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

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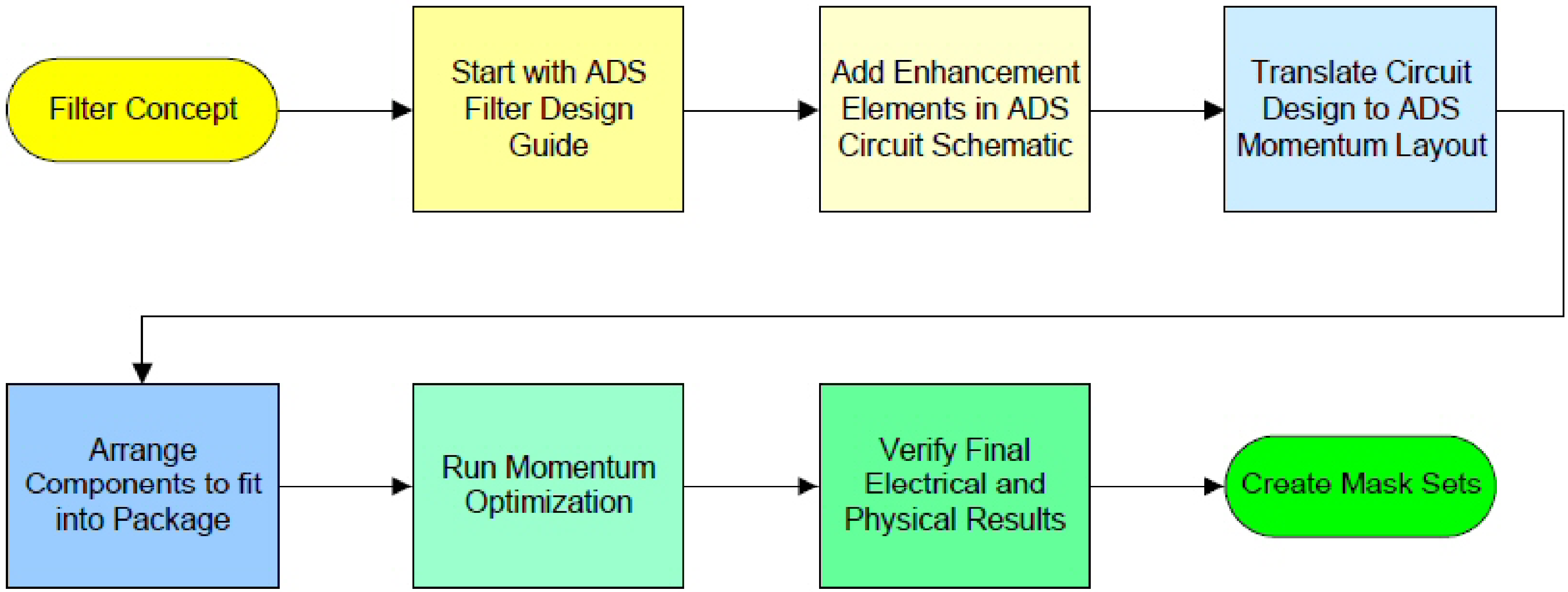
Contents:

- ***Motivation for the Work.***
- ***TFT Design and Manufacture Process of Absorptive Bessel Thomson Low Pass Filters.***
- ***Filter Footprint and It's Performance Influence.***
- ***Other Influences on Filter Performance.***
- ***"De-tuning" the Filter and Adding the Footprint Model.***
- ***Device Fabrication and Measurement Results***
- ***Summary and Conclusion***
- ***Future work***

Motivation For The Work:

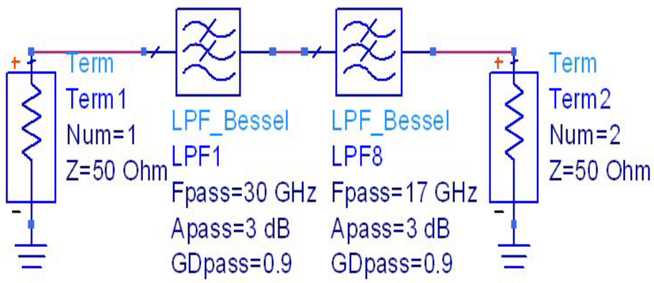
- **Today's multimedia communication pushes data rates toward 40 Gbps (and 100 Gbps in near future).**
- **Components need to be upgraded, by improved design, to support the higher data rates.**
- **As the frequency goes higher, component package size becomes very small and the tolerances and parasitics become very influential.**
- **The hidden parasitics and the package footprint's influence degrade the performance of the small device.**
- **Research is done to study the undesired footprint's impact.**
- **Footprint influence is incorporated into the device's design and fabrication to achieve manufactured components at high yields.**

