Direct Generation Of RF Signals using Photonic Heterodyne method For Radar Applications

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Abstract

Microwave or Millimeter wave signal generation using photonic methods provides low loss, less complex, wide bandwidth and Electro Magnetic Interference (EMI) free solutions. This work is based on the generation of commonly used 'L' and 'S' band of radio frequency (RF) signals by using Optical heterodyne method. The paper mainly focuses on the generation of the signals and its evaluation using both modeling and experimental methods. The work brings out some of the results obtained during the evaluation process of this method with the related observations. This method can also be extended for the generation of higher band of RF signals as well as for other frequency modulated signals.

1. Introduction

Microwave Photonics (MWP) is the study of high speed photonics devices operating at the microwave or millimeter wave frequencies and their uses in microwave or photonic systems. The generation, processing, conversion as well as the distribution of microwave signals via broad band optical links are possible with the advancements in the field of MWP [1], [2]. MWP can generate microwave signals with advantages of high frequency, large bandwidth and superior noise performance [3]. Bringing together the worlds of RadioFrequency (RF) and Optoelectronics, the field of MWP has recently attracted great interest from both the research and the commercial communities where its importance has been identified in emerging applications including medical imaging, future 5G networks, and sub terahertz systems. It offers the unique abilities to enable key functionalities in microwave systems such as filtering, arbitrary waveform generation, frequency up/down conversion and instantaneous measurement that are either complex or even not directly possible in the radiofrequency domain. The role of MWP develops an opening to widespread applications and it becomes important to replace systems that rely exclusively on discrete optoelectronic devices and fiber-based components [4].

The frequency tunable microwave or millimeter wave is desirable for many applications such as radar, wireless communication, software defined radio, sensor networks and modern instrumentation etc. Conventionally, a microwave signal is generated based on electron circuitry by using many stages of mixers, where as the present work is based on the generation of microwave signals by using optical heterodyne method [5]. This method is capable of generating an electrical signal with frequency up to THz band, limited only by the bandwidth of the photodetector. By beating two optical waves from two free running laser diodes would lead to a microwave or millimeter signal with phase noise since the phase of the two optical waves are not correlated. Techniques to generate low-phase-noise microwave or mm-wave signals with the two optical waves are broadly classified into various categories that include Optical injection locking, Optical phase-lock loop (OPLL), Dual-wavelength laser source method and Microwave signal generation using external modulation techniques [6].

The work mainly focuses on the generation of RF signals specifically suitable for radar applications by using two phase correlated laser sources operating at required wavelengths. The method is evaluated using both modeling and experimental methods. The Modeling is performed using a standard simulation environment (Optisystem) and the same has been evaluated against the experimental results [7].

2. Methodology

In this method, microwave signals are generated by beating two optical waves at the photodetector (PD) [8]. Due to the limited bandwidth of PD, the radio frequency signal corresponds to the difference in the wavelengths will be generated.

The signal at the output of the PD is given by [8],

$$I(t) = R|E(t)|^2 = R|E_1(t) + E_2(t)|^2 \quad (1)$$

Where R is the responsivity of the PD. $E_1(t)$ and $E_2(t)$ represents two optical input signals.

This is equivalent to

$$RP_1 + RP_2 + 2R\sqrt{(P_1P_2)} \cos[(\omega_1 - \omega_2)t + (\phi_1 - \phi_2)] \quad (2)$$

Where, P_1 and P_2 represent corresponding input signal powers, ω_1 and ω_2 represents the input signal frequencies and ϕ_1, ϕ_2 represent the phase of the input signals.

The current at the output of the PD is given by

$$I_{RF} = 2R\sqrt{(P_1 P_2)}\cos[(\omega_1 - \omega_2)t + (\phi_1 - \phi_2)] \quad (3)$$

The same methodology is adapted for the generation of different radio frequency signals in various bands like ‘L’ and ‘S’ bands.

The above concept can be represented by Figure 1, where respective RF and Optical signals are measured using a Real Time Signal Analyzer (RTSA) and an Optical Spectrum Analyzer (OSA).

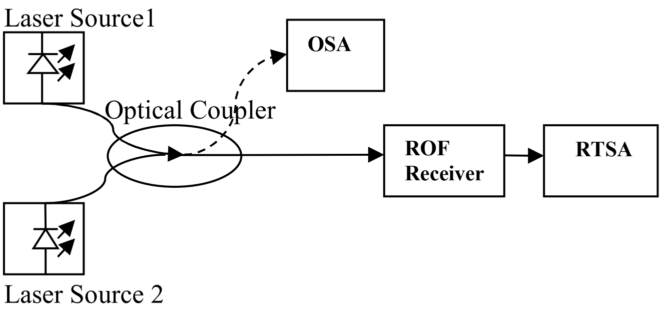

Figure 1. Conceptual Diagram of Microwave Signal Generation.

