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Experimental demonstration of optical prefiltering in WDM-SCM optical networks employing ultraselective optical bandpass filter

J. Capmany, D. Pastor, A. León, P. Chamorro and D. Santos

The authors provide an experimental demonstration of optical prefiltering of RF channels in a wavelength division muliplexed-subcarrier multiplexed (WDM-SCM) system employing a previously reported ultraselective optical bandpass filter.

Introduction: Wavelength division multiplexing (WDM) technology is becoming established as the preferred option for multichannel optical communications, since it provides a means for the implementation of flexible, upgradable and scalable networks [1]. Furthermore, pure wavelength multiplexing can be combined with electronic multiplexing techniques to provide further channel granularity for the allocation of different services.

An interesting option is represented by so called wavelength division muliplexed-subcarrier multiplexed (WDM-SCM) systems where WDM is combined with subcarrier multiplexing in the RF domain. In these systems, one or more wavelengths are modulated by RF or microwave bands composed of subcarriers containing analogue or digital channels. The RF band can either carry telecommunication services (such as CATV channels) or even signalling channels, necessary, for example, for the operation, administration and maintenance of WDM networks.

In the context of an all optical network, it may be useful to select within a given WDM channel a given SCM channel directly in the optical domain using optical prefiltering techniques (i.e. with no intermediate optoelectronic conversion) and without affecting the rest of the WDM band.

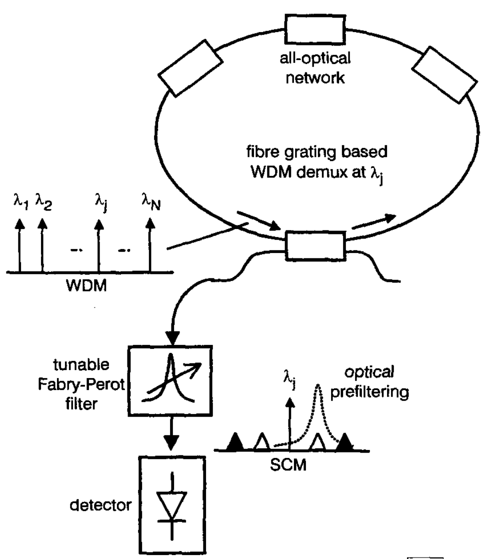

Fig. 1 *Layout of WDM-SCM system illustrating concept of optical prefiltering of SCM channels within optical carrier*

Optical prefiltering has been proposed and experimentally demonstrated [2 – 4] in single wavelength SCM systems. Both analogue [2] and digital [4] SCM channels have been successfully recovered using in-line fibre Fabry-Perot (FFP) filters. However in WDM-SCM systems this configuration cannot be employed since the periodic nature of the FFP spectrum will also affect RF channels carried by other optical carriers.

A solution to this problem is to employ a purely optical bandpass filter with a high resolution bandwith compatible with that of the SCM channels. A filter with such characteristics composed of a fibre grating and an FFP in tandem has been recently proposed [5] and it is applied in this Letter to experimentally demonstrate the feasibility of optical prefiltering in WDM-SCM networks.

Operation: The concept of optical prefiltering in WDM-SCM is illustrated in Fig. 1. In essence the wavelength channel containing the SCM signal of interest must be previously WDM demultiplexed and, subsequently, any desired RF channel within the SCM band must be prefiltered using a second optical filter. To implement the two stage filtering we propose the use of an ultraselective bandpass filter previously reported [5], shown in the inset of Fig. 2.

