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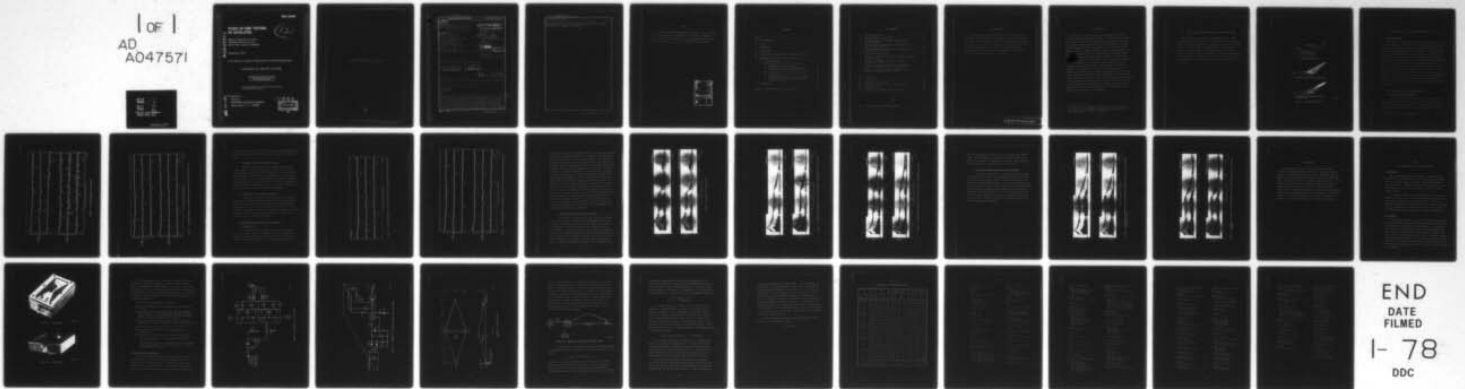
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STUDY OF EMP TESTING OF SATELLITES

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Stanford Research Institute
333 Ravenswood Avenue
Menlo Park, California 94025

September 1975

Final Report for Period 16 September 1974—15 August 1975

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20. ABSTRACT (Continued)

✓ ARES can be tolerated. A potentially inexpensive and effective scattering structure made by stringing wires in the terminating half of the ARES was designed and is recommended for the ARES.



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PREFACE

The authors gratefully acknowledge the assistance of Mr. Jon Farber of DNA, who was the Project Officer for this contract. Measurements were performed by Mr. G. Wagner, and the design and construction of the E-field probe by Mr. G. R. Hilbers of Stanford Research Institute.

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I INTRODUCTION

This report describes the work performed on a 1/30 scale model of the ARES to obtain information for dispersed EMP testing of satellites in the ARES facility at Kirtland Air Force Base, Albuquerque, New Mexico. The objective of the work was to propagate a dispersed EMP in the ARES that would satisfactorily test satellites. The appendix contains descriptions of H and E field sensors constructed for DNA that will be used for field measurements in the actual ARES.

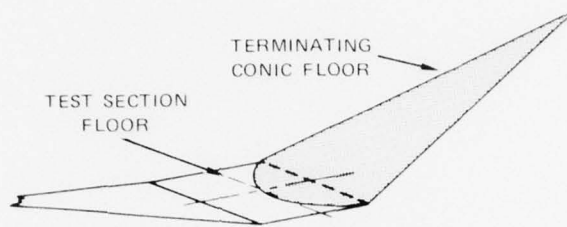
II PREVIOUS WORK

Final Report 1¹ on work performed through August 1974 describes the non-uniform field existing in the ARES. At frequencies below 25 MHz, the 75 cables that simulate the upper plate of the parallel transmission line resonate strongly since the lines are shorted together at both the input and terminating ends. The resonances may be eliminated by cross-wiring the cables to minimize coupling of signals causing resonance, or by terminating the cables in series resistances that would form matched terminations. In fields produced within the ARES model, cross-wiring simulated by 1-inch by 1-inch mesh (2.5 ft by 2.5 ft full scale) top plate eliminates resonances, but at frequencies above approximately 25 MHz, the field shows non-uniformity in an irregular manner as a function of frequency. The non-uniformity of fields at high frequency may be explained by considering that the signal is propagated as rays, since the vertical dimensions of the ARES are many wavelengths of the signal wavelength. Reflection of the rays from the terminating cone creates constructive and destructive interference locations within the ARES. Efforts to scatter the high-frequency signal with triangular cross-sectional scattering of the structure on the bottom plate of the terminating section and with the mesh top plate were ineffective.

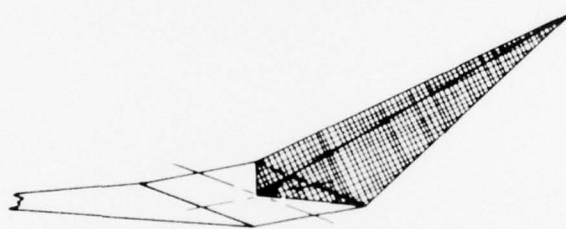
¹S. Dairiki and W. E. Scharfman, "Study of EMP Testing of Satellites," Final Report 1, Contract DNA001-74-C-0105, SRI Project 3077, SRI, Menlo Park, California 94025 (July 1975).

III RECENT WORK ON SCATTERING STRUCTURE WITH MESH TOP PLATE

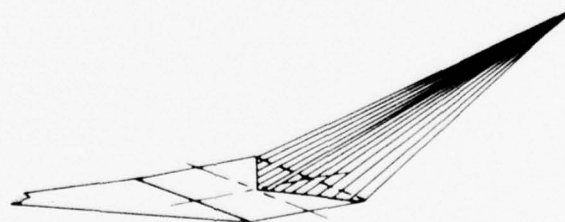
Since the triangular cross-section scattering structures on the terminating section were ineffective, a round conical shaped scattering structure made of aluminum sheet was constructed, with the base extending halfway into the test section of the ARES model, as illustrated in Figure 1a. Field measurements of the ARES model with the 1-inch by 1-inch mesh top plate showed no improvement in the field non-uniformities at high frequencies. Evidently, a mesh or solid top plate traps most of the high-frequency reflected signals within the ARES, even with the use of a scatterer.



(a) ROUND SOLID SCATTERER



(b) TRIANGULAR CROSS-SECTION MESH SCATTERER



(c) TRIANGULAR CROSS-SECTION WIRE SCATTERER
(recommended design)

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FIGURE 1 SCATTERING STRUCTURES

