Ultra-Wideband Pulse Generation Based on Dispersion-Diversity Multicore Fiber

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Abstract: We experimentally demonstrate, for the first time, reconfigurable arbitrary waveform generation using a dispersion-diversity heterogeneous multicore fiber by synthesizing a variety of tunable high-order ultra-wideband pulses (up to 7 samples).

1. Introduction

Multicore fibers (MCFs) have opened a new window of possibilities for microwave signal processing and radio-over-fiber distribution applications, in addition to conventional high-capacity digital communications [1]. As we demonstrated in the past [2], using dispersion-engineered heterogeneous MCFs to process and distribute microwave signals simultaneously results in compact fiber-distributed signal processing. This approach is based on designing MCFs specifically to function as tunable sampled true time delay lines (TTDLs), where each core provides a separate radiofrequency (RF) signal with a given time delay. Many reconfigurable microwave signal processing functionalities can be implemented with TTDLs, including RF signal filtering, radio beam-steering for phased-array antennas, and arbitrary waveform generation (AWG). Considering the last functionality, a different number of fiber-based techniques have been demonstrated in the past, such as frequency-to-time mapping [3], phase-modulation to intensity-modulation conversion [4], and microwave signal filtering [5]. These approaches have in common the use of a single chromatic dispersion value in a standard singlemode fiber, either to apply a conversion or to obtain a given time delay. In addition to the wavelength dimension, we propose the inclusion of the space dimension to increase the performance flexibility and versatility of the system by exploiting a variety of chromatic dispersion values in a single fiber.

In this work, we report the experimental demonstration of optical AWG taking advantage of the spatial and dispersion-diversities provided by a heterogeneous 7-core fiber developed for tunable TTDL operation. We synthesize a variety of Ultra-wideband (UWB) pulses following a reconfigurable microwave photonic approach where the number of taps varies from 2 to 7 according to the number of cores exploited.

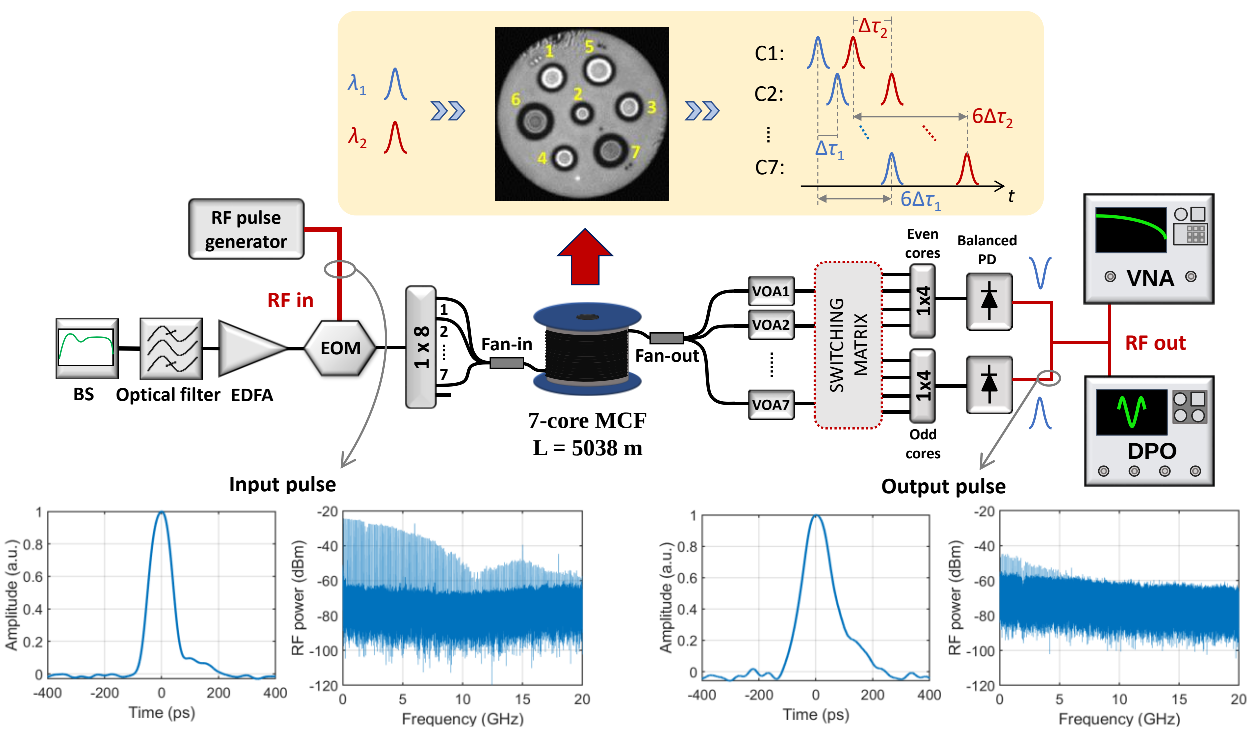

Fig. 1. Experimental setup for AWG based on a dispersion-diversity multicore fiber.

2. Principle

Figure 1 shows the experimental setup implemented for the proposed AWG system. Its basic principle of operation consists of the propagation of a single RF-modulated temporal pulse along the 7 cores of a dispersion-engineered heterogeneous MCF to obtain 7 time-delayed replicas of the original pulse. Then, a set of variable optical attenuators (VOAs) control the sample amplitudes and a switching matrix sends each core output to the desired branch of the balanced photodetector (PD) to obtain the positive and negative pulses. We use an RF pulse generator with a 12.5-Gb/s bit rate to create an 80-ps temporal width pulse with a 5-ns repetition rate. A filtered broadband source (BS) is used as the optical carrier to avoid optical coherence in photodetection. The MCF has a length of L = 5038 m and consists of 7 trench-assisted step-index cores with different radial dimensions and dopant concentrations, [2]. The maximum intercore crosstalk is below -30 dB. The fiber cores were designed to feature linearly incremental group delays with an incremental chromatic dispersion of ΔD = 1 ps/km/nm at λ_0 = 1530 nm, so that the MCF behaves as a tunable TTDL, [2]. The time-delay between adjacent pulses can be continuously tuned by the MCF itself as $\Delta\tau = \Delta D\cdot(\lambda - \lambda_0)\cdot L$, so that a 150-ps tunability range is achieved by sweeping the optical wavelength of the BS, λ, between 1530 and 1560 nm. The electrical response of the generated waveform is measured at the output of the balanced PD in both time and frequency domains by using a digital phosphor oscilloscope (DPO) and a vector network analyzer (VNA), respectively.

3. Experimental results

Figure 2 gathers the measurement of different waveforms that were synthesized by choosing the proper combination of cores with a given tap weight at the optical wavelength of 1550 nm in comparison with the simulated ones. Figs. 2 (a) and (b) represent a monocycle waveform (2 samples) with different polarity. The polarity of a given waveform can be inverted by changing the path of each core in the switching matrix. Figs. 2(c)-(f) show, respectively, the resulting waveforms for a doublet (3-sample), triplet (4-sample), quadruplet (5-sample) and 7-sample combinations. The tap weights for each case are listed in Fig. 2 caption. The generated waveforms are in good agreement with the expected results, with slight mismatches that can be attributed to either the nonsymmetrical waveform of the input RF pulse or noise. First, as we can see in Fig. 1, the baseband pulse presents a non-negligible tail at the right-hand side of its amplitude that can invade the temporal slot of the following samples and affect their amplitude and shape. This phenomenon affects especially higher-order waveforms where the pulses from several cores are combined. In second place, the inevitable noisy response of the filtered broadband source (see the floor noise level on the pulse RF spectrums of Fig. 1) produces non-negligible power fluctuations that can affect the shape of the waveforms, especially those containing taps with low amplitudes. The combination of both effects can be clearly appreciated in the 7-sample waveform, where there are amplitude fluctuations at the beginning and end of the waveform.