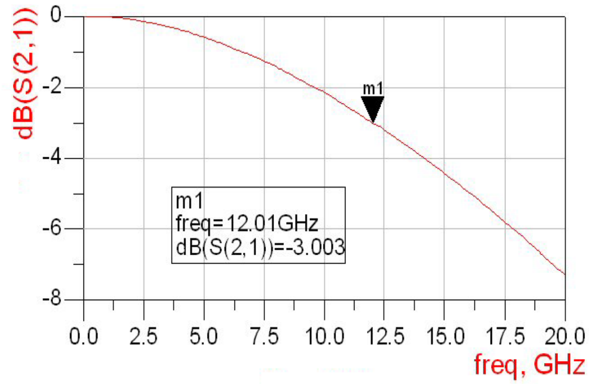
TFT Filter Design Process:

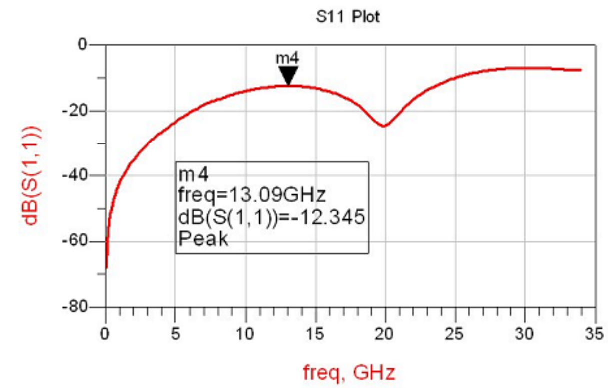


- **This flow enables TFT to engage OEM designers that are in need for custom surface-mountable filters.**
- **Starts with customer filter requirements formed into target specifications.**
- **TFT’s niche: Taking ideal filter functions, adding in absorption and increasing orders to arriving at custom, high performance filters that can be manufactured at high yields, low cost, and surface mountable.**

Design Process: Ideal Setup



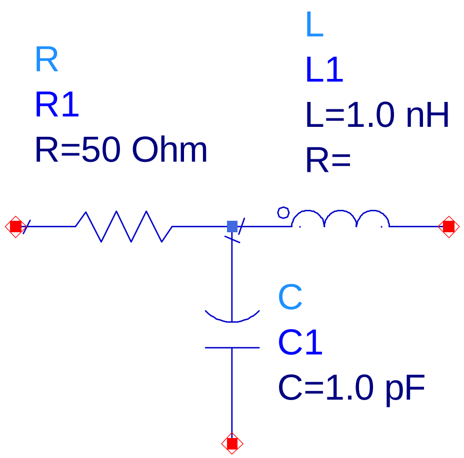




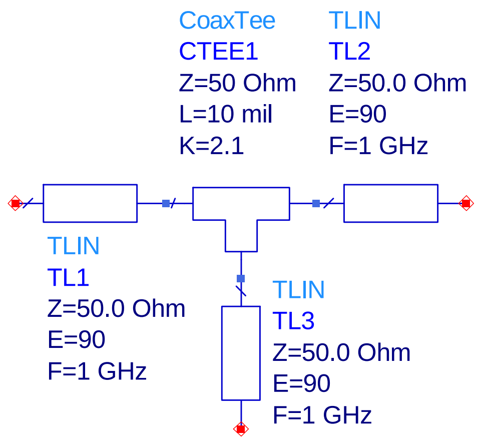
- Target "spec corners" are finalized between customer and TFT.
- Find the "Ideal Filter Cut-off":
  - Customer's bandwidth is defined and modeled in the ideal simulation.
  - The system bandwidth in series with an ideal filter will result in the low-pass filter's cut-off target.
  - The filter's "internals" can now be designed at the appropriate cut-off.
- Complete the ideal filter design until all target specifications are met.

Design Process: Ideal to Real

Ideal Elements:



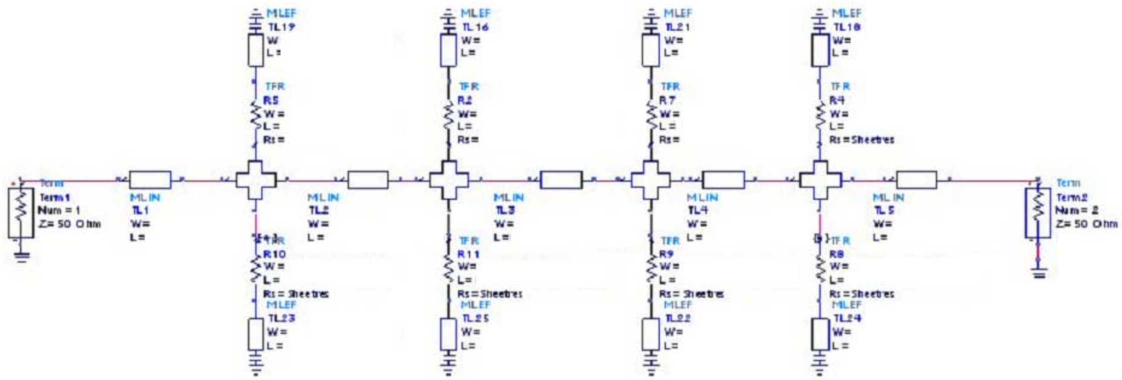
"Enhanced" Elements:



