Supercontinuum based all-optical Digital communication system at 2THz

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Abstract

An all-optical Supercontinuum based communication system at 2 THz is modeled using photonic crystal fiber of length 1km, and its performance using digital modulation techniques such as Amplitude Shift Keying (ASK) is evaluated using standard metrics such as eye diagram and bit error rate. From the above mentioned valuations, one can obtain its robustness, hence leading to secure communication systems at terahertz data rates, which forms the novelty of the present work.

Keywords: Supercontinuum, Ultrashort Pulses, Amplitude Shift Keying, Photonic Crystal Fiber, Terahertz Communications

1. Introduction

Recent trends show an ever-increasing demand for instant and reliable communication, with faster data rates. The consequence is that photonic components are increasingly finding applications in high frequency communications systems. As optical fibers have advanced in leaps and bounds in recent times, a particular group of fibers, the photonic crystal fibers (PCF) emerge as the forerunners in high frequency robust communication systems [1]. Because of its ability to confine light, or with confinement characteristics not possible in conventional optical fiber [2], PCF is now finding applications in fiber-optic communications [3, 4], fiber lasers [5], nonlinear devices [6], highly sensitive sensors [7], and other areas. This is perhaps the single most successful fiber design to date based on structuring the fiber design using air holes and has important applications regarding high numerical aperture and light collection especially when implemented in laser form, but with great promise in areas as diverse as biophotonics [8]. [15] also discusses Liquid-Core PCF, which provides better robustness against perturbations.

One of the fast-developing regions of the electromagnetic spectrum is the Terahertz range, also called as millimeter waves. Terahertz (THz) waves offer tens and hundreds of gigahertz bandwidths [9, 10], and it is shown that this frequency band unlike Microwaves, is only a minor health threat [9, 10]. The main issue for THz wave propagation is atmospheric attenuation, which is dominated by water vapor absorption in the THz frequency band. From experiments on the propagation of THz waves in air, it is observed that there are a number of THz transmission windows [9, 10].

The present work models an all-optical communication system based on supercontinuum, using photonic crystal fibers as the channel, and evaluates its robustness. The modulation technique used here is amplitude shift keying (ASK)[12]. The propagation of hyperbolic secant ultrashort pulses with digital modulation techniques at Terahertz frequencies using the principles of supercontinuum forms the novelty of the present work.

2. Methodology

The generalized nonlinear Schrodinger Equation governing the Signal Propagation in PCF is given as follows:

$$\begin{aligned}
&\frac{\partial A}{\partial z} + \frac{\alpha}{2}A + \frac{i\beta_2}{2}\frac{\partial^2 A}{\partial T^2} - \frac{\beta_3}{6}\frac{\partial^3 A}{\partial T^3} - \frac{i\beta_4}{24}\frac{\partial^4 A}{\partial T^4} \\
&= i\gamma\left(1 + \frac{i}{\omega_0}\frac{\partial}{\partial T}\right)\left(A(z,T)\int_{-\infty}^{\infty} R(T')|A(z,T-T')|^2 dT'\right), \\
&R(t) = (1-f_R)\delta(t) + f_R h_R(t) \text{and} \\
&h_R(t) = \frac{\tau_1^2+\tau_2^2}{\tau_1\tau_2^2}\exp(-t/\tau_2)\sin(t/\tau_1),
\end{aligned} \tag{1}$$

where $T = t - \beta_1 z$.

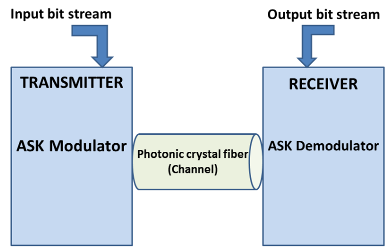

Figure 1: Block diagram of all-optical communication system based on supercontinuum

Here $A(t, z)$ describes the pulse envelope in time t at the spatial position z, β corresponds to the group velocity dispersion (GVD) coefficient, α is the confinement loss and γ is the nonlinear parameter responsible for self phase modulation. R(t) can be evaluated using the above relations, where for standard silica PCF, $\tau_1 = 12.2$fs and $\tau_2 = 32$ fs[16]. $f_R = 0.18$. Since four types of pulses, namely soliton, similariton, square and sinusoid are considered, the values for β and γ are determined for terahertz propagation of solitons from [15] with a FWHM pulse width of 56.5fs and a central wavelength of 850nm[15]. A Silica Core PCF is considered, where the small pitch Λ is taken as 1μm and the diameter-pitch ratio, d/Λ is given as 0.6. Such a photonic crystal fiber exhibits a Zero Dispersion wavelength of 742nm, and the Group Velocity Dispersion of 110.26 ps/nm at the operating wavelength of 850nm. The values for Group Velocity Dispersion constants β_2, β_3, and β_4 are given as -0.0104 ps^2/m, $3.78x10^{-5}ps^3$/m, and $1.02x10^-6ps^4$/m respectively. The nonlinear factor γ is given as 0.1518 $W^{-1}m^{-1}$, and the confinement loss α is given as 0.019 dB/m. Incorporating the above-mentioned values, the nonlinear Schrodinger equation is numerically solved using the Split Step Fourier method (SSFM)[14]. The SSFM method relies on computing the solution in small steps, and treating the linear and the nonlinear steps separately. It is necessary to Fourier transform back and forth because the linear step is made in the frequency domain while the nonlinear step is made in the time domain. In our model, we use the Predictor-Corrector Symmetrized Split Step Fourier Method (PC-S-SSFM) to model the Photonic crystal fiber[14]. A nominal fiber noise of 25dB SNR is also added to the propagating signal.

