DYNAMIC OPTICAL TRANSVERSAL FILTERS BASED ON A TUNABLE DISPERSION FIBER BRAGG GRATING

J.Mora (1), B.Ortega (2), M.V.Andrés (1), J.Capmany (2), D.Pastor (2), J.L.Cruz (1), S.Sales (2)

(1) Instituto de Ciencia de los Materiales, Universidad de Valencia.
Dr. Moliner, 50, 46100 Valencia (SPAIN)
Tel: +34 96 386 47 60 Fax: +34 96 398 31 46
Jose.Mora-Almerich@uv.es

(2) Departamento de Comunicaciones, Universidad Politécnica de Valencia.
Camino de Vera, s/n, 46022 Valencia (SPAIN)
Tel: +34 96 387 97 12 Fax: +34 96 387 73 09
bortega@dcom.upv.es

ABSTRACT: We demonstrate a fibre optic radio frequency notch filter with continuous tuning by using a uniform fibre Bragg grating. The uniform grating is dynamically chirped by using a magnetic field and a magnetostrictive transducer.

I. INTRODUCTION

The possibility of processing microwave and radio-frequency (RF) signals directly in the optical domain by means of fiber-optic based structures is currently attracting the attention of many research groups. In those RF systems, the RF signal is carried by the intensity modulated light beam, and different processing applications such as optical control of array antennas, microwave and millimeter wave signal generation or the fabrication of flexible transversal notch filter is a subject of interest in the field of microwave photonics [1-4].

We focus on wide dynamic range and high resolution tunable notch filters required by many RF systems, i.e. radar technology, and combine this with the well known technology of optical fibre Bragg gratings (FBG) [5]. In the literature, there has been many previous approaches based on linearly chirped fibre gratings [6], showing linear and continuous tuning, or those reconfigurable devices based on tunable laser arrays [7-9] and, also, optical broadband sources with spectral slicing based devices [10]. However, this contribution presents a simpler new configuration with higher performance and low costs.

On the other hand, intense work has been done in the fabrication of dispersion variable fibre Bragg gratings for dispersion compensation applications in current optical high speed communicaction systems [11-13]. Most of them use voltage-tuned local heating to vary the chirp characteristic of FBG [11] or piezoelectric transducers to strain the grating [12], showing important induced dispersion changes. We previously worked on tuning and chirping FBG using magnetic fields [14] showing advantages such as good dynamic response and easy implementation.

In this paper, we propose the use of a single uniform fibre Bragg grating to implement a tunable RF notch filter. The grating is chirped by means of a non uniform magnetic field applied to a magnetostrictive rod [14], and therefore, dispersion characteristic of the grating can be changed dynamically. Setting the optical wavelengths at fixed values, we achieve a tunable transversal filter by changing the dispersion slope of the grating.

II. DEVICE DESIGN

The configuration of the proposed transversal filter follows the schematic shown in figure 1. N optical taps will be fixed for a given device, from samples spectrally equiespaced [8], $\Delta\lambda_t$, inside the optical bandwidth of the filter, $\Delta\lambda_T$=(N-1) $\Delta\lambda_t$, which will be given by the design parameters explained below. Therefore, a multi-wavelength but not tunable source is required to operate the tunable notch filter. Optical signal is then amplitude modulated by using an electro-optical external modulator, which RF signal is supplied by the networks analyzer. The modulated optical signal is launched into the uniform FBG, placed in a device which changes the chirp of the grating by using magnetic fields.

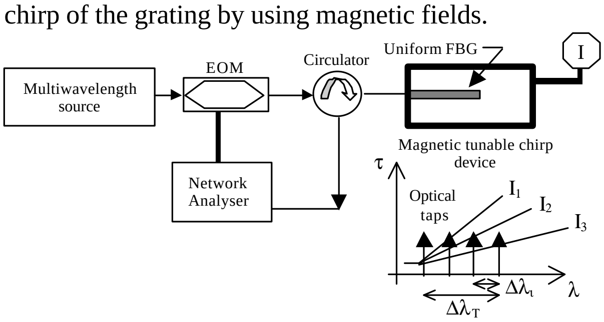

Figure 1. Schematic diagram of the configuration of the new uniform FBG-based tunable transversal filter.

