RF ANECHOIC CHAMBERS THE ALTERNATE TEST SITE

INTRODUCTION

Electromagnetic compatibility is a matter of increasing concern. In recognition of this concern, international agencies have introduced specific standards for levels of radiated RF emissions which can be tolerated from different types of equipment and for the immunity standards which must be met by certain groups of equipment.

Designing EMC into a device is the first part of the solution. Being able to measure the EMC standards which have been achieved is quite another problem.

The military and other agencies, such as the FCC in the United States, and CISPR and VDE in Europe, have attempted to describe test procedures and test site requirements which should be followed when manufacturers evaluate their equipment against the standards set by these agencies.

For the most part, an outdoor "open field site" is suggested when radiated emission measurements are to be performed, and an "RF shielded enclosure" is preferred for immunity testing.

Both of these sites can be used successfully when certain other test conditions exist. The creation of a set of such favorable conditions is often beyond the control of the test engineer. For example, an "open field site" is influenced by environmental and electromagnetic "pollution" from TV and radio stations, weather conditions and any other RF radiating device in the vicinity.

A reliable, consistent and convenient alternative test site is needed. The RF anechoic chamber is the alternative test site.

SUSCEPTIBILITY TESTING

Requirements. Electromagnetic susceptibility (EMS) and electromagnetic vulnerability (EMV) testing requirements exist in both military and industrial environments.

(Part 2), MIL-STD-461B as applied to avionics equipment requires field intensity levels as high as 10V/m from 14 kHz to 30 MHz, 5V/m from 30 MHz to 10 GHz, and 20 V/m from 10 GHz to 40 GHz for certain applications. For external equipment to an aircraft, the field strength requirement is 200V/m over a defined frequency band.

In Part 5 of the standard for surface ships, 100V/m from 14 kHz to 30 MHz and 200V/m up to 10 GHz and above is required as a test field intensity.

MIL-STD-1385 (Navy) concerns the Hazards of Electromagnetic Radiation to Ordinance, and vulnerability test levels of field intensities up to 300V/m and power densities of up to 175 milliwatts/CM² sqr cm are requested.

Industry now routinely evaluates the susceptibility of various equipment, including computers and automobiles, at field intensities up to 200V/m. Standards are continuously under review, and it is anticipated that even higher intensity levels may become routine in the future.

Suitable Test Conditions. In order to isolate the test site from the eccentricities of the environment, and to control the potential interference caused by the test, it is normal to follow the recommendation of MIL-STD-462 and use a high quality RF shielded enclosure around the test site.

By careful attention to each penetration of the shielded enclosure, such as access doors, electrical service entries and ventilation openings, shielding systems can easily provide RF isolation from the environment of at least 100 dB to frequencies of 10 GHz and above.

Thus, interference at the test site due to ambient RF conditions is eliminated. However, the enclosure itself introduces the problem of extraneous energy reflected from the inside surfaces of the shielding, which will set up standing wave patterns inside the chamber at many resonant frequencies. Chamber resonances and standing waves cause test results to be inconsistent and unreliable, depending upon the type of test being conducted. In addition, slight differences in a test setup from day to day can change the amplitude distribution in the room, and therefore the field intensity at the test point, indicating a false level of equipment vulnerability.

Standing wave patterns may be substantially reduced when the inside surfaces of the shielded room are lined with a high quality RF absorbing material. In order to be properly effective over the complete test spectrum, the materials should be tailored to the lower room resonances which can be calculated from the equation.

$$F\,(\mathrm{MHz}) = 150\sqrt{\left(\frac{\ell}{a}\right)^2+\left(\frac{m}{b}\right)^2+\left(\frac{n}{c}\right)^2}$$

where ℓ, m and n are positive integers, only one of which can be 0 at any one time for resonance to occur. The a, b and c are the length, width, and height of the room in meters.

In a chamber 6 m × 6 m (20 ft × 20 ft), for example, the fundamental resonance would occur at approximately 35 MHz, and the TE_{120} mode at approximately 55 MHz.

Below the fundamental or "cut-off" resonance, a relatively even field distribution can be expected. Even at fundamental resonance, the amplitude change across a test region centrally situated in the chamber may be acceptable for most purposes.

However, at higher harmonic frequencies deep pattern nulls will occur in the test region, and it is at these frequencies that the RF absorber reflectivity should be considered. At 55 MHz the wavelength in free space is 5.45 m, (almost 18 ft). However, in a chamber having dimensions on the order of a wavelength, the transmission impedance will differ from free space and the electrical wavelength will vary.

No specific recommendations concerning acceptable amplitude variations across the test region occupied by the equipment under test (EUT) are published in the usually applied testing standards. However, it is acknowledged that the use of electromagnetic wave absorbing materials on some or all chamber surfaces will improve the test reliability by limiting test region amplitude variations.

The best available design for susceptibility chamber testing is for amplitude variation to be less than ±5 dB across the designated test region. Whenever practical, all chamber surfaces should be covered by an absorber material. It is possible, however, to create a good test site when the chamber floor is not absorber-treated. In such a case, the test antenna should be capable of changing elevation to create an "in-phase" relationship between direct and floor-reflected energies at the test position.

Since chambers are "broadband" test sites, a quality broadband absorber should be applied to the chamber surfaces. Good materials for this purpose are solid, homogenously impregnated, pyramidally profiled units of polyurethane foam. A compatible range of floor absorbers which will take distributed loads of 2400 kg/M² are available. These materials can be walked on continuously; and will take heavy loads on pneumatic tired vehicles or "air pallets" when the EUT is a large or heavy item.

The effective attenuation of the reflected signal as compared to the direct signal on an absorber covered surface is termed the absorber "reflectivity". A chart of typical material reflectivity for differing material thicknesses in terms of the incident energy wavelength is shown in Figure 1.

The reflectivity level at the test region of the chamber is related to the amplitude variation across the test region, and consequently the measurement uncertainty, in accordance with Figure 2.

