A new alternative for board-level EMI shielding

New technology couples the shielding effectiveness of metal cans with the superior design flexibility and reduced weight of plastics.

DONALD M. YENNI, JR.
MARK G. BAKER
CURT MAYNES
3M Company, Electronic Handling & Protection Division
Austin, TX

Today's consumer electronics market is pushing manufacturers to provide products that are smaller and faster and have higher performance than ever before. Some of the more visible results of this can be seen in recent design progressions for mobile phones and other wireless communication devices. Since plastic is the material of choice for the housings of these products, EMI shielding is a major issue. There are relatively few standard technologies now available that EMI engineers can use to prepare their systems to meet today's emission and susceptibility challenges. Recently, however, a new technology has been introduced for EMI shielding at the printed circuit board (PCB) level that couples the shielding effectiveness of metal cans with the superior design flexibility and reduced weight of plastic.

This article describes the basic makeup of this new material, its capabilities, and the theory behind its functionality. Some experimental analysis of the new material's shielding performance, both in the far field and in a near-field test application, will be presented. An overall cost and performance comparison between this new technology and those currently used in the consumer electronics industry will be provided, along with a discussion of the pros and cons of each.

EMI SHIELDING AT THE PCB LEVEL

Recent advancements in mobile communications require that a variety of electronic functional blocks all be able to peacefully coexist in very close proximity. This is of particular concern to wireless product manufacturers that have had to integrate both RF and digital functions onto a single PCB. In order to permit the noisy/susceptible groups of components making up these functional blocks to operate properly and simultaneously, manufacturers have had to employ localized shielding to electrically isolate them from one another. In addition, total emissions from the finished products must be within limits set by the various controlling government bodies (e.g., FCC, CISPR, VCCI) in today's global market.

The three EMI containment technologies most widely used today are metallized injection-molded plastic housings, stamped metal cans, and die cast (or molded) metal shields. Other technologies that are sometimes used to augment these basic PCB-level shielding systems are conductive gaskets and conductive paint or plating on the inside surface of the equipment housing.

HEAT STAKABLE PLASTIC SHIELDING CAPS

Recently, a unique new shielding technology has been introduced that provides a thermoformed, conductive multicavity plastic cap that is applied directly to a PCB by means of heat staking or thermal bonding (Figure 1). Once the cap has been applied, it has been shown to withstand the rigors of the standard tests required by the mobile phone industry. If rework or repair is required, the cap can be peeled off from the PCB.

Material Description

The new heat stakable plastic shielding cap material is composed of two layers (Figure 2). The first layer, which gives the material its stability, consists of a 0.13-mm thick film of polycarbonate. The second layer is a thermally extensible mat of tin/bismuth alloy fibers enclosed in an ethylene vinyl acetate (EVA) hot-melt adhesive resin. It is this metal fiber mat that gives the composite material its EMI shielding characteristics.

Shielding Cap Formation

The metallurgy of the metal fiber mat is key to the material's ability to be thermoformed into complex, multicavity shielding structures. During forming, the material is heated up to the softening temperature of the polycarbonate backing (175° C). At 138° C, the metal fibers become molten and are thus able to extend with the softened plastic backing as it is forced into the mold by vacuum or pressure. As the molded cap cools, the metal fiber mat resolidifies, maintaining its electrical continuity and thus its shielding effectiveness. The ability of this new material to be formed in this way allows a great deal of flexibility in the design of multicompartment or complex shields.

Shielding Cap Attachment

The formed shielding cap is thermally bonded and electrically connected to the PCB using a specially shaped die. As the heated die contacts the flanges of the cap, the hot melt adhesive is activated, fixing the cap mechanically to the PCB ground trace. During this operation the temperature of the EVA adhesive rises to about 90° C. The solid shielding fibers on the flanges of the cap are then forced through the adhesive and into electrical contact with the PCB grounding pad. No additional gasketing, conductive adhesives, soldering, mechanical fasteners or further processing is necessary to complete the circuit shielding.

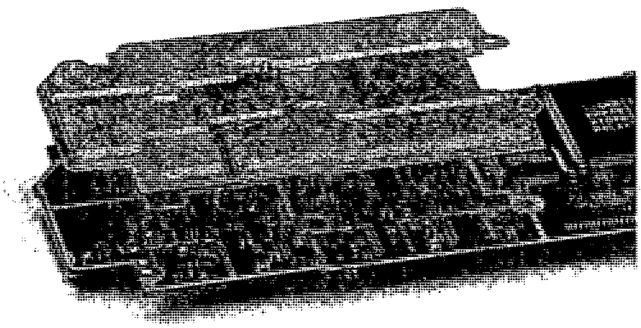

Figure 1. Heat-bondable, multicavity, EMI shielding cap (potential application for mobile phone).

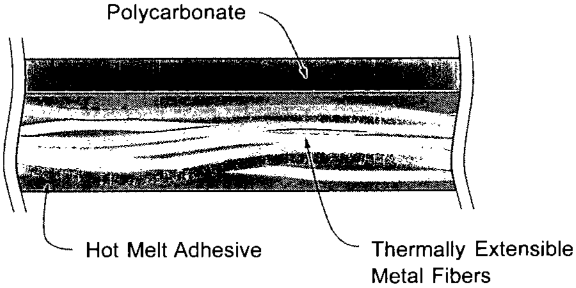

Figure 2. Layered construction of heat-bondable EMI shielding material.

The major variables involved in the attachment of these caps to the PCB are the thermal-bonding die temperature, pressure, and dwell time. These values vary somewhat with the size of the cap and, to a greater extent, the thermal characteristics of the PCB (Table 1). Larger caps require greater pressure whereas PCB's with higher heat capacity require longer sealing times.

The hot-melt adhesive has been specifically formulated to solidly hold the cap to the PCB during typical climatic and vibrational stress tests required by many consumer wireless product manufacturers. Even when the board is reheated to temperatures exceeding 85° C after application, the bond does not relax. In fact, extended exposure to temperatures as high as 125° C has actually been shown to cause the adhesive to become more aggressive.

Shielding Cap Removal

The EVA adhesive resin is designed to have a "controlled release" property that allows the cap to be removed by peeling it off the board. This can be done by hand using a small pair of pliers. Since removal occurs at room temperature, the strength of the PCB trace adhesive is not compromised (as can happen during the heated removal of soldered cans) so it is unlikely that peeling the cap off would cause damage to the PCB traces. The peel force of a cap thermally bonded to a typical PCB with gold traces and a row of vias down the center of the trace was found to be about 2.0 N/mm (90° peel).

Shielding Effectiveness

Full characterization of a material as an EMI shield is

CAP ATTACHMENT VARIABLES	TYPICAL RANGE OF VALUES
Thermal-bonding die temperature	160° - 190°C
Pressure holding thermal-bonding die against cap flange in a 3" dia. cylinder)	5 - 40 psi
Dwell time for seal	2 - 10 seconds

Note: During this operation the temperature of the PCB trace beneath the cap flanges reaches a peak temperature of about 90° C. This limits the heat exposure of adjacent components to an insignificant level.

Table 1. Typical thermal-bonding parameters.

accomplished by evaluating its performance in both the near and far field. Far-field measurements (measurements made with the shield at a distance from the source greater than the wavelength divided by 2π) are commonly used to indicate the ability of the material to prevent external sources from interfering with product operation. In other words, such measurements measure the material's ability to address the issue of product susceptibility. In addition, far-field measurements, because of their relative accuracy and reproducibility from one laboratory to another, are often used for material comparisons.

Near-field measurements, on the other hand, provide a more realistic picture of the shielding provided by a low-profile cap on a PCB. The shielding surface of such caps is generally located closer to the signal source than a distance of the wavelength divided by 2π. A knowledge of near-field performance is therefore required to determine the cap's ability to handle PCB emissions and to reduce circuit-to-circuit interference. Because the results of near-field measurements tend to be very circuit specific, emitters with different transmission patterns will frequently produce different shielding numbers.

