

# Optimizing Low Pass Filter Bandwidth for Generating Electrical Duobinary Signal for 40 Gb/s Optical Duobinary Systems

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## Abstract

*In the optical duobinary modulation format, low pass filter generated three level electrical signal is needed for the optical duobinary signal. To achieve optimum performance to generate duobinary signal, eye diagram of the three level electrical signal should produce binary eye amplitude, which must be certain percent of the signal eye amplitude. Low pass filter's bandwidth should be set up based on the driving circuitry's bandwidth. In this work, we studied to optimize the low pass filter's bandwidth to generate the duobinary signal pattern for the 40 Gb/s duobinary modulation format. While designing filter, we considered the influence of the filter's footprint and filter's launch pad loss. We extensively discussed the impacts of these parameters, which could cause the S-parameters to deviate from the ideal frequency response of the filter. Considering these criterions along with driving circuitry's bandwidth, we designed and fabricated 12 GHz 9<sup>th</sup> order absorptive low pass bessel filter to generate the electrical duobinary signal for duobinary modulation format for 40 Gb/s optical duobinary system. Using measured S-parameter data of fabricated filter, we simulated the transmitter model for 40 Gbps duobinary signal generation. We produced eye diagram with the transmitter model, which illustrates the optimum three level electrical signal.*

*Key words: Electrical duobinary signal, duobinary modulation format, low pass filter, 3dB bandwidth, bessel filter.*

## Introduction:

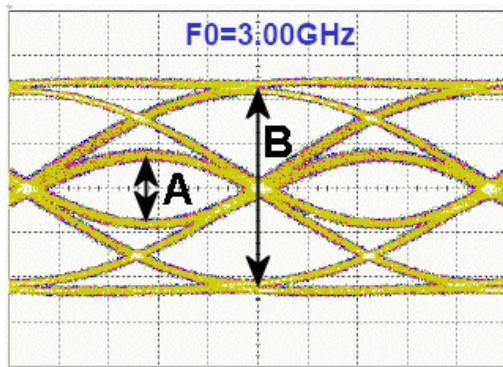
The role of the passive component filter is becoming very critical in present day's ultra high speed data transmission, specially in optical communication systems. Many optical modulation techniques heavily rely on electrical filtering at both end of the electro-optical system. Among several advanced optical modulation format, optical duobinary modulation format has been proven to have excellent spectral efficiency, high tolerance to chromatic dispersions, and reduced influence of coherent crosstalk in high capacity transmission [1]. Various realization techniques of optical duobinary signal transmitters have been discussed [2-5]. Among those, electrical low pass filters (LPF) generated duobinary signal is the most cost-effective; it also illustrates high dispersion tolerances [5]. In this realization technique, the system heavily depends on the bandwidth of the LPF, which affects the pulse shape of the electrical signal. Moreover, the modulator's bandwidth and driving circuit's bandwidth also contribute to the optical duobinary signal's pulse shape generation.

It is well known that fifth order electrical low pass bessel filter having a -3dB bandwidth equal to the quarter of the data rate,  $\sim B/4$ , is typically used

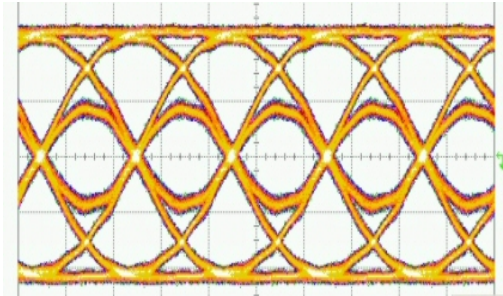
in the duobinary transmitter to generate three level electrical duobinary signal pattern, which is used to drive the optical modulator to generate optical duobinary signal [6-8]. Many research efforts have been done to optimize the LPF's bandwidth to achieve better system performance. For 10 Gb/s duobinary system, receiver sensitivity has shown to be improved by employing 3 GHz LPF [9], better ASE noise limited performance can be achieved using 2.8 GHz LPF [10], and by adjusting the chirp of non-ideal modulator, the optimum bandwidth of LPF is illustrated to be 2.7 GHz [11]. Accordingly, along with LPF's -3dB bandwidth, the driving circuitry's and modulator's -3dB bandwidth affects the generation of optical duobinary signal. To achieve optimum performance, the LPF's bandwidth should be set up based on the driving circuitry's and the modulator's -3dB bandwidth. In this work, we conducted studies to optimize the bandwidth of the LPF to generate duobinary signal pattern for the 40 Gb/s duobinary system. We considered the influence of driving circuit's bandwidth to generate three level electrical duobinary signal. To the best of our knowledge, no analysis has been reported on optimizing LPF's 3dB bandwidth for generating 40 Gbps optical duobinary signal.

