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WDM MM-WAVE-BAND RADIO-ON-FIBER SYSTEM USING SINGLE SUPERCONTINUUM LIGHT SOURCE IN COOPERATION WITH PHOTONIC UP-CONVERSION

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***Abstract* - We propose to use a supercontinuum light source for WDM millimeter-wave-band radio-on-fiber (ROF) systems. 2-channel WDM 60-GHz-band ROF signals are generated and transmitted over 25-km standard single mode fiber using a photonic up-conversion technique.**

I. INTRODUCTION

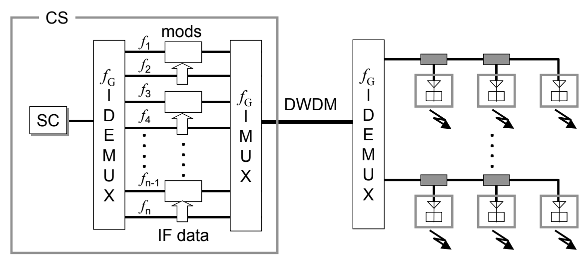
For future millimeter-wave-band (mm-wave-band) ROF systems, it is important to apply dense wavelength division multiplexing (DWDM) to support a large number of base stations (BSs) connected to a central station (CS) [1]-[3]. However, in accommodating a huge number of wavelength channels, the cost and the complexity as well as the system reliability inherent to the transmitters using individual light sources will become a serious problem. Although a mode-locked laser diode (MLLD) is an option for the multi-wavelength light source, we have shown that only a few modes were practically available for the data transmission in the WDM ROF system [4].

A supercontinuum (SC) light source [5]-[6], where the spectral range of an optical frequency comb generated by a seed pulsed laser is broadened by means of optical nonlinearities of a properly designed fiber, has been energetically developed to realize low cost DWDM transmission systems. In the DWDM system with an SC light source, the continuous-wave light sources for all the channels are replaced by a single SC light source in conjunction with a wavelength demultiplexer. Very recently, 50-GHz spaced optical carriers on the ITU grid over a seamless spectral range from 1425 to 1675 nm was reported [7]. However, it has not been clearly understood whether the SC light source is applicable to WDM ROF systems.

In this paper, we propose, for the first time to our knowledge, WDM mm-wave-band ROF system using a single SC light source for the multi-wavelength light source. The frequency interval of the SC comb for WDM systems reported so far ranges in microwave and millimeter wave regions (between 5 GHz and 50 GHz). Therefore, the photonic up-conversion technique will be preferably employed, where the beat signal is generated with square-law photo-detection of two SC modes, the one modulated by an IF signal and another unmodulated. In the experiment, we demonstrate the generation of 125-GHz spaced 2-channel WDM 60-GHz-band ROF signals using a SC light source and a photonic up-conversion. We also demonstrate the transmission over 25-km standard single mode fiber (SMF) in order to qualify the SC light source for the WDM mm-wave ROF systems.

II. WDM MM-WAVE-BAND ROF SYSTEM USING SINGLE SC LIGHT SOURCE IN COOPERATION WITH PHOTONIC UP-CONVERSION

Fig. 1 illustrates the proposed WDM mm-wave-band ROF system using a single SC light source. The SC light source generates a broadband frequency comb with the spacing of f_G. Individual SC mode, whose frequency is denoted by f_1, f_2, f_3, …, f_n is extracted by a demultiplexer (DEMUX). In the figure, we employ the photonic up-conversion technique where the optical modes at f_{2i+1} (i: integer number) are modulated by IF data independently. The modulated signals and the remaining unmodulated SC modes at f_{2i} both for the whole channels are mixed by a multiplexer (MUX) and transmitted together to



CS: central station, mods: optical modulators, BSs: base stations, SC: supercontinuum light source (mode spacing: f_G)

Fig.1 A WDM mm-wave-band ROF system using a single SC light source for the multi-wavelength light source.

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remote BSs. The modulation format for the optical modulators could be any one of optical double sideband (DSB), DSB suppressed carrier (DSB-SC), single sideband (SSB) with optical carrier or SSB-SC. To accommodate a large number of BSs by exploiting the full potential of the broadband SC light source, frequency-interleaving technique [8]-[11] can be applied. In that case, the whole SC modes are modulated independently. The modulation format should be either DSB or SSB having an optical carrier in order to share the optical carriers with neighboring WDM channels.

Here, the photonic up-conversion performs the frequency conversion from IF- to RF-band through an optical link by taking advantage of the stability among the SC modes. Therefore, no mm-wave-band components are required in the CS. Since only two SC modes are used for the photodetection in our photonic up-conversion technique, degradation of system performance due to the chromatic fiber-dispersion effect does not become serious in principle. This feature will be shown in the experiment described in the following sections.

III. EXPERIMENT

A. SC Light Source

The SC light source used in the experiment is NTT Electronics, NIESP-SC-001, which is driven by a seed MLLD with the repetition rate of 25 GHz (= f_G). The SC modes are ranging from 1534 nm to 1599 nm with +/– 5 dB flatness, except for several nanometers around the seed laser wavelength (1565 nm). The output power of the individual SC mode around 1552 nm and the total output power of the SC light source is – 8 dBm and + 22 dBm, respectively. We have confirmed that the measured phase noise of 50-GHz beat signals generated from two 50-GHz-spaced SC modes (e. g. – 96.1 dBc/Hz at 10 kHz offset and 1552 nm wavelength) is superior to a typical signal generator. The detailed results will be reported in another paper.

B. Single Channel Experiment

First, we carried out single channel experiment in order to verify the feasibility of the SC light source for the ROF systems. Fig. 2 shows the experimental setup. The SC output is launched to an arrayed waveguide grating (AWG) DEMUX with 25-GHz channel spacing via a 3-nm optical bandpass filter (OBPF). The OBPF is used for eliminating the crosstalk due to the periodical characteristic of the AWG with the free spectral range of 3.22 THz (= 25 nm at 1550 nm). The SC modes are extracted to the AWG output ports, where the undesired modes are suppressed by less than – 30 dB around 1552 nm. Two SC modes with 50 GHz (= 2 f_G) spacing are used for the ROF signal generation. One of the extracted SC modes is modulated by an IF-band signal f_{IF} (= 10 GHz) carrying a 156-Mb/s DPSK data with a $LiNbO_3$ Mach-Zehnder modulator (LNM). 60-GHz-band ROF signal, therefore, can be generated after combining the signal and the remaining SC mode as an optical carrier by a directional coupler as shown in the inset (c) of Fig. 2. The generated ROF signal is transmitted over 25-km SMF to a remote receiver. Another OBPF with the 3-dB bandwidth of 0.5 nm is used to reduce out-of-band ASE noise. The received ROF signal is detected with a photo detector (PD). The desired RF signal (f_{RF} = 2f_G + f_{IF} = 60 GHz) is filtered by an electrical BPF. Finally, the bit error rate (BER) of the decoded 156-Mb/s data is measured as a function of the received optical power, which is measured at the input of the PD.

Figs. 3 (a) and (b) show the measured optical spectra of the ROF signal after the directional coupler, where the SC mode is modulated in DSB and DSB-SC formats, respectively. Frequency separation between the carrier and the desired sideband is 60 GHz as

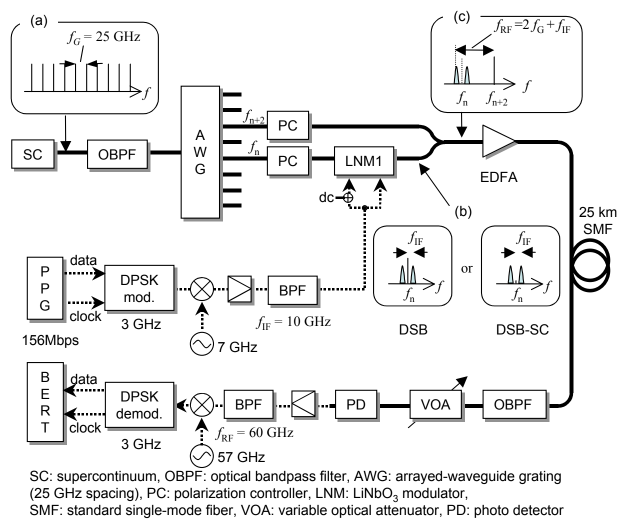

Fig. 2 Experimental setup for single channel transmission.

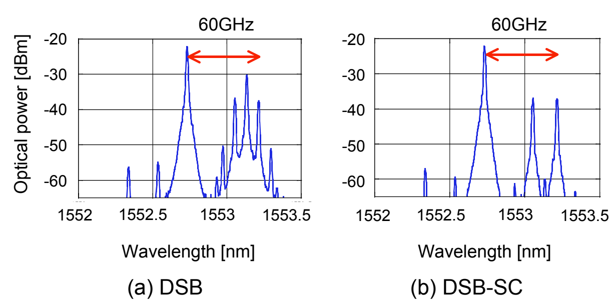

Fig. 3 Measured optical spectra of the single-channel ROF signal when the modulation formats are (a) DSB and (b) DSB-SC, respectively.

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indicated by arrows. Fig. 4 shows the measured BERs versus the received optical power. The back-to-back BERs for both cases were also measured for comparison. In each case, no BER floor (> 10^{-10}) was observed. The power penalty due to the transmission of 25-km SMF was less than 0.2 dB. This is because that the undesired sideband of the ROF signal is effectively suppressed by the AWG, which can be seen in Fig. 3. Therefore, the proposed system is, in principle, free from the signal-fading problem due to the chromatic dispersion of the transmission fiber as described in the previous section. The back-to-back receiver sensitivity, which is defined by the received optical power when BER = 10^{-9}, for DSB and DSB-SC are measured to be – 8.5 dBm and – 9.3 dBm, respectively. The difference in the receiver sensitivity is mainly due to the total optical power difference between the two modulation formats, which can be calculated to be 0.6 dB from Fig. 3. We also confirmed error-free operation (BER < 10^{-9}) in a single-channel transmission at 1546 nm and 1559 nm, which correspond to the first port and the last port of the AWG used in the experiment.

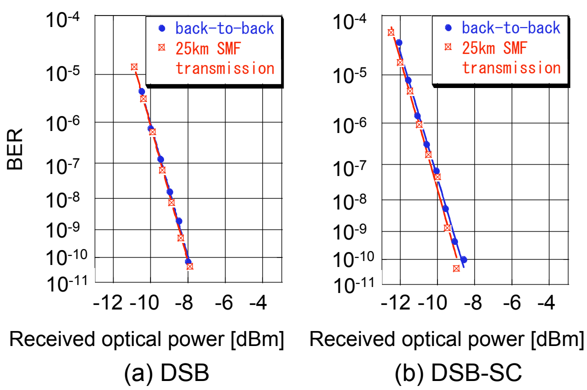

Fig. 4. Measured BERs as a function of the received optical power.

C. 2-ch WDM Experiment

Next, we carried out 125-GHz spaced 2-ch WDM ROF transmission experiment. Fig. 5 shows the experimental setup. Four SC modes at f_n, f_{n+2}, f_{n+5} and f_{n+7}, extracted to the corresponding AWG output ports, are used as shown in Fig. 5, where the frequency separation between f_j and f_{j+2} (j = n, n+5) is 50 GHz. The channel spacing which corresponds to f_{n+5} – f_n is 125 GHz. The SC modes at f_n and f_{n+5} are independently intensity-modulated by IF-band signals with two LNMs (LNM1 and LNM2), respectively. In the WDM experiment, the SC modes are modulated only in DSB format. Two pieces of 100-m SMF inserted in the paths of channel 2 are used for decreasing the correlation between the data. The 60-GHz-band WDM ROF signals can be generated after combining the two modulated signals and the two optical carriers by another AWG as shown in the inset of Fig. 5.

The generated WDM ROF signals are transmitted together over 25-km SMF to a remote receiver. We used a four-cavity-type OBPF with the 3-dB bandwidth of 0.6 nm in order to select either channel of the WDM ROF signals. The received ROF signal is detected with a PD.

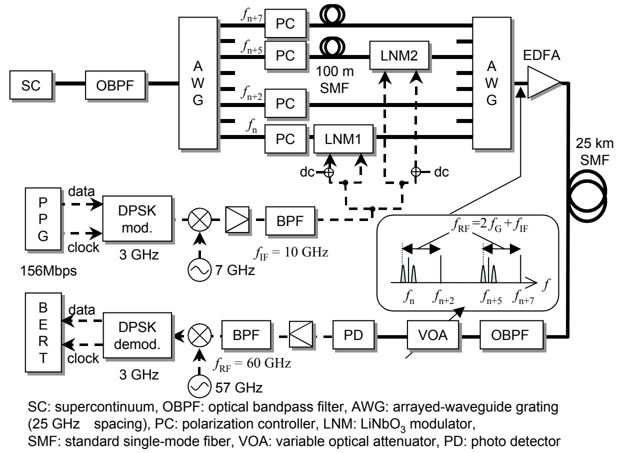

Fig. 5 Experimental setup for WDM transmission.

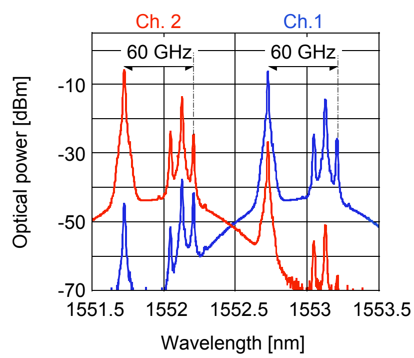

Fig. 6 Measured optical spectra of the two ROF signals (channels 1 and 2) before PD.

Fig. 6 shows the measured optical spectra of the two ROF signals (channels 1 and 2) after the 0.6-nm OBPF. As can be seen in the figure, the undesired channel is effectively suppressed by the OBPF. One can estimate the 60-GHz signal level of the undesired channel to be suppressed by about – 60 dB of the desired signal level. Fig. 7 shows the measured BERs of channels 1 and 2 versus the received optical power. The error-free operation for both channels is simultaneously achieved after the 25-km SMF transmission. The improved receiver sensitivity compared to the results obtained in the previous single

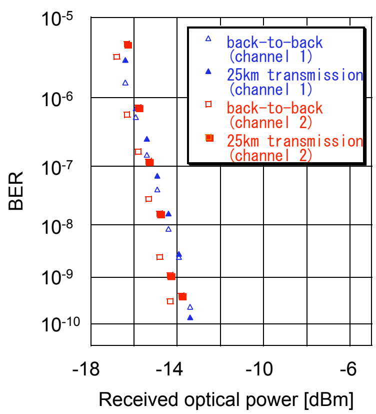

Fig. 7. Measured BERs as a function of the received optical power.

channel experiment is due to the modified high-sensitivity receiver. The small difference in the optical receiver sensitivity for channels 1 and 2 may be attributed to the loss difference of the two channels between the AWGs. The power penalties due to the fiber transmission are less than 0.4 dB for both channels. This is once again because the undesired sidebands of the ROF signals are effectively suppressed by the AWGs, which can be seen in Fig. 6. From these results, we can conclude that the SC light source is a potential multi-wavelength light source for WDM mm-wave-band ROF systems.

IV. CONCLUSIONS

We have proposed to use a SC light source for WDM millimeter-wave-band ROF systems for the first time to our knowledge. We carried out single-channel and 2-ch WDM ROF signal generations using a SC light source with the comb-frequency spacing of 25 GHz. 60-GHz-band ROF signals were generated from 50-GHz spaced SC modes with photonic up-conversion, where one of the SC modes were modulated by 10-GHz IF signal. Error-free operations were successfully confirmed after 25-km SMF transmission.

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