THEORY

The far-field shielding effectiveness of the material from which the thermally bonded shielding caps are made, is almost exclusively the result of reflective attenuation. Its shielding or attenuation performance can be thought of as essentially a waveguide-below-cutoff with essentially no loss due to absorption. Its far-field shielding effectiveness in decibels (dB) is described in terms of the wavelength (λ) and the largest opening between fibers (δ) by the equation:

$$SE = 20 \log 10 \, [(\lambda/2)/(f * \delta)] \quad (1)$$ [1]

Because the wavelength (λ) is equal to the speed of light (c) divided by the frequency (f), Equation 1 can be rewritten to describe the far field shielding effectiveness of a mesh in terms of the spacing between fibers (δ) as follows:

$$\begin{aligned} SE &= 20 \log 10 \, [(c/2)/(f * \delta)] \\ &= 104 - 20 \log 10 \, (f * \delta) \quad (2) \end{aligned}$$

where f and d are expressed in terms of MHz and mm, respectively.[2]

EXPERIMENTAL MEASUREMENTS

The dimension δ is a direct function of the spatial arrangement of the metal fibers present in the fiber mat. A typical sample of the heat stakable plastic shielding material was examined using an optical microscope and observed to have a distribution of openings between fibers as shown in Figure 3. The average major diameter of these openings (δ) was 0.30 mm.

The shielding effectiveness of this sample (δ = 0.30 mm) was measured experimentally using the test method described in ASTM D4935. The coaxial transmission line test cell used for this evaluation was reduced in size compared to the one described by ASTM D4935 in order to provide attenuation data up to about 10 GHz. (The ASTM 4935 test cell, which was originally designed for use up to 1 GHz, exhibited numerous resonances above about 3 GHz.) The device was flanged at its midsection to eliminate concerns about electrical contact with the shielding layer of the sample (even if the shielding is buried between non-conductors) by relying on displacement current across the flange to transmit the signal. Shielding effectiveness determination required measurement of both a reference sample (to provide the incident field data) and a load sample of the same material (to provide the shielded measurement). Measurements were made using a Hewlett Packard 8510C Network Analyzer. The shielding effectiveness of the specimen (δ = 0.30 mm) is shown in Figure 4 compared to the theoretical data calculated according to Equation 2. As can be seen, the experimental data, with the exception of what are likely some minor cavity-

continued on page 44

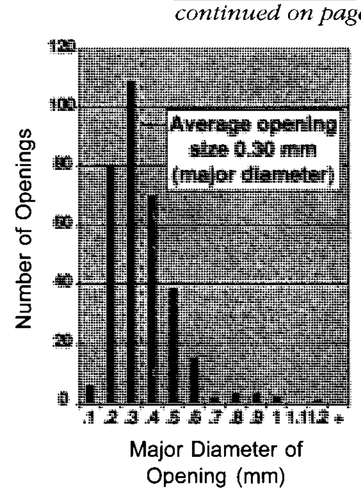

Figure 3. Distribution of opening sizes in heat-bondable EMI shielding material. Area inspected was approximately 1.5% of total sample.

induced resonances, agrees well with that predicted by Equation 2.

One of the major advantages of using the test method described in ASTM 4935 is that it provides very reproducible shielding results (within ± 3 dB, even with different equipment at different locations)[3] for a wide variety of materials. Shielding data for several of the materials in wide use for PCB-level shielding are compared in Figure 5. These low frequency measurements were made using a Hewlett Packard 8566B Spectrum Analyzer.

Electrical Isolation Effectiveness

One of the major functions of a PCB shield is to isolate electrical systems within the same piece of equipment from one another. If this is not done properly, the equipment will function erratically or perhaps not at all, depending on the specific characteristics of the circuits involved and the direction of the emission "lobes" within the functional blocks. For example, if very high emissions from a circuit happen to be directed out of a hole or slot in the shield, this can cause a problem for anything in its path.

A general measurement of the shielding isolation effectiveness of the new plastic shielding cap was accomplished using a test PCB (Figure 6) with two small antennas mounted on it. This test board was designed so that the antennas (simulating two different circuits on the same PCB) were located in the center of each capped section of the PCB. Each of the antenna wires was about 25 mm in length, elevated about 1 mm above the PCB ground plane, and terminated through a 50-ohm resistor. The multi-compartment shielding cap was heat staked directly to the ground plane. In most practical situations, shields are attached to traces on the PCB surface which are in turn connected to a ground plane

