A DEMULTIPLEXING SCHEME USING AN ARRAYED-WAVEGUIDE GRATING FOR A DWDM MM-WAVE FIBER-RADIO SYSTEM BY OPTICAL FREQUENCY INTERLEAVING

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Abstract: We propose a demultiplexing scheme for a DWDM mm-wave fiber-radio system by optical frequency interleaving. The scheme consists of a Fabry-Perot etalon, an optical circulator and a 2 x N arrayed-waveguide grating, which is designed to steer the input signals with the frequency difference equals to the millimeter-wave carrier frequency into the same output waveguide.

Introduction

Recent progress in transmission capacity of dense wavelength-division multiplexed (DWDM) signals in a trunk optical fiber line now allows transmission of data beyond 10 Tbit/s over more than 100 km [1], [2]. The DWDM technology has to be applied to future millimeter-wave fiber-radio systems in order to take the capability to deal with the large amount of data capacity. There have been several reports to increase the spectral efficienty of such DWDM fiber-radio systems [3], [4]. Very recently, we proposed to use optical frequency interleaving to realize a DWDM mm-wave fiber-radio system. In this paper, we propose a possible demultiplexing scheme for the system. The scheme consists of a Fabry-Perot etalon, an optical circulator and a 2 x N arrayed-waveguide grating, which is designed to steer the input signals with the frequency difference equals to the millimeter-wave carrier frequency into the same output waveguide.

Principle of the DWDM mm-wave fiber-radio system

Fig. 1 (a) shows an optical spectrum of DWDM millimeter-wave fiber-radio signals with optical SSB modulation format. Using the optical SSB modulation, the spectral efficiency can be doubled compared to the optical DSB modulation. In the sense of cost reduction, it is preferable to use the channel spacing in accordance with ITU grid because of the availability of optical components. Therefore, the minimum channel spacing in this case is 100 GHz. In this scheme, however, the optical spectrum can not be fully utilized because the bandwidth of the millimeter-wave signal is much narrower than the millimeter-wave carrier frequency. This shortcoming can be overcome simply by interleaving the optical frequency as shown in Fig. 1 (b). In this case, channel spacing of 25 GHz can be achieved even if the millimeter-wave band

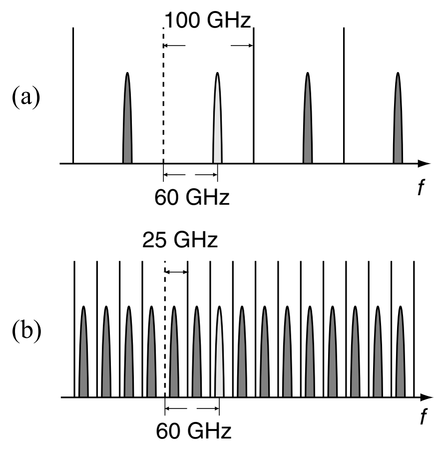


Fig. 1: Optical spectra of DWDM millimeter-wave fiber-radio signals with optical SSB modulation format, (a); conventional scheme and (b); recently proposed scheme.

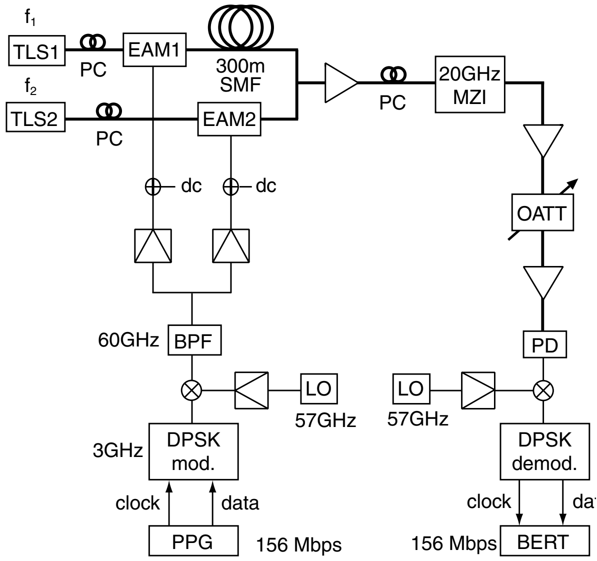
from 59 GHz to 66 GHz is fully used for the subcarrier multiplexed signals. When the bandwidth of the millimeter-wave signal is several hundred MHz, ultimate sub-GHz channel spacing is possible if ultra-narrowband demultiplexing filters and highly stable laser sources are obtained.