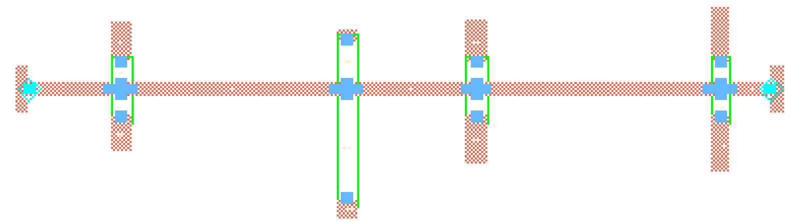
Set Materials & Goals:

- **Moving from the ideal to the Enhanced Elements allows the designer to "materialize" the design by defining the substrate, the material properties, and the geometry elements and their size and shape. Coupling effects are not included at this point.**
- **Goals are setup based on the target specification. This allows for optimization to be ran in the ADS simulation.**
- **Package size and geometry are given first considerations at this point.**

Design Process: Real to Lay-out



“Enhanced” Elements Circuit Layout



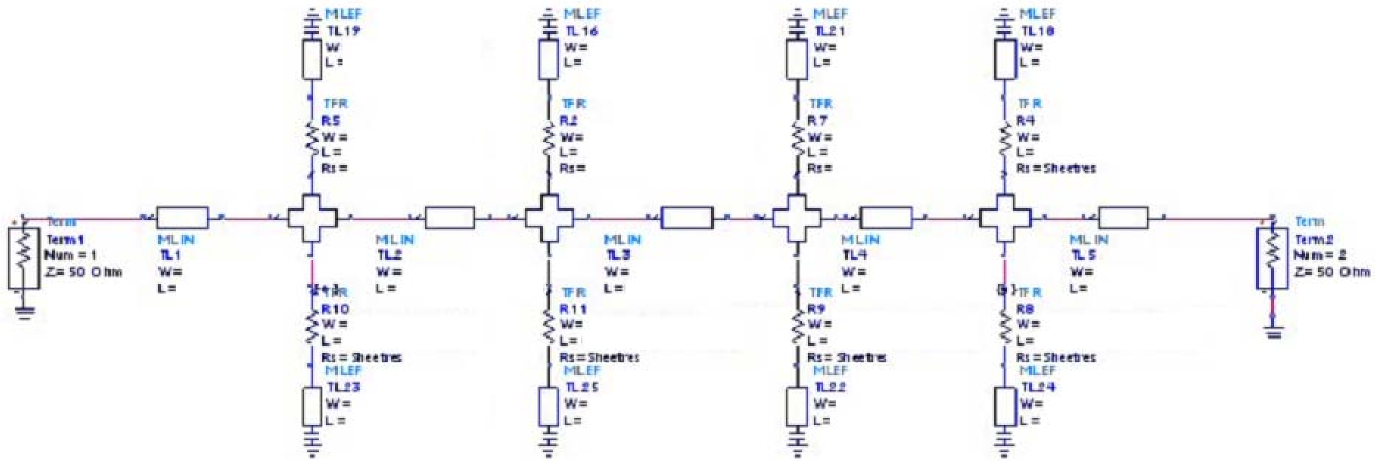
Momentum 2.5D Layout

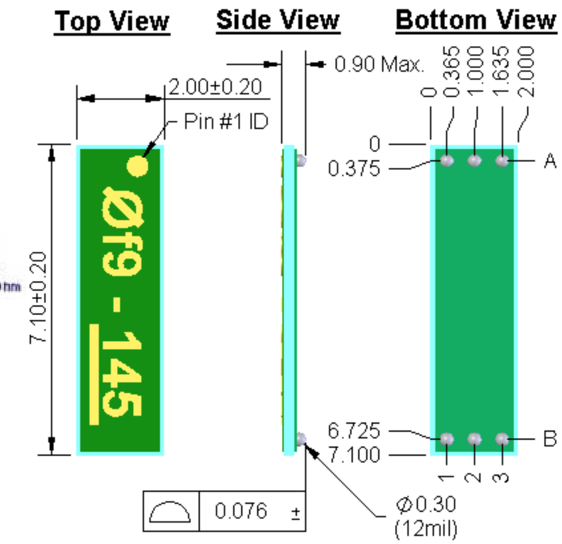
- After the “Enhanced Element” circuit lay-out has been optimized in ADS, the designer can then run yield and sensitivity analysis in order to:
  - Verify the validity of the design
  - Understand the material and process expectations
  - Establish specification tolerances vs. manufacturing yields.
- If specifications are satisfied and manufacturability is confirmed, the design is moved into the ADS Momentum simulator.
- Momentum optimization is ran for high level verification of the design.
- Package design is finalized for electrical, mechanical, and thermal.

