10 APRIL 1961

THE INSTITUTE OF RADIO ENGINEERS

INCORPORATED

SECTION CORRESPONDENCE

PLEASE ADDRESS REPLY TO

Mr. R. J. Farber
59-25 Little Neck Pkwy.
Little Neck 62, L. I.

April 10, 1961
8209-61-R3149

Mr. Vincent J. Mancino, Chairman
Subcommittee 27.4
34 William Street
South Dartmouth, Massachusetts

Dear Vince,

This will acknowledge receipt of the proposed Standard 61 IRE 27.4 PS1 draft by your subcommittee. I have not yet had the opportunity to go through it and so my comments are not directed toward the standard draft itself but toward the procedure which you appear to be following. Has this standard proposal now been approved by your subcommittee? The normal path for such a draft should be from 27.4 through 27 and then to the Standards Committee with other interested committees having a chance to comment during the Standards Committee consideration process. I can understand that you would be concerned about comments from the Radio Transmitters Committee and can appreciate that their comments with regard to this document will be valuable. The thing I am trying to determine is where the proposal stands with respect to the regular Committee 27 procedures since it must enter the Standards Committee via Committee 27 and the document I received in the mail was the first indication that I have had that matters have proceeded as far as they apparently have.

Will you please straighten me out on this. Thank you for your cooperation.

Sincerely yours,

R. J. Farber, Chairman
Committee 27

cc: S. I. Cohn

MANCANO

10 APRIL 1961

THE INSTITUTE OF RADIO ENGINEERS, INC.
1 East 79th Street, New York 21, N. Y.

61 IRE 27.5 C
April 10, 1961

TO: Members of IRE Subcommittee 27.5

FROM: C. W. Frick, Chairman

SUBJECT: Measurement of effectiveness of shielding enclosures

Last November a writeup on proposed measurement methods was circulated to the Subcommittee members. It was based on the best information we were able to obtain after investigating all the sources we knew of.

The consensus of the comments received was generally favorable to the use of this writeup as a basis for a proposed IRE standard. However, some objection was raised to certain methods proposed therein and alternative methods have been suggested which are claimed to give better results. The Subcommittee does not have enough information at present to be able to suggest those alternatives for trial use.

We wish to give adequate consideration to any methods that have proved useful. One of our members, Mr. R. B. Schulz, has covered the methods we have been considering in a paper of which he is co-author, copy of which is attached. This is paper No. 4.3 1961 IRE Convention Record. Appendix A Measurement Methods covers the material in our November 1960 writeup. It would be highly desirable if Subcommittee members and others wishing to propose methods different from these would prepare similar papers. Such papers should include sufficient details so that different observers could try out the methods and compare results.

If prospective authors of such papers will notify the Subcommittee of their intentions effort will be made to allow reasonable time before we recommend a proposed IRE standard. Meanwhile, to obtain broader circulation as planned, copies of this letter with the attached paper are being sent to the members of Committee 27 and of Committee 10.

C. W. Frick, Chairman
Subcommittee 27.5

Enclosure

SHIELDING ENCLOSURE PERFORMANCE UTILIZING NEW TECHNIQUES

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Summary

Techniques for measuring shielding enclosures have been revised to serve as a basis for both an IRE standard and a government specification, intended to be compatible. The selected methods provide for measurement at any frequency from 100 cps to 10 Gc with use of three spot frequencies being recommended as standard procedure. At 15 kc, the source field is set-up by a tilted, single turn loop around the enclosure; at the lowest natural resonant frequency (normally between 10 and 100 mc), the source field is set-up by a dipole antenna; at X band, the source may be a horn, parabola or other radiator. In each case, an appropriate pickup device is used to measure the field at the center of the enclosure. Procedures given have attained a state of refinement as the result of use in the measurement of various styles of enclosures. Measurements so obtained are presented for commercial enclosures manufactured by three major producers.

Introduction

In an attempt to obtain more meaningful data from measurements of shielding performance and to keep the measurement effort for such data to a minimum, new techniques had been developed and reported earlier.[1] Since it is anticipated that the new techniques will be incorporated as the technical basis for both a revision of a government specification[2] and for a forthcoming IRE standard, it was essential that the techniques be proven by actual measurement of various enclosures. This paper reports in appendices the measurement procedures as revised in the course of actual application to various enclosures. These are still subject to revision before adoption in either an IRE standard or a government specification. The main body of the paper presents comments on the procedure and measurement data obtained in accordance with it.

Experimental Results

Introductory Remarks

In order to obtain basic technical information to substantiate the practicality of measurement techniques originally proposed and to determine where modification of such techniques would be desirable, new shielding enclosures were measured in the manufacturing plants of three major producers, and at several customer installations. In addition, measurements were made on several enclosures that have been in operation for extended periods of time.

Manufacturers are designated simply by the letters A, B, and C. Such marking of identification is deemed desirable since the enclosures measured are not necessarily representative of typical enclosure performance of a given manufacturer, due to variations in filter performance, utility entrances, and other special considerations for specific limited applications.

The measurement methods, and the corresponding results obtained are presented under headings of the applicable frequency range, and a means for presenting data from shielding measurements is suggested. Emphasis is not so much on the results themselves, but on the means for obtaining them.

Measurements at Low Frequencies (Below 200 Kc)

1. Comments on Procedure. The transmitting loop is a single turn which surrounds the room and is tilted so that its plane includes a diagonal of the enclosure and is otherwise tilted as in Figure A-1. It is easily constructed by utilizing the two shortest possible wire lengths around the enclosure (spaced at least 1 inch from the shield to limit loop-to-enclosure capacitance) between each extremes of an enclosure diagonal. Since such a loop causes shielding currents to flow across all seams of an enclosure, only one measurement is necessary to obtain an indication of the complete shielding effectiveness at a given low frequency (below 200 kc).

One newly installed enclosure measured was integral with the building structure along two side walls. In this case, the loop wire surrounding the enclosure was run through door openings and a window opening in adjacent rooms in such a manner that the enclosure was at the approximate center of the source loop, which then was much larger in size than the shielding enclosure itself. It might be suspected that results obtained could be affected by closed conducting paths within the loop caused by conduit and pipes. However, the relatively high impedance of such circuits compared to that of the shielding enclosure can have little effect on the measurement. Consequently, it is practical to use the basic measurement technique even for enclosures in confined areas.

2. Low-Frequency Data. Low-frequency plots for five double copper-screening types of enclosures are given in Figure 1 and for three double galvannealed-steel enclosures in Figure 2. Peculiar peaks and dips in the curves are believed to be due to filter performance in the vicinity of the lower cut-off frequency.

