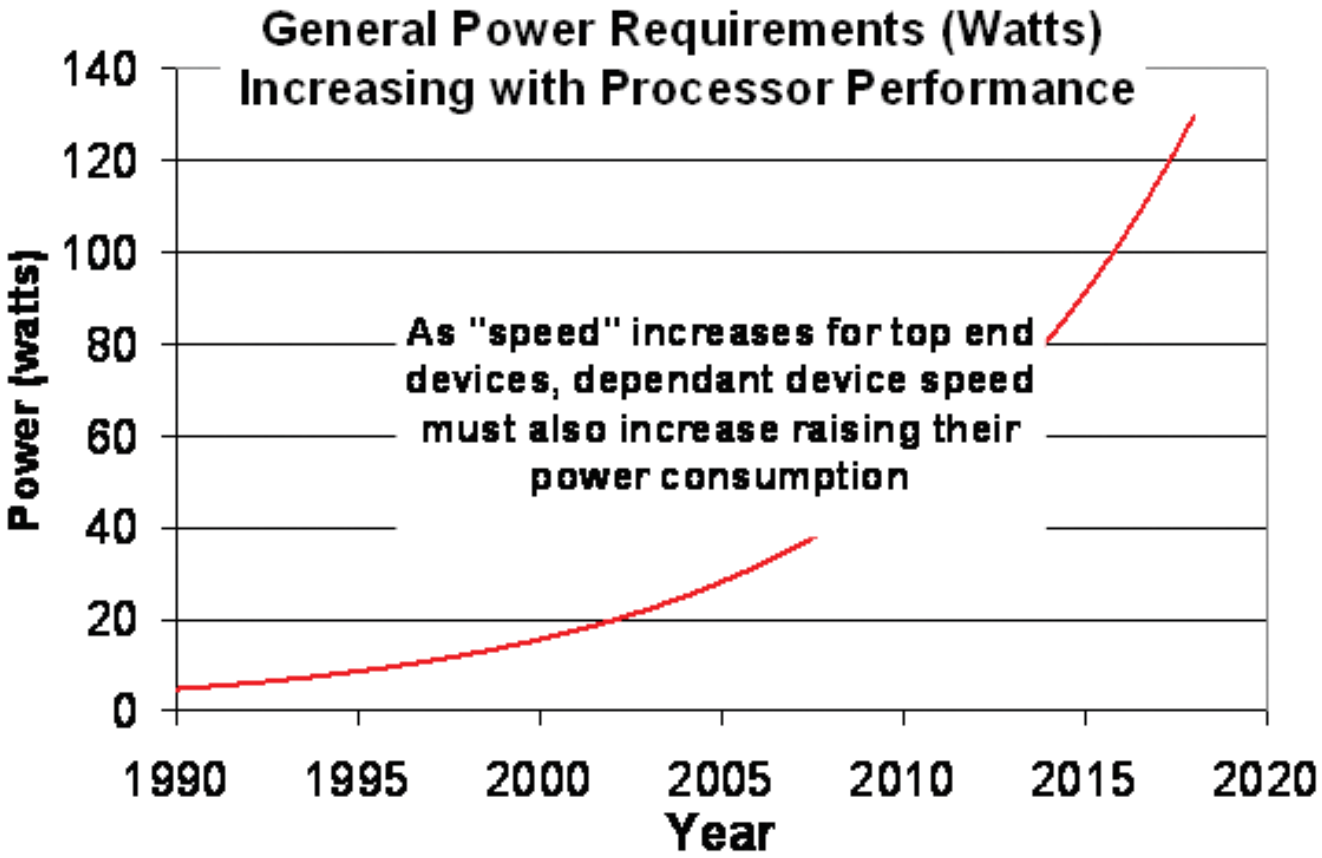
No More Silos Allowed for Thermal and EMI Engineers as Frequencies Rise

Jeff McCutcheon, senior technical specialist,3M Electronics Markets Materials Division

Are you a “Themimech” engineer? If not now, you might be soon! As the rising frequencies of many applications are now forcing engineers to be aware of and plan for issues related to rising frequencies in electronic devices and systems, they are now required to participate in mutually supportive designs. A “Themimech” engineer is one who recognizes that due to ever increasing frequencies, the potential for thermal cooling will be needed: The “Th”. The engineer further recognizes that as frequencies rise, EMI issues become a great challenge to mitigate: The “emi”. And finally, all electronics are part of a system thus, must pass vibration, environmental and design aesthetics and robust integration design is required: The “mech”. The themimech engineer no longer works in their “silo” of design, rather works to provide an integrated solution required to meet the ever-increasing frequencies of design and the associated thermal and EMI design challenges.

