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SUPPRESSION OF RESONANT MODES IN MICROWAVE PACKAGES

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ABSTRACT

Undesirable resonant cavity modes of a metal package are shown to be effectively damped by placing a dielectric substrate coated with a resistive film in the cavity. Theoretical predictions are confirmed experimentally. The application of the technique is demonstrated for a practical packaging problem.

INTRODUCTION

Electrical circuits must often be enclosed in a metal package both to protect the circuit from material contamination and to provide electrical isolation. Many circuits, especially monolithic microwave integrated circuits (MMICs), must be placed in metal packages which are large enough to support resonant modes at the circuits' frequencies of operation. Since these resonant modes usually have a high quality factor, even a very loose coupling between the circuit and these modes can disturb circuit operation.

This undesirable interaction between the circuit and the resonant cavity modes of the package can be reduced or eliminated by damping the resonant cavity modes. Conventional microwave absorbers may be placed in the package for this purpose, as has been done by Hallford and Bach (1). However, circuit reliability may be compromised if microwave absorbers based on organic materials such as silicon rubber with a potential for outgassing are placed in the package with GaAs MMIC's. Many microwave absorbers based on inorganic materials are difficult to machine down to the small thicknesses required for microwave frequencies.

It was suggested by Williams (2) that the resonant modes of a rectangular metal package might be damped by fixing a dielectric substrate coated with a thin resistive film to one of its walls, thus solving the reliability and machining problems associated with many conventional microwave absorbers. A theoretical treatment was used to predict the film resistivities which would best damp the lowest order cavity mode. No experimental results were given, and the technique was not demonstrated in a practical application.

In this work a series of experiments are performed, confirming the theoretical predictions of Williams (2) over a wide range of substrate thicknesses and film resistivities. The application of this technique to a hybrid phase shifter in which coupling to a resonant mode of the package degrades circuit performance is also discussed. The undesirable interaction of the phase shifting circuit and a resonant package mode is shown to be suppressed effectively by the introduction of the lossy film.

EXPERIMENTAL CONFIRMATION

Williams (2) calculated the unloaded quality factor (Q_u) of resonant modes damped by the introduction of a dielectric coated with a resistive film. The unloaded quality factor of the resonance is its quality factor when no external damping due to measurement equipment is present. The unloaded quality factor was calculated from the measured S-parameters of the cavity by the technique outlined by Matthaei, Young, and Jones (3). The experimental apparatus shown in Fig. 1 was devised for this purpose. The alumina substrates coated with thin resistive films were inserted into the microwave resonator to damp the resonant mode. The two coaxial connectors were installed in the bottom of the cavity and connected to small coupling loops for the purpose of exciting the resonant modes of the cavity.

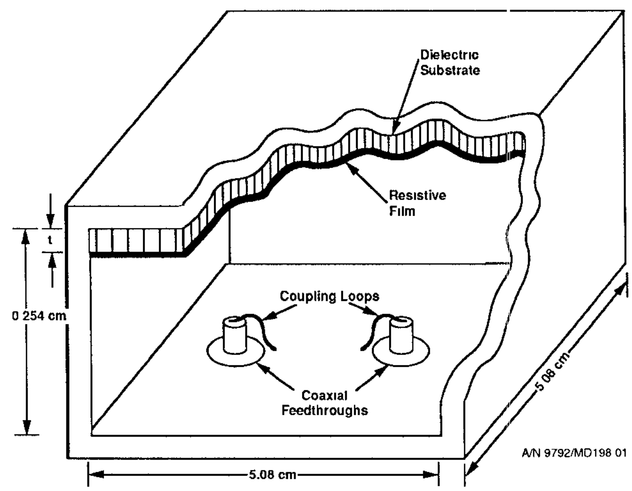

Fig. 1. The experimental resonant cavity. The wire loops couple energy into and out of the resonant cavity mode.

