RF-Microwave Multi-Layer Integrated Passives using Fully Organic System on Package(SOP) Technology

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***Abstract* - This paper presents high-density, fully organic multi-layer interconnects and integrated passives for RF and microwave System on Package(SOP) development. The components developed in this technology include novel CPW-microstrip transitions, high Q passives, as well as a planar antenna on a package. High Q passives, designed to be implemented using the featured CPW-microstrip transitions in this organic multi-layer technology, demonstrate the feasibility of implementing SOP technology for RF and microwave applications. This technology also employs a lifted slot antenna with vertical feed to reduce loss at the feeding point and to minimize pattern distortion.**

I. INTRODUCTION

A fully organic multi-layer multi-chip module process is a potential technology of choice for the next generation wireless communication system implementation. Digital communications have made major advancements using organic material taking advantage of low cost fabrication[1]. In order to support advancements in IC technologies, packaging and interconnection methods that promote integration is vital. As frequency increases, the high degree of interconnection at the chip level must continue up through the packaging level[2]. Multi-layer ceramic technology[3]-[4], as well as Si have had major advancements in this area.

Passive development is extremely important in terms of performance, compactness and cost advantages; which result from a high level of integration[5]-[6]. This paper addresses that development by focusing on transmission lines, inductors, and antennas. The multi-layer technology presented here increases the performance and frequency range just as 3-D Si MMIC technology[7]. A hybrid microstrip and waveguide interconnect scheme with a via bridge is presented here, where an insertion loss of .52dB/in and return loss of 15dB is achieved up to 12GHz. The CPW-microstrip high-density interconnection scheme allows flexibility in circuit design, which results in the reduction in size of electronic devices while overcoming space restrictions[8]. The inductor Q presented here is as high as 115 at 5.4GHz. In this paper, results are presented for 2 and 3-turn simple inductors as well as a multi-layer cascade design for higher turn inductors. As the number of turns increase, the cascade design enhancement dramatically improves the self-resonant frequency. One of the major issues for developing SOP is how to integrate an antenna efficiently. Fabricating the antenna directly on the package has size advantages as well as reduced feeder loss. For the multi-layer organic (MLO) package process, a lifted slot antenna (LSA) with via feed is proposed. Slot antennas with CPW have been studied actively for microwave and mm-wave application since a slot radiator and feeds can be made on the same conductor plane [9], [10]. However unwanted slot modes at the feed point may increase feed loss and alter the radiation pattern. In this paper, by utilizing multi-layer structure and a vertical feed scheme, slot modes are reduced. The antenna has been designed at 5.8GHz and has gain of 3.7 dBI and bandwidth of 14%.

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II. Multi-layer Packaging Technology

A fully multi-layer organic(MLO) technology is used here. It consists of a double-sided FR-4 board; each laminated with two organic layers, 62.5μm. The substrate was fabricated using thin-film sequential build-up (SBU) on the organic laminates (300 mm x 300 mm) using metal-insulator-metal construction. The dielectric used was a photoimageable dry film epoxy ($\varepsilon_r = 3.72$, $\tan\delta = 0.026$). Microvias with 100μm diameter were used for the interconnection between the metal layers. Metallization consisted of electroless and electrolytic copper plating, and UV lithography was used for pattern definition. This fabrication process allows for controlled impedance and precise patterning on a low-cost, high-density platform, Fig. 1. This technology offers a significant advantage in terms of material and assembly costs over the hybrid ceramic-organic process [11,12]. Using this technology, we introduce high Q passives to be implemented using a hybrid interconnection scheme, as well as a lifted slot antenna implementation, Fig. 2.

