SUSCEPTIBILITY SOURCES

This article discusses the problem and some suggested solutions for establishing higher electric-field intensities of 1 to 100 V/m from DC to 1 GHz in an economical manner. Principal applications are for EMI susceptibility testing. Efficient device(s) used to establish these fields from the output of RF oscillators are called *special susceptibility antennas.* The word antennas is used in a poetic manner since the devices do not radiate. Rather, they are either large transmission lines operating in the dominant TEM mode or are large plates used to accommodate big specimens at low frequencies.

With certain exceptions, antennas used for radiated emissions measurement are equally useful for susceptibility testing. As long as the law of reciprocity exists there would seem to be no problem in using an antenna for both applications. However, two problems exist with *some* of these antennas:

(1) They are power limited (law of reciprocity does not apply).
(2) They are inefficient.

Before proceeding with the discussion and solution of these problems, an illustration is presented.

MIL-STD-461A requires that a field intensity of 1 V/m over the designated frequency spectrum be established at a test specimen distance of 1 meter, in order to measure radiated susceptibility levels for compliance testing. In the case of a 41″ rod antenna, this requires delivering one watt or more power over the spectrum from 10 kHz to 30 MHz. At the lower end of this spectrum, where the antenna is especially inefficient, the power required may reach several watts. At these levels the tuning inductor of the rod may saturate, overheat, and burn out.

In MIL-STD-826A, still in effect on some contracts or in Notice 3 to MIL-STD-461A (USAF), the required susceptibility field intensity at the test specimen is 10 V/m below a frequency of 35 MHz. Clearly, the rod antenna is useless since it is power limited. Furthermore, at frequencies of 30 MHz to 200 MHz, available antennas are either power limited or do not exhibit adequate efficiencies. Thus, either burnout is still a concern or substantial power levels may be needed to develop the required field intensities. Relatively large tunable RF powers, such as 10 watts or more over the UHF spectrum, are expensive to instrument. As a practical matter this side steps the real problem at its source, viz., using efficient antennas.

This article reviews in both a tutorial and pragmatic way how one may achieve the required radiated susceptibility field intensity in an efficient, reasonably-priced manner. Specifically, the article reviews the topics of the LF Cage angenna, (DC to 1 MHz), parallel-plate lines (DC to 30 MHz), miniature parallel-plate lines (DC to 1 GHz), and the transmission-line antenna (10 kHz to 50 MHz).

TRANSMITTER ANTENNA FACTORS & EFFICIENCY

Antenna Factors (AF), as described and used in the preceding chapter, refer to an antenna used in a receiving mode of operation. This term relates the field intensity to a measured voltage using both an antenna and a receiver or sensitive voltmeter. A new term, called transmitter antenna factor (TAF), will be defined and used to rate performance efficiency of an antenna when it is employed to develop radiated susceptibility fields or, more simply, a field intensity at a defined distance. Antennas will then be rated in terms of a TAF, such that the higher the number, the more effective is an antenna in performing radiated susceptibility testing.

TAF DEFINITION

The transmitter antenna factor (TAF) is defined in the following manner:

$$\mathrm{TAF} = \frac{E}{V_t} \tag{1}$$

$$\text{or, } \mathrm{TAF}_{dB} = 20 \log_{10}(E/V_t) \tag{2}$$

where,

E = field intensity in units of V/m at the test specimen distance (one meter or other) away from the developing source or transducer.

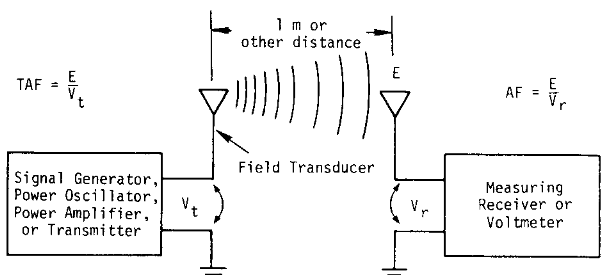
V_t = voltage at the transmitter (or oscillator or power amplifier output) antenna input terminals in units of Volts (see Fig. 1)

The units of TAF are V/m per Volt input. Since the object is to achieve the highest radiated field intensity possible (V/m) for the least transmitter input voltage (or power), it follows that relatively high values of TAF are preferred. Another way of stating this is, that for a stipulated value of field intensity required by a specification, relatively high values of TAF permit correspondingly lower values of V_t (or transmitter power) since, from Eq. (1):

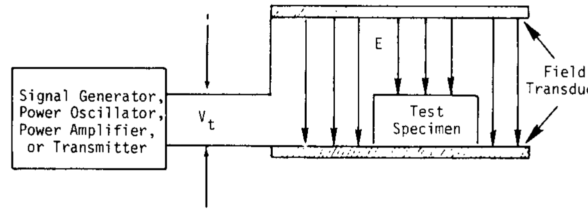
$$E = V_t \times \mathrm{TAF} \tag{3}$$

MEASURING TAF

From Fig. 1 it is seen that TAF vs. frequency can readily be measured in terms of V_t and E for any transmitting antenna at one meter or other distance. All that is required, is that the antenna factor (AF) of the measuring antenna be known for the near or far field, as applicable, at a one meter separation.



(a) Specimen Outside of Field-source Device



(b) Specimen Inside of Field-source Device

Figure 1. Field Transducers used to illustrate "Transmitter Antenna Factors," TAF.

