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Reduction of Cavity Resonance In Wireless Applications

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Abstract: This paper presents a radio-frequency (RF) evanescent-mode cavity resonator for passive wireless sensor applications. The evanescent-mode resonator is composed of a cavity with a center post. The resonant frequency of the resonator is determined by the dimension of the cavity, the gap between top membrane electrode of the cavity, and the center post.

I. INTRODUCTION

Printed circuit-board design has become quite complicated these days. one reason for this phenomenon is the increase in availability of commercial applications, many of which are wireless in nature. such applications have increased clock and processor speeds, and therefore emit higher frequencies. unfortunately, the higher frequencies often lead to a number of critical challenges for the designer– not the least of which is reducing and eliminating cavity resonance. commercial applications like consumer electronics, notebook computers, wireless lan devices, network servers and switches, wireless antenna systems, and cellular base stations are especially vulnerable to this problem. microwave absorbing materials now provide designers with a viable method of eliminating both simple and complex cavity resonances. microwave materials offer a proven method for reducing or eliminating resonance. both magnetically and dielectrically loaded materials can be used. microwave cavities have certain resonant frequencies that oscillate. microwave-absorbing materials are a demonstrated, viable method for eliminating both simple and complex cavity resonances. the energy can be attenuated when lossy magnetic or dielectric materials are introduced into the cavity. however, less-expensive dielectrically loaded foam materials despite their thickness and conductivity, can also help safeguard circuit boards. either approach can eliminate cavity resonances.

II. HEADING S

Inside a material matrix. The filler consists of one or more constituents that do most of the absorbing. The matrix material is chosen for its physical properties (temperature resistance, weatherability, etc.). Absorbers are characterized by their electric permittivity and magnetic permeability. The permittivity is a measure of the material’s effect on the electric field in the electromagnetic wave and the permeability is a measure of the material’s effect on the magnetic component of the wave. The permittivity is complex and is generally written as

$$\varepsilon^* = \varepsilon' - j\varepsilon''$$

ABSORBER TYPES:

Free space: Free space absorbers come in two broad types, reflectivity absorbers and insertion loss absorbers. Reflectivity absorbers reduce the reflection level compared to a perfect reflector (metal plate). Insertion loss absorbers reduce the signal travelling from point A to point B

Reflectivity-narrowband: Any single layer homogeneous material will resonate when its thickness is equal to ¼ wavelength. A useful visualization is that the incoming wave will be partially reflected by the front surface of the material while part is transmitted. This transmitted wave then propagates through to the back of the absorber where it undergoes total reflection and propagates back through the front face of the absorber.

Absorber Forms:

- MAGNETIC ABSORBERS: These are thin (.1 to 3 mm) polymeric materials filled with magnetic particles. These materials have both high permeability (magnetic loss properties) and high permittivity (dielectric loss properties). This combination of properties makes these materials very effective in eliminating high frequency EMI. Laird Technologies has two product types that are used for commercial applications:

Q-Zorb HP (high permeability) uses novel magnetic fillers to achieve extremely high permeabilities at low frequencies. This allows for relatively thin materials to provide EMI reduction at frequencies below 2 GHz. This material comes in thicknesses of .15 mm and .5 mm.

Q-Zorb HF (high frequency) is the optimum choice for cavity resonance problems from 2-18 GHz and higher. The material is available in thicknesses from .5mm to 3.2 mm and is supplied in sheets or as die cut components. Both materials are UL-VO and ROHS compliant. They can be supplied with pressure sensitive adhesive (PSA) for ease of installation.

- Dielectric– Dielectric absorbers have no magnetic properties (i.e. μ=1). The loss mechanism is purely dielectric. The loss can arise from a variety of sources within the dielectric. Dielectric absorbers are usually made in a low cost foam form but can also be used with elastomers. Advantages are low cost and weight. Disadvantages are higher conductivity preventing usage in contact with electronic equipment and their lack of performance in most cavity resonance applications due to their lack of magnetic absorption.

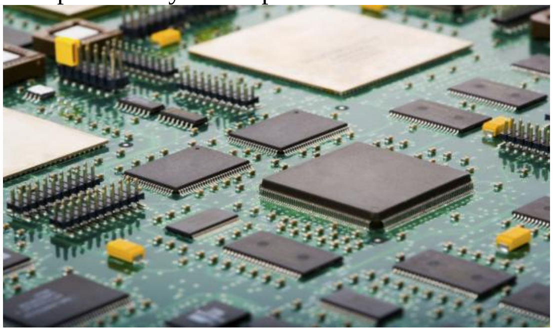
- Moldable: Both magnetic and dielectric absorbers are available in moldable forms. This could be a two part liquid which cures at room or elevated temperatures or could be in the form of injection moldable pellets.

The Microwave Absorber:

Preventative solutions for cavity resonance problems do exist, such as the use of standard shielding materials like finger stock, fabric-over-foam and board-level shields. While these solutions offer some safeguard against cavity resonance, they tend to become less effective as frequencies increase. Even worse, some of the more traditional shielding solutions (e.g., finger stock and conductive elastomers) can actually contribute to the resonance problem by providing a conductive path for energy, which in turn contains the energy inside the cavity. This contained energy can adversely affect other components on the board and may keep the board from functioning properly.

Even when circuit board designers are confronted with the likelihood of a cavity resonance problem in their design, they are often too time-constrained to take appropriate action. They simply don’t have the time required to go through the complex resonance modeling exercise necessary to select a viable material for their cavity.

For those designers who can no longer afford to approach the issue of cavity resonance with a passive attitude, an alternative solution is now available - use of microwave absorbers (blocks of materials which absorb microwave energy) applied directly to the cover of the microwave module. As opposed to having to re-engineer a circuit board cover or relocate circuit elements, the simple addition of the microwave absorber to the cavity provides an inexpensive, quick and proven way to dampen and even eliminate cavity resonance



In general, the most effective absorbers (e.g., silicone rubber sheets) for cavity resonance dampening are magnetically loaded with iron or ferrites and are characterized by high permittivity and permeability plus a high magnetic loss. Material thickness is another important parameter, as the effectiveness of the resonance dampening is directly proportional to the thickness. The material’s effectiveness is also directly proportional to the frequency. Some materials will work better, for example, in the lower microwave range, while others will work better at the higher microwave and millimeter-wave range.

Thinner material is often used at higher frequencies. In fact, magnetic material at a thickness of around 0.040 inch has proven to be effective for use in the lower microwave range (up to 10 GHz), while 0.020 inch to 0.030

inch materials have been effective in the upper microwave range. In addition, 0.010-inch thick absorber materials are effective for the millimeter-wave bands.

Emerson & Cuming Microwave Products Value Proposition

Emerson & Cuming Microwave Products is a world leader in the development and manufacture of microwave absorbing materials. As a company strongly committed to addressing the complex issue of cavity resonance, it now offers a range of microwave absorber solutions - including foam and silicone rubber sheets - which are suitable for use in wireless and other high-frequency applications. These solutions include:

- **Foam Dielectric Absorbers**

Foam absorbers are the least expensive of all microwave absorber materials available on the market today and are often used in base stations. They are conductive and come no thinner than 1/8 inch, but if the circuit design can accommodate that material thickness and out-gassing is not an issue, then foam is often the ideal solution for eliminating cavity resonance.

✓ ECCOSORB® LS – High Loss , Flexible, Foam Microwave Absorber

The ECCOSORB® LS absorber from Emerson & Cuming Microwave Products is the company’s most widely known, used and recommended urethane foam sheet product. It features high loss, low density, is very flexible, and can be easily cut with a knife, scissors or die. A carbon loading system makes it electrically conducive. While it is not weatherproof, it can be treated with an optional weather-resistant CERSEAL coating. Compared to thinner, more expensive rubber absorbers, ECCOSORB® LS is a very low cost solution which is useful in lowering cavity Q’s (high quality factors) in RF amplifiers, oscillators, cabinets containing microwave devices, computer housings, and low-noise blocks (LNBs).