Different magnetic tunable chirp devices will be used all through the work in order to show alternative configurations, and will be described below. In any case, magnetic fields will be driven by electric currents, I, so different values of I will lead to different linear strain gradients along the grating. Therefore, the time delay slope, m, are different, so delay differences between adjacent taps changes, $\Delta\tau_\iota = m\cdot\Delta\lambda_\iota$ and filter response is given by [8]:

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

where P_k represents the output power from the kth optical tap, R is the receiver responsivity, Ω is the RF frequency and $\Delta\tau_\iota$ represents the incremental differential delay between adjacent optical taps.

Since higher strain gradients lead to broader grating bands and lower delay slopes, total optical bandwidth, $\Delta\lambda_T$, will be given by the 3 dB bandwidth of the chirped grating achieved with the highest time delay slope within the operation range with fixed wavelength taps (see figure 1).

III. EXPERIMENTAL RESULTS

A 4 cm long uniform FBG of 0.28 nm 3dB bandwidth and maximum reflectivity of 99.3 % is held on the magnetostrictive rod and subjected to a non uniform magnetic field created inside of a 4-cm long solenoid consisting of 800 turns of an equivalent radius of 1.58 cm. Figure 2 shows the axial dependence of the magnetic field, with a maximum of 18.80 mT/A in the centre of the helical coil. Two curves corresponding to magnetic field at currents of 3 A and 5 A show the slope of the magnetic field can be changed by varying the driving current.

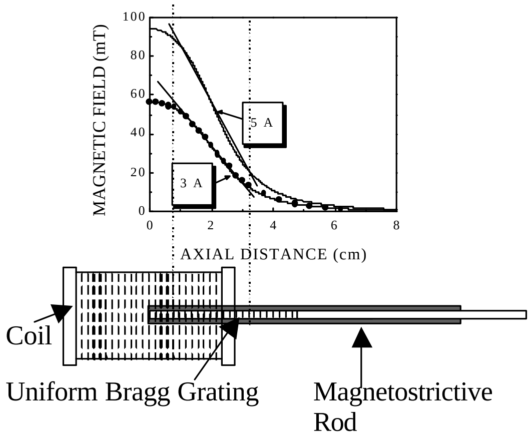

Figure 2. Axial dependence of the magnetic field along the magnetostrictive rod when a solenoid is used.

When magnetic field is applied to the magnetostrictive rod, the material suffers an elastic lengthening in the direction of the magnetic field, and, therefore, provided the grating is located in the axial area where field variation is quasi linear, it is linearly chirped with a slope which depends on the applied current.

Figure 3 shows the spectral response of the original uniform FBG, and resulting linearly chirped gratings when different electric currents are applied to the coil. Currents of 3 and 5 A lead to broader bandwidths of 0.39 and 0.56 nm and linear time delay slopes of 916 and 475 ps/nm, respectively. In this figure, $\Delta\lambda_T$ is about 0.39 nm, and different values for RF filters would be given by chirp values obtained for currents between 3 and 5 A. Although figure 3 shows a nice linear behaviour, it is desirable to achieve higher values of chirp.

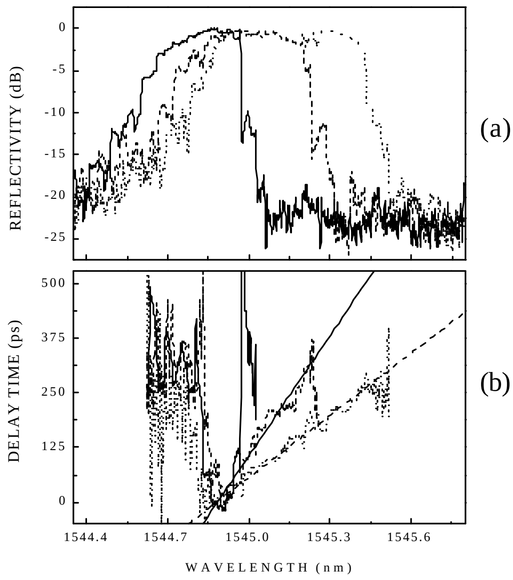

Figure 3. Uniform fibre grating response (solid line) when different electric currents are applied: (----------) 3 A, (························) 5 A. (a) Reflectivity, (b) Time delay characteristic.

