Improved Techniques for the Measurement and Modeling of Plastic Surface Mount Packages to 20 GHz

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Abstract—A general technique is presented for modeling and characterization of RFIC plastic packages from DC to 20 GHz, and is applied to an industry standard SSOP-8. An improved Thru-Reflect-Line (TRL) measurement method suited for package modeling is presented. The modeling approach includes the use of measured data, Finite Element Method (FEM) electromagnetic modeling of the package, and a new circuit synthesis technique to obtain an accurate equivalent circuit. Excellent agreement is obtained to 20 GHz between modeled and measured results, demonstrating the utility of the technique.

I. INTRODUCTION

The need for accurate RFIC plastic package models has become more important as frequency allocations for consumer products have reached the GHz region. In addition, the level of integration of these products is increasing, and their frequencies are beginning to extend into the mmW region [1]. At the same time, the use of plastic packages for RFIC applications continues to be important because of their flexibility and low-cost for higher level assembly.

However, the measurement and characterization of plastic packages for these higher frequency applications has typically not extended beyond the 3-5 GHz range [2,3]. This is due to the difficulties in obtaining accurate package measurements at the higher frequencies, and in developing equivalent circuit models that account for the multiple resonances in the structure. In this paper, we extend the measurement frequency of a standard SSOP-8 package to 20 GHz, and synthesize a lumped-element equivalent circuit model of the device that accurately predicts its performance over this entire frequency range. We believe that this is the highest frequency yet for the development of an accurate lumped element equivalent circuit model of these devices. These results can be used for accurate modeling of the behavior of RFICs embedded in a typical plastic package environment.

II. EQUIVALENT CIRCUIT SYNTHESIS

One limitation of traditional high-frequency equivalent circuit models of plastic packages is the difficulty in capturing the multiple resonances associated with each portion of the device (bondwire, leadframe, paddle, etc.). A distributed element transmission line model has been developed [3], but it is very difficult for commercial circuit simulators like SPICE to efficiently simulate transmission line based structures [4].

The starting point for the improved synthesis technique is the measured impedance data on the individual ports of the package. The package topology used is illustrated in Figure 1, where the input bond wire (pin 2) is shorted to the ground return bond wires on pins 1 and 3 via the paddle, although other topologies can be modeled as well.

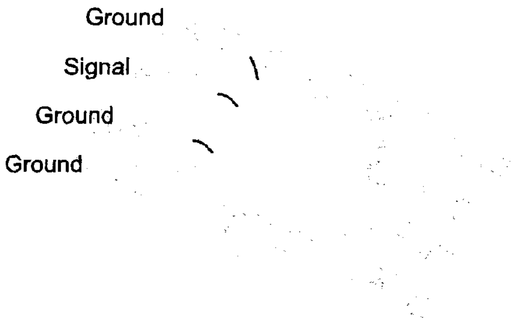

Figure 1: Sketch of SSOP8 topology.

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The measured impedance frequency response (Z11) of the SSOP-8 package is illustrated in Figures 2 and 3.

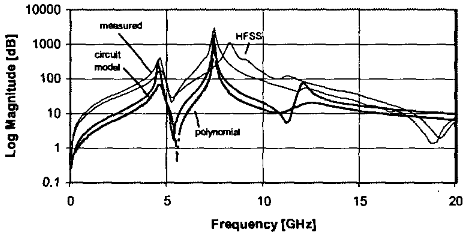

Figure 2: Z11 magnitude plot of synthesized circuit, polynomial, HFSS model and measured data.

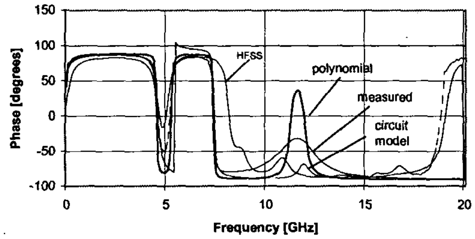

Figure 3: Z11 phase plot of synthesized circuit, polynomial, HFSS model and measured data.

This technique could be expanded to other configurations. For instance, the impedance parameters can be obtained for any set of two pins (with all other pins grounded), and equivalent circuits synthesized using the transfer impedance function Z21. The complete package could be modeled in this fashion.

We assume that for this package configuration there is no current from port 2 [5]. The measured response contains one simple and two complex zeroes and three complex poles. It is evident that a simple zero must be included to accurately model the DC performance of the package; all other poles and zeroes are assumed complex. The number of zeroes is determined by the local minima across the measured bandwidth and assuring the response does not diverge at infinity. The number of poles then matches the number of zeroes.

The resulting Laplace input impedance can be written:

$$Z=\frac{(s+A)(s^2+\frac{\omega_1}{Q_1}s+\omega_1^2)(s^2+\frac{\omega_2}{Q_2}s+\omega_2^2)}{(s^2+\frac{\omega_3}{Q_3}s+\omega_3^2)(s^2+\frac{\omega_4}{Q_4}s+\omega_4^2)(s^2+\frac{\omega_5}{Q_5}s+\omega_5^2)}$$

where A is the DC offset, and ω_i and Q_i are constants determined from the measured data. The response of the expanded polynomial is then employed for circuit synthesis.

