RADIATION MONITOR CALIBRATION TECHNIQUES

The techniques used to calibrate and evaluate electromagnetic leakage probes or radiation probes are as important as the fundamental design of the probes themselves. These probes are utilized in the measurement of potentially hazardous electromagnetic fields and must therefore exhibit the maximum integrity that can be achieved. Because there is no single technique that can provide a valid calibration over the extreme range of frequencies that probes encompass, three different methods are used. One covers the high frequency range from about one to eighteen gigahertz, a second technique covers the low frequency range from ten megahertz to five hundred megahertz and the midrange, from five hundred to one thousand megahertz, is calibrated by yet another technique.

The design of electromagnetic probes are not discussed below. Instead, this article will primarily direct itself toward describing calibration techniques and some probe evaluation procedures (such as pulse power testing).

HIGH FREQUENCY (1—18GHz) CALIBRATIONS

An anechoic sled provides the necessary mechanism for calibrations. Figure 1 details the structure. The rails run parallel with a minimum of deviation in tilt and lateral motion. The transmitting pedestal is free to move along the track. The front surface has at least 1/2 meter of radiation absorbing material extending radially about the transmitting horn. The receiving pedestal has at least 1 meter of absorbing material on all sides of the radiation probe under calibration.

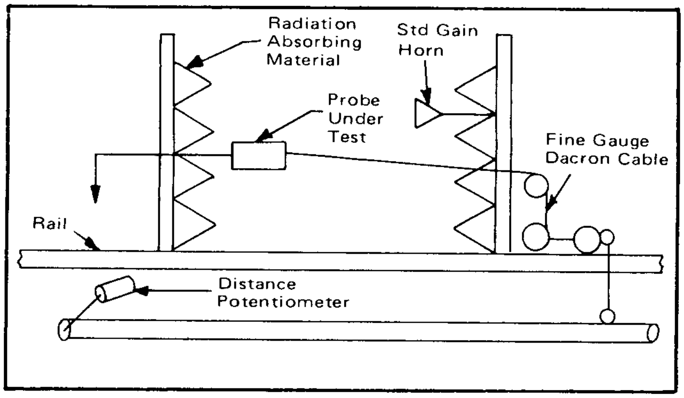


Figure 1. Anechoic Sled Schematic

The transmitting pedestal is linked to a looped "piano" wire in proximity to, and parallel to, one of the rails. This wire is coupled to a precision potentiometer which provides an accurate indication of the position of the pedestal. The potentiometer output and the output of the monitor under test provide exitation to a rectilinear recorder.

The transmitting horn is aligned with its axis parallel to both rails. The probe under test is similarly aligned with the axis coincident with the axis of the transmitting antenna. Interconnecting or output leads of the probe run normal to the electric vector of the propagated wave. All other equipment is positioned behind their respective pedestals.

The output of the probe instrumentation, such as a recorder output, is connected to the "Y" axis of the rectilinear recorder. The "X" axis of the recorder is connected to the precision potentiometer to provide a measure of the distance between the aperture surface of the transmitting antenna and the plane of measurement of the probe under test.

