Wavefade™ Filters
Product Overview

In modern digital communications, care must be taken when transmitting digital sequences of bits through the physical layer. In particular, systems engineers must be aware of the impact both the magnitude and phase response of the associated components and transmission lines will have on the quality of the received bits. When it comes to the filtering of digital signals, it is often assumed that Bessel-Thompson (BT) filters are the best option in both transmitter and receiver applications because of their "maximally flat" group delay characteristics. As opposed to the generally higher stopband rejection achievable with the classic Chebychev, Butterworth and Elliptical filter types, BT filters achieve a significantly flatter group delay response at the expense of decreased stopband rejection [1].

The primary benefit of a flat group delay filter is that bit-pattern dependent distortions will be minimized. This is caused by the fact that all of the frequency components comprising the transmitted pulses will pass through the filter with the same time delay. Therefore*, it is necessary to use filters with flat group delay (i.e. linear phase) in order to achieve the highest eye quality in terms of overshoot/undershoot and eye symmetry*. For the above reasons, reference receiver compliance testing using the ITU-T G.957 standard requires a nominal 4th order BT electrical filter response [2]. Unfortunately, even the 4th order BT filter is limited in group delay performance beyond the cutoff frequency. In order to obtain flat group delay beyond cutoff, higher order filter designs are required. In practice, however, higher order BT filters can be exceedingly difficult to implement due to inductor/capacitor tolerancing and parasitics. Such technical challenges become increasingly problematic for filters above 10 GHz.

For the limitations described above, the WAVEFADE™ filter family has been introduced by Marki Microwave to surpass the performance of 4th order BT filters. Using a proprietary filter technology, WAVEFADE™ filters offer superior, ultra-flat group delay response while still maintaining a quasi-Bessel magnitude response (see Fig. 1). Therefore, WAVEFADE™ filters can supplant all "conventional" BT 4th order filters in order to achieve ultra-flat group delay characteristics without affecting the nominal magnitude

