Abstract— This paper presents a simple technique for generation of Impulse Radio Ultra-wideband pulses in optical domain. This system can transmit the data in Giga-bits-per-second range for 32 users across a 1 km optical fiber link using Dense Wavelength Division Multiplexing (DWDM). A multiple access technique using Direct Sequence Ultra-wideband (DS UWB) pulses has also been presented. Moreover, we have analyzed the relationship between the input data rate and signal bandwidth and also studied the effect of pulse width on the bandwidth of a signal.

I. INTRODUCTION

Ultra-wideband (UWB) is an up-and-coming technology in wireless communication that has the potential to provide high data rate broadband wireless access. Though it is an emerging technology at present, the concept is not new at all. The history of using UWB for wireless communication goes back to early 1900s when Marconi used UWB pulses in his spark-gap radio transmitter to transmit Morse code sequences. The prominent qualities of UWB attracting attention of researchers from around the globe are its low complexity, low cost, reduced power consumption and increased data rate. The mere limitation of UWB is its short range which can be overcome by the use of Radio over Fiber technology [1]-[4] entailing the use of Optical Fibers to carry signals from the head-end to user premises. This technology is commonly referred to as UWB-over-fiber.

The generation of UWB pulses has always been a challenge because the wide bandwidth requires the signal to be considerably narrow in the time domain. Moreover, to fully exploit the advantages of UWB, there is a need for optical generation of UWB pulses to avoid the use of high cost electrical components, required to produce such narrow signals and to exceed the speed limitations offered by the electrical components. Numerous solutions have been proposed in the past demonstrating all-optical generation of UWB pulses. Recent approaches include the use of cross phase modulation [5], cross-gain modulation in a semiconductor optical amplifier (SOA) [6], intensity modulator to generate polarity switchable UWB pulses [7], LiNbO$_3$ Intensity modulator using the transfer function’s wavelength dependant characteristics [8] and the use of Phase Modulator and asymmetric Mach-Zehnder interferometer (AMZI) to generate UWB pulses [9]. The problem associated with phase modulation and gain modulation [5] and [6] is that they require two laser sources resulting in increased system complexity. In [7] and [8], the generation is limited to a single UWB pulse which confines the use of this technique to a limited number of applications. Also, the requirement of two wavelengths in [4] renders the system expensive and complicated while [9] requires two Asymmetric Mach-Zehnder interferometers (AMZIs) to be cascaded which causes the design to face stability issue.

In this paper, we introduced a technique to generate UWB signals in optical domain and demonstrate a DWDM based distribution mechanism. A Mach-Zehnder modulator is used to modulate electrical Gaussian pulses. An optical delay line followed by a correlator is used to differentiate the optical Gaussian pulses and thus Ultra-wideband monocyte pulses are generated. Owing to the use of optical components only, this technique results in an ultrafast optical pulse source. In addition, we present a simple technique for the transmission of optically generated Direct Sequence (DS) UWB and the provision of multiple-access capability in future high speed wireless network.

II. OPERATING PRINCIPLE

The schematics of the proposed design are shown in fig. 1. The electrical Gaussian pulses are generated from the incoming data by the help of a Gaussian pulse generator. These electrical pulses modulate a Mach-Zehnder modulator and optical Gaussian pulses are produced.

Mathematically, the Ultra-wideband monocycle pulse is given by the first order differential of a Gaussian pulse. The width of resultant UWB pulse can be adjusted by manipulating the input Gaussian pulse. In our design, differentiation is performed by splitting the optical Gaussian pulse into two equal components. One component is passed through an optical delay line, delaying the signal in time by an amount equal to one half of the width of Gaussian pulse. Then a correlator is used to relate the later component with the former. In this way, during the time in which the non-delayed component goes through its ascending values, represented by section 1 in fig. 2, the delayed component is zero and the correlation results in nothing but the non-delayed component itself. Next, during section 2 in fig. 2 the correlation results in the values forming section 5 in the UWB monocyte. During the section 3 of correlation, the non-delayed Gaussian pulse has a constant value, thus the correlation of the delayed component with this constant value results in an inverted copy of the delayed component (section 6), producing UWB pulse in optical domain. The working of the differentiator is demonstrated in fig. 2. The delayed and non-delayed components are shown and formation of UWB monocyte is depicted.

As an application of the fore-mentioned technique we provide an example of a high speed wireless communication system where multiple-access technique is required to distinguish users on a common medium.
Sharing signals have important applied applications in various disciplines such as automobile anti-collision system for expressway, satellite communication and location among satellite formation. [10-12].

Assume that user 1 is transmitting a 0, user 2 is also transmitting a 0 and user 3 transmitting a 1, represented by a -1, -1 and 1 respectively. The spreading code for user 1, user 2 and user 3 is [1 1 1], [1 0 1] and [1 0 0 1] respectively.

Upon multiplication of user input with their corresponding orthogonal codes and subsequent summation, the waveform obtained to be transmitted over the optical fiber is shown in fig. 3.

