Simulation of Multi–Chip Module Package Resonance Using Commercial Finite Element Electromagnetic Software

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Abstract

Techniques have been developed to predict package resonance frequencies in multiple cavity, MMIC based, T/R modules, using the HP High Frequency Structure Simulator package. This method accounts for partially filled waveguide modes, perturbations due to GaAs MMICs and their metal spacers, and the effects of imperfect cavity end walls. Calculated results are compared to measured package resonances and module performance data.

Introduction

Package resonance is always a concern in microwave module design, particularly for electrically large modules. In a recent T/R module design, we observed narrow band dips in transmit output power and receive input return loss. Because simple cavity resonance formulas predicted the possibility of resonances in our package, although not at the observed frequency, we began a study of cavity resonance in our package. This paper describes our combination of experimental observations and electromagnetic simulation of our package using the HP High Frequency Structure Simulator software.

Module Description

The T/R module modeled for this study includes two receive channels, one of which is shared with the transmit chain, and uses 19 GaAs integrated circuits and high dielectric matching circuits. The receive gain is about 30 dB, with the transmit small signal gain higher than 40 dB. The transmit chain alone includes four large HPA MMICs, each with off–chip matching networks, which results in a cavity which is electrically large.

The T/R module package under question (see Figure 1) is similar to many now in use in the industry, although larger than most so far reported. It consists of a Kovar ring wall brazed to a copper/molybdenum base plate, sealed with a welded Kovar lid. High temperature co–fired ceramic (HTCC) alumina feedthroughs are brazed into notches in either end of the package wall. The overall size of the interior cavity is about 1.1"x4.0". An alumina substrate is epoxied into the package to provide DC and RF interconnects between components. This substrate is about 30 mils smaller in each dimension than the package interior. MMICs on metal spacers are mounted to the module base plate through cutouts in the substrate. To improve end–to–end isolation and raise cavity resonant frequencies, the large cavity is divided into three sub–cavities with spring walls surface mounted to the substrate and grounded with a row of via holes.

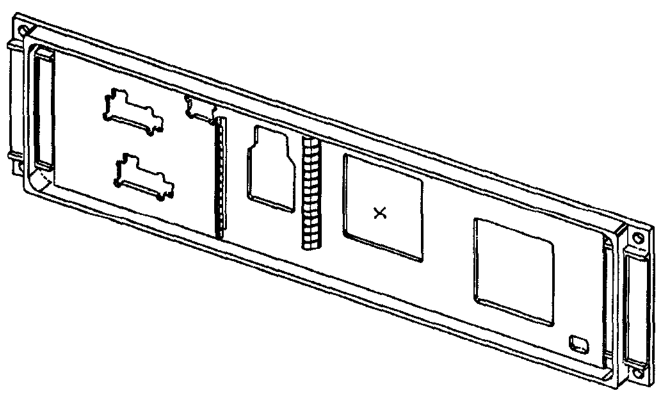

Figure 1: Module Package

Module Performance

When these modules were populated and tested, narrow band performance dropouts were consistently observed at 5.3 GHz, in both transmit output power and receive return loss. These dropouts disappeared when the lid was removed, and moved and flattened when metal shims were applied to the lid in the large transmit cavity. No spurious signals were generated. These observations indicated to us the possibility of cavity resonance.

Cavity Resonance Prediction

The ideal cavity resonance equation for unfilled and completely filled cavities suggested that a 5.3 GHz cavity resonance was possible. More rigorous solutions for partially filled cavities (one layer of dielectric completely extending from side to side) also predicted in–band resonant modes. None of the predicted resonances (see Table 1) fell exactly on the observed 5.3 GHz dropout point, and so we sought a better solution, which would account for the MMICs, spacers, spring walls, and feedthroughs.

The Hewlett–Packard High Frequency Structure Simulator (HFSS)[1] is a commercially available, full 3D, finite element based electromagnetic field simulator. Both dielectric and metal objects are physically modeled. The modeled region is fed with (infinitely long) cylindrical waveguide of arbitrary cross section, for which impedances and propagation constants are computed. The computed electric and magnetic fields and currents can be visualized, and S–parameters of the driving port modes are calculated. Objects may be modeled with or without loss effects. Version 2.06 was used for this work.

