NBS TECHNICAL NOTE 1014

U.S. DEPARTMENT OF COMMERCE / National Bureau of Standards

Electromagnetic Interference (EMI) Radiative Measurements for Automotive Applications

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Electromagnetic Interference (EMI) Radiative Measurements for Automotive Applications*

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Table of Contents

List of Figures

List of Figures (Continued)

Electromagnetic Interference (EMI) Radiative Measurements for Automotive Applications

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This report describes the measured results of the electromagnetic (EM) environment encountered by three different-sized vehicles exposed to a selection of CB and mobile radio transmitters and broadcast stations. The vehicle in these situations is immersed in the near field of the radiating signals and the measured data is near-field data. This report gives measured data of electric and magnetic fields measured independently. The purpose of the report is to identify the EM environmental conditions under different circumstances in order to estimate EMC testing criteria for vehicles and their electronic systems.

Key words: Mobile-radio; near-field strength levels; vehicular electromagnetic environment; vehicular near-zone electric fields; vehicular near-zone magnetic fields;worst-case EM fields.

1.0 Introduction

As the automotive industry moves from mechanical and hydraulic control systems to electronic control systems, the reliability of these electronic systems becomes paramount from a safety standpoint. Although these electronic systems can provide economical fuel use and low pollution, they increase the need to plan for electromagnetic compatibility (EMC) with the environment in which they operate. Shielding and filtering are well-known ways of achieving EMC, but they cost money. Reliable measurements are the key to knowing the electromagnetic environment and to determining when one has achieved sufficient compatibility with the environment at a minimum cost.

To help achieve a reliable data base, the National Bureau of Standards (NBS), with the support of the National Highway Traffic Safety Administration, has made measurements of both electric and magnetic field strength levels around different types of vehicles in a variety of situations. NBS has also developed methods to measure susceptibility of electronic components to these fields.

The electromagnetic environment in which a vehicle must operate is extremely variable as to range of frequency, range of magnitude, type of field, and direction of source. It is extremely difficult to make sufficient measurements to completely describe this diverse environment. Therefore, an attempt has been made to identify the worst (highest) field strength levels that exist and measure them. The relative effect (energy content) of field increases as the square of field strength level, and this coupled energy is what has the potential for disrupting or degrading electronic systems. Another factor which was influential in determining which environments should have priority in measuring the levels in a measurement program is the distance from the source. A relatively weak transmitter that is nearby produces much stronger fields than a relatively powerful transmitter at a distance. For these reasons, the field strength levels measured were mostly around vehicles with onboard transmitters or close to transmitters.

The data base provided should give some guidance to manufacturers as to what field strength levels their products may encounter, and thus establish susceptibility test bounds.

2.0 Measurement Factors

There are a number of factors that influence not only the levels of field strength around vehicles but also the measurement strategy. Some of these factors are: size and shape of vehicle; number, power, frequency, and proximity of sources; transmitter and antenna characteristics; ground effects; and interactive effects. Changes in vehicle design such as increasing use of plastics, fiberglass, and electronic systems will alter the type of data base needed.

The need to make vehicles more fuel efficient forces weight reductions. One way this is achieved is through the increased use of fiberglass and plastics. This will impact the electromagnetic shielding effectiveness of body structures, usually negatively.

Increased use of microelectronics increase both electromagnetic environmental data needs and design requirements. These microelectronic systems are increasingly vulnerable to EMI as their power requirements decrease -- it takes approximately the same amount of energy to disrupt a system as it does to operate it. Some microprocessors require milliwatts or less for operation.

2.1 Field Strength Levels Around Passenger Cars

Field strength levels were measured around both a full-sized and a compact passenger car under a number of conditions. Three frequencies in the land mobile bands were used: 40.27 MHz in the 30 to 50 MHz band, 162.475 MHz in the 150 to 170 MHz band, and 416.975 MHz in the 400 to 520 MHz band. Different types of antennas, different antenna locations, different types of ground planes, and different types of metallic structures adjacent to the vehicle were used. Fields were measured around a vehicle adjacent to another with an on-board transmitter. Measurements were also made in the high frequency band, e.g., at nominal frequencies of 4, 7, 14, 21, and 27 MHz. These measurements were made with a nominal 100 watts of transmit power. Figure 1 is a photograph showing how the measurements were made. Limited measurements were made around a vehicle parked near fixed, high-power transmitters such as FAA radars, AM and FM radio stations, and VHF and UHF TV stations. Figures 2, 3, and 4 show samples of these field strength levels for the case where the transmitter is located in the car.

Several important points were observed: field strength levels vary greatly with location around the vehicle; the location of hot spots varies greatly depending on many different parameters; fields encountered when a vehicle is on a metallic ground plane are usually higher than for one on a nonmetallic ground plane, especially at locations under the vehicle; the field strength levels usually decrease with increasing frequency, approximately as the inverse of the square root of the frequency; the field strength levels tend to vary inversely with the size of the vehicle.

Although the objective of these measurements was to determine the highest levels that could be expected, one region was excluded; the region within one-half meter of the antenna. In this region, the field strengths are extremely high, over an order of magnitude higher than the highest fields elsewhere. If any of the electronic systems, cables, or personnel are located within this region, many more serious problems should be expected, and/or more expensive protection measures will have to be used.

A specific warning is appropriate for personnel to stay away from an antenna that is located on a fender or bumper of a car. Antennas located in the center of the roof are generally inaccessible to people, and also have better electrical characteristics due to the presence of a better ground plane.

2.2 Field Strength Levels Around a Tractor-Trailer

Federal Motor Vehicle Safety Standard (FMVSS) 121 requires strict stopping and controlling requirements for trucks. Many manufacturers have opted to comply with FMVSS-121 by employing electronic antiskid brake systems. These electronic systems then require EMC with the environment in which they must operate.

NBS has measured fields around a tractor-trailer under a variety of conditions. These are illustrated in figures 5 and 6. Field strength levels were measured when on-board mobile transmitters were used as well as for adjacent vehicles with transmitters. In contrast to a passenger car, a metal ground plane does not significantly change field strength levels over those conditions that would exist on asphalt or concrete for a truck. Figure 6 shows the effects of a mobile transmitter adjacent to a tractor-trailer.

2.3 Factors that Influence Field Strength Levels

Major factors that influence field strength levels include radiated power, type of antenna, location of antenna, standing wave ratio (VSWR), location around vehicle, frequency, electrical characteristics of ground on which vehicle rests, nearby metallic objects or walls, resonant structures, shape of vehicle, size of vehicle, and size of apertures.

Most of these factors apply simultaneously, making exact analysis difficult. The field strength is proportional to the square root of radiated power. Antenna location and type cause variations, but not in a predictable manner. The highest field strengths around a vehicle are usually near sharp corners, near resonant structures such as wheels, and on the underside of a vehicle located on a metal ground plane. Fields decrease generally with increasing frequency, approximately as the inverse of the square root of frequency. A full-sized car on a metal ground plane usually has higher field strength levels than it does on dry asphalt. Other nearby metallic objects tend to increase field strength levels. Sharp corners give higher electric field strength levels than smooth surfaces or more rounded corners. At higher frequencies, an aperture such as a window allows stronger fields inside the vehicle than it will at lower frequencies. Vehicle dimensions are such that the vehicle itself becomes a resonant structure between 20 and 40 MHz, depending on the size of the vehicle. This may be a very troublesome portion of the frequency spectrum.

Magnetic field strength levels are highest near corners of large apertures such as windshields.

A mismatched antenna causes a high standing wave ratio, resulting in less radiated power than for matched conditions, and hence lower external field strength levels. However, the antenna, cables, microphones, etc., then have higher field strength levels in their immediate vicinity than would exist under matched conditions.

2.4 Effects of Multiple Electromagnetic Sources

The existence of multiple sources at different frequencies and different power levels is a common occurrence in highly populated areas. Two examples are, first, the multitude of CB radios in an area and, second, broadcast towers with many transmitting antennas colocated on the same tower.

How these multiple sources must be treated depend on the answers to several questions:

1. Will a device respond to energy at more than one frequency? An example of a device that responds to energy over a wide range of frequency is a neon bulb. An example of a device that responds only to energy at one frequency (narrow band of frequencies) is a radio with ideal selectivity.

2. Is the energy from several sources related, i.e., are the signals coherent? An example of two related sources is a radio relay station which receives on one frequency and transmits the same signal on another frequency. In this case, two transmitters are transmitting the same information on two different frequencies, one with a slight time delay from the other. An example of two unrelated signals are those radiated from two different radio stations. Unless special efforts are made to phase-lock or otherwise relate two sources, each is controlled by its own crystal, tank circuit, and modulation. It is physically "unaware" of the existence of any other transmitters.

3. What are the magnitudes of the different signals relative to each other? Different transmitters may use different power levels, may have different gain antennas (the energy may be more concentrated in one direction), may be at different distances, and may be at different frequencies.

4. How are the receiving-device, energy transducers aligned? Electric and magnetic field strengths are vector quantities, and hence have directional as well as magnitude qualities. An alignment that couples maximum energy from one source may couple no energy (or any amount from zero to maximum) from a different source.

The four factors brought out by these questions complicate analyses for multiple sources to an overwhelming degree if some simplifications are not possible. The following simplifications are often justified:

1. Devices will respond to energy at more than one frequency. If not, only one source will cause a response, and single-source analysis is appropriate.

2. Different sources are incoherent. It is technically possible to relate sources, but there are few cases where this is desirable; therefore, it is seldom done. Sixty hertz power systems are an important, low-frequency exception.

3. Nothing should be assumed about the relative magnitudes of different-frequency signals at some point.

4. Worst-case alignment (or orientation) should be assumed. This gives maximum coupling of energy, and although seldom achieved, may be achieved at some time or other, unless all sources and receiving devices are immobile.

With these simplifying assumptions, a relatively direct mathematical analysis can be used. Power (energy per unit time) is proportional to E x H where the E and H vectors are related by the intrinsic impedance of the medium, $\eta = E/H$; in an idealized free-space, far-field condition, $\eta = \eta_0 = 376.7$ ohms. Therefore, power is proportional to $|E|^2/\eta$; for three unrelated signals, $E_1 \sin \omega_1 t$, $E_2 \sin \omega_2 t$, and $E_3 \sin \omega_3 t$, each brings power proportional to E_1^2/η, E_2^2/η, and E_3^2/η. That is, $P_T = P_1 + P_2 + P_3$. The effective resultant E_T

that would have brought an equivalent amount of power as the total of the three uncorrelated signals is:

$$E_T = \sqrt{E_1^2 + E_2^2 + E_3^2} \ .$$

Table 1 shows how different relative magnitudes would combine:

Table 1

E_1 (V/m)	E_2 (V/m)	E_3 (V/m)	$E_T = \sqrt{E_1^2 + E_2^2 + E_3^2}$ (V/m)	E_T' (dB) above 1 V/m $E_T' = 20 \log_{10}(E_{T/1})$
1	1	1	1.732	+4.771
1	.8	.8	1.510	+3.579
1	.5	.5	1.225	+1.761
1	.5	.1	1.122	+1.004
1	.3	.3	1.086	+0.719
1	.3	.1	1.049	+0.414
1	.1	.1	1.010	+0.086
1	0	0	1.000	0.000

Unless two signals are of approximately equal amplitude, the magnitude of the combined signals is less than 2 dB greater than for a single signal. If there is a factor of two (or more) difference, the magnitude of the combined signals shrinks to less than 1 dB greater than for a single signal.

If there should be 10 equal signals of unity amplitude, E_T would equal 3.162, which is 10 dB higher than any for a single signal. Fortunately, this seldom occurs, as it is difficult to colocate 10 transmitters to achieve 10 equally strong signals. At a long distance this can be done, but then all the signals are weak, and singly or collectively cannot cause much effect.

The measurement of multiple signals is complicated by these same factors, but the same simplifying assumptions cannot be made. The degree of coupling at particular orientations has a large effect on the uncertainties that must be attached to measured data.

2.5 Uncertainties in the Reported Field Strength Levels

Electric and magnetic fields around vehicles are not related as they are in the far field. This is because the vehicle is an antenna itself and perturbs fields from any source, near or far. E and H are related in unknown ways and must be measured separately. E and H are vector quantities, and under these perturbed conditions, no prior knowledge is available as to their direction or magnitude. The measuring devices have to respond to each parameter (E or H) independently, must not themselves perturb the fields in unknown ways, and should measure the magnitude of the vector quantity, regardless of the direction of the vector -- the probe should have an isotropic response. The person handling the probe may perturb the field. Variations in frequency, temperature, and the field strength levels the probes are immersed in may affect the probe uncertainty. The following discussion gives a total uncertainty as a function of these conditions.

2.5.1 Electric Field Probes

The probe used for electric field measurements was designed to minimize the uncertainties one encounters when making near-field measurements [1]. The probe has an isotropic response, and the lead wires do not significantly perturb the fields being measured.

The uncertainty in the field strength levels reported are determined as follows:

1. The probe was calibrated to an uncertainty of $\pm$ 1 dB [2].

2. The probe response is not perfectly isotropic, with variations of ± 0.5 dB under normal use. Sometimes it was necessary for the person doing the measurement to be between the source and the probe. The resulting field perturbation was estimated to cause an uncertainty no greater than ± 3 dB. In any case, the basic probe uncertainty is unchanged.

3. A temperature instability causes a total probe/instrumentation total zero drift uncertainty of ± 0.40 volts per meter for field strength levels above 10 volts per meter. At field strength levels below 10 volts per meter, the probe has an increasing uncertainty, increasing to ± 3.5 dB at one volt per meter.

4. At frequencies below 10 MHz, a frequency-dependent bias correction has been added. The correction is zero dB at 10 MHz, -3 dB at 3 MHz, and zero dB again at 850 kHz.

For field strength levels above 10 volts per meter for single vehicle measurements, the total uncertainty is ± 1.5 dB over the entire frequency range over which they were used. If there are two vehicles involved, this uncertainty should be increased to ± 4.5 dB for the values shown between the vehicles.

2.5.2 Magnetic Field Probes

The probes used to measure the magnetic fields were also developed at the National Bureau of Standards [3]. The probes do not have an isotropic response as the electric field probes do, since only a single loop is used. Otherwise, they are constructed in a similar manner as the electric field probes and have nonperturbing lead wires. Because the magnetic probes must be oriented for maximum field strength, their overall measurement uncertainty is greater than the measurement uncertainty of the electric field probes. The magnetic probes consist basically of a loop with a detector built into the center of the loop and nonperturbing, high-resistance line connecting the loop to the meter. Three different probes were used to make the measurements in three frequency bands from 7 to 160 MHz.

The overall measurement uncertainty using the magnetic field probe is estimated to be ± 5 dB.

3.0 Presentation of Measured Data

Figures 2 through 6 are illustrative of hundreds of pages of data that could be presented of measurement results under many different conditions. A worst-case, specific set of conditions was selected at each frequency. Usually this was when a vehicle was on a metal ground screen with an onboard transmitter. For each set of data for such a specific set of conditions there are a wide range of values of field strength around the vehicle.

A first attempt at compiling all these data involved use of statistical descriptors such as the average, standard deviation, and upper tolerance limit. However, the way the values were measured introduced serious (and deliberate) bias toward selection of the higher values during measurements. This also made some of the measured distributions not normal, even though the total population of values is probably normally distributed.

The use of a real-time probe allowed us to locate and measure the "hottest" spots, those where field strength levels were highest. This gave a more accurate measure of the high levels than could be obtained with true random sampling and statistical prediction of upper tolerance limits.

Figure 7 is illustrative of the method finally selected for presenting a condensed form of the measured data. All of the measured values were ordered and ranked according to percentiles for a particular set of conditions and at one frequency. Box and whisker graphs of percentiles were used. The percentile key is given in the upper right region of each figure. Several frequencies were used for similar conditions. Six percentiles were used: 100 for the highest value measured, and 95, 90, 75, 50, and 25 values. Sometimes 90 and 95 were the same, since no interpolation was used and thus there is only one bar inside the box. The box was used to indicate the range of values for the highest proportion of data. It also indicates the most carefully measured values. Although values were measured at many random spots, the probe sensitivity limited the lower levels that could be measured. In some cases, particularly at low frequencies, there were few or no regions that had low field strength levels. At the higher frequencies, there were a wide range of values and many "cold" spots. Therefore, the lower percentiles have been included to provide this information, even though there is an unknown uncertainty in those values.

Figures 8 through 16 summarize measured data for several specific conditions and size of vehicle.

Two other factors, power and distance from source, have to be considered in calculating worst-case values that may occur anywhere. The values in the HF frequency range (3-30 MHz) should be increased by a factor of two, since higher power levels than NBS used are both legal and available. In the case of AM broadcast stations, a distance correction is needed, since service vehicles may be driven within 3 meters of some AM broadcast stations. Since near-field conditions exist, the field strength may not vary linearly with distance (1/d), but may vary as $(1/d)^x$ where x may be as high as 3. This means that for these very close distances, measurements are more accurate than predictions from calculations.

3.1 Magnetic Field Measurements

The magnetic field strength levels (H) measured in the near field are summarized in figures 17 through 22.

The maximum levels of H do not occur at the same spatial locations as the maximum E-field levels. The maximum H-field levels tend to occur near edges of large apertures, e.g., corners of front and rear windshields. The larger the aperture, the higher the level of H. At higher frequencies, the smaller (side) windows become resonant and have higher field strength levels. The H-field strength variations with frequency show a pattern similar to E-field strength variations, i.e., decreasing levels with increasing frequency, resonances excepted. The H-field values were not measured above 162 MHz, so comparisons cannot be made at 417 MHz.

The H-field strength levels are comparable to E-field strength levels on an energy density basis of comparison. (A free-space, far-field H-to-E conversion is used for simplicity.) If anything, the H-field levels are slightly lower than the E-field levels.

Inside a vehicle H-field strength levels are significantly lower than comparable E-field strength levels.

3.2 Summary of Measurement Results

All measurement results are summarized in table 2. Table 2 lists the type of vehicle, type of ground surface, frequency, type of field, number of measurements, and five percentile values: 100, 95, 90, 75, and 50, and a comment column. The 25 percentile values were shown on the figures merely to indicate the ranges of levels measured. However, due to the poor probe sensitivity at the lower field strength levels and due to the emphasis on measuring worst-case levels, the 25 percentile values are not used on the summary curves. The units of measure for the electric fields are volts per meter; the units of measure for the magnetic fields are amperes per meter, with the far-field volts-per-meter equivalent in parenthesis. It is recognized that converting amperes per meter to volts per meter is not valid under near-field conditions, but this permits the reader to easily compare the magnitudes of the magnetic field results with the electric field results on an energy density basis. The magnetic field strength levels reported were measured with a magnetic field probe -- they were not obtained by converting from E-field results.

Several methods of treating the measured data for each vehicle-frequency-antenna situation were tried. Levels inside a vehicle, levels under a vehicle, and other groupings of data from various spatial regions around the vehicle were tried. No one grouping seemed to give consistently lower or higher results; therefore, the total number of measurements for a given condition was used to describe the levels around the vehicle.

For instance, the average of levels measured under a vehicle was usually lower than the average of the total if the vehicle was on a nonmetallic surface; if the vehicle was on a metallic surface, this same group of levels measured under the vehicle was higher than the total. Similarly, other regions varied due to other effects.

The measurement results listed in table 2 have been consolidated further to show the results for given sets of conditions.

Results of E-field measurements for a full-sized car, a compact car, and a tractor-trailer are summarized in figures 7 through 16. Similar results of H-field measurements are summarized in figures 17 through 22. Results of E-field measurements around vehicles in the vicinity of commercial broadcast stations are summarized in figures 23 through 29; "D" on the figures is the distance from the vehicle to the base of the antenna in meters.

The worst-case (highest) levels for each of the three types of vehicles is summarized by percentile in figures 30, 32, 34, 36, and 38. These curves are then "normalized" by increasing the actual field strength levels measured with 100 watt sources to those levels representative of a higher legal power level radiating source. This normalization is only in the HF frequency band, 3 to 30 MHz. At other frequencies, the maximum legal power levels were used for the measurements. These normalized results are shown in figures 31, 33, 35, 37, and 39.

Suggested levels for testing automotive electronics are given in figure 40. These are based on figues 31, 33, 35, 37, and 39. There are a few resonant conditions that exceed the values suggested in figure 40. The resonances measured generally occurred between 20 MHz and 50 MHz; this frequency range will undoubtedly be a troublesome portion of the spectrum since vehicle dimensions are such that the vehicle itself becomes resonant.

From our observations, we conclude that there are three phenomena present, each supported by a thread of technical logic.

