Novel High-Q Spectrum Sliced Photonic Microwave Transversal Filter Using Cascaded Fabry-Pérot Filters

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Abstract: **A simple and novel photonic microwave filter of high Quality factor (Q-factor) is proposed implementing two Fabry-Pérot filters in cascaded form. Results showing Q-factor as high as 959 and an overall Free Spectral Range of 47.93GHz have been obtained. The advantage of this configuration is that a high Q-factor is obtained without the need of any suppression of passband RF-spectral distortion. The overall spectral response of the filter shows that this configuration is suitable for 40GHz band with very good sidelobe suppression level.**

Index Terms**: Erbium Doped Fiber Amplifier (EDFA), Fabry-Pérot (FP) filter, Free Spectral Range (FSR), microwave photonics, Q-factor, spectrum slicing.**

I. INTRODUCTION

In recent years, high performance microwave and millimeter-wave filters are implemented using photonic technologies due to their unique advantage over electronic approaches [1]. They take the advantage of wide pass band operation, low loss propagation and immunity to interferences. In addition to these advantages, microwave photonic filters also offer high dynamic range, high compactness and fast reconfiguration and wider tuning capabilities [2]. N. You and R.A. Minasian demonstrated a structure based on a passive small FSR filter which operates with a large delay line difference, to significantly increase the Q-factor of the overall filter to 983 [3].

Photonic microwave filter architectures based on broadband optical spectrum slicing are simple and low-cost techniques when compared to the traditional RF technologies. Also multiple taps can be realized [4]. The approach uses a single length of fiber, relying on dispersion to impart different time delays to different wavelengths, and one, or at most two, detectors. The chosen wavelengths are selected from a single broadband source using optical filters, thus avoiding the requirement for multiple, accurately wavelength stabilized lasers. The technique of spectrum slicing has led to renewed interest in it as a method of Dense Wavelength Division Multiplexing (DWDM) of channels in optical communication systems. A low-cost, broadband Amplified Spontaneous Emission (ASE) spectrum from a pumped erbium doped fiber or a Superluminescent Laser (SL) is spectrally sliced by using a multiwavelength filter to obtain filter taps as many as required for a desired Finite Impulse Response (FIR) [4,5]. In such a spectrum slicing based scheme, J. Capmany et.al. demonstrated a configuration with Q-factor as high as 237 with a hybrid superposition approach of electrical and optical filter transfer functions [6]. The paper [7] by Y.Chang et.al. demonstrated a high-Q photonic microwave filter by the combined use of an ultrabroadband, incoherent, Continuous Wave (CW) Super Continuum (SC) and a dispersion profiled fiber using different optical fiber dispersive media. It reported a Q-factor as high as 140. Another such filter employed a Group Velocity Dispersion (GVD) profiled optical fiber in the previously mentioned filter to compensate the inherent wavelength chirping of the Fabry-Pérot Interferometer (FPI). The reported Q-factor of the resulting filter was 140 but it suffers from passband RF-spectral distortions [8].

In this paper we propose a simple and novel configuration of a spectrum sliced microwave photonic filter that provides a high Q-factor. This configuration is implemented by cascading two FP filters of different FSR. This enables the use of the filter in the 40GHz range and also gives a single bandpass transfer function. The FP filters provide much cleaner spectral slicing since the spectral roll-off of the Fiber Fabry-Pérot (FFP) resonances is higher than the roll-offs of Michelson Interferometer (MI) and Mach-Zehnder Interferometer (MZI) [5]. The advantage of this configuration is that the high Q-factor is obtained without the need for any suppression of passband RF-spectral distortion. As per the literature survey of the spectrum sliced photonic microwave filters, this configuration yields a high Q-factor of 959 and is operating in 40GHz band.

II. FILTER TOPOLOGY AND OPERATION

A. General Model

The main idea of the proposed configuration is that to carefully choose two filter configurations, one with a low FSR (FSR_1 and with transfer function $H_1(\Omega)$) and selective resonances and the other with a higher FSR (FSR_2 and with transfer function $H_2(\Omega)$) and broader resonances. This will cause the overall filter to yield a transfer function given by $H_1(\Omega)H_2(\Omega)$, which has the resonance selectivity of the second filter and the broad FSR value of the first.

The general layout of the filter is shown in Fig.1. The optical source is a low-cost, broadband ASE spectrum (using LED or SLD) from a pumped Erbium Doped Fiber Amplifier (EDFA). However the ASE signal level is usually very small and it requires further amplification in order to overcome the losses introduced by the remaining components of the filter. The optical power from the source is spectrally sliced by use of two cascaded multiwavelength FP filters to obtain the equivalent set of spectrally equispaced optical sources. The output light from the cascaded combination of FP filters, subsequently modulated by RF signal by means of an Electro Optical Modulator (EOM).Then it is fed to an optical dispersive element providing a linear group delay characteristic. The output signal from the dispersive element is then fed to a photodetector and subsequent RF circuit.

B. Theoretical Formulation

Single-Sideband (SSB) modulation is employed for the RF signal to eliminate deleterious carrier-suppression effect [9]. When single FP filter is used, the RF transfer function of the filter [5] is given as

$$|H_{RF}(\Omega)| = R\left|\sum_{k=1}^{N} P_k e^{-j[\Omega(k-1)\Delta\tau]}\right| \qquad (1)$$

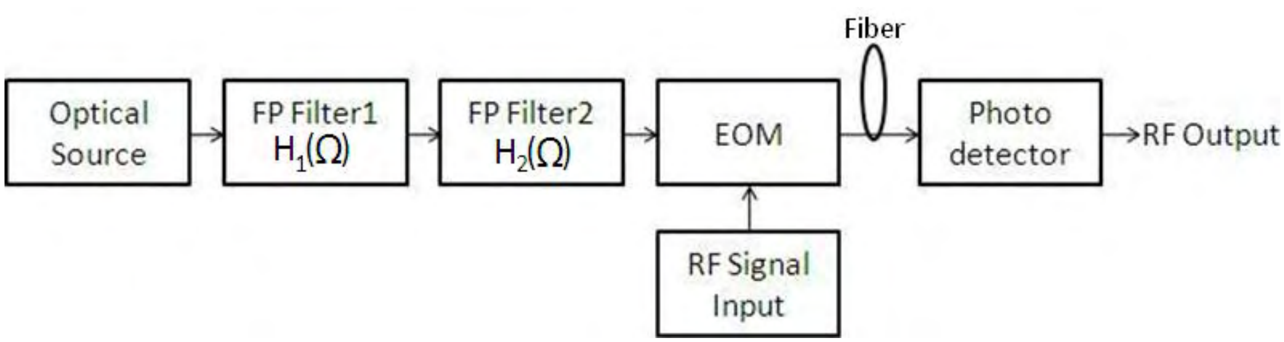

Fig.1. General Layout of the proposed configuration.

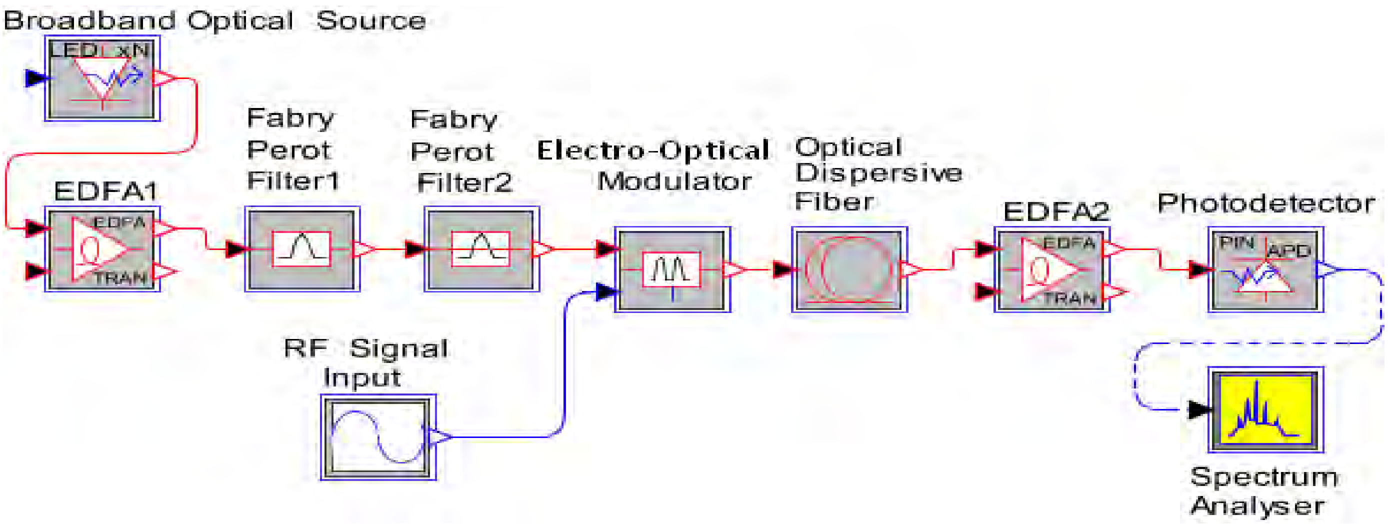

Fig. 2. Proposed topology of the spectrum sliced photonic microwave filter.

where P_k represents the output power from the k^{th} slice of the broadband source, R is the receiver responsivity, Ω is the RF frequency, and Δτ represents the incremental differential delay experienced by two adjacent spectral slices of the broadband source. It is given by Δτ=D.L.Δλ where D (ps/km.nm) and L (m) are the dispersion and length of fiber respectively and Δλ is the wavelength spacing. Equation (1) represents the spectral response of a FIR filter where the number *N* of signal samples is equal to the number of significant spectral slices generated by the optical filter.

When two FP filters are cascaded, the overall transfer function is given as

$$|H_{overall}(\Omega)| = |H_1(\Omega)H_2(\Omega)|$$
$$= R\left|\sum_{m=1}^{N} P_m e^{-j[\Omega(m-1)\Delta\tau 1]} \sum_{n=1}^{N} P_n e^{-j[\Omega(n-1)(\Delta\tau 2)]}\right|$$
$$= R\left|\sum_{m=1}^{N}\sum_{n=1}^{N} P_m P_n e^{-j\Omega[(m-1)(\Delta\tau 1)+(n-1)\Delta\tau 2]}\right| \quad (2)$$

where $\Delta\tau_1$ and $\Delta\tau_2$ represent the incremental differential delays of the filters respectively.

III. NUMERICAL RESULTS AND DISCUSSIONS

The MATLAB simulation platform was used to demonstrate the operation of the proposed microwave photonic filter shown in Fig.2. To obtain sharply apodised sliced spectrum with N = 34 taps, only a 9nm portion (centered at 1531.8nm, the wavelength corresponding to the ASE maximum of EDFA1) of the ASE output from EDFA1, was fed to the cascaded FP filters with different FSR. The optical spectrum at the output of LED source is shown in Fig.3. which was obtained using OptSim toolkit.

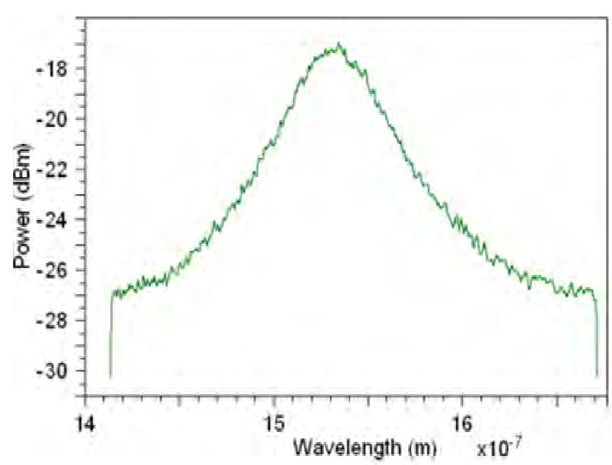

Fig.3 Output optical spectra of LED source.

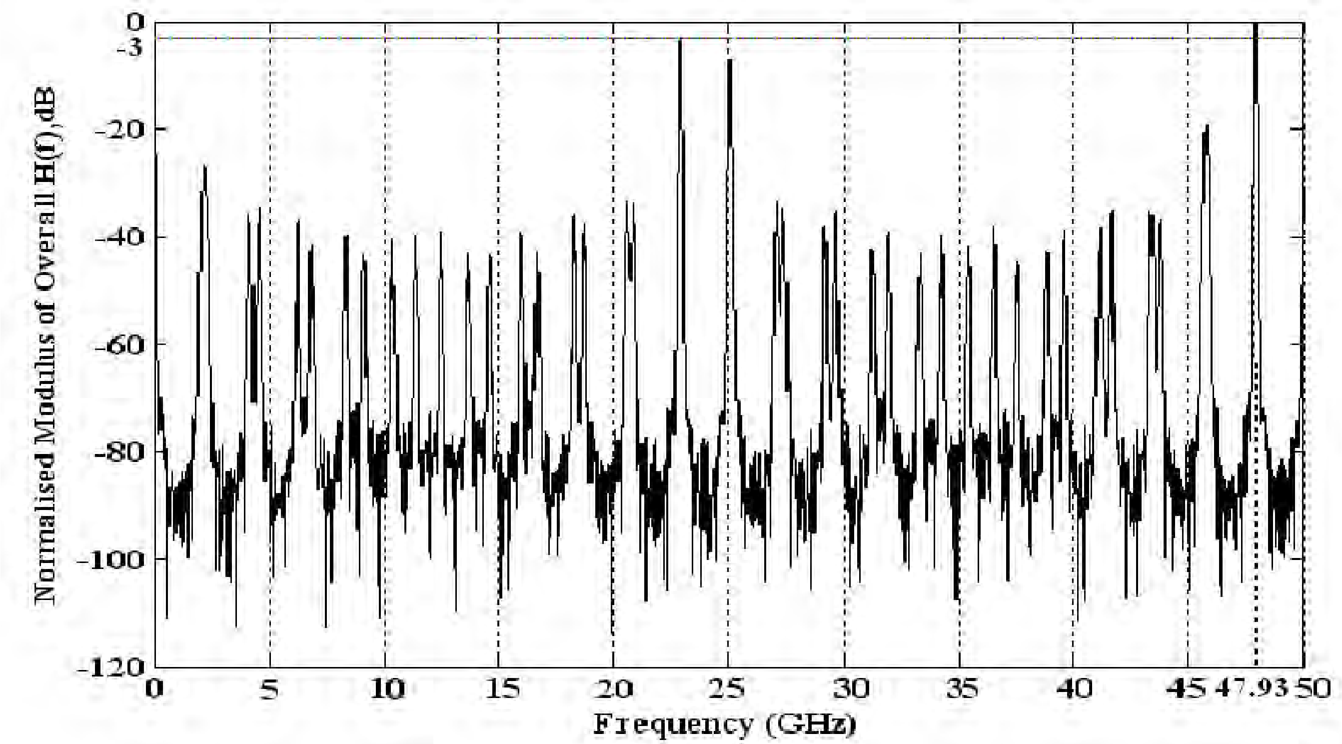

Fig.4. Spectral characteristics of proposed configuration with the cascaded FP filters.

This comprises cascaded unbalanced delay lines that have delay differences $\Delta\tau_1$ and $\Delta\tau_2$, which introduce a series of notches that suppresses several harmonic responses of the multiple-wavelength bandpass filter. The output from the FP filters was fed to the optical dispersive element implemented by means of a coil of 46km of single mode standard fiber with dispersion parameter D=17ps/km.nm and wavelength spacing of 0.28nm. The output signal is amplified by EDFA2 and fed to a photodetector. Two FP filters with chromatic dispersion delay of ($\Delta\tau_1$ = 438ps = 17ps/km.nm x92kmx0.28nm) and ($\Delta\tau_2$= 480ps = 17ps/km.nm x 101km x 0.28nm) were used in the proposed configuration sequentially.

To achieve a high Q-factor, the transversal filter should operate at a higher-order 'resonance' of its periodic response. In this case, more specifically employing the 21^{st} resonant peak of FP filter with dispersion delay $\Delta\tau_1$ coincides with the 23^{rd} resonant peak of FP filter with dispersion delay $\Delta\tau2$. This yields a very high FSR value. Higher FSR gives higher Q value. More specifically FP filters are used to slice the broad spectrum of the source. It provides very narrow and clear spectral slices which has low 3dB BW. The higher the Q-value, better the frequency selectivity. The filter frequency response of the proposed configuration for the range from 0 to 50GHz is shown in Fig. 4.

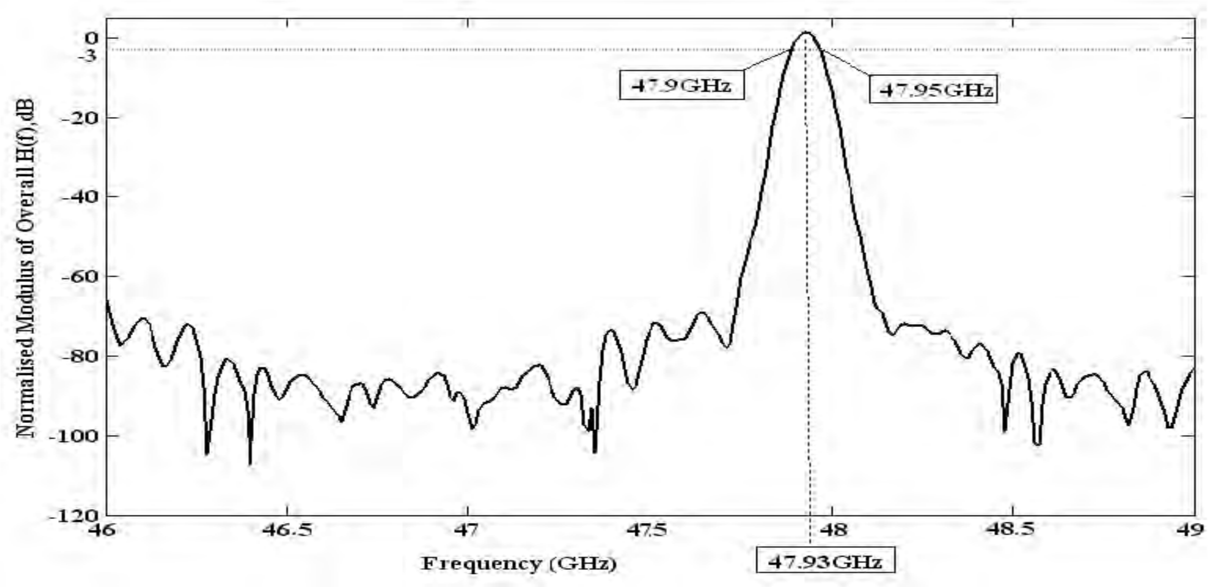

Fig.5. Offset of response of the simulated filter configuration at the FSR of 47.93 GHz.

Fig.5. shows the offset of the response of the simulated filter configuration at the FSR of 47.93GHz. The Q-factor of the overall filter is given as [10]:

Q-factor = (Overall FSR) / (3dB bandwidth) (3)

The overall FSR of 47.93GHz and a 3dB bandwidth of 50MHz were obtained from Fig. 5. This yields a Q-factor of approximately 959. As per the literature survey, this is the highest Q-factor reported so far for a spectrum sliced photonic microwave filter and operating in 40GHz band. Since the number of taps is restricted to 34 for both the FP filters and the line spacing is also uniform (0.28nm), the RF spectral distortion is negligible. Also, since the wavelength–spacing is uniform, the time delay is also uniform between each filter tap, thus eliminating the need for a specially designed dispersion profiled fiber as is used in [7]. This makes the proposed configuration cost-effective.

IV. CONCLUSION

Thus a novel photonic microwave filter was demonstrated by implementing two FP filters in a cascaded form. The authors report a Q-factor as high as 959 with FSR of 47.93GHz using the proposed layout. This configuration is simple to implement and has the advantage of a high Q-factor without any requirement of suppressing the passband RF-spectral distortion. The overall spectral response of the filter shows that this configuration is suitable for 40GHz band with very good sidelobe suppression level. There is a scope for enhancing the tunability and reconfigurability of this configuration.

REFERENCES

[1] Robert A. Minasian, "Photonic Signal Processing of Microwave Signals", *IEEE Trans. Microw Theory Tech.*, vol.54, no.2, pp. 832-846, February 2006.

[2] R. Sukanesh, R. K. Jeyachitra, et.al, "Investigation of the techniques deployed in spectrum slicing for microwave photonic filters," *IEEE Int. Conf. Computation, Commun. Networking (ICCCN), Karur, India, pp. 1-6,* December 2008.

[3] N.You and R.A.Minasian, "High-Q optical microwave filter**,"** *Electron. Lett.*, vol. 35, no. 24, pp. 2125-2126, November 1999.

[4] A. P. Foord et al., "Synthesis of microwave and millimetre-wave filters using optical spectrum slicing," Electron. Lett., vol.32, no.4, pp.390-391, March 1996.

[5] J.Capmany, D.Pastor. and B.Ortega, "Fiber optic microwave and millimeter-wave filter with high density sampling and very high sidelobe suppression using subnanometer optical

spectrum slicing,' *Electron. Lett.*, Vol.35, No.6, pp.494-497, March 1999.

[6] J. Capmany, J. Mora, B. Ortega, and D. Pastor, "High-Q microwave photonic filter with a tuned modulator," *Opt. Lett.*, vol.30, pp. 1299-1301, September 2005.

[7] Y. Chang, H. Chung, and J. H. Lee, "High Q microwave filter using incoherent, continuous-wave supercontinuum and dispersion-profiled fiber," *IEEE Photon. Technol. Lett.*, vol. 19, no.24, pp. 2042-2044, December 2007.

[8] J. H. Lee, Y. Chang, S. B. Lee, "Spectrum slicing based, high-Q, photonic microwave filter using the combination of incoherent continuous wave supercontinuum and dispersion profiled fiber," *IEEE OFN/NFOEC* 2008.

[9] J.Capmany, D.Pastor. and B.Ortega, "New and flexible fiber-optic delay-line filters using chirped Bragg gratings and laser arrays," *IEEE Trans. Microw Theory Tech.*., vol. 47, no. 7, pp. 1321-1326, July 1999.

[10] Lina ZHOU, Xinliang ZHANG, Enuming XU, "Q value analysis of microwave photonic filters", *Front. Optoelectron. China*, vol. 2, no. 3, pp. 269-278, February2009.