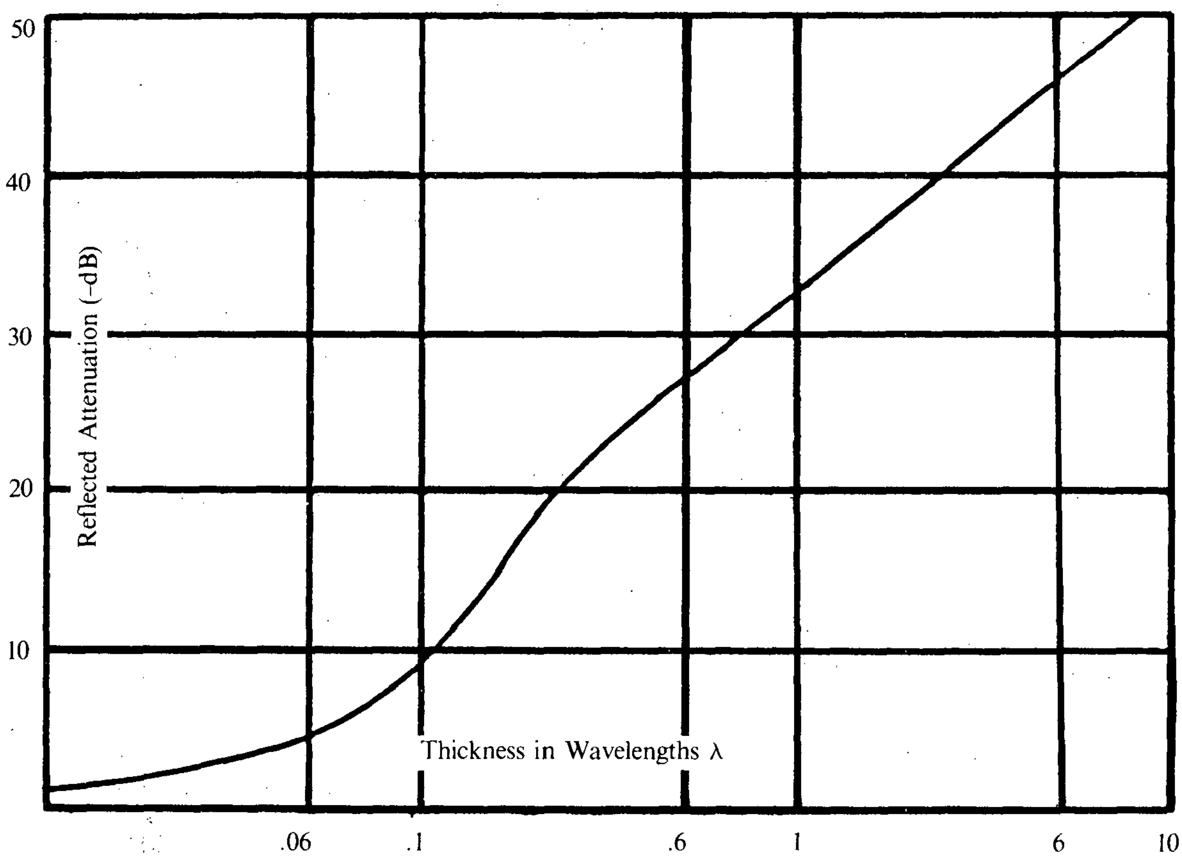

Figure 1. Broadband Pyramidal Absorber Material Reflectivity Levels.

If a susceptibility test is to be performed, and the field change across the test equipment or between different areas of the room should be no more than ±5 dB, the chamber reflectivity must be -6 dB and the materials on the chamber surfaces should be .07 wavelengths deep. This represents 0.38m (15 in), at 55 MHz. Having calculated the exact absorber depth required, the chamber should be lined with the next deeper standard material from the available product range.

It should be noted that absorber treatment of an RF shielded enclosure to produce an anechoic test chamber will have the following important benefits.

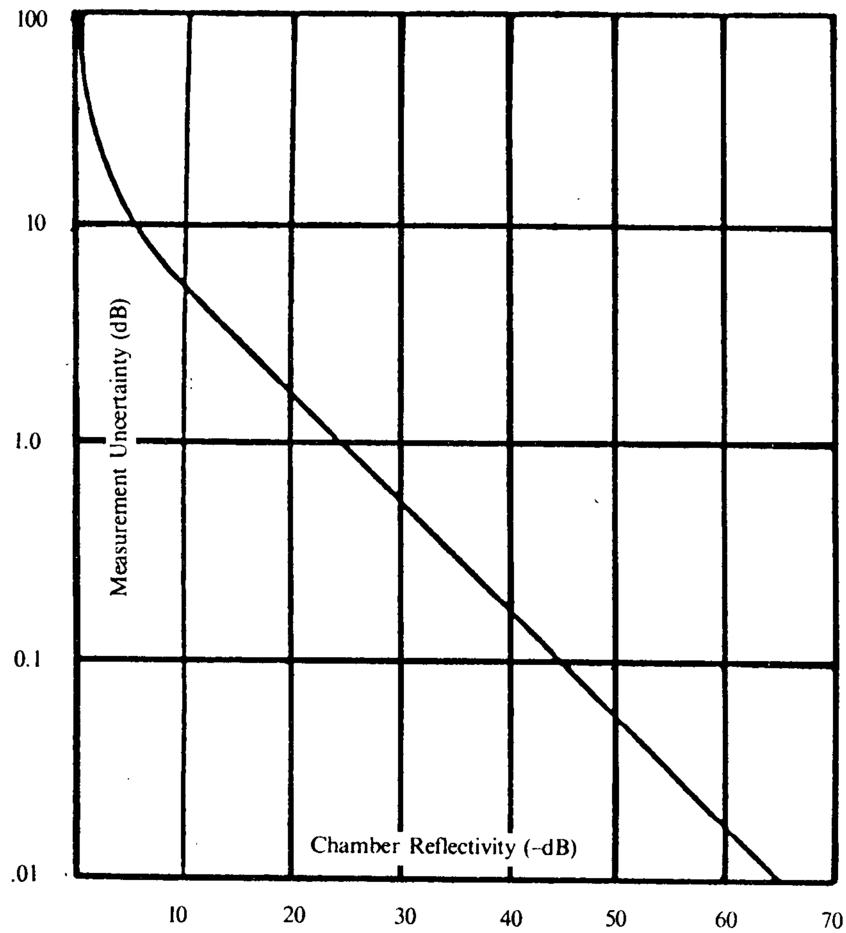

Figure 2. Chamber Measurement Uncertainty.

