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EMI SHIELDING TEST METHOD FOR SMALL WIRELESS DEVICES

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ABSTRACT

We introduce a new cavity-to-cavity isolation standard for measuring the electric field attenuation of EMI/RFI shielding systems used in small wireless devices. The test specimen, which represents the shielding system under evaluation, is a "ladder box" strip containing three small, isolated, five-sided box compartments. The test sample is placed on a printed-circuit board, which contains a ground trace and an antenna beneath each compartment. The antennae are connected to a network analyzer, which is used to measure the EMI/RFI shielding between cavities.

The approach is utilized to compare different materials and methods used for shielding small compartments in wireless devices. The shielding systems comprise of both a substrate and an interface. Various substrates such as metal, metal-coated plastic, painted plastic, and filled conductive plastic are evaluated in conjunction with conductive silicone gaskets.

Key words: EMI shielding, conductive elastomers, conductive plastics

BACKGROUND

Electromagnetic interference (EMI) shielding is critical to the proper functioning of devices [1,2], in particular small wireless devices such as cellular handsets. There are numerous methods for measuring EMI shielding [1,3,4]. Unfortunately, there exist few, if any, reliable standard techniques for measuring the shielding performance of materials and solutions in a geometry characteristic of that found in small wireless devices.

One standard method for measuring the shielding performance of a material is ASTM D4935[3]. According to this method, an approximately 5¼" (13.3 cm) disk is placed in a specially designed, enlarged coaxial transmission line, which is configured between a signal generator and receiver. The shielding effectiveness is calculated as the change in received power of the sample vs. the reference.

The ASTM D4935 method, however, has numerous disadvantages with regard to measuring EMI shielding performance for small wireless device applications. First, the valid frequency range of the test typically does not exceed 1 GHz, whereas the range of interest for small wireless devices is often, if not usually, higher. In addition, the geometry of the specimen is dissimilar to that found in small devices. Furthermore, the test evaluates substrates with no regard for how they terminate. Finally, experience indicates that the test does not adequately discriminate shielding materials in term of their actual relative performance in small wireless device applications.

Shielding effectiveness can also be measured using a shielding chamber similar to that described in Mil Std 285[4]. Transmitting and receiving antennae are placed on opposite sides of a wall of the chamber. The test sample is placed in a custom fixture which rests in a "window" in the wall. Shielding effectiveness is measured as the difference in attenuation with and without the sample in place.

The shielding chamber method is generally considered a better test in comparison to the ASTM. Unlike the ASTM method, this test can be used to measure at significantly higher frequencies, evaluate an entire shielding system including its termination, and test virtually any shaped sample part as long as one produces an appropriate fixture.

On the other hand, the chamber technique has several disadvantages with respect to small device applications. The test is intended for and exhibits the most reliable data for large sized panels and high length gaskets. Data for small samples is difficult to measure accurately. This is deepened by the fact that the method is both highly labor intensive and highly capital intensive.

Furthermore, in considering small device compartments, traditional test methods inflate the shielding effectiveness. For a given shielding solution, a traditional test method may indicate, for example, an attenuation of 80-100 dB. However, the actual shielding effectiveness, using the same materials and approach, may be only 30-50 dB in a small device application.

This is in part due to how test samples are terminated. For example, the area of the outer flange in the ASTM D4935 fixture is 2.4” (6.1 cm) and extremely flat and stiff. The flange used on a shielded room wall is typically in the range of ¼” to ½” (0.6-1.3 cm) and is also usually flat and stiff. However, the area of termination of a shield in a small wireless device is a different order of magnitude. In addition, the ASTM test fixture and shielded room wall do not represent the lack of mechanical conformity found in a small wireless device.

Another consideration is the near vs. far field[5]. Electromagnetic shields behave differently in the near and far fields. The electromagnetic shields used on a small wireless device such as a mobile phone are in the near field. Traditional test methods, such as those described above, evaluate primarily the far field.

The distance from a radiating source defines the near and far fields. The general rule of thumb for near field is any distance below one-half the wavelength. For example, if a mobile phone antenna or component is radiating at 1.9GHz, the wavelength is about 6” (15 cm). The near field is therefore less than about 3” (8 cm) from the source in the phone.

