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Experimental Demonstration of 2 Gbps IR-UWB Transmission over 100m GI-POF using Novel Pulse Generation Technique

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Abstract *We propose a novel generation technique for IR-UWB signal employing the weighted sum of modified doublets. We experimentally demonstrate a DSP-based BER measurement of 2 Gbps IR-UWB over 100m PF GI-POF for in-building network applications.*

Introduction

In recent years, there has been increasing demand for high-bandwidth wireless services. Users want to share multimedia applications among networked consumer electronics, personal computers and mobile devices accessed at home and perhaps remotely. However, the increasing demand for high bandwidth multimedia wireless services is hampered by the lack of available spectrum. The short-reach radio Ultra Wideband (UWB) technology has been adopted by the US Federal Communications Commission (FCC) as an attempt to make more radio spectrum available and also is named one of the most promising techniques for next generation short-range broadband wireless communications and sensor networks. Accordingly, there is growing interest in this technique due to its many abilities such as: co-existence with other wireless services, tolerance to multipath fading, low probability of interception, and passing through walls while maintaining communication¹. However, due to the low power spectral density (PSD) of -41.3 dBm/MHz in the frequency range from 3.1-10.6 GHz regulated by FCC, the communication distances are limited, typically less than 10 meters. To increase the coverage area, UWB signals should be carried over wired lines such as coaxial cable or optical fiber. Due to the low loss, large bandwidth and immunity to electromagnetic interference, distribution of UWB signals over optical fiber, better known as UWB-over-fiber is considered a promising solution².

A carrier-free Impulse Radio Ultra Wideband (IR-UWB) system is one of the UWB system approaches that do not need a complicated frequency mixer, intermediate frequency carrier and filter circuits. Furthermore, it has good pass-through performance and localization capability with high resolution due to the base-band transmission and high bandwidth respectively. Hence, the cost can be greatly reduced compared to that of multi-band orthogonal frequency multiplexing scheme and it is much

more suitable for indoor wireless communications.

However, one of the fundamental points which need a great consideration in IR-UWB circuits and systems design is the selection of the impulse signal type as it determines the performance of the IR-UWB system. Gaussian based monocycle pulses and doublets can provide better bit-error rates and multipath resilience among different impulse signals³. However, these pulses do not fully satisfy the FCC rules. Hence, more sophisticated pulse generation techniques based on higher-order Gaussian derivatives such as the fifth order have been introduced⁴ as well as a linear combination of two low-order derivatives of Gaussian pulse with different pulse shapes^{5,6}. However, all previously proposed pulse generation concepts show either increasing complexity or power inefficiency.

In this paper, we propose a simple and new pulse generation concept which can reduce complexity and cost of the system. Our approach is based on the concept of a weighted sum of a modified doublet with its inverted and delayed version. By this process, the proposed pulse has more zero crossings in the temporal response, leading to a more power efficient and fully FCC-compliant pulse even in the most severely power-restricted GPS band from 0.96-1.61GHz. This proposed approach has been simulated and experimentally demonstrated.

IR-UWB transport using plastic optical fibers

For large-scale short-range applications, multi-mode fibers (MMFs) offer the advantage of easy installation as their larger core diameter and numerical aperture allow large alignment tolerances. More importantly, plastic optical fibers (POFs) can enable short-range low-cost broadband transmission links, best suited to in-home and in-building networks environments. When compared to silica MMFs, graded-index POF (GI-POF) offers further advantages such as smaller bending radius (<5mm), better tolerance to tensile load and stress, and simpler

connectorization⁷. Therefore, impulse radio UWB (IR-UWB) over GI-POF provides an attractive solution for simple and low cost in-building networks.

Theory and Simulation Results

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 σ is the pulse width. The spectrum of this signal does not fit completely within the FCC mask; hence additional signal processing is required. We propose the use of a weighted sum of a modified doublet with its inverted and delayed 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 with respect to the other, $a_{11} = +1$ and $a_{12} = -1$. The effect of the pulse shaping factor, σ and delay component, τ is to vary the pulse width and the central frequency of the modified doublet and the resulting pulse. The smaller the delay component, the narrower the pulse in the time domain and hence its frequency spectrum becomes wider. 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 results of normalized doublet pulses in the time-domain before and after a linear combination of the pulses are given in Fig. 1. Notice that the resulting pulse has more zero crossings compared to the monocycle and modified doublet pulses, which causes its energy to move to higher frequency ranges. This linear combination concept has in principle the same effect as higher-order derivative operations of Gaussian pulses.

