Low Cost 60 GHz Radio over Fiber System Based on Gain-Switched Laser

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Abstract

A radio over fiber (RoF) transmission system based on a gain-switched laser as an optical comb source is proposed and demonstrated. 10-Gb/s 16 quadrature amplitude modulation (16QAM) signal generation and transmission over 25-km standard single-mode fiber (SSMF) is experimentally demonstrated using a 60-GHz carrier. The phase noise on the 60-GHz carrier induced by the time delay between the selected two optical tones from the comb source is explored, and its effect on system performance is investigated.

1.Introduction

Broadband 60 GHz millimetre wave (mmW) transmission has attracted great interests, which meets the demands of high-speed data wireless communication, thanks to the unlicensed spectral band of 7 GHz that is available in most countries [1]. However, due to the enormous propagation loss at 60 GHz, the typical transmission distance for 60-GHz signals range from a few meters to tens of meters. To extend the area of coverage, radio over fiber (RoF) technology has attracted much attention in the last decade for the optical generation and transmission of RF signals [2]. In particular, broadband 60-GHz signal generation can be centralized in order to simplify the design of mmW base stations (BSs).

Coherent heterodyning is a common technique to generate low phase noise mmW by beating two coherent optical tones [3, 4]. One of the conventional approaches for coherent optical tone (comb) generation is based on mode-locked lasers (MLLs) [3]. However it suffers from cavity complexity and does not offer free spectral range (FSR) tunability. Moreover, the optical linewidth of the individual comb lines can be relatively large and the imperfect phase coherence between two optical tones may induce significant phase noise on the generated mmW signal. Wavelength tunable comb generation by use of external optical modulators is another approach where the FSR and the central wavelength of the comb can both be varied [4]. However, the large insertion loss of the modulator, coupled with the modulation efficiency and the instability induced by bias drift can prove prohibitive. Previously, we reported on the use of gain-switching to generate an optical comb [6]. Such a comb source enables simple and cost efficient generation of lightwaves with precisely controlled channel spacing, and offers high phase coherence between the optical tones. From the signal generation perspective for RoF systems, there are a number of approaches that have been investigated in the past few years [7, 8]. As in [7], the digital signal with an advanced modulation format can be firstly electrically up-converted to an intermediate frequency (IF) band, and then to the 60 GHz band with the photonic approach. However, the electrical up-conversion of the digital signal to the IF band increases the complexity of the system. Another technique based on wavelength division multiplexing (WDM) can be used to simplify the transmitter of the RoF system [8]. The two optical tones generated with a two-tone generator are separated by an optical arrayed waveguide grating. One optical tone is then modulated with the IQ baseband signal. The digital modulated optical tone is re-combined with the other unmodulated optical tone. 16-quadrature amplitude modulation (QAM) signal at 92.5 GHz is generated by the beating between the two tones. However, the 16QAM modulation is based on a polarization coherent synthesis method, which requires two dual parallel Mach-Zehnder modulators (DP-MZM) and increases the complexity of the system.

In this paper, we propose a 60-GHz RoF system based on a gain-switched laser comb source. Generation and transmission of a 10-Gb/s 16QAM 60-GHz signal over 25 km standard single-mode fiber (SSMF) using 5 MHz linewidth comb source are experimentally demonstrated. In the system, the phase noise induced by the time delay between the two optical tones can be significantly reduced by compensating the optical paths difference in the two WDM channels. Therefore the proposed system can be operated with low-cost gain-switched laser comb source.

