Experimental Generation of FCC-Compliant UWB Pulse using FBGs

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Abstract *A simple and robust technique for the generation of power-efficient, FCC-compliant UWB pulses is proposed and experimentally demonstrated. An FBG shapes the source spectrum and a length of SMF performs the frequency-to-time conversion.*

Introduction

Ultra-wideband (UWB) radio is of interest for many short-range indoor wireless communications applications, motivating research into generation of the appropriate UWB pulses [1-4]. Most pulse generation techniques are electronic and mainly focus on the widely adopted Gaussian monocycle and doublet pulses [1]. UWB systems are highly power-limited, and pulse shaping techniques that eke out the greatest legally-allowed transmission power are critical to enhancing performance. While easily generated, Gaussian monocycles are poorly adapted to the spectral mask imposed by the Federal Communications Commission (FCC) in the US [5].

Optical pulse generation techniques for UWB have also been proposed based on optical spectral shaping and frequency-to-time conversion using a dispersive medium [2-3]. The pulse shaping device in [2] consists of a free space bulky grating, a large focal length lens to angularly disperse the frequency components, and an LCM to modulate the amplitude of frequency components. Although this arbitrary waveform generator can be used to generate the desired UWB pulses, it can not be used in many applications due to the large size and high optical loss. Based on the general concept provided in [2], an all-fiber pulse shaper was recently proposed in [4] in which two optical filters with complementary spectra are placed in two arms of an interferometer to shape the power spectrum as the shape of the Gaussian monocycle or doublet pulses. However, the RF spectrum of the generated pulse contains a non-FCC-compliant baseband spectral component below 1 GHz due to the wide Gaussian pedestal of the source. In addition, the interferometric structure of the system makes it very sensitive to the environmental changes such as temperature or vibration.

In this paper we propose a new approach to generate an UWB pulse based on the concept in [2] using the fiber Bragg grating (FBG) that is both FCC-compliant and maximizes the transmitted power. We exploit pulse design techniques proposed in [6] to design pulses with maximum transmitted power (i.e. maximum spectral efficiency) while respecting the FCC mask. We use a balanced photodetctor (BPD) to completely remove unwanted DC components. Note a DC block is insufficient as the DC component results from an additive, unwanted rectangular pulse superimposed on the desired pulse shape. Note that this unwanted pulse is present in all optical pulse shaping techniques based on frequency-to-time conversion. We take advantage of all-fiber components that are insensitive to environmental changes.

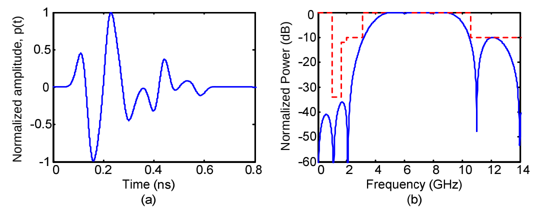

Fig.1. Designed UWB pulse (a) and its spectrum (b).

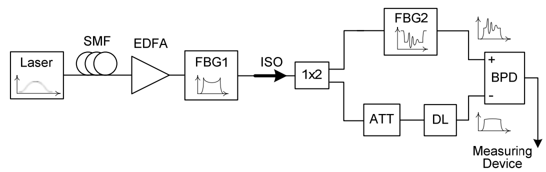

Fig.2. Block diagram of the experimental setup.

UWB pulse design

To design a UWB pulse that maximizes transmitted power while respecting the FCC mask, we follow the approach in [6], designing the optical pulse per:

$$p(t) = \sum_{n=0}^{M-1} w[n]\, g(t - nT_0) \qquad (1)$$

where, $g(t)$ is Gaussian monocycle and $w[n]$ are M real coefficients with spacing T_0. M is constrained by fabrication complexity of the FBG, and $w[n]$ and T_0 are optimized numerically. In this paper we used M =14 and T_0 = 35.7 ps. The designed UWB pulse and its spectrum are plotted in Fig. 1. The pulse duration is 0.7 ns and the spectral utilization efficiency is 67%. A larger M would provide better efficiency, but it also results a longer pulse duration, and a complex form requiring high resolution in FBG writing process. Note that M equals 2 and 3 results in Gaussian monocycle and doublet pulses, respectively.