IV MEASUREMENTS IN THE ARES MODEL WITH WIRE TOP PLATE

A. Field Measurements

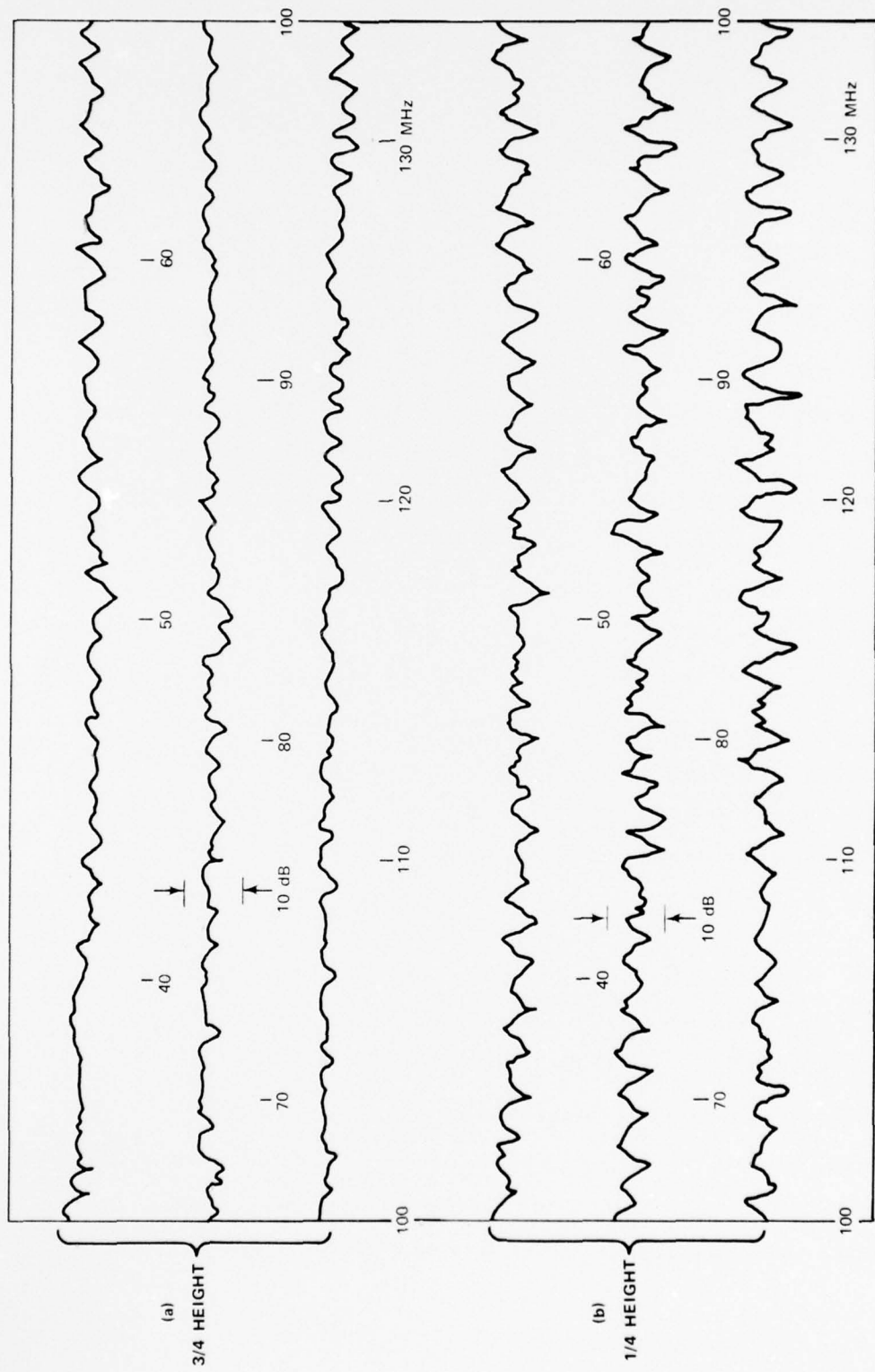
High-frequency field measurements were made within the model of the original configuration of the ARES with the 75-wire top plate at several distances from the input terminals of the model and at several heights to obtain vertical profiles of the field variations. Field measurements, compensated for sensor and cable response, are shown in Figure 2, for three-quarters and one-quarter of the height between the bottom and top plates, and at a distance equivalent to 67 meters from the input terminals of the ARES. This location is in the input conic section where the satellite will be positioned. Rapid and largest variations of ± 6 dB in field amplitude as a function of frequency occur at one-quarter of the height between the plates rather than near the wires of the top plate where the large variations are caused by resonances for lower frequencies. Similar measurements² made on the actual ARES at a slightly different height show 10 dB peak-to-peak variations and are consistent with model measurements.

B. Field Measurements with Scattering Structures

1. Round Conic Scattering Structure

The round conic scattering structure shown in Figure 1a that was ineffective with the mesh top plate is effective with a wire top plate, as illustrated in Figure 3. The variations above 30 MHz have been smoothed and the worst result, which occurs for the one-quarter height,

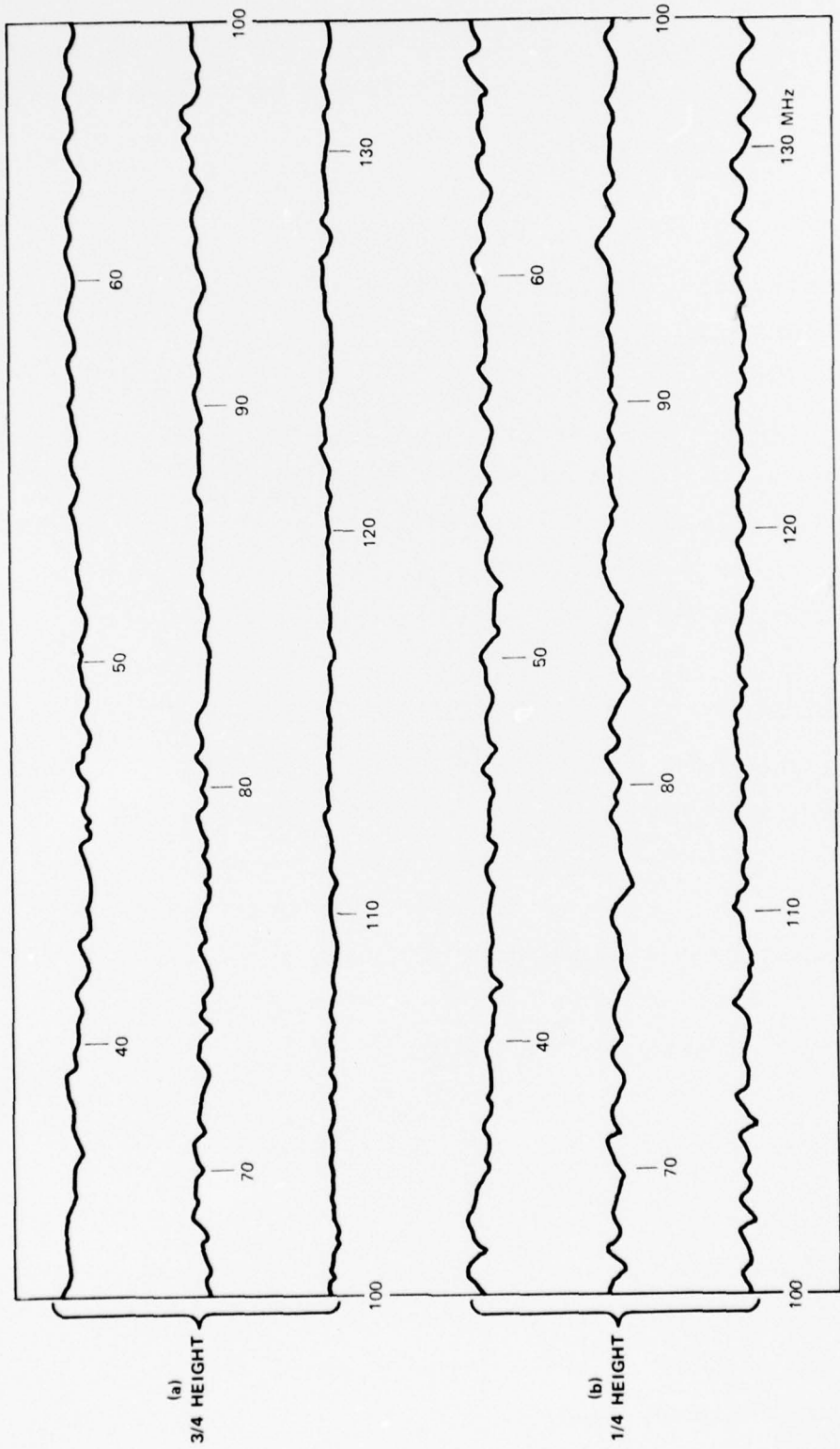
²R. Hutchins, BDM, private communication.



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FULL SCALE EQUIVALENT FREQUENCY

FIGURE 2 FIELD MEASUREMENTS IN ARES MODEL



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FULL SCALE EQUIVALENT FREQUENCY

FIGURE 3 FIELD MEASUREMENTS IN ARES MODEL WITH ROUND CONIC SCATTERING STRUCTURE

shows a total variation of ± 3 dB over the entire measured frequency range, but shows less than half the total variation over any limited frequency range.

2. Triangular Mesh Conic Scattering Structure

Because of the effectiveness of the curved conic section, a simpler triangular conic section made from one-quarter inch hardware cloth, illustrated in Figure 1b, was investigated as a scattering structure. The vertex of the triangular cone extended to the center of the test floor area. Results of the measurement of the field at one-quarter height, presented in Figure 4, are similar to those for the curved conic section. Grounding or ungrounding the edges of the conic section to the test floor area did not make any perceptible difference.

