Feasibility analysis of a reconfigurable photonic filter using a programmable optical processor for radar applications

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Abstract— **Reconfigurable filter design is gaining acceptance for applications having multifarious hardware components, the essential requisite for the same to be deployed demands ease of use in network, flexibility in design and controllability. This work discusses about a reconfigurable optical filter by Wavelength Selective Switching using Liquid Crystal on Silicon technology for filtering of control and synchronization signals for radar applications. This is carried out through experimental studies using various types of commonly used radar signals over photonic links. Thus the paper highlights some of experimental observations and its analysis results in support of filter application which leads to effective and EMI free networks.**

I. Introduction

LCoS (Liquid Crystal on Silicon) is a reflective technology that uses the liquid crystals on a substrate. The opening and closing action of the crystals modulates the light to create image. Wavelength Selective Switching (WSS) has undergone advancements to address Reconfigurable Optical Add-Drop Multiplexer (ROADM) applications in optical networks as this design is gaining importance owing to the increase in complexity and density of the networks [1][2]. The LCoS based WSS uses an integrated LCoS chip originally developed for projection display applications. This device uses polarization-dependent optical phased array beam steering with many pixels per channel [3]. ROADM switching allows individual or multiple wavelengths carrying data to be routed, added and/or dropped from a link without interrupting the remaining channels [4]. Some devices which use WSS are also capable of tuning direction as well as wavelength of the network [5]. LCoS is attractive with switching in WSS due to dynamic addressing capability enabling new functionalities in the particular bands of wavelength which are switched together owing to the fact that they can be switched using software control. RF as well as microwave photonics require these setups for accurate filtering and signal processing [6] [7]. These filters provide better facilitation when they can be dynamically reconfigured, tuning their bandwidth, shape, and center frequency using optical signal processing methods [8]. The design for such a device capable of processing the optical signal can be improved as application demands [9].

II. Filter Configuration

Digital signals are directly modulated using CW laser sources using a Wavelength Division Multiplexing (WDM) test environment by assigning them specific suitable wavelengths. The signal to be filtered (λ1) is divided using a splitter for monitoring purpose. The output of the splitter and other modulated signals are fed to a WDM multiplexer. The block diagram of hardware setup for filter configuration is shown in Fig.1. The figure also shows how the same setup can be reconfigured for filtering of high frequency RF signals. A related work was carried out for filtering of high frequency RF and Microwave signals having wide range of frequencies with different modulation formats to demonstrate the application of optical filter for these kinds of signals but detailed discussion of this experimental study is not included within the scope of this paper. Then the multiplexed signal is fed to a photonic filter which works on the principle of LCoS technology [9]. The optical filter is configured to obtain the required wavelength. Further the filtered signal is passed through a photodetector to obtain the corresponding electrical signal. The output signal is verified against input signal using an oscilloscope for various parameters like amplitude and delay variations.

It is very essential to analyze the performance of the filter with different laser carrier wavelengths. So, both input and output signal amplitudes for specific wavelengths are measured on an Optical Spectrum Analyzer (OSA). Further the power levels are measured at different checkpoints, A,B,C and D to estimate the link power budget and record the losses due to each link component in this experimental setup The filter is designed in such a way that based on the requirements; the desired wavelength can be filtered from the multiplexed signal.

