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28GHz-Band Antenna-Coupled Electrode Electro-Optic Modulator for Receiving Two Orthogonal Polarization Components Simultaneously

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Abstract

We have been studying an antenna-coupled electrode electro-optic (EO) modulator based on an antenna-coupled-electrode on $LiNbO_3$-crystal. EO modulators are applicable as a passive wireless-optical signal converter with an integration of planar antenna and are expected to be a key device for the realization of "Massive Machine Type Communications" in Fifth-generation (5G) mobile communication systems. An antenna-coupled electrode EO modulator is also applicable for an EO senser for quasi-millimeter and millimeter wave. In this paper, we report on a new antenna-coupled electrode EO modulator that can receive two orthogonal polarization components simultaneously. The ability to simultaneously receive two orthogonal polarization components is effective for expanding communication capability.

The experimental results of good polarization separation, directivity and data transfers are reported.

1 Introduction

In recent years, research on the Fifth-generation (5G) mobile communication and the next generation (Beyond-5G/6G) mobile communication are in progress in the world. 5G mobile communication systems mainly use the 28 GHz band of quasi-millimeter waves. However, millimeter-wave have the disadvantage of large propagation loss in free space and cables. Therefore, radio-over-fiber (RoF) technology, in which radio signals are converted into optical signals and transmitted through silica optical fibers, is expected to extend the transmission distance [1]-[3]. In addition, the wireless-optical fusion technology is also important for precise antenna measurements in the millimeter-wave bands used for 5G and Beyond-5G [4].

We have been conducting research on the antenna-coupled electrode electro-optic (EO) modulator and EO sensor using an antenna-coupled electrode and $LiNbO_3$ crystal [5]-[10]. The antenna-coupled electrode EO modulator can directly convert wireless signals into optical signals without external power supply. In this research, we have investigated a new antenna-coupled electrode EO modulator that can simultaneously receive two orthogonal polarization components. The ability to simultaneously receive two orthogonal polarization components is effective for expanding communication capability. The experimental results of good polarization separation, directivity were confirmed. In addition, reception characteristics of ~5Gbps NRZ (Non-Return to Zero) modulated radio signals are also reported.

2 Basic structure of the new EO modulator

The basic structure of the proposed EO modulator is shown in Figure 1. The substrate consists of a *z*-cut $LiNbO_3$ EO crystal substrate and a low-dielectric constant substrate of SiO_2 glass bonded together. The antenna-coupled electrodes consist of multiple patch antenna for receiving radio signals and multiple standing-wave resonant electrodes for applying an electric field to the $LiNbO_3$, which are coupled by micro-strip lines. In this configuration, four patch antennas and four resonant electrodes are arranged in a center-symmetric structure on the substrate as shown in Figure 1 to receive two orthogonal polarizations.

The basic operation of the device is as follows. When a millimeter-wave wireless signal is irradiated to the modulator, each antenna receives the wireless signal, and the received signal is supplied to the resonant electrodes through the micro-strip lines. Half-wavelength resonance occurs both in the *x*- or *y*-direction in each patch antenna depending on the polarization of the irradiated wireless signal, and the two micro-strip lines are connected to each patch antenna so as to supply only the *x*- or *y*- polarization-based signal to the corresponding electrode, and the resonant electrode for the x- and y-polarization component is automatically selected. Therefore, a standing wave according to the polarization component of the radio signal is generated along the corresponding electrode. This electric field is enhanced for optical modulation by the resonance, and is modulated the light wave propagating along the resonant electrode by the Pockels effect of $LiNbO_3$. Thus, the EO modulator can discriminate the two orthogonal polarization components of the wireless signals and convert the two orthogonal polarization wireless signals into optical signals.

Figure 2 shows the simulation results of the electric fields induced on the surface of the antenna-coupled electrode and Figure 3 shows the electric fields induced on the surface of the standing wave resonance electrode when irradiated with 28 GHz *x*-polarization signal. We can see that the electric fields are induced along Resonant electrode1 (Fig. 3a), and almost no electric field is induced along Resonant electrode2 (Fig. 3b) by the *x*-polarization signal irradiation. There is a difference of about 400 times in the field enhancement factor, which indicates that the polarization separation is enough. Figure 4 shows the simulation results when irradiated with 28 GHz *y*-polarization signal. The result indicates that polarization separation is enough as in the case of *x*-polarization irradiation.

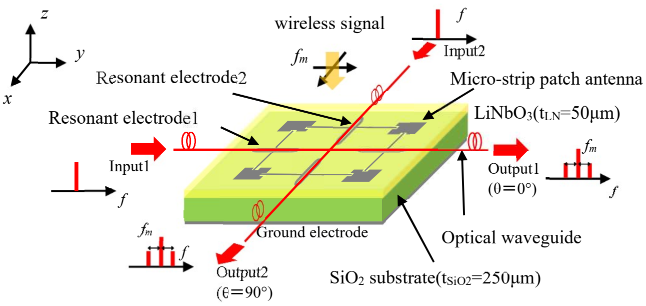

Figure 1. Basic structure of the proposed EO modulator.