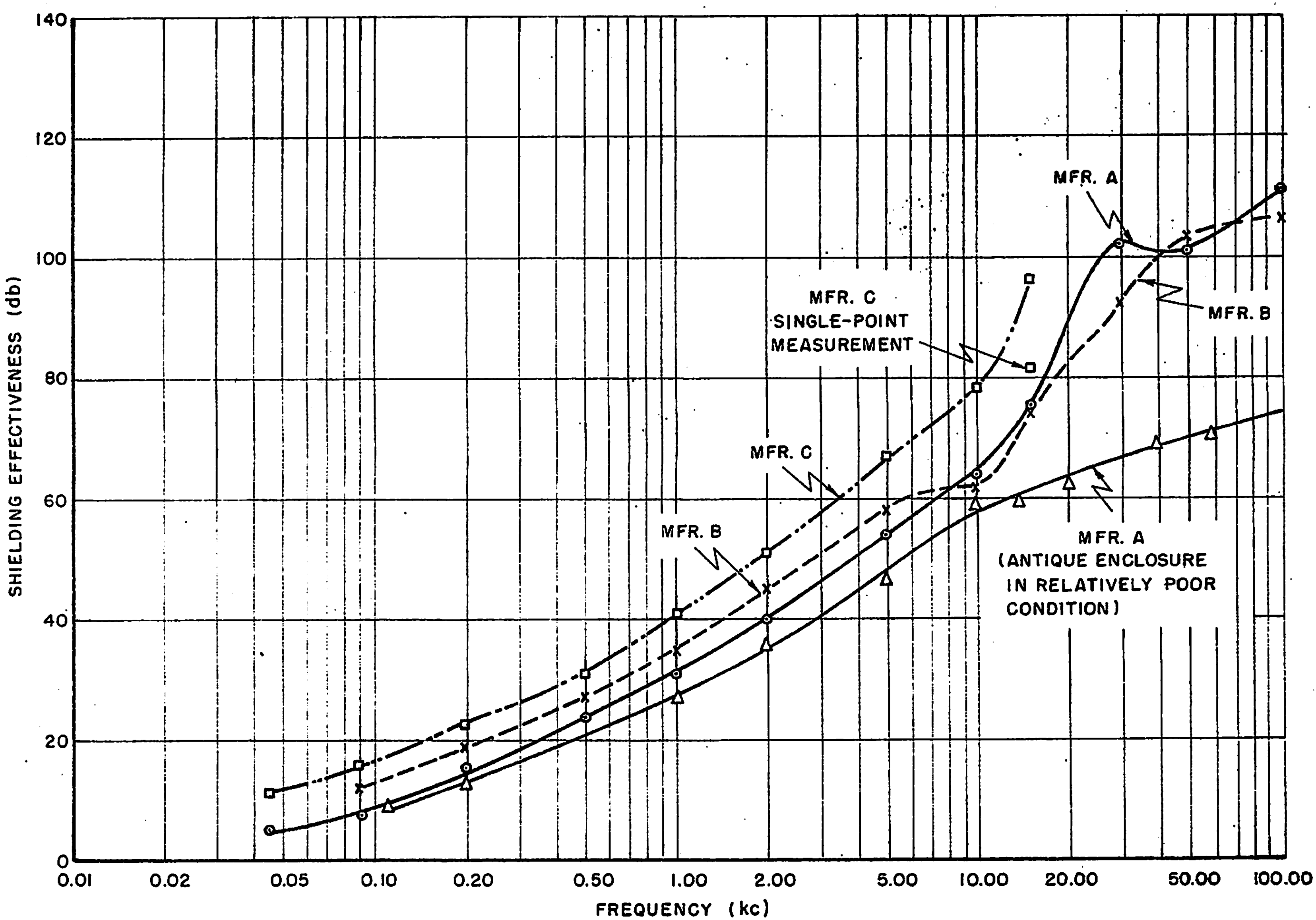


FIG. I LOW FREQUENCY SHIELDING EFFECTIVENESS OF DOUBLE COPPER SCREENING ENCLOSURES

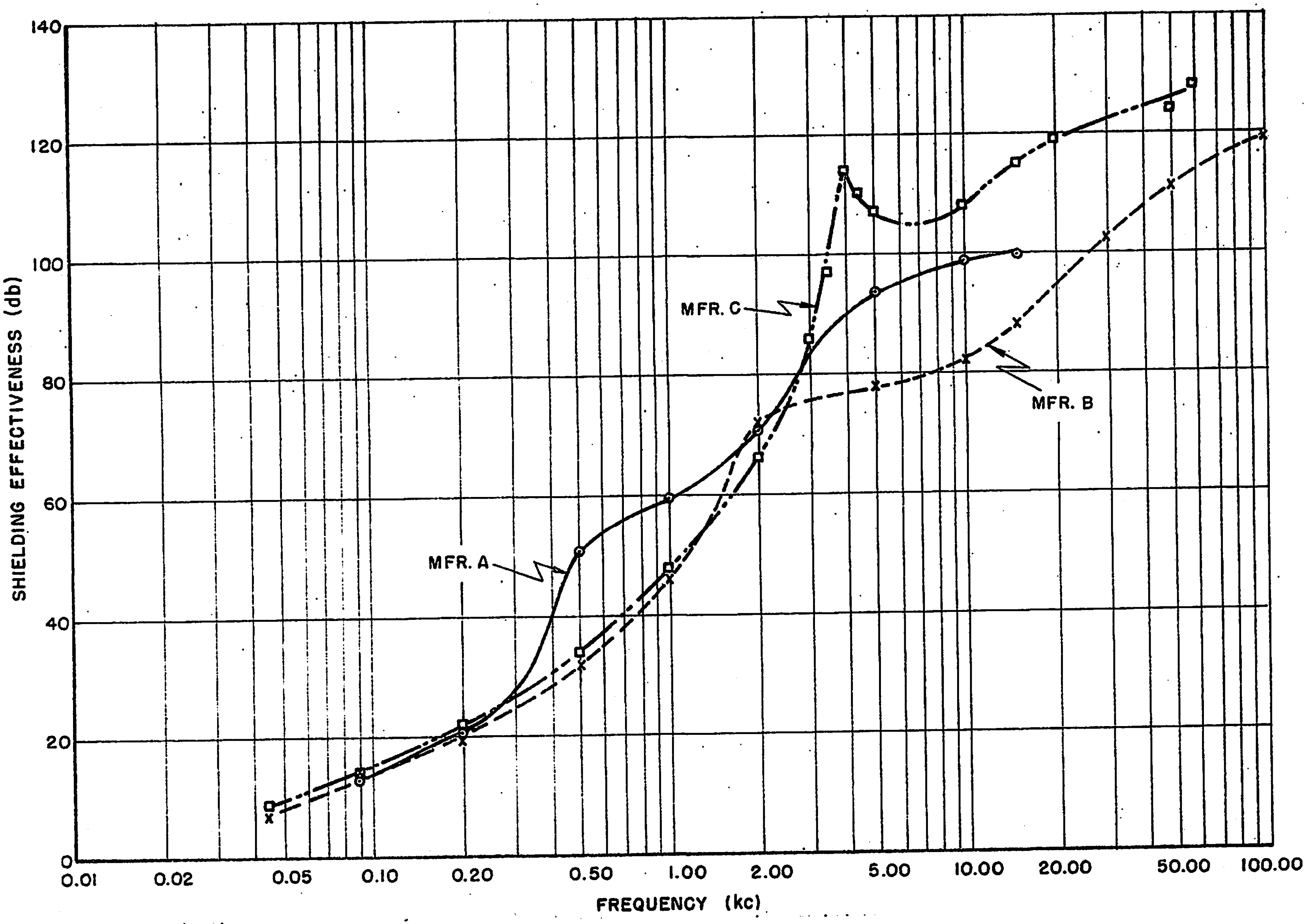


FIG. 2 LOW FREQUENCY SHIELDING EFFECTIVENESS OF DOUBLE GALVANNEALED STEEL ENCLOSURES

In Figure 1, the lower curve is included only for comparison purposes since it represents the performance of a very old enclosure. For new enclosures, the spread in measurement is only 6 db at 45 cps, increasing to 22 db at 15 kc.

In Figure 2, the spread in data is only 2 db at 45 cps and as much as 36 db at 4 kc, the 15 kc spread being 27 db.

Comparison of the two sets of curves shows remarkable similarity below 100 cps, and increasing superiority with frequency above 100 cps for the double galvannealed-steel enclosures.

The data obtained by the new measurement technique can be expected to indicate somewhat higher values of shielding effectiveness than those commonly obtained by a small-loop-to-small-loop technique. The new technique essentially averages out all received signals, whereas the other technique requires the use of two small loops to scan all available seams and suspected weak spots, from among which the poorest reading is taken as the value of shielding effectiveness.

Measurements at High Frequencies (200 Kc to 20 Mc)

Since measurements in the high-frequency range are not considered basic to an estimate of enclosure performance and since they do not differ from previously used techniques, no measurements were conducted in this frequency range.

Measurements in the VHF-UHF Range (20 Mc to 1 Gc)

1. Comments on Procedure. As the tests progressed, variations in techniques were tried in order to further simplify the procedure. As a result, a method was found to determine the lowest natural resonant frequency by a simple experimental technique, described in detail in Appendix A. Basically, the method permits excitation of the enclosure cavity at a fairly high level by first operating with an enclosure door open slightly. A scanning operation with the signal source and a field-strength meter soon establishes the true resonant frequency of the enclosure. With source and field-strength meter both tuned to this frequency and the enclosure door closed, the signal picked up inside the enclosure is measured as E_2.

For this measurement, it was determined that it is practical to have all the receiving equipment inside the enclosure. Since a characteristic of this resonance is high electric field strength at the center of the enclosure and low strength at the walls, a person moving slightly in a corner of the enclosure will cause little disturbance of the field pattern. Hence, the pickup antenna may be placed at the center of the enclosure and be connected by cable to a field-intensity meter near a corner and facing the corner so that a person stationed in the corner of the room may operate the equipment, as shown in Figure A-5.

2. Data for Lowest Natural Resonant Frequency. Measurements made by the above technique are given in Table I. Several facts are noteworthy of mention. First, fairly good agreement exists between calculated resonant frequencies and experimental determinations. The true resonant frequency is easy to determine. Secondly, a wide variation in shielding effectiveness was observed. It appears that this resonance measurement is a very sensitive indicator of VHF-UHF performance.

Microwave Measurements (Above 1 Gc)

1. Comments on Procedure. The measurement setup inside the enclosure was again basically similar to that of Figure A-5, but with microwave equipment employed. Severe RF leakage into the microwave tuning head of the field-strength meter was experienced from the cable connecting this head and its power supply. Careful positioning of the cable between equipment cases was utilized to minimize leakage pickup, although it was never completely eliminated. Better shielding and filtering of this cable may be required to obtain more accurate measurements, although the equipment was usable with care.

For a signal source, a radar transmitter for airborne application was used, with the antenna operating in a search mode as an optional technique. In this manner, an entire wall of a shielding enclosure was illuminated and with the variation in path length due to mechanical scanning by the particular radar used, it was not necessary to vary the distance of the radar from the enclosure for maximum pickup. Because of the sector-scanning antenna, the measuring capability (77 db in this case) was less then with a carefully positioned stationary antenna. However, it proved both adequate and convenient for all measurements undertaken.

Use of a sweeping radar causes the field strength indicating meter to fluctuate widely. The maximum value of the meter swing was taken as a reading. It should be noted that, if the two required readings within and without the enclosure were to fall on different portions of the meter scale, error would be introduced due to the effects of indicating meter inertia which is proportional to deflection, whereas the meter calibration is logarithmic. By using an external variable attenuator, both readings may be kept at the same value and the shielding effectiveness is then obtained directly from the difference in attenuator readings.

2. Microwave Data. Measurements performed in the above manner are recorded in Table II.

The low values of measurements obtained in the microwave tests are attributed to the use of enclosure power-line filters not intended for operation at the measurement frequency. In the one instance of highest performance, the filter used had been designed to cover the measurement range

Table I

Resonant-Frequency Measurements of Shielding Effectiveness

Enclosure	Manufacturer (Remarks)	Shielding Effectiveness (db)	Resonant Frequency (mc.)		Interior Dimensions (inches)		
			Calculated	Measured	L	W	H
Single sheet copper	C (Old installation)	112	78.9	77.5	120	87	96
Double copper screening	A (Antique enclosure in poor condition)	68	83.4	80.9	120	98	90
	C	109	69.9	68.6	159	119	110
Double galv-annealed steel	A (Contained multi-bility of utility entrances)	76	60.6	60.6	136	118	134

Table II

Microwave (9.37 Gc) Measurements of Shielding Effectiveness

Enclosure	Manufacturer	Shielding Effectiveness (db)	Rated Upper Frequency for Filter Application (mc)
Single sheet copper	C	32	400 Input leads not in conduit, old installation.
Double copper screening	A	30	400 Input leads not in conduit, old installation;
	C	77	Although 1000, filter was designed for higher cutoff. Input leads not in conduit.
Double galvannealed steel	A	46	1000

but was rated for a lower upper-frequency limit since it had not yet been thoroughly checked above 1 Gc by the manufacturer.

Presentation of Results

For measurements at the three proposed standard frequencies, results may best be presented in tabular form. In such a manner, a summary of the results of performance measurements for enclosures measured are given in Table III.

Conclusions

The proposed measurement procedures affect the entire industry concerned with the manufacture of shielding enclosures. Consequently, considerable care was taken in development of the procedure to assure that the techniques are kept as simple as possible consistent with obtaining meaningful results. It is believed that the proposed measurement technique accomplishes this desirable objective.

Practicality of the technique extends to the measurement of enclosures in confined locations. Even under severe space restrictions, it offers the first practical technique for the measurement of shielding effectiveness capable of testing at low frequencies all seams of an enclosure, including those at floor and ceiling.

Measurement at the lowest natural resonant frequency measures the enclosure at a point in the spectrum of inherent weakness. In this region, therefore, it describes the minimum performance that can be expected. A very practical advantage in making such a measurement is that it requires a minimum of signal power to effect the measurement.

Measurements at the proposed standard frequencies result in a minimum of data capable of providing a good description of enclosure performance.

Since the object of the research program was a valid measurement technique, tests were applied to enclosures of various capabilities whether or not they were representative of the types tested. Consequently, it is recommended that the experimental results of this report not be considered representative of maximum performance capabilities.

Acknowledgments

The authors wish to acknowledge the basic original work on measurement techniques developed by Dr. L. C. Peach of the Illinois Institute of Technology. They also wish to thank the many members of IRE Subcommittee 27.5 for constructive criticism that led to refinements in the techniques and to thank for his understanding patience Mr. L. W. Thomas of the Navy Department, Bureau of Ships, who sponsored the work at Armour Research Foundation of I.I.T. and Mr. A. P. Massey, formerly of the Bureau of Ships.