### Simulation and Discussion:

From TFT's existing product, 9<sup>th</sup> order absorptive “enhanced” low pass bessel filter that provides similar group delay performance of 5<sup>th</sup> order low pass bessel filter but better return loss, we observed that 3.0 GHz absorptive “enhanced” bessel LPF generates the best 10 Gb/s duobinary signal. We used Sumitomo’s “Low Voltage Drive Modulator” for signal generation. Electrical eye diagram for the duobinary signal generated by that filter is shown in Figure 1. Here, 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 communication system’s modulator, shown in Figure 2.

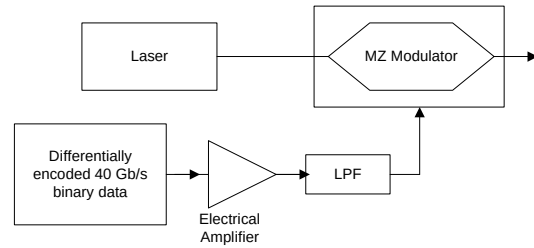


**Fig 1. 10 Gb/s Duobinary electrical eye diagram**



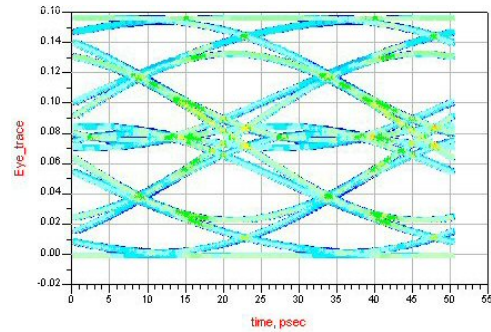
**Fig 2. 10 Gb/s Duobinary electrical eye diagram using Narda L3 transmitter**

Using information from these observations as a foundation, we have moved on to studying 5<sup>th</sup> order bessel filters, which have -3dB bandwidth of 8 GHz through 15 GHz that provide similar ratio of binary eye amplitude to signal eye amplitude for 40 Gb/s system. Differentially encoded 40 Gb/s electrical NRZ data needs to pass through the driver and 5<sup>th</sup> order low pass Bessel Thompson filter to generate the three level duobinary electrical signal. Then the duobinary electrical signal drives the Mach Zender Modulator (MZM) to produce optical duobinary signal. Figure 3 illustrates the optical duobinary transmitter system model.

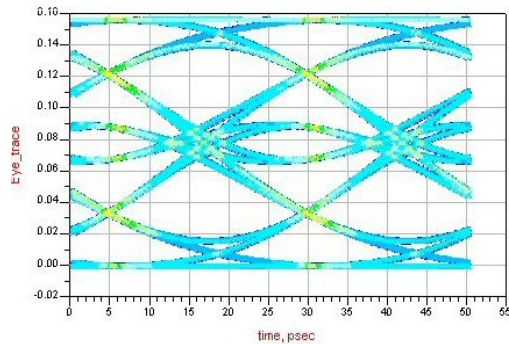


**Fig 3. Model used to generate duobinary signal**

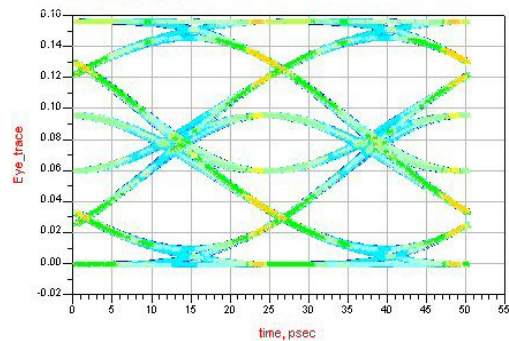
Fig 4 illustrates the duobinary eye diagrams generated by ADS simulation using various low pass ideal bessel filters. Fig 4a, 4b, 4c, and 4d illustrate the eye diagram generated by LPF of having -3dB cutoff frequency of 8 GHz, 9 GHz, 10 GHz and 11 GHz respectively.



