Simultaneous transmission of 2.5-Gb/s baseband and 5.8-GHz-band radio frequency signals on a single wavelength using optical diplexer and mixed-signal multiplexer

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Abstract. Simultaneous transmission of 2.5-Gb/s baseband and 5.8-GHz-band radio frequency (RF) signals on a single wavelength via a fiber link is successfully demonstrated using the optical diplexer and the newly designed novel baseband/RF mixed-signal multiplexer (MUX) with no mixer. The bit error rate (BER) $<10^{-12}$ of the baseband signal is maintained when the RF input power is less than −14 dBm after 10-km-long distance transmission. The maximum carrier-to-noise ratio (CNR) of the RF signal is measured as 23 dB with no additional amplifier. The measured insertion loss for the RF signal of the mixed-signal MUX is 1.2 dB at 5.8 GHz, and the isolations between the two bands are about 20 dB for the baseband and 30 dB for the RF band, respectively.
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Subject terms: fiber optic application; multiplexing; simultaneous transmission; system-on-package (SOP).

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1 Introduction

Passive optical network (PON) technologies realize sophisticated and economical optical access networks for providing broadband services and also provide multiple services such as cable television (CATV), telephony, as well as high-speed Internet access. In addition, there will be growing demand for broadband wireless access such as wireless Internet and mobile communications. In particular, the hybrid broadband optical system and optical feeder architecture for wireline and wireless access nodes are promising;[1] these can transmit baseband and radio frequency (RF) signals simultaneously via a preinstalled optical fiber. Therefore, the future networks providing multiple services will have to deal with the optical, RF, and digital signals in a unique platform. This has led to 3-D packaging approaches, referred to as system-on-package (SOP).[2] There are two ways to transmit multiband signals simultaneously. One is the wavelength division multiplexing method,[3,4] which can multiplex multiple optical carrier signals to carry different signal bands. Another is the mixed-signal multiplexing method,[5,6] which can multiplex multiple RF signals and baseband data streams electrically. In the latter case, isolation between bands becomes very important, because baseband and RF signals are multiplexed in a single platform.

In this paper, we have proposed the architecture of a hybrid bidirectional optical subsystem, which can provide multiple services such as wireline Internet and wireless Internet or CATV on a single wavelength using an optical diplexer in fiber-to-the-home (FTTH) networks, and we have designed a novel baseband/RF mixed-signal multiplexer (MUX) to implement the cost-effective and high-performance simultaneous transmission subsystem for fiber-optic applications.

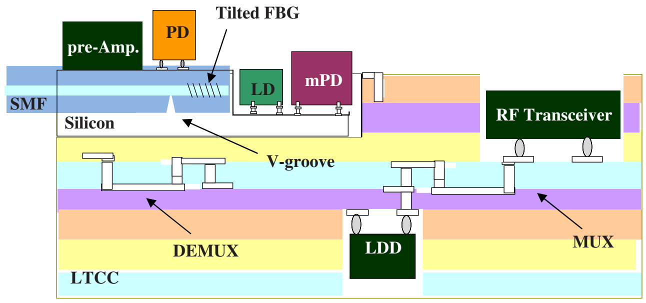

Fig. 1 The architecture of the proposed hybrid bidirectional optical subsystem.

2 Architecture of Proposed Hybrid Bidirectional Optical Subsystem

Figure 1 shows one of the candidate architectures of the proposed hybrid bidirectional optical subsystem using the fiber in-line–type optical diplexer module based on the silicon optical bench and the newly developed mixed-signal MUX based on low-temperature cofired ceramic (LTCC) substrate through hybrid integration. After the multigigabit baseband and RF signals are multiplexed by the mixed-signal MUX in the transmitter part, the multiplexed signals are converted to optical signals by the laser diode (LD) and transmitted on a single wavelength over a fiber link. In the receiver part, the core mode of the optical signal is coupled into the cladding mode by the tilted fiber Bragg grating

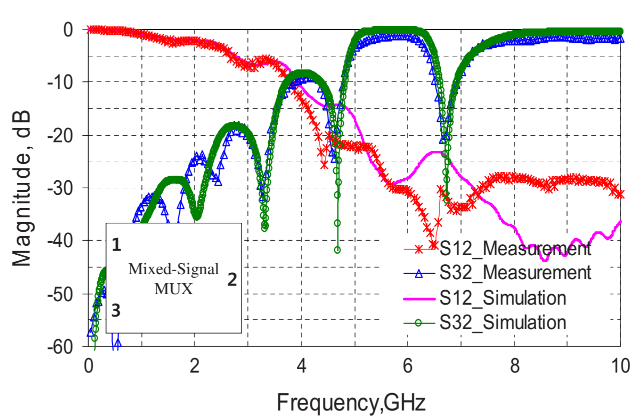

Fig. 2 The S-parameters of the mixed-signal MUX.