References

1. Kanellakos, D. P., R. B. Schulz, L. C. Peach and A. P. Massey, "New Techniques for Evaluating the Performance of Shielded Enclosures", Proc. Fifth Conference on Radio Interference Reduction and Electronic Compatibility, October 1959.

2. U. S. Government Specification MIL-STD-285, "Attenuation Measurements for Enclosures, Electromagnetic Shielding, for Electronic Test Purposes, Method of", 25 June 1956.

APPENDIX A. MEASUREMENT PROCEDURES

Object and Scope

The object of the work described is to provide uniform methods for determining the relative effectiveness of shielding enclosures. A shield is defined in the IRE Standards on Industrial Electronics as "material used to suppress the effect of an electric or magnetic field within or beyond defined regions".* A shielding enclosure is a structure composed of such material. Its function may be (a) to provide an interference-free location for the operation of sensitive radio or electronic equipment, where unwanted electromagnetic fields would otherwise be present, or (b) to confine unwanted radiation to a limited space, and thereby reduce the possibility of interference with other equipment.

Test procedures described herein are conducted under conditions simulating those of (a), but some degree of reciprocity exists and, therefore, the tests may be applied to structures intended for the conditions of (b) as well as those intended for the conditions of (a). The test procedure is based upon measurement of shielding effectiveness for an enclosure in the usual shape of a rectangular parallelepiped. For other shapes, the large-loop procedures may be modified using Appendix B as a guide to such modifications.

Provision is made for determining effectiveness at any desired frequency over the range from below 0.1 kc to above 10 Gc. When it is desired only to estimate the general effectiveness over the entire frequency range, tests are required at only three standard frequencies: (a) 15 kilocycles, (b) the lowest natural resonant frequency of the enclosure (between 10 and 100 mc for the usual structure), and (c) in X band (approximately 9.3 Gc). Measurement results at these three standard frequencies may be used as a standard basis for comparison of performance of shielding enclosures for a given lowest natural resonant frequency or given size of enclosure.

In the low frequency portion of the spectrum below 200 kc, two different test methods are given, but the test utilizing a large loop encircling the enclosure is preferred where the enclosure location permits its use. The alternate

*See 55 IRE 10.51 published in Proc. IRE v. 43, Sept. 1955, p. 1072.

Table III

Proposed Standard Presentation of Performance Data

Type of Enclosure	Manufacturer	Shielding Effectiveness (db)		
		15 kc	Lowest Natural Resonant Frequency	9.37 Gc
Single sheet copper	C (Old installation)		> 112 at 77.5 mc	32
Double copper screening	A (Antique enclosure in poor condition)	60	68 at 80.9 mc	30
	A	75		
	B	74		
	C	81		
	C	96	> 109 at 68.6 mc	77
Double galvannealed steel	A	100	76 at 60.6 mc	46
	B	88		
	C	114		

The table above gives some idea of the range of values obtainable from measurements of shielding effectiveness. More important, the number of measurements made at each proposed standard frequency is adequate to establish confidence in the revised measurement technique.

method must be viewed as only a partial test of shielding effectiveness. A new enclosure installed in an inaccessible area should have the transmitting loop installed with the enclosure. For an existing enclosure that is not readily accessible, the alternate large-loop test requiring accessibility of only one face of the enclosure is used.

In the high-frequency region from 200 kc to 20 mc and below the lowest natural resonant frequency, a method utilizing only small loops for both source and receiver may be used. Since this old method produces less accurate and less consistent results than the large-loop techniques not applicable in this region, no standard test frequency is suggested in this frequency range.

For the VHF-UHF range from 20 mc to 1 Gc, dipole-to-dipole tests are used, where the transmitting dipole may be resonant but the receiving dipole must be much smaller than its resonant length.

In the microwave range of 1 Gc and higher, measurements are conducted between source and receiver antennas in any combination of highly directive antennas such as horns or parabolic reflectors. In lieu of a highly directive antenna for signal pickup, an omnidirectional antenna of short effective length, not greater than 1/8 wavelength, may be used.

Definition of Shielding Effectiveness

For the purpose of this paper, the following definition will apply:

Shielding Effectiveness of electromagnetic shielding enclosures, expressed in decibels is 20 times the logarithmic ratio of electric or magnetic fields, produced externally, and determined at a point in space contained within a shielding enclosure, in the absence and presence of the enclosure respectively. The numerical value of the shielding effectiveness S is expressed by the equations:

$$S_H = 20 \log_{10} \frac{H_1}{H_2} \qquad \text{(A-1)}$$

$$S_E = 20 \log_{10} \frac{E_1}{E_2} , \qquad \text{(A-2)}$$

where

H_1 = Magnetic field in absence of enclosure

H_2 = Magnetic field within enclosure

E_1 = Electric field in absence of enclosure

E_2 = Electric field within enclosure,

and

S_H is the effectiveness with respect to the magnetic field, utilized in the frequency range from below 0.1 kc to 20 mc; and S_E is the effectiveness with respect to the electric field, utilized in the frequency range 20 mc to 10 Gc and higher.

Note 1: The effective impedances involved are dissimilar in the absence and presence of the enclosure and, thus, shielding effectiveness is not a true power ratio, but depends on the particular test procedure employed.

Note 2: In many applications of shielding enclosures, the interfering generator is inside the enclosure and the point of interest is outside the enclosure. The true "effectiveness" under this condition is not expected to differ from the effectiveness as defined by more than 6 db, provided the specified source and receiver antennas are interchanged. For either large-loop test, there is no difference.

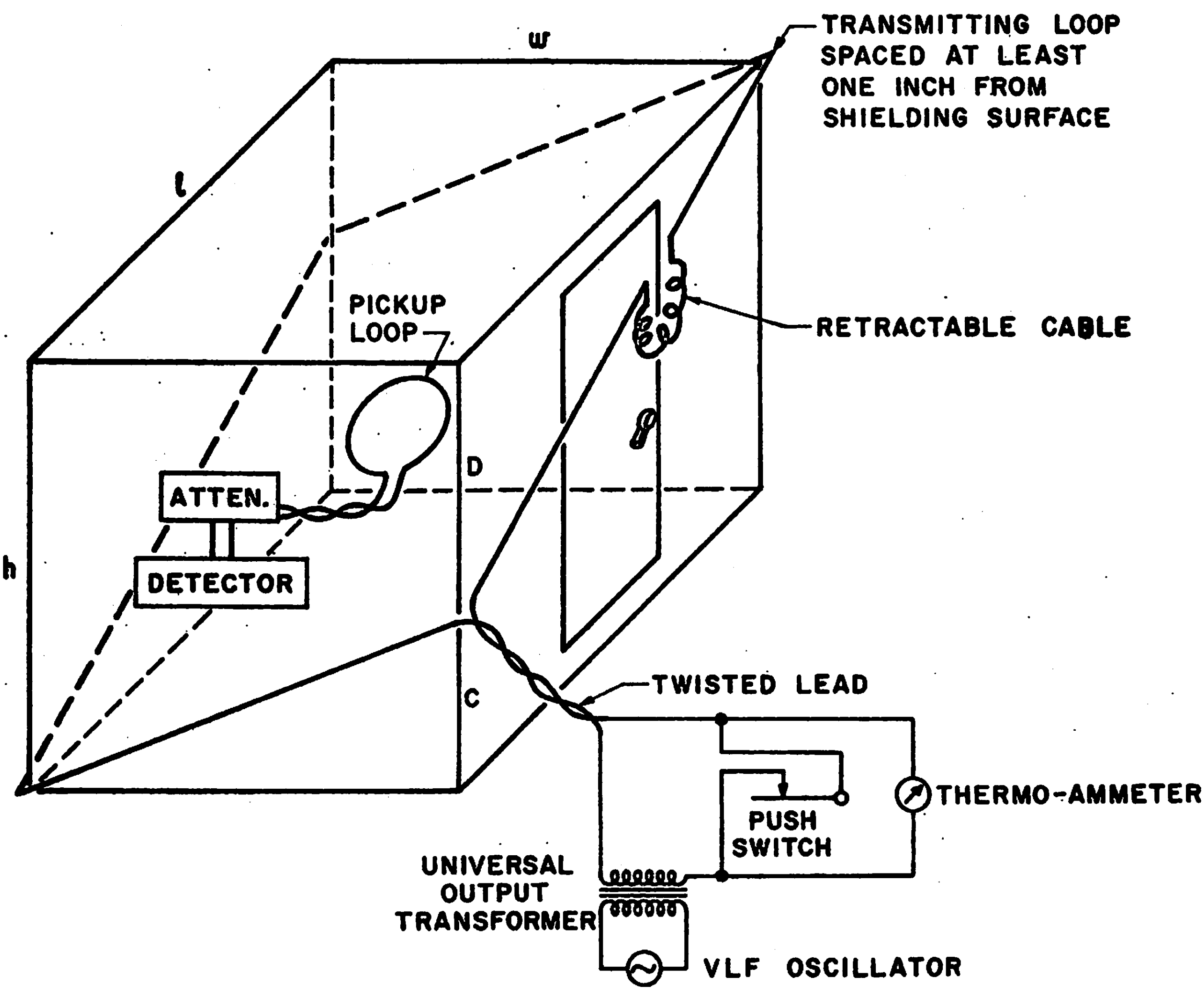
Method of Measurement

The measurement method described in this paper is based on the placement of a source of an E-M field (transmitter) outside the shielding enclosure to be tested and a detector inside the enclosure, together with provision for the removal, or simulation of the removal, of the enclosure. Test procedures according to the general method differ somewhat depending on the frequency at which the test is made. For any given test, only one of the two ratios S_H or S_E will apply. Below 20 mc, the shielding effect for the magnetic field is usually of particular interest and therefore S_H is determined. At higher frequencies, the shielding effect for the electric field is usually of interest and, therefore, S_E is determined.

All RF cables, power lines, and other utilities entering the shielding enclosure are to be in place when tests are conducted. When the small-loop test is used, special care should be taken to make measurements in the vicinity of utility entrances, doors, access panels, and panel-to-panel seams.

