Band-divided receiver for optical wideband signal

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A new receiver structure that alleviates the required sampling rate of analogue-to-digital converters for optical transmission is presented. The structure divides the received wideband signal into a number of narrowband signals with no guard band. A prototype of the band-divided receiver, which processes a 6 GHz-bandwidth received signal, is developed and experimentally evaluated in a real-time OFDM receiver. It is shown that a single-polarisation 12 Gbit/s OFDM signal can be demodulated using a 1.5 GS/s ADC.

Introduction: Over 100 Gbit/s/ch high-speed optical transmission is essential to meet the demands posed by the oncoming traffic expansion. In recent years, much attention has been focused on coherent receivers using digital signal processing. Some papers have reported coherent high-speed transmission with orthogonal frequency division multiplexing (OFDM) [1–3]. In addition, real-time implementation of coherent receivers has become one of the hot topics in the optical communication field [4, 5]. Such a coherent receiver can realise high frequency utilisation. However, a very high-speed analogue-to-digital converter (ADC) is needed to convert the wideband analogue signal into a digital signal. The cost of this ADC greatly increases the cost of the receiver.

A multi-band receiver that can handle an optical OFDM signal has been proposed to solve this problem [6]. The OFDM signal is transmitted to the receiver as a number of sub-bands, and each transmitted signal is demodulated in a different FPGA. This receiver can alleviate the required sampling rate of an ADC because each OFDM signal is narrowband. However, frequency utilisation is poor because there is a guard band between each sub-band.

In this Letter, we propose a new receiver structure that enables wideband OFDM signal transmission with no guard band. The proposed receiver divides the received wideband signal into a number of narrowband signals by analogue bandpass filtering, and the narrowband signals are demodulated independently. This proposal makes it possible to realise low-cost receivers for optical wideband signals with no loss in frequency utilisation efficiency.

Band-divided receiver prototype: A band-divided receiver is an attractive way to reduce the required sampling rate of an ADC that does not need a guard band. Fig. 1 shows its concept. The receiver is a heterodyne receiver structure to enable analogue bandpass filtering in the electric domain. The electric intermediate frequency (IF) signal, which is converted from received optical signal, is input to the receiver. In the receiver, the signal is divided into a number of narrowband signals by analogue bandpass filters (BPFs), the passbands of which cover the entire bandwidth with no omission. Each narrowband signal is converted into an in-phase/quadrature (I/Q) baseband (BB) signal. I/Q BB signals are output, and each signal is converted into a digital signal by a low-speed ADC. The digitised signal is input to a DSP, and the desired signal, which passes through the passband of the analogue BPF, is extracted by a digital BPF and demodulated. In this way, each narrowband desired signal can be obtained by a two-step BPF, i.e. analogue and digital BPF.

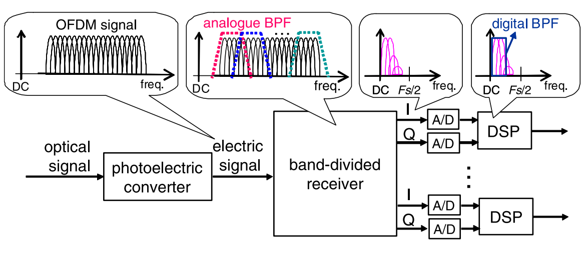

Fig. 1 *Concept of band-divided receiver*

We designed and fabricated a band-divided receiver prototype that can process a 6 GHz-bandwidth received IF signal centred at 10.5 GHz, assuming the use of a commercially available analogue BPF and ADC, which operates at 1.5 GS/s. The prototype comprises eight analogue BPF-quadrature demodulator pairs. Each BPF is a fifth-order Chebyshev filter. The designed receiver divides the 6 GHz-bandwidth IF signal into eight 750 MHz signals by eight BPFs, each of which has a unique 750 MHz passband. Each 750 MHz-bandwidth signal is downconverted into a BB I/Q signal pair at the quadrature demodulator. Consequently, the receiver outputs eight pairs of 375 MHz-bandwidth I/Q signals. Considering the skirt-characteristic of the analogue BPF and sampling rate Fs, double oversampling is needed to lower the interference generated by aliasing. Since the analogue BPF attenuates 15 dB over $Fs/2$ as shown in Fig. 2, double oversampling is needed to achieve SIR (signal-to-interference ratio) $>$ 20 dB, which satisfies the assumption of QPSK transmission. This indicates that the 1.5 GS/s ADC is suitable for the band-divided receiver prototype.

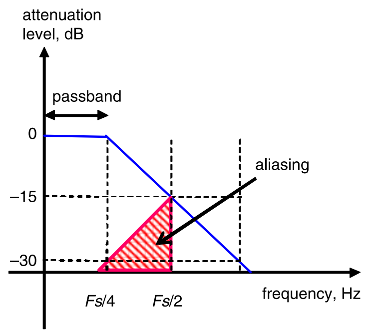

Fig. 2 *Attenuation level of analogue BPF*

Experimental setup and results: Fig. 3 shows the experimental setup. The OFDM signal data, which was generated by an arbitrary waveform generator (AWG) at 9 GS/s, was mapped with differential QPSK (DQPSK), assigned to 128 subcarriers, and transformed into a time domain signal by inverse fast Fourier transformation (IFFT) with a size of 192. The signal was injected into a quadrature modulator and converted into an IF signal by mixing it with a 10.5 GHz local signal. The IF signal was converted into an optical signal by a Mach-Zehnder modulator (MZM). The optical carrier was 1552.12 nm. One of the sidebands was removed by an optical BPF (OBPF), and the resulting signal was transmitted to the receiver. The received signal, which passed through an OBPF and a polarisation controller (PC), was mixed with the same laser as used in the transmitter and converted into an electric signal by a balanced photodetector (BPD). The signal was fed to the band-divided receiver, and then one of the output I/Q signal pairs was fed to an FPGA board. In the FPGA board, the I/Q signal pair was sampled by an 8-bit resolution 1.5 GS/s ADC. The digitised signal was window synchronised, and the signal was transformed into a frequency domain signal by FFT with a size of 32, i.e. oversampled FFT. The signal assigned to the 16 middle subcarriers was extracted and detected.

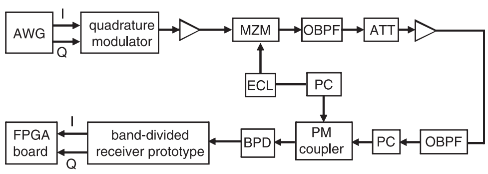

Fig. 3 *Experimental setup*

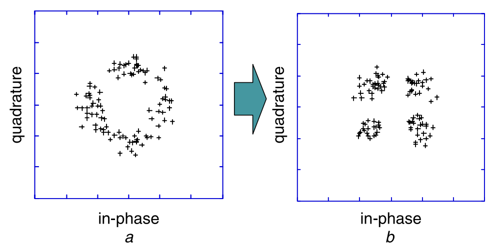

Fig. 4 *Constellation before and after delay detection*

a Before delay detection
b After delay detection

Fig. 4 shows the constellation before and after delay detection. Although the constellation moved owing to the phase noise of the laser, the received signals could be detected because of delay detection. We verified that the OFDM signals were demodulated without any bit errors.

Conclusion: We propose a band-divided receiver that alleviates the required ADC sampling rate with no guard band. Experiments show that a single-polarisation 12 Gbit/s OFDM signal can be demodulated by the band-divided receiver prototype using 1.5 GS/s ADCs. The results verified that our prototype, which divides the wideband signal into eight narrowband signals, can reduce the required ADC sampling rate by 75% with no loss in frequency utilisation efficiency.

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One or more of the Figures in this Letter are available in colour online.

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