A WDM Fiber-Radio Experiment Incorporating a Wavelength-Self-Tunable Single-Side-Band Filter

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Abstract — **Optical single-side-band (OSSB) sources compensate for deleterious chromatic dispersion effects in fiber-radio systems. A wavelength-self-tunable filter based on an iron doped indium phosphide photorefractive crystal is used to provide OSSB signals. The device is incorporated into the WDM fiber-radio transmission of two optical signals modulated at a 16 GHz frequency and carrying 140 Mbit/s data streams.**

I. INTRODUCTION

Hybrid fiber-radio architectures are an attractive solution for broadband access networks. In such systems, a central office (CO) transmits optical carriers modulated at radio frequencies (RF). Then, the transmitted signals propagate over fiber links to remote base stations (BS). At these locations, a photodiode converts the optical signal into an electrical signal, which is then amplified and transmitted by an antenna. Finally, the broadband services are delivered to the customer by a radio link. Moreover, in fiber wireless access, the data throughput capacity can be multiplied by using WDM techniques.

Nevertheless, the standard amplitude modulation of optical carriers generates double side-band (DSB) signals. Thus, due to the chromatic dispersion effects in the fiber, the photodiode (PD) recovered power level P_{RF}, suffers a periodical fading depending on the fiber length L and the modulation frequency f_m (Eq.1).

$$P_{RF} \propto \cos^2\left(\frac{\pi L D \lambda^2 f_m^2}{c}\right) \qquad (1)$$

where c is the velocity of light, λ is the optical carrier wavelength and D is the fiber dispersion parameter.

The power fading drawback is eliminated when a single side-band signal is used. This can be achieved using modulation techniques [1, 2] or filtering techniques [3, 4]. Our approach is to use a filtering technique based on the photorefractive effect in an iron doped indium phosphide (InP:Fe) crystal. In fact, SSB signals are obtained by Bragg diffraction of the lower side-band and of the carrier of the input DSB signals. In addition, since the input DSB signal drives the dynamic Bragg gratings induced in the crystal, the device is wavelength-self-tunable (WST) [5].

In this paper we report a WDM fiber-radio system experiment implementing a WST-SSB filter. The system radio frequency was 16 GHz and was phase modulated with a 140 Mbit/s data stream. Two optical SSB signals were transmitted over a 14 km fiber link before one was photodetected and subsequently radio transmitted over a 3 m distance. Finally the eye pattern of the down-converted received signal was observed.

II. DYNAMIC BRAGG GRATING GENERATION IN AN INP:FE PHOTOREFRACTIVE CRYSTAL

A photorefractive material is an electro-optic crystal in which light illumination generates carriers. InP:Fe belongs to this category and is particularly interesting since it reacts to the 1.55 μm wavelengths used for optical fiber telecommunications. Therefore, a control beam in this wavelength range can be used to generate a Bragg grating inside an InP:Fe crystal. In fact, thanks to a simple interference pattern, the photorefractive effect leads to a periodic variation of the refractive index. Thus, according to the Bragg condition, the diffraction of a signal beam of wavelength λ_s is possible. Eq. 2 gives the relation between λ_s and the control wavelength λ_c that generates the grating. Note that λ_c is greater than λ_s.

$$\lambda_s = \lambda_c\sqrt{1-\left(\frac{\sin\theta}{n}\right)^2} \qquad (2)$$

where n is the crystal average refractive index. The parameter θ is the angle separating the signal beam from the control beam. Obviously, the value we set θ at fixes the wavelength difference $\Delta\lambda$ between λ_s and λ_c. Consequently, regarding an optical DSB signal, θ can be set so that $\Delta\lambda$ coincides with the wavelength difference between the carrier and the side-bands. Therefore, in this configuration (Fig. 1), we divide the DSB signal into two beams, using the first one as the control beam and the second one as the signal beam. In this way, the three control lines ($\lambda_{1,2,3}$) generate three Bragg gratings ($G_{1,2,3}$). Then according to the relation (Eq.2) that exists between a control wavelength λ_i and a signal wavelength λ_{i-1}, G_2 and G_3 will diffract the signal lines λ_1 and λ_2 respectively. Then,

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these diffracted carrier and lower side-band constitute a SSB signal that is collected at the device output.

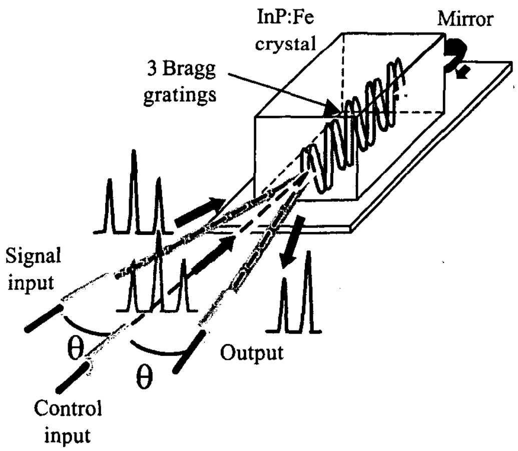


Fig. 1. WST-SSB filter concept.

