Vector Modulation Scheme using Three Phase Modulator

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***Abstract*— A novel optical I-Q modulator circuit consisting of three phase modulator in parallel is proposed. Theoretical analysis is done by the minimization of an error function of an under-determined system, which delivers specific optical phase relationship and modulation constraints to achieve I-Q modulation. A single sideband modulation with carrier suppression is obtained at the output of the proposed architecture, which is in agreement with the analytical development. Numerical demonstration of the performance of the architecture is done by industry-standard software simulation. Scenarios considering both ideal and imperfect power balances and phase relations to the phase modulators are also considered.**

I. Introduction

The ever increasing bandwidth demand with the evolution of communication systems motivated the employment of multi-level modulation formats based on coherent technologies [1]. Among different choices of modulation techniques, I-Q modulators offer high speed data transmission, advanced modulation formats and better control over generation and transmission of signal [2]. In [3], a wideband photonic microwave SSB up-converter and an I-Q modulator using a polarization division multiplexing dual parallel Mach-Zehnder modulator (PDM-DPMZM) has been designed and experimentally demonstrated. Reference [4] suggests an electro-optical up-conversion mixer architecture which offers the function of an I-Q modulator to base-band complex-valued modulating signals.

In this report, a photonic circuit architecture enabling optical I-Q modulation is proposed. The circuit consists of three phase modulators (PM) in parallel, in contrast to the conventional architectures with four PM. It also offers an SSB frequency electro-optical up-conversion function. The architecture can be applied in a zero intermediate frequency (zero-IF) transmitter for direct modulation over the carrier which can result in the reduction of equipment cost and complexity [5].

II. Theory

Fig. 1 illustrates the proposed I/Q modulator which mainly consist of three phase modulator in parallel, each PM is followed by an optical phase shifter. Every PM is driven by a signal v_p, where p=0, 1, 2. The optical phase introduced at each arm of the configuration is $\Delta\varphi_p = p(-2\pi/N)$ where N is the number of the PMs in the architecture. The total transmission of the configuration can be expressed as

$$f = 1/2\begin{bmatrix}\exp(i(\pi v_0)/v_\pi) + \exp(-i\,2\pi/3)\exp(i(\pi v_1)/v_\pi) \\ +\exp(-i\,4\pi/3)\exp(i(\pi v_2)/v_\pi)\end{bmatrix} \Rightarrow f = 1/2(i\pi/v_\pi)[v_0 + v_1\exp(-i\,2\pi/3) + v_2\exp(-i\,4\pi/3)] + \cdots \quad (1)$$

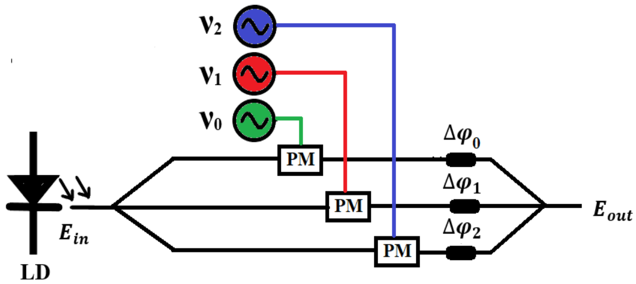

Fig. 1. Schematic diagram of the proposed I-Q modulator. LD: laser diode; PM: Phase modulator

For I-Q modulation purpose,

$$v_0 + v_1\exp(-i\,2\pi/3) + v_2\exp(-i\,4\pi/3) = v_I - iv_Q \Rightarrow \begin{bmatrix}1 & \cos(2\pi/3) & \cos(4\pi/3) \\ 0 & \sin(2\pi/3) & \sin(4\pi/3)\end{bmatrix}\begin{bmatrix}v_0 \\ v_1 \\ v_2\end{bmatrix} = \begin{bmatrix}v_I \\ v_Q\end{bmatrix} \quad (2)$$

which is an under-determined system of the form $\mathbf{Ax} = \mathbf{y}$ that does not have a unique solution. One way is to minimize the error function which leads to the constraint –

$$\mathbf{A}^\dagger\mathbf{Ax} = \mathbf{A}^\dagger\mathbf{y} \quad (3)$$

where $\mathbf{A}^\dagger$ is the adjoint operator of $\mathbf{A}$. Now $\mathbf{A}^\dagger\mathbf{A}$ is square but for an undetermined system it still has a determinant of zero, equivalently there are solutions to:

$$\mathbf{A}^\dagger\mathbf{Az} = \mathbf{0} \quad (4)$$

To resolve the uniqueness, the solution of smallest norm can be found by using the eigenvectors of $\mathbf{A}^\dagger\mathbf{A}$ which can be used to invert (3) excluding the eigenvector with zero eigenvalue. This leads to the relationship –

$$\begin{bmatrix}v_0 \\ v_1 \\ v_2\end{bmatrix} = \frac{1}{6}\begin{bmatrix}4v_I + 0v_Q \\ -2v_I + 2\sqrt{3}v_Q \\ -2v_I - 2\sqrt{3}v_Q\end{bmatrix} \quad (5)$$