Joule effect is a limiting factor in the maximum current carried by the solenoid in figure 2, but can be overcome by biasing the device with a magnet placed at one end of the magnetostrictive rod. The magnetic field provided by the magnet also varies linearly along the z-axis, and the total effect on the strained grating is shown in figure 4. Therefore, higher chirp values can be obtained with lower intensities than values in figure 3, and then, heating effect is reduced.

Figure 4 shows an initial bandwidth of the grating of 0.65 nm with 500 ps/nm delay slope, and bandwidths of 1.08 and 1.18 nm with delay slopes of 357 and 309 ps/nm when electric currents in the coil are 2 and 4 A. By using this setup, $\Delta\lambda_T$ has been increased up to 0.65 nm.

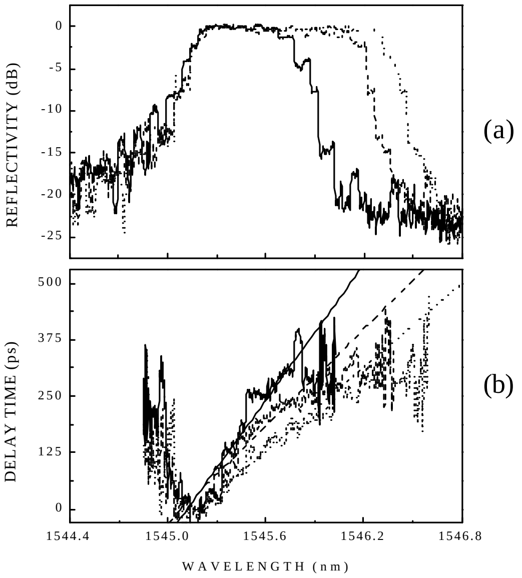

Figure 4. Uniform fibre grating response when the device is biased with the magnetic field created by a magnet (solid line) and when different electric currents are applied: (----------) 2 A, (···········) 4 A. (a) Reflectivity, (b) Time delay characteristic.

A three tap transversal filter was implemented using this configuration with optical wavelengths set at 1545.24, 1545.56 and 1545.88 nm. Experimental results fitted to the theory are shown in figure 5. We find the first notch at 2.83, 3.35 and 3.57 GHz, and consequently, the free spectral range, FSR, of the obtained filters are 6.36, 8.14 and 9.39 GHz, at 0, 2 and 4 A, respectively. Experimental results show no total cancellation of the RF signal at frequency notches because of the lack of phase matching between taps due to deviations from the ideal linear behaviour of the spectral dependence of the chirped grating time delay characteristic.

It is shown the strong dependence of the operation of the filter on the linear chirp characteristic of the grating. In order to achieve better performance, an alternative magnetic tunable chirp device is also proposed. The magnetostrictive rod was located inside a ferromagnetic material of variable transversal section along z-axis. The tapered section was designed to create a linear magnetic field along z-axis when feeded with a magnetic circuit (see figure 6).

Different currents were applied to the coils of the magnetic circuit. Figure 7 shows the time delay curve for the obtained chirped gratings. It is shown the time delay slope of the original uniform FBG, which was a 5 cm-long grating of 99.5% reflectivity and 3 dB-bandwidth of 0.31 nm, and the resulting chirped gratings when electric currents of 1.5 and 2 A are applied.

