Insertion Loss of Multi-layered Shielded Enclosures

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SHIELDED ENCLOSURE SYSTEMS

Shielded enclosures can be divided into three groups. Welded enclosures feature a single wall construction, generally of a substantial thickness. Modular panel construction uses a double wall panel with a single or homogeneous joint system. The multiwall system usually uses up to four layers of materials. Depending on the contractual requirements, these layers may be of differing materials.

Field test results of these systems are well-known and are accurately predicted. Industry acceptance of all of these construction methods and systems is universal, and experts recognize that each of these systems offers advantages and optimum applications. Ultimately, the effectiveness of the multi-layered shielding system is determined by the magnetic field.

The magnetic field is the focus here since it represents the most predictable and significant field of calculation and subsequent measurement. The other two fields, electric and plane wave, are not just unpredictable in performance, but are almost 100-percent reflective with regard to the impinging waves of energy, and the resulting attenuation.

The electric field is of a high impedance voltage coupled with a very low magnetic field driving force or current. When this field impinges upon an outer RF wall, nearly 100 percent of the impinging voltage is reflected back towards the transmitting site. Thus the attenuation of the electric field is assumed to be nearly 100 percent of the impinging or transmitted energy. Usually this is an attenuation of far greater than 120 dB, likely in the area of 140 dB. The most common specification requirement is 100 dB.

In the case of a plane wave, a somewhat similar situation occurs, in that the reflected wave constitutes the majority of the impinging signal, which is the attenuation of the plane wave. A significant portion of this wave is magnetic or current. Because the driving voltage is significantly lower than an electric field, there is a poor magnetic or current penetration of the shield media. Cracks or gaps in the shield media are easily found by this wave, but total penetration of the shield is nearly impossible. Even foils are effective attenuators. High voltage (and high impedance) plane waves, such as those found in radio telephones and the like can easily penetrate a single layer foil shield. Incidents are frequently noted in

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MRI and similar RF shields found in hospitals and medical enclosures, where the use of a single layer shield is most common. The shielded enclosures still meet the specified attenuation requirements, usually 100 dB from 100 kHz through 1 GHz. This is because a very sensitive receiver is used, and a 100 dB or better dynamic range of the test equipment is actually below the transmit power of the radio telephones or other sources.

In order to exclude the signals from radio telephones and the like, either a heavy single wall (1/8 inch), or a multi-layer shield must be used. The usual shield in these instances is based on a modular panel construction, which, from a cost standpoint, is superior.

ATTENUATION

The attenuation of an RF field in a single shield is the absorption of the impinging field, which is assumed to be polarized, or at least partially so. The first field is the magnetic field, which follows the shield media domain lines (in a ferrous metal), or the path of least resistivity (in non-ferrous metals). As these magnetic currents follow the lines of least resistivity, the resistance attenuates the energy as heat. It also follows that there will be residual current that will penetrate completely through the shield media.

The second field is the very small electric field that accompanies all magnetic fields. This voltage, though very small, is assumed to be totally reflected from the outer wall of the impinging shield. The electric field is thus eliminated as a potential insertion loss, but constitutes a reflective loss.

As the magnetic currents pass within the shield media, there are several events which occur simultaneously. When the magnetic currents pass along the lines of low resistivity, heat is generated, which adds to the attenuation of the current. In passing, the currents tend to create their own surrounding radiated fields. These fields radiate in all directions. Some radiate back through the media to the impinging wall. There, they are radiated as a voltage from the inner surface of the wall. Most of this energy is a magnetic current, but a small portion is an electric field. Depending upon the shield material and mass, some of the magnetic current will re-pass through the shield media to the inner wall surface.

The polarization of the field passing through the shield media will change due to internal reflections and the re-transmission of the field from the inner wall. In the transition of the energy through the thickness of the shield media, one or more reflections may occur. As the energy finally reaches the inner wall surface, varying polarities will have occurred. This means that those re-transmitted and reflected signals will now have been changed into varying polarizations. This will add slightly to the overall attenuation.

