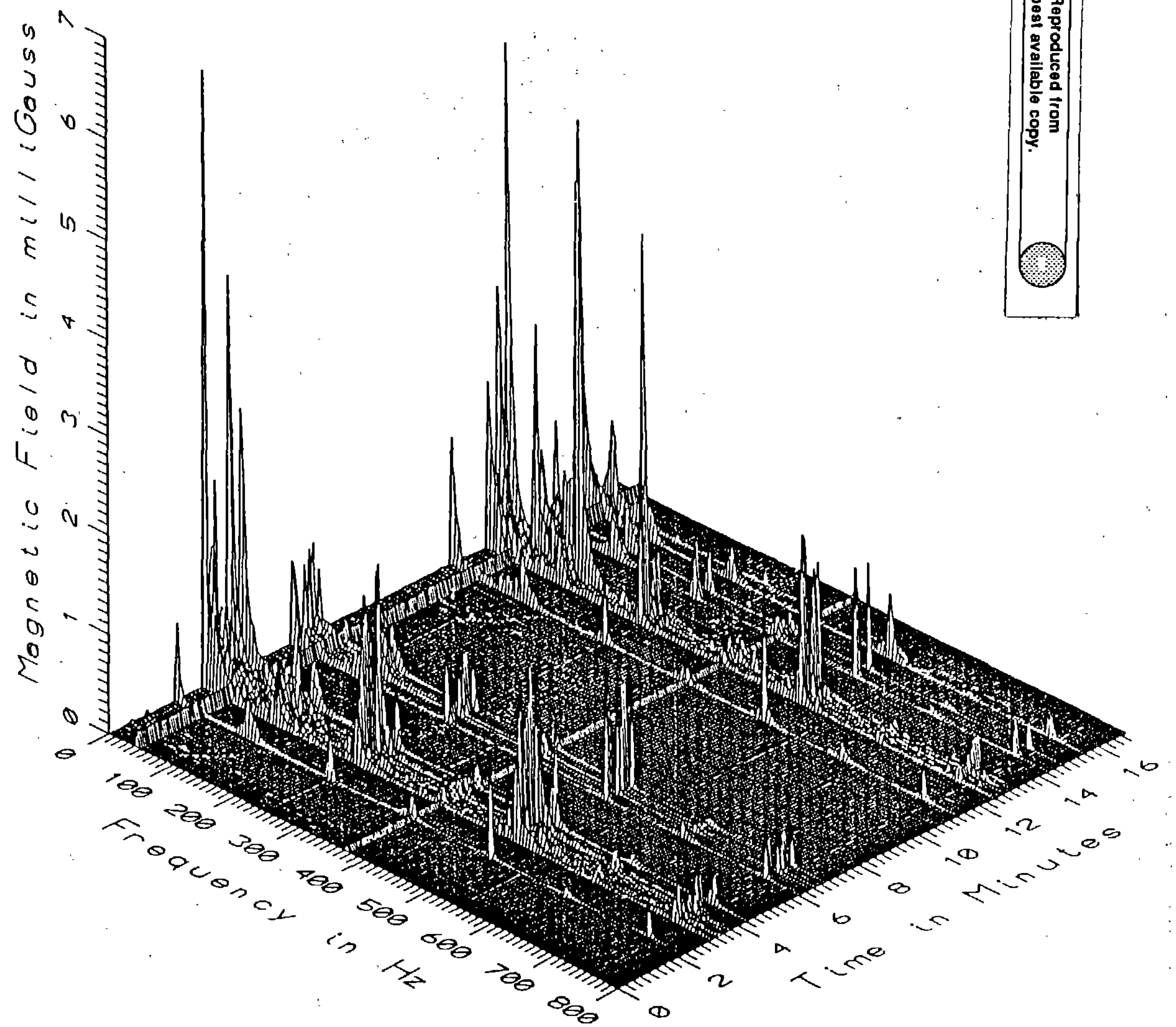


Figure 6-5 Flux density versus frequency and time for measurements with a coil-type sensor at the center of the north edge of the braking resistor yard.

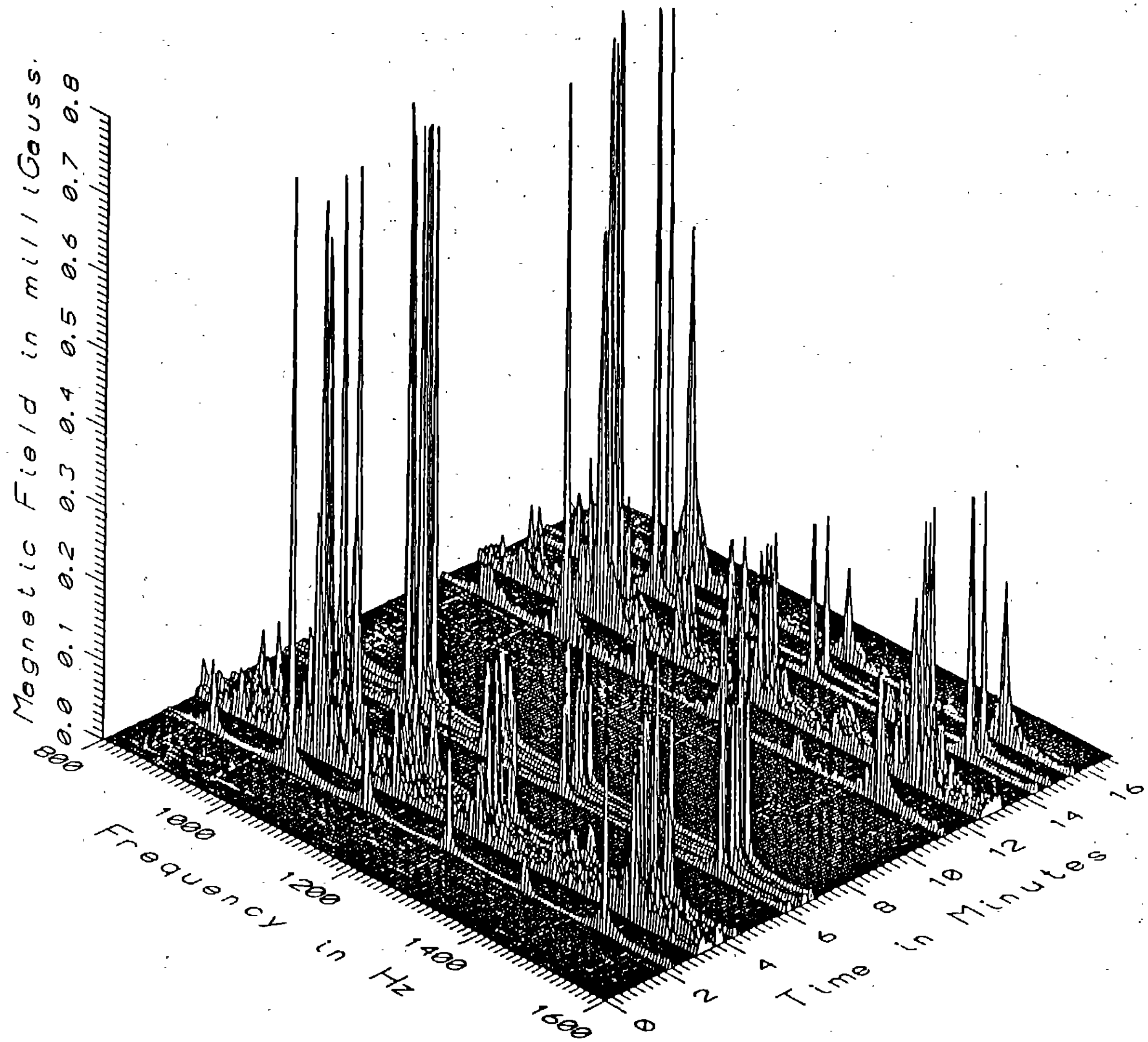


Figure 6-6 Flux density versus frequency and time for the same conditions in Figure 6-6 but at higher frequencies.

dependant. From review of the field data from the five probes, it is believed that the 50 Hz field originates from a source west of the resistor bank not the resistors themselves.

The maximum field values given in Table 6-3 also fail, in some cases, to show attenuation with increased distance from the resistor yard. That appears to result from occasional contamination of the resistor bank field data with stronger fields from the guideway as the vehicle passes by. Figure 6-7 shows attenuation curves for the time-varying magnetic fields in the 65 to 300 Hz range. During most of the times associated with resistor bank fields shown in Figure 6-5, there is an orderly and expected attenuation of field level away from the resistors. At time 770 seconds, there is the clear presence of a stronger field coming from the opposite direction, presumably the guideway. Because of this occasional contamination of the resistor bank magnetic field measurements by fields from other sources, one has to use the maximum field values given on Table 6-3 with some caution. When in doubt, the field by time and distance curves in Appendices S and T should be consulted.

The static field situation near the resistor bank is very similar to that near the transformer yard in that normal earth-strength static fields are found at the edge of the yard. The two static field sensors located at greater distances from the resistor banks (4 m and 11 m) each had one inoperative axis, hence, measurements of total static field were not obtained at those locations. The lack of effects of the static geomagnetic field levels close to the resistor banks mitigates the need for attenuation measurements.

Although the average time-varying magnetic fields near the resistor bank are small (approximately 1.5 mG) and attenuate rapidly with increased distance from the yard, they are highly intermittent and frequently have values in the 25 to 30 mG range for short periods of time.

6.4 Inverter Building

Two sets of repetitive waveform measurements were made at the northeast corner of the inverter building in the area indicated on Figure 6-1. The field versus frequency and time and field versus distance from the inverter building and time are contained in Appendices W and X. Summary data for these measurements are given in Table 6-4.

The characteristics of the magnetic field near the inverter building appear to be radically different between the first test (Appendix W) and the second (Appendix X). The vehicle was reportedly running during both tests. Magnetic fields depicted in Appendix W appear to be background levels of low level relatively continuous fields predominantly at the power frequency and its harmonics. Those shown in Appendix X are highly variable in both

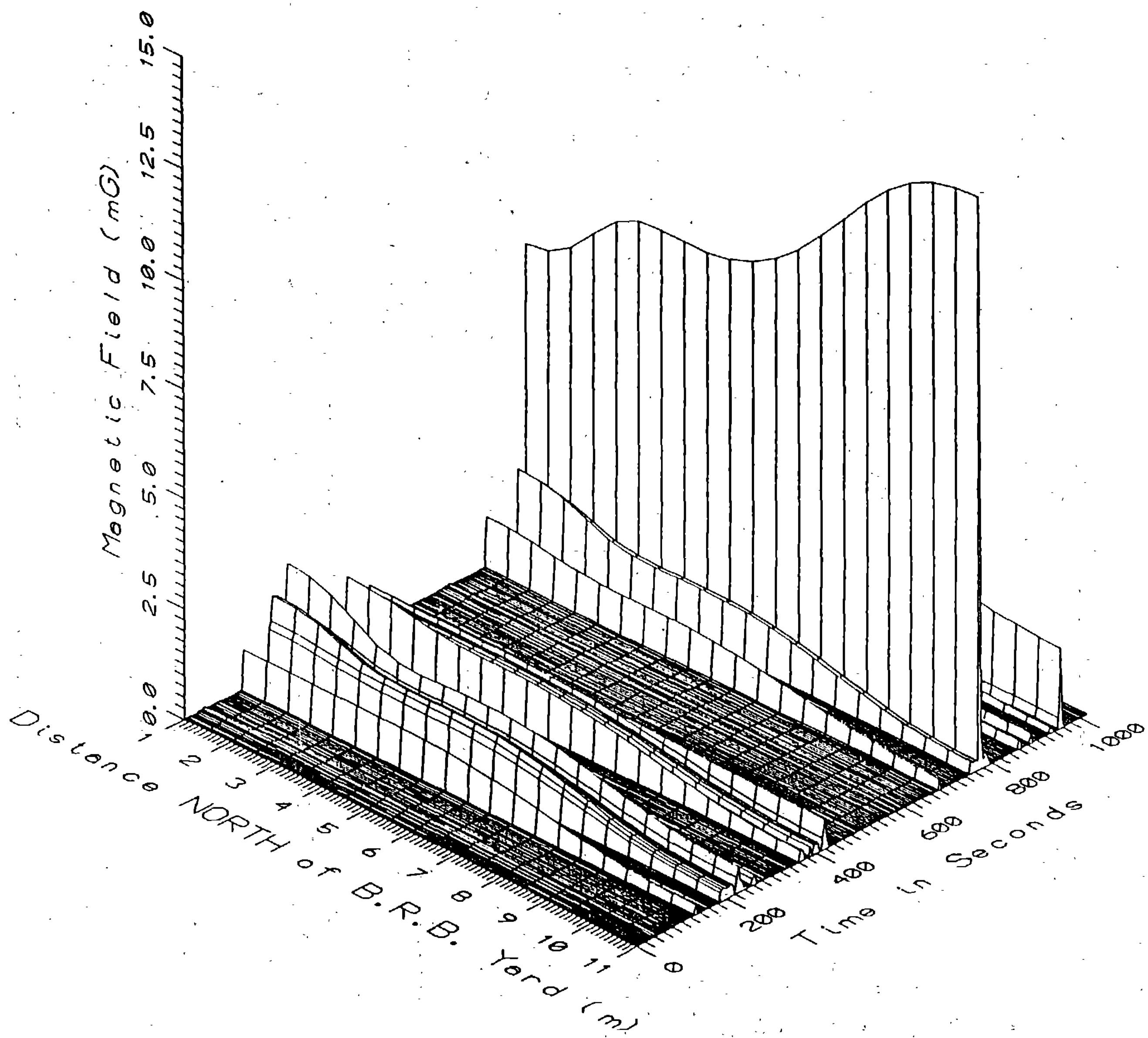


Figure 6-7 Field versus time and distance from the resistor yard for time varying magnetic fields in the 65 to 300 Hz range.

TABLE 6-4

SUMMARY DATA FOR THE MAGNETIC FIELD MEASUREMENTS AT THE NORTHEAST CORNER OF THE INVERTER BUILDING

INVERTER BUILDING, NORTH EDGE		TOTAL OF 219 SAMPLES				
FREQUENCY BAND	DISTANCE NORTH OF BUILDING (m)	MINIMUM MAGNETIC FIELD (mG)	MAXIMUM MAGNETIC FIELD (mG)	AVERAGE MAGNETIC FIELD (mG)	STANDARD DEVIATION (mG)	COEFFICIENT OF VARIATION (%)
STATIC	5.00	280.86	399.55	334.24	16.50	4.94
STATIC	15.00	*	*	*	*	*
STATIC	25.00	473.16	483.42	480.30	1.69	0.35
5-45 Hz	5.00	1.24	176.21	13.21	21.08	159.50
5-45 Hz	15.00	0.14	8.37	0.94	1.50	160.14
5-45 Hz	25.00	0.06	7.72	0.61	1.16	189.86
50-60 Hz	5.00	1.13	17.35	2.51	2.19	87.24
50-60 Hz	15.00	0.35	1.48	0.55	0.13	23.76
50-60 Hz	25.00	0.15	1.14	0.25	0.12	49.05
65-300 Hz	5.00	0.56	58.46	10.98	12.90	117.51
65-300 Hz	15.00	0.06	5.97	0.38	0.52	137.83
65-300 Hz	25.00	0.03	3.18	0.19	0.34	177.44
305-2560 Hz	5.00	0.25	10.65	2.40	1.91	79.66
305-2560 Hz	15.00	0.06	3.57	0.24	0.42	178.91
305-2560 Hz	25.00	0.06	1.78	0.16	0.25	154.01
5-2560 Hz	5.00	2.05	177.39	19.78	23.12	116.86
5-2560 Hz	15.00	0.48	8.52	1.31	1.55	118.31
5-2560 Hz	25.00	0.20	7.77	0.78	1.20	154.50

NOTE: * Data lost due to probe failure.

the time and frequency domains. These fields have characteristics similar to those of the fields at the south side of the transformer bank. Spatial distributions clearly indicate that the fields originate in the direction of the inverter building in both cases. Interestingly, the fields reported in Appendix W are similar in nature to those measured with the single probe between the inverter building and transformer yard (point A in Figure 6-1) during the high guideway measurements reported in Appendix N. It is not clear from the available information whether the difference in field conditions results from the vehicle stopped versus running from differences in operational modes, or whether during the short time interval of the first measurement, an occasional quiescent condition occurred. Because of this uncertainty, both data sets are combined in the summary data of Table 6-4. However, since there were only 6 samples in the first data set with the lower steady fields and 219 samples in the second data set where the vehicle was clearly running, the average field values in Figure 6-4 are heavily weighted by the larger data set.