Today, expensive, high power processors and graphic devices run at ever increasing speeds and generate a "hot" 50-80 watts (W) and above. These designs allow for “specialists” in focused designs that may consume 100 percent of an engineer’s time. Many sophisticated microprocessors run at GigaHertz (GHz) speeds and 100 W and higher power levels. As these devices add function and speed, they lead to new thermal and EMI management issues with evolving solutions.

(GRAPH 1: WATTS INCREASE FROM 1993 TO 2003)



An Emerging Issue for 70-80 Percent of All Devices
The increasing speed of expensive processors is forcing less expensive "associated board" or “dependant” devices to keep up. Consequently, thermal management and EMI are becoming issues for traditional lower frequency or power devices, such as Application Specific Integrated Circuits (ASICs), memory, power resistors, controller chips, LEDs, and other traditionally lower power devices that comprise 70 to 80 per cent of all devices. For many engineers, this is not only an expansive challenge but also a first-time issue with devices that once ran lower speeds and consumed less than 0.25 W but evolved to 0.50-20 W. For example, a controller chip running at 0.25-1.0 W a few years ago may now be as high as two to five W and a much higher frequency. Engineers who may have thought that heat and EMI were not a problem in their areas of responsibility now have to consider new requirements, as do engineers responsible for the faster or "hot" devices. Engineers working on these emerging designs may only spend 20 percent of their time on such issues as they also provide support for other design considerations, thus the need to be a “Themimech” engineer.

As one begins a “Themimech” engineering assignment, good questions are the starting point to understanding potential solutions and their selection process:

• What is the speed and power level of the device and how hot will it get?
• What new EMI challenges exist at these new higher frequencies?
• Is the current EMI “Faraday cage” design robust or are new materials/design approach needed?
• Do I need the lowest thermal impedance thermal interface material between the

package and heat sink?
• Can I combine thermal and EMI solutions?
• Does my new heat sink act like an antenna re-radiating the chip device noise?

The design challenges, however, are not as daunting as they may first appear with a good understanding of today's thermal and EMI material options. The performance requirements of a higher speed 50-100 W device may not be the same as for a < 20 W device. An engineer may use the lowest thermal impedance interface material for high-power applications to meet the maximum temperature specification. The lowest possible thermal impedance of various thermal interface materials, however, is not necessary for the lower power density device to be within the temperature specification window. EMI solutions are strongly frequency influenced, so even though an application may need an improved EMI solution as frequency rises, it often can use newer "off the shelf" EMI solutions. As a result, a greater number of thermal management and EMI options and cost/value alternatives are available to lower power device engineers.

Emerging higher frequency applications can be reviewed in three phases:
1) Thermal Impact of Higher Frequencies
2) EMI Impact of Higher Frequencies
3) Can a Hybrid Thermal/EMI Solution Meet both Thermal and EMI Design Needs ?

A powered silicon device operates at a desired range of frequency and generates heat and EMI. As the frequency increases, the heat generated can degrade or destroy its functionality. To prevent that from happening, this heat must be removed from the chip as quickly as possible.

The concept is basically the same for an LED, except that the design carries heat away from the diode. As light output is increased, so is the heat generation in the device. EMI for an LED is typically associated with the LED driving electronics.