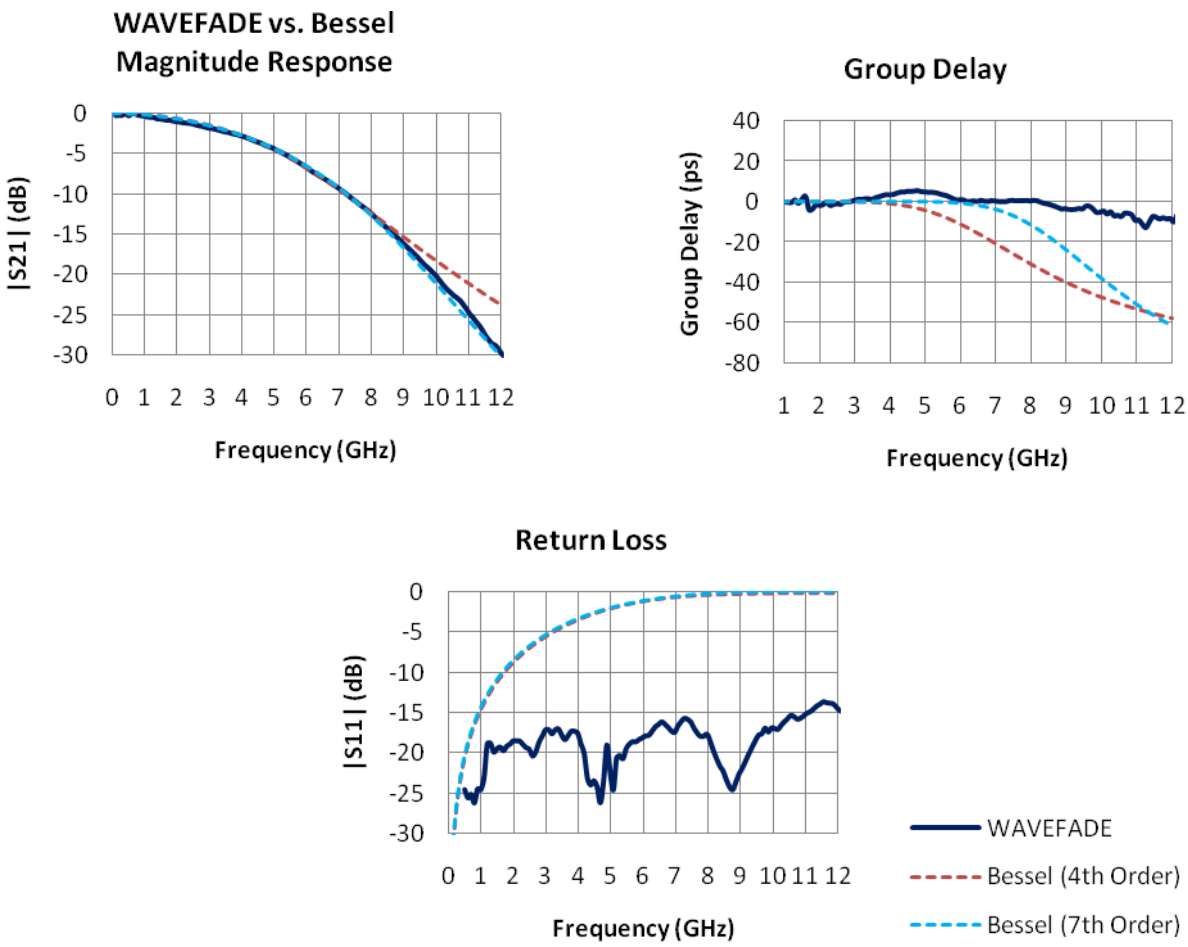

Fig. 1. Magnitude, group delay, and return loss comparison for a 4.2 GHz filter. Comparison shows superior performance of WAVEFADE™ filter over conventional 4th and 7th order Bessel filters.

response required by the ITU-T standard. Moreover, while BT filters implemented using classical L-C networks will be reflective in the stopband, WAVEFADE™ filters are absorptive by design and hence provide superior impedence matching in both the passband and the stopband (see Fig. 1). The absorptive quality of WAVEFADE™ filters can be of significant importance in digital systems since reflections are known to cause unwanted interference and increased jitter in amplification stages [3]. Another potential application includes the use of WAVEFADE™ filters at mixer RF and IF ports in order to pass in band signals and absorb out-of-band reflections without the need for additional fixed attenuators.

