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Suppression of Radiating Harmonics Electro-Impulse Deicing (EIDI) Systems

October 1991

DOT/FAA/CT-TN90/33

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16. Abstract

This report addresses electromagnetic compatibility (EMC) with two different configurations of electromagnetic deicing systems. Both Electro-Impulse Deicing (EIDI) and Eddy Current Repulsion Deicing Strip (EDS) are investigated. With EIDI, rigid coils are mounted behind the wing; while with EDS, the impulse coils are built thin and flexible with printed circuit board technology. An important consideration in the certification of electromagnetic impulse deicing systems is electromagnetic compatibility (EMC). When the capacitor bank discharges, a large current pulse travels down a transmission line to the coil. The coil is one source of radiation. Another source is the cabling and connections to the coil. In work conducted for the FAA in 1988, it was found that excessive electromagnetic emissions resulted from the operation of a Low Voltage Electro-Impulse Deicer (LVEID) in conjunction with a composite wing. The goal of this project was to investigate and develop techniques for controlling emissions without the benefit of shielding. In this study it was determined that both EIDI and EDS could be brought within the RTCA/DO-160B standards through proper shielding and termination of the pulse power cable. An alternative topology of EDS with the impulse coil on the wing exterior surface did not meet the standard.

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This effort to suppress unwanted electromagnetic emissions in Electro-Impulse Deicing (EIDI) and Eddy Current Repulsion Deicing Strip (EDS) systems was sponsored by the FAA Technical Center at Atlantic City International Airport, New Jersey. The FAA is represented by Mr. Charles O. Masters, the program manager of aircraft icing engineering and development programs. His assistance was of great value in accomplishing our task. We also wish to thank Mr. Patrick Andre of the Eldec Corporation for his assistance with electromagnetic interference (EMI) testing.

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LIST OF ABBREVIATIONS

EDB	Eddy Current Repulsion Deicing Boot
EDS	Eddy Current Repulsion Deicing Strip
EIDI	Electro-Impulse Deicing
EMC	Electromagnetic Compatibility
EMI	Electromagnetic Interference
FAA	Federal Aviation Administration
LVEIDI	Low Voltage Electro-Impulse Deicing
RTCA	Radio Technical Commission for Aeronautics
SCR	Silicon Controlled Rectifier

EXECUTIVE SUMMARY

Unwanted radiation from electromagnetic deicing devices including Electro-Impulse De-Icing (EIDI) systems and Eddy Current Deicing Strip (EDS) constitutes a continuing concern for the Federal Aviation Administration (FAA) and others in assuring electromagnetic compatibility (EMC) with aircraft avionics systems. In work conducted for the FAA by two contractors in 1988 it was found that excessive electromagnetic emissions resulted from the operaton of EIDI in conjunction with a composite wing. Electric field measurements in accordance with RTCA/DO-160B Section 21 were in excess of standards unless appropriate shielding was utilized.

Testing at ELDEC's EMI facility as well as in-house testing has shown that both EIDI and EDS systems can meet RTCA/DO-160B Section 21 category Z requirements. Category Z is the most stringent of the DO-160B emission standards. Through isolation of the pulse power supply and shielding of the pulse cable measured emissions were reduced to within Category Z standards.

INTRODUCTION

This report addresses two different configurations of electromagnetic deicing systems. The most common of these is Electro-Impulse De-Icing (EIDI) [1]. In EIDI small coils are mounted just behind the wing leading edge surface. The face of the coils are mounted with a small gap to the back side of the wing leading edge surface. Often times a high conductivity doubler plate is bonded to the back side of the wing leading edge surface to increase electromagnetic coupling to the coil. A bank of capacitors is discharged through the coil creating an impulse of force. The force impulse is the result of induced eddy currents in the wing leading edge being repelled by the coil.

A variation on EIDI is Low Voltage Electro-Impulse Deicing (LVEIDI) in which the capacitor bank is adjacent to the coil [2]. Line losses to the coil are significantly reduced but more capacitor banks are required. Conventional EIDI was employed for these tests to focus attention on the radiation resulting from the coil. Figure 1 shows the general topology of the EIDI system employed in these tests.

A related technology is the Eddy Current Repulsion Deicing Strip (EDS) [3]. In EDS the impulse coils are built thin and flexible with printed circuit board technology. The coils are mounted external to the wing leading edge, and electromagnetically interact with either the wing leading edge behind or an outer conducting strip. Similar to EIDI an impulse of force created by induced eddy currents removes the ice. Both EIDI and EDS are based on the same electromagnetic impulse deicing principle. Figure 2 shows the general topology of the EDS system employed in these tests.

An important consideration in the certification of electromagnetic impulse deicing systems is electromagnetic compatibility (EMC). When the capacitor bank discharges a large current pulse travels down a transmission line to the coil. The coil is one source of radiation. Another source is the cabling and connections to the coil.

In work conducted for the FAA in 1988 [4,5] it was found that excessive electromagnetic emissions resulted from the operaton of a Low Voltage Electro-Impulse Deicer (LVEIDI) in conjunction with a composite wing. Electric field measurements in accordance with RTCA/DO-160B Section 21 were in excess of standards. It was shown that emissions could be reduced to the level required to meet standards by wrapping the composite wing section in appropriate shielding material, however this approach was deemed impractical for aircraft applications. Emissions from an LVEIDI coil installed in an aluminum wing were within standards. Similar results were obtained by other investigations of EIDI electromagnetic compatibility [6].

It would be preferable if the EIDI and LVEIDI system would generate less radiation, reducing or eliminating the requirement for shielding. The problem of electromagnetic emissions outside of the wing is particularly severe when the wing is constructed of composite materials rather than aluminum. This is due to the absence of the shielding effect of aluminum or other electrically conducting materials. The goal of this project was to investigate and develop techniques for controlling emissions from EIDI without the benefit of shielding.

TEST PLAN

The test plan calls for techniques to initially be developed in the Electroimpact lab. Techniques are then to be verified in the Eldec EMI test chamber. Two specific techniques were initially proposed (see points 3 and 4 of the test plan). The test plan is summarized below:

1. A test platform will be constructed. An EIDI module will be mounted in a test frame with the doubler plate held in front of the coil. No wing will be employed to represent the worst case with respect to shielding. A baseline radiation level will be measured. From the preceding year's work this is considered an excessive level in view of the RTCA/DO-160B standards [4]. The goal will be to bring these emissions down by 20 dB and then to confirm that the system is in compliance through testing in the Eldec EMI test chamber.

2. An EIDI module will be equipped with a ringing choke. A ringing choke initially blocks the voltage from the coil and then transfers the voltage as the choke saturates. Radiation from the choke is a secondary problem which will be examined. The effect of the ringing choke on the EMI emissions of the module will be documented.

3. An EIDI module will be equipped with a soft switch, presumably a large transistor. With a transistor in contrast to an SCR the transition from blocking to conduction can be controlled. A turn-on period of 10 μsec would have a negligible influence on EIDI effectiveness but should dramatically reduce electromagnetic emissions.

4. Testing and development work will be extended to the eddy current repulsion deicing strip (EDS) and to the eddy current repulsion deicing boot (EDB) [3]. The EDB is a variation of EDS in which the outer material is rubber rather than a metal strip.

5. EMI control schemes will be tested at the Eldec Corporation test facility. Radiated E field measurements will be taken in accordance with Fig. 21-8 of RTCA/DO-160B.

ELECTROIMPACT EMI CHAMBER RESULTS

To gain experience with the techniques proposed for EMI control an in-house testing capability was developed. It consisted of a 6'x8'x6' EMI test room, a calibrated RVR-30M Electrometrics antenna and a Hewlett Packard 8590A spectrum analyzer. The spectrum analyzer drives a Hewlett Packard pen plotter for documentation of output. This facilitated more cost effective experimentation and testing prior to verification tests at the Eldec EMI facility.

Initial calibration testing was done on an EIDI module set on an open table in the laboratory. The results from these tests were inconsistent . Pat Andre from Eldec was hired as a consultant to help explain the phenomenon that the output was only slightly affected by the distance from the transmitting EIDI coil to the antenna. Radiation from

the pulse power supply and cabling was suspected. Mr. Andre also pointed out that the riveted ground plane was not adequately bonded. Just by soldering the joints a dramatic reduction in emissions was observed.

It was proposed to utilize the EMI screen room and place the pulse power supply outside the room. Both the transmitting antenna and pickup coil would be inside the room. This would effectively shield the receiving antenna from the power supply. An inside view of the EMI room with the receiving antenna is shown in Figure 3. Figure 4 shows the recording instrumentation outside the EMI room. The cables were shielded with braided copper. Two holes were cut in the wall for passage of the pulse cable and the antenna lead to the spectrum analyzer.

Still, unusual results were observed. Fairly significant emissions were recorded in the EMI chamber which did not seem to emanate from the EIDI coil. It was recommended that a grounded bulkhead fitting be employed at the point where the antenna lead leaves the EMI chamber. In addition, it was recommended that the cable shielding be split and terminated from both sides on the screen room wall. These improvements are shown in Figures 5 and 6. A dramatic reduction in measured emissions resulted from these changes.

Parting and separately terminating the two lengths of cable shielding at the EMI room penetration point proved to be an effective technique for separating out radiation caused by the power supply. This isolation technique is shown graphically in Figure 7. This technique was also employed for tests conducted later on at Eldec.

The ringing choke concept was then tested but was determined to be ineffective. The choke was increased in inductance up until the point at which the peak EIDI current was compromised. Still, the measured EMI was just marginally affected. A ringing choke was constructed from moly cores wound with five turns of 4 AWG cable which in turn led to the EIDI module. The number of cores employed was steadily increased from two to six in search of an effect on measured EMI. With six cores the peak EIDI coil current had decreased by ten percent. This decrease in current is undesirable but still no significant effect was observed on the EIDI emissions. Figure 8 shows the ringing choke wired in series with the pulse power supply.

It was also determined to be impractical to employ transistors as a soft switch. The largest transistors available can at most handle three hundred amps peak. For our tests we built up a six gang switch . The cost and complexity of such a switch renders the concept impractical. Experiments were conducted with the six gang transistor switch shown in Figure 9. Transistors are Powerex model KS224515. This six gang switch required a complex drive circuit, also shown.

The EMI emissions were significantly reduced just by isolating the power supply and properly shielding the pulse cable. Further reductions were achieved by grounding the doubler plate of both the EIDI module and the EDS module. At this point emission scans in the Electroimpact EMI chamber were within the RTCA/DO-160B Category Z standards.

By enclosing the EIDI module in a Faraday cage of thin aluminum foil emissions were further reduced to near background levels. The pulse cable was still encased in woven copper sheathing. The open sides of the coil and coil target were enclosed in three layers of thin conductive foil. Emission results in general were lower than recorded in the previous year with the LVEIDI module. This implicates the modular power supply as being a source of radiation since in this experiment the power supply is external to the chamber.

It was hypothesized that by grounding in several places the possibility of circulating ground currents is created. These circulating currents could in turn radiate and result in measurable emissions. To test this hypothesis in the Electroimpact EMI room the EIDI module and drive cable were isolated from ground except at the penetration of the chamber wall (see Figure 10). The results from this technique were ambiguous and the technique was not employed in Eldec testing.

EDB MODULE RESULTS

Tests were also conducted with the EDB module shown in Figure 1. In EDS the pulse coil is surrounded by a conducting metal sheet which in our experiments is solidly grounded. In contrast the EDB pulse coil is encapsulated in a rubber sheet and is mounted over the metal wing surface [3]. Therefore with EDB there is no opportunity to shield or ground the pulse coil. High emission levels were recorded with EDB. A scan of EDB emissions from the Electroimpact EMI room is shown in Figures 11a and 11b. The EDB tests were not repeated in the Eldec EMI chamber since there was no hope for a favorable result.