In these increasing "power/frequency" applications, the heat must be removed or the devices will be damaged. The thermal management for low power is basically the same as for higher power devices, but there are many more options for the lower power devices as the "power density" of "watts dissipated/surface area" is lower. All devices need to move the heat from the "hot" device to a cooler location. This can be accomplished by moving heat away from the hot device with a heat spreader or heat sink. The heat spreader or heat sink dissipates the heat into the environment. The key to thermal management is an effective coupling of the "hot" device and the heat spreader or heat sink using a Thermal Interface Material (TIM). The primary purpose of the TIM is to improve thermal flow between these hot and cooler locations, so there are no hot spots or high thermal resistance that could lead to a device overheating.

Lower Power Thermal Interface Material Options
Thermally conductive interface materials are available for non-adhesive assembly that also requires a separate mechanical attachment, such as a clip, screw or compression fit to hold the surfaces together. Adhesive versions that can be used without additional mechanical attachment features hold the surfaces together by a

combination of adhesion and cohesion. Adhesion is the force that holds surfaces together through mechanical and/or molecular attraction. Cohesion is the attraction of particles within the adhesive that holds the mass together.

Non-adhesive systems are widely used and include thermal greases, phase change materials, and gap-filling pads. Adhesive systems include thermosetting liquids-such as two-part epoxies, pressure-sensitive adhesive (PSA) tapes, and thermoplastic or thermosetting bonding films. With non-adhesive systems, engineers do not need to balance as many final properties as adhesive systems. For example, increasing the density of thermally conductive fillers in liquid adhesive increases viscosity and can adversely affect application. Too much filler in adhesive tape can lessen conformability and wet-out, increasing interfacial thermal resistance to heat flow. On the other hand, a higher filler load in a thermal grease may simply yield higher bulk conductivity, but not change the assembly method of added clips. But as indicated in the chart below, there are pros and cons for each TIM solution system.

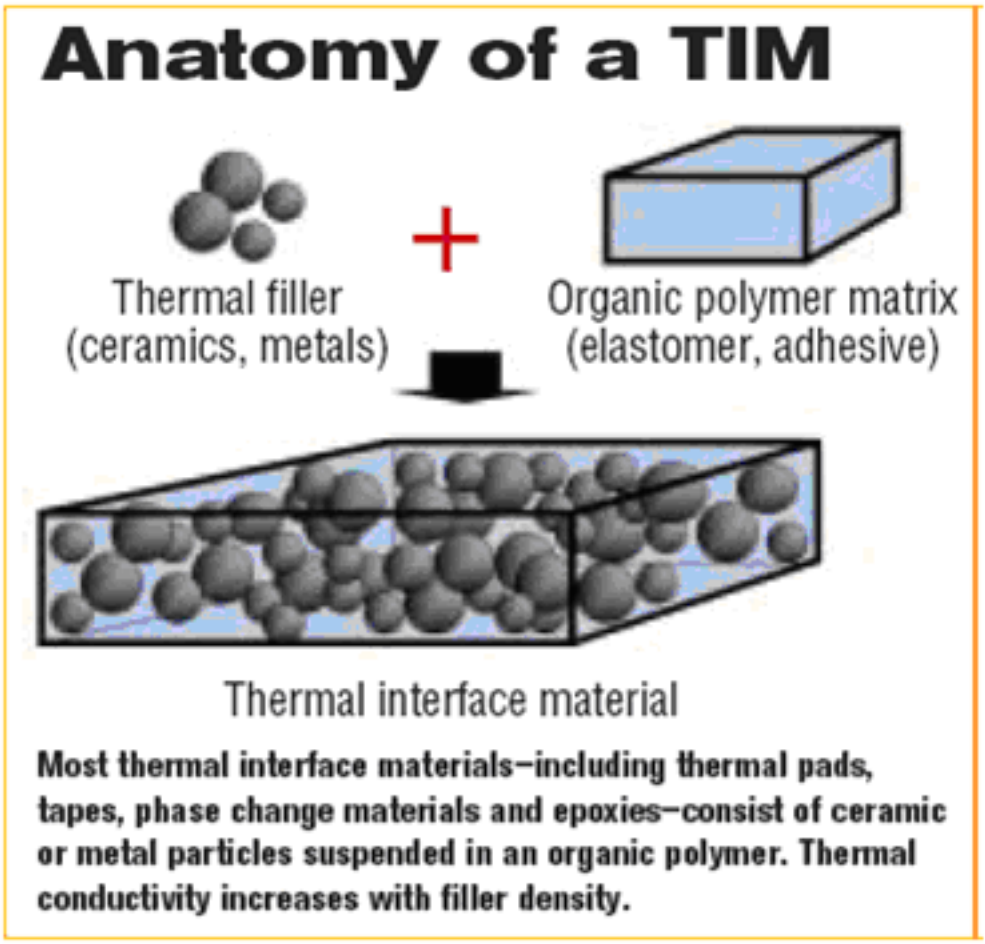
(CHART 1: COMPARING THERMAL INTERFACE OPTIONS PROS AND CONS)

