Optimum Low Pass Filter Bandwidth for Generating Duobinary Signal for 40 Gb/s Systems

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Abstract: We optimized 3 dB bandwidth of Low Pass Filter to generate electrical Duobinary signals for 40 Gb/s Duobinary systems. We fabricated 12 GHz 9th order absorptive “enhanced” Bessel LPF using BGA package and 17 GHz 9th order absorptive “enhanced” Bessel LPF using wire bond package to generate electrical Duobinary signal.

1. Introduction:
Optical Duobinary modulation has been illustrated to have higher spectral efficiency in high capacity transmission [1], and have better tolerance to chromatic dispersions due to narrower spectral bandwidth [2]. It also enjoys higher threshold for the onset of stimulated Brillouin scattering (SBS) [3]. Various implementations of Duobinary transmitters have been discussed [4-5]. Among all of those, the implementation based on the three-level electric signals generated by electrical low pass filters (LPF) is not only the most cost-effective and but also shows best dispersion tolerances [5]. In this format, the system heavily depends on the bandwidth of the LPF, which affects the pulse shape of the electrical signal. Nonetheless, the modulator and driving circuit’s bandwidth, as well as driving voltage, also contributes to the pulse shape.

It is well known that the fifth order electrical low pass Bessel filter having a 3 dB bandwidth equal to the quarter of the data rate, \( \sim B/4 \), is typically used in the Duobinary transmitter to generate the Duobinary signal pattern, which is then used to drive an optical modulator to create the optical Duobinary signal [6-8]. Many research efforts have been done to optimize the LPF’s bandwidth to achieve better performance. For 10 Gb/s Duobinary systems, receiver sensitivity has shown to be improved by employing 3 GHz LPF [9], and better ASE noise limited performance can be achieved with 2.8 GHz LPF [10]. By adjusting the chirp of non-ideal MZM, the optimum bandwidth of LPF is illustrated to be 2.7 GHz [11]. Accordingly, along with LPF’s 3 dB bandwidth, the driving circuitry’s and the modulator’s 3 dB bandwidth affects the generation of the Duobinary signal. To achieve optimum performance, the LPF’s bandwidth should be set up based on the driving circuitry’s and the modulator’s 3 dB bandwidth. In this work, we conducted studies to optimize the bandwidth of the LPF to generate the Duobinary signal pattern for the 40 Gb/s Duobinary systems. We considered the influence of driving circuit’s bandwidth to generate three level Duobinary electrical signal. To the best of our knowledge, no analysis has been reported on optimizing LPF 3 dB bandwidth for generating 40 Gb/s Duobinary signal.

2. Simulation and Discussion:
From TFT’s existing product, 9th order absorptive “enhanced” Bessel filter that provides similar group delay performance of 5th order Bessel filter but better return loss, we observed that the 3.0 GHz absorptive “enhanced” Bessel filter generates the best 10 Gb/s Duobinary signal using Sumitomo’s “Low Voltage Drive Modulator”. The electrical eye diagram for the Duobinary signal generated by that filter is shown in Fig1. Here, the binary eye amplitude (A) is 45% of the signal eye amplitude (B). We also observed similar eye ratio while studying 10 Gb/s Duobinary eye diagram on a Narda L3 system, shown in Fig 2. Using information from these observations as a foundation, we have since moved on to studying 5th order Bessel filters which have 3dB bandwidth of 8 GHz through 15 GHz that provide similar binary eye amplitude to signal eye amplitude ratio for 40 Gb/s systems.
Fig 3 illustrates the optical Duobinary transmitter system model. The differentially encoded 40 Gb/s electrical NRZ data passes through the driver and 5th order low pass Bessel Thompson filter to generate the three level Duobinary electrical signal. The Duobinary electrical signal drives the Mach Zender Modulator (MZM) to produce optical Duobinary signal. Fig 4 illustrates the Duobinary eye diagrams generated by ADS simulation of various low pass ideal Bessel filters. For LPF of 8 GHz through 15 GHz, binary eye amplitudes are 11%, 17%, 26%, 39%, 46%, 54%, 59%, and 69% of the signal amplitude, respectively. These results show the optimal bandwidth would be in between 11 and 12 GHz. Jitter produced by the eye of 12 GHz LPF is 1.44 ps while 11 GHz LPF produced 2.88 ps of jitter. From this result, we believe the 12 GHz Bessel filter will produce the best 3 level electrical Duobinary signal among all the filters that were simulated. However, if the driver circuitry’s 3 dB bandwidth is deviated from 40 GHz, then the filter’s bandwidth will have to be changed.

