

The Hidden Component of High Speed Filter Design: The Footprint Influence

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Abstract

It is very intriguing to design passive filters in a very small package, in the frequency domain of 10 GHz and above. Modeling the device footprint and correctly incorporate the model in the design work to design passive filter is key to successfully manufacture surface mount filter components that perform as expected, once they are mounted to the printed circuit board. This requires accurate correlation to the filter model and the measured first article component. In this work we studied footprint and its influence in the final product. We developed filter design procedure using simulation software. We considered the impact of the parasitic of the input signal lines, printed circuit board's footprint parasitic, and filter's signal launch pad loss. We discussed an efficient way to design low pass passive filters in Ball Grid Array package; we optimized the design flow to manufacture filters. Then we designed and manufactured 12 GHz 9th order absorptive low pass Bessel filter, whose size is 2.0 mm X 7.1 mm. We compared the measured data of the fabricated filter with the simulation results. We discussed the use of Coaxial Measurement Modules, which contains the filter with optimized design footprint.

Key words: Low pass Bessel filter, Ball Grid Array, parasitic, footprint, 3dB bandwidth, printed circuit board.

Introduction:

In present day's ultra high speed data transmission system, passive component filter plays very important function to achieve high system performance, especially in frequency range of 10 GHz or higher. As precise filter performance can improve the system performance, any imperfection of any filter parameter can also severely diminish the system performance. Critical filter design is required to insure that all parameters of the filter are met at both ends of the system. Accurate 3 dB bandwidth, stable group delay along with forward and reverse return loss characteristics are important in designing high frequency passive filters.

For designing correct low pass filter (LPF) for ultra high speed applications, the designer should consider the influence of hidden parasitic. Parasitic could emerge from component's input output pads, printed circuit board's (PCB) parasitic, board's material loss, filter's launch pad loss along with system's bandwidth. Moreover, attributable to different measurement setups, the electrical loss and reflections from the filters and PCB footprints, PCB material and measurement cable generated loss could also cause the S-parameters to deviate from the ideal filter shape. Several research works have been done to study the footprint and parasitic influence. Device footprint has been studied by exploring parasitic in

the FET level and future device scaling path has been proposed [1]. QFN package devices were studied to eliminate footprint influence generated in the QFN package [2]. Parasitic capacitance and inductance has been measured for several different ball grid array (BGA) packaged Integrated Circuits [3]. High frequency characterization has been analyzed for Thin-Film redistribution layers for embedded wafer level BGA [4]. High frequency behavior was investigated for thermal cycling effect on BGA structure [5]. Chip scale package was examined for capacitance influence intended for high frequency characterization [6]. Efficient footprint pattern has been studied for Planar array and Dipole antenna design [7-9].

In this work, we specifically studied BGA package component for passive filter design. We studied the parasitic of a small packaged absorptive low pass bessel filter. We explored the parasitic capacitance and inductance from the package and board's footprint for high frequency signal transmission. We incorporated the capacitance and inductance from the package to design and manufacture absorptive low pass bessel filter having -3dB cut off frequency of 12 GHz. We compared the measured results of the filter to the simulation design. To the best of our knowledge, no analysis had been reported on utilizing footprint influence to design and

manufacture high frequency absorptive low pass bessell filter.

Simulation and Discussion:

In today's simulation rich design environment, a very challenging task is to have meaningful correlation between measured data of the manufactured device with parent simulation goals. More often than not design engineers fail to recognize the hidden influence associated with the device's footprint, resulting producing inferior device. While designing low pas filter, the design engineer must be aware of the undesired influence of the footprint and parasitic. Circuit simulation model needs to be optimized for these unwanted influences.

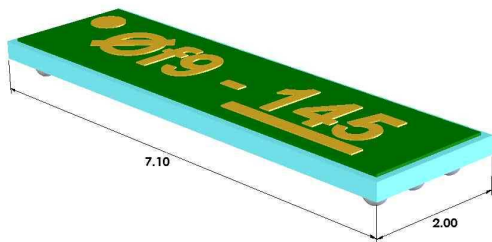


Fig 1a. Top view of TFT's 12 GHz LPF

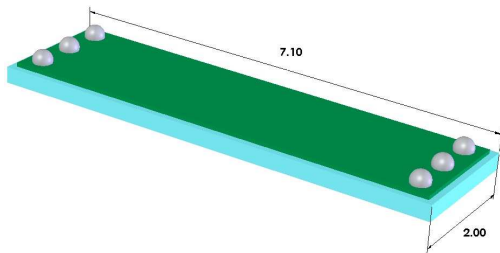


Fig 1b. Bottom view of TFT's 12 GHz LPF

We have identified several major sources for these undesired affects. One important source is the parasitic capacitance in between signal input paths. Figure 1a and 1b demonstrate TFT's 12 GHz absorptive low pass filter in BGA package. Package is designed for ground signal ground (GSG) configuration. There are three spheres at each of the input and output sides of the packaged device. Middle sphere in the input side carries input signal while middle sphere in the output side carries output signal. Outer 2 spheres at each side carry the ground path on the reverse side of the chip. Size of each sphere's diameter is 0.71 mm and the distance between each sphere is 0.635 mm. These solder spheres of the package introduce parasitic capacitance in between each of them and also to the filter component. Furthermore, as the frequency changes, the parasitic capacitance changes and it influences the filter characterization.

