A PARALLEL-STRIP LINE FOR TESTING RF SUSCEPTIBILITY

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Abstract

This paper presents a technique for establishing known, high intensity RF fields suitable for testing the susceptibility of electronic equipment to these fields. The technique overcomes a deficiency in tests for radiated susceptibility which are required by military specifications, such as MIL-I-26600. Such tests fail to use field intensities that are representative of the environments in which electronic equipment will be installed.

It is becoming more important not only to use realistic field strengths, but to know these field strengths to a fair degree of accuracy. The system designer will have more assurance of system compatibility if components have been tested to meet the requirements of the installation environment.

A significant amount of time and money can be saved if susceptibility problems are recognized and solved prior to equipment installation.

Test Setup

The technique, discussed here, was developed to produce known field intensities comparable to those generated by high power, airborne HF communication transmitters. Evaluation of the system has been completed over the 2 to 30 mc frequency range.

The test field was established by what is essentially a parallel-strip transmission line loaded with its characteristic impedance. In Fig. 1, the field of importance is that which exists between the upper conductor and its image on the lower conductor. Once the magnitude of this field was established, the line could be used for susceptibility testing by placing equipment between the conductors. Development of the line was divided into four phases:

1. Construction and calibration of a field sensing device.

2. Construction and calibration of the transmission line.

3. Evaluation of the line.

4. Application to susceptibility testing.

These phases are discussed in detail in the following paragraphs.

Field Sensor

A small, shielded loop probe (Fig. 2) was constructed for use as the field sensing device. The ratio of magnetic to electric field pickup was approximately 30 db. Using the standard calibration arrangement setup, shown in Fig. 3, the probe was calibrated in terms of output voltage, as a function of magnetic field intensity at 2, 10, 20 and 30 mc.

The length of coaxial cable between the probe and meter was kept as short as possible because long cables resulted in calibration curves that were nonlinear and at frequencies above 10 mc, meter readings varied with the physical location of longer cables. The calibration field was established by a 0.25 meter diameter loop. The capacitance of the calibration loop feed line was minimized by use of one foot long open wire line with the conductors 0.5 inch apart. A 50 ohm coaxial section was used initially but the loop exhibited a resonant effect below 30 mc. This was detected by application of a constant voltage to the loop and measurement of the relative loop current (with a Stoddart 91550-1 RF current probe) as the frequency was varied.

The final loop configuration exhibited a linearly decreasing loop current as frequency increased, indicating that the loop and feed line were not resonating. The calibration loop current was determined by measuring the voltage drop across a 10 ohm deposited carbon, precision resistor which was placed in series with, and as close to the loop as possible. The field at the center of the loop is given by the expression:

$$H = \frac{I}{D} \quad \frac{\text{amps}}{\text{meter}}, \tag{1}$$

where

I = loop current in rms amperes
D = loop diameter in meters.

Moving the shielded probe from the center of the loop by an amount equal to the radius of the probe produced a negligible change in induced voltage. This indicated that the field at the center of the calibration loop was essentially constant over the probe area.

During calibration, the probe output voltage was measured by the substitution method through use of an accurately metered signal generator. Although, because of losses, the probe output voltage did not increase linearly with frequency, the calibration curves were straight lines for each frequency. The nonlinearity is of no consequence in obtaining the final calibration curve for the transmission line. Probe calibration curves are shown in Fig. 4.

Transmission Line Construction and Calibration

The second phase, for which the probe was calibrated, was to construct and calibrate the transmission line. Because of the physical simplicity of the line, only the means by which the line was loaded is discussed. All other construction details are shown in Fig. 1. In actual use, the upper conductor could be made to pivot from the wall or hang from the ceiling, thus facilitating removal of the line when not in use.

Connection of the load to the line is illustrated in Fig. 5. This configuration is adequate for testing purposes but should be improved, especially if large bodied resistors are used. Care should be taken to minimize shunt capacity across each resistor. To minimize inductance and because of the physical size of the line, it was necessary to use copper straps for load resistor leads.

The required value of load resistance was determined by measuring the open-circuit capacitance and short-circuit inductance of the line and applying the expression

$$Z_O = \sqrt{\frac{\ell}{c}}\ , \qquad (2)$$

where

ℓ = short-circuit inductance
c = open circuit capacitance.

In measuring the inductance, five copper straps were used to short the line. The combined inductance of the straps was only 3 percent of the total short-circuit inductance. The value of characteristic impedance determined by this method was 90 ohms. To check this, an RF bridge was used to measure the input impedance of the loaded line between 2 and 40 mc. This test showed that the 90 ohm load was incorrect and the optimum load was determined by trial and error. The final value of load resistance that yielded the best results over the entire frequency range was 80 ohms. Table I is a tabulation of the input impedances of the line.