What is more, the device works for a given modulation frequency f_m in a 2 GHz bandwidth [6]; on the other hand, since the input DSB signal drives the filter, the latter is wavelength-self-tunable. This property is the main advantage of this technique with respect to integrated SSB modulation sources or other filtering techniques using fixed Bragg gratings.

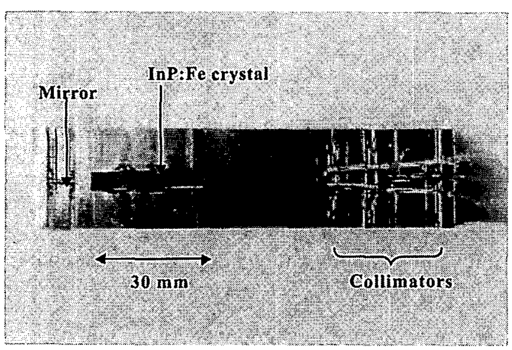


Fig. 2. WST-SSB filter built with a 30 mm long InP:Fe bulk crystal.

The picture in Fig. 2 shows the way the WST-SSB filter was implemented for the subsequent experiments. The InP:Fe crystal used was 30 mm long with a mirror glued behind in order to permit the control beam interference. The input and output accesses used collimators whose angles were placed by means of micro-positioning systems. In addition, during experiments, it is useful to place a polarization controller at the control input so as to optimize the amplitude of the refractive index gratings.

Moreover, the InP:Fe physical parameters confer on the filter a few ms response time as well as a fiber to fiber diffraction efficiency of about 2% [7].

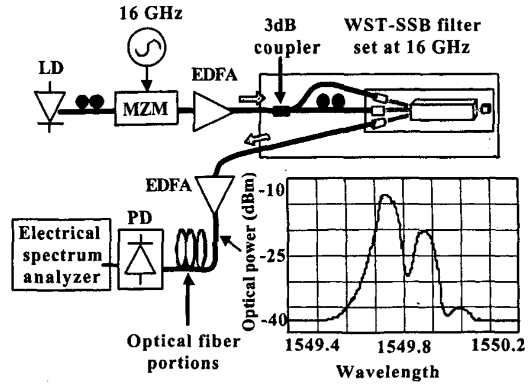


Fig. 3. Setup of the chromatic dispersion compensation experiment using the WST-SSB filter.

III. Chromatic Dispersion Effect Compensation Experiment

In order to validate the WST-SSB device, a radio over fiber experiment was implemented. The RF was chosen to be 16 GHz. Then, a WST-SSB device was built to operate at this central frequency thanks to the appropriate adjustment of θ at 2.34 degrees. A Mach-Zehnder modulator (MZM), driven by a 16 GHz electrical signal, externally modulated an optical carrier emitted by a laser diode. The resulting DSB signal was amplified by an erbium doped fiber amplifier (EDFA) and injected into the two WST-SSB filter inputs by means of an optical coupler. At the output the SSB signal was also amplified by a second EDFA and transmitted into fibers whose lengths varied between 0 and 24 km. The first EDFA was necessary because of the 9 dB insertion loss in the MZM, whereas the second one compensated the filter low reflectivity and the loss in the fibers. Therefore, a constant optical signal power level was injected into the PD at the fiber output. Then the recovered RF electrical signal was measured at the electrical spectrum analyzer. The dashed line and the solid curve in Fig. 4 represent power levels recovered with a DSB signal and a SSB signal respectively. Measurements show that there is no fading when the SSB signal is employed. However, for a DSB optical signal, the photodetected power level decreases by more than 20 dB for a 14 km fiber length. In addition, this experimental validation of the device was completed with an output signal measurement at the optical spectrum analyzer (OSA). As shown in Fig. 3 the diffracted signal was single-side-band with a 22 dB upper side-band rejection. Nevertheless, it is to be noted that the diffracted lower side-band (λ_1) level is higher than the diffracted carrier (λ_2) level. This was predictable since grating G_1 is of higher amplitude than grating G_2. Finally, using different laser diodes, we also verified that the SSB diffracted signal followed a carrier wavelength change.

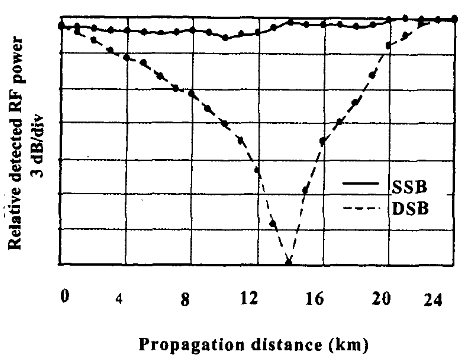
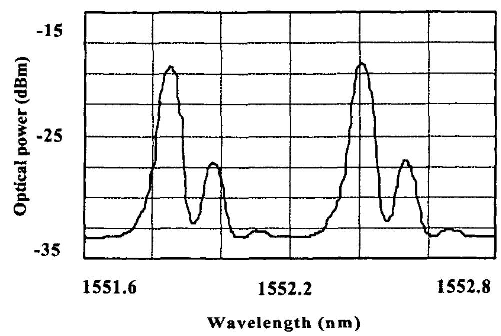


Fig.4. Recovered electrical power levels versus fiber length, for an optical DSB signal and for a SSB signal obtained using a WST-SSB filter.

