Design of Multilayer Spiral Inductor Resonator Filter and Diplexer for System-In-a-Package

Gye-An Lee[1], Mohamed Megahed[2], and Franco De Flaviis[1].

[1] Department of Electrical and Computer Engineering University of California, Irvine
Irvine, CA, 92697, USA

[2] Skyworks Solution, Inc.
5221 California Drive, Irvine, CA 92612, USA

Abstract – **Compact L-shape multilayer spiral inductor resonator filter and diplexer using inductor type resonator are proposed. The design is based on the self-resonant frequency of the spiral inductors and electromagnetic coupling between the resonators. The filter is built and measurement results show good agreement with the simulation data. Multilayer structure can be used to significantly reduce the footprint and enhance the electromagnetic coupling effects between the resonators. The center frequency and bandwidth of the inductor resonator filter can be directly optimized from the physical arrangement of resonators. Finally, this new filter topology is applied to the design of a diplexer.**

I. INTRODUCTION

Recent advances in integration technology and device performance paved the way for higher level of System integration In a Package (SIP) [1]. Recent wireless and mobile communication systems use miniature Radio Frequency (RF) module design technologies to satisfy low-cost and compact size requirements. Theses requirements are critical for some specific application such as filter, diplexer and coupler, which occupy large real estate of complete mobile communication system. However, they need large real state area in mobile systems. The System-In-Package (SIP) technology not only provides interconnects to both digital and RF circuits, but also includes a unique feature of building integrated passive components. Most of today embedded passives in SIP are made on Low Temperature Co-fired Ceramics (LTCC) technology, which eliminates Surface Mount Technology (SMT) and reduces the size of the filter [2]. While LTCC filter can reduce the lateral size due to relatively high dielectric constant, it may not represent the most economical solution. In order to solve these problems, an inductor resonator filter based on the self-resonance frequency of spiral inductor was proposed to create small bandpass filter in a package [3]. With multilayer technology, broadside coupling can be used to enhance the coupling effects among the resonators. This multilayer technology can be used to reduce the size of the inductor resonator filter. In addition, arbitrary arrangement for the resonators can be achieved due to enhanced coupling mechanism.

In this paper, we present new multilayer arbitrary shape inductor resonator filter using inductor type resonators without any external component. Proposed multilayer inductor resonator filters are designed based on low-cost laminate substrate. Typical design rules for laminate substrate technology are used in the proposed filter and diplexer for SIP. Design and analysis of the filter performance will be presented. Finally, diplexer based on the proposed multilayer spiral inductor resonator filter is designed to defenestrate the other application.

II. MULTILAYER SPIRAL INDUCTOR RESONATOR FILTER

The one-layer inductor resonator filters use edge-coupled resonators to achieve electromagnetic coupling among resonators [3]. However, with multilevel technology, broadside coupling can be used to enhance the coupling among the resonators, as well as decreases the size of the inductor resonator filter. The broadside coupling can be achieved by overlapped metal area using multilayer structure. The broadside coupling can be optimized with proper overlap structure. As overlap area is increased, the coupling effect is also increased. In addition, arbitrary arrangement for the resonators can be done due to the coupling mechanism used in this filter design.

II. A. L-shape spiral resonator filter

The cross-sectional view of typical package laminate substrate layers and the top view of two-layer L-shape spiral resonators filter is shown in Fig. 1. The electromagnetic

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coupling between resonators in L-shape multilayer filter is enhanced due to the broadside coupling compared to the edge coupled one-layer filter. The multilayer bandpass filter using inductor type resonators has the following dimensions, resonator area 1740 μm x 1740 μm with track width and space of 60 μm. The dimensions and material of multilayer inductor resonator filter were based on typical package substrate characteristics. The newly developed inductor resonator bandpass filters can be used to effectively use the available space on package substrate using an arbitrary shape bandpass filter. The filter layout can be optimized based on the available real state in L, T, and I configurations. For example, L-shape bandpass filter is optimum if placed near the corner of the package substrate. The arrangement of inductor type resonator filters is flexible and can be optimized for the available real state, on one or two metal layers, to meet specific center frequency and bandwidth.