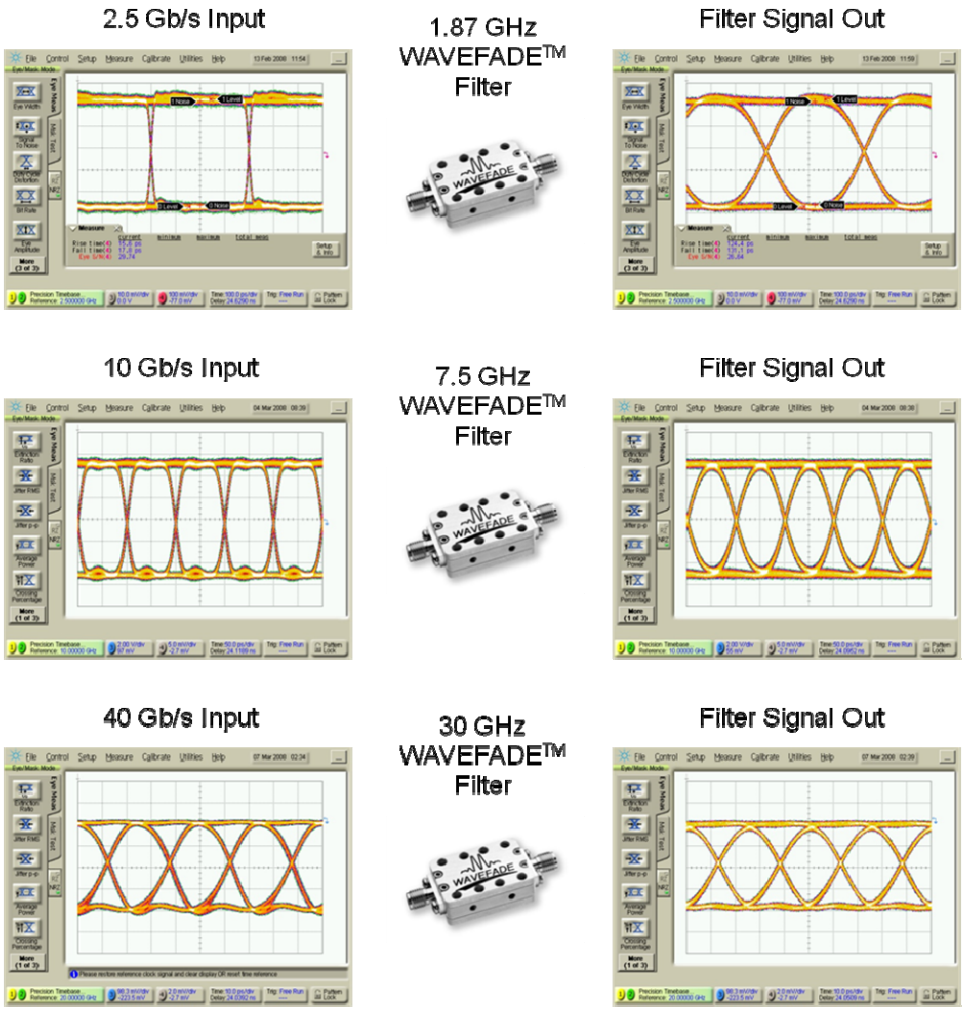

Fig. 2. Input PRBS patter and filtered output for 2.5 Gb/s, 10 Gb/s and 40 Gb/s. WAVEFADE™ filters used are designed to comply with the ITU-T G.961 recommendation. Data measured using a 70 GHz Agilent DCA sampling scope module. 40 Gb/s PRBS generated using a 4:1 Centellax MUX.

EXAMPLE APPLICATIONS

Receiver Filter Compliance Testing

Based on standards set by the ITU-T G.957 recommendation, the industry-accepted choice for electrical filter response in telecommunications systems is a 4th order BT filter with a cutoff frequency at 0.75*Bit Rate. Using this standard, equipment manufacturers can test the quality of their transmitters and receivers using widely available electrical filters

and sampling oscilloscopes. Marki Microwave WAVEFADE™ filters are designed to meet this filter specification. In Fig. 2, eye diagrams are shown which demonstrate the clear, open eyes obtained when filtering a 2.5 Gb/s, 10 Gb/s and 40 Gb/s signal with the corresponding electrical compliance filter. The desirable magnitude response and group delay response yields filtered eye diagrams with high Q-factor, minimal added jitter and near-perfect symmetry about the middle of the bit period.

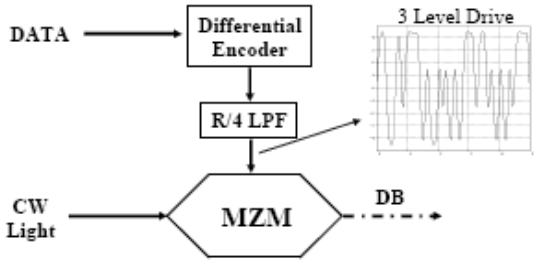

Fig. 3. Typical lowpass filter optical Duobinary transmitter architecture.

Duobinary Modulation

A challenging task for fiber-optic engineers is that of generating optical Duobinary modulation (also known as Phase Shaped Binary Transmission or PSBT). Duobinary is a popular choice in fiber-optic systems because it is a spectrally compressed modulation format which achieves robust chromatic dispersion tolerance while utilizing standard direct detection optical receivers [4]. This latter point differentiates Duobinary from other possible modulation formats choices like differential phase shift keying (DPSK) which require additional costly hardware at the receiver end. The trade-off for using Duobinary is that it requires additional hardware at the transmitter and suffers an inherent sensitivity penalty compared with other formats. Nevertheless, Duobinary has proven to be a robust format in both 10 Gb/s and 40 Gb/s systems and commercially available transmitters are currently offered by several vendors [5].

In its most common implementation, Duobinary is created using a differential encoder, an electrical driver amplifier, an electrical filter with a cutoff around 25-35% of the data rate and a Mach-Zehnder modulator as shown in Fig. 3. The key point regarding the creation of optical Duobinary is that a flat group delay is needed in the electrical components and modulator in order to create the most robust transmitted eye diagram possible (see [6] and [7]). WAVEFADE™ filters are ideal for this application owing to their extremely flat group delay far beyond the cutoff frequency. Additionally, since WAVEFADE™ filters are easily implemented with cutoff frequencies in the range of 12-16 GHz, they are ideal candidates for use in 40 Gb/s duobinary transmitters. The measured results showing the electrical drive signal generated with WAVEFADE™ filters for 10 Gb/s and 40 Gb/s duobinary are depicted in Fig. 4. Notice the highly symmetrical “3-level” waveform which can be created using a WAVEFADE™ filter with an approximate 25-35% of the data rate cutoff frequency. Of particular interest is the “tightness” of the +1, 0 and -1 crossing and the limited jitter created by the filtering process. These factors combine to give the best transmitter performance possible.

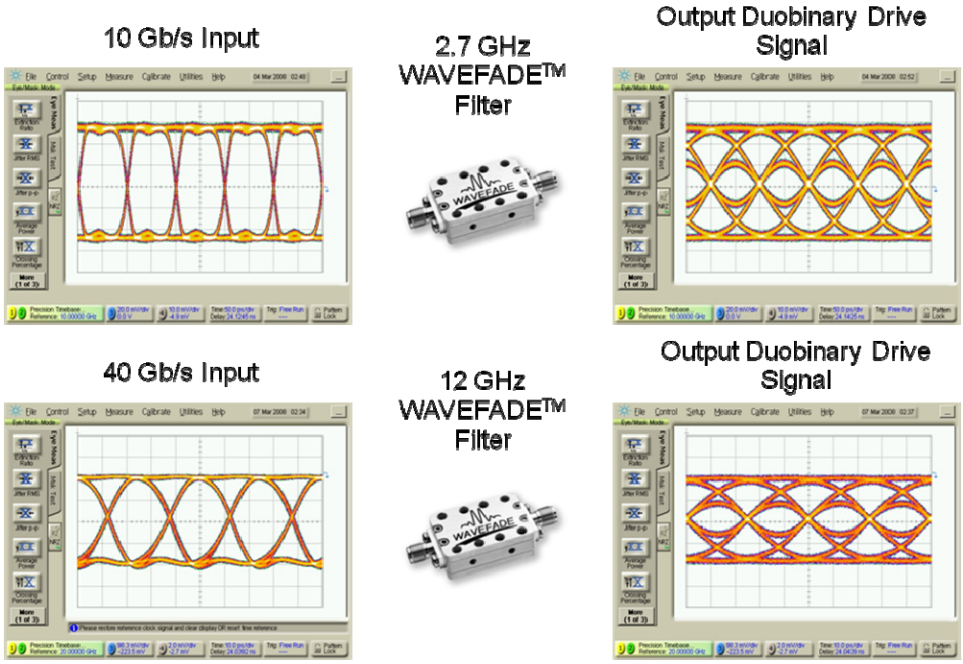

Fig. 4. Both measurements taken using an Agilent DCA sampling scope with 70 GHz sampling head and Precision Timbase trigger. The 42.8 Gb/s signal is generated using 4*10.7 Gb/s channels multiplexed with a Centellax 4:1 MUX.

CONCLUSION

WAVEFADE™ filters offer unsurpassed group delay performance. Because they are not created using conventional L-C implementations, WAVEFADE™ filters have been shown to yield ultra-flat group delay far beyond cutoff and excellent impedence match in both passband and stopband. Moveover, owing to their unique construction, WAVEFADE™ filters can be made with cutoff frequency from 1 GHz to beyond 30 GHz and are **not** limited by lumped L-C paracitics or tolerances.

WAVEFADE™ filters are excellent solutions for compliance filter testing, Duobinary modulation and any other application where an absorptive, Bessel-like lowpass filter response is required. For more information regarding our WAVEFADE™ technology, or to inquire about the potential use of WAVEFADE™ filters for your own unique application, please contact Marki Microwave.

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