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Microwave Photonic Filter Using Optical Heterodyning with Least Signal Distortion Up to 10 Gbps

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***Abstract*— Microwave photonics and its application in signal processing is a field of intensive research and has been attracting new researchers from past few decades. Processing of microwave or mm-wave signal in optical domain came into picture in the early 90s which works on the concept of delay lines filters such as FIR or IIR filters, later on coherent photonic filters starts gaining its popularity. This paper proposes a novel microwave photonic filter architecture of a coherent regime which is simple to setup and provides better bandwidth. The working principle behind this filter is closely related to optical heterodyning so that high power output can be recovered at the photodiode. In, optical communication to recover data at receiver end, we need a clock recovery and data recovery circuit after an optical receiver, but these recovery circuits are quite complex in structure, thus, this filter provides least distorted high power output so that data can be recovered without using a recovery circuit.**

Keywords*— *Microwave Photonics, FBGs, optical heterodyning, photonic filter

I. Introduction

Filtering of microwave signals in the electrical domain through microwave filters has always been a major concern, as the conventional electrical microwave filters are bulky, bandwidth limited and not immune to electromagnetic interference [1]. Therefore, intensive research in the field of optical domain is done is last few decades a to make microwave photonic filter, as Photonics possesses many inherent attractive properties like low loss, light weight, high bandwidth and immune to electromagnetic interference [2]. Apart from the advantages mentioned above microwave photonic filters have high tunability and very high Q factor. These two properties in Microwave photonic filters are unique as tunability and a high Q factor is impossible to sustain in conventional microwave filters. These types of filters have its applications in warfare, astronomy, unknown frequency estimation, etc. [3], [4].

This paper introduces a novel setup of a microwave photonic filter of a coherent regime which provides narrower bandwidth as compared to other incoherent photonic filters. This setup is simulated successfully on OptiSystem and the frequency response is compared to frequency response the incoherent nonuniformly spaced microwave delay line filter [5], [6] and as a result, a narrower bandwidth is obtained from the proposed filter which is essential for high frequency-selectivity and provides higher power signal output. There is a need for a recovery circuit at the out of photodiode to detect the data as the signal is of low power the chances of signal distortion is more and its quite difficult to detect the data if the power of received signal is low, the simulation results show that signals up to 10 Gbps can be successfully recovered from the filter without using any clock recovery and data recovery circuit recovery circuit in electrical domain, which is also a subject of interest. The setup smartly uses the concept of optical heterodyning. The concept of optical heterodyning states that it is a phenomenon [7] in which two optical waves of different wavelength beat a photodetector to produce an electrical beat note at the output having a frequency corresponding to the wavelength spacing of two optical waves is used to reproduce microwave signals from an optical domain in the electrical domain. Hence using this concept and basic optical devices like LASER, Mach-Zehnder Modulator, Fiber Bragg Gratings, and photo detector an optical signal processing unit is idealised and simulated.

II. Principle of Operation

Microwave photonic filters are broadly divided into two regimes incoherent and coherent filters. An incoherent photonic filter is generally implemented using a delay line with FIR or IIR configuration [8], [9]. However, coherent microwave photonic filters have a common laser source and do not possess a delay line in its circuit. The proposed technique is of the coherent regime and easy to implement.

The block diagram of the proposed microwave photonic filter is shown in Fig.1. The setup consists of a CW laser source, RF (Microwave frequency) input, Mach-Zehnder Modulator (MZM), FBG for filtering out the sidebands produced by MZM. The laser source is modulated with an RF signal through MZM, in frequency domain this MZM produces sideband with the frequency gap corresponds to the input RF input, as the modulated spectrum moves further one of the first order sidebands is filtered out and reflected back from FBG, the reflected sideband is then beat upon the photodiode along with the reference laser source to produce back the RF signal. Here, microwave filtering depends upon the sideband produced by

MZM. The difference between any two sidebands that is produced by MZM is equal to the frequency of an RF signal given on the input of MZM as shown in fig. 2.