Table 1. TRANSMITTER ANTENNA FACTORS (TAF) OF EMISSION AND SUSCEPTIBILITY ANTENNAS

Antenna Type	Below 1MHz	1-30MHz	30-200MHz	0.2-1GHz	1-10GHz
Capacitive Probe	Unusable	NA	NA	NA	NA
Passive Rod	-25to-15dB	-15to-5dB	NA	NA	NA
Active Rod	Unusable	NA	NA	NA	NA
Tunable Dipole	NA	NA	-3dB	-3dB	NA
Broadband Dipole	NA	NA	-10to-3dB	NA	NA
Bi-Conical Sp.	NA	NA	-14to-3dB	NA	NA
Conical Log Sp.	NA	NA	NA	-13to+1dB	NA
Log Periodic	NA	NA	NA	-8to+6dB	NA
Ridged Guide	NA	NA	NA	+3to+10dB	NA
Long-Wire	-6to+0dB	-6to+0dB	NA	NA	NA
Cage Antenna	-10to0dB	NA	NA	NA	NA
Large Chamber	-19dB	NA>3MHz	NA	NA	NA
Parallel Plate	+3dB	+3dB	NA	NA	NA
Strip-Line	+12dB	+12dB	+12dB	NA**	NA
Paraliel-Line	-4to+2dB	-4to+2dB	NA>50MHz	NA	NA
Conical Log Sp.	NA	NA	NA	NA	+3to-1dB
Ridged Guide	NA	NA	NA	NA	+7to10dB

* For example, efficient antennas (TAF > -5dB) below 200 MHz and costing about $500 to $1,000 can preclude the need for power amplifiers costing $3,500 to $10,000.
** See special configuration for DC - 1 GHz; TAF ≃ +16 dB.

$$AF = \frac{E}{V_r} \tag{4}$$

where,

V_r = voltage at receiving input terminals,

by substituting for E in Eqs. (1) and (4), it follows:

$$TAF = \frac{AF \times V_r}{V_t} \tag{5}$$

Thus, one measures the transmitter voltage, V_t required in Fig. 1 to produce an input voltage, V, by substitution techniques. This technique is directly useful when the antennas are in the near field of each other provided the antenna factor, AF, was so computed.

MEASURING TAF (SAE METHOD)

The recommended SAE ARP-958 method for measuring and computing the antenna factor of an antenna based on an *identical-pair* procedure. This procedure is valid as long as the two antennas are in the far-field of each other. For a one meter separation, this corresponds to a minimum usable frequency of about 100 MHz for low-gain antennas.

REPRESENTATIVE TAF VALUES

In this article, it will be shown that values of TAF of the order of 0 dB for susceptibility testing are highly efficient antennas, They assure relatively low RF power requirements (e.g., about 2 watts) to produce field intensities of 10 V/m. Values of TAF of the order of −10 dB or less are to be avoided since they require RF power outputs of the order of 20 watts or more to develop field intensities of 10 V/m. This is wasteful and inefficient, and results in the need for expensive high-power oscillators and/or amplifiers when they should not be required due to the use of inefficient antennas in the first place.

Table 1 lists the antennas reviewed in both the previous and this chapter. The entries are the TAF values for the frequency ranges shown. Upon examining the table the following is concluded and/or recommended regarding the use of antennas and chambers for radiated susceptibility testing:

(1) The passive-rod antenna is highly inefficient (−5 to −25 dB) and should be avoided.

(2) The parallel-plate or strip-line chambers should be used below 30 MHz for relatively small test specimens and either the long-wire or parallel-line antennas used for medium-size specimens.

(3) The bi-conical antenna should be avoided at its low frequency end (TAF = −14 dB) and either a strip-line chamber (for small specimen) or the parallel-line antenna should be used from 20 to 50 MHz.

(4) The conical log spiral is 9 to 16 dB poorer than the ridged-guide antenna below 1 GHz and should not be used unless there exists power to spare.

LF CAGE ANTENNA, DC TO 1 MHz

The cage antenna is used for relatively large test specimens at low-frequencies (LF) for radiated susceptibility measurements. The cage antenna is merely a parallel-plate configuration terminating a feeder line in which the test specimen is placed between the parallel plates as shown in Fig. 2. The plate areas are typically chosen to be several times larger than the cross-sectional area of the test specimen, and the plate separation or height, h, is chosen to be about twice the height of the largest test specimen expected to be measured. In essence then, the cage antenna is merely a large physical capacitor of small value connected across a 50-ohm output line termination of a signal generator or power amplifier.

The equivalent capacitance of the cage will vary from about 10 to 100 pf with values of 30 pf being typical for a 10 ft.^{2} plate area and 8 ft. height. at 10 MHz, this corresponds to a shunt reactance of about 500 ohms across a 60 ohm feeder line and 50 ohm-termination. Therefore, as seen below, the cage capacitance is not the upper-frequency limiting consideration.

The equivalent feed and termination inductance of the cage, as described later in this section, is of the order of 1 μh. Thus, its value becomes significant when this reactance is about 20% of the 50 ohm termination. This takes place at about 2 MHz and becomes one of the principal upper-frequency limiting factors.

