Analysis on the filtering of microwave-signals employing multi-mode optical sources with arbitrary envelopes

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Abstract: - Filtering of microwave-signals can be realized by electro-optical techniques taking advantage of the chromatic fibre-dispersion parameter as well as the use of a multimode optical source. In this work, it is shown the non-influence on the filtering when multimode optical sources exhibiting arbitrary envelopes are used. For this goal, numerical simulations modelling multimode optical sources exhibiting Gaussian, Lorentzian, and Cos^2 envelopes are realized. An experimental result obtained for the case of a multimode optical source exhibiting a Lorentzian–envelope permit to demonstrate the validity of this analysis.

Key-Words: -Microwave-signals, multimode optical source, chromatic dispersion, optical fibre communications

1 Introduction

Optical fibre links are now established as the prime telecommunications systems due to high-capacity and high-speed for transmitting information such data, voice, video, etc. In this sense, fibre optic-microwave links have been growing interest with the development of microwave radio systems and mobile communication networks [1]. The large bandwidth of optical systems makes them interesting for filtering microwave and millimetre-wave signals employing electro-optical techniques [2-4]. In this way, in recent publication the implementation of a microwave filter primarily based on the use of dispersive optical fibre and multi-longitudinal mode optical sources is reported [5]. Inclusively, a potential application of this technique has been carried out successfully in the area of optical telecommunications employing the microwave-signal filtered as a microwave-carrier [6]. In this sense, now the aim of this work is to show analytically the non-influence of the shape-envelope of the multimode optical source on the filtering of the microwave-signal. For this goal, we analyse and discuss the filtering and tuning of these microwave-signals when multimode laser diodes (MLD) exhibiting Gaussian, Lorentzian, and Cos^2 envelopes are used. We also consider the chromatic dispersion parameter of the optical fibre.

This work is organized in five sections: Section 2 presents briefly the principle used to obtain the filtering of microwave signals. In section 3, numerical simulations corresponding to the use of different multimode optical sources are presented. Section 4 is devoted to compare the theoretical results with an experimental verification employing a multimode optical source exhibiting a Lorentzian-shaped envelope that permits to demonstrate the validity of the discussion. Finally, in section 5 the conclusions of this work are presented.

2 Principle used

The optical system that permits the filtering of a microwave-signal is sketched in Fig. 1. The reader is referred to [5] for a detailed description of the principle of operation. We indicate in the following the main characteristics of the system.

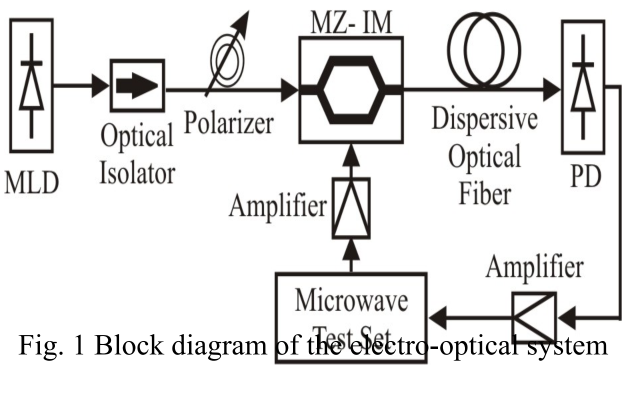

Fig. 1 Block diagram of the electro-optical system

The frequency response of this system is proportional to the real part of the Fourier transform of the power spectral density of the optical source used. A low-pass band and a series of band-pass windows compose the frequency response. The low-pass response is limited to a maximum frequency given by

$$f_{lp} = \frac{2}{\pi D L \Delta\lambda} \qquad (1)$$

where D is the dispersion parameter, L is the length of the fibre, and Δλ is the spectral width of the optical source. The centre frequencies of the band-pass windows can be calculated as

$$f_n = \frac{n}{D L \delta\lambda} \qquad (2)$$

where n is an integer (n=1,2...) and δλ is the free spectral range (FSR) between two adjacent longitudinal modes of the MLD. Equation (2) indicates that the band-pass response occurs at integer multiples of the frequency f. The associated bandwidth of each band-pass window is given by

$$\Delta f = \frac{4}{\pi D L \Delta\lambda} \qquad (3)$$

The power spectrum of multimode optical sources considered in this analysis can be expressed in terms of optical power-spectrum, P(σ), where σ is the wavenumber (σ = 1/λ) as [7]