1. Each curve shows a resonant peak in the 20 to 40 MHz frequency range. Vehicle dimensions (approximately 5 meters) are such that a half-wavelength resonance can be expected. There may be other resonances at higher frequencies that were not observed due to the wide frequency separation in the higher test frequencies (above 40 MHz).

2. The field strength levels decrease inversely with the square root of frequency except for the resonant peaks. This follows a skin-effect loss. The metallic vehicle body structure has losses that increase proportionally to the square root of frequency. The more energy that is dissipated in skin-effect losses, the less is available for nondissipative electromagnetic fields.

3. The larger the vehicle, the lower the field strength levels in and around it, for equal levels of excitation power. The vehicle is an antenna, but the larger the volume for constant excitation power, the lower the energy density (and hence field strength levels) for this larger volume.

4.0 Susceptibility Measurement Factors

Once a data base is established that tells what field strength levels can be expected (under worst-case conditions), designing and building equipment that is compatible with this environment depends on test methods that indicate to what degree this compatibility has been achieved -- or predict what will happen in this diverse environment.

4.1 Protective Measurement Suggestions

A designer must select the levels to which he wishes to "harden" his electrical components or systems. In this context, harden means to shield and filter systems so as to provide immunity to electromagnetic fields. If he wishes a minimum of reliability that will get his product through a certain proportion of the time, he may choose to harden his system to withstand field strength levels indicated by the 50 percentile levels during susceptibility testing. One who builds a product that will be used regularly under worst-case conditions (e.g., a highway patrol car or other vehicle with an onboard, high-power transmitter) may wish to harden to levels indicated by the 100 percentile curve.

These values may be changed as additional data are acquired, but the curves presented do have a substantial basis.

4.2 Susceptibility Evaluation

The levels measured around specific systems and the levels suggested for general use as guidelines provide a basis for tests by manufacturers who wish to harden their electronic systems so as to avoid future problems.

This hardening costs money, and overdesign adds unneeded cost. NBS is developing reliable measurement techniques and instrumentation so that manufacturers will be able to determine when they have achieved the needed degree of hardening. We have worked with some users to develop measurement guidelines for making the necessary measurements. At present, these measurements involve use of a TEM cell for component testing, as suggested in the Society of Automotive Engineers Standard J1113 [4]. There are several specific factors that apply to testing anti-skid brake systems. These same factors may or may not apply to testing other electronic systems.

The important factors in susceptibility evaluations concern uniformity of test field, increments between test frequencies used, and time duration of the test field. Since thermal time constants of electronic braking systems are relatively long, one- to two-second duration test fields are needed at each frequency. Other components and electronic circuits will have other time constants. Swept frequency techniques are best. If they are not available, frequency increments must be carefully chosen. Test frequencies should be incrementally changed by no more than 18 percent between 0.5 and 10 MHz, 4.8 percent between 10 and 20 MHz, 2.4 percent between 20 and 50 MHz, 1.6 percent between 50 and 150 MHz, and 1.2 percent between 150 and 1000 MHz. This calls for 310 measurements, not an excessive number for prototype evaluation, but too many for a production unit. This frequency spacing will catch resonant circuits with a Q less than 40 at frequencies above 20 MHz. Below 20 MHz, vehicle dimensions are small enough with respect to wavelength to reduce the probability of having resonant circuits, at least in vehicle wiring and metal work. If digital circuits are being tested, special attention should be given to any clock frequencies.

A metallic test object causes distortions when placed in test fields. These distortions are to be expected, regardless of the test chamber. The two questions this raises in EM susceptibility testing are:

1. Do the fields distort the same way in a test chamber as they do in their operational environment?

2. How should the spatial variations in these perturbed fields be reported?

The answer to the first question is not known yet for TEM cells (or other enclosures). The second question must be answered in some statistical method; which particular way is best is not clear as yet.

Present TEM cell size and frequency limitations are such that only component-sized systems may be effectively tested. No practical, reliable whole-system (vehicle) test facility is available with present technology. Shielded rooms, anechoic chambers, and open space testing all have major shortcomings. Until vehicle test chambers are developed, special care must be taken in testing susceptibility of electronic components to compensate for the lack of whole-system test facilities.

Use of TEM cells at frequencies high enough to allow modes of higher order than the fundamental TEM mode is suggested. Even though measurement uncertainties become extremely large, susceptibility defects will usually show up and often can be cured. Such misuse of a measurement system to achieve reliable, safe vehicle operation is insignificant compared to brake failure.

A future part of this measurement program will address the interactive aspects of different sources and modulated signals, as nonlinear effects may cause significantly different effects from a single frequency, continuous-wave source.

A warning is necessary concerning biological hazard to personnel performing susceptibility tests. Presently accepted U.S. hazard levels are 194 volts per meter (10 milliwatts per square centimeter) as measured in the far field. Test levels from the previously suggested limits will be higher than this. According to the ANSI Standard, the average power (proportional to E^2) is averaged over a 0.1 hour (6 minute) time interval in biological hazard calculations. Most electronic systems respond more quickly than this. Although a TEM cell is a closed system, lead wires and cables can bring out high level fields if they are not filtered. These fields may be dangerous to personnel or disruptive to instrumentation.

4.3 Electromagnetic Radiation Hazard to People

Many of the field strength levels measured are much higher than allowed by current ANSI Standards [5] (194 volts per meter) for personnel exposure. This could have serious implications for those who use, manufacture, and regulate these systems.

Only a few of the factors that determine these field strength levels can be controlled; the rest cause unpredictable variations in field strength levels. The most obvious factor to control is the radiated power. In some situations where maximum range or reliability of communication is required, reduction of radiated power may not be an acceptable choice. Considerable additional work might be done to determine whether some of these other factors may be used to reduce the field strength levels in a predictable and repeatable way, but except for reducing power levels, the other parameter variations caused unpredictable changes.

An antenna located at the center of the roof is less hazardous to people than one located on a fender or bumper; the presentation of data does not show this clearly.

A further consideration is that in the future the field strength levels allowed by ANSI standards for personnel exposure may be lowered, and other mandatory standards by OSHA or EPA could be imposed.

5.0 Test Limits for Field Strength Levels

The tremendous amount of measured data was treated statistically to provide a perspective of field strength levels that exist around vehicles.

Emphasis must be placed on the fact that these are worst-case levels. Most vehicles, most of the time, will be in environments which have field strength levels two or more orders of magntiude lower than these covered in this report. However, many, if not most, vehicles, at some time or other, will be close to a transmitter and will be exposed to field strength levels comparable to those reported.

The judgment used in determining composite, worst-case levels as a function of frequency is not infallible. A no-risk situation may be unachievable; the objective is to achieve an acceptable, low-risk condition. The use of a set of levels allows the designer to share in the risk-level determination. Figure 40 shows four curves. The 100 percentile curve is high enough that all measured values reported are equal to or less than values given by this line. Similarly, 95 percentile, 90 percentile, and 50 percentile curve brackets the corresponding measured levels.

There are two distinct susceptibility measurement problems; one is the test level; and the other is the comparability of component vs. whole-system testing. The component may be resonant at relatively high frequencies; a whole vehicle may be resonant at relatively low frequencies. The levels either encountered or required may be the same, just at different frequencies. The higher levels will be due to resonances, and will be "Q" times the incident, unperturbed level of field strength, where Q is a resonance factor that relates stored energy to dissipated energy. Q's of up to 15 have been observed in these tests. An incident, nonperturbed level of 150 volts per meter would be boosted to 2250 volts per meter by a resonant structure with a Q of 15. If the structure is not at a resonant frequency, it will perturb the field by a 1/3 to 3 factor (e.g., an unperturbed, 150 V/m field may vary from 50 V/m to 450 V/m) at various locations, but the extreme increase in level occurs only at a resonant frequency.

One exception occurs near the base of an AM transmitter (550 kHz to 1.6 MHz) that uses a 5/8 wavelength tower. Unperturbed fields of over 800 volts per meter have been measured 3 meters from the base of a 50 kilowatt, 5/8 wavelength transmitting tower (KOA, Parker, Colorado). Service vehicles may come within 3 meters of a transmitter tower. At AM frequencies, there should be no resonances, since even a tractor-trailer is short compared to wavelengths in the AM frequency range.

The 90 percentile test level should be sufficient to cover most cases, even though the other limits indicate that higher field strength levels have been measured.

Susceptibility testing can be done at a component level using a TEM cell or other transmission line structure. There may be unknown shortcomings to component testing in TEM cells; a component mounted on a vehicle becomes electrically connected to the rest of the vehicle through cables and mounts; there are different resonant frequencies due to different sizes and shapes of structures. At present, whole vehicle testing is not possible with practical means.

Magnetic field strength test levels are shown on the right-hand side of figure 40. These numbers are obtained from free-space, far-field conversion (i.e., $\eta = 376.7 = E/H$). The actual numbers measured, shown in figures 17 through 22, are comparable or less than the limits of figure 40.

Values have not yet been measured above 420 MHz, but the limit lines were extrapolated to 1 GHz. The measured decrease in levels with frequency is expected but should be verified by measurements to 1 GHz.

6.0 Summary and Conclusions

As the number of electronic systems used on vehicles increases, the need to know the electromagnetic environment in and around these vehicles increases. This information is needed by system designers so they can design safe electronic systems that are compatible with this electromagnetic environment. Measurements of electric and magnetic field strength levels are reported for the near-field levels in and around full- and compact-sized passenger vehicles and tractor-trailer vehicles. These measurements were made with all common combinations of mobile transmitters and antennas. The rf transmitting sources used the maximum legal output power (110 W) at nominal frequencies of 40, 162, and 416 MHz, and nominal 100-watt power levels in the HF band (3 to 30 MHz). Illegal power levels (100 watts) of CB transmissions at 27 MHz were used through a special authorization by the Interagency Radio Advisory Committee (IRAC).

Fields in and around vehicles with on-board transmitters range mostly between 10 and 300 volts per meter, with some exceptions. Field strengths in and around vehicles adjacent to vehicles with transmitters range mostly between 5 and 100 volts per meter. Data are reported for fields on vehicles on normally conducting ground surfaces such as concrete and asphalt as well as for vehicles on metal ground screens.

The results of the electric field strength measurements in the near-field regions of fixed, high-power transmitters are also reported. These sites include AM, FM, and TV broadcast stations and high-power military and FAA fixed transmitters. The electric field strengths in the near-field region of the AM broadcast station in the frequency range between 550 kHz and 1.6 MHz are found to be much higher than those at other fixed, high-power transmitters, particularly for AM transmitters with 5/8 wavelength towers.

The curves shown in figure 40 summarize the field strength levels measured or anticipated and are suggested for susceptibility test criteria.

Some factors needed for electromagnetic susceptibility testing of components are discussed. Either continuously swept frequency testing or closely stepped frequency testing is suggested in order to detect resonant situations which greatly increase incident field strength levels. Other important factors are device time constants, personnel and test equipment safety, and perturbations of test fields caused by objects under test.

Finally, worst-case field strength levels for susceptibility testing are given. These are based on measured data around vehicles. Four different levels are given in order to allow designers and manufacturers some latitude in determining the degree of electromagnetic compatibility they desire to achieve.

7.0 Acknowledgments

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We wish to acknowledge the assistance of Tom Bremer, Nancy Tomoeda, John Workman, and Connie Haagenson for their help in making many of the measurements.

8.0 References

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E, Electric Field Strength Units: V/m

H, Magnetic Field Strength Units: A/m(V/m)

Vehicle type	Surface type	Frequency	Field type	No. of measurements	Percentile values					Comments
		MHz	E or H	N	100	95	90	75	50	
Full-size car	Metal ground	3.910	E	27	342	267	242	228	180	Ant left rear fender 100 w
Full-size car	Metal ground	7.280	E	32	164	159	148	130	108	Ant left rear fender 100 w
Full-size car	Metal ground	14.310	E	42	146	126	116	95	67	Ant left rear fender 100 w
Full-size car	Metal ground	21.400	E	40	383	319	260	213	106	Ant left rear fender 100 w
Full-size car	Metal ground	27.610	E	46	251	202	202	184	106	Ant left rear fender 100 w
Full-size car	Dry ground	40.27	E	56	190	171	150	104	58	Ant center of roof 110 w
Full-size car	Dry ground	40.27	E	47	196	178	116	75	48	Ant right rear fender110 w
Full-size car	Dry ground	162.475	E	61	201	116	82	54	30	Ant center of trunk 110 w
Full-size car	Dry ground	416.975	E	51	60	58	56	37	13	Ant center of roof 110 w
Full-size car	Metal ground	40.27	E	21	368	300	300	242	150	Ant center of roof 110 w
Full-size car	Metal ground	40.27	E	36	371	260	238	171	95	Ant right rear fender110 w
Full-size car	Metal ground	162.475	E	31	116	116	82	67	48	Ant center of roof 110 w
Full-size car	Metal ground	416.975	E	34	82	75	58	58	48	Ant center of roof 110 w
Car beside tx-car	Dry ground	40.27	E	20	48	37	37	21	15	Ant center of roof 110 w
Car beside tx-car	Dry ground	40.27	E	35	88	60	50	48	26	Ant right rear fender110 w
Car beside tx-car	Dry ground	162.475	E	18	75	75	75	34	21	Ant center of roof 110 w
Car beside tx-car	Dry ground	162.475	E	22	38	38	34	26	19	Ant center of trunk 110 w
Car beside tx-car	Dry ground	416.975	E	13	42	42	26	26	21	Ant center of roof 110 w
Full-size car	Near metal wall	40.27	E	23	212	184	184	150	82	Ant center of roof 110 w
Full-size car	Near metal wall	162.475	E	14	190	190	95	82	58	Ant center of roof 110 w
Full-size car	Near metal wall	416.975	E	12	95	95	58	48	48	Ant center of roof 110 w
Compact	Dry ground	3.91	E	36	322	295	274	249	213	Ant left rear fender 110 w
Compact	Metal ground	3.91	E	36	322	310	277	265	228	Ant left rear fender 110 w
Compact	Dry ground	7.28	E	43	232	205	192	174	130	Ant left rear fender 110 w

Table 2 (continued)

E, Electric Field Strength Units: V/m

H, Magnetic Field Strength Units: A/m(V/m)

Vehicle type	Surface type	Frequency	Field type	No. of measurements	Percentile values					Comments
		MHz	E or H	N	100	95	90	75	50	
Compact	Metal ground	7.28	E	46	343	201	192	169	145	Ant left rear fender 100 w
Compact	Dry ground	14.31	E	32	178	158	143	134	112	Ant left rear fender 100 w
Compact	Metal ground	14.31	E	37	178	178	171	148	106	Ant left rear fender 100 w
Compact	Dry ground	21.39	E	36	213	165	136	118	88	Ant left rear fender 100 w
Compact	Metal ground	21.39	E	35	289	277	233	202	106	Ant left rear fender 100 w
Compact	Dry ground	27.61	E	39	169	116	108	80	56	Ant center of roof 80 w
Compact	Metal ground	27.61	E	42	233	207	196	143	116	Ant center of roof 80 w
Compact	Dry ground	27.61	E	36	184	174	143	105	74	Ant left rear fender 80 w
Compact	Metal ground	27.61	E	37	392	356	336	285	196	Ant left rear fender 100 w
Compact	Dry ground	40.27	E	33	171	134	106	95	67	Ant right rear roof 100 w
Compact	Metal ground	40.27	E	39	233	196	138	106	74	Ant right rear roof 100 w
Compact	Dry ground	162.475	E	28	88	75	48	29	21	Ant left rear roof 100 w
Compact	Metal ground	162.475	E	23	80	67	58	34	28	Ant left rear roof 100 w
Compact	Dry ground	416.975	E	24	82	54	50	45	15	Ant center of roof 80 w
Compact	Metal ground	416.975	E	21	56	54	52	37	15	Ant center of roof 80 w
Tractor-trailer	Dry ground	27.6	E	35	112	106	72	60	48	Ant on the roof 100 w
Tractor-trailer	Metal ground	27.6	E	33	106	106	93	82	67	Ant on the roof 100 w
Tractor-trailer	Dry ground	40.27	E	43	223	178	158	111	82	Ant on the roof 60 w
Tractor-trailer	Metal ground	40.27	E	51	190	184	171	111	82	Ant on the roof 60 w
Tractor-trailer	Dry ground	162.475	E	34	126	116	95	67	30	Ant center of roof
Tractor-trailer	Dry ground	416.975	E	40	67	52	48	26	10	Ant center of roof
Tractor-trailer	Dry ground	3.91	E	13	161	161	81	76	51	Ant on left rear fender
next to	Dry ground	7.28	E	8	116	116	116	92	58	Ant on left rear fender
Car with tx	Dry ground	14.31	E	14	134	134	82	58	48	Ant on left rear fender
	Dry ground	21.39	E	7	58	58	58	48	48	Ant on left rear fender
	Dry ground	27.61	E	9	95	95	95	58	40	Ant on left rear fender
	Dry ground	27.61	E	6	75	75	75	75	58	Ant on center of roof100 w

Table 2 (continued)

E, Electric Field Strength Units: V/m

H, Magnetic Field Strength Units: A/m(V/m)

Vehicle type	Surface type	Frequency	Field type	No. of measurements	Percentile values					Comments
		MHz	E or H	N	100	95	90	75	50	
Tractor-trailer	Dry ground	40.27	E	21	95	95	82	58	34	Ant center of roof 110 w
next to	Dry ground	40.27	E	21	67	58	50	26	21	Ant center of roof 110 w
Car with tx	Dry ground	40.27	E	21	41	40	34	26	21	Ant right rear fender110 w
	Dry ground	162.475	E	13	58	58	42	21	15	Ant center of roof 110 w
	Dry ground	416.975	E	11	47	47	26	18	15	Ant center of roof 110 w
	Dry ground	416.975	E	13	38	38	26	18	12	Ant center of roof 110 w
Tractor-trailer	Dry ground	40.27	E	20	171	116	95	48	21	Ant center of roof 110 w
next to	Dry ground	162.475	E	20	58	37	34	26	12	Ant center of roof 110 w
Tractor-trailer with tx	Dry ground	416.975	E	21	45	37	30	21	15	Ant center of roof 110 w
Full-size car	Metal ground	7.28	H	32	.239(90)	.212(80)	.207(78)	.112(42)	.090(34)	Ant left rear fender 100 w
Full-size car	Dirt ground	7.28	H	39	.425(160)	.319(120)	.239(90)	.143(54)	.066(25)	Ant left rear fender 100 w
Full-size car	Metal ground	27.6	H	33	.425(160)	.358(135)	.311(117)	.260(98)	.179(67)	Ant left rear fender 100 w
Full-size car	Dirt ground	27.6	H	23	.260(98)	.226(85)	.179(67)	.098(37)	.056(21)	Ant left rear fender 100 w
Full-size car	Metal ground	40	H	31	.358(135)	.358(135)	.239(90)	.170(64)	.093(35)	Ant right rear fender100 w
Full-size car	Dirt ground	40	H	28	.451(170)	.332(125)	.319(120)	.082(31)	.032(12)	Ant right rear fender100 w
Full-size car	Dirt ground	162	H	56	.370(139)	.179(67)	.159(60)	.074(28)	.035(13)	Ant center of trunk 100 w
Full-size car	Metal ground	162	H	58	.372(140)	.231(87)	.186(70)	.109(41)	.048(18)	Ant center of trunk 100 w
Compact	Dry ground	7.28	H	21	.504(190)	.504(190)	.404(152)	.281(106)	.234(88)	Ant left rear fender 95 w
Compact	Metal ground	7.28	H	20	.504(190)	.441(166)	.404(152)	.327(123)	.181(68)	Ant left rear fender 95 w
Compact	Dry ground	27.61	H	32	.478(180)	.430(162)	.308(116)	.085(32)	.064(24)	Ant center of roof 100 w
Compact	Metal ground	27.61	H	30	.390(147)	.348(131)	.223(84)	.181(68)	.106(40)	Ant center of roof 100 w
Compact	Dry ground	40.27	H	28	.664(250)	.467(176)	.329(124)	.215(81)	.096(36)	Ant center of roof 82 w
Compact	Metal ground	40.27	H	26	.611(230)	.518(195)	.358(135)	.215(81)	.159(60)	Ant center of roof 82 w
Compact	Dry ground	40.27	H	40	.473(178)	.451(170)	.297(112)	.242(91)	.127(48)	Ant right rear fender100 w
Compact	Metal ground	40.27	H	38	.473(178)	.438(165)	.411(155)	.297(112)	.186(70)	Ant right rear fender100 w
Compact	Dry ground	162.475	H	32	.332(125)	.215(81)	.207(78)	.080(30)	.037(14)	Ant right rear fender100 w
Compact	Metal ground	162.475	H	35	.372(140)	.305(115)	.234(88)	.098(37)	.042(16)	Ant left rear fender 100 w
Tractor-trailer	Dry ground	27.6	H	28	.518(195)	.459(173)	.340(128)	.223(84)	.133(50)	Ant on the roof 100 w
Tractor-trailer	Metal ground	27.6	H	29	.557(210)	.393(148)	.308(116)	.223(84)	.119(45)	Ant on the roof 100 w
Tractor-trailer	Dry ground	40.27	H	29	.929(350)	.717(270)	.571(215)	.324(122)	.186(70)	Ant on the roof 100 w
Tractor-trailer	Metal ground	40.27	H	28	.956(360)	.749(282)	.690(260)	.358(135)	.215(81)	Ant on the roof 100 w