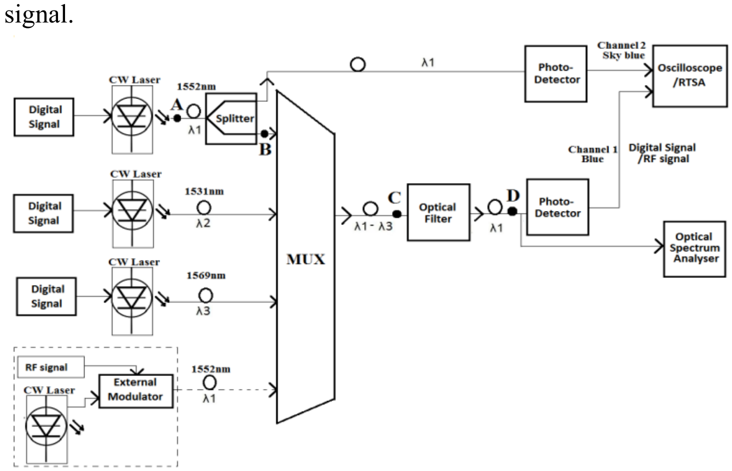

Fig. 1 Hardware setup for filter configuration

III. Realisation Setup

The above configuration is realized using various opto-electronic components using an experimental setup as shown in Fig.2 and Fig. 3. Three low frequency digital signals are directly modulated using DFB lasers that are part of a WDM unit operating with wavelengths 1531nm, 1552nm and 1569nm respectively. The digital signal operating with 1552nm wavelength (test wavelength) is divided using a splitter of WDM unit. An output of the splitter and other modulated signals are optically multiplexed using an Array Waveguide Grating (AWG) based multiplexer of WDM unit. The multiplexed signal is passed through a reconfigurable optical filter (Wave shaper 4000S) which works on LCoS technology. It is configured in such a way that only a wavelength of 1552nm is filtered out of multiplexed signal and the other signals are attenuated. In waveshaper, the light from the input fiber is reflected from the imaging mirror and then angularly dispersed by the grating, reflecting the light back to the cylindrical mirror which directs each optical wavelength to a different portion of the LCoS. Further the beam steering image applied on the LCoS is directing the light to a particular port [10]. The spectrum corresponding to the test wavelength signal is observed using an OSA to find the losses at link check points as mentioned in previous section. The observed multiplexed spectra and the filtered signal are observed on OSA. The signal is then passed through a photodetector of the WDM unit and then observed on the Oscilloscope (MSO 4054) against the input for attenuation and delay measurements.

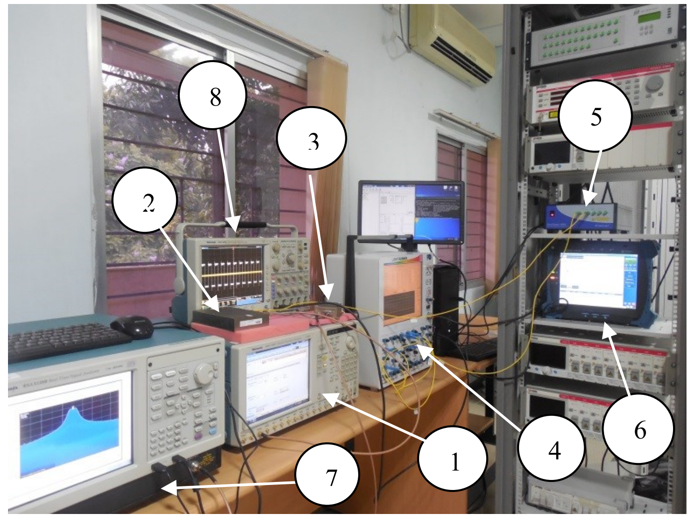

Fig.2 1-Arbitrary Wave Generator AWG7122C Tektronix, 2-RoF Transmitter module FTAT1801GB Finisar, 3-RoF Receiver module-FTAR1801GB Finisar, 4- WDM unit, 5- Photonic filter-Waveshaper-4000S, 6- Optical Spectrum Analyzer(OSA) EXFO FTB 500, 7- Real Time Spectrum Analyzer-RSA5126B Tektronix, 8- Oscilloscope-MSO4054