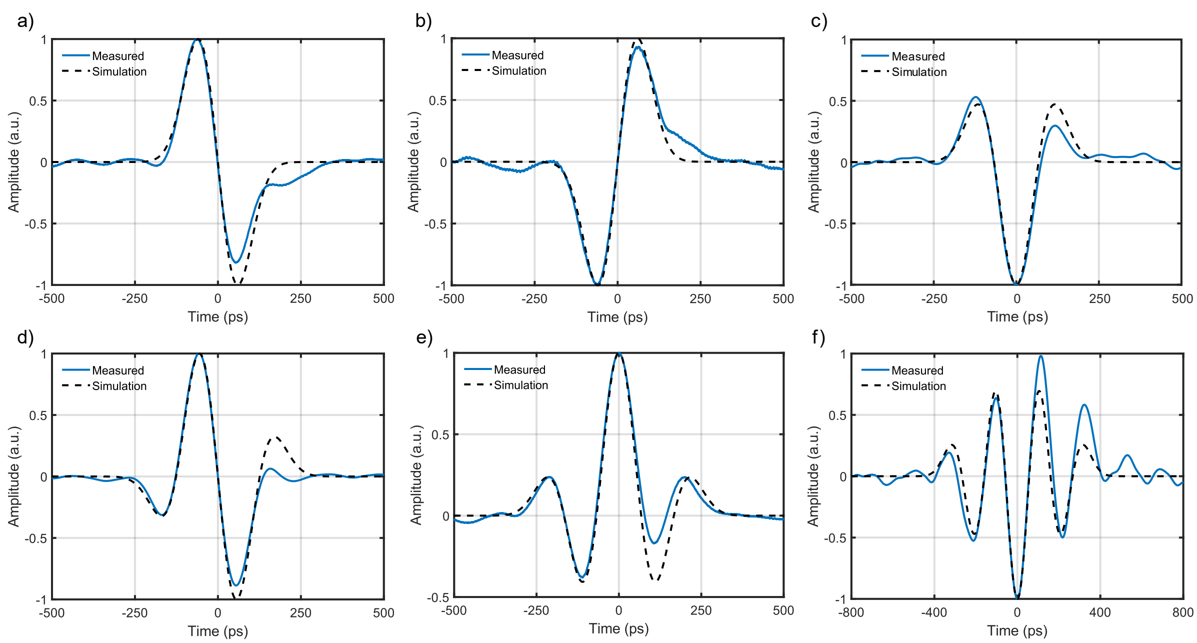

Fig. 2. a) Monocycle waveform with weights [1, -1], b) monocycle waveform with weights [-1, 1], c) doublet waveform with weights [0.5, -1, 0.5], d) triplet waveform with weights [-0.35, 1, -1, 0.35], e) quadruplet waveform with weights [0.25, -0.5, 1, -0.5, 0.25] and f) 7-sample waveform with weights [0.25, -0.5, 0.75, -1, 0.75, -0.5, 0.25].

One of the main advantages of this architecture relies on the tunability of the TTDL, which provides the capability to continuously tune the temporal pulse separation with the optical wavelength. This waveform tunability can be useful for a system that needs to adapt to different regulations or to change the temporal and spectral properties of the generated waveform dynamically. Fig. 3(a) shows the measured waveforms of a monocycle at the optical wavelengths of 1550, 1555 and 1560 nm, which correspond to a pulse separation of 100, 125 and 150 ps, respectively. Fig. 3(b) represents the measured spectra along with the representation of the ideal 2-sample RF filter (black dashed line) for the previous waveforms, where we see how the interference pattern is adequately generated for the abovementioned time delays. As a second example, Figs. 3(c) and (d) represent, respectively, the measured temporal waveforms and RF spectra for the quadruplet configuration at the optical wavelengths of 1550, 1555 and 1560 nm. We see, again, satisfactory waveform tunability, although in this case both the temporal waveforms and their spectra experience some distortion due to amplitude mixing with adjacent samples and noise since we have increased the number of samples (as discussed in the previous paragraph).

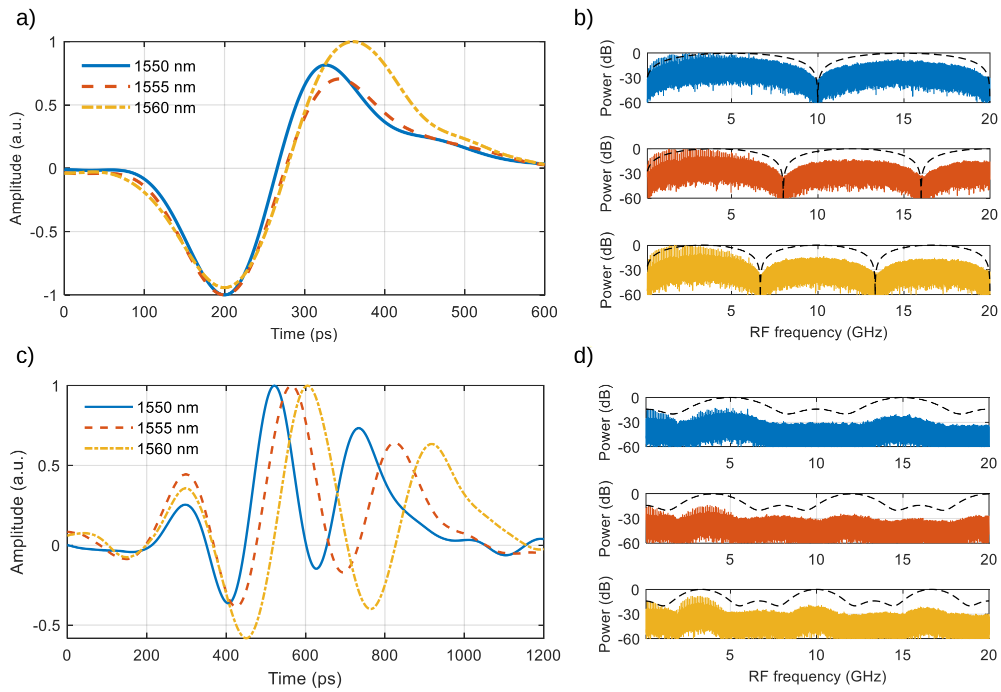

Fig. 3. Monocycle waveforms generated at different optical wavelengths (a) and their respective electrical spectrum (b). Quadruplet waveforms generated at different optical wavelengths (c) and their respective electrical spectrum (d).

4. Conclusions

We experimentally demonstrate, for the first time, reconfigurable AWG by exploiting the spatial and dispersion diversities provided by a heterogeneous MCF that acts as a sampled tunable TTDL. We implemented different waveforms by incoherently filtering a baseband 12.5-Gb/s bit-rate pulse by combining the output of up to 7 cores with a given group delay. Tunability is provided by adjusting the differential group delay between samples as one varies the optical wavelength, thanks to the dispersion-diversity behavior of the fiber, which features evenly-spaced incremental core chromatic dispersion values close to 1 ps/nm/km.

Acknowledgments

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