Modeling and Evaluation of Radio over Fiber Communication Systems on Employing Nanophotonic Devices

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Abstract—**Radio over Fiber refers to a technology whereby light is modulated by a radio signal and transmitted over an optical fiber link to facilitate wireless access. The present work purports to the modeling of radio over fiber systems in the MATLAB environment on employing specially designed photonic crystal fibers, consisting of subwavelength-core dielectric photonic nanowires embedded in their cladding, as optical channels between the main central station and the set of base stations and silicon photonic based electro-optic modulators. Data transmission at terahertz frequencies using orthogonal frequency division multiplexing schemes with cyclic error control coding along with digital modulation schemes such as amplitude shift keying and binary phase shift keying have been implemented. Different carrier signals such as solitons, similaritons, square, and sine waves are considered. In simulating the radio over fiber system, three different media are considered. In the first stage of signal propagation, photonic crystal fibers embedded with photonic nanowires in their cladding are considered and signal propagation through them is numerically modeled using the predictor-corrector symmetrized split step Fourier method. In the second stage, electrical transmission lines that are modeled as microstrips using S-parameters are considered. In the last stage of signal propagation, wireless channel modeled using additive white Gaussian noise and multipath fading, is considered. The performance of the aforementioned communication system is reviewed using standard metrics such as bit error rate and eye diagrams. It is shown that solitons are more robust carriers for terahertz communications compared to the other carriers and that it is possible to achieve a relatively distortion free communication system even amidst the worst possible SNR levels.**

Keywords-Radio over fiber, photonic crystal fiber, photonic nanowire, OFDM.

I. INTRODUCTION

Due to the immense growth of wireless communications in the present day information technology, a plethora of demands pertaining to high user density, high speed data transport, fast internet applications for multimedia services, etc., have to be met. This calls for a tremendous increase in channel bandwidth for both the present and future wireless networks. One way of increasing the network capacity with the allocated frequency bandwidth is to reuse the frequencies for different transmissions among the radio cells in a cellular network. By deploying a large number of micro- and pico-radio cells in the same area, one can increase the available channel bandwidth and user numbers to a great extent. It is a well known fact that optical fibers can be efficiently employed as interconnects for these large number of radio cells. Radio over Fiber (RoF) technology thus pertains to the scenario where light is modulated by a radio signal and is transmitted over an optical fiber link to facilitate wireless access. In RoF communication systems, wireless signals are transported in optical form between a central station and a set of base stations before being radiated through the air [1]. Each base station is adapted to communicate over a radio link with at least one user's mobile station located within its radio range. As optical fibers have high bandwidth, low attenuation, and light weight and are of low cable cost, they are generally preferred to radio frequency (RF) cables as channels for transmitting RF signals. Moreover, Rof communication systems have the provision for providing dynamic allocation of carrier frequencies, enhanced micro-cellular coverage and capacity. As the base station design of RoF systems are less complex, they have emerged as a cost effective approach for reducing radio system costs by simplifying the remote antenna sites, by enhancing the sharing of expensive radio equipment located at the central station and finally distributing RF signals to remote stations for broadband applications. The present work proposes the use of specially designed photonic crystal fibers (PCF) consisting of a subwavelength-core dielectric photonic nanowire embedded in a properly designed PCF cladding [2] as optical channels between the main central station and the set of base stations and silicon photonic based electro-optic modulators [3].

The growing demand for instant and reliable communication means that photonic circuits are increasingly finding applications in optical communications systems. One of the prime candidates to provide satisfactory performance at low cost in the photonic circuit is silicon. Eventhough silicon photonics is less well developed as compared to some other material technologies, it is poised to make a serious impact on

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the telecommunications industry, as well as in many other applications, as other technologies fail to meet the yield/performance/cost trade-offs [4]. Silicon photonic devices can be made using existing semiconductor fabrication techniques, and because silicon is already used as the substrate for most integrated circuits, it is possible to create hybrid devices in which the optical and electronic components are integrated onto a single microchip [4]. Silicon microphotonics can potentially increase the internet's bandwidth capacity by providing micro-scale, ultra low power devices.