Table I - Line Input Impedances

Frequency (mc)	Input Impedance (ohms)
2	80 + j.75
5	80 + j4.0
10	79 + j9.2
15	79 + j15.3
20	80 + j21.5
25	83 + j27.2
30	84 + j30.6
40	84 + j27.6

Calibration measurements were made after the line was properly loaded. The resulting calibration curve allows the user to establish a known field by measuring only the current in the line. To calibrate the line, the probe was centrally located between the conductors so that the plane of the probe was perpendicular to the lower conductor and parallel with the length of the line. The probe cable was brought out to the field intensity meter in a position as far from the line as the five foot cable would allow. To determine the current in the line, a high impedance RF voltmeter was connected across one of the load resistors. It was found that stray pickup was eliminated by taping the meter leads to the ground plane and positioning the meter on the ground plane as far from the load as possible.

Probe output voltage was recorded for each value of line current. Starting with a line current of 2 ma data was taken until the output voltage corresponded to a field of approximately .03 a/m as shown on the probe calibration curve for the frequency in use. Probe output voltage measurements were made by the substitution method as for probe calibration.

The curves of probe output voltage vs. line current, and probe output voltage vs. field intensity were combined, for each frequency, to obtain line calibration curves of field intensity as a function of line current. The resulting calibration curves at 2, 10, 20 and 30 mc deviated from one another by no more than 8 percent. Although the curves should coincide, this result would be difficult to obtain. For practical purposes an average calibration curve was drawn and is shown in Fig. 6.

The simplicity of the line allows it to be dismantled and rebuilt without invalidating the calibration curve. It was found that data obtained after a period of 6 months, with different instrumentation and in a different shield room, was within 5 percent of original measurements. The values of field intensities on the curve are those which exist at the center of the line. The extent to which the field varies with different locations between conductors will be discussed later.

Evaluation

A theoretical calculation was made to check the validity of the line calibration curve. It required that the line be properly loaded and that only the TEM mode of propagation be sustained. The first requirement was met and the second shown to be satisfied by the fact that the line calibration curves were nearly coincident. That is, for a given current, the field intensity was independent of frequency. In addition, the physical dimensions of the line are small compared to a wave length.

The approach requires a knowledge of the electric field intensity and the intrinsic impedance of the field. As will be shown later, the field at the center of the line is relatively uniform. Therefore, the field impedance is 377 ohms and the average electric field intensity may be determined by dividing the line voltage by the separation between the conductors. With these quantities, the magnetic field intensity was found from H = E/377. The measured value of magnetic field intensity was 12 percent above the calculated value. In a technology where 2 db (25 percent) is usually considered small, it was felt that the accuracy of the calibration curve was quite adequate.

Field intensities were measured using the probe at several locations between the conductors while maintaining a constant line current. Each probe location was identified by the coordinates x, y and z; where x is the penetration between conductors measured from the front edge, y is the probe height and z is the distance from the feed end of the line. The curves of Fig. 7 illustrate the relative uniformity of the field between the conductors.

Additional field distribution was obtained by model testing. Models of the line and shield room cross-sections were made using a conductive silver paint on Teledeltos (resistive) paper. A dc potential was applied to the model line conductors and equipotential lines were plotted between the conductors using a vacuum tube voltmeter. These lines coincide with magnetic flux lines and give a qualitative illustration of the field uniformity. Fig. 8 shows the model field plot of the line.

Similar plots were made to determine limits on physical parameters such as spacing between the upper conductor and wall. It is desirable to maintain at least 12 inches between the upper conductor and wall although a 6 inch minimum separation would be usable if some degradation in field uniformity is accepted. For a minimum of 12 inches between the wall and upper conductor the maximum tolerable separation between conductors appears to be 18 inches. Conductor separations greater than 18 inches require wider conductors and extreme care in loading the line. Such a line is not recommended and, in most cases, not required. Naturally, the wider the conductors and the more remote they are from the walls, the more uniformly the field will be distributed. However, any change in size or spacing changes the characteristic impedance of the line.

Two tests were performed to determine the degree of field distortion resulting from the placement of metal boxes between the conductors. The two test conditions are shown in Fig. 9, with P_1 and P_2 designating the probe positions. In each case probe penetration distance was 12 inches at a height of 6 inches above the lower conductor. In one configuration three boxes were positioned adjacent to one another to simulate an equivalent box measuring approximately 8 x 10 x 20 inches. The second configuration employed three boxes, each measuring approximately 6 x 10 x 8 inches.

The line current was adjusted to a preselected value for each condition and probe position shown in Fig. 9. The probe output without the test samples between the conductors was determined. The test samples were then inserted between the conductors and change in probe output was measured. The line current was then adjusted until it was equal to the original preselected value. The probe output was determined and compared to the value of the probe output obtained without the test samples between the conductors.

The data, presented in Table 2, indicate that line current may be adjusted with the test samples inserted in the line and that a field, within 20 percent of the intensity measured without test samples in the line, may be maintained. One exception is at 30 mc, condition 2, for which the field intensity increased almost 30 percent at one probe position but changed less than 12 percent at the other position. However, as the separation between the upper conductor and the test sample increased the field distortion decreased.