Table 2 (continued)

E, Electric Field Strength Units: V/m

H, Magnetic Field Strength Units: A/m(V/m)

Vehicle type	Surface type	Frequency	Field type	No. of measurements	Percentile values					Distance from Transmit Antenna (m)	Comments
		MHz	E or H	N	100	95	90	75	50		
Full-size car	Dry ground	.85	E	24	222	212	196	171	134	130 m (300 yd)	KOA, tx, 50 kW, 5/8 ant
Full-size car	Dry ground	.85	E	22	18	15	15	13	11	164 m (160 yd.)	KOA, tx, 50 kW, 5/8 ant
Full-size car	Dry ground	1.6 107.5	E	30*	164	157	106	95	82	9 m (30 ft)	KLAK-AM 5kW, FM 56 kW tx
Full-size car	Dry ground	1.6 107.5	E	29*	58	30	26	21	13	36 m (120 ft)	KLAK-AM 5 kW, FM 56 kW tx
Full-size car	Dry ground	100.3	E	27	9	8	8	6	5	91 m (100 yd)	KLIR-FM tx, 100 kW
Full-size car	Dry ground	101.5	E	33	42	40	34	30	21	30 m (100 ft)	KHEP-FM tx, 100 kW
Full-size car	Dry ground	101.5	E	25*	26	21	21	18	15	182 m (200 yd)	KHEP-FM tx, 100 kW
		180								18 m (60 ft)	KAET-TV, tx, Channel 8, 117 KW vis 16.2 kW aur
		204								18 m (60 ft)	KTAR-TV, Channel 12, 316 kW vis, 46.8 kW aur
		60								91 m (100 yd)	KTVK-TV tx, Channel 3, 100 kW, vis 15.1 kW aur
Full-size car	Dry ground	90.7 518	E	44*	60	54	50	34	18	3 m (10 ft) 3 m (10 ft)	KRWG-FM tx, 100 kW, KRWG-TV tx, Channel 22
Full-size car	Dry ground	90.7 518	E	42*	45	42	40	26	21	18 m (60 ft) 18 m (60 ft)	KRWG-FM tx, 100 kW KRWG-TV tx, Channel 22, 1620 kW vis, 350 kW aur
Full-size car	Dry ground	54	E	22	42	37	34	26	21	30 m (100 ft)	KWGN-TV tx, Channel 2, 100 kW vis, 20 kW aur
Full-size car	Dry ground	66	E	26	11	9	9	7	7	46 m (50 yd)	KOA-TV tx, Channel 4, 100 kW vis, 35 kW aur
Full-size car	Dry ground	82	E	34	58	40	30	21	15	46 m (50 yd)	KRMA-TV tx, Channel 6, 100 kW vis, 15.1 kW aur
Full-size car	Dry ground	82	E	7	21	21	21	15	13	273 m (300 yd)	KRMA-TV tx, Channel 6, 100 kW vis, 15.1 kW aur
Tractor-trailer	Dry ground	0.85	E	22	921	921	824	759	568	3 m (10 ft)	KOA, 5/8 λ ant, 50 kW
Tractor-trailer	Dry ground	0.85	E	22	412	391	349	240	184	21 m (70 ft)	KOA, 5/8 λ ant, 50 kW
Compact	Dry ground	0.85	E	13	368	368	368	319	212	3 m (10 ft)	KOA, 5/8 λ ant, 50 kW

*Resultant field strength from more than one transmitter.

Fig. 1 Photo of NBS probe being used to make near-field electrical field strength measurements.

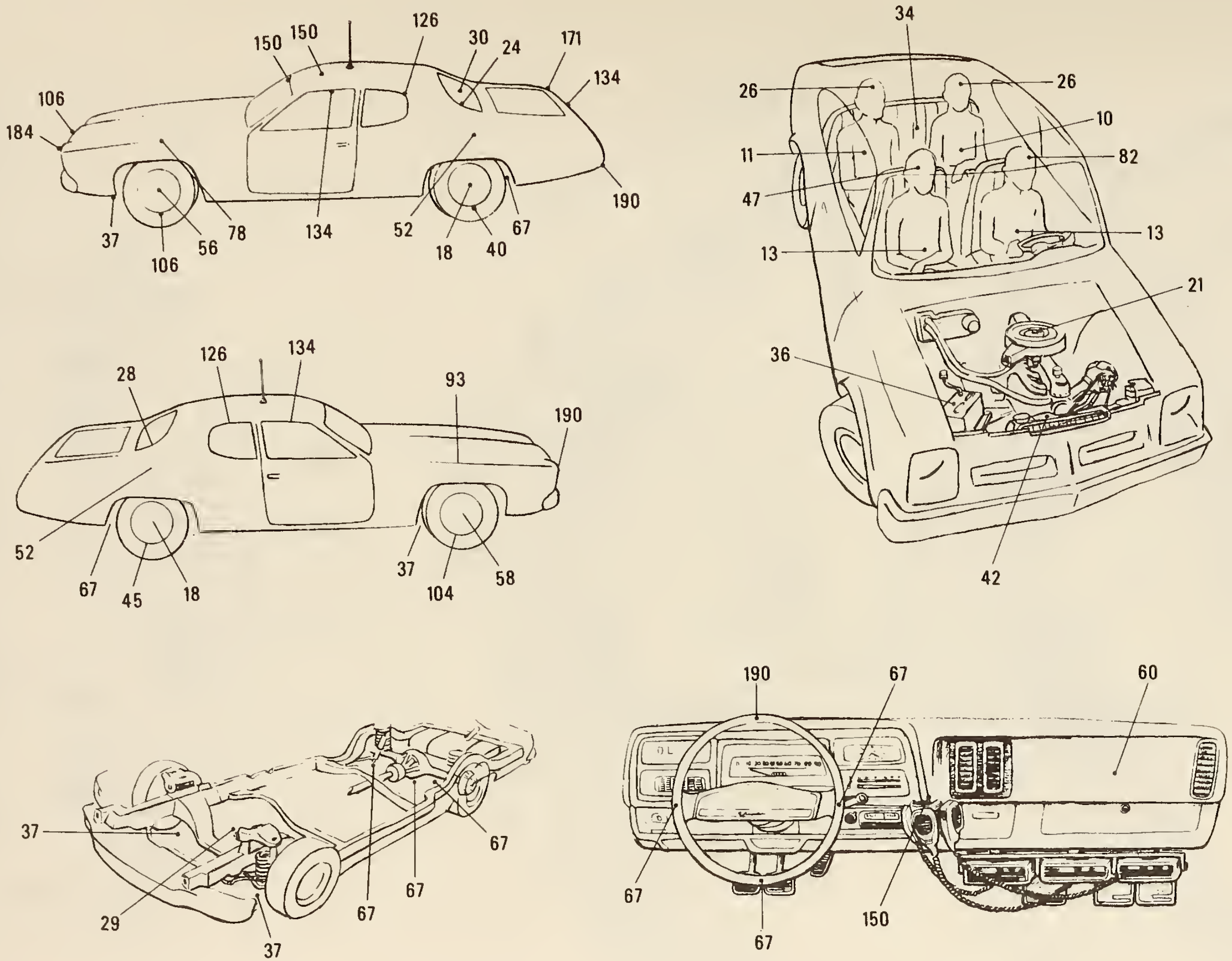


Fig. 2 Electric field strength levels (V/m) at various locations around a full-sized passenger vehicle on dry ground with an onboard 110 watt transmitter, 40.27 MHz, with a base-loaded antenna located at the center of the roof top.

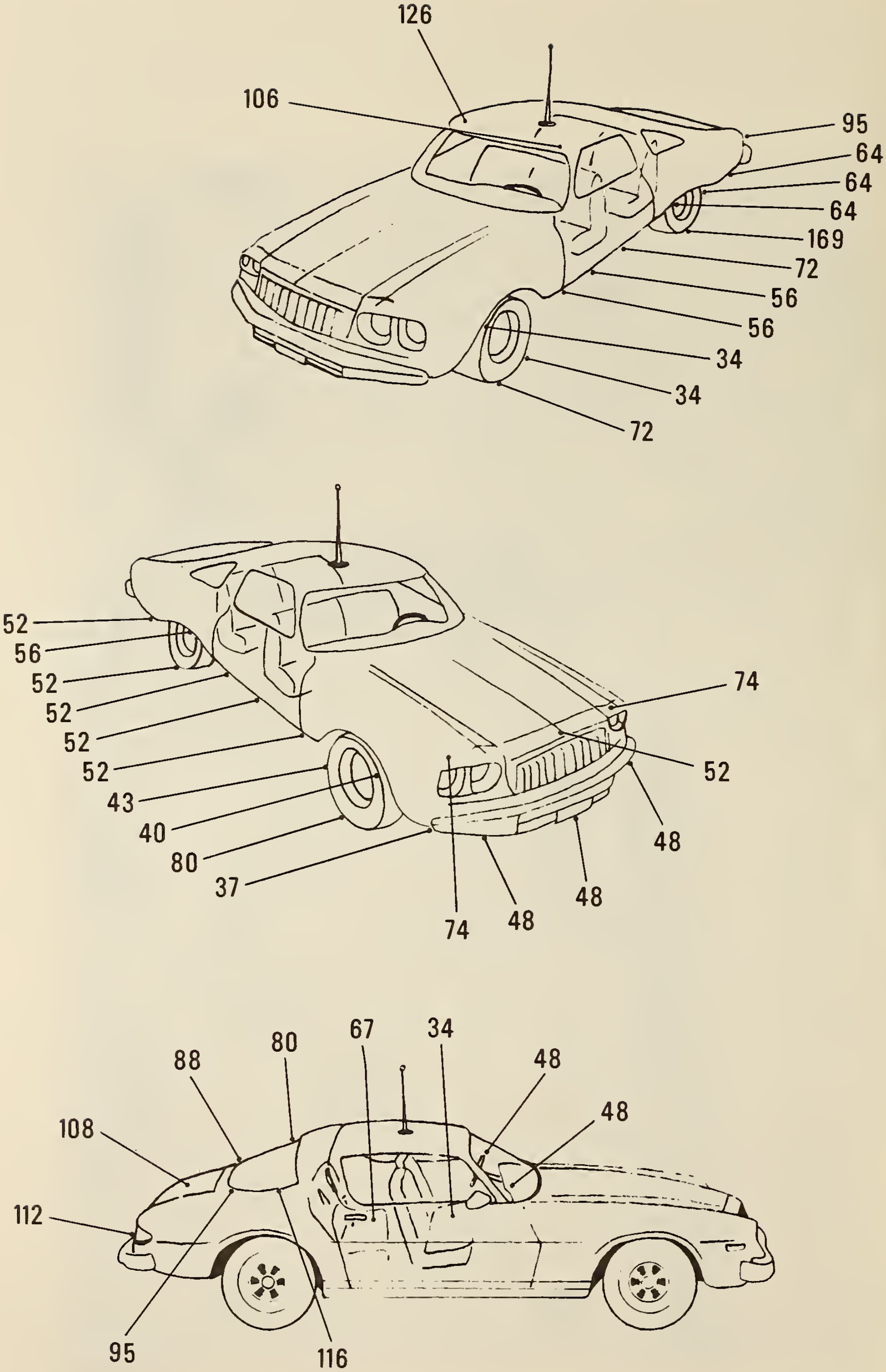


Fig. 3 Electric field strength levels (V/m) at various locations around a compact vehicle on dry ground with an onboard 100 watt transmitter, 27.610 MHz, with a base-loaded antenna located at the center of the roof top.

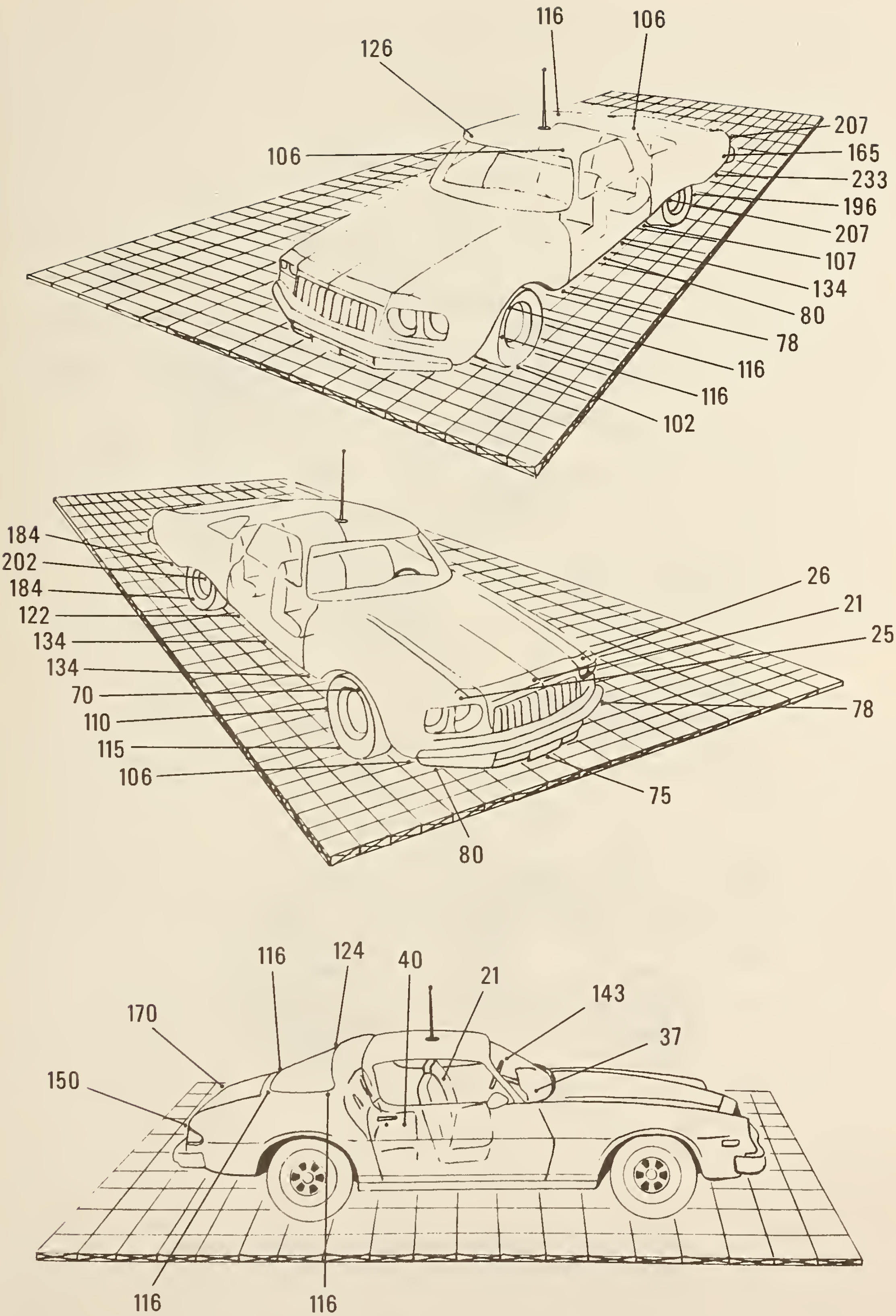
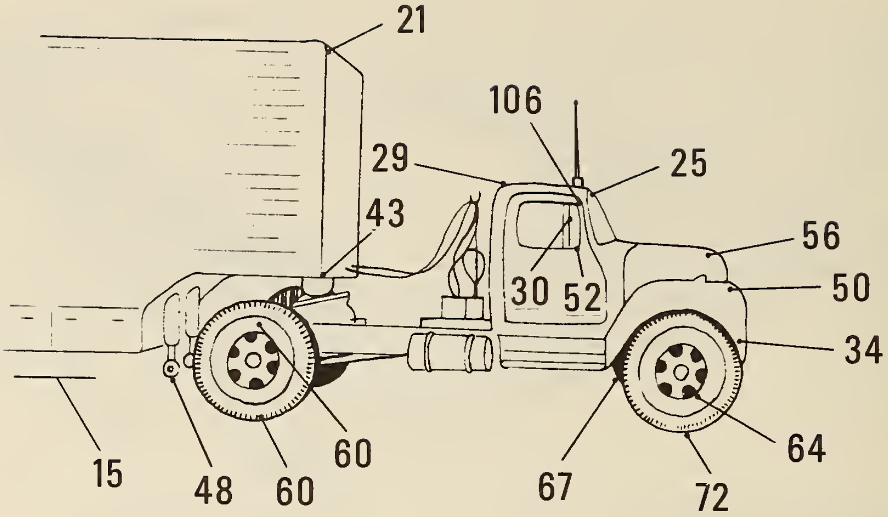


Fig. 4 Electric field strength levels (V/m) at various locations around a compact vehicle on a metal ground plane with an onboard 100 watt transmitter, 27.610 MHz, with a base-loaded antenna located at the center of the roof top.



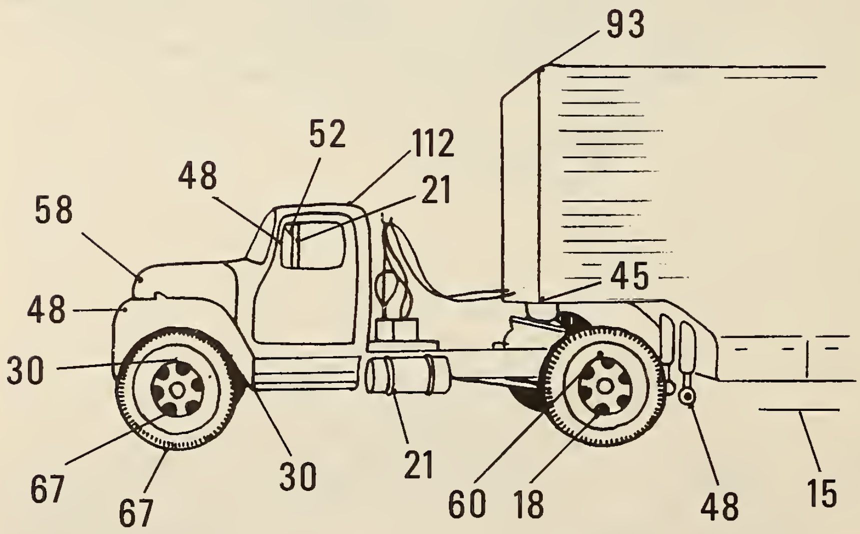


Fig. 5 Electric field strength levels (V/m) at various locations around a tractor-trailer vehicle on dry ground with an onboard 100 watt transmitter, 27.610 MHz, with a base-loaded antenna located at the center of the roof top.

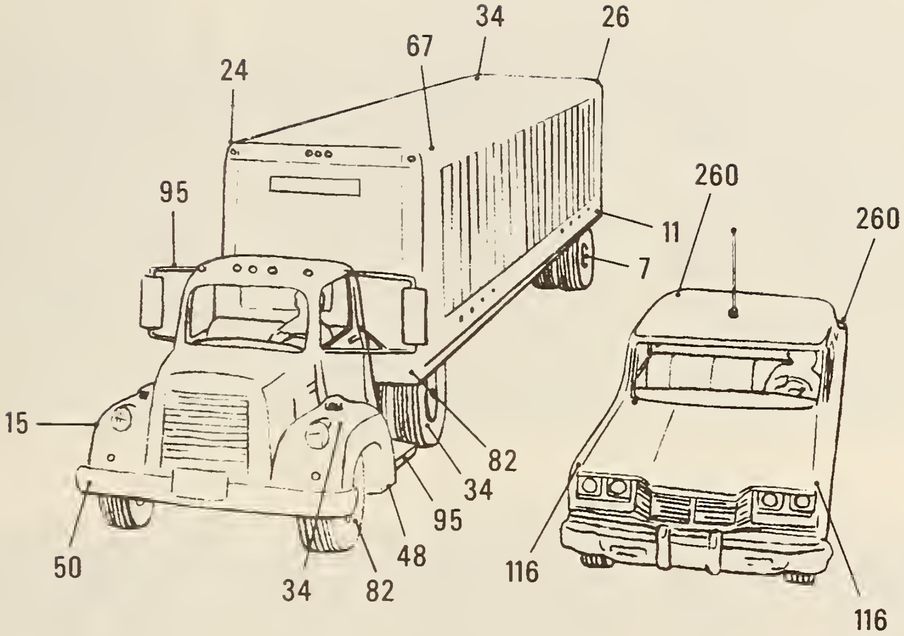


Fig. 6 Electric field strength levels (V/m) at various near-field locations, 110 W transmitter, 40.27 MHz, base-loaded antenna located at the center of the roof top of the passenger vehicle, on dry ground.

