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25-GHZ CHANNEL SPACING DWDM MULTIPLEXING USING AN ARRAYED WAVEGUIDE GRATING FOR 60-GHZ BAND RADIO-ON-FIBER SYSTEMS

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Abstract: We propose and demonstrate a DWDM multiplexing scheme using an arrayed-waveguide grating for optically frequency interleaved 60-GHz band radio-on-fiber systems. No noticeable power penalty was observed after 25-km SMF transmission when the channel spacing was 25 GHz.

Introduction

For future millimeter-wave (mm-wave) radio-on-fiber (RoF) systems, it is important to apply dense wavelength division multiplexing (DWDM) to support a huge number of base stations connected to a central station [1]. Optical frequency interleaving is attractive in order to increase the optical spectral efficiency of such a DWDM mm-wave RoF system [2]-[4]. So far, we proposed to use arrayed waveguide grating (AWG) for demultiplexing (DEMUX) [5] and demonstrated DEMUX function in a 60-GHz band RoF system with 25-GHz channel spacing [6]. Because of the narrow filtering characteristics of the AWG, only a single sideband of double sideband (DSB) RoF signal was filtered. Therefore, signal fading due to fiber dispersion was effectively reduced.

In this paper, we propose and demonstrate a multiplexing (MUX) scheme using an AWG for the frequency interleaved DWDM RoF system. In the experiment, 25-GHz separated 2-channel optical DSB signals modulated by a 60-GHz mm-wave carrying a 156 Mbps data are optically multiplexed. After transmission over 25-km standard single mode fiber (SMF) and DEMUX, we observe no noticeable power penalty in the received data. Moreover, the proposed MUX scheme allows us to enhance the modulation index of the multiplexed RoF signals, which results in improvement of the receiver sensitivity.

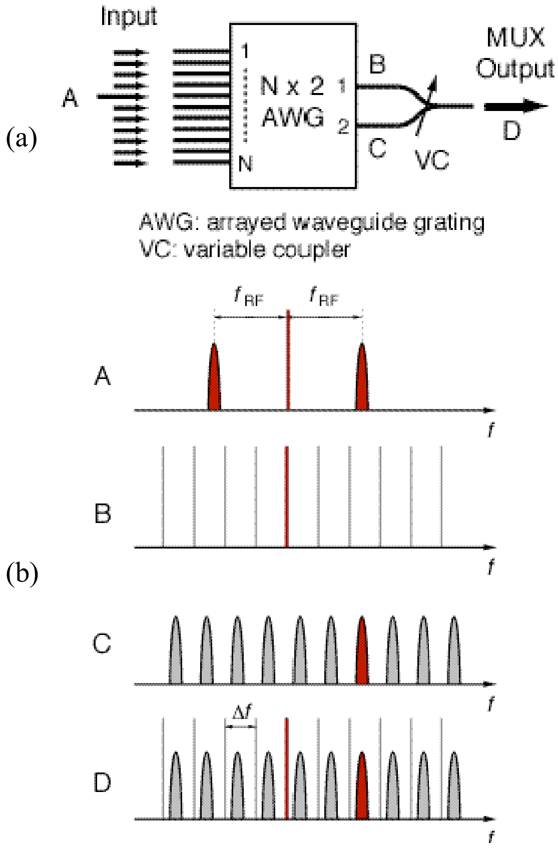


Fig. 1 (a) Configuration of the proposed multiplexing scheme. (b) Optical frequency spectra of A; one of the input channels, B and C; filtered carriers and single sidebands by N x 2 AWG. D; multiplexed output by variable coupler VC. f_{RF} and Δf are the microwave carrier frequency and the channel separation, respectively.

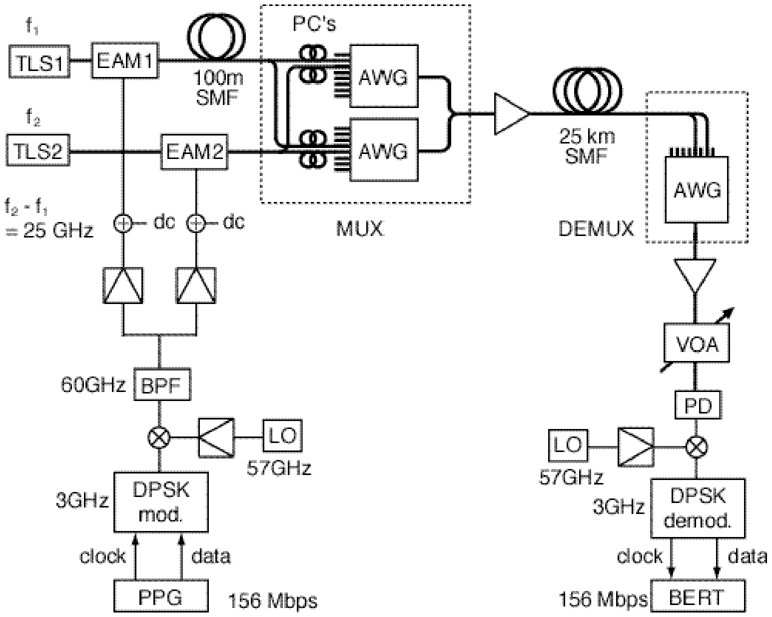
Principle of operation

Fig. 1 (a) shows the configuration of the proposed MUX scheme which consists of an AWG with N input and 2 output waveguides (N x 2 AWG), where N is the total channel number of RoF signals, and an optical variable coupler (VC). The AWG is designed to filter the carrier and one of the sidebands of each input channel to the output waveguides, respectively. This can be done by properly adjusting the position and the separation of the input and output waveguides at the interfaces between the channel waveguides and slab waveguide regions. The filtered carriers and sidebands shown in B and C of Fig. 1 (b) are then combined by the VC. The modulation indices of the multiplexed RoF signals can be simultaneously controlled simply by changing the coupling ratio of the coupler. As can be seen from the spectra of the input RoF signal and the multiplexed output shown in A and D of Fig. 1 (b), the proposed scheme operates not only as a frequency interleaved DWDM multiplexer but also as SSB filters for RoF signals of whole channels.

Experiment

Fig. 2 shows experimental setup. Two CW lights from tunable laser sources (TLS1 and TLS2) whose optical frequencies are depicted by f_1 and f_2 are independently intensity modulated by means of two electro-absorption modulators (EAM1 and EAM2) driven by a 60-GHz (= f_{RF}) mm-wave signal carrying a 156-Mbps differential phase shift keying (DPSK) data of channels 1 and 2 to generate two-channel optical DSB RoF signals. The channel spacing $f_2 - f_1$ was set to be 25 GHz (= Δf). A 100-m long SMF is used after EAM1 in order to decrease the correlation between the data. Since the proposed N x 2 AWG is not available, we used two N x 1 AWG's with 25-GHz channel spacing and combined in parallel for the MUX operation. Each AWG is tuned so that the carrier and one of the sidebands of each input channel are filtered out to the output waveguides, respectively. In the experiment, we used a 3-dB coupler for combining carriers and sidebands instead of variable coupler. The multiplexed RoF signals are transmitted over 25-km long SMF. For DEMUX, we used the same AWG as used in the MUX although the ideal channel separation of the AWG was 60 GHz (= f_{RF}). The demultiplexed RoF signal is detected by a high-speed 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 PD.

Figs. 3 show the optical spectra of (a) RoF signals of channels 1 and 2 before MUX, (b) multiplexed signals, and (c) demultiplexed signal (channel 1), respectively. As seen in Fig. 3 (b), the



TLS: tunable laser source, EAM: electro-absorption modulator, PC: polarization controller, SMF: standard single-mode fiber, AWG: arrayed waveguide grating (25 GHz spacing), VOA: variable optical attenuator, PD: photo diode

Fig. 2 Experimental setup.

carriers and the lower sidebands of channel 1 and 2 are filtered. The undesired sidebands were suppressed by > 40 dB. After the DEMUX, the carrier and the sideband of the undesired channel were suppressed by 29 and 18 dB of the desired carrier and sideband, respectively. Note that the suppression ratio after DEMUX should be improved if properly designed AWG is used for DEMUX.

In the BER measurement, two polarization controllers (PC's) for desired channel in MUX shown in Fig. 2 were adjusted to minimize BER. The other two PC's, which were for the undesired channel, were adjusted to maximize BER in order to evaluate the worst case. These ensure that the BER, where the influence of the interchannel interference is maximized, is measured. Fig. 4 shows the measured BER of channel 1 versus the received optical power. ○ indicates back-to-back BER when only the desired channel was modulated and the undesired TLS (TLS2) was turned off. × also indicates back-to-back BER but when both channels were optically modulated. □ indicates the BER after 25-km SMF transmission when both channels were modulated. In each case, no BER floor (> 10^{-9}) was observed. No noticeable power penalty was observed even after the SMF transmission. We obtained nearly the same results for channel 2.

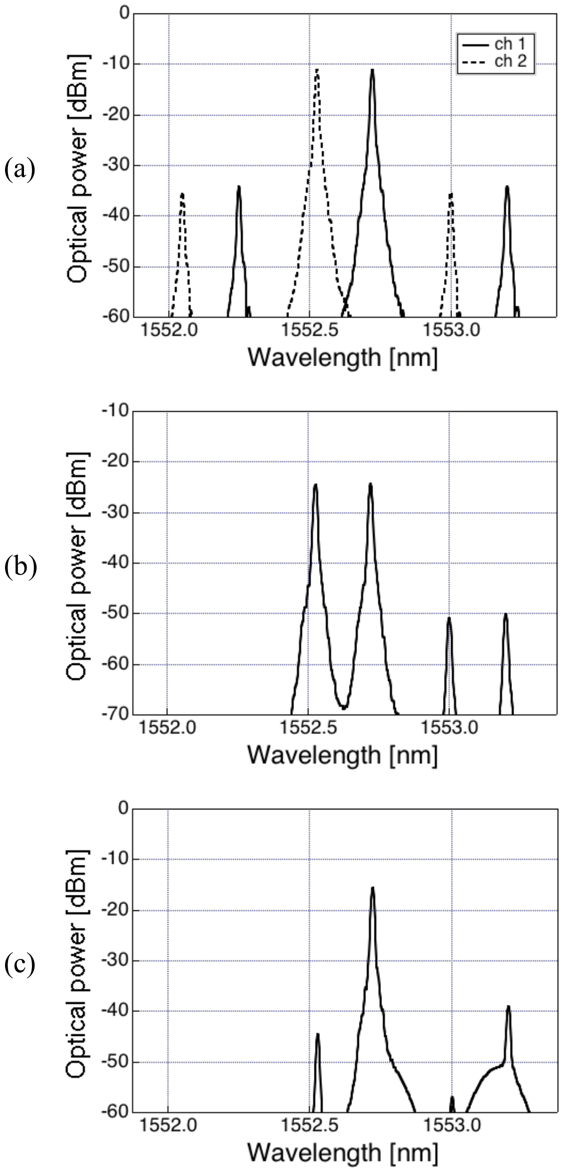


Fig. 3 Optical spectra of (a) RoF signals of channel 1 and 2 before MUX, (b) multiplexed signals, and (c) demultiplexed signal (channel 1).