This expanded impedance from the equation can be decomposed into a topology that will contain the minimum number of elements. Brune's Impedance Synthesis Method [6], was used to synthesis the circuit, as illustrated in Figure 4.

Table I lists the resulting component values for the circuit. Figures 2 and 3 compare the measured, polynomial-fit and equivalent circuit modeled results, and the agreement is outstanding over the entire range of frequencies.

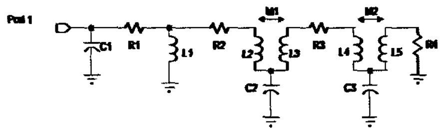

Figure 4: Synthesized One-Port Circuit Model for Package of Figure 1.

Table 1: Element Values for Synthesized Circuit of Figure 4.

Element	Value
C1	1.563 pF
C2	0.05818 pF
C3	0.4692 pF
L1	0.3189 nH
L2	12.15 nH
L3	6.452 nH
M1	8.853 nH
L4	0.5802 nH
L5	0.4686 nH
M2	0.5214 nH
R1	0.4170 Ω
R2	0.0539 Ω
R3	6.979 Ω
R4	1073 Ω

III. ELECTROMAGNETIC SIMULATION

In addition to the lumped element simulation, a Finite Element Method (FEM) simulation using Ansoft's High Frequency Structure Simulator (HFSS) [7] was done. This simulator tool can speed the lumped element modeling process by providing impedance parameters without building expensive test packages. It can also provide electromagnetic field information not easily obtained otherwise, such as surface current density.

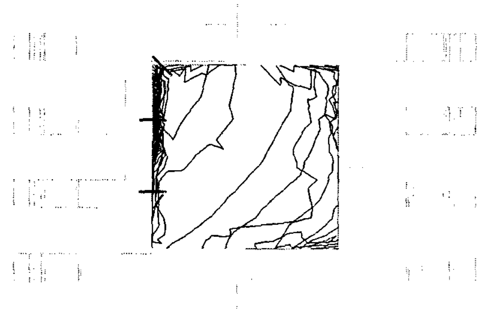

Figure 5: Top view of HFSS model cut plane. Surface current intensity contours are shown on paddle surface.

Before the simulation could be conducted, the dielectric constant (K) and loss tangent of the plastic was measured. A simple waveguide resonator method was used [8] and the resulting K value at varied from 3.4 to 3.65 over the 1 to 20 GHz band width. The loss tangent varied from 0.011 to 0.020 over the same frequencies.

Figure 2 and 3 include the HFSS simulation data. It can be seen that excellent agreement with the measured data is obtained below 8 GHz, and good agreement is obtained to 20 GHz. The HFSS simulation predicts a resonance slightly off the 7.5 GHz measured resonance. This is probably due to slight inconsistencies between the physical package and that drawn in HFSS.

In Figure 5, a cutplane was taken at the level of the top of the paddle and the magnitude of the surface current was plotted. It can be seen that the current is not symmetric over the paddle, and the return path is predominately to the corner of the paddle of pin 1, rather than a symmetric distribution over the paddle. This can be explained by the fact that the grounded pin 1 runs nearly halfway down the edge of the paddle, and since all locations on a (perfect) conductor must be at the same potential, more current is needed on one side than the other. This effect will result in a significant asymmetry in the equivalent circuit of the package pins. This type of information can be used to design packages with improved high frequency performance, similar to the research that has reduced the losses in spiral inductors [9].

IV. EXPERIMENTAL RESULTS

In order to verify the usefulness of the modeling approach, a dummy SSOP-8 plastic package - supplied by TopLine [10] - was modified to have one wirebond from leads 1, 2 and 3 attached to the paddle, as illustrated in Figure 1. The wirebonds were 1 mil in diameter and spanned approximately 25 mils. The plastic material above the paddle was removed and the wires left exposed to air.

The SSOP8 was placed in a custom fixture manufactured by Inter-Continental Microwave (ICM) [11]. The fixture has the measurement planes located at the contact point of any desired lead and has all other pins grounded through vias, with the exception of the pin opposite the desired input pin. The calibration is performed with a Thru-Open-Short-Load (TOSL) calibration to 500 MHz and Thru-Reflect-Line from 500 MHz to 26.5 GHz. The S-Parameters are then used to obtain the impedance Z11. This plot was used to obtain the pole-zero placement as illustrated in Figure 2.

Figure 2 and 3 is a Z-parameter plot of the agreement between measured data and the previously mentioned modeling techniques for this package configuration from 50 MHz to 20 GHz. Excellent agreement is obtained across the entire frequency range, despite the use of lumped element equivalent circuit.

V. CONCLUSION

A new technique has been presented for the measurement and equivalent circuit modeling of plastic packages to frequencies nearly into the mmW region. Good agreement is obtained between measured and modeled responses to 20 GHz. Electromagnetic modeling was used to illuminate asymmetries in the flow of surface current through the package, and this information was employed to optimize the resulting model. This information can be used to provide more insight into package design and modeling.

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