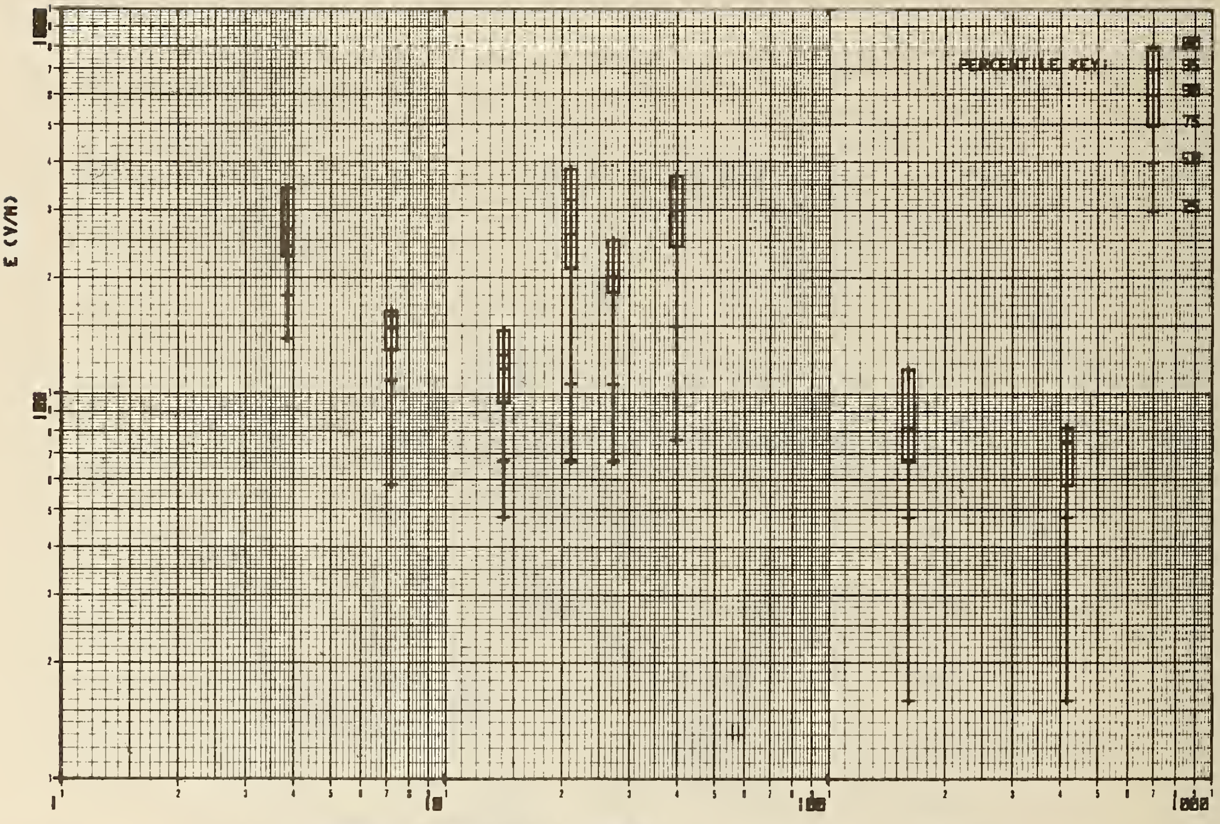


FIG. 7 - E FIELD, FULL SIZE CAR, METAL GROUND

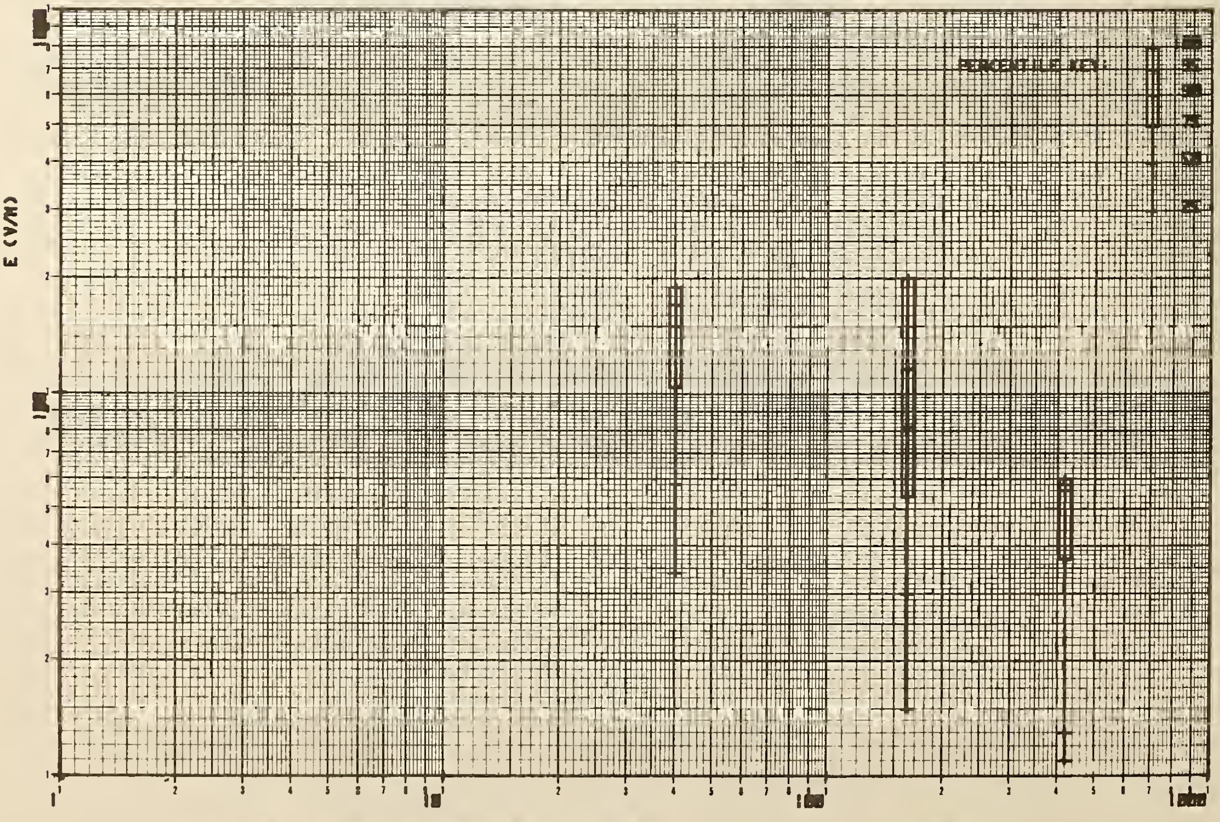


FIG. 8 - E FIELD, FULL SIZE CAR, DRY GROUND

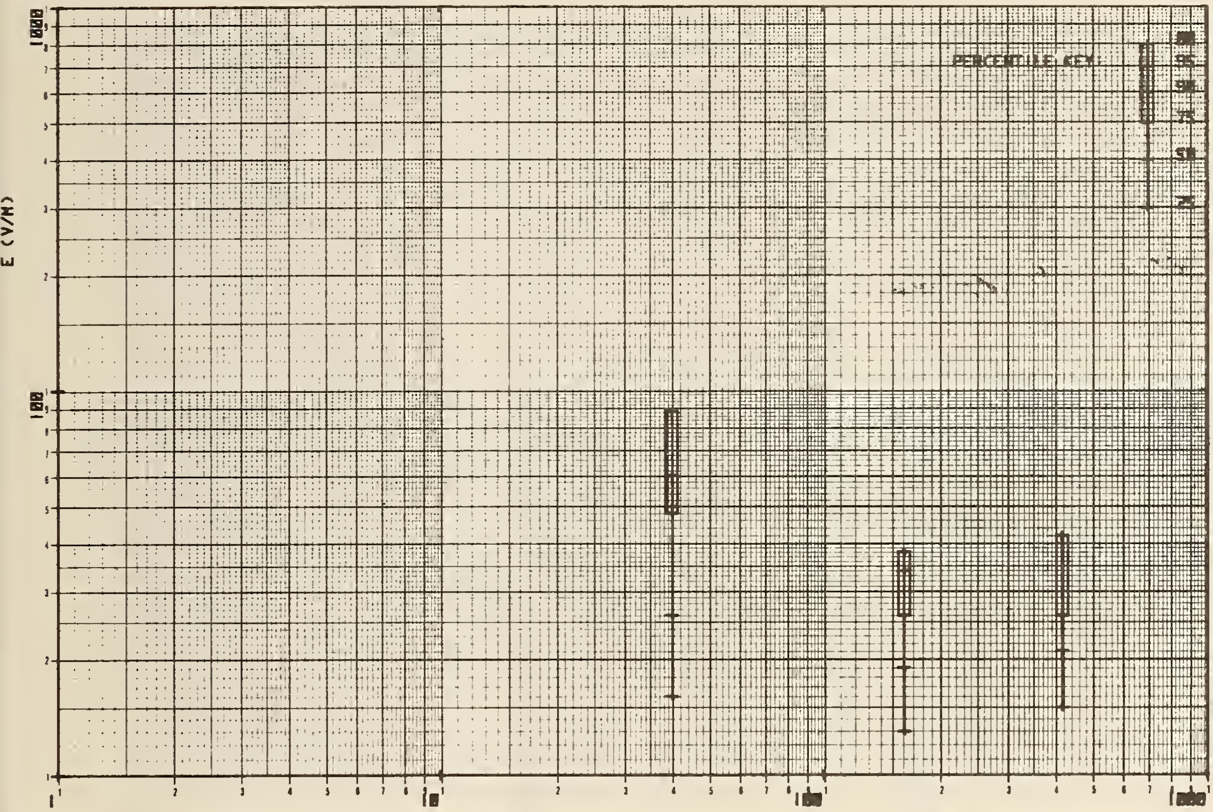


FIG. 9 - E FIELD, CAR BESIDE TRANSMITTING CAR

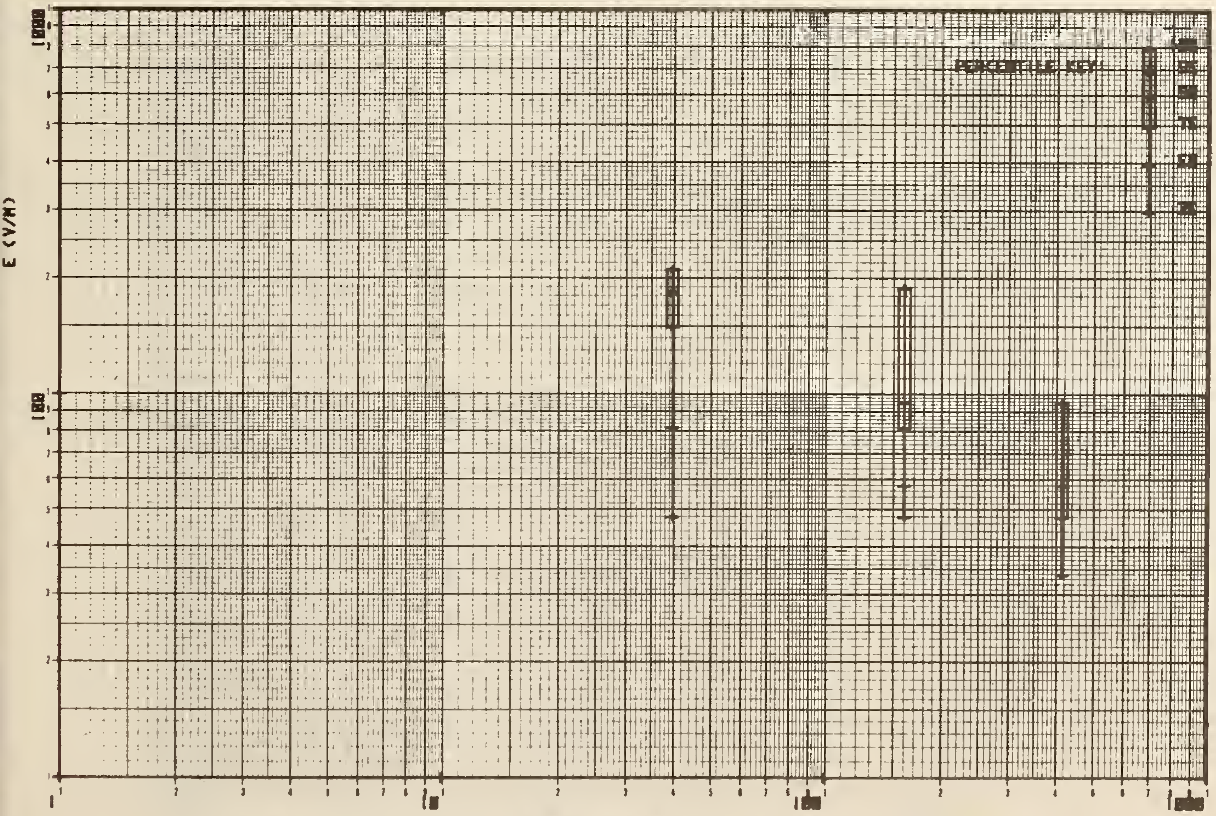


FIG. 10 - E FIELD, FULL SIZE CAR NEAR METAL WALL

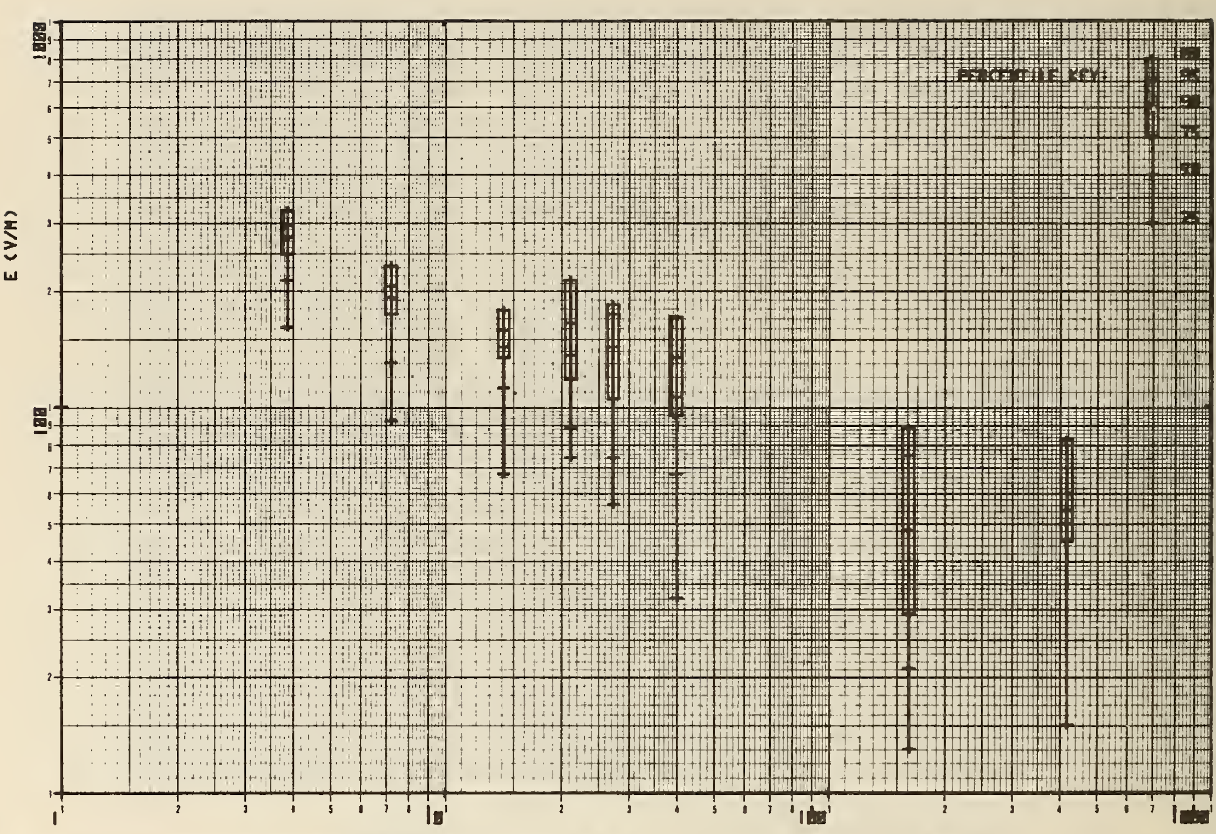


FIG. 11 - E FIELD, COMPACT CAR, DRY GROUND

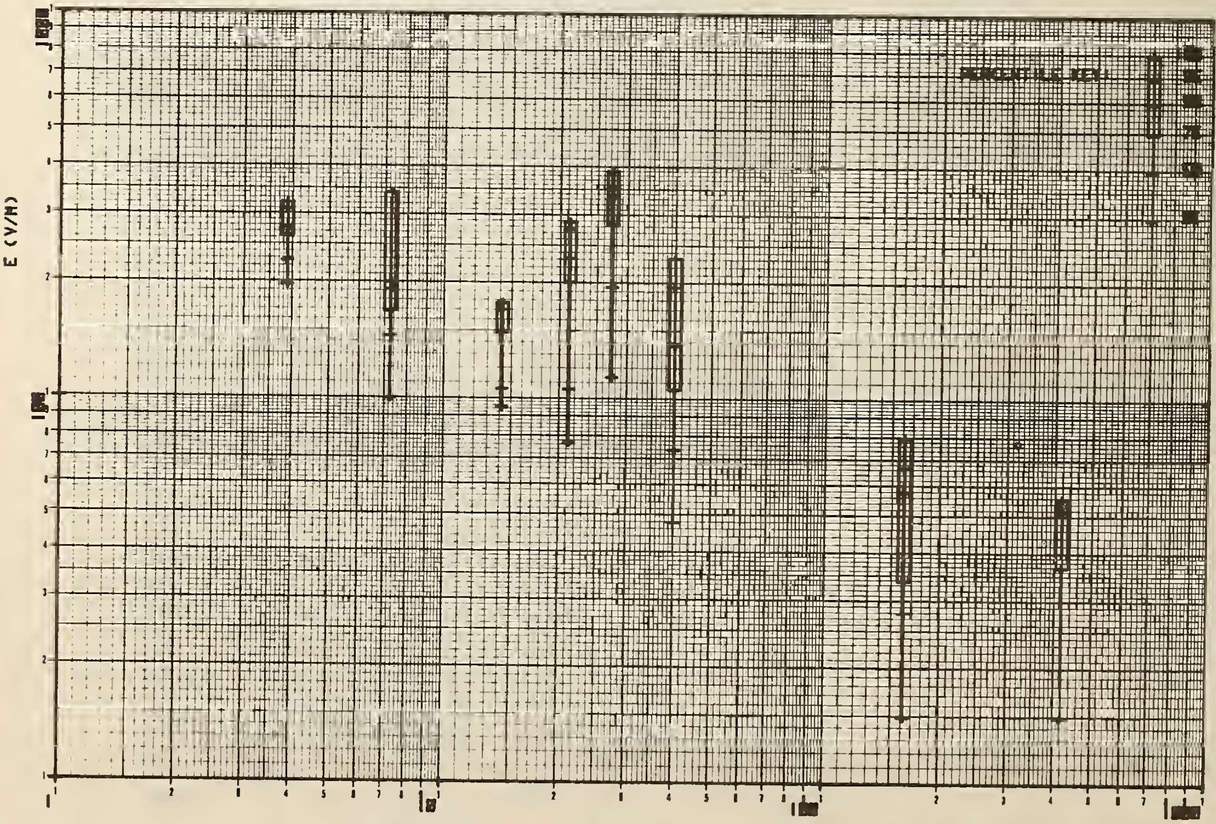


FIG. 12 - E FIELD, COMPACT CAR, METAL GROUND

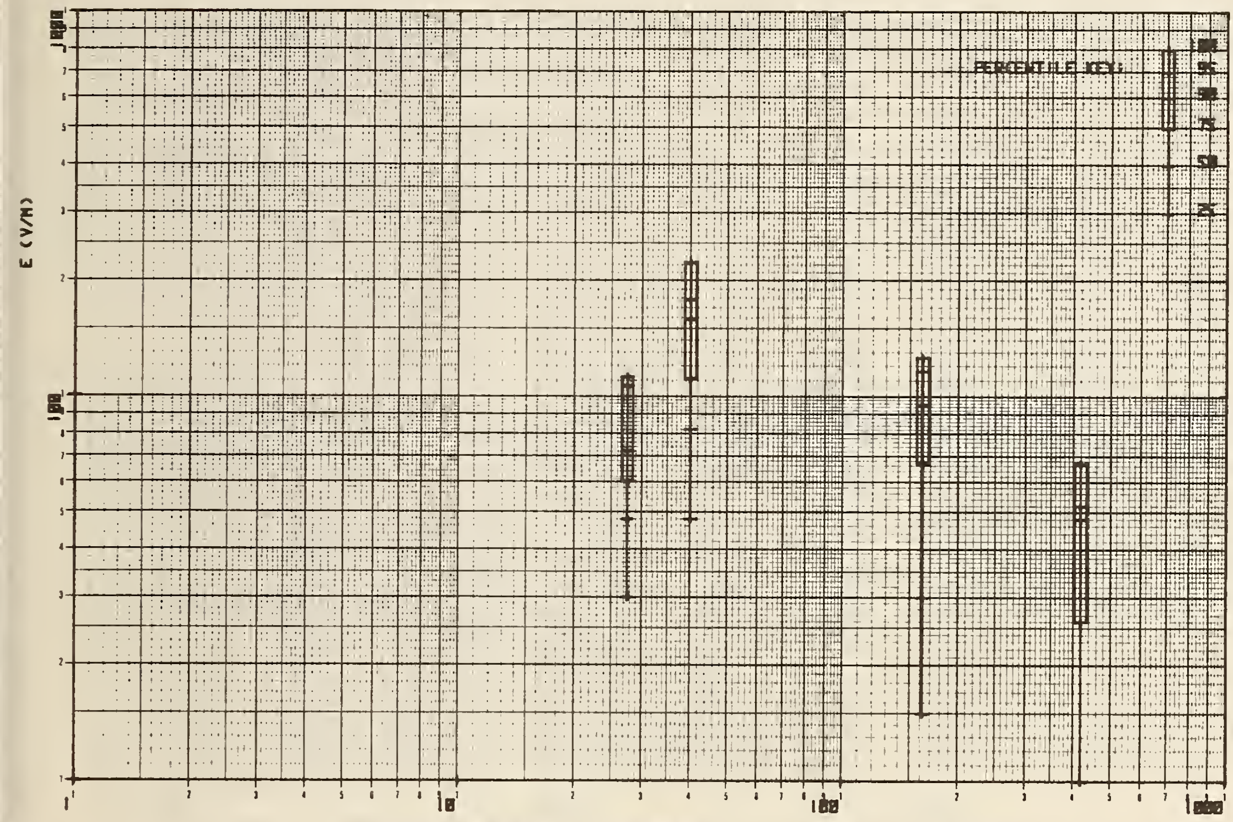


FIG. 13 - E FIELD, TRACTOR-TRAILER, DRY GROUND