APPLICATION CONSIDERATIONS

The cage angenna will work well up to a frequency for which the total length, L, shown in Fig. 2 is less than about 0.1λ. For signal generator to cage coaxial line lengths of about 10 feet, cage dimensions of about 10 feet and height of 4-12 feet, the total length L is approximately 30 feet. Thus, for L ∼ 30 feet = 0.1λ, the maximum usable frequency is about 3 MHz. If the configuration is larger, the maximum frequency is lower, and vice versa. Other parasitic effects tend to limit this upper frequency.

It is concluded that the cage antenna works well up to about 1 MHz since it is terminated in the impedance of the signal generator, typically a 50 ohm, 10 watt, non-inductive resistor. Since the length of line from signal generator to the resistor is less than 0.1λ at the highest frequency, the

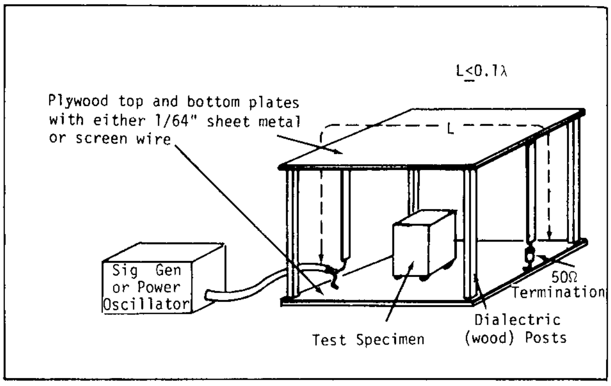


Figure 2. LF Cage Angenna showing Test Specimen in Place

input impedance seen by the signal generator is approximately 50 ohms regardless of the characteristic impedance of the cage. Thus, the field intensity vs frequency within the cage will be as flat as the frequency response of the signal generator.

TAF FACTORS OF THE CAGE ANTENNA

The cage antenna is relatively efficient in terms of the transmitter antenna factors (TAF) it exhibits, i.e., it develops a reasonably good field intensity per signal generator output voltage. Applying Eq. (1) to the cage, the TAF is:

$$\mathrm{TAF} = \frac{E}{V_t} = \frac{V_t/h}{V_t} = \frac{1}{h} \tag{6}$$

For a typical cage height from four to ten feet (about 1 to 3 meters), the TAF is:

$$\mathrm{TAF}_{dB} = 20 \log_{10}\left(\frac{1}{h}\right) \tag{7}$$

$$= -10 \text{ to } 0 \text{ dB}$$

For a height of about seven feet (h = 2 meters), for example, the TAF is −6 dB and a field intensity of 10 V/m can be obtained with an output voltage of 20 V from an oscillator capable of furnishing $V_t^2/R = 8$ watts. If it is really desired, an oscillator capable of furnishing 2 watts, can perform (make available its internal voltage) into an open circuit. The 50 ohm impedance termination of the cage may be removed and then twice the V_t voltage will appear when compared to a terminated situation. Thus, a two-watt signal generator output normally providing 10 volts into 50 ohms, will develop 20 volts to an open circuit. Since field intensity, not power extraction, is desired, the resultant field would be 10 V/m. This practice of not terminating a signal generator or power amplifier at VLF may not always be possible since some generators have a VSWR mismatch cutout to avoid damage. When this is possible, the TAF factors offered by the cage antennas will be twice as great or −4 to +6 dB.

CONSTRUCTION CONSIDERATIONS

The cage antenna is very simple and cheap and can be built in a few hours. The upper and lower parallel plates can be constructed from either (1) 1/64″ sheet aluminum attached to a cheap grade of plywood on supporting 2″ x 2″ or 2″ x 4″ studding used at the corners and in between as often as needed to support the frame. Nails can be used to hold the configuration into place since their lengths are very small compared to the parallel-plate separation.

Because the cage antenna is only intended to be used up to about 1 MHz, no special precaution is required regarding the feed and termination lines. A half inch wide copper or brass foil exhibits an inductance of about 0.1 μh/foot. Ten feet of this foil or strip feeding a 10 foot high cage, and 10 feet used in termination corresponds to a total series inductance of 2μh. At 1 MHz the resultant reactance is j12 ohms which when added to a 50 ohm terminating resistor results in an impedance of 52 ohms—a negligible change. Thus, the signal generator coaxial line has its outer braid soldered to the lower parallel plate and the center conductor is soldered to the 1/2-inch foil which runs up and is soldered to the top parallel plate. In a like manner, the foil is used to terminate a 10-watt (or higher, if necessary), 50 ohm, non-inductive resistor to the load end of the cage, as shown in Fig. 2.

LARGE MF CAGE TEST CHAMBER

The preceding section discussed the LF-cage chamber used for susceptibility irradiating test specimens in size up to a standard dualbay, 19″ console. Economy of cage design and fabrication simplicity resulted in a practical upper frequency of about 1 MHz without developing significant standing-wave and non-uniform field problems. This section extends the cage-chamber approach in the form of a very significant refinement in that:

(1) Test specimen sizes up to a vehicle (automobile, small tank or truck, or missle) can be accommodated.
(2) Upper frequency range is extended to 3 MHz.
(3) Both free-space and high/low-impedance fields can be simulated.
(4) Field intensities of the order of 100 V/m are achieveable.

