



AEROSPACE INFORMATION REPORT

AIR1209™

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Construction and Calibration of Parallel Plate Transmission Line
for Electromagnetic Interference Susceptibility Testing

RATIONALE

AIR1209 has been reaffirmed to comply with the SAE Five-Year Review policy.

FOREWORD

Changes in this reaffirm are format/editorial only.

1. SCOPE:

This Aerospace Information Report (AIR) is intended to provide information relating to the construction, calibration, and usage of parallel plate transmission lines in electromagnetic compatibility susceptibility testing.

2. REFERENCE DOCUMENTS:

- 2.1 MIL-STD-462, Electromagnetic Interference Characteristics, Measurement of
- 2.2 AFSC-DESIGN HANDBOOK DH 1-4, "ELECTROMAGNETIC COMPATIBILITY", Design Note 6B-1.
- 2.3 A Parallel-Strip Line for Testing RF Susceptibility, B. E. Roseberry and R. B. Schulz, Presented at the 6th National Symposium on EMC, Los Angeles, California, June 1964.
- 2.4 Parallel Strip-Line Calibration, B. E. Roseberry, Motorola, Inc., Scottsdale, Arizona, December 12, 1968.

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3. GENERAL CHARACTERISTICS:

The Parallel Plate Transmission Line (PPL) is a versatile item of test equipment. It may be used to generate low impedance magnetic fields, high impedance electric fields, and plane waves for environmental or electromagnetic compatibility testing of electronic equipment. The PPL will produce these fields efficiently, since the electric field component is essentially contained between the parallel plates. The line response is uniform from DC to an upper frequency limit of 25 MHz or more, depending upon its physical size and the terminating impedance. The direction and magnitude of the E and H field vectors, and the direction of propagation of the plane wave are known. Its response as a receiving transducer or antenna is uniform and essentially limited to energy emanating from within the confines of the line, with respect to the E field.

4. CONFIGURATIONS AND USAGE:

The PPL may be used in three ways:

- a. **Unterminated** - In this configuration the PPL is a parallel plate capacitor antenna rather than a transmission line. It produces an E field of high impedance. Only a vestige of H field is present, caused by the displacement current flowing in the capacitor.
- b. **Terminated in its characteristic impedance** - This configuration produces a unidirectional plane wave, with the E field vector normal to the conductive plates and the H field normal to the E field and to the direction of propagation.
- c. **Terminated in zero impedance** - The short circuited line is a single turn loop or magnetic dipole of extremely low impedance. The only E field exhibited by this configuration is that caused by the IR drop in the conductors. Thus the field produced has an impedance approaching zero ohms. This usage of the line would require the construction of a termination with the conductive elements replaced by a metallic conductor.

The PPL is also eminently suited for quantitative measurements of energy radiated from equipment enclosures, since its response is uniform from zero frequency to the upper frequency limit determined by its physical size. It may be used without a shielded enclosure in many instances, since it is relatively insensitive to E field or plane wave energy originating outside of the line, up to its operational frequency limit. Its use provides significant advantages for use in a shielded enclosure as well, since its coupling factor to space is much lower than that of conventional antennas. The anomalies caused by reflection of energy from the interior surfaces of the enclosure are essentially eliminated.

4.1 AFSC DH 1-4 Line:

Figures 1, 2, and 3 show construction of a parallel plate line incorporating the following features and improvements:

- a. The longitudinal slots in the parallel plates prevent transverse current and help to maintain the TEM mode of propagation.
 - b. The termination reduces coupling between the end of the line and the shielded room wall. Each layer of conductive plastic (377 ohms/square) reduces the energy passing through by 6 dB/layer so that coupling is reduced by 36 dB (18 dB outgoing and 18 dB reflected back in) for the three layers.
 - c. The input is designed as a wave launcher rather than a matching section. The shape of the launcher has been determined empirically to minimize variations of wave front homogeneity at the sending end. The input is suitable for low-impedance (4 ohms) spike generators or conventional 50-ohm signal sources.
- 4.1.1 Grounding: Investigations have indicated that for this configuration grounding the bottom plate to the ground plane on one side along its entire length creates a non-uniform field, concentrated along the grounded side. It is recommended that the bottom plate be grounded only at the termination, over the entire width of the bottom plate.
 - 4.1.2 RF Power: The parallel plate line termination will accept 250 watts continuously. Figure 4 indicates the typical RF power required to generate a 10 V/meter field. Each line should be calibrated individually.
 - 4.1.3 Line Characteristic Impedance: The characteristic impedance of a line having a height-to-width ratio of unity has been determined by bridge measurements of the open- and short-circuited line to be approximately 118 ohms. A distributed load of 40π ohms, consisting of three sheets of conductive plastic having a resistance of 120π ohms per square connected in parallel a voltage (V) to power (W) ratio that was independent of frequency up to the upper frequency limit of the line. The Figure 4 curve was produced from data taken on a line with one metre strip width and one metre separation between the strips. These data correlate well with other data taken on other lines of unity height-to-width ratio with conductor widths and separations of 10, 30, 60 and 76 centimetres. The upper frequency limit of these lines varies as the inverse of the width and spacing.
 - 4.1.4 Placement in Shielded Enclosure: The line should not be located adjacent to a shielded room wall or other conductive surface. Separation between the sides of the line and the shield room wall should be at least 1.5 times the strip separation to avoid distortion of the field within the line. The line should be grounded to the ground plane or wall at the load end with a ground strap of the same width as the line.

