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Calibration Techniques and Procedures for Ground-Plane-Version Electric and Magnetic Field Sensors

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The Harry Diamond Laboratories Woodbridge Research Facility (WRF) has used a small parallel-plate transmission line (2-1/2 in. high and 12 in. wide) to calibrate ground-plane-version electric and magnetic field sensors. Because this transmission line is relatively small compared to the size of the sensor being tested, some uncertainties have existed.

The acquisition and subsequent use of a transverse electromagnetic (TEM) cell have increased the accuracy of calibrating these electric and magnetic field sensors because the TEM cell has the capability of creating a well-known plane-wave electromagnetic field within the TEM cell.

This document reports the newly established calibration procedure to be followed when the TEM is used to calibrate ground-plane-version electric and magnetic field sensors. Also included is a complete description of the field sensors tested and the derivation of the calibration procedure.

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1. Introduction

The Harry Diamond Laboratories (HDL) Woodbridge Research Facility has used a small parallel-plate transmission line to calibrate ground-plane-version electric and magnetic field sensors. This parallel plate is 2-1/2 in. high, 12 in. wide, and 48 in. long. Stanford Research Institute (SRI) ground-plane-version sensors were calibrated periodically by placing the sensor at the bottom center of this parallel-plate transmission line. The ground-plane-version SRI sensors are 8.45 in. in diameter, while their height may vary from 0.145 to 1.15 in. Some sensor calibration factors were uncertain because the parallel-plate transmission line was small in comparison to the sensor. A sensor that occupies a large volume of the parallel-plate transmission line can distort and reflect the field incident on the sensor. Therefore the field near the sensor will be enhanced and may not have a uniform field distribution.

To correct this problem, HDL has purchased a transverse electromagnetic (TEM) cell to replace the parallel-plate transmission line. The TEM cell is an expanded coaxial transmission line that propagates a TEM wave. The cell can simulate a plane wave electromagnetic field in free space and provides quite uniform electric and magnetic field components over much of the volume between the center conductor and the outer shield. Since the cell will replace the small parallel-plate transmission line in calibrating these sensors, it has become necessary to establish a new calibration procedure.

2. TEM Cell

The model CC102-1 TEM cell used during this investigation was purchased from Instruments for Industries (IFI), Inc., to calibrate the ground-plane electric and magnetic field sensors currently being used by HDL. Because of its broadband, linear phase, and amplitude characteristics over much of the volume of the cell, a TEM cell is an ideal choice for establishing well-defined electromagnetic fields needed for accurate sensor calibration.

The TEM cell is a completely enclosed test chamber that consists of a rectangular transmission line section, tapered region, and transition section. The center conductor (or septum) is a 1/16-in.-thick rectangular thin sheet of aluminum tapered down at each end. The cell is a 50-Ω transmission line, with each end terminated to a conventional 50-Ω type-N coaxial connector. HDL's CC102-1 TEM cell was modified so that SRI's ground-

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plane-version sensors could be mounted directly to the floor of the cell. The cell is 77 in. long, 38 in. wide, and 26 in. high. The septum is 27 in. wide, with a distance of 11.8 in. between the septum and cell floor. The cutoff frequency of the CC102-1 model is 136.6 MHz, and the first resonant frequency is 157.2 MHz for TE01 mode. The performance and a description of HDL's CC102-1 model are furnished in another report.[1]

The gain of the cell at a point midway between the septum and the cell floor is 3.33 V/m/V (or 10.45 dB); i.e., an input signal of 1 V will produce a 3.33-V/m electric field at this location.

3. Sensor Description

HDL currently uses electric and magnetic field sensors which were designed and constructed by SRI in 1972. These sensors were designed to measure both pulsed or continuous electromagnetic fields.

Each sensor is mounted on a circular metal plate which provides both a finite ground plane and mounting surface for the sensors. These sensors were originally designed to be mounted to any side of a 1-m^3 metal box (mapping box). The mapping box provided shielding for the instrumentation located in it, i.e., oscilloscope, camera, coaxial cables, bias tee, and power supply. The mapping box also provides a finite-size ground plane for the sensors.

These sensors have since been modified so that they could be mounted on the end of a 12-in. uniform metallic cylinder which contains a fiber-optic transmitter, a battery pack, a bias tee, and coaxial cables. With the advent of fiber optics, the mapping box was no longer needed and could be replaced by this much smaller and convenient enclosure. Sensor modifications include drilling and countersinking four holes in each sensor mounting plate and smoothing any nylon screws that protrude out the back of the sensor. See appendix A for detailed drawings of each sensor.

3.1 Electric Field Sensors

Six different E-field sensors (E010 to E502) are needed to measure field strengths ranging up to 200 kV/m when the mapping box or fiber-optic

[1]Youn M. Lee, Transverse Electromagnetic Cell Performance Verification Test Report, Harry Diamond Laboratories, HDL-TR-2069 (November 1985).

cylinder are used. Each sensor has its own measurement range. The E010, which is the most sensitive, can measure very small signals, while the E502, which is the least sensitive sensor, can measure very large signals. Using a sensor outside its defined measurement range should be avoided. Underdriving a sensor will reduce the signal-to-noise ratio of a measurement, thus giving a noisy output. Overdriving an E-field sensor might damage the active components present in its preamplifier.

These sensors are flush-mounted, top-loaded monopoles. A short monopole is capacitively loaded by a circular top-mounted conductive plate. This copper plate is etched on a 6-in.-diameter fiberglass disk. For sensors E010, E100, and E200, this conductive plate is 3.312 in. in diameter. The dielectric medium of these three sensors is air, but the sensors are surrounded by fiberglass. Sensors E300 and E400 have a plate size of 0.905 in. and use a polystyrene dielectric. Sensor E502 does not use a top plate. Sensors E200, E300, E400, and E502 all use capacitive voltage dividers to reduce the signal intensity to a suitable recording range. The physical characteristics of these sensors are found in table 1. Each E-field sensor is connected to a built-in unity gain preamplifier which provides an input impedance of 10 MΩ shunted by a total of 10.5 pF and a low output impedance to drive 50-Ω signal cables. Although the peak output voltage for linear operation is 700 mV, SRI recommends that this value be kept at 500 mV. The 3-dB bandwidth of this preamplifier is 5 kHz to 160 MHz. A bias tee must be connected to each E-field sensor to provide the 12 Vdc needed to operate the preamplifier.[2] See appendix A, figure A-8, for a schematic drawing of an E-field preamplifier.

Table 1. Physical Characteristics of SRI's E-Field Sensors

Sensor series	Top plate			Divider plate			
	Diameter (in.)	Height (in.)	Dielectric	Ratio	Diameter (in.)	Height	Dielectric
E010	3.312	1.125	Air	N/A	N/A	N/A	N/A
E100	3.312	0.125	Air	N/A	N/A	N/A	N/A
E200	3.312	0.125	Air	10:1	2.76	0.01	Polystyrene
E300	0.905	0.02	Polystyrene	50:1	2.34	0.01	Polystyrene
E400	0.905	0.02	Polystyrene	50:1	4.52	0.005	Polystyrene
E502	0.0	0.0	—	50:1	4.52	0.005	Polystyrene

[2]Bruce C. Tupper, Roy H. Stehle, Russel T. Wolfram, and V. Donald Cone, EMP Instrumentation Development, Stanford Research Institute (June 1972).

Sensor E010 is a modified E100 series sensor. To increase the sensitivity of the E100 sensor, we raised its top-mounted plate 1 in. above its mounting flange. This will, in effect, increase the signal level by decreasing impedance mismatch. This modification increased sensor sensitivity by 16 dB without sacrificing bandwidth. Because of the increased sensitivity, this sensor cannot be used in fields greater than 20 V/m when it is mounted on the mapping box or the metallic cylinder. Sensor E502 is a modified E400 series sensor. To decrease the sensitivity of the E400 sensor, we removed the top plate and extended the center post to 0.090 in. This modification decreased the sensitivity by 10 dB without sacrificing bandwidth.

When the output of these sensors is positive, it corresponds to an electric field polarized in the direction pointing directly at the sensor face.

3.2   Magnetic Field Sensors

Only one type of H-field sensor is used to measure H-field intensities up to 265 A/m. This corresponds to E-fields up to approximately 100 kV/m.[2] This sensor consists of a semicircular, shielded half-loop coaxial cable. The half-loop has an outer diameter of 2.25 in. and is made of UT-141A 50-Ω semirigid miniature coaxial cable. A Tektronix CT-2 current probe is used to measure the short-circuit current induced on the inner conductor. The shield on this cable is connected to the ground plane at one end and gapped at the other end to minimize electric field coupling. The CT-2 probe has a transfer impedance of 1 Ω (1 mV/mA). These H-field sensors have a bandwidth of 90 kHz to 200 MHz and a rise time of 2.5 ns.

Like E-field sensors, H-field sensors are mounted on an 8-1/2-in. circular plate for easy mounting on the mapping box or metallic cylinder. The sensor is protected by a white plastic cover which is marked with an arrow indicating the field direction needed for a positive output voltage. These sensors are passive devices and therefore do not require a bias tee when used.

[2]Bruce C. Tupper, Roy H. Stehle, Russel T. Wolfram, and V. Donald C ne, EMP Instrumentation Development, Stanford Research Institute (June 1972).

4. Field Strength Within the TEM Cell

4.1 Electric Field

The electric field strength, E, for a reference point midway between the inner conductor and the floor is given as

$$E = \frac{V_d}{b} \ (\text{V/m}) \ , \tag{1}$$

where V_d is the applied voltage to the cell (i.e., the voltage potential between the inner conductor and the floor) and b is the distance (in meters) between the inner conductor and the floor (0.3 m for TEM CC102-1).

During calibration, each sensor is mounted directly onto the floor of the TEM cell. Since the fields within the cell vary slightly with location, it was necessary to accurately determine the field strength present at the location at which the sensors would be placed.

The field strength present at the location at which the SRI ground plane sensors would be calibrated was determined by measuring the fields at this location with two miniature D-dot sensors whose responses had been accurately calibrated by the National Bureau of Standards (now the National Institute of Standards and Technology). Using these calibrated sensors, we determined that the fields present at this location were 2 dB less than the fields present at the reference midpoint. Equation (1) now becomes

$$E = \frac{0.79 \ V_d}{b} \ (\text{V/m}) \ . \tag{2}$$

For this investigation, the cell was driven by a signal generator which had been amplified by a power amplifier. The voltage potential V_d can be determined by multiplying the generator output voltage ($V_g (f)$) by the gain of the power amplifier ($G_{amp} (f)$) used. Equation (2) now becomes

$$E = \frac{0.79 \ [V_g (f) \times G_{amp} (f)]}{b} \ (\text{V/m}) \ . \tag{3}$$

4.2   Magnetic Field

Since the TEM cell closely simulates a planar wave in free space, the wave impedance is then 120 $\pi\Omega$. The magnetic field inside the cell is simply

$$H = \frac{E}{120\pi} \quad (\text{A/m}) \; .\tag{4}$$

With the use of equation (3), this becomes

$$H = \frac{0.79 \, [V_g\,(f) \times G_{amp}\,(f)]}{b \times 120\pi} \quad (\text{A/m}) \; .\tag{5}$$

5. Sensor Calibration

5.1   Development of a New Standard Operating Procedure

Two sensors of each series were used in establishing a new standard operating procedure. The TEM cell was driven by an HP 8601A generator/ sweeper whose output had been amplified by a 50-dB linear power amplifier. The cell was terminated with a 50-Ω 600-W termination. The sensor responses were recorded with an HP 8407A network analyzer (see fig. 1 and 2 for equipment setup). To monitor the overall calibration procedure and minimize measurement error, sensor output was also recorded at six different frequencies ranging from 250 kHz to 100 MHz, using a Tektronix 485 oscilloscope. Results of this measurement are plotted and overlayed on the results of the measurement made with the network analyzer (see app A, fig. A-12 through A-23).