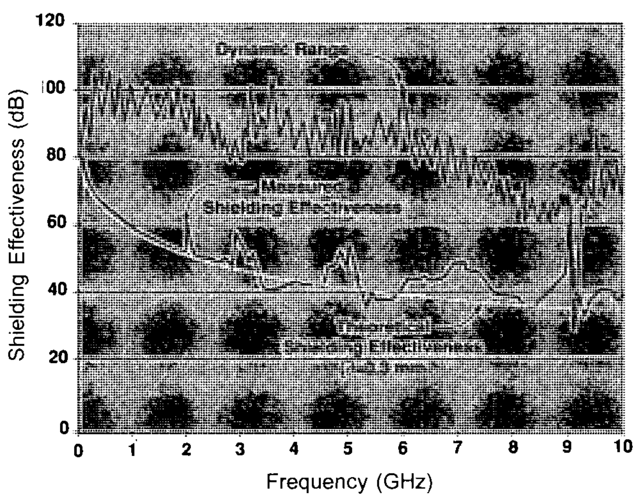

Figure 4. Comparison of experimental and theoretical far-field shielding effectiveness of heat-bondable EMI shielding material.

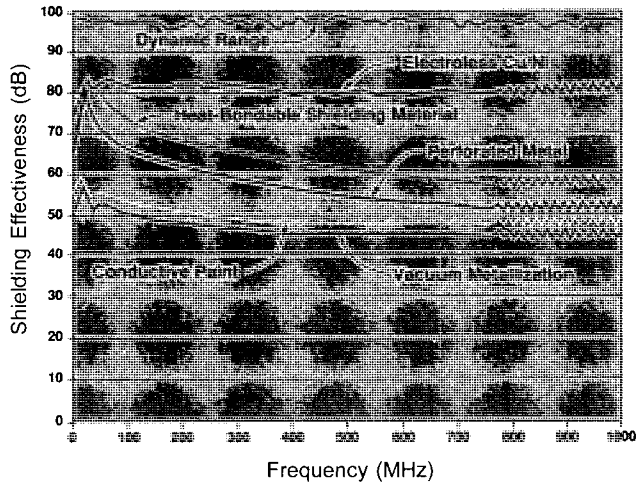

Figure 5. Comparison of the shielding effectiveness of several materials used as PCB-level EMI shields.

sublayer by vias. For this test, direct connection of the cap to the ground plane was made to avoid the shield-compromising effects of the resistance along these vias to the sublayer, particularly at the higher frequencies. Although this test technique is specific to the radiation pattern and characteristics of the specific antennas used, the resulting information shows, at least generally, the electrical isolation capability of the new material.

Isolation measurements were made between the two chambers of a thermally bonded cap by applying a signal from a Boonton 2100 Synthesized Sweep Generator to one antenna and monitoring the response at the other antenna using a Hewlett Packard 8566B Spectrum Analyzer. The frequency range evaluated was from 2 to 6 GHz. The cap was then removed to conduct the reference measurement. To establish the dynamic range of the test setup, the same procedure was followed using two copper shields soldered to the ground plane. The isolation provided by the heat staked cap (Figure 7) ranged from about 58 dB at 2 GHz to 42 dB at 6 GHz. The dynamic range for these measurements was between 65 and 80 dB across the entire frequency range.

The authors recognize that antenna board tests such as described here have certain limitations. The short wires used as antennas on the test PCB were not well tuned, except at their quarter wave length resonance (about 4 GHz). This was verified by monitoring the S11 of each antenna using a Hewlett Packard 8510C Network Analyzer. Cavity resonances that appeared to vary in their frequency of occurrence based on the dimensions of the cap prevented obtaining useful data above 6 GHz.

Metallized, Injection Molded Plastic Housings

Both electrolessly plated and vacuum-metallized injection molded plastic enclosures are frequently

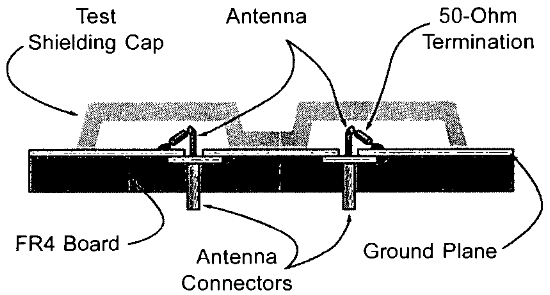

Figure 6. Test board configuration for simulating compartment-to-compartment shielding (isolation).

used to isolate the various sections of circuitry on a PCB (Figure 8). These partitioned shields are held against the PCB ground traces by clamps, screws, spring clips, or, in some cases, even the equipment housing itself.