1. Improve measurement reliability.
2. Ensure repeatability.
3. Ensure that field intensity levels can be achieved, under a wide variety of conditions, with the minimum signal amplification budget.
4. Prevent excessive, potentially dangerous, field intensities from being created outside the monitored test region.

RADIATED EMISSIONS MEASUREMENTS

Requirements. Many international bodies have published standards for radiated electromagnetic energy levels for a wide variety of devices. In addition, the test methods and detailed standards for the test site have been established.

FCC Rules and Regulations, Volume II, (Oct 82) Parts 2, 5, 15 and 18 apply to products to be marketed in the United States. FCC MP-4 details the Method of Measurement of Radio Noise Emissions from Computing Devices and a detailed description of a test site is published in FCC bulletin OST 55. The American National Standard Draft Addition to ANS C63.4 also describes in detail suitable test sites and test procedures.

Other international standards are as follows:

Canadian Standards Association, CSA 108.8 - 1983

Official Journal of the European Communities, 82/499/EEC

VDE 0875/6.77, 0875-102/6.83, 0877-1/11.8.1 and 0877-3/4.80

West Germany Regulation No. 1115/1982

CISPR Draft Standard on DPE/EOM published in July 1983 details both Limits of Interference and Measurement Methods.

Suitable Test Conditions. When radiated emission levels are established for devices such as computers, it is common to define the test procedure and test site conditions. Usually an open field site with a reflective ground plane is suggested but the anechoic chamber, when properly designed, can provide a convenient and consistent facility.

The open field site, which is the subject of most standard test procedures, has a number of obvious disadvantages.

1. Testing is influenced by ambient signals such as radio and TV stations.
2. If a relatively "clean" site is found, it may be several miles away from the industrial situation where the equipment is manufactured, making routine testing an expensive and lengthy procedure.
3. Open sites are at the mercy of the weather. Even covered sites can be influenced by rain and snow conditions.
4. Real estate is expensive and a clear site area may represent a significant investment, depending upon location.

Once again, a quality RF shielded enclosure, with proper design of access doors and service penetrations will provide better than 100dB of isolation to electromagnetic interference which could effect measurements. This means that an RF shielded anechoic chamber test site can be situated anywhere in or around an industrial environment.

The standard by which a site quality is judged is the value of "site attenuation" as measured at the site and compared to a theoretical value.

The ANS C63.4 Draft, for example, states:

> A measurement site shall be considered acceptable for electromagnetic radiation measurements if the measured site attenuation is within 4 dB of the calculated site attenuation for the "standard site".
>
> Field strength measurements on sites which meet this criteria shall be acceptable without correction or adjustment of the measured product emission data.

Site attenuation is measured over a reflective ground plane using two calibrated antennas separated by a horizontal distance, R in meters. Standard values of R may be 3 m, 10 m or 30 m. The transmit antenna is fixed at a distance h_1 above the ground plane and the receive antenna is searched in height until a maximum field strength level is found. Variations in field strength, as the receive antenna height is adjusted, are due to phase changes between the direct signal and the signal reflected from the specular region of the ground plane.

Standard site attenuation is the comparision of the maximum signal level detected by radiation, as compared to direct coupling of the signal at the terminals of the two antennas.

For a standard ideal site, attenuation of the radiated signal in decibels is

$$A = -20 \log F + 48.92 + AF_T + AF_R - E_D^{max}$$

F = Frequency in MHz.

AF_T = Antenna factor of the transmitter in dB.

AF_R = Antenna factor of the receiver in dB.

E_D^{max} = Maximum electric field in the range of the receiving antenna height scan from a theoretical half wave dipole with one picowatt of radiated power.

FCC site description from Bulletin OST-55 requires that acceptable sites demonstrate site attenuation to within ±3 dB of theoretical.

This error allowance is determined from the cumulative effects of errors in each antenna factor and in the calibration of the instrumentation, each of which will contribute ±1 dB to the error budget. The potential exists therefore for a site to be measured as acceptable when the measured attenuation is on the 3 dB limit, but it is not known whether the equipment or the site is responsible for the error.

Unlike the open site, the chamber offers consistent conditions without environmental influences. However, the chamber walls and ceiling are sources of extraneous reflected energy which will interfere with direct and floor reflected energy to create a standing wave pattern in the chamber. The VSWR of the standing wave and the relative position of the points of maximum and minimum field strength to the EUT and receive antenna will influence the site attenuation characteristic of the chamber.

If the chamber walls and ceiling can be covered by an absorbing material, which is effective at the low frequencies of chamber operation and resonance, the resonant mode structures in the chamber will be substantially "dampened" and the chamber will approach an ideal ground reflection site.

A simple computer model of a chamber can be developed which will predict the amplitude variations across the test region by analysis of the interference of signals generated by a source antenna at the position of the EUT and the six images of that antenna in the chamber surfaces. The relative intensity of five of these images in the walls and ceiling can be reduced to represent the reflectivity of the absorber materials.

This interference pattern can then be used to predict chamber site attenuation. A typical set of predictions for changes in the position of the source within a chamber are reproduced in Figure 3, which also shows the set of absorber reflectivity values assumed.

If chamber reflectivity levels, as dictated by the absorber quality, can be controlled to −15 dB, or lower, at the lowest chamber resonant frequency in the bandwidth of test, the site attenuation in the chamber should be within ±3 dB of a theoretical, ideal site.

ABSORBER, MATERIALS FOR UHF AND VHF FREQUENCIES

The FCC has described in its brochure OST 55 the conditions which would characterize an acceptable test site. Computer manufacturers have made use of both open field sites and RF shielded anechoic chambers to perform this testing. The anechoic chamber is a very attractive option when compared to an open field site, but the electromagnetic field conditions in the chamber must be adequately controlled by RF absorbing materials which cover the chamber walls and ceiling, so that test conditions are equivalent to the open field.

It is essential that absorber manufacturers have the ability to characterize materials for operation at UHF and VHF frequencies. Traditionally, broadband pyramidal