To correctly calibrate a sensor, three important criteria should be met:

1. All equipment used in the calibration process (i.e., amplifiers, attenuators, termination) must be operated within its specified region.

2. Field strength inside the T⁻M cell should be at a level within the dynamic range of the sensor being tested.

3. The HP 8407A network analyzer must be operated within its calibrated region.

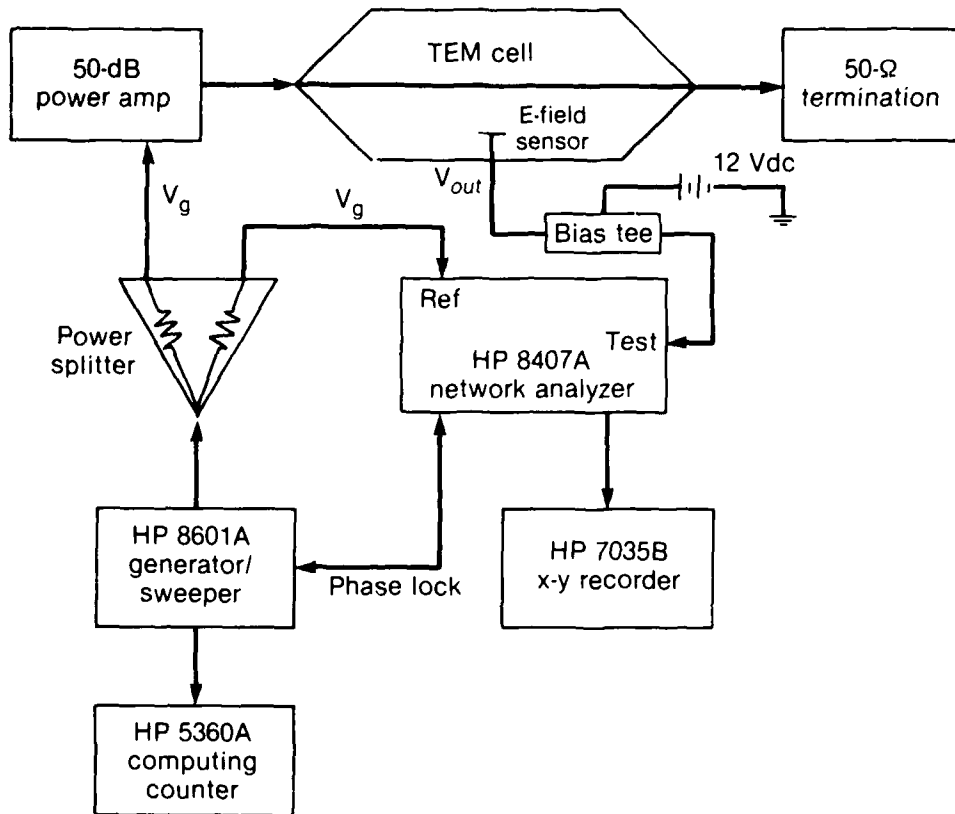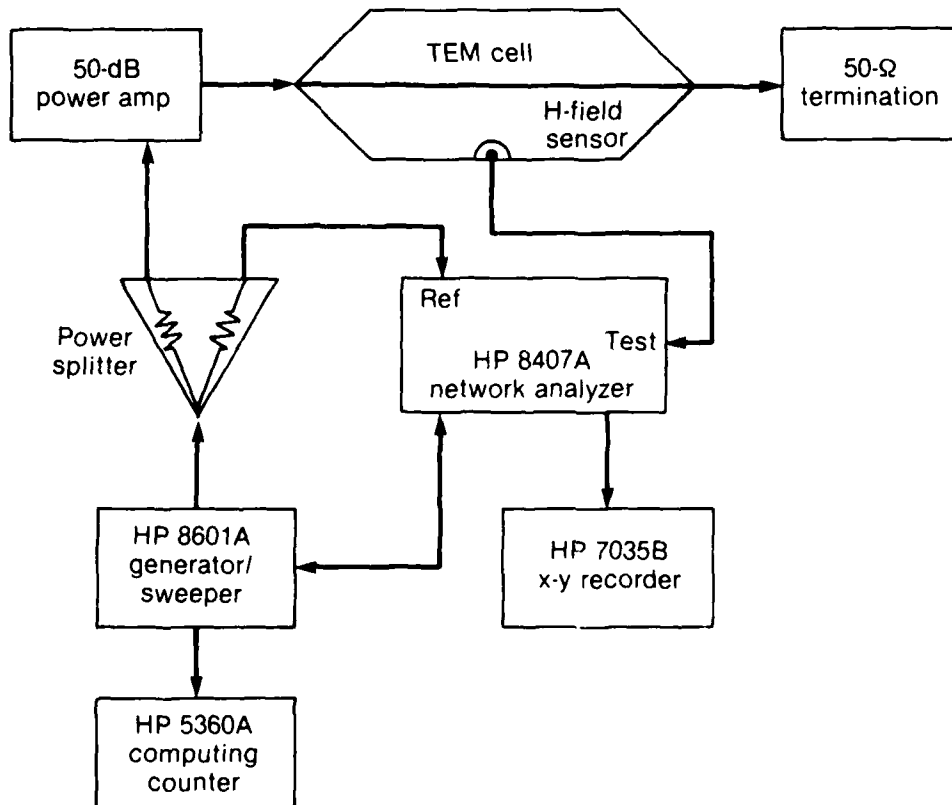**Figure 1. Typical system setup for calibrating ground-plane E-field sensors.**

50-dB power amp

TEM cell

50-Ω termination

E-field sensor

V_{out}

12 Vdc

V_g

V_g

Bias tee

Power splitter

Ref

Test

HP 8407A network analyzer

HP 8601A generator/ sweeper

Phase lock

HP 7035B x-y recorder

HP 5360A computing counter

Figure 2. Typical system setup for calibrating ground-plane H-field sensors.

50-dB power amp

TEM cell

50-Ω termination

H-field sensor

Power splitter

Ref

Test

HP 8407A network analyzer

HP 8601A generator/ sweeper

HP 7035B x-y recorder

HP 5360A computing counter

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Since each series of sensor operates within its own dynamic range, different field strengths must be set up in the TEM cell for each of the sensors. Table 2 shows the necessary setting to be used when the HP 8601A signal generator is used with the ENI 50-dB amplifier. These settings assure that each sensor is being properly excited. Also listed in table 2 are the HP 8407A network analyzer settings needed to assure that the analyzer is operated within its calibrated region for each type of sensor.

The ENI 50-dB amplifier used during these tests has an output power rating of 100 W. Because of this, field strengths greater than 277 V/m could not be achieved. With this limitation, E300, E400, and E500 series sensors cannot be tested within their recommended operating ranges. However, because of the large dynamic range of the network analyzer, when these E-field sensors were tested below the recommended operating range, their frequency responses appeared to be very accurate. This means that these sensors need not be operated within their recommended levels while they are being calibrated inside the TEM cell. Plots of the measured sensor frequency responses appear in appendix A (fig. A-12 through A-23). The free-field sensor calibration factors that were computed from these measurements can be found in tables 3 and 4.

The calibration factors which were determined in the TEM cell represent free-field values. In reality, these sensors will be used in connection with either a 1-m^3 metallic cube (mapping box) or an 11-in. metallic cylinder.

The presence of these objects, together with the sensors, will increase or "enhance" the intensity of the fields near the sensor. To account for this effect, we have determined enhancement factors for the mapping box and the cylinder.[3] These enhancement values have been included with the free-field calibration factor for an overall total calibration factor (see tables 3 and 4 for these enhanced calibration factors).

Once the calibration factor of the sensors has been computed, the dynamic range of the sensor can be easily calculated. SRI advises that the output of these sensors should range anywhere from 30 to 500 mV. Using 30 mV as

[3]*Bruce T. Benwell and Youn M. Lee, The Effects of Mounting a Metallic Cylinder Behind a Ground-Plane-Version Electromagnetic Field Sensor, Harry Diamond Laboratories, HDL-TR-2153 (January 1989).*

a sensor's lower boundary and 500 mV as its upper boundary, we have calculated sensor field ranges; these are listed in figures 3 to 5.

Table 2. Parameter Settings of HP 8407A Network Analyzer for E-Field and H-Field Sensor Calibration

Sensor	Nominal input to 50-dB power amplifier (mV)	Level control ref	Level control test	Ref channel position	Dial settings for sweeper output level (dBm)	Nominal field strength at TEM cell reference point
E010	22	Dir	Atten	Bottom	−22	23 V/m
E100	70	Dir	Dir	Bottom	−10	74 V/m
E200	220	Atten	Atten	Middle	+3	232 V/m
E300	220	Atten	Atten	Middle	+3	232 V/m
E400	220	Atten	Dir[a]	Middle	+3	232 V/m
E502	220	Atten	Dir[a]	Middle	+3	232 V/m
H100	155	Atten	Atten	Middle	+1	435 mA/m

[a]*To calibrate the network analyzer, the level control switch must be set to "Atten." The actual sensor output response will be exactly 40 dB lower than what is plotted.*
Note — Dir = direct; Atten = attenuation.

Table 3. E-Field Sensor Calibration Factors

Sensor	Calibration factor in free field (V/m/V)	Calibration factor when mapping box is used (V/m/V)	Calibration factor when fiber-optic cylinder is used (V/m/V)
E010	72.3	45.6	40.7
E102	421.0	265.0	237.0
E103	467.0	294.0	263.0
E201	4567.0	2875.0	2567.0
E204	3933.0	2475.0	2210.0
E302	35047.0	22061.0	19697.0
E303	45672.0	28749.0	25669.0
E403	236947.0	149149.0	133169.0
E404	228902.0	144085.0	128648.0
E502	784603.0	493878.0	440963.0

Table 4. H-Field Sensor Calibration Factors

Sensor	Calibration factor in free field (A/m/V)	Calibration factor with mapping box (A/m/V)	Calibration factor with cylinder (A/m/V)
H106	41.5	39.6	41.5
H108	41.5	39.6	41.5
H104	43.0	41.0	43.0

Figure 3. E-field sensor measurement ranges — free field.

E010   35 V/m
E100   200 V/m
E200   2000 V/m
E300   17 kV/m
E400   115 kV/m
E500

0.02 12   115   1000   7000   24K   350K
Electric field (V/m)
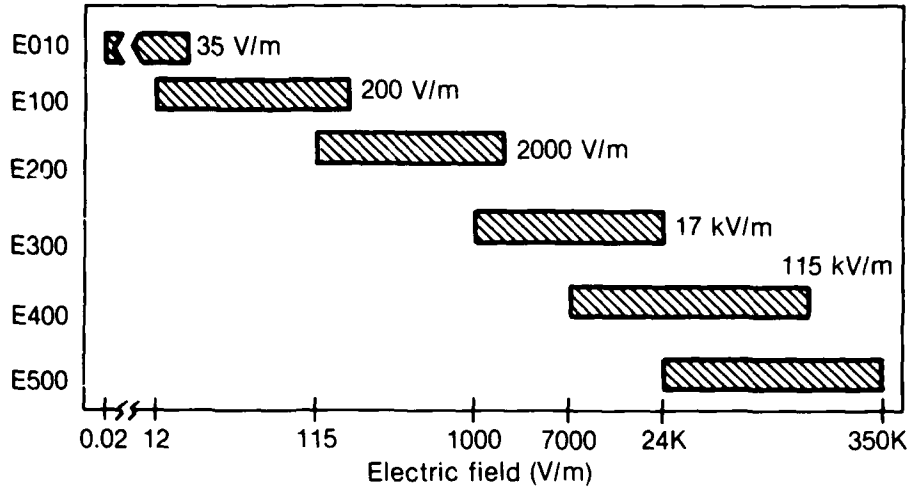
Figure 4. E-field sensor measurement ranges when mapping box is used.