i) Power spectrum of a multimode optical source exhibiting a Gaussian envelope

$$P(\sigma) = \frac{2P_0}{\Delta\sigma\sqrt{\pi}} \exp\left(-\frac{4(\sigma-\sigma_0)^2}{\Delta\sigma^2}\right) \cdot \left[\frac{2P_0}{\delta\sigma\sqrt{\pi}} \exp\left(-\frac{4\sigma^2}{\delta\sigma^2}\right) \otimes \sum_{-\infty}^{+\infty} \delta(\sigma - n\partial_0)\right] \qquad (4)$$

ii) Power spectrum of a multimode optical source exhibiting a Lorentzian envelope

$$P(\sigma) = \frac{2\Delta\sigma P_0}{\pi\Delta\sigma^2 + 4\pi(\sigma-\sigma_0)^2} \cdot \left[\frac{2P_0}{\delta\sigma\sqrt{\pi}} \exp\left(-\frac{4\sigma^2}{\delta\sigma\sqrt{\pi}}\right) \otimes \sum_{-\infty}^{+\infty} \delta(\sigma - n\partial_0)\right] \qquad (5)$$

iii) Power spectrum of a multimode optical source exhibiting a Cos^2 envelope

$$P(\sigma) = \frac{P_0}{\Delta\sigma} \cos^2\left(\frac{\pi(\sigma-\sigma_0)}{2\Delta\sigma}\right) \cdot \left[\frac{2P_0}{\delta\sigma\sqrt{\pi}} \exp\left(-\frac{4\sigma^2}{\delta\sigma\sqrt{\pi}}\right) \otimes \sum_{-\infty}^{+\infty} \delta(\sigma - n\partial_0)\right] \qquad (6)$$

where P_0 is the source power, $\sigma_0 = 1/\lambda_0$ (centre wavenumber), $\Delta\sigma = \Delta\lambda/\lambda_0^2$ (spectral width at half maximum), δσ (spectral width of each mode) and ∂_0 (free spectral range), ⊗ stands for the convolution product. In these expressions, the first term corresponds to the envelope whereas the term between brackets corresponds to the impulse train of the modes.

3 Simulations

In a first step and before to realize numerical simulations, the multimode optical source (**LPS-SMF28-1550-FC**) available at our laboratory was characterized by means of an Optical Spectrum Analyser (Agilent, Model 86143B) in order to determine their main optical parameters. Figure 2 corresponds to the optical spectrum exhibiting a Lorentzian–shaped power-spectrum, a centre wavelength of λ_o = 1.541 μm, a spectral width at half maximum of Δλ = 10 nm and a FSR of δλ = 1.1 nm.

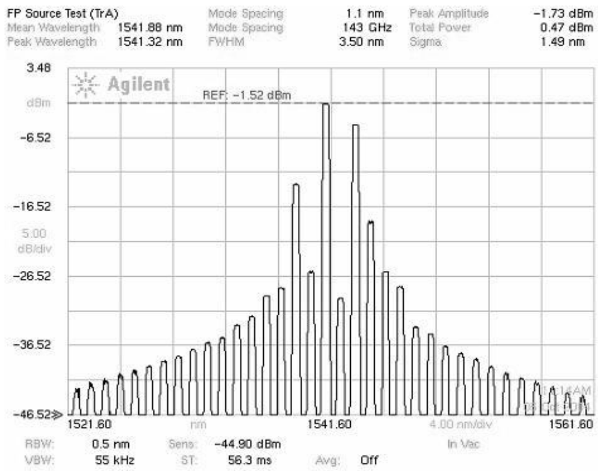

Fig. 2 Emission spectrum of the MLD operating at drive current of 29 mA

In a second step, we have modelled the power spectrum of the multimode sources determined by expressions (4), (5), and (6). Figures 3, 4, and 5, correspond to the Power spectrum of a multimode optical source exhibiting a Gaussian, Lorentzian, and Cos^2 envelope, respectively. All the spectres are centred at σ_0 =0.6489 μm^{-1} (λ_0 =1.541 μm) exhibiting a ∂_0 =0.9090 nm^{-1} (δλ =1.1 nm) and the same width Δσ at half maximum.

Finally, in a third step we have obtained the real part of the Fourier transform of the power spectral density of the optical sources given by expressions (4), (5), and (6). In all the cases we have considered a L=28.3 Km of Single-Mode standard Fibre and a chromatic dispersion parameter of D=17 ps/nm-Km. Figure 6 correspond to frequency response for these three cases.