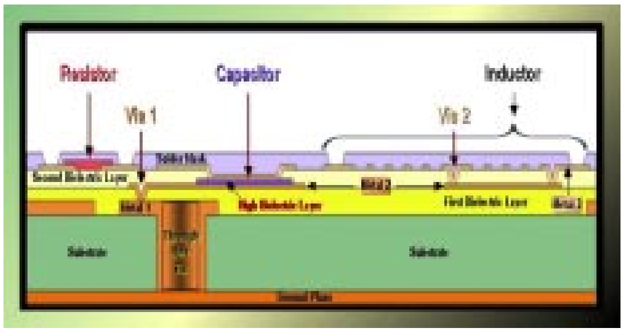

Fig. 1. Fully-organic multi-layer SOP technology.

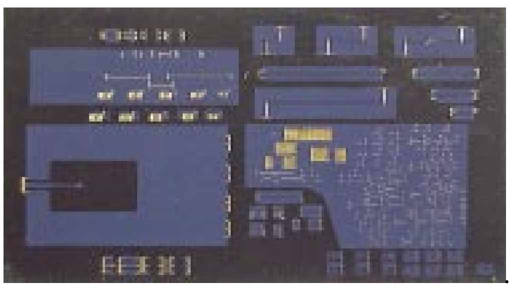

Fig. 2. Multi-layer organic test coupon showing, passives, LSA, and Ms-to-CPW interconnections.

III. Design Approaches

A. CPW-microstrip Interconnects

A hybrid CPW-microstrip interconnect scheme has been tested. The CPW line is fabricated on FR-4 board to allow MMICs or surface-mount packaged chips to be attached through flip-chip or soldering process, respectively. Both microstrips are established on the laminant layer through via transitioning from CPW to the microstrip signal lines. Embedded R, L, C can be fabricated in this microstrip configuration. This design was first tested without the via bridge shown in Fig 3. The return loss in this case is 11dB at 3GHz, while reaching 10dB at 12GHz. Via bridges were then added from the top metal to the CPW grounds surrounding the transition to increase the capacitive effects of the transition. The resulted return loss is better than 17dB at 3GHz, while reaching 15 dB at 12 GHz. The increase in performance can clearly be seen in Fig 4.

B. Multi-layer Inductors

One of the important factors of an inductor is the quality factor (Q). We, therefore, highlight results for extremely compact 2 and 3-turn inductors having a line width and gap of 4 mil. For the 2-turn inductor, the Q is 115 and the inductance, $L_{eff,}$ is 2.9nH at 5.4GHz, with a self-resonant frequency exceeding 10GHz, Fig. 6. The 3-turn inductor realizes a Q of 84 and a L_{eff} of 6.9nH at 2.9GHz, with a self-resonant frequency of 4.8Ghz. We also investigate achieving high Qs at the frequency range of interest by designing multi-layer cascade inductors, Fig 5. The top metal and bottom metal spiral separately and are connected at the center of the spiral. This design enhancement greatly affects the studied inductors with turns greater than 3 as the performance of these inductors greatly deteriorate at 1GHz and above. Since the top and bottom spiral are overlapped and strongly coupled, this enhancement allows the inductor to perform in the frequency of interest by increasing its self-resonant frequency, while yielding an impressive Q and L_{eff}. Fig. 7 shows that the 6-turn cascade inductor yields a Q of 48 and L_{eff} of 18nH at 1.4GHz, while increasing it's frequency of operation to 2.55GHz from approximately 1.4GHz in the simple case. Also, the 4-turn cascade inductor yields a Q of 66 and L_{eff} of 8.5 at 2.3GHz, which greatly exceeds the performance of the simple 4-turn inductor as well.

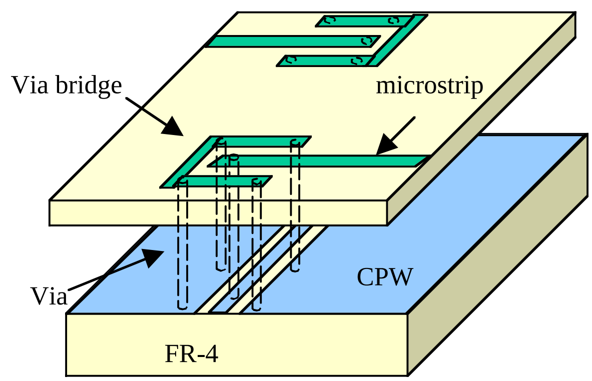

Fig. 3. CPW-microstrip transition with via bridge.