E010   20 V/m
E100   140 V/m
E200   1350 V/m
E300   12.5 kV/m
E400   74 kV/m
E500

0.015 8   80   750   4400   15K   200K
Electric field (V/m)
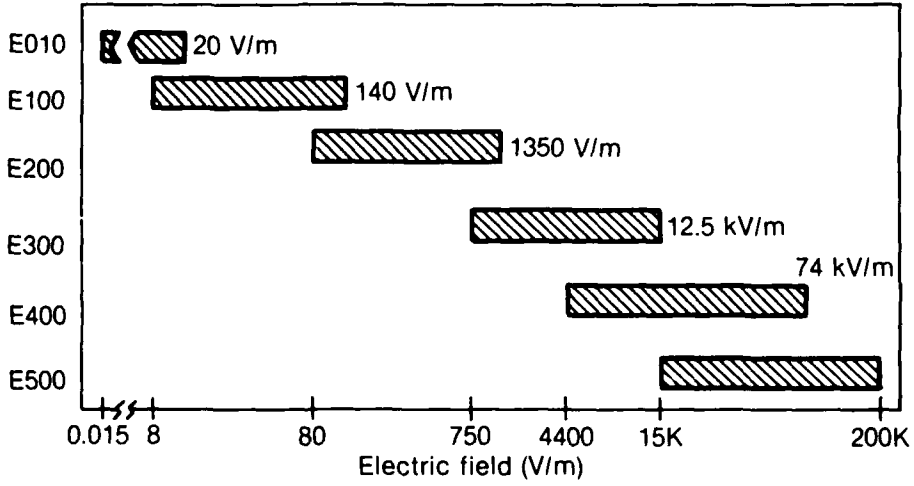
Figure 5. E-field sensor measurement ranges when metallic cylinder is used.

E010   20 V/m
E100   125 V/m
E200   1200 V/m
E300   12 kV/m
E400   65 kV/m
E500

0.015 7.5   70   700   4000   15K   200K
Electric field (V/m)

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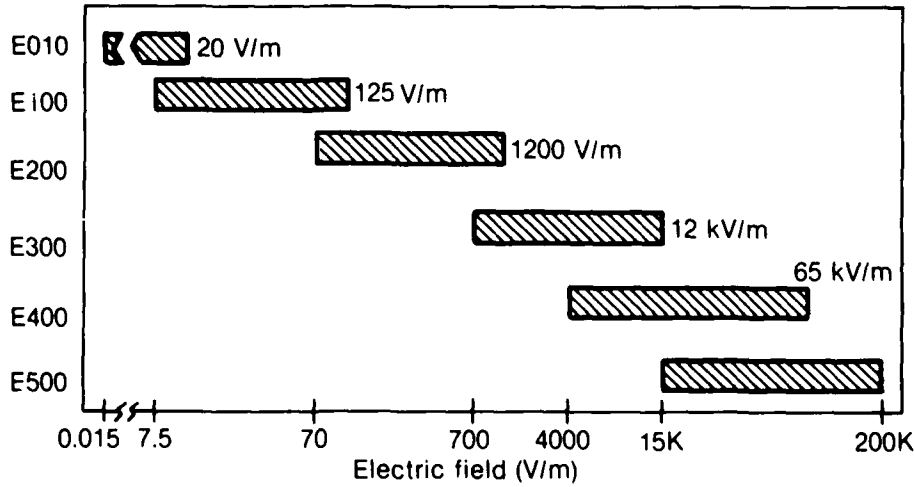
5.2 Derivation of Calibration Formulas

The calibration factor of a sensor will be defined as the ratio of the applied field strength to sensor output voltage:

$$CF_E = \frac{E}{V_{out}} \quad (V/m/V) \quad \text{for E-fields ;} \tag{6}$$

$$CF_H = \frac{H}{V_{out}} \quad (A/m/V) \quad \text{for H-fields ;} \tag{7}$$

where

CF_E = calibration factor for E-field sensors,
CF_H = calibration factor for H-field sensors,
E = electric field strength (V/m),
H = magnetic field strength (A/m),
V_{out} = sensor output voltage (V).

With the use of equations (3) and (5), equations (6) and (7) now become

$$CF_E = \frac{0.79 \, [V_g(f) \times G_{amp}(f)]}{b \times V_{out}} \quad (V/m/m) \, , \tag{8}$$

$$CF_H = \frac{0.79 \, [V_g(f) \times G_{amp}(f)]}{b \times V_{out} \times 120\pi} \quad (A/m/V) \, . \tag{9}$$

5.3 Sensor Calibration Using a Network Analyzer

Since the network analyzer measures the ratio of sensor output V_{out} by the generator output V_g (see fig. 1 and 2),

$$V_o = 20 \log \frac{V_{out}}{V_g} \quad (dB) \, , \tag{10}$$

where

V_o = network analyzer output reading,
V_{out} = output of sensor, and
V_g = output of generator (input to 50-dB amplifier).

Substituting equation (10) into equations (8) and (9), we obtain

$$CF_E = \frac{0.79 \, G_{amp}(f)}{b \times 10^k} \quad (V/m/V) \, , \tag{11}$$

$$CF_H = \frac{0.79 \, G_{amp}(f)}{b \times 10^k \times 120\pi} \quad (A/m/V) \, , \tag{12}$$

where $k = V_o/20$.

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Converting equations (11) and (12) into decibels, the free-field sensor calibration factors are

$$CF_E = 20 \log_{10} \frac{0.79}{b} + G_{amp}(f)\,(\text{dB}) - V_o(f)\,(\text{dB}) \; , \qquad (13)$$

$$CF_H = 20 \log_{10} \frac{0.79}{b} + G_{amp}(f) - V_o(f) - 51.53\,(\text{dB}) \; . \qquad (14)$$

Adjusting these equations for the effects of the 1-m^3 mapping box or metallic cylinder,

$$CF_E = 20 \log_{10} \frac{0.79}{b} + G_{amp}(f)\,(\text{dB}) - V_o(f)\,(\text{dB}) - E_e \; , \qquad (15)$$

$$CF_H = 20 \log_{10} \frac{0.79}{b} + G_{amp}(f)\,(\text{dB}) - V_o(f)\,(\text{dB}) - E_h \; , \qquad (16)$$

where E_e equals electric field enhancements of mapping box or cylinder and E_h equals magnetic field enhancements of mapping box and cylinder.

6. Sensor Calibration Procedures

The following procedures should be used during calibration to assure correct and accurate calibration factors.

(1) Place the sensor to be calibrated in the mounting ring at the bottom of the model CC102-1 TEM cell.

(2) If an H-field sensor is being calibrated, point the arrow on the sensor away from you (perpendicular to long axis of TEM cell). This configuration will measure the major H-field component.

(3) If an E-field sensor is being calibrated, connect the bias tee to the sensor and supply the bias tee with 12 Vdc.

(4) Set the network analyzer to the appropriate settings for the sensor used; see table 2 for these settings. Calibrate the network analyzer to manufacturer specifications (i.e., zero-dB reference, frequency response, etc).

(5) Attach the network analyzer to the TEM cell as shown in figure 1 for E-field sensors or figure 2 for H-field sensors.

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(6) Turn on the 50-dB power amplifier, record the sensor's response, and compare that with the corresponding response in appendix A.

(7) Read sensor output (V_o in decibels) and the gain of the amplifier used at 50 MHz and substitute these values into equations (13) and (14) as shown below:

$$CF_E = 20 \log_{10} \frac{0.79}{b} + G_{amp}(f) - V_o(f) \quad \text{(dB)}$$

$$CF_H = 20 \log_{10} \frac{0.79}{b} + G_{amp}(f) - V_o(f) - 51.53 \quad \text{(dB)} \ .$$

The operator must make sure that the sensor's response curve is generally flat and conforms with the examples shown in appendix A. If there are any large discrepancies in response, the sensor must be checked for proper operation or sent for repair.

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Appendix A. — Electric and Magnetic Sensor Dimensions, Components, and Responses

Contents

Figures

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A-1. Introduction

The Stanford Reseach Institute (SRI) sensors used in the Harry Diamond Laboratories (HDL) calibration procedure study are described in section 3 in the main body of this report. This appendix provides the dimensions, components, and response curves of the sensors when they are placed inside the transverse electromagnetic (TEM) cell.

A-2. Sensor Dimensions and Their Components

Figures A-1 through A-7 are center-cut side views of the SRI sensors. The E010 sensor is identical with E100 sensor series except that the separation between the upper plate and the ground plane is 1.125 in. HDL modified one of the E100 sensors by increasing the separation distances between the upper plate and the ground plane in order to increase the sensitivity of the sensor. The E502 sensor is identical to the E400 series sensor except that the upper plate was removed and the center conductor extended. This modification decreased sensitivity by 10 dB. Figure A-8 shows the diagram of the E-field sensor preamplifier and bias tee. Figures A-1 through A-8 are redrawn from SRI's report.[1]

A-3. Instrumentation Response

The calibration factor of a sensor is computed based on its response measurement. In order to compute calibration factors accurately, one must consider responses of all the instrumentation used during the measurement and incorporate these responses into the computation.

A-3.1 Power Amplifier

The power amplifier used in this effort was an ENI model 3100L 50-dB 100-W rf power amplifier. Its frequency of operation ranges from 250 kHz to 105 MHz and its maximum input is 1 V. Figure A-9 shows the response of this amplifier. The average amplification provided by this amplifier is approximately 49 dB. Figure A-10 shows the measurement setup for the responses shown in figure A-9.