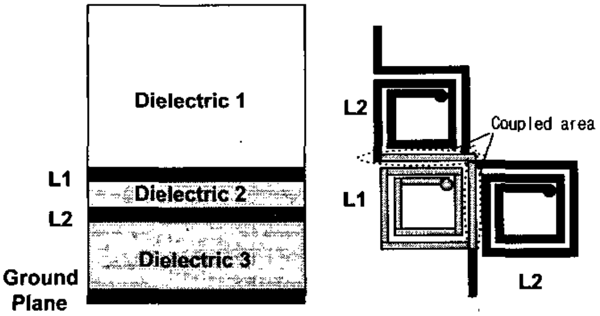
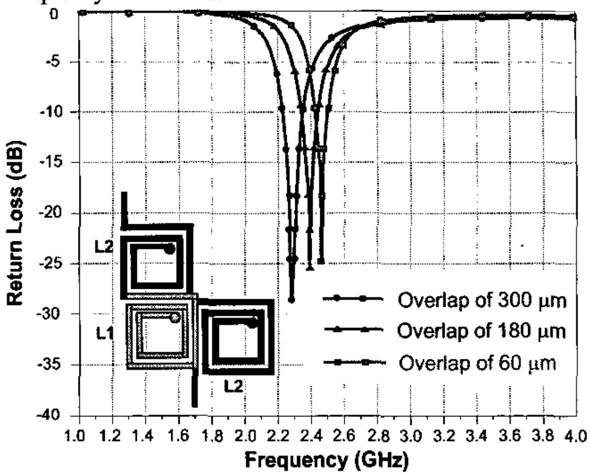


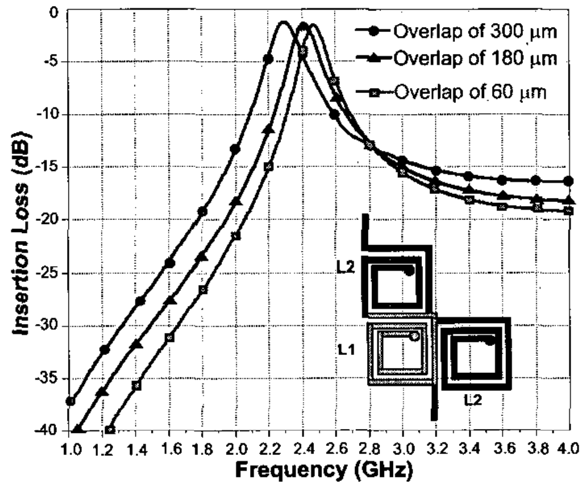
Fig. 1 Cross-section and top view for L-shape bandpass filter using two-layer.

II. B. Multilayer spiral resonator filter

Multilayer structure can be used to significantly reduce the footprint of the filter and enhance the electromagnetic coupling effects between the resonators. The center frequency and bandwidth variations with different multilayer structure configurations are simulated using 3-D electromagnetic simulator, HFSS. The return and insertion loss for the multilayer L-shaped spiral inductor resonator filters are shown in Fig. 2. Three different configurations are simulated. The resonator dimensions and aspect ratios are the same for all three configurations. However, the overlap between the resonators segments located on layer 1 and layer 2 are changed. The spiral inductor resonator segments overlap changes from 300 μm to 60 μm. The 300 μm overlapped inductor resonator filter case has larger bandwidth, and equals to 195 MHz, compared to 180 μm structure, 170 MHz, and 60 μm case, 150 MHz, cases. However, the center frequency of the 300 μm case has the lowest center frequency, and equals to 2.27 GHz, while the center frequency for 180 μm and 60 μm cases equal to 2.4 GHz and 2.47 GHz, respectively. The center frequency of multilayer filter with different overlap changes due to the variation of mutual inductance and loading effect from the increase in couplings between resonators. The increases in the mutual inductance between the resonators enhance the self-inductance of each resonator resulting in increasing the effective inductance of each resonator. The coupling effects between resonators can be modeled by cascading an electrical line length and the mutual coupling. These mutual inductance and loading effects increase electrical line lengths of the resonators and shift the resonance frequency downward.



(a)



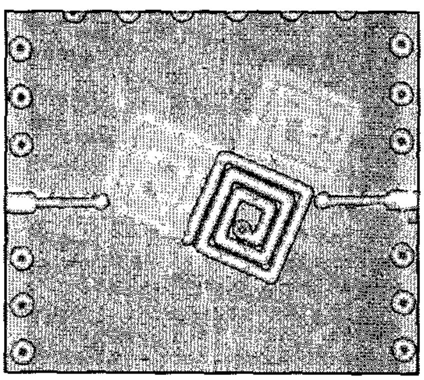
(b)

Fig. 2 (a) Return and (b) Insertion losses for 300 μm, 180 μm, 60 μm overlap distance of coupled multilayer filters.

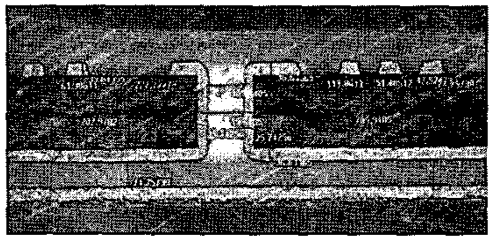
These results in decreasing the center frequency of the spiral inductor resonator filter. On the other hand, stronger electromagnetic coupling between the resonators results in larger bandwidth of the filter, as expected. Therefore, the center frequency and bandwidth of the arbitrary shape spiral inductor resonator filters can be optimized using proper multilayer configurations and electromagnetic coupling.

III. MEASUREMENT RESULTS

Fig. 3 (a) and (b) show the top view and cross-sectional view of a fabricated inductor resonator filter on four layers laminate substrate, respectively. The filter is located on metal layer. The ground layer is 200 μm apart from the resonators filter layer. The filter is connected to ground layer using vias. Probing pads are included for 2-ports microwave measurement. The bandpass filer is built on typical package laminate substrates dimension and materials, which was available at the time of the design. The characteristics of the materials are as follows, core layer height of 200 μm, ε_r of 4.2, and substrate loss of tan $\delta = 0.009$, dielectric layer 1 height of 50 μm, ε_r of 3.4, and substrate loss of tan $\delta = 0.015$, and molding layer height of 900 μm and ε_r of 4.3. The newly developed multilayer L-shape bandpass filter consists of a lateral area of 8.5 mm^2, metal width of 180 μm, metal thickness of 27 μm, and metal space of 60 μm. The fabricated filter is measured using HP 8510C Network Analyzer and Universal Test Fixture. Standard short, open, thru are fabricated on the laminate substrate. A standard TRL-method [4], using the load from the Universal Test Fixture calibration kit, is performed.



(a)



(b)

Fig. 3 (a) Top and (b) Cross section views for the fabricated L-shape inductor resonator filter on laminate substrate.

The measured insertion and return losses are shown in Fig. 4. The insertion loss in the passband and return loss of the measured L-shape inductor resonator filter equal to 1.8 dB and 14 dB, respectively. The center frequency of the passband equals to 2.4 GHz. The measured multilayer L-shape bandpass filter was fabricated based on the available laminate substrate technology. These results show enhanced coupling effects increase the performance of the spiral inductor bandpass filer. Newly developed spiral inductor resonators can be used to implement compact filter even on relatively low dielectric constant material.

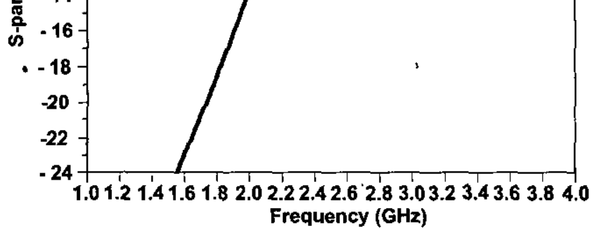


Fig. 4 S-parameters for measured L-shape inductor resonator bandpass filter.