Application

Application of the line for susceptibility testing is shown in Fig. 10. The general procedure does not differ greatly from the standard method of radiated susceptibility testing using an antenna. The front of the test samples should be 2 to 3 inches in from the edge of the lower conductor and the cabling and supported as shown. Separation between the upper conductor and test samples should be at least 2 inches. The maximum dimensions that can be accommodated by a line with 12 inch conductor separations is 10 x 10 x 20 inches. These limits may change if it is not required that the test sample be rotated to test all three planes of susceptibility, as shown in Fig. 11. As equipment miniaturization advances are made physical dimensions will become less of a limiting factor. In addition to its application in specification testing, the line may be used for experimentally evaluating small shield enclosures for circuit components prior to final equipment design.

Future development of the line will include extension of usable frequency range and evaluation as a transient field source. As would be expected, extending the frequency below 2 mc has not been a problem. With the line shorted it may be used as a magnetic field source at power frequencies and associated harmonics. Since a 2 gauss field would require a line current of approximately 150 amperes, even at 400 cps, a practical means of driving the line must be developed for the lower frequencies. However, no insurmountable problems are anticipated in making the line useful from dc to 30 mc.

Conclusion

The test field established by a parallel-strip transmission closely approximates uniform plane waves over the RF spectrum below 30 mc. The technique discussed has the advantage of allowing the experimenter to know the magnitude of the test field far more accurately than if an antenna were used as a field source. Electrical field intensities as high as 10 volts per meter can be established with a signal generator capable of 3 volts output across 50 ohms. The simplicity of the line allows a high degree of repeatability in establishing a known field and should enhance its usefulness as a standard technique for qualifying equipment in the presence of high intensity fields.

TABLE 2 EFFECT OF TEST SAMPLES ON MAGNETIC FIELD

		PROBE POSITION P_1				PROBE POSITION P_2		
	f (mc)	Probe Output (mv)	H $(\frac{ma}{m})$	I_L (ma)	Remarks	Probe Output (mv)	H $(\frac{ma}{m})$	Remarks
Condition 1								
I_L set without box	30	2680	20.6	25		2710	20.8	
Box inserted	30	2850	21.9		6.3 % increase in H	2840	21.8	4.8 % increase in H
I_L set with box in line	30	2750	21.1	25	2.5 % increase in H	2750	21.1	1.5 % increase in H
Condition 2								
I_L set without box	10	730	15.4	20		730	15.4	
Boxes inserted	10	820	17.3		12.3 % increase in H	750	15.8	2.5 % increase in H
I_L set with boxes in line	10	780	16.4	20	6.5 % increase in H	760	16.0	3.9 % increase in H
I_L set without boxes	20	1360	15.2	20		1360	15.2	
Boxes inserted	20	1600	17.9		17.8 % increase in H	1520	17	11.8 % increase in H
I_L set with boxes in line	20	1600	17.9	20	17.8 % increase in H	1520	17	11.8 % increase in H
I_L set without boxes	30	2030	15.6	20		2220	17	
Boxes inserted	30	2380	18.3		17.3 % increase in H	2280	17.5	2.95 % increase in H
I_L set with boxes in line		2470	19	20	29.5 % increase in H	2470	19	11.8 % increase in H

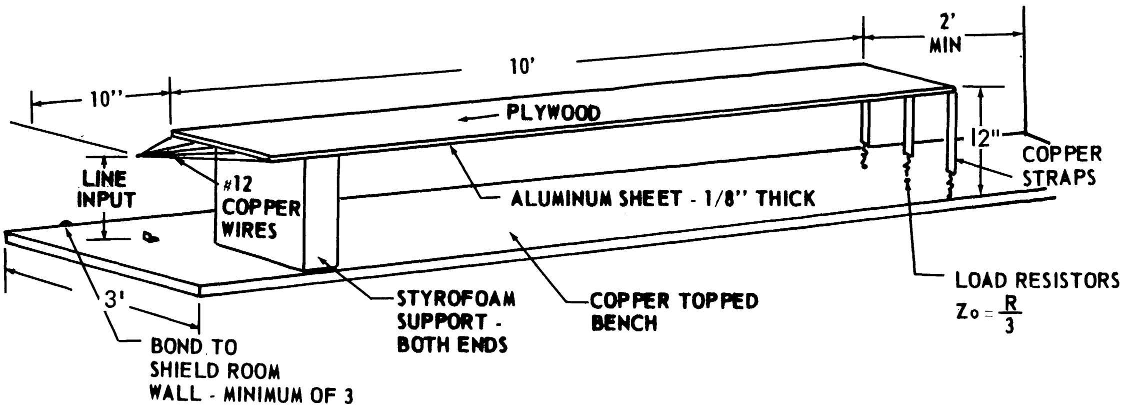

FIG. 1. PARALLEL-STRIP TRANSMISSION LINE.