The large MF chamber discussed herein can produce uniform fields over a 20-foot diameter sphere. By feeding the transmitter to one end of the chamber and terminating the other, a 377-ohm, free-space condition is obtained. By splitting the transmitter output to drive both ends of the chamber in phase, a field impedance in excess of 4 kΩ (high-impedance field) results in the central portion; for opposite phase excitation, a field impedance of less than 40 ohms (low-impedance field) is achieved. This remarkable flexibility at high field intensities permits either far-field or near field (E or H fields) electromagnetic conditions to be simulated.

DESIGN CONSIDERATIONS

The large-cage test chamber is shown in the photograph in Fig. 3 together with plan and elevation views. The parallel-wall portion of the chamber defines a 30-foot cube test area consisting of two vertical parallel plates, open on all four sides in the vertical plane. Thus, the electrical field of this dominant mode TEM transmission line is horizontally oriented. Configured in this manner, emissions to the outside world due to edge-fringing effects or tendency to

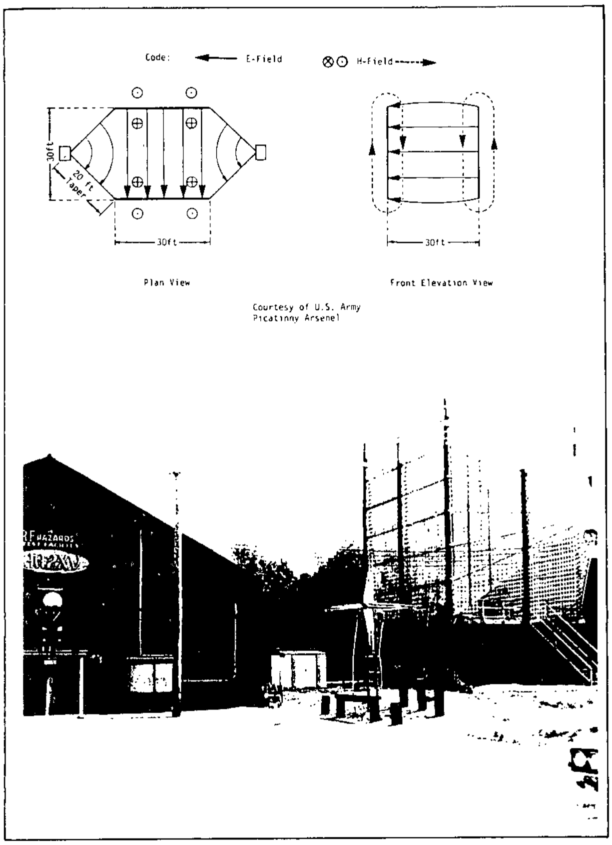


Figure 3. Large MF 135 Ohm Test Chamber for Simulating Free Space and High/Low Impedance Fields

radiate at higher frequencies would be insignificant. Proximity effects necessitate that the chamber be elevated off ground and driven by a balun to achieve balanced operation of both plates and impedance matching of the 135-ohm chamber to 50-ohm coaxial driving and terminating lines. Test specimens are rolled under the chamber where a trap door is opened. A nylon-cord pully system is attached to missile or other test specimens which allows them to be lifted into the center of the chamber at any attitude for irradiation.

To facilitate connecting baluns to the chamber and to minimize impedance mismatch discontinuities at higher frequencies, the chamber is tapered at both ends to preserve a line impedance of 135 ohms throughout the length of the taper. This results in an overall length of about 70 feet or 0.22λ at the upper frequenci)y of operation, 3 MHz. The 30-foot plate separation corresponds to about 0.09λ at 3 MHz which is well below $\lambda/2$ to prevent higher-order modes and to avoid excessive radiation.

FREE-SPACE OPERATION

To achieve free-space operation of the chamber, the input balun is driven from a variable-frequency transmitter system and the output balun is terminated in two power loads through hybrid A, shown in Fig. 5. For this operation the hybrid (a four-terminal, phase/power splitter device) acts as a simple power divider. Both the electric and magnetic fields are relatively uniform throughout the chamber as suggested in Figs. 4 and 5. Because of matched-impedance operation, the constant fields with axial chamber distance results in a free-space impedance condition of $Z_o = E_x/H_y = 377\Omega$ as shown in Fig. 4.

NEAR-FIELD SIMULATION

Because real-life specimens are not always operated in the far field of a potential culprit emitter, it is beneficial to