2.1. Transmitter

The modulation schemes used in the present work is ASK. In digital modulation, an analog carrier signal is modulated by a discrete signal. In Amplitude Shift Keying (ASK), the amplitude of an analog carrier signal varies in accordance with the bit stream (modulating signal), keeping frequency and phase constant[12]. The level of amplitude can be used to represent binary logic 0s and 1s. One can think of data signal as an ON or OFF switch. In the modulated signal, logic 0 is represented by the absence of a carrier, thus giving OFF/ON keying operation and hence the name (On-Off Keying) OOK is given. A block diagram illustrating the proposed communication system is shown in fig.(1), and the various components are explained as follows.

The transmitter component consists of a message generator and modulator. The message generator is modeled by a sequence of randomly generated bits, and Reed Solomon error control coding of (n,k) of (255,233) is then applied to this bit stream, where the parity lengths are determined from the number of bits generated.

Following the message generation block, the bit stream is then fed to an ASK modulator. This is represented as a generic mathematical model where, a hyperbolic secant pulse is chosen as carrier, and the ASK modulator outputs one cycle of the carrier for every logical '1' and zero amplitude for every logical '0'[12].

2.2. Channel

The Channel of the proposed communication system is a fiber link, and in this case Photonic crystal Fiber is chosen. This is because of the versatility and the agility of PCF fibers in Terahertz regime. Mathematically, this is modeled using the Split-Step Fourier method[14], and the link length is taken as 1km.

2.3. Receiver

The receiver component consists of two parts, an ASK Demodulator and the output message decoder. The output of this block is fed to ASK demodulator which is mathematically modeled to give a logic '1' when carrier presence is detected and logical '0' when no carrier is detected. This generates a bit stream on which the error control decoding and detection is applied. The result is a bit stream that is the output of the communication system.

3. Results and Discussions

The Supercontinuum based communication system is implemented in MATLAB using a train of ultrashort (5fs) hyperbolic secant based pulses as a carrier waveform, at a repetition rate of 2THz, for a PCF length of 1km. The message generation part consists of a bit stream generator, modeled here as a random bit stream of 128 bits, followed by an error control coding block, where Reed Solomon of (n,k) of (255,233) is used. This is then sent to an ASK modulator, which is represented mathematically as the product of bit stream and ultra-short pulse train. Since the carrier waveform is designed at a repetition rate of 2THz, and since each bit modulates one cycle of the carrier, the transmitted bit rate is 2Tbps. The output of this stage is a modified train of the carrier, with the carrier cycle existing when the bit is a '1' and zero amplitude when the bit is a '0'. The transmitted bit stream of 128 bits is shown in fig.(2). The ASK modulated signal is shown in fig.(3). A zoomed in sample of the modulated signal for the first bit is illustrated in fig.(4). The spectrum of this ASK modulated signal is shown in fig.(5). As can be seen from fig.(5), the spectrum depicts a supercontinuum extending from 400nm to 1500nm. This signal is then propagated through the PCF, and the output

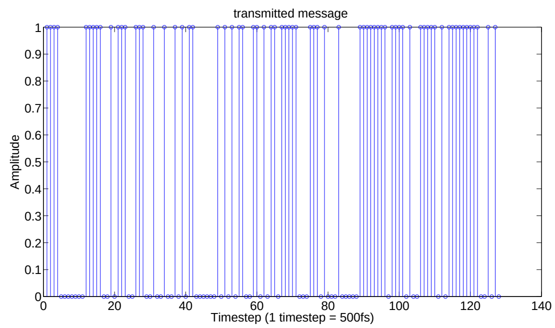

Figure 2: Transmitted bit stream of 128 bits

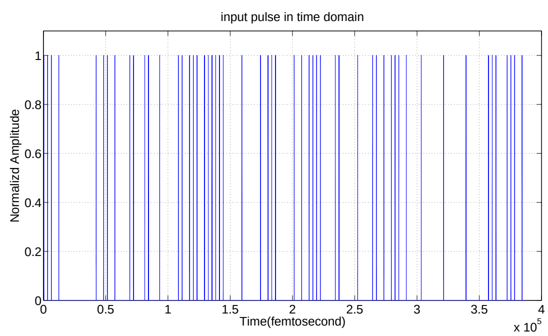

Figure 3: ASK Modulated waveform

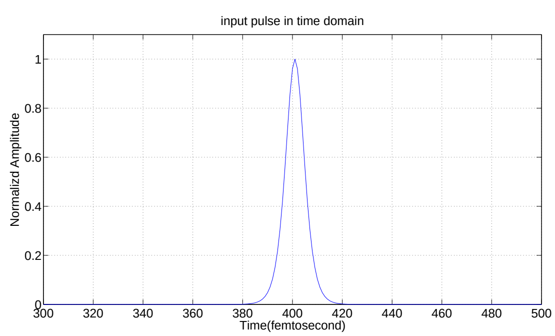

Figure 4: Zoomed in version of the ASK Modulated waveform for the first bit

of the PCF is shown in fig.(6). The spectrum is shown in fig.(7). This output is then fed to an ASK Demodulator, which is based on the principle of thresholding and averaging. The output of this block is a bit stream as shown in fig.(8).

