Effect of Different Low Pass Filters Electrical Performance on 100 Gbps Metro Network Systems

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Abstract: We studied Low Pass Filter’s electrical performance effects on 100 Gbps DP-QPSK system. We manufactured different types of 22 GHz LPF for 100 Gbps system’s receiver side and analyzed performance difference based on filter’s performance. OCIS codes: (060.4510) Optical Communication; (120.2440) Filters.

Introduction
Demand for ultra high bandwidth has resulted in the recent deployment of 100 Gbps systems for Ethernet transport. State-of-art for the 100 Gbps systems is 1x100 Gbps, for ultra long haul transmission, and 4x25 Gbps, for relatively short distance metro network applications. Advanced modulation schemes have emerged to achieve the single wavelength for 100 Gbps Ethernet transport; having the true baud rate of 112 Gbps with Forward Error Correction (FEC) and Ethernet overload. To achieve 100 Gbps systems for metro network applications, Optical Duo-binary (OBD) and Dual polarization-multiplexing with Quadrature phase-shift-keying (DP-QPSK) are two promising solutions. At the receiver side, DP-QPSK is using Coherent detection, while the ODB format uses Direct Detection. Both systems employ 5th order electrical low pass filter at the receiver side to reduce ASE noise and inter symbol interference (ISI), resulting in improved SNR performance. Along with other electrical and optical components, these receiver side filters play a significant role on the system performance. Many research efforts have been done to realize the impact of low pass filter bandwidth to optimize the system performance. Pfennigbauer et al [1] investigated filter bandwidth and its impact on preamplified receiver sensitivity. Mo et al [2] studied the optimization of receiver filter bandwidth for externally modulated MSK signals. Winzer et al [3] evaluated the filtering effect on RZ-DPSK system. Zheng et al [4] showed that receiver sensitivity can be improved by optimizing filter bandwidth for 40Gbps systems. The Filter’s -3dB bandwidth needs to be around 0.8 times the symbol rate. Both in direct detection and coherent detection, receivers have four electrical lines with symbol rates of 27.75 Gbps. For 27.75 Gbps symbol (baud) rates, the filters -3dB bandwidth needs to be around 22.2 GHz. For this study, we developed and manufactured Butterworth and Bessel filter with the -3dB cutoff frequency of 22.2 GHz; we then employed the filters in the system’s receiver side. The resulting system performance was analyzed to distinguish the impact of low pass filters electrical performance.

Discussion on Low Pass Filter Development
To obtain maximum advantage from the low pass filter in the system’s receiver side, design engineers must pay attention not only to the filter’s cutoff frequency, but also stop band rejection, group delay response as well as return loss characteristics. Moreover, filter size needs to be small enough to fit in extremely small receiver modules, while parasitic influence and signal loss due to the filter’s footprint, and PCB material needs to be addressed. Considering these stringent requirements, we employed novel techniques to develop a 5th order enhanced absorptive Bessel filter, which matches the S21 parameter and group delay characteristics of an ideal 5th order Bessel filter, but provides improved return loss characteristics. Return loss is suppressed to -10dB up to 1.5 times the cutoff frequency.

System model and experimental setup
Even though both the ODB and DP-QPSK systems differ in modulation schemes and to some extent in components, in receiver side, they each have four electrical lanes with nominal symbol rates of 27.75 Gbps. The receiver modules are responsible for converting the incoming optical signal to an electrical signal that stretches the importance of a low pass filter before the signal is digitized. For this study, we chose a DP-QPSK system, illustrated in Figure 1. Its system configuration can be divided into 3 main sections: DP-QPSK transmitter, transmission link, and coherent receiver, followed by DSP. As the signal is generated by the DP-QPSK transmitter, it propagates through the fiber where it experiences dispersion and polarization effects along with ASE noise. The signal then passes through the coherent receiver and Electronic Dispersion Compensation circuit (EDC) before it reaches the DSP for decoding and error correction. The receiver consists of four pairs of photodiode (PD), trans-impedance amplifiers (TIA) and electrical
Bessel filters. Fiber dispersion is compensated by utilizing EDC and Viterbi-Viterbi phase estimation is used to compensate for the phase and frequency mismatch. In the system configuration, we added 20 spans of 90 km SMF fiber totaling 1800 km. ASE noise is added from the EDFAs with OSNR being scanned. The receiver side shows four 22 GHz individual filters’ presence for four 27.75 Gbps baud rate lane.