ELDEC EMI CHAMBER RESULTS

Both an EIDI and an EDS module were brought to Eldec for testing on March 27, 1990. The equipment was set up as follows:

1. The 450V impulse power supply was external to the EMI screen room.

2. A coaxial pulse cable was run from the power supply to the coil. Two separate pieces of copper braid shielding were employed so that both the inner and outer sections would separately terminate at the screen room entry point. The external portion of the cable shielding was terminated on the outside surface of the EMI shield room on one end and the metal power supply enclosure on the other end. Copper braid shielding on the internal portion of the cable terminated on the inside surface of the screen room on one end and the ground plane under the coil on the other end.

3. For some tests an aluminium foil Faraday cage was constructed around the back of the coil. This consisted of three (3) layers of aluminium foil fastened to and spanning from the coil aluminium front plate to the copper braid of the coaxial cable in the back. The coil and connections are thereby enclosed within a Faraday cage. This configuration can be seen in Figures 12 and 13 taken from the Eldec testing.

4. All shielding was grounded to the ground plane of the antenna including the doubler plate of the coil. Grounding of the cable shielding can be seen in Figure 12.

5. For all tests the coil is in the horizontal orientation. The coil orientation for EIDI and EDS tests at Eldec is shown in Figures 12, 13 and 14.

The emissions scans recorded at Eldec are contained in Appendix A. The EMI room instrumentation scans the frequency bands and spikes are recorded at the moment the module discharges. On the measurement for broadband electric field radiation three antennas are required to scan the frequency band. The RTCA DO/160B Fig. 21-7 gives standards for emissions from 150 kHz to 1.215 GHz. The first antenna scans from 150kHz to 30 MHz. The second antenna gives coverage from 30 MHz to 200 MHz. The third yields the response from 200 MHz to 1GHz. Therefore the entire scan is shown on three consecutive plots.

The Eldec test results contained in Appendix A are summarized in Tables 1 and 2:

TABLE 1

RADIATED E-FIELD MEASUREMENTS FROM AN EIDI MODULE

Fig. No.	Description	Results
Tests A-1 through A-4 with three layers of aluminum foil shielding (Figure 8 and 9):		
A-1	150 kHz to 30 MHz	within standards
A-2	30 MHz to 200 MHz, horizontal polarization	within standards
A-3	30 MHz to 200 MHz, vertical polarization	within standards
A-4	200 MHz to 1 GHz	within standards
Tests A-5 through A-8 without aluminum foil shielding:		
A-5	150 kHz to 30 MHz	within standards
A-6	30 MHz to 200 MHz, horizontal polarization	within standards
A-7	30 MHz to 200 MHz, vertical polarization	within standards
A-8	200 MHz to 1 GHz	within standards

TABLE 2

RADIATED E-FIELD MEASUREMENTS FROM AN EDS MODULE

Fig. No.	Description	Results
Tests A-9 through A-12 with three layers of aluminum foil shielding (Figure 10):		
A-9	150 kHz to 30 MHz	within standards
A-10	30 MHz to 200 MHz, horizontal polarization	within standards
A-11	30 MHz to 200 MHz, vertical polarization	within standards
A-12	200 MHz to 1 GHz	within standards
Test A-13 with one layer of aluminum foil shielding:		
A-13	150KHz to 30 MHz	within standards
Tests A-14 through A-17 without aluminum foil shielding:		
A-14	150 kHz to 30 MHz	within standards
A-15	30 MHz to 200 MHz, horizontal polarization	within standards
A-16	30 MHz to 200 MHz, vertical polarization	within standards
A-17	200 MHz to 1 GHz	within standards

CONCLUSIONS

Parting of the pulse cable shielding at the EMI room penetration point proved to be an effective technique for separating out radiation caused by the power supply. The shielding is separately terminated onto the wall at each side of the penetration point. This technique alone proved effective at bringing both the EIDI and EDS module emissions to within the required RTCA Category Z emission standard when set on the test table unshielded by a wing. Further reductions in emissions were achieved by enclosing the open sides of both the EIDI and EDS modules with aluminum coil. Emissions from an EDB module exceeded the standard due to the absence of shielding inherent in this topology.

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9. "Military Standard, Electromagnetic Interference Characteristics, Measurement of," Mil Std 462, rev May 1, 1970.

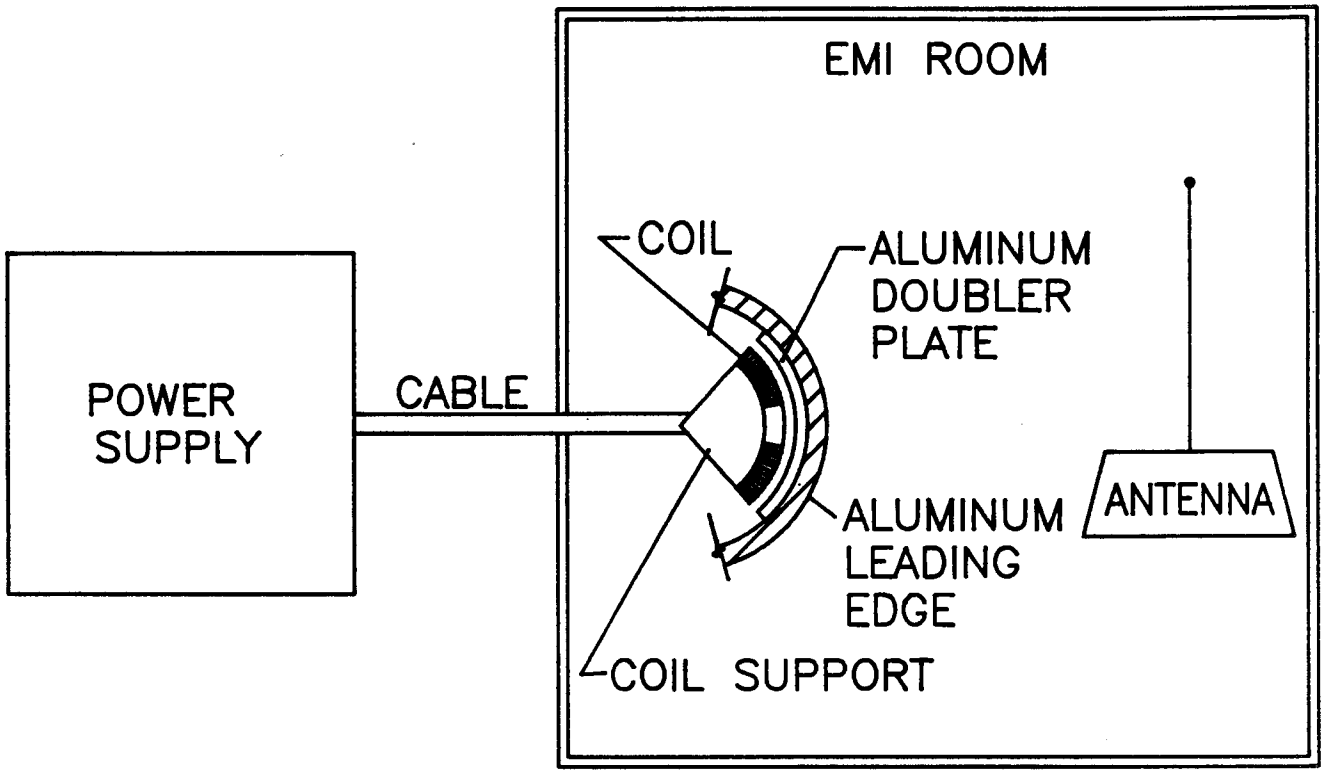

Figure 1. Electro-impulse deicing (EIDI) system topology tested in this research

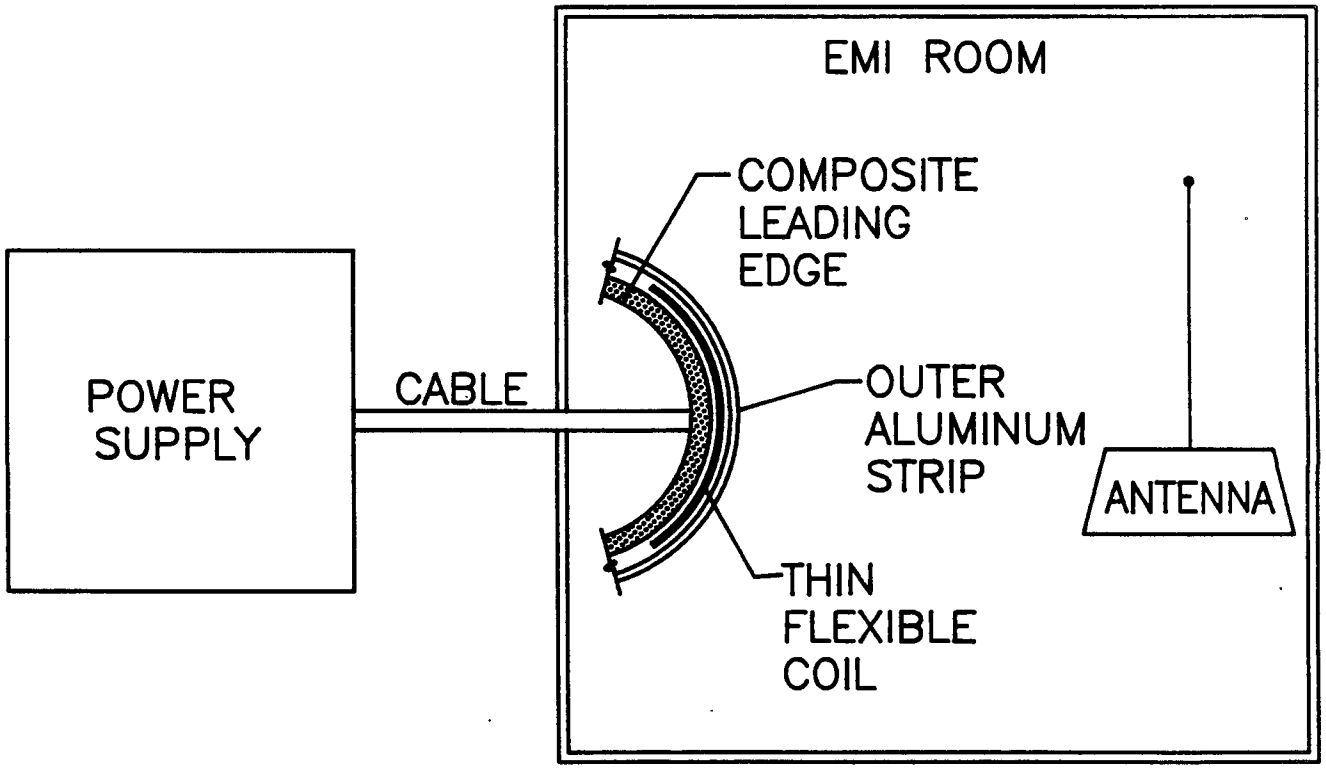

Figure 2. Eddy current deicing strip (EDS) topology tested in this research

Figure 3. Eddy current deicing boot (EDB) in the EMI chamber

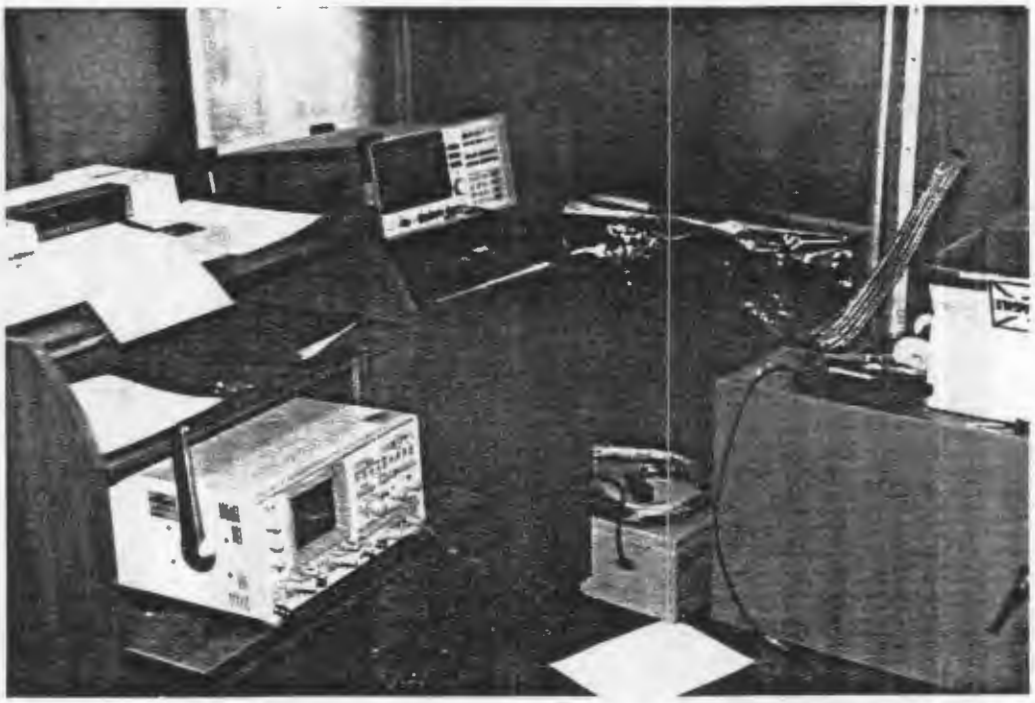

Figure 4. Spectrum analyzer at Electroimpact

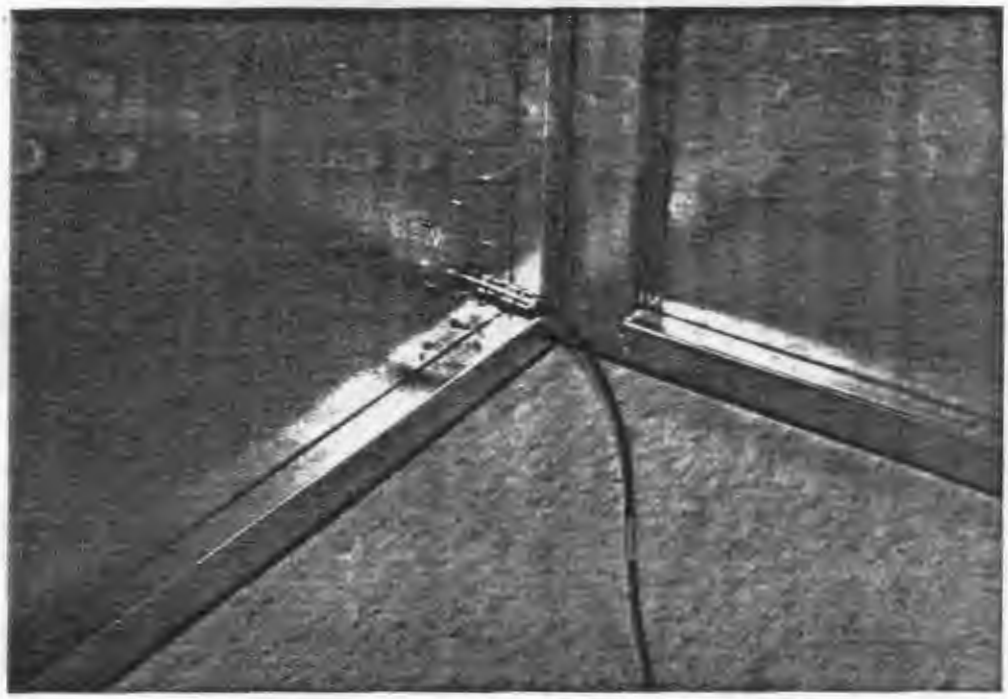

Figure 5. Bulkhead fitting for antenna lead

Figure 6. EIDI module in Electroimpact EMI room showing the pulse cable bulkhead connection

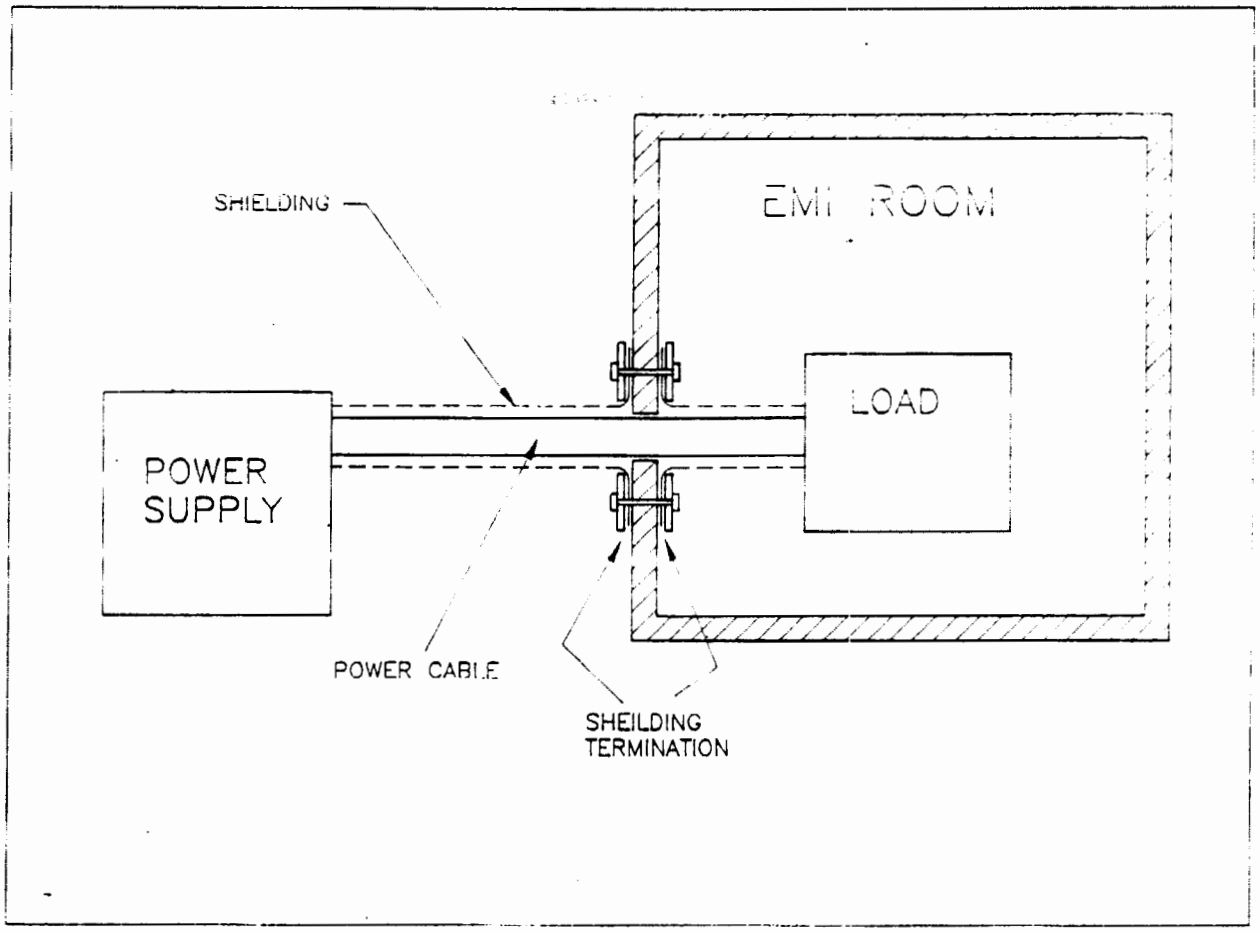

Figure 7. Termination technique employed for shielding over EIDI pulse cable.