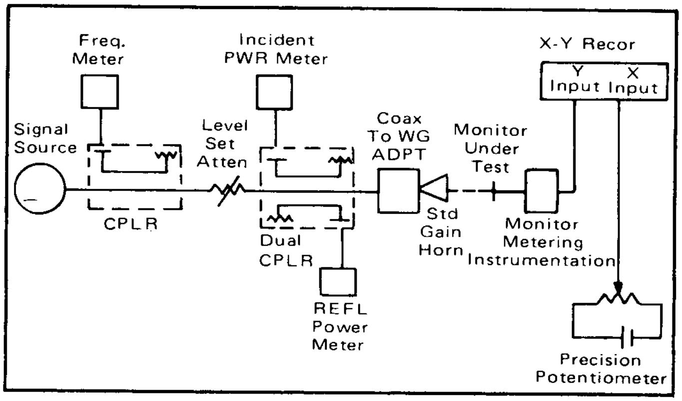


Figure 2. Anechoic Sled Test Set-up

Behind the transmitting pedestal, the equipment is connected as illustrated in Figures 2, 3 and 4. Three factors must be considered when measuring the transmitted power: 1) coupling factors of the incident directional coupler from its side arm to the output connection (Refer to Note 1.); 2) reflected power due to mismatch at the output coupler port and the antenna input; 3) insertion loss of the adapter between the standard gain horn and the monitoring directional coupler. The true transmitted power, together with the near zone gain of the standard gain horn and the separation distance between this transmitting horn and probe under test, will establish a standard field for calibration.

A basically broad band device, such as a traveling wave tube amplifier is used for signal generation or amplification. A low pass filter and isolator (not shown in Figure 2) are used at the output of this signal source to ensure that the signal is free from harmonics and to prevent "pulling" of the oscillator, if it is not buffered. Coarse adjustment for transmitted power is made by adjustment of signal source output control. Fine adjustment is provided by the level set attenuator.

With no power applied, the transmitting pedestal is moved to the point where the aperature of the standard gain horn and the measurement plane of the probe coincide. This allows their axis to be aligned and establishes a reference point for the separation distance.

The separation distance is dependent upon available power. This distance is used for calibration and should be greater than $a^2\lambda^{-1}$ (where a is the maximum dimension of the standard gain horn). Smaller distances may be used, but the correction function for the horn gain will be larger.

A small gauge dacron cable is fastened between the probe support and the transmitting pedestal to ensure that the distance between them remains constant. The probe support allows the probe to move along its axis and remain parallel to the rails. As the transmitting pedestal is moved (approximately 2 wavelengths), the distance between the receiving pedestal and the probe under test will vary and the distance between the probe and the transmitting pedestal will remain constant. The probe output is recorded on a rectilinear recorder as a function of probe or transmitting position. Exact knowledge of transmitted power is not necessary provided that it remains constant during the procedure.

Note 1: Conventional calibration of directional couplers is from the side arm to the incident port, as opposed to the output port, as required here.

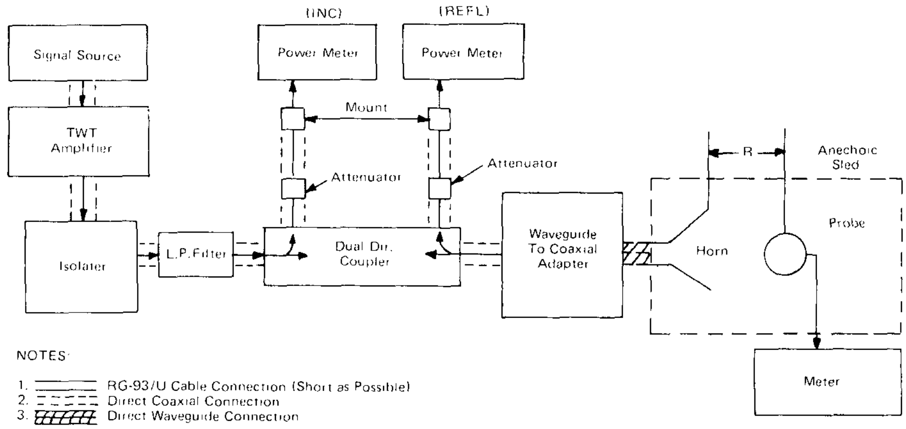


Figure 3. Electromagnetic Test Set Up For Probe Calibrations From 1.7 — 12.4 GHz

The recorded trace will reveal a sinusoidal variation of probe output as a result of scattering from the surface of the receiving pedestal. The probe is then positioned at a position where the rectilinear trace shows a zero crossover of the sinusoid. The dacron cable is then disconnected. The amplitude of the trace will vary as a function of the effectiveness of the lossy material used. Generally, the scattering from anechoic materials is greater at lower frequencies. At higher frequencies this scattering may be insignificant and this procedure may be eliminated.