IV. DIPLEXER DESIGN

The diplexer designed in this section is based on the circuit topology of L-shape multilayer spiral inductor resonator. The two passbands of the desired diplexer are centered at 900 MHz and 1.8 GHz for exist wireless communication application. The bandwidths for both bands are 60 MHz and 90 MHz, respectively. The passband response of L-shape spiral inductor resonator filter, which has low self-resonance frequency, is designed at 900 MHz for low-frequency channel. Another filter with similar circuit structure is designed at 1.8 GHz for high-frequency channel application. The center frequency and bandwidth variations with different multilayer filter structures can be optimized with optimized overlap area. Newly developed diplexer using two L-shape spiral inductor filters is simulated using 3-D electromagnetic simulator, HFSS.

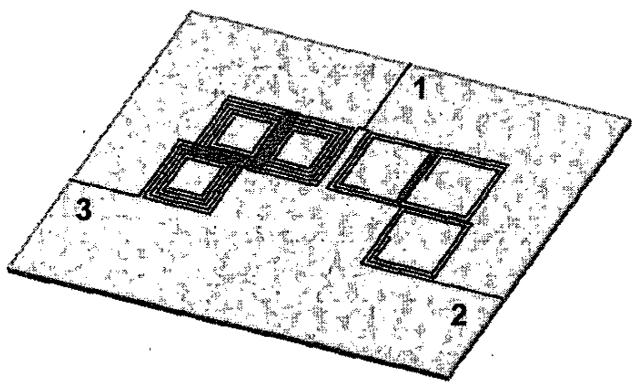


Fig. 5 The layout of diplexer with tow L-shape spiral inductor resonator filters.

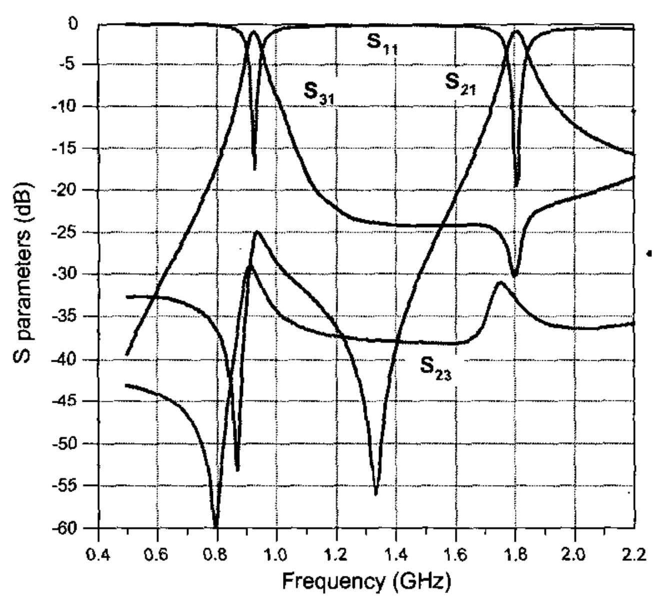


Fig. 6 S-parameter results of diplexer with two L-shape spiral inductor resonator filters.

The circuit layout of diplexer is shown in Fig. 5. The newly developed diplexer with tow multilayer L-shape bandpass filters consists of a lateral area of 8.5 mm x 4 mm, metal width of 180 μm, metal thickness of 27 μm, and metal space of 60 μm. The L-shape filter, for high frequency and low frequency channel, has 2.5 and 5 turn numbers, respectively. The diplexer is formed by connecting these two filters at the input port. Fig. 6 (a) depicts the response of the designed diplexer. The insertion losses are about 1.38 dB and the return losses are greater than 17 dB for both bands. The rejection of the other channel's signal is increased to be more than 23 dB because one of the zero of each channel filter has been tuned to be at the center frequency of the other channel.

V. CONCLUSION

A new multilayer L-shape inductor resonator filter and diplexer are presented. The design can achieve compact structure, even on low cost relatively low dielectric constant material. The design is based on the self-resonant frequency of the spiral inductors and electromagnetic coupling effects between resonators. The measured results show good agreement with simulation result. The compactness of newly developed bandpass filter and diplexer makes the design and integration of passive circuits attractive for further development and applications in System-In-a-Package.

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