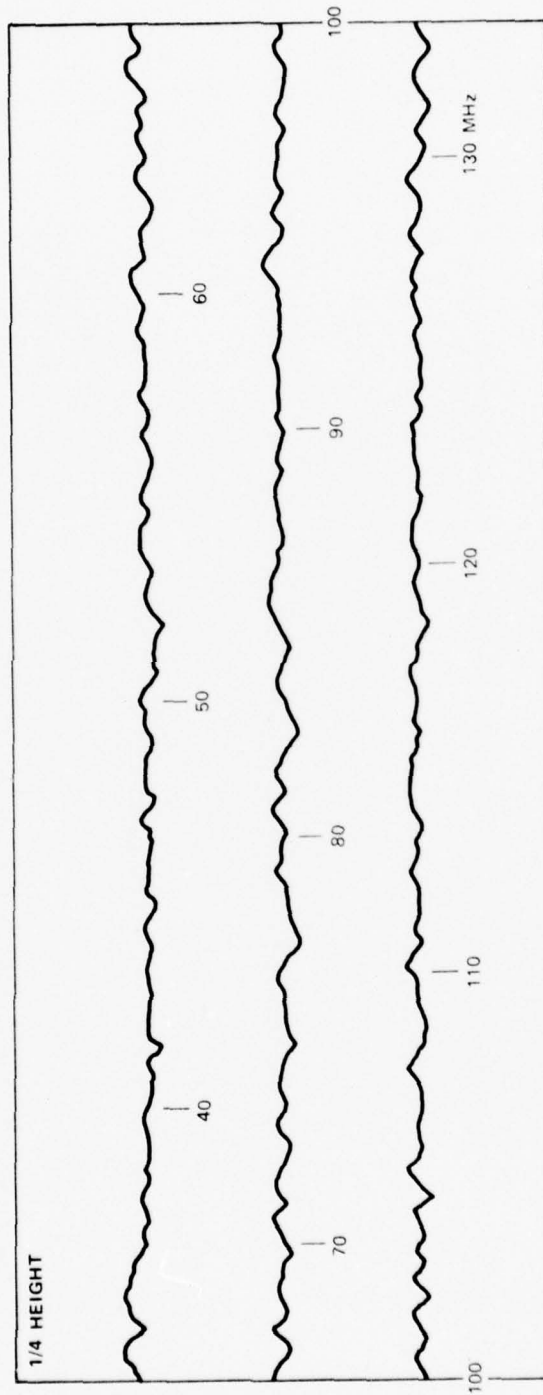
3. Triangular Wire Conic Scattering Structure

A potentially inexpensive scattering surface for the ARES was simulated by a triangular conic section with 115 wires, as illustrated in Figure 1c. Measurements at one-quarter and three-quarter heights, presented in Figure 5, show that the results are similar to those for the curved and triangular shaped conic sections. For purposes of testing satellites, the modification to the ARES model should include this scattering surface constructed with wires.

C. Current Measurements on Satellite-Like Structures

1. Cylindrical Rod

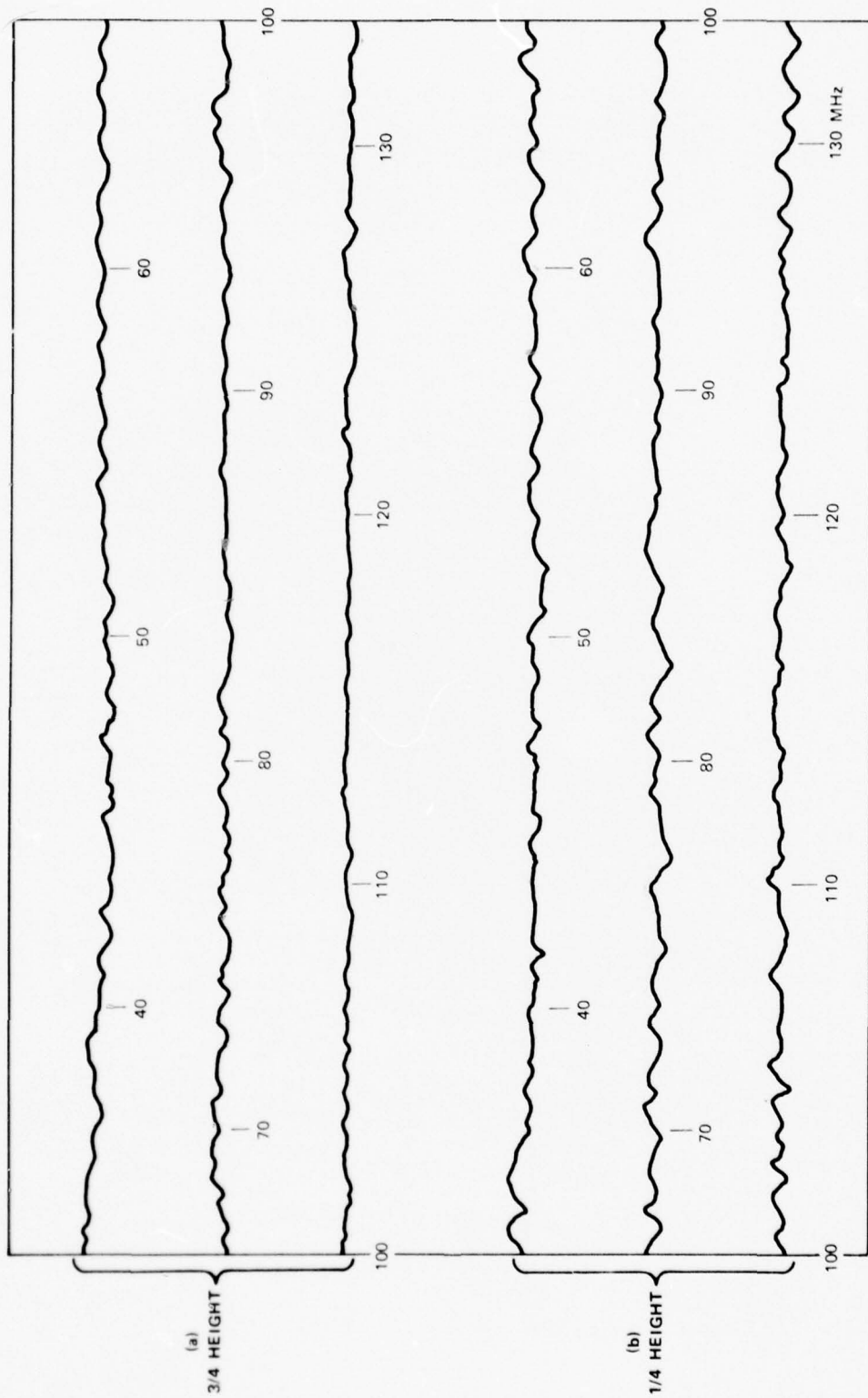
A cylindrical brass rod, equivalent to a full-scale diameter of 13.7 m by 0.05 m, which is the length of the fleet communications satellite, was centered and placed vertically in the 75-wire top plate ARES model at a distance equivalent to 67 m from the input terminal. A



FULL SCALE EQUIVALENT FREQUENCY

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FIGURE 4 FIELD MEASUREMENTS IN ARES MODEL WITH TRIANGULAR MESH CONIC SCATTERING STRUCTURE



FULL SCALE EQUIVALENT FREQUENCY

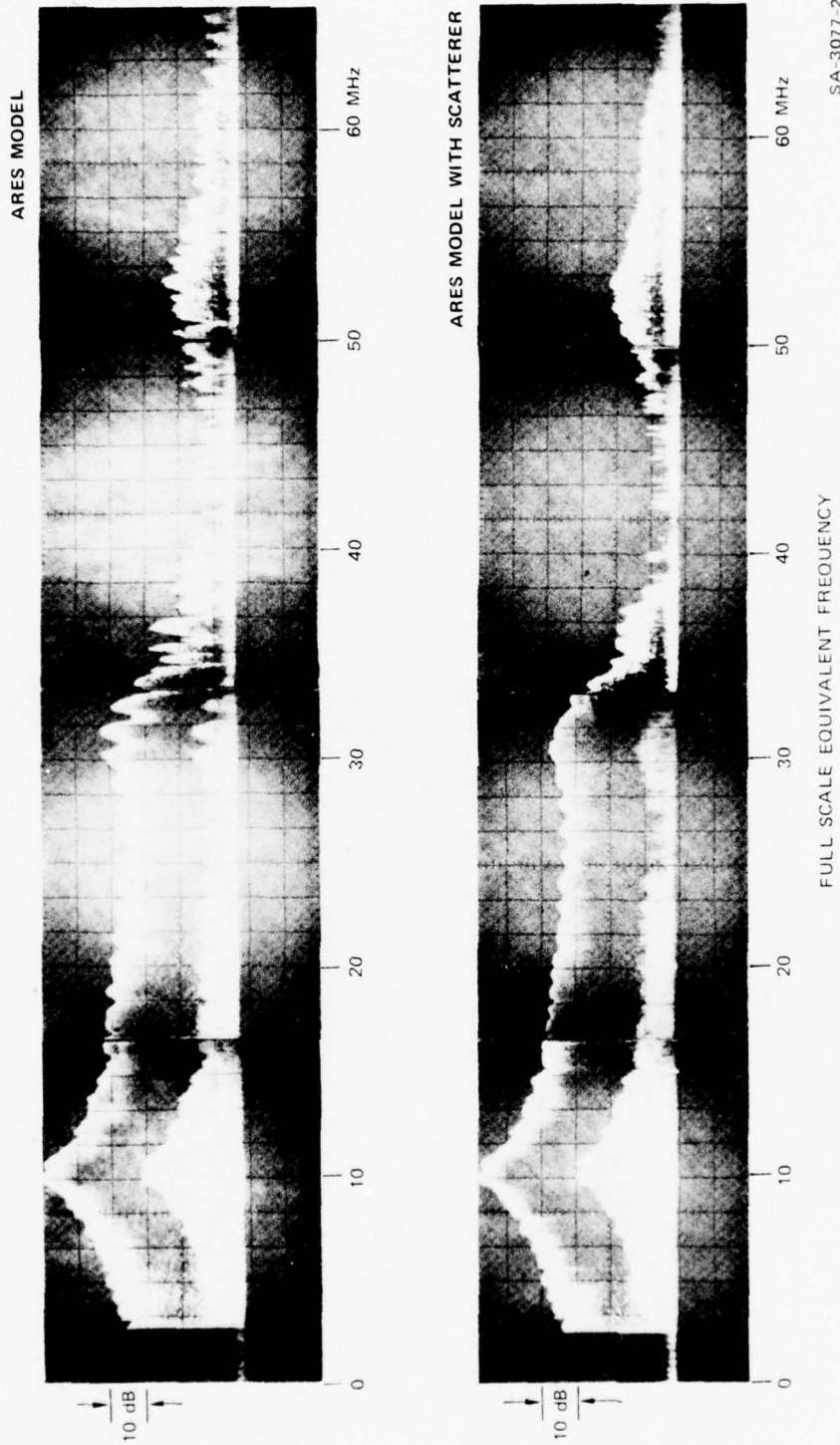
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FIGURE 5 FIELD MEASUREMENTS IN ARES MODEL WITH TRIANGULAR WIRE CONIC SCATTERING STRUCTURE