Thermal Interface Options

Technology	Thermal conductivity vs air*	Pro	Con
Grease	20-185x	Thin, low cost. Thin = low impedance. Good wetting.	Messy. No adhesion, so mechanical attachment of heat sink is necessary. Silcone contamination.
Liquids	20-125x	Thin = low impedance. High bond strength Good wetting	Messy. Pot life of epoxy. Needs cure time and fixturing.
Phase change	20-125x	Good wet-out. Less messy than grease. Thin = low impedance.	No adhesion, so mechanical attachment of heat sink is necessary. Initial heat cycle.
Tapes	20-40x	Good wet-out. No mechanical fasteners. Ease of use.	Typically used in applications less than 20 watts.
Pads	35-500x	Greater thicknesses. Very soft, comfortable. Gap filling.	Light adhesion, so mechanical attachment is necessary. Cost due to thickness.
Solder, metal phase change materials	500-1,000x	Thin thickness. High conductivity. Gap filling.	Difficult to apply. Low viscosity when melted. High-cost materials.

* The thermal conductivity of air is 0.02 watts per meter-kelvin.

(ILLUS. 3: GENERAL STRUCTURE OF ADHESIVE, TAPES, AND PADS WITH FILLER)



Thermal grease solutions vary widely on cost and performance based on the end use application need. For lower power devices, the effective thermal resistance can be very low due to good wet-out, thinness, and modest to high bulk conductivity. Grease fills surface irregularities – even grossly uneven areas, if enough grease is applied. Common application is between a processor chip and heat sink. For lower power devices, grease may not be needed as the power density is lower, and other options, such as a thermal tape, would allow for an assembly with no clips or screws saving assembly cost and potential for silicone migration.

Non-silicone greases are designed to be siloxane-free. Non-silicone grease generally have good performance, but may not have the very high temperature environmental resistance of the silicone greases.

Liquid applied thermal epoxies or acrylic adhesive systems may provide structural strength bonds with thin bond lines and good wet-out for low impedance. Epoxy systems can be either a one-part heat curing system or two-part room temperature curing system. With an acrylic adhesive, an activator is applied to one surface followed by the base resin. For low power devices, a thermal epoxy can be a good option as the thermal resistance meets the lower power needs and no mechanical attachment is needed. Thermal epoxies can also be used for potting and heat spreading of heat away from individual devices to surrounding structures and can also provide environmental protection.

Phase Change Materials (PCM) may be die cut and easier to use versus grease. "Phase change" refers to the melting of the binder at the time of application. The melting binder wets-out both surfaces for a thin thermal joint with low impedance. Common application is between a Central Processing Unit CPU [C2]and heat sink. For low power devices, the generally higher PCM performance and need for added mechanical attachment have lead to limited use.

Silicone or acrylic elastomer thermal pads loaded with thermally enhanced fillers are thick, soft, and conformable to fill gaps and achieve good gap filling to ensure a good thermal path. A typical application is between the hot device and heat spreader and/or chassis. For low power applications, thermal pads can be a viable option as the gap filling may be needed due to design limitations. For low power applications, the lower cost acrylic thermal pads offer a cost advantage over the silicone-based pads and lower power application generally do not need the higher temperature resistance of the silicone pads.