Two types of receiver side low pass filters for DP-QPSK system were developed. One, an absorptive 5th order Bessel filter, where the return loss was suppressed up to -10 dB to 1.5 times the filter BW. Resistive material was incorporated to accomplish the absorptive nature of this filter. The other was a 5th order Butterworth filter. Both filters’ -3dB cutoff frequency was developed to be 22.2 GHz. The Bessel filter provides excellent group delay performance, which significantly improves the system performance. However, the Butterworth filter suppresses the out of band frequency noise, which reduces the ISI phenomenon, resulting in enhanced system performance.

Filter manufacture and comparison between simulation and measurement results
Based on the simulation results, we manufactured low pass filters in 0805 (1.2 mm x 2.0 mm) size leadless LGA package. The Filter’s input is a micro-strip line, having ground-signal-ground (GSG) configuration. Plated copper was used as the transmission line for the filters LC component; Nichrome was used for the resistive material. Substrate was 96.6 % alumina. The filters patterned side was covered with passivation for moisture prevention. The signal pad is kept to 350 um x 300 um for good solder joint contact.

Figures 2a, and 2b show the measured data plots of both filters along with simulation results of an ideal 5th order 22.2 GHz Bessel filter. Fig. 2a shows the insertion loss data plot, Fig. 2b shows the return loss data plot. In the plots, red color curve represents an ideal filter simulation result, blue color represents the absorptive Bessel filter output and black color represents the Butterworth filter output. The Absorptive Bessel filter’s -3dB cutoff (Fc) frequency is measured as 23.2 GHz, and the Butterworth filter’s Fc is measured as 21.5 GHz. Both of the filter’s cutoff frequencies are within the 5% tolerance of ideal Bessel filter’s Fc. Fig. 2b shows that the absorptive Bessel filter’s return loss is suppressed to -10 dB up to 33 GHz, while the Butterworth filter’s return loss is -5 dB at the 21.5 GHz, which is the filter’s -3dB cutoff frequency. Results show the Bessel filter’s group delay ripple is 5 ps up to 25 GHz. As expected, the Butterworth filter’s data shows a much sharper roll off than the Bessel filters. Even though the Butterworth filter’s S21 comes up high at around 34 GHz, it stays significantly lower at out of band frequencies.
System performance result with different filter
We used the filters measured results in the DP-QPSK systems simulation model shown in figure 1, and observed the results. We analyzed the BER output for the systems performance result. Figure 3 shows the BER results against the OSNR for the 2 different filters. The BER curve associated with specific filter is mentioned with the plot. From the result, we can realize that the Absorptive Bessel filter provides better performance than Butterworth filter.

![BER curve due to Butterworth filter in system's receiver side](image1)

![BER curve due to Absorptive Bessel filter in system's receiver side](image2)

Figure 3 illustrates that for different OSNR level, the absorptive Bessel filter provides lower BER value than Butterworth filter. Since the symbol (baud) rate is 27.75 GHz, the desired filter bandwidth should be in between 21 to 25 GHz. Here the absorptive Bessel filter provides the better result due to a sharper insertion loss fall-off beyond 25 GHz, excellent return loss up to 33 GHz, and minimum group delay distortion. What may appear counter-intuitive at first sight is the impact of the Butterworth filter’s performance. It has the steepest fall-off beyond 21 GHz; however, has higher group delay ripples and worse return loss than the absorptive Bessel filter in this study. This result shows that not only does the LPF’s bandwidth impacts the system performance, but also the return loss and group delay have significant effect on the Metro Network system performance.

Conclusion:
We studied the impact of the Low Pass filter’s electrical performance on a 100 Gbps metro network system’s performance. We developed and manufactured one 5th order Bessel filters and one 5th order Butterworth filter. We compared the simulation and the measured results of the filter’s electrical performance. We modeled DP-QPSK 100 Gbps system for the metro network application. We used the filter’s data in the model and observed the system performance differences due to different types of filters. The BER results illustrate that the 5th order absorptive Bessel filter enhances the 100 Gbps metro network system’s performance most.

References: