Design of Terahertz Radio over Fiber – Beyond 4G

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***Abstract*—A Radio-over fiber communication system operating at Terahertz frequency is designed, considering the underlying physics of nanoelectronic and nanophotonic devices, and performance of non-conventional soliton based carriers is evaluated, accounting for novelty of this work.**

I. Introduction

The era of ultra-high-speed communication systems using millimeter-waves in Terahertz range has set in, giving way to a plethora of applications. Added incentive for such ventures come from the fact that Terahertz pose comparatively minor health threat, and from the fact that this frequency sees a convenient confluence of electronic and photonic technologies[1]. Of particular importance is the wireless communication system, currently in the era of multi-carrier OFDM 4G[2]. The implementation of such systems in the Terahertz range will have to encompass a few radical changes in way of design of devices, circuits, modulation techniques and suitable carriers. One convenient architecture to implement this is the Radio-Over-Fiber architecture[2]. The present work deals with design and modelling of such an architecture, taking into account suitable nanoelectronic and nanophotonic device physics, and evaluating various carrier options to achieve as minimum distortion as possible. The implementation of millimeter-wave mobile systems with non-conventional soliton carriers forms the novelty of the present work.

II. The Radio over Fiber Model

The model of the Terahertz Radio-over-Fiber implemented in the present work is as shown in Fig.1. The following subsections outline each component of this model highlighting the model considerations.

A. Carrier generation and modulation

The carrier chosen for the model are hyperbolic secant solitons, the main principle of the carrier generation is a balance between dispersion effects and nonlinearity. To achieve such effects, the nonlinear nature of the transfer characteristics of semiconductors such as MOSFETS are used. This "transfer characteristic" engineering, coupled with parasitics generated at Terahertz frequencies are put to good effect in generating soliton carriers. The next step involves modulating the digital message in the form of bits onto the generated soliton carrier. In the present work, Amplitude-Shift-Keying (ASK) is chosen, and hence the modulator consists of a simple NMOS pass transistor. Fig.2 shows the layout of the generator-modulator, created using 16nm high-k strained silicon technology and the obtained spectrum at THz. A Spice netlist was extracted indicating the parasitics. Fig.3. shows the final ASK modulated waveform. Also the present work models multiple access corresponding to OFDMA, where the modulated outputs of different users are added in the channel. Orthogonality is maintained by choosing the frequencies as multiples of fundamental.

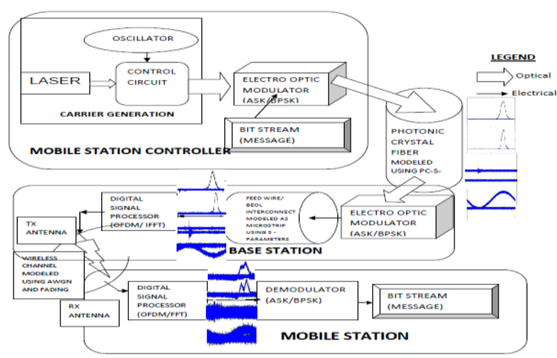

Fig. 1. Radio-over-fiber model for mm-waves

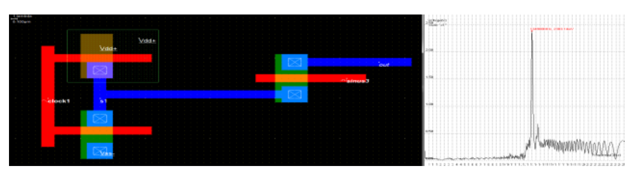

Fig. 2. Soliton generator-modulator and spectrum

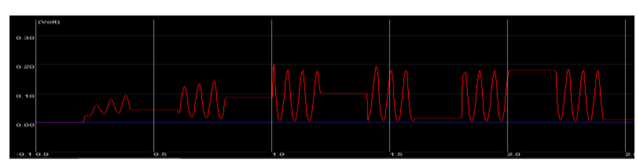

Fig. 3. ASK modulated waveform

B. Electro-optic conversion

The next step involves converting the signal from electrical to optical domain to facilitate transmission through the fiber link. The present work uses the model of Silicon LED developed by Ohtsu et al[4] using dressed-photon near-field technology. The transfer characteristics is given by Optical power $P = 0.04I^2$ where I is the diode current.

