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Photonic Generation of Higher Order UWB Signals Using Optical Amplifiers

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Abstract: Photonic generation of UWB signals is an emerging technique as it requires no complex optical-electrical or electrical-optical conversion. There are a number of techniques employed to generate lower order UWB signals photonically. But applications that uses UWB signals demands higher order wave. Also the generation scheme should consider optimum hardware utility and inturn the reconfigurability of the components used. Considering these criteria this paper analyses the techniques of generating UWB signals using optical amplifiers. Optical amplifiers that works based on the principal of spontaneous and stimulated emission has the inherent property of reconfigurability in response to the applied bias current and its dopant concentration. Utilizing these properties this paper aims at generating higher order UWB signals using optical amplifiers.

Keywords- Semiconductor Optical amplifier (SOA), Erbium Doped Fiber Amplifier (EDFA), Power Spectral Density (PSD), Mach Zehnder Modulator (MZM), Ultra Wide Band.

I. Introduction

Ultra-wideband (can also be known as UWB, ultra-wide band and Ultraband) is a radio technology which may be used at a very low energy level for short-range, high-bandwidth communications using a large portion of the radio spectrum. UWB transmissions transmit information by generating radio energy at specific time intervals and occupying a large bandwidth. Since its transmission resembles that of frequency hopped sequence transmission it is less prone to noise. A February 14, 2002 FCC Report and Order authorized the unlicensed use of UWB in the frequency range from 3.1 to 10.6 GHz. The FCC power spectral density emission limit for UWB transmitters is −41.3 dBm/MHz. Usage of photonics in generation of UWB includes Mach Zehnder Modulator (MZM) transmission curve utilization, Microwave Photonic Filtering (MPF) and utilizing nonlinear effects such as cross gain modulation (XGM), cross phase modulation (XPM) and four wave mixing (FWM) [x]. In most of these schemes, low-order derivative UWB signals (i.e., first- and second- order) are easily generated. Low order UWB signals have a strong power spectral density (PSD) between 0 GHz and 2 GHz, which mismatches the power dip required in that frequency range and hence lead to severe interference with GPS [i]. But, high-order UWB signals have low PSD in the low frequency region, which essentially reduces the interference with GPS system. Photonic methods of generating UWB signals using optical amplifiers results in higher order UWB generation [ii]. Properties of optical amplifiers like Semiconductor Optical Amplifier and Erbium Doped Fiber Amplifier is being exploited in this paper for efficient generation of UWB signals of our required range.

II. Operating Principle

The basic working principle of these optical amplifiers is stimulated and spontaneous emissions in response to an applied incident wave photon. In response to an incident wave of photons the atoms from lower energy level gets excited to a higher energy level. If the number of light sources in the excited state at time t is given by N(t), the rate at which N decays is:

$$\partial N(t)/\partial t = -A_{21}\,N(t) \qquad \textbf{(1)}$$

The Equation (1) gives the rate of spontaneous emission. In the equation, A21 is a proportionality constant for this particular transition in this particular light source. The constant is referred to as the Einstein A coefficient. In a group of such atoms, if the number of atoms in the excited state is given by N2, the rate at which stimulated emission occurs is given in equation

$$\partial N_2/\partial t = -\partial N_1/\partial t = -B_{21}\,\rho(f)\,N_2 \qquad \textbf{(2)}$$

In Equation (2) the proportionality constant B21 is known as the Einstein B coefficient for that particular transition, and ρ(f) is the radiation density of the incident field at frequency f. The rate of emission is thus proportional to the number of atoms in the excited state N2, and to the density of incident photons. Using this inherent property of optical amplifiers the atoms that are to be excited to higher energy states is varied in accordance to user defined input bias current in case of semiconductor optical amplifier and dopant length in case of Erbium doped fiber amplifier. By incorporating such a kind of reconfigurability in the inputs given the frequency of our generated output signal is made flexible. The equation governing the frequency of our obtained output is

$$\Delta f \alpha \frac{1}{2\pi\tau_c} \qquad \textbf{(3)}$$

As could be inferred from Equation (3), the cut-off frequency is inversely proportional to the carrier lifetime, which is the lifetime of the excited atoms. By varying the carrier lifetime, which inturn depends on the inputs given, UWB signals of our requirement is being generated.