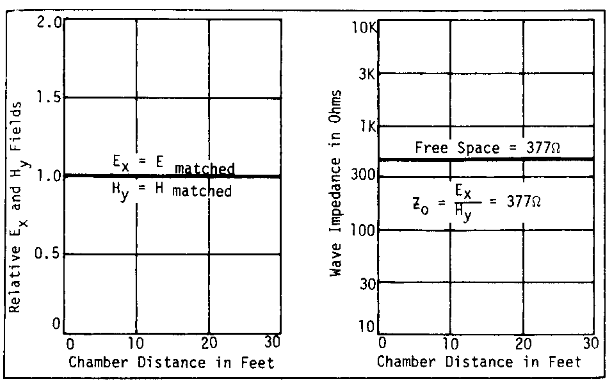


Figure 4. Free Space Operation of MF Chamber

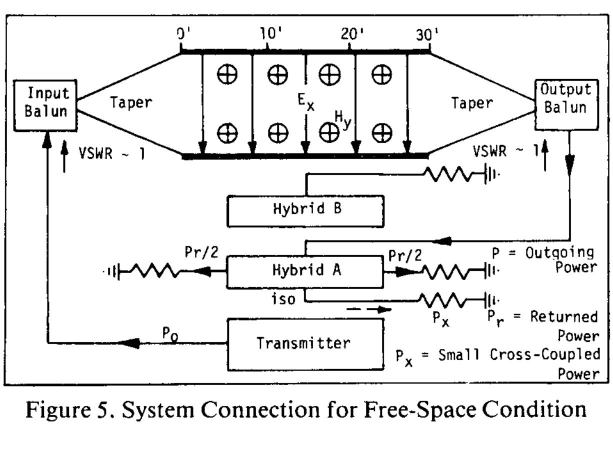


Figure 5. System Connection for Free-Space Condition

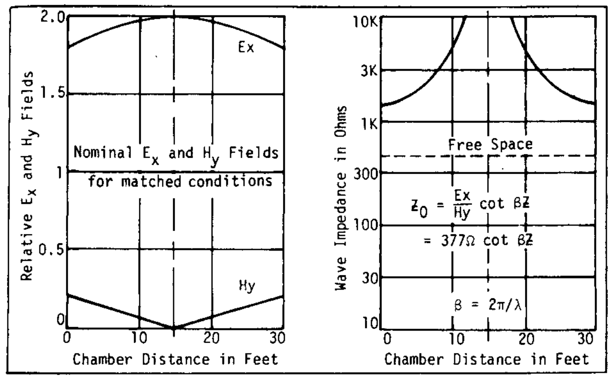


Figure 6. High Impedance Field (Open-Circuit) Operation of MF Chamber

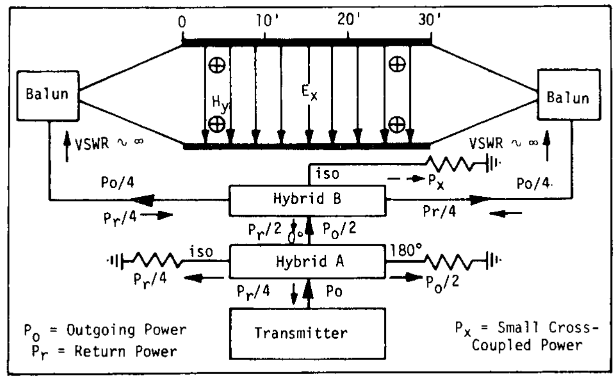


Figure 7. System Connection for High-Impedance

examine performance for either high-impedances (predominantly electric field) or low-impedance (predominantly magnetic field) conditions. Accordingly, the chamber may then be driven at both ends either in phase or out-of-phase, respectively.

The expected performance of a high-impedance operation is first investigated with reference to Fig. 6. When both baluns are driven in phase, as shown in Fig. 7, the resultant electric fields combine at the center of the chamber. This produces an intensity twice that which would exist if one balun only were driven with the same power and the other balun terminated in its characteristic impedance similar to the earlier free-space operation. As shown in Fig. 6, this also produces a zero magnetic-field intensity at the chamber center since the currents produced by each balun source are equal and opposite.

The net effect from the above operation is to produce a very-high impedance at the center of the chamber since $Z_o = E_x/H_y$ (E_x is twice normal, and $H_y \sim 0$). For this situation the impedance Z is:

$$Z = 377\Omega \cot\left(\frac{2\pi z}{\lambda}\right) \tag{8}$$

where,

- z = axial distance from center of chamber at 15 ft. mark.
- λ = wavelength corresponding to the frequency of operation.

The impedance in Eq. (8) is plotted in Fig. 6 for 3 MHz operation. Notice that over the central 10 feet of the chamber, the impedance is greater than 4 kΩ. For lower frequencies, the impedance is correspondingly higher as observed in Eq. (8). For worst-case conditions (3 MHz and edge of chamber where z = 15 ft.), the impedance is greater than 1 kΩ.

Regarding the system connection to achieve the above operating mode, the transmitter in Fig. 7 drives hybrid A which splits half its power to the 180° load arm and half to the 0° port. At hybrid B, the power again divides equally and is presented in phase to each balun. Other than due to minor losses, all the power is reflected back since a VSWR $\sim \infty$ is exhibited at each balun. The returned power is combined in phase again at hybrid B where it is delivered to hybrid A and split as shown. The net result is that the transmitter sees 25% of its output power reflected, which corresponds to a VSWR of 3:1.

The connection for producing low-impedance fields is similar to that for high-impedance fields except for those at hybrid B where the connections to the input and isolated terminals are interchanged. This produces equal amplitude voltages which are in phase opposition.

The corresponding low impedance fields are identical to those shown in Fig. 6 except that the relative amplitudes of E_x and H_y are interchanged. Consequently, the impedance becomes:

$$Z = 377\Omega \tan \left(\frac{2\pi z}{\lambda}\right) \tag{9}$$

Therefore, the impedance in Fig. 6 would now be inverted about 377Ω and have a value in the central 10 feet of the chamber of less than 40 ohms at 3 MHz. The impedance is correspondingly lower at lower frequencies of operation.

TAF FACTORS OF THE MF CHAMBER

The above MF Chamber is not especially efficient in terms of the transmitter antenna factors (TAF) it exhibits, i.e., it develops a modest field intensity per unit of transmitter output voltage. Applying Eq. (1) to the chamber, the TAF is:

$$\mathrm{TAF} = \frac{E}{V_t} = \frac{V_t/h}{V_t} = \frac{1}{h} \tag{10}$$

For the 30 foot (h = 9.2m) plate separation, Eq. (10) yields, TAF = 1/9.2 = 0.11 V/m per Volt input ≈ − 19 dB.