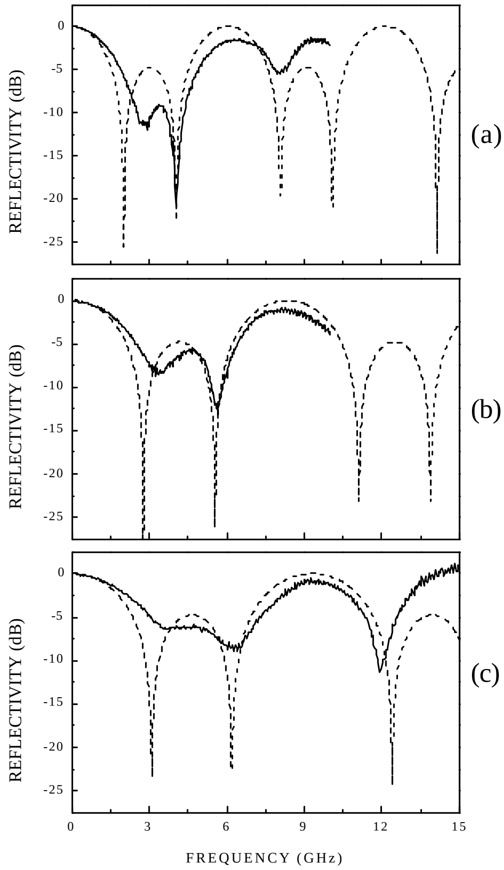

Figure 5. Frequency response of a transversal notch filter for various tunings (———— , experimental and ··········, theoretical calculations): (a) 0 A, (b) 2 A, (c) 4 A.

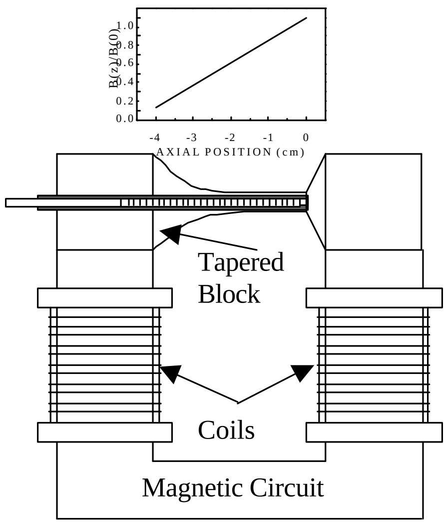

Figure 6. Magnetic field dependence along axial distance when a ferromagnetic material is used in a magnetic circuit.

When the electric current is applied, in addition to the chirped grating, we also observe the original delay characteristic because of 1 cm of the grating is far from the effect of the magnetic field, being unaltered. Delay curves show ripples because of the lack of apodisation of the FBG [15].

Delay slopes in linear bands are 80 and 290 ps/nm for 1.5 and 2 A currents, and tunable transversal notch filters could be implemented as was shown in figure 5.

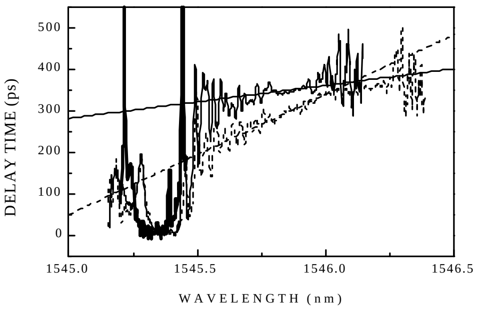

Figure 7. Delay response of the uniform FBG (thick line) when different electric currents are applied: (——) 1.5A, (············) 2 A.

IV. CONCLUSIONS

We have demonstrated a new technique to implement tunable radio-frequency notch filters based on a uniform fibre Bragg grating. The control of the chirp is performed by using non-uniform magnetic fields and a magnetostrictive alloy as a transducer. Thus, dynamic linear chirp of the gratings has been demonstrated by changing an electric current. The time delay slope determines the frequency response of the transversal filter when optical wavelengths are fixed along the total optical bandwidth of the device. This filter shows a good degree of flexibility, low cost and easy fabrication compared to previous ones based on chirped FBG and tunable lasers. As an example, demonstrated chirps from 300 to 900 ps/nm would give FSR filters of 11 to 33 GHz for 0.1nm equiespaced taps (5 to 17 GHz for 0.2nm). Also, fast response of magnetostrictive alloys (< 1 ms) provides other advantage related to dynamical operation if we compare our proposal for chirping gratings to others based on thermal mechanisms.