Terahertz (THz) waves offer a number of interesting features, due to the tens and hundreds of gigahertz bandwidths available, and the fact that this frequency band poses only a minor health threat. Also, as millimeter-wave communication systems mature, the focus of research is, naturally, moving to the THz range [5]. In the present work, terahertz generation is achieved between the central station and the set of base stations by modeling PCF nanowires [2].

Orthogonal Frequency Division Multiplex or OFDM is a modulation format that is finding increasing levels of use in today's radio communications scene. An OFDM signal consists of a number of closely spaced modulated carriers. When modulation of any form - voice, data, etc. is applied to a carrier, then sidebands spread out either side. It is necessary for a receiver to be able to receive the whole signal to be able to successfully demodulate the data. As a result when signals are transmitted close to one another they must be spaced so that the receiver can separate them using a filter and there must be a guard band between them. This is not the case with OFDM [6]. Although the sidebands from each carrier overlap, they can still be received without the interference that might be expected because they are orthogonal to each another. This is achieved by having the carrier spacing equal to the reciprocal of the symbol period. The distribution of the data across a large number of carriers in the OFDM signal has some further advantages. Nulls caused by multi-path effects or interference on a given frequency only affect a small number of the carriers, the remaining ones being received correctly. By using error-coding techniques, which does mean adding further data to the transmitted signal, it enables many or all of the corrupted data to be reconstructed within the receiver. This can be done because the error correction code is transmitted in a different part of the signal. In the present work, the performance of the proposed RoF system is analyzed for various types of carrier signals on employing (n,k) cyclic error control coding along with random interleaving in order to enhance the efficiency of the entire RoF system.

II. MODELING OF RoF SYSTEM

The architecture of a typical RoF system is shown in Fig. 1. The block diagram of the entire RoF system is given in Fig. 2. The proposed RoF system consists of two main domains, namely, the optical domain and the electrical domain, which are portrayed in Fig. 3. The various stages employed in the implementation of the aforementioned block diagram using MATLAB are outlined below. To begin with, the electrical bit streams are generated after the input electrical signal is passed through an electrical on and off switch. Theses electrical bit streams are represented in MATLAB program as logical zero bits or logical one bits. The message is fed as a serial bit stream to the silicon photonics based electro-optic modulator [3]. If the message is an analog signal, appropriate ADC (analog to digital conversion) and signal conditioning is done prior to this step.