Pressure-sensitive thermally conductive adhesive tapes are neat and easy to use. They bond on contact without mechanical fastening and provide good wet-out for low impedance. Common application is bonding a heat sink to a controller chip or a strip of LEDs on to an aluminum extrusion heat sink, that also acts as part of the mechanical design.. The acrylic thermal tapes are cost effective for low power devices and generally meet the thermal resistance needs of the application.

Only Buy the Thermal Performance Needed for Low Power Density Applications

With the emerging increase in frequency and/or higher power in traditionally low power devices, the need for an effective and easy to implement TIM solution is desired. There is no reason to buy more thermal conductivity or effective thermal resistance than necessary to meet the desired specification. Modest thermal resistance products such as thermally conductive tape and acrylic thermal pads are leading the way to low power density thermal solutions that meet performance and cost objectives.

3M Thermally Conductive Adhesive Transfer Tape Series 8800 was engineered specifically as a cost-effective alternative with the necessary strength, conductivity, and reliability for lower power devices. The four tapes have a tacky pressure-sensitive adhesive without a carrier but with high cohesive strength. The full thickness of the tape is adhesive loaded with thermally conductive ceramic fillers that provide a preferential heat-transfer path. Specialized chemistry provides a next generation of performance in terms of softness for conformability to non-flat surfaces, high adhesion, good wetting, and good thermal interface. Improved wet-out improves both mechanical and thermal performance.

(CHART 2: VALUES FOR EACH TAPE – THICKNESS, CONDUCTIVITY, AND IMPEDANCE)

Thermal Performance of Thermally Conductive Tapes

Product	Conductivity (watts/meter-kelvin)	Impedance* Thickness (mils)	Impedance* (degree C-square inch/watt)
8805	0.6	5	0.48
8810	0.6	10	0.88
8815	0.6	15	1.17
8820	0.6	20	1.5

* Impedance is tested between an aluminum panel and power resistor to reflect "real world" surfaces and interfaces.

3M's Series 8800 thermally conductive adhesive transfer tapes were engineered specifically to meet the cost and performance needs of low-power devices. Each tape consists of a tacky PSA without a carrier, but with high cohesive strength. Spanning the full thickness of the tape, the adhesive is loaded with thermally conductive ceramic fillers.

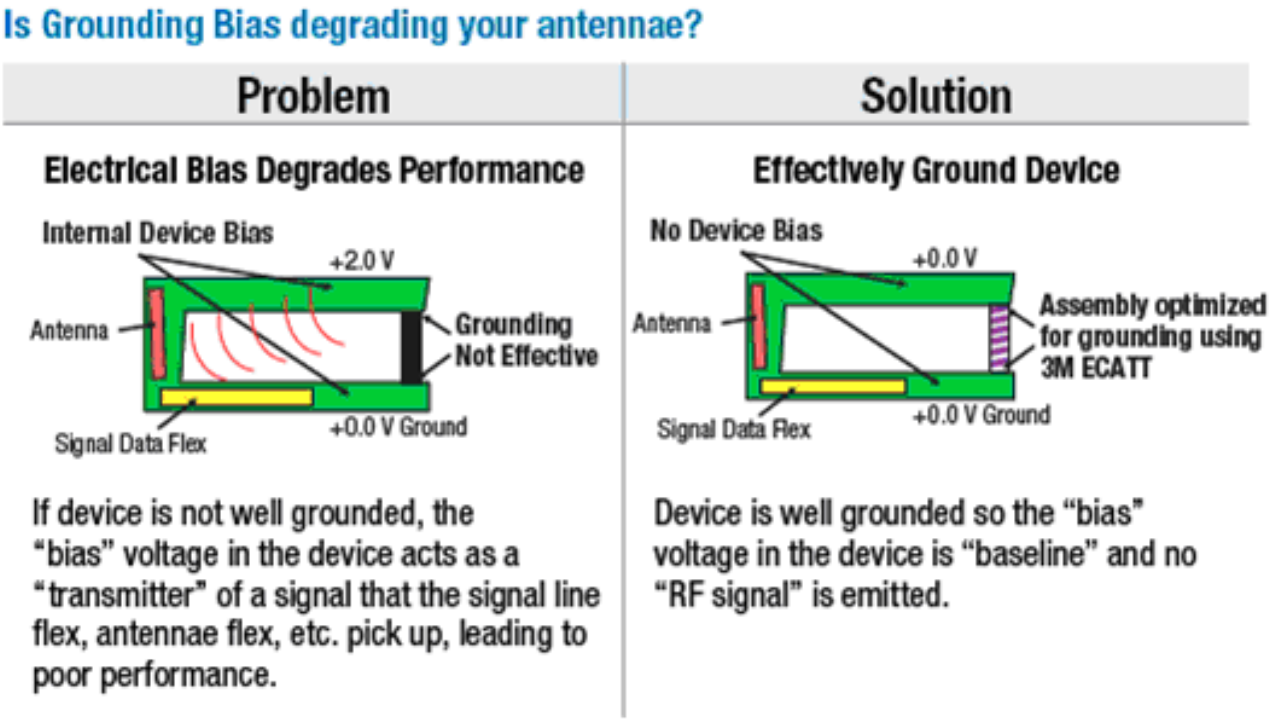
In independent laboratory testing conducted by Underwriters Laboratories, the 8805-8815 tapes met the UL-746C testing requirements for operating temperature, humidity resistance and dielectric breakdown strength.

