Dampening cavity resonance using absorber material

By implementing microwave absorbent material, unwanted cavity resonances are effectively dampened to prevent microwave radiation in circuits where PC-board is used as a cover.

By Paul Dixon

Today, many microwave circuit designers are noticing that their circuits do not perform as well as predicted when they enclose them with circuit board covers. As a result, cavity resonances are set up inside the cavity, which changes the impedance conditions required for proper operation of some circuit elements. With operational frequencies increasing, this is becoming a prevalent issue in microwave circuit design.

What is a cavity resonance?

Solutions to the field equations inside an enclosed space reveal that standing wave modes may exist inside a cavity. These modes can exist in an empty rectangular cavity if the largest cavity dimension is greater than or equal to one-half a free-space wavelength. Below this cutoff frequency the cavity resonance cannot exist.

For a rectangular cavity, with dimensions a, b, c and a<b<c, and which is completely filled with a homogeneous material, the equation for the resonant frequency is

$$(f)_{mnp} = \frac{1}{2\sqrt{\varepsilon\mu}}\sqrt{\left(\frac{m}{a}\right)^2 + \left(\frac{n}{b}\right)^2 + \left(\frac{p}{c}\right)^2}$$

where ϵ is the material permittivity and μ is the material permeability.

In this configuration, the TE_{011} mode is the dominant mode or the lowest frequency at which a cavity resonance can be supported. The frequency of the dominant mode is inversely proportional to the magnitude of the material parameters. If your frequency of operation is below the cutoff frequency of the cavity, you will not have a problem with cavity resonance because it will not be able to exist.

Cavity resonance becomes an issue when a circuit, which is designed and built and works well, must be protected and/or shielded with a circuit board cover. For shielding purposes, the covers are made of or lined with metal. This creates a cavity above the circuit board where resonances can exist. With operating frequencies going higher into the microwave and millimeter-wave band, cavity resonance effects have become a major problem.

Solutions to the field equations yield the following for the TE_{011} mode.

$$E_x = E_0 \sin\left(\frac{\pi y}{b}\right)\sin\left(\frac{\pi z}{c}\right)$$

$$H_y = \frac{jbE_0}{\eta\sqrt{b^2+c^2}}\sin\left(\frac{\pi y}{b}\right)\cos\left(\frac{\pi z}{c}\right)$$

$$H_z = -\frac{jcE_0}{\eta\sqrt{b^2+c^2}}\cos\left(\frac{\pi y}{b}\right)\sin\left(\frac{\pi z}{c}\right)$$

$$\eta = \sqrt{\frac{\mu}{\varepsilon}}$$

Note that the standing wave has the characteristic such that the E and H fields are 90^{o} out of phase with each other. The impedance will therefore fluctuate wildly across the cavity causing unknown (usually bad) effects on circuitry including the introduction of instability to active devices. The H field also is at its maximum at the wall of the cavity, which may cause the shielding effectiveness to deteriorate at the resonant frequencies. Often what is perceived as a shielding issue requiring attention to shielding materials is actually a cavity resonance issue.

Relocating a particular circuit element to a different position in the cavity can often fix the problem. Intelligent positioning of posts or other objects to disrupt the standing wave can also be helpful, but both these methods can involve an investment in engineering design time and possible manufacturing delays.

Using microwave absorbent material in the cavity has proven to be effective at damping the resonance. Absorbers (particularly of the magnetic variety) have high values for permittivity and permeability as well as high loss values. Recall the basic definitions of permittivity and permeability as the ability to store electric and magnetic energy respectively. When introduced into the cavity, solutions to the field equations show that the energy resides primarily in the high e/μ material. This reduces the energy available in the empty area of the cavity containing the circuit, which reduces the impedance variation and its effect on the circuit.

Electromagnetic modeling of the field solutions inside a partially filled cavity is straightforward if somewhat complex and computationally difficult. Newer versions of popular circuit modeling software will incorporate libraries of absorber parameters to help predict the effect of the introduction of absorber material.

Types of material

In choosing an absorber material, it is important to recognize the difference between absorbers intended for use in free space and absorbers intended for use in cavities. A free-space absorber will generally be characterized as resonant at a particular frequency or narrow range of frequencies. This is due to the fact that the material absorbs best when it is a quarter-wavelength thick, and this of course only occurs at one frequency. Nothing is inherent in the material that resonates at that frequency. It is only due to the material thickness that the absorber resonates at one frequency in free space. Most microwave absorbent materials inherently absorb energy over a wide range of frequencies. Generally, loss tangents drop with increasing frequency, but this is offset by shorter wavelengths, causing the overall attenuation loss per cm of travel to increase. As noted above, high values for permittivity and permeability as well as high loss values are desirable. Also, in a standing wave the tangential E field is zero on the walls where the absorber is likely to be located, while the H field is a maximum, which makes a magnetic absorber more effective—albeit at a higher cost.

Important factors in choosing a cavity resonance absorber include:

1. absorber material.
2. thickness.
3. absorber placement in cavity.
4. ease of application.
5. cost.

Absorber material

As noted above, absorber for a cavity resonance application is inherently broadband. The parameters include high magnetic and/or dielectric loss over a broad range of frequencies. Some materials will work better in the lower microwave range, while others will work better at the higher microwave and millimeter-wave range. A perusal of a manufacturer's catalog would seem to imply that certain materials resonate at particular frequencies and that these materials are rather narrowband. This does not apply to a cavity resonance situation. In an enclosed space, this is not a factor and the proper metric is the material attenuation and/or permittivity and permeability, which are better measures of a material's ability to damp a cavity resonance.

The most effective absorbers for cavity resonance dampening are magnetically loaded with iron or ferrites. These materials are characterized by high permittivity and permeability plus a high magnetic loss, as shown in **Figure 1**. A common figure of merit is the attenuation expressed in dB/cm. This is calculated from the measured parameters and is a measure of the materials absorption properties expressed in dB attenuation per cm in travel through the material. It differs from insertion loss as it does not include reflections from mismatches at the surface of the material. The high permittivity/permeability means the energy will tend to reside inside the material (and hence away from your circuit) while the high absorption will lower the Q of the cavity and hence the magnitude of the VSWR.

Materials with only dielectric (nonmagnetic) properties can also be effective as cavity resonance absorbers. They are less effective than the magnetic absorbers due to the property of the electric field going to zero on a conducting wall while the magnetic field is maximum. Dielectric absorbers are generally made of a polyurethane foam material loaded with a conductive solution. Various grades are available but as with the magnetic absorbers, the highest value of the material parameters will give the best performance as a cavity resonance absorber. These absorbers must also be thicker (0.125 inch or more) to accomplish the equivalent damping as a magnetic absorber. However, this is sometimes offset by the fact that they are considerably less expensive. Foam dielectric absorbers can be a viable solution if your cavity allows a thick absorber. Another issue is that they are conductive, which can be a factor if they come into contact with active devices. Spray coatings or a polyethylene film can be used to minimize this risk.

Physical parameters of interest in choosing an absorber include temperature resistance, outgasing properties, adhesion properties, etc. Silicone elastomers have good high-temperature properties (177°C) and good outgasing properties and are the most popular on the market today. Other elastomer matrices include urethane, nitrile and neoprene.

Material thickness is rather straightforward to incorporate, as the resonance dampening effectiveness is directly proportional to the thickness. The effectiveness is also directly proportional to the frequency, which is resonating—meaning thinner material can be used at higher frequencies. Magnetic material at a thickness around 0.040 inch has proven to be effective in the lower microwave (up to 10 GHz) range while 0.020 inch to 0.030 inch has been effective in the upper microwave range and 0.010 inch for the millimeter-wave bands. A purely dielectric absorber is generally not available at a thickness less than 0.125 inch.

