Development of Integrated Three Dimensional Bluetooth Image Reject Filter

A. Sutono, J. Laskar, W.R. Smith

Packaging Research Center
School of Electrical and Computer Engineering
Georgia Institute of Technology
Atlanta, GA 30332-0250

National Semiconductor Corp.
11 Studebaker
Irvine, CA 92618

ABSTRACT

We present the design and implementation of an S-band compact planar integrated filter integrated in a multi-layer ceramic substrate. The center frequency of the 3.8 mm x 2.4 mm x 0.5 mm front end image reject filter is 2.4 GHz, suitable for use in a Bluetooth wireless LAN transceiver system. Measurement results show 3 dB insertion loss and 22 dB return loss at the center frequency.

INTRODUCTION

Passive components occupy a significant fraction of the total die real estate in a Monolithic Microwave Integrated Circuit (MMIC) and are an important factor that determine their performance [1]. On-board embedded passives allow a higher level of integration in the development of a wireless transceiver system. There is considerable potential for saving the assembly time and cost by reducing the MMIC real estate and the amount of discrete elements used in the module. Therefore, there is a need to establish a design methodology to implement compact high-performance embedded passives.

A multi-layer Ceramic-Based Multi-Chip-Module (MCM-C) technology is capable of embedding passive elements, such as transmission lines, resistors, inductors and capacitors [2]. It has been demonstrated in [3, 4] that three-dimensional embedded inductors can achieve a better Q performance than those implemented on-chip. The multi-layer design concept in [3] and [4] can be extended to other components as well such as filters, couplers and balance-unbalance (balun) devices. An on-board integrated ceramic filter [5] offers an alternative implementation on-chip active filtering [6] with trade-off in terms of size, loss performance, power consumption and dynamic range. We design and demonstrate a planar S-band embedded front-end image reject filter. This filter is implemented in a three-dimensional stripline lumped-element topology on a multi-layer Low Temperature Co-fired Ceramic (LTCC) substrate which is the designated board technology for the Bluetooth wireless LAN system [7]. The LTCC process utilizes screen printing as well as low-loss stacked via processes and high conductivity metalization useful for high frequency applications. The substrate material is the 3.6 mil thick 951 AT stackable ceramic tape from Dupont. The metalization of the buried layers is a 7 µm thick silver alloy and the surface metalization can be 9 µm silver-palladium alloy or 7 µm wire bondable gold.

FILTER TOPOLOGY

The specification derived from a system level investigation includes the center frequency of 2.45 GHz with a maximum insertion loss of 3dB and return loss of 20 dB or better. In addition, the attenuation at the image frequency of 2.175 GHz is required to be 15 dB or better. Figure 1 shows the three dimensional diagram of the filter depicting the layer-by-layer layout view.
The filter consists of two parallel LC resonators and three series capacitors \( C_b, C_s, \) and \( C_o \) as illustrated in the top figure in Figure 2. A cross sectional layout view along AA' in Figure 1 for each layer is illustrated in the bottom figure in Figure 2.

The input and output capacitors \( C_i \) and \( C_o \) are used for impedance matching while \( C_s \) is used for setting the trap frequency. This schematic is implemented in stripline topology where all the components are buried between two ground planes separated by six layers of dielectric (21.6 mils). In Figure 1, layer 6 is designated as the top most metalization layer and is used as the top ground plane of the stripline filter with ground-signal-ground coplanar waveguide measurement pads.