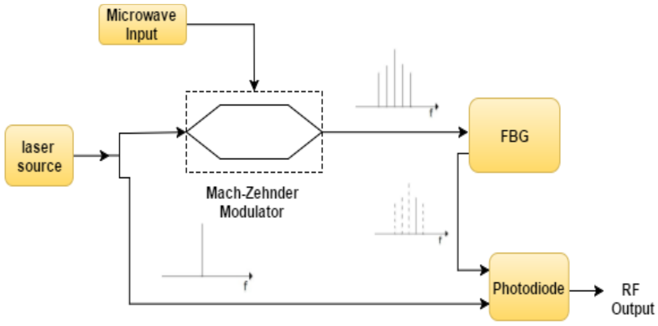


Fig. 1 Block diagram of proposed optical filter and spectrum of optical waves at each stage.

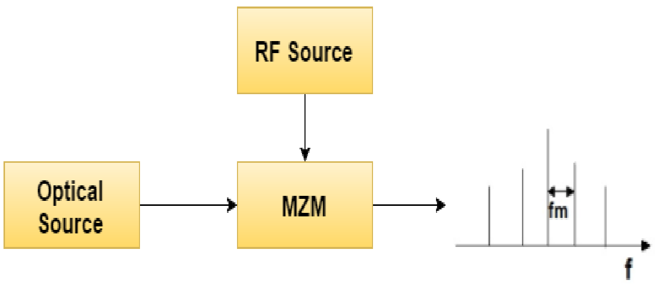


Fig. 2 Generation of sidebands using Mach-Zehnder Modulator.

But the question is how this setup is working as microwave photonic filter and the answer lies in the input RF frequency (f_1) and the FBG with a particular Bragg wavelength or reflected frequency i.e. $(f_l + f_1)$. Once the reflected frequency is being set at the first order sideband of MZM output which is equal to the addition of reference laser frequency $(f_l)$and RF input of specific frequency say (f_1) the fiber Bragg grating can only be reflect back the signal at $(f_l + f_1)$ frequency, hence if the RF frequency changes there will be no reflected signal from FBG and the output of the photodiode will be zero, thus this technique only filters out a particular frequency and works as a bandpass filter. The two major benefits of this setup are the high power output and narrower bandwidth of the frequency response of the filter. Narrower bandwidth depend upon the FBG and its fabrication, and higher output power depends upon the concept of optical heterodyning. Concept of optical heterodyning [7] says that when two optical waves of different wavelength beat upon a photodetector to produce an electrical beat note at output having a frequency corresponding to the frequency spacing of two optical waves. Let E_1 (t) and E_2 (t) be two optical waves given as:

$$E_1(t) = A_1.\exp(-jf_l(t) + \phi_1) \qquad (1)$$

$$E_2(t) = A_2.\exp(-jf_2(t) + \phi_2) \qquad (2)$$

Where, $f_2(t) = f_l(t) + f_1(t)$, which is the first ordered filtered sideband of modulated signal.

Eq. (1) and Eq. (2) are the optical signal that beat upon photodetector. The output current is given by:

$$I_0(t) = R[E_1(t) + E_2(t)].[E_1^*(t) + E_2^*(t)]$$
$$= R[E_1^2(t) + E_2^2(t) + E_1(t).E_2^*(t) + E_2(t).E_1^*(t)]$$
$$= R[E_1^2(t) + E_2^2(t) + A_2A_1\exp(-j(2\pi(f_l - f_2)t + \phi_1 - \phi_2) + A_2A_1\exp(-j(2\pi(f_l - f_2)t + \phi_1 - \phi_2)]$$
$$= R[E_1^2(t) + E_2^2(t) + 2A_2A_1\cos(2\pi(f_l - f_2)t + \phi_1 - \phi_2)] \qquad (3)$$

Eq. (3) shows that the output current of a photodiode depends upon responsivity and amplitude of optical waves. As the term $E_1^2(t)$ and $E_2^2(t)$ produces frequencies that are not detected on photodiode as these frequencies are out of the range of photodetector bandwidth. Hence only the term $2A_2A_1\cos(2\pi(f_l - f_2)t + \phi_1 - \phi_2)$ will be detected at the output of the photodetector as the produced signal will have frequency $f_1(t)$ I.e frequency of the input RF signal and will be produced at the output of photodiode. As the power of reference laser would be higher than the filtered sideband signal the out signal would be of RF frequency and the power would be nearly equal the reference laser power. Hence, exchange of power is done through this process.

III. Simulation Experiment

An experimental setup is simulated on OptiSystem. The setup consists of a CW (continuous wave) LASER source used at a frequency of 193.1 THz with power of 0 dBm. A Mach-Zehnder Modulator having an extinction ratio of 30 dB and a Fiber Bragg grating with reflected wave frequency 193.110 THz is used to filter out the sideband at this frequency and electrical filter analyzer is used which serves as Vector Network Analyser. Here, the laser source is modulated by the RF signal whose frequency is changing for obtaining the frequency response at the electrical network analyzer, the FBG is fixed at 193.110 THz reflection frequency so the frequency that would be generated at photodiode should be 10 GHz, thus only for 10GHz input the output will be obtained otherwise, the power of the signal will be very low or there will be zero. During this simulation, the first motive is to find the frequency response of this filter. The frequency response is obtained from electrical filter analysis and the data is plotted through MATLAB. Fig. 2 shows the simulation setup of proposed microwave photonic filter simulated on OptiSystem.

The frequency response of this photonic filter is recorded in electrical network analyzer, the Fig. 4 shows the frequency response of a microwave photonic filter and it can be concluded from the figure that the 3 dB bandwidth of the proposed microwave photonic filter is about 3 GHz with output power of -4.8 dBm. The response of the proposed microwave photonic filter is now compared with the incoherent photonic filter as mentioned in [5], which was again simulated on OptiSystem and results are plotted on MATLAB, whose filter response is shown in Fig. 5, this incoherent photonic filter has a 3 dB bandwidth of about 4.8 GHz which is much greater than our proposed photonic filter also the maximum power recorded for this filter is -9.34 dBm. This shows that the proposed photonic filter also produces an output signal with much greater power as compared to conventional incoherent filter.

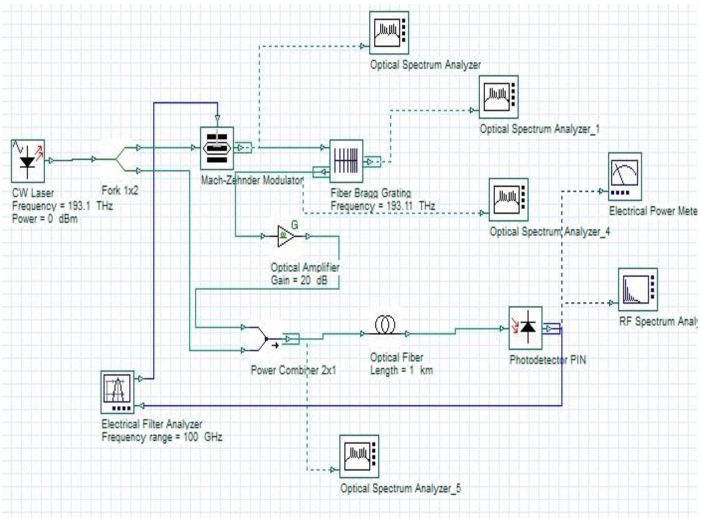


Fig. 3 Simulation setup of proposed microwave photonic filter.

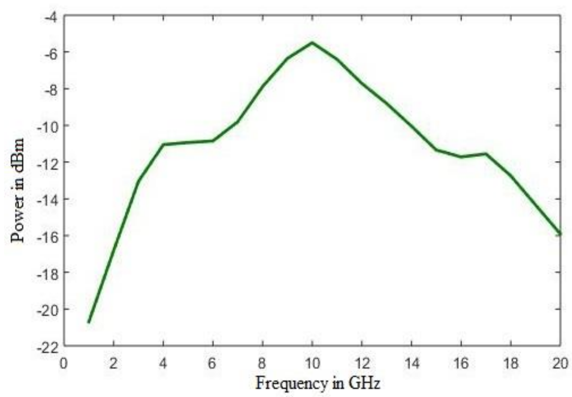


Fig. 4 Frequency Response of proposed microwave photonic filter.

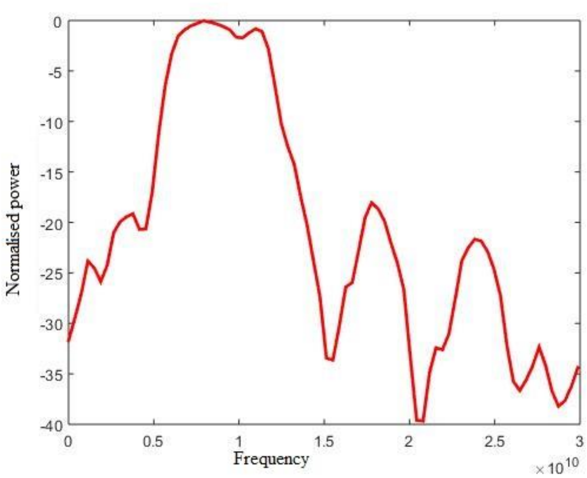


Fig. 5. Normalised frequency response of an incoherent photonic filter

By comparing the frequency response of both the filters it can be inferred that the proposed filter has a much narrower bandwidth as compared to other Incoherent photonic filter. Which is essential for bandwidth selectivity.

Another important aspect that was observed in this simulation was the quality of the signal at the output of the photodetector. The signal which is passing through this filter is a less distorted signal at the output, the distortion analysis is the first of its kind that is done on the Microwave Photonic Filter. Some of the analysis done on optical communication network was studied in [10],[11] where CMOS technology is used for data recovery but with the proposed filter the data can be successfully detected at the photodetector without using any recovery circuits and recovery algorithms, the successful regeneration of the electrical signal from an optical signal even though passing from an photonic filter is an achievement in itself and recovery of transmitted signals done up to 10 Gbps without using any algorithm and circuitry. These shown in the Fig.7 (a), 7(b), and 7(c).

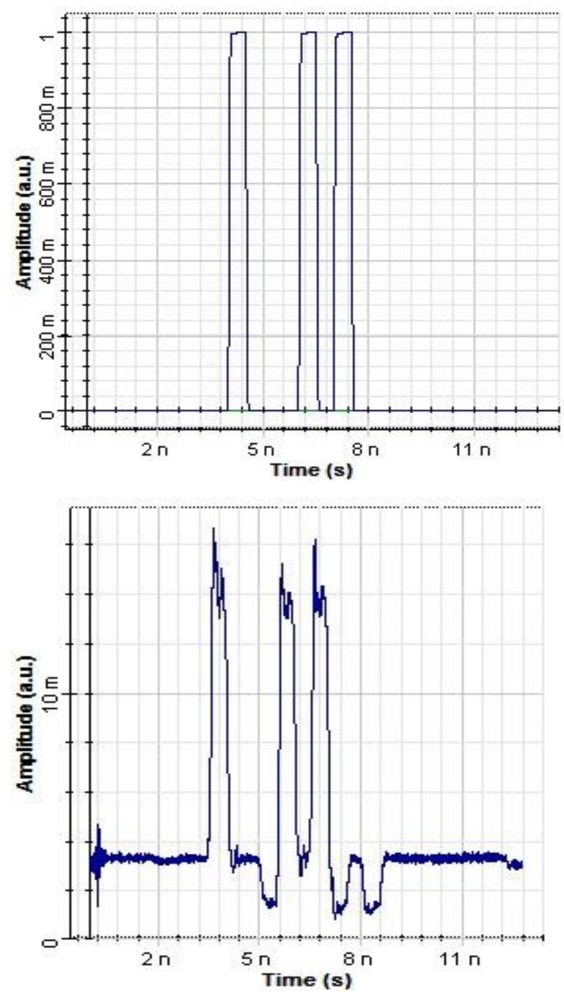


Fig. 5 Input and output signal at 1 Gbps bitrate.