The microwave signal is generated by beating two laser source outputs that are tuned to operate at different wavelengths based on the frequency to be generated. Initially the same has been modeled in a standard optical simulation environment and further it is evaluated against experimental results.

3. Component level Model evaluation

The modeling approach uses the model which comprises of various optical components for evaluation purpose. Optisystem is used to model and validate the optical heterodyne method with the generation of different RF signals. This modeling environment helps in designing, testing and optimizing various links in the physical layer based on the application requirements [7].

As per Figure 1, the model is generated by using various optical components and Figure 2 represents the model developed in the simulation environment for generation of microwave signals.

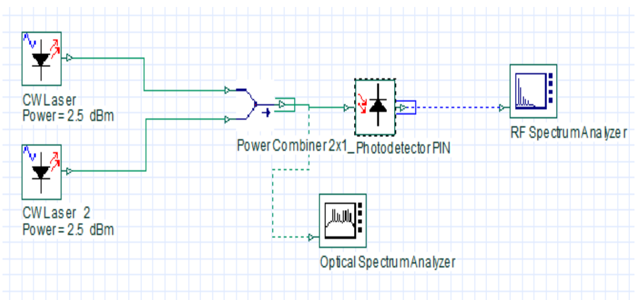

Figure 2. Model for Microwave Signal Generation.

In this paper, two typical test cases are brought for the evaluation of the methodology.

3.1 Test case1:

In this case, two laser sources operating at wavelengths 1556.313nm and 1556.321nm are used for the generation of ‘L’ band microwave signal. Both laser output signals are kept at an amplitude of +2.5dBm. The laser outputs are combined by using a 2 X 1 power combiner and fed to a PD. The generated optical and RF signals are observed using OSA and RF Signal analyzer respectively.

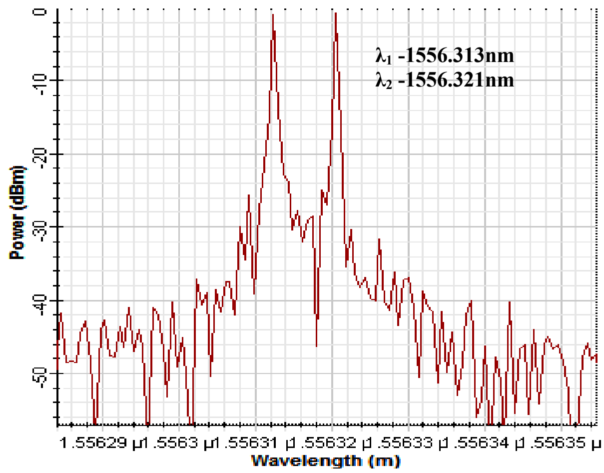

Figure 3. Power Combiner Output.

Figure 3 shows the output that is observed at the output of the power combiner using OSA. Here two peaks are observed at set wavelengths 1556.313nm and 1556.321nm respectively.

Figure 4 shows the 1 GHz (‘L’ band) signal generated at the output of PD.

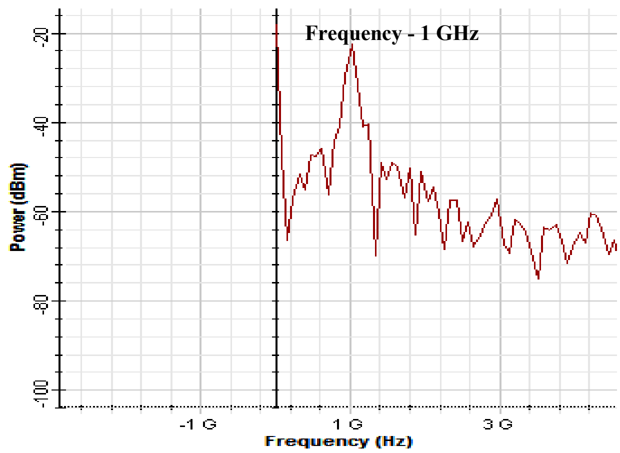

Figure 4. Modeling result- 1GHz (‘L’ band) signal.

3.2 Test Case 2:

Two laser sources operating at wavelengths 1556.313nm and 1556.337nm are used for the generation of ‘S’ band microwave signal. In this case also, laser output signals are kept at an amplitude of +2.5 dBm.

Figure 5 represents respective 3 GHz, 'S' band signal generated at the output of PD.