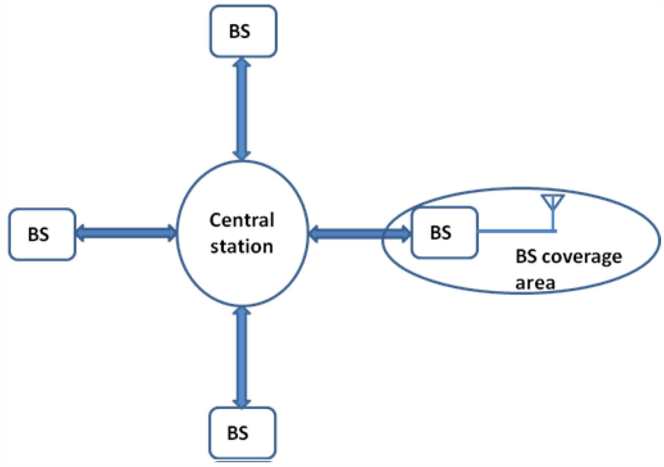

Figure 1. Architecture of a typical RoF system

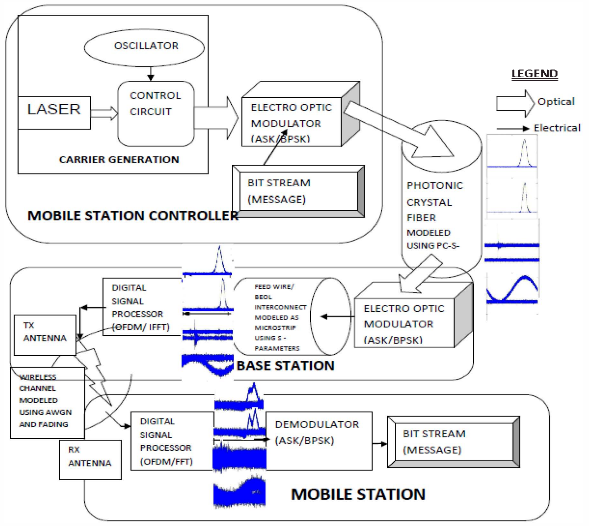

Figure 2. Block diagram of the proposed RoF system

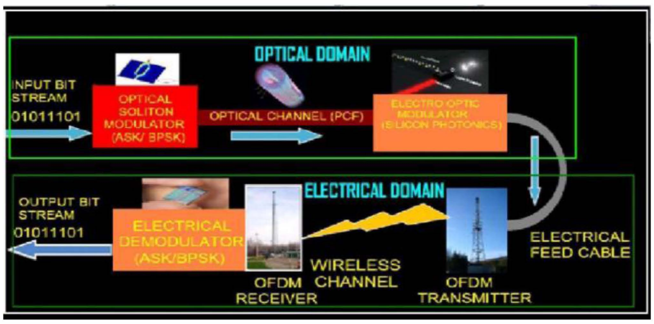

Figure 3. Optical and electrical domains of the proposed RoF system

This block is implemented here using the modulating expressions for various types of carrier signals such as solitons, similaritons, square waves and sinusoidal waves, and amplitude shift keying (ASK) and binary phase shift keying (BPSK) techniques are used. This represents the central station of the RoF system. The modulated optical signal now propogates through the aforementioned PCF consisting of a subwavelength-core dielectric photonic nanowire embedded in a properly designed cladding of the PCF. It has been reported in Ref.[2] that the inclusion of the photonic nanowire within the properly designed cladding of the PCF not only ensures terahertz propagation of the optical information confined within the central core due to the total internal reflection at the core-cladding boundary but also results in the suppression of the soliton self frequency shift (SSFS). It is for these two reasons that in the present work, the aforementioned PCFs have been chosen as the optical channels between the main central station and the set of base stations, thereby forming an important constituent of the RoF architecture shown in Fig. 1. Hence the governing equation (2) of [2] is taken as the equation modeling each optical channel between the central station and the set of base stations and hence is solved numerically using the predictor-corrector based symmetrized split-step Fourier method (PC-S-SSFM) approach in the MATLAB platform, an approach that can efficiently model the nonlinearity and fiber noise arising in such fibres. The signal after receiving is now fed to an electro-optic modulator to convert it into an electrical signal which is implemented in MATLAB as follows. In most VLSI and signal processing circuits, in order to minimize chip size, multilayered interconnects are used. The back end of line (BEOL) circuitry and interconnects are modeled as standard microwave transmission lines namely, microstrips. Typical BEOL geometry used is a copper conductor with a thickness of 0.1μm, line length of 1mm and width of 6μm and height of 100μm for the substrate (in the case considered in this work the substrate is silicon). The MATLAB code generates the microstrip for the above geometry - as an object- as well as computes the S-parameters for the corresponding lumped circuit approximation. Next the transfer function is computed and a rational functional fit is used to evaluate the time response of any given input signal. The electrical waveform is now fed to an OFDM modulator, coupled to a wireless transmitter. The OFDM block is represented by the IFFT function in MATLAB. This block, together with the electro-optic modulator, represents the base station of the RoF link. The wireless transmitter transmits the ultra wide band OFDM signal of THz frequencies. In the proposed model, OFDM with cyclic prefix is used. To simulate the wireless channel, an additive white Gaussian noise (AWGN) Source along with a Rayleigh model fading profle for a velocity of 50kmph is used. For the AWGN, a SNR of 8dB is set, as this is low enough to simulate the worst-case scenario for the wireless channel. The signal is finally received by the OFDM receiver, that represents the Mobile Station (Handset). This station demodulates the OFDM signal, represented here by the FFT function in MATLAB. Finally, the electrical demodulator demodulates the signal to extract the output message bit stream. This is represented here by the ASK/BPSK demodulator expressions.