This waveform modulates a Gaussian pulse train as shown in fig 4. The Gaussian pulse train must be synchronized with the data rate of the input for proper amplitude modulation of the pulses.

The modulated Gaussian pulse train is then used to generate UWB monocycle pulses in the optical domain through the above discussed generation mechanism. The UWB pulses carrying the cumulative data of multiple users are shown in fig. 5. The amplitude of the UWB monocycles corresponds to the amplitude of cumulative waveform carrying user data while the occurrence of positive and negative lobes corresponds to the polarity of the cumulative waveform.
III. SIMULATIONS AND RESULTS

The discussed design is simulated at an input data rate of 2 Gbps. The optical delay line used for the differentiation of Gaussian pulses has an inversely proportional relationship with input data rate. The input data rates corresponding to the optical delay required for proper differentiation are listed in Table-1. The value of optical delay can be calculated from the data rate and width of the Gaussian pulse. For example, if the input data rate is 2 Gbps, the width of a single bit comes out to be 1/(2*10^9) = 0.5 ns. So, if the Gaussian pulses are configured to be 0.1 bit wide, the width of the pulses in nanoseconds comes out to be 0.5*0.1 = 0.05 ns. Practically, due to limitations of the Gaussian pulse generator, the actual width is twice this value i.e. 2*0.05 = 0.1 ns. Hence, at a data rate of 2 Gb/s, an optical delay line of 0.05 ns (one half of Gaussian pulse width) is required for proper differentiation. From these calculations we can derive an equation to calculate the value of optical delay line ‘D’ from the data rate ‘R’ and pulse width ‘W’.

\[
D \text{ (sec)} = \frac{W \text{ (bits)}}{R \text{ (bits/sec)}}
\]  

(1)

UWB pulses generated using On-Off keying at 2 Gbps and the corresponding frequency spectrum are shown in fig. 6 & 7 respectively.

For comparison, the simulation has also been performed at a data rate of 1 Gbps. With the data rate reduced to one half, the inverse proportional relationship dictates us to double the optical delay offered. The required optical delay comes out to be 0.05*2 = 0.1 ns which can be verified from table-1. The UWB monocycle produced and the corresponding frequency spectrum, at an input data rate of 1 Gbps is shown in fig. 8 & 9.

<table>
<thead>
<tr>
<th>Sr. No.</th>
<th>Data Rate (Gb/s)</th>
<th>Optical Delay (ns)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.5</td>
<td>0.2</td>
</tr>
<tr>
<td>2</td>
<td>1</td>
<td>0.1</td>
</tr>
<tr>
<td>3</td>
<td>2</td>
<td>0.05</td>
</tr>
<tr>
<td>4</td>
<td>4</td>
<td>0.025</td>
</tr>
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TABLE I. DATA RATES CORRESPONDING TO REQUIRED DELAY

The width of the UWB monocycle in figure 6 is 0.2 ns while it is 0.4 ns in figure 8. These widths are twice the widths of the Gaussian pulses used to generate them. With the data rate reduced to one half, the width of the pulse in time domain is doubled. Intuitively, this should have an effect on the corresponding bandwidths of the pulses as well. From fig. 7 and 9 we can derive conclusions that there is a direct proportionality between the input data rate and UWB pulse bandwidth. Doubling the data rate doubles the bandwidth. This relationship is shown in the form a graph for two different values of Gaussian pulse width used for UWB monocycle generation in fig. 10.

Fig. 7. Frequency spectrum of UWB monocycle at 2Gb/s. The spectrum is centered at 5 Ghz and has a bandwidth of 6 GHz at -10dbm.

Fig. 8. UWB monocycle generated at 1 Gb/s. (Twice the pulse width at 2 Gb/s)

Fig. 9. Frequency spectrum of UWB monocycle at 1Gb/s. The spectrum is centered at 2 GHz and has a bandwidth of 3 GHz at -10dbm.

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Fig. 10. Relationship between input data rate and bandwidth for two different values of Gaussian pulse width used.

It is clear from the graph that increasing the width of Gaussian pulse, reduces the bandwidth of output UWB pulse, while the directly proportional relationship between input data rate and bandwidth stays the same. This is in compliance with the fact that, shorter the pulses in time domain, broader are their frequency spectra.

The output of Dense Wavelength Division Multiplexing is shown in fig. 11. The UWB pulses carrying the data of 32 different users are multiplexed using a frequency spacing of 100 GHz or a wavelength spacing of 0.8 nm. The shape of the signal for one user after travelling over a 1 km optical fiber link with an attenuation of 0.2 dB/km and dispersion of 16.75 ps/nm/km is shown in fig. 12. The signal is received using a PIN photo diode.

IV. CONCLUSION

A simple technique for optical generation of Impulse radio UWB pulses was presented along with the mechanism to transmit the data of 32 users over an optical fiber link using Dense Wavelength Division Multiplexing. The use of optical components to generate UWB pulses allows exceeding the limitations of electrical components and high data rates can be achieved. We found that the bandwidth available is directly proportional to the input data rate.

REFERENCES