**Fig 4a. Eye diagram generated with 8 GHz LPF**



**Fig 4b. Eye diagram generated with 9 GHz LPF**



**Fig 4c. Eye diagram generated with 10 GHz LPF**

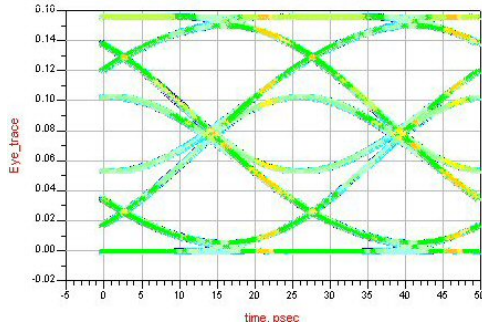


Fig 4d. Eye diagram generated with 11 GHz LPF

Fig 4e, 4f, 4g, and 4h demonstrate the eye diagram generated by LPF of having  $-3\text{dB}$  cutoff frequency of 12 GHz, 13 GHz, 14 GHz and 15 GHz respectively. For LPF of 8 GHz through 15 GHz, binary eye amplitudes are 11%, 17%, 26%, 39%, 46%, 54%, 59%, and 69% of the signal eye amplitudes respectively.

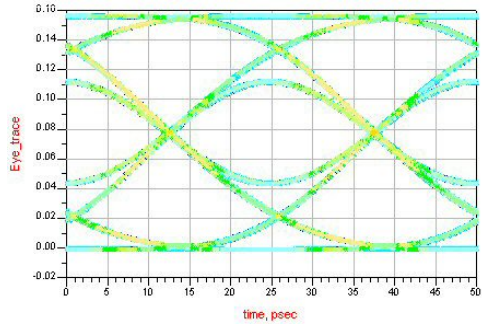


Fig 4e. Eye diagram generated with 12 GHz LPF

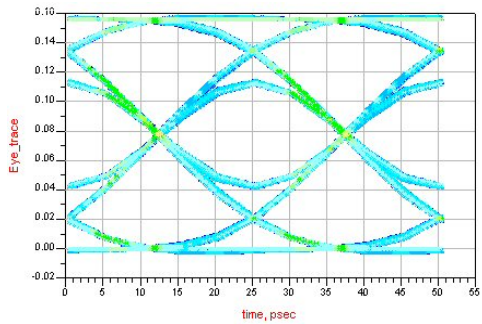


Fig 4f. Eye diagram generated with 13 GHz LPF

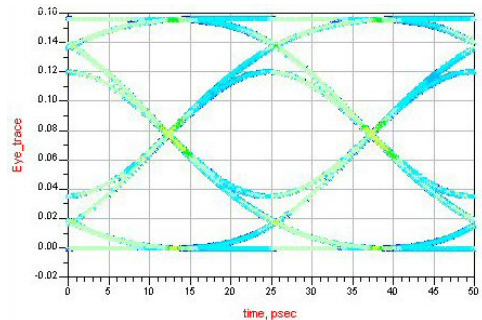


Fig 4g. Eye diagram generated with 14 GHz LPF

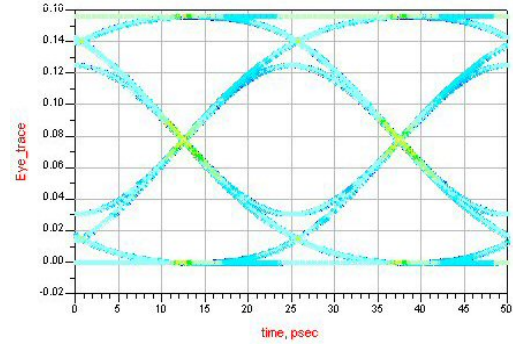


Fig 4h. Eye diagram generated with 15 GHz LPF

These results illustrate the optimal low pass filter bandwidth to generate best eye diagram would be in between 11 and 12 GHz. We observed that the 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 that among all the filters that were studied, 12 GHz low pass Bessel filter will produce the best 3 level electrical duobinary signal. However, if the driver circuitry's 3 dB bandwidth is deviated from 40 GHz, then the filter's bandwidth will have to be changed accordingly.

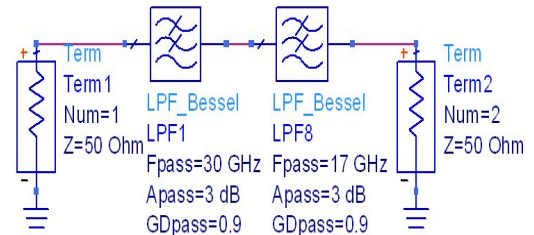
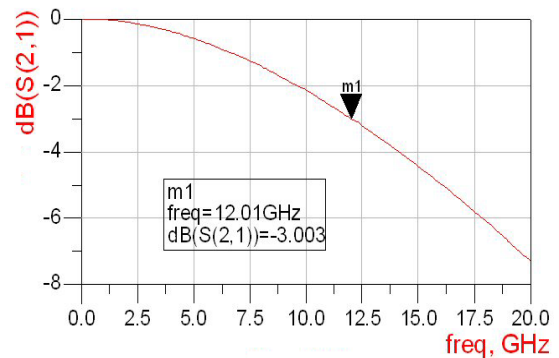


Fig 5a. Simulation Model of 30 GHz and 17 GHz Bessel filters together to generate 12 GHz Low Pass Bessel filter