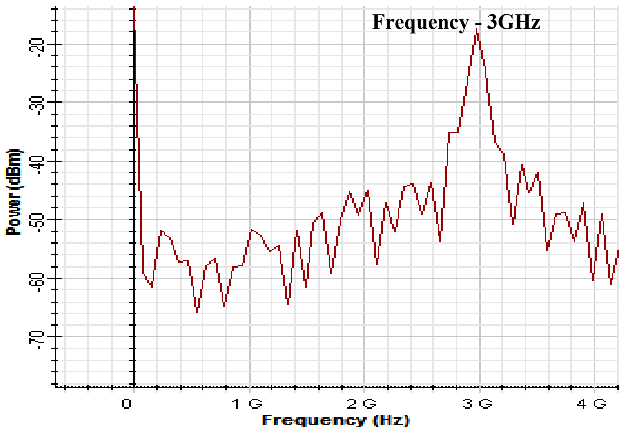

Figure 5. Modeling result- 3 GHz ('S' band) signal.

4. Experimental Setup.

Figure 6. Shows the experimental set up used for the generation of the microwave signals.

The setup mainly consists of DFB laser sources (Yenista OSICS - DFB)[9] for the generation required optical wavelength signals. Further the laser outputs are combined by using a power combiner available with a WDM unit (Light Runner). The coupled output is given to a wide band Radio over Fiber Receiver (RoF Rx) unit (Finisar FTAR1801GB). RF and Optical measuring instruments like Real Time Signal Analyzer (RTSA-Tektronix RSA5126B) and Optical Spectrum Analyzer (OSA EXFO - FTB500) are used to monitor the respective output signal levels.

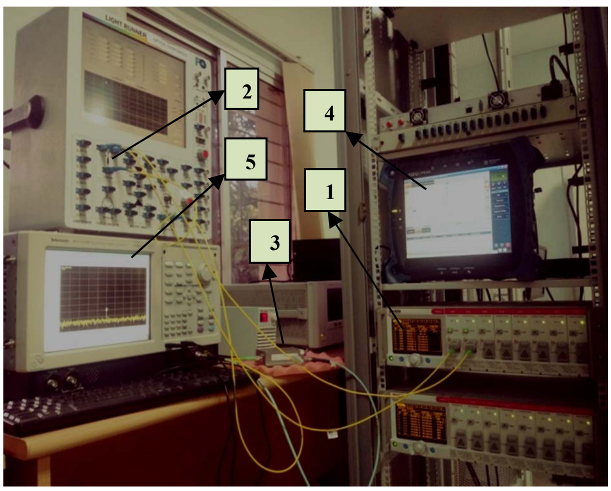

Figure 6. Experimental set up. 1- DFB Laser source, 2- Optical coupler from the light runner, 3- ROF receiver, 4- Optical spectrum analyzer, 5- Real Time Signal Analyzer.

For a better comparison, laser sources are tuned for same set of amplitude and wavelength values during the experimental study of generation of both 'L' and 'S' band RF signals.

4.1 Test Case 1:

Two Distributed Feedback (DFB) laser sources are tuned to operate at wavelengths 1556.313nm and 1556.321nm with amplitudes +2.5dBm are used for the generation 'L' band signal as similar to modeling environment. Figure 7 represents power combiner output observed on OSA. Because of the limitation on OSA display capability, two peaks were not distinguishable as observed with simulation results. The peaks were observed identical to simulation results in the case of higher band of RF signal generation which is not included within the scope of this paper. Therefore, in this case a peak is observed at 1556.317nm.

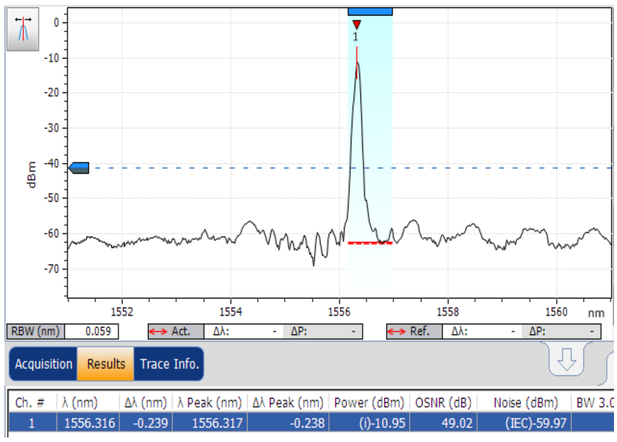

Figure7. Power combiner output for 1GHz signal generation.