Preliminary experiment

Fig. 2 shows the experimental setup. In the experiment, 10-GHz spaced 2-channel optical DSB signals multiplexed by frequency interleaving are used. Two CW lights from tunable laser sources (TLS1 and TLS2) whose optical frequencies are depicted by f_1 and f_2 are intensity modulated by electro-absorption modulators (EAM1 and EAM2) independently with a 60-GHz millimeter-wave carrying a 156-Mbps DPSK data. A standard single-mode fiber (SMF) with 300 m length is inserted after the EAM1 for decorrelating the DPSK data of channel 1 and 2. In order for DEMUX, we used two imbalanced Mach-Zehnder interferometers (MZI) fabricated on planar lightwave circuit with the frequency spectral range (FSR) of 40 GHz, which were used for a previous experiment [5]. Periodical transmission characteristics with the FSR of 20 GHz can be obtained by concatenating the two MZI's and tuning their transmission peak frequency. Using this scheme, DEMUX for the channel spacing of 10, 30 and 50GHz can be achievable. The demultiplexed optical signal is detected by a photodiode (PD). The bit-error rate (BER) of the decoded 156 Mbps data is measured as a function of the received optical power, which is measured at the input of the EDFA preamplifier.

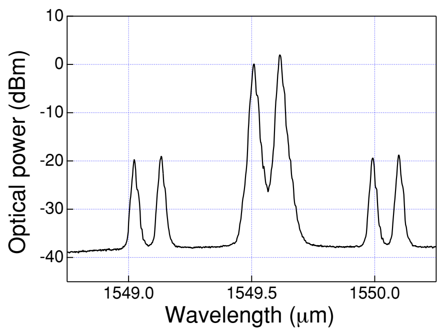
Fig. 3 shows the optical spectra of the multiplexed signals (a) before DEMUX and (b) after DEMUX, respectively. The frequency difference of the two TLS output f_1 - f_2 was set to be 10 GHz. The crosstalk, which is defined by a ratio of the undesired (channel 2) to the desired (channel 1) signal power is - 9.6 dB for carrier and - 6.2 dB average for sidebands. Note that the use of two 40 GHz MZI’s as a 20-GHz FSR demultiplexer for this experiment induces additional 6 dB insertion loss, and therefore 6 dB degradation in the crosstalk. The crosstalk can be easily improved by use of properly designed demultiplexing devices.

Fig. 4 shows the measured BER versus the received optical power. ○ indicates the BER

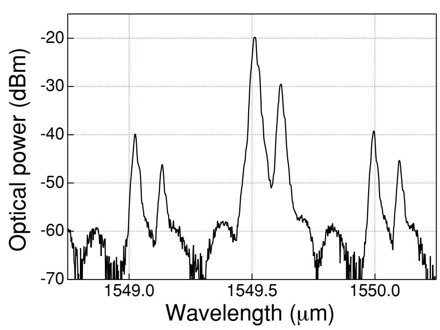


TLS: tunable laser source, EAM: electro-absorption modulator, PC: polarizatio controller, SMF: standard single-mode fiber, MZI: imbalanced Mach-Zehnder interferometer, OATT: optical variable attenuator, PD: photo diode

Fig. 2: Experimental setup for 2-channel optical DSB signals multiplexed by optical frequency interleaving. See text for detail of the 20 GHz MZI.



(a) Before demultiplexer.



(b) After demultiplexer.

Fig. 3: Measured optical spectra of the fiber-radio signals with the channel spacing of 10 GHz.

when both channels were modulated. + indicates the BER when only the desired channel (channel 1) was modulated. No BER floor (> 10^{-11}) was observed for both cases. The power penalty at BER = 10^{-9} was 2.7 dB.

Configuration of demultiplexer for the DWDM fiber-radio system.

