

High Efficiency Antenna Integrated Electro-Optic modulator for Sensing Applications

Abe Akhiyat, and John L.Volakis

Dept. of Electrical and Computer Engineering, College of Engineering and Computing
Florida International University, Miami, FL 33174, USA
Email: { aakhiyat, jvolakis } @fiu.edu

Abstract—The efficiency of Electro-Optic Modulators (EOM) is directly related to how the rf signal is imposed onto the optical signal. Other factors affecting this efficiency are: the selected architecture and the Electro-Optic materials responsible for modulation through the Electro-Optic Effect. In this paper we demonstrate a millimeter wave antenna integrated EOM that operates at 94 GHz. To improve efficiency, the antenna is integrated directly onto the active region of the electro-optic effect based EOM. Notably, conventional antennas had to be modified to achieve a feed port that is best suited for the selected EOM architecture. For the antenna design optimization, we devised a design procedure that is more suitable for these type of devices. We proposed a design methodology that insures an optimum Field Enhancement (FE) that is responsible for modulation. A novel overall EOM architecture that promotes increased efficiency that makes use of the inherently lossy EO material only where needed in the optical link by making use of an adiabatic transition from a passive Optical waveguide to active portion of the optical link.

Keywords—millimeter wave Antenna, electro-optical modulator

I. INTRODUCTION

Among applications making use of electro-optic modulators are optical communications and optical signal processing; radio frequency electromagnetic sensing; millimeter wave (mm-Wave) imaging using optical up-conversion; spectroscopy and bio-sensing applications. One type of EOM that has the capability to produce a pure phase modulation makes use of linear electro-optic effect [1], a characteristic of optical materials. Examples of these materials are: EO polymers, LiNbO₃ [2]. Commonly used types of EOM are Mach-Zehnder

modulators (MZM), plasmonic waveguide and Pockels-effect modulators based on dielectric waveguides. For these types, the most important figure of merit parameter is the modulation efficiency expressed as $V\pi L$, where $V\pi$ is the voltage required to achieve pi degree phase shift and L is the length of the active portion of the waveguide. The EOM performance is mainly driven the Pockels Effect properties of the EO material used. It's a material specific property that is expressed as n^3r , where n is the refractive index and r is the EO coefficient. Just as important for EOM efficiency using the waveguide approach is the optical loss in the optical link, and the architecture that permits easy processing properties.

To improve the EOM efficiency, for a prefixed EO Coefficient, we propose a direct antenna integration onto the EOM and ovoid using electrodes and long lossy conductor traces. An illustration is depicted in figure 1. Since the proposed EOM architecture is not a 50Ω system, conventional antenna design procedure is not applicable. We'll present a different design methodology. Notably, we propose a design that makes use of a TEM waveguide to achieve not only an optimal matching, but also an optimum field enhancement within the gap separating the antenna arms. This field enhancement property is the main contributor to modulation efficiency increase. Also proposed is the micro-processing steps to realize such device.

II. MILLIMETER WAVE ANTENNA INTEGRATED WITH ELECTROPTICAL POLYMER MODULATOR

A. Antenna Design Procedure

The proposed design is an on chip antenna integrated EOM with the focus on applications requiring high sensitivity, such as passive mm-wave imaging in the 94 GHz or 77 GHz regime, Where the sensing element is a millimeter wave antenna. Antennas under consideration are planar and make use of slots in the middle where a nonlinear optical wave guide resides. The electro-optical modulation take effect via direct incident millimeter wave radiation. The enhanced field within the slot is directly proportional to the modulation efficiency and sensitivity of the modulator. Therefore, an optimum antenna design with as large as possible FE is key. The field enhancement within the antenna slots is one of the main parameters in determining the EOM performance. The proposed architecture shown in figure 1 is a ground backed bowtie with extended bars at the apex of each arm. Notably, this design architecture can be tailored any planar that can tolerate a gap in the center to accommodate an electric FE, such a

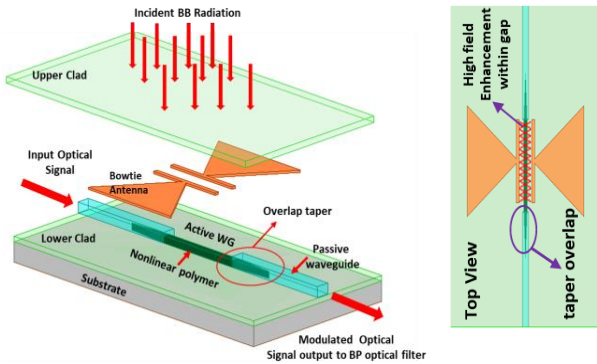


Fig. 1. Electro-Optic Modulator with an integrated bow-tie microstrip patch antenna. Left: components stack. Right: Top view

