Principle and Applications:

PriTel's Optical Clock Multiplier OCM

Pulse Repetition Rate Multiplication

Bit Pattern Multiplexing

Application to PRBS Generation at 160 GHz from 10 GHz PRBS

A common method of optical pulse-repetition-rate multiplication is Optical Time Domain Multiplexing (OTDM) using interleavers. While OTDM can be used to generate *n*-multiples of the input frequency, this discussion will focus on 2X.

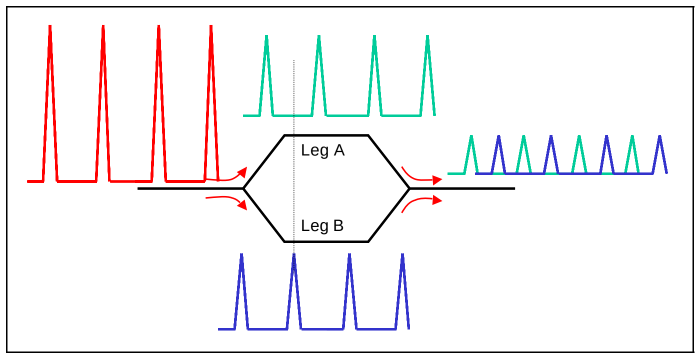

Figure 1

As diagrammed in Figure 1, the input Return-to-Zero (RZ) pulse stream is split into two pulse streams in a Mach-Zehnder interferometer. The stream in Leg A is delayed by ½ the pulse duty cycle relative to the second stream in Leg B, and then the streams are recombined. The interleaved pulses therefore have an effective repetition rate of 2X the input rate. The concept is simple, and it is the practical implementation of PriTel's OCM that yields stability and versatility of OTDM.

The optical pulses are RZ format, and the input pulse duration must be short enough that adjacent pulses have a minimum of overlap. For non-coherent pulses, overlap must be less than 10% above baseline. For coherent sources, this overlap must be smaller, typically less than 2%.

The amplitudes of the recombined pulses are reduced compared to the input stream. In the Mach-Zehnder design used by PriTel, the theoretical peak amplitude loss is 75% or 6dB. However, the theoretical average power loss is only 3dB because the repetition rate is increased by 2X. There are some additional practical losses resulting in a 5 to 6 dB loss per 2X stage in PriTel's OCM. Therefore, in concatenated systems, optical amplifiers may be required to boost the signal.

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In order to generate a true Pseudo-Random Bit Sequence (PRBS) by 2X multiplexing a lower rep rate PRBS pattern, one stream must be delayed by ½ the pulse duty cycle (**inter-pulse delay**), and one stream must be delayed by ½ the pattern length **(bit-pattern delay).** Information theory shows that the recombined data stream repeats the PRBS pattern at 2X the input rate. These two types of delay are accomplished in the PriTel OCM by using a Mach-Zehnder interferometer as shown in Figure 2.

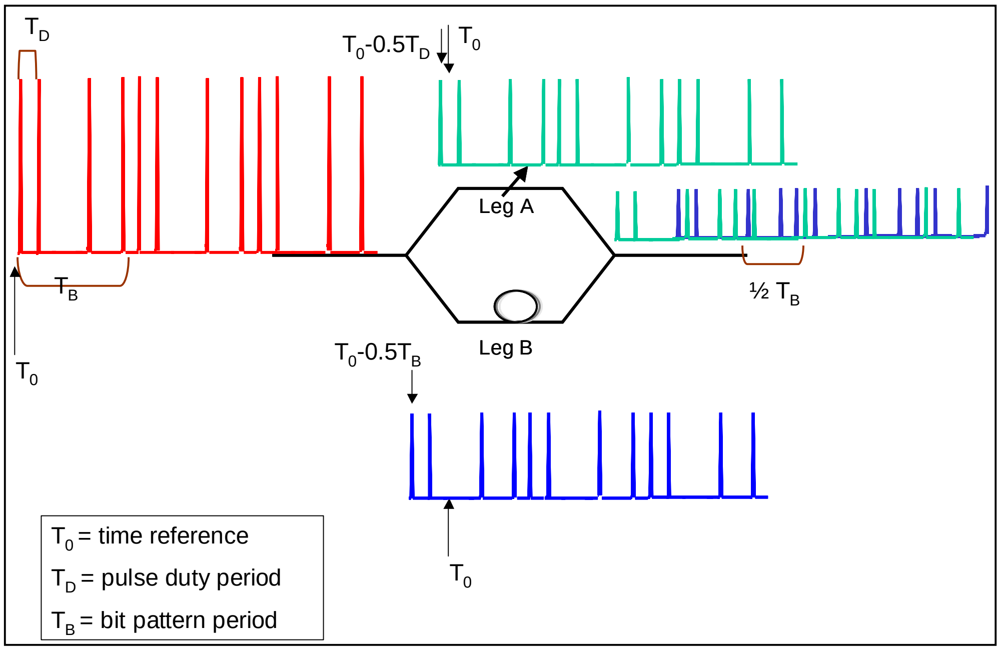

Figure 2

The **inter-pulse delay** is provided by Leg A of the interferometer which produces a delay equal to ½ the pulse duty cycle. When recombined with the pulses in Leg B, the interleaving occurs, and the effective pulse train is now 2X the input frequency.