This Study's Parameters:

- **This study was for a 40 Gbps optical communication system that used Duobinary modulation.**
- **The optimal cut-off for this system to produce the Duobinary electrical pattern was a 4th order 12 GHz Bessel low pass filter.**
- **For better system performance, the filter was desired to be absorptive to lower the return loss in the stop band.**
- **To achieve absorption, resistors were added in series to the capacitor stubs of the filters and additional orders were added to "push the filter back" so the Insertion Loss curve follows that of an ideal 4th order Bessel filter.**
- **Return loss of the filter is <-10 dB up to three times the Fc.**
- **Group delay of the filter is flat up to twice the Fc.**
- **9th order absorptive Bessel filter is manufactureable while maintaining the characteristics of 4th order ideal Bessel filter.**

Enhanced Elements and Package Considerations:

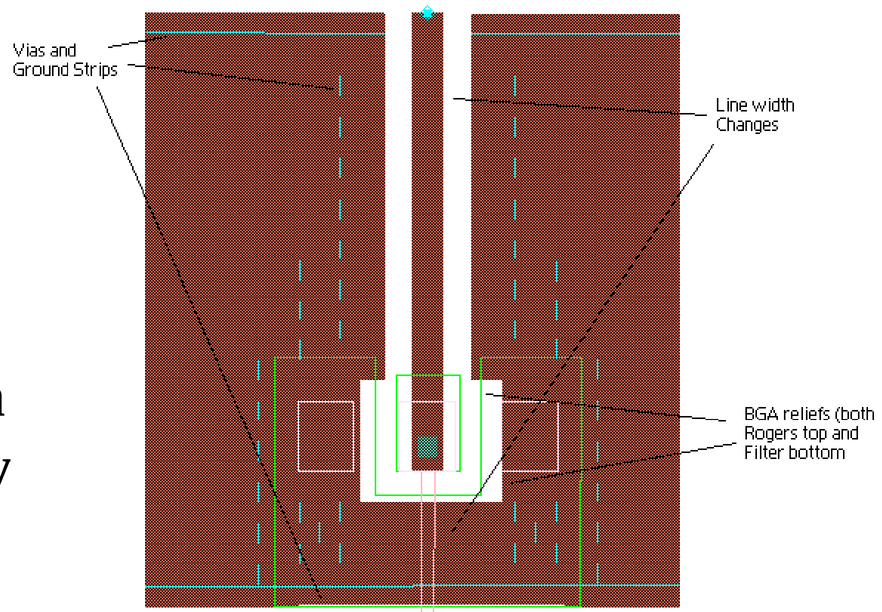


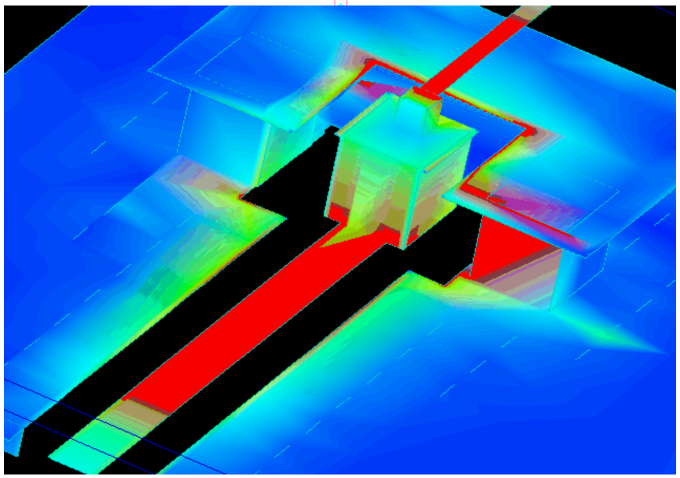


- For this study, TFT designers went with a 9th order absorptive Bessel LPF structure and optimized the design in the “Enhanced Element” model.
- Package consideration from the customer was for a BGA package for low cost and ease of handling considerations.
- From the geometries generated in the optimizer, the designers selected a Gnd-Signal-Gnd BGA configuration with 12mil spheres at a 25 mil pitch.
- To realize the filter for good Fab yields and ideal performance once mounted in the system’s PCB, the influence of parasitics must be understood.

Filter Footprint and It's Influence:

- Undesired footprint parasitics become an important phenomenon for small, high-speed devices, as it corrupts the component's desired function and performance.
- These footprint parasitics and launch transitions lower the cutoff frequency due to added loss and also degrades the Return Loss performance as well as other filter characteristics.
- Parasitic and footprint influences must be considered to fabricate filters with high yield and high performance.
- In this study, the modeling of the BGA footprint was realized and captured.

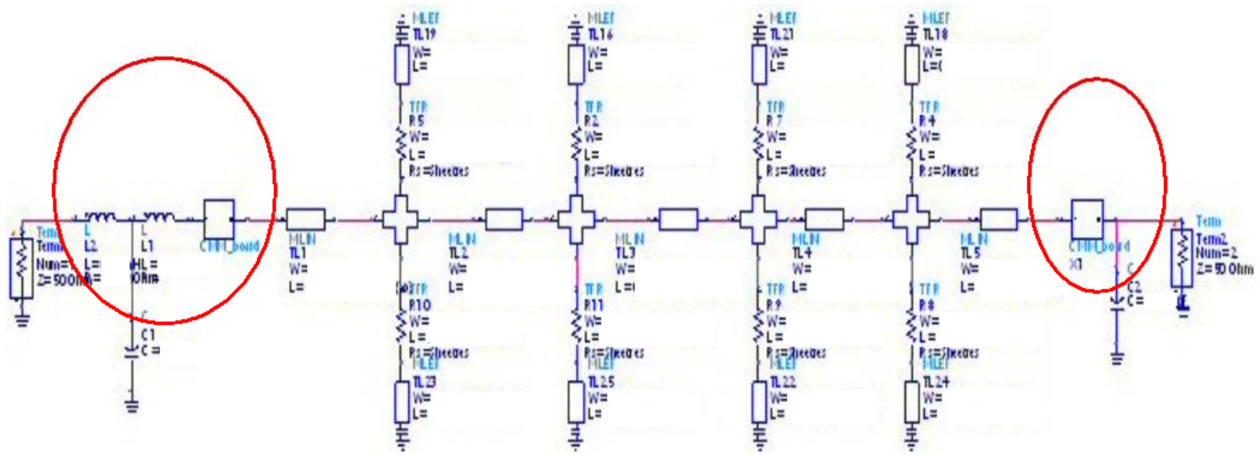




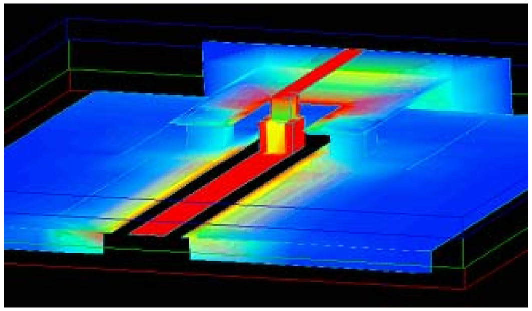
Other Influences on Performance:

- **Other import parasitic sources that compromise the filter's performance are:**
  - **The PCB's material construction and properties.**
  - **The layout configuration of the PCB leading into the mounting pads for the filter mount.**
  - **Transition from the PCB's mounting pads to the filter's I/O (Zo match).**
  - **Parasitic coupling between the filter elements.**
- **Ranking of these influences reveal that the Filter's footprint influence is the main contributor to performance degradation:**
  - **BGA footprint = 50%**
  - **Parasitic coupling in between filter elements = 25%**
  - **Signal launch pad loss = 10%**
  - **PCB loss = 10%**
  - **PCB material influence = 5%**

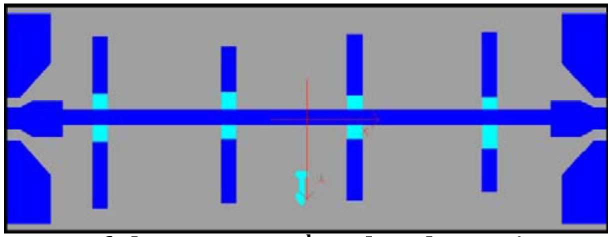
“De-tuning” the Filter and Adding the Footprint Model:



Enhanced elements in ADS circuit schematic, including the PCB-filter footprint model