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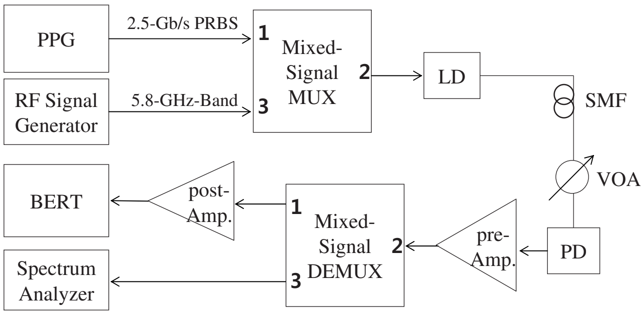

Fig. 3 Experimental setup for simultaneous transmission of baseband and RF signals.

(FBG) and then is out-coupled to photo detector (PD) by the V-grooved cladding. We previously reported the fiber in-line–type bidirectional optical subassembly using the tilted TFG and V-grooved cladding.[7–9] The multiplexed optical signals are received and converted to electrical signals and then amplified by the preamplifier. The amplified multiplexed signals are demultiplexed by the demultiplexer (DEMUX) and distributed to the target services, respectively. In this proposed architecture based on the 3-D packaging approaches, we can easily achieve excellent isolation properties not only between preamplifier and laser diode driver (LDD) but also between baseband and RF band using the cavity structure of the highly resistive LTCC substrate.

3 Design of Mixed-Signal Multiplexer

The conventional power divider is not suitable for optical application due to the 3-dB power loss and poor isolation properties. A coupled line directional coupler has excellent directivity and isolation properties as long as the impedance matching condition is satisfied. But this type of coupler has a weak coupling property. To achieve the tight coupling requires lines that are too close together to be practical. In order to overcome the weak coupling of the conventional coupled line coupler, we have newly designed the mixed-signal MUX. We modify the conventional single-section coupled line coupler using a coplanar waveguide resonator.[10] The mixed-signal MUX comprises the modified coupled line coupler for the RF signals and the step impedance 9th-order Bessel low-pass filter (LPF) for the broadband baseband signal. The MUX is optimized for a gigabit-Ethernet signal up to 2.5 Gb/s and a 5.8-GHz-band IEEE802.11a wireless local area network (WLAN) signal with no mixer, and it is also used as DEMUX.

4 Experimental Setup and Results

The S-parameters of the mixed-signal MUX are depicted in Fig. 2. Star symbols represent the measurement results of S-parameters, and the solid line represents the simulation results. The CST Microwave Studio is used for optimizing the design parameters. The simulation results are in good agreement with the measurement results. Low insertion loss for RF signal and excellent isolation characteristics between two bands is experimentally obtained. The measured insertion loss for RF signal is 1.2 dB at 5.8 GHz. The isolations between the two bands are about 20 dB for the baseband and 30 dB for the RF band, respectively. The step impedance Bessel LPF not only has a good group delay response but also reflects the RF signals. And the implemented MUX itself has the properties of a bandpass filter (BPF) that can transmit the entire band of IEEE802.11a WLAN signal.

Figure 3 shows the experimental setup for transmitting a baseband signal and an RF signal simultaneously using the optical diplexer module and the mixed-signal MUX. To investigate the performance of the proposed simultaneous transmission subsystem, we transmit 2.5-Gb/s non-return-to-zero (NRZ) signals of pseudorandom binary sequence (PRBS) $2^{23}-1$ and 5.8-GHz-band WLAN signals simulta-