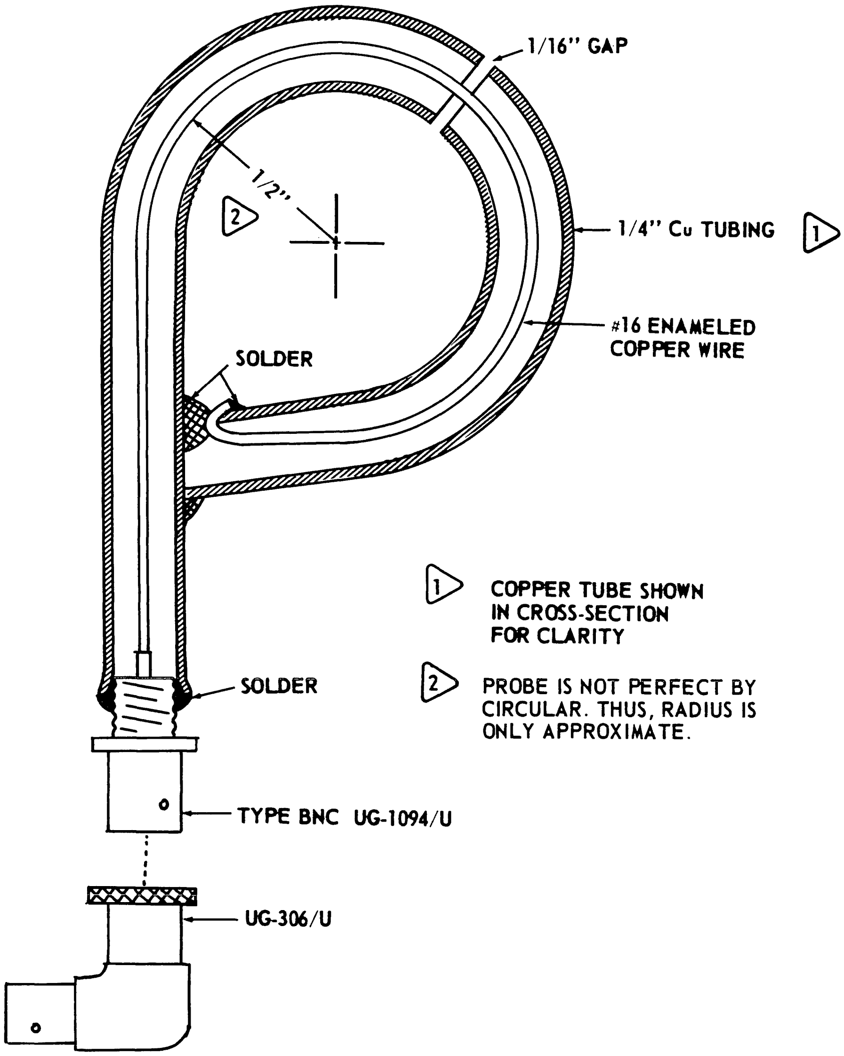

FIG. 2. LOOP PROBE.