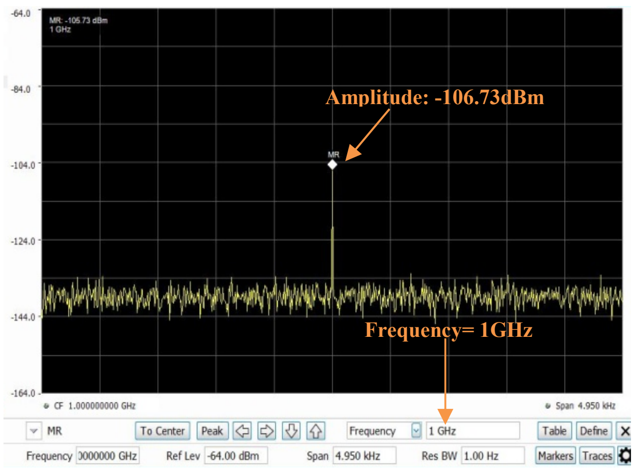

Figure 8. Experimental result- 1GHz, 'L' band signal.

Figure 8 represents the RF signal (1 GHz) generated at the output of PD.

4.2 Test Case2:

In this case also, two DFB laser sources are tuned for same wavelengths (1556.313nm and 1556.337nm) and amplitude levels (+2.5dBm) as similar to modeling environment. Figure 9 represents the respective RF signal (3 GHz) generated at the output of PD.

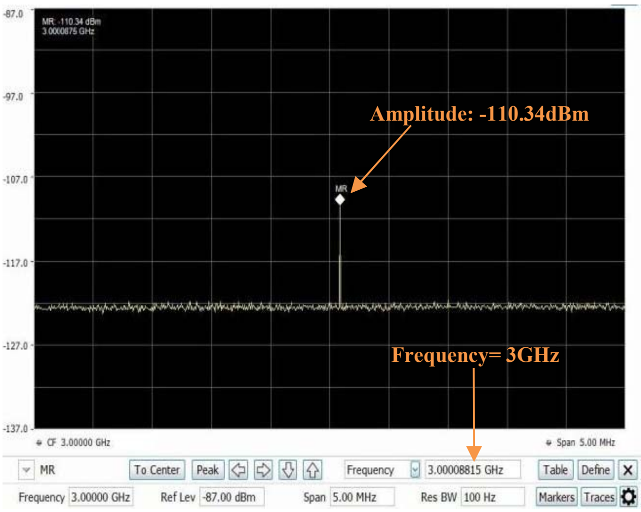

Figure 9. Experimental result- 3GHz, 'S' band signal.

5. Results and Discussions

For a better comparison, modeling and experimental studies used same set of laser wavelengths and amplitude levels for the generation of microwave signals in both 'L' and 'S' band of frequency signals. During experimental study, similar results are observed as that of model results. The experiment is also repeated with various wavelength values for the generation of same set of frequency signals. Even though the lasers are set to operate at an amplitude level of +2.5dBm, the inputs to the power combiner (L_1 and L_2) are observed differently due to cable losses.

Table1. Experimental Observations with variations in Laser operating wavelengths

Microwave Signal Frequency	Wavelengths		Laser outputs		Coupler Output (dBm)	RF Signal Amplitude (dBm)
	λ_1 (nm)	λ_2 (nm)	L_1 (dBm)	L_2 (dBm)		
1GHz	1553.136	1553.128	-3.85	-1.95	-3.65	-116.24
	1556.313	1556.321	-1.50	-2.05	-1.30	-105.73
	1559.876	1559.884	-3.95	-3.45	0.85	-103.40
3GHz	1553.136	1553.112	-4.25	-2.25	-4.15	-118.24
	1556.313	1556.337	-1.65	-2.25	-1.75	-110.34
	1559.876	1559.900	-4.65	-3.55	-2.20	-110.07

Table 1 summarizes various RF and Optical power levels obtained during the evaluation process. It is observed that RF signal level decreases with an increase in the frequency of the signal to be generated under same experimental environment. The experimental results also revealed that with increase in laser wavelengths, the amplitude of the generated microwave signal frequency increases. Therefore, it is proposed to choose suitable wavelengths based on the application requirements.

6. Conclusion

The paper discusses on the generation of microwave signals in 'L' and 'S' bands using photonic heterodyne methods for radar applications. The evaluation of the methodology is carried using both model and experimental results. The study brought out the variation of RF signal parameters with respect to selected laser operating wavelengths. The same concept can be further extended for the generation of higher order RF signals as well as for other frequency modulated signals. In addition to inherent photonic advantages, the adaptation of this method for direct generation of RF signals helps in avoiding bulky mixer stages normally used in conventional radar systems.

8. References

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