Design Techniques for Improved Microwave Performance of Small Outline Packages

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Abstract **General techniques to improve the microwave performance of plastic leaded packages have been developed. These techniques result in an improvement of the bandwidth and reduction of losses in the structure. The techniques were applied to an SSOP8 configuration, and the useful frequency range was extended from 6 GHz to well above 10 GHz.**

I. Introduction

As integrated circuit technology continues to advance to higher and higher levels of performance, designers are finding that the characteristics of traditional leaded packages present a major impediment to operation at higher frequencies. This problem is especially acute for newly emerging consumer-oriented wireless and fiber-optic systems, such as WLANs operating at 5 GHz and UWB systems, as well as low-cost OC-192 and 10G ethernet applications. In fact, the resonances and loss associated with the package at these frequencies can severely limit the performance of these systems.

Several higher performance package technologies have been developed over the years, including leaded ceramic [1], BGA [2], flip-chip [3], and mm-wave package topologies [4]. However, traditional plastic lead frame technology represents the "workhorse" of the handset and WLAN industries today, and it is important to develop improved designs based on this technology. The goal of this research is to develop improved package design approaches that will allow us to extend the useful frequency range of these devices into the X-Band region for standard applications.

II. Enhanced Performance of RF Lead-Frames Packages

The microwave performance of traditional plastic packages has been limited by the physical construction of the device — a metal lead frame embedded in a molded plastic dielectric. The mechanical requirements of the package itself also dictate the design of the package, especially thermal and lead pull-test limitations. As a result, the high frequency performance of the package itself has proven to be compromised. Previous papers [5-7] have concentrated on the *modeling* of these limitations, in the hope of improving the accuracy of the predicted performance. Our goal in this work is to *improve* the fundamental microwave performance of the package without compromising the mechanical and thermal reliability requirements of the basic design.

Traditional lead frame packages are traditionally modeled as coupled π-LCR networks[5-7] with multiple resonances associated with the discontinuities in lead frame design. These structures are inherently low pass — prior to resonance — and limit the applicable useful frequency range to several GHz in most cases [5]. A typical example of a high-performance microwave package is the classic SSOP8, shown in Fig. 1, where a 50Ω 4.5 mil through line has been inserted between ports 2 and port 7. In this case there are discontinuities associated with the board-lead frame transition, air-plastic transition, lead frame-bonding tab transition , and bonding tab-bond wire transition. Each transition creates multiple reflections and resonances in the electrical performance. A cross-sectional view of the package along with the multiple transitions is shown in Fig. 2.

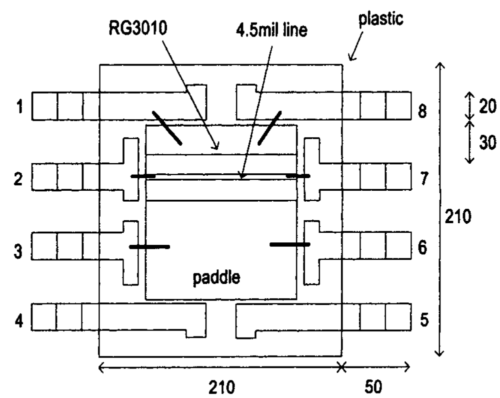

Fig. 1. Classic SSOP8 pin package with 50Ω through inserted between ports 2 and 7.

Sumitomo 6300H plastic is widely used in the industry for packages in this frequency range. A number of variants of this material are used, but they typically possess a relative dielectric constant ε_r of between 3.3 and 4, and with a loss tangent of approximately 0.02 The lead frame inductance Lc and bond-wire inductance is coupled to every other lead in the package [8] and capacitive coupling occurs as well through the various pins. These limit the frequency response of the circuit.

As an example of the typical high-frequency response of this configuration, Fig. 3 plots the HFSS simulated response of this package, as configured in Fig. 1. Pins 1, 3, 8, and 6 are connected to PCB ground and ground the paddle with wire bonds. Pins 2 and 7 are the input/output pins with a 50Ω 4.5 mil through line. Note the large S_{72}

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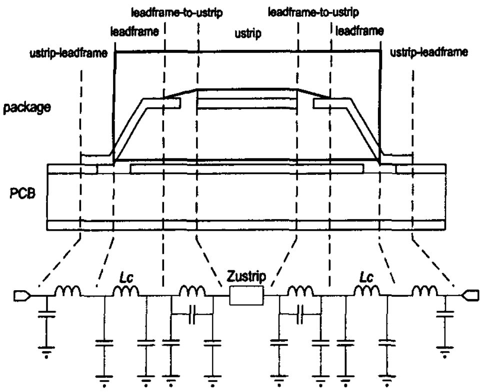

Fig. 2. Cross-sectional view of SSOP-8 interconnection between RFIC and PC Board. Multiple internal reflections are created by the various transitions.

resonance at 6 GHz would inhibit operation at frequencies above 5 GHz, and the isolation between ports 4 and 2 is only 8 dB at 7 GHz. The losses of the package, combined with the poor isolation limit the performance. This configuration is clearly problematic for operation above 6 GHz.