The field is again established, this time requiring exact knowledge of transmitted power. The indicated output of the probe under test is noted together with a mark showing the separation distance on the rectilinear recorder. The transmitting pedestal should be moved approximately one wavelength to a smaller separation distance between the standard gain horn and probe under test. The pedestal is then moved approximately two wavelengths, increasing the separation distance, while the probe output as a function of separation distance is recorded. The resultant cyclic variation is averaged to obtain theoretical power density point exclusive of multipath interference which causes the cyclic variation. The calibration of the probe can now be corrected for multi-path interference. If, at the calibration separation distance, the chart recorder shows a probe output of 7% above the average line (which represents the theoretical power density), the true field at the calibration distance is 7% above the theoretical power density. Noting what the probe was actually reading provides the unit with a calibration factor. It is assumed here that the probe output is linearily related to power density.

If the instrument under test does not have a recorder output, point by point measurements can be noted as the transmitting pedestal is moved 1 cm at a time. They may then be graphed and the preceding method of calibration followed.

This calibration technique results in a high degree of accuracy. The calculation of near zone gain has been shown to be within a 0.1 dB uncertainty. Coupler, attenuator and power meter calibration used for the measurement of transmitted power provide a total uncertainty of 0.2dB. Multipath interference can be resolved to an uncertainty of 0.1dB using the techniques described above. The measurement of distance contributes less than 0.05dB error. The total of all three contributions results in an uncertainty of less than ±0.5dB.

LOW FREQUENCY RANGE

In the Low Frequency Region, 500 MHz and below, calibration is accomplished using the National Bureau of Standards designed TEM Transmission Cells, (See Photo A.) TEM cells are sometimes referred to as Crawford Cells, named after the man who developed this technique. More detailed description is available in the published paper, "Generation of Standard EM Fields Using TEM Transmission Cells", IEEE transaction on Electromagnetic Compatibility, November 1974.

TEM cells are 50-ohm, rectangular, coaxial transmission cells. A standard field is established by transmission of a known power through the cell into a 50 ohm termination. The RF voltage on the septum or center conductor and the spacing between this septum and the outer conductor establish the calibrating field. The larger of the two cells shown, which functions

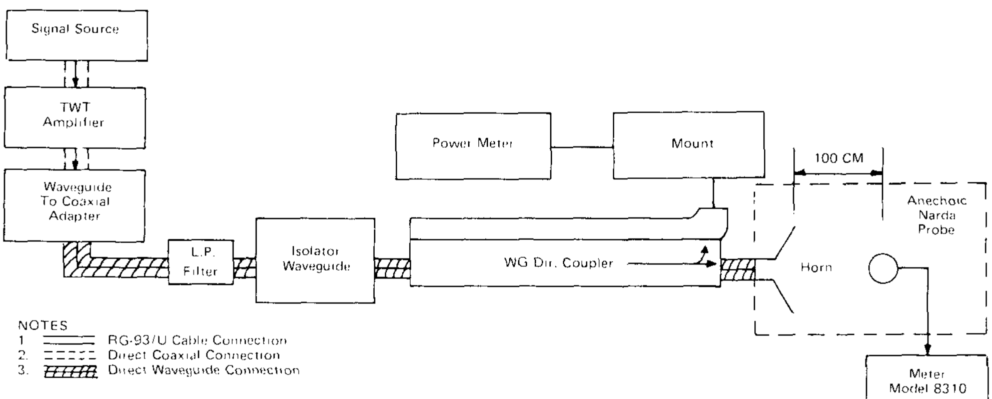
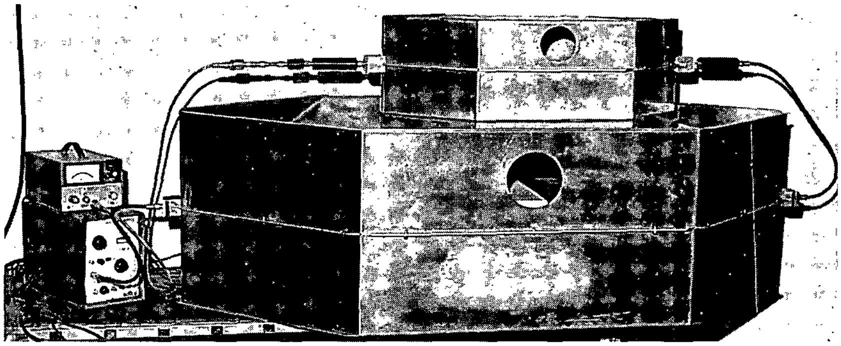