III. Experimental Setup:

A. *Using Semiconductor Optical Amplifier*

According to the principle of operation of SOA increasing the bias current results in higher order UWB signals. But this effect is seen only to a certain range of applied bias current after which gain saturation occurs. So in order to improve reconfigurability, we make use of a dual arm structure with one SOA in each arm as shown in Fig 1. The input RF signal is at first modulated with an Optical signal of 1550nm using Mach-Zehnder modulator. Mach Zehnder Modulator introduces phase changes in the output depending on the voltage applied. The output waveform is split by a 50:50 splitter, that splits its power equally among both its arm. The bias current of the SOA is varied in both the arms to obtain UWB waves with variable cutoff frequency. The output waveform of the upper arm is polarized to transverse electric mode polarization, which is passed through a delay line. In the lower arm the polarization mode is changed to transverse magnetic mode using a polariser. The output polarized waves from both the arms are combined using combiner at the output. The waves of differing frequencies, obtained as a result of varied bias current in SOA is offset in time using delay lines. The combiner output is the Ultra Wide Band signal of our desired range. Polarization combiner can be used to add up the signals in the two arms in a perfect orthogonal manner.

B. *Using Erbium Doped Fiber Amplifier*

The similar setup is being used for generation of UWB signals using Erbium doped fiber amplifiers is shown in Fig 2. The semiconductor optical amplifier is being replaced by Erbium doped fiber amplifier. An Erbium Doped Fiber Amplifier (EDFA) consists of a piece of fiber of length L, whose core is uniformly doped with Erbium ions Er^{3+}. A strong pump laser light at the proper wavelength (usually 980 nm or 1480 nm) is propagated into the core of the fiber in order to excite its ions. Depending on the dopant concentration the number of atoms excited to higher energy level varies, which inturn determines the frequency of the generated output wave. The differing frequency waves obtained from Erbium doped fiber amplifiers of differing dopant concentration in upper and lower arm is being combined at the output. The waves are maintained at differing polarization modes to prevent interferences when they are getting added up at the output. The dopant length is varied in order to obtain UWB signals of our required frequency range at the combiner output.

Results and Inferences

A. *Using Semiconductor Optical Amplifier*

The resultant spectrum obtained by implementing the setup of generation of UWB using SOA-MZM structure in OPTISYSTEM software is shown in Fig 3. As seen in Figure the result obtained in OPTISYSTEM covers the entire range of our desired frequency and also the spectra lowers at 1.5 GHz, 5.2GHz denoting mitigation of interference with the existing wireless systems at these frequencies. It could be inferred that the method of generation of UWB using SOA-MZM structure is a most efficient one since the components used are highly reconfigurable. The applied input for generating UWB in OPTISYSTEM is given in Table I.

Table I : Input Parameters Corresponding to SOA-MZM Output

Input Parameters	In first arm	In second arm
Input RF Frequency	2 GHz	
Bias current to SOA	800 mA	100 mA
Voltage applied at Mach-Zehnder modulator arm	5 Volts	

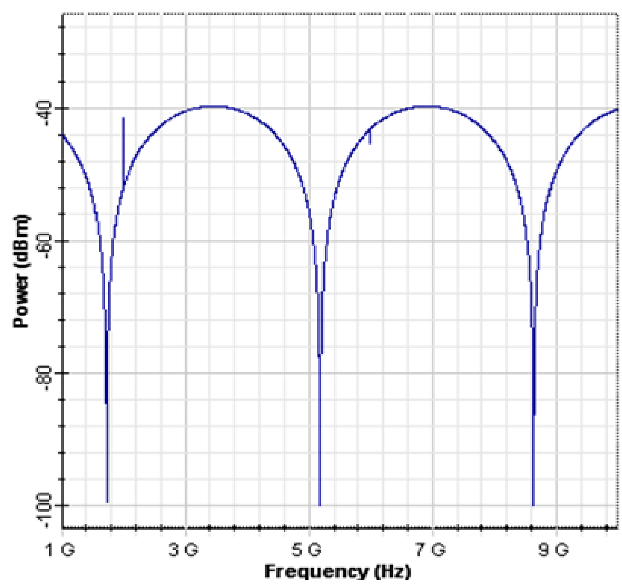

Fig 3 : Output spectrum using SOA-MZM in Optisystem

B. *Using Erbium Doped Fiber Amplifier*

The output UWB spectrum obtained using EDFA structure is shown in Fig 4. As could be seen the spectrum covers the entire range of desired frequency range. Also the obtained output spectrum well satisfies the power requirement levied by FCC norms. The generation scheme is highly reconfigurable to user requirement. Also the obtained output causes no interference to the existing wireless systems and can be used directly for wireless applications.