current probe was placed in the middle of the rod. The current amplitudes measured as a function of frequency in the ARES model, with and without the scattering structure, are presented in Figure 6. The current amplitudes are not corrected for probe and cable variations as a function of frequency, and hence they decrease rapidly above the equivalent frequency of 30 MHz. Below an equivalent frequency of about 30 MHz, the current amplitudes as a function of frequency are nearly identical. The peak-to-peak current variation is less than 2 dB down to the satellite EMP lowest significant frequency of 13 MHz. Evidently above 30 MHz, interference effects from ray path reflections cause peaks and nulls in the current induced in the rod when the ARES does not have the scattering structure. The smooth current variation results indicate that reflections are effectively scattered out of the ARES model with the wire top plate by the scattering structure. Measurements with a simulated wooden platform on which the satellite was placed, and measurements with the rod lowered by a quarter of the height between the upper and lower plates of the ARES gave practically identical current variations, indicating that the wooden platform and small vertical displacements are insignificant factors in the measurements.

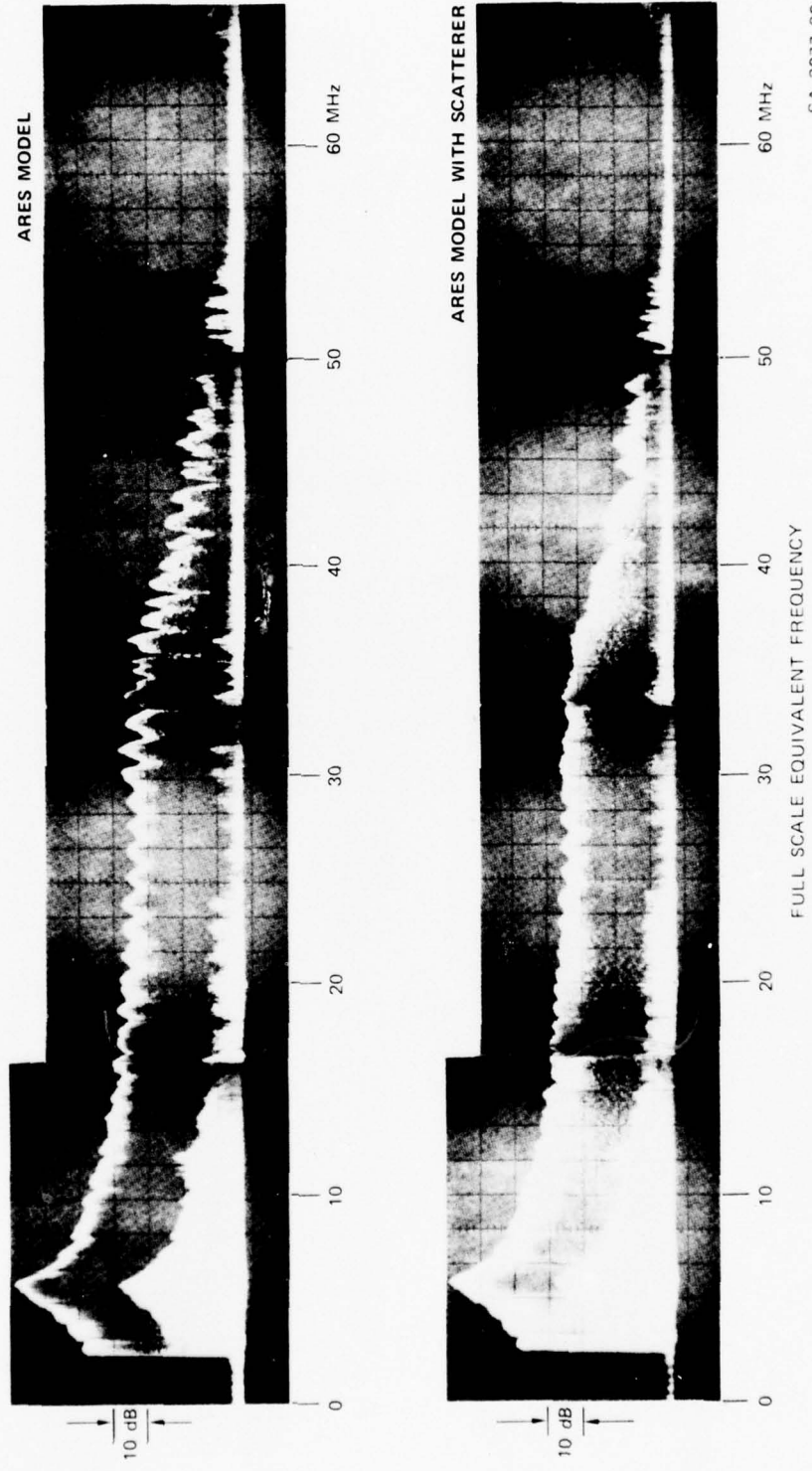
2. Cylindrical Rod with Simulated Solar Panels

Solar panels, simulated by brass sheets equivalent in dimensions to the solar panels of the fleet communications satellite, were attached to both ends of the 13.7-m by 0.05-m diameter rod. Currents were measured at the center of the vertically positioned rod first with the faces of the panels toward the input terminal and transverse to the length of the ARES and then with the edges of the panels facing the input terminals and longitudinal to the ARES. Figures 7 and 8 show the current amplitudes with and without the scattering structure in the ARES as a function of frequency. The panels electrically load the rod