Since the field by time and frequency plots near the inverter building have characteristics similar to those near the transformer yard, they will not be discussed again. Complete data are in the appendices. Instead, the field intensities and distributions will be discussed using the plots of field versus distance from the inverter building over time for the total time-varying fields given in Figures 6-8 and 6-9. They were taken from Appendices W and X respectively. Figure 6-8 shows the intensity of the total time-varying fields in the frequency range from 5 to 2560 Hz over a period of approximately 20 seconds. During this time, the field levels are low and uniform over time but attenuating with increased distance from the inverter building. Figure 6-9 or the quiescent period from approximately 110 seconds to 200 seconds along the time scale are very similar to the conditions shown in Figure 6-8 with the expanded field intensity scale. However, intermixed with these quiet periods are periods with substantially higher fields as demonstrated by Figure 6-9. These periods of higher fields continue to have a clear attenuation characteristic between 5 m and 15 m from the inverter building, but the field levels at 15 m and 25 m from the building are approximately uniform. This indicates that the buried feeder cables in the area of the sensors are contributing to the magnetic field at the 15 m and 25 m locations.

Static field levels during these measurements show no fluctuation in the static field attributable to operation of the TR07.

The apparent inconsistency between the two data sets measured near the inverter building appears to arise from the fact that the very short initial data set was collected purely by chance during a period when only low level quiescent field conditions existed. Examination of the larger data set demonstrates the existence of such quiet periods. Consequently, all of the data in Table 6-4

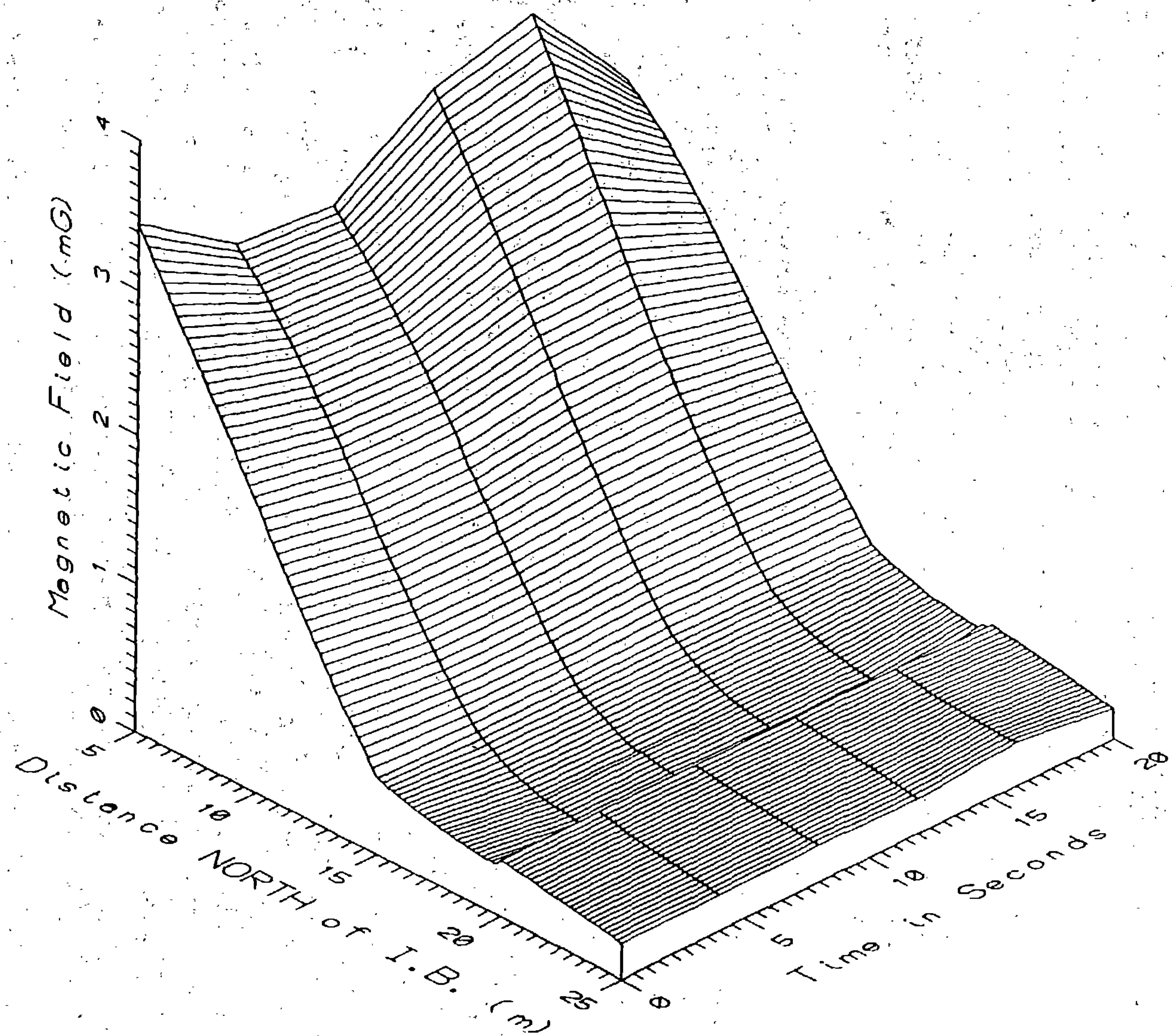


Figure 6-8 Field versus time and distance from the inverter building for time varying magnetic fields in the frequency range from 5 to 2560 Hz during the first measurements.

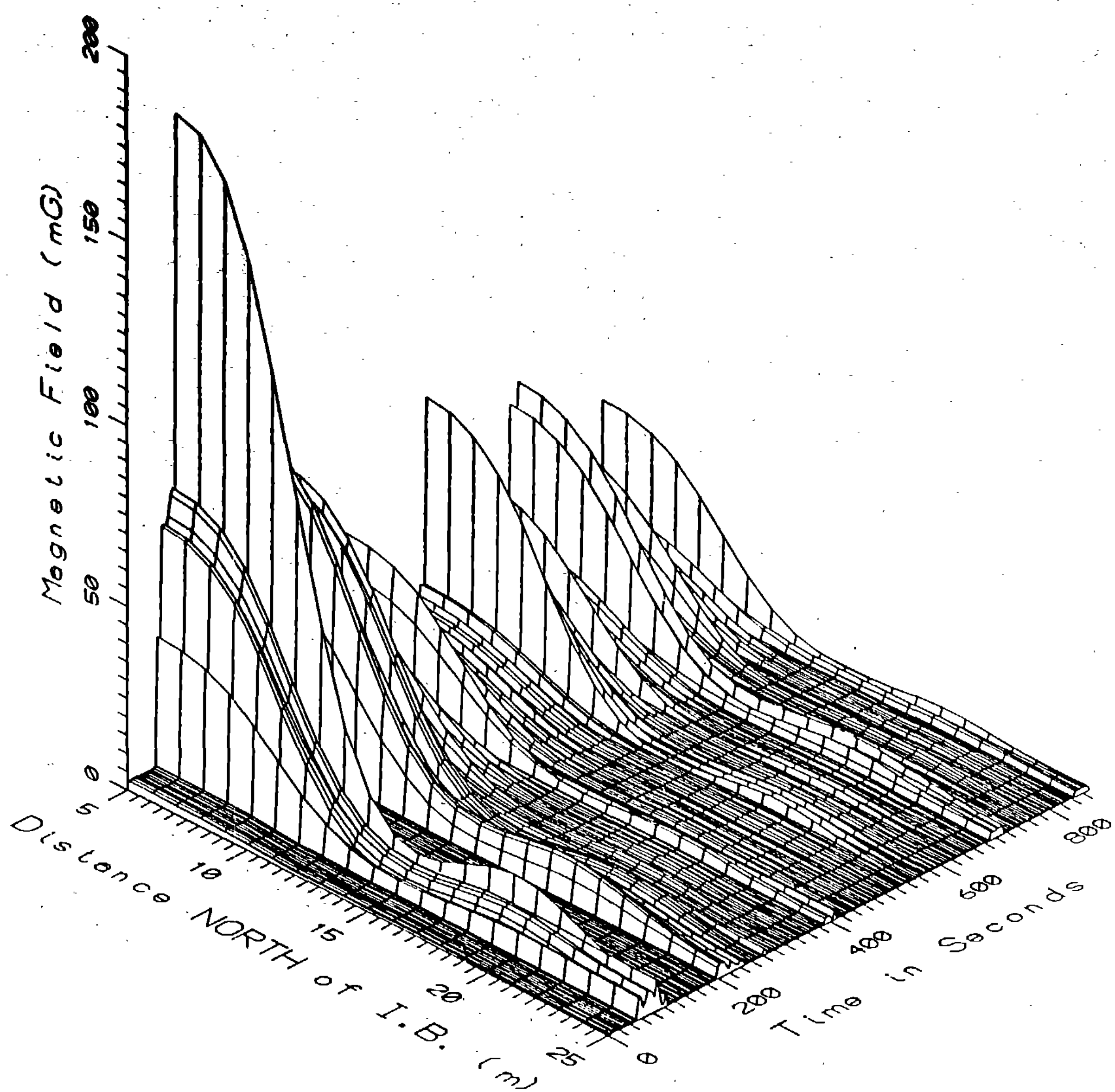


Figure 6-9 Field versus time and distance from the inverter building for time varying magnetic fields in the frequency range from 5 to 2560 Hz during the second measurements.

summarizing minimum, maximum, and average time-varying magnetic field conditions near the inverter building appear accurate.

6.5 Feeder Cables

The final component of the power supply system examined during the August 1990 magnetic field measurements was the feeder cables. Four sets of repetitive waveform data were collected at two of the sites labelled "E" and "F" on Figure 6-1. these measurements were complicated by the fact that the expected field from the buried cable was small, the background fields from other sources could be large, and the exact location of the cables was uncertain. The four relevant data sets are contained in Appendices W through Z.

Plots of total time-varying magnetic flux density as a function of distance along a line perpendicular to and crossing the presumed location of the feeder cables over time from the four data sets are provided in Figures 6-10 through 6-13. Similar plots for other frequency bands are included in Appendices W through Z.

The first test near the inverter building was during a quiescent period. Figure 6-10 indicates only very low fields, none of which appear to come from the presumed cable location.

Data from the second and longer test at this same location are given in Figure 6-11. These data provide some suggestion that part of the fields originate from one or more cables at the assumed location. Since there are reportedly four three-phase cables buried in this vicinity and they may not be in the same trench, the attenuation patterns which vary greatly from time to time may be a refection of the field patterns of the various cables. These data are summarized in Table 6-5. The average time-varying field levels at the locations 2 m east and 2 m west of the presumed cable location are typically about equal but larger than those at the more distant 6 m location. Therefore, the buried feeder cables appear to be the source of a substantial part of the field levels reported in this table.

The data in Figure 6-12 show field levels measured at ground level at 1 m increments east of the high steel guideway at a location presumed to cross the feeder cable to the south loop. Available information indicates that the cable is buried approximately 3.5 m east of the guideway centerline. The data reported in Figure 6-12 were recorded with the TR07 vehicle parked in the maintenance facility and represent background levels from other sources.

The second data set measured 1 meter above ground over the presumed cable location beneath the high steel guideway is reported in Figure 6-13. The higher field levels which occur as the overhead guideway is energized and the vehicle passes are clearly evident. The TR07 vehicle is south of the measurement point between the first and second vehicle passes (220 to 380 seconds) and after the

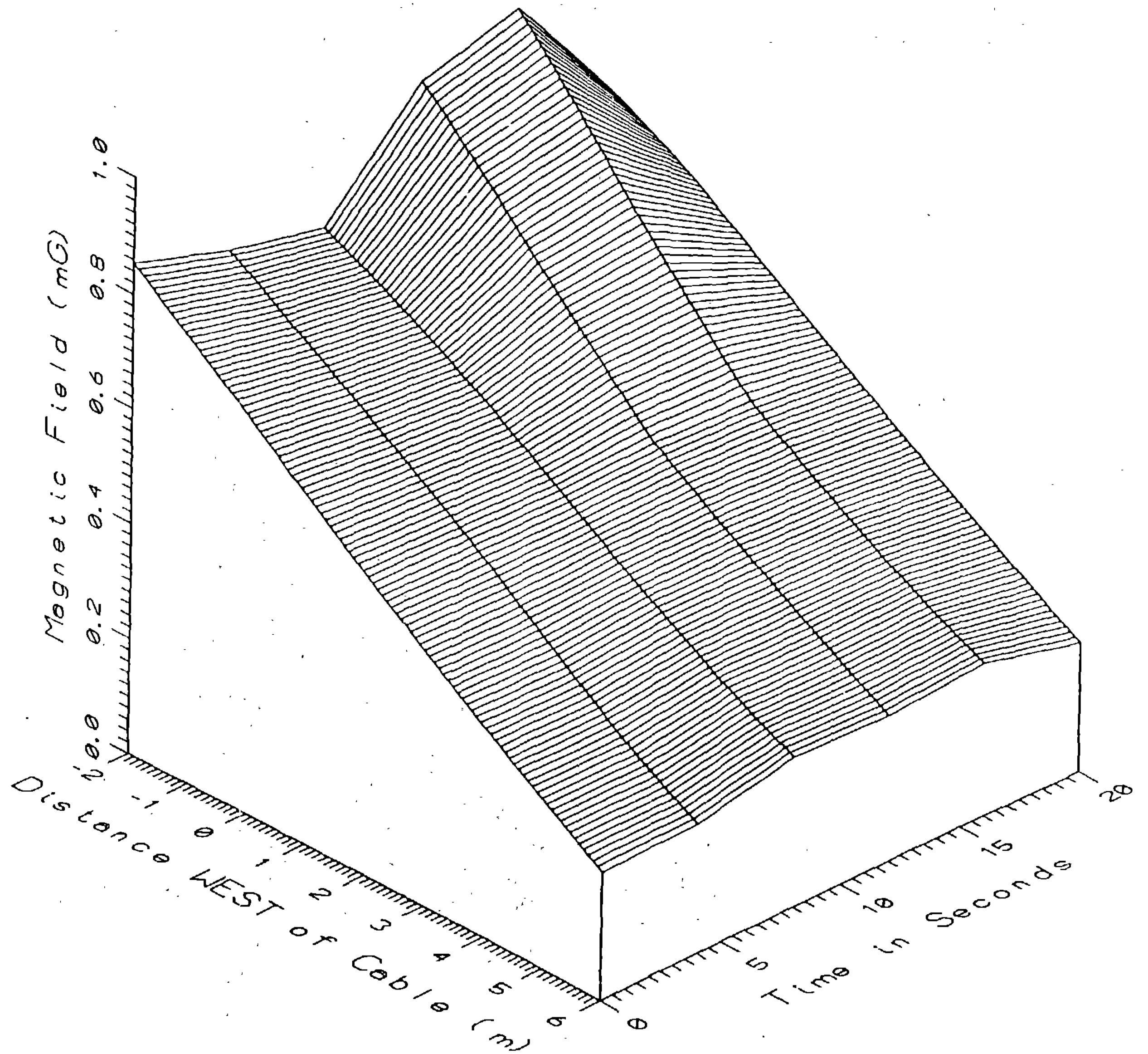


Figure 6-10 Total time varying magnetic flux density versus presumed horizontal distance from the buried feeder cable during the first test near the inverter building.