While the TAF for the chamber is about 10 db less efficient than the small cage and 15-20 dB less efficient than the long-wire antenna, this penalty is purely attributable to the very large test specimens that must be accommodated. If one were to compare the size of the specimens which can be accommodated by each exciter, the MF chamber can handle specimens 10 to 100 times the volume of the other two. The MF chamber is indeed a tour-de-force.

PARALLEL PLATE LINES, DC TO 30 MHz (MIL-STD-462)

There are many instances, when the field intensities required for susceptibility testing are relatively high (<<1 V/m) and where existing EMI emission antennas are either incapable of adequate performance and/or the price of power amplifiers or power oscillators is uneconomical. These conditions arise most often when a particular item will be placed in service where susceptibility hazards may exist over a specified frequency spectrum. The field intensities encountered can be 10-100 V/m such that special exciters may be needed for susceptibility testing. At frequencies below 30 MHz, these fields can be developed by the parallel-plate transmission line.

APPLICATION CONSIDERATIONS

The parallel-plate transmission line is an extension of the cage antenna concept. An important difference, however, is that the combined length of the parallel-plate line and its feeder cable at the upper frequency of application (30 MHz) significantly exceeds 0.1λ. Thus, its construction is more critical. The test item is placed between the two plates

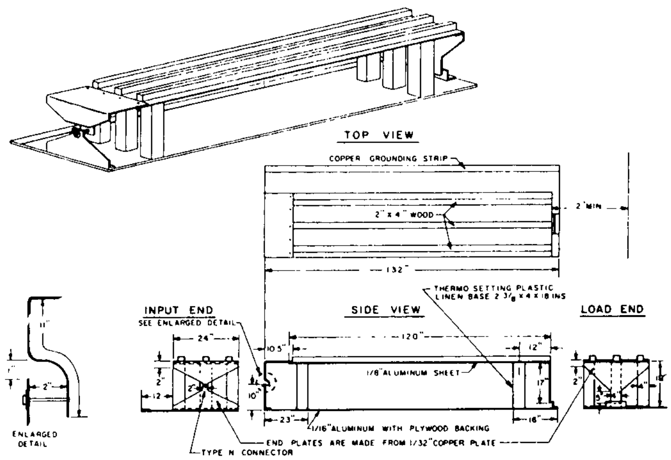


Figure 8. Typical Parallel Plate Line per MIL-STD-462

that compose the transmission line. Fig. 8 shows a parallel-plate line that is used for radiated susceptibility test RS04 in MIL-STD-462. While the utilization of this type of device in the past has not been widespread, it will likely see greater service in the future for test specimens whose largest dimension does not exceed about one meter and whose second greatest dimension does not exceed about one foot.

As discussed for the cage antenna below 1 MHz, the parallel-plate line is also a relatively large open-air capacitor that is used as a conductor pair to connect a load to a signal generator. At 1 MHz the overall length of all lines from signal generator output to load is less than 0.1λ. As the applied frequency increases, however, the behavior of the parallel-plate line becomes more truly like a transmission line. Thus, impedance mismatches between this line and either the source or load can develop significant standing waves to invalidate test measurements unless certain design considerations are followed.

One important consideration in the design of a parallel-plate line is the separation between plates and the widths of both plates. This, together with an air dielectric, defines its characteristic impedance. Typically, the line is driven by some source, such as a signal generator interconnected by a length of coaxial cable. The length of this line is unimportant *provided* an impedance match throughout the system is preserved.

Assume the dimensions of the test item are height, h; depth, d; and width, w. Either the physical dimensions of the test fixture are controlled by the size of the largest test item to be tested using this line, or the converse applies. The controlling dimension of the test item is generally its height, h, as placed in the line. In order to achieve by one standard, a sufficiently uniform field distribution, the parallel-plate separation should be at least three times the specimen height, h. Fig. 9 shows a dual view of the cross section of the line. The left half of the figure shows the uniform-field distribution that is achieved in the absence of the test item and the right half of the figure shows an approximate electric-field distribution achieved with the test item present whose height is one-third that of the line. The field intensity on the right is 50% (3.5 dB) greater. This cannot accurately be stated since the test item also creates an impedance mismatch which, when reflected back to the generator will present a lower or higher impedance depending upon the line length in units of λ. If the test specimen were allowed to be higher than one-third the plate separation, the resulting field intensity becomes more uncertain. As explained later, however, this situation is in reality not significant.

