Introduction to Microwave Absorbers

White Paper

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Executive Summary

Interest in microwave-absorbing material technology has been growing. As the name implies, microwave-absorbing materials are coatings whose electrical and/or magnetic properties have been altered to allow absorption of microwave energy at discrete or broadband frequencies. There are several techniques to achieve these properties. The goal of the absorber manufacturer is to balance electrical performance, thickness, weight, mechanical properties and cost.

Principles of Operation

Altering the dielectric and magnetic properties of existing materials will produce microwave absorbers. For purposes of analysis, the dielectric properties of a material are categorized as its permittivity and the magnetic properties as its permeability. Both are complex numbers with real and imaginary parts. Common dielectric materials used for absorbers, such as foams, plastics and elastomers, have no magnetic properties, giving them permeability of 1. Magnetic materials, such as ferrites, iron and cobalt-nickel alloys, are used to alter the permeability of the base materials. High dielectric materials, such as carbon, graphite and metal flakes, are used to modify the dielectric properties.

When an electromagnetic wave, propagating through a free-space impedance of Z0, is incident upon a semi-infinite dielectric or magnetic dielectric boundary of impedance Z1, a partial reflection occur. The magnitude of the reflection coefficient is governed by the following equation:

$$R = \frac{1 - Z_1/Z_0}{1 + Z_1/Z_0} \qquad [1]$$

Where

$$Z_0 = \sqrt{\frac{u_0}{e_0}} \qquad [2]$$

$$Z_1 = \sqrt{\frac{u_1}{e_1}}$$

To achieve a reflection coefficient of zero: Z0 = Z1. This condition is achieved when:

$$\frac{u_1}{e_1} = \frac{u_0}{e_0} \qquad [3]$$

The perfect absorber would therefore have u1 to e1 and be as large as possible to achieve absorption in the thinnest layer possible. Unfortunately, at microwave frequencies, u1 generally does not approach the magnitude of e1. However, other techniques can be used for microwave absorption. In general, practical microwave absorbers are one of two basic types: resonant or graded dielectric.

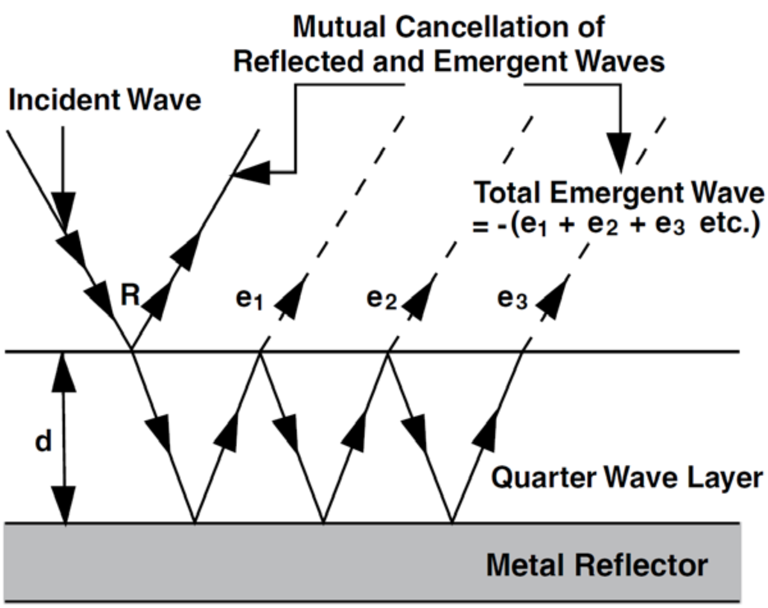


Figure 1. Resonant absorber showing out-of-phase condition existing between reflected and emergent waves.

Resonant Absorbers

The simplest type of resonant absorber is the Salisbury Screen. It consists of a resistive sheet spaced one-quarter wavelength from a conductive ground plane. The resistive sheet is as thin as possible with a resistance of 377 ohms per square matching that of free space. Figure 1 illustrates its operation. A wave incident upon the surface of the screen is partially reflected and partially transmitted. The transmitted portion undergoes multiple internal reflections to give rise to a series of emergent waves. At the design frequency, the sum of the emergent waves is equal in amplitude to, by 180° out of phase with, the initial reflected portion. In theory, zero reflection takes place at the frequency; in practice, absorption of greater than 30dB (99.9%) may be achieved (see Figure 2).