IV. WDM FIBER-RADIO EXPERIMENT

The previous experiment having confirmed the theoretical behavior of the device with respect to chromatic dispersion effects, a system implementation was necessary for further validation. With this aim in view, the WDM fiber radio data transmission shown in Fig. 6 was carried out. The transmitter implemented two tunable lasers whose emitted carriers were set to 1551.9 nm and 1552.5 nm respectively. Each carrier was directed to one path of an optical coupler through a polarization controller and the coupler output was fed to an MZM. A 16 GHz RF carrier, binary phase shift keyed by a 140 Mbit/s data stream, was used to drive the MZM (RF electrode). Again to compensate for the MZM insertion loss, the two optical DSB signals obtained at the MZM output were amplified by an EDFA before being fed to the optical coupler at the WST-SSB filter input. At this stage, six dynamic Bragg gratings were assumed to be generated inside the InP:Fe crystal. Thus, prior to implementing a fiber wireless transmission, the filter output spectrum was observed at the OSA. Fig. 5 shows that two SSB signals are obtained with a 14 dB upper-side-band rejection. Then, a 14 km fiber link was added between the transmitter and a remote base station. At this location, a Bragg grating was used to suppress the WDM channel at 1551.9 nm. Next, the RF signal recovered from the remaining optical SSB signal was amplified and radio transmitted over a 3 m distance. Finally, after amplification, the received signal was down-converted and the eye pattern was observed. The clear eye opening (Fig. 6) proves the good quality of the data transmission. Nevertheless, the latter could certainly be improved by the use of optimized RF amplifiers. Moreover, the current system experiment demonstrated that in spite of its low reflectivity, the WST-SSB filter can be implemented in a two channel WDM fiber-radio experiment.

Fig.5. WST-SSB output signal measured for a two channel



WDM input DSB signal with 16 GHz RF.

V. CONCLUSION

We have reported the compensation of the chromatic dispersion effects in a radio over fiber transmission using a WST-SSB filter. This filter operates independently of the carrier wavelength whereas the operating frequency is set to the desired microwave or millimeter-wave value by adjusting the signal injection angle. Nevertheless, due to the InP:Fe crystal physical characteristics, the device's fiber to fiber efficiency is only 2%. A new photorefractive crystal or InGaAsP integration of the device could improve the reflectivity. In addition, a WDM fiber-radio system experiment incorporating the device has been demonstrated for the first time. The RF frequency was 16 GHz and the eye diagram observed at the receiver showed good transmission of the 140 Mbit/s data stream.

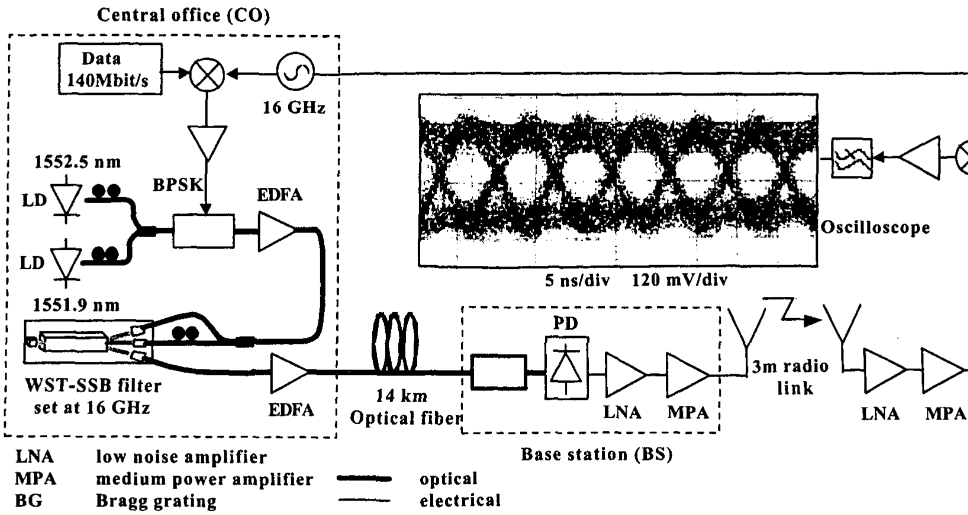


Fig. 6. Experimental setup of the system transmitting 140 Mbit/s data streams at a 16 GHz RF, incorporating the WST-SSB filter. The demultiplexing and the radio transmission of one channel follow the transmission of two WDM channels over a 14 km fiber link.

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