C. Fiber Link

The fiber link between the central and base station is modelled as a solid-core photonic crystal fiber at THz with 850nm central wavelength. The values for Group Velocity Dispersion constants upto the fourth order are given as -0.0104 ps^2/m, $3.78x10{-}5ps^3/m$, and $1.02x10{-}6ps^4/m$ respectively. The nonlinear factor is given as $0.1518W^{-1}m^{-1}$, and the confinement loss is given as 0.019 dB/m. The model is done using predictor-corrector symmetrised split step Fourier method, incorporating nonlinear effects such as Self-phase modulation and Stimulated Raman Scattering. Further, to characterize the fiber, an artificial all-optical OFDM system model at 2THz was constructed, and the performance of sech and square of sech carriers were evaluated against conventional square and sine carriers. Fig.4. shows the results.

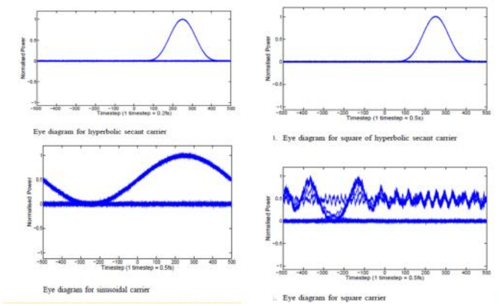

Fig. 4. Evaluation of carrier waveforms in PCF

D. Optical Amplification and Opto-electronic conversion

The optical amplifier was constructed using a photonic crystal square lattice structure with a 'T' shaped defect, with a rod radius of 60nm and a lattice constant of 500nm. Fig.5 shows the structure, band diagram as well as the transfer function.

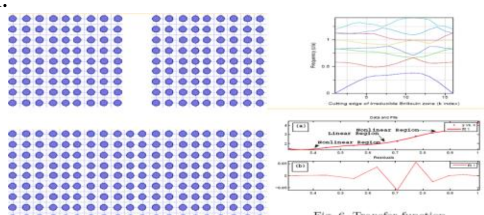

Fig. 5. Photonic crystal amplifier

Similar to the elctro-optic conversion, the opto-electronic conversion was modelled using dressed-photon based photodetectors as given in [5], which is characterised using the relation $I = (eP/hv)(G-1)$, where P is the input power, G is gain factor and I is the detector current.

E. Base Station Electronics

The electrical output then passes through a series of electrical interconnects, which can be effectively modelled as microwave transmission lines such as coplanar waveguides. This can then be characterised using TCAD based tools to understand the effects of Electro-thermal intermodulation distortion, as well as phonon based scattering. The TCAD based characterization of the coplanar structure is given by Fig.6.

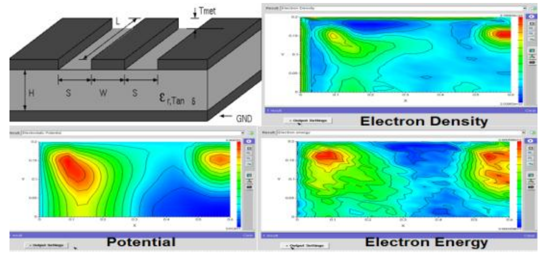

Fig. 6. TCAD Characteristics of coplanar waveguide

F. Mobile Receiver

The wireless channel is modelled using AWGN and Rayleigh's multipath fading model. Following this the receiver end consists of OFDMA demultiplexing and ASK demodulation.

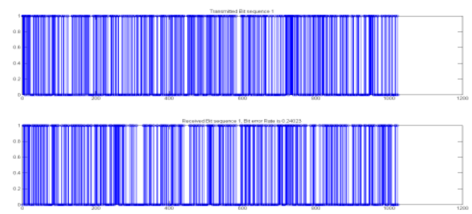

Fig. 7. Bit sequences of 2THz user

III. Results and Discussion

The components characterized in the previous section are used to model a 3-user OFDMA system with the assigned frequencies being 2THz, 1THz and 0.5THz. The transmitted bit sequence and the received bit sequence of the 2THz user is shown in Figs.7. The observed error rates for the 3 users were obtained as 24%, 20% and 20% respectively.

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