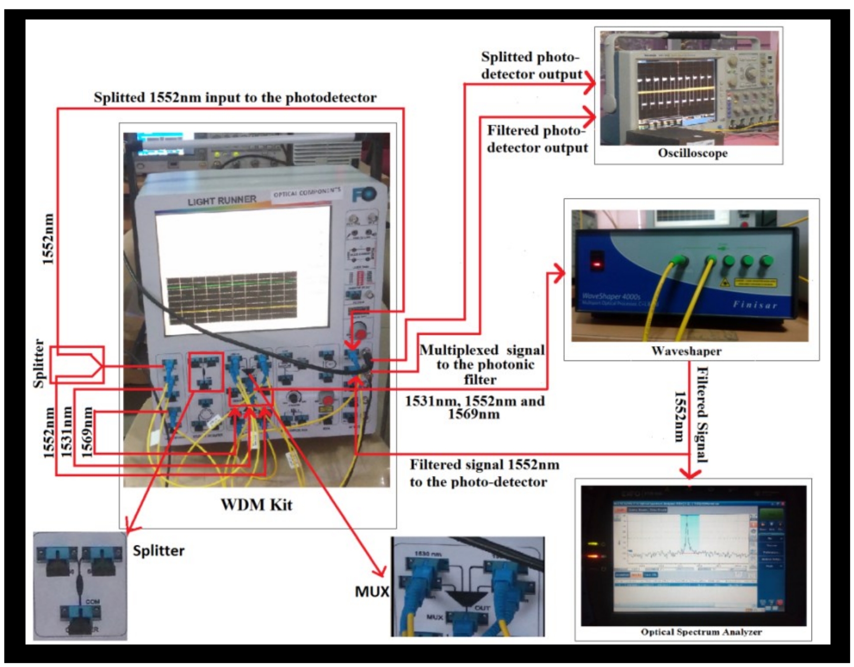

Fig. 3 Realisation setup

IV. Results and Discussions

The experiment is repeated for frequencies, that are commonly used for control and synchronization signals in radar applications. The filtered signal is monitored against the input transmit signal for variations in attenuation. Also the delay parameter is measured between the rising edge of the output signal with respect to the rising edge of input. The analysis is carried out by varying different parameters viz. frequency, duty cycle and laser power levels of the signal operating with the test wavelength of 1552nm. In addition, the experimental

study is also carried out to evaluate the efficiency of the filtering operation with change in carrier wavelength.
Following sections discuss about the performance evaluation of optical filter with variations in parameters like frequency, duty cycle, laser power level, nature of signal and also with the variation in carrier wavelength.

I. Variation in frequency:

Fig. 4 and 5 show the variation in filtered signal with change in frequency of the signals transmitted as 50 KHz and 100 KHz respectively. The experiment is repeated for signals in Megahertz range (2.4MHz) also. In this case, the duty cycle and carrier laser power levels are kept constant to evaluate the performance with the change in frequency. It is observed that the 50 KHz signal has undergone an attenuation of 19.48dB whereas the 100 KHz signal has undergone an attenuation of 20.93dB. So it can be concluded that the attenuation is directly proportional to the frequency of the signal whereas the delay is almost similar.

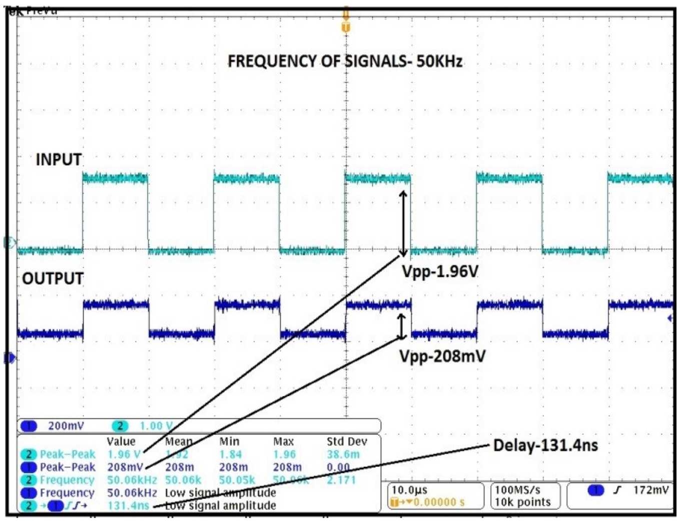

Fig. 4 Variation in signal frequency: 50% laser, 50% duty

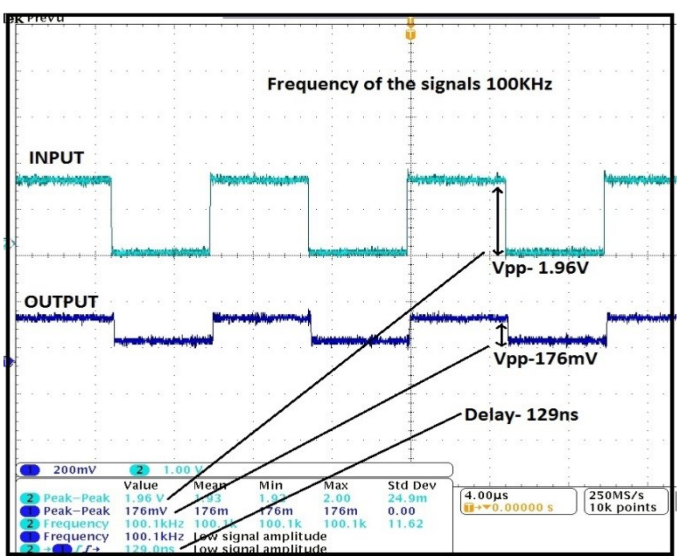

Fig. 5 Variation in signal frequency: 50% laser, 50% duty

II. Variation in duty cycle:

The experiment is repeated by varying duty cycle of the signal to be filtered by keeping carrier laser power level and signal frequency constant. Fig. 6 shows the snapshot of a test case result obtained for a duty cycle of 10% by keeping other parameters constant in comparison with Fig. 7. In this case, it is observed that the attenuation and the delay are almost in the same order.

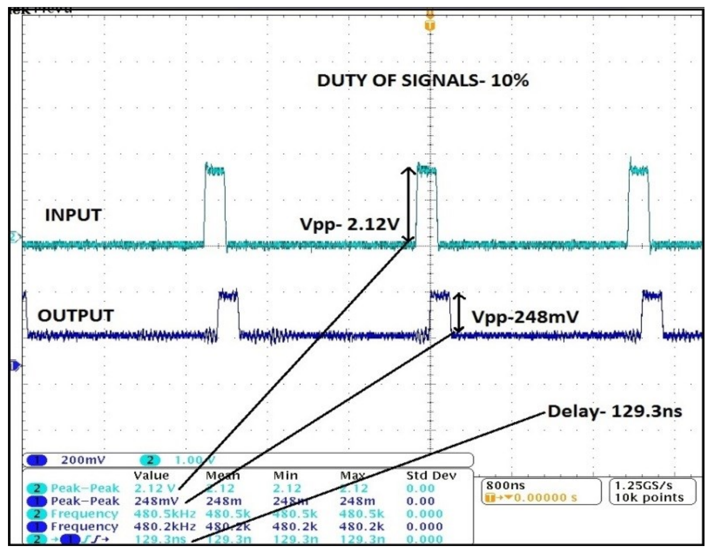

Fig. 6 Variation in signal duty: 480 KHz, 50% laser, 10% duty

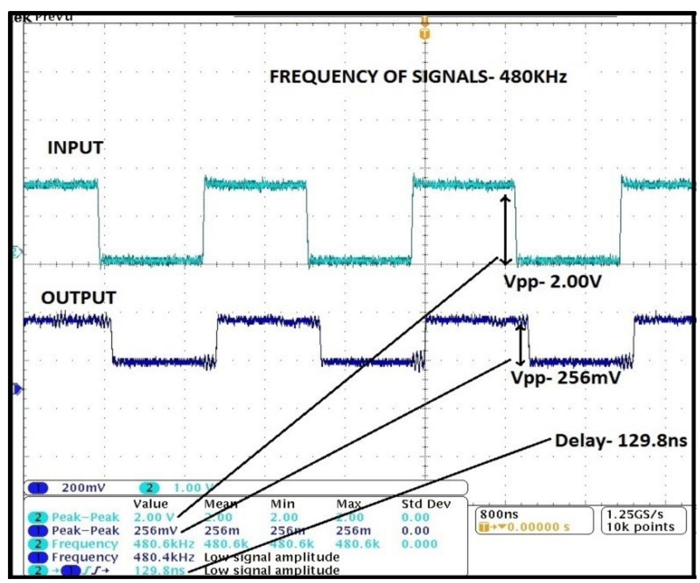

Fig. 7 Variation in signal duty: 480 KHz, 50% laser, 50% duty

III. Variation in Laser Power:

In this test case, the laser power level is increased to 70% in comparison with the test case of Fig. 7 where it was 50% by keeping other parameters like frequency and duty cycle constant. It is observed that the signal with 70% power level has an attenuation of around 18.30dB having delay of similar order as compared to previous case as shown in Fig.8.