A simulation result shown in Fig. 2 suggests that the spectrum of our pulse has a central frequency of 6 GHz and a -10-dB bandwidth of 7.5 GHz. The proposed pulse fits the FCC-mask better than the modified doublet even in the most severely power-restricted GPS band from 0.9–1.61 GHz. Furthermore, the proposed approach avoids the requirement for higher order derivatives of Gaussian pulses⁴ and different pulse shaping factors^{5,6}. Hence, the novelty of our approach lies in its simplicity to generate pulses by combining low-order derivatives with fixed constant pulse shaping factors in order to match optimally the FCC requirement. Furthermore, our IR-UWB pulse is efficient for air transmission using an antenna because of the absence of a DC-component

and also because most of its energy occupies higher frequency ranges compared to conventional pulses.

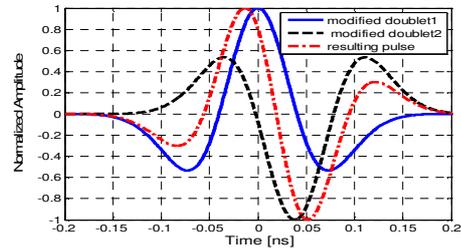


Fig. 1: Simulation result of modified doublet and resulting pulse

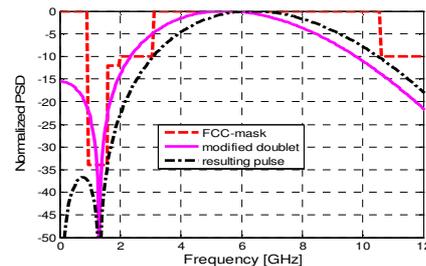


Fig. 2: Simulation result of FCC mask and PSD of modified doublet and resulting pulse

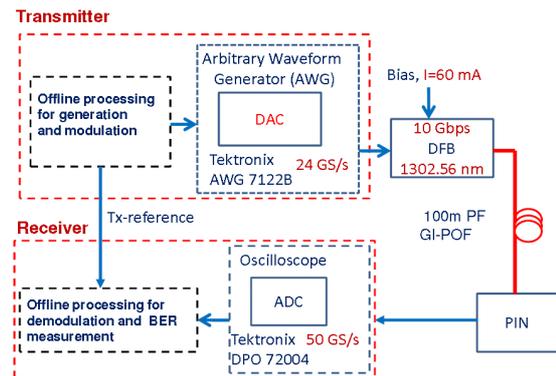


Fig. 3: Experimental Setup

Experimental results and Discussion

Based on the above principle, an experimental setup is shown in figure 3. Our IR-UWB pulse has been constructed off-line using MATLAB and sent to the arbitrary waveform generator (AWG) running at 24 GSamples/s. The generated electrical IR-UWB pulse from AWG was used to directly modulate a DFB laser at 1302.56 nm wavelength which was biased at 60 mA. Then the modulated signal is transmitted over 100 metres of 50- μ m core perfluorinated GI-POF (PF GI-POF) and detected by a 25 GHz photo-detector (PD) with a photosensitive area of 25 μ m. We use a real-time oscilloscope running at a sampling rate of 50 GSamples/s to show the time-domain waveform and obtain data for BER measurement. Finally, the electrical spectrum of the pulse is obtained for an FCC mask compliance analysis.

