Realization of Mach-Zehnder Modulator with Ultrahigh Extinction Ratio at Minimum Transmission Bias Point

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***Abstract*—For Mach-Zehnder modulator (MZM) with ideal extinction ratio, output optical spectrum contains only odd-order optical sidebands at minimum transmission bias point. However, fabrication of the MZMs with very high extinction ratio is not possible yet. Therefore, in practice output of an MZM also contains significant power in even-order optical sidebands at null point. In this paper, system for suppressing even-order optical sidebands at null point is presented. The system is implemented using components such as MZMs, phase shifters, power splitters and optical combiner. The variation of performance for the proposed system with phase offset in phase shifters and extinction ratio difference of parallel MZMs is also analyzed. The performance of proposed system is better than an MZM with an extinction ratio of 30dB for phase offset of ±10° in electrical phase shifters. The system performance is quite tolerant to large phase offset in optical phase shifter.**

Keywords— Mach-Zehnder modulator, microwave photonics, extinction ratio, optical millimeter wave generation, optical spectrum.

I. Introduction

Mach-Zehnder modulator has been the most frequently used modulator in optical communication systems. An MZM can be seen as an optical wave guide split into two arms, which are recombined back to one waveguide. The MZMs are essentially made up of materials that have anisotropic dielectric properties such as lithium niobate ($LiNbO_3$), indium phosphate (InP), or gallium arsenide (GaAs). Thus, by applying electric field across arms of an MZM, the propagating light gets phase modulated. The relation between output optical field and input electrical bias voltage is a cosine function, reflecting the nonlinear transfer characteristics of an MZM. However, degree of nonlinearity depends on the biasing conditions [1].

The biasing of an MZM depends on the type of application. MZMs are generally operated at the quadrature point for communication purposes, as the transfer characteristics at this biasing point is relatively linear. In microwave photonics, it is required to generate optical sidebands, hence MZMs are operated at highly nonlinear points i.e. maximum transmission bias point (MATP) or minimum transmission bias point (MITP). Odd-order optical sidebands are suppressed by operating MZM at MATP, whereas MITP is used to suppress even-order optical sidebands along with carrier [2]. In literature, different optical millimeter wave (mm-wave) generating configurations have been presented using MZMs, operated at MITP or MATP [3-10]. It is to be noted that suppression of spurious even-order optical sidebands in an MZM output operated at MITP increases as the extinction ratio (ER) increases. Hence, performance of most of the proposed optical frequency multiplication systems are extinction ratio dependent. M. Baskaran and R. Prabakaran in 2018 proposed the 16-tupling system employed using four cascaded MZMs [11]. However, for the proposed system, the assumed value of extinction ratio was 100dB, which is quite unrealistic. Therefore, need arises for realization of ultrahigh extinction ratio MZMs using practical MZMs.

A system for realization of an MZM with ultra-high extinction ratio at MITP using parallel MZMs is mathematically analyzed and supported by computer simulations. Such MZM configurations can be used to generate extinction ratio tolerant mm-waves. The remaining of the paper is organized as follows. Principle of the proposed system is discussed in Section II. Results along with discussion is presented in Section III. Conclusion is presented in Section IV.

II. Principle

The system setup for the realization of ultrahigh extinction ratio MZM at MITP is shown in fig. 1(b).The system consists of two MZMs connected in parallel using optical splitter and combiner. Fig. 1(a) shows an MZM with splitting ratio of 'γ', operated at MITP. For an MZM output can be mathematically written as [12, 13];

$$E_o(t) = \alpha E_i(t)\left[\gamma e^{j\pi\left(\frac{v_2(t)}{v_\pi}+\frac{v_{bias2}}{v_\pi}\right)} + (1-\gamma)e^{j\pi\left(\frac{v_1(t)}{v_\pi}+\frac{v_{bias1}}{v_\pi}\right)}\right] \quad (1)$$

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