Multilayer electroless plating techniques (e.g., copper-nickel) are usually capable of providing a very uniform conductive layer to plastic. The result is a fairly high degree of shielding (Figure 5). On the downside, however, these platings are expensive and not generally suited for high volume application.

Unlike electroless plating, vapor coating is a "line of sight" process, usually capable of providing uniform plating in only the shallowest and simplest of housing designs. Because vapor coating is a batch process, cost is also on the high side. Overall, vapor-metallized plastic housings tend to provide the least effective shielding of the technologies discussed here (Figure 5).

One of the major performance weaknesses of a rigid, metallized plastic shield is a lack of reliability in its electrical contact with the PCB. This contact is hampered by the fact that PCBs are not always perfectly flat. Intermittent contact with the grounding

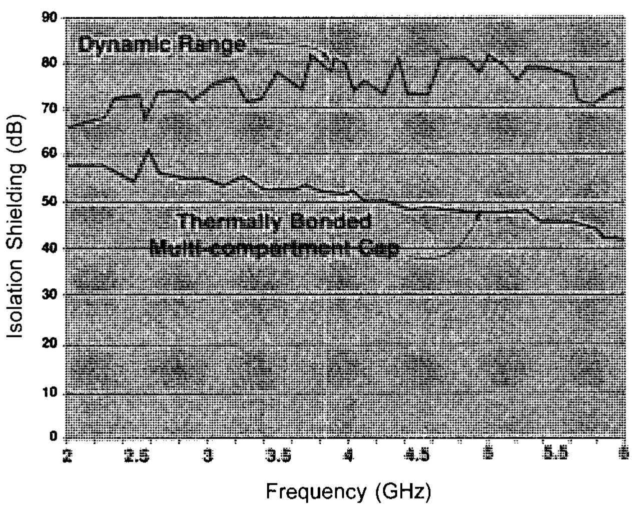

Figure 7. Isolation shielding effectiveness between adjacent compartments of a heat-bondable EMI shielding cap.

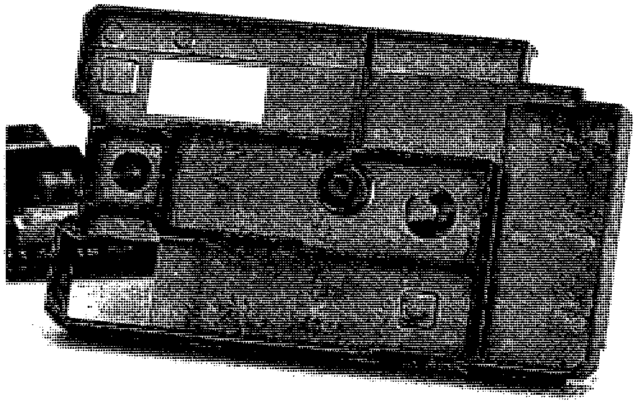

Figure 8. Metallized, injection molded plastic shielding cap.

traces of the PCB results in extended slots around the base of the shield, which greatly reduces shielding effectiveness. As higher frequency shielding becomes a concern, such rigid plastic housings often require some sort of conductive gasket between the edge of the plastic shield and the PCB ground trace to improve the uniformity of contact. These gaskets are usually made from a silver-filled elastomer and add a considerable amount to the cost of shielding.

METAL CANS

One of the more commonly used methods of board-level shielding, especially in the wireless industry, involves the use of stamped metal cans (Figure 9). These thin metal shields are available in both single and two-piece (removable lid) designs. They are stamped or folded to the appropriate shape and then soldered onto the PCB either by hand or during the reflow soldering operation. Single-piece cans that are placed onto the PCB at the same time as the components greatly restrict rework and inspection of the components beneath them. Cans with removable lids allow access to circuitry, but may require a manual assembly step to attach the lid during production.