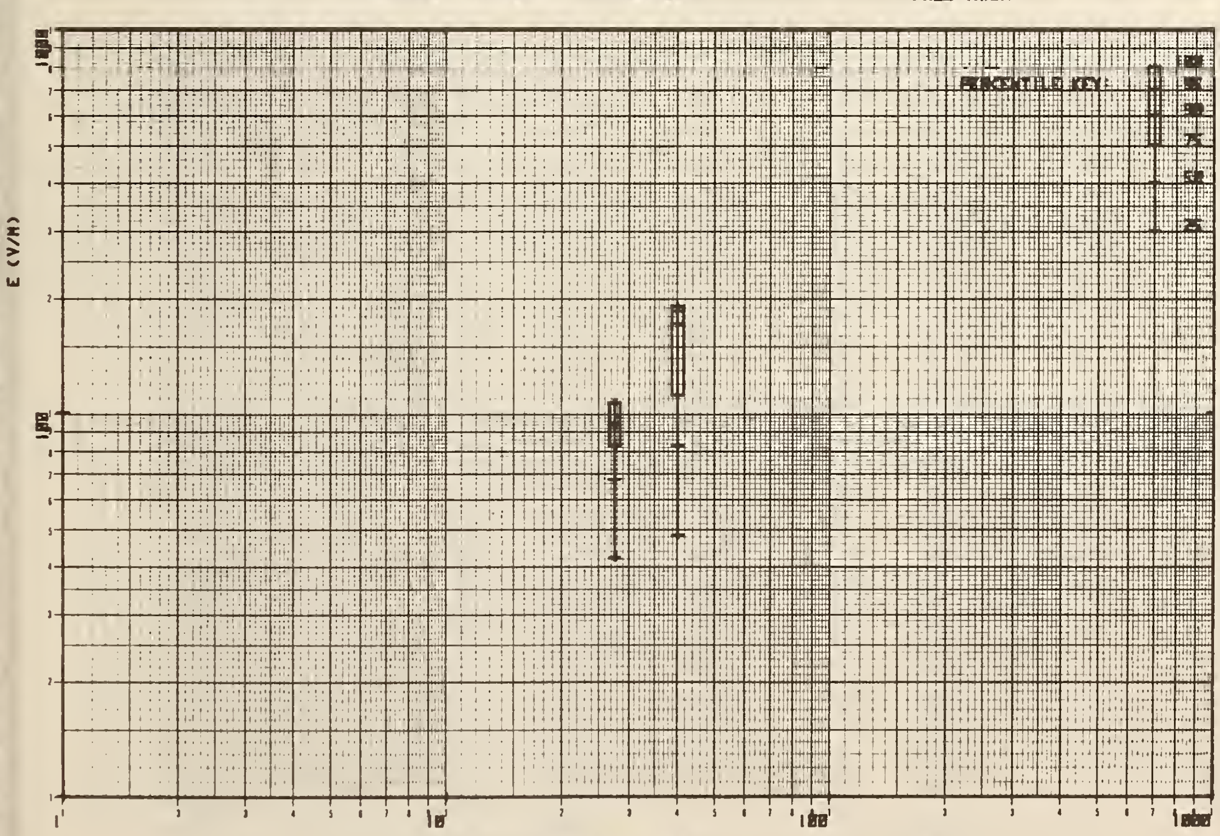


FIG. 14 - E FIELD, TRACTOR-TRAILER, METAL GROUND

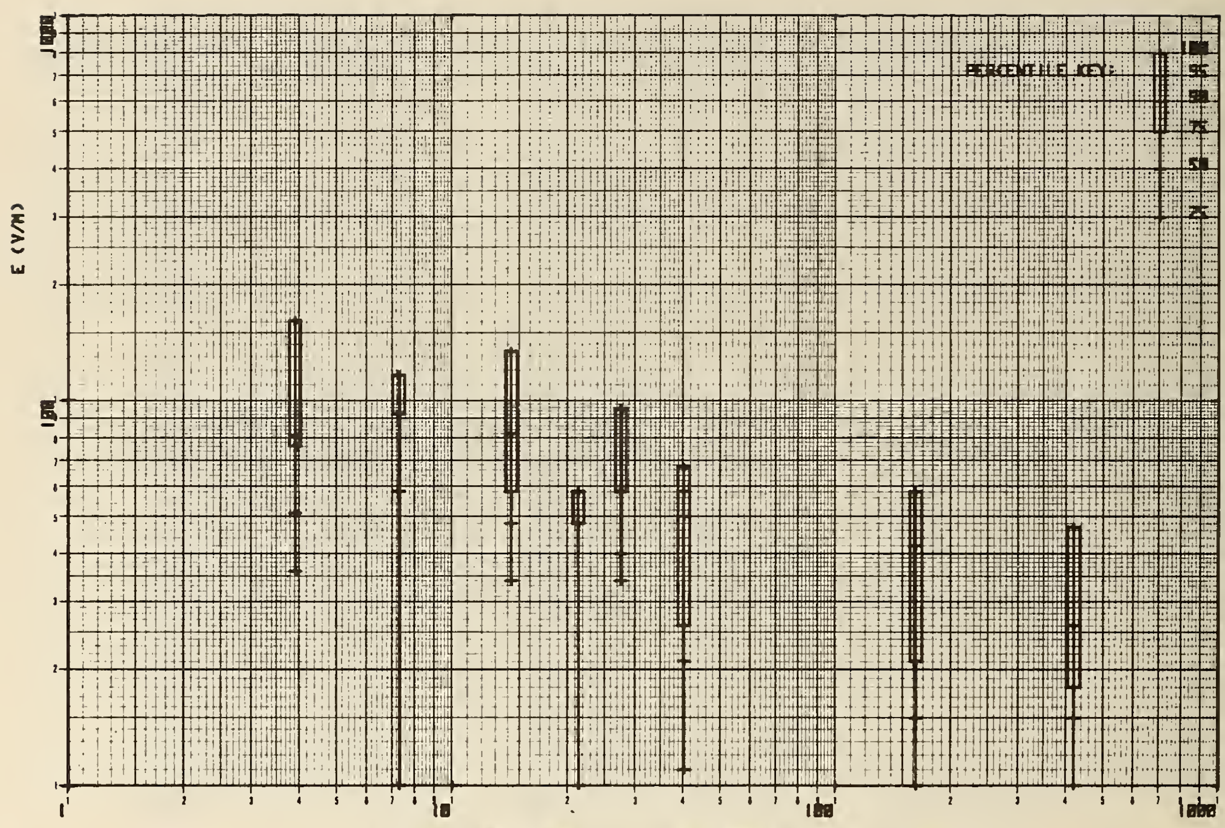


FIG. 15 - E FIELD, TRAC-TRAIL. BESIDE TX-CAR, DRY GROUND

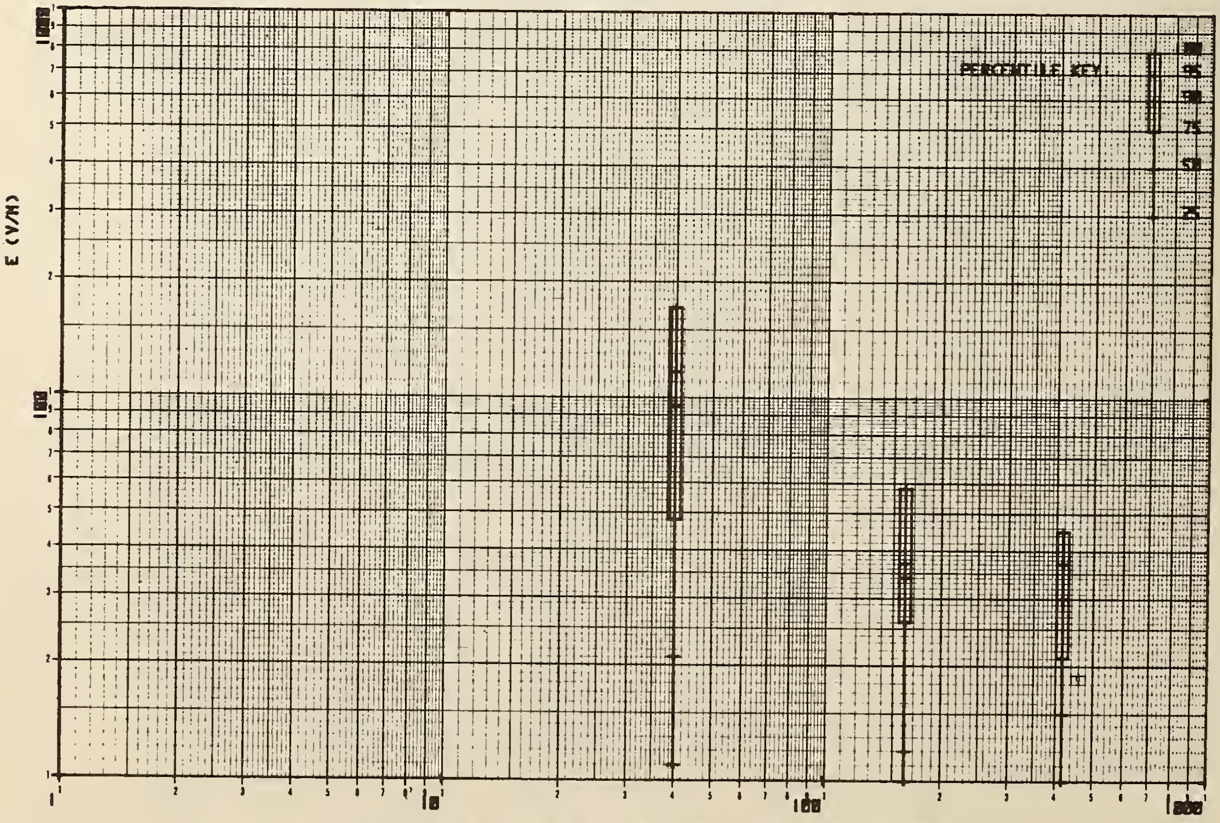


FIG. 16 - E FIELD, TRAC-TRAIL. BESIDE TX TRAC-TRAIL, DRY GROUND

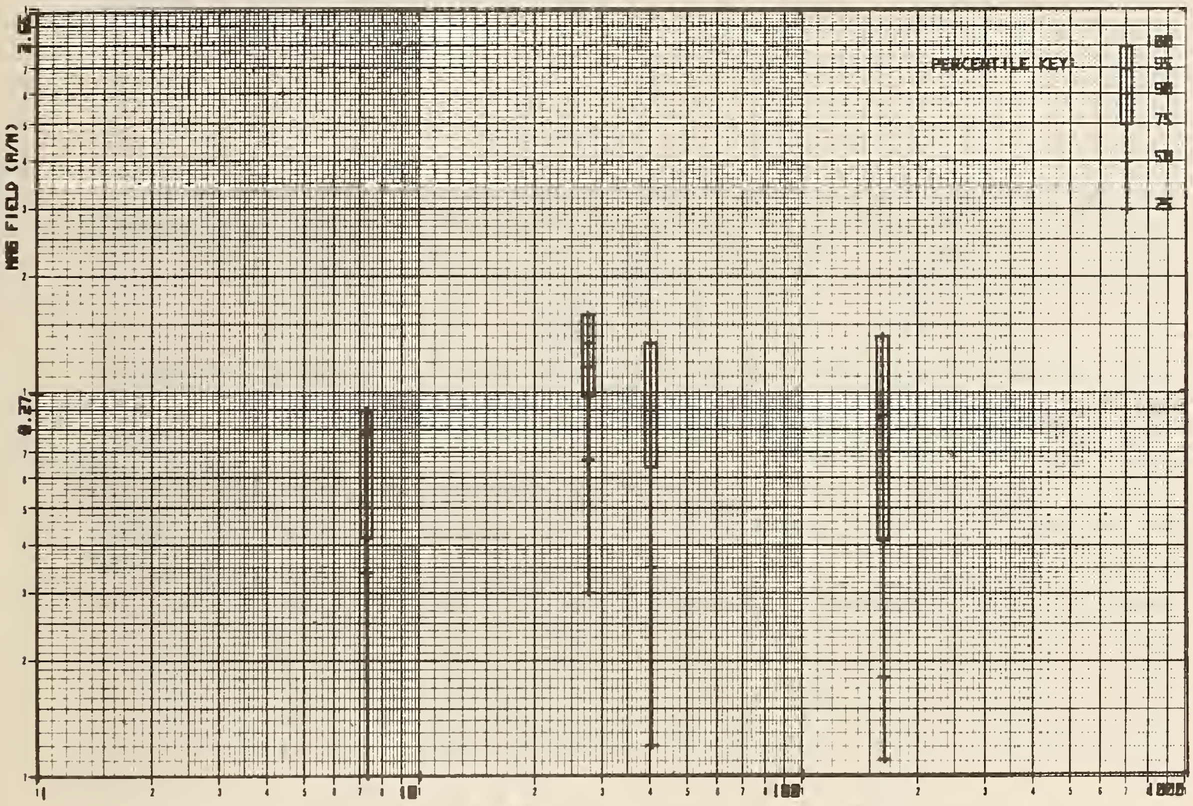


FIG. 17 - H FIELD, FULL SIZE CAR, METAL GROUND

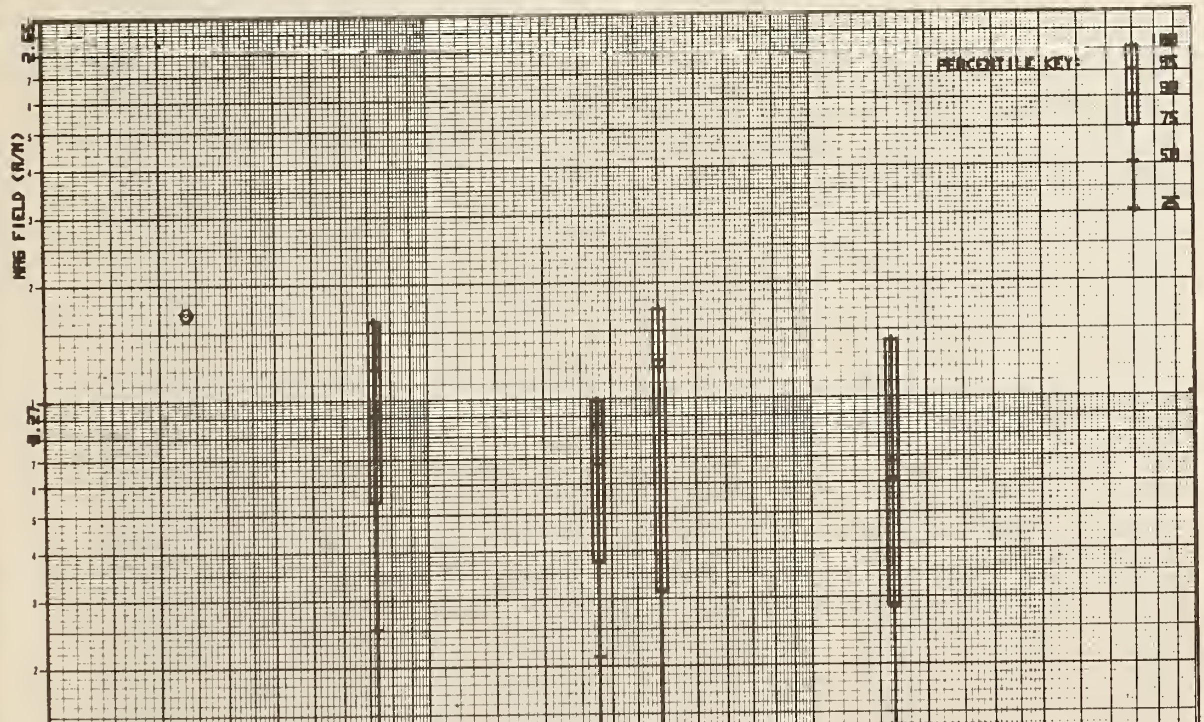


FIG. 18 - H FIELD, FULL SIZE CAR, DRY GROUND

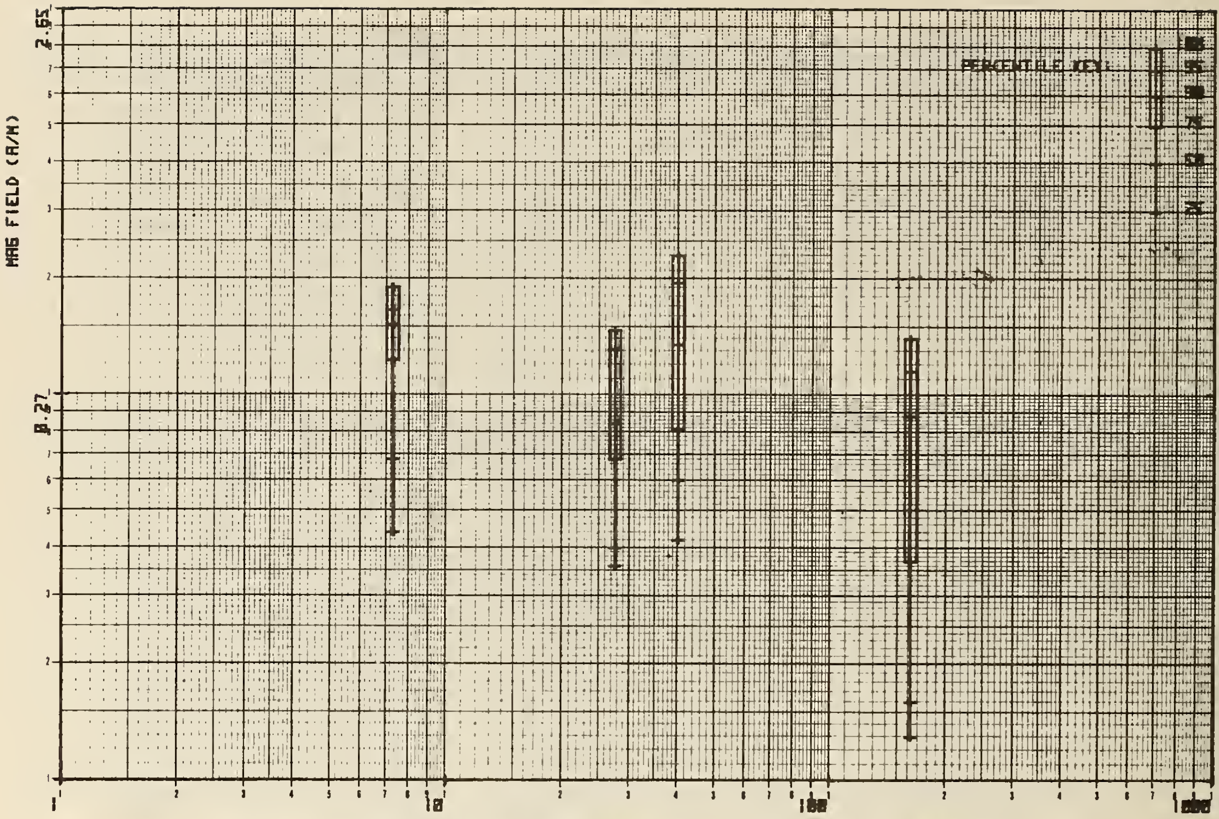


FIG. 19 - H FIELD, COMPACT CAR, METAL GROUND

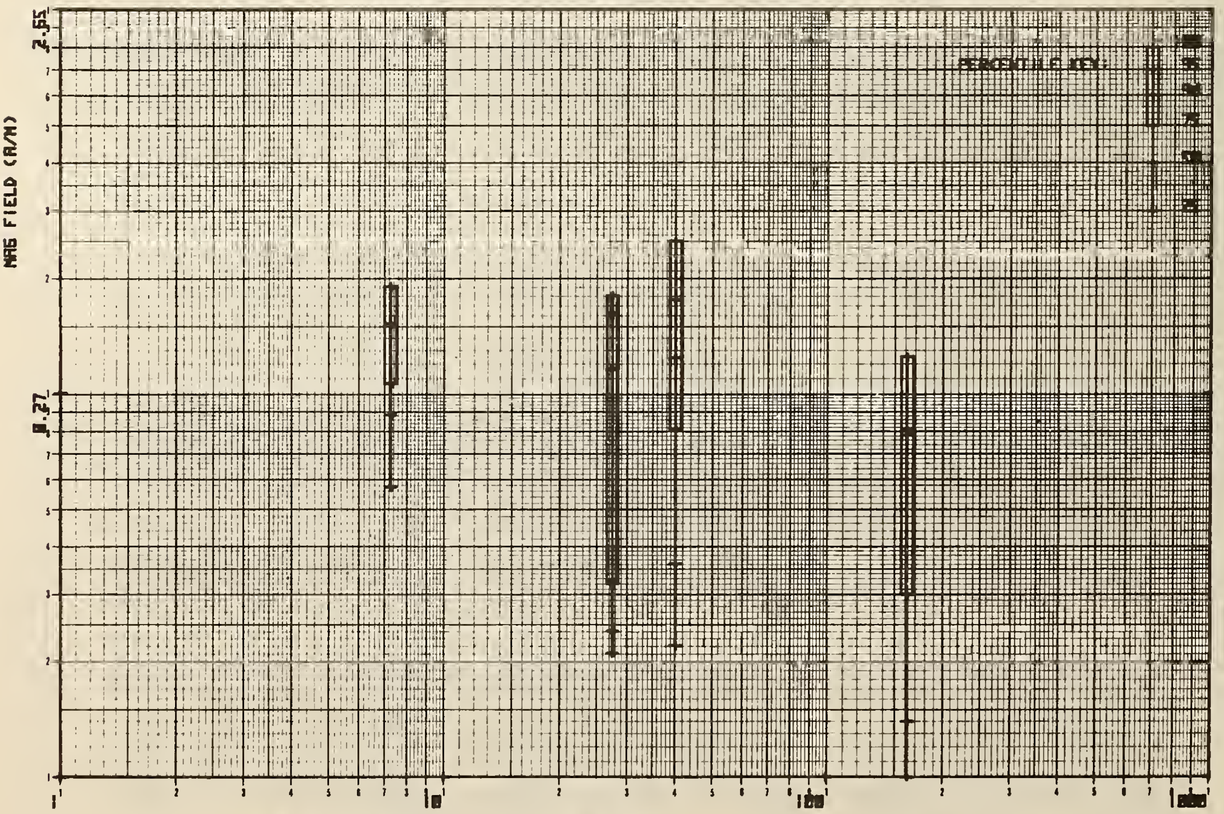


FIG. 20 - H FIELD, COMPACT CAR, DRY GROUND

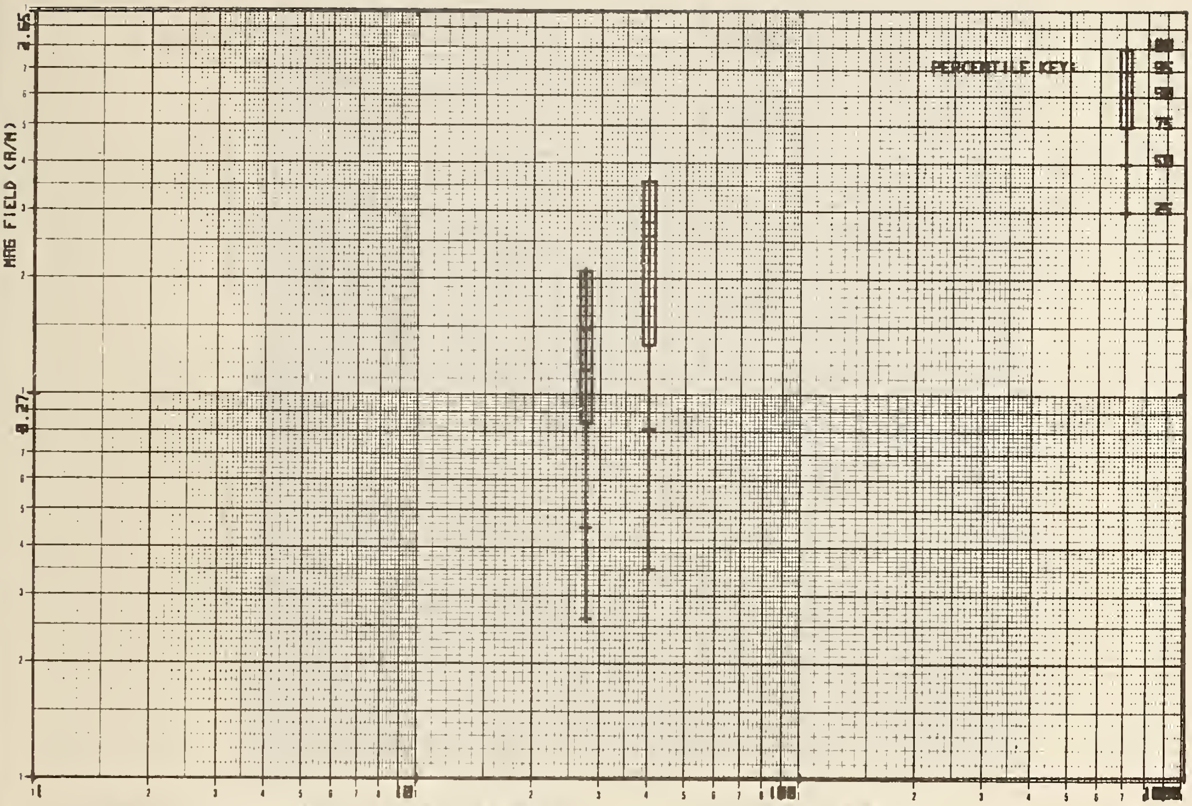


FIG. 21 - H FIELD, TRACTOR TRAILER, METAL GROUND

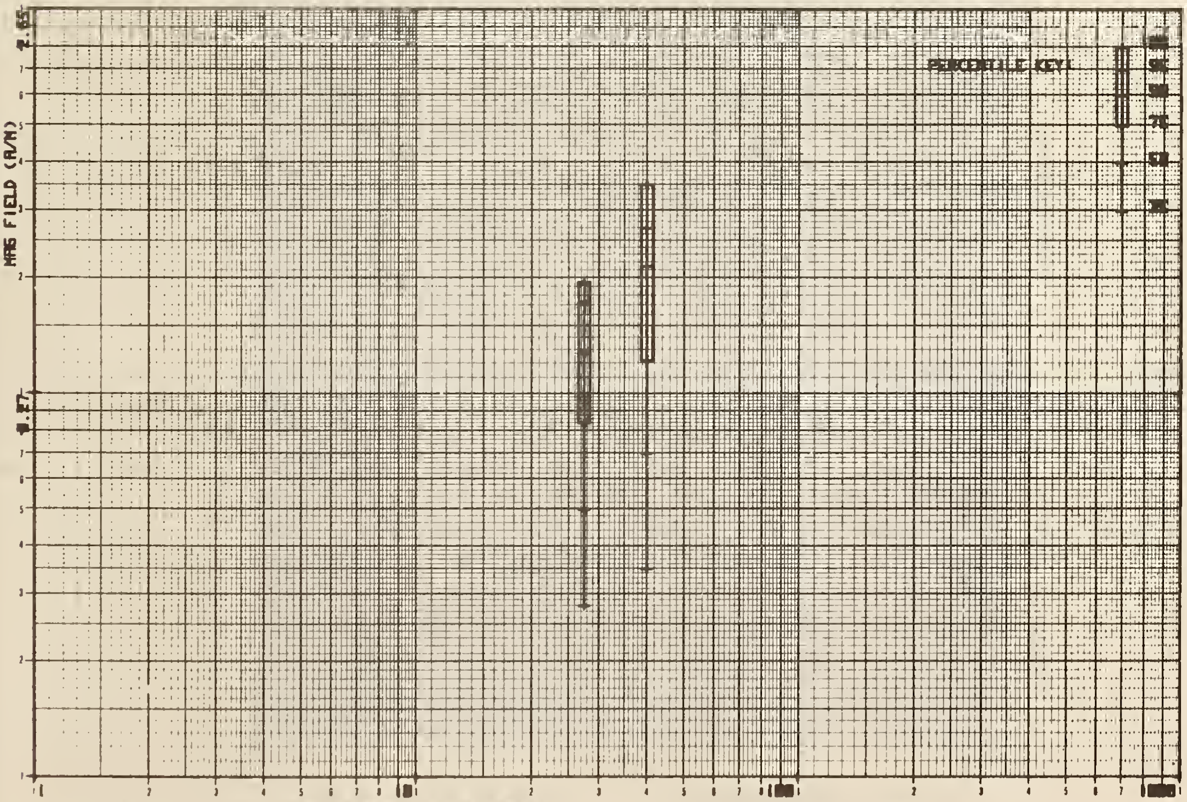


FIG. 22 - H FIELD, TRACTOR TRAILER, DRY GROUND

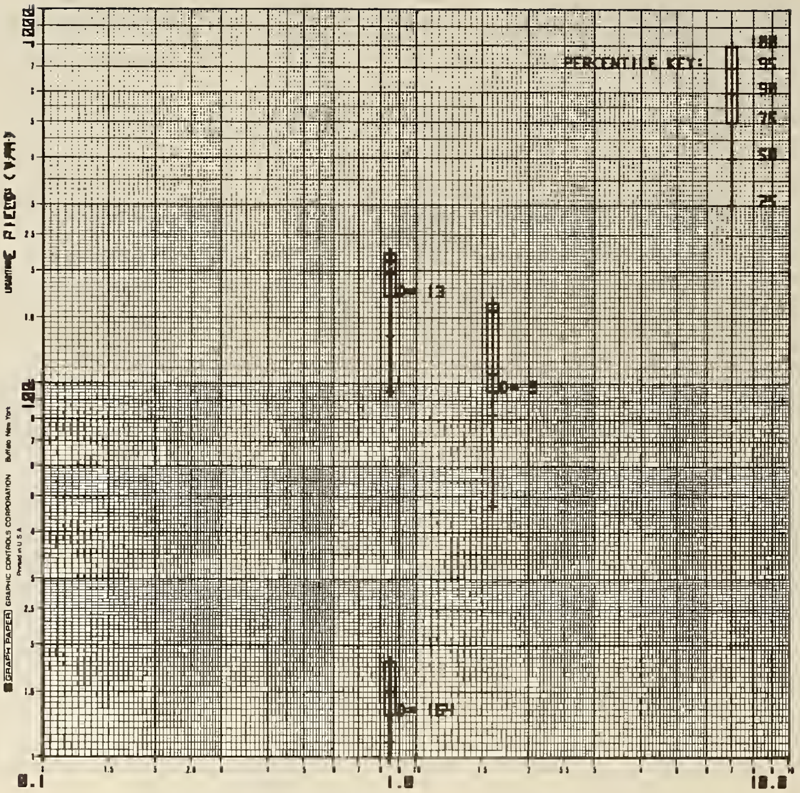


FIG. 23 - E FIELD, AM BROADCAST FREQ (MHZ)

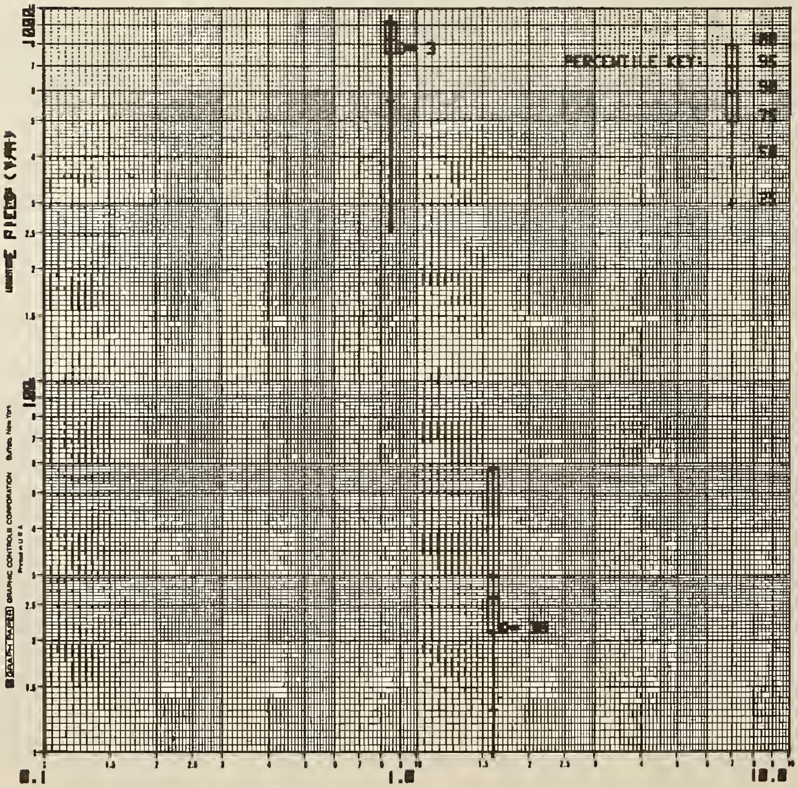


FIG. 24 - E FIELD, AM BROADCAST FREQ (MHZ)

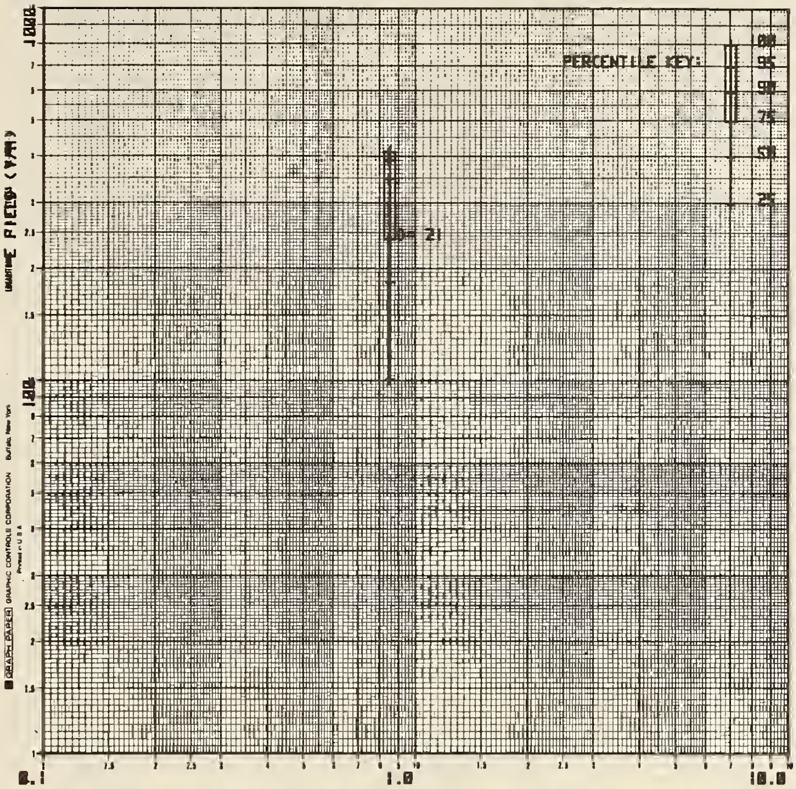


FIG. 25 - E FIELD, AM BROADCAST FREQ (MHZ)

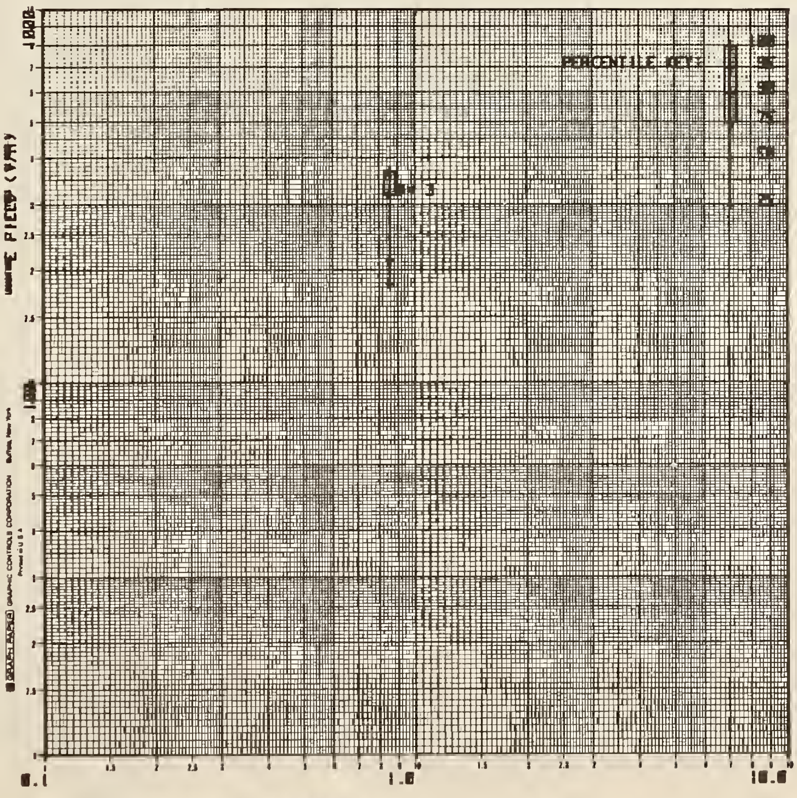


FIG. 26 - E FIELD, AM BROADCAST FREQ (MHZ)

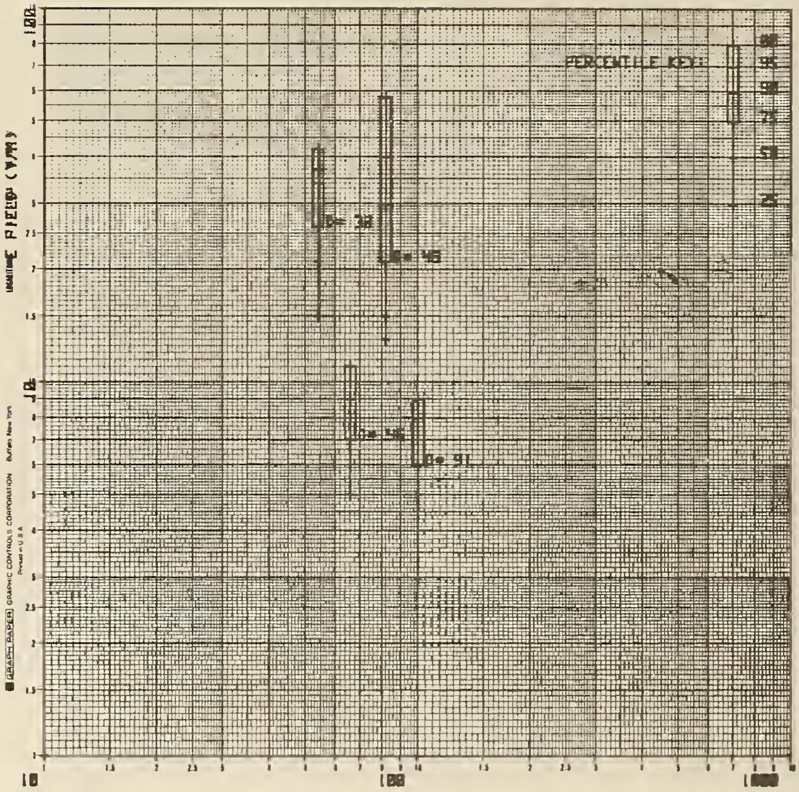


FIG. 27 - E FIELD, FM & TV BROADCAST FREQ (MHZ)

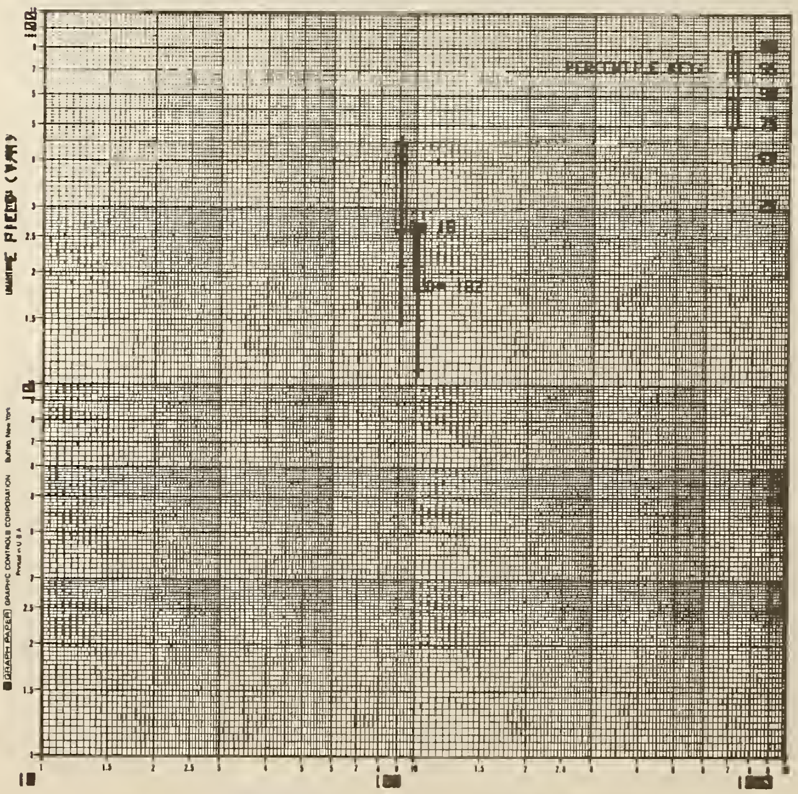


FIG. 28 - E FIELD, FM & TV BROADCAST FREQ (MHZ)