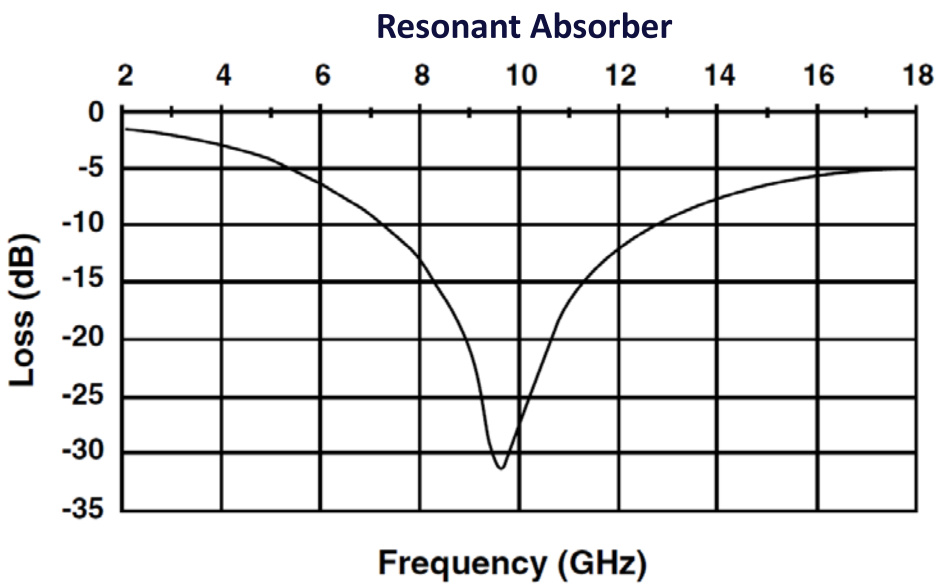


Figure 2. Salisbury Screen resonant absorber at 10GHz.

The inherent problems of the Salisbury Screen are poor flexibility, poor environmental resistance and increased thickness, especially at lower frequencies. Distributing dielectric and/or magnetic fillers into a flexible matrix, such as an elastomer, can produce a more practical absorber. Increasing the permeability and permittivity of the layer increases the refractive index ue, thus decreasing thickness by the relations 1/ ue. The dramatic difference in thickness achievable can be illustrated by comparing two microwave absorbers. RFSS-10 is a Salisbury Screen-type absorber tuned to 10GHz and is nominally 0.250" (6,4 mm) thick. RFSB-10 is an elastomer loaded with carbonyl iron filler and is 0.068" (1,7 mm) thick. The same electrical performance can be achieved in a material that is 25% as thick (although a weight penalty must be paid). The RFSB absorber is also very flexible and adaptable to outdoor environments.

Resonant materials can also be produced to absorb at multiple frequencies. By controlling the critical magnetic/dielectric loading and thickness of each layer, two discrete frequencies can be tuned. These flexible dual-band absorbers are standard production products and have the added advantage of broadband absorption. For example, a dual-band absorber with appropriate resonant points will have greater than 15dB absorption over an octave bandwidth (see Figure 3).