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[1] B. C. Tupper, R. H. Stehle, R. H. Wolfram, and V. D. Cone, EMP Instrumentation Development Final Report, SRI Project 7990, Stanford Research Institute, Menlo Park, CA (June 1972).
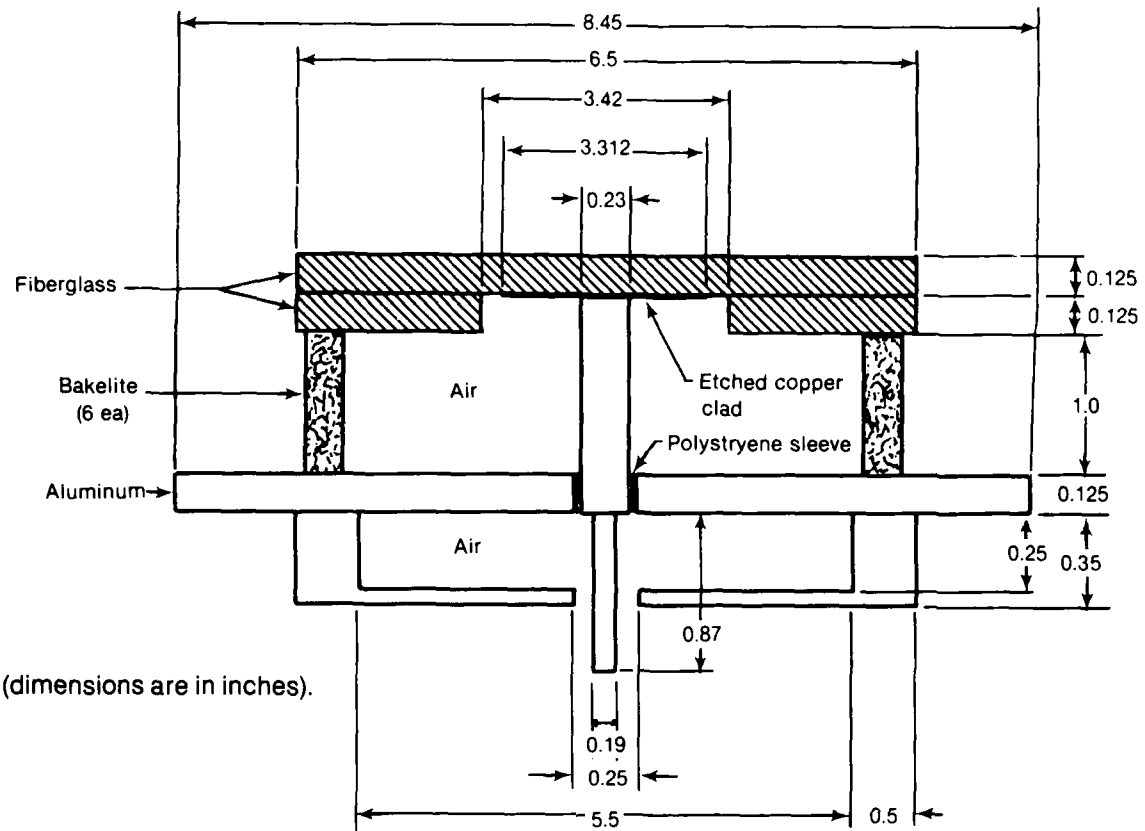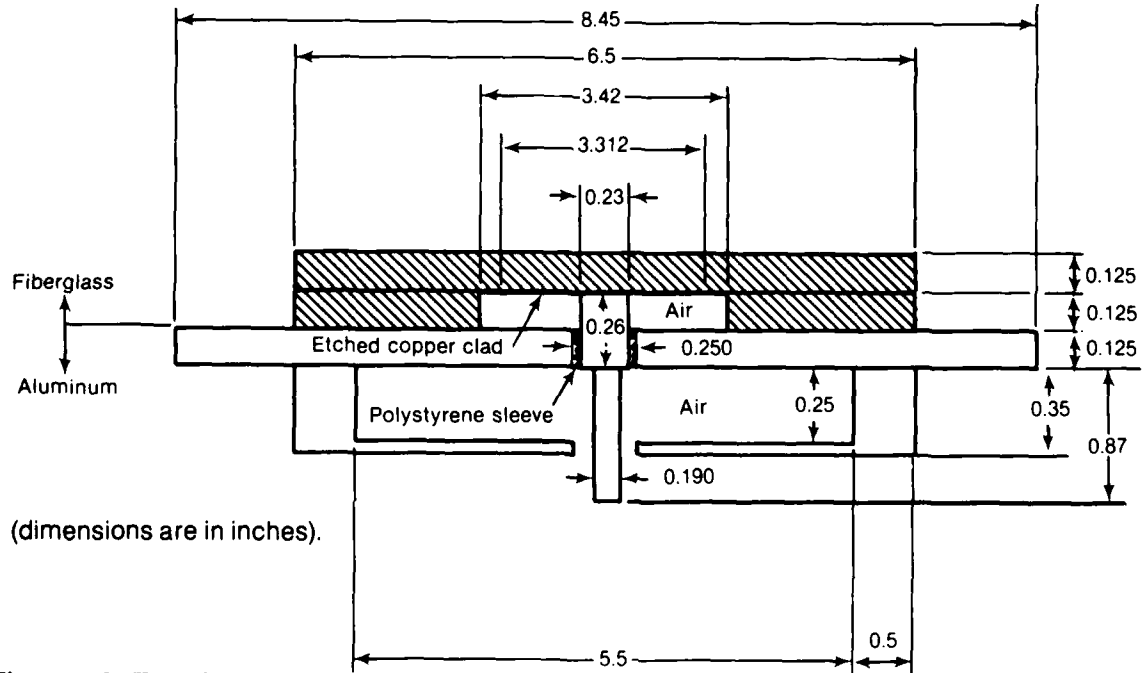
Figure A-1. Electric field sensor E010.

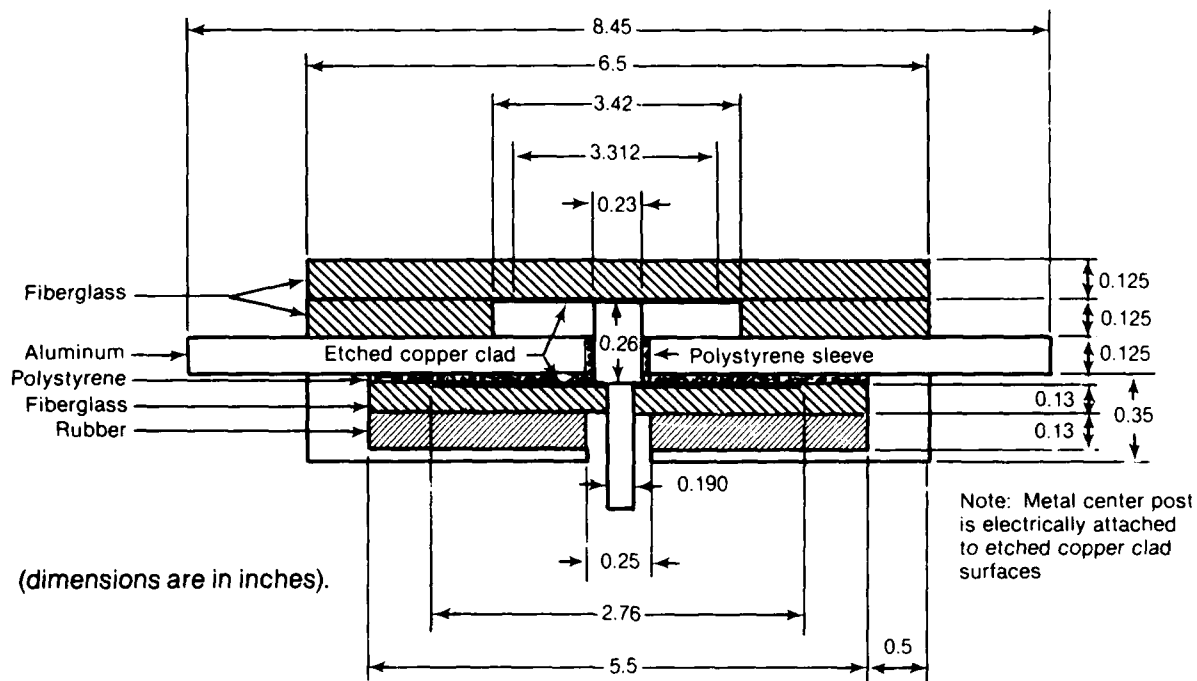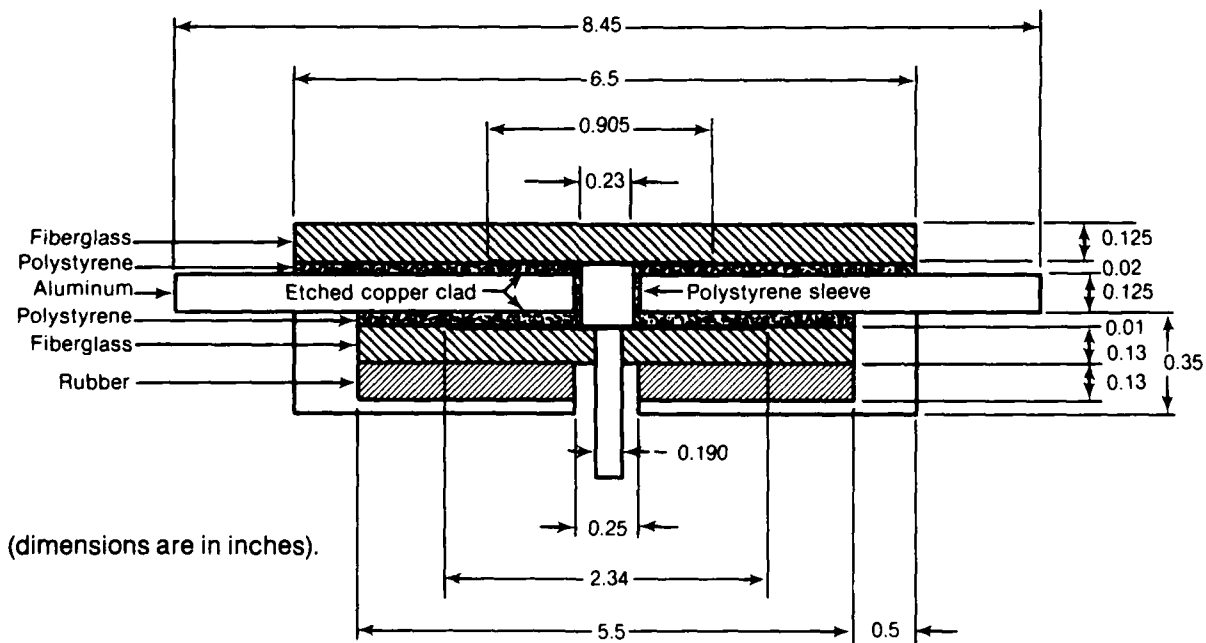**Figure A-2. Electric field sensor E100.**

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Figure A-3. Electric field sensor E200.

Figure A-4. Electric field sensor E300.