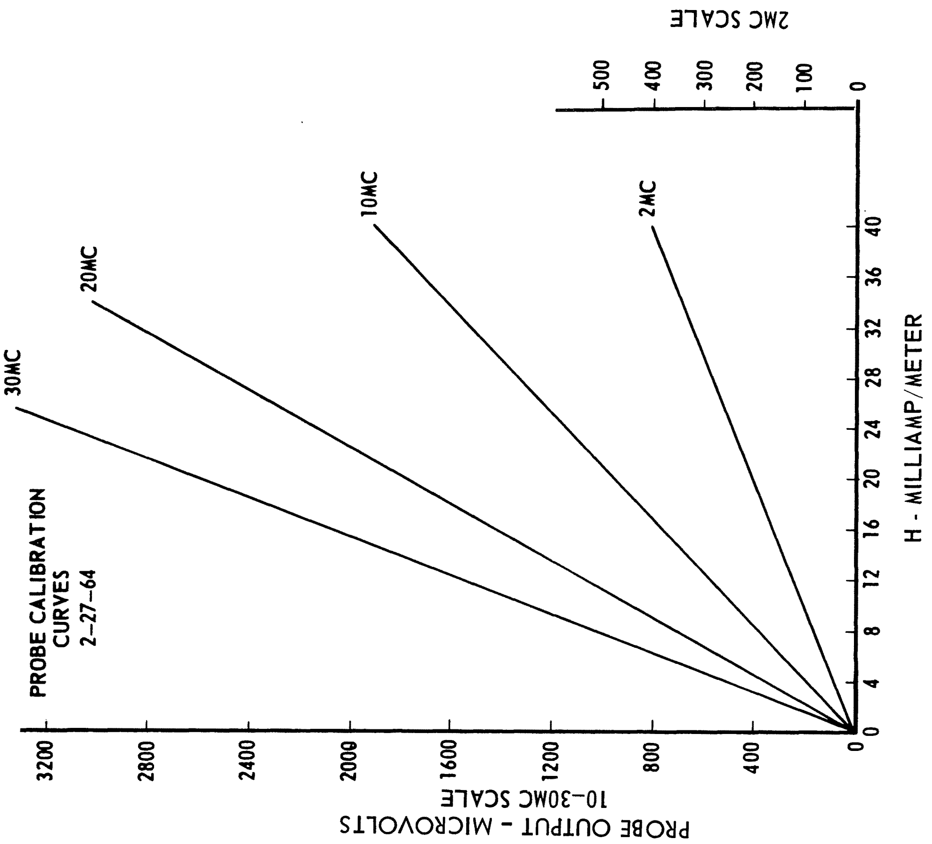

FIG. 4. PROBE CALIBRATION CURVES.

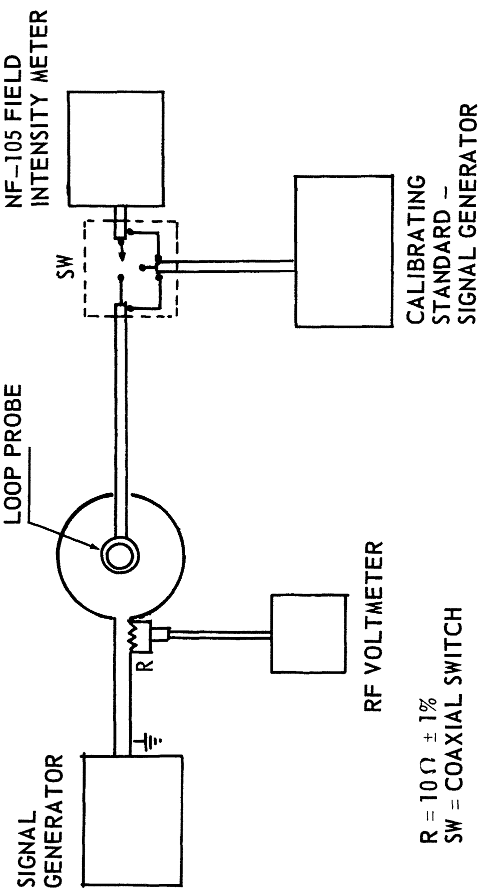

FIG. 3. PROBE CALIBRATION SETUP.

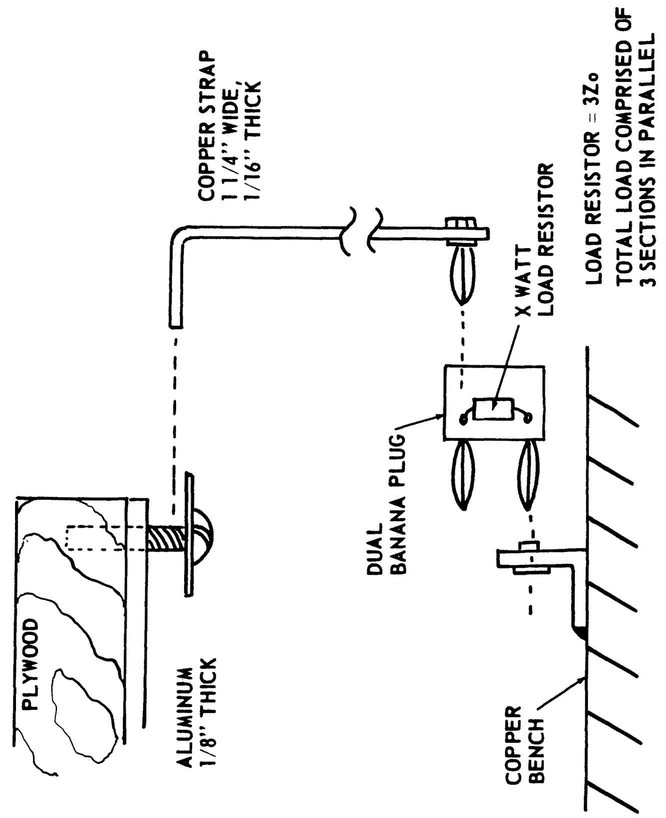

FIG. 5. LOAD CONFIGURATION.