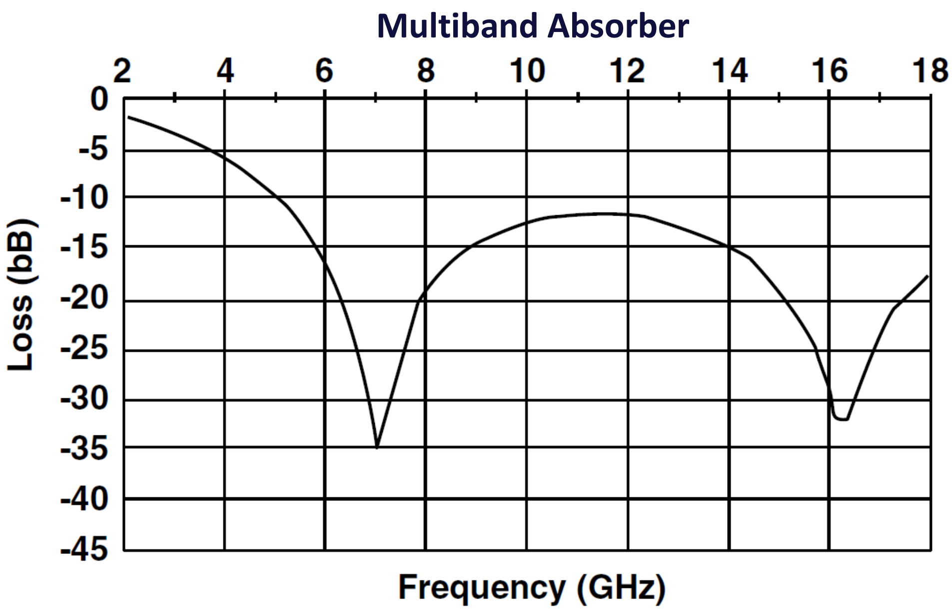


Figure 3. Dual-magnetic absorber - nitrile rubber 0.200" (5.1 mm) thick, 1.75 lb. sq.ft.

The performance indicated for resonant absorbers is at normal angles of incidence. The effectiveness of these materials drops off as the angle of incidence increases. Materials have been developed for situations where performance is needed at angles of incidence of 65° and greater. These absorbers are generally thin and heavily loaded with magnetic fillers. Such high-permeability absorbers have a greater than critical impedance at normal angles of incidence, thus resulting in performance that is poorer than the resonant type at normal angles but improves as angle of incidence increases. They are generally tuned for a high angle of incidence and horizontal polarization.

All dimensions shown are in inches (millimeters) unless otherwise specified.

Graded-Dielectric Absorbers

The other absorber category is the graded-dielectric absorber. Its principle of operation is quite different from that of the resonant type. Absorption is achieved by a gradual tapering of impedance from that of free space to a highly "lossy" state. If this transition is done smoothly, little reflection from the front face will result. Anechoic chamber materials accomplish this via the pyramidal shape of the absorber (see Figure 4). The absorbing medium is a conductive carbon in polyurethane foam. Absorption levels of greater than 50dB can be obtained with pyramids many wavelengths thick. These are impractical for electromagnetic interference (EMI) or radar cross-section (RCS) reduction. Good levels of reflectivity reduction (greater than 20dB) can be achieved in materials less than 1/3 wavelength thick. In this case, a very open-celled (10 pores per inch) foam is used. A gradual transition is achieved via a conductive carbon coating. Figure 5 depicts typical performance where reflectivity levels of -20dB are achieved from 4 to 18GHz and above at a thickness of 1.25" (31,8 mm).

This method of gradual impedance transition can be applied to other materials. Foams, honeycombs and netting are three such matrices where practical absorbers are being produced.