For low power applications where a gap filling solution is desired, the 3M Thermally Conductive Acrylic Thermal Pads 5589H and 5590H provide excellent thermal resistance, good thermal stability, good softness and a UL rating.

EMI Impact of Higher Frequencies
As the higher frequencies in traditionally low power devices lead to the need for thermal interface materials, the higher frequencies can also lead to the need for improved EMI shielding solutions. New compact, low-profile designs with IC devices in closer proximity to each other and within a contained EMI environment have also required new and innovative EMI solutions as the EMI issues are often related to not just the electric field of EMI, but now the magnetic field associated with EMI that can become a greater concern in "near field" conditions that are geometry based.

The EMI shielding solutions are needed as the higher frequencies and compact designs lead to a more complex EMI noise environment. High frequencies imply the following logic and design implications:
a) Higher Frequencies are needed in associated support/communication devices or flex circuits to support higher information data rates of processor and graphics devices
b) Higher Frequencies lead to an inherent lower "Signal to Noise" (S/N) in the circuit.

c) A lower S/N ratio means the old lower frequency noise floor of a design is too high and can lead to a higher error rate in transmitted data.
d) Higher data error rates are not acceptable, so the noise floor must be reduced to improve the S/N ratio. A higher data error rate in a digital photo would lead to bad "pixels"
e) A more robust S/N ratio is achieved by a reduced EMI environment accomplished by a lower contact resistance/more contact point grounding design, less internal device generated Radio Frequency RF bias, improved Faraday design features, ability to absorb EMI and circuit design layout.



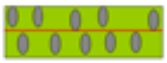
A lower EMI environment can be accomplished with improved EMI reflective shielding materials- such as the latest generation of copper foil tapes that are thinner and work well at higher frequencies, while allowing for lower profile solutions. The new generation of conductive fabric solutions that are laminated with a conductive adhesive allow for improved conformability, puncture resistance, ease of use and a tailored EMI Shielding level based on composition, such as the 3M AU-2190 based on a Gold plated fabric or the more economical CN-3190 that uses a lower cost Nickel plated fabric.