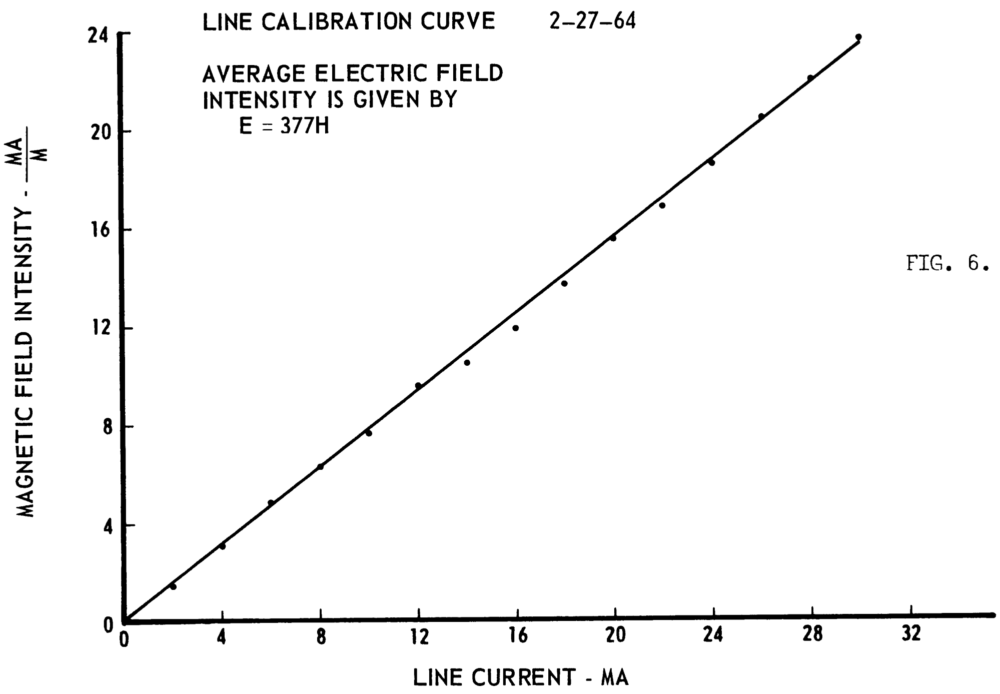

FIG. 6. LINE CALIBRATION CURVE.

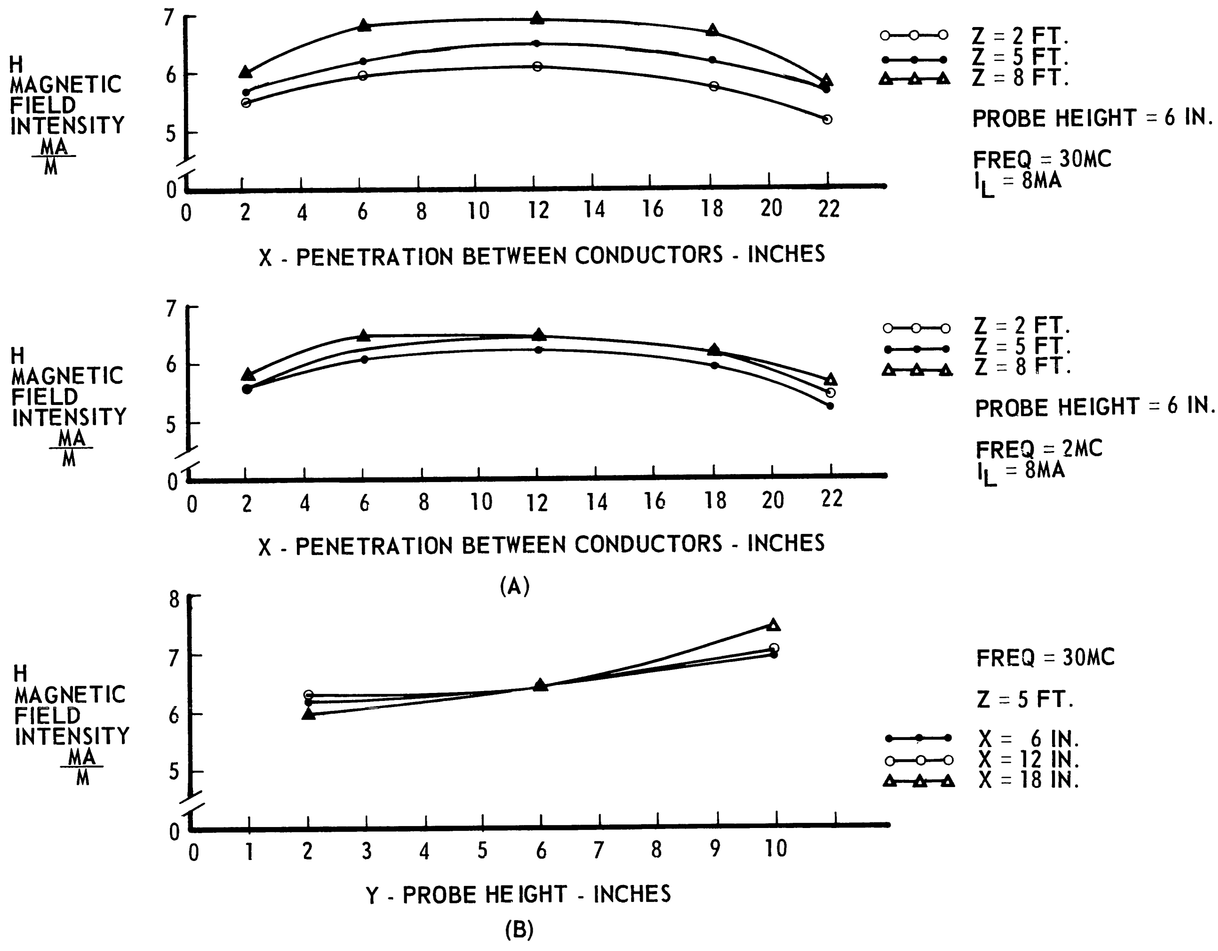

FIG. 7. FIELD DISTRIBUTION, (A) VARIATION IN H WITH PENETRATION, (B) VARIATION IN H WITH HEIGHT ABOVE LOWER CONDUCTOR.