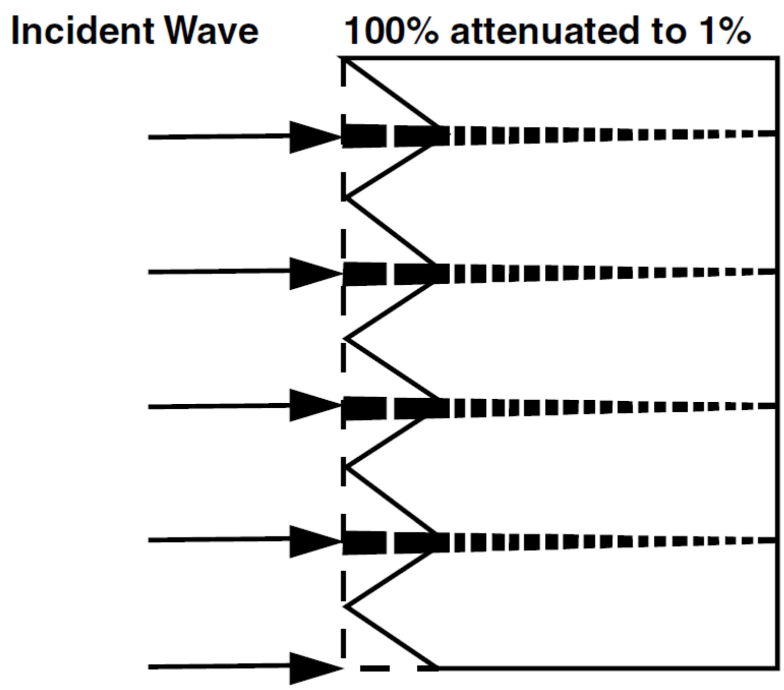


Figure 4. Broadband absorber with tapered impedance. The low loss front face can be obtained by physical tapering or control of dielectric properties.

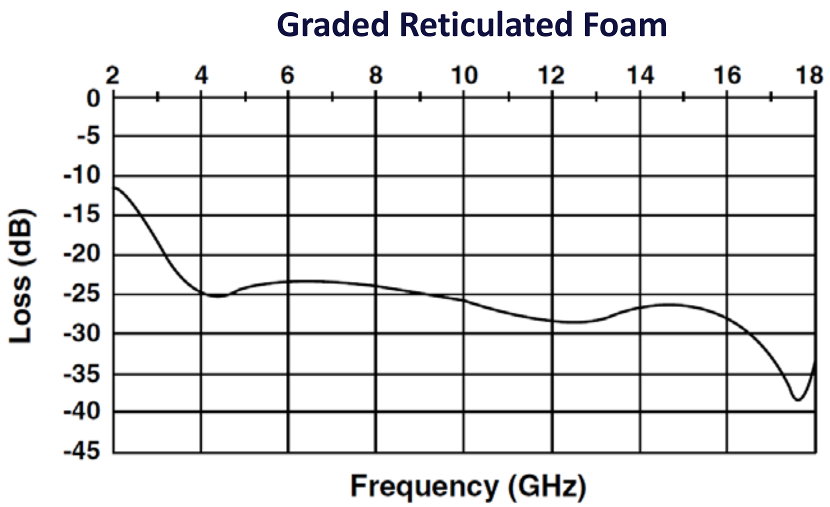


Figure 5. Broadband-graded reticulated foam absorber 1.25" (31.8 mm) thick.

Material Selection

A wide variety of absorber materials are available for use in EMI and RCS reduction. There are tradeoffs involved in the use of each candidate material. To optimize the use of absorbers in a design, there are three sets of parameters that should be critically analyzed: electrical, physical and application.

Although the "DC to daylight" goal has not been achieved, considerable strides have been made to broaden frequency coverage across the microwave region. In optimizing absorber use, the requirement must be defined as completely as possible. The following questions should be asked:

1. What frequency bands need coverage?
2. Is coverage needed over the entire region or just at specific frequencies? For example, if coverage cannot be achieved over the entire 2 to 18GHz region, will absorption at specific frequencies provide enough protection?
3. What is the order of importance in coverage? Perhaps at F0, 20dB absorption is needed. However, at F1, only 12dB is needed; at F2, 7dB is acceptable. By setting these priorities, a design can be more easily reached.
4. Will the absorber be used to absorb specular energy, or is the application such that high angles of incidence radiation and surface waves must be attenuated?

By answering these questions, the various tradeoffs in electrical performance can be examined and an optimum absorber solution derived.

Electrical Performance Guidelines

1. The broader the frequency coverage, the thicker, heavier and more expensive the absorber.
2. The lower the minimum frequency coverage, the thicker and heavier the absorber.
3. Normal incidence performance is better than off-normal performance for most types of absorbers, although they can be designed for off-normal performance.
4. Millimeter-wave materials are now being developed and used.

Of equal importance to the material's electrical performance is its physical performance, which includes environmental characteristics, temperature characteristics and mechanical properties. Again, a series of questions can help clarify the parameters of major importance:

1. What is the application environment? Will the absorber be enclosed or subjected to the outdoor environment?
2. What environmental forces will be degrading the absorber? Some examples are salt, water, ozone, oxygen, ultraviolet light, fuels, oils, chemicals, nuclear and stack gases.
3. Over what temperature range will the material be subjected, and within what thermal range must the material perform?
4. What mechanical stresses will be placed on the absorber? Examples are vibration, thermal shock, elongation or wind.
5. What is the expected lifetime of the absorber? For example, missile applications may not require the same degree of physical integrity as a shipboard application.

Physical Performance Guidelines

1. The elastomeric-type (rubber) absorbers have better environmental resistance than the broadband foam types. These types have been used successfully on surface ships for more than 50 years.
2. A variety of elastomers are available to aid in designing for a specific environment. Hypalon® is widely used in naval applications because of superior weather resistance and color fastness. Nitrile is used for fuel and oil resistance. Fluoro-elastomers and silicones have an excellent operating temperature range.
3. Broadband absorption is obtainable with the dual-layer elastomeric absorbers.
4. Broadband foam materials can be used for external environments, but steps must be taken to protect the absorber. Open-cell foams can be filled with low-loss plastics to make rigid panels for use outdoors. Broadband absorbers can be encapsulated in fiber-reinforced plastics to form flexible absorber panels that can be draped over reflectors.
5. The useful temperature range of most absorber material is -65° F to 250° F. Certain materials are available with higher maximum temperatures.

Absorber Types

Elastomeric Absorbers

These thin, flexible absorbers are best for outdoor use. The method of application is adhesive bonding to a metal substrate. Adhesives vary with the type of elastomer chosen and include: epoxies, urethanes, contact adhesives and pressure-sensitive adhesives (PSA). In general, neoprene and nitrile are the easiest elastomers to bond and have a variety of compatible adhesive systems available. Bond strengths in excess of 10 pounds per inch are typical. In some cases, it is necessary to cover a tight radius or complex curvature. An alternative to flat sheet material is conformally molded parts. Conformal molds increase the ease of bonding and reduce the likelihood of applying any built-in stresses into the material. For gasket applications, the elastomeric absorber may be extruded.

To improve weather resistance, the absorber is painted. Typically, an epoxy- or urethane-based paint is used. To avoid gaps between sheets, absorptive gap fillers are used to minimize any impedance mismatches from sheet to sheet. This technique also limits the formation of surface waves and reflections. Newer non-corrosive fillers, such as iron silicide, are also available for corrosive environments.

Broadband Absorbers

Open-cell foam absorbers are normally used in a protected environment, i.e. radomes or nacelles. Therefore, application becomes much less critical than for those on the exterior of a vehicle. The typical method of application is adhesive bonding. Again, a wide class of adhesives may be used, including contact cements, epoxies and acrylic PSA. In general, cohesive failure of the material will result before adhesive failure. The front surfaces may be painted or coated to further protect the absorber. Laird uses two methods to produce broadband absorbers for external use. The first method involves taking broadband foam or netting absorber and encapsulating it in a reinforced coated fabric. The bagging material is completely enclosed around the absorber making it weather proof. This radar-absorptive cover can then be used in external environments with no physical degradation to the absorbing medium.

A second method uses a closed-cell foam filling technique to produce rigid structural absorptive panels. Filled reticulated foam is lightweight and may be molded to a variety of shapes. It has broadband absorptive characteristics similar to the flexible reticulated foam absorbers. The rigid, closed-cell form may be painted and will be impervious to external environments. A variety of high-strength, lightweight, flexible fillers for filled reticulated foam are being developed. Filled reticulated foam and absorptive honeycomb may be used as the inner core for structural panels. The panel would consist of face sheets of fiberglass or Kevlar® facing the radar and graphite or metal as the ground plane. These panels are lightweight and high strength and can be used as structure in certain applications.

Applications

The two largest applications for radar-absorbing materials are for EMI and for radar cross section reduction in military and commercial electronics.

Military

Today's modern warship has a wide variety of electronic systems on board. Navigational and target-acquisition radar, countermeasure systems and a wide variety of communication equipment are all mounted on a large metal superstructure. This arrangement creates two major problems: false images from self-reflections and system-to-system interference.