Figure 4. Electromagnetic Test Set Up For Probe Calibrations From 12.4 — 18.0 GHz

Photo A. TEM Cell



below 200 MHz, is sufficient to accept both probe and instrument and is used to insure the compatibility of the total instrument in the high density fields.

The smaller of the two cells shown is an exact half scale of the larger cell. When conducted in series with a six dB pad between them, the larger cell driven, the smaller cell terminated, the force fields in both cells are equal but the potential on the center conductor is twice as large in the larger cell. A probe which truly responds to the electric or magnetic force fields will read the same when introduced into the fields in either cell. If a probe has poor common mode rejection and is responding to the potential distribution, it will read higher in the larger cell. This condition is indicative of a probe design that is incapable of making an accurate measurement.

These cells have yet another application. By replacing the 50-ohm termination of the cells with a short or open circuited cable at an appropriate distance from the center of the cell and at a specific frequency, either a total electric or magnetic field is established at the cell mid-point. The TEM cell may be used to ascertain that a probe is responding to a maganetic field. By positioning a short at the terminating end of the cell a quarter wavelength from the cell center, a minimum H field and a maximum E field result at that point. When an H field probe is positioned at that point the meter should indicate a null. As the probe is moved to either side of that position the indications rise.

The total uncertainty in calibration utilizing the TEM Cell is ±0.5dB. Uncertainty of power transmitted through the cell, including power meter and attenuator calibration, is ±5 percent. Its contribution to field strength error is 2.5 percent. The error in field strength, contributed by distance of the septum to ground, is ±1 percent. The non-uniformity of the electric field may contribute ±6 percent. The total uncertainty in power density calibration is ±12 percent or, essentially, ±.5dB.

At frequencies between 490 MHz and 1100 MHz, a technique based upon propagating the fundamental TE_{01} mode in a side wall slotted section of waveguide is used. One restriction here is that the probes are required to have a uniform E-field response over at least an 180 degree arc and couple lightly into the field.

Figure 5 shows a block diagram of the system. A dual-directional coupler is used to monitor both incident and reflected power. This coupler is followed by a waveguide-to-coax adapter for matching to the waveguide slotted line. This waveguide section is a standard rectangular guide which has a slot milled into it and a slide fitted into the side wall. The slot provides access for the probe elements into the guide center where a maximum and calculable power density field can be obtained. The slide holds the probe, with its antenna elements, in a plane that is normal to the broadwall of the guide. The slide also permits the antenna elements to be moved along the center axis of this calibrating plane. (See Figure 6.) No measurable energy will leak from the guide through the slot regardless of whether the probe is, or is not inserted.