Low-Frequency Test (Below 200 Kc)

The low-frequency or large-loop test immerses the shielding enclosure in a magnetic field oriented to induce appreciable components of current flow in the shield through its least effective portions, seams and joints. Shielded enclosures are normally constructed with lineal panel seams in each of three mutually perpendicular directions. In the large-loop test, all seams are subjected to shielding currents by encircling the enclosure with a transmitting loop tilted so that its plane includes a diagonal of the room and is otherwise tilted as in Figure A-1. The magnitude of the magnetic field generated at the center of this loop is determined indirectly from a measurement of the loop current and the enclosure dimensions, whereas the resulting field at the center of the enclosure is measured



NOTES: $C = \frac{w}{l+w} h$

$D = \frac{l}{l+w} h$

PICKUP LOOP IN PLANE OF LARGE LOOP OR CENTER OF ENCLOSURE

FIG. A-1 LARGE-LOOP TEST SETUP

directly. A supplementary benefit of the test set-up is the ease with which shielding defects can be located by an exploring loop.

a. Frequency Range. The large-loop test procedure may be employed anywhere in the frequency range from below 0.1 kc to 200 kc. A single-frequency measurement at 15 kc is adequate as a measure of low-frequency performance and is suggested as a standard low-frequency measurement frequency.

b. Test Equipment and Set-Up. All signal sources, pickup devices, and measuring equipment, as well as their arrangement with respect to the shielding enclosure, are considered to be in accordance with the following paragraphs and Figure A-1.

(1) Source of Magnetic Field. The test magnetic field shall be generated by current flow in a large planar loop encircling the enclosure at a spacing of at least 1 inch from the outer shielding material. Such a loop around a rectangular parallelopiped (the usual case) forms a parallelogram with acute angles at either extremity of an enclosure diagonal and obtuse angles at remaining wall corners. The obtuse angle vertices are positioned away from floor and ceiling by distances C and D, respectively, proportional to horizontal distances from the respective acute vertices. Specifically,

$$C = \frac{w}{\ell + w}\, h, \qquad \text{(A-3)}$$

$$D = \frac{\ell}{\ell + w}\, h, \qquad \text{(A-4)}$$

where ℓ, w and h are the enclosure dimensions of length, width and height, respectively. The large loop consists of a single turn of stranded, insulated copper wire, preferably No. 18 AWG "hook-up" wire. The loop wire can be fastened by means of rubber suction cups and/or masking tape to the exterior surface of the enclosure or to nearby objects such as building walls so that the wire is at least 1 inch away from the outer wall of the enclosure.

In order to avoid the obstruction of the door by the large loop, a retractable cable such as a retractable test-prod lead or telephone cord may be utilized as part of the loop at the jamb edge of the door, as in Figure A-1. For maximum convenience, the large-loop orientation should initially have been selected so that this cable is placed on the upper portion of the door.

A conventional RC oscillator is adequate to supply the loop current provided the impedance mismatch is minimized at the lower frequencies by use of a step-down or universal output transformer. Current through the large loop may be measured by the voltage drop across a known carbon resistor or by using a thermo-ammeter, preferably with a parallel momentary-open switch to protect it against overload.

For the conventional rectangular parallelepiped enclosure,* the magnetic field H_1 produced by this source can be calculated from the expression

$$H_1 = \frac{2I}{\pi w}\sqrt{\frac{1 + \left(\frac{w}{\ell}\right)^2}{1 + \left(\frac{h}{\ell + w}\right)^2}}\quad, \qquad \text{(A-5)}$$

where H_1 is expressed in ampere-turns per meter when

I = Coil current in amperes

h, ℓ, w = Enclosure exterior height, length and width, respectively, expressed in meters.

The given expression is an approximation valid for its intended use provided $w \leq \ell$ and $2h \leq \ell + w$, conditions which are normally satisfied.

(2) Detector. The detector may be either a field-strength meter equipped with a pick-up loop for the measurement of magnetic fields, or a combination of pickup loop and high-impedance RF voltmeter.

For a field-strength meter with loop pick-up, readings are normally given in terms of an equivalent electric field E_{eq} on the basis of plane-wave propagation. The corresponding magnetic field H_2 is then obtained from the expression.

$$H_2 = \frac{E_{eq2}}{120\pi}\quad, \qquad \text{(A-6)}$$

where H_2 is expressed in ampere-turns per meter when E_{eq2} is expressed in volts per meter.

If a pick-up loop and high-impedance-voltmeter combination forms the detector, the pickup loop may consist of 11 turns of closely spaced insulated wire on a 30-inch-diameter form. It is essential that current flow in the pickup loop due to its load be negligible. Hence. it would be connected to a voltmeter (or amplifier-voltmeter combination) of high input impedance only.

For the high-impedance voltmeter detector, the field H_2 in ampere turns per meter at the center of the enclosure is given by the expression

$$H_2 = \frac{V_2}{2\pi\, f\, N_1\, A\, \mu_o}\quad, \qquad \text{(A-7)}$$

where

V_2 = induced voltage in volts with pickup loop inside enclosure

f = frequency in cps

N_1 = number of turns of pickup loop (=11)

A = area of pickup loop in square meters (= 0.455 square meters)

*For other shapes of enclosures, refer to Appendix B.

μ_o = permeability of free space (= $4\pi \times 10^{-7}$ henry/meter).

Then,

$$H_2 = 2.5 \times 10^4 \frac{V_2}{f} . \qquad (A-8)$$

c. Basic Measurement Procedure. Both signal source and detector are arranged as shown in Figure A-1. All the measuring equipment is connected and warmed up for a length of time sufficient to become stabilized. The detector loop is positioned at the geometric center of the enclosure and the plane of this loop lies in the plane of the transmitting loop. Both the signal source oscillator and detector tuning (if tunable) are adjusted to the measurement frequency.

The oscillator output is adjusted until adequate for the measurement and the current in the transmitting loop should be indicated by a meter. (Currents of the order of 20 to 200 ma have been found satisfactory.) The magnetic field due to the source is then calculated from equation (A-5).

With all shielding-enclosure entrances securely closed, the detecting equipment should be resonated (if tunable) with the source and the meter reading noted. The received field should then be calculated with the aid of either expression (A-6) for a field-strength meter or expression (A-8) for a high-impedance voltmeter.

The value of low-frequency shielding effectiveness is finally determined by the use of equation (A-1).

d. Supplementary Procedure. The supplementary procedure is used when it is desired to locate shielding defects, such as poor door and seam contacts and leakage around power-line filters and air inlets. When this procedure is followed, it should be used prior to actual measurement of shielding so that shielding defects may be remedied before measurement.

The entire equipment setup is identical with the low-frequency measurement setup except that smaller receiving loops are used to probe the interior shielding surfaces. For preliminary probing, it is suggested that a pickup loop approximately 5 inches in diameter be used and, for more precise localization, a loop 1/2-inch in diameter.

Signal maxima are obtained at locations closest to the external loop wire; such maxima are not indications of room defects. However, exploration in directions parallel to the plane of the transmitting loop should yield approximately steady levels of received signals for uniform shielding; peaks appear in the vicinity of shielding defects.

Alternate Low-Frequency Test (Below 200 Kc)

This alternate low-frequency test is used over the same frequency range only when the main large-loop test cannot be performed on an existing shielding enclosure due to inaccessibility of one or more enclosure walls. New construction should either permit access to exterior enclosure faces or should have installed with the enclosure the large-loop wires for performing the test. This alternate test is a compromise which induces shielding currents across many, but not all, seams and joints. It is assumed that the entire front face of a room, including the door, is accessible.

A correspondingly limited incidental benefit of the test setup is the ease with which shielding defects may be located by an exploring loop in the manner previously described.

a. Test Equipment and Set-Up. Although the detector is the same as for the main large-loop test, the arrangements of signal sources, pick-up devices and measuring equipment with respect to the shielding enclosure are in accordance with the following paragraph and Figure A-2.

(1) Source of Magnetic Field. The test magnetic field is generated by current flow in a large planar loop around the periphery of the front face of the enclosure. Techniques for fastening the loop to the enclosure are the same as those described previously. Provisions for exciting the loop and measuring the loop current are also the same.

The magnetic field H_1 produced by this source is calculated from the expression

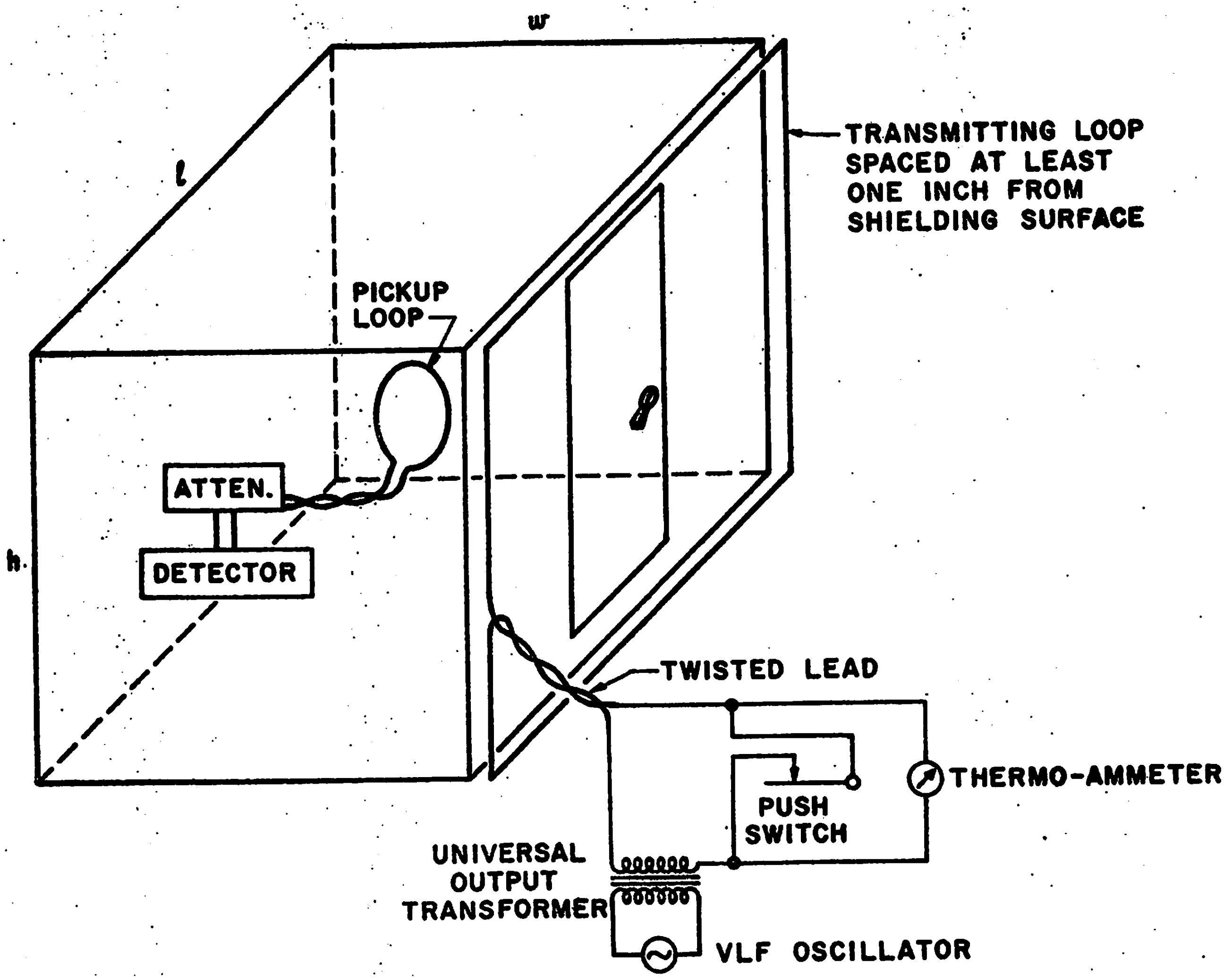
$$H_1 = \frac{2I}{\pi} \frac{h\ell}{\sqrt{\ell^2 + w^2 + h^2}} \left(\frac{1}{\ell^2 + w^2} + \frac{1}{h^2 + w^2} \right), \qquad (A-9)$$

where the quantities are defined following equation (A-5).