The metal sheet stock from which these shields are usually made is capable of providing excellent shielding (to the dynamic range of our equipment). These metal shields, however, are normally perfo-

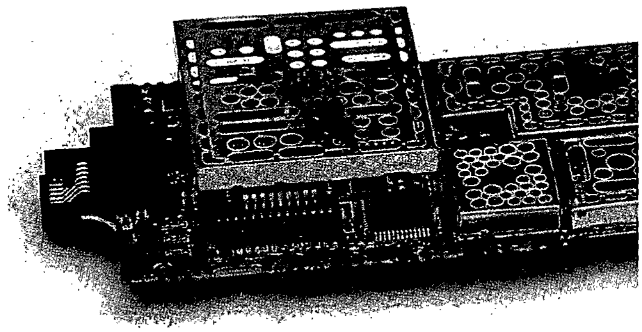

Figure 9. Stamped/folded metal EMI shielding cans.

rated or slotted. In the case of single-piece metal caps, holes must be added to prevent "popcorning" during reflow. The holes are also used to provide ventilation for the components, where required, and to help equilibrate the heat during the soldering operation so those components under the shields are properly reflowed. In the case of the "folded-type" metal cans, the corners of the can are usually left unsoldered, creating slits at each corner. All of these openings, as well as gaps left when the can flanges are soldered to the PCB, will compromise the effectiveness of the metal shield (Figure 10). Although these openings are electrically small and therefore not a big problem at today's frequencies of concern, they will become more critical as frequencies rise.

Two-part, or lidded caps, despite having the advantage of lid removability for rework or repair, introduce another concern. Over the long term, corrosion/contamination problems at the interface between the lid and frame of the can may occur. For this reason, single piece cans usually provide better and more reliable shielding effectiveness than the two-part or lidded caps. In addition, the two-part caps tend to add more weight and higher cost than other shielding technologies.

Cast Metal Housings

Die cast zinc and magnesium metal housings have been used for shielding covers in wireless communications equipment for some time (Figure 11). A number of mobile phone manufacturers using this technology, however, are presently evaluating newer techniques for providing magnesium alloy housings as a replacement for die cast parts. One of these new methods is called metal injection molding (MIM). This technology makes use of the characteristics of certain powdered magnesium alloys and plastics which allow themselves to be injection molded (i.e., they can be shear melted and processed using equipment similar to standard plastic injection molding machines). The plastic is then dissolved or burned out of the metal matrix, resulting in a part that requires further sintering to achieve its full density. More recently, parts made by a process called Thixomolding™ (magnesium alloy based) are also being evaluated. Such parts should also be capable of providing very good shielding.

All of these cast/molded metal technologies, because they form very rigid housings, usually require the use of some sort of a flexible conductive gasket to improve the electrical bond between their "footprint" and the PCB ground traces. Cast metal shields are also quite expensive and are among the heaviest of the shielding techniques in use today.

Some two-part lidded metal can designs use die cast frames as the walls that are mounted onto the PCB ground traces. The same problems with lid-to-frame electrical contact reliability that occur with stamped metal frames are noted with the die cast parts. There is the added issue, however, of being sure that the die cast frame and the metal from which the lid is made are galvanically matched materials to forestall electrolytic corrosion problems where they are joined.