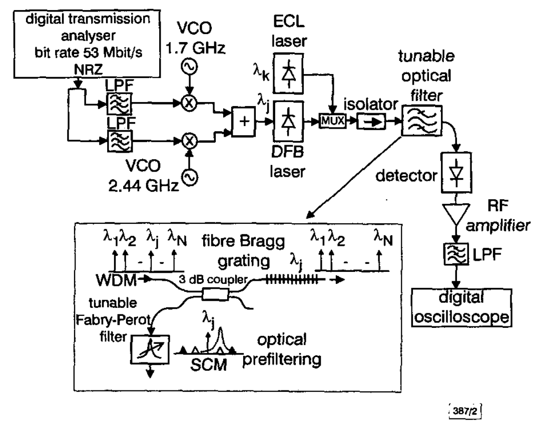

Fig. 2 *Experimetal setup of WDM-SCM system with optical prefiltering implemented in laboratory*

Inset: configuration of ultraselective optical bandpass filter

Experiment: A WDM-SCM system was assembled in the laboratory. The detailed system is depicted in Fig. 2. Owing to resource restrictions, the WDM band is composed of two carriers supplied by a distributed feedback (DFB) laser emitting at 1549.5nm and a tunable external cavity laser. The DFB laser is modulated by an SCM signal composed of two subcarriers located at 1.7 and 2.44GHz. Each subcarrier conveys a digital pseudorandom NRZ sequence at 53Mbit/s. The sequence length is 223-1. It was decided to modulate the RF subcarriers at speeds in the Mbit/s range rather than at higher speeds in the Gbit/s range as in [4] for two main reasons. First, there must be compatibility between the bandwidth of the RF channel to be selected and that of the available optical bandpass filter. The latter is 170MHz and therefore this figure sets an upper limit on the RF channel bandwidth to be prefiltered. The second reason is related to the fact that the usual load carried by RF channels in SCM systems is in the megabit per second range [6]. The RF channel separation was, in turn, lower (744MHz) than that of [4] (9.5GHz).

The composed WDM-SCM was fed to the optical system, consisting of an ultraselective bandpass filter, composed of a high reflectivity fibre Bragg grating (FBG) and a fibre Fabry Perot (FFP) in tandem, similar to that described in [5]. The FBG central wavelength is 1549.5nm and its 3dB bandwidth is 0.23nm (35GHz). The FFP filter parameters are (spectral period) FSR = 5GHz, finesse = 205, and the required voltage to completely tune a resonance over one FSR is 12V.

A computer controlled servo-loop was implemented for the tracking and locking of the FFP resonance to any SCM channel within the optical bandwith selected by the FBG. In a preliminary stage, the control system scans the FFP resonance to find the optical carrier corresponding to the WDM channel selected by the

FBG (coarse tuning). Once it locks to the desired optical carrier (for example by means of applying a given voltage V_o to the FFP piezoelectric transducer) a fine tuning voltage signal following the expression $\Delta V = 12 f_{RF}/FSR$ is added to lock the FFP to the subcarrier channel with RF frequency given by f_{RF}.

The wavelength of the tunable laser providing the second WDM channel was located at spectral separations of 100 and 200GHz from that of the first WDM channel, according to ITU specifications. No modulation was applied to this second WDM channel.

In all the cases, the second WDM channel was completely transmitted (as expected) by the FBG part of the ultraselective filter. Neither significant losses (excluding those corresponding to the FBG insertion loss) nor channel crosstalk was experienced for the WDM channel separations considered (100 and 200GHz).

The first WDM channel, centred at the reflection bandwith of the FBG, was extracted and the FFP sucessfully locked, first to the optical carrier and then, by means of the procedure previously described, to the desired SCM channel. Both channels could be optically prefiltered by proper resonance locking.

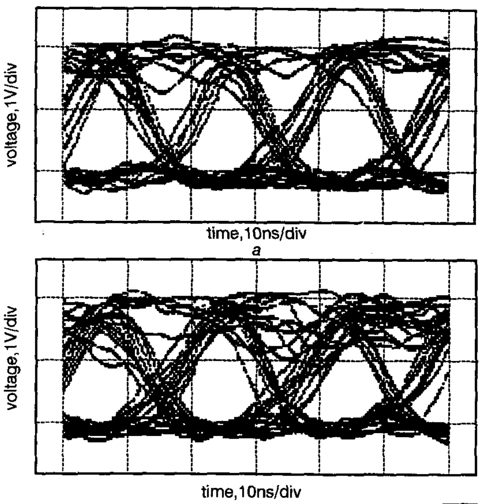

Fig. 3 *Eye diagrams corresponding to two different optically prefiltered SCM channels transported in WDM network by carrier corresponding to DFB laser*

a 53Mbit/s signal corresponding to digital baseband channel conveyed by subcarrier at 2.44GHz
b 53Mbit/s signal corresponding to digital baseband channel conveyed by subcarrier at 1.77GHz