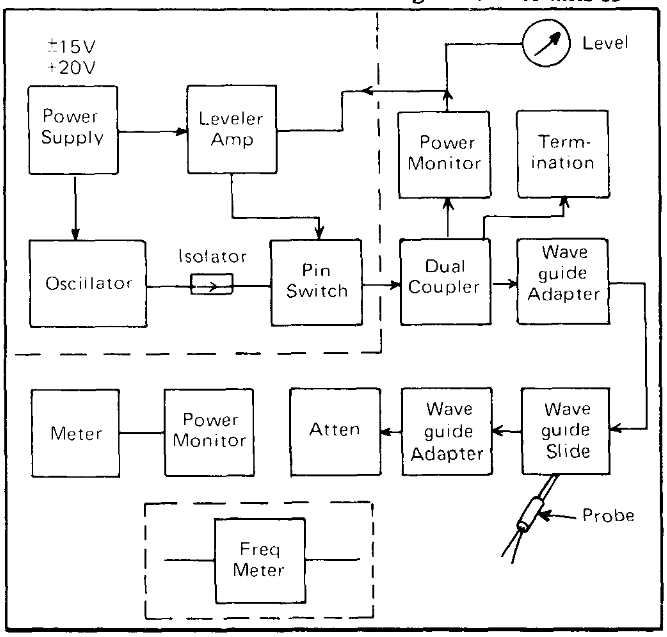


Figure 5. System Block Diagram

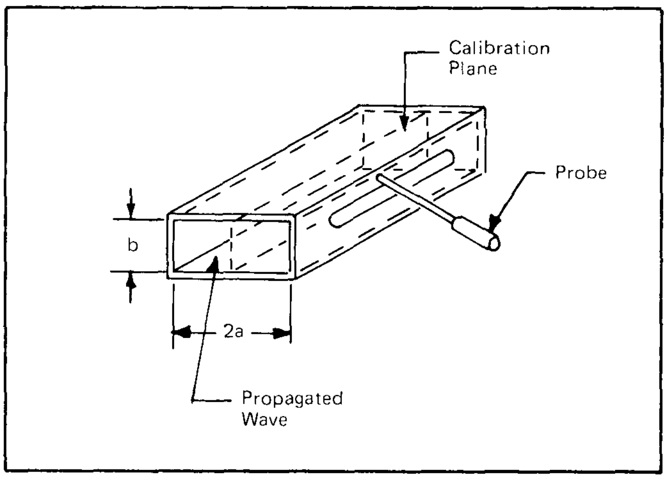


Figure 6. Slotted Waveguide Section With Calibration Plane. (The probe handle and coupling leads are essentially invisible because they're normal to the E-field

The system is calibrated at the point of maximum field strength in the plane normal to the propagation vector. The power density at this plane is calculated assuming a sinusoidal distribution of the E-field across the guide with a maximum near the center and zero at the side, which is normal TE mode E-field distribution. (See Figure 7.) The calibration plane is slightly off center due to the presence of the dielectric pressure plate, but the field is uniform in the orthogonal direction.

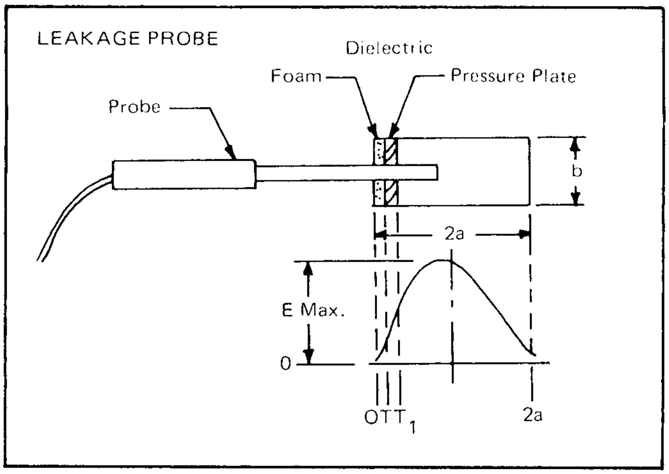


Figure 7. Electric Field Distribution Across Waveguide.(Basically, a TE01 mode. Asymmetrical distribution is caused by the dielectric at the sidewall.