continued on page 54

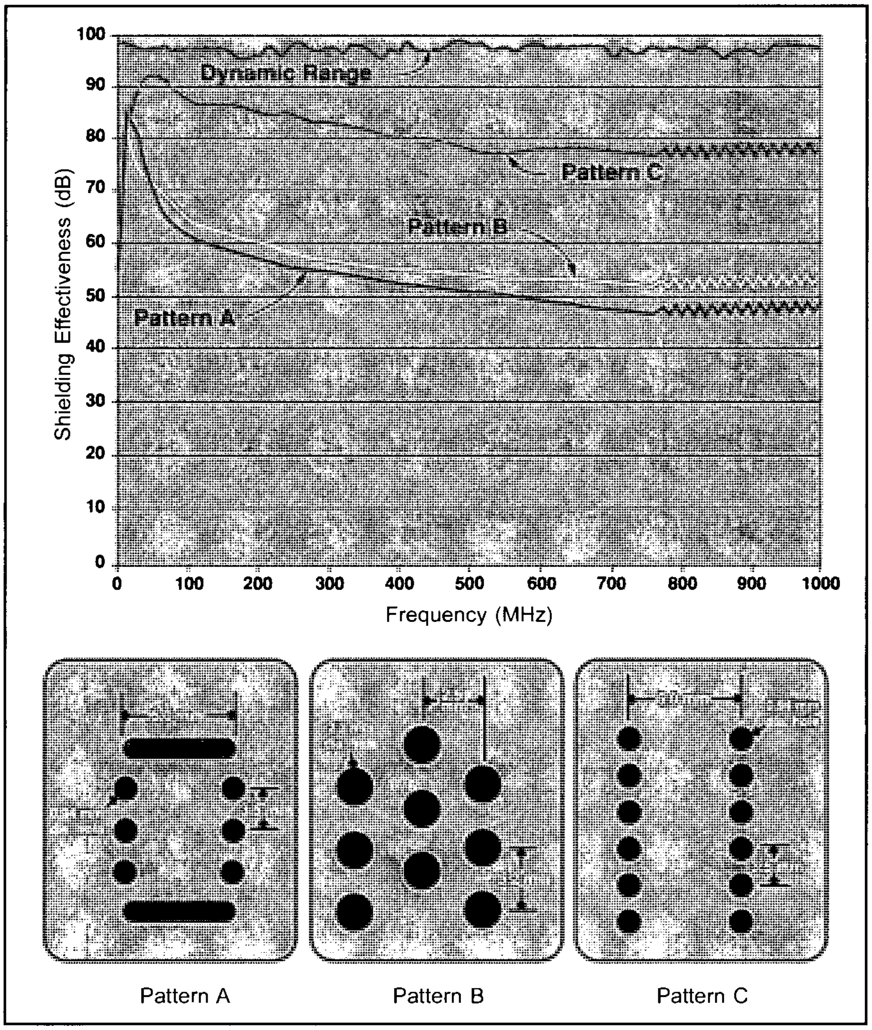

Figure 10. Relative shielding effectiveness of punched metal shields (various patterns).

 continued from page 46

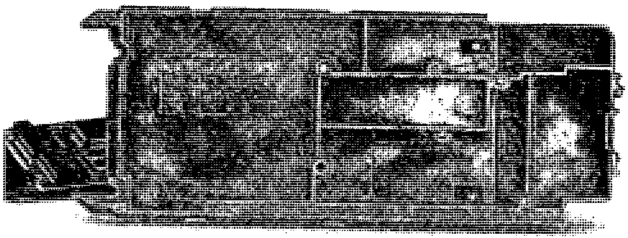

Figure 11. Magnesium housing for EMI shielding.

Conductive Paint

Conductive paint, generally filled with particles of nickel, copper, silver, or silver-coated copper, is often used to add reflective EMI shielding to plastic. This technique is generally used on the inside surface of plastic housings to help block overall EMI emissions from the product that could result in violation of governmental regulations. The shielding provided by conductive paint is generally less effective than that of previously described shielding materials (Figure 5). Overall costs can also be high due to the requirement for masking and added handling.

Cost Comparison

Table 2 includes a basic cost summary of each of the described PCB-level shielding technologies discussed in this paper. In addition, information is provided regarding the relative weight penalty for each technology as well as the potential PCB "real estate" savings due to cap design flexibility. This analysis was constructed specifically with reference to the mobile communications market; however, other users of PCB-level shielding can easily "customize" the analysis for their own products.

SUMMARY

This paper describes a new concept for PCB-level EMI shielding. Electrical attachment of these shields occurs at relatively low temperatures using a formed die. The attachment process is "manufacturing-friendly" and can result in significant overall cost savings throughout the shielded product's life cycle. The plastic caps rely on a random mat of fibers for their shielding effectiveness, which has been shown (in the far field) to be equivalent to or superior to many of the perforated and stamped metal cans in use today. The far-field shielding effectiveness of this material is easily predicted by theory. A simple technique for evaluating the shield's effectiveness in isolating two circuits (having very specific radiation patterns) on the same board was described. Various costs associated with each of the shielding techniques described was also presented.

