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A DWDM MM-WAVE FIBER-RADIO SYSTEM BY OPTICAL FREQUENCY INTERLEAVING FOR HIGH SPECTRAL EFFICIENCY

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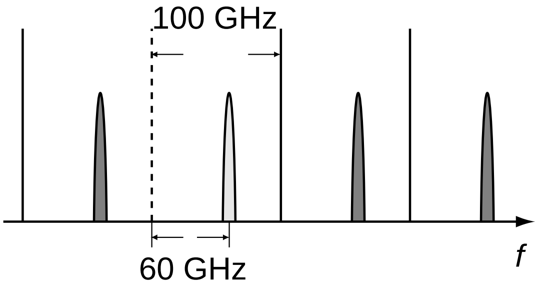
Abstract: We propose a simple method for fully utilizing optical bandwidth of DWDM millimeter-wave fiber-radio systems by optical frequency interleaving. Preliminary experiment with the channel separation of only 10 GHz showed the interchannel-crosstalk induced power penalty of 2.7 dB.

Introduction

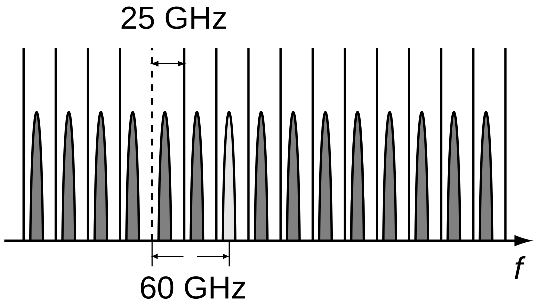
Recent progress in transmission capacity of dense wavelength-division multiplexed (DWDM) signals in a trunk optical fiber line now allows transmission of data beyond 10 Tbit/s over more than 100 km [1], [2]. The DWDM technology has to be applied to future millimeter-wave fiber-radio systems in order to take the capability to deal with the large amount of data capacity. There have been several reports to increase the spectral efficiency of such DWDM fiber-radio systems [3], [4]. In this paper, we propose a simple method to increase the spectral efficiency by optical frequency interleaving. We also show a possible configuration of demulptilexing scheme for the proposed system. The results of preliminary experiment with the millimeter-wave carrier frequency of 60 GHz and the channel separation of only 10 GHz are described to show the capability of the proposed method.

Principle of operation

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 separation in accordance with ITU grid because of the availability of optical components. Therefore, the minimum channel separation 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 separation of 25 GHz can be achieved even if the millimeter-wave band from 59 GHz to 66 GHz is fully used for the subcarrier multiplexed signals.

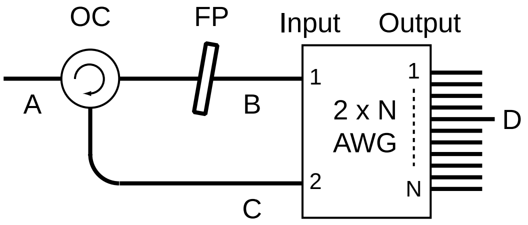


(a) Conventional scheme.



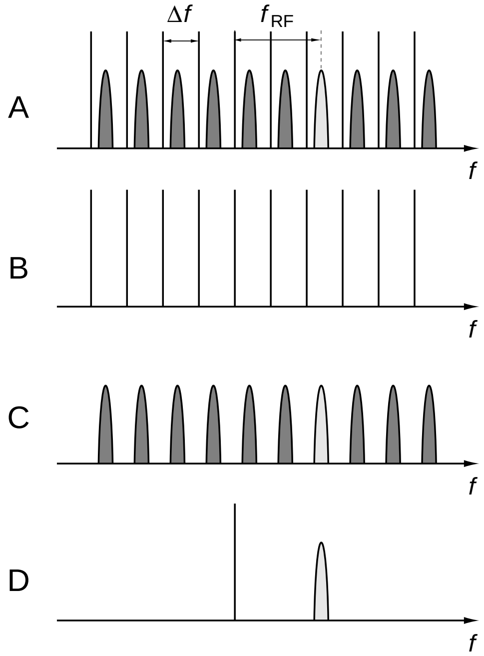
(b) Proposed scheme.

Fig. 1: Optical spectra of DWDM millimeter-wave fiber-radio signals with optical SSB modulation format.



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

(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. The AWG is designed to steer the input signals with the frequency difference of f_{RF} into the same output waveguide. f and f_{RF} are the channel separation and the microwave carrier frequency, respectively.

Fig. 2: A possible configuration of demultiplexer for the proposed scheme.

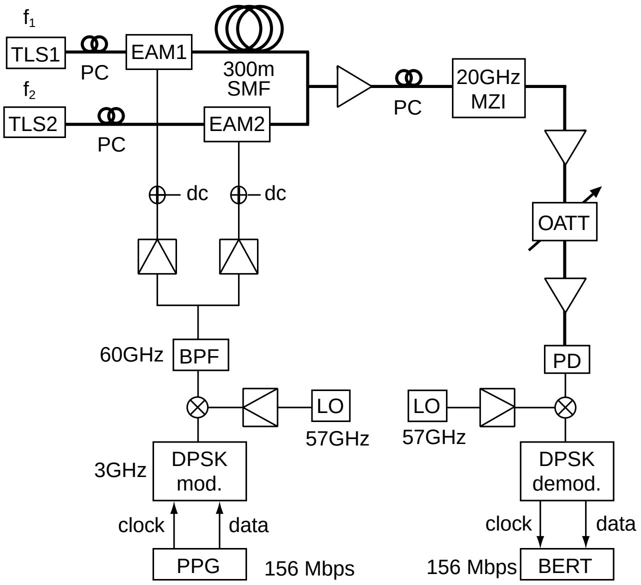
When the bandwidth of the millimeter-wave signal is several hundred MHz, ultimate sub-GHz channel separation is possible if ultra-narrowband demultiplexing filters and highly stable laser sources are obtained.

A possible configuration for demultiplexing (DEMUX) is shown in Fig. 2. A high-finesse Fabry-Perot etalon (FP) and an optical circulator (OC) are connected to an arrayed waveguide device with 2 input and N output waveguides (2 x N AWG). The FP is used for separating carriers and sidebands of the multiplexed optical signals. The AWG [7] is designed to steer the input signals with the frequency difference equals to the microwave carrier frequency f_{RF} into the same output waveguide. This can be done by properly adjusting the separation of the input waveguides at the interface between the channel waveguide and slab waveguide regions. 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.

Experiment

Fig. 3 shows the experimental setup. In the experiment, 10-GHz separated 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 separation 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.

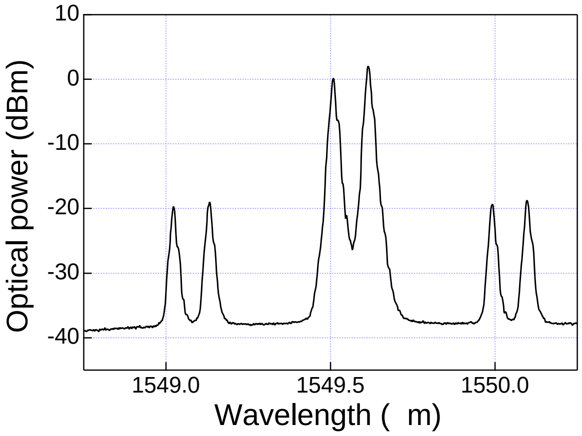


TLS: tunable laser source, EAM: electro-absorption modulator, PC: polarization controller, SMF: standard single-mode fiber, MZI: imbalanced Mach-Zehnder interferometer, OATT: optical variable attenuator, PD: photo diode

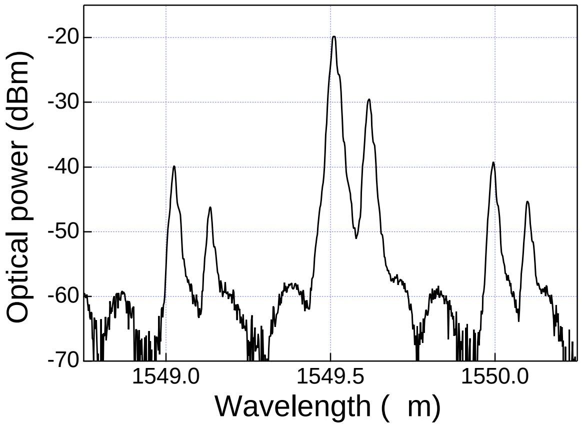
Fig. 3: Experimental setup for 2-channel optical DSB signals multiplexed by optical frequency interleaving. See text for detail of the 20 GHz MZI.

Fig. 4 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. 5 shows the measured BER versus the received optical power. ○ indicates the BER 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. The calculated *worst*-case power penalty due to the interchannel crosstalk [6] obtained from the result of Fig. 4 (b) was 2.2 dB. The small discrepancy between the theory and experiment is under investigation at this moment.



(a) Before demultiplexer.



(b) After demultiplexer.

Fig. 4: Measured optical spectra of the fiber-radio signals with the channel separation of 10 GHz.

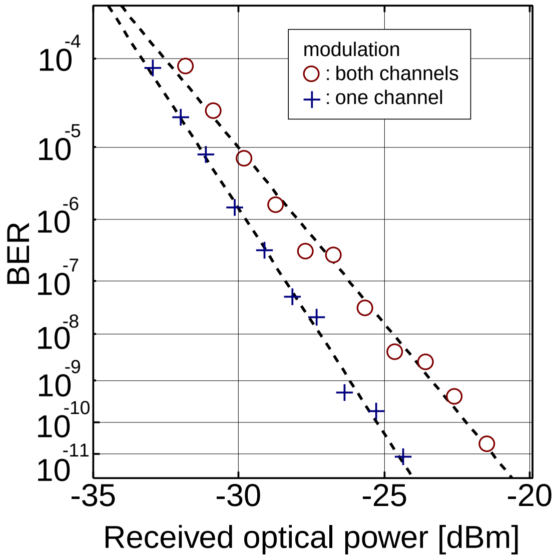


Fig. 5: Measured BER versus received optical power.

Conclusion

We have proposed a simple method to increase the spectral efficiency of DWDM millimeter-wave fiber-radio systems by optical frequency interleaving. In the experiment, 10-GHz separated 2-channel optical DSB signals modulated by a 60-GHz millimeter-wave carrying a 156 Mbps data were demultiplexed. Error-free operation and power penalty at BER = 10^{-9} of 2.7 dB were obtained even though the demultiplexer was not properly designed for this particular experiment. Future works include demultiplexing of multi-channel optical SSB signals.

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