Distortion of the field caused by scattering from the probe is evaluated with the slide. The slide is traversed through one-half wavelength and minimum and maximum indications are noted. The true calibration will be the average of these readings. Some scattered energy from the probe antenna cannot be evaluated by movement of the probe with the slide. This energy is that which is returned to the probe antenna due to reflection from the guide sidewalls, the phase of which does not vary as the probe is moved. It represents that portion of the scattered field that is normal to the sidewalls and, for the small dipoles generally used, it contributes an almost immeasurable error.

Standing waves within the guide will be caused by reflections from the terminating load as well as the scattering from the probe under test. If the probe has been well designed for its application, and couples lightly to the field, the standing waves will essentially be only a function of the reflection coefficient of the terminating load. The associated uncertainty at any random distance along the calibrating plane is:

$$\epsilon_1 = |\,(1 + \Gamma)^2 - 1\,| \times 100\%$$

The voltage reflection coefficient for a well made waveguide termination is 0.005, which would contribute a 1% uncertainty. This uncertainty is completely eliminated by averaging the minimum and maximum readings as the probe is traversed along the calibrating plane.

Position the probe for a maximum indication as it is inserted into the guide. This will locate the probe antenna in the center axis of the guide. The slope of the slide and error in maintaining this center axis contributed a very small error. Relative deviation of power density, as a function of distance from the center, is:

$$\epsilon_2 = \mathrm{Sin}^2\,(\pi\Delta a/2a)$$

If Δ a, the variation in waveguide width, is assumed to be 0.25 cm, which is a liberal tolerance, $\epsilon_2 = 0.005$ which means a 0.5% error.

Error, due to the ability to average the probe scattering error, is estimated at less than 1/2%. This is based upon typical maximum to minimum deviations as the slide is traversed approximately ±5%. If the incident power is maintained constant during the movement of the slide and probe, the variation caused by scattering from the probe is substantially reduced. This can be accomplished by a leveling loop with the monitor or reference point at the power meter at the incident arm of the directional coupler. With a high gain leveling loop, this variation can be reduced to almost zero. The residual variation will be caused by reflections from the termination, a reasonably good calibration could be obtained without the special sidewall slotted section of waveguide. Attenuation in the section of guide is negligible, being approximately 0.004 dB per foot.

Insertion loss of the coax-to-waveguide adapter may be accounted for using the two-adapter measurement method and attributing the loss equally to the two adapters, the insertion loss being one half of the total measured. The coupling factor of the directional coupler used to monitor incident power should be determined from the side arm to the output port of the main line as opposed to the usual calibration which is from the side arm to the incident port of the main line.

An estimate of the accuracy of this system is as follows:

Incident Power Measurement	±2.0%
Position and Slope Error	±0.5%
Coupler Coupling Factor	±1.0%
Insertion Loss Estimate	±0.5%
Averaging of Scattering Effect	±1.0%
Waveguide Tolerance	0.3%
TOTAL	5.3%

The calibration as described is for probes which have antenna elements in a single plane. Isotropic probes using multiple plane construction require a calculation of average power density over the entire surface being monitored. If three elements in mutually perpendicular planes are used, calibration is possible without more involved calculation, provided two of the elements are oriented in the center plane. This may not be practical to accomplish while maintaining the entrance port in the sidewall of the guide. Other access ports in the waveguide increase the flexibility of this waveguide technique.

PEAK PULSE POWER DENSITY

The waveguide sections provide for an additional test function. When the resistive termination of the waveguide is replaced with a sliding short, a standing wave can be established in the waveguide with a maximum at the center of the slide. A probe positioned at this point will be made subject to an extremely high field strength, far above the average value. The CW signal source is replaced with a pulse signal source, with the duty cycle set to .00033. Average power density, as indicated by the radiation monitor under test, is raised to fullscale on the probe's highest power density range. At 100 mW/cm² average indication peak power density will be 300 watts/cm². At 20 mW/cm² indication the pulse power density will be 60 W/cm².

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