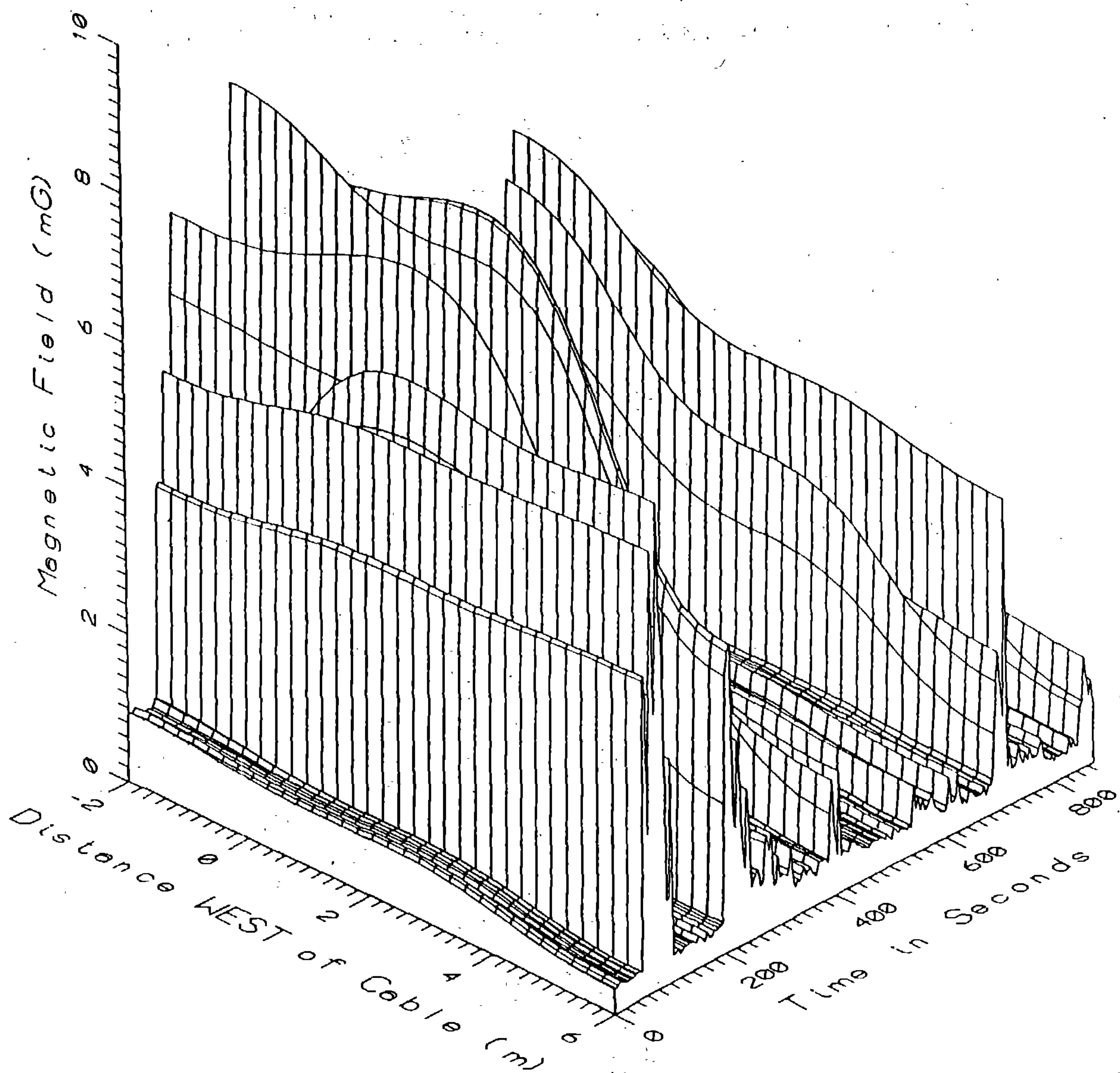


Figure 6-11 Total time varying magnetic flux density versus presumed horizontal distance from the buried feeder cable during the second test near the inverter building.

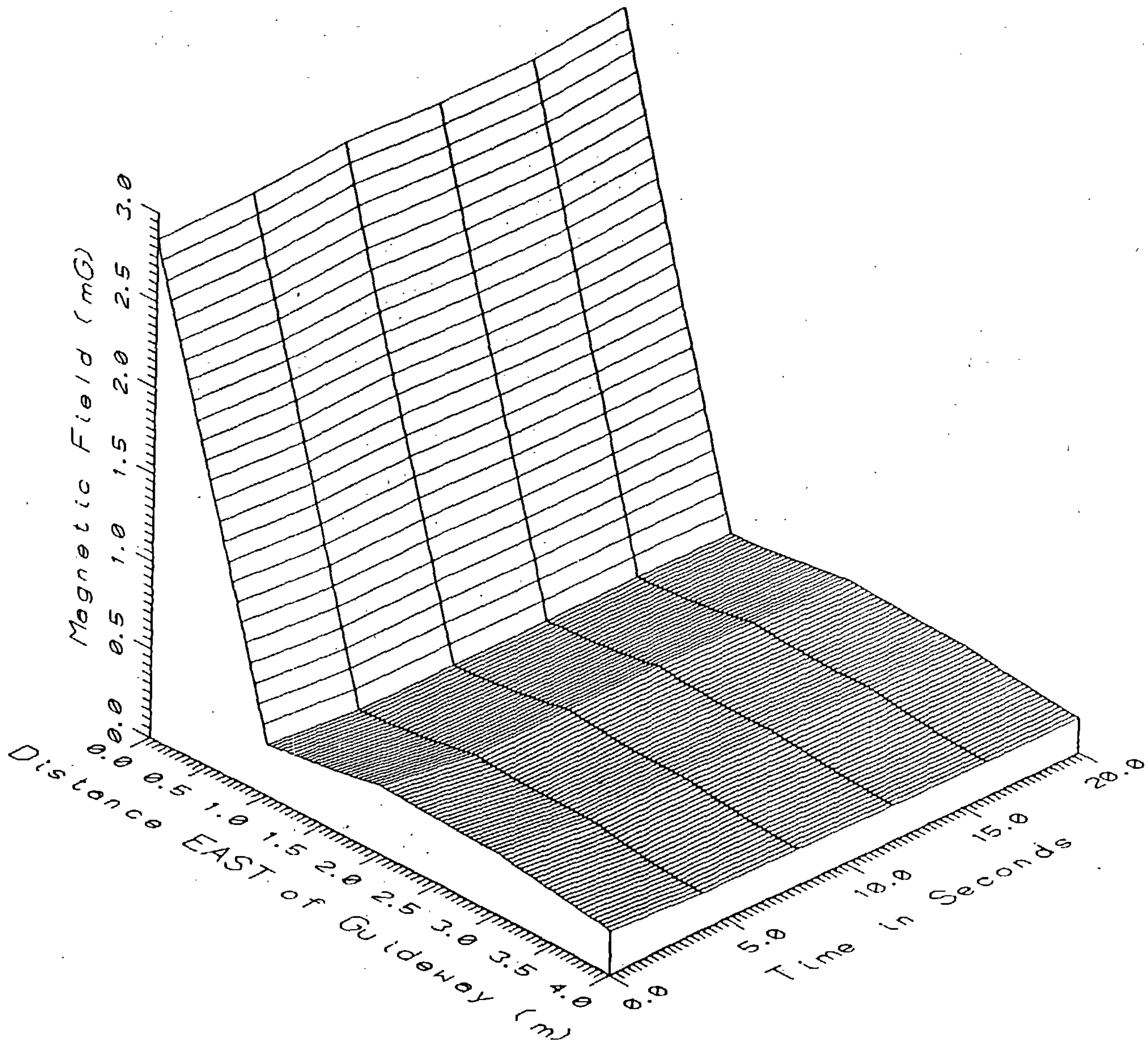


Figure 6-12 Total time varying magnetic flux density versus presumed horizontal distance from the guideway centerline during the first test beneath the high steel guideway (the presumed cable location is 3.5 m east of the guideway).

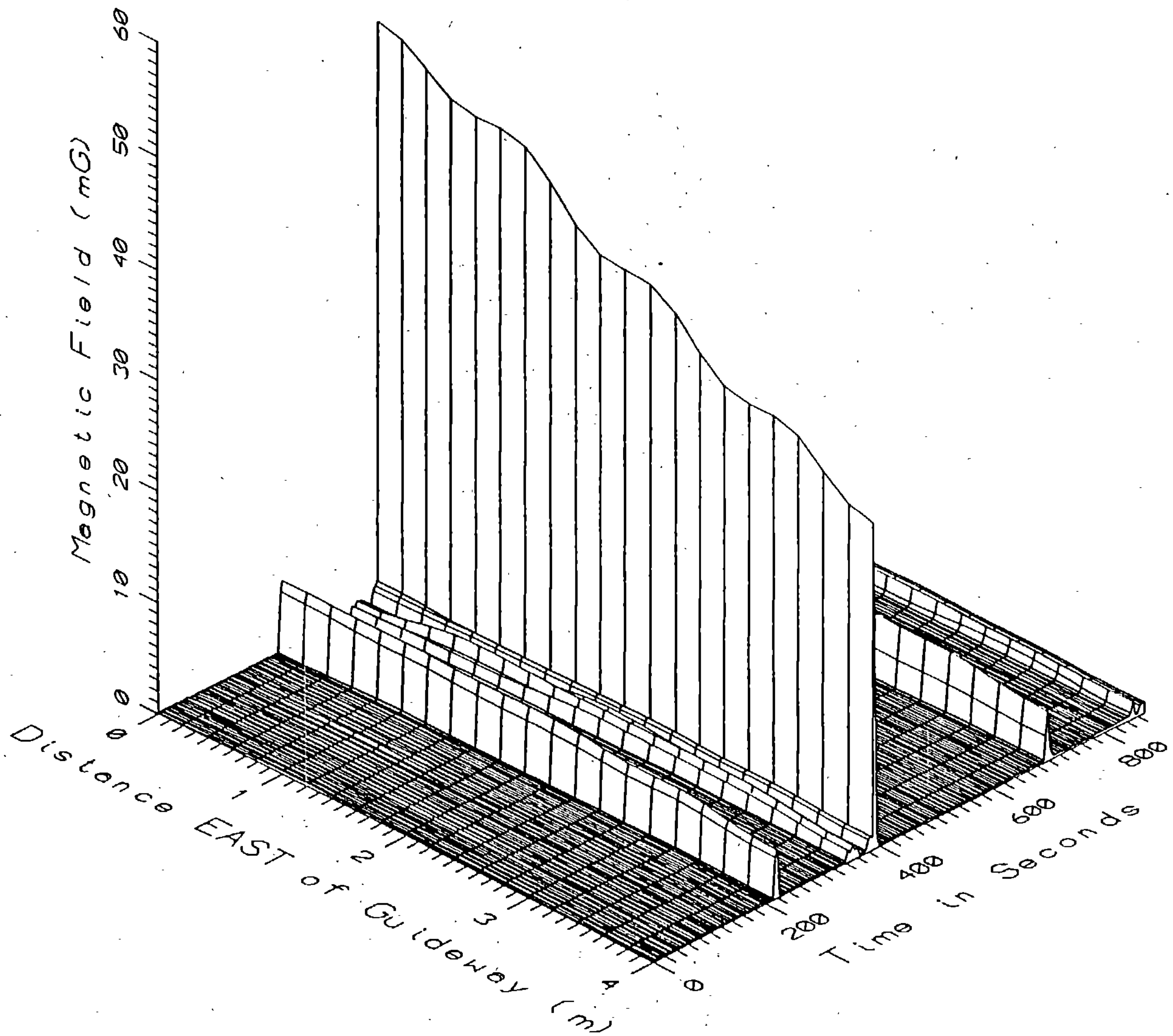


Figure 6-13 Total time varying magnetic flux density versus presumed horizontal distance from the guideway centerline during the second test beneath the high steel guideway (the presumed cable location is 3.5 m east of the guideway).

TABLE 6-5

SUMMARY DATA FOR MAGNETIC FIELD MEASUREMENTS ABOVE THE MAIN FEEDER CABLES AT A POINT 15 M NORTHEAST OF THE INVERTER BUILDING

INVERTER BUILDING BURIED FEEDER CABLE				TOTAL OF 219 SAMPLES		
FREQUENCY BAND	DISTANCE WEST OF CABLE (m)	MINIMUM MAGNETIC FIELD (mG)	MAXIMUM MAGNETIC FIELD (mG)	AVERAGE MAGNETIC FIELD (mG)	STANDARD DEVIATION (mG)	COEFFICIENT OF VARIATION (%)
STATIC	-2.00	435.86	458.84	451.10	3.62	0.80
STATIC	2.00	*	*	*	*	*
STATIC	6.00	473.66	505.54	495.24	5.21	1.05
5-45 Hz	-2.00	0.14	8.59	1.12	1.69	150.96
5-45 Hz	2.00	0.14	8.37	0.94	1.50	160.14
5-45 Hz	6.00	0.14	6.49	0.71	1.03	146.34
50-60 Hz	-2.00	0.41	1.14	0.56	0.11	19.08
50-60 Hz	2.00	0.35	1.48	0.55	0.13	23.76
50-60 Hz	6.00	0.13	0.89	0.22	0.11	48.27
65-300 Hz	-2.00	0.08	4.88	0.41	0.51	122.46
65-300 Hz	2.00	0.06	5.97	0.38	0.52	137.83
65-300 Hz	6.00	0.06	2.43	0.29	0.26	90.67
305-2560 Hz	-2.00	0.15	2.96	0.32	0.39	121.57
305-2560 Hz	2.00	0.06	3.57	0.24	0.42	178.91
305-2560 Hz	6.00	0.02	1.53	0.16	0.20	122.22
5-2560 Hz	-2.00	0.51	8.70	1.48	1.71	115.24
5-2560 Hz	2.00	0.48	8.52	1.31	1.55	118.31
5-2560 Hz	6.00	0.29	6.57	0.87	1.05	121.16

NOTE: * Data lost due to probe failure.

third pass (after 700 seconds). For the majority of the time when the vehicle is south of the measurement point, there is no indication of magnetic field from a buried cable. However, for short periods of time just before the vehicle returns to the measurement point, time-varying fields of approximately 2 or 3 mG were detected centered on a point approximately 2 m east of the guideway. These may well be the fields of the cable. Nothing else was detected.

The summary data for this data set are given in Table 6-6. Both the minimum and average time-varying magnetic fields in each frequency band show a slight increase at or near the middle probe location suggesting some influence from the buried cable. Of course, the maximum field values do not reflect the effect of the cable because the stronger field present as the vehicle passes completely masks the weak field of the cable.