Fig 5b.  $S_{21}$  Parameter of generated 12 GHz LPF from 30 GHz and 17 GHz LPF

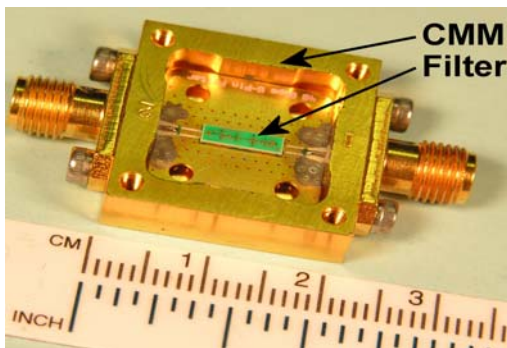
While designing the filter, design engineer must also consider the parasitic influence and signal loss due to the filter's footprint, printed circuit

board's (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 5<sup>th</sup> order bessel filter in series with 17 GHz 9<sup>th</sup> order bessel filter to produce the targeted, optimal 12 GHz LPF. Figure 5a demonstrates the simulation model of 12 GHz LPF. It shows the 30 GHz LPF of system bandwidth is in series with 17 GHz LPF producing 12 GHz LPF. Figure 5b illustrates the insertion loss simulation result of the designed filter.

To obtain the correct low pass filter for generating duobinary signal pattern for the 40 Gb/s application, the designer should also pay attention to the driver circuitry's bandwidth. In addition, different measurement setups, measurement cable and instrument's electrical loss, reflections, etc. could cause the S-parameters to deviate from the ideal filter shape, resulting poor filter performance. Considering these entire 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 5<sup>th</sup> order bessel filter, but provides improved return loss characteristics.

#### Component fabrication and measured results:

Based on the excellent simulation work of 12 GHz enhanced absorptive low pass filter 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. To maximize signal integrity performance, a wire bondable package can be used instead of BGA package.