For the above reasons, it would be highly advantageous for there to exist a standard test technique which considers specifically small wireless devices. The method should consider geometry, frequency range, and termination used in such devices. Furthermore, it should require relatively little labor such that reliable and reproducible data can be regularly generated.

DESCRIPTION OF TEST METHOD

This paper introduces a test method for measuring the cavity to cavity EMI attenuation of shielding solutions for small wireless devices. The test part, shown in Figure 1, is a “ladder box” consisting of three five sided cavities, each 1.5”(3.8 cm) square. The part is compressed against a printed circuit board, which contains an antenna for each cavity and a ground trace where the rib walls contact the board. An electrically conductive gasket is generally used to seal the interface. Shielding effectiveness is measured from one cavity to another using a network analyzer. The test configuration is shown in Figure 2.

Figure 1. “Ladder box” test part and PCB with three antennae for cavity to cavity shielding.

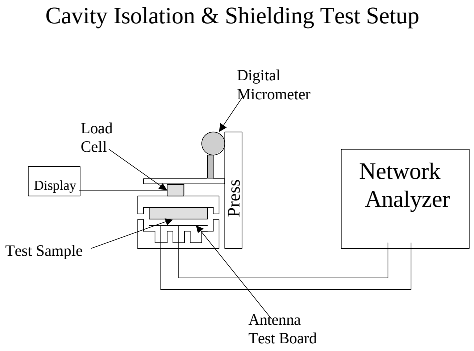

Figure 2. Test configuration.

The cavity isolation test method better simulates the conditions in a small wireless device. For example, the area of termination is similar to that in a small device. The rib contact area can be varied at will, but has typically ranged from 0.030” to 0.060” (0.8 to 1.5 cm). In addition, the compression force can be controlled to simulate level of conformity. Furthermore, the test geometry is more representative, and the method generates shielding effectiveness values in the near field as in small devices.

The printed circuit board was designed to simulate the radiation and reception of electromagnetic energy from the components and traces of a small wireless device. The components and traces that radiate on a small wireless device are physically located over a ground plane. The PCB incorporates three micro-strip patch antennae located in close proximity to each other.

Each micro-strip patch antenna was designed to operate over a wide frequency range and carry significant RF current and receive RF energy efficiently. The trace width of the antenna is 0.1" (0.25 cm) and is terminated with a 0.5watt, 50ohm surface mount resistor to the ground plane. An SMA connector is soldered to the bottom side of the PCB with the center conductor soldered to the antenna on the topside of the board. All three antennae are identical. The voltage to standing ratio (VSWR) is less that 1.1 to 1 from 500MHz to 8.5GHz and 1.3 to 1 from 8.5GHz to 12GHz.

The PCB consists of two ground planes tied together by over one hundred vias. The PCB is 0.06" (1.5 mm) thick consisting of Rogers 5880 material with a dielectric constant of 2.2 and a loss tangent of 0.0009. The bottom side of the PCB has a continuous ground plane. The top half of the boar has a continuous ground plane with three 1.5" (3.8 cm) cut outs, which contain the antennae.

The test procedure is simple, repeatable and quick. The cavity isolation test requires a small amount of equipment, takes less than 60 seconds to perform and is highly repeatable. The equipment required is a network analyzer, load cell, micrometer, press, printed circuit board, and nonconductive fixture. A Gage repeatability and reproducibility study indicated that there was little to no test operator dependence.

The test procedure has a simple three-step process. First, the network analyzer is calibrated through the frequency range of the test. A full two port calibration is performed with the test cables connected to the PCB for the transmission portion of the calibration. This provides the reference value from which the shielding effectiveness is derived. Second, the test part is placed in the fixture and is compressed to the desired load. Third, the reference value is compared to that value acquired with the test sample compressed against the PCB. The difference between these is the shielding effectiveness or cavity isolation.

In summary, the test technique has numerous advantages over existing methods. First, it represents geometry and conditions realistic of small wireless devices. Also, it is a fairly rapid test such that a statistical population of data can be generated in a reasonable amount of time. Furthermore, it is a test of a complete shielding system, which include the sealing of the interface.

EXAMPLE CHARACTERIZATIONS OF SHIELDING PERFORMANCE

The following section is a discussion of example characterization data obtained for various shielding solutions. These results are intended to represent typical shielding values for different generic shielding solutions. However, results can vary depending upon the specific materials and processes used.

All measurements were taken as the shielding effectiveness between two adjacent cavities of the ladder box sample. All ladder boxes, except where noted, were molded with a 0.060" (1.5 mm) wall and rib thickness. The data, except where noted, represents the arithmetic average of 5-10 samples.

Except where noted, a silicone elastomer gasket filled with silver-plated copper[1] was placed between the ladder box and the ground trace. The gasket was in the form of 60 mil sheet stock cut to the shape of the ground trace. The compression force used to press the sample against the PCB was 65 lbs. (289N). This equates to approximately 3.6 lbs./linear inch of interface (6.3N/cm).

Aluminum reference

An aluminum ladder box specimen was machined to a 0.040" (1 mm) wall thickness. This sample is intended to represent a benchmark reference of the practical maximum level of shielding measurable using this technique. The data depicted in Figure 3 indicates shielding levels in the 40-50 dB range. The sample was measured five times with a standard deviation (not depicted) within 1 dB for each frequency.

Solutions exhibiting attenuation in the 40-50 dB range using this cavity isolation test method should be considered as excellent shielding materials. Note, as discussed previously, that other traditional tests would typically characterize such materials with 80-100 dB of attenuation.

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[1] CHO-SEAL 1215

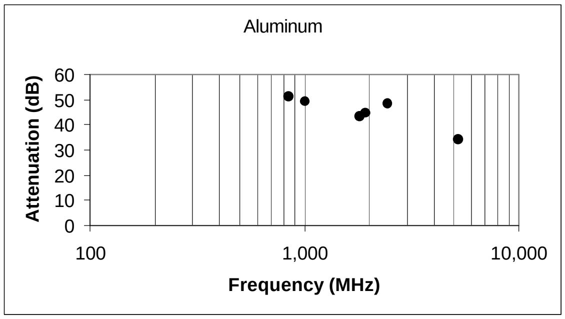

Figure 3. Shielding effectiveness data for 0.040” (1 mm) wall thickness aluminum.

Conductive acrylic paint

Ladder box housings were injection molded from PC/ABS plastic and sprayed with a 2 mil thick layer of silver-coated-copper filled conductive acrylic paint[2]. The arithmetic average is indicated with a dark circle and the one standard deviation range is indicated with bars in Figure 4. The shielding effectiveness is approximately 40 dB.

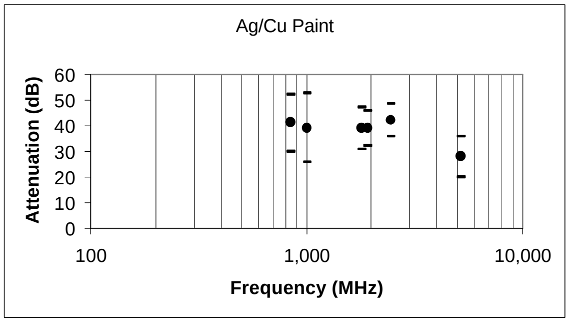

Figure 4. Shielding effectiveness data for 2 mil silver/copper conductive acrylic paint[2].

Electroless plating

Ladder box housings were injection molded from glass-filled liquid crystalline polymer and metal plated with copper and nickel[3]. The data is shown in Figure 5. The attenuation, is good, in the 30-40dB range.

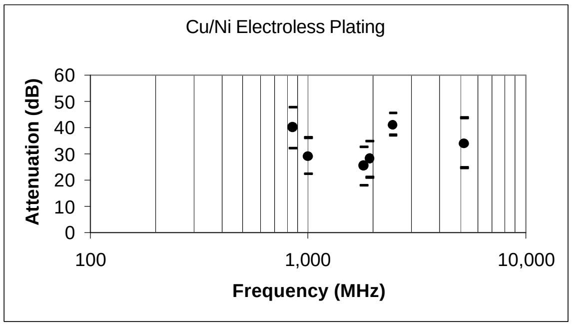

Figure 5. Shielding effectiveness data for Cu/Ni electroless plated plastic.

Metal spray conformal coating

Ladder box housings injection molded from glass-filled polyarylamide were sprayed with 1-2 mil of a tin/zinc alloy[4]. The shielding data is presented in Figure 6. The relatively thick layer of highly conductive metal provides a very high level of attenuation, in the 40-50 dB range, in comparison to the benchmark.

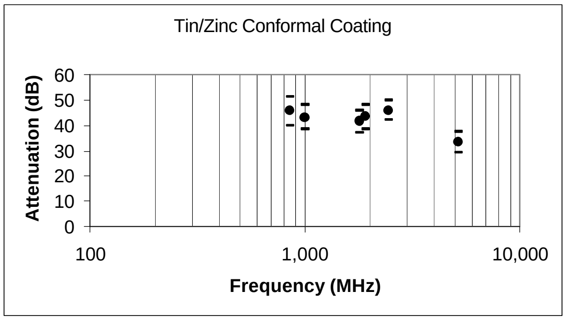

Figure 6. Shielding effectiveness data for tin/zinc alloy conformal coating[4].

Conductive plastic

A growing approach to EMI shielding is the use of thermoplastics containing electrically conductive fillers. A ladder box housing was injection molded with an electrically conductive PC/ABS composite. The composite uses a new and proprietary technology for optimizing the dispersion and aspect ratio of long fibers.

The shielding data is presented in Figure 7. The shielding is very good, in the 30-40 dB range.

The conventional prior art for conductive plastic technology has comprised typically of a “dry blend” process. Using the dry blend process, chopped and polymer-impregnated long fibers are physically mixed with virgin thermoplastic pellets. The physical mixture is then introduced “as is” to

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[2] CHO-SHIELD 2052

[3] Specification: 4-5µ Cu, 1µ Ni

[4] ECOPLATE 5030

the injection molding machine hopper without any pre-compounding stage.

A traditional dry blend PC/ABS compound was produced using the identical long fiber filler and the identical loading percentage as in the dispersion technology blend described above. The shielding data, presented in Figure 8, indicates a fair but distinctly lower degree of attenuation in comparison that in Figure 7.

These results correlate to those obtained in small wireless device applications. The dispersion-optimized materials have been found to perform effectively in small wireless device applications and essentially indistinguishably from coated plastic solutions. On the other hand, the dry blend technology, has more often failed in small wireless device applications.

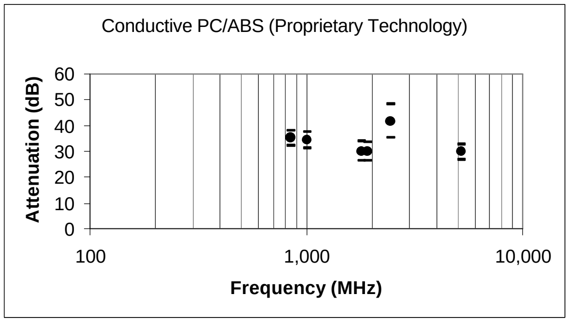

Figure 7. Shielding effectiveness data for electrically conductive PC/ABS composite with proprietary long fiber dispersion technology.

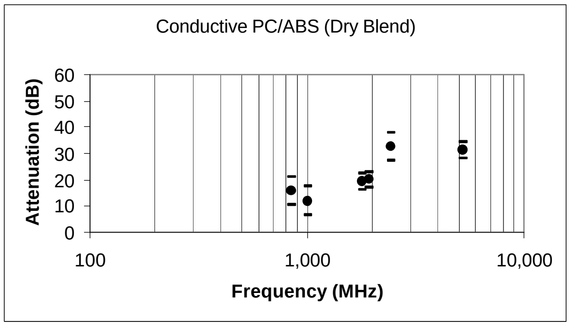

Figure 8. Shielding effectiveness data for electrically conductive PC/ABS composite using dry blend long fiber mixture.