4.1.5 Line Usage:

a. Frequency Range

0 Hz to 20 MHz with +29 dBm.
20 MHz to 50 MHz with +38 dBm.

b. Spacing from enclosure wall

1.5 times strip separation.

c. H/W Ratio

Unity

d. Maximum Test Sample Size

Maximum test sample size shall not exceed 0.75 times strip separation

4.2 MIL-STD-462 Type Line:

This line differs from the previous line in that it utilizes H/W ratios other than unity, discrete load resistors, and different grounding requirements. Figure 5 shows a typical line based on MIL-STD-462 construction but with slightly larger dimensions.

4.2.1 Line Grounding: The shield room, copper top, work bench may be used as the line ground plane, provided that it is wide enough and is bonded to the shield room wall in the usual manner. The top plate of the line should be kept at least one foot from the shield room wall to minimize field distortion in the line. If the entire line is constructed as a separate assembly, grounding has not proven to be critical, i.e., load end versus source end, provided that the line is at least one foot from the shield room wall.

4.2.2 Characteristic Impedance: It is recommended that the characteristic impedance of the line be determined initially by bridge measurement. The following are typical for three commonly used height-to-width ratios:

12 inch/24 inch	$Z_o = 80$ ohms
18 inch/24 inch	$Z_o = 83$ ohms
24 inch/36 inch	$Z_o = 105$ ohms

4.2.3 Line Usage: The normally used frequency range is 14 KHz to 30 MHz. Test sample size should be limited to 3/4 the plate spacing. 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.

5. CALIBRATION:

The electric field intensity in the line is equal to the voltage across the load divided by the line spacing in metres. For optimum accuracy, the impedance match of the load should be confirmed by monitoring the power required to maintain a constant load voltage versus frequency. With the line terminated in its characteristic impedance only the TEM mode appears in the line. Therefore, the electric field and the magnetic field are related by $E/H = 377$ ohms. Note that the field impedance in the line and the line characteristic impedance are not the same. However, varying the line load will change the E/H ratio in the line. Use of a calibrated loop probe to determine the magnetic field is necessary if an accurate value of the line field impedance is desired.

A small, shielded loop probe (Figure 6) is used as the field sensing device. Using the standard calibration arrangement setup, shown in Figure 7, the probe was calibrated in terms of output voltage, as a function of magnetic field intensity at 2, 10, 20, and 30 MHz.

The length of coaxial cable between the probe and meter is kept as short as possible because long cables result in calibration curves that are nonlinear and at frequencies above 10 MHz meter readings may vary with the physical location of longer cables. The calibration field is established by a 0.25 metre diameter loop. The capacitance of the calibration loop feed line is minimized by use of one foot long open wire line with the conductors 0.5 inch apart.

The loop configuration exhibits a linearly decreasing loop current as frequency increases, indicating that the loop and feed line are not resonating. The calibration loop current is determined by measuring the voltage drop across a 10 ohm deposited carbon precision resistor which is 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:

$$H = \frac{I}{D} \frac{\text{amps}}{\text{metres}}$$

where,

I = loop current in rms amperes

D = loop diameter in metres

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

During calibration, the probe output voltage is measured by the substitution method through use of an accurately metered signal generator. Although, because of losses, the probe output voltage does not increase linearly with frequency, the calibration curves are straight lines for each frequency. The nonlinearity is of no consequence in obtaining the final calibration curve for the transmission line. Typical probe calibration curves are shown in Figure 8.