III. RESULTS

The RoF system is implemented in MATLAB for different carrier waveforms, at a frequency of 2THz, for a PCF link of 1km, along with appropriate parameters for electrical and wireless domains as mentioned in the previous sections. Pulse widths of 50fs have been used for the solitons, which is possible to generate using Kerr lens modelocked Ti:Sapphire laser, which can generate pulse widths as low as 5fs [9]. 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 shown in three stages in Fig. 4, initially after passing through the PCF, next after passing through the microstrip, and finally when it is received after passing through the wireless channel. The first and the second stages are shown as insets and the third stage as the main figure in Fig. 4. Only ASK modulation is illustrated here. It can be clearly understood from Fig. 4 that the relative eye-height of the square and sinusoid are considerably reduced whereas the soliton and simlariton are more robust carrier candidates. Propogation through photonic crystal fiber degrades the solitons and similaritons to a lesser extent, compared to the squares and sinusoids due to the balance between nonlinearity and dispersion. Next, the square carriers undergo greater distortion when passing through the microstrip which acts as low pass filter, whereas solitons and sinusoids are less affected. In the wireless domain AWGN and multipath fading acts equally on all signals. But as is shown in Fig.5 which portrays the bit error rates as functions of signal to noise ratio (SNR) in dB, both the soliton classes emerge as robust carriers for both the modulation schemes for all noise levels considered. A more comprehensive study involving longer data bit streams with broader coverage of input patterns is underway. In Fig.6, the variation of relative eye heights with SNR is shown for both modulations, relative eye height being the ratio of the maximum eye opening to the the maximum height.