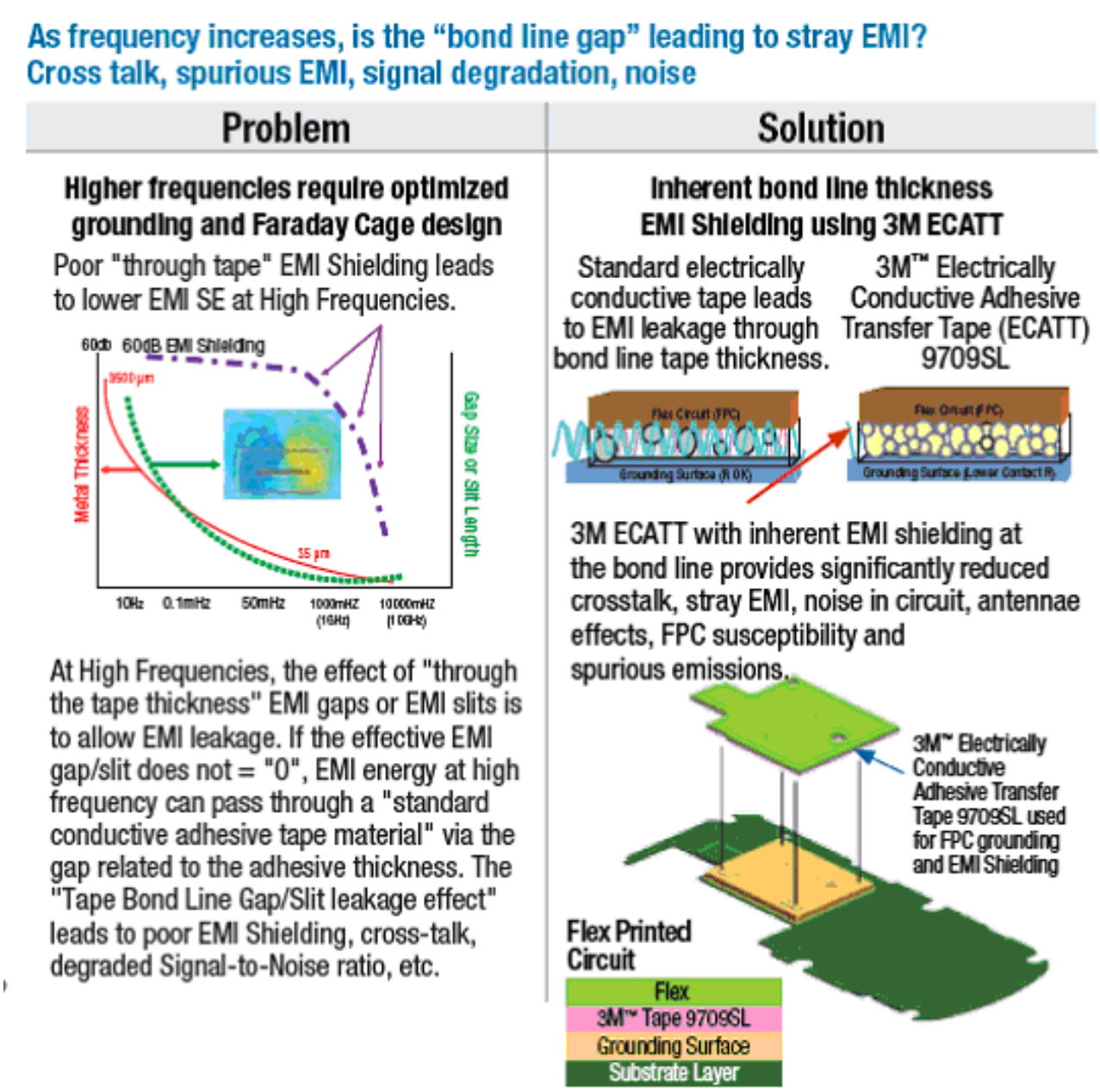
EMI "reflective" shielding solutions are now being complemented with EMI "absorbing" materials. EMI absorbing materials act like "acoustic absorber" sealing tiles or carpet in a room that is too loud acoustically. By adding acoustic sealing tiles or carpet in a conference room, the baseline noise level is greatly reduced, versus not using the acoustic solutions. By added EMI absorbing sheet and pad materials into an EMI environment, the EMI noise is absorbed and reduced, improving the system performance. The performance of the absorbing materials is generally related to the products permeability (materials level of interaction with the magnetic field (H) of EMI) and initial evaluation with a high performing absorber is suggested to provide an understanding of the absorber benefits in each design.