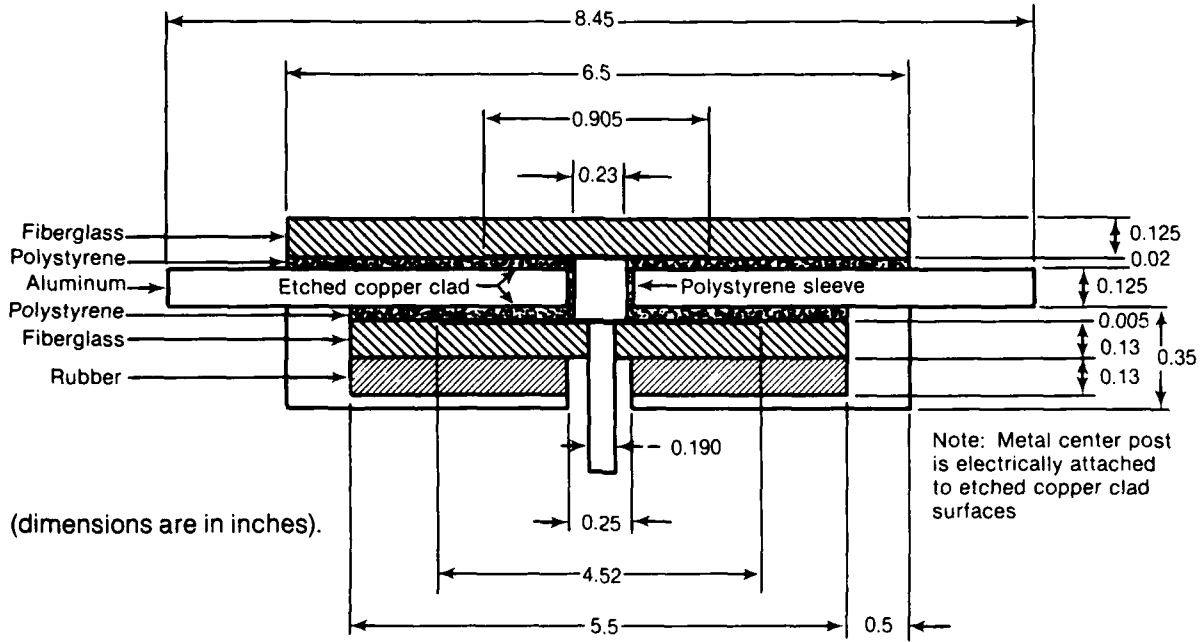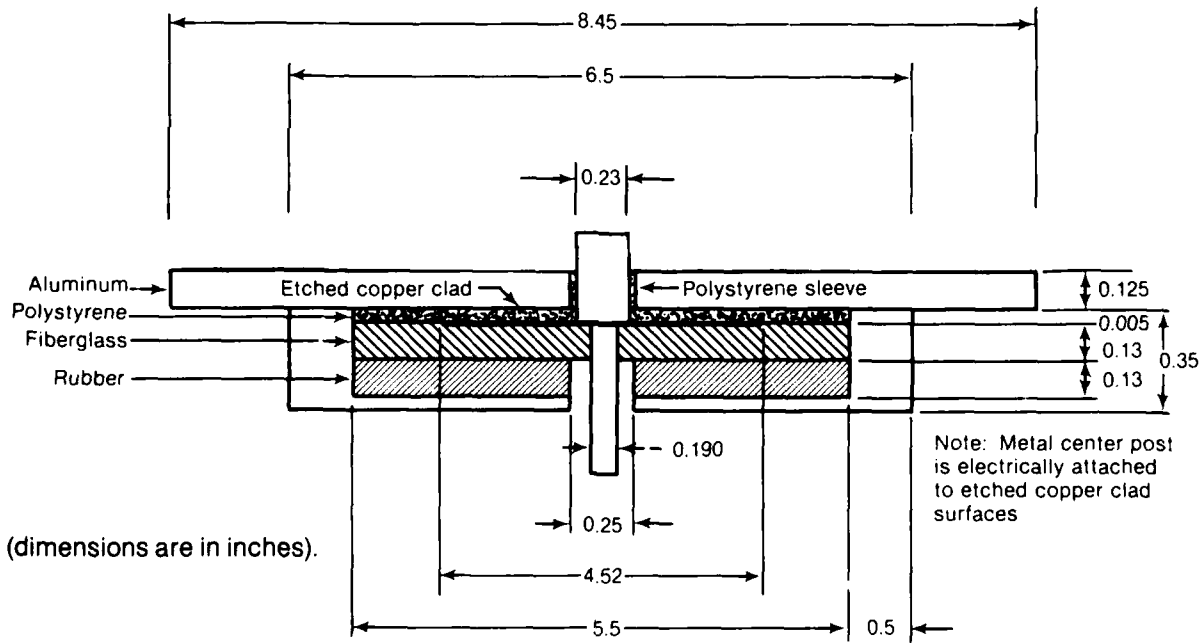23

Figure A-5. Electric field sensor E400.

Fiberglass
Polystyrene
Aluminum
Polystyrene
Fiberglass
Rubber

Etched copper clad
Polystyrene sleeve

8.45
6.5
0.905
0.23
0.125
0.02
0.125
0.005
0.13
0.13
0.35
0.190
0.25
4.52
5.5
0.5

Note: Metal center post is electrically attached to etched copper clad surfaces

(dimensions are in inches).

Figure A-6. Electric field sensor E502.

Aluminum
Polystyrene
Fiberglass
Rubber

Etched copper clad
Polystyrene sleeve

8.45
6.5
0.23
0.125
0.005
0.13
0.13
0.35
0.190
0.25
4.52
5.5
0.5

Note: Metal center post is electrically attached to etched copper clad surfaces

(dimensions are in inches).

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Figure A-7. Magnetic field sensor H100.

Figure A-8. E-field sensor preamplifier and bias tee.

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Figure A-9. ENI 50-dB rf power amplifier response: measured from (a) 300 kHz to 10 MHz and (b) from 10 to 100 MHz. (See fig. A-10 for measurement setup.
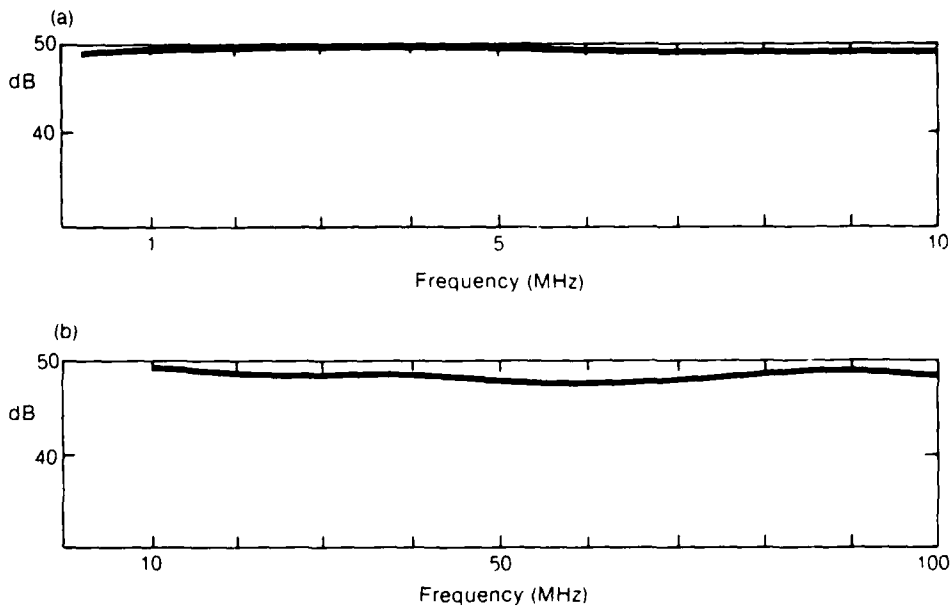
Figure A-10. Instrument setup to measure response of 50-dB rf power amplifier.
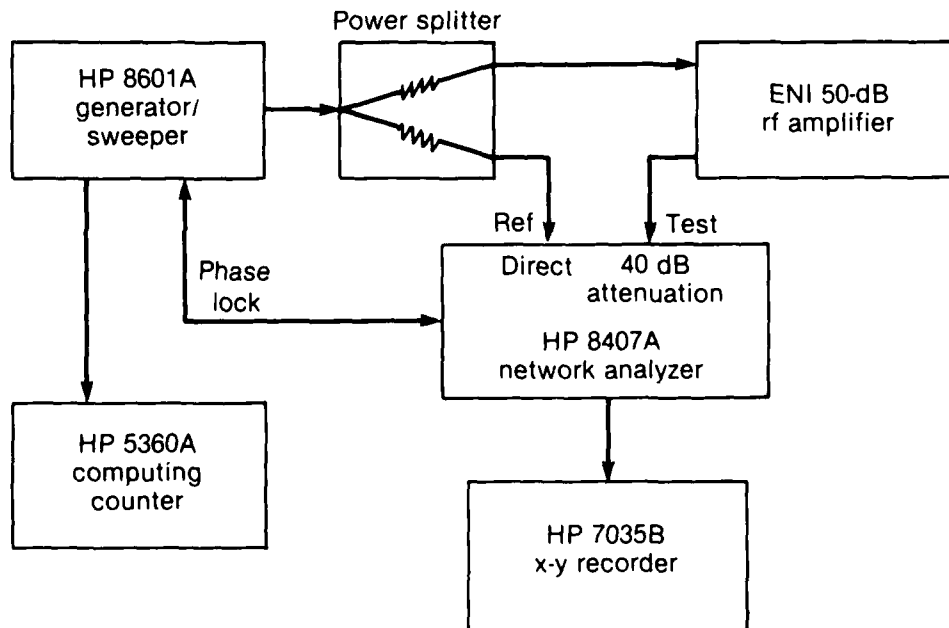

A-3.2 Network Analyzer

An HP 8407A network analyzer was used during this effort to record sensor response. The sensor is calibrated by the HDL calibration team every six months. In order to substantiate the sensor's proper operation, we used a Tektronix 485 oscilloscope to measure sensor response at six different frequencies. The results of these measurements were overlayed on the response curve of a sensor measured with the network analyzer. The operat-

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ing frequency of this equipment ranges from 110 kHz to 110 MHz. The HP 8601A generator/sweeper is calibrated along with the HP 8407A as part of a system.

A-3.3 Termination

The output port of the TEM cell is connected to a model 160B-600 50-Ω, 600-W coaxial termination manufactured by the Sierra Electronic Division of Philco. The reflection of this termination is shown in figure A-11.

Figure A-11. Philco Model 160B-600 600-W, 50-Ω termination reflection measured from (a) 300 kHz to 10 MHz and (b) 10 to 100 MHz.

(a)

Frequency (MHz)

(b)

Frequency (MHz)
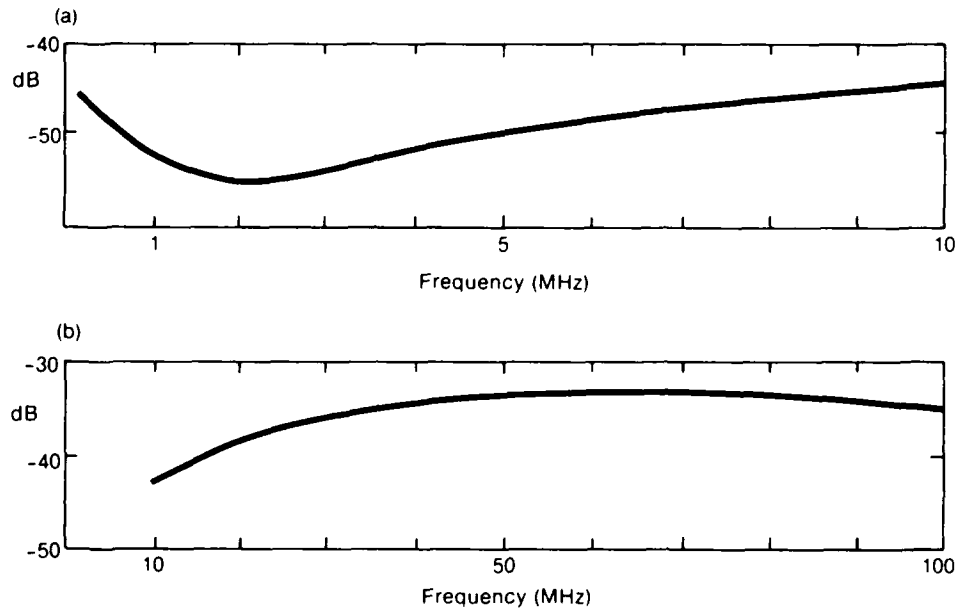
A-4. Sensor Response Curves

Sensor response curves are provided here for reference. The responses were measured for two sensors in each series, except E010 and E502. The typical measurement setup is shown in figures 1 and 2 (in the main body of the report). These response curves are shown in figures A-12 through A-23. A solid line indicates sensor response measured with the network analyzer.

The sensor responses measured with the Tektronix oscilloscope at six different frequencies are overlayed on the sensor responses measured with the network analyzer. The system setup for the Tektronix measurement is shown in figure A-24. As shown in figure A-24, an HP 462A small signal amplifier was used to increase the sensor output signal level. Figures A-25

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and A-26 show the responses of the HP 462A. These amplification factors must be subtracted from the measured output.