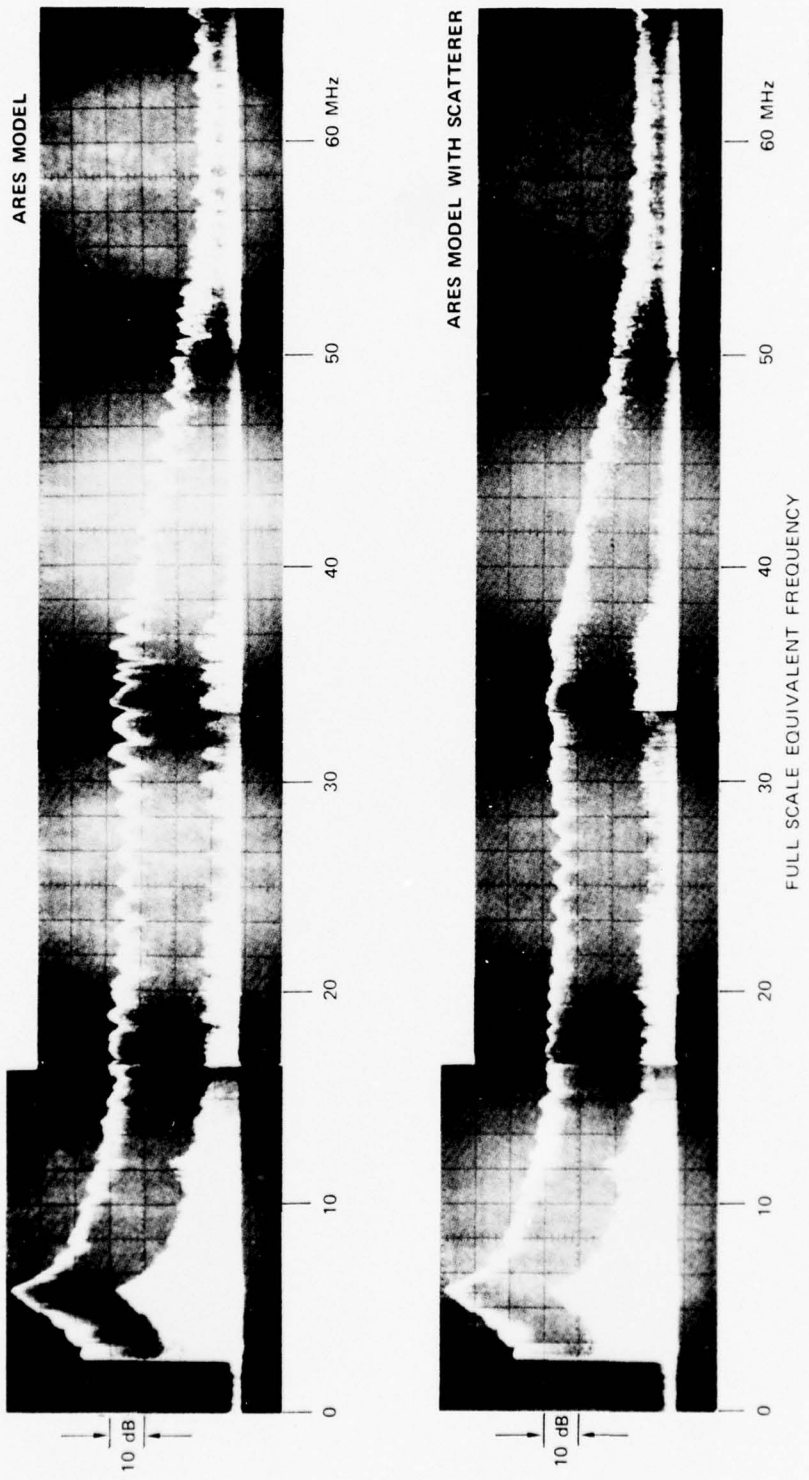
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FIGURE 6 CURRENTS ON CYLINDRICAL ROD



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FIGURE 7 CURRENTS ON CYLINDRICAL ROD WITH SOLAR PANELS TRANSVERSE TO LENGTH OF ARES



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FIGURE 8 CURRENTS ON CYLINDRICAL ROD WITH SOLAR PANELS LONGITUDINAL TO ARES

and cause the fundamental resonance of the rod to shift from 10 MHz to 7 MHz. Current variations in the figures show that the scattering surfaces are necessary for frequencies above 30 MHz. Below 30 MHz the current variations are within ± 1.5 dB, and are tolerable.

3. Cylindrical Rod with Panels and Spacecraft Module

A brass box in the shape of a spacecraft module, with a parabolic reflector to model the fleet communications satellite, was added to the rod with solar panels. Instead of being attached to the spacecraft module, the rod passed through it so as to keep the current probe at the same place on the rod. Figure 9 and 10 show the measurements made with the panels both transverse and longitudinal to the ARES and with and without the scattering surface. The effect of the module was to reduce the current variations as a function of frequency in the 30-MHz to 50-MHz range. However, the reduction is insufficient and the scattering structure would be required.