The 3M absorber AB-7000 has high permeability and thus provides excellent performance. But the 3M AB-5000 is a more economical absorber with less permeability, so it also may meet the required effective performance levels. With absorbers, it is best to establish their highest performance impact first (ie:AB-7000 using greatest thickness the application can use) as it may allow other design changes once a new EMI reduction as been demonstrated. Once the review is completed, other absorber types can be used to match the desired minimum absorber performance level to the design specification.

As frequencies rise, the need for improved contact assembly grounding within an electrical system and to external assemblies may be needed to optimize the performance of the entire system. Lower contact resistance can improve the Faraday cage performance to seal any leaks via slits or slots established by ground points. Lower electrical bias in a system can minimize RF signals generated on the system structure that radiate and can impact S/N of the data transmitted via a flexible circuit or reduce antenna S/N performance. Improved grounding may even be needed through-out an adhesive bond line gap to reduce EMI escaping or entering the system.

Understanding what electrically conductive tape products can be used to enhance and/or replace traditional methods of grounding with screws, clips or compression fit designs is critical. Electrically Conductive Adhesive Transfer Tapes (ECATT) are available in two primary types: Z & XYZ conductive and 4 total variations: 1) “Z” axis conductive solutions that are low volume loaded particle based 2) Highly volume loaded particle based XYZ conductive 3) Double coated foil tapes XYZ conductive and 4) Scrim/woven/mesh types XYZ conductive. The 3M ECATT tapes 9705, 7772, 9709S and 9725 represent one of each key design types. Tape 9705 is a Z-axis design, 7772 is a double coated aluminum foil type XYZ , 9709S is a highly loaded XYZ particle based design and 9725 is a scrim based XYZ design. As the conductive portion of the ECATT affects adhesion, grounding resistance level, shock and vibration performance, reliability with environmental aging, EMI shielding in the bond line, rework and surface contact conformance, each application must be optimized for which ECATT product best meets the end user grounding and EMI shielding design goals.

ECATT Product	Pictoral Design	Thickness (um)	Z or XYZ Conductivity. (Based on 3M Test Method)	Features - Advantages - Benefits
9705		50	Z	Z-Axis, Standard Adhesion Acrylic Adhesive, Silver Conductive Filler, 9706 is the higher adhesion version of the 9705.
9709S		50	XYZ	XYZ, "Bond Line Gap/Slit" EMI Shielding for High Frequency , Low contact Resistance to Stainless Steel, Improved Contact R conformance. 9707 is the higher adhesion version of 9709S.
7772		66	XYZ	XYZ, Double Coated Aluminum foil, Medium Adhesion Acrylic Adhesive, Nickel Conductive Filler
9725		55	XYZ	XYZ, Non-woven Conductive Scrim, Low Contact Resistance to Stainless Steel, Higher Adhesion Acrylic Adhesive, 9723 next level higher adhesion acrylic adhesive.



Thermal and EMI Hybrid Solutions

The next step in controlling the thermal and EMI in emerging higher frequency/higher power systems is the emergence of thermal and EMI hybrid material solutions. Customers are requesting multi-functional material solutions. Some products that combine thermal and EMI features are:

- The 3M AB6005 EMI Shielding-Absorber combines an EMI Shielding and Absorbing solution that is also designed to have good thermal heat transfer
- The 3M 9709S ECATT product provides good grounding performance and the product has the thermal performance similar to the 3M 8805 Thermally Conductive Adhesive Transfer Tape (TCATT), plus good EMI shielding in the "bond line gap thickness" due to the products high loading of conductive fillers.

Conclusion

Engineers looking for increasing power devices should be aware of the need for thermal and EMI management to ensure the robust performance of their design. Thermal and EMI materials options can be judicially selected to implement the TIM

and EMI performance needed to manage the higher power device. Design reviews should include the Hybrid Thermal/EMI solutions along with an understanding how new materials offer new design options to meet ever increasing power and higher frequency needs.

Note: Information contained herein should be considered representative or typical only and should not be used for specification purposes.

To discuss thermal and EMI material design solutions, contact Jeff McCutcheon (651-733-6199 or jeffmccutcheon@mmm.com [1]), 3M Electronic Markets Materials Division
USA: 800-362-3550; www.3M.com/electronics [2]

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