A gold plated cavity with inside dimensions of 5.08 cm by 5.08 cm by 0.254 mm formed the body of the resonator. Three alumina substrates of dimensions 5.08 cm by 5.08 cm by 2.54 mm were prepared for insertion into the cavity. The substrates were coated with a film of tantalum nitride, a resistive material. The resistivities of these films were measured by a 4-point probe and found to be 14, 25, and 100 ohms per square.

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The unloaded quality factor Q_{uo} of the cavity with an uncoated substrate fixed to the lid was measured first and found to be approximately 1000. The quantity Q_{uo} is a measure of the effect of ohmic and dielectric loss in the cavity. The effect of this loss was subtracted from the measured quality factor Q_{um} of the cavity when the film was inserted via

$$Q_u = (Q_{um}^{-1} - Q_{uo}^{-1})^{-1} \quad (1).$$

Q_u is the unloaded quality factor of the resonance which would be obtained if the cavity loss vanished.

In Fig. 2, the unloaded quality factor Q_u of the cavity resonance is compared to that calculated by Williams for several film resistivities and substrate thicknesses. (Several substrates were stacked to achieve the different substrate thicknesses shown in the figure.) In Fig. 3, the frequencies of the cavity resonance are plotted as a function of substrate thickness and film resistivity. The agreement in calculated and measured results is seen to be quite good in both figures.

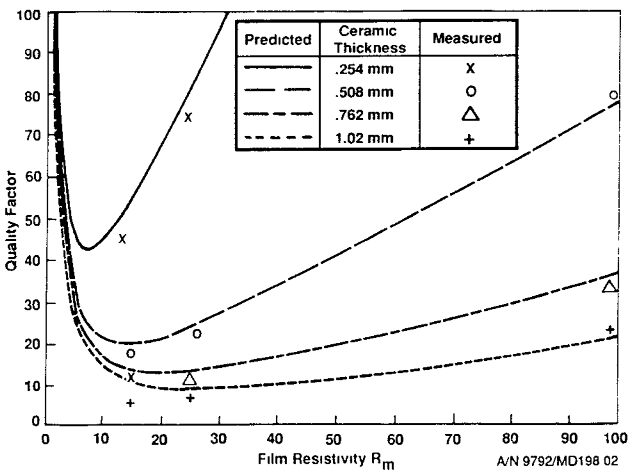

Fig. 2. The measured and calculated quality factors of the lowest order resonant mode of a rectangular cavity are plotted as a function of film resistivity for several different substrate thicknesses. The figure shows good agreement between the measured and calculated quality factors and clearly illustrates the existence of "optimum" film resistivities which maximally damp the resonant mode in the cavity.

It might be thought that a high quality electrical connection must be formed between the film coating the dielectric and the package in order to effectively damp the package modes. This was not found to be the case. The dielectric substrates in this experiment were simply placed into the cavity and no change of resonant mode quality factor or frequency was observed when a thin bead of silver epoxy was used to form an electrical connection between the film and the cavity wall. The unloaded quality factor of the resonance was found to be weakly dependent on the gap between the edge of the film and package wall, however, with the unloaded quality factor doubling when the distance between the edge of a 100 ohm per square film on a 0.762 mm thick alumina substrate and the package wall was increased to about 4 mm.

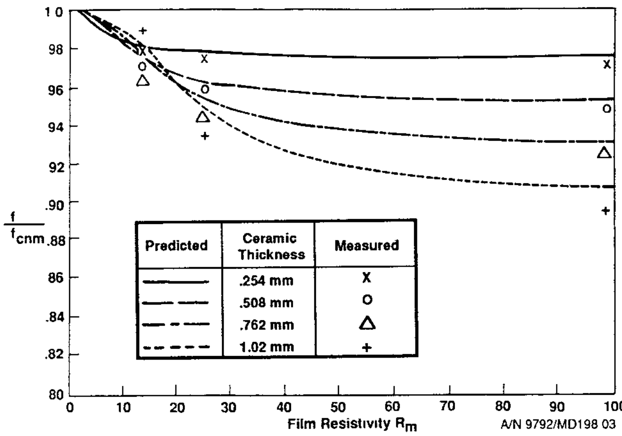

Fig. 3. The measured and calculated frequencies of the lowest order resonant mode of a rectangular cavity are plotted as a function of film resistivity for several different substrate thicknesses.

PRACTICAL APPLICATION

Fig. 4 shows the transmission coefficient of a five bit C-band phase shifter developed for a microstrip phased array. The phase shifter is large enough that the frequency of lowest order cavity mode is in the pass band of the phase shifter. The undesirable interference of the cavity mode and the passband causes the dip in the transmission coefficient at 6.15 GHz.

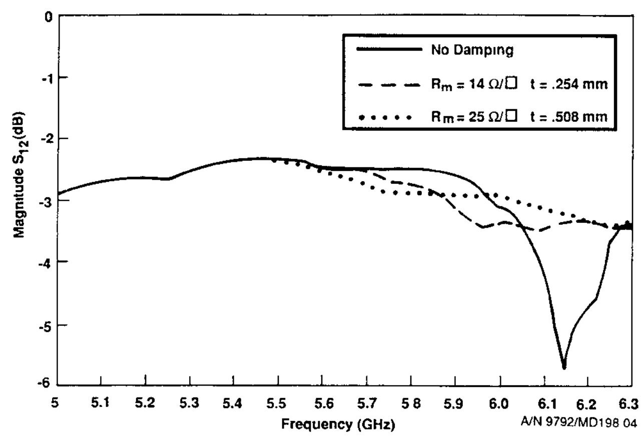

Fig. 4. The transmission response of the C-band phase shifter with and without mode suppression.

The film resistivities which optimally damp the lowest order resonance in the package were calculated for two substrate thicknesses, 0.254 and 0.508 mm, and are plotted in Fig. 5. In Fig. 4, the transmission coefficient of the phase shifter in which substrates 0.254 and 0.508 mm thick and film resistivities of 14 and 25 ohms per square respectively had been fixed to the lid are shown in dashed lines. The spacing between the substrate and the package walls was approximately 0.4 mm. The undesirable effect of the cavity mode is seen to be greatly suppressed.

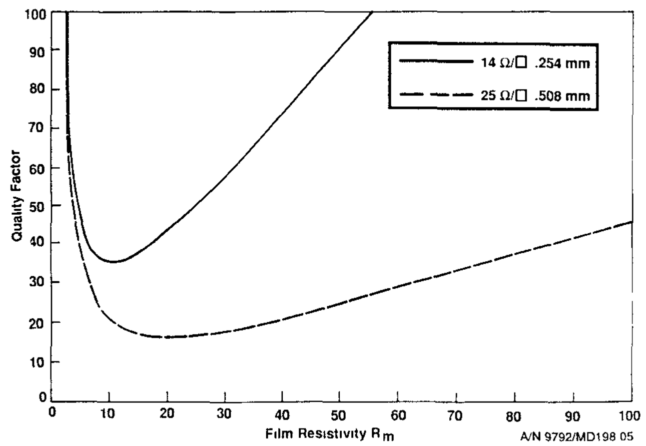

Fig. 5. The calculated quality factors of the lowest order resonant mode of the phase shifter package are plotted as a function of film resistivity for several different substrate thicknesses.

CONCLUSION

The damping of package modes was verified experimentally. The technique was applied to a practical phase shifter circuit and the undesirable effect of package mode suppressed.

REFERENCES

(1) B. R. Hallford and C. E. Bach, "Lid interaction protected shield enclosed dielectric mounted microstrip," U.S. Patent No. 3,638,148, Jan. 25, 1972.

(2) D. F. Williams, "Damping of the resonant modes of a rectangular metal package," IEEE Trans. Microwave Theory and Tech., Vol. MTT-37, No. 1, Jan. 1989.

(3) G. L. Matthaei, L. Young, and E. M. T. Jones, Microwave Filters, Impedance-Matching Networks, and Coupling Structures, McGraw-Hill, New York, 1964, Chapter 11.