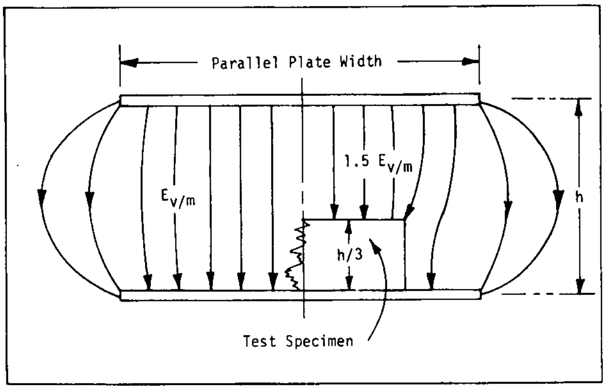


Figure 9. Cross Section of Parallel-Plate Line Showing Uniform Field Distribution on Left and Disturbed Field with Test Specimen on Right

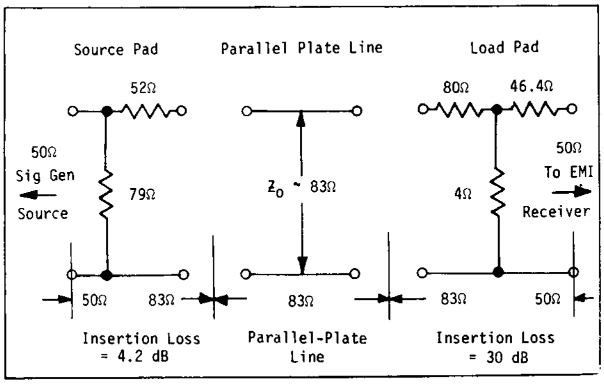


Figure 10. Impedance Matching Networks for connecting Parallel-Plate Line to Source Signal Generator and Terminating Load including EMI Receiver.

TAF FACTORS OF THE PARALLEL-PLATE LINE

The parallel-plate line is relatively efficient in terms of the transmitter antenna factors (TAF) it exhibits, i.e., it develops a reasonably high field intensity per unit of signal generator output voltage. Applying Eq. (1) in a modified form to the line, the TAF is:

$$\text{TAF} = \frac{E}{V_t}\alpha = \frac{V_t/h}{V_t}\alpha = \frac{\alpha}{h} \qquad (11)$$

ψηερε,

where,

α = voltage loss of the transmission-line, impedance matching network

For the parallel-line configuration specified in MIL-STD-462 (see Fig. 8), α = 4.2 dB = 0.62, and h = 18″ = 0.46 m. Thus, Eq. (11) yield 0.62/0.46 = 1.35 V/m per volt input, or a TAF ≈ 3 dB.

Other configurations than that in MIL-STD-462 discussed for the parallel-plate line are reviewed in a later section.

CONSTRUCTION CONSIDERATIONS

Among the design factors to be considered are (1) the field intensity that must be achieved, (2) the physical size of the item to be tested, and (3) the frequency range to be covered, viz., the maximum frequency to be used. There exists no practical limitations on the field intensity achieveable other than to assure for high fields, that the impedance-matching network and load are properly rated in power:

$$P = \frac{V^2}{R} = \frac{(E/\text{TAF})^2}{R}$$

For a field intensity of 10 V/m, the above TAF of 1.35 and R values of about 83Ω, Eq. (9) indicates that non-inductive, resistors of $(10/135)^2 \div 83 \cong 0.55$ watts are required (use 2 watts). Had E been 100 V/m then R ratings in excess of 55 watts would be required. IRC resistive card would then have to be used as discussed later in this article.

The physical size of the test item was previously discussed. For the MIL-STD-462 parallel-plate line, it is limited to about 1 ft. x 1 ft. x 3 ft. For larger specimens up to 30 MHz, the transmission-line (or other) antenna will have to be used, or up to 1 MHz, the cage or large cage antenna can be used.

Construction details of the MIL-STD-462 line are shown in Fig. 8. In order to make an 18″ height for a plate width of 24″, the impedance of the line must be raised. For the MIL-STD-462 line, the line impedance is 83 ohms. Therefore, it is necessary to use a 50 ohm to 83 ohm impedance matching network such as shown in the left in Fig. 10.

For convenience in monitoring the voltage as an analog of field intensity, a second network is shown in the right in Fig. 10. The resistor values are chosen to give a 30 dB loss since an EMI receiver will otherwise be confronted with levels up to 140 dB above its minimum sensitivity. Actually, a simple broadband (up to 30 MHz) RF voltmeter will suffice here. Since the field intensity E and output voltages are related by 1/h (Eq. 11), E = V/h = V/0.46m (18″ height = 0.46m) or E = 2.19 V. Because of the 30 dB loss pad, this value becomes: E = 2.19V x 31.6 = 69V.

Other than practical considerations, there is no maximum limits on the length of the parallel-plate line for impedance-matched conditions. MIL-STD-462A requires that 2 meters of test specimen cable length be exposed to the field in addition to the specimen, per se. Together with a maximum length of the test item of about 3 feet, this indicates that the minimum length of the line should be 10 feet. Accordingly, the length of the parallel-plate line shown in Fig. 8 is 120 inches. Together with 18″ of drive and load termination length, at 30 MHz, this corresponds to 0.35λ, a significant fraction of a wavelength, but again unimportant for matched impedance conditions.

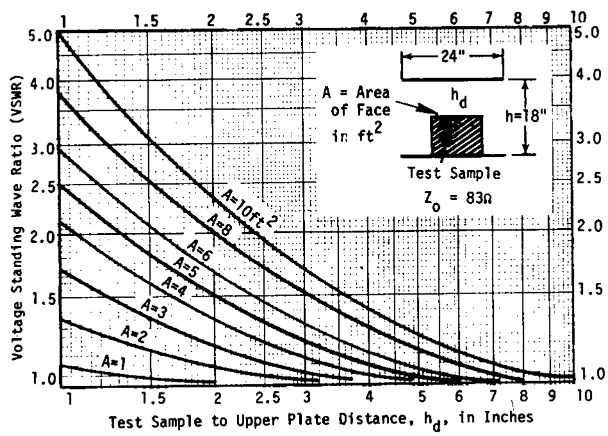


Figure 11. VSWR in Parallel-Plate Line from Test Specimen Discontinuities at 30 MHz

VSWR AND AXIAL ELECTRIC FIELD CONFIGURATION

It was remarked earlier that placing test specimens in the parallel-plate line is equivalent to introducing a capacitive discontinuity into or across the line. However, for other than very large specimens crowding the inside dimensions, it will be shown that the resulting VSWR is not really significant.