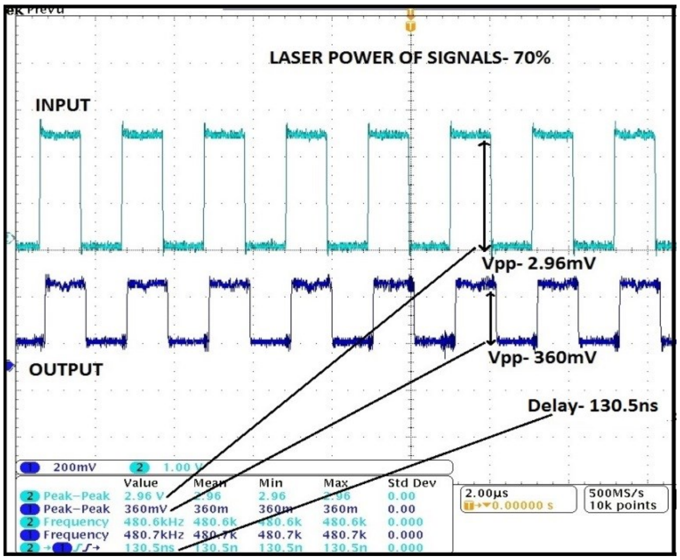

Fig. 8 Variation in signal power: 480 KHz, 70% laser, 50% duty

The experiments are repeated with a change in frequency, duty, laser power levels of the signal and also with the change in wavelength of carrier. The observations of the experiment are tabulated in Table 1 and Table 2 respectively.

It is evident from Table 1 and Table 2 that the total delay occurring in the link is almost constant irrespective of the test case environments. This can be attributed to the delay caused by individual link components. Table 1(a) reveals that with the increase in frequency the attenuation increases. Table 1(b) reveals that both attenuation and delay factors are independent with the change in duty cycle. From Table 2(a) it can be inferred that increase in laser power level results in higher photodiode currents at the receiver end resulting in more voltage and thus less attenuation. Table 2(b) reveals the performance of optical filter with respect to carrier wavelength. The filter unit used has a limitation of configuring only for C and L band wavelength signals. The detailed discussion on the same is given in the following section.

Table 1

With variations in

(a) Frequency

(1552nm, 50% Duty Cycle, 50% Laser Power)

Sl. No	**Frequency**	**Input (V)**	**Output (mV)**	**Attenuation (dB)**	**Delay (ns)**
1	50KHz	1.96	208	19.48	131.4
2	100KHz	1.96	176	20.93	129.0
3	2.4MHz	2.04	176	21.28	130.9

(b) Duty Cycle

(1552nm, 480 KHz, 50% Laser Power)

Sl. No	**Duty Cycle**	**Input (V)**	**Output (mV)**	**Attenuation (dB)**	**Delay (ns)**
1	10%	2.12	248	18.64	129.3
2	50%	2.00	256	17.85	129.8

Table 2

With variations in

(a) Laser Power

(1552nm, 480 KHz, 50% Duty Cycle)

Sl. No	**Laser Power**	**Input (V)**	**Output (mV)**	**Attenuation (dB)**	**Delay (ns)**
1	30%	1.02	116	18.88	128.0
2	70%	2.96	360	18.30	130.5

(b) Wavelength

(480 KHz, 50% Duty Cycle, 50% Laser Power)

Sl. No	**Wavelength (nm)**	**Input (V)**	**Output (mV)**	**Attenuation (dB)**	**Delay (ns)**
1	1531	4.72	360	22.35	130.0
2	1552	2.00	256	17.85	129.8
3	1569	5.52	720	17.69	135.9

IV. Variation in wavelength and power loss measurement:

The test wavelength was changed from 1552nm to 1531nm and 1569nm respectively to analyse the performance of the filter with change in operating wavelength. The filter under consideration can be configured for both C and L band of optical wavelengths. But with 1531nm being a boundary case condition in terms of wavelength, it is observed with a significant power loss of the order of 22.35 dB. Also the measurements are used to observe the performance of other components of the link in terms of power levels leading to power budget calculation. Fig. 9-12 show the measured power values for test wavelength of 1569nm as obtained on OSA at various checkpoints of the link viz. A,B,C and D. The total loss incurred in the link due to the components are computed from the above experiments. Fig.13 summarises the power values obtained at each checkpoint for the test wavelength. The loss in the splitter accounts 3.65dBm and the filter losses are around 2.16dBm. The total link loss is around 6.56dBm.