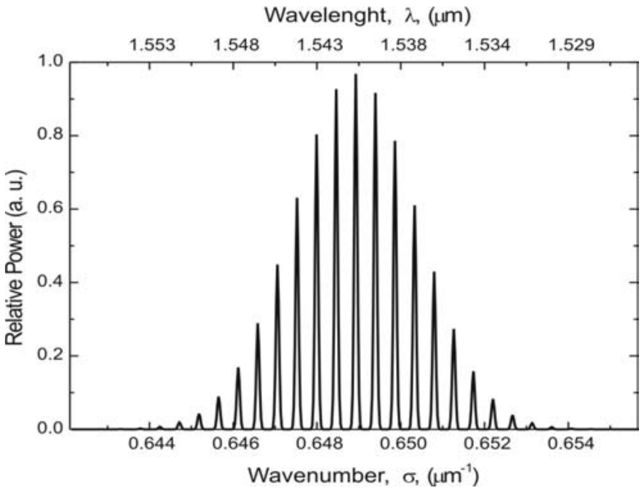

Fig. 3 Power spectrum of a multimode optical source exhibiting a Gaussian envelope

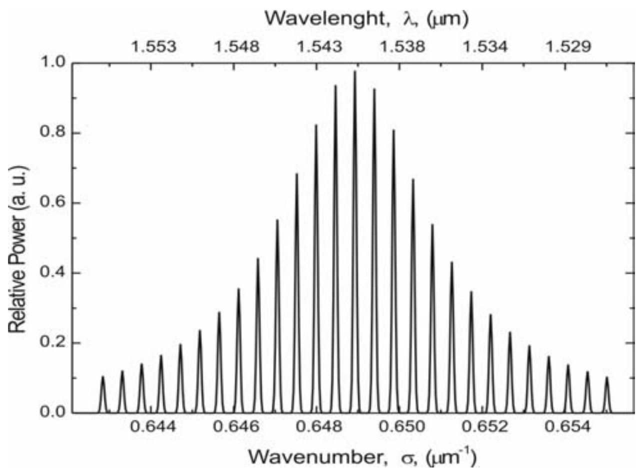

Fig. 4 Power spectrum of a multimode optical source exhibiting a Lorentzian envelope

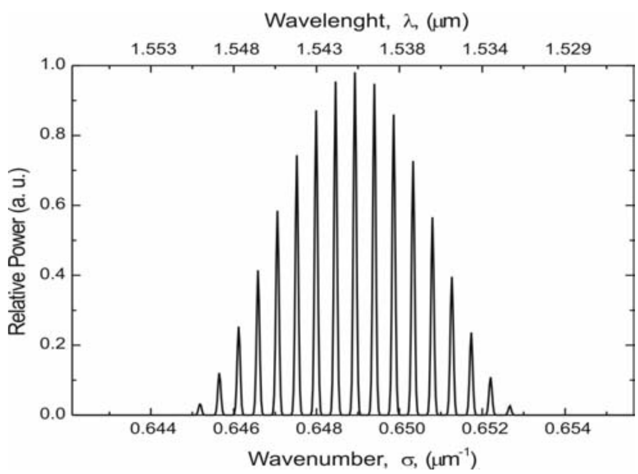

Fig. 5 Power spectrum of a multimode optical source exhibiting a Cos^2 envelope

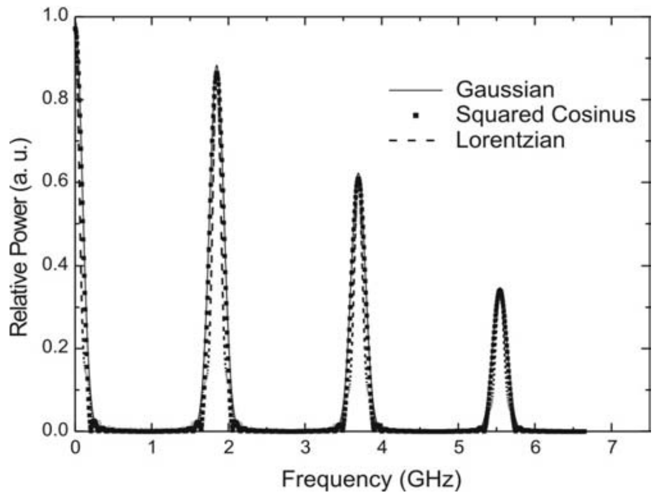

Fig. 6 Numerical simulations corresponding to the frequency response

These simulation results suggest that the frequency response of the optical system communication is practically the same for the three cases of the optical sources considered in our analysis.

4 Experimental result

This experiment was realized taking into account the optical transmission system sketched in Fig. 1. The system works as follows: The light from the MLD was intensity modulated by a X-cut $LiNbO_3$ Mach-Zehnder Interferometer (MZI) modulator (APE^{TM} Microwave Analog Intensity Modulator, AM-150). RF signal between 100 KHz and 4 GHz was applied to the modulator. The RF modulated light was fed to L = 28.3 km of Single-Mode standard Fibre (SMF, Alcatel α = 0.3 dB/Km at λ_o = 1.550 μm). The chromatic dispersion parameter at this wavelength is D = 17 ps/nm-Km. At the end of the fibre the light was detected using a fast photodiode (New Focus, model 1414). After amplification the signal was returned to the Electrical Spectrum Analyser (Agilent, Model CD-E4407B) for measurement the transfer function of the system. The trace of Fig. 7 corresponds to the frequency response of the system obtained by simulation and experimentally.

As expected from the system model, the value of the low-pass response is f_{lp} = 160 MHz, the first band-pass is located around of f_1 = 1.90 GHz and the second band-pass is located about f_2 = 3.89 GHz, the average associated bandwidth for these band-pass is Δf = 315 MHz.

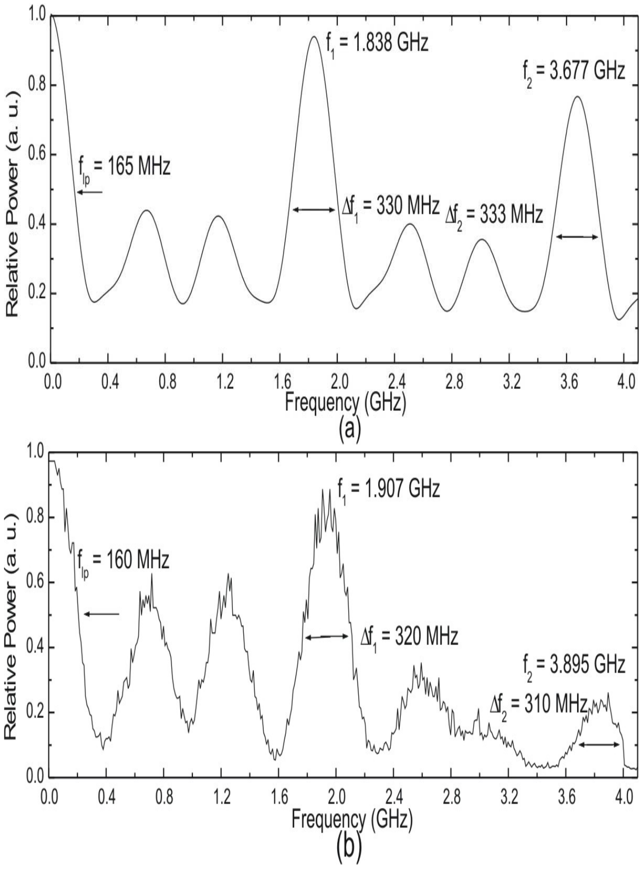

Fig. 7 (a) Simulated and (b) experimental frequency response of the electro-optical system when a multimode optical source exhibiting a Lorentzian envelope is used

This experiment demonstrates the filtering and the good tunability of the microwave-signal and confirms the non-influence of the optical spectrum on the frequency response of the optical system. The small difference observed between the positions of the band-pass windows obtained by simulation and experimental can be explained by the uncertainty error of the measurement of the FSR, and by the real value of the length of the SM-DSF.

5 Conclusion

The aim of this work was analyse the non-influence on the frequency response of an experimental optical system communication when multimode optical sources with arbitrary envelopes are used. We have corroborated that tuning of the microwave-signal depends basically of the chromatic dispersion parameter (D), the length of the link (L) and the FSR ($\delta\lambda$) of the multimode optical source used. This result can be easily generalized to the use of a multimode laser diode emitting at 1300 nm associated to Single-Mode Dispersion-Shifted Fibre. The carried out experiment has also served to compare the good agreement with the numerical simulations. At the present, these kinds of systems are being proposed to operate in standard optical telecommunications wavelengths at 1300 and 1550 nm.

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