![Figure 1. Three dimensional layout view of the filter.](image)

One of the inductors, \( L_1 \), that composes the LC resonator as well as the top plates of \( C_i \) and \( C_o \) are laid out on layer 4 which is two layer down from the top metalization layer 6. Figure 1 shows where \( L_1 \) is laid out as a U-shaped strip and the top plates of \( C_i \) and \( C_o \). The other strip used to realize \( L_2 \) depicted in Figures 1 and 2 is laid out on layer 3 right beneath \( L_1 \) to produce the required 0.33 nH mutual coupling \( M \). The inductor strips \( L_1 \) and \( L_2 \) are grounded through a via connection to the top and bottom stripline ground planes on layer 6 and 0, respectively as shown in Figure 1. The bottom plates of \( C_i \) and \( C_o \) which are also the top plates of \( C_s \) are fabricated on layer 3. The middle series 1.33 pF capacitor \( C_s \) is implemented as a series combination of two parallel plate capacitors as illustrated in Figure 2.

![Figure 2. Filter circuit schematic (top) and a cross sectional view along AA' in Figure 1 (bottom).](image)

Each capacitor is 2.66 pF implemented by two 1.33 pF capacitors in parallel as indicated by \( C_s \) in Figure 2. Therefore, the capacitor plates used to realize \( C_s \) are laid out on layer 3, 2 and 1 as indicated in Figures 1 and 2. Finally, the plates on layer 1 are also used to implement shunt capacitor \( C_R \) that composes the two LC resonators of the filter. Layer 0, which is a layer
below layer 1 where the top plate of \( C_R \) is laid out, is the bottom ground plane of the stripline which is also the bottom plate of \( C_R \).

**EXPERIMENTAL RESULTS**

Figure 3 shows the photograph of the actual filter with coplanar waveguide footprints for on-wafer measurement using coplanar waveguide probe and the top stripline ground plane. The overall size is 5.2 mm x 3 mm x 0.5 mm with the measurement pads and 3.8 mm x 2.4 mm x 0.5 mm without measurement pads.

![Figure 3. Photograph of the filter.](image)

Figures 4 and 5 show the measured data of the initial filter prototype superimposed with the electromagnetic simulation results using a commercial Method of Moments (MoM) simulator [8] and a custom simulator implementing the Partial Element Equivalent Circuit (PEEC) algorithm [9,10]. The PEEC simulator discretizes a structure into segments with each segment has a length of a tenth of a wavelength corresponding to the maximum frequency of interest. It then solves for the RLC matrices for each segment using quasi-static Maxwell equations. The custom simulator [10] optimized for multi-layer structures has some advantages in terms of simulation time and ease of interface to CAD tools such as Spice. As shown in Figure 4, the measurement and simulation results exhibit a good correlation.

![Figure 4. Measured and simulated return loss of the filter.](image)

The insertion loss of the filter at the center frequency of 2.4 GHz is 3 dB with the corresponding return loss and bandwidth of 22 dB and 270 MHz, respectively. Table 1 outlines the measured performance as compared to the specification. The 50 kHz shift in the center frequency is attributed to the additional parasitic mechanism at the transition from the stripline to
the coplanar waveguide measurement pads. It can be easily fixed by slightly shortening the non-overlapping portion of the inductor strips which yields smaller self inductance L. Appropriate amount of reduction of L not only corrects the center frequency, but also improves the insertion loss.

<table>
<thead>
<tr>
<th>Specification</th>
<th>Measurement</th>
</tr>
</thead>
<tbody>
<tr>
<td>Center Frequency (GHz)</td>
<td>2.45</td>
</tr>
<tr>
<td>Insertion loss (dB)</td>
<td>&lt;3</td>
</tr>
<tr>
<td>Return loss (dB)</td>
<td>&gt;20</td>
</tr>
<tr>
<td>Attenuation at image frequency (dB)</td>
<td>&gt;15</td>
</tr>
<tr>
<td></td>
<td>22</td>
</tr>
</tbody>
</table>

Table 1. Summary of the filter performance.

CONCLUSION

We have presented a compact design of a multi-layer embedded image reject filter suitable for the implementation of a highly integrated Bluetooth module. This development eliminates the need of a discrete filter and allows a higher integration leading to a further wireless module miniaturization. The filter meets all the specification with slight modification to correct the center frequency.

REFERENCES