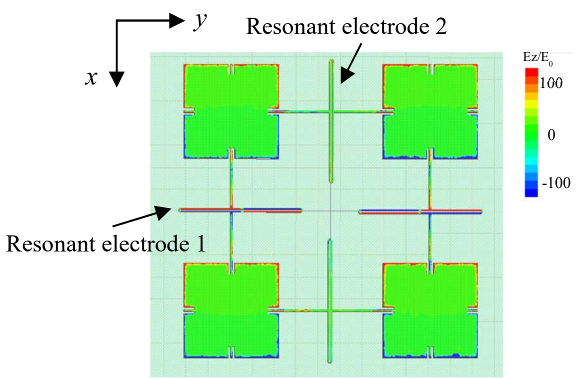

Figure 2. Calculated surface electric fields on the antenna-coupled electrode when irradiated with 28 GHz *x*-polarization signal.

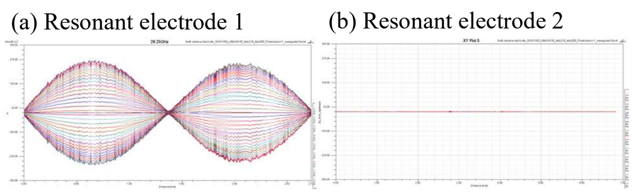

Figure 3. Calculated surface electric fields on the resonant electrodes when irradiated with 28 GHz x-polarization signal. (a) Resonant electrode for *x* polarization, (b) Resonant electrode for *y* polarization

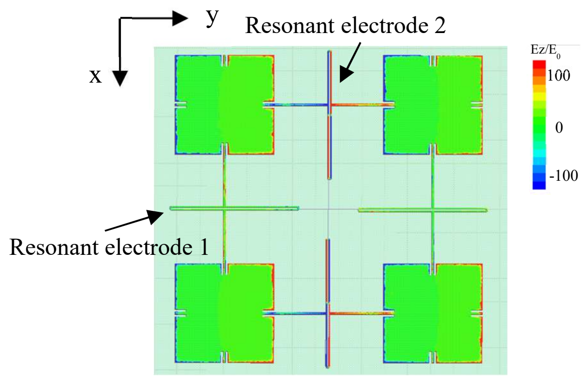

Figure 4. Calculated surface electric fields on the antenna-coupled electrode when irradiated with 28 GHz *y*-polarization signal.

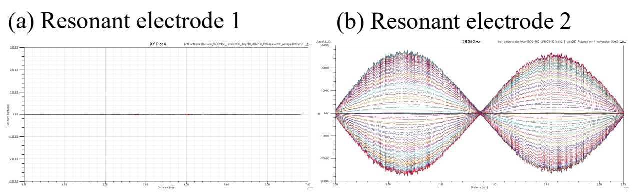

Figure 5. Calculated surface electric fields on the resonant electrodes when irradiated with 28 GHz *y*-polarization signal. (a) Resonant electrode for *x* polarization, (b) Resonant electrode for *y* polarization

3 Basic Experiments

The experimental set-up shown in Figure 6 was used to evaluate the frequency response after electrical signal reconversion. Two 1.55-μm band laser beams (~13 dBm) were input to two optical waveguides from the input-1 and input-2, and a 28 GHz band wireless signal from a vector network analyzer (VNA) was irradiated to the modulator using a standard gain horn antenna. Then, phase-modulated light corresponding to the polarization of the wireless signal is output from output1 and output2. The two phase-modulated output lights were converted into amplitude-modulated lights during the propagation through a 4-km single-mode silica optical fiber (SMF), which was then reconverted into an electrical signal by use of a high-speed photodiode (PD), and the frequency responses of S_{21} were observed by the VNA.

The results are shown in Figure 7. Clear polarization separation characteristics (~25 dB) are observed. The frequency responses of the modulator irradiated with the *x*- and *y*-polarization signal and reconverted to the electrical signal are shown in Figure 7(a), (b). Even after electrical signal reconversion, 3dB bandwidth is in the range of 27 GHz~29.5 GHz, which is enough to cover the 5G band. The measured polarization separation ratio was about 25 dB for each of the polarization direction, indicating sufficient polarization selectivity. Therefore, the proposed EO modulator is useful for antenna measurement applications and wireless communication.

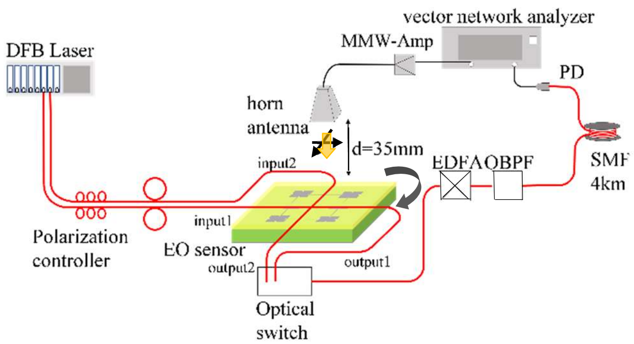

Figure 6. Experimental set-up for the measurement of modulator performances.