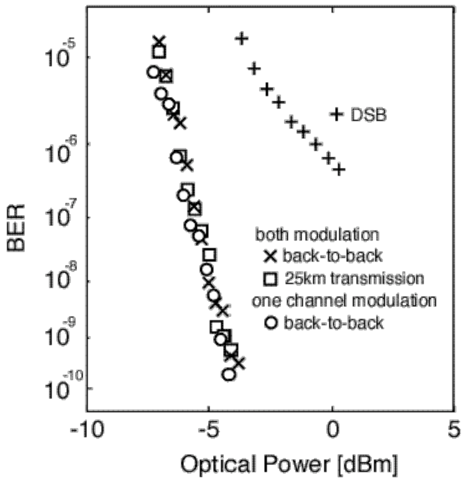


Fig. 4 Measured BER of channel 1 versus the received optical power.

In order to estimate the effectiveness of SSB filtering of the MUX, we made another BER measurement when only one channel is transmitted over the 25 km SMF. In this measurement, MUX and DEMUX were replaced by optical attenuators whose losses were equivalent to those of MUX and DEMUX. The result is also indicated in Fig. 4 depicted by DSB (+). BER < 10^{-7} couldn't be obtained because of signal fading due to chromatic dispersion of the SMF.

In order to enhance the modulation indices of RoF signals, we inserted a variable optical attenuator at the output of AWG for carriers in MUX (not shown in Fig. 2). Optical spectrum after DEMUX when the carrier to sideband ratio (CSR) was adjusted to 10 dB by the variable optical attenuator is shown in Fig. 5 (a). The CSR without the variable optical attenuator was 23 dB as shown in Fig. 3 (c). The receiver sensitivity, which was defined as the received optical power when BER = 10^{-9}, was measured as a function of the CSR. Fig. 5 (b) shows the result. The receiver sensitivity was improved by 6 dB when CSR was 10 dB. The modulation index of the optical SSB signal should be maximized when CSR is 0 dB. In the experiment, however, when CSR was < 10 dB, the receiver sensitivity was degraded. We believe this is due to degradation of signal-to-noise ratio of the received RoF signal. Theoretical analysis is currently being conducted.

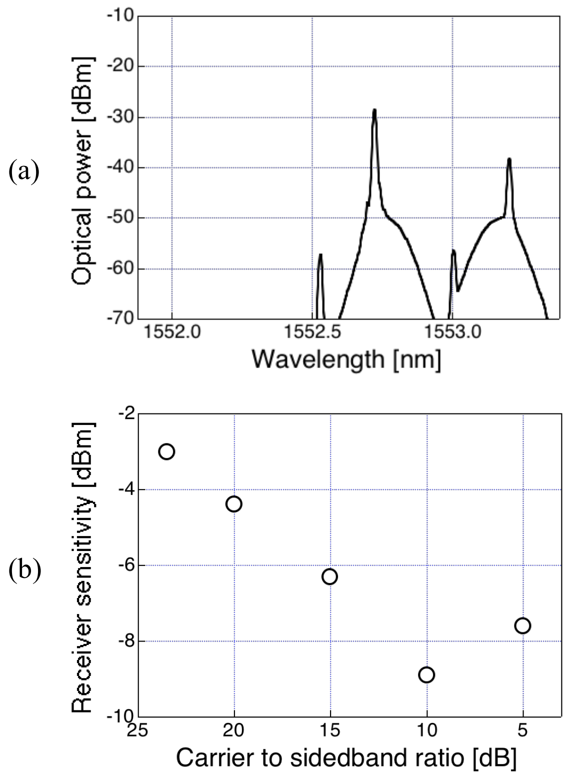


Fig. 5 Improvement of receiver sensitivity by increasing the modulation index of RoF signal. (a) Optical spectrum after DEMUX when the carrier to sideband ratio was adjusted to 10 dB. (b) Receiver sensitivity versus carrier to sideband ratio.

Conclusion

We have proposed and successfully demonstrated multiplexing of 25-GHz separated 60-GHz band RoF signals by optical frequency interleaving using an AWG. No noticeable power penalty was observed due to 25-km SMF transmission and interchannel interference. The receiver sensitivity was improved by 6 dB by increasing the modulation index of the RoF signal.

Acknowledgement

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