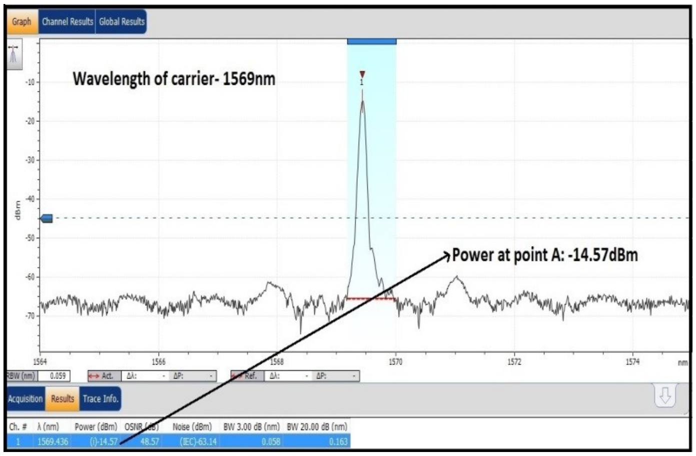

Fig. 9- 1569nm: Power value at checkpoint A: -14.57dBm

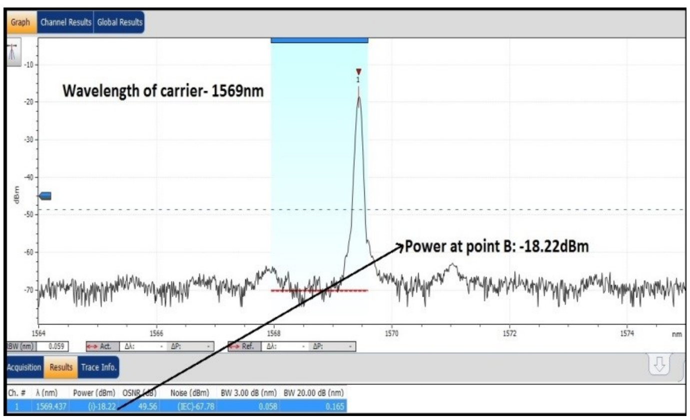

Fig. 10- 1569nm: Power value at checkpoint B: -18.22dBm

V. Variation with nature of signal:

The experiment is also carried out towards exploring the feasibility of photonic filters in radar applications for filtering high frequency RF signals. As part of the work, the measurements were carried out for various RF modulated signals such as CWRF, pulsed RF, Linearly Frequency Modulated (LFM) and Non-linearly Frequency Modulated (NLFM) respectively by varying different signal parameters. Fig. 14 and Fig. 15 show the LFM input at 5GHz and its corresponding output on RTSA respectively. The detailed analysis of photonic filter for high frequency RF signals is not included within the scope of this paper.