Considering modulation by a pure tone:

$$v_I = v_m\cos(\omega t) \qquad v_Q = v_m\sin(\omega t) \quad (6)$$

the drive signals can be found as

$$v_p = 2/3v_m[\cos(\theta_p)\cos(\omega t) + \sin(\theta_p)\sin(\omega t)] \quad (7)$$

where $\theta_p = p(2\pi/N)$. This choice of modulation provided at (6) leads to the SSB modulation with the same architecture. The total transmission in (1) can be expressed as

$$f(t) \approx J_1(m)\exp(i\omega_{RF}t) + J_2(m)\exp(-i2\omega_{RF}t)\exp(i\pi/2) + \cdots \quad (8)$$

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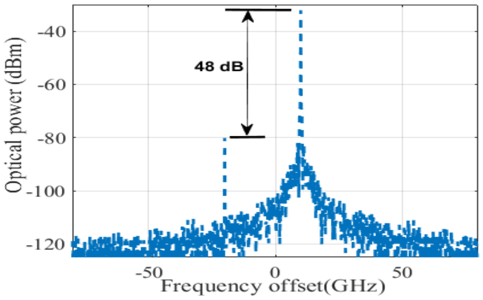

Fig. 2 Optical spectrum of the proposed architecture when acting as a SSB modulator

where m = $(\pi V_{RF})/v_{\pi}$ is the modulation index, V_{RF} is the amplitude and ω_{RF} is the angular frequency of the RF drive. Equation (8) suggest that the upper sideband (USB) operation can be obtained with opposite polarity between optical and RF phase shift. Same polarity can switch the SSB operation to lower sideband (LSB).

III. Simulation and Results

The proposed system is simulated using the Virtual Photonics Inc. (VPI) software package. A continuous wave distributed feedback (DFB) laser at a wavelength of 1550 nm with average power of 10 mW is used as the optical input. Three PMs are set in parallel with half wave voltage of each as 1V. A 10 GHz sinusoidal RF drive signal is applied to each of them. For USB operation, appropriate optical and RF phase angles are taken with opposite polarity to each other.

Fig. 2 shows the optical spectrum at the output of the configuration. As shown in fig. 2, the optical carrier and all the sidebands except the 1st harmonic at USB and 2nd harmonic at LSB are effectively suppressed. A spurious harmonic suppression ratio (SHSR) of over 48 dB is observed with an RF input of only 5 mV amplitude without any DC offset.

The linearity of the system described through the relation between the USB harmonic at +10 GHz and the LSB harmonic at −20 GHz is illustrated in fig. 3. It can be observed from fig. 3 that that the SHSR linearly decreases with the increment of RF input power. Other unwanted harmonics e.g. at +40 GHz emerges at the output for RF input power with greater than -10 dBm. Satisfactory performance with RF signals having low average power can be realized with the modulator here proposed depending upon the receiver sensitivity and noise.

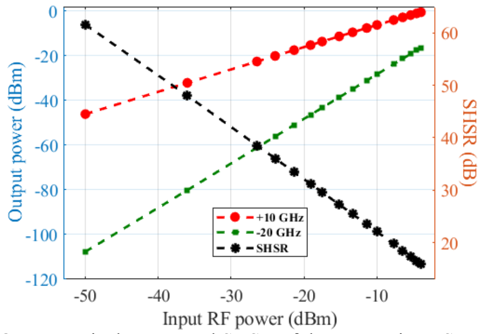

Fig. 3 Output optical power and SHSR of the two major USB and LSB harmonics interm of RF input power

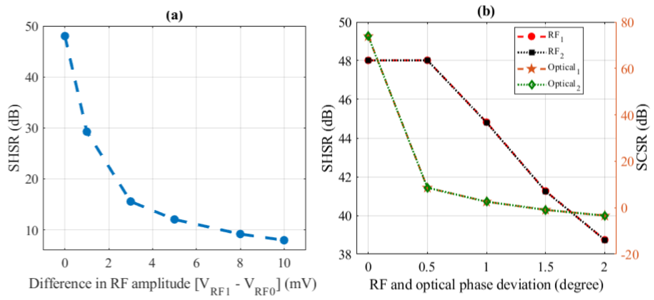

Fig. 4 (a) SHSR variation due to the difference of RF drive amplitude between PM_0 and PM_1, (b) the effects of the drift in optical and RF phase on SHSR and SCSR. Identical results are obtained when the phase deviations are mirrored

Drifts from the ideal condition are also investigated. Imbalance in RF drive powers to PM_0 and PM_1 is considered in fig. 4(a). The degradation in the performance appears from the unsuppressed 1st order harmonic at LSB whereas the optical power at -20 GHz harmonic remains almost consistent. Carrier also gains significant power above the noise level. It can be observed from fig. 4(a) that operation with SHSR greater than 20 dB can be achieved with a 40% imbalance in the abovementioned RF drives. The suppression of -10 GHz is also degraded when the RF phases are subjected to variation. Drift of more than ±0.5 in RF phase angle results this harmonic to be the major cause behind the decrement of SHSR, as shown in fig. 4(b). The effect of optical phase drift is more severe. From (1), it can be taken that the carrier suppression by design is dependent mostly on the precise choice of optical phase difference between the arms of the architecture. From fig 4(b), a sharp response against the optical phase drift in terms of spurious carrier suppression ratio can be observed.

IV. Conclusion

In summary, a new photonic circuit architecture is theoretically proposed as an I-Q modulator. Various advanced demonstration of phase modulators based either on silicon, InGaAsP, silicon–organic materials, or hybrid integration technologies makes the actual implementation of the architecture in a photonic-integrated circuit feasible.

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