False images or "ghosts" are indirect radar returns resulting from specular reflections of radar energy off the ship's own superstructures. False echoes cause navigation hazards and, if severe enough, can make radar navigation impossible. False returns to target acquisition and fire control systems can cause the system to "lock on" to the false images. These problems can be eliminated through the use of tuned-frequency elastomeric absorbers. Tuned to the frequency of the radar, the absorber is bonded to masts, stacks, yardarms and other reflecting structures. By properly situating the material, false echoes can be reduced by 40dB.

The lack of space available on modern warships causes electronic systems to be placed in close proximity. Often a signal or harmonics from one system will be received by or interfere with an adjacent system. This problem has become especially acute with the powerful broadband jamming equipment currently being deployed, but constructing absorber barriers can alleviate it. Depending on the systems involved, single-frequency, dual-frequency or broadband absorbers will be used.

Antenna pattern improvement is an area of universal application for microwave absorbers. Conductive objects in the near field of an antenna can greatly alter its free-space propagation characteristics. The net effect of this is a wider main beam with increased side lobes. This condition can reduce system discrimination and increase the possibility of side lobe jamming. The application of absorbing material to the conductive areas will effectively match out radiation propagated in these directions and return the system to its designed free-space characteristics. A variety of antennas use absorber material for this problem, and to coat feeds, struts and mounts, which act as reflectors.

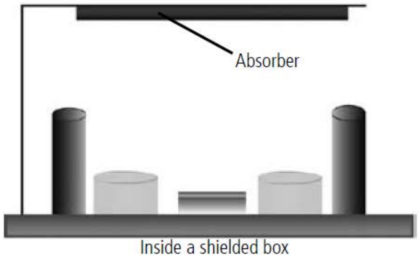
Commercial

There is a growing use of absorbers for reduction of interference in commercial electronics. High-frequency wireless devices often have powerful transmitters and sensitive receivers in close proximity inside a cavity or housing. Spurious signals can cause leakage or system interference, which degrades performance. Magnetic absorbers inside the cavity can reduce the "Q" of the cavity and absorb unwanted reflections. Applications for absorbers can be found in wireless LAN devices, network servers, VSAT transceivers, radios and other high-frequency devices. Custom shapes are die-cut from sheet material with pressure-sensitive adhesive for application inside the noisy cavity.

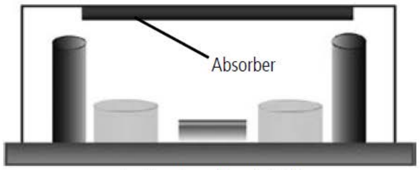
As devices such as computers and cell phones move to higher frequencies and speeds, the need for absorbers or absorbing shields will increase.

Available in Multiple Ways to Fit Individual Applications Application Notes

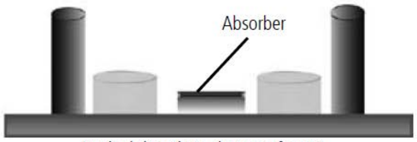
- Inside a shielded box: Internal EMI reduction, cavity resonance reduction, used in conjunction with a board level shield
- Applied directly to the top of high speed CPUs, LSIs, and ICs
- Suppress surface currents on the rear of an LCD
- Surface wave suppression
- Crosstalk suppression
- Improves antenna gain in RFID applications
- To avoid re-spinning a PCB due to EMI issues
- To absorb noise generated between PC boards
- To absorb noise radiated through openings in shielded cavities



Inside a shielded box



Inside a board level shield



Applied directly to the top of an IC

Application Methods

- Microwave absorbers are most commonly applied using pressure sensitive adhesive (PSA).
- Surface wave absorbing materials are most effective when used in conjunction with a reflective ground plane. This ground plane can be a metal shield, housing, or chassis. Laird can also provide these materials with an integral ground plane.
- Lossy foam materials are commonly used in applications where space is limited. These materials are most effective when used in conjunction with a reflective ground plane, but may also be effective when used in a plastic housing.

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