Figure A-12. E010 sensor response measured from (a) 300 kHz to 10 MHz and (b) 10 to 100 MHz. Data points indicate sensor response measured with TEK 485 oscilloscope. See figure 1 (in main body of report) for measurement setup and figure A-24b for measurement configuration.
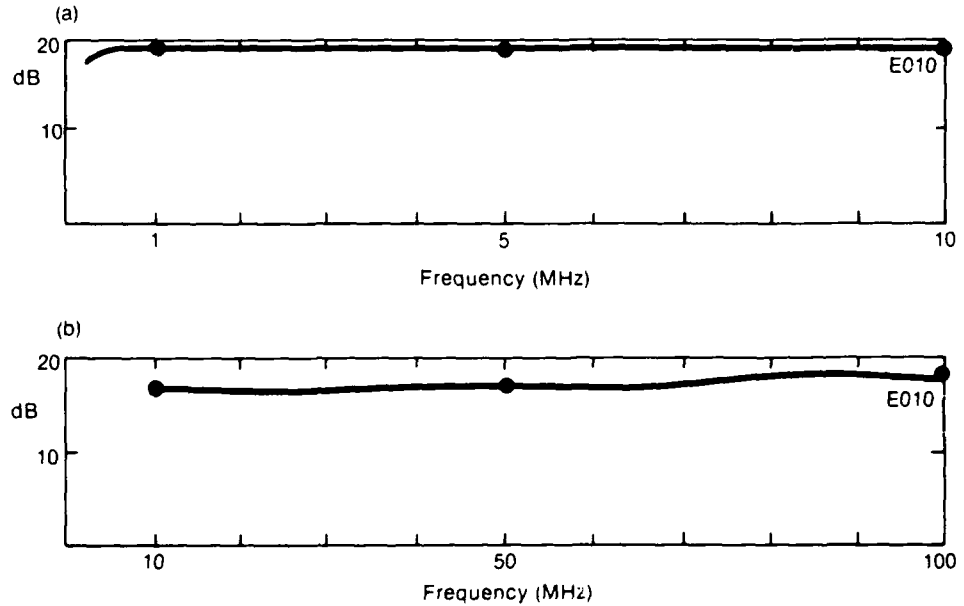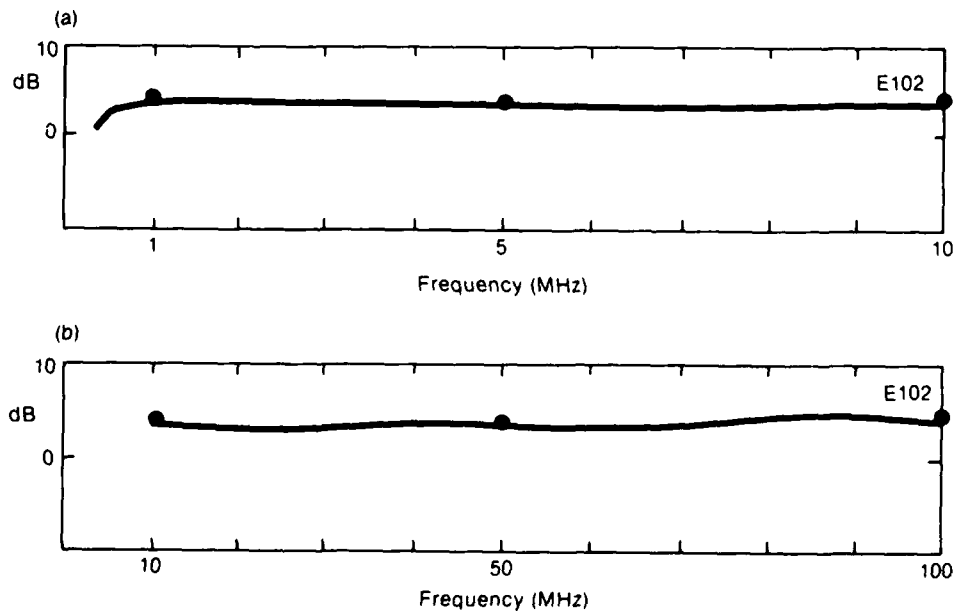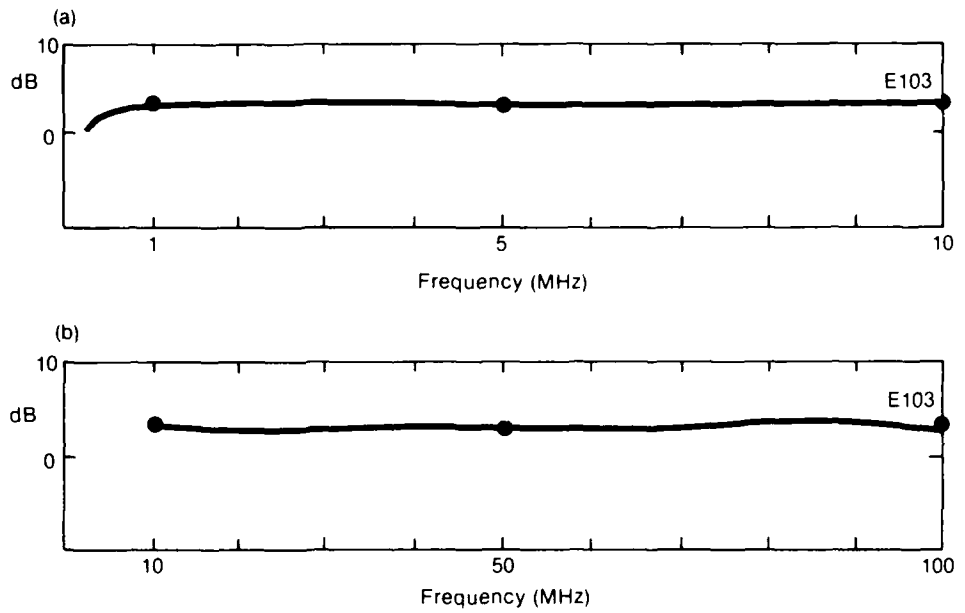

Figure A-13. E102 sensor response measured from (a) 300 kHz to 10 MHz and (b) 10 to 100 MHz. Data points indicate sensor response measured with TEK 485 oscilloscope. See figure 1 (in main body of report) for measurement setup and figure A-24b for measurement configuration.
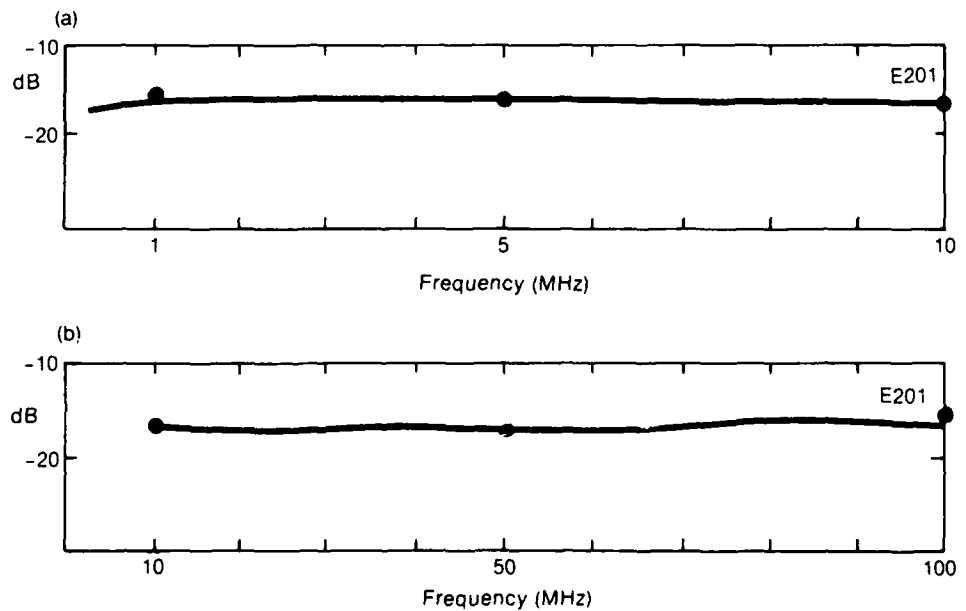

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Figure A-14. E103 sensor response measured from (a) 300 kHz to 10 MHz and (b) 10 to 100 MHz. Data points indicate sensor response measured with TEK 485 oscilloscope. See figure 1 (in main body of report) for measurement setup and figure A-24b for measurement configuration.

Figure A-15. E201 sensor response measured from (a) 300 kHz to 10 MHz and (b) 10 to 100 MHz. Data points indicate sensor response measured with TEK 485 oscilloscope. See figure 1 (in main body of report) for measurement setup and figure A-24b for measurement configuration.
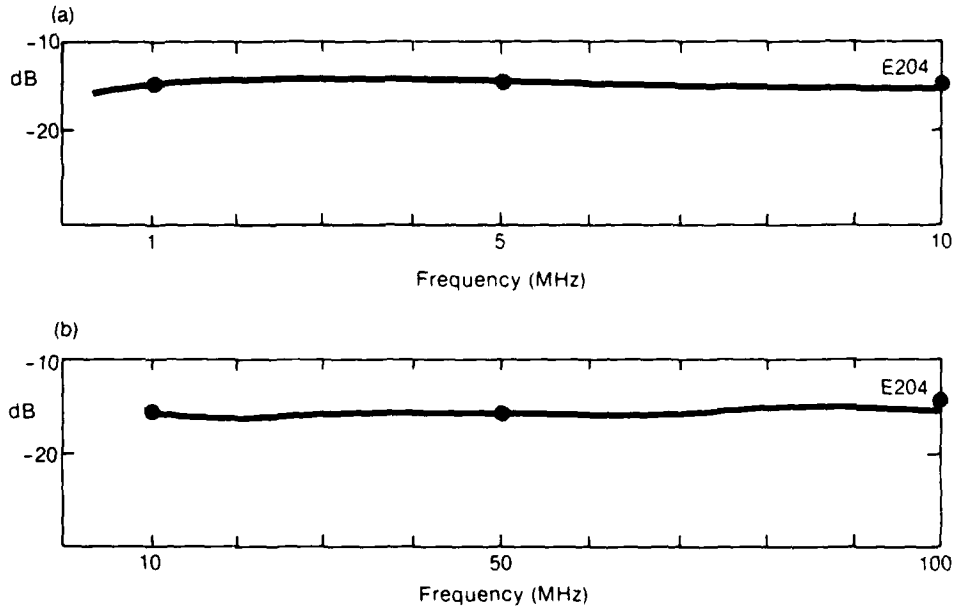

30

Figure A-16. E204 sensor response measured from (a) 300 kHz to 10 MHz and (b) 10 to 100 MHz. Data points indicate sensor response measured with TEK 485 oscilloscope. See figure 1 (in main body of report) for measurement setup and figure A-24b for measurement configuration.
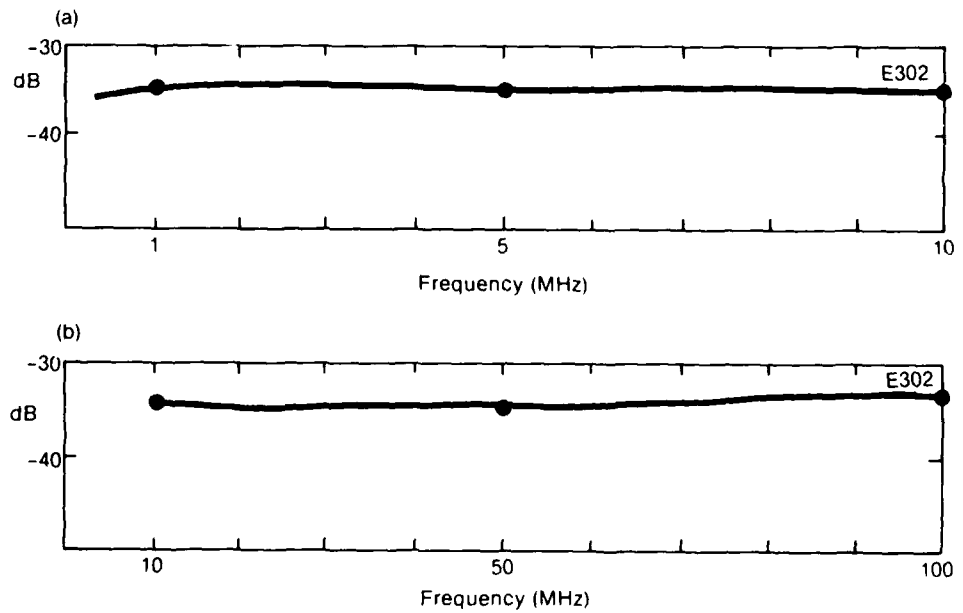

Figure A-17. E302 sensor response measured from (a) 300 kHz to 10 MHz and (b) 10 to 100 MHz. Data points indicate sensor response measured with TEK 485 oscilloscope. See figure 1 (in main body of report) for measurement setup and figure A-24b for measurement configuration.

