NUWC-NPT Technical Document 11,082
1 March 1999

EMI Measurement Testing Performed at Hanscom Air Force Base and Fort Devens Reserve for the DARPA Hybrid Electric Vehicle Program

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PREFACE

This document was prepared under Project Nos. 798B138 and Y900009, "Electric Vehicle EMI Measurement and Mitigation," principal investigator Anthony B. Bruno (Code 72A). The sponsoring activities are the Northeast Alternative Vehicle Consortium, the Defense Advanced Research Projects Agency, and the Office of Naval Research.

Reviewed and Approved: 1 March 1999

Richard L. Bonin
Head, Engineering, Test and Evaluation Department

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. AGENCY USE ONLY *(Leave blank)*

2. REPORT DATE
1 March 1999

3. REPORT TYPE AND DATES COVERED

4. TITLE AND SUBTITLE
EMI Measurement Testing Performed at Hanscom Air Force Base and Fort Devens Reserve for the DARPA Hybrid Electric Vehicle Program

5. FUNDING NUMBERS

6. AUTHOR(S)

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Anthony B. Bruno
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7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)

Naval Undersea Warfare Center Division
1176 Howell Street
Newport, RI 02841-1708

8. PERFORMING ORGANIZATION REPORT NUMBER

TD 11,082

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)

NAVC, DARPA, and ONR

10. SPONSORING/MONITORING AGENCY REPORT NUMBER

11. SUPPLEMENTARY NOTES

12a. DISTRIBUTION/AVAILABILITY STATEMENT

Approved for public release; distribution is unlimited.

12b. DISTRIBUTION CODE

13. ABSTRACT (Maximum 200 words)

In this study, various electric vehicles were tested to evaluate their potential electromagnetic interference (EMI) emissions when used in today's hostile commercial electromagnetic environment. The risks associated with particular emissions were assessed, including the possibility of the electric vehicle creating undesirable EMI emissions that could affect other systems. EMI emissions were measured on both military and civilian vehicles in an effort to build a database that can be used to identify EMI issues that affect electric vehicle performance.

14. SUBJECT TERMS

Electromagnetic Interference (EMI)   Electric Vehicles   DARPA Hybrid Electric Vehicle Program
Specialty Vehicle Manufacturing Corp.   Solectria Corp.

15. NUMBER OF PAGES
24

16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
Unclassified	Unclassified	Unclassified	SAR

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EMI MEASUREMENT TESTING PERFORMED AT HANSCOM AIR FORCE BASE AND FORT DEVENS RESERVE FOR THE DARPA HYBRID ELECTRIC VEHICLE PROGRAM

INTRODUCTION

Electromagnetic interference (EMI) is an unintentional form of electromagnetic energy that can often affect the performance of both the system creating the interference and external systems. EMI typically manifests itself as a loss of performance in systems that are exposed to the interference, e.g., communication range is reduced, computers malfunction, or monitoring systems fail. An extreme example of EMI would be an electric vehicle causing the inadvertent activation of bomb release mechanisms on aircraft.

Electric vehicles have both military and civilian applications. Because stealth is of fundamental importance in the battle space, identification of EMI issues that affect military electric vehicles is critically important.

In this study, the Naval Undersea Warfare Center (NUWC) Division, Newport, RI, tested various electric vehicles to evaluate their potential EMI emissions when used in today's hostile commercial electromagnetic environment. The risks associated with particular emissions were assessed, including the possibility of the vehicle creating undesirable EMI emissions that could affect other systems. Electromagnetic emissions from both military and civilian vehicles were measured in an effort to build a database that can be used to identify EMI issues that affect electric vehicle performance.

VEHICLES TESTED AND TEST LOCATIONS

The electric vehicles tested, which were available to NUWC Division Newport on loan from the manufacturer or were available as a group for vehicle demonstrations, were as follows:

- Specialty Vehicle Manufacturing Corporation (SVMC) Model 8118 Electric Cargo Van
- Solectria Corporation Pickup Truck
- Solectria Corporation Sunrise Sedan.

While the Naval Undersea Warfare Center (NUWC) Division Newport's EM testing facility at Fisher's Island, NY, is an EM quiet area and has been used to perform electric vehicle tests in the past, it was impossible to bring the vehicles to this NUWC facility, so other areas away from commercial noise sources had to be found. Measurements were made at two locations in Massachusetts. The first was Hanscom Air Force Base, which was chosen because both the SVMC cargo van and the Solectria pickup truck were housed there and readily available. The second was Fort Devens Reserve, which was chosen because of its proximity to Solectria Corporation, which meant that the Sunrise sedan would not have to be driven too far.

The vehicles at Hanscom Air Force Base were considered a test of opportunity because both vehicles were in operation at one location. It will be shown later in this report that the background electric field levels at Hanscom were much too high to obtain useful results. For this reason, the Solectria Sunrise sedan was measured at Fort Devens Reserve, but only after it was verified that background electric field levels were suitable.

TEST PROCEDURE

Electric and magnetic field emissions from the electric vehicles were measured in accordance with Society of Automotive Engineers (SAE) specification SAE-J551.[1] This specification is for open-field measurements, with the test vehicle's drive axle on jack stands so that its drive mechanism can be engaged. "Open-field" means that the measurements are performed in an electromagnetically quiet area, which is one where the background environment consisting of additional man-made noise sources is at or near the natural background level. Figure 1 illustrates a typical open-field test setup.

Once the background level was established, the vehicles were tested. Each vehicle was placed, in turn, in the test area with power applied to all components and systems that could be energized while the vehicle was in idle mode. These components would vary from vehicle to vehicle but usually consisted of power steering motors, brake pumps, motor controllers, and dc-to-dc converters. In the idle position, the main drive motor controllers were powered but not active, and the drive motors were not powered. The vehicle's drive axle was then placed on jack stands, and the vehicle was run at a constant speed (25 mph) to simulate driving conditions.

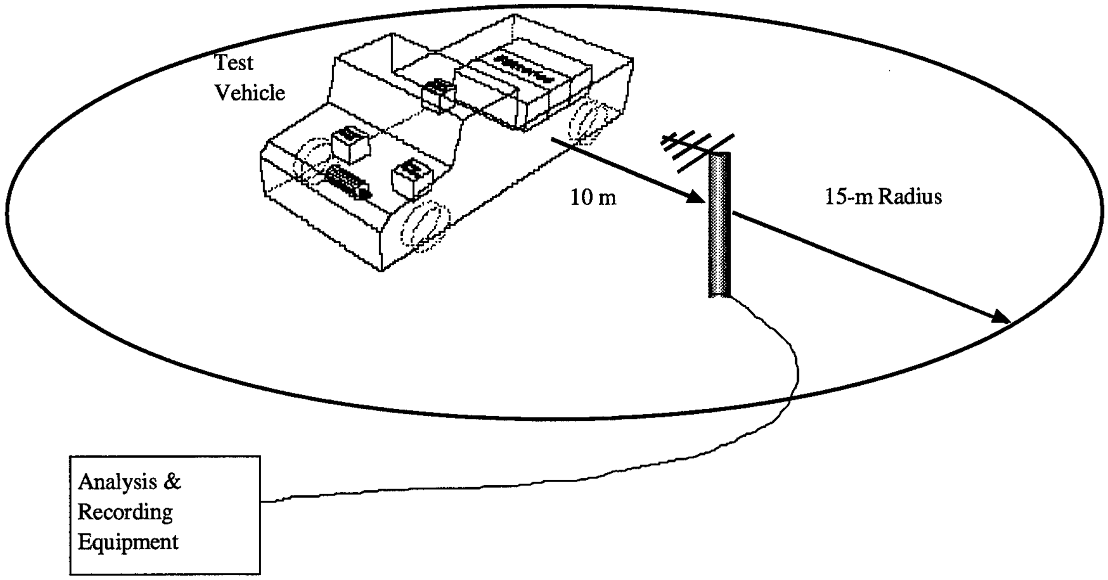


Figure 1. Typical Open-Field Test

Measurements were made with various calibrated antennas designed to detect electric and magnetic field emissions in various frequency ranges. Electric fields were measured from 9 kHz to 1 GHz, and magnetic fields were measured from 30 Hz to 30 MHz in accordance with MIL-STD-461C.[2] Table 1 summarizes the types of measurements performed on each of the electric vehicles.

Table 1. Measurement Summary

Vehicle	Converter Type	Open-Field Measurements
SVMC Electric Cargo Van	GE Traction System	Magnetic and Electric
Solectria Pickup Truck	Solectria	Magnetic and Electric
Solectria Sunrise Sedan	Solectria	Magnetic and Electric

The vehicle under test was placed in a clear area of 15-m radius. The various electromagnetic receiving antennas were placed on a nonmetallic tripod, and emissions were measured over the antennas' frequency range. The raw data were reduced with a spectrum analyzer, and results were plotted and stored on a computer disk for later retrieval.

Table 2 lists the various antennas, frequency ranges, and analysis bandwidths. Each antenna was located at a specific range from the vehicle, i.e., 1 m for magnetic measurements and 10 m for electric measurements. Each of the four sides of a vehicle could be observed with the complete suite of antennas, ranges, and polarization.

Table 2. Open-Field Antenna Characteristics

Antenna	Frequency Range	Polarization	Analysis Bandwidth
EMCO 5.5-in. Loop	30 Hz - 100 kHz	2 H, 1 V	10 Hz, 30 Hz
Empire Devices LP-105 12-in. Loop	150 kHz - 30 MHz	2 H, 1 V	10 kHz, 300 kHz
Monopole Antenna	1 kHz - 60 MHz	V	1 kHz
Biconical Antenna	20 MHz-300 MHz	V, H	10 kHz, 1 MHz
Log-Periodic Antenna	300 MHz - 1 GHz	V, H	10 kHz, 1 MHz

V = Vertical, H = Horizontal

Spot checks were performed first to determine if one of the vehicle sides contained electromagnetic "hot spots," which are areas where electromagnetic emissions are unusually high. Given the component layout of a particular vehicle, areas for concentration are typically associated with high-current devices, i.e., motor controllers and the electric motors. Therefore, most measurements were confined to the vehicle front and driver's side. Additional measurements were made inside the vehicle at the driver's location.

Zelaya[3] describes the open-field measurement test procedure in detail, including calibration, antenna factors, antenna patterns, and polarization.

In the following section, the measurements made on each of the vehicles are summarized. The selected magnetic and electric field spectra shown represent the highest levels observed for a particular vehicle. A set of measurements is defined as a complete spectrum of magnetic and electric field data at a particular range and for the vehicle side that gave the worst-case data. Note that magnetic field worst-case and electric field worst-case are not necessarily on the same vehicle side. These differences are noted in the annotations on the individual plots.

Magnetic field data are presented in units of dB re 1 pico-Tesla (pT). These units are specified in MIL-STD-461C. A pT is 10^{-12} Tesla, and 1 Gauss = 10^{8} pT; therefore, 1 mG = 100 dB re 1 pT. With this reference point, magnetic fields in mG can be read directly from the plots. Electric field measurements are presented in dB re 1 μV/m per MHz bandwidth. These units are specified in both MIL-STD-461C and SAE-J551.

TEST RESULTS

BACKGROUND FIELD PLOTS, HANSCOM AIR FORCE BASE

Figures 2a and 2b show the background horizontal and vertical magnetic fields, respectively, at Hanscom Air Force Base. These figures verify that the magnetic background level is below the limit line.

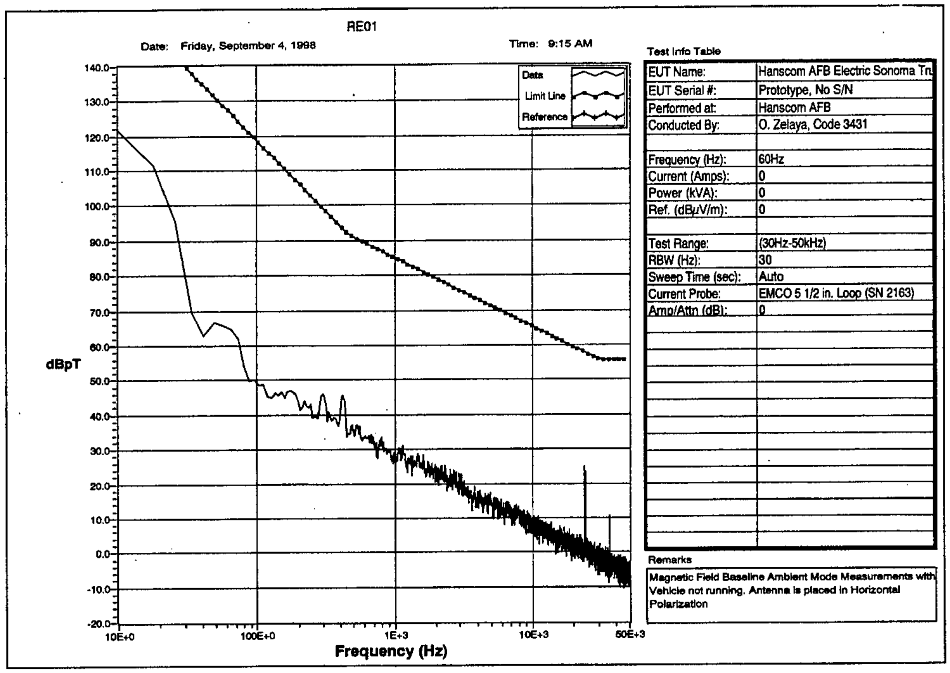


Figure 2a. Background Horizontal Magnetic Field at Hanscom Air Force Base

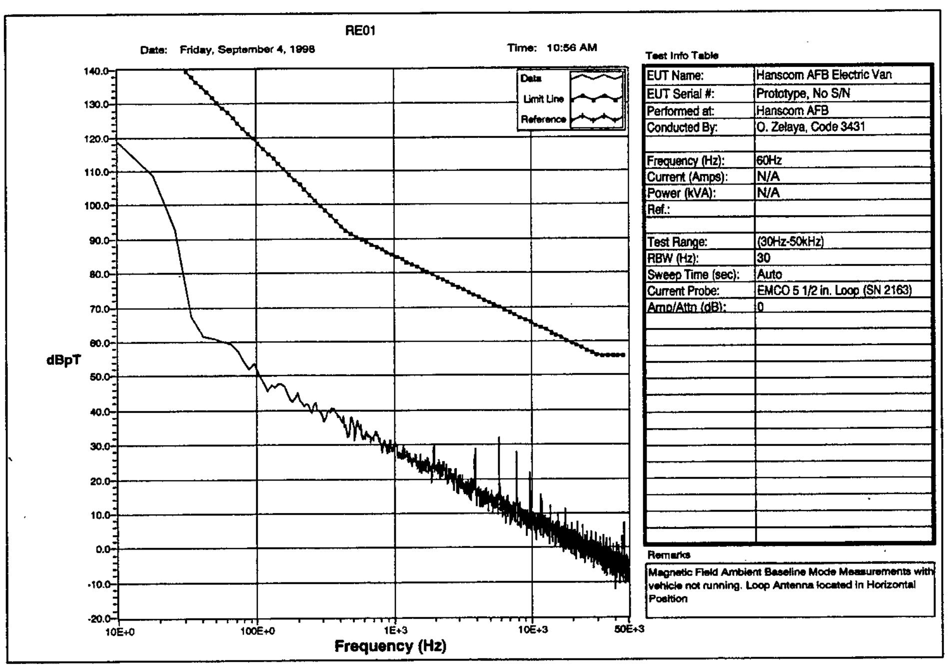


Figure 2b. Background Vertical Magnetic Field at Hanscom Air Force Base

Figure 3a shows the background electric field at Hanscom Air Force Base using the biconical and log-periodic antennas. Figure 3b is the background level using the monopole antenna. These plots reveal that many frequencies of the electric field exceed the limit line, thus making it virtually impossible to interpret the electric field data taken. Therefore, it was concluded that Hanscom Air Force Base was not a suitable location to make open-field EMI measurements, but since the vehicles were available the testing was attempted.

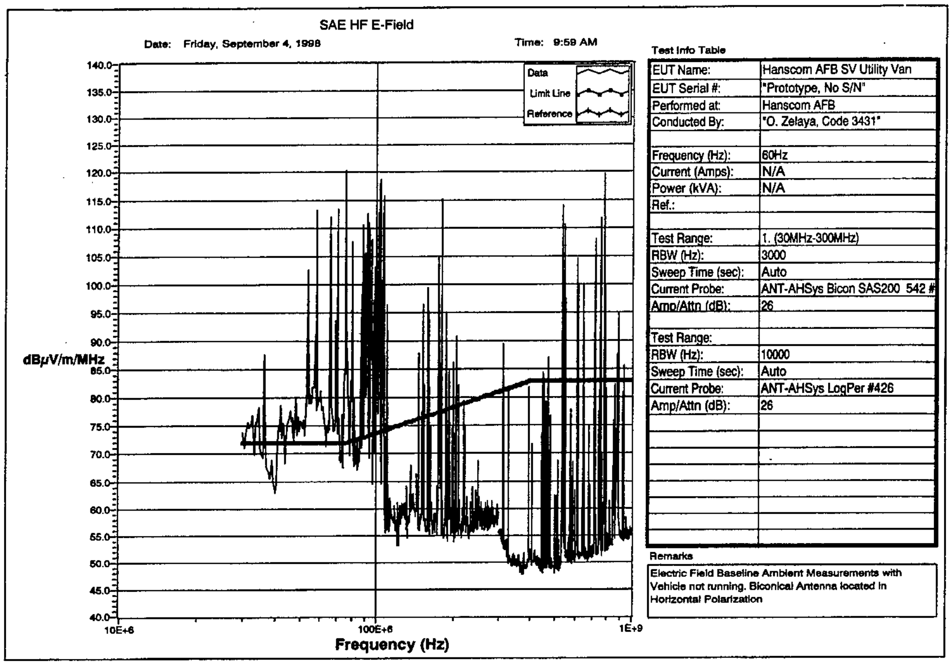


Figure 3a. Background Electric Field at Hanscom Air Force Base Using Biconical and Log-Periodic Antennas

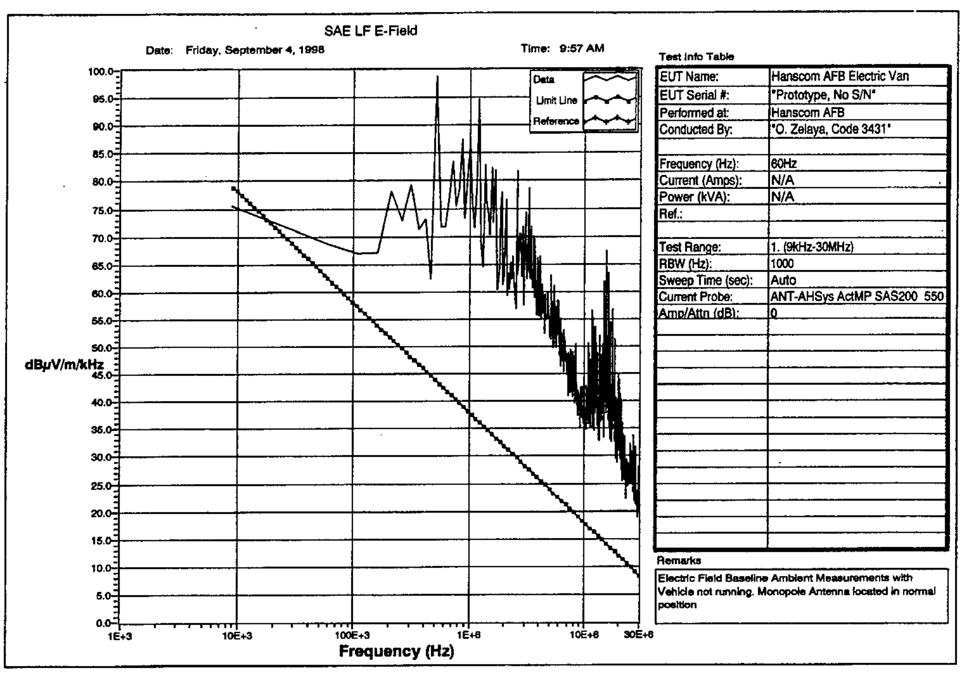


Figure 3b. Background Electric Field at Hanscom Air Force Base Using Monopole Antenna

BACKGROUND FIELD PLOTS, FORT DEVENS RESERVE

Figure 4 shows the background horizontal magnetic field measurement at Fort Devens Reserve. The data obtained reveal that the magnetic background level is below the limit line.

Figure 5 shows the measured background electric field at Fort Devens Reserve using the monopole antenna. Even though a tonal that is over the limit line is clearly visible at 1 MHz, it was deemed reasonable to continue with the data collection.

Figures 6a and 6b show the background electric fields—horizontal and vertical, respectively—measured with the biconical and log-periodic antennas. These plots show that most of the background electric fields are below the limit line, thus indicating that Fort Devens Reserve is a better area for open-field measurements than is Hanscom Air Force Base.

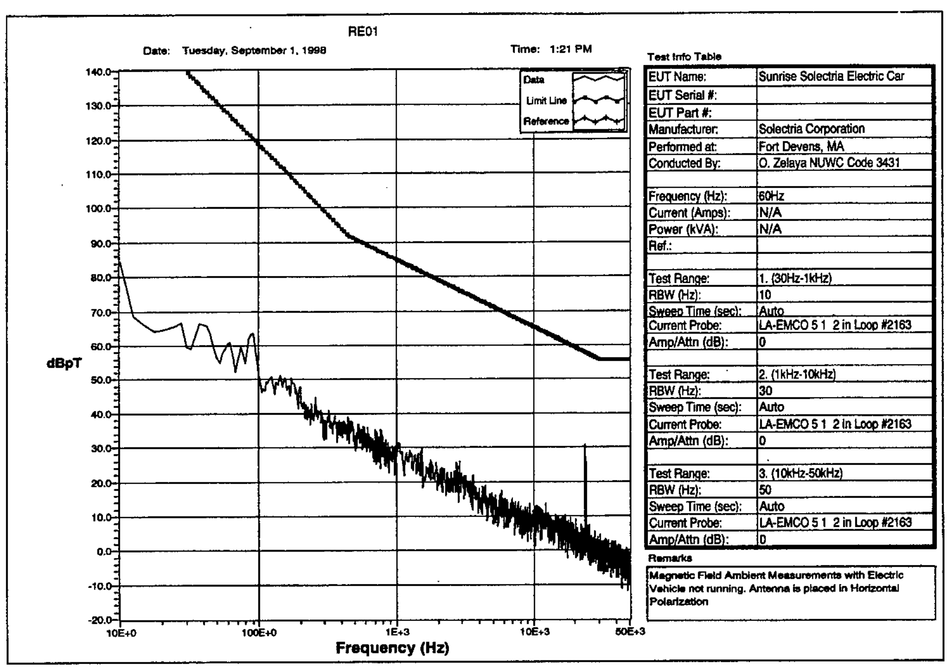


Figure 4. Background Horizontal Magnetic Field at Fort Devens Reserve

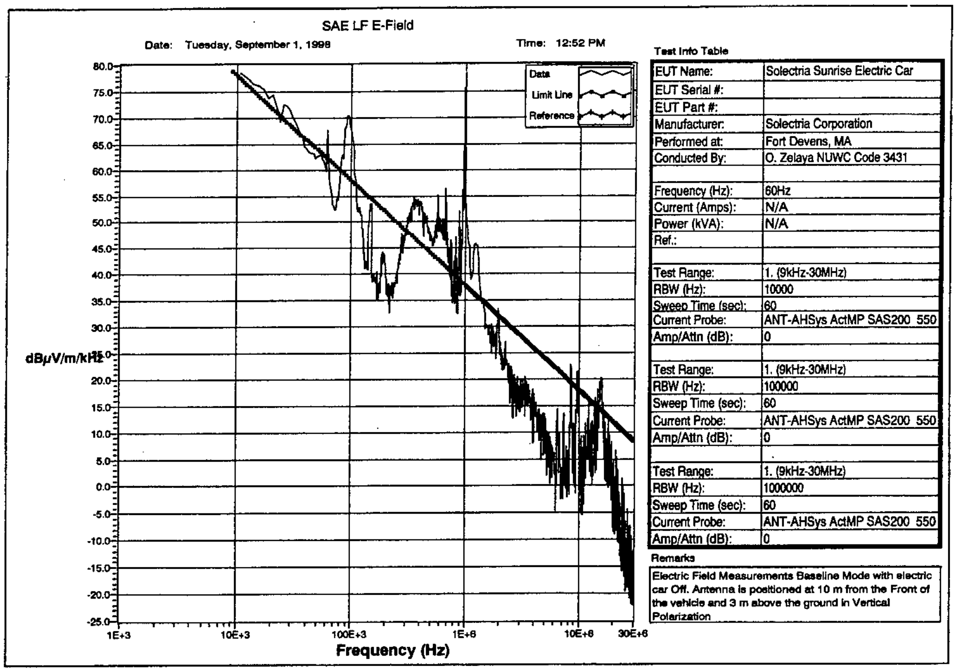


Figure 5. Background Electric Field at Fort Devens Reserve Using Monopole Antenna

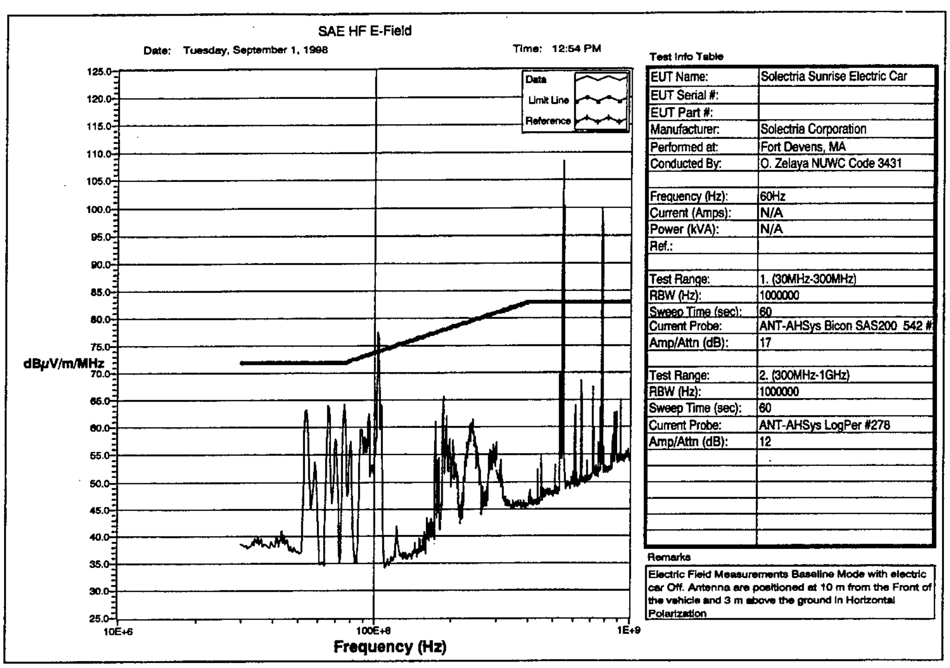


Figure 6a. Background Horizontal Electric Field at Fort Devens Reserve Using Biconical and Log-Periodic Antennas

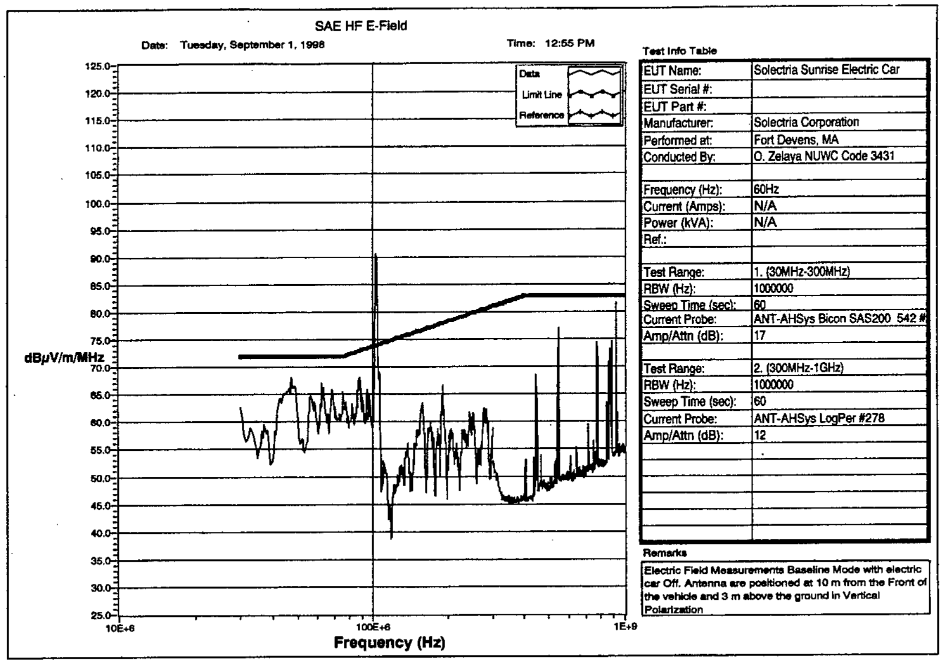


Figure 6b. Background Vertical Electric Field at Fort Devens Reserve Using Biconical and Log-Periodic Antennas

SPECIALTY VEHICLE MANUFACTURING CORPORATION (SVMC) MODEL 8118 ELECTRIC CARGO VAN

The SVMC 8118 electric cargo van (figure 7) is a medium-sized van containing the General Electric (GE) EV2000 Traction System. The van is a front-wheel-drive vehicle powered by a single ac electric motor, which receives its energy from an onboard 324-volt lead-acid battery system. The vehicle is also equipped with an auxiliary battery charging system, hydraulic assisted power steering, and regenerative braking.