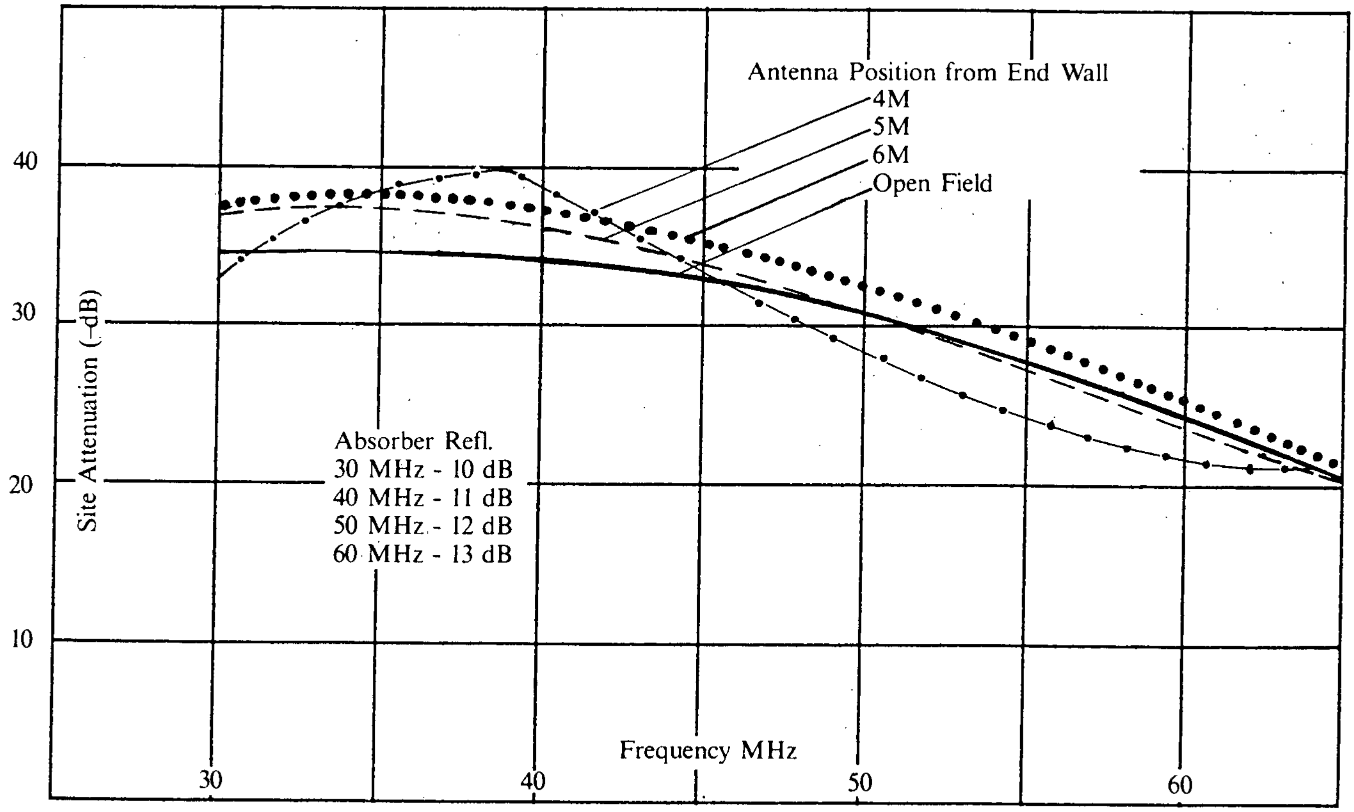

Figure 3. Computed Chamber Site Attenuation Values.

materials have been used extensively in chambers at microwave frequencies where the measurement of material performance on small quantities, or individual units, is able to be performed conveniently and accurately.

In order that an absorber sample be accurately measured for reflectivity in "free-space", a sample having a minimum side dimension of approximately eight wavelengths is required. At frequencies above 1 GHz this is practical, and factory testing using a bistatic test arrangement such as a "Free Space Arch" with high gain antennas is common practice.

At frequencies of 100 MHz and below, however, alternative techniques such as "closed waveguide" must be employed. An example of such a test device, which has been successfully used to optimize broadband absorbers for an FCC test chamber is as follows.

A VHF waveguide system was manufactured having a length of approximately 12 m and internal dimensions 2.4 m × 1.2 m. The open end of the guide accepts the absorber sample mounted to a waveguide "short circuit." Absorber units are conventionally 0.6 m × 0.6 m base area and the guide requires eight units for a measurement sample.

The waveguide has a travelling probe along one side which measures the standing wave in the guide, resulting from energy reflected back by the absorber sample. The operational guide frequencies are 65 MHz to 120 MHz.

The modes in which energy will propagate in a waveguide may be considered as a super-positioning of two plane waves propagating at equal amplitude along two axes at a converging angle (See Figure 4).

1. Figure 4 shows two plane waves propagating from left to right along the axes AA and BB, converging at an angle of 2.0°. The figure represents the condition at one instant in time.
2. Solid lines represent planes of maximum positive E field. Dashed lines represent planes of maximum negative E field perpendicular to the plane of the paper.
3. Where +E lines cross −E lines there are points of zero electric field.
4. These points of zero electric field lie on straight lines at an angle 0 to AA and BB.
5. As the waves progress with time the points remain on these lines. There are an infinite number of such lines and two adjacent ones are shown as PP and QQ.
6. Since PP and QQ are loci of zero, electric field intensity conducting planes containing these lines can be introduced, perpendicular to the plane of the paper, without disturbing the fields.
7. Conducting planes parallel to the plane of the paper can be introduced anywhere without disturbing the fields, as they are at right angles to its E field at all times.
8. Two conducting planes containing PP and QQ and two conducting planes parallel to the paper would intersect to form a rectangular tunnel or waveguide. It is assumed that the space between PP and QQ is the larger side of the rectangle, designated as "a".