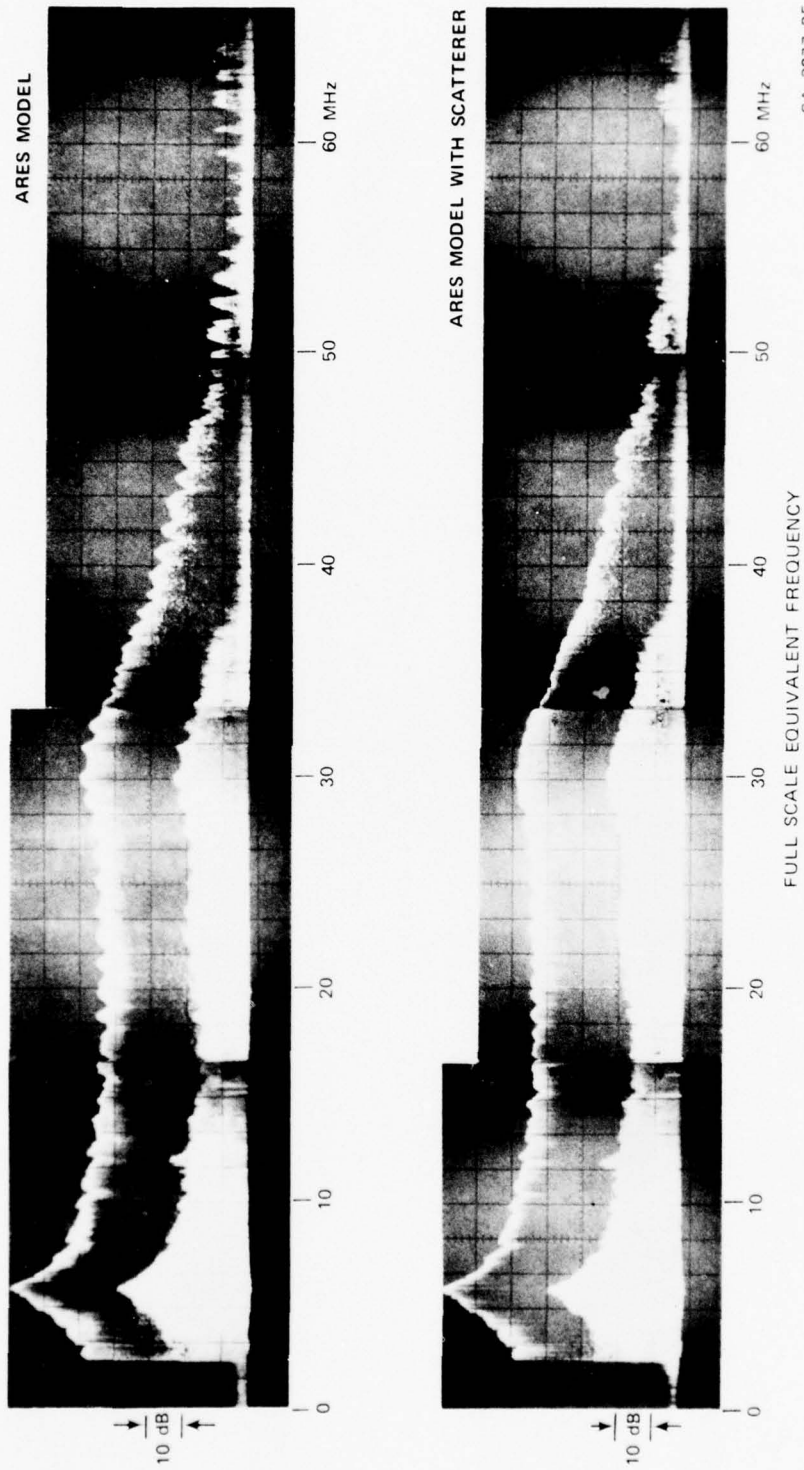


FIGURE 9 CURRENTS ON CYLINDRICAL ROD WITH SPACECRAFT MODULE AND SOLAR PANELS TRANSVERSE TO LENGTH OF ARES

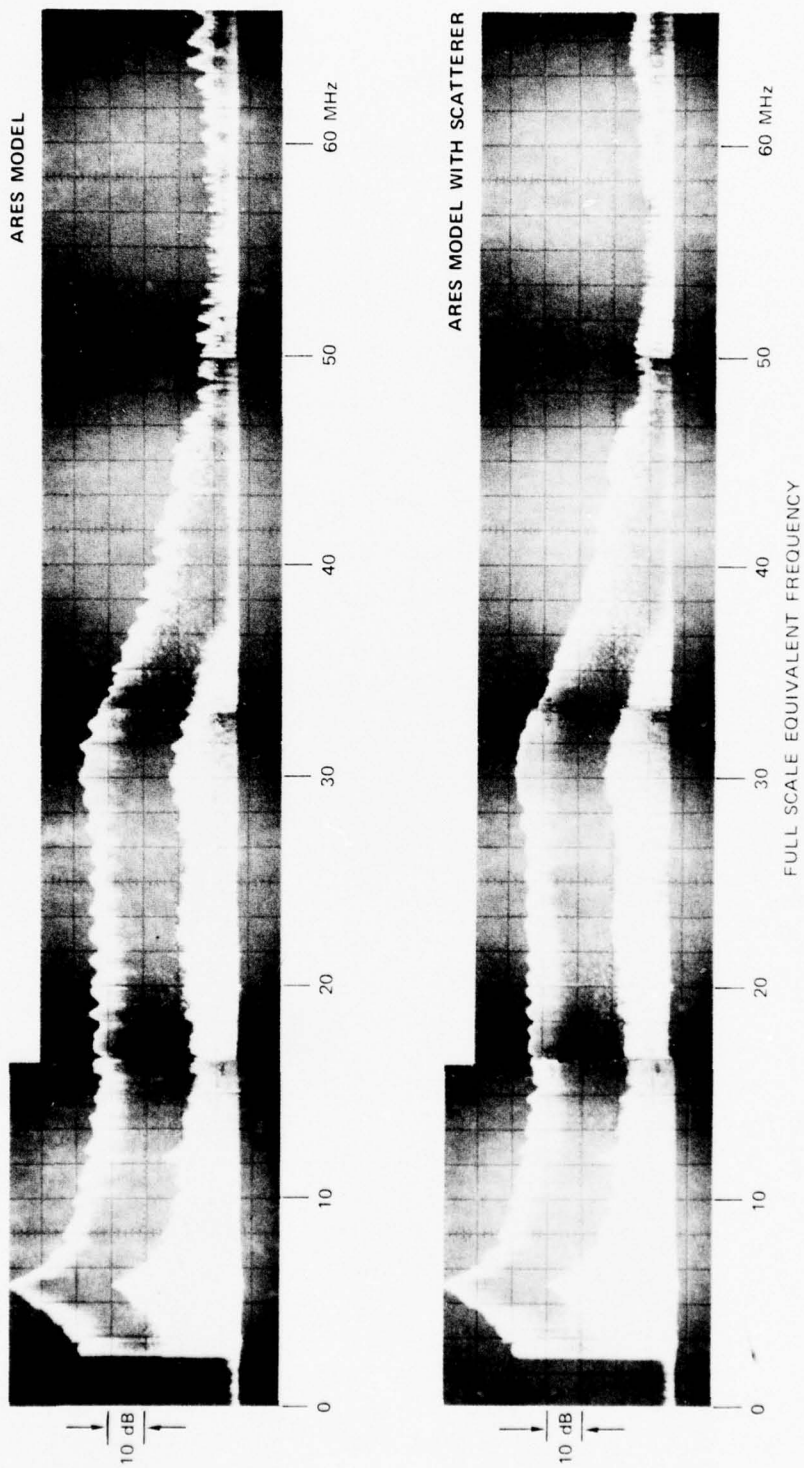


FIGURE 10 CURRENTS ON CYLINDRICAL ROD WITH SPACECRAFT MODULE AND SOLAR PANELS LONGITUDINAL TO ARES

V CONCLUSION

Measurements of the electric fields in the ARES model and of currents on satellite-like models indicate that a scattering structure to reduce the field variation within the ARES is necessary to decrease induced current variations on satellite-like objects for dispersed EMP tests. The 75-cable top plate of the ARES should remain as it is. Cross-wiring the cables eliminates low-frequency resonances but causes the scattering structure to become ineffective. Currents induced on a crude model of a communication satellite indicate that the low-frequency content of the dispersed EMP that causes wire resonances in the ARES are tolerable. These wire resonances could be reduced, if desired, by the addition of series damping resistors, as described in Final Report 1.

Appendix

DESCRIPTIONS OF H AND E FIELD SENSORS

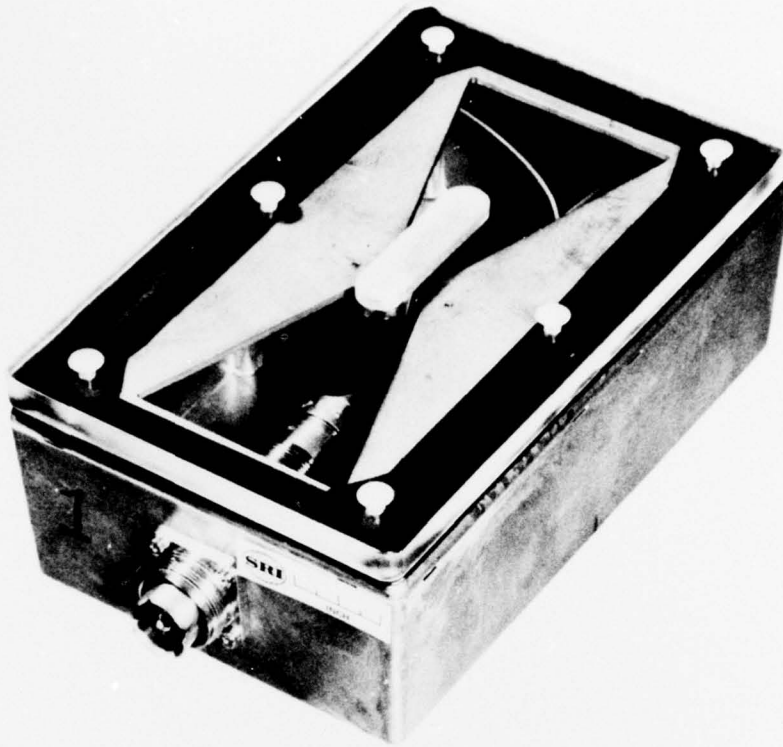
H-Field Probe

The H-field probe (Figure A-1) consists of a metal box with a butterfly slot cut into one side. The slot is shorted in the middle with a wire and the current in the wire is measured with Tektronix CT-1 current probe. The slot is covered with a plastic plate to keep foreign objects out of the box. The output of the box is a GR874 50-ohm connector.

The measured H-field is to be oriented along the slot and perpendicular to the wire. Since the wire short-circuits the slot, the output voltage is proportional to the magnetic field. The ratio of inductance to resistance is high enough that the measured H-field range is nearly independent of frequency from 0.1 MHz to 500 MHz, with the CT-1 current probe causing the frequency dependence below 0.1 MHz.

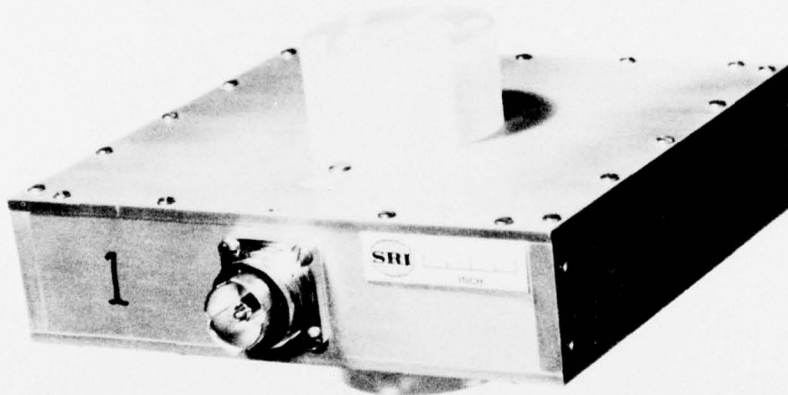
E-Field Probe

The E-field probe (Figure A-2) consists of a disc-cone shaped probe enclosed in plastic and mounted on the top and bottom of the metal box. The measured E-field is colinear with the disc-cones. The capacitance formed between the disc-cones and the metal box becomes charged by the electric field. Since the output of the disc-cones is applied to the input of a field emission transistor (FET), which has an input impedance much higher than the impedance of the disc-cones, the disc-cones may be considered to be looking into an open circuit. Thus, the outputs of the disc-cones are voltages proportional to the electric field and independent of the frequency.



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FIGURE A-1 H-FIELD PROBE



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FIGURE A-2 E-FIELD PROBE

The schematic diagram of the E-field probe is shown in Figure A-3. The metal box of the E-field probe has a VG1094/U BNC fitting and a GR874 50-ohm connector. The GR874 connector is the output of the probe. The BNC fitting is used as a switch and a charging plug. A BNC shorting plug switches on the battery to supply power for operation. The battery is charged by attaching a cord with a BNC fitting from the charger, as illustrated in Figure A-4.