Magnetic field data for the SVMC 8118 cargo van were acquired at a distance of 1 m with the vehicle operating at 32 mph. Figure 8, a plot of the vertical magnetic field data, shows no amplitude levels above the limit line.

Electric field data for the SVMC van were acquired at a distance of 10 m with the vehicle operating at 32–35 mph. Figure 9a shows the electric field data measured with the biconical and log-periodic antennas. Comparing figure 9a and figure 3a, one can see how difficult it is to discern any significant changes from the background levels.

Figure 9b shows the electric field data measured with the monopole antenna. Again, comparison of figure 9b and figure 3b demonstrates the difficulty in discerning significant changes from the background levels.

Figure 7. Specialty Vehicle Manufacturing Corporation (SVMC) Model 8118 Electric Cargo Van

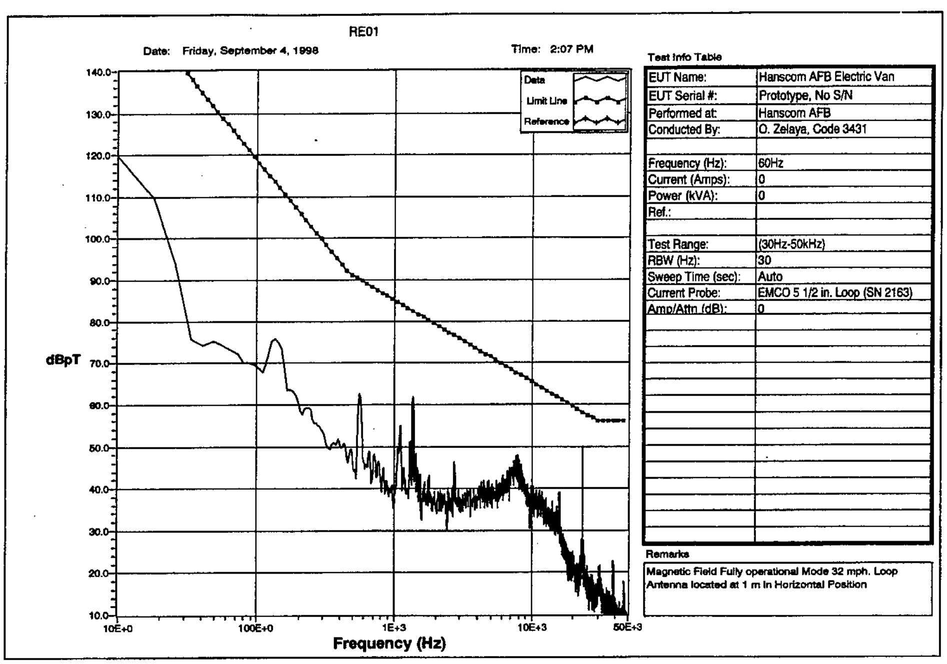


Figure 8. Vertical Magnetic Field of SVMC Electric Cargo Van

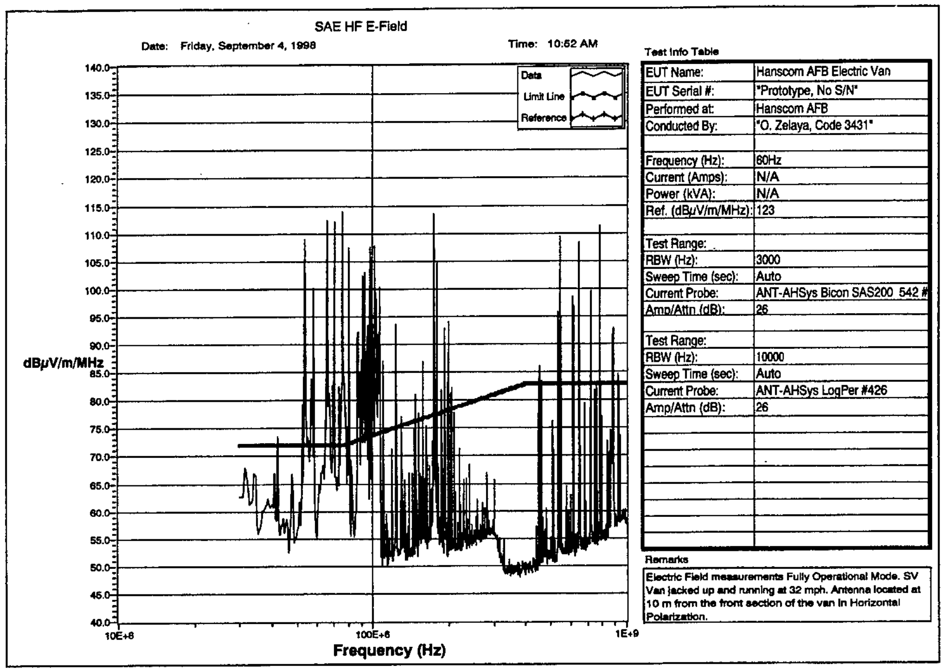


Figure 9a. Electric Field of SVMC Electric Cargo Van Using Biconical and Log-Periodic Antennas

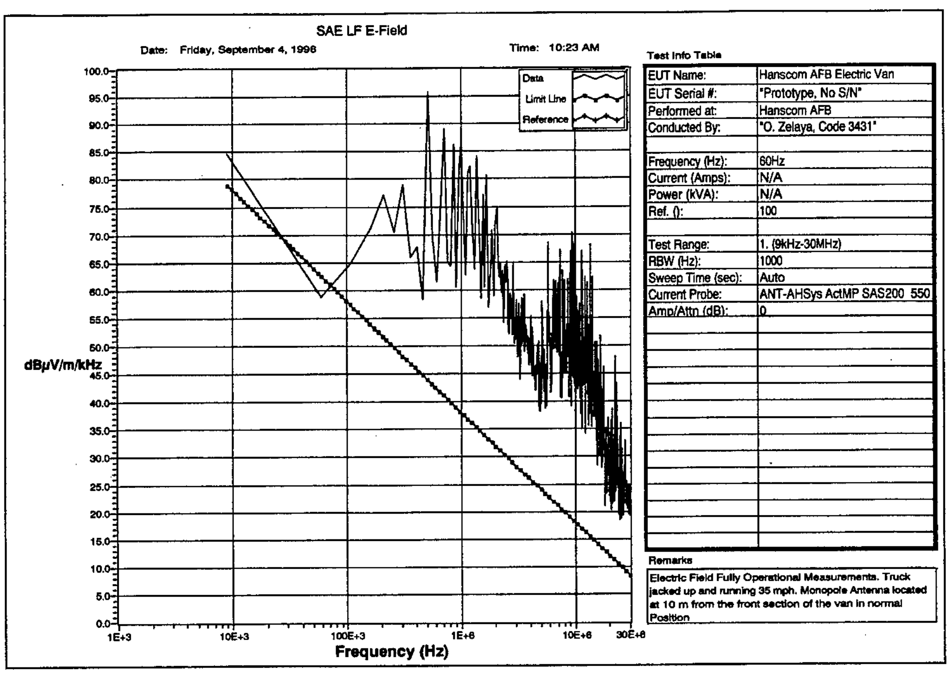


Figure 9b. Electric Field of SVMC Electric Cargo Van Using Monopole Antenna

SOLECTRIA PICKUP TRUCK

The Solectria Corporation pickup truck (figure 10) comes equipped with a high-efficiency ac induction drive system, with direct drive and regenerative braking. It also has an onboard battery charger and sealed, maintenance-free lead-acid batteries.

Magnetic field data for the Solectria pickup truck were recorded in the vertical polarization at 1 m above the hood or in front of the truck with the vehicle operating at 35 mph. Figure 11, a plot of the vertical magnetic field data, shows no amplitudes exceeding the limit line.

Electric field data for the Solectria pickup truck were acquired at 10 m from the vehicle with the vehicle operating at 35 mph. Figure 12a shows the electric field data measured using the biconical and log-periodic antennas. Comparison of figure 12a and figure 3a indicates how difficult it is to discern any significant changes from the background levels.

Figure 12b shows the electric field data measured using the monopole antenna. Again, comparing figure 12b and figure 3b reveals the difficulty in discerning significant changes from the background levels.

Figure 10. Solectria Pickup Truck

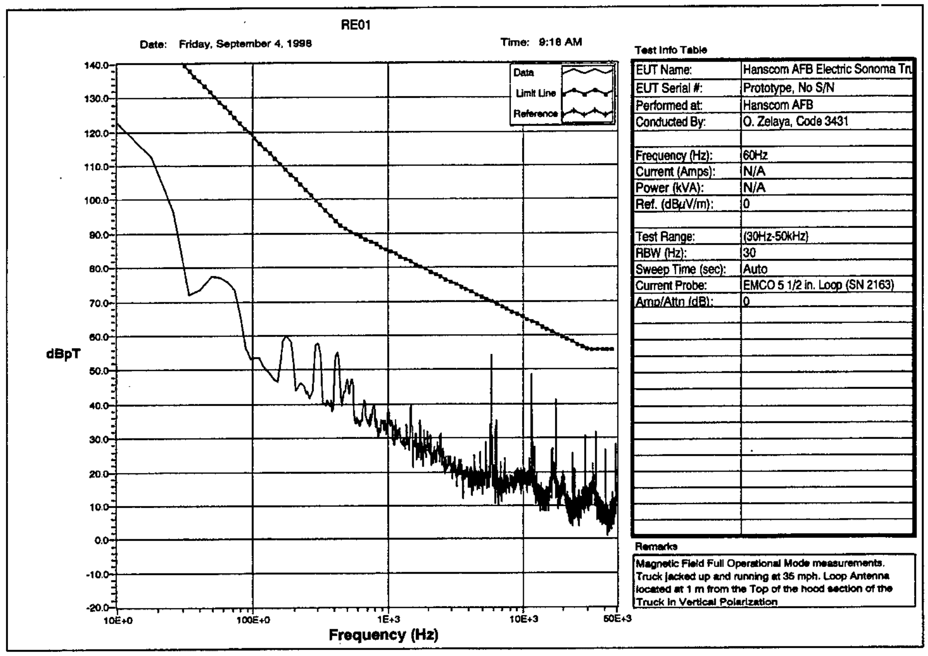


Figure 11. Vertical Magnetic Field of Solectria Pickup Truck

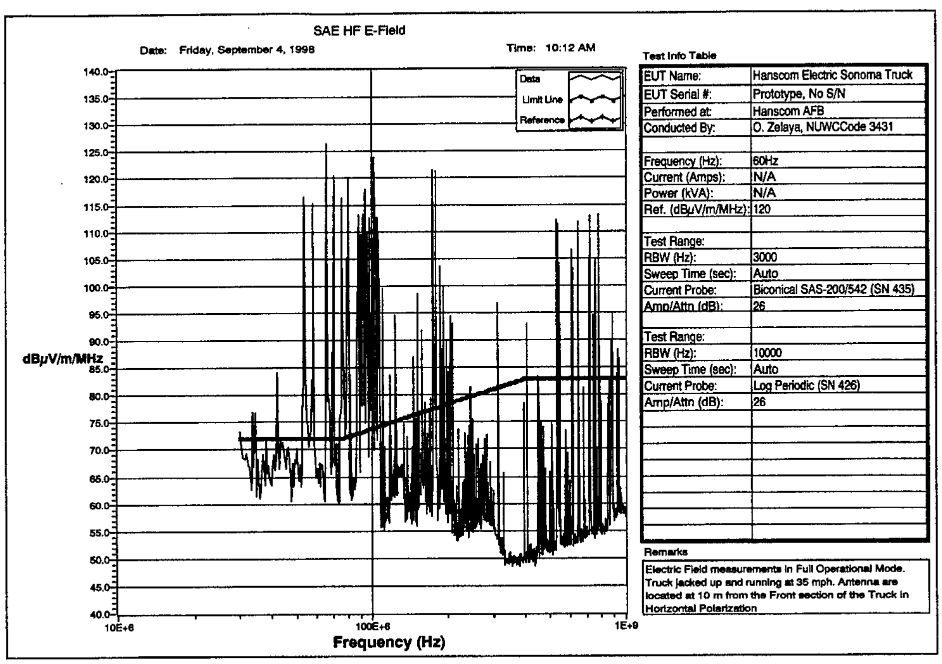


Figure 12a. Electric Field of Solectria Pickup Truck Using Biconical and Log-Periodic Antennas

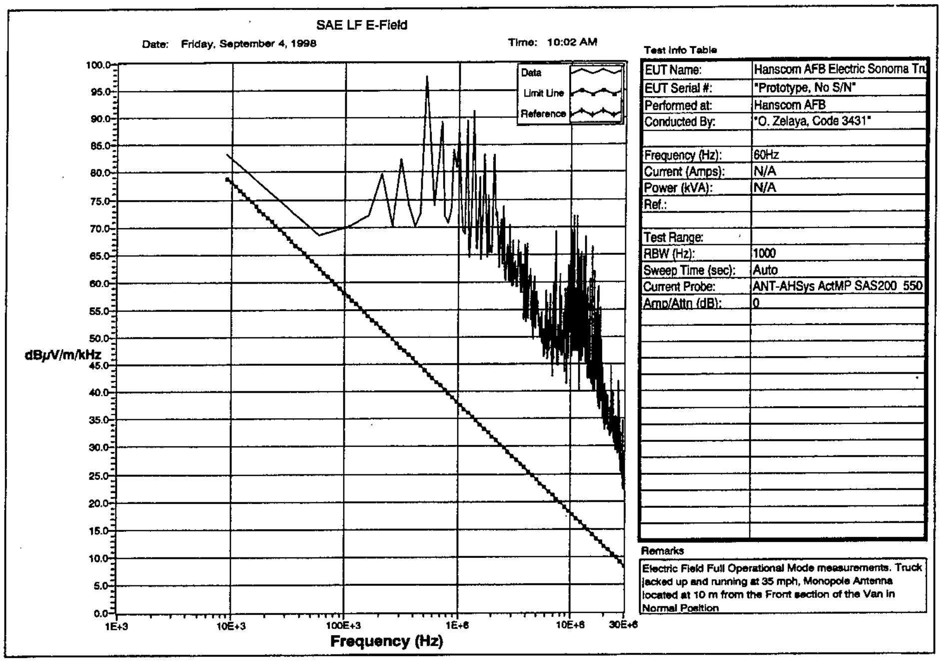


Figure 12b. Electric Field of Solectria Pickup Truck Using Monopole Antenna

SOLECTRIA SUNRISE SEDAN

The Solectria Sunrise sedan (figure 13) is a four-passenger, all-composite electric sedan employing Solectria's own 50-kW ac induction drive system, with regenerative braking and nickel-metal hydride batteries.

Magnetic field data for the Solectria Sunrise sedan were recorded in the horizontal polarization at a distance of 1 m with the vehicle operating at 50 mph. The horizontal magnetic field data (figure 14) show that no amplitudes exceed the limit line.

Electric field data for the Solectria Sunrise sedan were acquired at a distance of 10 m with the vehicle operating at 50 mph. Figure 15 shows the vertical electric field data measured using the monopole antenna. Comparison of figure 15 and figure 5 reveals a tonal at approximately 10 MHz that exceeds the limit line by about 28 dB re μV/m/kHz. It is believed that this emission comes from the motor controller, the ac induction drive system, or the dc-to-dc converter

Figure 16a shows the horizontal electric field data measured using the biconical and log-periodic antennas. Comparing figure 16a and figure 6a, one sees no significant amplitude changes from the background levels.

Figure 16b shows the vertical electric field data measured using the biconical and log-periodic antennas. Comparison of figure 16b and figure 6b shows no significant amplitude changes from the background levels.

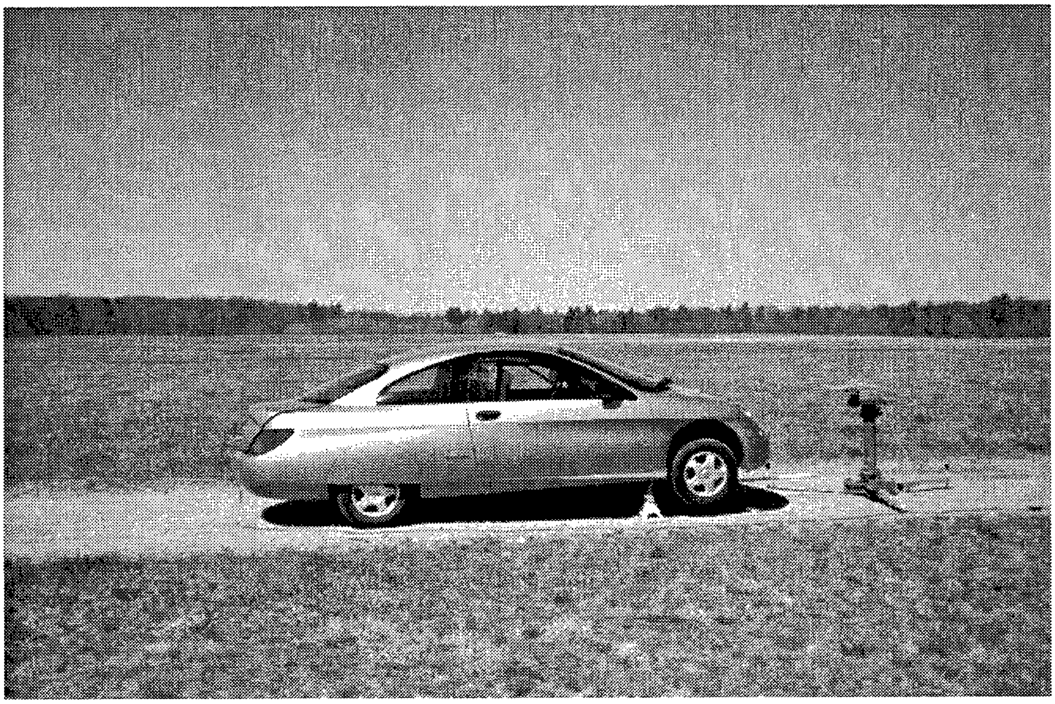
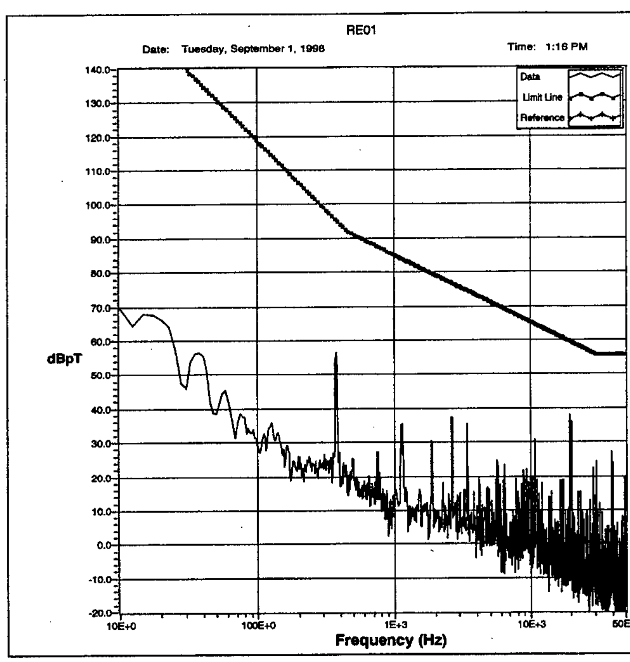


Figure 13. Solectria Sunrise Sedan



Test Info Table

EUT Name:	Sunrise Solectria Electric Car
EUT Serial #:	
EUT Part #:	
Manufacturer:	Solectria Corporation
Performed at:	Fort Devens, MA
Conducted By:	O. Zelaya, NUWC Code 3431
Frequency (Hz):	60Hz
Current (Amps):	N/A
Power (kVA):	N/A
Ref.:	
Test Range:	1. (30Hz-1kHz)
RBW (Hz):	10
Sweep Time (sec):	Auto
Current Probe:	LA-EMCO 5 1 2 in Loop #2163
Amp/Attn (dB):	21
Test Range:	2. (1kHz-10kHz)
RBW (Hz):	30
Sweep Time (sec):	Auto
Current Probe:	LA-EMCO 5 1 2 in Loop #2163
Amp/Attn (dB):	21
Test Range:	3. (10kHz-50kHz)
RBW (Hz):	50
Sweep Time (sec):	Auto
Current Probe:	LA-EMCO 5 1 2 in Loop #2163
Amp/Attn (dB):	21

Remarks

Magnetic Field Fully Operational Measurements with electric vehicle running idle at 60 mhp and antenna located at 1m Horizontal

Figure 14. Horizontal Magnetic Field of Solectria Sunrise Sedan

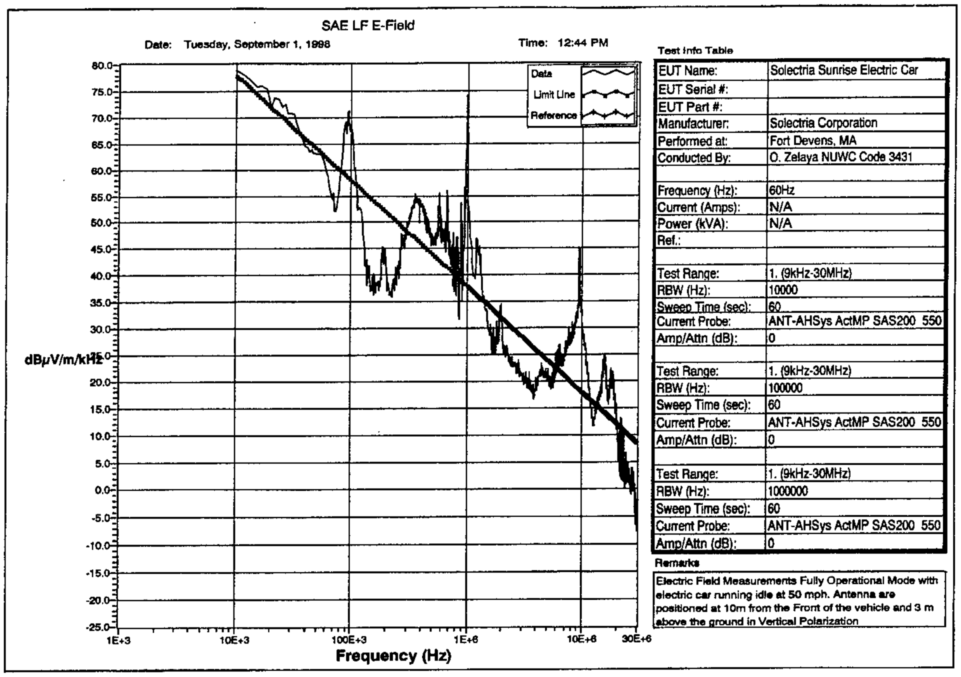


Figure 15. Vertical Electric Field of Solectria Sunrise Sedan Using Monopole Antenna

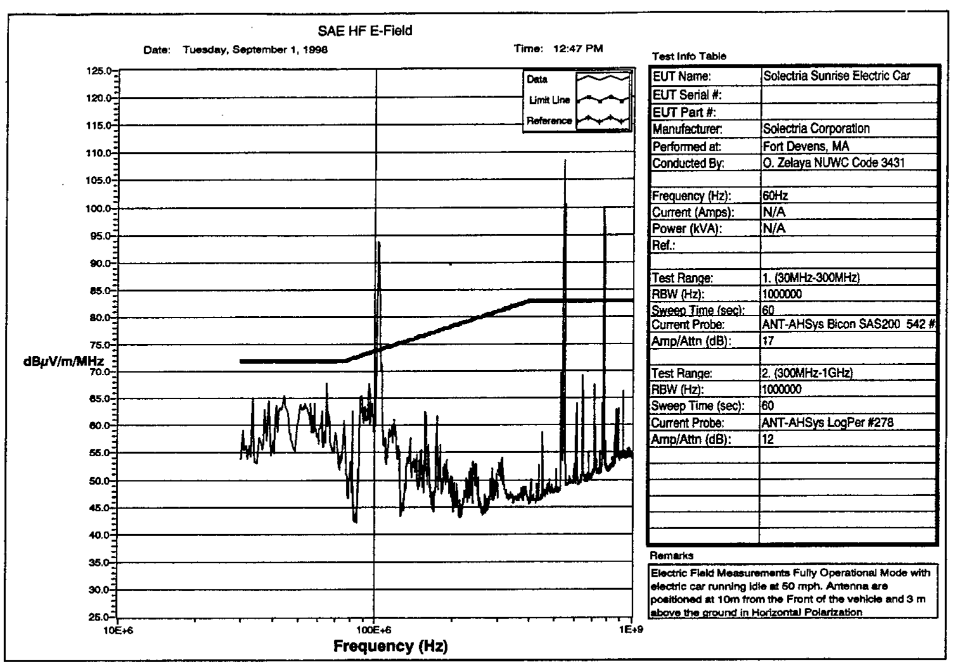


Figure 16a. Horizontal Electric Field of Solectria Sunrise Sedan Using Biconical and Log-Periodic Antennas

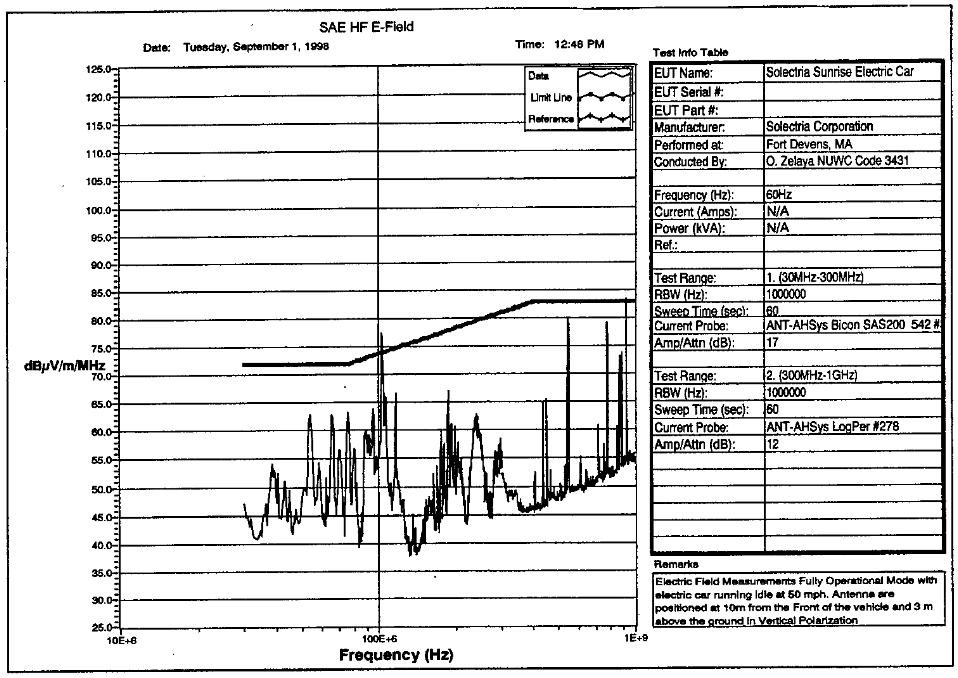


Figure 16b. Vertical Electric Field of Solectria Sunrise Sedan Using Biconical and Log-Periodic Antennas

SUMMARY

The data collected in this study have shown that the open-field measurement technique is valid. The only constraint that open-field measurements impose is that the background noise be at least 20 dB below the expected measurement levels. This condition can be met by choosing areas that are electromagnetically quiet, i.e., areas that are away from man-made sources of noise. The background data from Hanscom Air Force Base showed that the surrounding area was not a suitable location for open-field measurements. Nevertheless, the Hanscom measurements were made as a test of opportunity since both vehicles were available and at one location.

Measured field levels in most cases were below the specified limit line. No significant EMI was observed above the limit line except for a tonal at 10 MHz emitted by the Solectria Sunrise sedan. It is possible that this emission is coming from the Sunrise's motor controller, the ac induction drive system, or the dc-to-dc converter. This tonal is approximately 28 dB above the limit line and could potentially be a source of EMI to other onboard equipment. The tonal level is approximately 178 µV/m, which is five orders of magnitude below the Navy exposure limit of 63 V/m (30-300 MHz).[4]

REFERENCES

1. "Performance Levels and Methods of Measurement of Electromagnetic Radiation from Vehicles and Devices," SAE J551, Society of Automotive Engineers, March 1990.

2. "Military Standard, Electromagnetic Emission and Susceptibility Requirements for the Control of Electromagnetic Interference," MIL-STD-461C, 4 August 1986 (UNCLASSIFIED).

3. Oscar Zelaya, "Unit Test Procedure (UTPR) for Open Field Measurement of Electromagnetic Interference (EMI) for the ARPA Electric and Hybrid Electric Vehicle Program," NUWC-NPT Technical Memorandum 961037, Naval Undersea Warfare Center Division, Newport, RI, 3 May 1996 (UNCLASSIFIED).

4. "Navy Occupational Safety and Health Program Manual," OPNAVINST 5100.23D, paragraphs 2204.2 through 2204.13 and Appendixes 22-B, 22-C and 22-D, Office of Chief of Naval Operations, Washington, DC, October 1994 (UNCLASSIFIED).

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