2. Principle of RoF System Using Gain-Switched Laser

Fig. 1 shows the proposed RoF system based on a gain-switched laser. The laser is gain-switched by a RF signal (LO) to generate the comb source. A WDM demultiplexer (DEMUX) is employed to select different optical tones to

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different optical channels. For two optical channels with the frequency spacing of 60 GHz, one channel is set for digital signal modulation using an optical IQ-modulator and the other channel is set to be unmodulated. The optical channels are recombined and amplified by an Erbium doped fiber amplifier (EDFA) before being sent to another DEMUX after the SSMF, which is employed to separate different optical signals. Each pair of digital modulated and un-modulated optical signals with the frequency spacing of 60 GHz are combined and sent to a BS. In each BS, the 60-GHz data signal is generated by the beating of the two optical tones at the PD. The mmW signal is then amplified and sent to the end-user by using a pair of horn antennas. The FSR of comb source can be set to 12.5 GHz to meet the conventional dense WDM (DWDM) channel. Thus 62.5-GHz mmW signals will be delivered from the CS to multiple BSs.

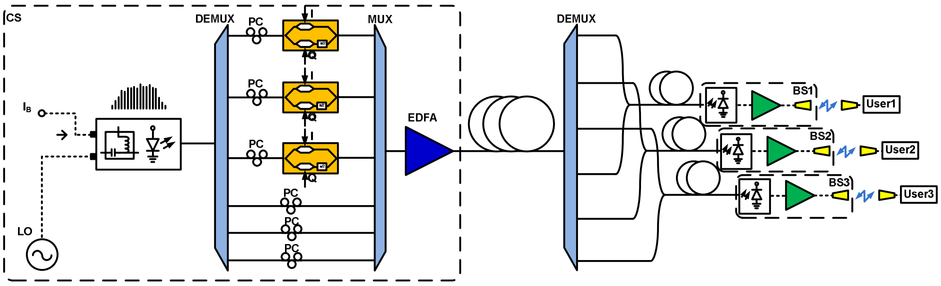


Fig. 1 Principle of 60 GHz RoF system based on gain-switched laser.

3. Experimental Investigation of RoF System Using Gain-Switched Laser

In this section, a point-to-point RoF transmission is experimentally demonstrated. Fig. 2 shows the experimental setup. In the central station (CS), the distributed feedback (DFB) (slave) laser is injection-locked by a Y-branch master laser with the linewidth of 5 MHz, in order to prove that the system can be operated with low-cost gain-switched laser with high linewidth. The wavelength of the master laser is tuned to match the slave laser and the linewidth of the comb lines depends on the linewidth of the master laser. The slave laser is then gain-switched with the aid of a 24 dBm, 20 GHz, RF signal (LO1). Here the FSR is set to 20 GHz in order to get better neighboring mode rejection by the optical filters in the system. A wavelength selective switch (WSS) is used to select two comb lines with a spectral spacing of 60 GHz at the transmitter. The two optical comb lines are amplified by EDFA1 and are then separated into two individual paths by passing them through a 100-GHz DEMUX. The optical comb line selected by channel 1 (Ch1) is sent to the DP-MZM. Both MZMa and MZMb are biased at the null point to achieve a high modulation depth. The I and Q signals are generated by an arbitrary waveform generator (AWG) with a sampling rate at 10 GS/s, passed through a low-pass filter (LPF), and are then amplified by two RF amplifiers (AMP2 and AMP3) and applied to the MZMa and MZMb respectively. In channel 2 (Ch2) of the DEMUX, the targeted optical comb line is not selected with complete rejection of the adjacent optical line, since the bandwidth of the DEMUX employed in the experimental setup is too large (over 80 GHz). A tunable optical filter is thus employed to reject the undesired comb lines. A variable optical attenuator (VOA) is used to equalize the optical power in the two channels in order to optimize the optical beating efficiency. A polarization controller (PC) is employed to match the polarizations of the optical signals in the two channels. The two optical signals are recombined and amplified by EDFA2, and an optical band pass filter (OBPF) is used to reject the out of band amplified spontaneous emission (ASE). The optical signal is then sent to the BS via either a 25-km SSMF or a section of back-to-back (BTB) fiber.

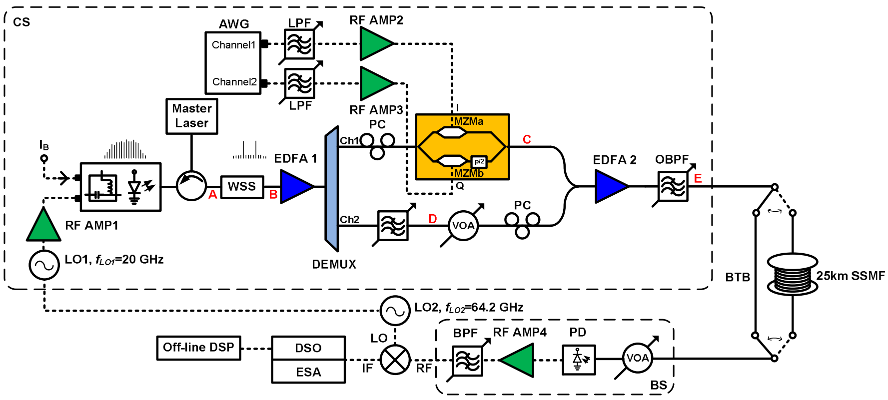
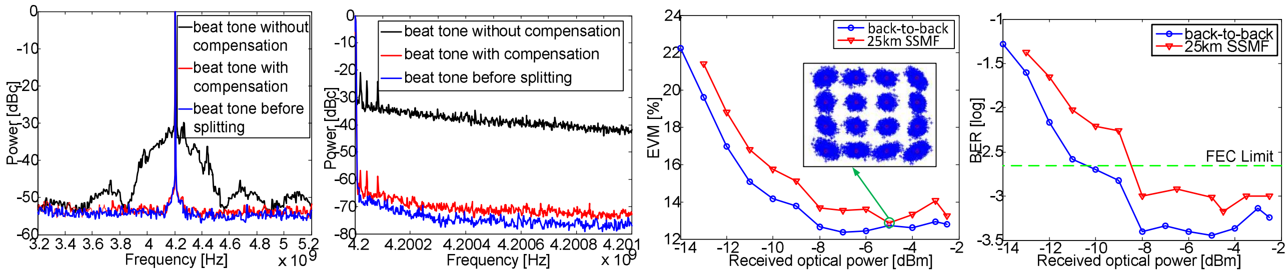


Fig. 2. Experimental setup.

In the BS, the optical signal is sent to the PD via a VOA. The 60-GHz signal is then generated by the beating of the two optical comb lines at the PD and amplified by a RF amplifier (AMP4). A 57.5 GHz to 62.5 GHz RF band pass filter (BPF) is employed to reject additive noise. To demodulate the 60-GHz signal it is initially down-converted to an IF using an external mixer which is driven by a LO signal (LO2) at 64.2 GHz. Thus the 60-GHz signal is down-converted to 4.2 GHz. The down-converted signal is sent to the digital storage oscilloscope (DSO) with the sampling rate at 20 GS/s to achieve analog to digital conversion. Off-line DSP including down-conversion, time synchronization and initial phase compensation, is applied to demodulate the IF signal. The error vector magnitude (EVM) and bit error rate (BER) are calculated in the DSP process.

The spectrum of the unmodulated 60-GHz signal without any particular optical length compensation is shown as the black curves in Fig. 3 (a) and (b). The phase noise of the 60-GHz signal induced by the time delay between the two optical tones is considerable. An optical length compensation can be implemented based on a theoretical analysis presented in [9]. Optical length compensation was then implemented in the 60-GHz RoF system employing the comb source with large phase noise on each line. Red curve and blue curve in Fig. 3 (a) and (b) show the spectra of the un-modulated 60-GHz signal with the optical length compensation, and before the splitting (point B in Fig. 2). It can be seen that the phase noise of the 60-GHz signal is substantially reduced by employing the optical length compensation.



(a) **(b)** **(c)** **(d)**

Fig. 3. Spectrum, EVM and BER of the down-converted 60 GHz signal. (a) and (b) spectrum of the down-converted un-modulated 60-GHz signal, (c) EVM of the 2.5-Gbaud 16QAM signal as a function of received optical power, (d) BER of the 2.5-Gbaud 16QAM signal as a function of received optical power.

Fig. 3 (c) and (d) show the EVM and the BER for the transmission of a 16QAM 60-GHz signal at 2.5 Gbaud as a function of the received optical power. Here 7% of the signal is reserved for forward error correction (FEC), thus the effective data rate is 9.3 Gb/s, with an FEC limit of 2.2×10^{-3} in terms of BER [10]. The receiver sensitivity is defined as the lowest optical power to ensure a BER lower than the FEC limit. EVM's as low as 12.87% were achieved in this case with an optical power receiver sensitivity of -8 dBm. The power penalty induced by the 25 km SSMF is less than 1 dB.

4. Discussion

As it is shown in Fig. 3, the optical receiver sensitivity for the transmission of a 10-Gbps 16QAM 60-GHz signal (P_{BS}) is -8 dBm. In the optical link shown as Fig. 1, the insertion loss for a 25-km optical link (IL_{Link}), and the loss of the WDM DEMUX (IL_{DEMUX}) are 5 dB and 6 dB respectively. As a result, the emission power of two 60 GHz spaced WDM channels (P_{Tx}) in the CS for error free transmission is

$$P_{Tx} = P_{BS} + IL_{Link} + IL_{DEMUX} = 3 \text{ dBm} \tag{1}$$

Considering that the output power of an EDFA should be maintained to around 10 dBm to ensure no nonlinearity in the fiber link [11], the proposed 60-GHz RoF system can support 5 users. It can be expected that the use of an additional low-noise amplifier (LNA) in the electrical receiver (after the 60-GHz mixer) can significantly improve the sensitivity of the receiver, so that the proposed RoF system can support more users.

The time delay between the two optical tones can break the phase correlation of the two tones and thus result in phase noise on the 60-GHz signal which could degrade the system performance. Optical fiber chromatic dispersion will induce a time delay between two different optical wavelengths. For 25-km SSMF transmission, the delay between two optical tones with 60-GHz frequency offset is

$$\tau_d = \frac{DL\Delta\lambda}{2} \tag{2}$$

where D is the dispersion parameter which is 17 ps/km•nm, L is the length of the fiber which is 25 km, $\Delta\lambda$ is the wavelength offset of the two optical tones which is 0.48 nm. Thus the delay between the two optical tones is 0.204 ns, which corresponds to 4.2 cm of optical fiber. For low-cost 60-GHz RoF system using high linewidth comb source, which have low coherence times, 0.204 ns time delay can potentially result in significant phase noise to the 60-GHz signal. The time delay caused by chromatic dispersion can be compensated using a variable optical delay line between two optical channels of the WDM DEMUX.

5. Conclusion

In this paper, a 60-GHz RoF system based on a gain-switched laser comb source is experimentally investigated. Compared with other RoF proposals, the proposed system has low complexity in the transmitter part and can support higher order modulation formats. Since the two optical tones are split in different optical paths to modulate one line, the time delay between the two optical paths may induce phase noise on the generated 60-GHz signal. The RoF system based on a gain-switched laser injection-locked by a Y branch laser (5-MHz linewidth) have been investigated. 2.5-Gbaud 16QAM 60 GHz transmission over 25 km SSMF targeting optical access networks has been demonstrated. The phase noise impact induced by the time delay between the two optical tones (caused by either chromatic dispersion or different optical length between WDM channels at the transmitter) can be substantially reduced with the outlined optical length compensation technique. For the experimented system, 5 users could be supported if the optical power applied to the 25-km SSMF link is 10 dBm. More users can be supported if electrical receivers with higher sensitivities are employed.

6. Acknowledgments

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