The proposed scheme for demultiplexing (DEMUX) is shown in Fig. 5. A high-finesse Fabry-Perot etalon (FP) and an optical circulator (OC) are connected to an arrayed-waveguide grating with 2 input and N output waveguides (2 x N AWG). The FP is used for separating carriers and sidebands from the multiplexed optical signals as shown in B and C of Fig. 5 (b). The AWG [6] is designed to steer the input signals with the frequency difference equals to the millimeter-wave carrier frequency f_{RF} into the same output waveguide as shown in D of Fig. 5 (b). This can be done by properly adjusting the separation of the input waveguides Δx_{in} at the interface between the input channel waveguide and slab waveguide regions. Δx_{in} can be obtained as the following equation assuming that $dn_s/d\lambda << dn_c/d\lambda$.

$$\Delta x_{in} = \frac{F\Delta L N_c}{n_s d}\frac{\lambda}{c} f_{RF}, \qquad (1)$$

where F, n_s, ΔL, N_c, λ, d and c are arc length and effective index of the slab waveguide, path length difference between neighboring arrayed waveguide, group index of the arrayed waveguide, wavelength in vacuum, the separation of the arrayed waveguides at the interface between the input slab waveguide and the arrayed waveguide regions, and the speed of light in vacuum, respectively [7]. The separation of the output waveguides Δx_{out} at the interface between the output channel waveguide and slab waveguide regions can be obtained as the typical AWG with the channel spacing of Δf,

$$\Delta x_{out} = \frac{F\Delta L N_c}{n_s d}\frac{\lambda}{c}\Delta f \,. \qquad (2)$$

In this way, demultiplexed signals are obtained from output waveguides of the AWG.

When fiber-pigtailed FP and OC are used, state of polarization of the carriers at B and sidebands at C of Fig. 2 should be adjusted or scrambled with higher rate than each signal bandwidth. Nevertheless, the phase drift between the two paths does not seriously influence the demultiplexed signals because the drift is normally much slower than the bit period of the signals.

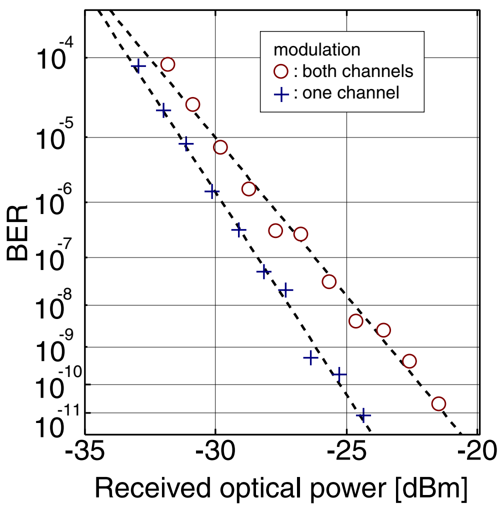
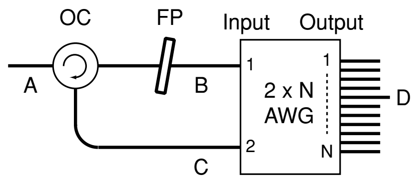
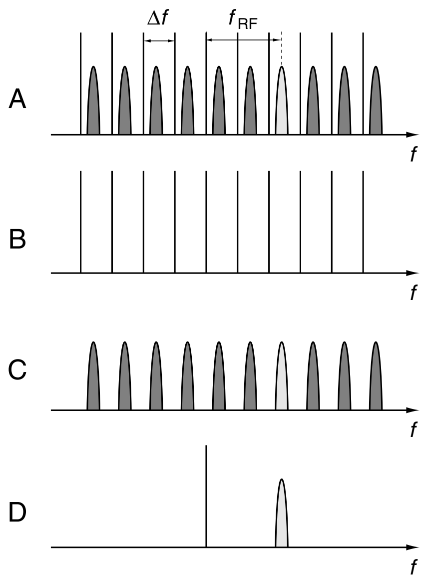


Fig. 4: Measured BER versus received optical power.



OC: optical circulator, FP: Fabry-Perot etalon, AWG: arrayed-waveguide grating

(a) Setup.



(b) Frequency spectra of A; multiplexed optical signals, B; transmitted carriers through FP, C; sidebands reflected by FP, and D; one of the outputs of 2 x N AWG.

Fig. 5: Proposed demultiplexing scheme for the DWDM millimeter-wave fiber-radio system.

Conclusion

We have proposed a demultiplexing scheme for a DWDM mm-wave fiber-radio system by optical frequency interleaving, where the preliminary experiment with 10-GHz spaced 2-channel optical DSB signals modulated by a 60-GHz millimeter-wave showed power penalty at BER = 10^{-9} of 2.7 dB even though the carrier crosstalk was only - 9.6 dB. The proposed demultiplexing scheme consists of a Fabry-Perot etalon, an optical circulator and a 2 x N arrayed-waveguide grating, which is designed to steer the input signals with the frequency difference equals to the millimeter-wave carrier frequency into the same output waveguide.

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