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Design of equalized holographic ROADMs for application in CWDM METRO networks

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ABSTRACT

In this paper a design for an equalized holographic ROADM (Reconfigurable Optical Add-Drop Multiplexer) is done. This device can address several wavelengths at the input to different output fibers, according to the holograms stored in a SLM (Spatial Light Modulator), where all the outputs are equalized in power. All combinations of the input wavelengths are possible at the different output fibers.

These type of ROADMs are designed for application in CWDM (Coarse Wavelength Division Multiplexing) networks, where the distance between the different wavelength allow the use of DML (Direct Modulation Lasers) without cooling, reducing the cost and the tolerances of the network components. Application in METRO networks and its interconnection with some PON (Passive Optical Network), as a part of the access to the subscriber, is reviewed.

1. Introduction

Coarse Wavelength Division Multiplexing (CWDM) technologies are being widely deployed internationally in metropolitan and access networks due to the increased demand for delivering more bandwidth to the subscriber, created by the need of enhanced services.

For metro, and mainly for access networks applications, an increment in capacity may be achieved with a cost-effective multiplexing technology without the need for the high channel counts and closely spaced wavelengths typically used in long haul networks. A channel space of 20 nm, as it is proposed in the G. 694.2 ITU Recommendation, can be used relaxing the processing tolerances and potentially lowering the cost of components. CWDM technology reaches those requirements and it has been proposed for these applications. It is in this context where these holographic ROADMs devices have a potential use.

Different technologies have been proposed for the implementation of ROADMs [1,2,14,15]; each one of them has its own advantages and drawbacks. The main characteristic of holographic ROADMs is the easy way of changing the tuning and power level of the signal at the output fibers by the dynamic implementation of different holograms on the SLM according to the requirements of the network management.

In Section 2 of this paper the structure of the device is described, based on the diffraction produced when the light goes through a grating or SLM where phase holograms are stored. Section 3 is dealing with the design of the holographic device, taking into account the focal distance for the lens, spatial period for the grating or size and number of pixels in the SLM and the mixed hologram operation; finally applications for this holographic ROADM in a METRO network node are described.

2. Holographic ROADM structure

2.1. Reflective holographic ROADM

The working principle of the dynamic holographic device is based on the wavelength dispersion produced in a diffraction component (grating, spatial light modulator...) as it is explained in depth in [3].

We use for this application a phase reflective spatial light modulator (SLM) and a fixed transmissive diffraction grating to select the corresponding output wavelength from an assemble of channels in the input, as it is shown in the Fig. 1. The active element of the SLM is a Ferroelectric Liquid Crystal (FLC) with a low switching time (less than 50 μs) that allows a real time operation (hologram reconfiguration frequency about 5–10 KHz). The role of the fixed diffraction grating is to provide more wavelength tuning range and greater total diffraction angle.

One of the reasons because we have chosen this type of implementation, “2f-folded”, is the reduced size of the device in comparison with other possible structure, “lineal-4f”, where the dimension in the optical axis is four times the focal distance of the lens used.

The SLM_FLC and fixed grating are illuminated by a collimated light coming from a single mode optical fiber, through a lens. At the SLM the light is reflected and comes back through a convergent lens

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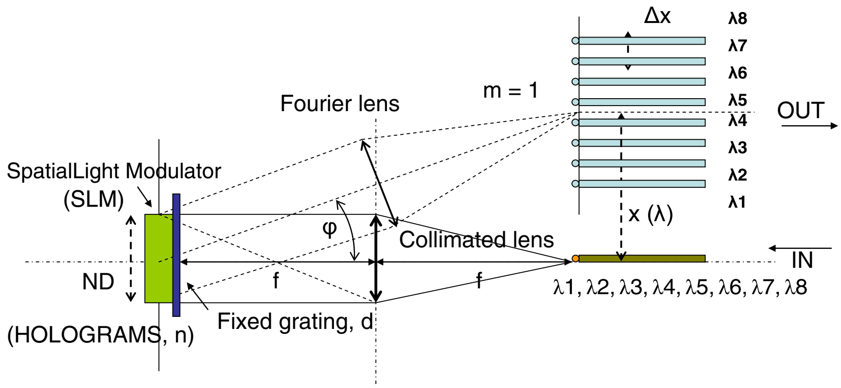

Fig. 1. Reflective holographic router.

that couples the first order of the diffracted light in the output optical fibers, like a spatial light filter. The output fibers are placed at the lens focal plane where the Fourier transform of the hologram, stored in the SLM, is located. For a practical design, both collimated and Fourier lenses could be the same with special care of the alignment. Unwanted cross-talk with other diffraction orders, [4], is avoided due to the separation between the output fibers.

2.2. 2 and 4-phases holograms

Different types of holograms can be used [5,6] in the SLM. In order to optimize losses, phase holograms are preferred instead of amplitude holograms due to their intrinsic 3 dB loss and 4-phase holograms are used instead of 2-phase (binary) holograms because of their greater efficiency (40.5%→81%), which is proportional to sinc^2 (π/M), where M is the number of phases.

Fig. 2 shows a bars hologram for 2 and 4-phases and their diffraction target in a far field approach. As we can see, the main difference in the holograms is the grey bars at the 4-phases holograms; in this case there is a white bar, a black bar and two different grey bars for addressing the 4-phases (π/4, 3π/4, −3π/4, −π/4); with regard to the diffraction target, other characteristic is the loss of the symmetry for the diffraction orders. Table 1 summarizes the relationships between phase and contrast for 2 and 4 phase holograms.

In Fig. 3 an example of holograms calculation is pointed out. The program calculates the inverse Fourier transform (F.T.)$^{-1}$ of the diffraction target (result) by an annealing optimization algorithm [7]. In this case both holograms have a calculation efficiency of 85% and the grey bars are clearly visible in the figure.

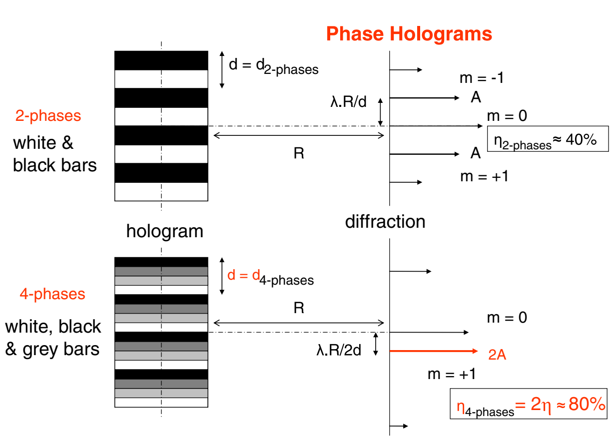

Fig. 2. Two/four-phases bars holograms.

3. Holographic ROADM design

For the design there are several transmission parameters to consider in a holographic ROADM:

3.1. Dynamic wavelength tuning

At the input of the router there are different wavelengths λ_1, λ_2,…. λ_n according to some ITU Rec. For the design of this holographic router, these wavelengths are in agreement with the G.694 Rec. for use in CWDM systems. The range of wavelengths is from 1271 nm to 1611 nm with a separation between channels of 20 nm; 4, 4 + 4, 8, 12 and 16 groups of channels are distributed along the complete range. Wavelengths around 1400 nm are not used in these systems to avoid the increment in the fiber attenuation due to the "peak of the water".

In a holographic router the tuning of this wavelength range is achieved by changing the spatial period of the hologram *ND*/*n*, where *n* is the number of pairs of bars (2-phases) or number of four bars (4-phases), *N* is the number of pixels and *D* the size of the SLM pixel. The expression which allows the selection of the output wavelength λ, according to the physical parameters and structure of the device, is [9]:

$$\lambda \approx \frac{x}{f} \cdot \frac{1}{\left(\frac{n}{ND} + \frac{2}{(M/2).d}\right)} \tag{1}$$

where *x* is the distance from the optical axis to the output fiber, *f* is the focal distance of the lens, *d* is the spatial period of the fixed diffraction grating and M has into account the number of phases. Fig. 4 shows some tuned wavelengths according to different values of *n*, for a typical holographic device.

For wavelengths close to the central, the filter response is very similar to the Gauss filter; for wavelengths far from the central, the filter response is similar to the 3nd order Bessel filter with less out band attenuation. Both of them have a lineal phase characteristic, which means, a constant group delay. These simulations are in agreement with experimental measurements shown in [3].

Table 1
Relationship between phases and contrast.

	2-PHASES		4-PHASES	
	% darkness	PHASE (rad)	% darkness	PHASE (rad)
Black	100	0	100	π/4
Grey1	–	–	66	3π/4
Grey2	–	–	33	−3π/4
White	0	π	0	−π/4