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## Optical Generation of IR-UWB Pulse based on Weighted Sum of Modified Doublets

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*We propose a relatively simple optical generation concept for impulse radio ultra wideband (IR-UWB) pulse over fiber transmission using a weighted sum of a modified doublet with its inverted and delayed version. The generated pulses not only fully comply with the FCC spectral mask but also are highly power efficient in the available spectrum. We verified our approach using both simulation and experimental demonstration. The concept has a potential to be integrated with other optical functions on a compact optical chip, making it very suitable for wide UWB deployment for high-speed wireless access at low cost for in-building network applications.*

### Introduction

Ultra Wideband has been indicated as one of the most promising techniques to be used for next generation short-range high-data-rate wireless communications. The growing interest in this technique is due to its many abilities such as: to co-exist with other wireless services, to be tolerant to multipath fading, to have low probability of interception, and to pass through walls while maintaining communication [1]. Due to the low power spectral density (PSD) of  $-41.3$  dBm/MHz in the frequency band of 3.1-10.6 GHz regulated by the US Federal Communications Commission (FCC), the communication distances are limited, typically less than 10 meters. To increase the area of coverage, UWB signals can effectively be distributed over wired lines such as coaxial cable or optical fiber. Due to the low loss, large bandwidth, immunity to electromagnetic interference, distribution of UWB signals over optical fiber, better known as UWB-over-fiber, is considered a promising solution [2].

One of the fundamental considerations affecting IR-UWB performance is the selection of the impulse signal type. As described in [3], Gaussian based monocycle pulses and doublets can provide better bit-error rates and multipath resilience among different impulse signals. Basically, these waveforms can be created through band-pass filtering of a Gaussian pulse, i.e., filtering acts in a manner similar to differentiating the Gaussian waveforms. Most approaches to generate IR-UWB signals were based on electronic methods [4]. In the past few years, there has been increasing interest in generation of UWB signals using optical technology due to its advantages such as large bandwidth, potential for optical integration, and immunity to electromagnetic interference. Most of the optical generation techniques focus on a conventional monocycle and doublet pulses [2]. However, these pulses do not fully satisfy the FCC rules around the most severely power-restricted Global Positioning System (GPS) band from 0.9–1.61 GHz and also they are power inefficient pulses as UWB is a power limited system. Hence, a more sophisticated pulse generation using Gaussian higher order derivatives such as the fifth order was introduced in [5]. A review of different pulse design techniques is given in

[6]. Recently, a four-tap microwave photonic filter optimized to comply with the FCC spectral mask is given in [7]. However, all recently introduced pulse generation concepts show increasing complexity, cost, and power inefficiency.

In this paper, we propose a simple and novel pulse generation concept which has the potential to be integrated in a compact optical chip, thereby reducing costs and increasing reliability. Our concept is basically a two-step approach. Firstly, we shape the Gaussian pulse into a modified doublet. Secondly, we combine the Gaussian doublet with its inverted and delayed version in a balance photo-detector. Via this process, we create more zero crossings in its temporal response, leading to more power efficient and better compliant pulses to the FCC rules. This proposed approach is simulated and experimentally demonstrated.

### Theory and Simulation Result

We use a modified doublet to describe our analysis due to its notch around the GPS band [8]. A general form of the modified doublet  $x(t)$  can be written as:

$$x(t) = \left[ 1 - 4\pi k \left( \frac{t}{\sigma} \right)^2 \right] \exp \left( -2\pi \left( \frac{t}{\sigma} \right)^2 \right)$$

where  $k$  is an arbitrary scaling parameter and  $\sigma$  is the pulse width. The spectrum of this signal does not fit excellently with the FCC mask; hence additional signal processing is required. We propose the use of a weighted sum of a modified doublet with its shifted and inverted version. The weighted sum  $y(t)$  is given by:

$$y(t) = a_{11}x(t) + a_{12}x(t - \tau)$$

where  $x(t)$  and  $x(t - \tau)$  are the inputs, one is delayed from the other,  $a_{11} = +1$  and  $a_{12} = -1$ . The effect of the values  $\sigma$  and  $\tau$  is to vary the pulse width of the modified doublet and the resulting pulse. The smaller the delay component, the narrower the pulse in the time domain and hence becomes wider in the frequency domain. In our analysis  $k = 1.13$ ,  $\sigma = 152$  ps and  $\tau = 38$  ps are the optimal values obtained from optimization processes regarding the power efficiency within the FCC spectrum. Simulation result of a normalized modified doublet pulses in the time-domain before and after a linear combination of the pulses is given in Fig. 1. Their corresponding spectra are shown in Fig. 2. Notice that the resulting pulse has more zero crossings compared to the conventional monocycle and doublet pulses, which causes its energy to move to higher frequency ranges. This weight sum concept has in principle the same effect as higher-order derivative operations of Gaussian pulses. One can also see that our concept represents a photonic microwave delay operation of the modified doublet with two tap-coefficients (+1, -1). A photonic microwave delay line with negative coefficients has a frequency response of a bandpass filter and can be implemented based on differential detection [9]. This filtering effect modifies both the pulse temporal shape and its spectrum. Hence, our approach benefits both from the modified doublet which has a notch around the GPS band and the filtering effect from a microwave delay operation in order to fully meet the FCC mask requirements with good power efficiency.

Simulation result shown in Fig. 2 suggests that the pulse fits the FCC-mask better than the conventional monocycle and doublet pulses even in the most severely power-restricted GPS band from 0.9–1.61 GHz. Furthermore, the approach avoids the requirement for higher order derivative of Gaussian pulses such as the fifth-order derivative recommended in [5]. The novelty of our approach lies in its simplicity to

generate pulses by combining low-order derivatives in order to match optimally the FCC requirement. Furthermore, our IR-UWB is efficient for transmission using antenna systems because most of the energy lies in the higher frequency band.