Another major source of undesired influence is the printed circuit board (PCB), where the filters get mounted. PCB's footprint needs to be optimized for the input and output spheres of the package. Ground plane of the PCB needs to be optimized so it does not introduce further parasitic to the filter. Moreover, signal experiences loss in the launch pad while enters from PCB to the device. Addition to the signal's launch pad loss, PCB's material loss will increase the signal loss while traveling to the device.

Another undesired parameter is the electromagnetic (EM) effects including coupling and parasitic among the filter elements. As the device package gets smaller, EM coupling between the closely placed elements increases, resulting reduction of the filter performance. For the satisfactory effort to incorporate these effects, filter designer must use 3-D planar electromagnetic software to accurately simulate the complex EM effects. Another parameter, that designer must be aware of, is the bandwidth of the system. The system bandwidth can reduce the filters desired bandwidth.

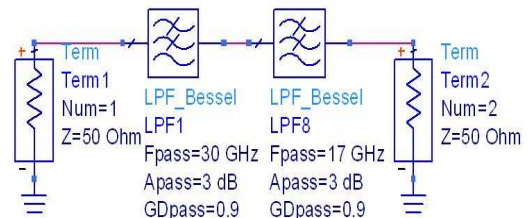


Fig 2a. Simulation model of 30 GHz and 17 GHz bessell filters together to generate 12 GHz low pass bessell filter

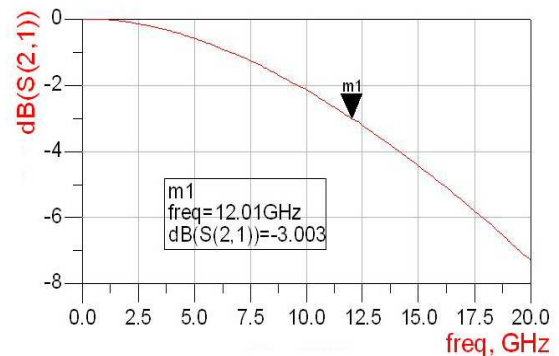


Fig 2b. S_{21} Parameter of designed 12 GHz LPF

We extensively studied these unwanted footprint influence. After manufacturing first article we have measured the time domain response as well as frequency domain response of the device. Investigating time domain response along with smith chart, we calculated the capacitance incorporated with input output pad and printed circuit board. Then we incorporated that to the filter design guide and

changed the filter model. We also incorporated the loss introduced by PCB. We detuned the filter design to accommodate these parameters. Using Advanced Design System's (ADS) momentum simulation engine, we utilized the electromagnetic coupling to improve the filter performance.

We also learned the bandwidth of the system and incorporated that to our filter model. We simulated a 30 GHz 5th order low pass bessel filter as the driving circuitry's bandwidth in series with 17 GHz 9th order low pass bessel filter to produced the targeted 9th order enhanced 12 GHz low pass absorptive bessel filter. Figure 2a illustrates the simulation model of the 9th order enhanced 12 GHz absorptive low pass bessel filter. Figure 2b shows the simulation results of the designed filter. The "enhanced" term describes an absorptive bessel filter that matches the insertion loss and a group delay characteristic of an ideal bessel filter, but provides significantly improved return loss characteristics.

Component fabrication and measured results:

Based on the excellent simulation work of 12 GHz LPF design, we fabricated the filter in a 2.0 mm X 7.1 mm BGA package. BGA package is very popular for low cost and easy handling. Figure 1a and 1b illustrate the fabricated filter's top and bottom view respectively. For measurement purpose, the filter was mounted on Rogers 4350 PCB. PCB along with the filter was placed in TFT's coaxial measurement module (CMM). Figure 3 illustrates the filter mounted in measurement module. CMM allows system design engineer to test the filter on the test bench. At a later time, the filter including the footprint can then be removed and directly transferred to the end system's board.