The majority of the signal emerging from the inner shield wall is still magnetic. The electric field content, which is the result of the internal reflections, remains at a minimum. Consequently, the inner wall transmission of this electric field remains at a minimum. The introduction of a second layer of shielding causes an additional change in the overall characteristics of the field, including both the polarity and attenuation. The impinging voltages cast upon the second layer of the wall are the non-polarized mix of voltages described in the previous paragraphs. The majority of voltage at this point is magnetic, but with an increased portion (still small) of electric field. The attenuation of an electric field is far greater than a magnetic field. That small portion of electric field that is internally generated is easily attenuated by the second media layer, and will not add greatly to the overall attenuation characteristics of the two layers. Three or more layers seem to have little additional attenuating effects, other than the calculated shield media attenuation.

This theory of RF shielding attenuation is most effective at the lower thickness of approximately 0.030 inch per layer. The reference here is to one or two layers of shield materials. As stated, three or more layers seem to have little additional effect, other than the calculated attenuation.

As the thickness of the shield material approaches 0.060 inch per layer, such as in welded enclosure construction, this theory starts to fall apart. The thickness of the shield material is now sufficient to provide attenuation similar to multi-layer construction.

It must also be kept in mind that the RF attenuation measurement as tested by MIL-STD-285 or a similar insertion loss test method entails receive antennas which are quite different than the receive antennas of a radio telephone or piece of communication equipment. Consequently, a radio telephone, communication transmitter, or similar device may ring or respond inside a single layer shielded enclosure.

SPECIFICATIONS

The usual specifications for such enclosures is 100 dB from 10 kHz through 1 GHz. The specifications never stipulate the power levels to be used by the transmitters or the sensitivity levels to be maintained by the receivers. Also, keep in mind that the specified and tested attenuation levels are a ratio of input to output voltages. How an enclosure that has been tested and certified to provide 100 dB over the specified frequency range can also allow a radio telephone or similar communication device to be detected within the enclosure is now understandable. This usually occurs when the power level of communication device is high. At the same time, the RF shield testing equipment is using a low-power transmitter and an ultra-sensitive receiver. Is this misleading? The answer is yes. However, it is perfectly ethical and legal. The testing equipment and testing procedures used are in complete accord with the contract specifications and the test procedures specified.

It *is* true that the general rule of the specifications do not include limits for the transmitter power levels, or the sensitivity levels of the receiver that must be used during testing. These are left up to the testing company to establish, in accordance with their test equipment and common experience. To insert test equipment parameters in a specification would be a most difficult and elusive task. If the basic requirement of the enclosure is to shield out certain communication equipment (or other signals), then that is what should appear in the specification. Ultimately, most shielded room suppliers would probably offer a guarantee of attenuation per standard specifications.

The best alternative is to include a minimum shield material and thickness in the specification. This would place the onus of performance upon the buyer, and not upon the supplier. There are also more than a few highly qualified consultants in this field who could help.

The following formulas can be useful in determining a minimum shield material and thickness. These are industry standards long held to be accurate. They are used in the calculation of various shield materials versus thickness attenuation (calculated).

$$dB = KT\sqrt{f}$$

$$f = \left(\frac{dB}{KT}\right)^2$$

$$T = \frac{dB}{K\sqrt{f}}$$

$$K = \frac{dB}{T\sqrt{f}}$$

The K factors are: steel, 16; copper, 28; brass, 20; aluminum, 5; T, material thickness in inches; f, frequency; and dB, attenuation in decibels

These formulas are accurate to ±1 dB up to 80 dB of attenuation. From 80 dB to 100 dB, the accuracy falls from ±1 dB to ±3 dB.

All calculations are for the magnetic field performance, which usually falls within the frequency range of 20 Hz to 100 MHz. The low frequency of 20 Hz is used because practically all low frequency magnetic field test equipment operates down to this frequency, and stops here. The formula given above, however, is accurate to the earth's magnetic field variations, which go down to about 3 Hz. As the magnetic field of direct current is approached, the formula is no longer accurate.

At the upper frequency of 100 MHz, the formula accuracy varies in proportion to the efficiency of the magnetic field antennas. At the lower frequencies, the usual requirements are for electron microscopy, cryogenic test areas, and the investigation of low frequency phenomenon. Usually, these items require control of the 60 cycle fields.

CONCLUSION

There is little mystery to the design of RF shields and magnetic shields that meet or exceed any specification. The application of basic formulas and design concepts can lead to a competitive and effective enclosure.

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