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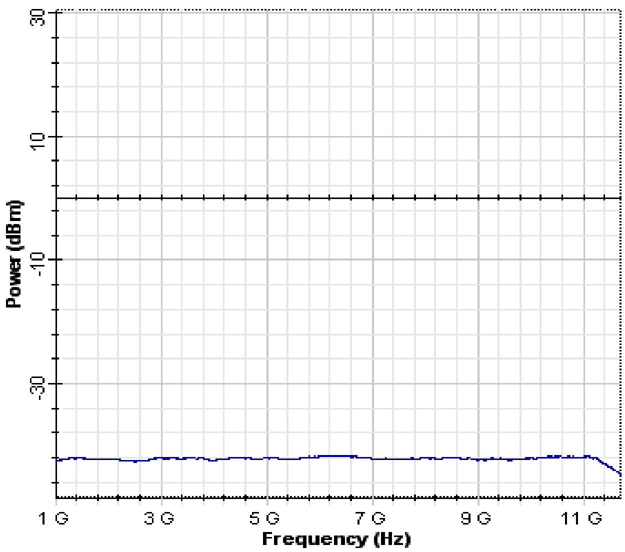

Fig 4 : Output spectrum using EDFA in Optisystem

Conclusion

It could be concluded from the above generation schemes that photonic generation using amplifiers like SOA, EDFA is an effective means for generating UWB signals due to their inherent property of reconfigurability. By tuning certain parameters of our layout components, UWB signals of our required frequency range and power level could be obtained. The proposed generation schemes also demands reduced hardware complexity. Utilizing these methods of generation, UWB signals of specific bandwidth could be obtained using a single wavelength input. The output UWB signals could be used for short range communication or can be transmitted through fiber for long range communication.

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Fig 1 : Experimental layout for generation of UWB using SOA-MZM structure

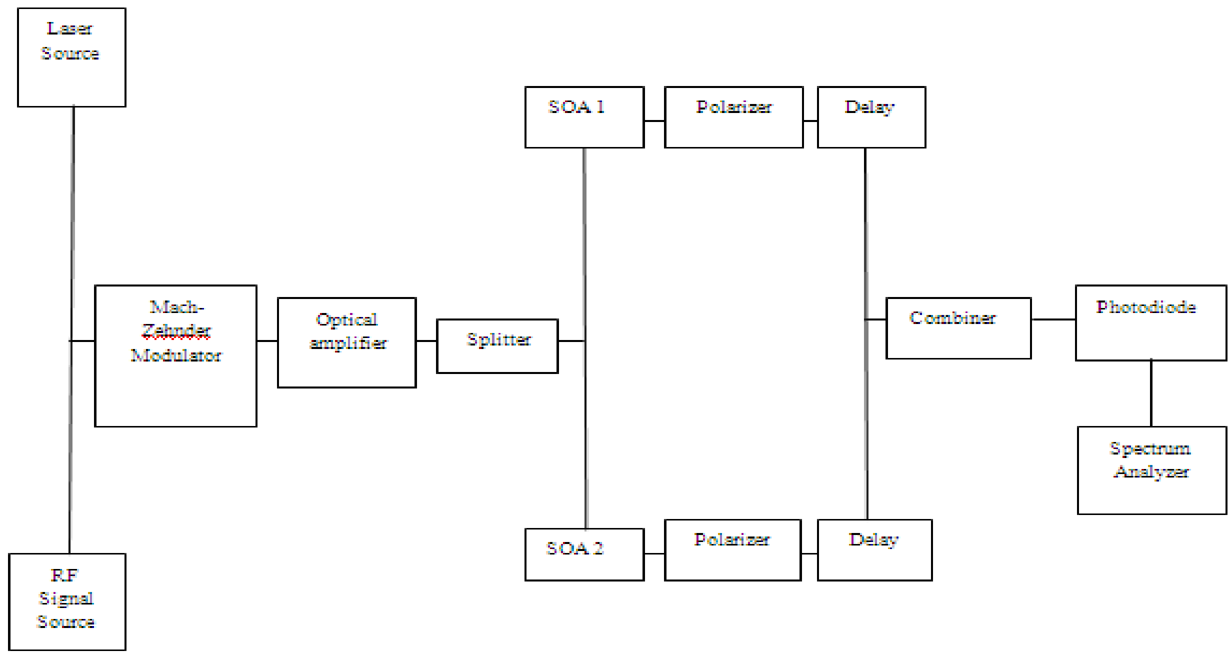

Fig 2 : Experimental layout for generation of UWB using EDFA structure