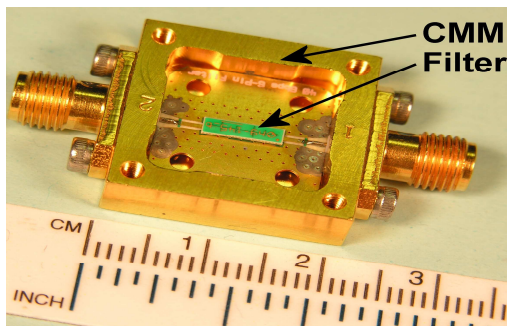


Fig 3. 12 GHz enhanced Bessel LPF mounted in Coaxial Measurement Module (CMM)

The measured data was compared with simulation results. Figure 4a, 4b, and 4c illustrate the insertion loss (S21) plot, forward return loss (S11) plot, and reverse return loss (S22) plots of the measured data and simulation result of the designed

filter respectively. In the plots, the red line corresponds to the simulation results and blue line corresponds to the measured results. As the S21 plot suggests, -3dB bandwidth of the fabricated part is 12.3 GHz, which is within 3% of the simulation results. All three plots of insertion loss and return loss demonstrate excellent correlation between designed and manufactured results of 9th order enhanced absorptive low pass bessel filter.

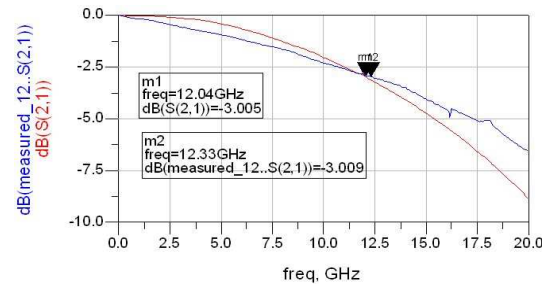


Fig4a. Insertion loss (S21) plot of simulated and measured 12 GHz LPF

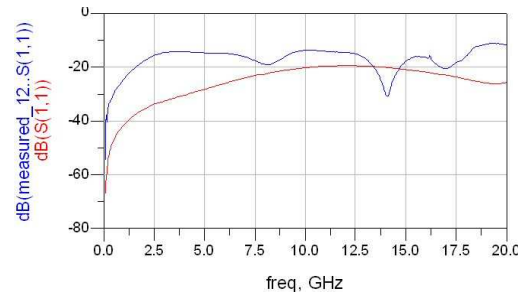


Fig4b. Forward return loss (S11) plot of simulated and measured 12 GHz LPF

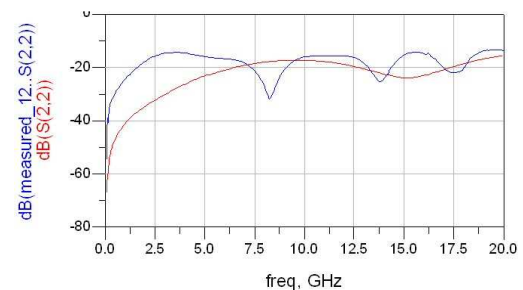


Fig4c. Reverse return loss (S22) plot of simulated and measured 12 GHz LPF

We used this filter to produce 3 level electrical duobinary signal for optical duobinary modulation format. We modeled an optical duobinary transmitter model in simulation environment. In the model, we used measured data of 12 GHz absorptive bessel LPF and drove optical modulator to generate three level duobinary electrical signal.

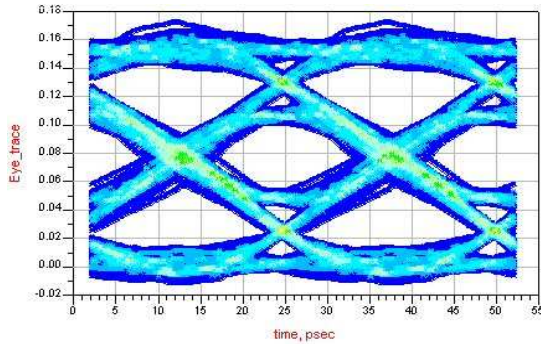


Fig5. Electrical Duobinary eye diagram produced by the fabricated 12 GHz Bessel LPF

Using simulation model, we generated eye diagram of 40 Gbp/s duobinary signal. Figure 5 illustrates the eye diagram of the duobinary signal generated with the enhanced 12 GHz absorptive low pass Bessel filter. The eye diagram represents excellent three level electrical duobinary signal.

Conclusion:

Continues growth of the Internet and multi portal communication has been pushing the data transmission system to higher speed. As the signal gets to the speed to 10 GHz and higher, component manufacturers need to be careful to accommodate the undesired affects presented by the footprint. The hidden footprint influence can severely diminish the performance of the component as well as resulting poor yield. It is very important for component design engineer to fully understand the influence presented by several sources of the footprint. In this work, we explored the footprint influence of the electronics component design. We studied the capacitance introduced by the low pass filters input output pads and printed circuit board. We investigated the complex electromagnetic coupling of closely placed filter elements. These hidden parasitic were incorporated to design and manufacture a 9th order 12 GHz enhanced low pass Bessel filter. Measured data was compared with simulation results, which shows excellent correlation between simulation and manufactured component. Finally we used the manufactured filter's measured data to obtain three level electrical duobinary signal for duobinary modulation format for 40 Gb/s optical duobinary transmission system.

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