It is quite difficult to compute cavity resonance directly with HFSS. Calculations of complicated geometries (such as T/R modules) are time intensive. A single frequency may take four to twelve hours. Solutions with loss are even slower. Without loss, the resulting high Q cavity resonance phenomena are very narrow band, and will almost certainly be missed at the frequency steps required for reasonable solution times. Simplifying the geometry to speed up solutions requires removal of the perturbations that make 3D electromagnetic simulation necessary in the first place. Planar electromagnetic solvers can be used for some resonance problems, and are well suited to cases where the circuit metalization has a strong impact on the resonant frequency. They do not handle the non–planar discontinuities around the MMICs and their spacers.

The first way to improve resonant mode prediction uses the 2D port solution capability of HFSS. Because HFSS computes the eigen–mode solution for the port waveguides, including propagation constants, a simple model of the package cross–section can be quickly solved. In our case, it showed that no lengthwise propagating modes were possible below about 4.75 GHz. Using the computed propagation constants and the approximate cavity sizes (hard to determine exactly because of the finite width of the spring walls), frequencies were identified for which the cavities were a half wave long. These frequencies were still well away from the observed 5.3 GHz.

Separation of the entire package into sections results in models that can be solved in reasonable periods of time. Because the large HPA cavity appeared to be the most likely culprit, we focused our initial work on it. As mentioned above, a simple waveguide with the same cross section as the module can be simulated at ten frequencies in less than two hours on an HP–735/99 workstation with 272 Mbytes of RAM (your mileage may vary). This gives the unperturbed propagation constants of the cavity. The addition of dielectric and metal slabs representing the MMICs, spacers, and substrate cutouts of one cavity increases the computation time to only four to five hours. With one end of the perturbed waveguide shorted with a structure representing the HTCC ceramic feedthroughs (see Figure 2), the result is a one–port with the correct down and back phase over the MMICs. The resulting S–parameters are de–embeded to the position of the spring wall.

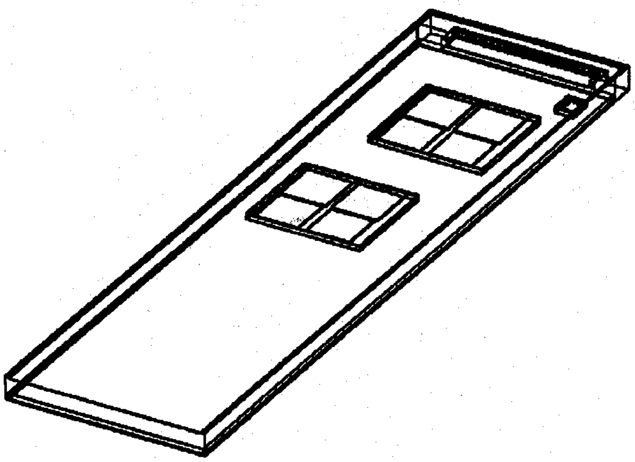

Figure 2: One–Port Model of HPA Cavity

A similar model is constructed for the spring wall (see Figure 3). A waveguide with the package cross–section is interrupted with a spring wall iris. The two–port S–parameters are de–embeded to the center of the wall. Due to the complexity of the spring wall and grounding vias, this model takes significantly longer to run, on the order of six to eight hours.

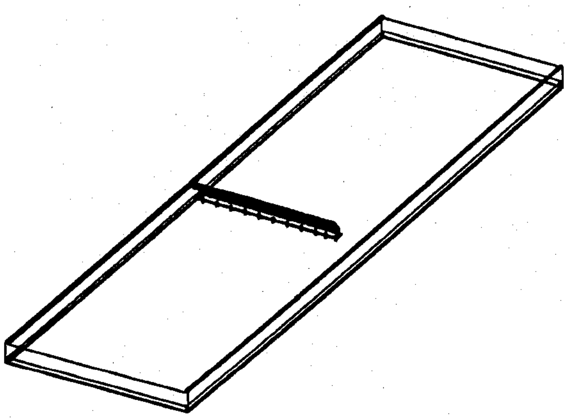

Figure 3: Two–Port Model of Spring Wall

Both sets of S–parameters can now be loaded into a network simulator package. Although the response was calculated at only a few frequencies, the phase of both sets of S–parameters is very smoothly varying, and is very amenable to interpolation at intermediate frequencies. The two–port representing the spring wall is prepended to the one–port block modeling the rest of the cavity, and the resulting one port is simulated at several hundred frequencies (about 0.5 seconds on the HP–735). Extremely narrow band resonances are clearly visible in the reflection coefficient phase (see Figure 4).