E-M simulation of the footprint launch

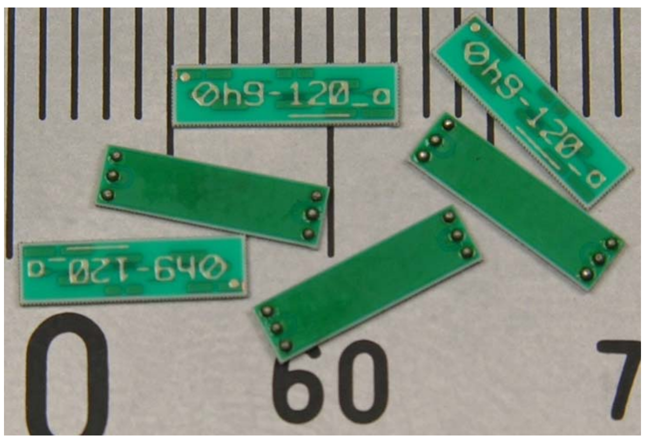


Layout of the 12 GHz 9th order absorptive LPF

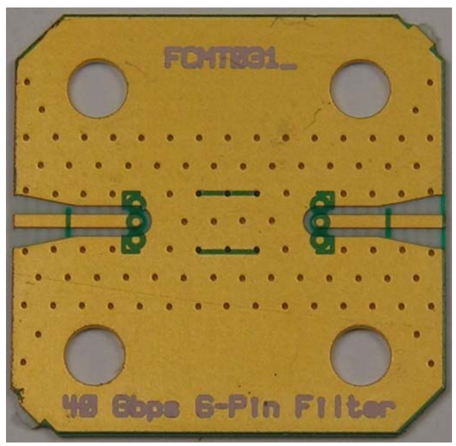
- ❑ The Enhanced Element simulation model was expanded to include the model of the undesired influence of the BGA footprint launch.
- ❑ Optimization was ran to tune the expanded model until the footprint influence is minimized.
- ❑ The “filter internals” are de-tuned and optimization is re-ran in the Enhanced Element and Momentum simulation models.
- ❑ Moved to lay-out and mask generation. Ready to Fab.

Device Fabrication and Measured Results:

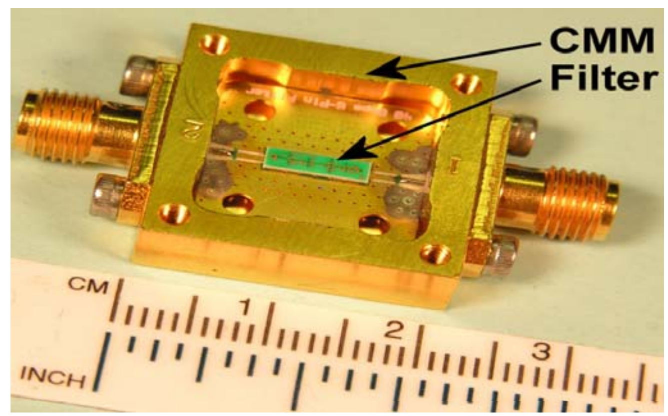
- After successful completion of the modeling of the filter with the footprint model, TFT fabricated the absorptive Bessel LPF.
- Filter is contained in the 6-pin, Gnd-Signal-Gnd BGA package. The filter pattern is on the top surface. Bottom surface is Gnd.
- For testing in real world PCB system environment, the filter is soldered to the Rogers PCB and then mounted in the CMM.
- Measured data is compared with simulation result.



- 6-pin Gnd-Sig-Gnd BGA pkg.
- 2808 (7.2mm x 2.0mm) pkg.
- Alumina subst. of 0.25 mm thick.



Evaluation board's PCB material is Rogers 4350, 10 mil thick, ½ oz. Cu.

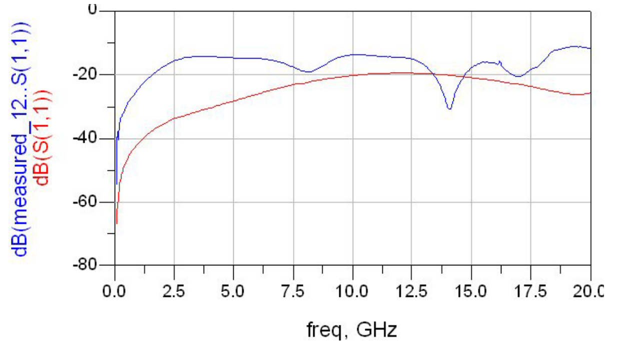


Evaluation board with filter

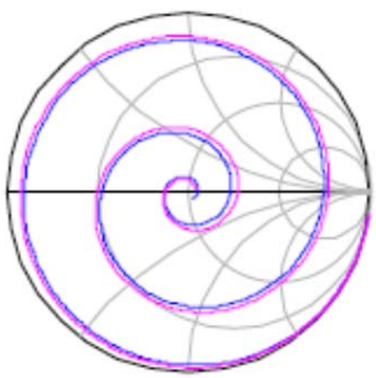
Correlations to the Simulation Model:

<u>Frequency Domain Analysis of the 12 GHz LPF:</u>

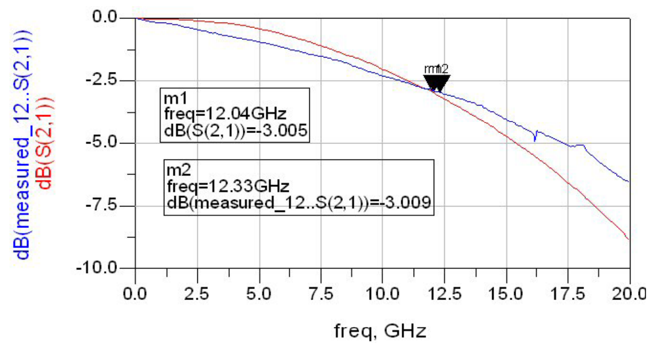
- **To gain good correlation back to the model, Frequency plots and Smith chart plots should be considered.**
- **Frequency measurements have good correlation to the simulation model that include the footprint influence.**



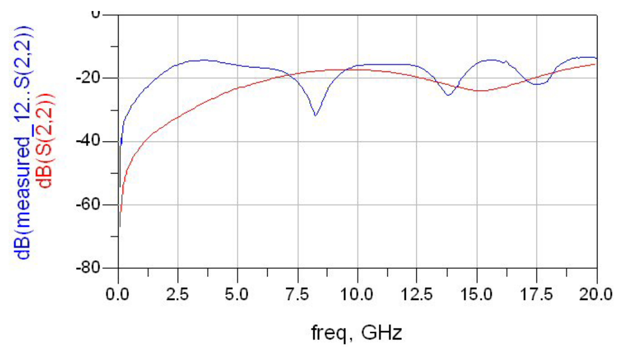
Forward Return Loss (S11) plot of simulated and measured



Smith Chart plot of simulated and measured



Insertion Loss (S21) plot of simulated and measured

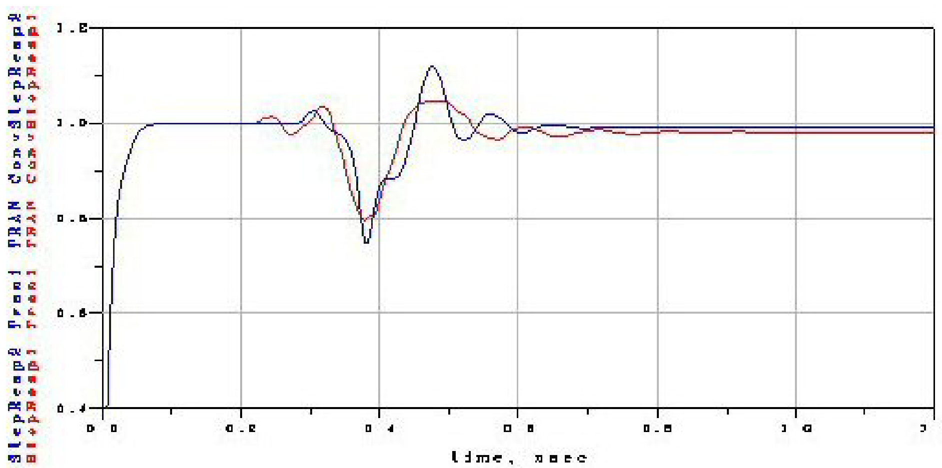


Reverse Return Loss (S11) plot of simulated and measured

Correlations to the Simulation Model:

<u>Time Domain Analysis of the 12 GHz LPF:</u>

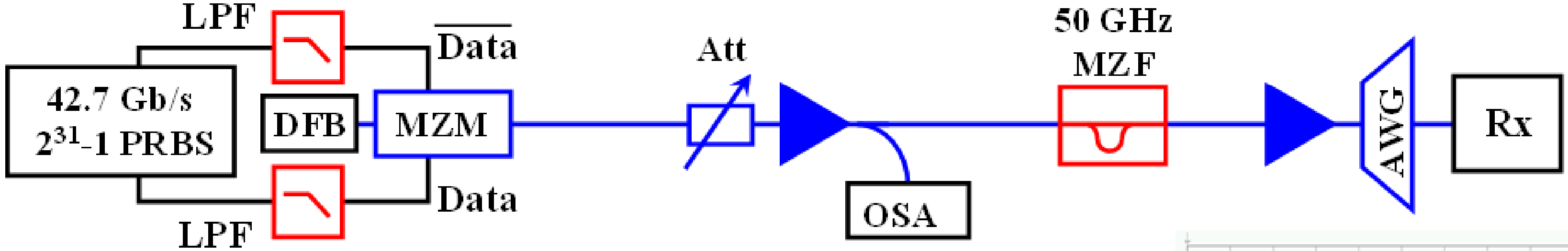
- **The plot below shows correlation between measured and the simulated model, including the footprint influence.**
- **Time domain analysis is the “check” for correlation between simulated and modeled. The model tuning is accomplished by achieving correlation in the frequency plots, the Smith chart, and the TDR plot.**