(2) Basic Alternate Measurement Procedure. The detector loop is positioned at the geometric center of the enclosure and the plane of this loop is parallel to the plane of the transmitting loop. Otherwise, the procedure is the same as for the main case but with the source field being calculated by Equation (A-9).

High-Frequency Test (200 Kc to 20 Mc)

The high-frequency or small-loop test is used over the frequency range from 200 kc to 20 mc. This procedure does not immerse the entire shielding enclosure in a strong magnetic field, but only localized areas; it can test only these areas. The average value of shielding effectiveness so obtained is taken as the measure of enclosure performance. To obtain this average value, decibel values of shielding effectiveness must not be averaged; instead, all H_2 readings are averaged and this average value of H_2 is used in equation (A-1) for shielding effectiveness.



NOTE: PICKUP LOOP AT CENTER OF ENCLOSURE AND PARALLEL TO LARGE LOOP

FIG. A-2 ALTERNATE LARGE-LOOP TEST SETUP

a. Test Equipment and Set-Up. All signal sources, pickup devices, and measuring equipment, as well as the arrangement of these units with respect to the shielding enclosure, should be in accordance with the following paragraphs and Figure A-3.

(1) Source of Magnetic Field. The test magnetic field is generated by current flow in a 12-inch diameter loop. The loop is constructed from a single turn of No. 6 AWG copper wire and conventional signal generator is used to supply the loop current.

With the small source loop, the field H_1 produced by the source without an intervening shielding layer need not be obtained by calculation but is readily measured using a pickup loop spaced from the transmitting loop by 24 inches plus the thickness of the shielding barrier, the same total loop-to-loop distance utilized when a shielding barrier intervenes. If the detector is a field-strength meter, a reading is made of equivalent electric field strength E_{eq1} which may be converted to magnetic field strength H_1 by the equation

$$H_1 = \frac{E_{eq1}}{120\pi} \quad , \qquad \text{(A-10)}$$

where H_1 is expressed in ampere-turns per meter when E_{eq1} is expressed in volts per meter. If both H_1 and H_2 are expressed as equivalent electric field strength, equation (A-10) need not be used.

If the detector is a high-impedance voltmeter, the magnetic field strength is given by

$$H_1 = 1.7 \times 10^6 \frac{V_1}{f} \quad , \qquad \text{(A-11)}$$

where V_1 is the induced voltage in volts with the pickup loop outside the enclosure.

(2) Detector. The detector is similar to that previously described except for frequency range and except that the pickup loop is identical with the 12-inch transmitting loop. Equation (A-8) is then replaced by the expression

$$H_2 = 1.7 \times 10^6 \frac{V_2}{f} \quad . \qquad \text{(A-12)}$$

b. Measurement Procedure. The measurement is made in accordance with Figure A-3, with both transmitting and receiving loops each spaced 12 inches away from the shielding barrier and coplanar in a plane perpendicular to a metal seam or other suspected defect being measured. It would appear desirable to scan the available areas of the enclosure in order to disclose defects. In lieu of scanning, four well-spaced spot measurements at seams or other potentially weak places are considered sufficient if readings are in good agreement; otherwise more readings are taken until confidence is established that the readings are truly representative.

c. Precautions. For either type of detector, a test is made to insure that no case leakage exists at the detector. When the detector pickup is disconnected at the case, the detector should show no indication above its inherent background level.

VHF-UHF Test (20 Mc to 1 Gc)

The VHF-UHF test determines the performance of an enclosure for plane waves over a frequency range of 20 mc to 1 Gc, which usually includes that of resonance. Although tests may be performed throughout the entire frequency range, the lowest natural resonant frequency is suggested as the standard test frequency for the range. Even if the lowest natural resonant frequency falls below 20 mc, the test procedure of resonance shall still be that given below. It may at first appear difficult to locate this frequency because the figure of merit or Q of the shielding enclosure acting as a resonant cavity is quite high. However, the approximate value of lowest natural resonant frequency can be readily calculated as a guide to experimental location. Higher-frequency resonances are normally less pronounced and, consequently, need not be measured to determine the maximum deterioration in shielding effectiveness due to resonance.

a. Frequency Range. VHF-UHF measurements of shielding effectiveness may be made at any frequency within the range of 20 mc to 1 Gc and it is suggested that the lowest natural resonant frequency f_r of the enclosure be considered a standard measurement frequency. For a rectangular parallelepiped (the usual shape of a shielded enclosure),

$$f_r = \frac{150}{h} \sqrt{1 + \left(\frac{h}{\ell}\right)^2} \quad , \qquad \text{(A-13)}$$

where f_r is in megacycles when the height h and length ℓ of the largest side wall are in meters. Alternatively, this frequency may be obtained from Figure A-4.

b. Test Equipment and Setup. All signal sources, pickup devices, and measuring equipments, as well as the arrangement of these with respect to the shielding enclosure, are in accordance with the following paragraphs and Figure A-5.

(1) Source of VHF-UHF Electromagnetic Field. Because of the high attenuation introduced by the shielding enclosure at the mid-frequency region, a high-power signal generator (capable of delivering at least 10 watts into a matched load) must be used.