Conductive plastic with overmolded gaskets

The following results demonstrate that the cavity isolation test method can be used to determine the influence of both substrate and interface material.

Ladder box housings were molded with an electrically conductive polyamide 6/6 composite using the proprietary dispersion technology. Electrically conductive silicone profiled gaskets were insert molded onto the interface region of the part ribs as shown in Figure 9. Unlike the previous specimens, the molded gasket served as the interface, and no sheet stock gasket was used.

Two different grades of conductive elastomers were used. The first was a silver-plated copper powder filled silicone[5] with a maximum electrical resistivity specification of 0.004 Ω-cm. The second was a silver-plated glass powder filled silicone[6] with a maximum electrical resitivity specification of 0.01 Ω-cm. The silver/copper gasket should, in general, exhibit greater shielding effectiveness than the silver/glass gasket.

The shielding data for the two gaskets on conductive polyamide are shown in Figure 10. The data for the silver/copper gasket is shown in circles, and the data for the silver/glass is shown in triangles.

The silver/copper gasket over conductive polyamide solution has a statistically significant attenuation advantage over the silver/glass solution. This indicates that both substrate and interface are important, and demonstrates that this shielding test method can isolate both effects.

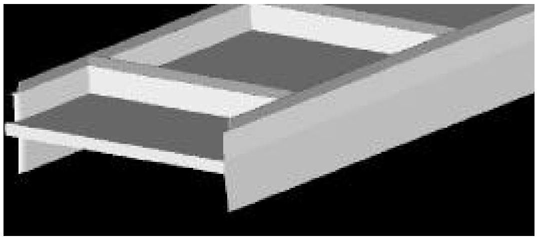

Figure 9. Conductive silicone overmold.

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[5] CHO-SEAL 1273

[6] CHO-SEAL 1310

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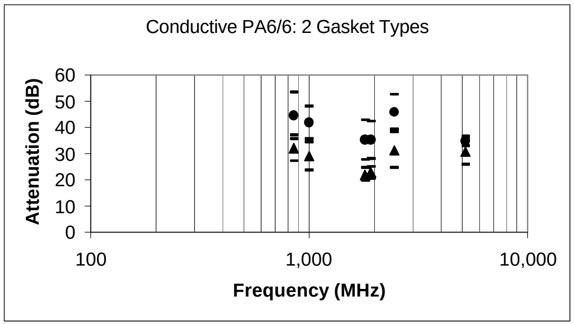

Figure 10. Shielding data for electrically conductive polyamide 6/6 composite[6] with insert molded silicone gaskets: silver-plated copper filled[7] (circles) and silver-plated glass filled[8] (triangles). Bars represent ± 1 standard deviation.

CONCLUSIONS

1. We have developed a test method which can be used to evaluate EMI shielding in a small wireless device geometry.
2. The test method better simulates the conditions of shielding solutions in small wireless devices in comparison to traditional shielding test methods.
3. The technique is simple and reproducible. It is neither labor-intensive nor capital-intensive. It can be used to generate statistical data.
4. The method can be used to compare different shielding technologies used in small wireless devices including conductive coatings, conductive interface gaskets, and conductive plastics.
5. The method has demonstrated that by using proprietary materials technology to optimize filler dispersion, filled conductive plastics can perform on par with other effective shielding technologies.

REFERENCES

[1] Kodali, V.P., Engineering Electromagnetic Compatibility, IEEE Press, 1996
[2] Montrose, M.I., EMC and the Printed Circuit Board, IEEE Press, 1999.
[3] ASTM D4935-99, Standard Test Method for Measuring the Electromagnetic Shielding Effectiveness of Planar Materials, ASTM, 2001.
[4] MIL-STD-285, Military Standard, Method of Attenuation Measurements for Enclosures, Electromagnetic Shielding, for Electronic Test Purposes.
[5] Straus, I., Conformity, Annual Guide 2002, p.88-93.