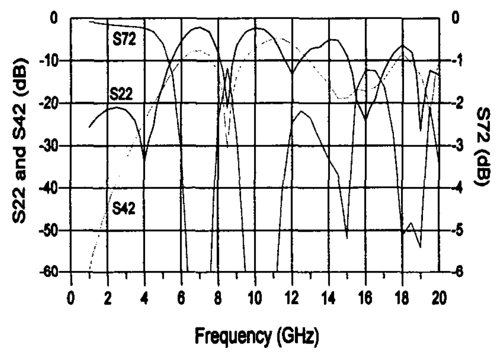

Fig. 3. SSOP8 package HFSS simulated response. Note the large S_{72} resonance at 6 GHz, and the isolation between ports 4 and 2 is only 8 dB at 7 GHz.

The key to the improvement of the package microwave performance is minimization of the impedance discontinuities from the PC board to the bond wire-bonding tab interface. This can be accomplished by treating the lead frame as a modified Embedded CoPlanar Waveguide with Finite Ground Plane (ECPWFG)[9], and then modifying the lead frame design to insure a 50Ω characteristic impedance to the bond wire transition. The derivation of the characteristic equations for the ECPWFG transmission line — including the resulting characteristic impedance — can be found in [9]. Design curves for characteristic impedance are given in Fig. 4 for various width (a), space (b) and pin pitch (c) ratios for Sumitomo 6300H material.

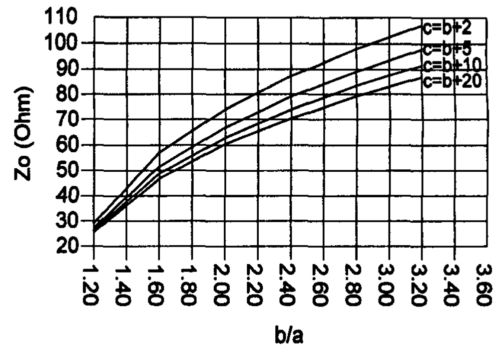

Fig. 4. Characteristic impedance results for ECPWFG [9]. These reults can be used to optimize the design of the improved package lead frame.

This improvement is accomplished in the proposed "modified SSOP8" design shown in Fig. 5. Pins 1-3 and 6-8 form a ECPWFG structure with finite ground plane. A 50Ω characteristic impedance is maintained to the bond-wire interface, by modifying the lead frame dimension as the signal transitions from the PC board into the plastic, and then within the plastic as the signal approaches the bonding pad. The Classic SSOP8 pin has flatted heads on the ends of the lead frame leads that are embedded in the plastic body. This provides mechanical stability for the leads so that they can withstand some pull tension in placement and temperature cycling on a PC board. Unfortunately, this leads to a significant parasitic capacitance at the end of the lead frame, contributing to the low-frequency resonance.

The Modified SSOP8 presented in Fig. 5 has the curves of the lead frame embedded in the plastic, and performs the same function as the hooks in the classic SSOP8 pin, but minimizes the impedance discontinuity. As a result, the mechanical stability of the modified design is comparable to that of the classic design, while exhibiting enhanced microwave performance. In addition, the improved electrical design of the package maintains a 50Ω impedance to the bond-wire interface

Fig. 6 plots the HFSS simulated response of the improved package configuration, where the useful range has been extended to nearly 10 GHz. In comparison to the simulated results of Fig. 3, the insertion loss S_{72} has been improved to be less than 1 dB at 10 GHz, and the isolation has been improved to better than 11 dB up to 20 GHz. This improvement is attributed to the redesign of the lead frame to minimize the impedance discontinuities at each transition. This lead-frame design is potentially useful to signal bandwidths into the X-band region of operation, and can be applied to a wide variety of high-frequency circuits.

The isolation improves because of the close coupling of the electric fields on the signal line to the grounds on either side. Also, the ECPWFG configuration insures that the H field only encircles the signal line — since it is in an

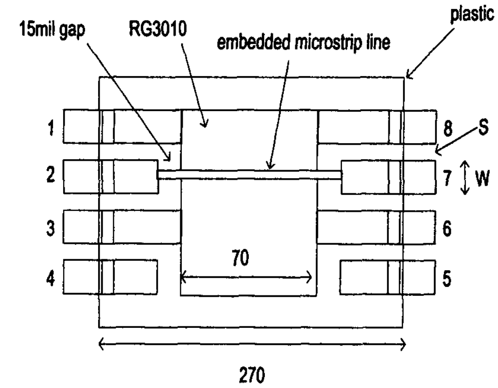

Fig. 5. Proposed modified SSOP8 pin with embedded 50Ω thru line. The lead pitch is varied to present a 50Ω characteristic impedance to the bond wire transition. All dimensions in mils.

even mode — thwarting any magnetic field loops encircling nearby conductors. This reduces the coupling between the adjacent signal pins in the new package configuration.

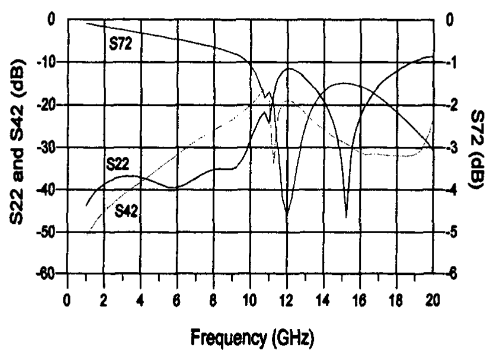

Fig. 6. Fig. 6: HFSS simulation of proposed modified SSOP8 ECPWFG package, showing improved performance to 10 GHz. The lower frequency resonances have been minimized by redesign of the lead frame transitions.

This improved lead frame approach can be extended to an even smaller sized package like the Miniature Shrink Small Outline Package (MSSOP). This design is smaller in size than the SSOP8, and has improved frequency response in the classic configuration. However, improvements in the lead frame design can extend the operating frequency range even farther. Fig. 7 illustrates the simulated return loss (greater than 20 dB to 14 GHz), insertion loss (less than 1dB to 15 GHz) and isolation (better than 15 dB to 15 GHz) for a body size of 165 x 110mil, pin width 15 mil, and pin width of 8.4 mil. The dielectric constant of the plastic is that of Sumitimo 6300H, $\epsilon_r = 3.6$. Once again, the lead frame has been redesigned using the ECPWFG configuration to assure a near 50Ω environment to the bond wire interface.

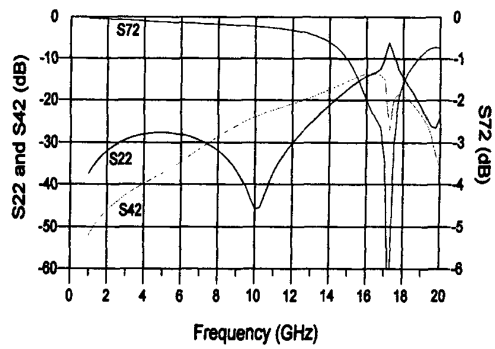

Fig. 7. Modified MSSOP8 package simulated response. In this case, the frequency range has been extended to 15 GHz.

III. Measured Performance of Improved SSOP-8 Packages

To judge the circuit response of an ECPWFG-based package, and the improvement achievable with these design techniques, an improved prototype SSOP-8 was constructed and measured, based on the techniques discussed in the previous Section. The encapsulant used was Smoothcast 321, a two part mixture that requires no special curing [10-11]. It has an ϵ_r of 2.8 and loss tangent of 0.068 at 5 GHz. The lead frame was machined from 4 mil copper and bent into a gull-wing configuration. The lead frame was then placed into a cavity and encapsulant applied and cured.

After trimming the lead frame, the package was mounted on a PC board of Rogers 4350 10 mil thick. A custom TRL calibration kit was developed and used to measure the package.

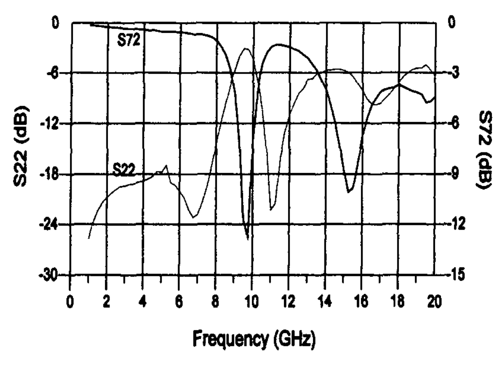

Fig. 8. Modified SSOP8 package measured response. Note that the input return loss and insertion loss have been improved compared to the standard configuration (Fig. 3).

There is an impressive improvement over the traditional SSOP8 through the use of the improved package, which we attribute to the modified lead frame design. In particular, note that the first resonance of S_{72} has been increased from

6 GHz (Fig. 3) to approximately 10 GHz. In addition, the return loss of the improved package is better than 18 dB to almost 8 GHz. These improvements could be extended to even higher frequencies in the MSSOP8 package, and could be applied to any traditional plastic package medium.

IV. Conclusions

An improved design methodology has been presented for the optimization of the microwave performance of standard RFIC plastic packages. It was demonstrated that acceptable loss and isolation can be achieved at frequencies up to 15 GHz through appropriate re-design of the lead frame. An experimental version of these techniques was constructed, which demonstrated a significant improvement in the performance of the SSOP8 package, although the techniques are applicable to other packages as well. These results illustrate the potential for low-cost implementation of RFICs well into the X-band region of operation.

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