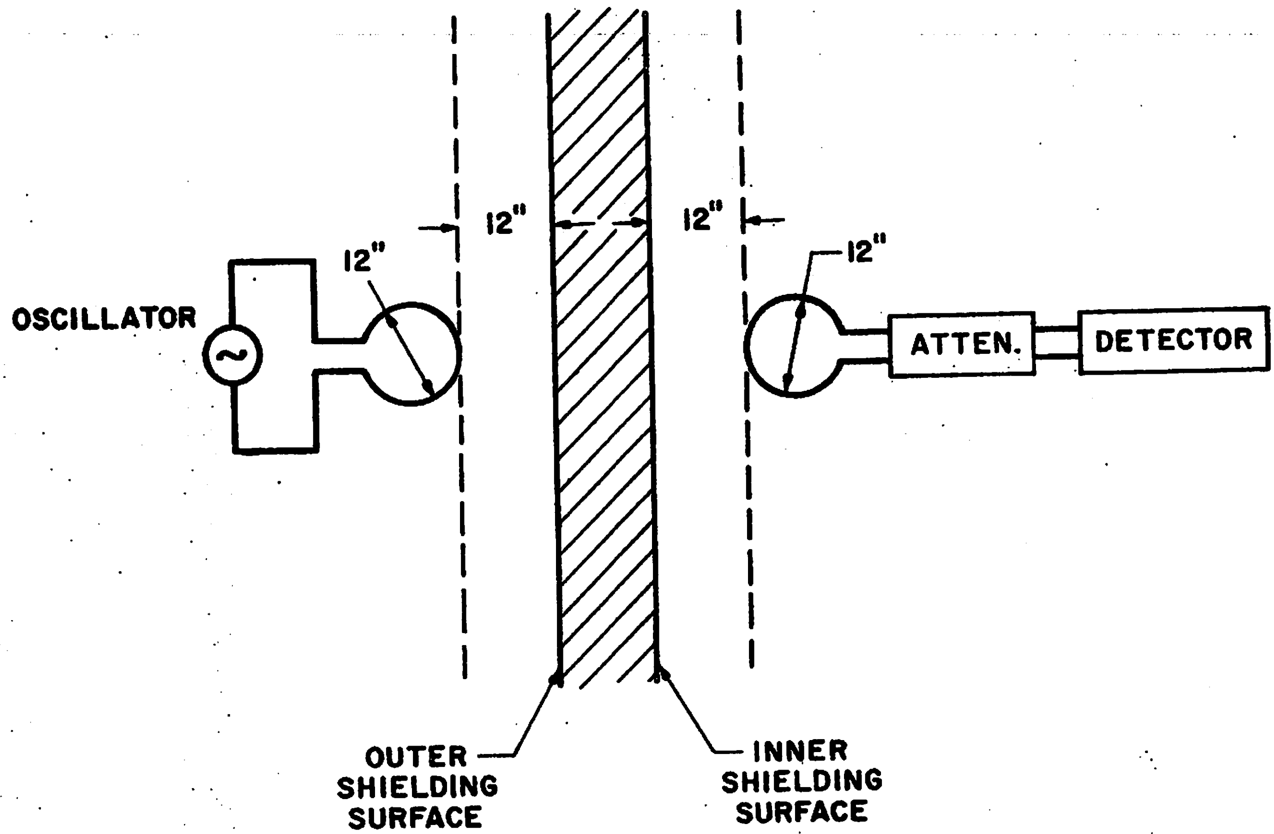


FIG. A-3 SMALL-LOOP TEST SETUP

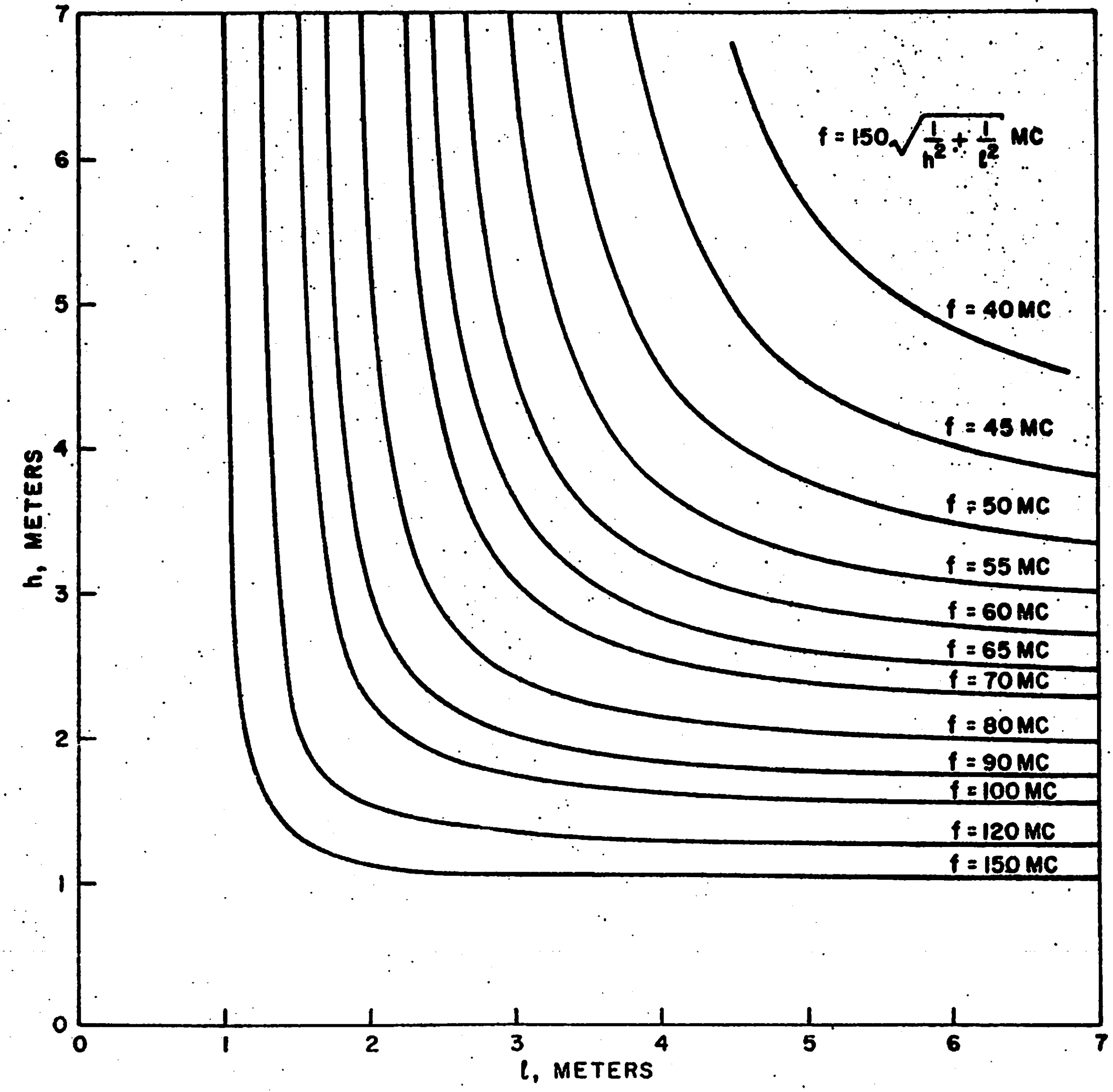


FIG. A-4 LOWEST NATURAL RESONANT FREQUENCY CHART

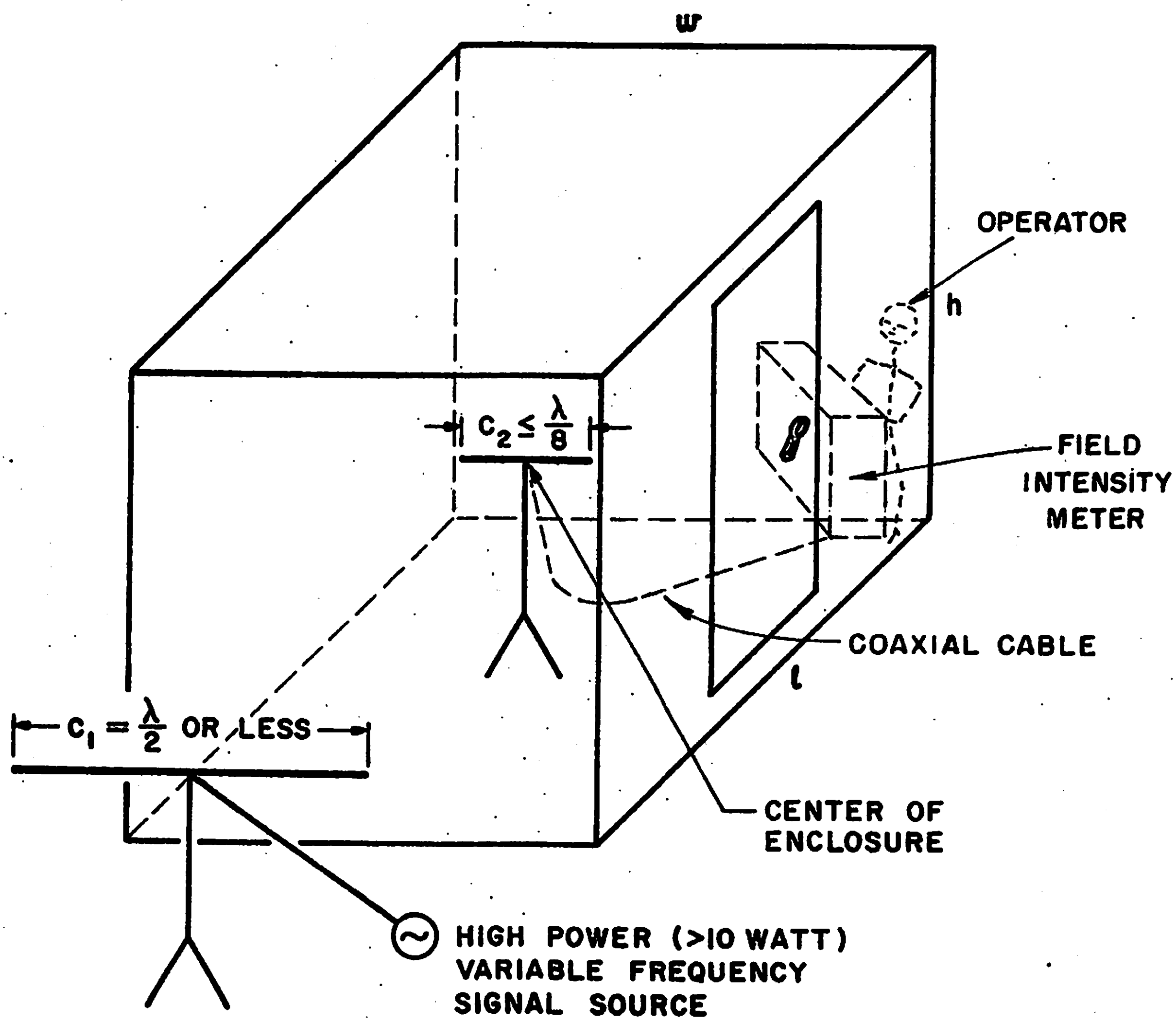


FIG. A-5 MID-FREQUENCY TEST SETUP

The generator shall feed a half-wave dipole antenna through a 50-ohm doubly shielded cable at the frequency of test; the transmitting antenna then produces in the vicinity of the enclosure free-field waves whose impedance is that of a plane wave.

(2) Detector. For the lowest natural resonant frequency, the electric field strength is maximum at the center of the enclosure and its polarization is perpendicular to the plane of the larger side wall. Hence, at the center of the enclosure shall be placed another dipole antenna, but one whose length c_2 is electrically short ($c_2 \leq \lambda/8$). Its impedance will then not change appreciably either (a) as the frequency sweeps past the resonance frequency of the enclosure or (b) when the antenna is taken outside the enclosure.

The output of the receiving antenna is brought through a coaxial cable to a field-strength meter located near a corner of the enclosure and facing that corner. The individual conducting the measurement should be located in this corner of the enclosure to minimize any effect of body motion on the results, since at the lowest natural resonant frequency the electric field is minimum in the enclosure corners.

c. Measurement Procedure. The transmitting antenna is oriented horizontal and parallel to a smaller wall of the enclosure as depicted in Figure A-5; this orientation favors the lowest mode of excitation (TE_{011}). It should be separated from the enclosure until a maximum indication is obtained at the field-strength meter. This distance of the center of the transmitting antenna from the enclosure wall corresponds to an integral multiple n of half-wavelengths ($n\lambda/2$). However, to prevent interaction of the antenna with the enclosure walls, n should be kept greater than 3. In order to find the lowest natural resonant frequency experimentally, a door of the enclosure is left ajar slightly to permit increased signal strength inside the enclosure without disturbing its resonance. The generator frequency is then varied in very small steps around the calculated resonant frequency and the field-strength meter is each time tuned for maximum signal. The strongest of all such received signals occurs at resonance. Once this frequency is located the door of the enclosure can then be securely closed and the pickup signal measured.

The signal coupled by the antennas is also measured outside the enclosure when spaced the same distance and oriented the same way as when one was inside and the other outside. The measure of shielding effectiveness at the lowest natural resonant frequency is taken as the total increase in attenuation of the calibrated attenuators in the output circuit of the signal generator and the input to the field-strength meter to give the same reading indication of field-strength on the indicating meter that existed for reception through the enclosure shield.

d. Precautions. The source antenna should be placed at least 3 half-wavelengths away from the enclosure wall in order to prevent interaction between the antenna and wall. For a similar reason, the pickup antenna should not be greater than 1/8 wavelength.

Inside the enclosure, the person conducting measurements should ascertain that his body position has no substantial effect upon the results.

Microwave Test

The electrical parameters ϵ (dielectric constant), μ (permeability), and σ (conductivity) of shielding materials change with frequency. Since the reflection and attenuation losses, and therefore the shielding effectiveness, depend on these parameters as well as on inter-panel contact resistances, a test of the performance of the shielding enclosure at high frequencies is necessary. The shielding effectiveness is very much affected by both the spacing between shields (in the case of multiple-shield enclosures) and the spacing and size of the perforations in screening materials (if used). The space between shields can support high standing waves whenever the spacing is equal to $n\lambda/2$, where λ is the wavelength and n is an integer; this situation can theoretically bring about a 3-db decrease in shielding effectiveness below the value of a single shielding layer. The radiating antenna should be kept sufficiently far from the enclosure wall (1) to prevent the former's radiation pattern from being changed appreciably and (2) to keep to a minimum the amount of reflected energy feeding back into the antenna and thus protect the source (normally a magnetron). This distance should be at least five feet.

a. Frequency Range. The microwave type of test applies to all frequencies including 1 Gc and higher, although the standard test frequency suggested is in X-band between 9.0 and 9.6 Gc, nominally 9.3 Gc.

b. Test Equipment and Setup. All signal sources, pickup devices, and measuring equipments, as well as the arrangement of them with respect to the shielding enclosure, are in accordance with the following paragraphs and Figure A-6 if horn antennas are used. For other antennas, analogous setups may be used.

(1) Source of Microwave Electromagnetic Field. The signal source is a microwave generator of adequate output power feeding a horn, parabolic reflector, or other directional microwave antenna. A typical source may be a radar transmitter unit.