- **Silicone Rubber Sheets**

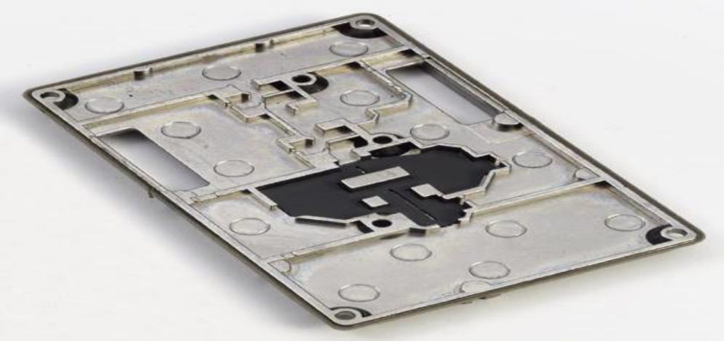
Silicone rubber sheets are typically used for higher temperature applications where a non-conductive, high reliability, thin absorber (as thin as 0.010 inches) is required. Because of these characteristics, the military and aerospace industries commonly design in these absorbers for applications where out-gassing is also a concern.

✓ ECCOSORB® BSR – High-Loss, Ultra-Thin, Elastomeric Absorber

This family of thin (0.25 to 2.54 mm) and flexible, high-loss absorbers is comprised of two types of electrically non-conductive silicone rubber sheets. ECCOSORB® BSR-1 and ECCOSORB® BSR-2 have a typical frequency range that will cover from 5 GHz well into the mm wave range and can be easily cut with a knife or scissors, and fitted to compound curves. Low out-gassing properties make the ECCOSORB® BSR family suitable for space applications. They have been specifically engineered for use in applications requiring the reduction or elimination of cavity resonance.

✓ ECCOSORB® GDS – High-Loss Silicone Rubber Sheet

ECCOSORB® GDS is a thin, flexible, electrically non-conductive silicone rubber sheet with a typical frequency range of 6 GHz up to 35 GHz . Designed to be impervious to moisture and to not support fungal growth as per MIL-STD-810E, these absorbers can be cut and fitted to compound curves. Low out-gassing properties make ECCOSORB® GDS suitable for space applications. When bonded to a metal surface, the absorbers dampen cavity resonances in microwave modules.



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✓ ECCOSORB® MCS – Thin, Flexible Broadband Absorber

This thin, flexible, high-loss, magnetically-loaded, electrically non-conductive silicone rubber sheet has a frequency range from 800 MHz to 18 GHz (see Figure 4). ECCOSORB® MCS was designed to function continuously at a service temperature of 350°F, with short term exposure to higher temperatures, and is impervious to moisture. It can even be subjected to outdoor environments and high altitudes, including space, with no adverse effects. Its low out-gassing properties make it suitable for use in space applications. ECCOSORB® MCS can be cut and fitted to compound curves and is ideal for use in reducing cavity resonances in microwave modules.

Complementing the leading features and functionality of these microwave absorber materials is the unique value proposition offered by Emerson & Cuming Microwave Products. The company:

- Has a long history of excellence and expertise in making components for the military. It was founded in 1948 with this goal in mind.
- Offers the benefits associated with the infrastructure of a large company (e.g. R&D facilities etc…), but with the personal customer service and responsiveness of a small company.
- Was the first to become ISO certified (ISO 9001:2000) and to use automation in manufacturing. This automation increases yields up to 95-100%, ensures electrical consistency and enables the company to run upwards of 20,000 square feet of foam per day.
- Offers global manufacturing via facilities in Randolph, Massachusetts and Westerlo, Belgium with sales offices ad agents worldwide.
- Has state-of-the-art R&D facilities capable of rapid design and development with quick prototype turnaround and short production lead times.

Cavity Resonance Reduction: Often after a circuit is designed and tested it must be properly shielded and physically protected before it can be put into use. This usually involves covering the entire circuit with a metallic cover. While providing adequate shielding and protection the cover can introduce problems of its own. It can create conductive cavities that will resonate if stimulated at one of its resonant frequencies. This cavity resonance introduces E and H fields across the cavity that can seriously impact the circuit performance. The correct absorber material when introduced to the cavity can damp the resonance, enabling proper operation of the circuit. In a rectangular cavity the resonant frequencies are given by Where m, n, and p are indices indicating the number of half wavelengths across the x, y, and z dimensions of the cavity respectively. The cavity will resonate at frequencies determined by the cavity dimensions. The dominant resonant mode is similar to the TE01 waveguide mode but chosen with the first zero of sin(βz). This mode is designated the TE011 mode. The TE011 mode is the lowest frequency at which the cavity can support a cavity resonance. Below this frequency, a cavity resonance will not exist. For an empty cavity, the cutoff frequency corresponds to where the longest dimension of the cavity is equal to 1/2 free space wavelength. The equations governing the field distribution of the TE011 mode are as follows

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

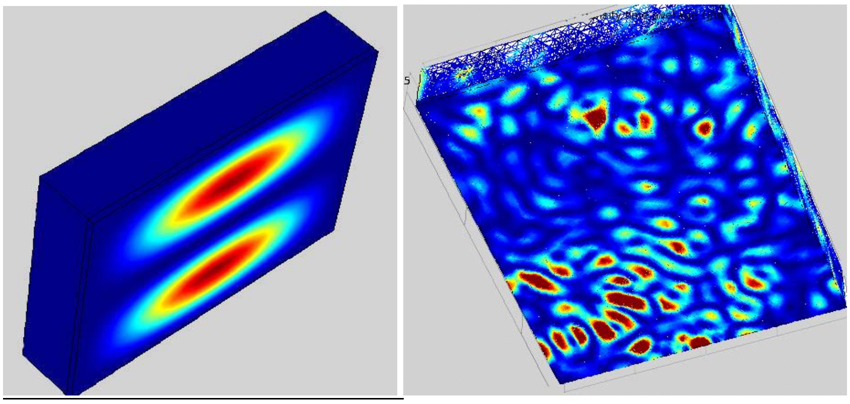
$$H_y = \frac{jbE_0}{\eta\sqrt{b^2+c^2}}\sin\left(\frac{\pi y}{b}\right)\cos\left(\frac{\pi z}{c}\right)$$

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

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

ABSORBER APPLICATIONS:

1.Millimeter wave absorbers: Different modes of analysis and absorber types are needed in the RF/microwave band depending upon whether the absorber is used in free space or inside an enclosed cavity. Absorbers for free space reflectivity or insertion loss use a different design philosophy than for cavity resonance reduction. Most applications in the RF/microwave realm are clearly one or the other. The physics will change somewhat as we move into millimeter waves. Even a physically small cavity or enclosure could encompass several wavelengths at millimeter wave frequencies. Where is the line dividing a free space application from a cavity application? Since there is no hard boundary separating free space from cavity resonance, electromagnetic modeling must be used. Modeling of the field distribution inside cavities of different dimensions compared to a wavelength indicate a breakdown of cavity resonance behavior at a cavity size around 5 wavelengths. At millimeter wave frequencies this could be smaller than 1”. This quasifree space region requires different absorber solutions, requiring different absorber types than those used at lower frequencies



2.Reflection Reduction:Any system that transmits energy can experience interference from reflections back to the transmitter. Also, unwanted reflections can interfere with other systems. Often the reflection source can not be moved as with a building or a ship’s mast. Absorbers can then be used to reduce the reflection level. Typical reflectivity reduction for weather resistant outdoor absorber material is –20dB which will eliminate 99% of the reflection. Care must be taken that the chosen absorber is designed to absorb at the transmit frequency.

Radar Cross Section reduction (RCSR): Absorbers can also be used to reduce the radar cross section of a target object. By reducing the reflection level the object will present a smaller cross section. However, due to the narrowbanded performance of thin radar absorbent material (RAM) and the thickness and weight of broadband RAM, it is difficult to achieve effective radar cross section reduction using absorber alone.

ABSORBER TEST METHODS:

1.Attenuation: It is a measure of how much a wave propagating through a material is attenuated. It is not a direct measurement but is calculated from the material’s complex permittivity and permeability. The definition is that if all space is filled with the material, a wave will attenuate at this rate per unit distance. Attenuation is usually expressed in dB/cm. Attenuation values do not relate directly to any particular measurement and the reader should be cautioned about using the numbers to predict reflectivity. It is used to compare the relative absorption of different materials. In any real world situation, the material impedance must also be taken into account.