The instructions for charging are as follows:

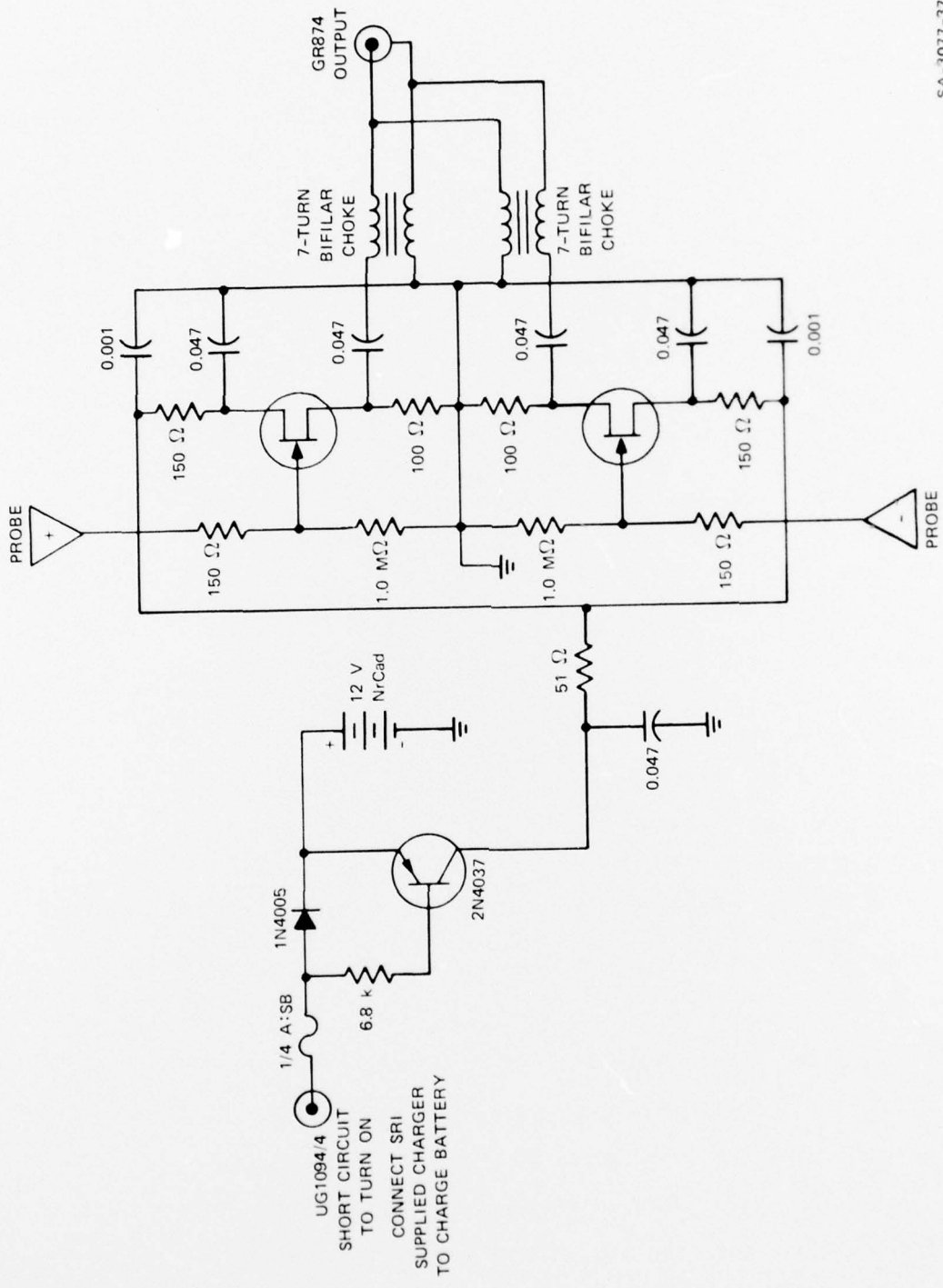
- Plug in the SRI-supplied battery charger with switch in charge position.
- Connect charger to probe using cable with BNC type fittings at each end. The meter, which now indicates current in mA, should indicate about 45 mA. An overnight (8-16 hr) charge should be enough for running the probe all day (8-16 hrs).
- Turn switch on charger to battery check position. The meter now indicates voltage with one-half scale equal to about 13 volts.

The instructions for using the E-field probe are as follows:

- Install short circuit BNC plug to charging connector to turn the circuit on.
- Connect RF output cable to probe and measuring instruments.
 - The measured electric field is perpendicular to the broad side of the probe.
 - The output cable should be perpendicular to both the electric field and the direction of the field propagation to minimize cable coupling to the field.

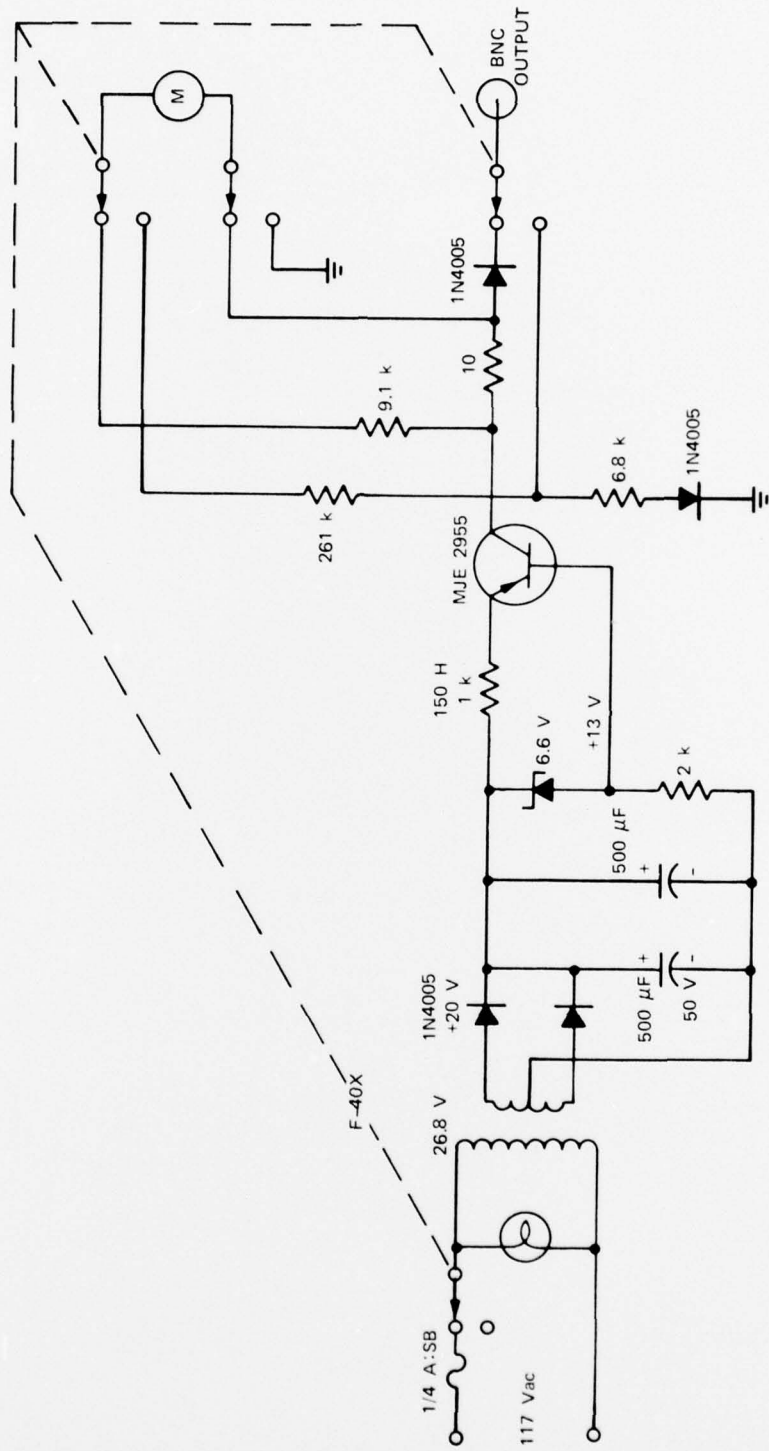
H- and E-Field Probe Calibrations

The H- and E-field probe calibrations were performed in a calibration line that is a small parallel plate transmission line over a ground plane, as illustrated in Figure A-5. The 25-cm height of the parallel plate is less than half the wavelength of the highest design frequency of 500 MHz and aids in reducing the excitation of higher order



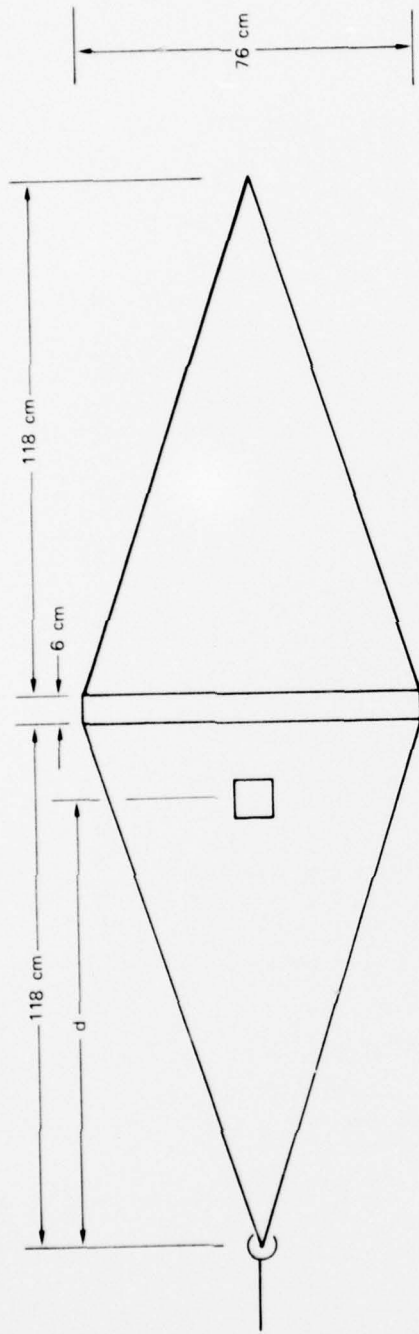
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FIGURE A-3 SCHEMATIC OF E-FIELD PROBE