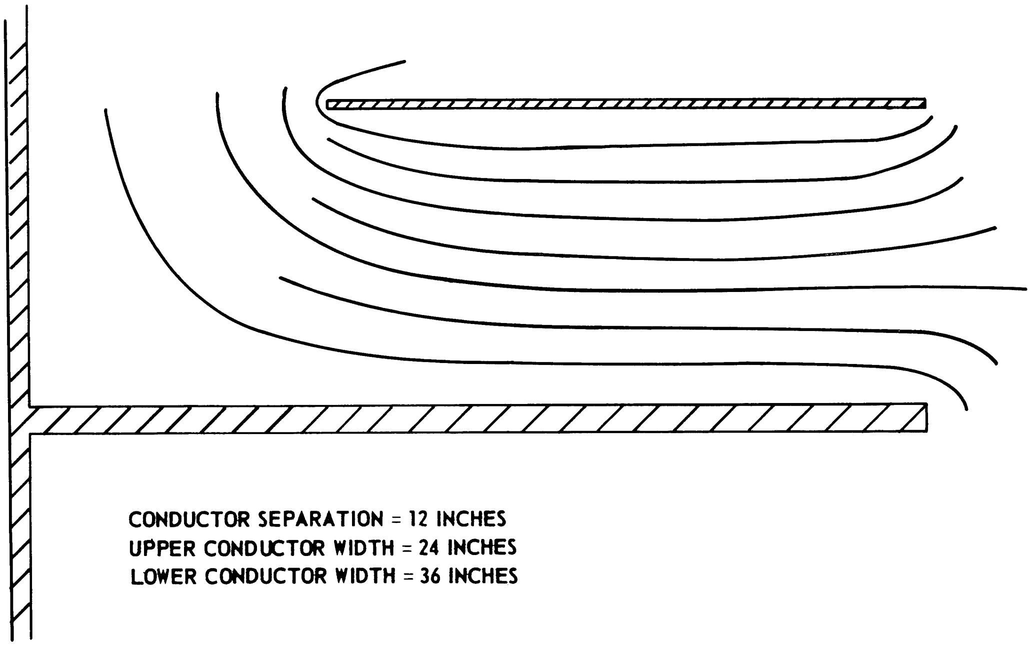

FIG. 8. MODEL PLOT OF MAGNETIC FLUX LINES.

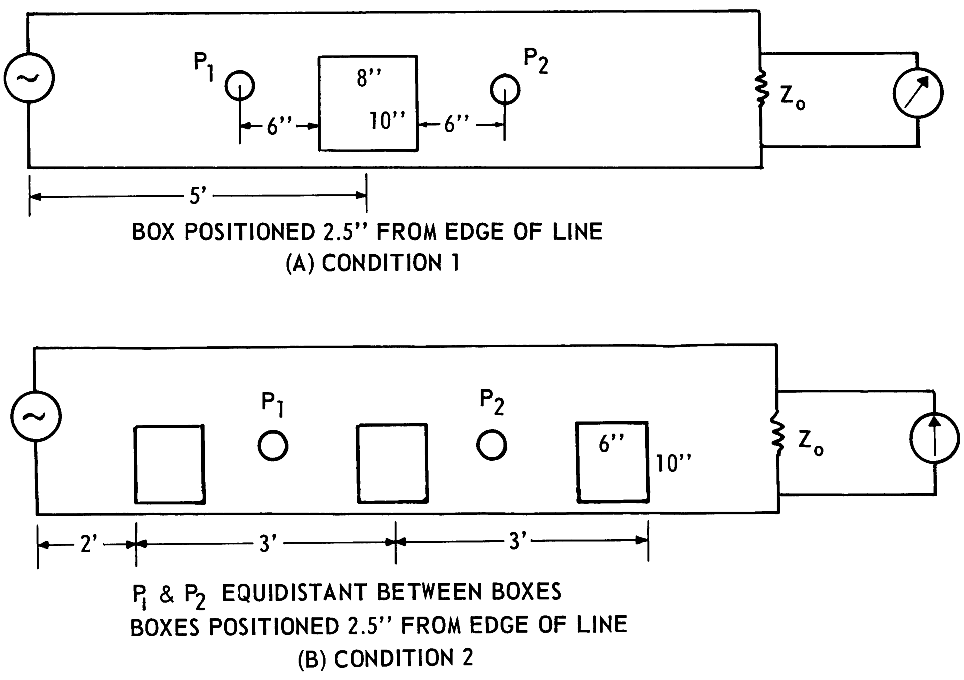

FIG. 9. BOX PLACEMENT FOR FIELD DISTORTION TESTS.