The value of the capacitive discontinuity, C_d, offered by the test specimen may be approximated by:

$$C_d = 0.22A \left[\frac{1}{h_d} - \frac{1}{h} \right] \text{pf} \qquad (13)$$

where,

A = area in sq. in. of the test specimen face parallel to the plates

h_d = height or distance between upper plate and face of test specimen

h = height or spacing of parallel plates

The reactance, X_c of this capacity is:

$$X_c = \frac{1}{2\pi f C_d} \qquad (14)$$

When shunting the load impedance, Z_L, the resulting impedance, Z_d due to the capacitive discontinuity is:

$$Z_d = \frac{-jX_c Z_L}{Z_L - jX_c} \qquad (15)$$

The VSWR developing from this mismatch is:

$$\text{VSWR} = \frac{Z_L}{Z_d} = \frac{Z_L - jX_c}{-jX_c} \qquad (16)$$

Eq. (13) is calculated for various values of X_c for an upper design frequency of 30 MHz in terms of A and h_d, for h = 18″ and Z_L = 83Ω. The results of this are shown in Fig. 9. For VSWRs less than 1.5, the minimum allowable distance between the psecimen face and the upper plate is about 3″ for a surface area of 8 ft. sq. Thus, a factor of 4″ (10 cm) is conservative as called out in RS04 of MIL-STD-462. For example, for a test specimen having a face surface area of 2 sq. ft., the distance between upper plate and specimen can be 1 inch which corresponds to a VSWR of less than 1.4

LARGE STRIP LINES, DC TO 1 GHz

This section is a continuation of the concept of the DC – 30 MHz parallel-plate line set forth in MIL-STD-462 and presented in the preceding section. The useful upper frequency of the configuration to be discussed is at least 200 MHz. It will be shown that field intensities in excess of (1) 1 V/m are obtainable with laboratory signal generators which supply outputs of 0 dBm at 50 ohms, or (2) 10 V/m for utputs of +20 dBm (−10 dBw). Transient broad-band fields as high as 500 V/MHz/m up to 5 MHz, 50 V/MHz/m up to 50 MHz, or 10 V/MHz/m up to 200 MHz can be obtained using this strip-line configuration with a high-voltage impulse generator or equivalent.

The line geometry of the chamber to be discussed limits the useful test specimen size to about a cigar box or smaller size. The line can be built for about $150 in parts plus about one day of technician time. For small test specimens, such as heart pacers, it is considerably more economical to use the strip line and available laboratory signal generators for susceptibility testing than to use the bi-conical and other antennas from 10 kHz to 200 MHz which require a power amplifier costing an additional $3,500.

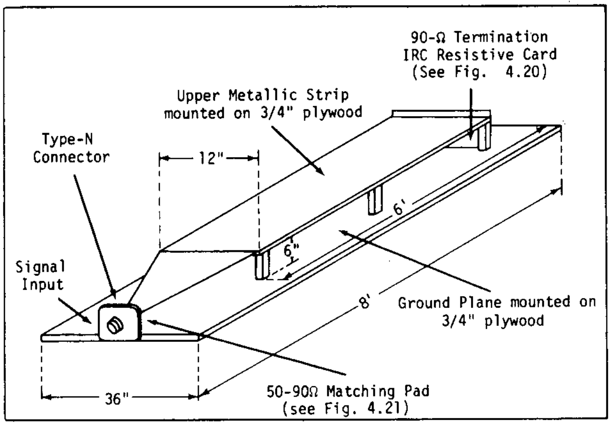


Figure 12. 90 ohm Strip Transmission Line

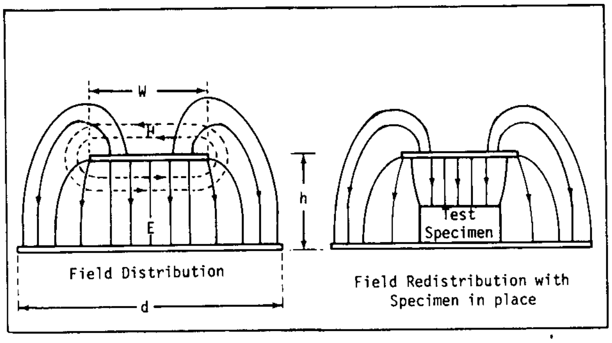


Figure 13. TEM Field inside of Strip Line

APPLICATION CONSIDERATIONS

The strip-line test configuration is shown in Fig. 12. The line operates in its dominant TEM mode from DC to over 200 MHz. The electric and magnetic field configurations are shown in the left in Fig. 13. The re-adjusted electric-field lines are shown in the right with a test sample in place. Since the test item produces an impedance mismatch, the cross-sectional area of this specimen should be kept to less than about 20% of the w•h area so the VSWR will not exceed about 2:1 during specimen testing (see Eq. 16).

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