The designer must also consider the loss due to the filter’s footprint, the PCB material, and the filter’s launch pad. We observed that these losses act as a 30 GHz LPF “electrical environment”. We simulated a 30 GHz 5th order Bessel filter in series with 17 GHz 5th order Bessel filter to produce the targeted, optimal 12 GHz LPF. Fig 5 shows the simulation model and the $S_{21}$ parameter of the results.

To obtain the correct low pass filter for generating Duobinary signal pattern for the 40 Gb/s application, the designer should consider the driver circuitry’s bandwidth as well as PCB footprint and the filter’s launch pad loss and use simulation to insert that bandwidth in series with the actual filter design. For different measurement setups, the electrical loss, reflections, etc. from the PCB footprints and materials could cause the S-parameters to deviate from the 30 GHz ideal filter shape. Considering these criterions, we designed a 12 GHz “enhanced” low pass Bessel filter for generating the Duobinary signal pattern for 40 Gb/s systems. The “enhanced” term describes an absorptive Bessel filter that matches the $S_{21}$ parameter and group delay characteristics of an ideal 5th order Bessel filter, but provide improved return loss characteristics.

3. Component simulation, fabricated filters, and measured results:

Moving to fabricated components, ADS simulation on a 30 GHz bandwidth “electrical environment” in series with the simulation of a TFT 14.5 GHz “enhanced” Bessel filter was completed and resulted in a final cut off
of 12.0 GHz. Based on the simulation results, we fabricated the filter in a 2.0 mm x 7.1 mm BGA package. BGA package was used for easy handling and lower cost.

For measurement purpose, the filter with BGA package was mounted in TFT’s Coaxial Measurement Module (CMM), as shown in Fig 7. The simulation and measurement results of the 9th order 12 GHz absorptive Bessel filter are shown in Fig 6. In the plots, the red line corresponds to the simulation results and blue line corresponds to the measured results. The 3 dB bandwidth of the fabricated part is 12.3 GHz, which is within 3% of the simulated result. In Fig 8, we inserted the measured S-parameter filter data back into the ADS simulation model to produce the Duobinary eye diagram of the system. Here, the binary eye amplitude is 42.3% of the signal eye amplitude. We believe the jitter is due to the lossy electrical environment of the CMM system.

To acquire maximum signal integrity performance we fabricated another LPF in a 1.95 mm x 4.95 mm wire bondable package. The filter was designed to provide 3 dB cut off frequency of 17.0 GHz. For the wire bondable package we did not have the influence of CMM, which has bandwidth of 30 GHz. After fabrication, filters were gold plated for better conductivity. We used probe to measure the performance of fabricated filter. Then we used to filters to drive modulator with 42.7 Gb/s PRBS $2^{32} - 1$ signal. Figure 9 shows the simulated results along with measured results of the filters with and without the driver. In the plots, the red line corresponds to the simulation results, blue line corresponds to the measured results and black line corresponds to the measured results using the driver. For the insertion loss measured result without the driver is very similar to the simulation results up to 25 GHz. Both forward and reverse return loss is lower than –10 dB up to 30 GHz.
Figure 10 illustrates eye diagram of 42.7 Gb/s PRBS 2^{32}–1 signal using the filter with and without driver. Timing jitter of the filter is 0.74 ps and filter, and the filter with the driver produces timing jitter of 0.86 ps.

4. Conclusion:
We studied the impact of combining the driving circuitry’s 3 dB bandwidth in series with the 5th order Bessel low pass filter’s bandwidth to generate the three level electrical signal for the 40 Gb/s Duobinary system. From simulation of several filters with different 3 dB bandwidths, we concluded that 12 GHz LPF will provide best Duobinary electrical signal for the 40Gb/s Duobinary system. We designed and fabricated a 9th order 12 GHz “enhanced” Bessel low pass filter. The eye pattern output results from the 12 GHz fabricated filter component’s measured data shows good three level electrical Duobinary signal for the 40 Gb/s Duobinary system. For better signal integrity performance we designed and fabricated 17.0 GHz “enhanced” Bessel low pass filter. Fabricated parts were compared with simulated design. Filter was driven Narda L3 Communication’s diver (Narda Module FOMDA-40-13) with 42.7 Gb/s PRBS 2^{32}–1 signal. Eye diagrams were produced by the driven signal.

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6. References: