Dual-Parallel Y-Coupled Lithium Niobate Electro-Optic Modulator with 15.2 dB SFDR gain

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***Abstract*—The concept of dual-parallel linearization of Y-coupled $LiNbO_3$ electro-optic modulation is presented in this paper. Characterization of a fabricated device exhibits 15.2 dB SFDR enhancement over a conventional Mach-Zehnder interferometer, finding application in photonic-ADC technology.**

Keywords- electro-optic devices, parallel linearization

I. Introduction

Analog applications as radio-over-fiber (RoF) optical transmission of wireless signals [1] or optical signal processing techniques like photonic-ADC sensing of ultra-low power radio [2] require electro-optic modulators (EOM) with excellent dynamic range. This is of special importance when the final application involves the photonic processing of several radio signals in coexistence, i.e. different wireless signals with different dynamic ranges are jointly processed. The most restrictive case, considering the wireless state of the art, is sensing and/or RoF transmission of ultra-wide band (UWB) radio [2], which exhibits powers spectral densities (PSD) lower than -41.3 dBm/MHz in the frequency band from 3.1 to 10.6 GHz, in presence of WiMAX. This paper proposes a linearized EOM based in a dual-parallel $LiNbO_3$ Y-junction to address the dynamic range limitation.

II. Dual-Parallel Y-coupled with E-wall Linearization Concept

The linearized EOM concept herein proposed is a dual architecture comprising two parallel active $LiNbO_3$ Y-branch directional couplers with phase reversal travelling wave electrodes and ferroelectric domain inversion. This architecture derives from [3] and is enhanced integrating two couplers staked with $\pi/2$ electrical phase shift and e-wall isolation [4]. Fig. 1 depicts the device structure. The incoming light is optically split in two arms (E_1 and E_2) which are fed to two parallel Y-junctions. Each of the Y-branch directional couplers is comprised by an integrated Z-cut Lithium-Niobate crystal substrate. Adequate operation requires isolation by a metallic e-wall between the junctions.

Both upper and lower Y-junctions shown in Fig. 1 are formed by two parallel waveguide in $\Delta\beta$ reversal configuration [5]. The gap between the waveguides is calculated allowing optical coupling via evanescent field. One waveguide in each Y-junction has a positive ferroelectric orientation while the other has a negative one, i.e. each arm include a central RF electrode (L_1) which applies electric field into the waveguide generating a positive phase variation in one arm and negative in the other. This is actually a push-pull configuration as in the second section (L_2) the ferroelectric domain inversion is applied to the opposite waveguide, resulting in an inverted situation when the light propagates though the waveguides.

Successful linearization of the electro-optic response of the overall architecture depends on two factors: First, the L_1 and L_2 parameters, which stand for the length of the first and second section electrodes respectively. And second, the V_U and V_L voltages applied to the upper and lower Y-junctions respectively. Both voltages must be precisely set to produce a phase shift of $\pi/2$ in order to achieve adequate linearization.

After simulation studies, the target parameters selected for fabrication are: L_1=27.88 mm, L_2=12.12 mm, Lc=12.12 mm, and gap of 15.35 µm (total length 40 mm). The Y-junctions fabricated were named UCELLS5 and UCELLS21. The main characteristics measured after fabrication are shown in Table I.

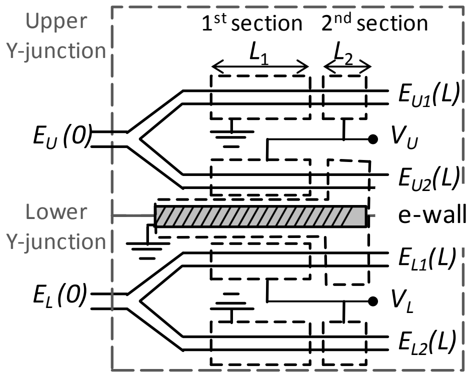

Figure 1. Proposed dual-parallel Y-coupled device structure with e-wall

TABLE I. Fabricated Y-junction Specifications

	UCELLS5	***UCELLS21***
Optical losses @ 1542 nm [a]	4.1 dB	4.2 dB
Exctinction Ratio on DC @ 1542 nm	35 dB	24 dB
Vπ on DC port @ 1550 nm	5.5 V	7 V

a. Including splicing and optical connectors

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III. Experimental Characterization

Fig. 2 shows the experimental set-up to evaluate the performance of the proposed dual-parallel Y-junction structure. The characterization of the proposed dual-parallel Y-junction structure is compared with single and dual-parallel architectures with conventional Mach-Zehnder modulators measuring the spurious free dynamic range (SFDR) as:

$$SFDR = P_{\text{1st harmonic}} \,/\, \max\,(P_{\text{distortions}}, P_{\text{noise}}) \qquad (1)$$