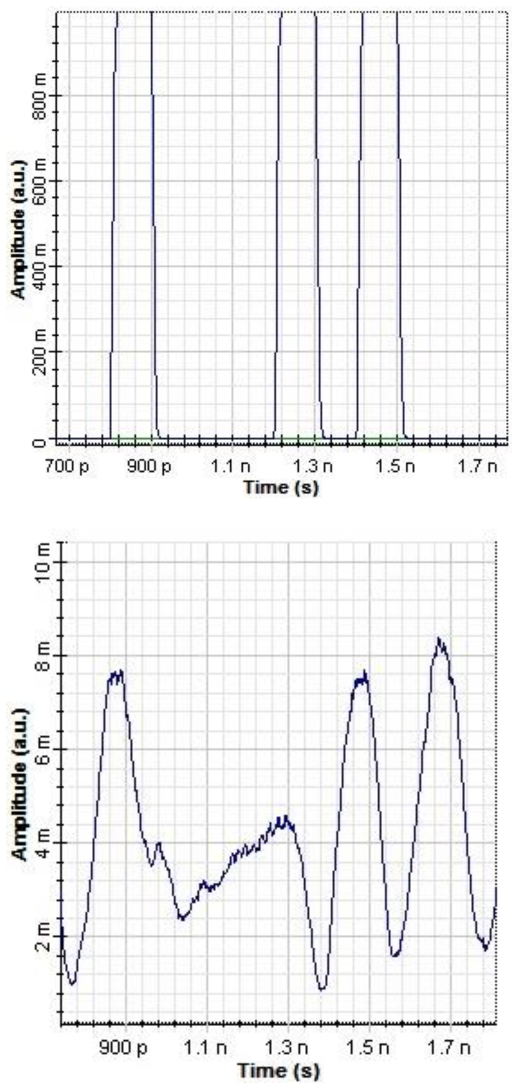
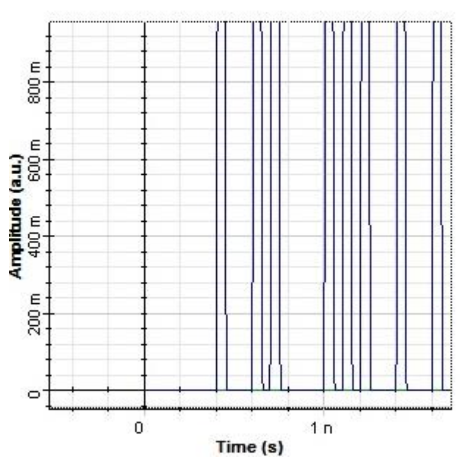


Fig. 6 Input and output signal at 5 Gbps bitrate



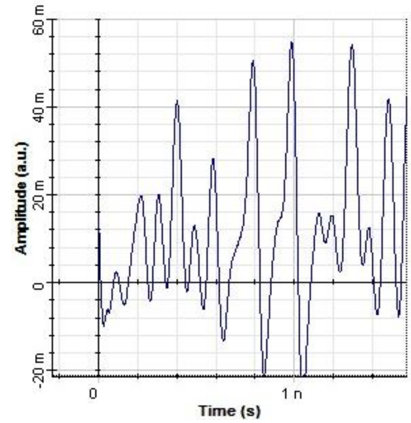


Fig. 7 Input and output signal at 5 Gbps bitrate

In Fig. 6 the photonic filter is set at the center frequency of 1 GHz and the output data is recovered at 1 GHz at photodetector which is observed through an oscilloscope on comparing the input and output data at 1GHz we find it an exact replica of the input signal with lesser amplitude. Further moving to Fig. 7 the center frequency of the filter is now set at 5 GHz, about again comparing the input-output signals we find that still, it is manageable to recover the data at the output of the photodetector and in fig. 8 the output of the filter is set to be observed at 10 GHz, in comparing the input and output figure it should be noted that the delay element starts coming into the picture due to chromatic dispersion thus a DCF fiber can be used to avoid this problem but after 10 Gbps it is not possible to recover the signal without any recovery circuit. Thus, up to 10 Gbps by using the proposed microwave photonic filter not only the particular frequency is filtered out but also the data at that frequency can also be recovered without using clock recovery and data recovery circuit.

IV. Conclusion

A novel microwave photonic filter of the coherent regime is being discussed in this paper. This photonic filter smartly uses the optical heterodyning technique to filter out a particular microwave frequency using FBGs and reference laser. A simulated setup is being proposed through OptiSystem in which a microwave photonic filter is being setup and a frequency response of this setup is successfully observed through Matlab, which is far better than other conventional incoherent photonic filters. This setup also provides vital information about signal distortion and it is observed that up to 10 GHz a filtered modulated binary signal can be easily reproduced in the electrical domain without using any recovery circuit. Hence, it provides a wide variety of applications in optical communication and optical sensing [12].

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