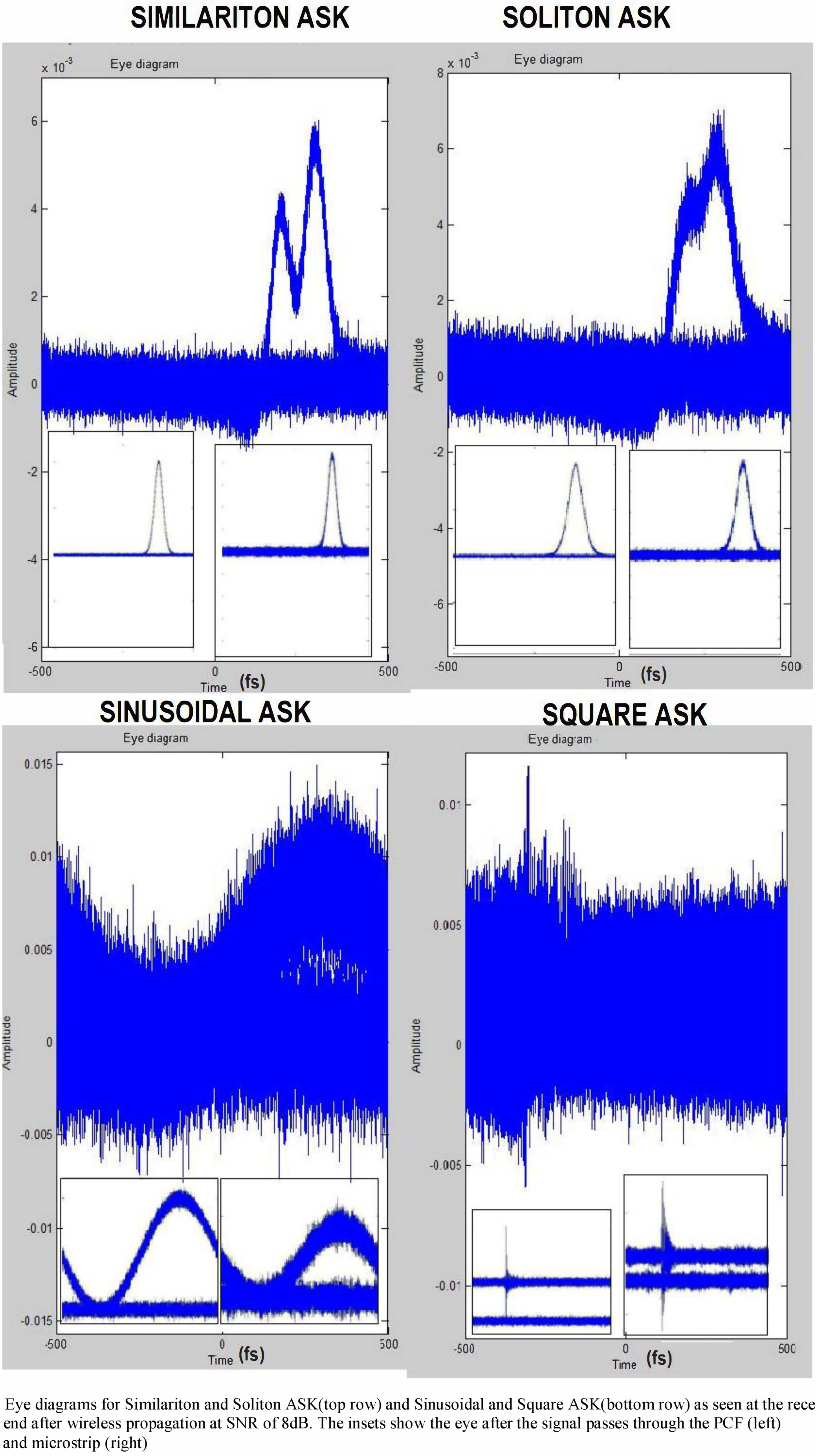

Figure 4. Eye diagrams for Similariton and Soliton ASK(top row) and Sinusoidal and Square ASK(bottom row) as seen at the receiver end after wireless propagation at SNR of 8dB. The insets show the eye after the signal passes through the PCF (left) and microstrip (right)