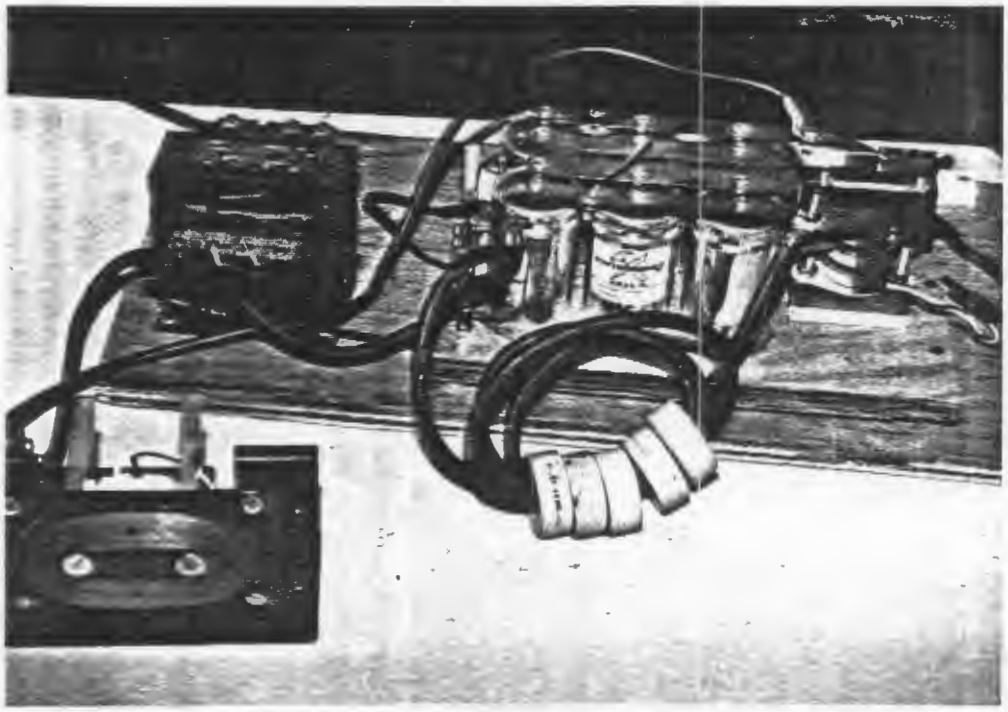

Figure 8. Ringing choke unsucessfully used to reduce EMI emissions

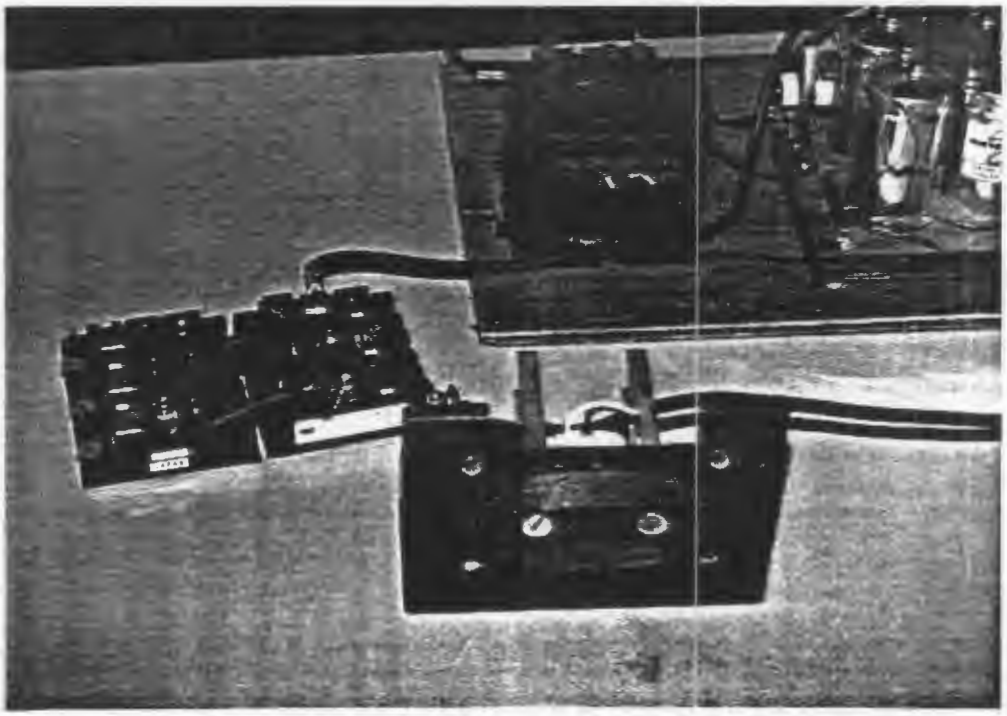

Figure 9. Transistor soft switch used in an attempt to reduce EMI emissions

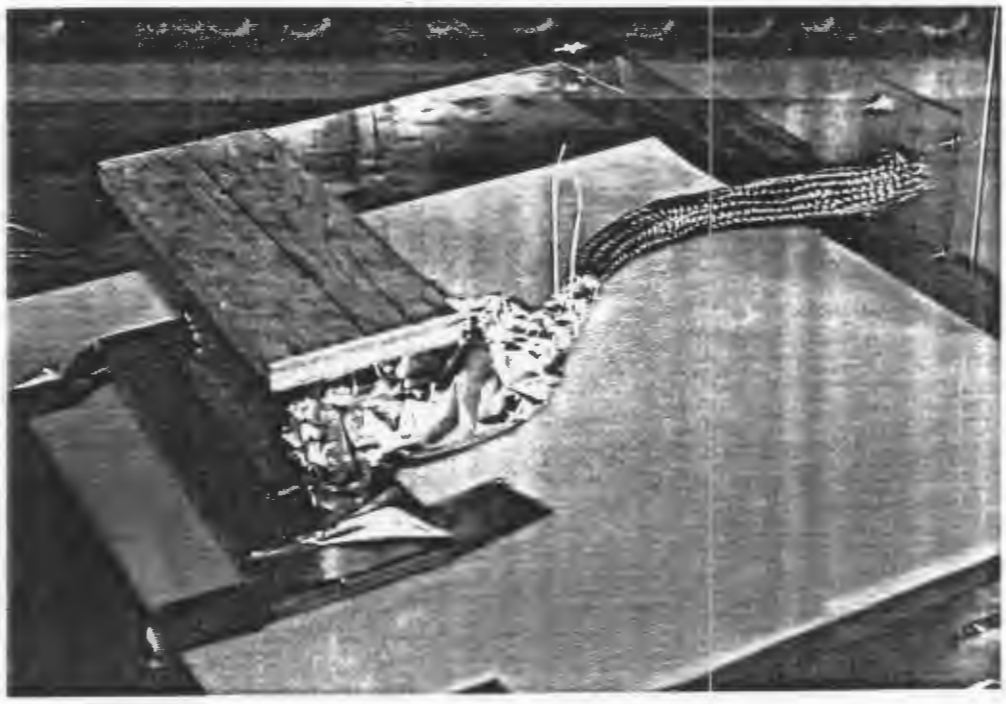

Figure 10. EIDI module with aluminum foil shielding

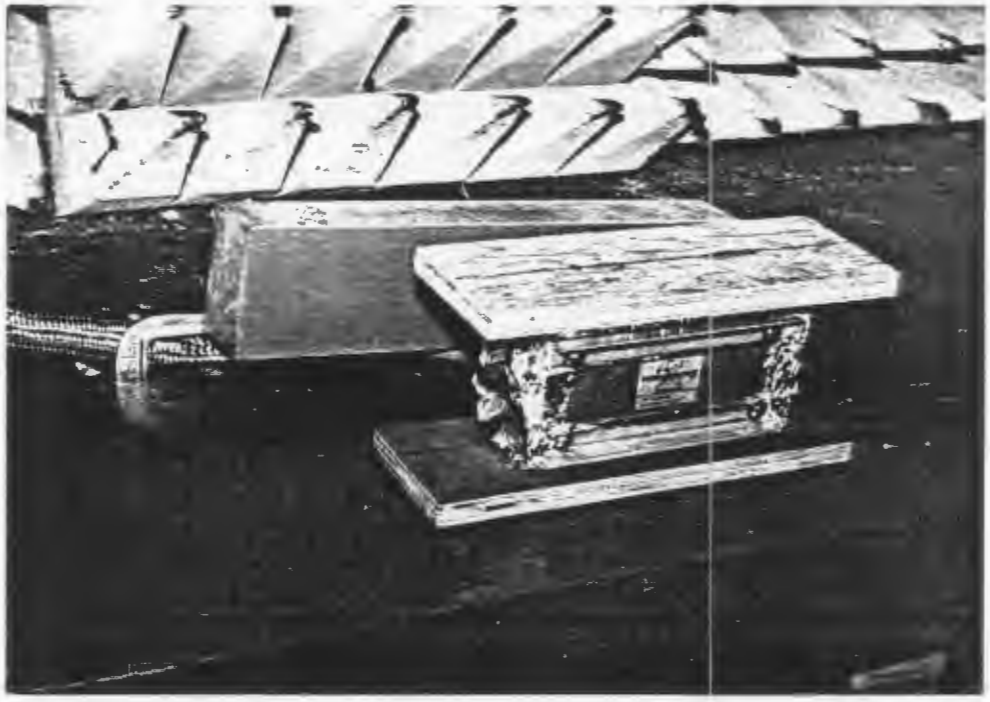

Figure 12. EIDI module in the Eldec EMI chamber

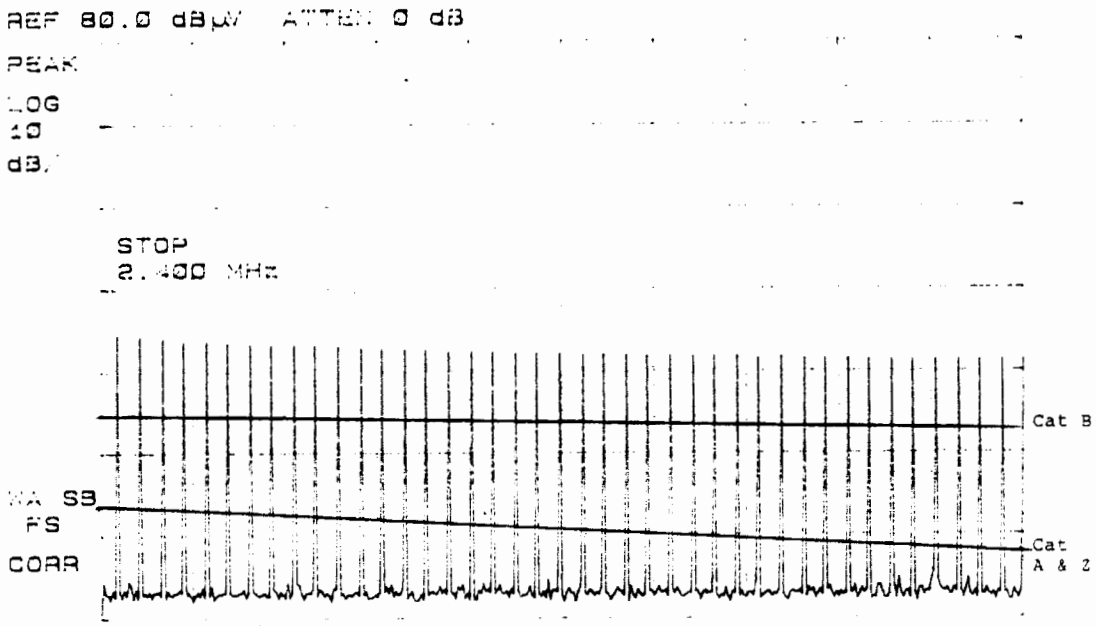

Figure 11A. Radiation measured from EDB module in the Electroimpact screen room in the frequency range 1.1 to 2.4 MHz. Emissions exceed standards.

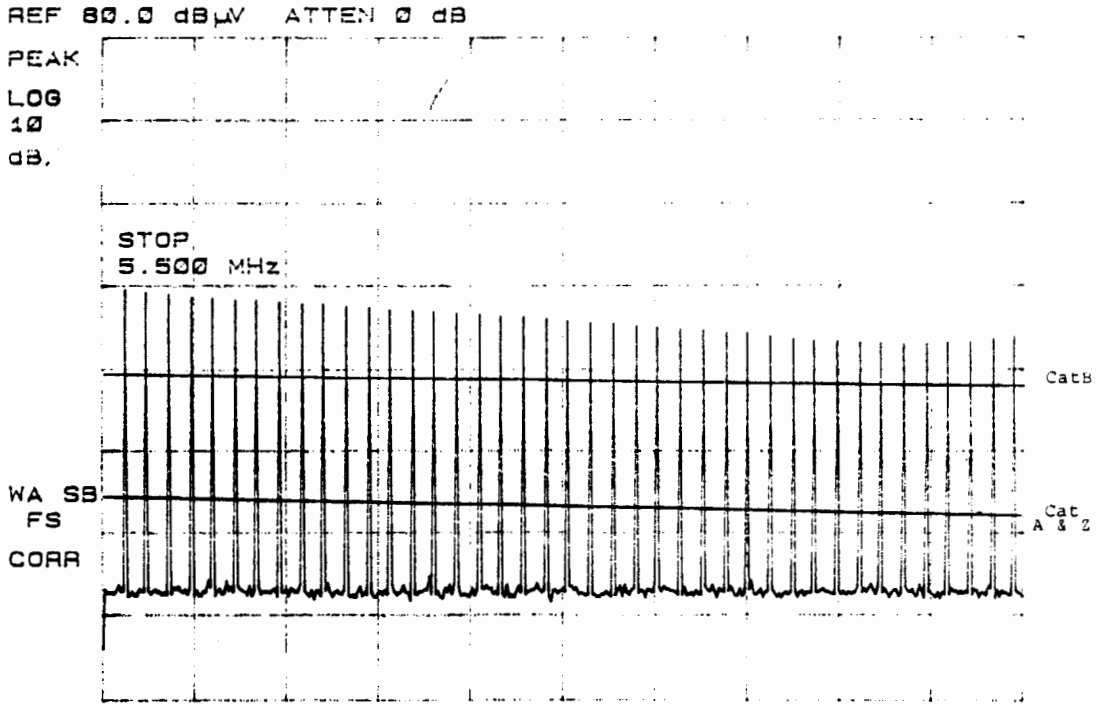

Figure 11B. Radiation measured from EDB module in the Electroimpact screen room in the frequency range 2.4 to 5.5 MHz. Emissions exceed standards.