2. NRL Arch: The NRL Arch is the industry standard for testing the reflectivity of materials. Originally designed at the Naval Research Laboratory, the NRL Arch allows for quick, repeatable non-destructive testing of microwave absorbent materials over a wide frequency range. Reflectivity is defined as the reduction in reflected power caused by the introduction of an absorbent material. This reduction in power is compared to a ‘perfect’ reflection which is approximated very well by the reflection off a flat metallic plate. As seen in the diagram below, an NRL arch consists of a transmit and receive antenna which are oriented towards a metal plate. To measure normal incidence reflectivity the antennas are located as close to each other as physically possible. Absorbent material is often used to minimize antenna cross talk. The antennas can be located anywhere on the arch to allow measurements of performance at off normal angles of incidence with the practical limitation of the ability to separate the signal from the material under test from the direct antenna to antenna cross talk. In general a network analyzer is used for measurements on an NRL Arch to provide both the stimulus and the measurement. A calibration is performed by measuring the resultant power reflecting off the metal plate over a broad frequency range. This is established as the ‘perfect’ reflection or 0 dB level. The material under test is then placed on the plate and the reflected signal measured in dB. Time domain gating may be used to eliminate antenna cross talk and reduce the error introduced by room reflections.

III. INDENTATIONS AND EQUATIONS

THE EQUATIONS GOVERNING THE FIELD DISTRIBUTION OF THE TE011 MODE ARE AS FOLLOWS

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

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

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

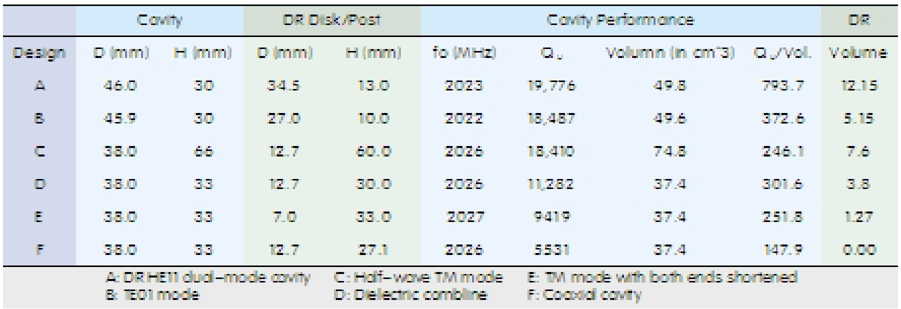
$$\eta = \sqrt{\frac{\mu}{\varepsilon}}$$

permittivity is complex and is generally written as

$$\varepsilon^* = \varepsilon' - j\varepsilon''$$

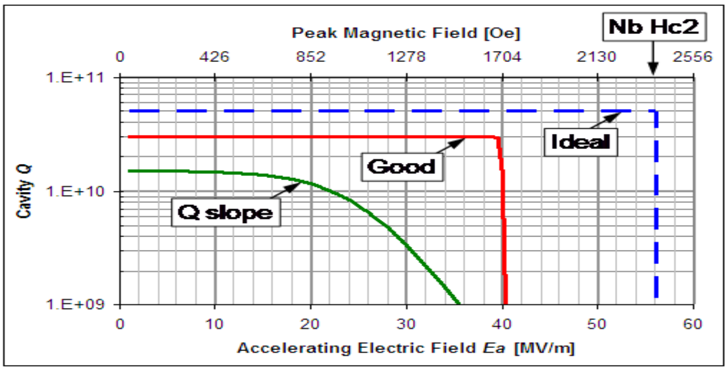
FIGURES AND TABLES

▼Table 2. Cavity Q, volume of single mode DR cavity



	Cavity		DR Disk/Post		Cavity Performance				DR
Design	D (mm)	H (mm)	D (mm)	H (mm)	fo (MHz)	Q_u	Volumn (in cm^3)	Q_u/Vol.	Volume
A	46.0	30	34.5	13.0	2023	19,776	49.8	793.7	12.15
B	45.9	30	27.0	10.0	2022	18,487	49.6	372.6	5.15
C	38.0	66	12.7	60.0	2026	18,410	74.8	246.1	7.6
D	38.0	33	12.7	30.0	2026	11,282	37.4	301.6	3.8
E	38.0	33	7.0	33.0	2027	9419	37.4	251.8	1.27
F	38.0	33	12.7	27.1	2026	5531	37.4	147.9	0.00

A: DR HE11 dual-mode cavity
B: TE01 mode
C: Half-wave TM mode
D: Dielectric combline
E: TM mode with both ends shortened
F: Coaxial cavity



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