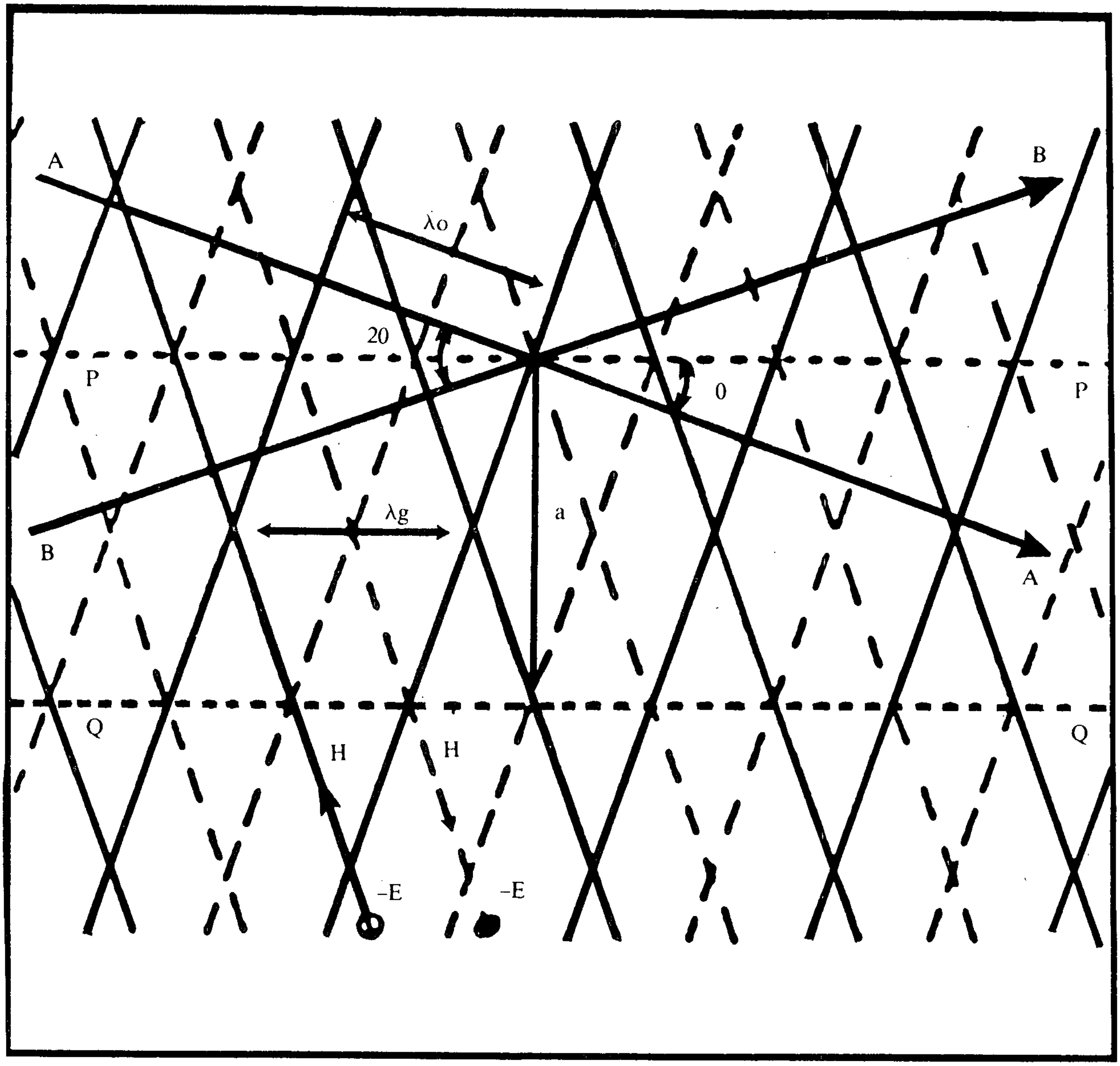

Figure 4. Superimposed Wave Fronts.