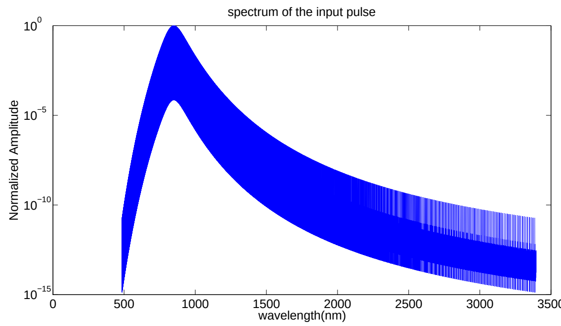

Figure 5: Spectrum of the ASK Modulated waveform with a central wavelength of 850nm

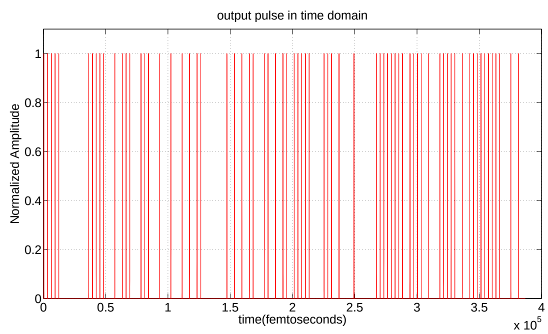

Figure 6: Output signal of the photonic crystal fiber

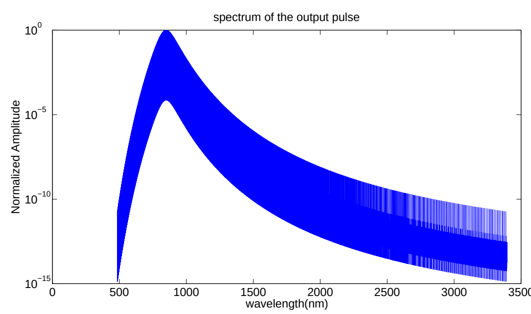

Figure 7: Spectrum of the PCF output with a central wavelength of 850nm

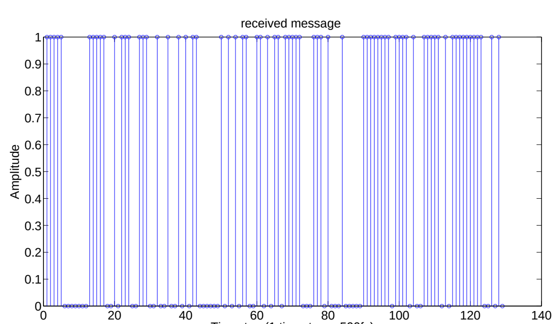

Figure 8: Received bit stream

The photonic crystal fiber is modeled using the Predictor-Corrector Split Step Fourier Method for a length of 1km. For the case of solitary waves (sech pulses), the fiber properties of group velocity dispersion and nonlinearity are taken from [15].

The performance of the system is assessed by using two important metrics, the eye-diagram and the Bit Error Rate (the fraction of erroneous bits). The Eye diagram is a superimposition of wave cycles for all the bits[16]. The bit error rate is obtained as 0, indicating the near-perfect distortion performance. The eye diagram for a message length of 128 bits is shown in fig.(9).

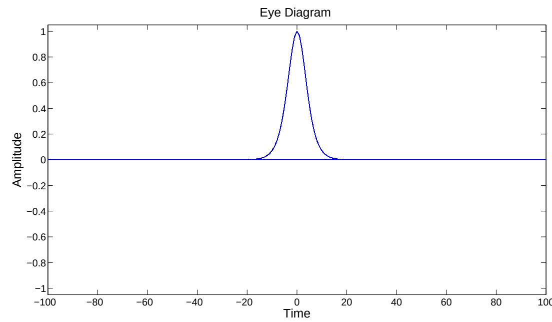

Figure 9: Eye diagram for ultrashort hyperbolic secant based received signal

4. Conclusion

A model of an all-optical communication system using supercontinuum based on photonic crystal fiber has been developed that describes fairly accurately, the various channel effects. It is evident from the results that hyperbolic secant pulses are relatively robust carriers for THz communications compared to squares/sinusoidal carriers and this may enable a distortion free communication system, even in the worst possible SNR levels. The modulation scheme chosen here is ASK in order to avoid phase complexities in split-step Fourier method calculations. This can be extended in future to include other phase-based modulation schemes such as bipolar phase (BPSK) and Quadrature phase (QPSK).

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