FBG-Based Optical Interface to Support a Multisector Antenna in a Spectrally Efficient Fiber Radio System

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***Abstract*—We propose and demonstrate a fiber Bragg grating (FBG)-based optical interface for use in a spectrally efficient fiber-radio network with multisector antennas. The system has the novel feature of being specifically developed for use in existing wavelength-division-multiplexed network infrastructures. The proposed scheme supports transport of a remote local oscillator (LO) and three subcarrier multiplexed data channels, destined for different antenna sectors, using a single wavelength. The composite signal was contained within a 25-GHz band, selected via a 25-GHz dispersion-flattened FBG. Recovery of the LO and data channels is performed via optical filtering, using either a novel single grating incorporating multiple phase shifts or multiple narrow bandwidth gratings. Our measurements show that all channels within the 25-GHz band are successfully recovered with less than 2-dB optical power penalty between channels. The use of the 25-GHz grating exhibits an improvement in sensitivity of 3 dB for all data channels.**

***Index Terms*—Gratings, millimeter-wave (mm-wave) radio communication, optical fiber communication, optical filters, subcarrier multiplexing (SCM).**

I. Introduction

THE development of wireless communication systems operating at millimeter-wave (mm-wave) frequencies will assist in the delivery of future broad-band services with data rates >1 Gb/s [1]. To accelerate a commercial deployment of fiber-radio architectures, existing wavelength-division-multiplexed (WDM) broad-band optical network infrastructures based on ITU grid spacings must be efficiently utilized. While transporting the radio signal over fiber in a mm-wave format has the advantage of simplifying the antenna base-station (BS) architecture, optical channel spacings in excess of 60 GHz may be required [2], thereby limiting the transport scheme to one mm-wave channel per WDM wavelength. In particular, for a fiber feed network incorporating BSs with multiple sectorized antenna interfaces, each sector needs to be fed by separate mm-wave signals, requiring multiple WDM channels to provide the full interconnection to the central office (CO) which is spectrally inefficient. To improve the optical spectral efficiency, the radio signal feeding each sector can be transported as a low frequency subcarrier multiplexed (SCM) signal on a single WDM wavelength. However, this approach requires a mm-wave local oscillator (LO) at the BS for frequency upconversion to mm-wave frequencies, increasing both BS complexity and cost. To overcome this problem, a number of techniques involving the simultaneous transmission of the LO and data signals from the CO to the BSs have been proposed. These techniques include the transmission of the LO at a mm-wave frequency [3], or as a lower frequency harmonic of the LO [4], [5]. However, such schemes have drawbacks for application in a multisector fiber radio network, such as spectral inefficiency, the potential to generate higher order side modes or the requirement for complex electronics in the BS [3]–[5].

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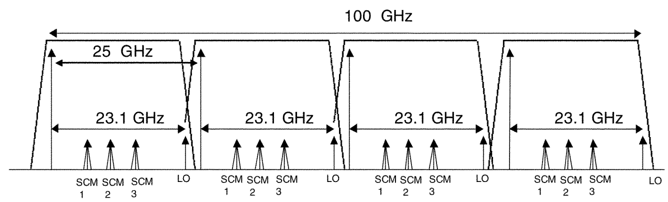

Fig. 1. Wavelength allocation scheme for a spectrally efficient WDM fiber-radio network incorporating simultaneous SCM and remote LO delivery.

In this letter, we propose and demonstrate a fiber Bragg grating (FBG)-based interface for a fiber-radio network which utilizes remote optical LO delivery together with multiple sector signal transport, contained within a 25-GHz frequency band. The proposed architecture offers an improved optical spectral efficiency and overcomes disadvantages associated with other LO delivery and recovery schemes. The interface incorporates novel FBG designs and simple narrow-band optical filtering not previously demonstrated to recover an LO and data signals.

II. Design of the FBG for LO and Intermediate Frequency (IF) Filtering

To improve the spectral efficiency of multisector fiber-radio networks, three data channels were assigned to each access network wavelength. The subcarrier frequencies (7.1, 10.22, and 13 GHz) and LO signal frequency of 23.1 GHz were chosen such that the electrical bandwidth lies within a 25-GHz band [7]. The electrical signal then modulated the carrier wavelength using optical single sideband with carrier $(\mathrm{OSSB}+\mathrm{C})$ modulation which allows the LO and SCM signals to be contained within the 25-GHz band and reduces fiber chromatic dispersion effects [8]. Fig. 1 depicts the allocation of the LO and SCM channels with their corresponding optical carriers as can

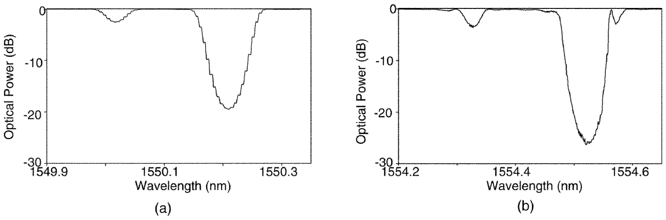

Fig. 2. Measured transmission responses of FBG designs for LO recovery. (a) Two concatenated FBGs and (b) single novel FBG structure with eight phase shifts of 64°.

be implemented in existing access network infrastructures. Successful recovery of the LO and SCM channels contained within a signal band is achieved at the BS using narrow-band optical filtering techniques implemented via novel FBGs. This detection process requires a portion of the optical carrier to be filtered with the LO modulation sideband, with the remaining carrier power detected with the SCM channels. To achieve the reflectivity profiles necessary for this filtering, two different FBG designs were implemented, both reflecting half the carrier and all of the LO, while passing the SCM signals unaffected. The first design consisted of a concatenation of two separate FBGs with bandwidths of less than 10 GHz and transmission strengths of -2.5 and -18 dB, as shown in Fig. 2(a). The second FBG was designed to have an improved transmission notch rolloff and depth, when compared with the two grating cascade. Fig. 2(b) shows the transmission response of this novel FBG design which consists of a single grating structure incorporating a total of eight strategically located phase shifts of 64°. A 25-GHz dispersion-flattened grating was also fabricated for the filtering of the carrier, LO, and three SCM signals within a 25-GHz band to feed the appropriate multisector BS. Since the focus of this work was the implementation of the FBG-based interface and recovery of the LO and data signals via narrow-band optical filtering, transmission of a single wavelength 25-GHz band was investigated. Future work will address the transmission of multiple wavelengths in the fiber-radio network.

III. Experiment

Fig. 3 shows the experimental setup. At the CO, the three SCM signals were modulated in binary phase-shift keying format via a 60-Mb/s $2^{15} - 1$ pseudorandom binary sequence data signal, amplified, and combined with the LO signal. The resulting radio-frequency (RF) signal was then applied to a dual-electrode Mach–Zehnder modulator via a hybrid coupler and used to modulate, in OSSB + C format, the output from a tunable laser source. The signal was amplified by an erbium-doped fiber amplifier to compensate for the 10-km single-mode-fiber (SMF) link loss and input into a bandpass filter (BPF) to remove amplified spontaneous emission (ASE) noise. It was then incident on the FBG(s) via a circulator, with the transmitted and reflected spectrums from the two concatenated gratings as inserts in Fig. 3. Both the reflected LO and transmitted SCM signals were detected (in the BS) via high-speed photodetectors (PDs). A variable optical attenuator was used in the SCM optical arm to vary the received optical power, which was measured at the input to the SCM PD. The RF signal was then electrically filtered to separate the SCMs, amplified, and upconverted using the recovered 23.1-GHz LO to produce a frequency at 30.2, 33.32, or 36.1 GHz. Further upconversion of these signals to the 37-GHz range now requires the operating frequency of the LO at the BS to be less than 7 GHz. This BS LO is, thus, less expensive and more readily available than the mm-wave LO that would be required at the BS if there was no 23.1-GHz remote LO delivery. Finally, the 36-, 37-, or 38-GHz mm-wave signals were passed through a 37-GHz BPF, transmitted to the customer unit and downconverted to 2.5 GHz, fed into an electronic phase lock loop and the recovered data input into the bit-error-rate (BER) testset for BER measurements.

IV. Results and Discussion

Fig. 4(a) and (b) shows the measured BERs for the 60-Mb/s data recovered from each SCM signal after optical filtering using the concatenation of two FBGs or the novel single phase-shifted FBG, respectively. Six curves are shown in each figure, corresponding to recovery of the 7.1-, 10.22-, or 13-GHz SCM signals with or without adjacent SCM frequencies also transmitted. The results in Fig. 4 show an optical power penalty spread of only 2 dB at a BER of 10^{-9} between all three SCM channels, demonstrating the ability to successfully utilize narrow-band optical filtering techniques for remote LO recovery, in a spectrally efficient fiber-radio network. In particular, the results show how the novel phase-shifted grating offers comparable performance to a grating cascade. The small difference in the slope of the BER curves for the 13-GHz SCM is due to the different phase response of the 13-GHz RF filter. The 7.1-GHz SCM channel exhibits the best performance using both filtering schemes, although the 10.22- and 13-GHz SCM channels show a change in sensitivity when using the phase-shifted grating. This can be attributed to small dispersion differences between the two FBG designs and some experimental error, however, the power penalty spread between all three SCM channels remained the same with either filtering scheme. In addition, the observed power penalty was less than 0.25 dB in both Fig. 4(a) and (b), when each SCM is recovered either with or without the adjacent SCM channels transmitted. This very small power penalty is within experimental error, illustrating how multiple SCM data channels and a remote LO can be simultaneously transmitted and recovered with minimal degradation and distortion arising from adjacent channels.

To further demonstrate the successful application of FBGs as narrow-band optical filters in a fiber-radio architecture with remote LO delivery, the 25-GHz dispersion-flattened grating and second circulator were inserted after the 10 km of SMF. Fig. 5 shows the measured BERs for data recovery from each SCM signal, via filtering with the phase-shifted FBG, when all SCM channels are transmitted. A comparison with Fig. 4(b) shows that the power penalty spread remains 2 dB at a BER of 10^{-9} with the BER trends between data channels maintained. The use of the 25-GHz FBG has the advantage of improving the optical sensitivity for all channels by 3 dB due to the additional filtering of ASE noise it provides. It should be noted that while the 60-Mb/s data rate demonstrated in the experiment was determined by RF component availability, the proposed architecture can be easily extended to higher bit rates with no expected change to power penalty spreads.

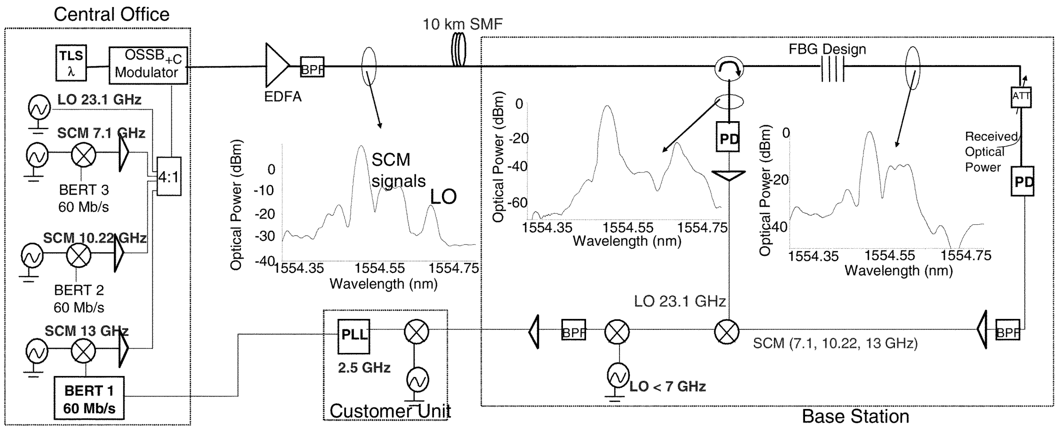

Fig. 3. Experimental setup to demonstrate simultaneous delivery and recovery of a remote LO and three IF SCM data signals, in a 25-GHz band, using novel FBG optical filtering techniques.

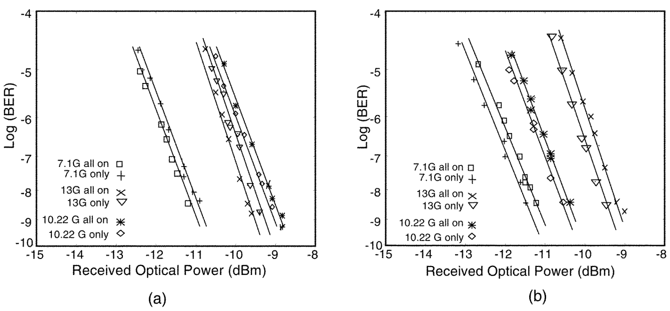

Fig. 4. Measured BER performance for three SCM channels, using remote LO delivery and optical filtering via (a) two cascaded FBGs or (b) a single eight-phase-shifted FBG.

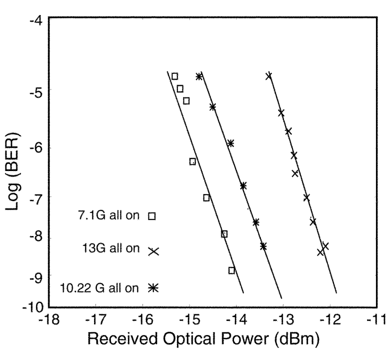

Fig. 5. Measured BER performance for three SCM channels, using remote LO delivery and optical filtering via a 25-GHz dispersion-flattened FBG in conjunction with an eight-phase-shifted FBG.

V. Conclusion

An FBG-based interface has been proposed for use in a spectrally efficient fiber-radio mm-wave network. The network utilizes remote LO delivery together with multisector SCM data transmission, with the narrow-band optical filtering techniques overcoming disadvantages associated with other proposed remote LO delivery and recovery schemes. The performance of two different types of FBG designs, one incorporating multiple phase shifts, was compared in an experimental system application. The demonstration investigated the transmission and recovery of an LO and three SCM data signals located within a 25-GHz band using a single wavelength. Successful recovery of the LO and all SCM channels was achieved with a power penalty spread of less than 2 dB for all channels, after transmission over 10 km of fiber, for both types of FBG designs. The additional use of a 25-GHz grating filter does not degrade individual data channel performance and assists in improving the optical sensitivity. The demonstrated optical filtering technique for LO recovery is simple and inexpensive, ultimately reducing BS complexity and cost, with the simultaneous transmission of three data channels allowing for multisector capability in the network. These advantages, combined with the improved spectral efficiency, are key components for accelerating the initial deployment of mm-wave fiber-radio networks in existing WDM infrastructures.

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