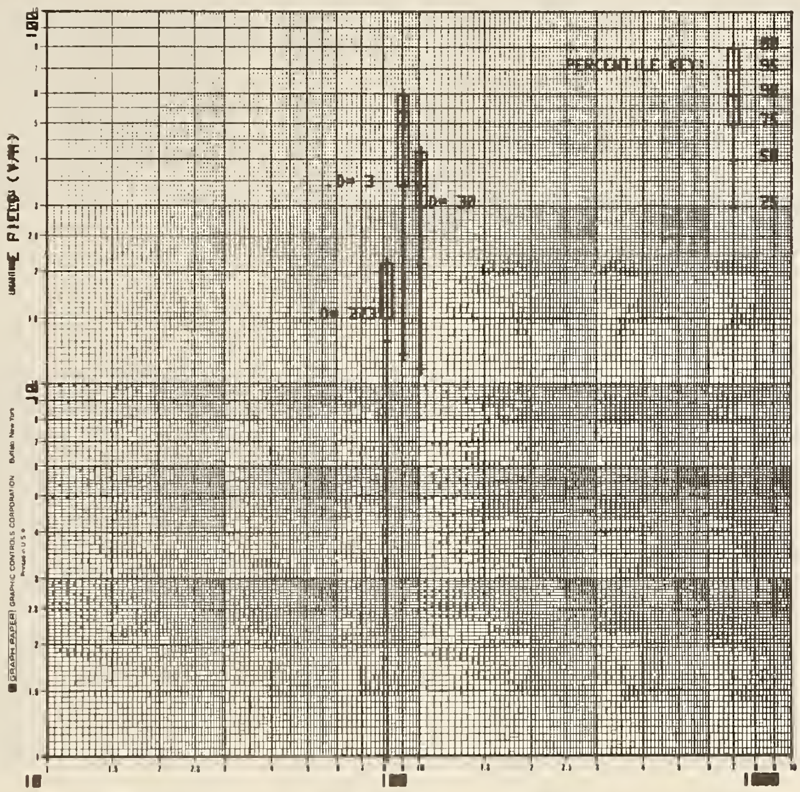


FIG. 29 - E FIELD/ FM & TV BROADCAST

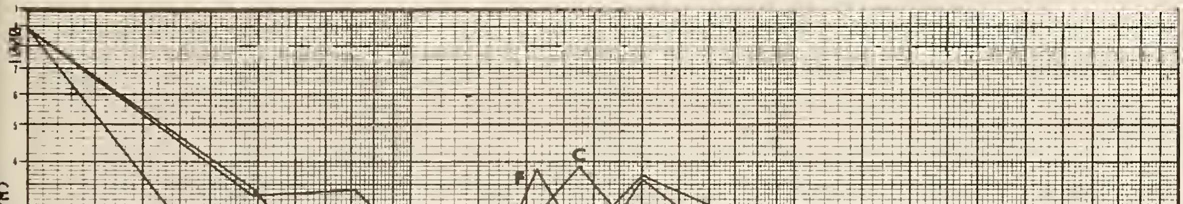


FIG. 30 - E FIELD/ WORST CASE/ 100 PERCENTILE

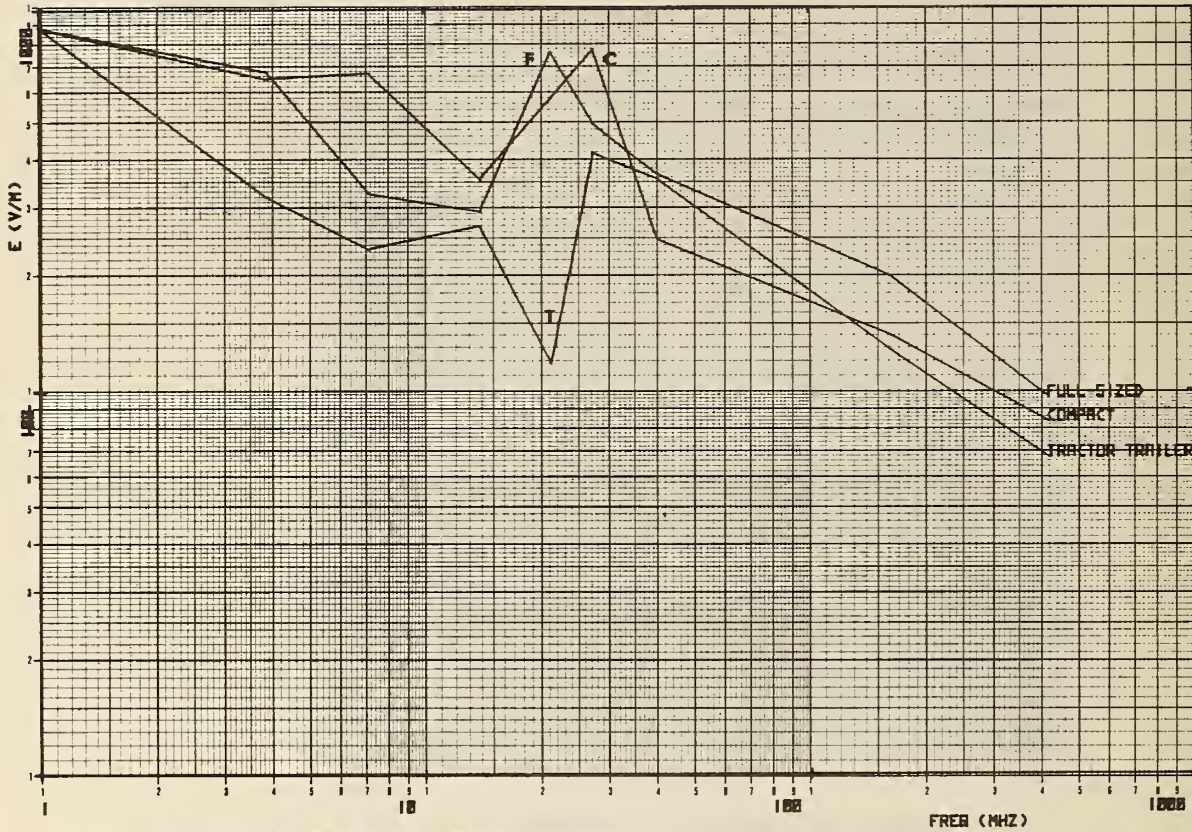


FIG. 31 - E FIELD, WORST CASE, NORMALIZED, 100 PERCENTILE

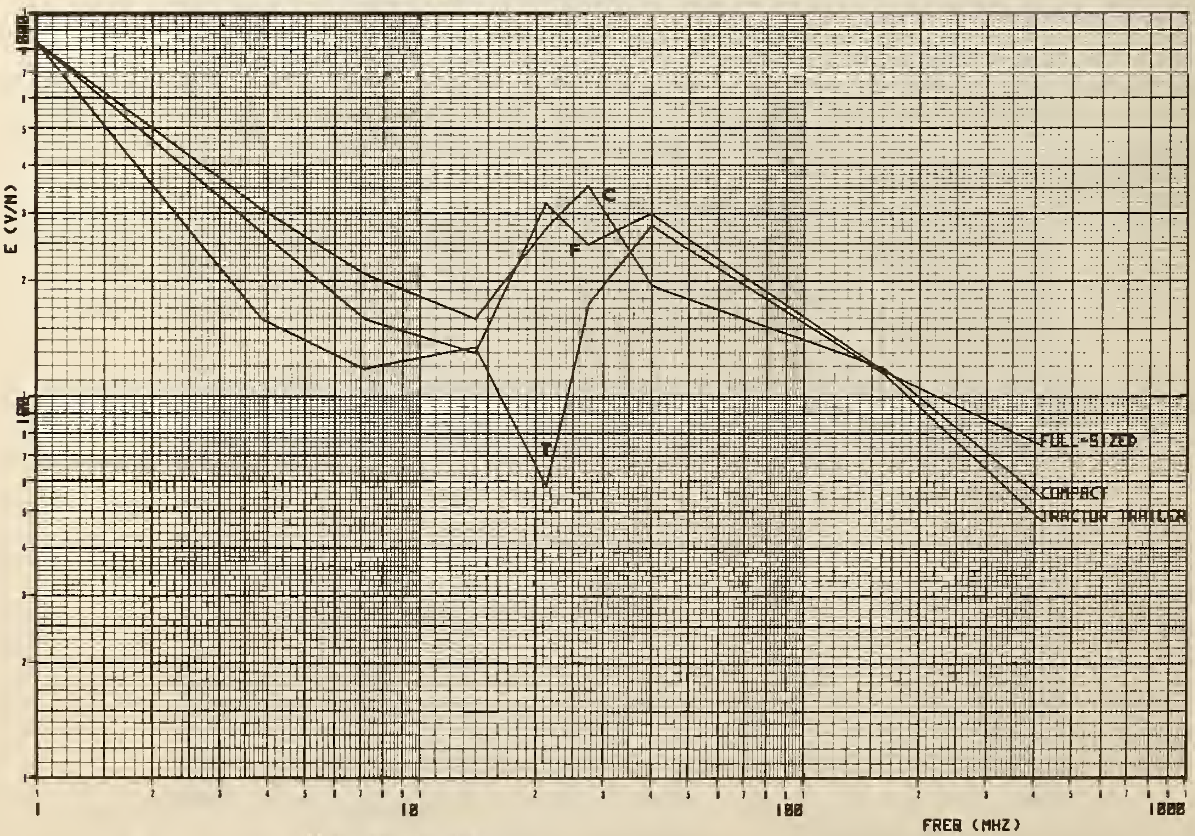


FIG. 32 - E FIELD, WORST CASE, 95 PERCENTILE

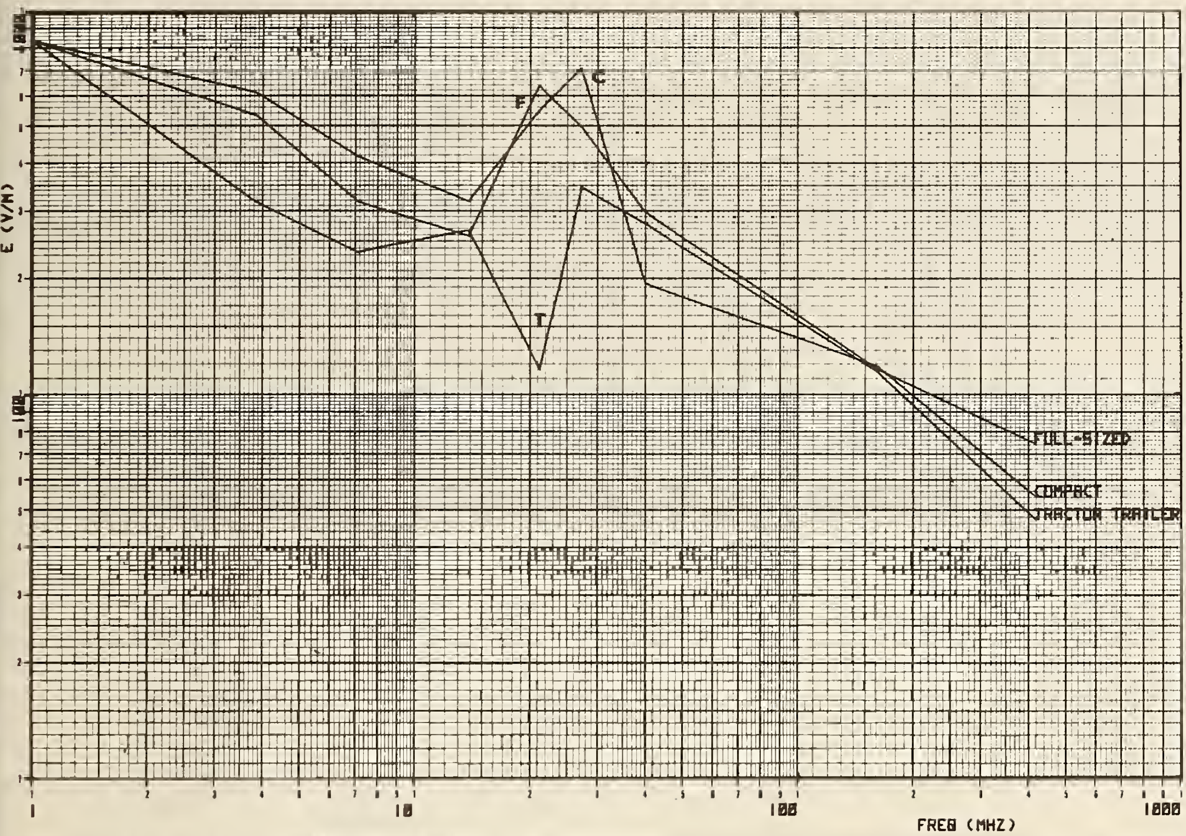


FIG. 33 - E FIELD, WORST CASE, NORMALIZED, 95 PERCENTILE

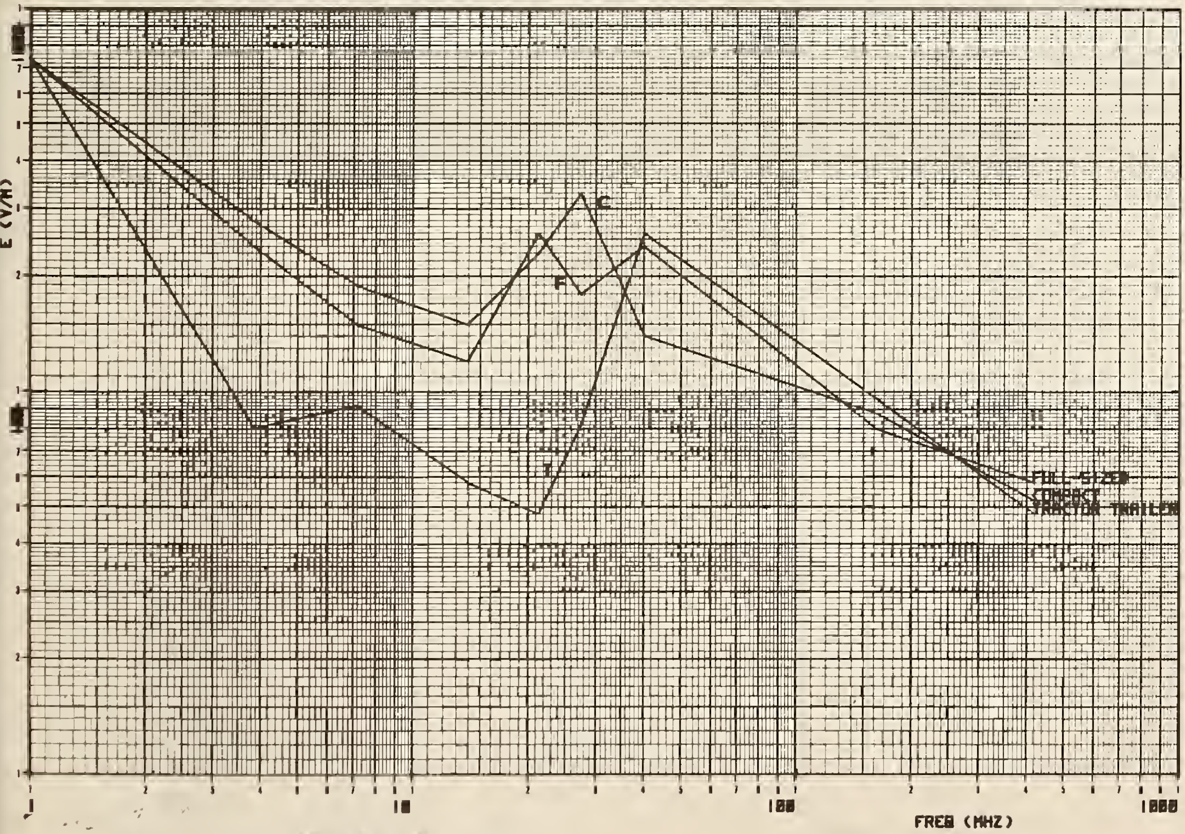


FIG. 34 - E FIELD, WORST CASE, 90 PERCENTILE

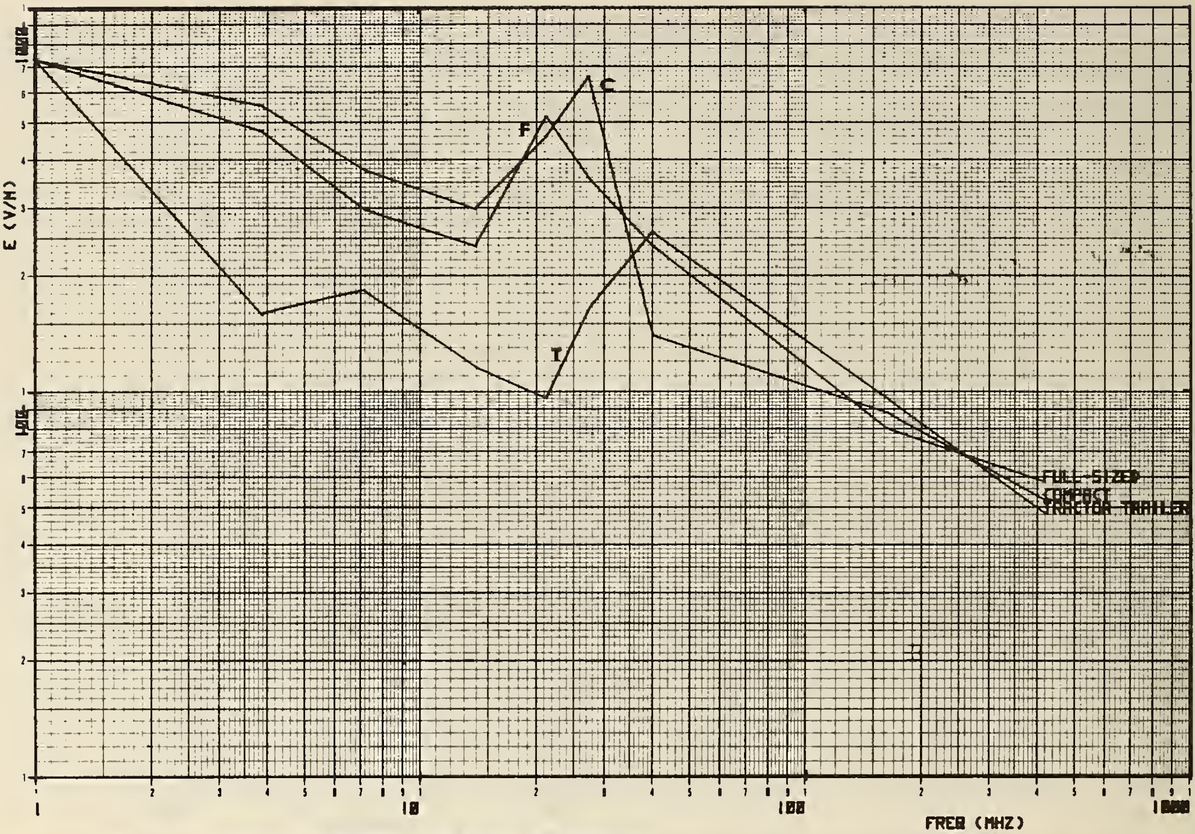


FIG. 35 - E FIELD, WORST CASE, NORMALIZED, 90 PERCENTILE

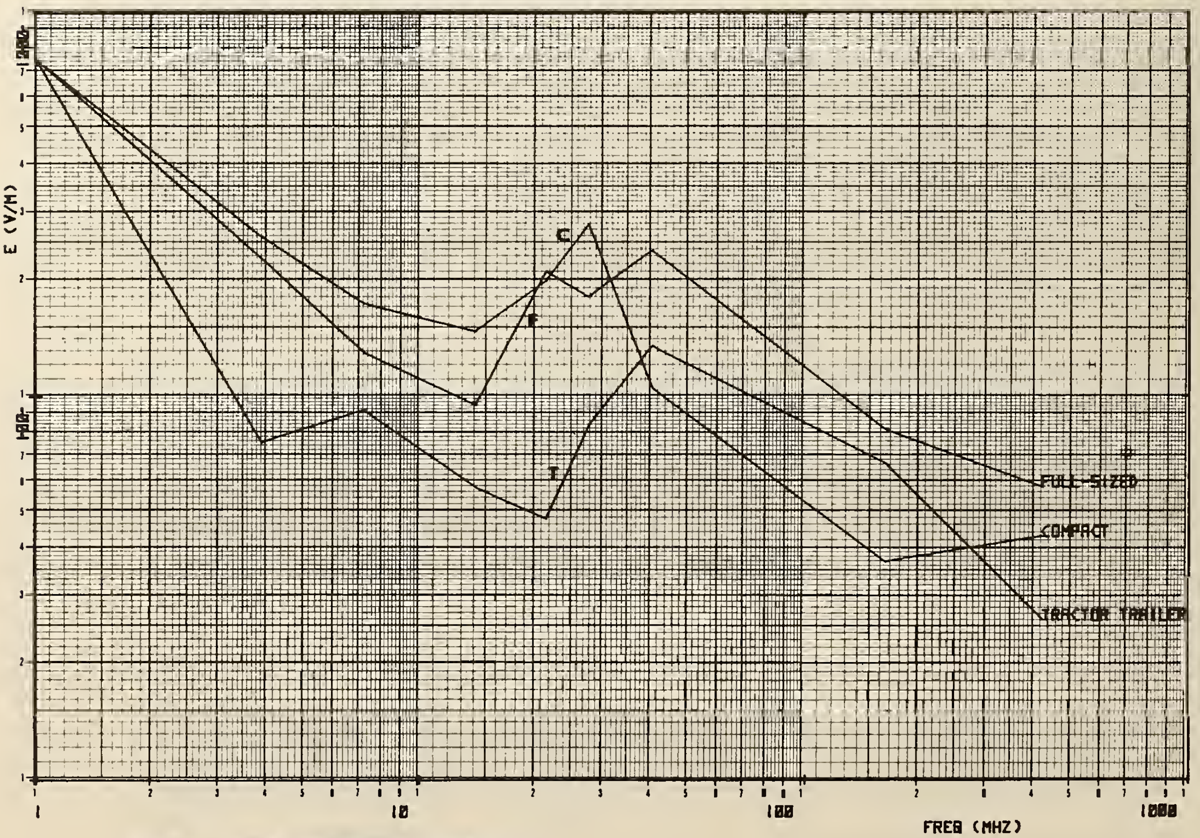


FIG. 36 - E FIELD, WORST CASE, 75 PERCENTILE

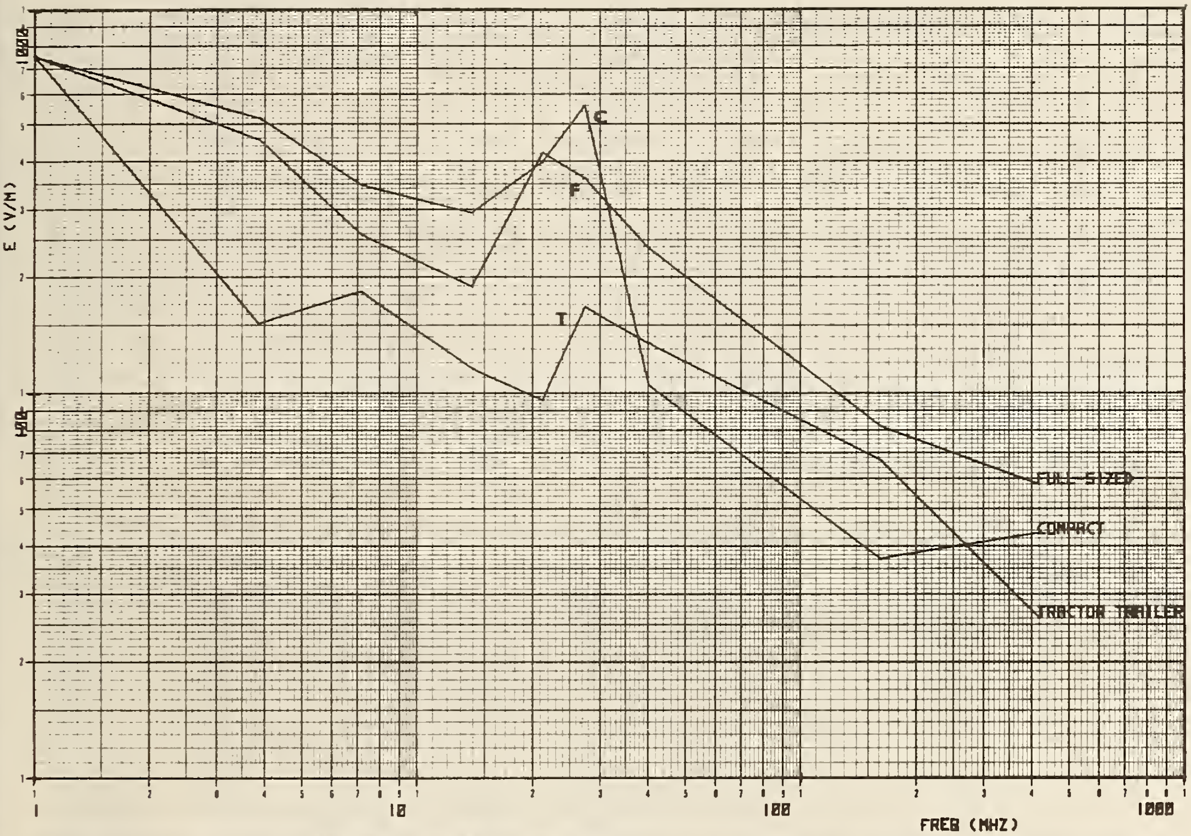


FIG. 37 - E FIELD, WORST CASE, NORMALIZED, 75 PERCENTILE

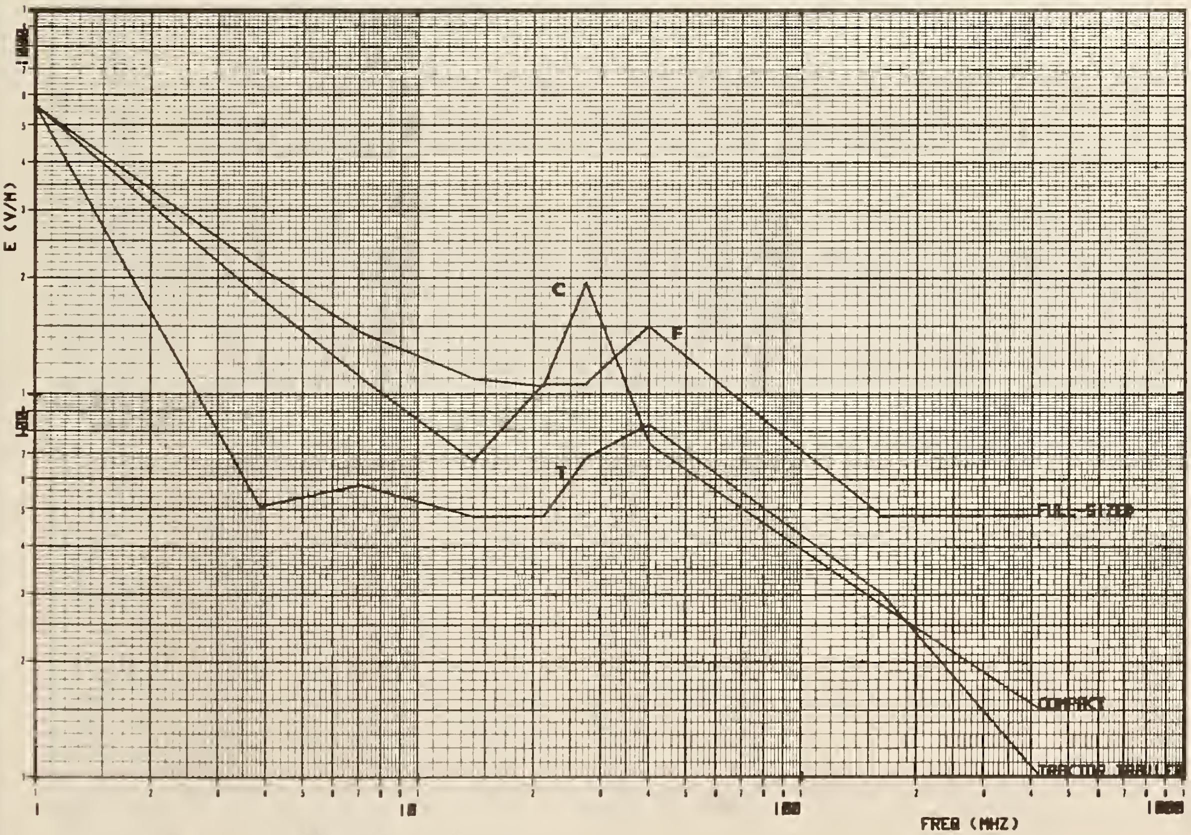


FIG. 38 - E FIELD, WORST CASE, 50 PERCENTILE

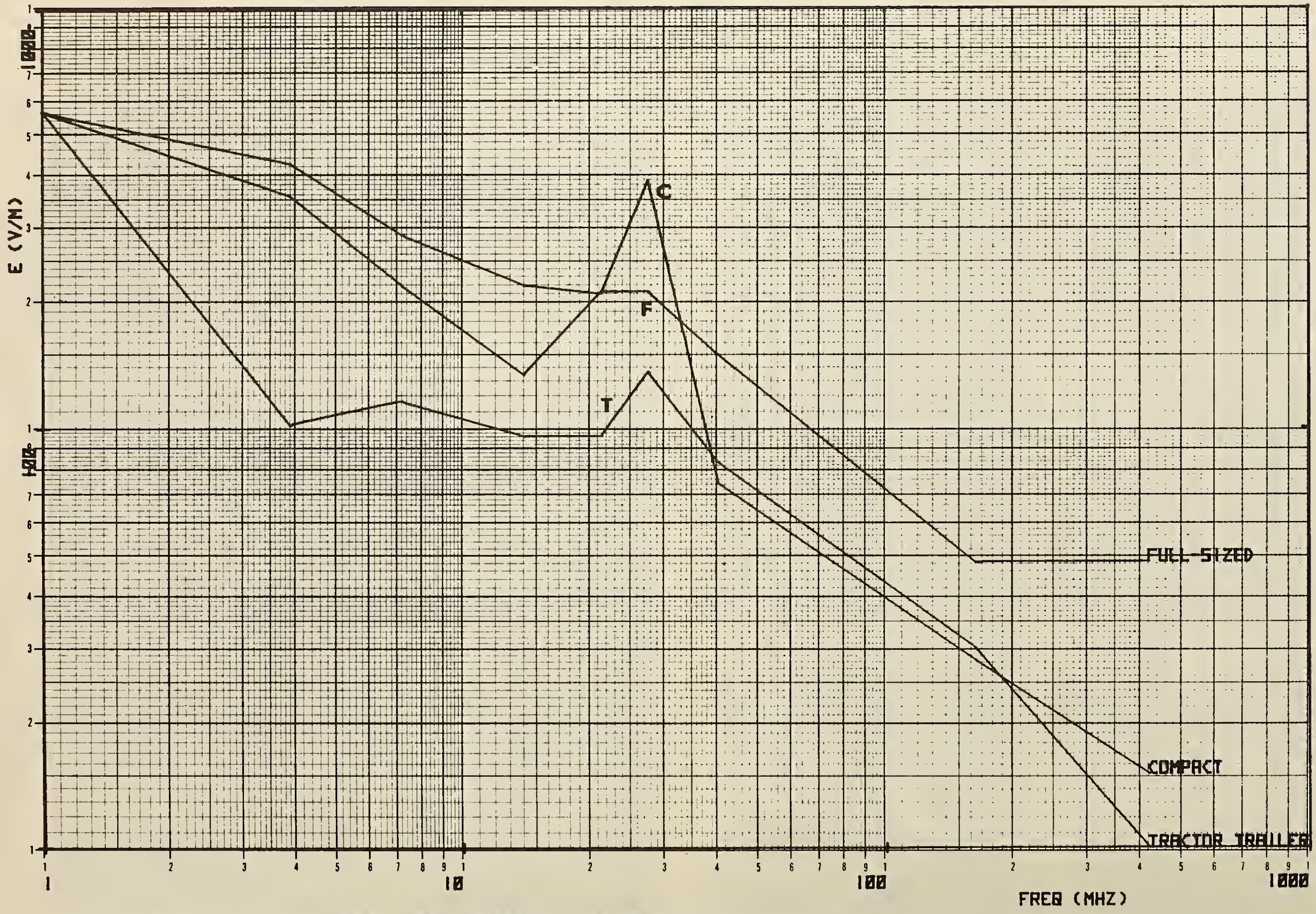


FIG. 39 - E FIELD, WORST CASE, NORMALIZED, 50 PERCENTILE

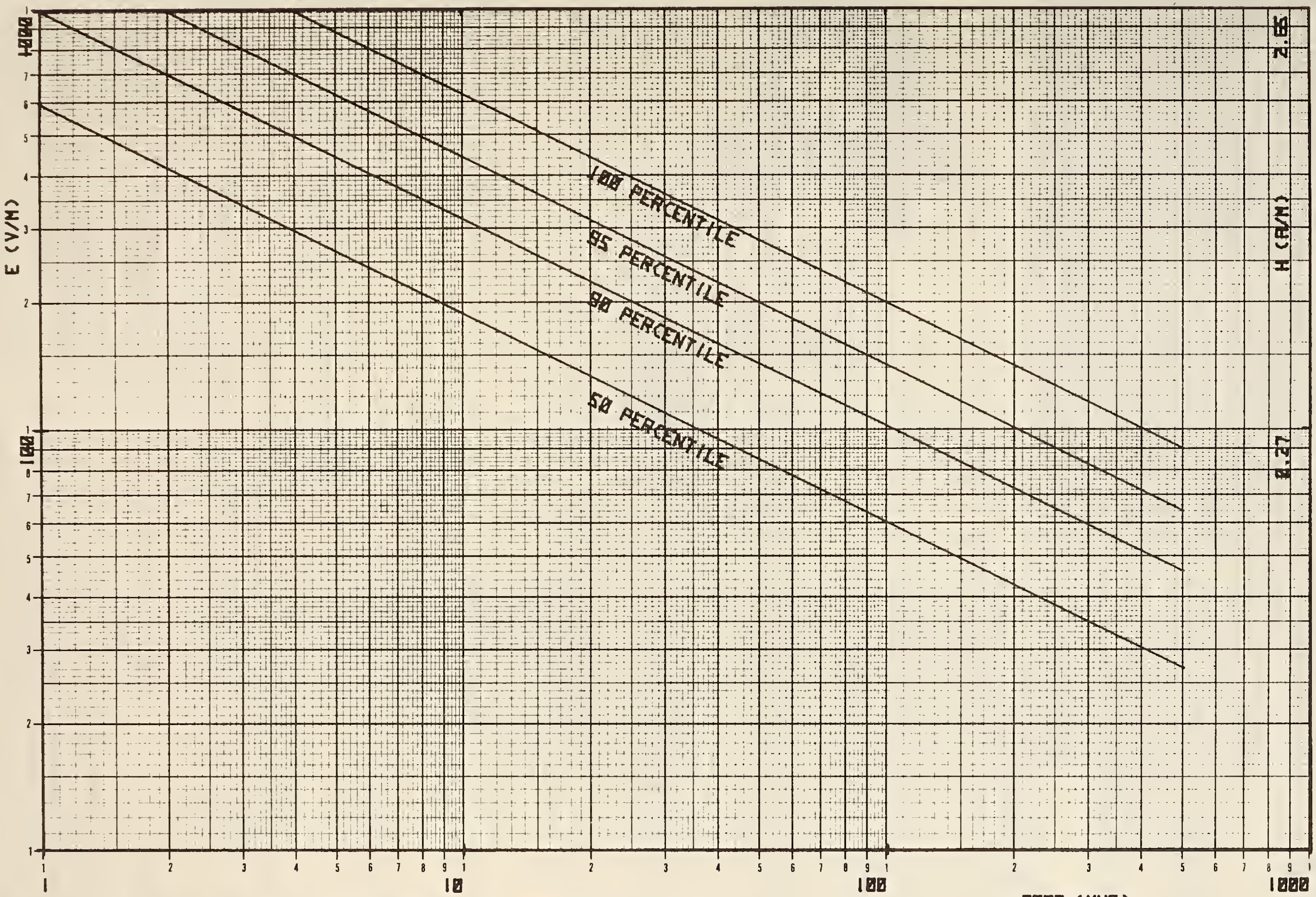


FIG. 40 - E AND H FIELD, PERCENTILE-BASED TEST LIMITS

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15. SUPPLEMENTARY NOTES

☐ Document describes a computer program; SF-185, FIPS Software Summary, is attached.

16. ABSTRACT *(A 200-word or less factual summary of most significant information. If document includes a significant bibliography or literature survey, mention it here.)*

This report describes the measured results of the electromagnetic (EM) environment encountered by three different-sized vehicles exposed to a selection of CB and mobile radio transmitters and broadcast stations. The vehicle in these situations is immersed in the near field of the radiating signals and the measured data is near-field data. This report gives measured data of electric and magnetic fields measured independently. The purpose of the report is to identify the EM environmental conditions under different circumstances in order to estimate EMC testing criteria for vehicles and their electronic systems.

17. KEY WORDS *(six to twelve entries; alphabetical order; capitalize only the first letter of the first key word unless a proper name; separated by semicolons)*

Mobile-radio; near-field strength levels; vehicular electromagnetic environment; vehicular near-zone electric fields; vehicular near-zone magnetic fields; worst-case EM fields.

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