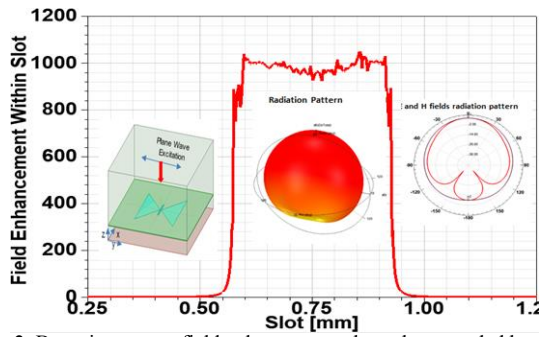


Fig. 2. Bow-tie antenna field enhancement along the extended bars and radiation patterns

standard patch antenna. Since the FE with the antenna gap is a key contributor the overall EOM efficiency, conventional planar antenna design methodology based on 50Ohm system, due to imposed impedance termination, does not result an optimum FE. We have devised a strait forward design methodology that result in an optimum FE. The procedure takes on a Floquet waveguide approach to determine patch dimensions, followed by Eigen Mode analysis to verify the resultant resonant frequency for verification. Summary of the procedure is as follow: Determine the planar antenna such as a microstrip bowtie or patch traversed by a gap initial dimensions for a predetermined substrate height and material using standard formulas. Then, design a waveguide with opposing side pairs to be PEC & PMC such that it allows for: 1. TEM mode propagation 2. Plane wave (377Ohms) interface to the waveguide. 3. S-parameter computation and phase information. Note: The waveguide height and PEC walls separation need be carefully determined as to make sure any TE and TM modes in the waveguide are decayed and cut-off. The properly sized planar antenna and associated substrate are inserted into the waveguide to compute the resonant frequency by observing the reflected phase from the surface of the patch. To accomplish this, the wave port is de-embedded to the surface of the patch. Resonance frequency corresponds to where the reflected phase is zero. Introducing or adjusting the narrow split in the patch, will shift the resonant frequency to a different value. Resizing the antenna will walk back or forth the resonance frequency to the desired value. To determine antenna parameters, once resonant dimensions are determined, they can be simulated by inserting into a radiation box fed using a plane wave port. Figure 2 shows conductor backed bowtie antenna FE in the slot and (gain of 10^3) and the corresponding radiation pattern.

B. EOM Integration & Microfabrication Process flow

The EO phase modulator design uses a large Pockels-effect EO polymer to achieve high efficiency and high speed. To further improve sensitivity, the nonlinear EO polymer is used only in the active region where the phase modulation takes place within the device, while an off-the-shelf product, hybrid *polymer* is employed for propagation through the optical link. To mitigate the loss in the nonlinear portion of the waveguide, an adiabatic

transition was designed that allows for a smooth transition from the passive to the active portion of the waveguide which tapered at both ends to minimize reflection. The fabrication of the antenna integrated EOM photonic chip was done through micro fabrication steps summarized in figure 3. Figure 4 shows sample images of fabricated waveguides and bowtie antennas.

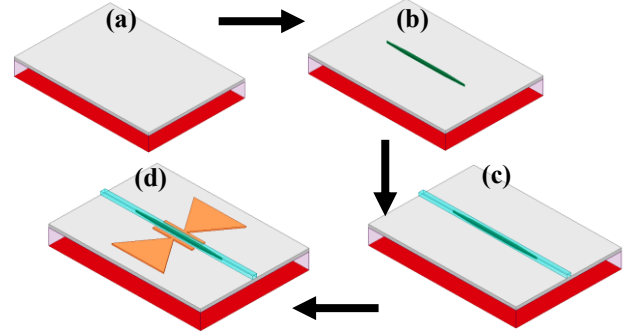


Fig. 3. EOM summary of the micro-fabrication process flow (a) Metal backed substrate with lower cladding (b) Patterned active polymer waveguide tapered at both ends (c) Passive waveguide to enclose the active waveguide (d) Antennas patterned allowing the optical waveguide in the gap, the whole upper surface is passivated with upper cladding material.

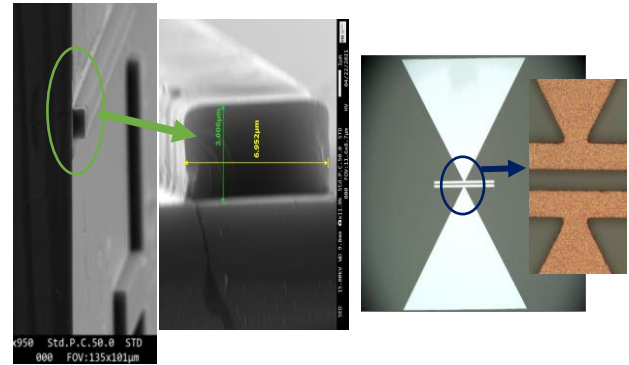


Fig. 4. SEM image of the optical waveguide (left) fabricated bowtie antenna showing 8um gap detail and location of the polymer insertion (right)

III. CONCLUDING REMARKS

At the conference, we will discuss the efficacy of the proposed architecture that promotes maximum sensitivity using polymer material only in the active area of modulation. Importantly, we will present fabrication and measurement details.

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