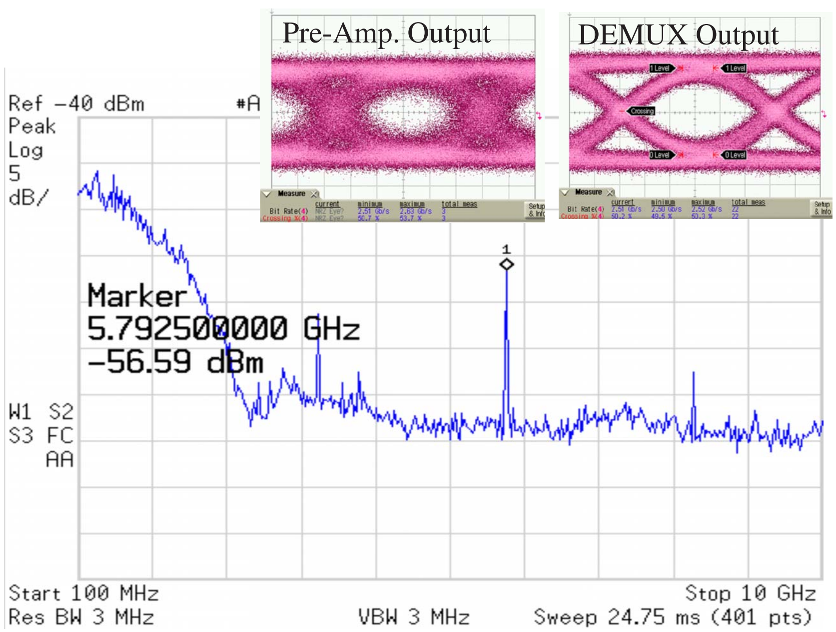

Fig. 4 Measurement results of the frequency spectrum and the eye diagrams.

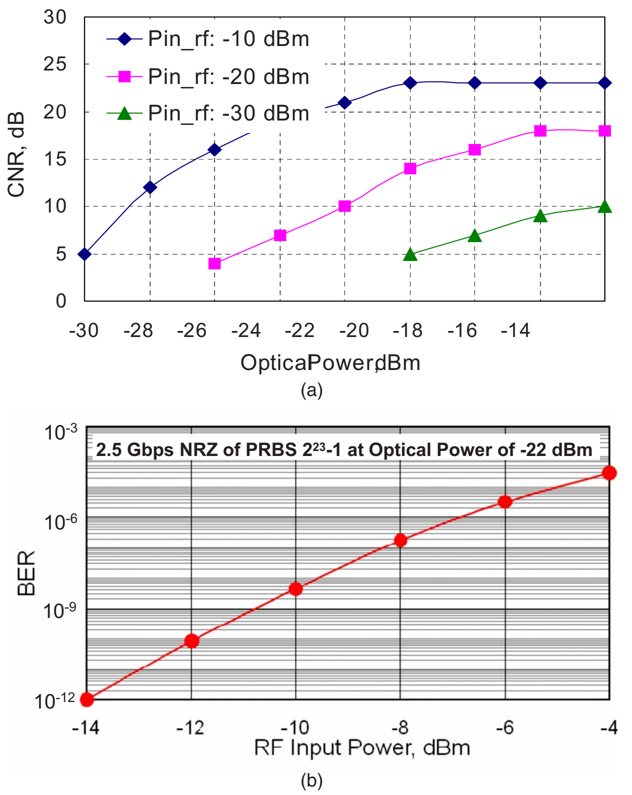

Fig. 5 Measurement results of (a) CNR for the RF signal and (b) BER for the baseband signal.

neously on a wavelength of 1550 nm over a 10-km-long single-mode fiber (SMF). Figure 4 shows the measured frequency spectrums of multiplexed signals at the output of the preamplifier and the eye diagrams at the output of the preamplifier and the baseband output of DEMUX. As a result, there are two harmonics at 3.3 GHz and 8.3 GHz due to the intermodulation between the two bands. However, the eye diagram of the baseband output of DEMUX is much clearer than that of the preamplifier output due to the proper elimination of the RF signal, as shown in the inset in Fig. 4. Figure 5(a) shows the carrier-to-noise ratio (CNR) characteristics at the RF output port of the DEMUX versus the average optical power with different RF input power from −30 dBm to −10 dBm, and Fig. 5(b) shows the bit error rate (BER) characteristics of the demultiplexed baseband signals of 2.5 Gb/s at the optical power of −22 dBm versus RF input power. We observe that the CNR of the demultiplexed RF signal is saturated at the specific power or greater, as shown in Fig. 4(c), and can be further improved with a low-noise amplifier (LNA). The maximum CNR at the RF input power of −10 dBm is 23 dB when the average optical power is more than −20 dBm. The BER $<10^{-12}$ of the baseband signal is maintained when the RF input power is less than −14 dBm.

5 Conclusions

We have designed a novel baseband/RF mixed-signal MUX to implement a cost-effective and high-performance simultaneous transmission subsystem for fiber-optic applications. We experimentally obtain excellent properties for the newly designed mixed-signal MUX, and we successfully transmit 2.5-Gb/s baseband and 5.8-GHz-band RF signals simultaneously on a single wavelength via a fiber link using the optical diplexer and the mixed-signal MUX and confirm that there is no severe power penalty. The newly developed mixed-signal MUX is easily integrated on any kind of platform and can also provide multiple services with an optical diplexer module. The proposed hybrid bidirectional optical subsystem is suitable for bidirectional simultaneous transmission of more than two bands, and the cost reduction through simplification in design, process, and module integration using the SOP approaches can be realized.

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