(2) Detector. The detector consists of a horn, parabolic reflector, or other directional microwave antenna, or an omnidirectional antenna of short effective length ($\leq \lambda/8$), a variable attenuator; and field-strength measuring equipment or a spectrum analyzer on which the lowest readable signal level is used as a reference-level indicator. For measurement of the source field, a dummy load and directional coupler is also required for a horn-antenna setup.

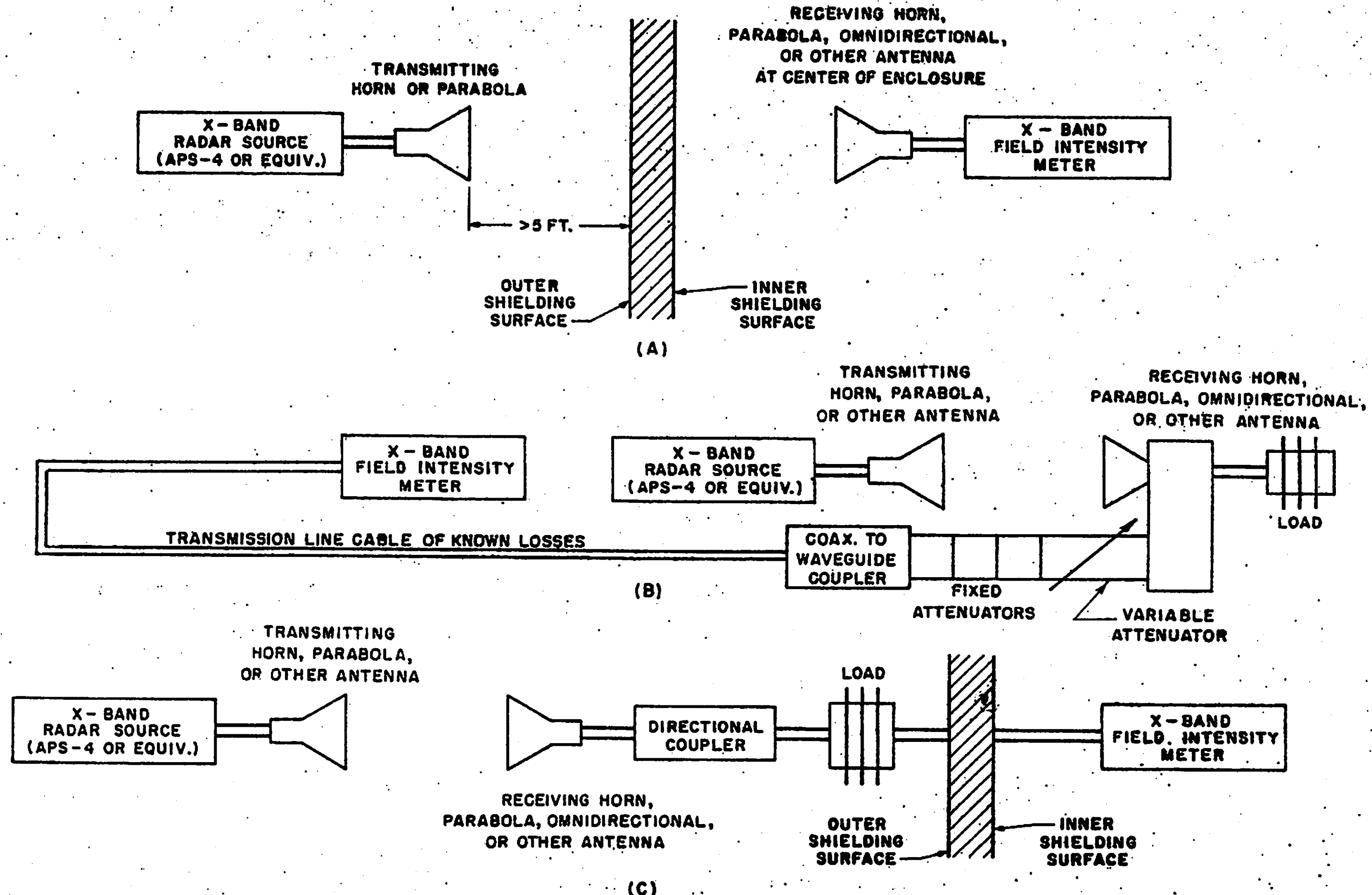


FIG. A-6 MICROWAVE TEST SETUP

c. Basic Measurement Procedure. Refer to Figure A-6. The measure of shielding effectiveness for the enclosure is taken as the increase in the db setting of the attenuator used in the output of the detector to obtain the same reference level in the detector when the enclosure is removed. Because the strong field generated may penetrate the cases of the detector, the attenuators, or the transmission line cables, these equipments are placed away from the direct path of the transmitting antenna or its reflections, as is shown in Figure A-6B. The distance between the receiving and transmitting antennas is maintained fixed.

The position of the transmitting antenna with respect to the enclosure may be anywhere around the enclosure and in any orientation to the panel seams, door, etc., but directed perpendicular to the wall and not near a corner. At any one point, the shielding effectiveness will be a maximum if the distance between shields of a multiple-shielded enclosure is equal to $(2n+1) \lambda/4$, and a minimum if the distance is equal to $n \lambda/2$. These two distances represent small variations in the nominal one-or-two-inch separation of a doubly-shielded enclosure. Measurements may be made at one point and the two shielding layers, if non-rigid, may be pulled slightly apart or pushed slightly together. Both maximum and minimum attenuations are recorded and the average value used.

The receiving antenna is placed at the center of the enclosure and, if directional, facing and colinear with the transmitting antenna. The attenuators, couplers, and cables used are to be connected in series and shall have been previously calibrated at the frequency of test. A directional coupler and dummy load may be used to obtain a decrease in the signal source before it is fed directly into the waveguide attenuators in order not to exceed in average power the attenuator ratings. When tests are made with the enclosure wall in place (Figure A-6C), the directional coupler, coaxial-to-waveguide coupler, and connecting cable are removed and the receiving antenna is connected directly to the waveguide attenuators. The attenuators used must have a total attenuation in db at least as high as the shielding effectiveness of the enclosure to be measured and the total inserted attenuation is taken into account.

d. Measurement Variations. Several variations in measurement technique may be employed.

(1) Variation 1. For the source measurement in the absence of a shielding barrier, the barrier need not be removed provided the receiving antenna, attenuator, and load are all used outside the enclosure while the detector is inside. Such operation can be effected by means of a transmission-line connector through the shielding barrier.

(2) Variation 2. A scanning type source such as radar may be used in a search mode instead of using a fixed antenna. Under such conditions, the field-strength indicating meter gyrates considerably and the peak of the movement may be read as the received signal. It is important that measurements made both within and without the enclosure utilize the same meter deflection in order to minimize errors due to inertia of the meter movement.

e. Precautions. A number of precautions must be observed in the microwave test:

(1) The transmitting horn is placed at least 5 feet from any point on a shielding barrier to be tested.

(2) In order to prevent detector overload, a directional coupler and dummy load and/or attenuator should be employed between the pickup unit and the detector.

(3) A test should be made to assure that no leakage exists at the detector, attenuators, or cables. The detector should show no indication above inherent background noise when either cable is disconnected and the end is capped, and should show no indication as the transmitter is turned on and off when a metallic plate is placed up against the receiving antenna to completely cover the horn opening if a horn antenna is used.

If the detector shows no indication above inherent receiver background when the receiving antenna is inside the enclosure, the db increase in attenuation to obtain receiver background when the receiving antenna is placed outside the enclosure will indicate that the shielding effectiveness is at least the inserted amount of attenuation and the signal source is not sufficiently strong or the detector is not sensitive enough for a full measurement.

(4) No cable or other obstruction (except the shielding barrier) may be placed between the transmitting and receiving antennas.

(5) When a scanning type of source is used, the indicating meter must register the same scale reading for both measurements in order to minimize errors due to inertia of the meter movement.

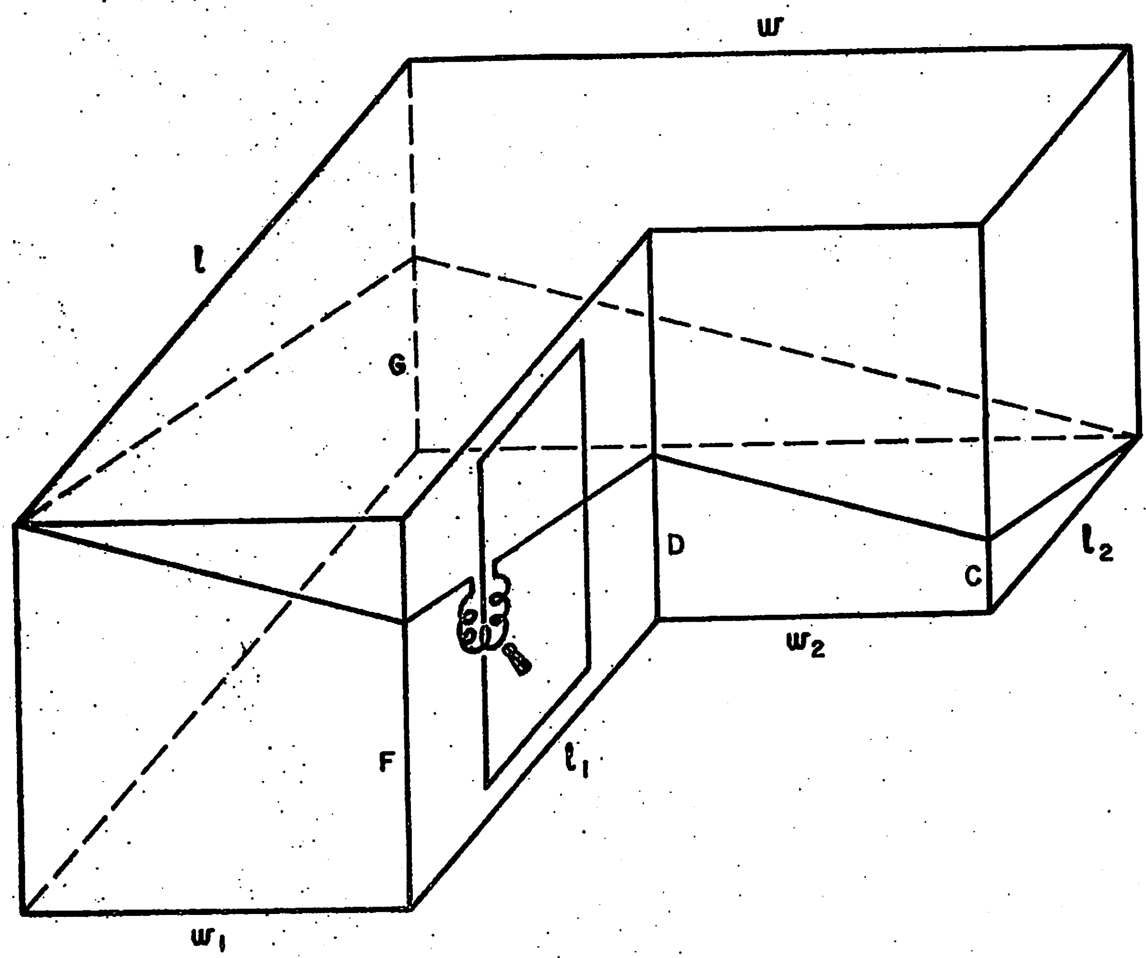
APPENDIX B

LARGE-LOOP TESTS ON SHIELDING ENCLOSURES OF LESS CONVENTIONAL SHAPES

L-Shaped Enclosure

For the L-shaped enclosure of Figure B-1, the large-loop wire shall surround the entire enclosure as shown. In this case, distances of the wire from the floor at the various corners are