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Figure A-18. E303 sensor response measured from (a) 300 kHz to 10 MHz and (b) 10 to 100 MHz. Data points indicate sensor response measured with TEK 485 oscilloscope. See figure 1 (in main body of report) for measurement setup and figure A-24b for measurement configuration.
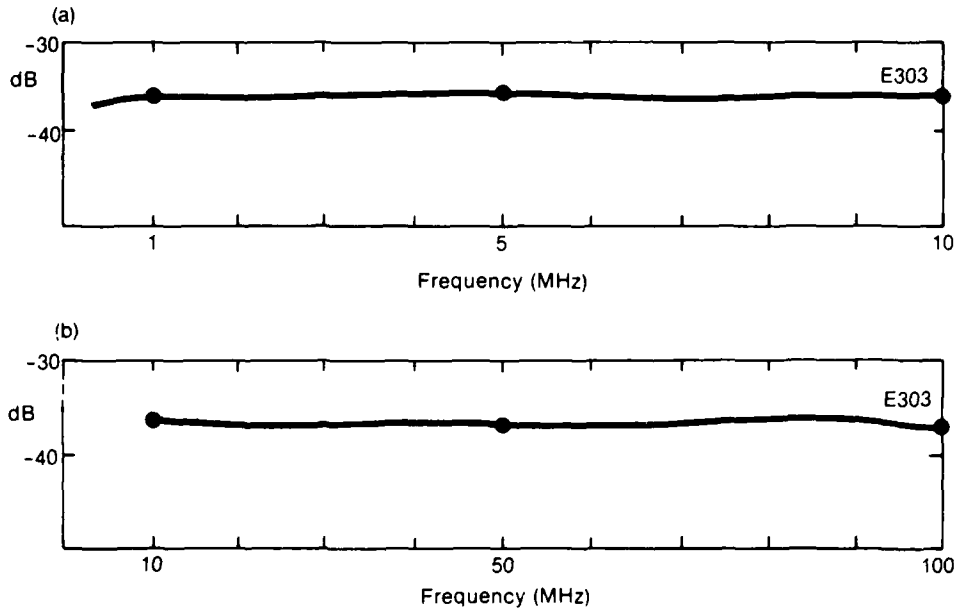

(a)

E303

dB

-30

-40

1   5   10

Frequency (MHz)

(b)

E303

dB

-30

-40

10   50   100

Frequency (MHz)

Figure A-19. E403 sensor response measured from (a) 300 kHz to 10 MHz and (b) 10 to 100 MHz. Data points indicate sensor response measured with TEK 485 oscilloscope. See figure 1 (in main body of report) for measurement setup and figure A-24b for measurement configuration.
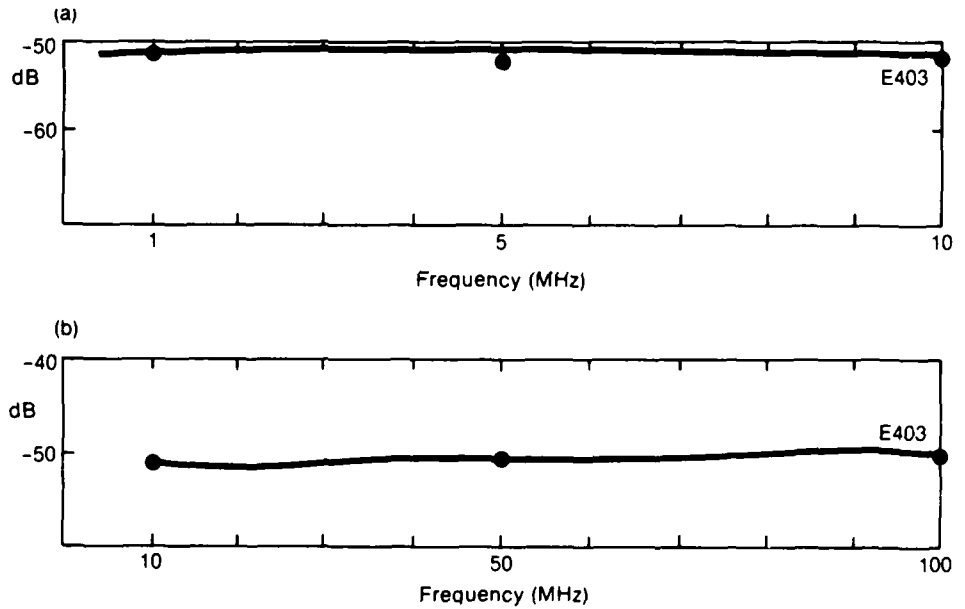

(a)

E403

dB

-50

-60

1   5   10

Frequency (MHz)

(b)

E403

dB

-40

-50

10   50   100

Frequency (MHz)

32

Figure A-20. E404 sensor response measured from (a) 300 kHz to 10 MHz and (b) 10 to 100 MHz. Data points indicate sensor response measured with TEK 485 oscilloscope. See figure 1 (in main body of report) for measurement setup and figure A-24b for measurement configuration.
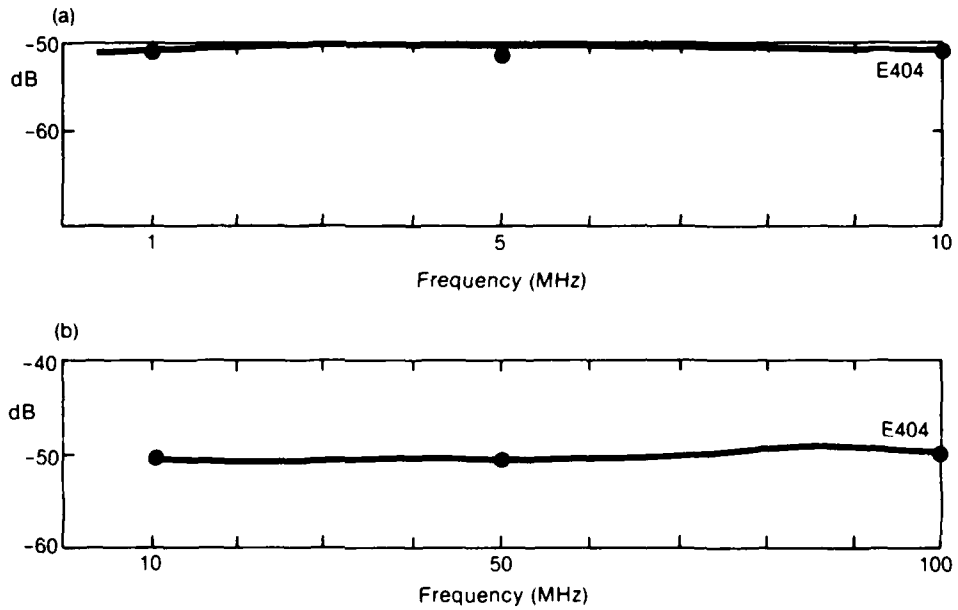

Figure A-21. E502 sensor response measured from (a) 300 kHz to 10 MHz and (b) 10 to 100 MHz. See figure 1 (in main body of report) for measurement setup and figure A-24b for measurement configuration.
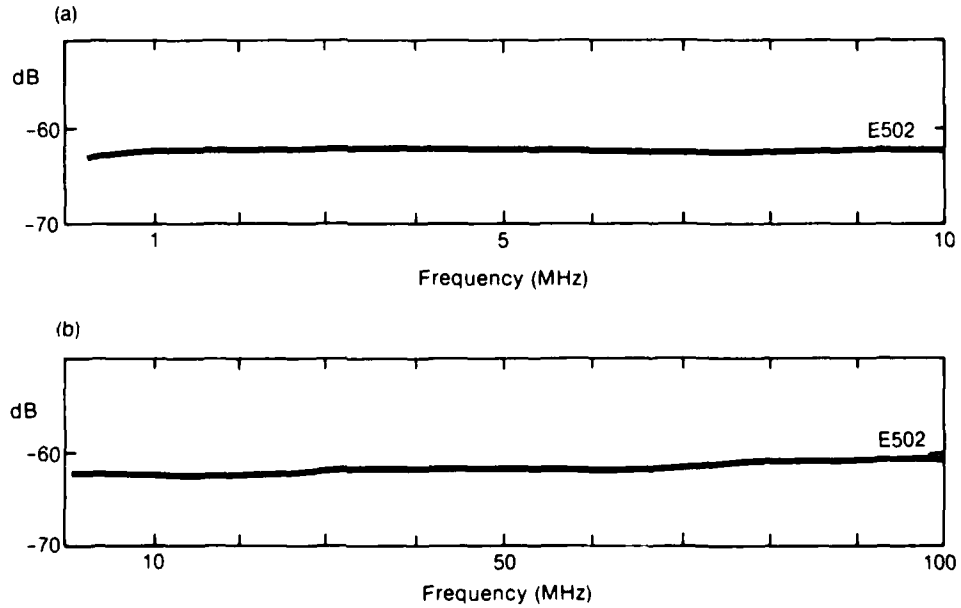

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Figure A-22. H106 sensor response measured from (a) 300 kHz to 10 MHz and (b) 10 to 100 MHz. Data points indicate sensor response measured with TEK 485 oscilloscope. See figure 2 (in main body of report) for measurement setup and figure A-24a for measurement configuration.
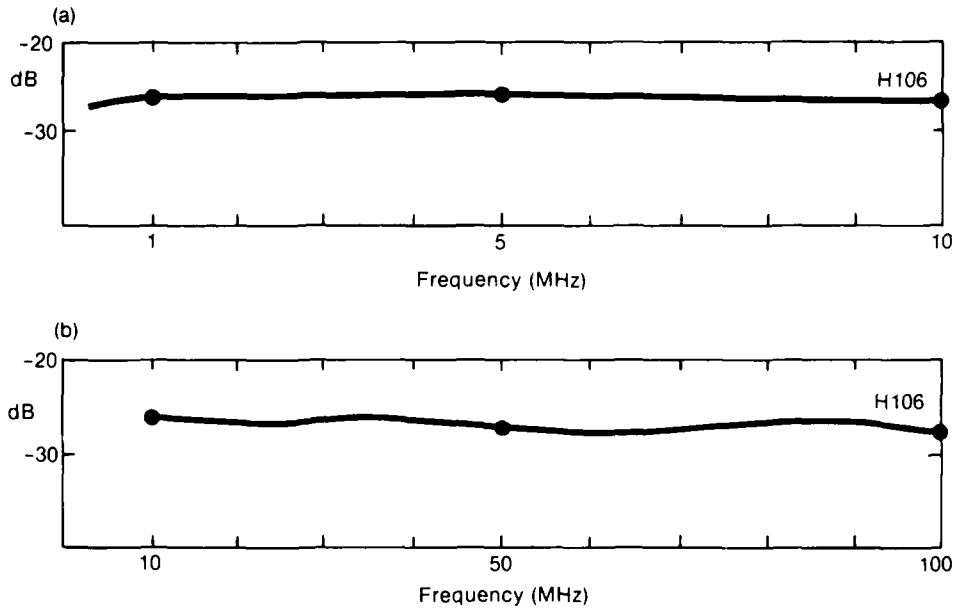
(a)