REFERENCES

1. Donald R. J. White, "A Handbook on Electromagnetic Shielding Materials and Performance," (Don White Consultants, Inc., 1980), p. 219.
2. D. M. Yenni, Jr and M. G. Baker, "One-Step Thermoformable EMI Shielding" ITEM 1996, pp. 56–62, 272.
3. B. A. Kinningham and D. M. Yenni, Jr., "Test Methods for Electromagnetic Shielding Materials" 1988 IEEE International Symposium on Electromagnetic Compatibility Proceedings, pp. 223–230.

DONALD M. YENNI JR. received an MS degree in mechanical engineering from Purdue University in 1966. Since that time, he has worked for 3M, where he is now a senior specialist in the Electronic Handling & Protection Division, headquartered in Austin, Texas. He holds several patents in the areas of electrostatic

**Typical values were used for Calculations		Cap Shield	Metal Cans (plus solder)	Two-part (lidded) Metal Cans (plus solder)	Injection Molded Plastic with Metallization and (4) Screws	Injection Molded Plastic with Metallization and Gasket	Die Cast Magnesium Shielding Cover
Product	Material characteristics weights relative to Cap Shield	-	+35%	+65%	+25%	+55%	+65%
	Shield costs @ 1MM parts; four compartments (3-4) required	$0.35	$0.40 - 0.45	$0.60 - 0.70	$0.65-0.75	$1.00	$0.40
Design Stage	PCB Layout	Multi-cavity shapes possible	Individual cavity, rectangular shapes only	Individual cavity, rectangular shapes only	Multi-cavity shapes possible	Multi-cavity shapes possible	Multi-cavity shapes possible
Tooling (Excluding Appl. Equip.)	Tooling Costs	$10,000 estimate per each design change	$30,000 per shield/tool	$70,000 per shield/tool set	$50,000 per shield/tool	$50,000 per shield/tool	$60,000 per shield/tool set (including Trim Die)
Assembly Operation	Manual application equipment costs	One time $10,000 per 1.2M caps/yr assembly station*	Existing equipment	Existing equipment	Manual assembly costs	Gasket dispensing equipment or outsourcing, curing ovens; Manual assembly costs	Manual assembly costs
	Robotic application equipment costs	One time $40,000 per 3.6M caps/yr assembly station*	Additional tape and reel location on equipment	Additional tape and reel location on equipment	One time $40,000 per 3.6M caps/yr assembly station	-Gasket dispensing equipment or outsourcing, curing ovens; One time $40,000 per 3.6M caps/yr assembly station	One time $40,000 per 3.6M caps/yr assembly station
	Manual assembly time	10-15 seconds	N/A	N/A	30+ seconds	30+ seconds	30+ seconds
	Robotic assembly time	5 seconds	N/A	N/A	10 seconds	10 seconds	10 seconds
Post Manufacturing	Repair/ rework (based on industry est.)	Cost of replacement cap and reapplication ($0.50)	Can removal equipment, replacement can costs ($2.00-$3.00)	Labor time ($1.00-$1.25)	Labor time ($1.00-$1.20)	Labor time ($0.50-$1.00)	Labor time ($1.00-$1.20)

*** Once application equipment has been obtained, future product changes require only a thermal-bonding die (about $500 per assembly station).***

Table 2. Cost analysis of EMI shielding technologies.

and EMI control products and has authored numerous technical publications in both fields. Currently he is a member of SPE, IEEE, the ESD Association and a certified N.A.R.T.E. ESD engineer. Phone: (512) 984-3176; E-mail: dmyenni1@mmm.com

MARK G. BAKER *Mark G. Baker received a B.S. degree in electronics engineering technology from DeVry Institute of Technology in 1986. Since then he has worked for Thermotron Industries as a field service engineer, and as a technical service engineer and product development engineer with the 3M Electronic Handling & Protection Division in Austin Texas. He has several years experience in electro-mechanical design, metrology, and electrostatic control. He is currently a member of the ESD Association and the IEEE. Phone: (512) 984-5973; E-mail: mgbaker1@mmm.com*

CURT MAYNES *is an Advanced Technical Service Engineer for 3M Company, Electronic Handling & Protection Division. He received BS in Electrical Engineering from the University of Notre Dame in 1993. Since 1997, he has provided technical and product application support for 3M Static Control and EMI shielding products. He is currently a member of IEEE and the ESD Association. Phone: (512) 984-4073; E-mail: cemaynes@mmm.com* □