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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.

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.