Photonic filtering of microwave signals in the frequency range of 0.01-20 GHz using a Fabry-Perot filter

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Photonic filtering of microwave signals in the frequency range of 0.01-20 GHz using a Fabry-Perot filter

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Abstract. We demonstrate experimentally the efficiency of tuning of a photonic filter in the frequency range of 0.01 to 20 GHz. The presented work combines the use of a multimode optical source associated with a dispersive optical fiber to obtain the filtering effect. Tunability effect is achieved by the use of a Fabry-Perot filter that allows altering the spectral characteristics of the optical source. Experimental results are validated by means of numerical simulations. The scheme here proposed has a potential application in the field of optical telecommunications.

1. Introduction

Microwave photonic filters (MPF) have significant advantages inherent to photonics such as large bandwidth, low loss, insensitivity to electromagnetic interference, tunability and re-configurability. [1]. Moreover, it is desirable that MPF are tunable. This feature allows wide flexibility to the filters because its frequency response can be tuned at specific desired frequencies. In this sense, several techniques have been reported for implementing tunable MPF: by using variable optical delay lines [2, 3], by combining tunable lasers and dispersive optical devices [4, 5], by tuning chromatic dispersion combined with fixed optical wavelengths [6], or by using chirped fiber Bragg gratings [7]. However, the implementation of the techniques previously cited is complicated and expensive in practice. In this paper we show a novel technique based on the use of a multi-longitudinal mode laser diode (MLLD) associated with a dispersive optical fiber that allows microwave signals to be filtered [8]. The originality of this work resides in demonstrating the high tuning flexibility of the electrical frequency response in the range of 0.01-20 GHz. Tuning effect is achieved by the use of a Fabry-Perot filter (FPF) that allows altering the spectral characteristics of the optical source. Experimental results are validated by means of numerical simulations. This novel technique has the possibility of continuous tuning over a very wide range, easy operation, and a relatively simple configuration. The scheme here proposed has a potential application in the field of optical telecommunications.

2. Principle of operation

The basic schematic diagram of the microwave photonic filter used in this work is shown in figure 1. Its frequency response is determined by the real part of the Fourier transform of the MLLD emission spectrum. Such response includes a low-pass band centered at zero frequency and multiple harmonic band-pass windows. The center frequency of the *n*-th harmonic band-pass window is determined by

$$f_n = \frac{n}{DL\delta\lambda} \quad (1)$$

where n is a positive integer (n=1, 2,…), D (ps·nm^{-1}km^{-1}) is the optical fiber chromatic dispersion, L (km) is the optical link length and $\delta\lambda$ (nm) is the free spectral range (FSR) between two adjacent longitudinal modes in the MLLD emission spectrum. As can be seen from equation (1), the *n*-th band-pass window is centered at a resonance frequency which is an integer multiple of the first central frequency, f_1. Therefore, tuning of the band-pass windows can be achieved by varying the value of $\delta\lambda$. For this goal a FPF allows a very precise adjustment for the FSR of the MLLD used.

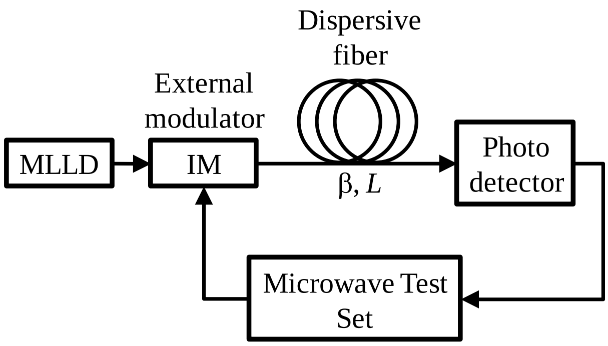

Figure 1. Microwave photonic filter [8].

3. Experimental and numerical simulations results

The proposed filter topology is shown in figure 2. For the experiment, we have used an MLLD emitting at 1553.65 nm with an FSR = 1.0 nm. We used an optical isolator (OI) to avoid reflection to the optical source. The use of the FPF allowed a very precise adjustment for the FSR of the MLLD. An Erbium-Doped-Fiber-Amplifier (EDFA) (IPG Photonics, model EAD-C, λ_{pump} = 970 nm), was used in order to guarantee a good level of the transmitted optical signal. A polarization controller permitted matching the polarization of the light. The use of a Wavelength Division Multiplexer (WDM) allowed splitting the optical signal in two; the 1300-nm port was connected to an Optical Spectrum Analyzer (OSA) (Anritsu, model MS9710B), and the 1550-nm port was coupled to the input of the Mach-Zehnder intensity modulator (MZ-IM) (Photline, model MX-LN-10). This was done for monitoring the filtered spectrum each time the experiment was performed, ensuring that the highest

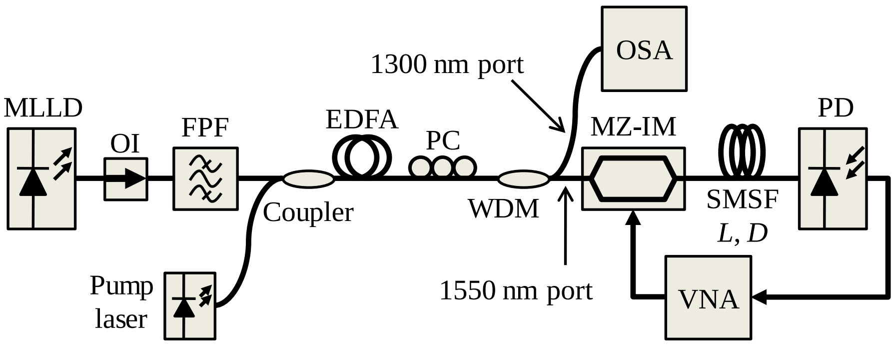

Figure 2. Experimental setup used for filtering microwave signals in the frequency range of 0.01-to-20 GHz using a Fabry-Perot filter (FPF).

optical power is used for performing the transmission. An RF signal sweep between 0.01-20 GHz issued from a Vector Network Analyzer (VNA), (Anritsu, model 37369, BW = 0.04-40 GHz), was applied to the modulator. The intensity-modulated optical signal was then launched into a 6-Km coil of Single-Mode-Standard-Fiber (SM-SF) with a chromatic fiber-dispersion D = 16.67 ps·nm^{-1}km^{-1} @ λ=1550 nm (see figure 3 where the dispersion of a SM-SF as a function of the wavelength). Finally, the optical signal was recovered with a fast photo-detector (PD) (MITEQ, model DR-125G-A), and its electrical output was coupled to the second port of the VNA where the frequency response was measured.

In order to corroborate filtering and tuning effects, some numerical simulations were carried out. Simulations were achieved by evaluating equation (1) and computing the Fourier transform of a given optical spectrum. Equation (2) allows modeling an optical spectrum corresponding to a MLLD with a Gaussian envelope [9]

$$P(\lambda)=\frac{2P_0}{\Delta\lambda\sqrt{\pi}}\exp\left(-\frac{4(\lambda-\lambda_0)^2}{\Delta\lambda^2}\right)\left(\frac{2P_0}{\sigma\lambda\sqrt{\pi}}\exp\left(-\frac{4(\lambda-\lambda_0)^2}{\sigma\lambda^2}\right)*\sum_{-\infty}^{\infty}\delta(\lambda-n\delta\lambda)\right) \quad (2)$$

where λ is the wavelength, P_0 is the maximum power emission, λ_0 is the peak wavelength, $\Delta\lambda$ is the full width at half maximum (FWHM) of the optical source, $\sigma\lambda$ is the FWHM of each emission mode, $\delta\lambda$ is the FSR between the emission modes, n is a positive integer (n=1, 2,…) and * stands for convolution. Figure 4(a) corresponds to the emission spectrum of the MLLD obtained by the use of equation (2), whereas figure 4(b) illustrates the real optical spectrum of the MLDD used in this experiment and, finally, figure 4(c) shows the filtered and amplified optical spectrum. The two last optical spectrums were recorded by means of the OSA.

Figure 5(a) corresponds to the simulated and experimental frequency response of the photonic filter where a well-shaped band pass window centered at 10 GHz is clearly observed. In this case, the FSR = 1.0 nm. Figure 5(b) illustrates the simulated and experimental frequency response of the system corresponding to the use of the filtered optical spectrum where now the FSR = 3.0 nm. We can clearly see the presence of five band-pass windows centered at f_1 = 3.4, f_2 = 6.7, f_3 = 10.2, f_4 = 13.5, and f_5 = 16.8 GHz, which confirms the robustness of this technique. Due to the gain of the photo-detector used, electrical amplification stages were not necessary. Finally, table 1 summarizes the theoretical, simulated, and experimental results corresponding to the location of the band pass windows when FSR=3.0 nm. Theoretical results are computed by the use of equation (2). Although tuning is achieved by changing the FSR of the source, it cannot be continuous but in steps, due to the mode separation.

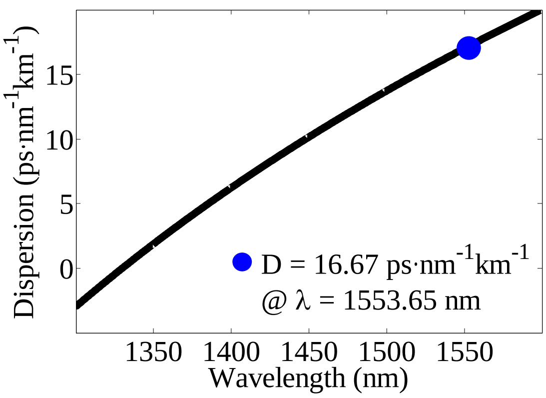

Figure 3. Dispersion of a single mode standard fiber, as a function of wavelength.

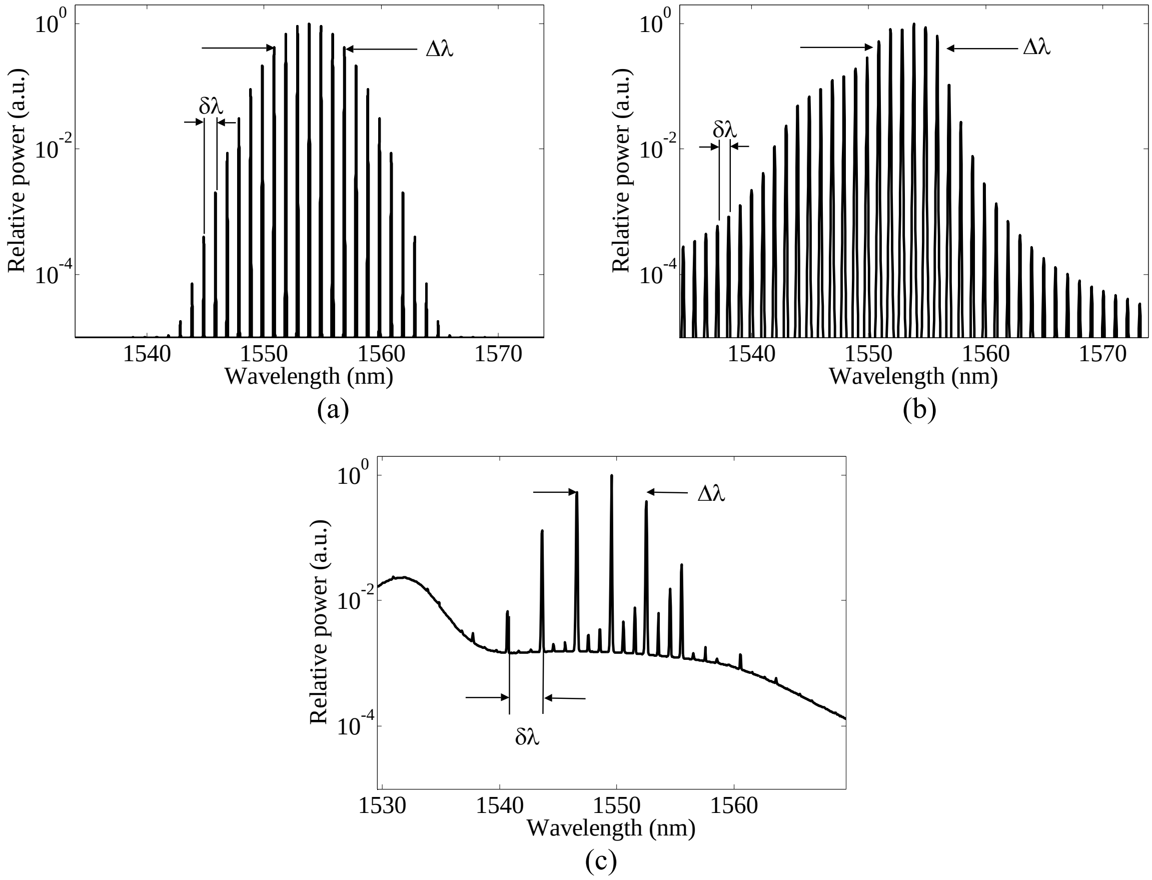

Figure 4. (a) Optical spectrum obtained by the use of Eq. (2). (b) Real optical spectrum of the MLLD with FSR = 1.0 nm, (c) Filtered and amplified optical spectrum FSR = 3.0 nm. In this case, modes extinction was obtained by means of the Fabry-Perot filter, and the filtered spectrum was then amplified with the EDFA.

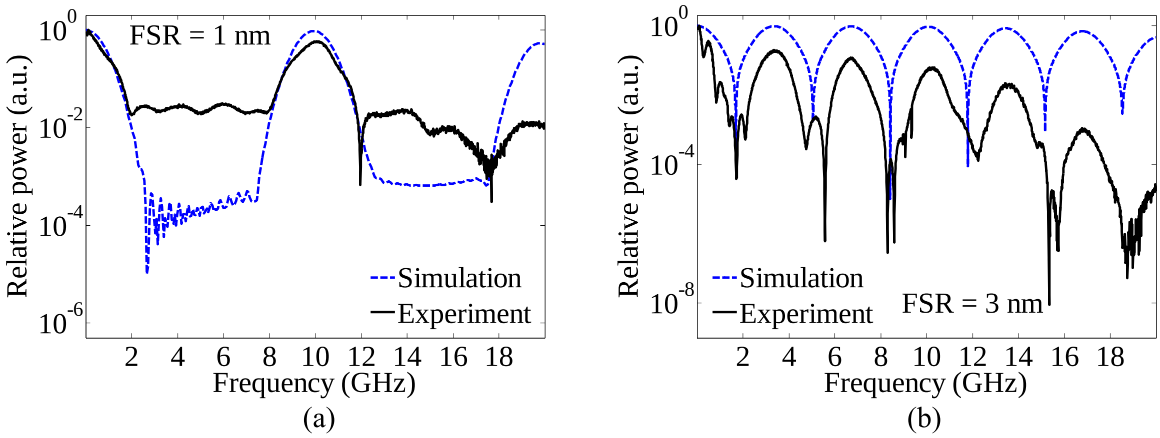

Figure 5. Experimental and simulated frequency response. (a) Considering the real optical spectrum (FSR = 1 nm). (b) Considering the filtered optical spectrum (FSR = 3.0 nm) $f_1 = 3.4$, $f_2 = 6.7$, $f_3 = 10.2$, $f_4 = 13.5$, and $f_5 = 16.8$ GHz.

Table 1. Theoretical, simulated and experimental results.
FSR = 3 nm, L = 6 km and D=16.67 ps·nm^{-1}km^{-1}.

Frequency (GHz)	Theoretical	Simulated	Experimental
f_1	3.3	3.4	3.4
f_2	6.6	6.7	6.7
f_3	9.9	10.0	10.2
f_4	13.3	13.5	13.5
f_5	16.6	16.8	16.8

4. Conclusions

A novel scheme to evaluate a microwave photonic filter in the frequency range of 0.01-20 GHz has been presented in this paper. Filtering of microwave signals was supported by the use of chromatic fiber-dispersion parameter, the length of the optical link, and the free spectral range of the multi-longitudinal mode laser diode. Tuning was achieved by varying the free spectral value of the multi-longitudinal mode laser diode, by the use of a Fabry-Perot filter. We have conducted one experiment in order to verify the validity of this technique and we have obtained good agreement between the theoretical and experimental results. Simulations of the frequency response of the system were carried out using ideal numerical optical spectrums and recorded real optical spectrums. The main factor which limits the highest frequency that can be reached by the microwave photonic filter is the cutoff frequency of the PD used. However, thanks to the optical to electrical transfer gain of the PD, the use of electrical amplifiers was not necessary. The results here reported open the possibility to exploit the frequency range from 0.01 to 20 GHz and to transmit information coded on some band-pass. Band-pass windows can be used as electrical-carriers having an application in the field of optical telecommunications similarly as successfully demonstrated in [10].

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