Finally, magnetic tunable chirp devices based on a uniform FBG, presented in this paper, could be used as well as dynamic dispersion compensators in high bit rate telecommunication systems.

ACKNOWLEDGEMENTS

The authors wish to acknowledge the financial support of the Spanish CICYT projects TEL99-0437, TIC98-0346 and 1FD97-0684.

REFERENCES

[1] A. Molony, C.Edge, I.Bennion, 'Fibre grating time delay for phased array antennas', Electronics Letters, vol. 31, pp. 1485-1486, 1995.

[2] J.E.Román, M.Y.Frankel, P.J.Mattews, R.D.Esman, 'Time-steered array with grating beamformer', Electronics Letters, vol. 33, pp. 652-653, 1997.

[3] B.Ortega, J.L.Cruz, J.Capmany, M.V.Andres, D.Pastor, 'Variable delay line for phased array antenna based on a chirped fibre grating', IEEE Transactions on Microwave Theory and Techniques, vol. 48, pp. 1352-1359, 2000.

[4] D.B.Hunter, R.A.Minasian, P.A.Krug, 'Tunable optical transversal filter based on chirped gratings' Electronics Letters, vol. 31, pp. 2205-2207, 1995.

[5] M.Y.Frankel, R.D.Esman, 'Fiber-optic tunable transversal filter', IEEE Photonics Technology Letters, vol. 7 pp. 191-193, 1995.

[6] W.Zhang, J.A.R.Williams, L.A.Everall, I.Bennion, 'Fibre optic radio frequency notch filter with linear and continuous tuning by using a chirped fibre grating', Electronics Letters, vol. 34, pp. 1770-1772, 1998.

[7] D.Pastor, J.Capmany, 'Fiber optic tunable transversal filter using laser array and linearly chirped fibre grating' Electronics Letters, vol. 34, pp. 1684-1685, 1998.

[8] J.Capmany, D.Pastor, B.Ortega, 'New and flexible fiber-optic delay line filters using chirped Bragg gratings and laser arrays', IEEE Transactions on Microwave Theory and Techniques, vol. 47, pp. 1321-1327, 1999.

[9] J.Capmany, D.Pastor, B.Ortega, 'Efficient sidelobe supression by source power apodisation in fibre optic microwave filters composed of linearly chirped fibre grating by laser array', Electronics Letters, vol. 35, pp. 640-642, 1999.

[10] A.P.Foord, P.A.Davies, P.A.Greenhalgh, 'Sysnthesis of microwave and millimetre-wave filters using optical spectrum slicing', Electronics Letters, vol. 32, pp. 390-391, 1996.

[11] B.J.Eggleton, J.A.Rogers, P.S.Westbrook, T.S.Strasser, 'Electrically tunable power efficient dispersion compensating fiber Bragg grating', IEEE Photonics Technology Letters, vol. 11 pp. 854-856, 1999.

[12] M.M.Ohn, A.T.Alavie, R.Maaskan, M.G.Xu, F.Bilodeau, K.O.Hill, 'Dispersion variable fibre Bragg grating using a piezoelectric stack', Electronics Letters, vol. 32, pp. 2000-2001, 1996.

[13] K.M.Feng, J.X.Cai, V.Grubsky, D.S Starodubov, M.I.Hayee, S.Lee, X.Jiang, A.E.Willner, J.Feinberg, 'Dynamic dispersion compensation in a 10 Gb/s optical system using a novel voltage tuned nonlinearly chiped fiber Bragg grating', IEEE Photonics Technology Letters, vol. 11 pp. 373-375, 1999.

[14] J.L.Cruz, A.Díez, M.V.Andrés, A.Segura, B.Ortega, L.Dong, 'Fibre Bragg gratings tuned and chirped using magnetic fields', Electronics Letters, vol. 33, pp. 235-236, 1997.

[15] K.Ennser, M.N.Zervas, R.I.Laming, 'Optimization of apodized linearly chirped fiber gratings for optical communications', IEEE J.Quantum Electronics, vol. 34, pp. 770-778, 1998,