Filterless frequency sextupling and 18-tupling optical millimeter-wave generation using Mach-Zehnder modulators

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Filterless photonic technique for millimeter-wave generation using three cascaded-parallel Mach-Zehnder modulators with frequency multiplication factor of 6 and 18 has been proposed in this paper. A local oscillator of 5 GHz frequency is 18-tupled to 90 GHz and sextupled to 30 GHz respectively. The proposed system works as frequency sextupler in broad range of modulation index of 1-2.2 with optical side band suppression ratio well above 30 dB. At modulation index of 4.88, the system operates as a frequency 18-tupler with acceptable tolerance to small variations in the modulation index. Further, the proposed system performance is independent of extinction ratio change of optical modulators.

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1. Introduction

Different materials such as lithium niobate ($LiNbO_3$), gallium arsenide (GaAS), potassium dihydogen phosphate (KH_2PO_4, KDP), ammonium dihydrogen phosphate ($NH_4H_2PO_4$ or ADP), etc. lack inverse symmetry or are non-centrosymmetric. Therefore, when electric field is applied across such materials, their refractive index also shows proportional change. This effect is called as Pockels effect and finds application in optical modulators such as Mach-Zehnder modulator (MZM) [1]. Mach-Zehnder modulators apart from optical data modulation for communication applications, have been proposed for optical frequency synthesis. In such systems, MZMs are used to generate optical sidebands and are either operated at maximum transmission bias point (MATP) or minimum transmission bias point (MITP). In general, biasing at MATP and MITP is used to generate even order optical bands and odd order sidebands respectively. However, there is also presence of unwanted optical bands due to non-ideal splitting ratio (γ) of power coupled to arms of MZM. Thus, amount of power is γ units in one arm and $\beta = (1-\gamma)$ units in another arm of an MZM. Extinction ratio (ER) is related to splitting ratio (γ) as, $\gamma = \left(1 - \frac{1}{\sqrt{\epsilon_r}}\right)/2$, where $\epsilon_r = 10^{(ER)/10}$. For example $\gamma \approx 0.484$ implies the extinction ratio of about 30 dB. Fig. 1 shows how extinction ratio varies with splitting ratio. The ideal splitting ratio is $\gamma = \beta = 0.5$ implies zero output power in case of perfect destructive interference at the modulator output. Thus, in order to completely eliminate the generation of unwanted optical bands the key solution is to fabricate modulators with very high extinction ratio. T. Kawanishi et al. have proposed integrated optical modulator with ER as high as 70 dB [2-4]. The proposed structure is composed of a two sub-MZMs integrated with main MZM. To obtain such high value of ER, we require three non-fluctuating DC supplies to bias two sub-MZMs and main MZM to actively control amplitude balances and phase difference in two arms respectively. In other proposed technique, with the help of photorefractive trimming local micro-size tailoring of refractive index is done to improve ER [5, 6]. However, currently most of commercial modulators have extinction ratio below 35 dB.

In literature, different MZM based setups have been proposed to generate millimeter-waves with the assumption that ER of MZM is 35 dB [7], 40 dB [8, 9], 60 dB [10, 11], and 100 dB [12-14]. An 80 GHz mm-wave is generated by 10 GHz local oscillator signal with 62 dB OSSR and 54 dB RFSSR where both SSRs are tolerant towards extinction ratio by Asha et al. [15]. Furthermore, it can be observed in most of these proposed systems that optical side band suppression ratio (OSSR) of the optical bands saturate as the ER increases above 50 dB. In this work, we have proposed to generate an 18-tupled frequency with extinction ratio independent optical sideband suppression ratio (OSSR) and radio frequency spurious sideband ratio (RFSSR) of 38 dB and 32 dB respectively.