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

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***Abstract*—Most of the commercial Mach-Zehnder modulators (MZM) have extinction ratio below 30dB. At maximum transmission bias point, the MZM output contains only even-order optical sidebands along with carrier band, if extinction ratio is very high. However, in practice output also contains spurious odd-order optical sidebands. In this paper, we propose a system for suppressing spurious odd-order optical sidebands in an MZM at maximum transmission bias point. The system is employed using parallel MZMs, electrical phase shifters, optical splitter and optical combiner. The proposed system realizes an MZM with ultrahigh extinction ratio at maximum transmission bias point. The performance of proposed system is better than that of an MZM with extinction ratio of 30dB even at an offset of about ±10° in phase shifters.**

***Keywords— Mach-Zehnder modulator, microwave photonics, extinction ratio, external modulator, optical spectrum.***

## I. Introduction

The Mach-Zehnder modulator is an external modulator that has been widely used for analog and digital photonic communication systems. The MZM is an integrated device in which the input light signal gets split into two arms, and an external electrical signal can modulate the light through each of the arm. The two arms are combined to generate intensity-modulated or phase-modulated optical signal at the output of MZM. Mach-Zehnder modulators are fabricated using materials exhibiting anisotropy in dielectric properties such as lithium niobate ($LiNbO_3$), indium phosphate (InP), or gallium arsenide (GaAs). The MZM exhibits nonlinear transfer characteristics as relation of output optical field and input bias voltage is a cosine function. However, degree of nonlinearity depends on operational biasing point on the cosine shaped transfer characteristics [1].

Due to restricted electron response, generation of higher frequency signals such as millimeter-wave (mm-wave) in electrical domain is quite uneconomical and cumbersome. Thus, optical frequency multiplication is extremely important for next generation communication systems, as higher frequency can be generated from lower frequency local oscillator. Different optical mm-wave generation techniques had been proposed in literature such as – Stimulated Brillouin scattering (SBS) [2], Four-Wave Mixing (FWM) [3, 4], and optical heterodyne [5-7], direct [8] and external modulation. Using SBS approach the system becomes bulky. Four-Wave Mixing approach make use nonlinear systems which lack operational stability. In optical heterodyne, two independent lasers operating at different wavelengths are combined and detected by photodiode. Although the technique is quite simple, but it results in noisy output signal because of phase mismatch in two independent lasers. Optical mm-wave generation using MZM offers better reliability, frequency tunability and higher frequency multiplication factor. Mach-Zehnder modulators are most commonly biased at maximum transmission bias point (MATP), quadrature bias point (negative or positive slope), and minimum transmission bias point (MITP). The quadrature bias point is preferred in applications where high transfer-function linearity is required. In microwave photonics, MZMs are used to generate optical sidebands for optical frequency multiplication. Generally, MATP is used to suppress odd-order optical sidebands, and MITP is used to suppress even-order optical sidebands along with carrier [2]. Different optical frequency multiplication systems has been proposed in which MZMs are operated at MITP or MATP [9-16]. Suppression of odd-order optical sidebands in an MZM output operated at MATP is limited by extinction ratio (ER). As extinction ratio increases, the suppression of spurious odd-order optical sidebands also increases. Therefore, the system performance of optical frequency multiplication systems may depend on extinction ratio of MZMs.

Most of the commercial MZMs have the extinction ratio under 30dB and fabrication of MZMs with higher extinction ratio is still uneconomical. As a result, output of MZM contains spurious optical sidebands due to power mismatch in the two arms. M. Baskaran et al. had proposed filterless 16-tupled mm-wave generation using four cascaded MZMs [17]. However, it has been assumed that the MZMs have the extinction ratio of 100dB, which is quite impractical. In this paper, a system for realizing MZM with ultra-high extinction ratio using parallel MZMs is proposed. The rest of paper is organized as follows. Principle of proposed system is discussed in Section II. Results along with discussion and conclusion are presented in Section III and Section IV respectively.

## II. Principle

The system setup for realization of ideal splitting ratio MZM is shown in fig. 1(b). Fig. 1 (a) represents the normal operation of MZM with any arbitrary value of splitting ratio. In this section, first the principle of operation of proposed system is discussed followed by comparison with an MZM having ideal splitting ratio. The proposed setup is employed using laser diode, radio frequency source, MZMs, electrical phase shifters, optical splitters and an optical combiner. The light signal is fed to parallel MZMs using optical splitter and,