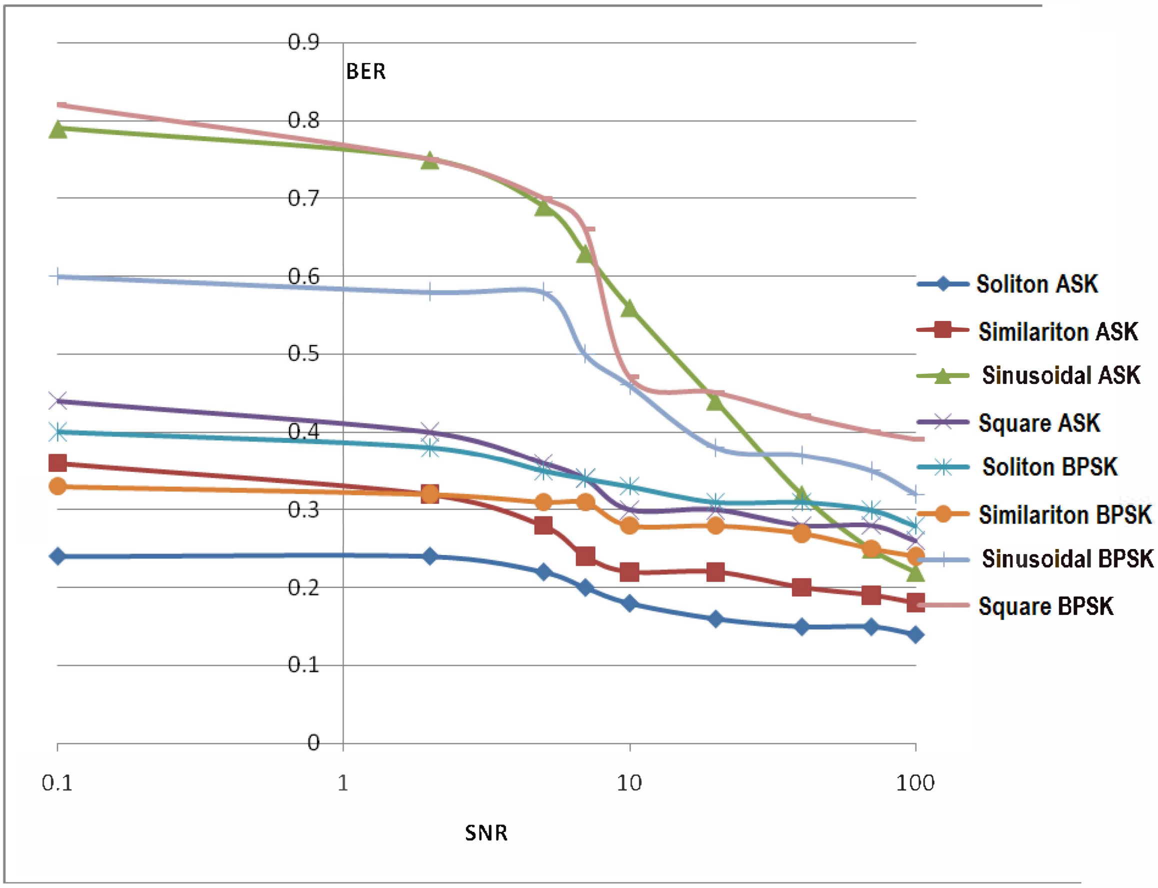

Figure 5. Bit Error Rate as a function of SNR(dB) for ASK and BPSK

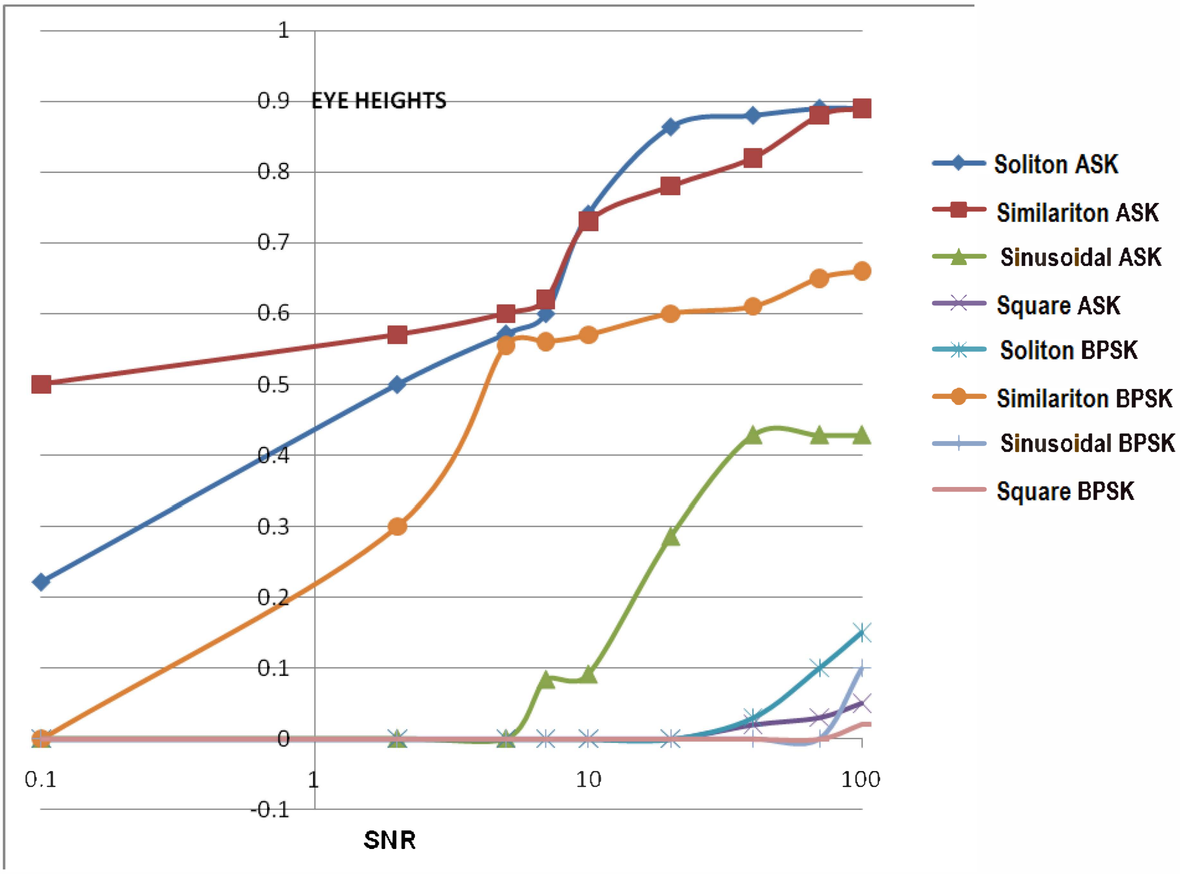

Figure 6. Eye Height as a function of SNR(dB) for ASK and BPSK

IV. CONCLUSION

It is evident from the results that solitons and similaritons are ideal carriers for THz communications compared to square/sinusoidal carriers, thus attempting to achieve a distortion free communication system, independent of the modulation scheme, even in the worst possible SNR levels. Thus a RoF communication system employing nanophotonic devices has been modeled that describes fairly accurately, the various channel effects over optical and electrical domains.

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