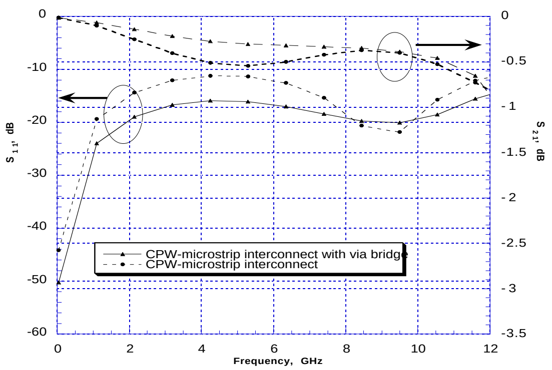

Fig. 4. Return and insertion loss of CPW-microstrip transitions with and without via bridge.

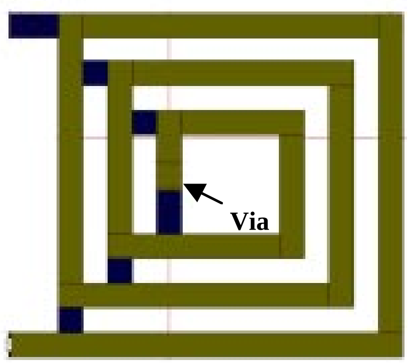

Fig. 5. 6-turn multi-layer cascade inductor.

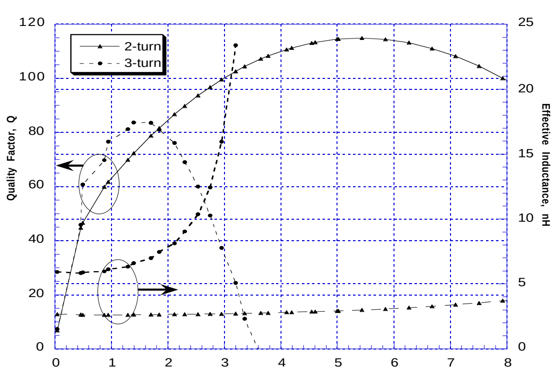

Fig. 6. Q and effective inductance of simple 2 and 3 turn spiral inductors.

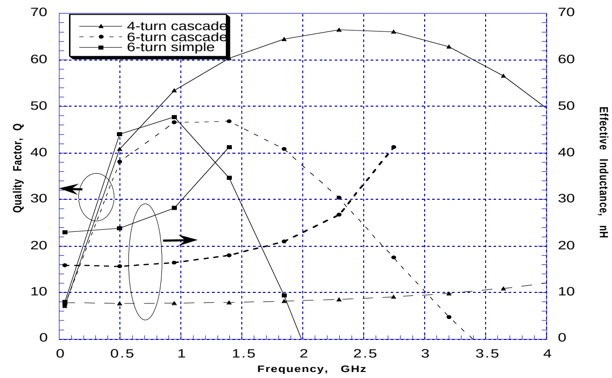

Fig. 7. Q and effective inductance of 4, 6 turn cascade and simple 6-turn inductors.

C. *Lifted Slot Antenna*

The configuration of the lifted slot antenna (LSA) is shown in Fig. 8. This design has been proposed due to the high loss and thin dielectric make-up of the MLO technology. The inner conductor patch is located on the top metal and the ground plane is at the bottom layer. LSA is similar to the traditional slot antennas except for the feed. In this design, to avoid the unwanted slot modes that may occur at the junction between the slot radiator and CPW feed, the via is used for feeding the patch on the top layer and embedded CPW transmission line. The location of the via connection and width of the microstrip line were properly selected to get impedance matching between the radiator and the feed. The antenna structure has been optimized at 5.8 GHz using IE3D and the return loss and radiation patterns are shown in Fig. 9 and Fig. 10, respectively.