The setup includes the dual-parallel Y-junction architecture fed by a 3.1 GHz (10 dBm) RF tone. This frequency is the first frequency of the UWB band. Applied V_U corresponds directly to the RF tone, and V_L includes a π/2 phase shift. The RF tone is modulated on a continuous wave (CW) light (1550 nm, 11 dBm) splitted in two branches (7 dBm, E_U and E_L) polarization controlled. Both Y-junctions are biased at quadrature (0.9 V UCELLS5, 2.88 V UCELLS21). The resulting optical signals are combined and photodetected (PIN, 0.7 A/W). Electrical amplification (21 dB gain, 5.8 dB noise figure) is used at the RF ports and after photodetection. Fig. 3 shows the electrical spectrum measured with the dual-parallel linearized architecture proposed. The SFDR is labeled in the figures. Fig. 4 shows the laboratory setups for single and parallel architectures with conventional Mach-Zehnder modulators (Photline MX-LN-10-PD).

It can be observed that in the case of conventional optical links, the 3rd harmonic leads to the highest degradation, as can be observed in the case a single Mach-Zehnder modulator (Fig. 5(a), SFDR of 19 dB). In the case of the parallel architectures, the higher distortion component falling inside the UWB band is the 2nd order harmonic (SFDR of 34.2 dB for the proposed dual-parallel Y-junction, SFDR 24 dB for a parallel Mach-Zehnder). The proposed dual-parallel Y-coupled structure gives 15.2 dB gain in SFDR compared with a single Mach-Zehnder, and 10.2 dB improvement compared with the parallel Mach-Zehnder arrangement.

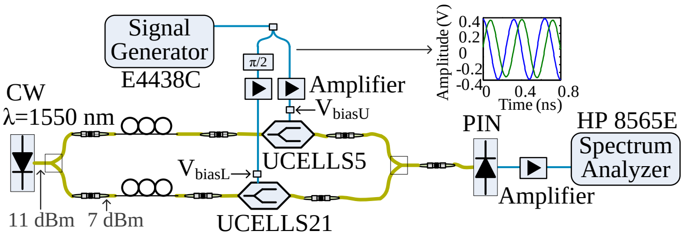

Figure 2. Experimental setup for dual-parallel Y-coupled linearized characterization

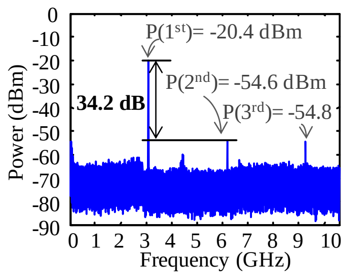

Figure 3. Measured electrical spectrum for dual-parallel Y-coupled linearized proposed architecture

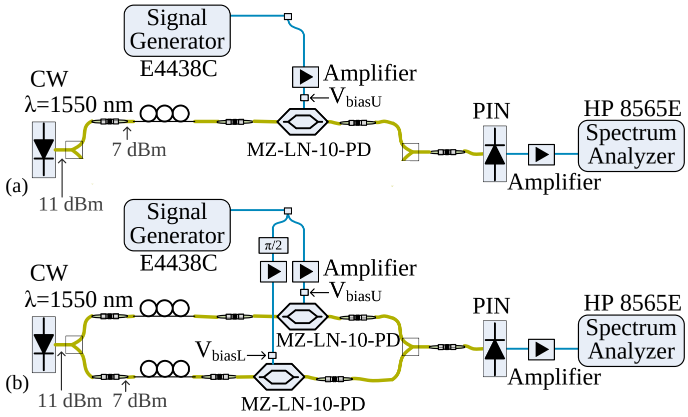

Figure 4. Experimental setup (a) single and (b) dual-parallel architecture with conventional Mach-Zehnder modulators

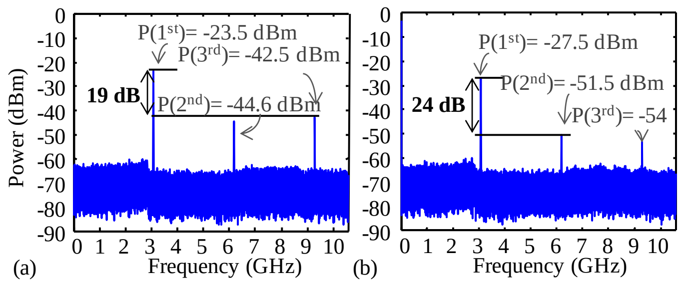

Figure 5. Measured electrical spectrum for (a) single and (b) dual-parallel architecture with conventional Mach-Zehnder modulators

IV. Conclusion

The concept dual-parallel $LiNbO_3$ Y-Coupled linearized electro-optic modulation has been proposed. Two linearized Y-junctions have been fabricated, being the performance especially sensible to the fabrication process. Fabricated devices have been characterized exhibiting 15.2 dB SFDR gain over a conventional $LiNbO_3$ Mach-Zehnder modulator and 10.2 dB SFDR gain over a parallel Mach-Zehnder architecture. This linearization concept finds application in highly-linear applications like radio-over-fiber transmission of wireless signals in coexistence and photonic-ADC sensing.

References

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