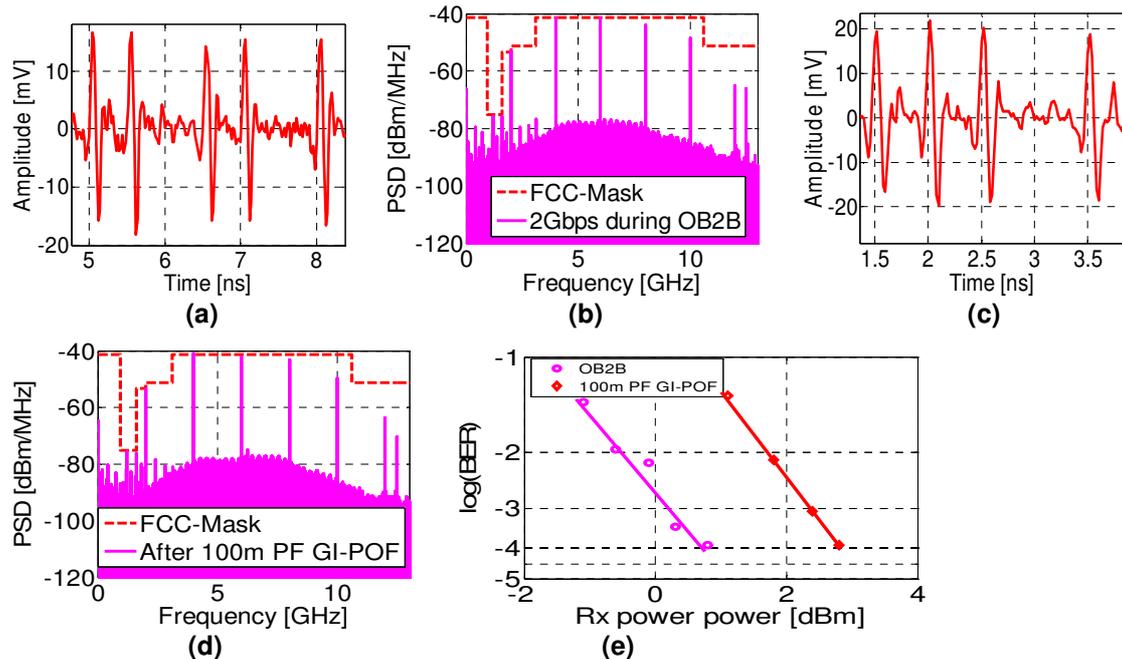


Fig. 4: (a): IR-UWB pulse optical back-to-back (b): FCC mask and PSD of 2 Gbps transmission during optical back to back (c): IR-UWB pulse after 100m PF GI-POF (d): FCC mask and PSD of 2 Gbps transmission after 100m PF GI-POF (e): BER measurement

Several modulation formats can be used for IR-UWB, however for simplicity and low-cost, on-off keying (OOK) is employed to directly modulate the DFB laser. The received data during the optical back-to-back case is shown in Fig. 4a. The PSD of the pulse in the optical back-to-back case is shown in Fig. 4b. Due to the OOK modulation scheme, the discrete spectral comb-lines appear in the spectrum and the spacing between the comb-lines is 2 GHz which corresponds to the bit-rate of the transmission system. Notice that the resulting spectrum is narrow compared to the optimally simulated pulse; this is due to the low sampling frequency of the AWG which indirectly forces the delay to be large, $\tau=41.67$ ps. After 100m PF GI-POF transmission, the time-domain waveform and PSD of the pulse are shown in Fig. 4c and Fig. 4d respectively. The results clearly show successful transmission of 2 Gbps without any significant distortion which is mainly due to the high bandwidth of the PF GI-POF fiber.

Fig.5 shows the BER results of 2 Gbps IR-UWB signal transmission. For each BER measurement point, 8190 IR-UWB bits following a $2^{13}-1$ PRBS pattern are transmitted and recorded using a 50 GSamples/s Digital Processing Oscilloscope. The BER is subsequently computed using a DSP algorithm in a bit-for-bit comparison between the transmitted and received data. The DSP algorithm distinguished between binary "1" and "0" by comparing the average power within the central window of each bit-slot to an adaptive

decision threshold. According to the result of the BER measurement, the 100m PF GI-POF transmission shows a penalty of around 2 dB, due to the random mode mixing and modal noise at the receiver.

Conclusion

We proposed a novel technique to generate an IR-UWB pulse by a weighted sum of a modified doublet with its inverted and delayed version. We experimentally demonstrated for the first time an FEC-limited DSP-based BER measurement of 2 Gbps IR-UWB transmission over 100m PF GI-POF. The generated pulse fully complies with the FCC-indoor spectrum mask even in the most severely power-restricted band from 0.96 GHz to 1.61 GHz. We believe that our newly proposed IR-UWB over PF GI-POF has a potential application in a simple and low-cost high-speed short-range communication networks for in-building networks.

Acknowledgment

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