TABLE 6-6

SUMMARY DATA FOR MAGNETIC FIELD MEASUREMENTS ABOVE THE SOUTH LOOP FEEDER CABLE APPROXIMATELY 3.5 M EAST OF THE HIGH STEEL GUIDEWAY

HIGH STEEL GUIDEWAY, PILLAR 2421 - BURIED FEEDER CABLE TO SOUTH LOOP 3.5m EAST OF G/W TOTAL OF 219 SAMPLES						
FREQUENCY BAND	DISTANCE EAST OF G/W (m)	MINIMUM MAGNETIC FIELD (mG)	MAXIMUM MAGNETIC FIELD (mG)	AVERAGE MAGNETIC FIELD (mG)	STANDARD DEVIATION (mG)	COEFFICIENT OF VARIATION (%)
STATIC	0.00	659.52	674.80	671.00	3.22	0.48
STATIC	1.00	*	*	*	*	*
STATIC	2.00	577.24	583.30	580.61	2.10	0.36
STATIC	3.00	544.32	553.79	550.52	1.83	0.33
STATIC	4.00	507.92	523.24	519.45	1.55	0.30
5-45 Hz	0.00	0.05	29.55	0.30	2.00	659.57
5-45 Hz	1.00	0.10	28.17	0.45	1.90	424.89
5-45 Hz	2.00	0.06	22.89	0.32	1.57	482.43
5-45 Hz	3.00	0.06	16.44	0.28	1.13	400.21
5-45 Hz	4.00	0.04	13.36	0.21	0.91	425.71
50-60 Hz	0.00	0.06	16.81	0.19	1.13	593.09
50-60 Hz	1.00	0.08	14.69	0.21	0.98	470.37
50-60 Hz	2.00	0.10	11.85	0.21	0.79	377.10
50-60 Hz	3.00	0.10	9.79	0.19	0.65	340.19
50-60 Hz	4.00	0.08	8.00	0.15	0.53	346.63

NOTE: * Data lost due to probe failure.

TABLE 6-6 (CONTINUED)

HIGH STEEL GUIDEWAY, PILLAR 2421 - BURIED FEEDER CABLE TO SOUTH LOOP 3.5m EAST OF G/W
TOTAL OF 219 SAMPLES

FREQUENCY BAND	DISTANCE EAST OF G/W (m)	MINIMUM MAGNETIC FIELD (mG)	MAXIMUM MAGNETIC FIELD (mG)	AVERAGE MAGNETIC FIELD (mG)	STANDARD DEVIATION (mG)	COEFFICIENT OF VARIATION (%)
65-300 Hz	0.00	0.02	39.00	0.36	2.73	749.08
65-300 Hz	1.00	0.02	35.94	0.36	2.53	701.97
65-300 Hz	2.00	0.01	31.79	0.34	2.25	665.61
65-300 Hz	3.00	0.02	28.48	0.30	2.01	671.83
65-300 Hz	4.00	0.01	24.60	0.24	1.73	710.19
305-2560 Hz	0.00	0.01	2.48	0.04	0.18	405.28
305-2560 Hz	1.00	0.05	2.28	0.08	0.17	205.66
305-2560 Hz	2.00	0.07	1.92	0.10	0.15	153.77
305-2560 Hz	3.00	0.08	1.66	0.11	0.13	124.19
305-2560 Hz	4.00	0.06	1.30	0.08	0.10	130.00
5-2560 Hz	0.00	0.10	51.80	0.57	3.56	627.56
5-2560 Hz	1.00	0.18	48.02	0.70	3.30	474.09
5-2560 Hz	2.00	0.15	40.98	0.60	2.85	473.87
5-2560 Hz	3.00	0.16	34.36	0.54	2.39	442.27
5-2560 Hz	4.00	0.12	29.14	0.42	2.02	476.29

7.0 CONCLUSIONS

Sections 3 through 6 of this report present the results of the analysis of extensive magnetic field data measured within the Transrapid TR07 vehicle, along the guideway, at the passenger station, and in the vicinity of the power supply equipment used to operate the system. As described in those sections, the magnetic fields at all of the aforesaid locations have complex frequency spectra and are highly variable over time. These characteristics of the magnetic fields in the TR07 vehicle and near associated equipment differ from those of the magnetic fields produced by electric power lines where the fields are predominantly 50 or 60 Hz and somewhat more temporally stable. This section of the report will compare and contrast the magnetic fields of the Transrapid System to those of other magnetic field sources common in the environment and to various ELF magnetic field standards.

7.1 Summary of Transrapid Field Levels

Passenger Compartments. The time-varying magnetic fields in the passenger compartments of the TR07 vehicle that are in the frequency range from 2.5 Hz to over 2 kHz were highly variable over time. The average field levels ranged from approximately 100 mG near the floor of the vehicle to approximately 20 mG at standing head level. Aside from the strong height dependance, the magnetic field levels were not strongly dependant on the location within the passenger compartment. The standard deviation of the magnetic field intensity over time was typically 40% of the mean value but maximum values at any height above the floor were often two and one half times the average levels. Typically, 70 to 80 percent of the time-varying magnetic fields were at frequencies below 47.5 Hz.

The static magnetic field level within the passenger compartments was dominated by the geomagnetic field at standing head level but resulted mainly from the vehicle near the floor. Fields in between were a varying mixture of fields from those sources. Average static magnetic field level (including the geomagnetic field of approximately 500 mG) near the floor was 835 mG and reduced to approximately 500 mG at standing head level. Static fields were more spatially variable but slightly more stable over time than the ELF fields. More extensive summary data for the field levels in the engineer's compartment and the passenger compartment are in Table 3-2.

The static and ELF magnetic field environment in the engineer's compartment is similar to that in the passenger compartment except there is less reduction in field intensity with increasing height above the floor. While the floor level field strengths are similar in both compartments, the field strength at other heights above the floor tend to be higher in the engineer's compartment. This difference is most pronounced at head level where the average time-varying magnetic field level in the engineer's compartment is about two and one half times greater than the average head level field in the passenger compartment. Static magnetic fields are also higher in the engineer's compartment than in the passenger compartment, but to a lesser extent. More extensive summary data for the engineer's compartment are in Table 3-5.

Near the Guideway. Elevated magnetic field levels only exist near the guideway for very brief periods of time when the guideway is energized and the vehicle is passing by. The maximum time-varying magnetic field levels within three meters of the centerline of the guideway are comparable to average field levels onboard the vehicle (65 to 95 mG) but occur for only a brief period of time. The higher fields are found near the low guideway because of its nearer proximity. At 10 m from centerline of the guideway, guideway height is less a factor in field level and the maximum time-varying magnetic field levels have fallen to approximately 20 mG. Like the fields onboard the vehicle, the magnetic fields along the guideway have a complex frequency spectrum with the largest field at frequencies below 47.5 Hz. Unless the TR07 vehicle stops and levitates, the system does not produce a static field near the guideway.

Passenger Station. Magnetic field levels at the passenger station are similar in nature to those along the guideway. Time-varying field levels at the near edge of the loading platform approach 300 mG as a vehicle passes by but people are not permitted on the platform while the vehicle is moving. Within the waiting area of the station, the maximum time-varying magnetic field produced by a passing vehicle on the energized guideway is approximately 20 mG. Like other locations along the guideway, the magnetic field is predominantly low frequency components below 47.5 Hz and occurs for only brief instances as the vehicle passes on the energized guideway near power equipment.

Magnetic fields near power equipment have different frequency and time characteristics than those onboard the TR07 vehicle or along the guideway. Furthermore, field characteristics near one piece or group of equipment differ from those near another. Although the time-varying magnetic fields near the principal pieces of equipment have very complex frequency and temporal characteristics, the average field intensities are generally below approximately 2 mG. The significant exception to that trend is the elevated field levels near the inverter building (approximately 20 mG at 5 m distance). Since this entire area is fenced with limited personnel access, frequent human exposure to magnetic fields from the power supply equipment is unlikely.

Feeder cables are the only major component of the power supply system which may be outside controlled areas. All of the attempts to measure the magnetic fields above these cables were complicated by the small fields from the cable in comparison to fields from other nearby sources. Although this situation made measurement of the cable fields somewhat imprecise, the data show that the time-varying magnetic field over the cables was less than 2 mG and attenuated quickly with distance from the cable.

The power supply equipment had no measurable effect on the static magnetic field other than passive perturbation of the field due to ferromagnetic material used in construction of structures and equipment.

A more complete summary of the magnetic field levels near the power supply equipment is provided in Tables 6-2 through 6-6.

7.2 Environmental Magnetic Field Levels

The predominant source of static field in the environment is the earth's geomagnetic field. The unperturbed geomagnetic field intensity varies over the surface of the earth from roughly 350 mG to 660 mG. The geomagnetic field level of 500 mG measured at Emsland, Germany is typical of unperturbed mid-latitude geomagnetic field levels. The presence of iron and steel components in buildings, vehicles, and structures perturbs the geomagnetic field in the vicinity of those objects making the geomagnetic field intensities routinely encountered by people somewhat more variable. Field levels ranging from 200 mG to 1000 mG are frequently found.

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

The overwhelmingly predominant source of ELF magnetic fields in the environment is the 50 or 60 Hz magnetic field produced by virtually all equipment or facilities which generate, distribute, or utilize electric power. Due to the electrification of our modern society, power frequency (60 Hz in North America, 50 Hz in Europe and many other places) magnetic fields are ubiquitous. Numerous authors have reported environmental levels of power frequency magnetic fields for specific situations. Nair, et al[6] provides a summary of that information as well as useful insight into the parameters which affect power frequency magnetic fields. Figure 7-1 shows the range of power frequency magnetic field levels which may be found at various distances from three important sources of magnetic field.

Power frequency magnetic fields in American homes arise primarily from three sources: outdoor power lines; house wiring; and household appliances. Field levels for power lines and appliances are summarized on Figure 7-1. Field levels from house wiring differ greatly from home to home. The total power frequency

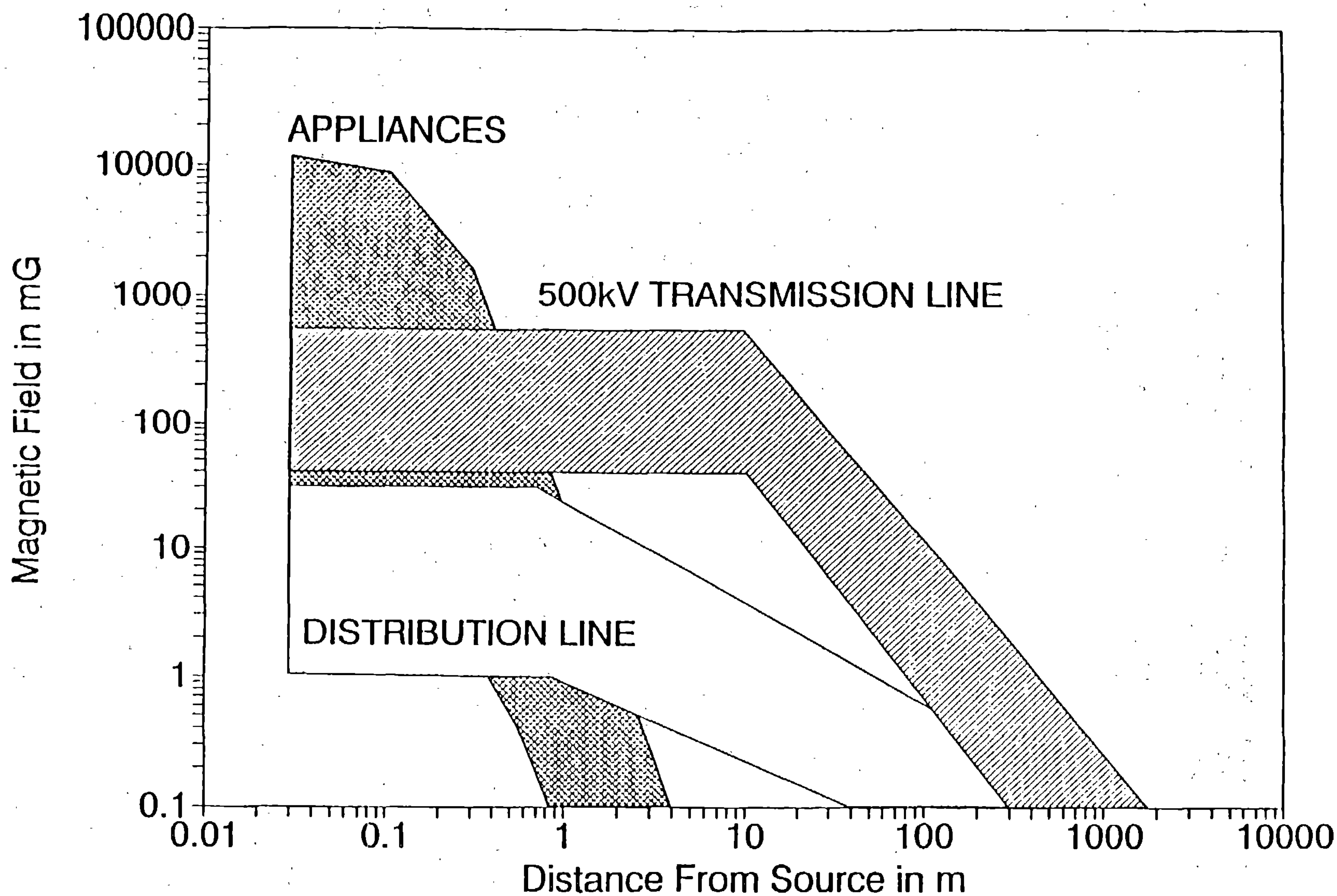


Figure 7-1 Illustration of how the magnetic field intensity at ground level changes with horizontal distance from three common sources of power-frequency magnetic fields. The bands represent variation across individual sources in each group. Adapted from Nair et al[6].

magnetic fields in homes is typically about 0.7 mG[6,7] at the center of each room but can vary substantially from room-to-room or home-to-home. Magnetic field levels in excess of 10 mG at the center of a room are atypical but not terribly uncommon.

Power frequency magnetic field levels in the workplace are highly variable. In offices and most commercial establishments, the power frequency magnetic field environment is similar to or somewhat higher than that in homes. But in certain industrial settings, considerably higher ELF magnetic field levels are encountered[8]. Unfortunately, field characterization in the workplace is limited to a small number of measurements which lack validity as indicators of "typical" or "overall" estimators of workplace magnetic field levels.

These common environmental sources of ELF magnetic field are predominantly power-frequency field sources. Magnetic fields near power line and substations may have low order harmonic components, but these are generally only a small percentage of the fundamental power frequency component[7]. The harmonic content of residential and most workplace magnetic fields is also generally quite low, but on occasion can become a significant part of the total field. High harmonic content appears most frequently in magnetic fields near appliances containing non-linear electrical load control devices. Figure 7-2 shows a field by frequency and time plot for the magnetic field produced by a triac-controlled vacuum cleaner. Although the harmonic content is relatively large, only the lower order harmonics have significant amplitude. Essentially no energy is present at frequencies below the power frequency. This is characteristic of the magnetic fields produced by many appliances with electronic controls.

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

Other significant sources of non-power-frequency ELF magnetic fields are headphones and telephone receivers which produce relatively intense voice-frequency magnetic fields in the vicinity of the user's ear. However, these fields attenuate quickly with distance from the earpiece. Certain pieces of industrial and medical equipments also produce relatively large ELF magnetic fields at frequencies other than 50 or 60 Hz, but they are not frequently encountered by the general public.

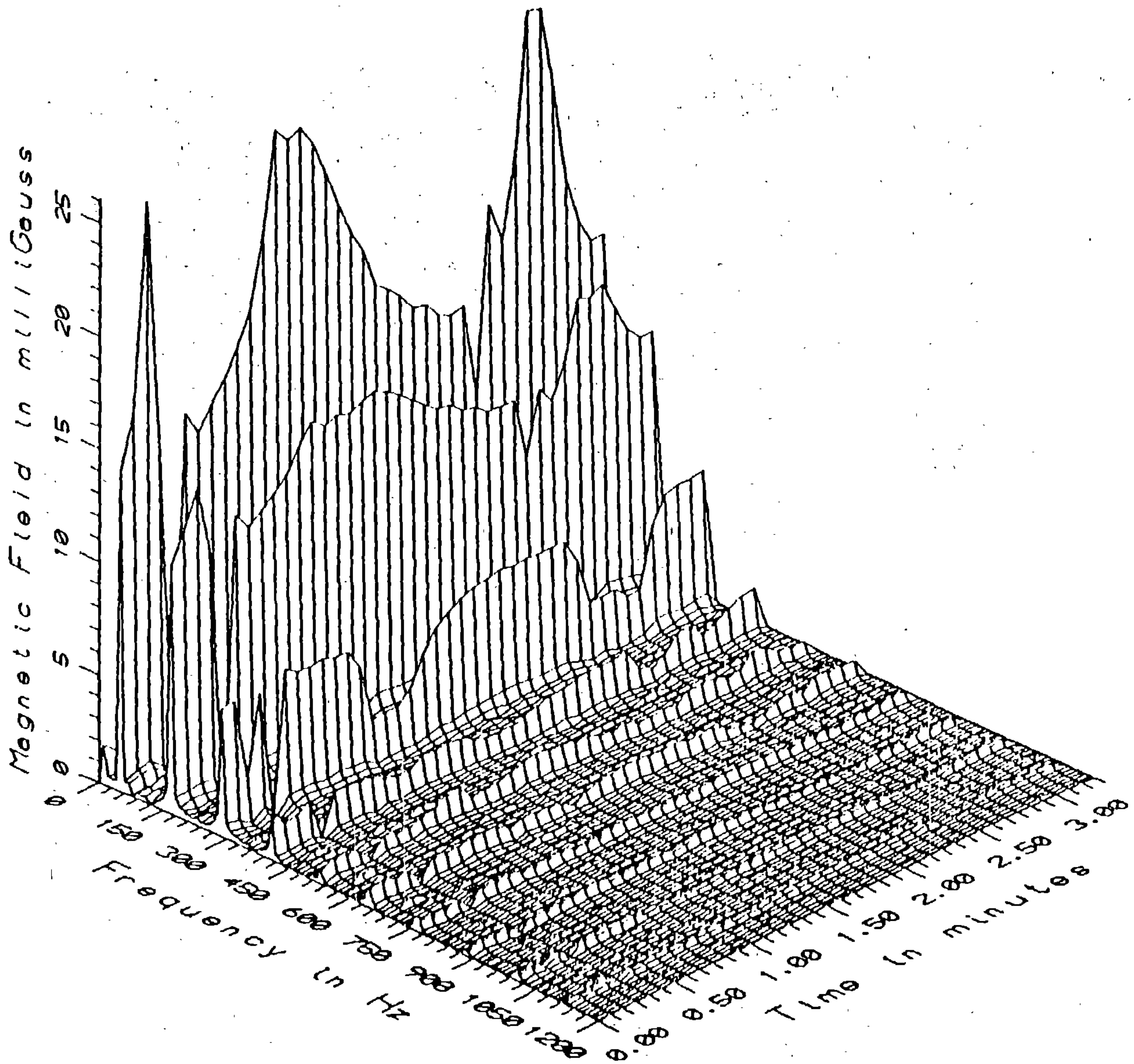


Figure 7-2 Magnetic field 30 cm from a shop vac.

7.3 Comparison of Transrapid Fields to Other Environmental Magnetic Fields

Much of the concern about ELF magnetic field levels is driven by uncertainty as to whether such fields exert an adverse effect on human health. By the very nature of that uncertainty, existing scientific knowledge provides no sound insight as to what aspects of ELF magnetic exposure, if any, are of biological concern[6]. Consequently, public acceptance of magnetic field exposures is presently based more on equity and comparability to other exposures than it is to quantifiable characteristics of the field itself. It is in that light that this section compares and contrasts the magnetic fields produced by the Transrapid TR07 System to other environmental magnetic fields.

Static Fields

The static fields encountered onboard the TR07 vehicle (mean values from 500 to 1000 mG) are generally within the range of static fields encountered daily in the perturbed geomagnetic field (250 to 1000 mG). The peak values encountered near the floor of the vehicle are comparable to those near a refrigerator which is equipped with a magnetic door seal. The magnitude of the static field onboard the TR07 vehicle has substantial temporal variability. Sizeable changes in static field intensity occur more frequently and more rapidly than do most changes in the geomagnetic field which result from walking past a perturbing steel object such as a steel column or beam.

Static field conditions at the station, along the guideway, or near power supply equipment are essentially all geomagnetic fields with no significant contribution from active operation of the TR07 System.

Field Frequency

The frequency characteristics of the time-varying magnetic fields onboard the TR07 vehicle, at the station, near the guideway, and near the power supply are unique from those that have been measured to date anywhere else in the environment. There are no compelling scientific data available which demonstrate that field frequency is a significant parameter in adverse effects of ELF magnetic field exposure on human health or how that parameter should be evaluated[6]. However, there are a number of proposed mechanisms of interaction and a variety of experimental studies which suggest that frequency characteristics of the magnetic field are equally important as intensity parameters for eliciting a biological response. Consequently, a comparison of fields from various sources should include a comparison of frequency characteristics.

The magnetic fields onboard or near the TR07 System generally have their largest components at frequencies below the power frequency; a frequency range where other common field sources produce little or no magnetic fields. Undoubtedly, there are industrial or scientific facilities which produce magnetic fields in these subpower frequency ranges but there are no data currently available for comparison.

The fields produced by the TR07 in the power frequency range are generally a small portion of the overall field while the converse is true for most environmental fields. The notable exception is near the transformer yard where the power frequency field predominates. Onboard the TR07 vehicle and along the guideway, the field varies in frequency within the power frequency band of 47.5 to 62.5 Hz while for other common sources, the frequency is stable at 50 Hz or 60 Hz.

The magnetic fields produced by the TR07 propulsion system in the frequency range of 62.5 Hz to 302.5 Hz are in terms of frequency comparable to environmental magnetic fields produced by harmonic distortion in the power frequency electric current in wiring and appliances. Again, there is the difference that the frequency of the TR07 System is more continuously variable throughout the frequency range than the discrete harmonic steps of most environmental fields.

The higher frequency magnetic fields produced by the TR07 System at frequencies well above 300 Hz are for purposes of comparison to environmental fields like those below the power frequency. Very little data are available on environmental magnetic fields in the frequency range above 300 Hz.

Time Characteristics

The magnetic fields produced by the TR07 System are highly variable over time, especially at the station and along the guideway. Most other sources of environmental ELF magnetic fields tend to be more stable in frequency and intensity over time. To date, characterization of intermittent fields near appliances and industrial equipment is very limited, consequently there does not exist a data base against which the temporal fluctuations of the TR07 fields can be compared.

Although the intermittency of magnetic fields has been suggested as a factor of possible biological significance, experimental data supporting that suggestion is rather limited.

Amplitude Characteristics

Notwithstanding the aforementioned need to compare the temporal and frequency characteristics of various ELF magnetic fields, this subsection will compare the measured field levels onboard and near Transrapid TR07 facilities to reported environmental field levels from various power frequency sources. The lack of comparable environmental field data in several of the frequency bands makes any other approach unworkable. The reader must be aware that the comparison of the total ELF fields of the TR07 System to the predominantly power frequency environmental field levels currently reported in the literature is an "apples and oranges" comparison because frequency and temporal characteristics have been ignored in this comparison.

Passenger Compartment

Figure 7-3 shows the range of total time-varying magnetic fields measured in the passenger compartment of the TR07 vehicle as a function of height above the floor (from Table 3-2 or Figure 3-15) plotted over the graph of typical power line and appliance field levels[6] reported in Figure 7-1. As the graph illustrates, the intensity of the ELF magnetic field within the vehicle falls well within the range of magnetic fields near appliances but attenuates less rapidly. The TR07 field levels are well above those typically found in homes or offices at locations away from appliances but within the range of magnetic fields found in the vicinity of larger electric power transmission lines.

Engineer's Compartment

Figure 7-4 shows the range of total time-varying magnetic fields recorded in the engineer's compartment as a function of height above the floor (from Table 3-5 or Figure 3-24). As in the preceding figure, these data are plotted over the graph of typical power frequency field levels given in Figure 7-1. Again, the engineer's compartment field levels are comparable to those near appliances or larger transmission lines but greater than those in most homes and offices. The fields in the engineer's compartment are not outside the range of fields encountered in other specialized workplaces.

Near the Guideway

Power frequency magnetic fields at various distances from the guideway (taken from Tables 4-2 to 4-4) are plotted over the attenuation curves for power frequency magnetic fields from other common sources in Figure 7-5. As described above, the field levels near the guideway vary greatly with time. Maximum fields which occur for brief periods when the guideway is energized and the vehicle is passing by are comparable in intensity to the power frequency magnetic fields near larger transmission lines, but these fields do not extend as far from centerline as do transmission line fields.

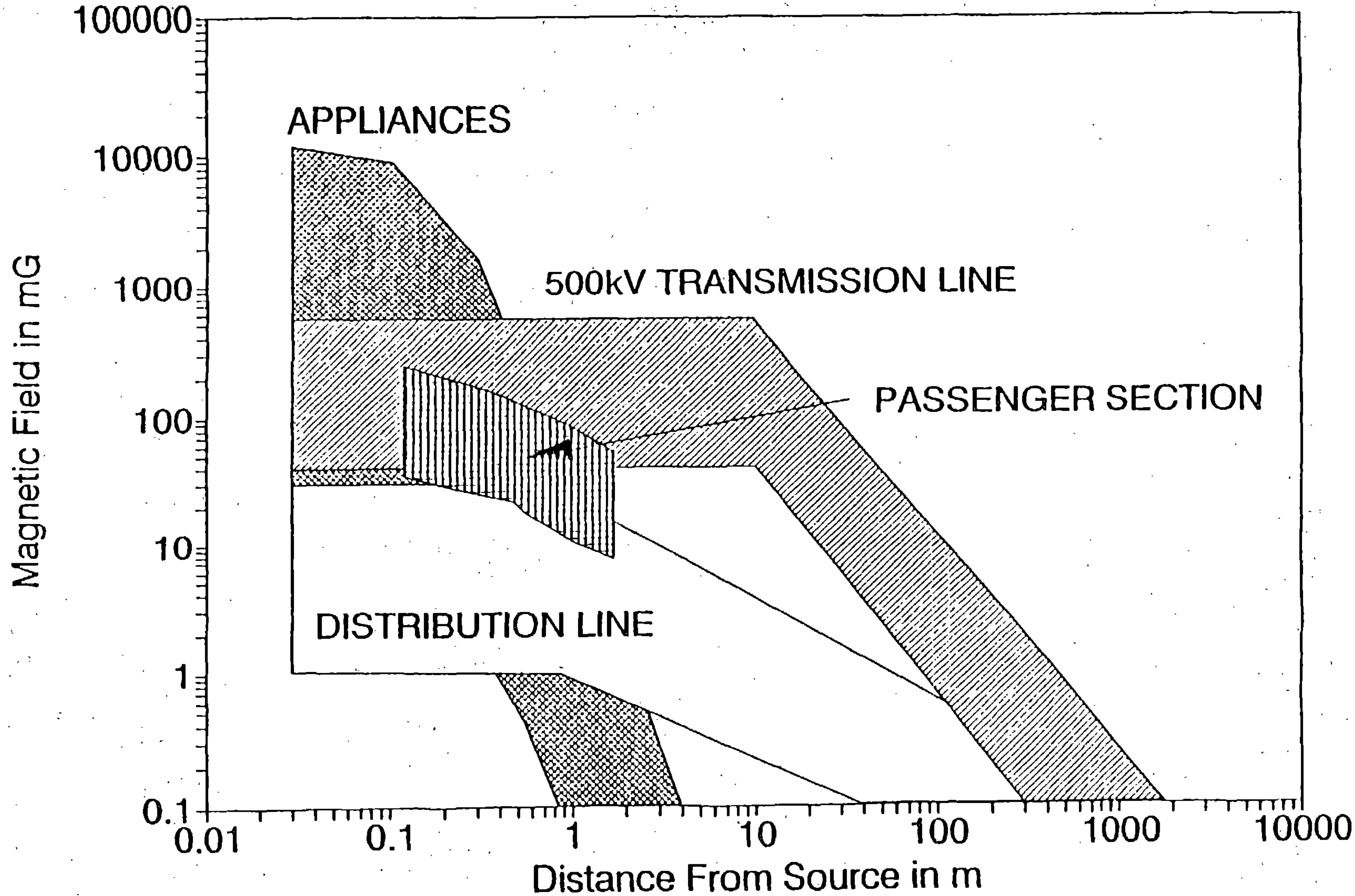


Figure 7-3 Comparison of the range of time varying magnetic field within the passenger compartment of the TR07 vehicle as a function of height above the floor to power frequency magnetic fields from other sources.

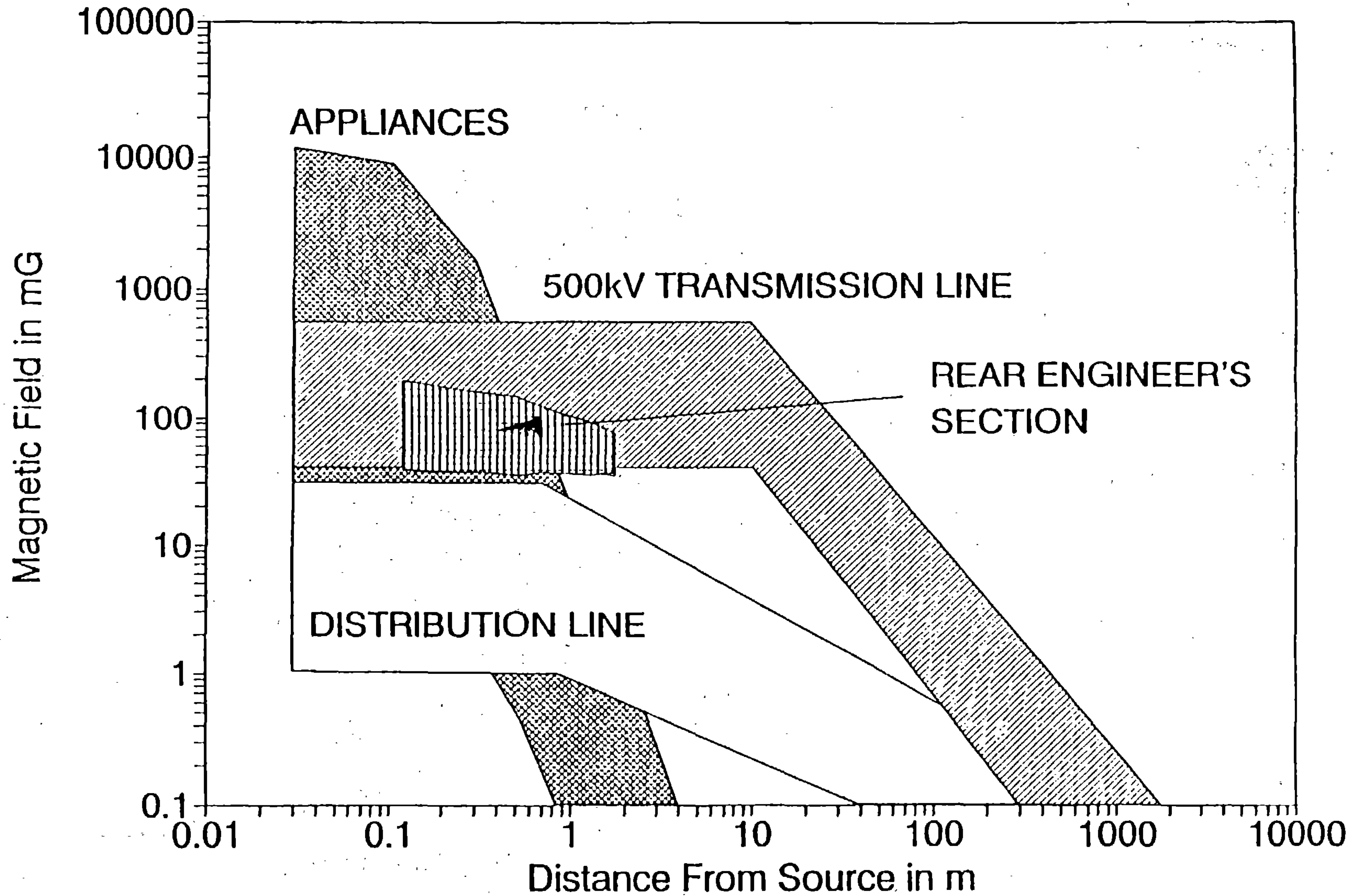


Figure 7-4 Comparison of the range of time varying magnetic field within the engineer's compartment of the TR07 vehicle as a function of height above the floor to power frequency magnetic fields from other sources.

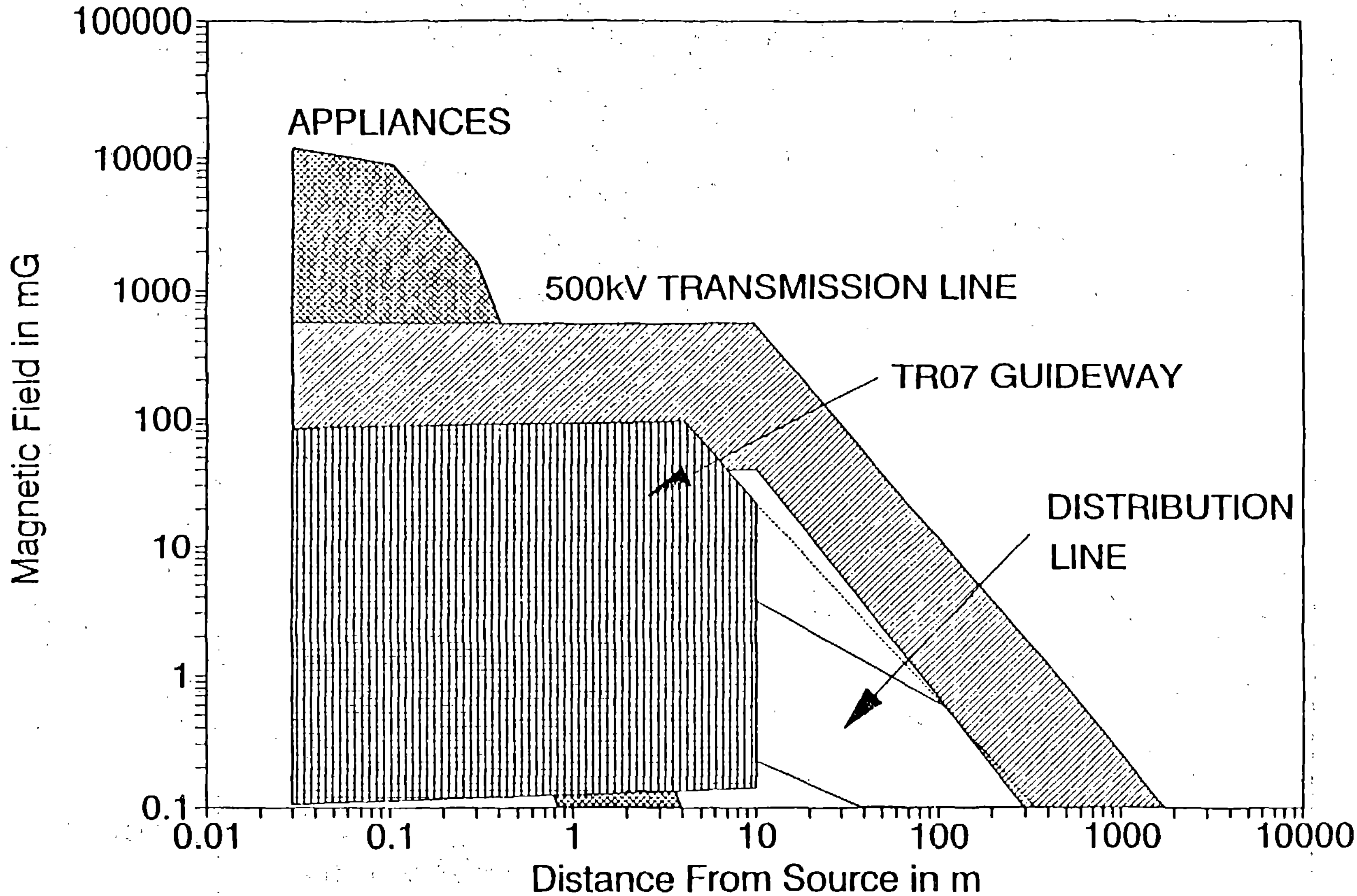


Figure 7-5 Comparison of the range of time varying magnetic field near the guideway of the TR07 vehicle to power frequency magnetic fields from other sources.

Magnetic fields from the guideway undoubtedly extend beyond ten meters where the most distant measurement was taken. Expected maximum values beyond the 10 meter point are indicated as a dashed line. The majority of the time, the guideway is not energized and the magnetic fields are well less than those in most homes or near typical electric distribution lines. The minimum field levels measured near the guideway are background fields from sources other than the guideway. The actual minimum field from the guideway is well less than the minimum level depicted on Figure 7-5.

Passenger Station Platform

The range of time-varying magnetic fields measured at the passenger station (Table 5-1) is shown in relationship to the power frequency magnetic fields from other sources on Figure 7-6. Since fields are only present as the vehicle passes, the maximum field shows attenuation characteristics similar to those near the guideway. Other times, the minimum field is very small and arises from sources other than the guideway. Since field measurements were only taken at two locations, only the hatched portion of the curve representing station field levels is documented. Expected minimum field levels beyond that range, indicated by dashed lines, are projected based on floor level fields within the vehicle and extrapolation based on the established field attenuation pattern away from the guideway. As with the peak fields at other locations along the guideway, the magnetic fields at the passenger station platform are comparable to those near an electric transmission line but occur for only brief periods of time and do not extend as far from centerline of the facility.

Transformer Yard

The range of total time-varying magnetic fields at various distances from the edge of the transformer yard taken from Table 6-2 is plotted over typical attenuation curves for power frequency magnetic fields from common sources in Figure 7-7. As discussed in Section 6, it is suspected that on some occasions, the measured magnetic field near the transformer yard was corrupted by strong magnetic fields from other sources. Hence, the maximum field levels may be a poor indicator of overall field attenuation characteristics. Consequently, the mean values of the transformer yard data at each measurement point are plotted and are believed to provide a better indication of the overall field attenuation pattern. As Figure 7-7 indicates, the magnetic field levels near the transformer yard are of similar magnitude or less than the power frequency magnetic fields of other electrical facilities such as distribution lines at comparable distances. At 10 m from the transformer yard, the ELF magnetic field level is of the same magnitude as the power frequency magnetic field in

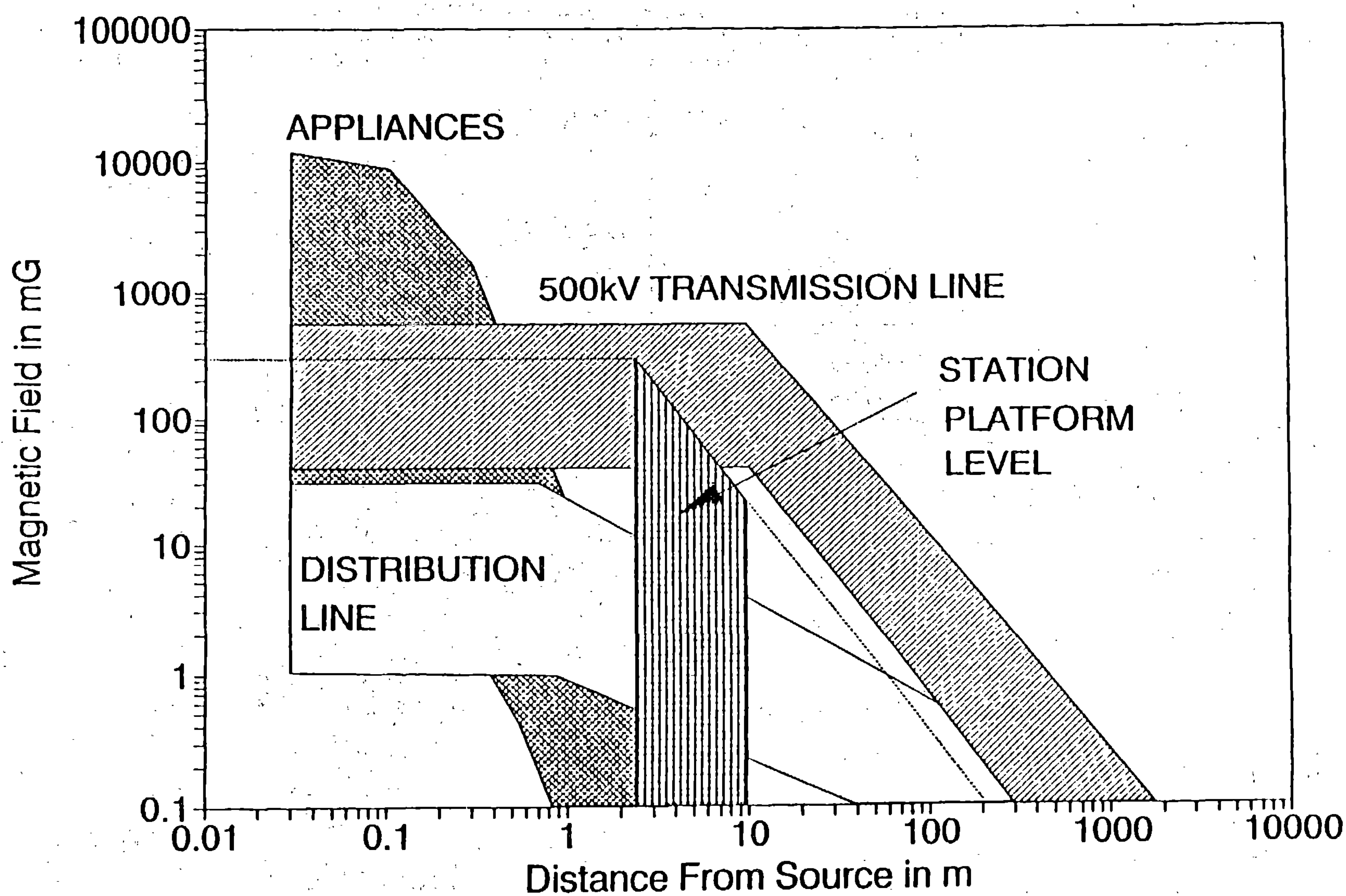


Figure 7-6 Comparison of the range of time varying magnetic field at the TR07 station platform level to power frequency magnetic fields from other sources.

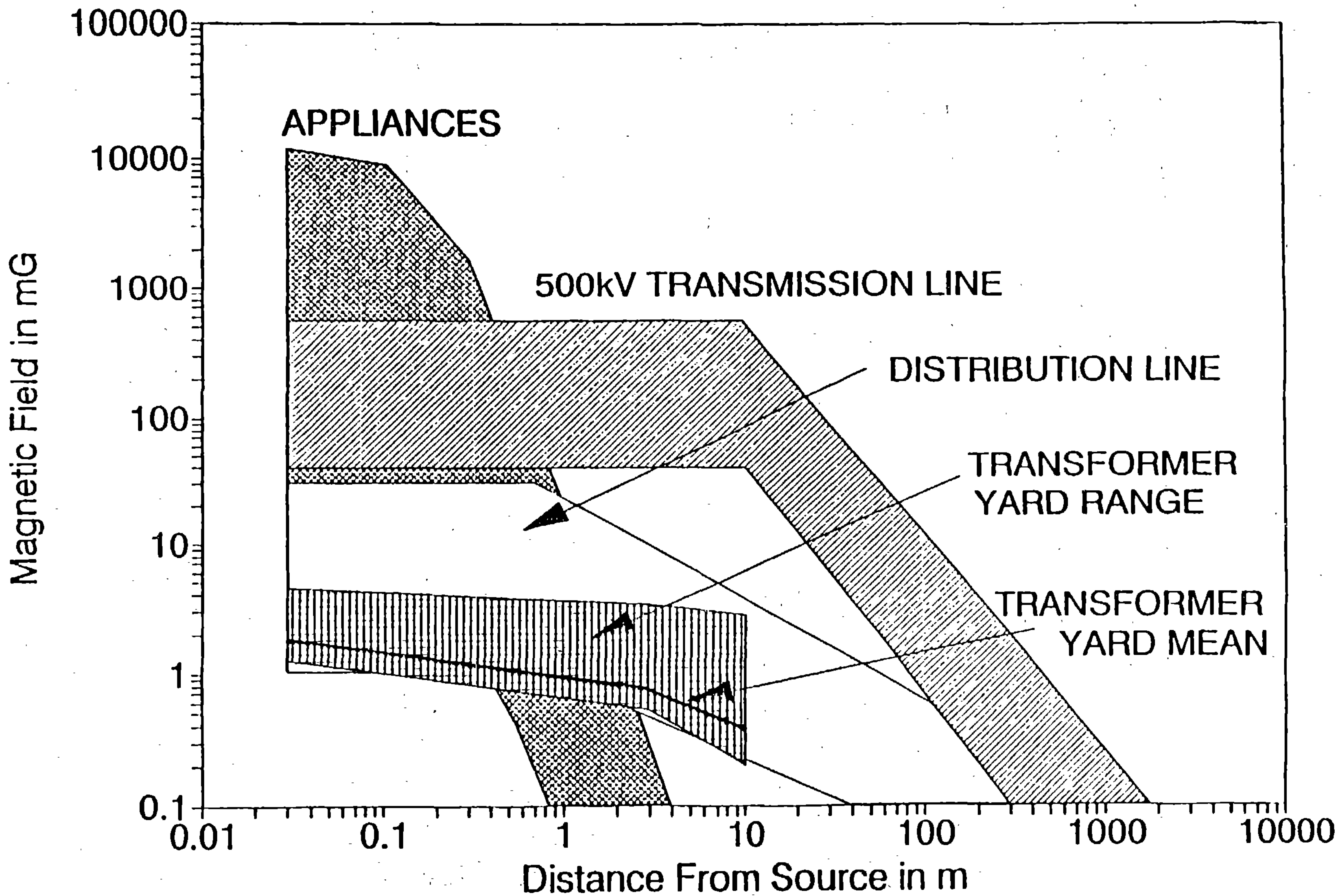


Figure 7-7 Comparison of the range and mean level of time varying magnetic field at increasing distances from the edge of the transformer yard to power frequency magnetic fields from other sources.

typical American homes. Measurements were not made beyond 10 m from the yard, but extrapolation of the indicated attenuation pattern suggests that the field level from the transformer yard will attenuate at least as rapidly as that indicated for distribution lines.

Braking Resistors

Data for time-varying magnetic fields near the braking resistor yard from Table 6-3 are compared to power frequency magnetic fields from common sources in Figure 7-8. The field levels are highly variable depending on whether the TR07 vehicle is using its dynamic braking capability. The magnitude of magnetic fields near the resistor banks is generally equal or less than the magnitude of power frequency magnetic fields found at comparable distances from distribution lines. The maximum magnetic field appears to increase with greater distance from the resistor banks but that is a result of data corrupted by occasional high levels of magnetic fields from a vehicle passing on the nearby guideway. The mean values of the field provide a better indication of the overall field attenuation rate because they are only minimally affected by occasional fields from other sources. Extrapolation of the resistor bank data to distances greater than 10 m indicates that the resistor bank magnetic fields will remain equal to or weaker than the power frequency magnetic fields from distribution lines at comparable distances.

Inverter Building

Magnetic field data measured near the inverter building and reported in Table 6-4 are compared to power frequency magnetic fields from other sources in Figure 7-9 using the same format used for the earlier comparisons. Extrapolation of the field levels outside the range of measurements is probably unreliable in this case for a variety of reasons. Nevertheless, the comparison indicates that the magnitude of the time-varying magnetic field levels outside the inverter building are in the range of intensities of power frequency magnetic fields at comparable distances from major electric power facilities.

Underground Feeder Cables

The measurements of the relatively weak time-varying magnetic fields above the buried feeder cables were complicated by the presence of large magnetic fields from other sources. Consequently, the summary field data in Tables 6-4 and 6-5 provide only an upper bound for cable field levels. The data from summary Table 6-4 are plotted in Figure 7-10 for comparison to power frequency magnetic fields from more common

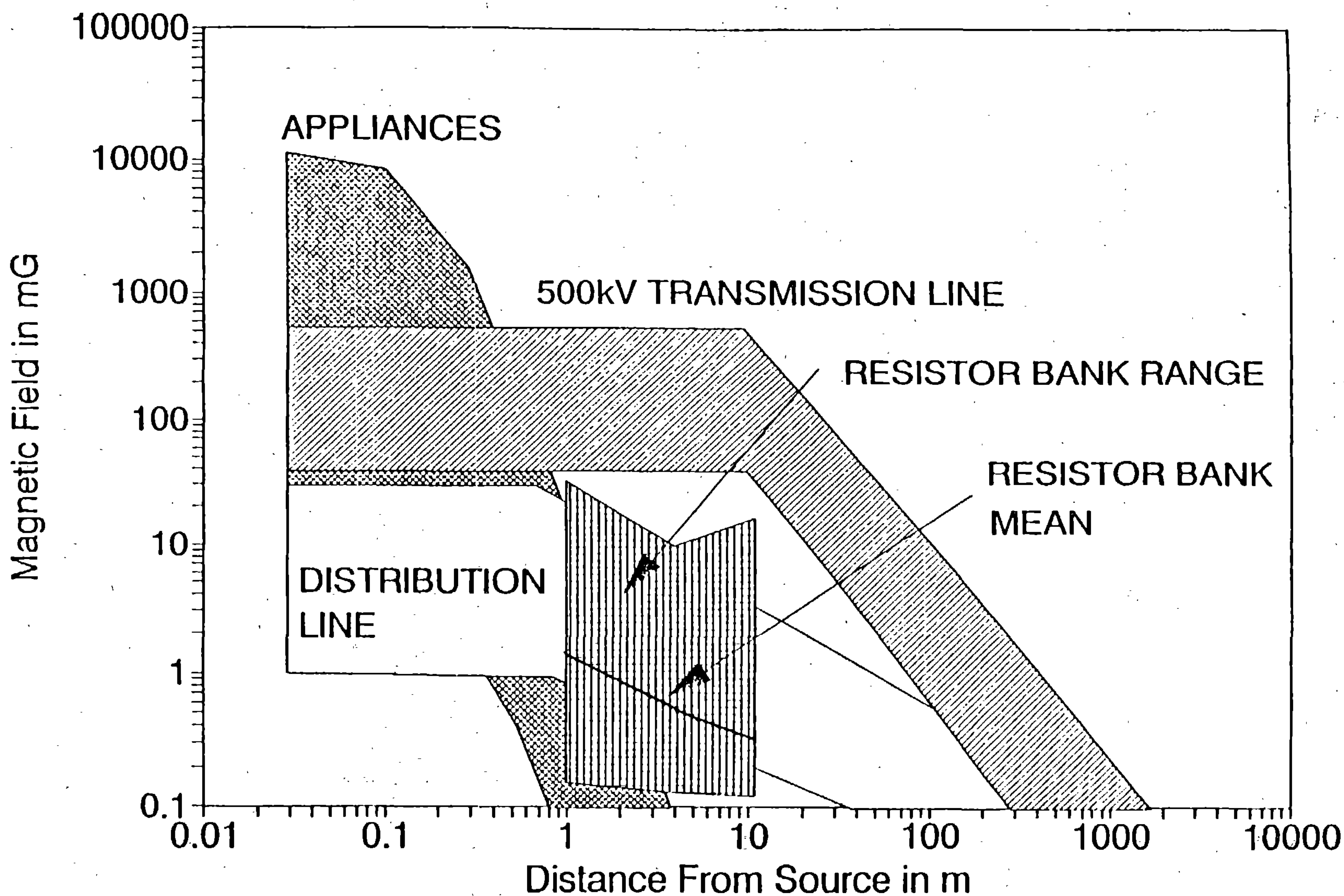


Figure 7-8 Comparison of the range and mean level of time varying magnetic field at increasing distances from the edge of the braking resistor yard to power frequency magnetic fields from other sources.

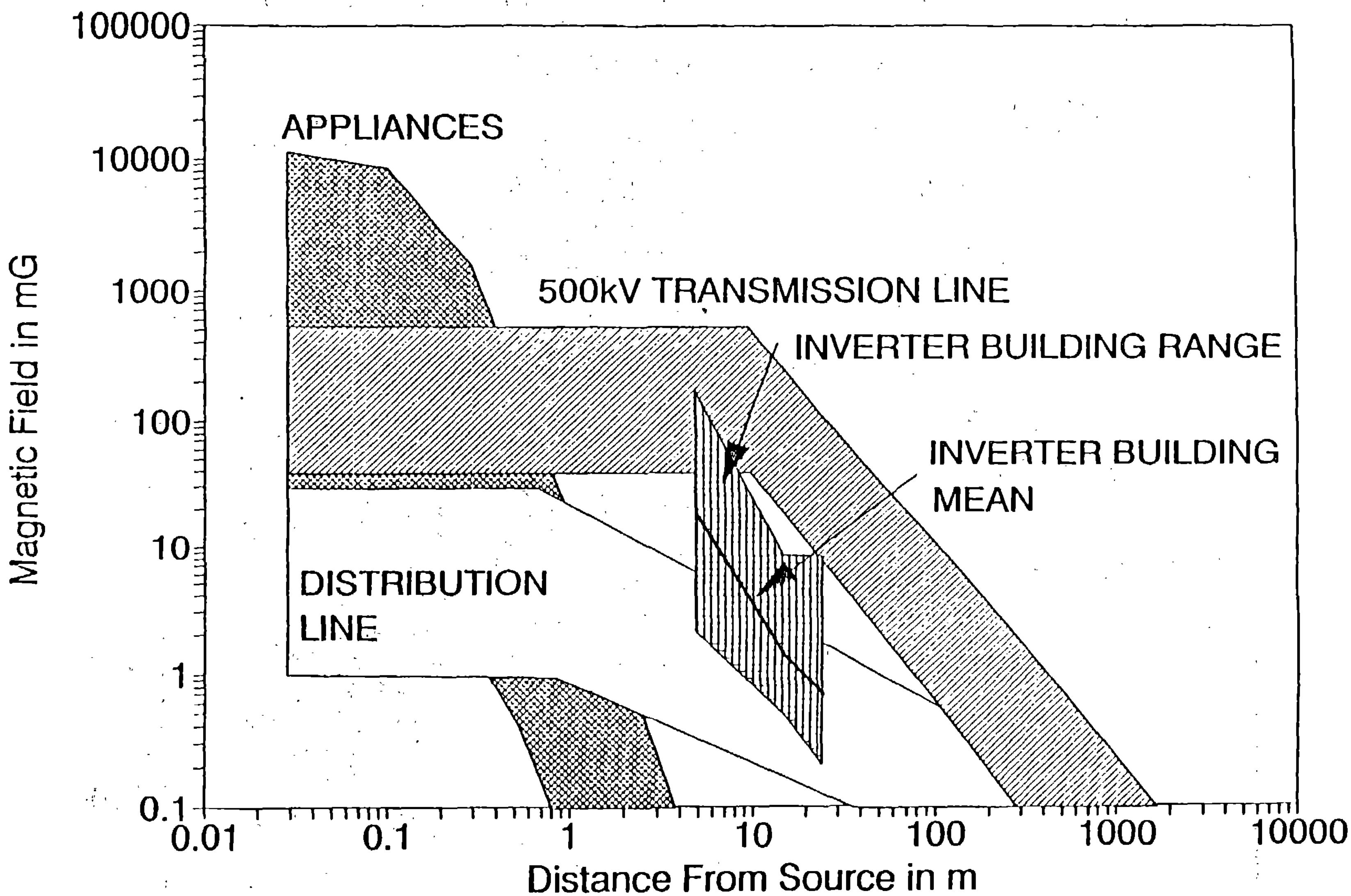


Figure 7-9 Comparison of the range and mean level of time varying magnetic field at increasing distances from the inverter building to power frequency magnetic fields from other sources.

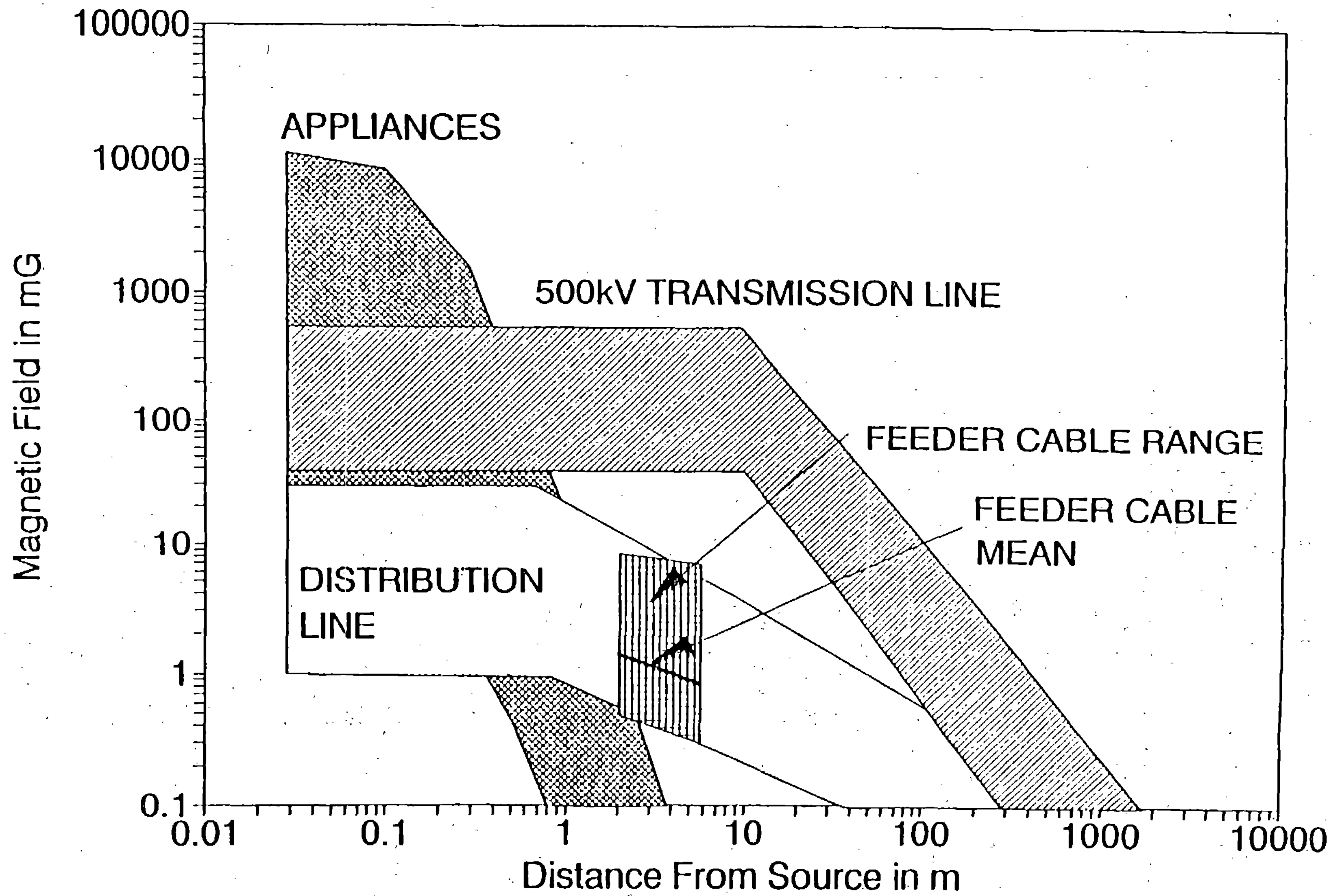


Figure 7-10 Comparison of the range and mean level of time varying magnetic field at increasing distances from the centerline of the underground feeder cables to power frequency magnetic fields from other sources.

sources. Bearing in mind that these data only represent an upper bound of the actual cable fields, one concludes that the intensity of the magnetic fields above the feeder cables are certainly no higher than the magnetic fields of a common overhead distribution line.

Another way to summarize the comparison of Maglev magnetic fields to those of other environments is given in the following tables. In an attempt to aid the non-expert in interpreting the data, the magnetic field data is listed in terms of minimum, maximum, and averages of the data sets. For the present, the frequency partitioned in the 50-60 Hz band and for the 5 to 2560 Hz band will be the most useful in making comparisons to previous measurements of other electro-technologies. Static fields can be compared to the range of geomagnetic fields and anecdotal data from various investigators including the authors on variances noted within commercial buildings.

Recognizing the need to make the best judgments with the information in hand, the following tables have a final column which makes a crude comparison to other environments. The sources of the data sets are referenced in this report. Since the report is concerned with a technology which the general public will utilize for only small fractions of a day, the comparison is made to common environments known to routinely contain similar magnetic fields. The comparison is crude because not all individuals will necessarily be equally exposed in these other environments. Noting these limitations, we have used the following generalizations:

Homes - Magnetic flux densities of up to 50 milligauss in the power frequency band are routinely found near appliances which are used each day. Static fields vary modestly from geomagnetic ambient depending on proximity to furniture and fixtures containing ferromagnetic material.

Worksites - Magnetic flux densities in excess of 500 milligauss in the power frequency band are routinely found near electrical equipment and electrical hand tools. Static fields vary significantly depending on building construction and industrial processes.

No Data - The bulk of the data used to quantify these environments was collected by instruments that were limited in frequency bandwidth to either 50 to 60 Hz, 50 to 300 Hz, or 40 to 1000 Hz and which reported a single resultant value over this range. Therefore, the tables show No Data for the 5 to 45 Hz band and the 300 to 2560 Hz band. Very limited data exists in the 65 to 300 Hz band but the reporting is not sufficient to project an estimate.

In the following tabulations, the data are presented by general regions where classes of exposure might be of specific interest. They are:

Onboard Passenger Areas	Table 7-1
Onboard Engineer's Area	Table 7-2
Near Guideway	Table 7-3
Passenger Station	Table 7-4
Outside Transformer Yard	Table 7-5
Near Feeder Cables	Table 7-6

7.4 Comparison of Transrapid Fields to Existing Standards

The United States has no national standards which establish limits on the intensity of ELF magnetic fields, however Germany has. There are two guidelines established by international organizations and one established by a domestic professional trade organization. Furthermore, there are two state level standards limiting ELF magnetic fields, however, they presently apply only to electric power lines and substations. This subsection of the report will compare the magnetic field levels onboard the TR07 vehicle or near related facilities to the field levels permitted under the above mentioned standards.

World Health Organization

The World Health Organization's Environmental Health Criteria 69[9] addresses ELF magnetic fields. The document concludes that available scientific knowledge does not permit establishment of a definitive limit for static or time-varying magnetic fields. The document indicates that adverse human health effects are unlikely at static field levels less than 2 T (20,000 gauss) or with time-varying magnetic fields which induce current densities of less than 10 mA/m^2 within tissue or extracellular fluids. Based on available scaling data for magnetically induced currents in the human body, the 10 mA/m^2 threshold is reached at power frequency field levels of approximately 10 Gauss. Since the criterion is based on induced current, the permissible time-varying field level is inversely proportional to frequency. Since the TR07 fields are predominantly low frequency fields, the onboard field levels are at least two orders of magnitude less than the World Health Organization criterion on time-varying magnetic fields. An even greater margin of compliance is found for static magnetic fields and time-varying magnetic fields at other locations.

TABLE 7-1

SUMMARY DATA FOR MAGNETIC FIELD MEASUREMENTS WITHIN THE PASSENGER COMPARTMENTS OF THE TR07 VEHICLE

PASSENGER SECTION, CAR#2		TOTAL OF 95 SAMPLES			
FREQUENCY BAND	HEIGHT ABOVE FLOOR (cm)	MINIMUM MAGNETIC FIELD (mG)	MAXIMUM MAGNETIC FIELD (mG)	AVERAGE MAGNETIC FIELD (mG)	ENVIRONMENTS WITH SIMILAR AVERAGE MAGNETIC FIELDS
STATIC	175.26	169.20	981.62	497.48	Work Sites
STATIC	111.76	225.96	1036.18 *	633.55 *	Work Sites
STATIC	46.99	69.84	1110.38 **	611.14 **	Work Sites
STATIC	12.70	166.81	1501.63 ***	834.42 ***	Work Sites
5-45 Hz	175.26	5.00	53.46	16.98	No Data
5-45 Hz	111.76	7.44	76.76	26.06	No Data
5-45 Hz	46.99	17.46	141.44	47.58	No Data
5-45 Hz	12.70	31.37	235.53	89.77	No Data
50-60 Hz	175.26	0.85	18.93	3.83	Homes
50-60 Hz	111.76	1.22	27.17	5.18	Homes
50-60 Hz	46.99	2.60	29.42	7.74	Homes
50-60 Hz	12.70	3.76	42.60	14.80	Homes
65-300 Hz	175.26	2.70	25.02	10.95	No Data
65-300 Hz	111.76	3.11	29.55	13.72	No Data
65-300 Hz	46.99	5.63	35.46	18.45	No Data
65-300 Hz	12.70	10.65	88.22	32.48	No Data
305-2560 Hz	175.26	0.20	1.97	0.78	No Data
305-2560 Hz	111.76	0.23	2.29	1.00	No Data
305-2560 Hz	46.99	0.43	2.46	1.15	No Data
305-2560 Hz	12.70	0.45	4.57	1.93	No Data
5-2560 Hz	175.26	7.58	53.62	21.13	Work Sites
5-2560 Hz	111.76	9.92	76.92	30.55	Work Sites
5-2560 Hz	46.99	21.13	143.19	52.42	Work Sites
5-2560 Hz	12.70	34.84	253.50	98.37	Work Sites

NOTES:

* The fluxgate sensor was saturated on one of the three axes for four of the 95 measurements.

** The fluxgate sensor was saturated on one of the three axes for two of the 95 measurements.

*** The fluxgate sensor was saturated on one of the three axes for 20 of the 95 measurements.

TABLE 7-2

SUMMARY DATA FOR THE MAGNETIC FIELD MEASUREMENTS WITHIN THE REAR ENGINEER'S COMPARTMENT OF THE TR07 VEHICLE

REAR ENGINEER SECTION, CAR#2		TOTAL OF 20 SAMPLES			
FREQUENCY BAND	HEIGHT ABOVE FLOOR (cm)	MINIMUM MAGNETIC FIELD (mG)	MAXIMUM MAGNETIC FIELD (mG)	AVERAGE MAGNETIC FIELD (mG)	ENVIRONMENTS WITH SIMILAR AVERAGE MAGNETIC FIELDS
STATIC	175.26	656.31	839.18	729.84	Work Sites
STATIC	111.76	655.67	954.96	791.35	Work Sites
STATIC	46.99	730.83	1108.22 *	926.43 *	Work Sites
STATIC	12.70	792.03	1098.48 **	986.02 **	Work Sites
5-45 Hz	175.26	13.57	49.19	29.64	No Data
5-45 Hz	111.76	16.83	80.83	37.29	No Data
5-45 Hz	46.99	22.41	138.84	52.00	No Data
5-45 Hz	12.70	31.11	180.31	75.53	No Data
50-60 Hz	175.26	2.16	24.17	11.30	Homes
50-60 Hz	111.76	2.17	24.65	11.53	Homes
50-60 Hz	46.99	1.92	22.35	11.59	Homes
50-60 Hz	12.70	3.08	29.41	16.28	Homes
65-300 Hz	175.26	27.42	55.76	42.46	No Data
65-300 Hz	111.76	28.58	61.99	45.21	No Data
65-300 Hz	46.99	24.36	66.93	45.72	No Data
65-300 Hz	12.70	24.60	85.48	55.28	No Data
305-2560 Hz	175.26	0.93	4.20	1.92	No Data
305-2560 Hz	111.76	0.91	4.17	1.96	No Data
305-2560 Hz	46.99	0.80	3.83	1.84	No Data
305-2560 Hz	12.70	0.94	4.28	2.09	No Data
5-2560 Hz	175.26	35.02	73.30	53.62	Work Sites
5-2560 Hz	111.76	37.13	98.37	60.47	Work Sites
5-2560 Hz	46.99	35.32	149.50	71.44	Work Sites
5-2560 Hz	12.70	39.80	190.89	96.59	Work Sites

NOTES: * Fluxgate sensor was saturated on one of the three axes for 5 of the 20 measurements.

** Fluxgate sensor was saturated on one of the three axes for 9 of the 20 measurements.

TABLE 7-3

SUMMARY DATA FOR MAGNETIC FIELD MEASUREMENTS BENEATH THE LOW CONCRETE GUIDEWAY IN THE SOUTH LOOP

LOW CONCRETE GUIDEWAY IN SOUTH LOOP				TOTAL OF 194 SAMPLES	
FREQUENCY BAND	DISTANCE EAST OF G/W (m)	MINIMUM MAGNETIC FIELD (mG)	MAXIMUM MAGNETIC FIELD (mG)	AVERAGE MAGNETIC FIELD (mG)	ENVIRONMENTS WITH SIMILAR AVERAGE MAGNETIC FIELDS
STATIC	0.00	501.89	552.55	548.54	Homes
STATIC	4.00	443.03	448.87	447.02	Homes
STATIC	10.00	487.89	490.48	488.81	Homes
5-45 Hz	0.00	0.06	69.00	1.04	No Data
5-45 Hz	4.00	0.04	87.03	0.74	No Data
5-45 Hz	10.00	0.03	12.49	0.16	No Data
50-60 Hz	0.00	0.07	21.75	0.45	Homes
50-60 Hz	4.00	0.11	15.77	0.27	Homes
50-60 Hz	10.00	0.11	2.92	0.16	Homes
65-300 Hz	0.00	0.03	40.47	1.95	No Data
65-300 Hz	4.00	0.01	37.62	0.67	No Data
65-300 Hz	10.00	0.01	18.77	0.17	No Data
305-2560 Hz	0.00	0.08	2.96	0.21	No Data
305-2560 Hz	4.00	0.07	1.70	0.11	No Data
305-2560 Hz	10.00	0.05	0.60	0.06	No Data
5-2560 Hz	0.00	0.14	81.50	2.53	Work Sites
5-2560 Hz	4.00	0.16	96.13	1.21	Work Sites
5-2560 Hz	10.00	0.15	22.74	0.34	Homes

TABLE 7-4

SUMMARY DATA FOR MAGNETIC FIELD MEASUREMENTS AT THE PASSENGER STATION

GUIDEWAY AT LOADING PLATFORM, EAST PROFILE				TOTAL OF 358 SAMPLES	
FREQUENCY BAND	DISTANCE EAST OF G/W (m)	MINIMUM MAGNETIC FIELD (mG)	MAXIMUM MAGNETIC FIELD (mG)	AVERAGE MAGNETIC FIELD (mG)	ENVIRONMENTS WITH SIMILAR AVERAGE MAGNETIC FIELDS
STATIC	2.50	320.01	370.49	357.71	Homes
STATIC	5.50	545.79	549.15	547.37	Homes
5-45 Hz	2.50	0.03	287.27	1.52	No Data
5-45 Hz	5.50	0.01	12.35	0.13	No Data
50-60 Hz	2.50	0.04	20.52	0.21	Homes
50-60 Hz	5.50	0.02	6.27	0.09	Homes
65-300 Hz	2.50	0.01	75.16	0.60	No Data
65-300 Hz	5.50	0.01	14.89	0.13	No Data
305-2560 Hz	2.50	0.05	7.95	0.12	No Data
305-2560 Hz	5.50	0.00	1.27	0.01	No Data
5-2560 Hz	2.50	0.08	297.44	1.74	Work Sites
5-2560 Hz	5.50	0.04	19.48	0.23	Homes

TABLE 7-5

SUMMARY DATA FOR THE MAGNETIC FIELD MEASUREMENTS AT THE SOUTH EDGE OF THE OUTPUT TRANSFORMER YARD

OUTPUT TRANSFORMER YARD, SOUTH EDGE				TOTAL OF 230 SAMPLES	
FREQUENCY BAND	DISTANCE SOUTH OF YARD (m)	MINIMUM MAGNETIC FIELD (mG)	MAXIMUM MAGNETIC FIELD (mG)	AVERAGE MAGNETIC FIELD (mG)	ENVIRONMENTS WITH SIMILAR AVERAGE MAGNETIC FIELDS
STATIC	0.00	493.09	506.27	499.15	Homes
STATIC	3.00	*	*	*	Homes
STATIC	10.00	*	*	*	Homes
5-45 Hz	0.00	0.06	2.00	0.32	No Data
5-45 Hz	3.00	0.02	1.69	0.16	No Data
5-45 Hz	10.00	0.02	1.79	0.09	No Data
50-60 Hz	0.00	1.14	4.49	1.66	Homes
50-60 Hz	3.00	0.54	2.03	0.77	Homes
50-60 Hz	10.00	0.19	0.69	0.26	Homes
65-300 Hz	0.00	0.30	3.13	0.44	No Data
65-300 Hz	3.00	0.16	2.73	0.23	No Data
65-300 Hz	10.00	0.05	2.61	0.10	No Data
305-2560 Hz	0.00	0.18	0.75	0.25	No Data
305-2560 Hz	3.00	0.08	0.40	0.12	No Data
305-2560 Hz	10.00	0.02	0.17	0.04	No Data
5-2560 Hz	0.00	1.24	4.59	1.80	Homes
5-2560 Hz	3.00	0.57	3.50	0.85	Homes
5-2560 Hz	10.00	0.20	2.84	0.32	Homes

NOTE: * Data lost due to probe failure.

TABLE 7-6

SUMMARY DATA FOR MAGNETIC FIELD MEASUREMENTS ABOVE THE MAIN FEEDER CABLES AT A POINT 15 M NORTHEAST OF THE INVERTER BUILDING

INVERTER BUILDING BURIED FEEDER CABLE				TOTAL OF 219 SAMPLES	
FREQUENCY BAND	DISTANCE WEST OF CABLE (m)	MINIMUM MAGNETIC FIELD (mG)	MAXIMUM MAGNETIC FIELD (mG)	AVERAGE MAGNETIC FIELD (mG)	ENVIRONMENTS WITH SIMILAR AVERAGE MAGNETIC FIELDS
STATIC	-2.00	435.86	458.84	451.10	Homes
STATIC	2.00	*	*	*	Homes
STATIC	6.00	473.66	505.54	495.24	Homes
5-45 Hz	-2.00	0.14	8.59	1.12	No Data
5-45 Hz	2.00	0.14	8.37	0.94	No Data
5-45 Hz	6.00	0.14	6.49	0.71	No Data
50-60 Hz	-2.00	0.41	1.14	0.56	Homes
50-60 Hz	2.00	0.35	1.48	0.55	Homes
50-60 Hz	6.00	0.13	0.89	0.22	Homes
65-300 Hz	-2.00	0.08	4.88	0.41	No Data
65-300 Hz	2.00	0.06	5.97	0.38	No Data
65-300 Hz	6.00	0.06	2.43	0.29	No Data
305-2560 Hz	-2.00	0.15	2.96	0.32	No Data
305-2560 Hz	2.00	0.06	3.57	0.24	No Data
305-2560 Hz	6.00	0.02	1.53	0.16	No Data
5-2560 Hz	-2.00	0.51	8.70	1.48	Homes
5-2560 Hz	2.00	0.48	8.52	1.31	Homes
5-2560 Hz	6.00	0.29	6.57	0.87	Homes

NOTE: * Data lost due to probe failure.

International Radiation Protection Association

The International Non-Ionizing Radiation Committee (INIRC) of the International Radiation Protection Association (IRPA) has developed an interim standard[10] limiting human exposure to power frequency (50/60 Hz electric and magnetic fields). The established magnetic field limit for 24 hours per day of the general public is 1 gauss. Short term exposures of up to a few hours per day are permitted to 10 gauss. Permitted occupational exposure levels are five times that permitted for the general public. The one gauss continuous exposure limit is more than ten times above the average floor level time-varying magnetic fields within the vehicle. Magnetic field levels near related facilities are generally weaker hence have an even greater margin of compliance.

The numerical field limits in the IRPA standard apply explicitly to power frequency magnetic fields. However, the text of the standard clearly demonstrates that the standard is based on induced current concerns. Hence, acceptable field limits at frequencies other than 50 or 60 Hz would be related to the 50/60 Hz threshold by the ratio of the power frequency to the frequency of the magnetic field. For the predominantly low frequency magnetic fields generally produced by the TR07 System, the margin of compliance with the standard would be greater if the implied frequency correction was made. The clear exception to that generalization is the predominantly high frequency fields near the transformer yard and resistor banks. But since the magnetic field is so low near these equipment, compliance would still exceed a ten-fold margin if the implied frequency correction was made.

German Standard DIN VDE 0848

The German Electro-Technical Commission Standard DIN VDE 0848, Part 4 establishes limits for time-varying magnetic field strength in the frequency range from 2 Hz to 30 kHz. It is intended to protect people from direct adverse effects of field exposure. Appropriate limits for static fields, time-varying fields less than 2 Hz and for indirect effect (e.g. currents or voltages induced in other objects) are still in preparation.

The standard establishes limits on both RMS and peak field strength which are frequency dependant. The maximum RMS flux density for continuous whole body exposure is:

$$B_{RMS} = \frac{270}{f^{0.4324}}$$

The corresponding numerical value at the 50 Hz power frequency is 50 gauss. Maximum permitted peak field levels are 50% greater than the RMS limits. Intermittent whole body exposure (up to five minutes per hour) may be 50% greater than the continuous exposure limits.

The standard addresses magnetic fields at one or more discrete frequencies and provides a method for summing field components at multiple discrete frequencies. Unfortunately, it does not address the broadband field components which do not occur at specific definable frequencies.

The fields onboard the TR07 vehicle or in the vicinity of associated facilities will certainly be in compliance with the standard regardless of the method used to treat the broadband frequency characteristics of the field. The margin of compliance will be on the order of 100 to one or more.

<u>American Conference of Governmental Industrial Hygienists</u>

The American Conference of Governmental Industrial Hygienists (ACGIH) has established a "threshold limit value" for 60 Hz magnetic fields at 100 gauss[12]. The document recommends that routine occupational exposures should not exceed the 100 gauss value but states that the value is to be used as a guide, not a strict determination of safe and unsafe levels. This criterion is considerably less restrictive than those of the WHO and IRPA. Consequently, the fields associated with the TR07 System comply with the standard with a 1000 to 1 margin.

<u>State Powerline Limits</u>

The states of Florida and New York have adopted standards[13,14] specifically limiting the intensity of the power frequency magnetic fields at the boundaries of transmission lines' rights-of-way or substation property lines to values from 150 mG to 250 mG depending on the type of transmission line. Both standards are established on a "status quo" basis rather than a health or safety basis. Although neither apply to transportation systems, they do provide some guidance as to the levels of magnetic fields which have been judged tolerable at the boundaries of linear facilities which are in that respect similar to a Maglev guideway. The maximum magnetic field levels measured near the TR07 guideway was less than 100 mG, or approximately two thirds of the field value permitted at the edge of transmission line rights-of-way in Florida and New York.

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