$$C = \frac{\ell_2}{\ell + w} h \qquad \text{(B-1)}$$



$$C = \frac{l_2}{l + w} h \qquad F = \frac{l + w_2}{l + w} h$$

$$D = \frac{l_2 + w_2}{l + w} h \qquad G = \frac{w}{l + w} h$$

FIG. B-1 L-SHAPED ENCLOSURE

$$D = \frac{\ell_2 + w_2}{\ell + w} h \qquad \text{(B-2)}$$

$$F = \frac{\ell + w_2}{\ell + w} h \qquad \text{(B-3)}$$

$$G = \frac{w}{\ell + w} h\,. \qquad \text{(B-4)}$$

Consider the L shape to be made of two rectangular parallelepipeds of sides ℓ_1, w_1, and ℓ_2, w_2. For each portion, the field is measured by a pickup loop in the plane of the large loop, since any contribution from the other portion is negligible. Although the pickup loop will also be at the center of a horizontal plane within the enclosure portion, it will now not be centered along a vertical line through the center. As before, the source field H_{1A} for portion A of the enclosure is

$$H_{1A} = \frac{2I}{\pi w_1} \sqrt{\frac{1 + \left(\frac{w_1}{h}\right)^2}{1 + \left(\frac{h}{\ell_1 + w_1}\right)^2}}\,, \qquad \text{(B-5)}$$

and for portion B of the enclosure the source H_{1B} is

$$H_{1B} = \frac{2I}{\pi \ell_2} \sqrt{\frac{1 + \left(\frac{\ell_2}{w}\right)^2}{1 + \left(\frac{h}{\ell_2 + w}\right)^2}}\,. \qquad \text{(B-6)}$$

The corresponding diminished fields H_{2A} and H_{2B} measured by a field strength meter are:

$$H_{2A} = \frac{E_{eq2A}}{120\,\pi}\,, \qquad \text{(B-7)}$$

$$H_{2B} = \frac{E_{eq2B}}{120\,\pi}\,. \qquad \text{(B-8)}$$

If a high-impedance voltmeter is used, the detected fields are

$$H_{2A} = 2.5 \times 10^4 \frac{V_{2A}}{f}\,, \qquad \text{(B-9)}$$

$$H_{2B} = 2.5 \times 10^4 \frac{V_{2B}}{f}\,. \qquad \text{(B-10)}$$

The measure of shielding effectiveness S_H for the enclosure in toto is taken as that obtained from the averaged shielding ratios, or

$$S_H = 20 \log_{10} \frac{\frac{H_{1A}}{H_{2A}} + \frac{H_{1B}}{H_{2B}}}{2} \qquad \text{(B-11)}$$

<u>Straight-Walled Enclosures of Other Configurations</u>

Straight-walled enclosures having other, more complicated shapes may be handled in a manner similar to that for the L-shaped enclosure provided opposite walls are at least parallel. If opposite walls are not parallel, the source field H_1 may be considered to be that which arises from a parallel-walled enclosure of the same floor area.

<u>Spherical Enclosures</u>

For the spherical enclosure of Figure B-2, the source field H_1 generated is

$$H_1 = \frac{I}{d}\,. \qquad \text{(B-12)}$$

<u>Cylindrical Enclosures</u>

For enclosures in the shape of a right circular cylinder as in Figure B-3, the large loop forms an ellipse. The source field H_1 may be taken as that from a circular loop of equivalent area. Hence, the equivalent diameter d_{eq} is

$$d_{eq} = \sqrt{2a \cdot 2b} = d\left[1 + \left(\frac{h}{d}\right)^2\right]^{1/4}, \qquad \text{(B-13)}$$

where d is the cylinder diameter and h is the enclosure height, both in meters. Then, the source field H_1 generated is

$$H_1 = \frac{I}{d\left[1 + \left(\frac{h}{d}\right)^2\right]^{1/4}}\,. \qquad \text{(B-14)}$$

<u>Divided Enclosures</u>

For enclosures that contain partitions to obtain two or more shielded areas within one enclosure as in Figure B-4, the shielding effectiveness of the enclosure in toto may be obtained in the same manner as for the L-shaped enclosure by averaging the shielding ratios for each section. In addition, it may be desirable to obtain the shielding effectiveness of one section with respect to an adjacent section. Such a determination may be made using the alternate low-frequency or large-loop test of Appendix A where, in this case, the shielding partition is considered as the accessible face about which the large-loop wire is placed.

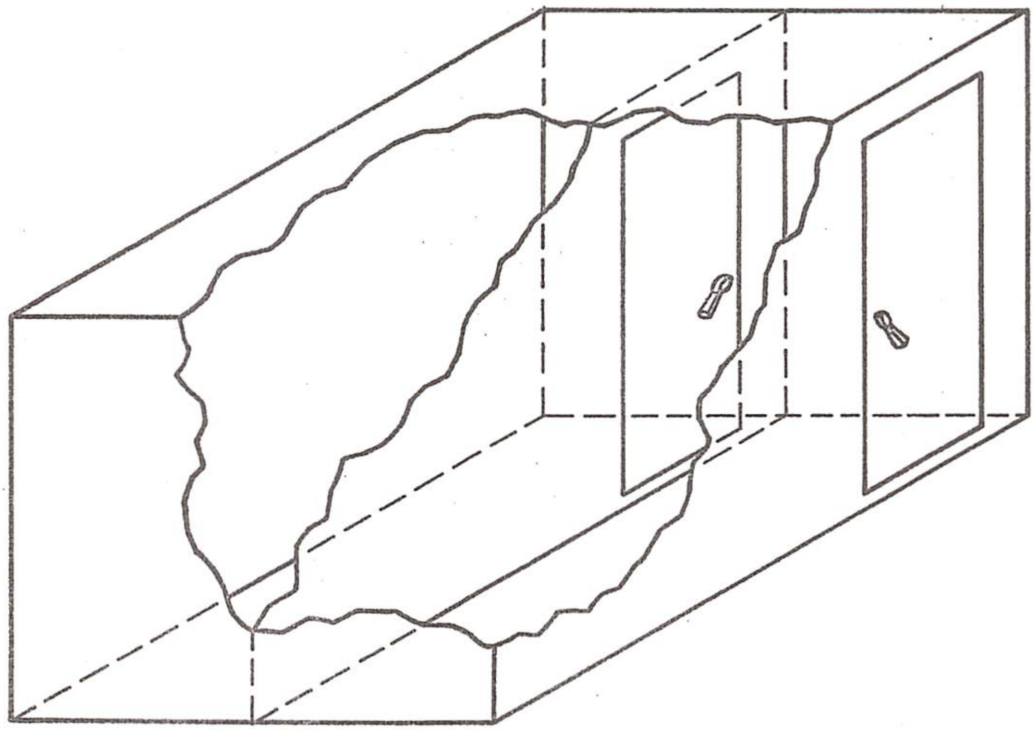


FIG. B-4 DIVIDED ENCLOSURE

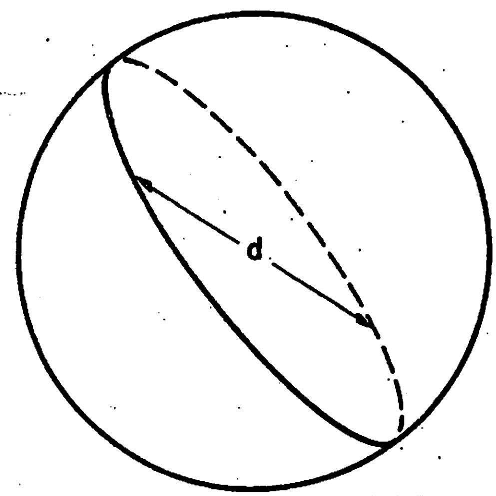
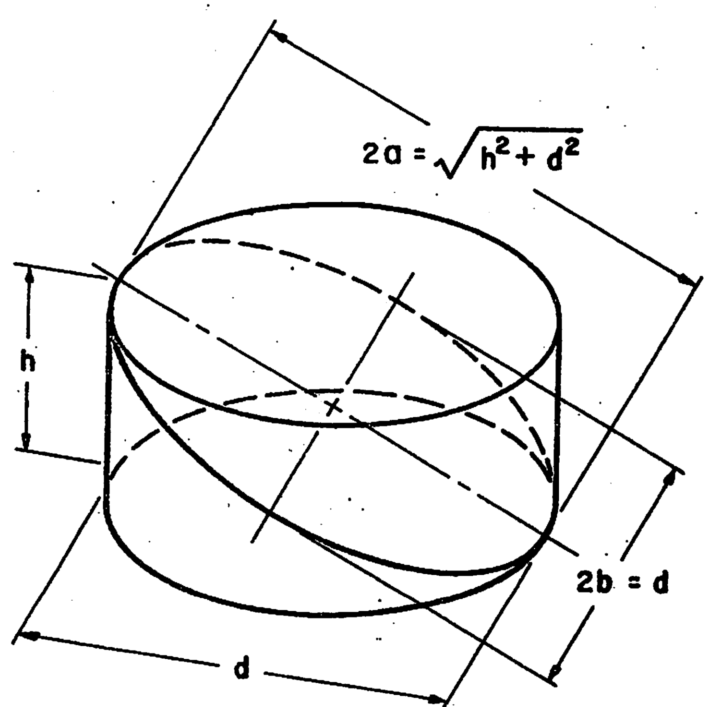


FIG. B-2 SPHERICAL ENCLOSURE



$$d_{EQ} = \sqrt{4ab} = d\left[1 + \left(\frac{h}{d}\right)^2\right]^{\frac{1}{4}}$$

FIG. B-3 CYLINDRICAL ENCLOSURE

MANCANTE