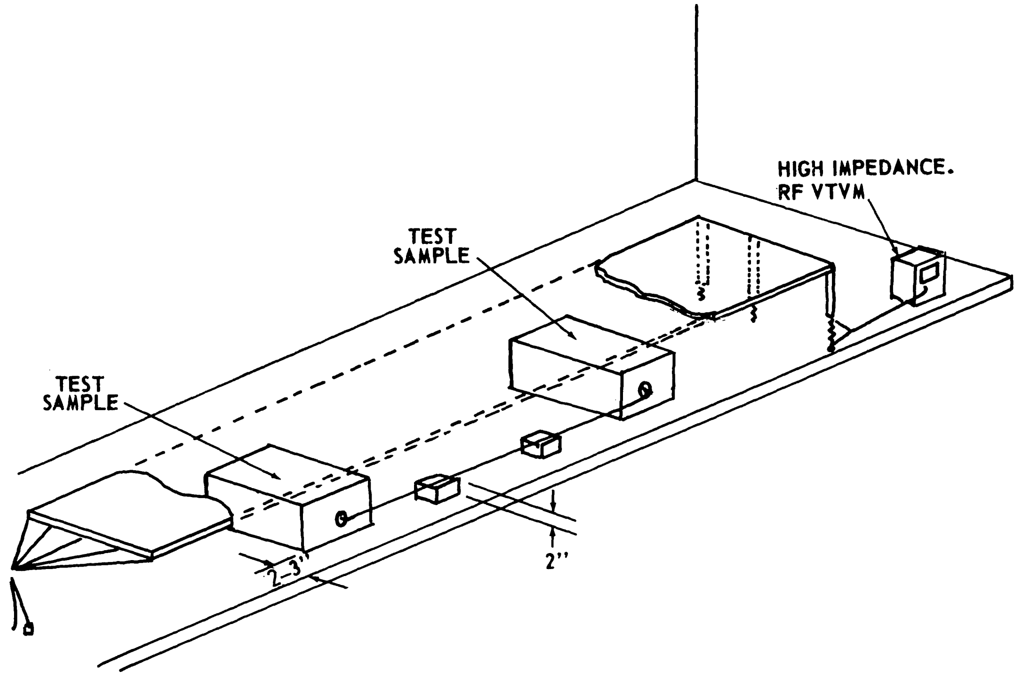

FIG. 10. TYPICAL SUSCEPTIBILITY TEST SETUP.

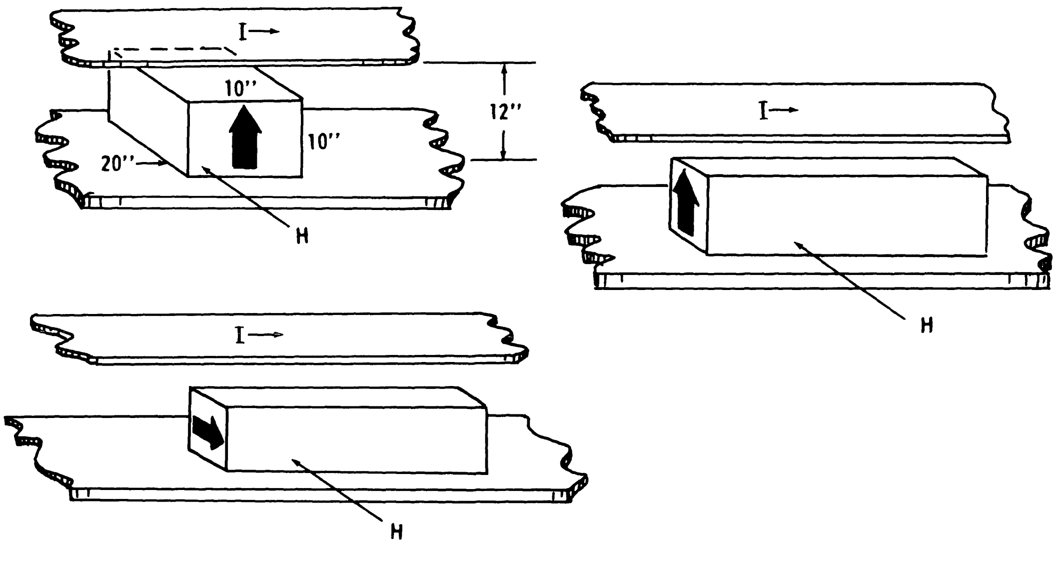

FIG. 11. POSITIONING OF TEST SAMPLE.