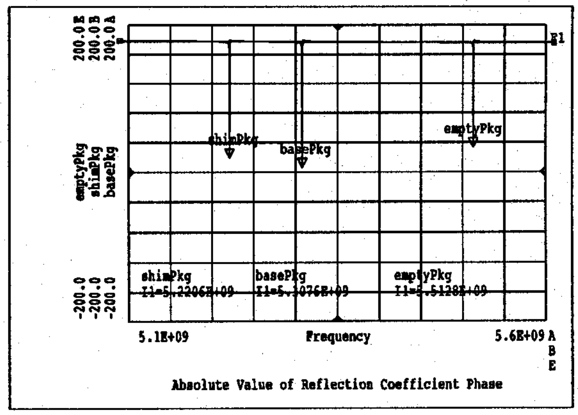

Figure 4: Absolute Value of Reflection Coefficient Phase (Combined Model)

Simulation Results

So far, the largest cavity, which seems most likely to be the source of the observed dropout, has been simulated. Ignoring the effects of circuit metalization, but including all MMICs as dielectric slabs, a resonance frequency of 5.308 GHz has been calculated. Resonance frequencies calculated from unperturbed waveguide propagation constants are much lower, below the waveguide cutoff frequency in some cases, indicating that the effects of the MMICs, their spacers, and the end walls are significant. Runs which include lid shims show the downward movement of resonant frequency predicted by cavity perturbation theory.

Cavity Resonance Fixture Measurements

To test the suspicion that resonance is responsible for the observed performance dropout, and to verify the HFSS model, a simple resonance test fixture is used. The module package is flipped upside down on a metal plate pierced with a small monopole probe, and moved to maximize resonance while the input frequency is swept[2]. Several test cavities, as well as an actual, MMIC filled module, have been tested. Results for an empty cavity are shown in Figure 5, and results

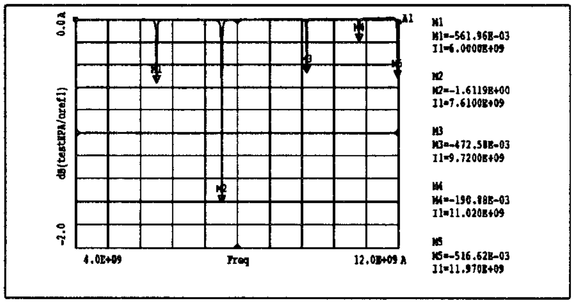

Figure 5: Amplitude of Reflection Coefficient: Simple Cavity

for the HPA cavity with substrate and spring walls, but no MMICs, is shown in Figure 6. The

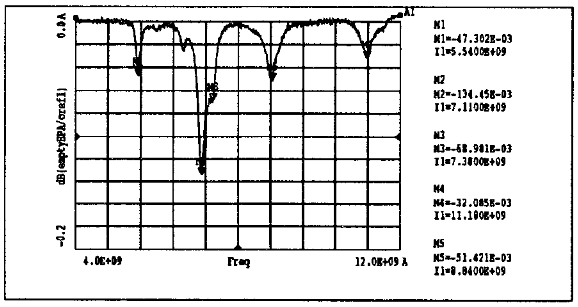

Figure 6: Amplitude of Reflection Coefficient: Empty Package HPA Cavity

results of the resonance fixture test are in close agreement with the simple cavity formulas, confirming the measurement technique, and with the electromagnetic simulation method.

Conclusions

An accurate prediction of package resonance for a complex module can be made using finite element electromagnetic simulation software. The predicted resonance frequency of the cavity studied is very close to the observed dropout frequency, and to resonance test measurements. With help of the field visualization capabilities of HFSS, methods of resonance and feedback suppression can be devised.

Acknowledgements

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References

[1] Hewlett–Packard Company, Test and Measurement, 5301 Stevens Creek Blvd., Building 51L–SC, Santa Clara, CA 95052

[2] Donald W. Griffin, "A New Instrument for the Measurement of Resonant Field Distributions in Microwave Housings and Packages," IEEE 1990 Microwave MTT–S International Microwave Symposium Digest, p. 621

Table 1: Computed Resonance Frequencies

Approximate Cavity Size	Resonant Frequency					Observed Dropout Frequency
	Empty Cavity	Filled Cavity	Partially Filled Cavity	HFSS Waveguide Prediction	HFSS Perturbed Prediction	
1.1"x1.37"	6.88 GHz	2.19 GHz	6.25 GHz	5.04 GHz	n/a	5.3 GHz
1.1"x0.56"	11.83 GHz	3.76 GHz	10.69 Ghz	above 6 GHz	n/a	
1.1"x2.12"	6.05 GHz	1.92 GHz	5.5 GHz	below 4.75 GHz	5.308 GHz	