Experiment and discussion

To generate the UWB pulse, we shape the spectrum of a passive mode-locked fiber laser (MLFL) by using a fiber Bragg grating based on the desired time domain pulse. The spectrally shaped pulse is then sent to a dispersive medium (e.g. SMF) to perform fre-

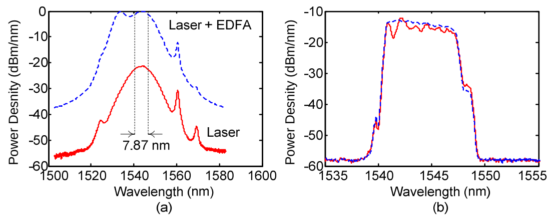

Fig.3. (a) Spectrum of the source before and after EDFA, (b) spectra in the two arms of the BPD.

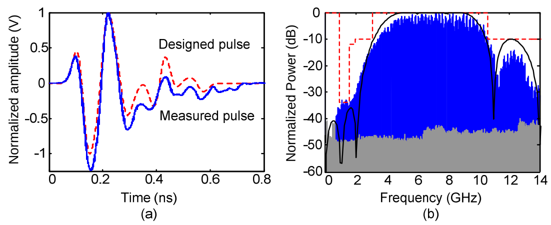

Fig.4. Measured UWB pulse (a) and the spectrum (b).

quency-to-time mapping. The generated pulse is the summation of the desired pulse shape and a rectangular pulse with the same width, which can be removed by using a BPD.

The block diagram of the setup is shown in Fig. 2. The MLFL generates 270 fs sech^2 pulses with a repetition rate of 31.25 MHz. The laser pulse is sent to a 5.46 Km of SMF with total dispersion of 88.9 ps/nm to map 7.87 nm bandwidth of the source to 0.7 ns. We used the SMF before spectral shaping to avoid duplicate use of fiber in the second arm of BPD. The first FBG is a chirped grating (phase mask chirp=2.5 nm/cm) with an apodization profile designed to flatten the mode-locked source spectrum over a 7.9 nm bandwidth.

The optical signal is then divided into two arms. In the first arm, we use the second chirped grating (0.498 nm/cm) with a more complex apodization profile optimized to imprint the desired pulse shape on the spectrum of the source. The gratings are written via a UV beam scanning technique. The apodization profiles are applied by dithering the phase mask with an estimated resolution of 300 μm. Both FBGs are 14cm long and are used in transmission.

In the second arm, the optical delay line (DL) and the variable attenuator (ATT) are used to balance the amplitude and the delay of the two arms. We used an isolator to prevent the back and forth reflections between the two FBGs. The optical spectra of the two arms are measured by an optical spectrum analyzer. The power spectral density (PSD) of the MLFL before (solid line) and after EDFA (dashed line) are plotted in the Fig. 3(a). The PSDs of the two arms is shown in Fig. 3(b), where the solid and dashed lines represent the PSDs after the FBG2 in the first arm and after DL in the second arm, respectively. As we expected the FBG1 cuts the source spectrum and compensates the shape of the source to the almost flat spectrum.

The two arms are connected to a 10 GHz DSC-710 BPD. The detected UWB pulse shape (Fig. 4a) is then viewed by a 40GHz sampling scope (Agilent 86100A) and the corresponding electrical power spectrum (Fig. 4b) is measured by a high speed RF spectrum analyzer (HP 8565E). Comparing the designed pulse (dashed line) with the measured pulse (solid line) in Fig. 4a, we see a general good match, despite some modifications in the peaks and small variations in the tail of the pulse attributable to imperfections during FBG writing process. The electrical PSD of the pulse in Fig. 4(b) scrupulously respects the FCC spectral mask (dashed line) and follows well our design (solid line). The reduced power in frequencies above 10 GHz is mainly due to the frequency response of the BPD that inflicts more than 5 dB loss at 14GHz compared to the DC level. The gray curve in this figure represents the noise floor of the BPD and the RF spectrum analyzer. We note that the pulse has almost a flat spectrum between 4 to 9 GHz range.

Conclusions

While easily generated, Gaussian monocycles are poorly adapted to the spectral mask imposed by the FCC. Electrical techniques for generation of more complex UWB pulses encounter many difficulties due to the extreme bandwidth of the pulse. In this paper, we proposed and experimentally demonstrated optical generation of a power-efficient, FCC-compliant UWB pulses using fiber Bragg gratings. In this state-of-the-art experiment we used 14 coefficients to design the UWB pulse per (1) and achieved 67% of the maximum allowed transmitted power. We also proposed the use of BPD to remove the undesired, rectangular shaped pulse superimposed on the desired pulse, which exists in all techniques involving frequency-to-time conversion. The frequency-to-time conversion implemented via dispersion in a length of SMF could instead be implemented by including the dispersion in the first FBG in our setup, provided it was used in reflection. This solution would lead to an even more compact optical subsystem. In addition, the system is quite stable without serious sensitivity to the environmental changes such as temperature or vibration.

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