H106

Frequency (MHz)

(b)

H106

Frequency (MHz)

Figure A-23. H108 sensor response measured from (a) 300 kHz to 10 MHz and (b) 10 to 100 MHz. Data points indicate sensor response measured with TEK 485 oscilloscope. See figure 2 (in main body of report) for measurement setup and figure A-24a for measurement configuration.
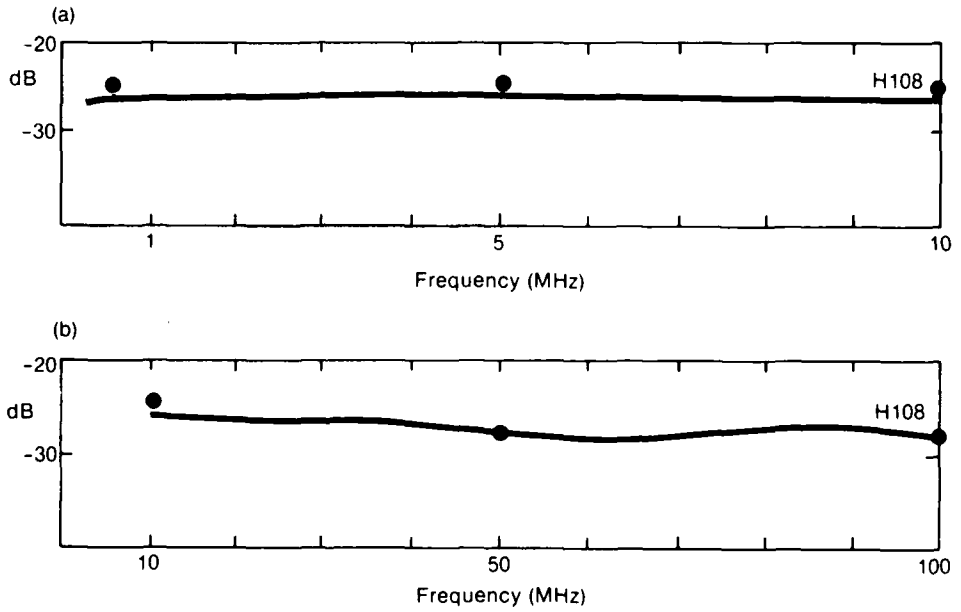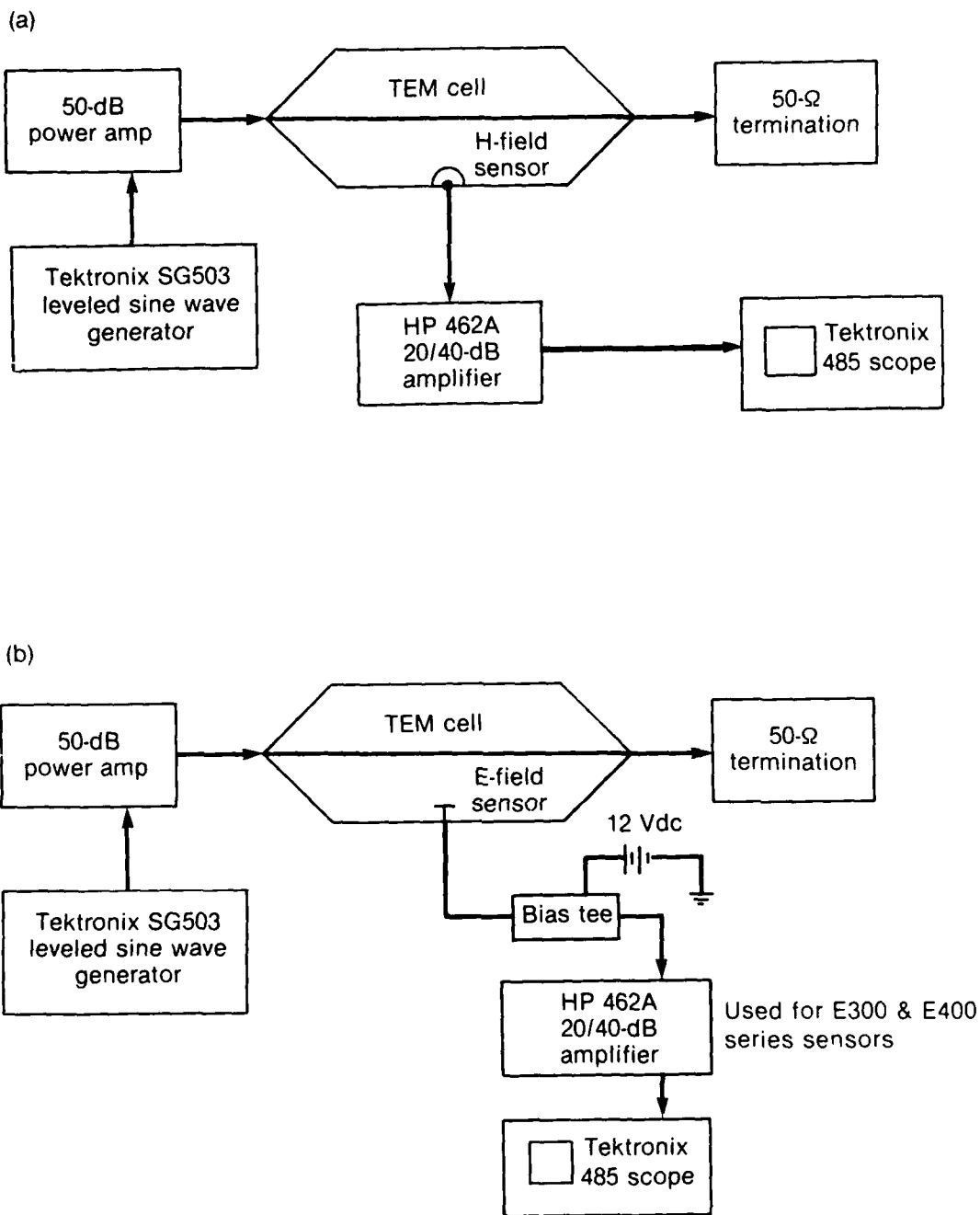
(a)

H108

Frequency (MHz)

(b)

H108

Frequency (MHz)

34

(a)

(b)

Figure A-24. Measurement setup for response of (a) H-field and (b) E-field sensors measured with Tektronix 485 oscilloscope.

Figure A-25. HP462A amplifier response with 20-dB gain setting measured from (a) 300 kHz to 10 MHz and (b) 10 to 100 MHz. See *figure A-24* for measurement setup.

(a)
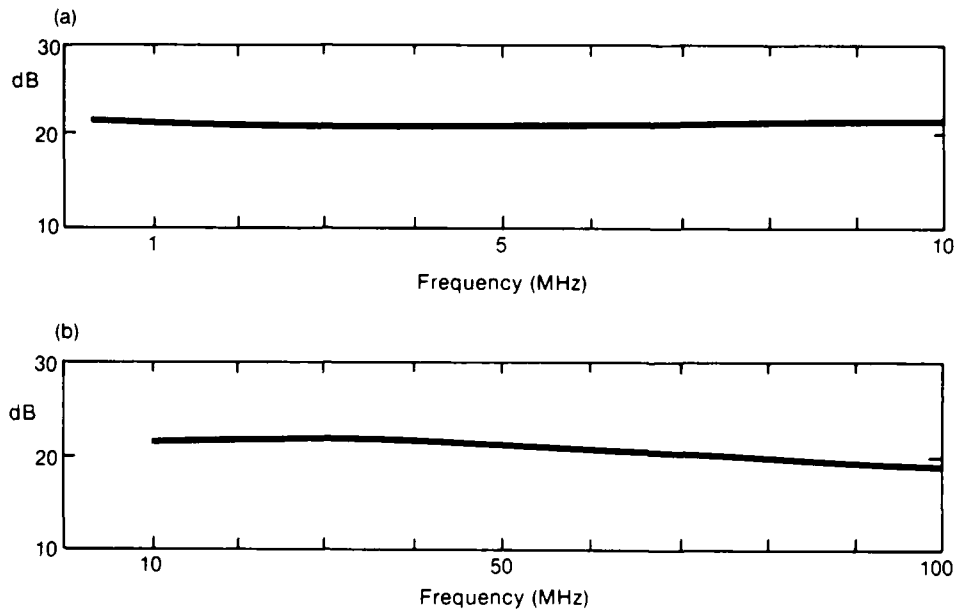

Frequency (MHz)
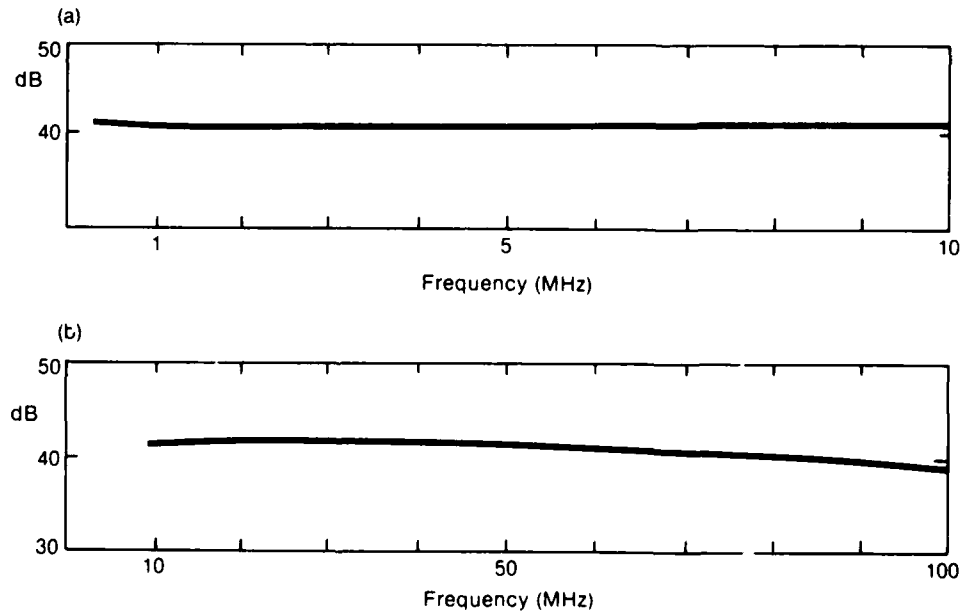
(b)

Frequency (MHz)

Figure A-26. HP462A amplifier response with 40-dB gain setting measured from (a) 300 kHz to 10 MHz and (b) 10 to 100 MHz. See figure A-24 for measurement setup.

(a)

Frequency (MHz)

(b)

Frequency (MHz)

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