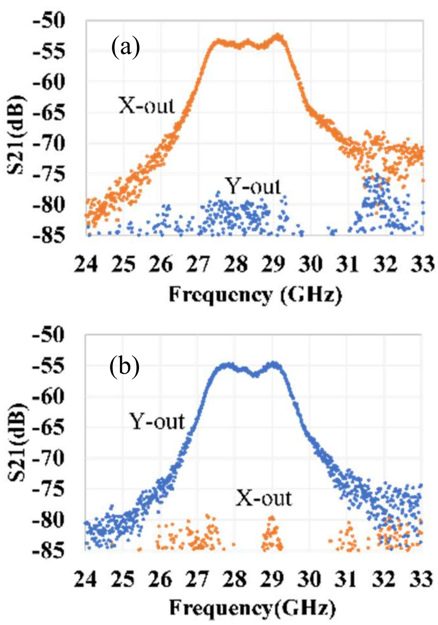

Figure 7. Frequency response of the reconversion electrical signals corresponding to (a) *x*-polarization, (b) *y*-polarization.

4 Date transfer experiment

Next, we conducted data transmission experiments using the EO modulator. We used the experimental set-up shown in Fig. 8 for the measurement for pseudo-random binary data transmission. A 28.4 GHz wireless signal was intensity-modulated with a pseudo-random signal of 1 to 5.5Gbps, and the *y*-polarized wireless signal was irradiated from the horn antenna to the EO modulator. Figure 9 shows the received signal waveforms when irradiated with a 2.5 Gbps wireless signal. Clear eye-pattern was confirmed and data transmission of over 4 Gbps NRZ modulated signal was successfully achieved. Figure 10 shows the data rate dependence of eye aperture ratio. Figure 10 shows that data transmission of ~5 Gbps NRZ modulated signal is possible with a standard error correction technology. Based on the above, we believe that data transmission of approximately 10 Gbps is possible if two orthogonal polarization components wireless signals are irradiated simultaneously, and that over 20 Gbps data transmission is also possible by using QAM signals.

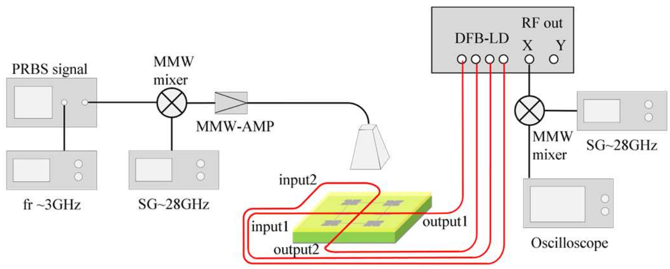

Figure 8. Experimental set-up for the measurement of data transmission using the EO modulator.

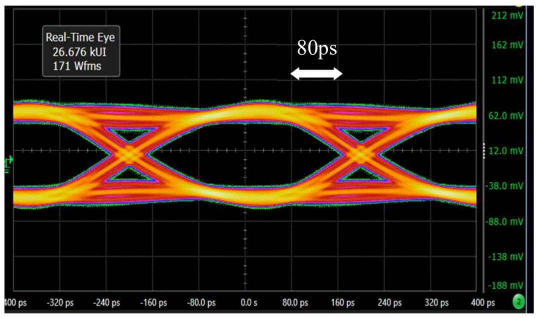

Figure 9. Measured temporal signals waveform observed by oscilloscope. (2.5Gbps PRBS)

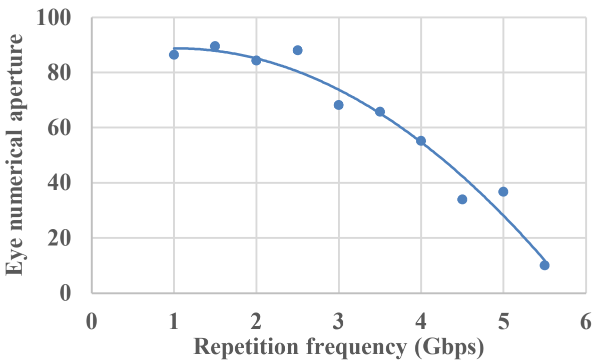

Figure 10. Measured Eye numerical aperture. (*y*-polarization)

5 Conclusion

In this paper, we reported on a new antenna-coupled electrode EO modulator that can simultaneously receive two orthogonal polarization components operating in the 28 GHz band. The frequency response and polarization separation were verified. This EO modulator is expected to be used as a radio-optical signal converter for RoF systems and a new EO sensor for precise antenna measurements in the 28GHz-band. In addition, we also succeeded the data transmission experiment of ~5 Gbps. We are now trying to evaluate data transmission at over 20 Gbps by using QAM signals.

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