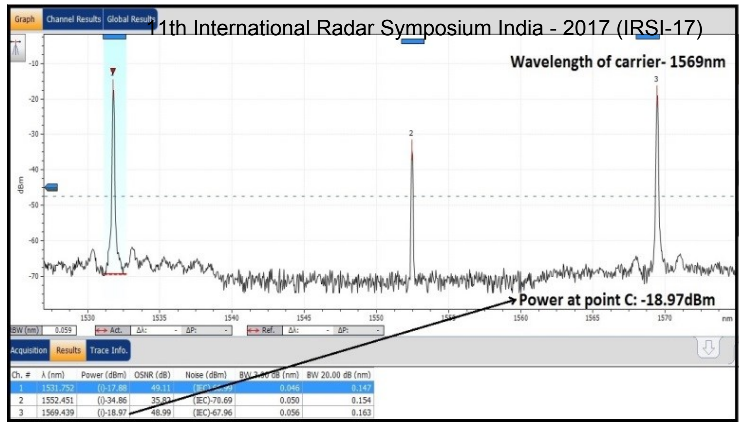

Fig. 11- 1569nm: Power value at checkpoint C: -18.97dBm

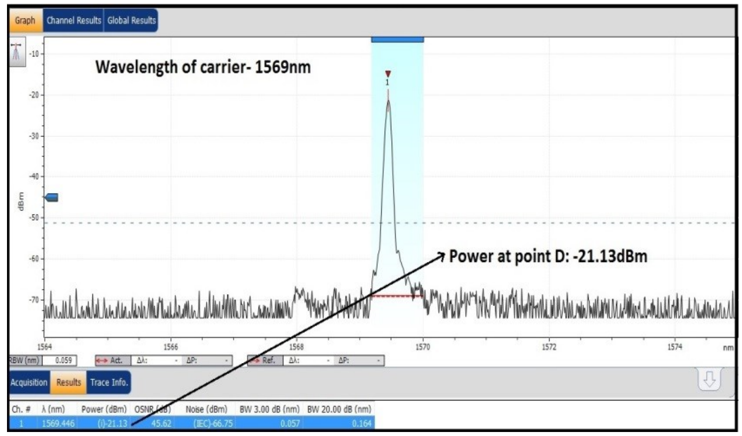

Fig. 12- 1569nm: Power value at checkpoint D: -21.13dBm

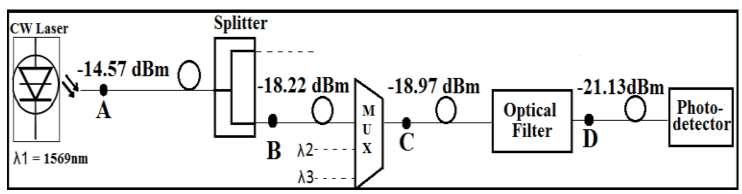

Fig. 13- Link budget

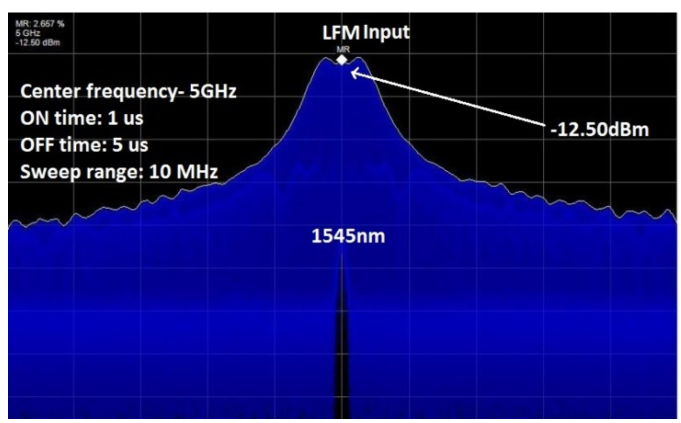

Fig. 14- LFM input

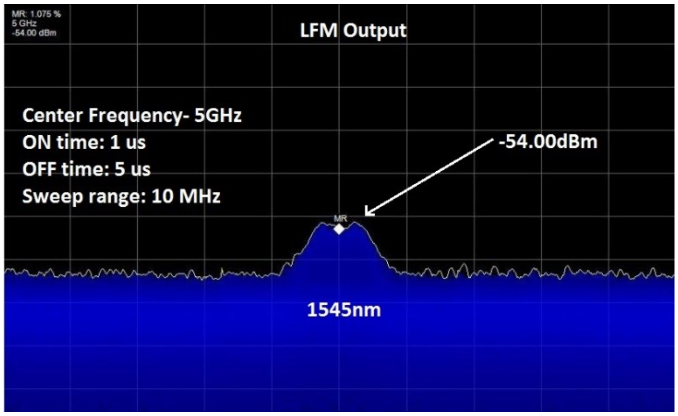

Fig. 15- LFM output

CONCLUSION

This work is carried out mainly to observe the performance of the optical filter which works on the principle of LCoS technology for filtering control and sync signals that are commonly used in radar applications. Normally, the input signals frequency and duty vary based on specific application requirement. So in this work, the performance is observed with variations of above parameters. In addition, the filter characteristics are observed for various wavelength and laser power levels. Analysis results of this experimental study revealed that the application of this filter can be efficiently carried out both for filtering of signals either in optical or electrical domain. The paper also discusses on how the filter can be configured for high frequency RF signals when both RF and digital signals are multiplexed through a single fiber link. The usage of this filter as ADD/DROP filter in optical signal distribution networks further reduce the number of photonic links. This will lead to a less complex, low cost and light weight EMI free antenna array for phased array radar systems.

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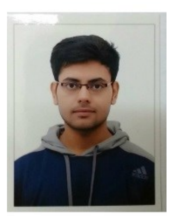

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