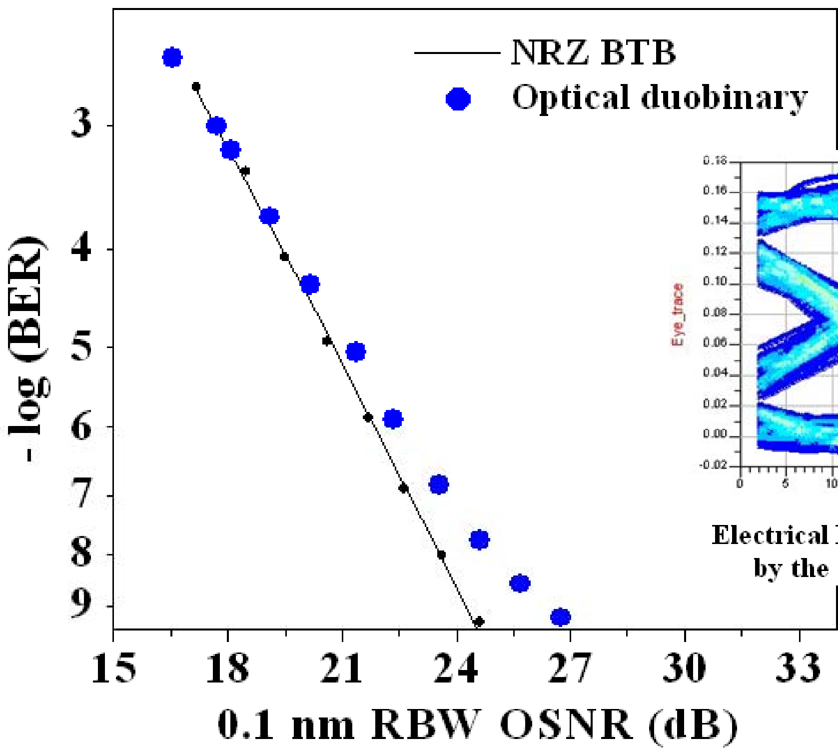


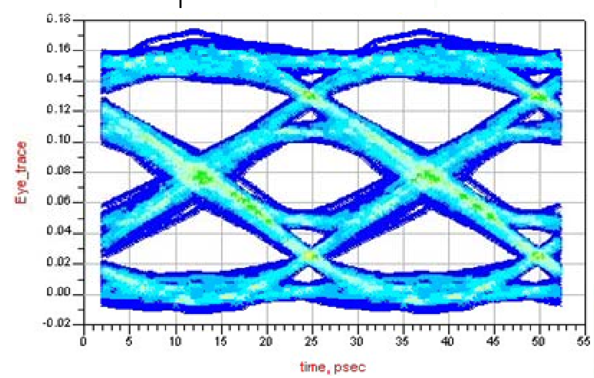
TDR plot of   simulated and measured

In System Performance Validation:

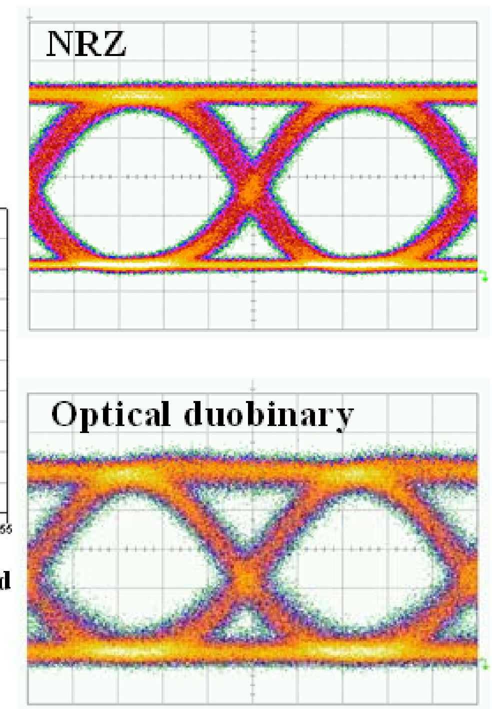
Back-to-Back Optical Duobinary (ODB) of a UCL 40 Gbps System:







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



Summary and Conclusion

- We discussed the TFT design process for custom absorptive low pass Bessel filters for production builds.
- We discussed how filter designs are incomplete for full production systems due to attention not paid to the influence of the mounting environment, the filter footprint and launch point.
- We modeled and analyzed the filter footprint and created a simulation model of the footprint.
- We discussed how to add the footprint model back into the filter simulation to create a "de-tuned" filter that when matched with the footprint model resulted in a superior performing filter for real world applications at lower costs.
- Absorptive LPF was fabricated using the new design technique and showed successful results in the end system.

Future Work

- Future work will be done on the absorptive low pass filters for 100 Gbps Duobinary. Expansion of the series to higher frequencies.
- Source of each parasitic influence will be investigated more.
- Test equipment's inherent influence can be studied.
- Further study to move the high order absorption LPF filters closer to the ideal 4^{th} order Bessel functions.
- Better footprint models can be achieved, especially at high frequencies between 20 GHz to 40 GHz.
- Next step is to move these absorptive filters to the Gaussian filter approach to achieve pure scalability.

Thank you!

- ***Contact us so that we can help meet your high performance passive component requirements.***

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