9. The field components shown between PP and QQ represent the fields inside a waveguide for the simplest and most common mode, TE_{10}.
10. The solid and dashed field lines represent the direction of the magnetic field in Figure 4.

Each wave has a sinusoidal variation in space and time, and will therefore produce the effect of a forward propagating energy pattern having a sinusoidal amplitude variation created by the constructive and destructive interference of the two component waves. The axis of propagation of the pattern is offset from each of the components.

When a waveguide is excited to transmit energy, the side walls of the waveguide assume two parallel positions in the energy pattern which pass through the lines of zero electric field, resulting from destructive interference between the two component waves. The sinusoidal variation occurs along the axis of the guide when the guide supports the common fundamental TE_{10} mode.

The distance between consecutive points of maximum E field on the guide axis is the guide wavelength (λg). The distance between points of maximum E field in each of the two component waves is the free space wavelength (λo).

λ g is longer than λ o in accordance with the following:

$$\lambda_g = \frac{\lambda_o}{\cos\theta}$$

and $\lambda_g = 2a.\tan\theta$

(a = width of waveguide)

or

$$\frac{1}{4a^2} = \frac{1}{\lambda_o^2} = \frac{1}{\lambda_g^2}$$

If $\theta = 90°$, $\lambda_g = \infty$. The value of λ_o which yields this condition is the cut-off wavelength λ_c.

At frequencies below cut-off, where $\lambda_o > \lambda_c$, the waveguide will not propagate energy.

When $\lambda = \infty$ and $\lambda_o = \lambda_c$ then $\lambda = 2a$

and: $$\left(\frac{1}{\lambda_o^2} = \frac{1}{\lambda_c^2} + \frac{1}{\lambda_g^2} \right)$$

As the operating frequency of the waveguide approaches cut-off and $\theta°$ approaches 90°, the waveguide impedance rapidly approaches infinity. In a waveguide the wave impedance is:

$$Z_{m,n} = Z_o \left[1 - \frac{K_{m,n}^2}{K} \right]^{-\frac{1}{2}}$$

$$K_{m,n}^2 = \left(\frac{m\pi}{a}\right)^2 + \left(\frac{n\pi}{b}\right)^2$$

$$K = \frac{2\pi}{\lambda}$$

Z_o = Impedance of Free Space = 377 ohms

Consequently it may be calculated that the following distinct differences exist between wave propagation in free space and in the waveguide. (See Table 1.)

It is therefore concluded that measured return loss of an absorber material, used as a load in the waveguide, will differ from the return loss which the same material would exhibit in a free space or large anechoic chamber condition. It can be expected that the difference will be more and more pronounced at frequencies approaching cut-off, and at higher frequencies, and results approaching the high end of the fundamental resonance band will be more representative of a chamber test condition.

However, it is apparent that accurate comparative measurement can be made in the waveguide, and it is an excellent tool to optimize materials for low frequency performance in a VHF test chamber. Materials optimized and controlled by this testing technique have been used in chambers designed for both 3 m and 10 m range length measurement of radiated fields.

The first such chamber, measuring approximately 14 m × 11 m × 7 m having absorber materials 2.4 m deep on all walls and the ceiling and site attenuation levels have been determined to be within 3 dB of theoretical. When antenna uncertainty is removed by comparing the chamber site attenuation with an approved open field site using the identical test equipment, the chamber is generally within 2 dB of the open field at frequencies down to 30 MHz.

This article was written by Brian Lawrence, Vice President, Keene Corporation, Ray Proof Division, Norwalk, CT. It is a revised version of a paper which was delivered at the 1984 IEEE International EMC Symposium in Tokyo. It is used here with permission.

Frequency (MHz)	Wavelength (Ft)	Waveguide Wavelength	Impedance Z_o (ohms)	Waveguide Impedance (ohms)	Waveguide Incident Angle ($\theta°$)
65	15.14	44.09	377	1098	69.9
80	12.30	19.03	377	583	49.7
100	9.84	12.42	377	476	37.6
120	8.20	9.52	377	438	30.6

Table 1.