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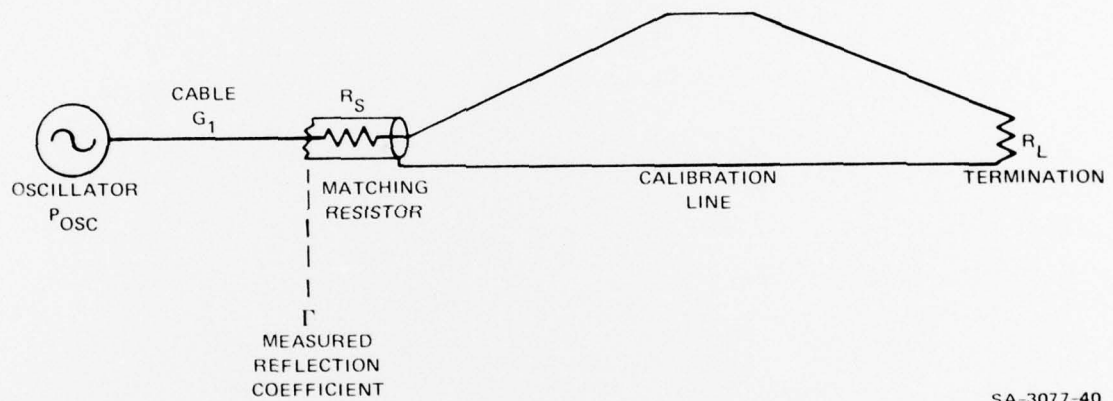
FIGURE A-4 SCHEMATIC OF BATTERY CHARGER FOR E-FIELD PROBE



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FIGURE A-5 CALIBRATION LINE

modes. Tapered sections 118 cm long connect the parallel plate section, which is 76 cm wide but only 6 cm long, to an input Type N coaxial cable and the termination resistance. Reflectometer measurements gave the best termination resistance for the line of $R_L = 70$ ohms. The 6-cm length of the parallel section gave the calibration line device best uniform field over the frequency range of 10 MHz to 500 MHz. To absorb reflections at the input end of the tapered section, a resistor, $R_S = 20$ ohms, was inserted in series with the type N connector at the input end of the tapered section so that a 70-ohm resistance was seen from the input tapered section toward the oscillator.



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FIGURE A-6 SCHEMATIC OF CALIBRATION LINE INPUT CIRCUIT

The schematic of the oscillator connected to the calibration line is illustrated in Figure A-6. The power, P_L , in the calibration line is given by

$$P_L = P_{OSC} G_1 (1 - |\Gamma|^2) R_L / (R_L + R_S)$$

where G_1 is the power gain in the cable between the oscillator and the input absorbing section to the tapered line, Γ is the reflection coefficient measured at the input to the calibration line including R_S .

The gain in the cable is less than one and represents losses. The voltage

developed across the plates of the device is the square root of the product of the power in the field, P_L , and the characteristic resistance, R_L , of the device. Since the electric field, E_L , is the voltage across the plates divided by the height, h , the magnitude of the electric field may be expressed by the height of the line and the equipment parameters as

$$E_L = \frac{R_L}{h} \frac{P_{OSC} G_1 [1 - |\Gamma|^2]}{R_D + R_S} .$$

The output voltage V_0 of the probe into a 50-ohm load is the product of the effective height, h_E , of the sensor and the electric field E_L . The probe's output is propagated through a cable of power gain, G_2 , to a spectrum analyzer with input resistance that matches the cable's characteristic resistance of $R_2 = 50$ ohms. The input power, P_A , to the spectrum analyzer that is displayed on the cathode ray tube is equal to $V_0^2 G_2/R_2$ or $(E_L h_E)^2 G_2/R_2$. The effective height, h_E , of the probe is expressed in terms of equipment parameters, and measured results by eliminating E_L to give

$$h_E = \frac{h}{R_L} [R_2(R_L + R_S)/G_1 G_2 (1 - |\Gamma|^2)] (P_A/P_{OSC}) .$$

The calibration measurements are performed with a frequency-swept CW signal over the desired frequency range. The output of the swept frequency CW oscillator is maintained at a constant output level P_{OSC} . The cable gain, $G_1 G_2$, and the reflected power, $|\Gamma|^2$, are measured. The output power from the sensor is measured as input power, P_A , to the spectrum analyzer over the frequency range from 10 MHz to 500 MHz.

Data for calibrating the probes were extracted for frequencies of 100, 200, 300, 400, and 500 MHz with the sensors located in the line at a distance of 70, 90, 100, and 126 cm from the input to the tapered section. Since the parallel plate section is so short, the probes are

located in the tapered sections with height, h . The output power of the oscillator, P , was maintained at +10 dBm. The extracted data and resulting effective heights are listed in Table A-1. The reflection coefficient, Γ , is small and varies because of the presence of the probe in the line but the transmitted power that is proportional to $(1-|\Gamma|^2)$ is practically constant. The effective heights determined for different frequencies and different distances, d , vary because of the standing wave pattern in the line. The averaged values for the effective heights rounded off to two significant figures are 1.1×10^{-3} V/V/m and 1.5 V/V/m for the H and E-field sensor, respectively, and are estimated to be correct within 10 percent.

The magnetic field is obtained from the H-field sensor's output voltage, V_o as measured into 50 ohms by

$$H = V_o / 377h_E \quad .$$

Table A-1

CALIBRATION DATA AND EFFECTIVE HEIGHTS

S MHz	$G_1 G_2$ dB	d cm	h cm	$ \Gamma ^2$ dB	H-Field Sensor		E-Field Sensor	
					P_A dBm	h_E V/V/m	P_A dBm	h_E V/V/m
100	-0.6	70	14.5	-13.0	-33.0	1.08×10^{-3}	-29.3	1.07×10^{-3}
		90	18.5	-12.5	-35.2	1.07×10^{-3}	-31.7	1.61×10^{-3}
		100	21.0	-12.3	-36.2	1.09×10^{-3}	-32.6	1.65×10^{-3}
		126	25.0	-12.3	-36.6	1.24×10^{-3}	-34.6	1.56×10^{-3}
200	-0.8	70	14.5	-11.0	-33.2	1.10×10^{-3}	-30.0	1.59×10^{-3}
		90	18.5	-14.5	-36.6	0.92×10^{-3}	-32.0	1.57×10^{-3}
		100	21.0	-14.5	-37.9	0.90×10^{-3}	-33.4	1.52×10^{-3}
		126	25.0	-12.5	-38.0	1.08×10^{-3}	-37.2	1.18×10^{-3}
300	-1.0	70	14.5	-13.0	-32.6	1.18×10^{-3}	-30.7	1.47×10^{-3}
		90	18.5	-9.0	-34.9	1.11×10^{-3}	-31.8	1.73×10^{-3}
		100	21.0	-10.5	-38.0	0.92×10^{-3}	-31.6	1.97×10^{-3}
		126	25.0	-11.0	-39.6	0.89×10^{-3}	-37.2	1.22×10^{-3}
400	-1.1	70	14.5	-10.0	-33.2	1.15×10^{-3}	-30.0	1.66×10^{-3}
		90	18.5	-16.0	-35.5	1.08×10^{-3}	-33.6	1.35×10^{-3}
		100	21.0	-12.0	-36.5	1.12×10^{-3}	-35.6	1.24×10^{-3}
		126	25.0	-15.5	-40.4	0.81×10^{-3}	-35.1	1.53×10^{-3}
500	-1.5	70	14.5	-17.0	-32.0	1.32×10^{-3}	-31.2	1.45×10^{-3}
		90	18.5	-14.0	-35.9	1.09×10^{-3}	-34.0	1.36×10^{-3}
		100	21.0	-17.0	-35.9	1.16×10^{-3}	-37.2	1.05×10^{-3}
		126	25.0	-17.5	-39.0	1.02×10^{-3}	-36.2	1.41×10^{-3}
Averaged effective heights						1.07×10^{-3}		1.49×10^{-3}

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