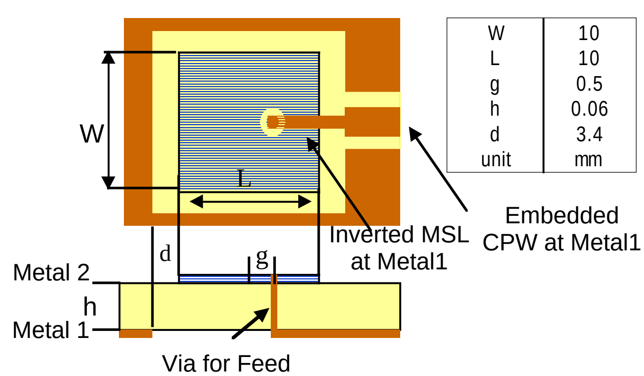

Fig. 8 Lifted Slot Antenna

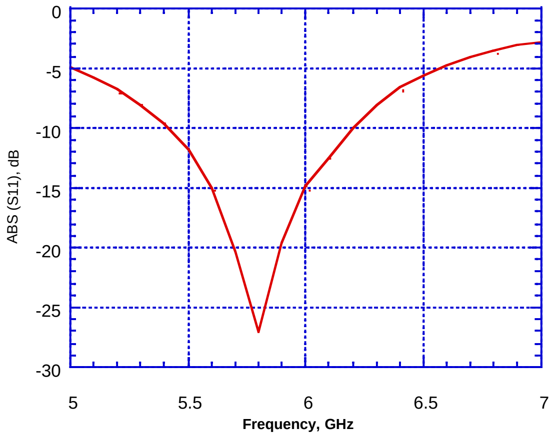

Fig. 9 Return loss of LSA

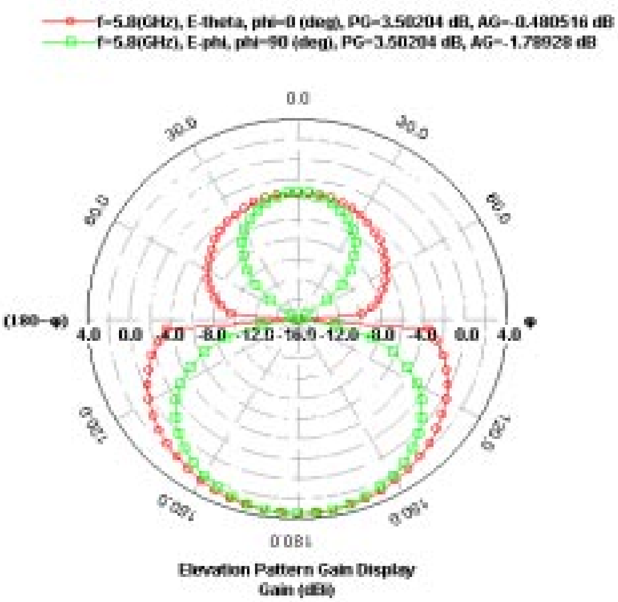

Fig. 10 Radiation Patterns of LSA

IV. Conclusion

We present passive development building blocks in a multi-layer organic-based packaging environment. A compact interconnect architecture employing a hybrid topology demonstrates applicability to 12GHz. Planar spiral inductors with Q factor of 115 at 5.4 GHz are presented, as well as multi-layer cascade inductors, which enhance the self-resonant frequency. Finally, a lifted slot antenna (LSA) has been successfully designed for 5.8 GHz. We demonstrate feasibility of using fully-organic multi-layer technology as a cost effective, high density RF/microwave packaging solution.

ACKNOWLEDGEMENT

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