In Fig. 3 we show the eye diagrams corresponding to the SCM channels at 2.44 and 1.7GHz, respectively. In both cases the results include the crosstalk from the non-selected RF channel due to the non-ideal selectivity of the FFP filter. A clear open eye is identified in both situations, demonstrating the feasibility of the filtering scheme.

Conclusion: We have presented an experimental demonstration of optical prefiltering in WDM-SCM systems using a previously reported ultraselective optical bandpass filter. The bit rate of the SCM channels (53Mbit/s) is compatible with the actual values conveyed in their standard applications (digital video signals and signalling channels).

Acknowledgments: The authors wish to acknowledge financial support from the Spanish CICYT via project TIC-95-0859-C02-01.

15 December 1998
Electronics Letters Online No: 19990241
DOI: 10.1049/el:19990241

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Numerically optimised upgrade of 458km installed fibre to single-wavelength 40Gbit/s soliton system in the presence of PMD

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The potential for an upgrade of 458 km (eight amplifier spans) installed dispersion shifted fibre (DSF) lines in Sweden to a single-wavelength 40Gbit/s soliton link without in-line control is numerically studied by extensive system simulations. The polarisation mode dispersion (PMD) is found to be the most important capacity limiting factor. The system tolerates an accumulated differential group delay (DGD) of more than 25% of the bit period.

Introduction: Solitons have an inherent robustness to distributed disturbances such as polarisation mode dispersion (PMD) [1] as well as variations in the local fibre parameters. Together with the introduction of the dispersion managed soliton [2], this indicates that the upgrading of already installed fibre to soliton systems is a realistic way to achieve single-wavelength bit rates of the order of tens of gigabits per second over terrestrial distances [3]. We have numerically optimised a single-wavelength 40Gbit/s soliton system without in-line control over 458km (eight amplifier spans) installed dispersion shifted fibre in Sweden. Both polarisation division multiplexed (PDM) and parallel-polarised (PP) transmission was studied. The system length is typical for the distance between large metropolitan areas in industrialised countries.

Numerical simulation tool and system parameters: Our numerical simulation tool was presented in [4]. Chirp-free solitons making up a pseudo-random bit sequence of length 15 were launched, applying 2^{10} temporal sampling points. The noise factor in the flat-gain erbium doped fibre amplifiers (EDFAs) was set to 5dB. The polarisation mode coupling length was set to a realistic value of 500m [4], which was also the step length. The receiver consisted of an optical receiver filter (120GHz wide Fabry-Pérot filter of finesse 120), and an ideal detector followed by a fifth-order 28GHz electrical Bessel lowpass filter. The statistical nature of PMD and the amplified spontaneous emission (ASE) in the EDFAs were modelled by studying the received electrical eye pattern over 100 individual runs [4]. Because PMD has Maxwellian statistics, we did not translate the resulting Q values into bit error ratios because ordinary formulas assume Gaussian statistics. We chose instead to define the maximum transmission distance where Q was larger than 7 and transmission-induced eye penalty less than 1dB and jitter variance less than 2.5ps.

Each 57km amplifier span consisted of four fibre lengths (2.8–27.8km long) in a terrestrial ring structure in Sweden. The 16 available parallel fibres made a certain selection possible for our eight individual amplifier spans. The local fibre parameters, zero dispersion wavelength, attenuation (average value 0.27dB/km) and PMD (measured by commercial equipment from GAP/EXFO), were determined from measurements. A dispersion slope of