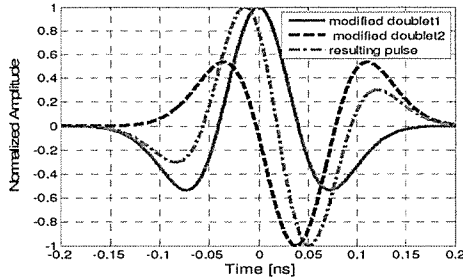


Fig. 1. Modified doublet, its inverted and delayed version, and the resulting pulse.

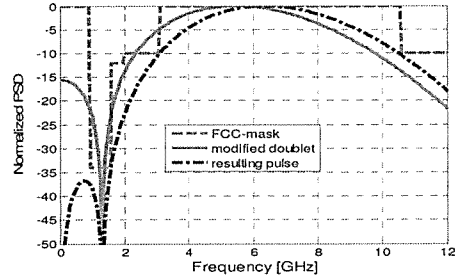


Fig. 2. PSD of the modified doublet, resulting pulse and FCC mask.

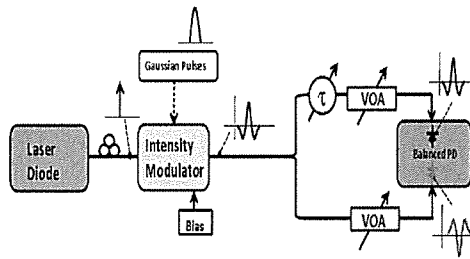


Fig. 3. Experimental setup

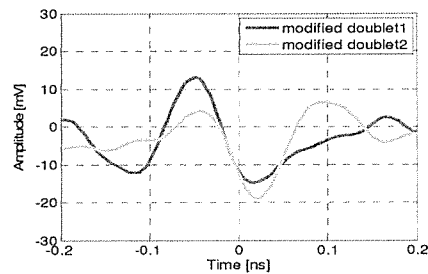


Fig. 4. PSD of the modified doublet, resulting pulse and FCC mask.

## Experiment Setup and Result Discussion

To verify the simulation results, the experimental setup used is shown in Fig. 3. In the setup, a laser diode at 1550.56 nm with an optical power of +4 dBm input to an intensity modulator (IM) which was driven by a Gaussian pulse train with a peak amplitude of 262.8 mV generated by an arbitrary waveform generator running at 24 GSamples/s. The modulated signal was divided into two arms using a 50:50 coupler and a fixed fiber delay was inserted in one of the arms. The signals in the both arms are detected by a 12-GHz balanced photodetector (BPD). This bandwidth is sufficient to detect signals in the FCC 3.1–10.6 GHz range. A real-time oscilloscope running at a sampling rate of 25 GSamples/s is employed for the time-domain waveform and RF spectral analyses. The electrical spectrum is compared with the FCC mask for compliance verification and power efficiency analysis.

When a Gaussian pulse is sent to the system and IM is biased to the non-linear region of its transfer function, then a doublet is produced due to the peak inversion mechanism as introduced in [10]. By proper adjustment of the bias voltage, modified doublets can be produced on each arm. The optimal bias voltage is found to be 6.4 V for this IM. It should be noted that this bias voltage can be reduced by using a more advanced IM. This setting achieves a modified doublet with duration of 276 ps. The output waveform of BPD of each arm is shown in Fig. 4 for the case when the relative delay between the arms is 60 ps. The optical delay line can be varied to further optimize the pulse duration and shape. Due to the differential detection of BPD, pulses at the upper arm will be subtracted by pulses in the lower arm, leading to the desired pulses. The resulting pulse

has more zero crossings after subtraction process in BPD is depicted in Fig. 5. The resulting power spectral density relative to the FCC mask can be seen in Fig. 6. It is clearly visible that the PSD of the pulse leads to higher power efficiency while respecting the FCC mask. Furthermore, the experimental results both in the time and frequency domain validate our predictions in the simulation results.

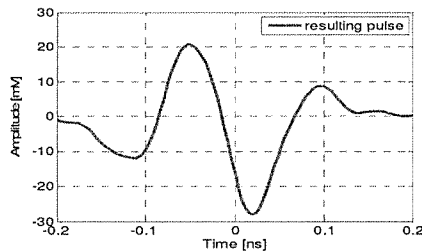


Fig. 5. Proposed UWB-IR pulse shape

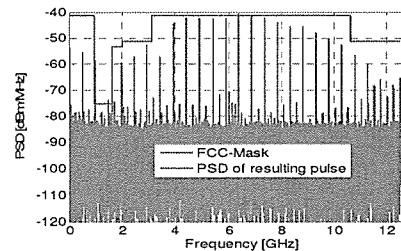


Fig. 6. PSD of proposed pulse versus FCC mask

## Conclusion

We propose a novel concept for the optical generation of IR-UWB signals. This concept combines optical and electrical signal processing in order to have a simple structure and an excellent pulse performance. The optical processing is responsible for creating identical but delayed modified Gaussian doublets while the electrical processing for inverting one of the doublets and combining them. The concept has been validated both by simulations and experiments. The generated pulse fully complies with the FCC-indoor spectrum mask even for the most severely power-restricted GPS band 0.96–1.61 GHz. Furthermore, the pulse power spectrum is extremely close to the mask, showing its high power efficiency. Finally, the concept can potentially be simplified by photonic integration leading to a small size, high reliability and cost-effective wide-deployment of high-speed UWB access.

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