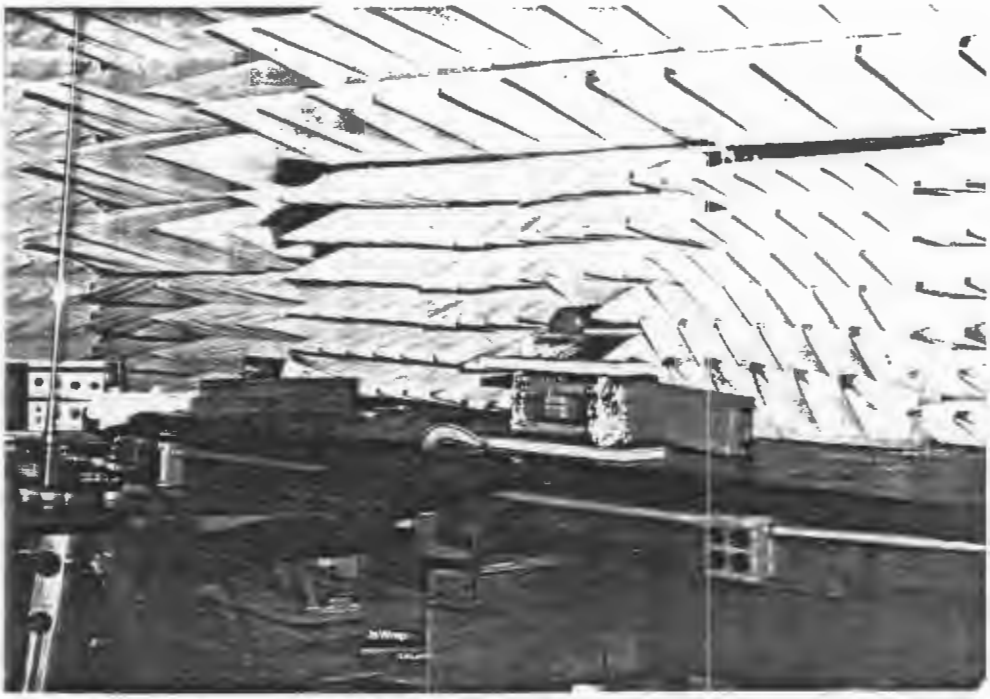

Figure 13. Whip antenna and EIDI module in Eldec EMI chamber

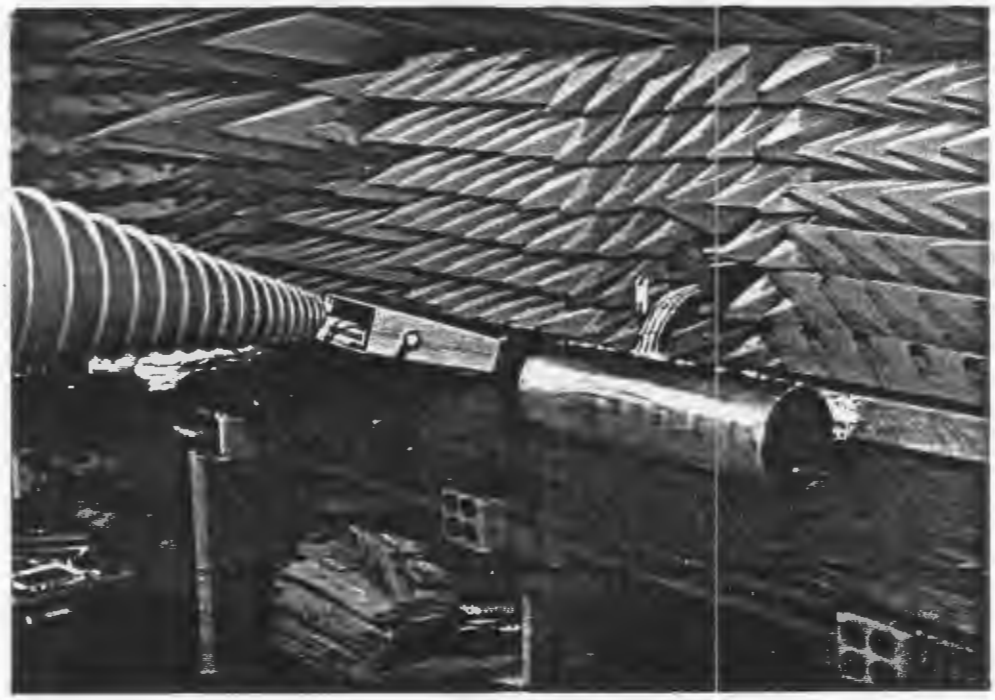

Figure 14. Conical antenna and EDS module

APPENDIX A

EMISSIONS SCANS RECORDED IN THE ELDEC EMI CHAMBER

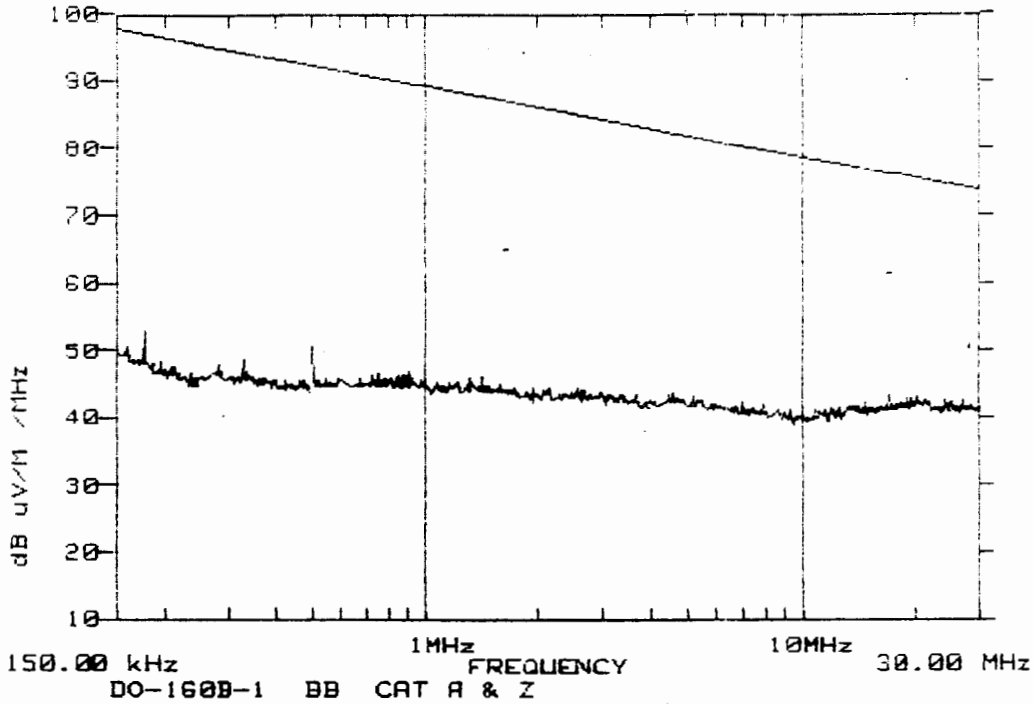

Figure A-1. E-field measurements from an EIDI module with three layers of aluminum foil shielding in the frequency range 150 kHz to 30 MHz. Results are within standards.

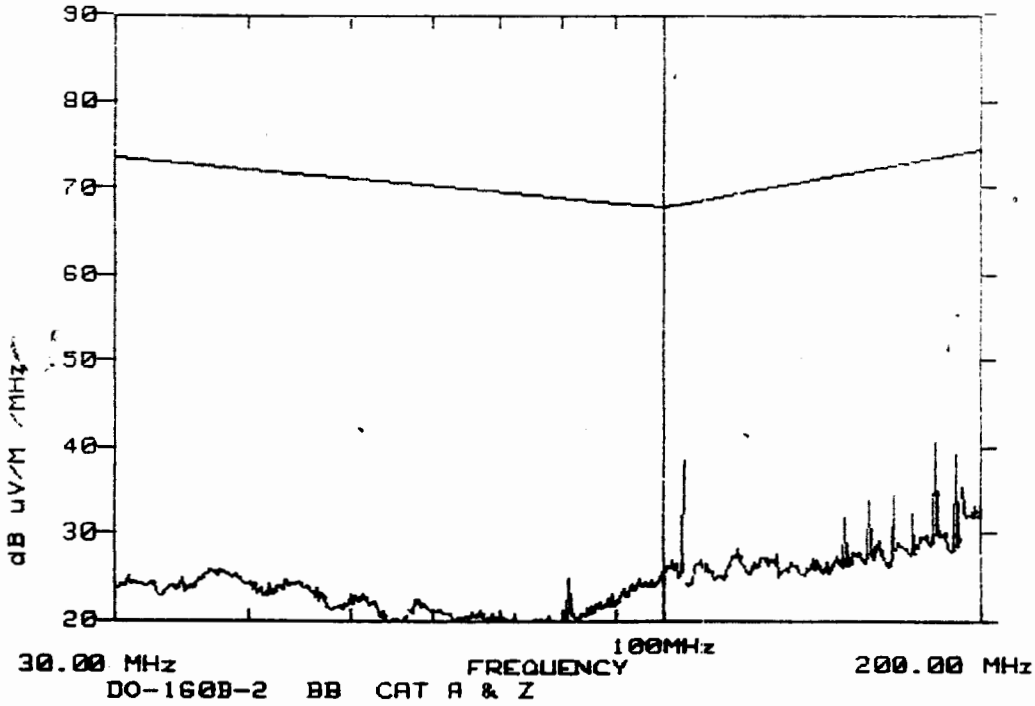

Figure A-2. E-field measurements from an EIDI module with three layers of aluminum foil shielding in the frequency range 30 MHz to 200 MHz. Polarization is horizontal. Results are within standards.

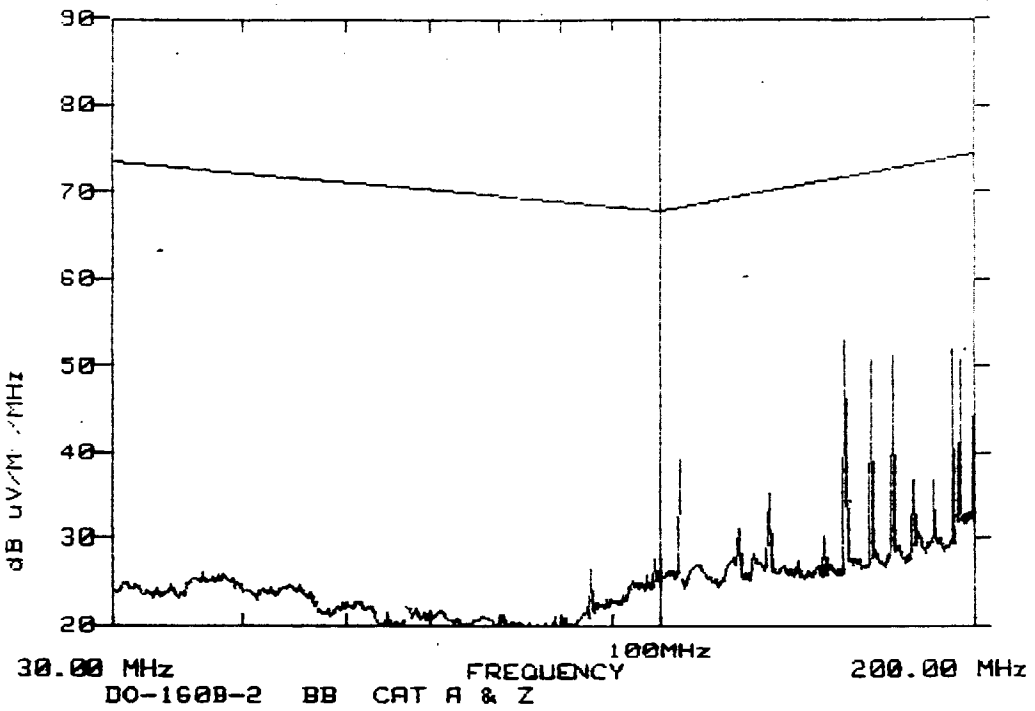

Figure A-3. E-field measurements from an EIDI module with three layers of aluminum foil shielding in the frequency range 30 MHz to 200 MHz. Polarization is vertical. Results are within standards.

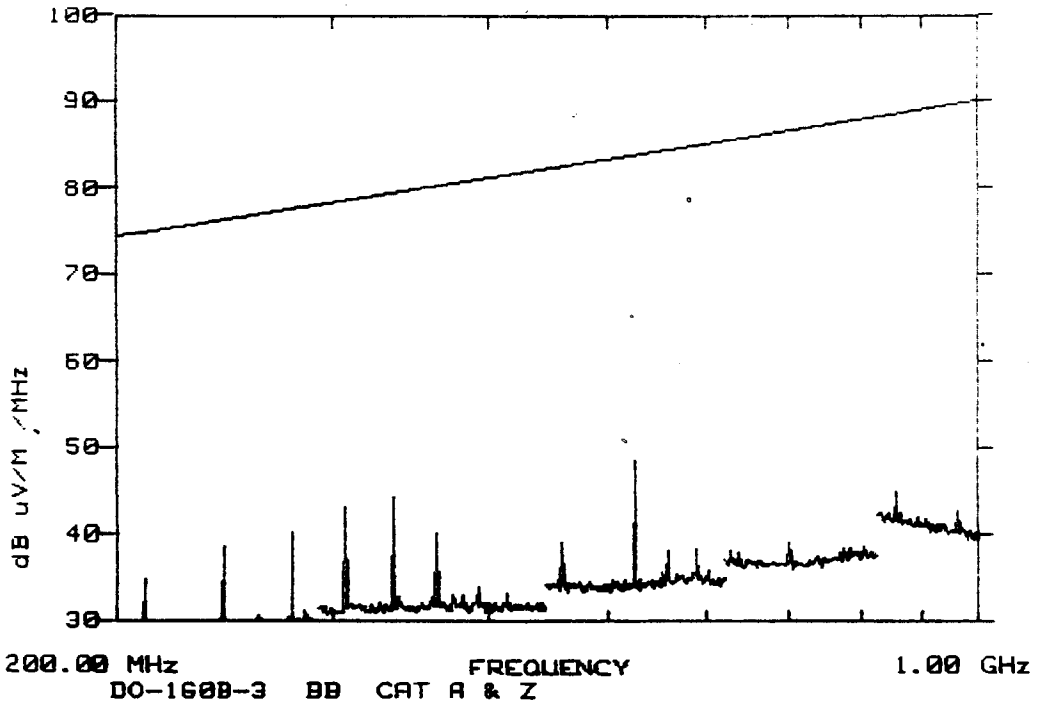

Figure A-4. E-field measurements from an EIDI module with three layers of aluminum foil shielding in the frequency range 200 MHz to 1 GHz. Results are within standards.

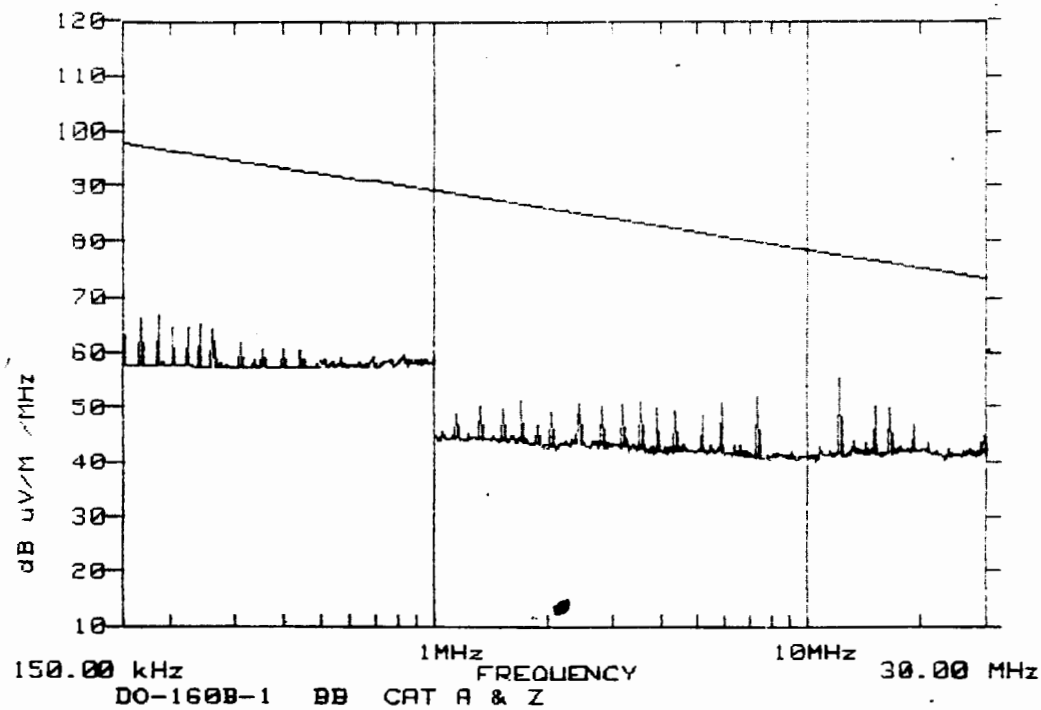

Figure A-5. E-field measurements from an EIDI module without aluminum foil shielding in the frequency range 150 kHz to 30 MHz. Results are within standards.

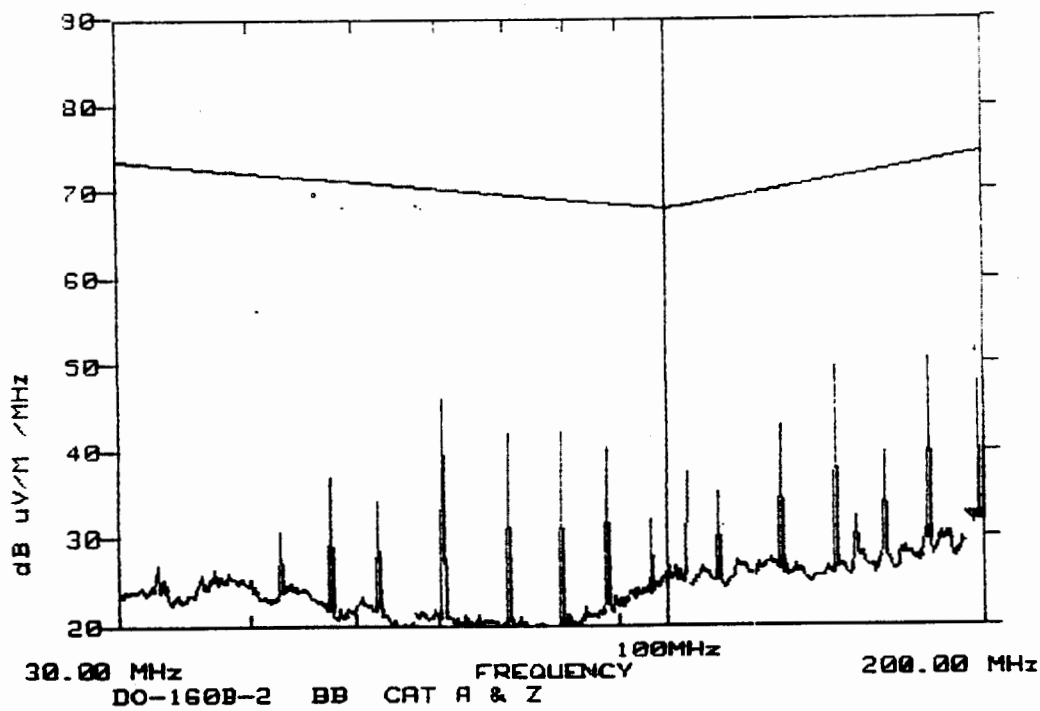

Figure A-6. E-field measurements from an EIDI module without aluminum foil shielding in the frequency range 30 MHz to 200 MHz. Polarization is horizontal. Results are within standards.

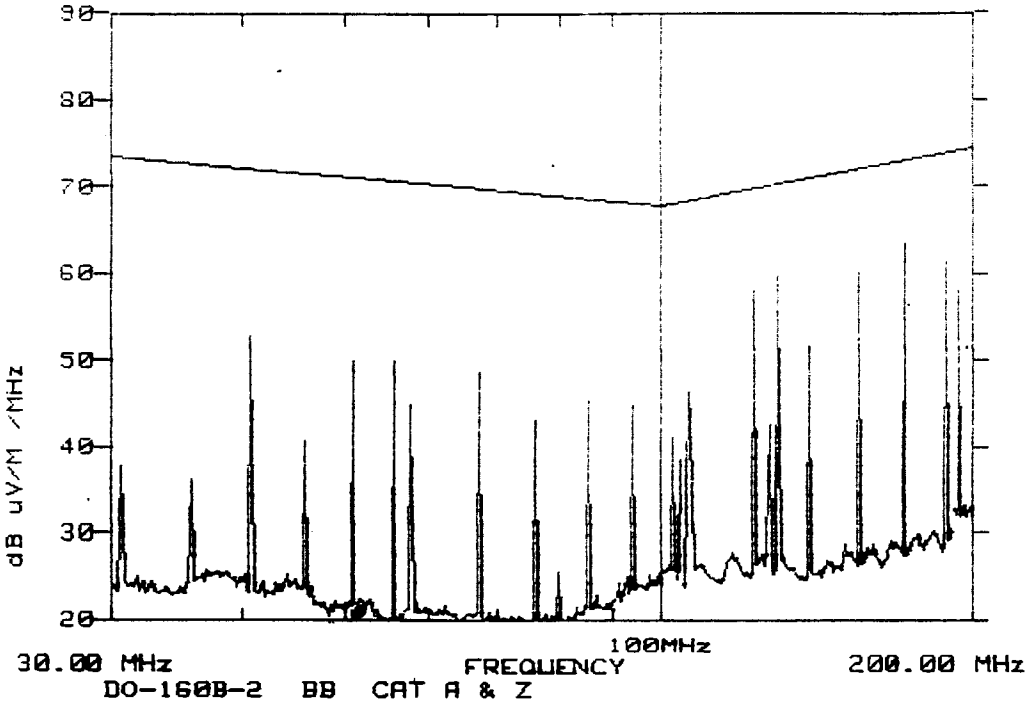

Figure A-7. E-field measurements from an EIDI module without aluminum foil shielding in the frequency range 30 MHz to 200 MHz. Polarization is vertical. Results are within standards.

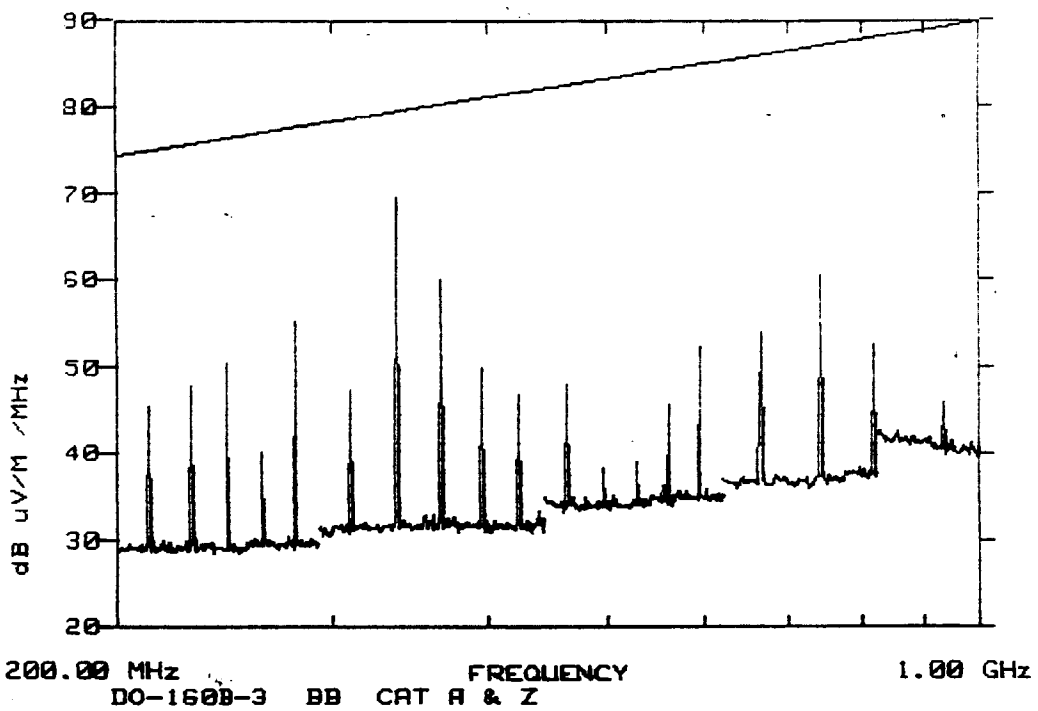

Figure A-8. E-field measurements from an EIDI module without aluminum foil shielding in the frequency range 200 MHz to 1 GHz. Results are within standards.

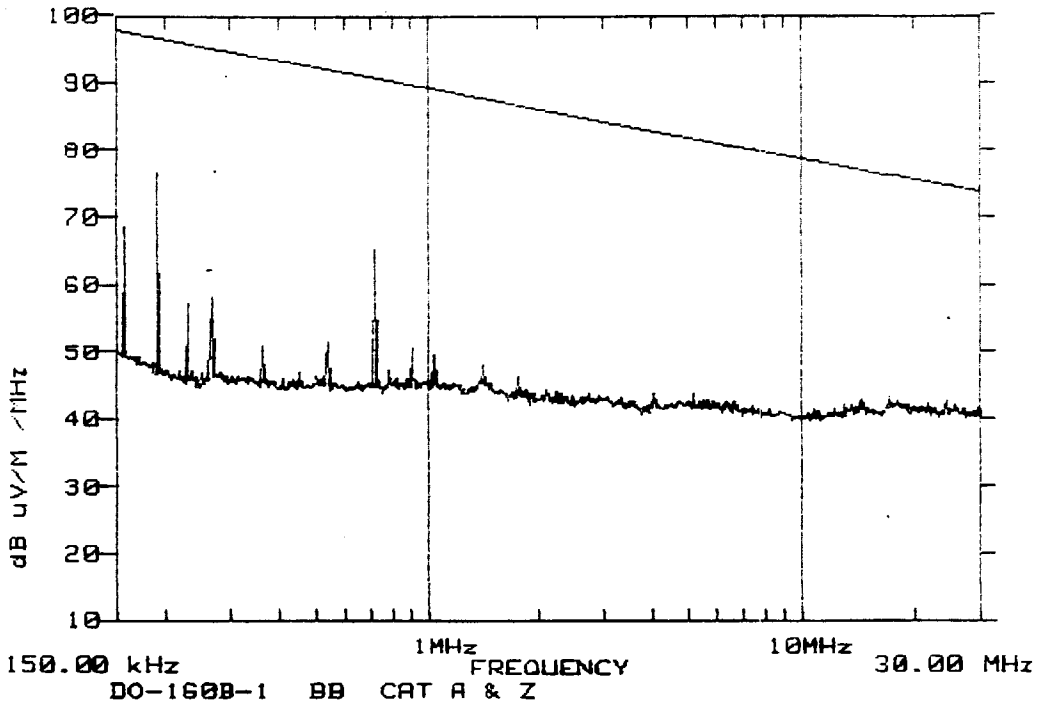

Figure A-9. E-field measurements from an EDS module with three layers of aluminum foil shielding in the frequency range 150 kHz to 30 MHz. Results are within standards.

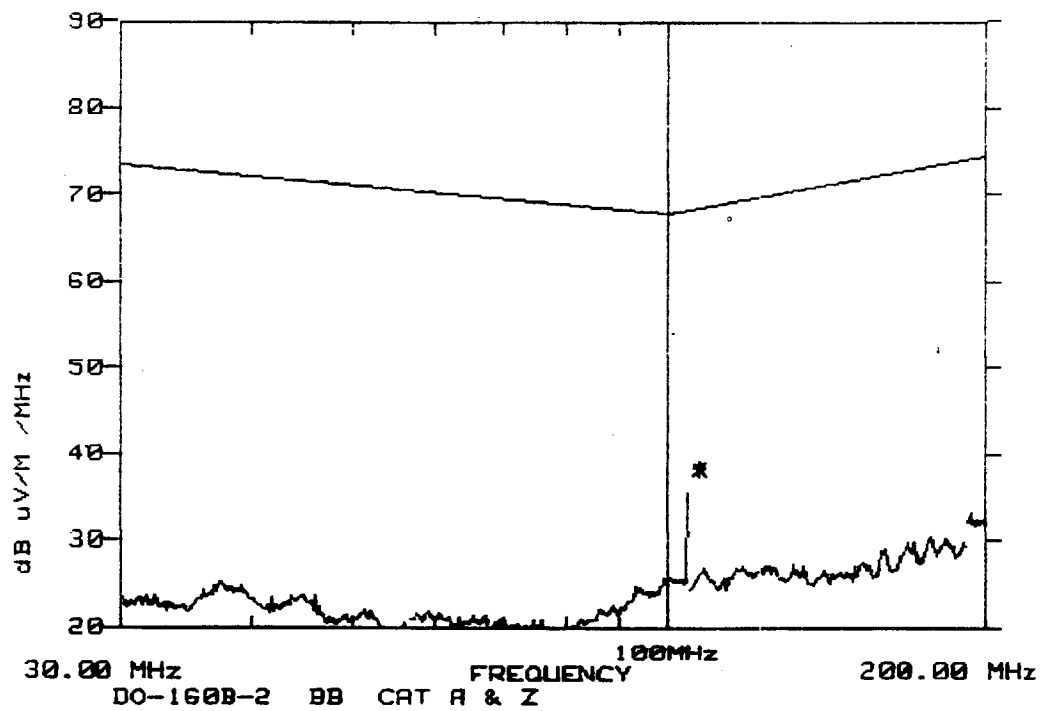

Figure A-10. E-field measurements from an EDS module with three layers of aluminum foil shielding in the frequency range 30 MHz to 200 MHz. Polarization is horizontal. Results are within standards.

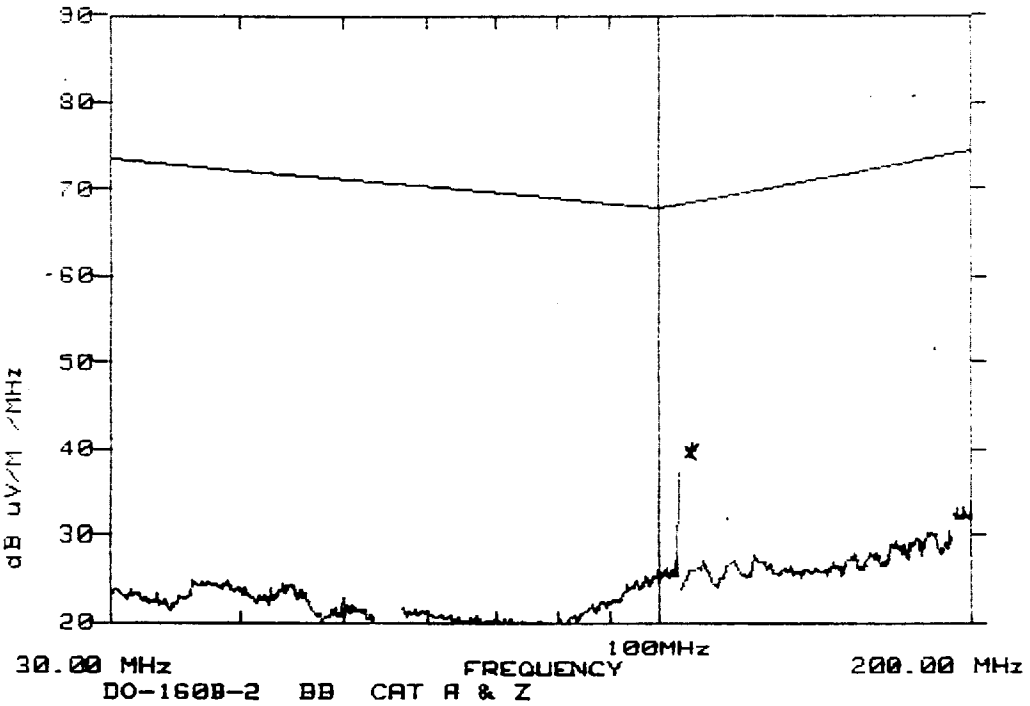

Figure A-11. E-field measurements from an EDS module with three layers of aluminum foil shielding in the frequency range 30 MHz to 200 MHz. Polarization is vertical. Results are within standards.

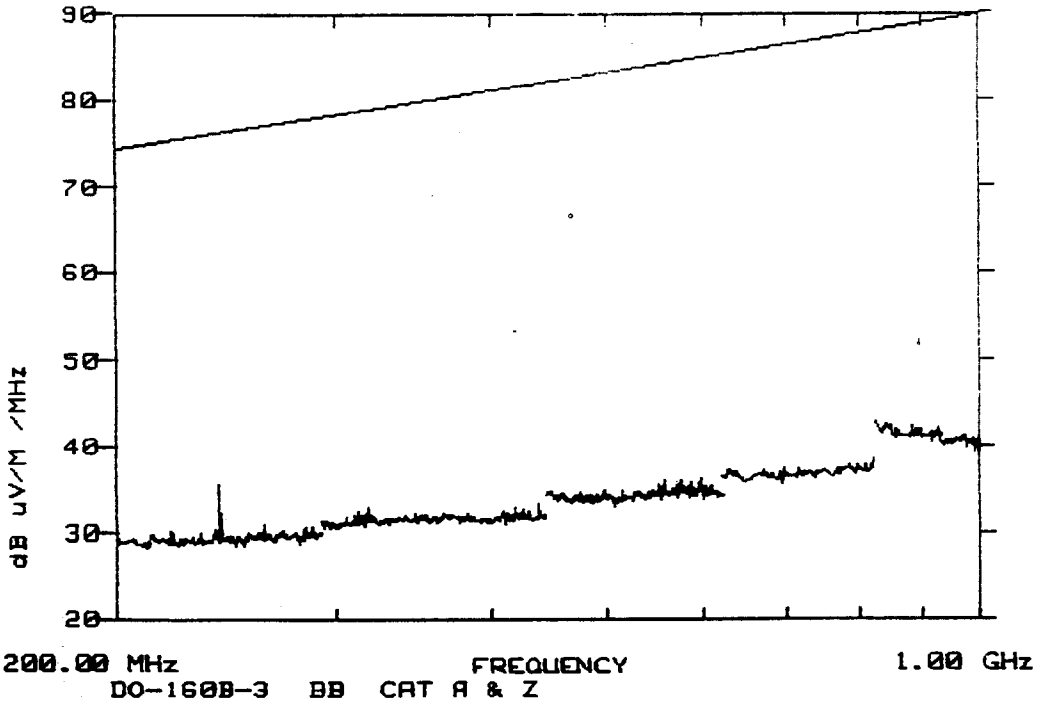

Figure A-12. E-field measurements from an EDS module with three layers of aluminum foil shielding in the frequency range 200 MHz to 1 GHz. Results are within standards.

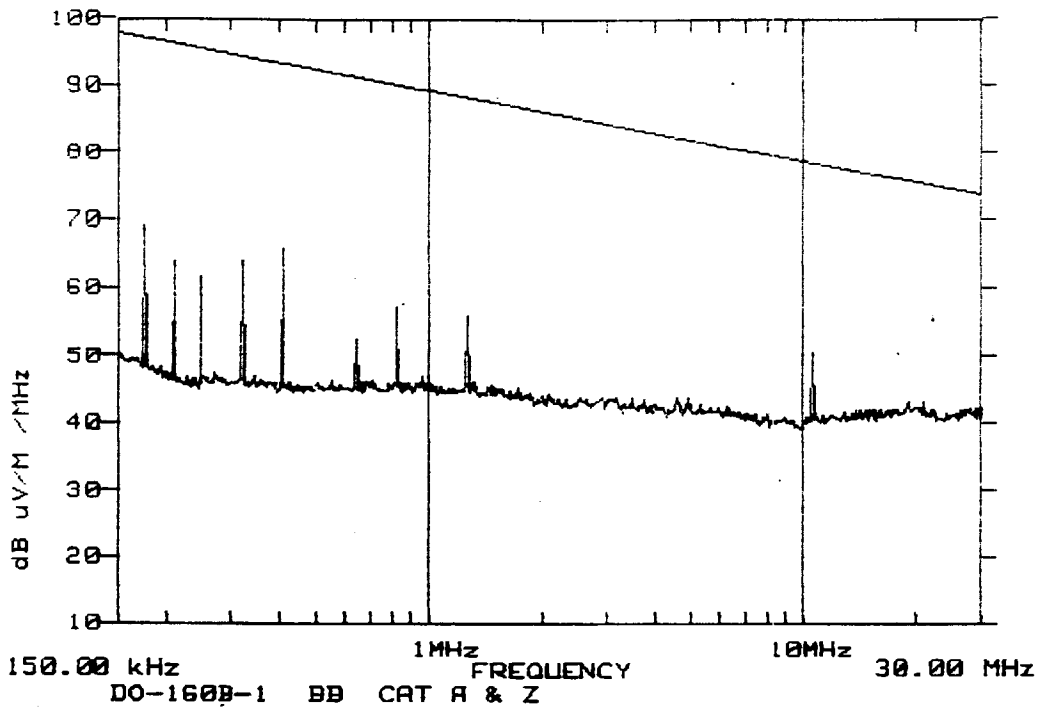

Figure A-13. E-field measurements from an EDS module with one layer of aluminum foil shielding in the frequency range 150 kHz to 30 MHz. Results are within standards.

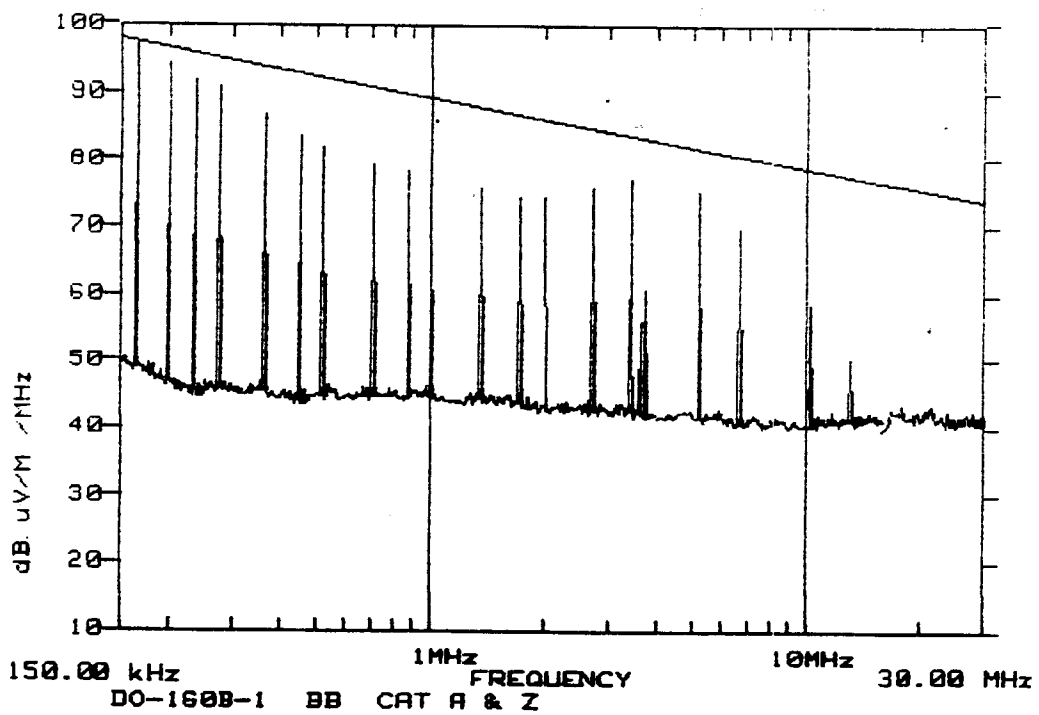

Figure A-14. E-field measurements from an EDS module without aluminum foil shielding in the frequency range 150 kHz to 30 MHz. Results are within standards.

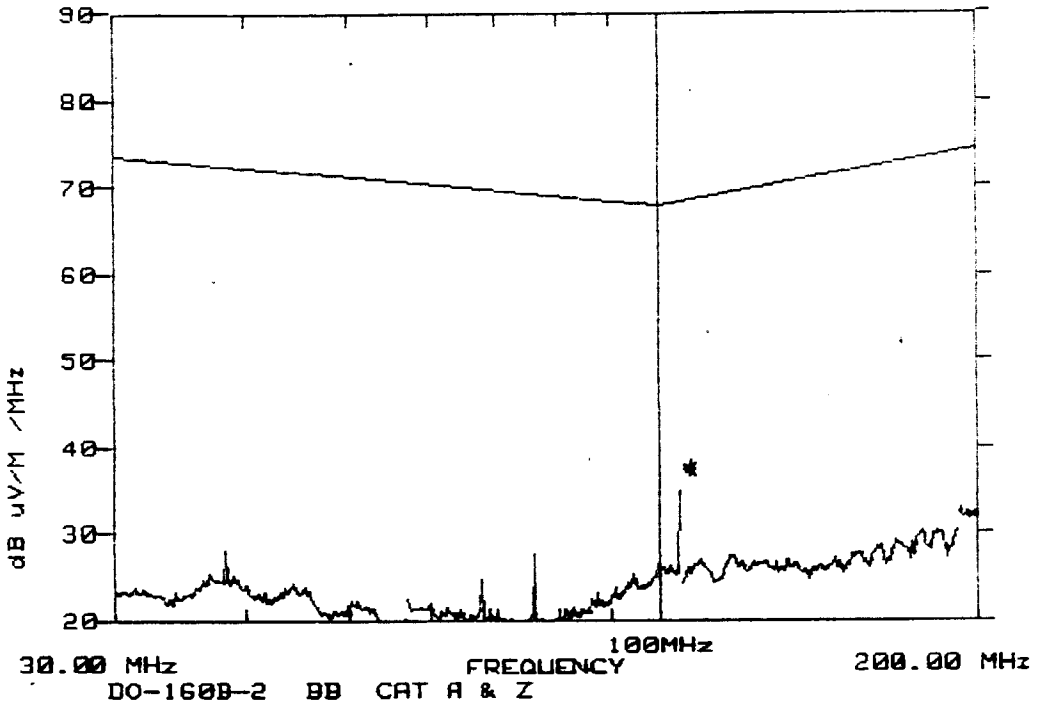

Figure A-15. E-field measurements from an EDS module without aluminum foil shielding in the frequency range 30 MHz to 200 MHz. Polarization is horizontal. Results are within standards.

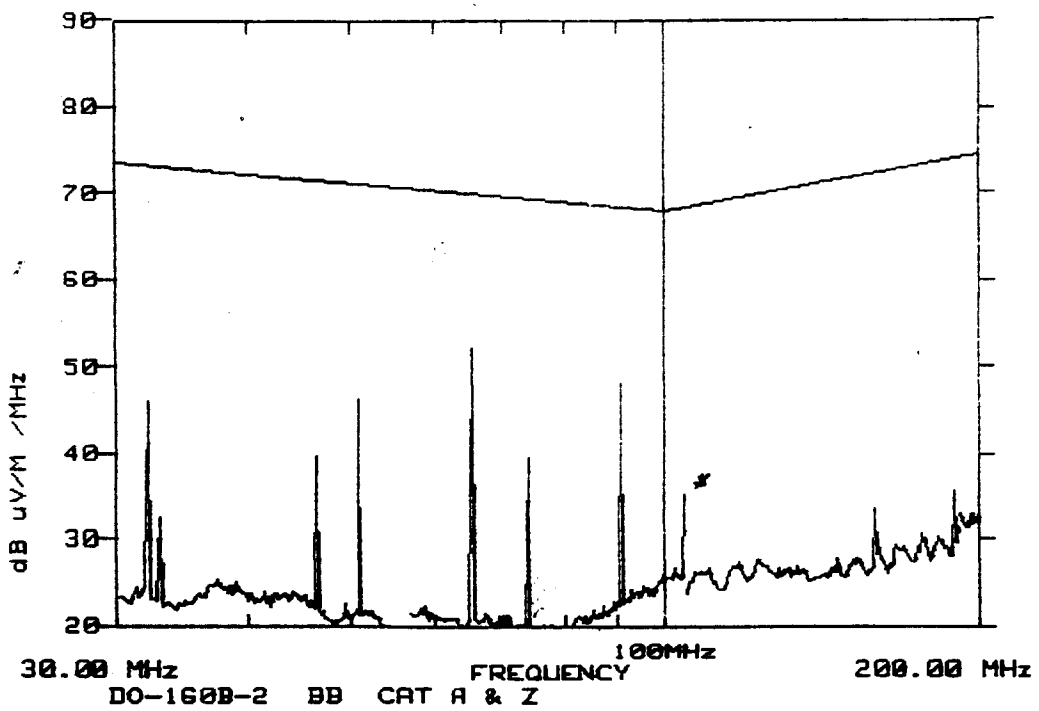

Figure A-16. E-field measurements from an EDS module without aluminum foil shielding in the frequency range 30 MHz to 200 MHz. Polarization is vertical. Results are within standards.

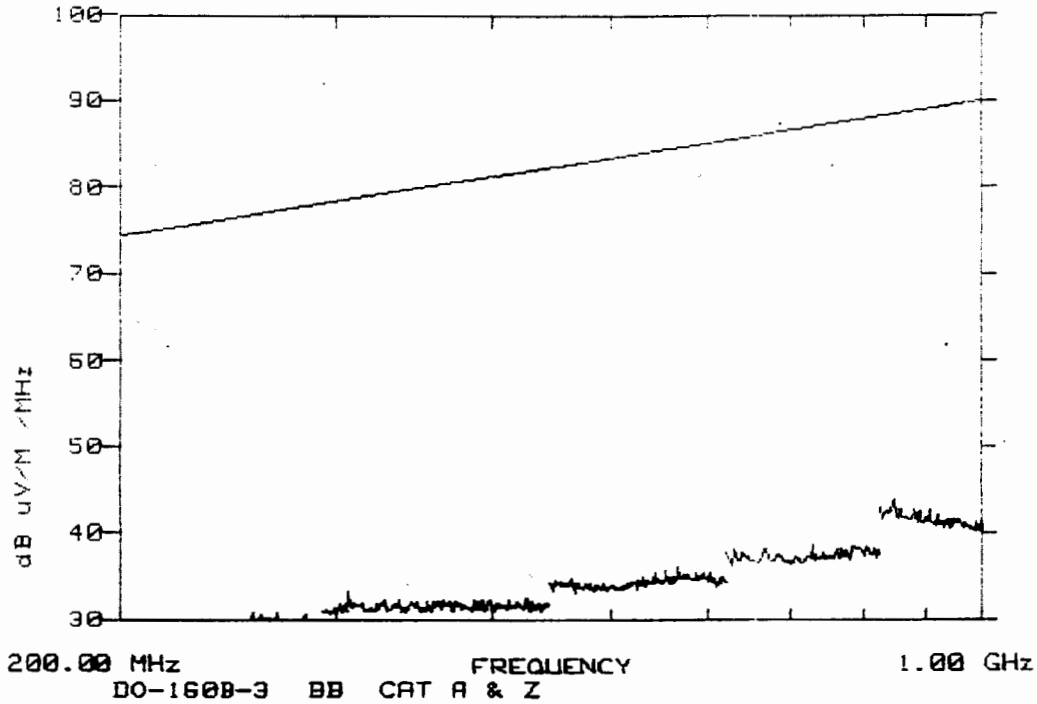

Figure A-17. E-field measurements from an EDS module without aluminum foil shielding in the frequency range 200 MHz to 1 GHz. Results are within standards.