Absorber placement in cavity

It is rarely if ever necessary to treat all the cavity walls with absorber. It is usually not even necessary to treat the entirety of one wall. Unfortunately though, analytic tools to determine the optimum absorber placement have not yet been developed, leaving the engineer with a cut-and-paste trial and error method. Absorber manufacturers usually have generous sample policies for just this reason. It is difficult to determine *a priori* where the optimum absorber placement would be. Sometimes the absorber acts to damp the resonance. Other times it acts to shift the standing wave resonance (SWR) peaks to a less detrimental location. Fortunately, there are general guidelines for absorber placement. Placing the absorber at the standing wave maximums is a good place to start. Most cavities are somewhat rectangular in shape and the equation provided above can determine the possible resonant frequencies. Often, just the dominant mode must be damped. In this case the field is at a maximum at the midpoint of the cavity. If the problem is a second-order mode, there will be two field maximums at 1/3 and 2/3 of the way across the cavity, etc. Determination of m, n, and p in the above equations plus knowledge of the frequency causing the problem will help determine the optimum absorber placement.

Elastomer and foam absorbers can be easily cut with a die or a razor blade. Most are available with a peel-and-stick, pressure-sensitive adhesive. This has become the applica-

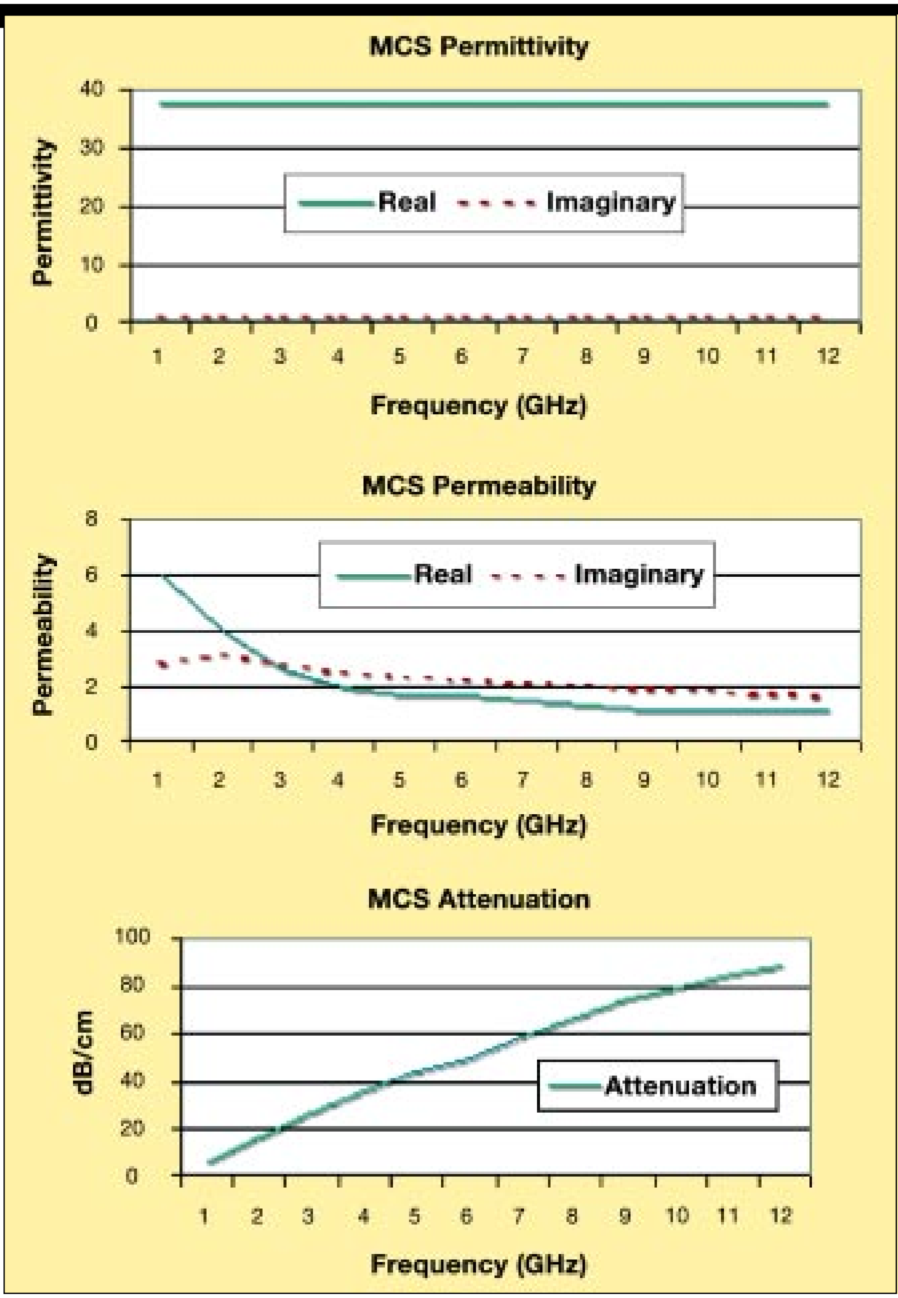

Figure 1. Thin flexible broadband absorber like Eccosorb MCS exhibits a high permittivity and permeability and magnetic loss tangent, making it ideal for cavity resonance dampening.

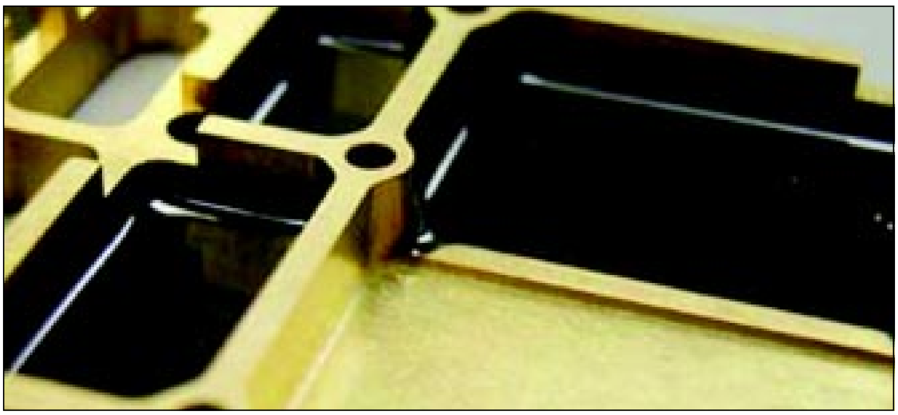

Figure 2. Mold-in-place technology fills any size or shape cavity with a high performance microwave absorber.

tion method of choice as it eliminates the need for solvent-based material and messy adhesives. The adhesion qualities of today's pressure-sensitive adhesive (PSA) materials are outstanding. For more permanent applications, an epoxy mold-in-place solution is available as shown in **Figure 2**. For this application the absorber matrix is an epoxy where the material is molded directly into the cavity for a permanent solution.

Cost is always the most important variable. Most budgets did not originally allow for absorber material. Absorber is still considered to be something of a band-aid applied only because the engineer "failed." Absorbers tend to be a cost-effective solution as opposed to re-engineering a circuit board cover or relocating circuit elements to eliminate a problem.

As mentioned previously, foam dielectric absorbers are the least expensive. If you have the room for an absorber 1/8 inch thick and outgasing is not an issue, then these are the materials of choice. If you must use a thinner material and/or outgasing is important, then a silicone-based, magnetically loaded elastomer is your best choice. Using a peel-and-stick pressure-sensitive adhesive is the most cost-effective means of applying the absorber. Thinner materials will cost less so it is worth your time to experiment with various thicknesses to determine the thinnest possible. Finally, experiment with absorber placement to determine the minimum area of coverage necessary to solve your problem.

Conclusion

With frequencies increasing faster than circuit board cavity sizes are decreasing, the problem of cavity resonances will only increase. Clever engineering redesigns can often be used to solve these problems, but often the quickest, most cost-effective solution will be using absorber material to damp the resonance. RFD

ABOUT THE AUTHOR

Paul Dixon is the senior microwave engineer for Emerson & Cuming Microwave Products in Randolph, Mass.. He received a B.S. degree in astrophysics from Michigan State University in 1982 and a masters in microwave engineering from the University of Massachusetts-Amherst in 1986. He was a microwave engineer for Emerson & Cuming from 1986-1992 and technical director of Microsorb Technologies from 1992-96. In 1996 he returned to Emerson & Cuming (now Emerson & Cuming Microwave Products). He is responsible for electromagnetic design and testing of absorber material and dielectrics.