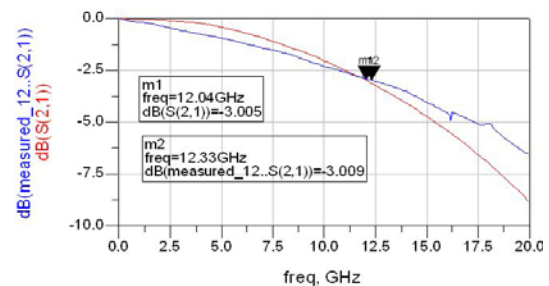


**Fig 6. 12 GHz enhanced Bessel LPF mounted in Coaxial Measurement Module (CMM)**

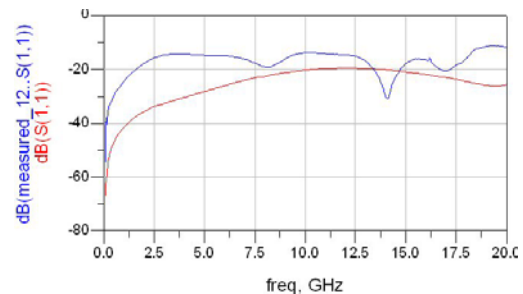
For measurement purpose, manufactured filter was mounted in Rogers 4350 printed circuit board. PCB along with the filter was placed in TFT's coaxial measurement module (CMM). Figure 6 illustrates the filter mounted in measurement module. CMM allows system design engineer to test the filter

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.

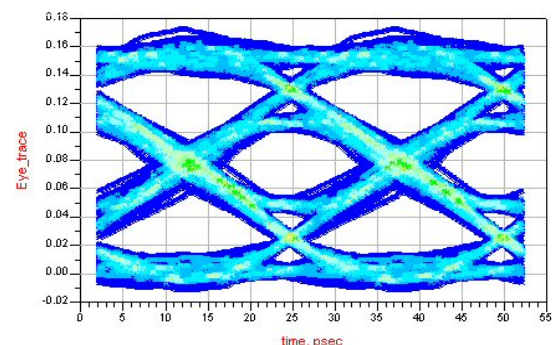
The simulation and measurement results of  $S_{21}$  and  $S_{11}$  plots of 9<sup>th</sup> order 12 GHz absorptive bessel filter are illustrated in Fig 7a and 7b respectively. In the plots, the red line corresponds to the simulation results and blue line corresponds to the measured results. The -3dB bandwidth of the fabricated part is 12.3 GHz, which is within 3% of the simulated result. The plots demonstrate good correlation between designed and manufactured part.



**Fig7a. Insertion loss ( $S_{21}$ ) plot of simulated and measured 12 GHz LPF**



**Fig7b. Return loss ( $S_{11}$ ) plot of simulated and measured 12 GHz LPF**



**Fig8. Electrical Duobinary eye diagram produced by the fabricated 12 GHz Bessel LPF**

We inserted the measured S-parameter filter data back into the ADS simulation model to produce the duobinary eye diagram of the system. Figure 8

illustrates the eye diagram of the duobinary signal generated with the manufactured 12 GHz Bessel LPF. Here, the binary eye amplitude is 42.3% of the signal eye amplitude. This eye diagram represents excellent three level electrical duobinary signal. We believe the produced jitter in the eye diagram is due to the lossy electrical environment of the CMM system.

### Conclusion:

In this work, we studied the impact of low pass filter's -3dB bandwidth to generate three level electrical signal for the duobinary modulation format for 40 Gbps optical communication system. We investigated several LPF with different cutoff frequency to find out optimum LPF bandwidth for 40Gbps duobinary modulation format. We examined the influence of combining the driving circuitry's 3 dB bandwidth in series with the Bessel low pass filter's 3dB bandwidth for producing excellent low pass filter. From simulation of several filters with different 3dB bandwidths, we concluded that 12 GHz low pass filter will provide best duobinary electrical signal for the duobinary modulation format for 40 Gbps optical communication system. We designed and fabricated a 9<sup>th</sup> order 12 GHz "enhanced" low pass Bessel filter. Measured result of the manufactured filter has been compared with the simulated designed filter. The eye pattern output result from the fabricated filter's measured data shows good three level electrical duobinary signal for the 40 Gb/s duobinary modulation format.

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