For flexibility in input rep rate (e.g., Forward Error Correction), the PriTel OCM has a variable delay in Leg A; the control for this delay is labeled SYNC.

The **bit-pattern delay** in Leg B has a fixed delay equal to ½ the bit-pattern length. For example, 2^7-1 at 10 Gbps has a bit-pattern length of 12.8 ns; so, the fixed delay is 6.4 ns. For applications with different bit-pattern lengths, the PriTel OCM can be configured for a set of fixed delays. This gives the PriTel OCM a high degree of flexibility in both rep rate and bit-pattern length.

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Rejection of the input frequency is important. The primary cause of poor input frequency extinction is unequal amplitudes of the pulses from Leg A and Leg B. This appears as an amplitude modulation at ½ the output frequency and thereby regenerates the input frequency. PriTel's OCM addresses this problem by adjusting the amplitude of the pulses in Leg A using the control labeled EQUALIZER. Unequal spacing of the interleaved pulses can also cause generation of subharmonics. The SYNC adjustment in the OCM can be used to suppress these frequencies.

For high rep-rate applications, the required narrow pulses can experience broadening in the multiplexer. For example, at 160 Gbps, the input pulses must be $\leq$ 1.6 ps. PriTel carefully selects components to minimize the effects of chromatic dispersion.

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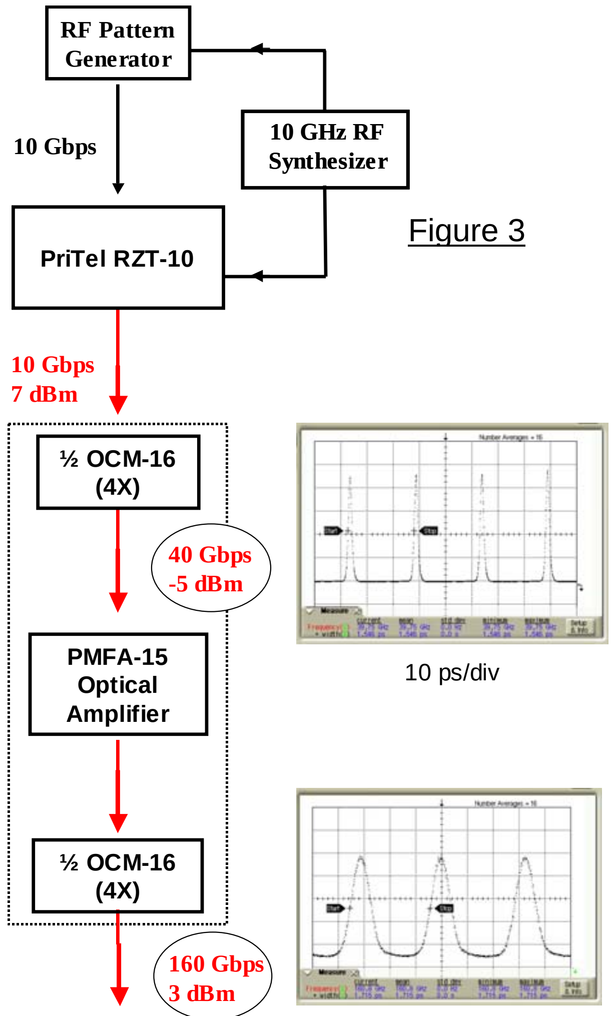

Figure 3

2 ps/div

Figure 3 shows a typical application of the OCM-16 to a PriTel RZT-10 fiber laser. The electrical pattern data at 10 Gbps are delivered to the RZT-10, which uses an embedded data modulator to impress the electrical pattern on the 10 GHz optical clock stream.

The first two stages of the OCM-16 provide 4X multiplication. A polarization-maintaining EDFA, such as the PriTel PMFA-15, is used to boost the signal for the last two stages of 16X multiplication. This configuration provides the best S/N ratio.

Typical pulse shapes and power levels at the various points in the system are shown in the figure.

All fiber cable connections must be polarization maintaining.

Higher multiples of the input rep rate can be obtained by cascading the OCM units. Above 160 Gbps, however, consideration must be made of the pulse width and pulse broadening. In addition, the stability over time must be very good, and temperature control of the fiber cavities is typically required. PriTel has experience at 640 Gbps PRBS multiplication from 40 Gbps PRBS.

Because the PRBS fixed delay is a function of rep rate and bit-pattern length, applications having a variable rep rate and/or bit-pattern length require a corresponding set of fixed delay cables for Leg B of the OCM.

References: Y. Ueno et al., "Ultrahigh-speed data regeneration and wavelength conversion for OTDM systems (Invited Talk)," 27th European Conference on Optical Communication (ECOC 2001), Sept. 30-Oct. 4, 2001, Amsterdam, Netherlands, paper Th.F.2.1.

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