# Demonstration of CSRZ Signal Generator Using Single-Stage Mach-Zehnder Modulator and Wideband CMOS Signal Mixer

Sae-Kyoung Kang, Dong-Soo Lee, Hyunwoo Cho, and Jesoo Ko

**In this paper, we demonstrate an electrically band-limited carrier-suppressed return-to-zero (EB-CSRZ) signal generator operating up to a 10 Gbps data rate comprising a single-stage Mach-Zehnder modulator and a wideband signal mixer. The wideband signal mixer comprises inverter stages, a mixing stage, and a gain amplifier. It is implemented by using a 0.13 µm CMOS technology. Its transmission response shows a frequency range from DC to 6.4 GHz, and the isolation response between data and clock signals is about 21 dB at 6.4 GHz. Experimental results show optical spectral narrowing due to incorporating an electrical band-limiting filter and some waveform distortion due to bandwidth limitation by the filter. At 10 Gbps transmission, the chromatic dispersion tolerance of the EB-CSRZ signal is better than that of NRZ-modulated signal in single-mode fiber.**

**Keywords: CSRZ, modulation format, optical transmitter, CMOS integrated circuit.**

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## I. Introduction

The rising importance of communication in today's information-oriented society has led to an explosive increase in demand for high-capacity communication systems. To satisfy the network service providers' need to offer low-cost high-quality service, many high-speed transmission technologies based on installed optical fibers have been studied [1]-[5].

Advanced modulation formats other than conventional non-return-to-zero (NRZ) signals have been studied to mitigate the signal degradation caused by fiber nonlinear effects and dispersion [4]-[7]. Among these formats, carrier-suppressed return-to-zero (CSRZ) format has been especially highlighted because of its optical phase reversion from 0 to $\pi$ in successive bits, resulting in reduced intersymbol interference. However, the conventional CSRZ signal generator suffers from relatively high cost due to two cascaded modulators, which are still the most expensive components in optical transmitters [6].

Recently, a cost-effective electrically band-limited CSRZ (EB-CSRZ) signal generator has been proposed using a single Mach-Zehnder (MZ) modulator in conjunction with an electrical mixer and a band-limiting low-pass filter (LPF) [7]. In this paper, we demonstrate the proposed CSRZ signal generator employing a new wideband CMOS signal mixer fabricated by using 0.13 µm CMOS technology.

## II. CSRZ Signal Generator Using a Wideband Signal Mixer

### 1. CSRZ Signal Generation Scheme

The configuration and operation principle for the EB-CSRZ

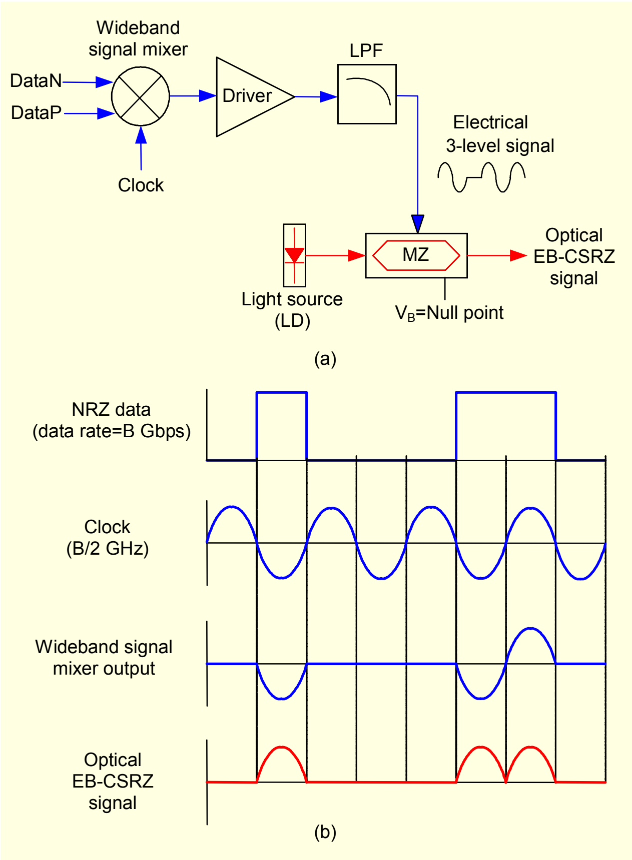


Fig. 1. EB-CSRZ signal generator using a single-stage modulator and a wideband signal mixer: (a) configuration and (b) operation principle.

signal generation is shown in Fig. 1. It consists of a wideband signal mixer, a driver amplifier, an LPF, a single-stage chirp-free MZ modulator, and a continuous wave (CW) light source as shown in Fig. 1(a).

From Fig. 1(b), the electrical NRZ data (data rate = B Gbps) is mixed with a B/2 GHz clock signal by employing a wideband CMOS signal mixer. The mixed output signal has 3 levels (-1, 0, and +1) and is sufficiently amplified by the driver amplifier. This signal passes through the LPF for electrical bandwidth limitation. After passing the LPF, the band-limited signal is transmitted to the MZ modulator, which is biased at the transmission null point to modulate a CW light from a laser source. Through the above procedure, the optical EB-CSRZ signal with an LPF is generated with a narrower spectrum than that of a CSRZ signal without an LPF [7], [8].

This spectrum narrowing is achieved by the band-limiting effect due to the LPF. However the EB-CSRZ signal is significantly distorted as the bandwidth of the LPF becomes narrower. Hence, the cut-off frequency of the LPF should be carefully selected considering a trade-off between optical spectral width and signal distortion. In this work, the LPF bandwidth of 0.6B (6 GHz at B=10 Gbps) was used because it was reported to give optimum performance of increased dispersion tolerance without significant signal distortion for high-speed communication systems [7].

## 2. Wideband Signal Mixer Design

In the proposed configuration, the wideband signal mixer is a key component because it removes “pulse carver” generating CSRZ pulses in a conventional CSRZ transmitter [6], [7]. The circuit diagram of the fabricated CMOS signal mixer is shown in Fig. 2. It consists of inverter stages, a mixing stage, an input-output-connected inverter, and a gain amplifier. DataN (or dataP)-to-output and clock-to-output transmission responses of the wideband signal mixer should provide a wide bandwidth from DC to 7 GHz for a 10 Gbps data rate to obtain a clear three-level signal. The isolation response between dataN (or dataP) and the clock is less than 20 dB at -3 dB bandwidth.

The key design consideration is how to handle the flow of the clock signal. This flow is controlled by turning on and off a switching device corresponding to the NRZ data signal. As shown in Fig. 2, the inverters, that is, the input stages of the NRZ data and the clock signal, have the same transistor size and the same signal path length to the input gate from each pad in order to alleviate phase difference between the two signals. As a core block mixes the two signals the mixing stage is implemented by employing a transmission gate. The input-output-connected inverter operates as a load of the input stage (inverter 2 in Fig. 2) for the clock signal and an input bias stage for the gain amplifier (AMP in Fig. 2). The gain amplifier uses no output buffer and is designed to drive 50 Ω loads. The tail current is set to 9.15 mA.

Figure 3 shows the simulated results of the wideband CMOS signal mixer with 10 Gbps NRZ data and 5 GHz clock.

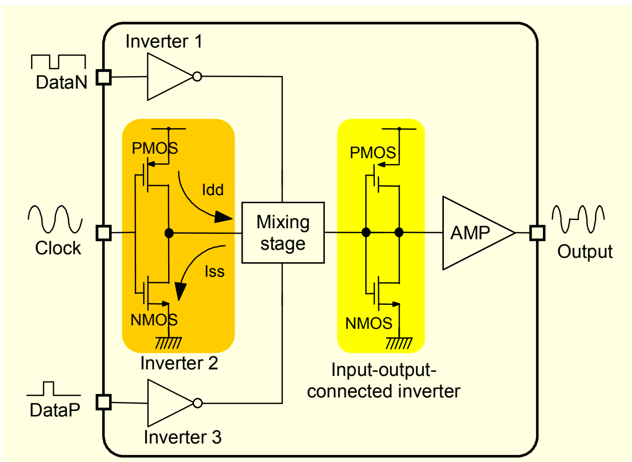


Fig. 2. Simplified circuit diagram of the wideband CMOS signal mixer.

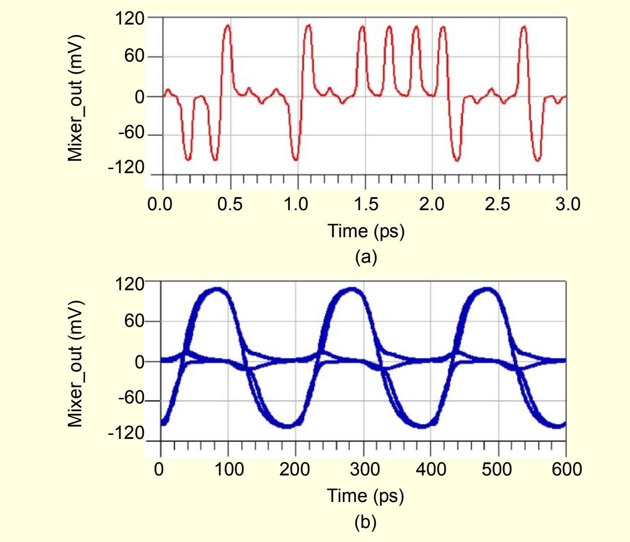


Fig. 3. Simulated results of the wideband CMOS signal mixer: (a) three-level signal generation and (b) eye diagram.

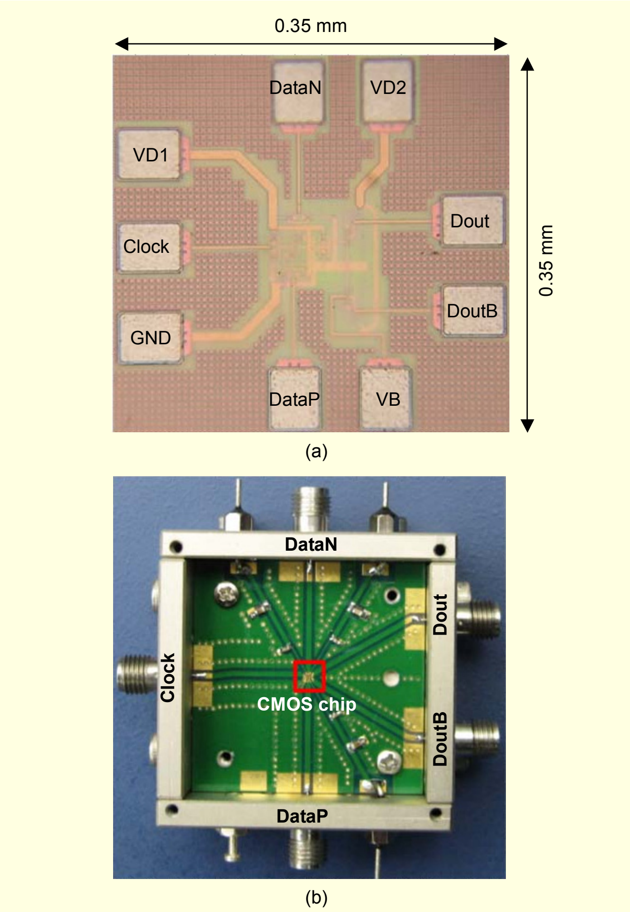


Fig. 4. (a) Chip microphotograph and (b) module photograph of the wideband CMOS signal mixer.

Figures 3(a) and (b) illustrate a three-level signal such as -108 mV, 0 V, and +108 mV, and the clearly open eye diagram

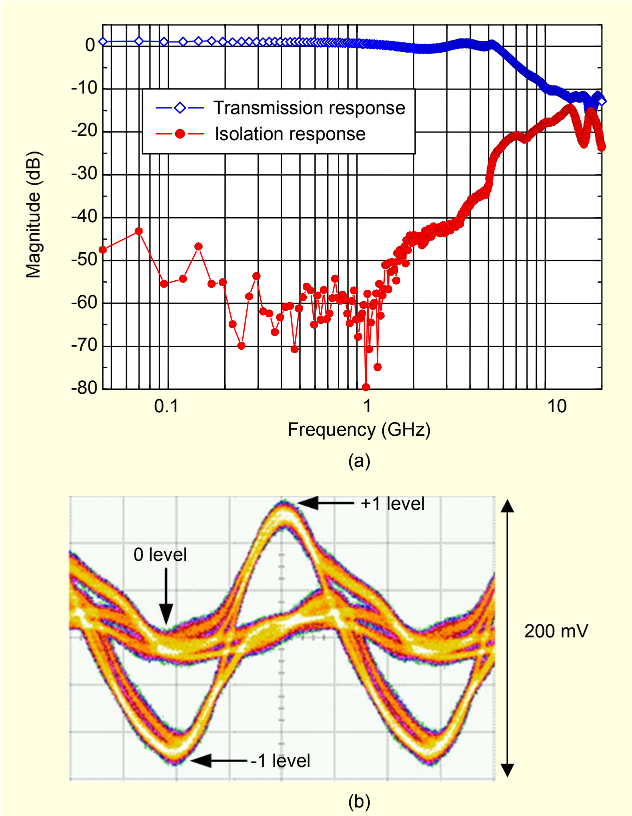


Fig. 5. Measured results of the wideband CMOS signal mixer: (a) frequency response and (b) eye diagram.

generated by the wideband signal mixer. The voltage fluctuation at the 0 level is about 24 $mV_{p\text{-}p}$ and results from switching between the clock and the NRZ data signals in the mixing stage.

The signal mixer was fabricated using 0.13 μm CMOS technology with seven-layer copper metallization and a two-poly process. The manufactured nMOS transistors have an $f_t$ of 100 GHz and $f_{max}$ of 50 GHz. The measured power dissipation of the signal mixer is about 15 mW at supply voltage of 1.5 V.

Figures 4(a) and (b) illustrate chip microphotograph and photograph of the packaged module for the wideband CMOS signal mixer. The module size is 3.5 cm×3.5 cm×2 cm, which includes the CMOS chip with an occupied area of 0.35 mm × 0.35 mm.

Figures 5(a) and (b) show the measured frequency response and eye diagram from the wideband CMOS signal mixer, respectively. As shown in Fig. 5(a), it has a -3 dB bandwidth of about 6.4 GHz transmission characteristic from the clock signal port to the output of the signal mixer through the mixing stage illustrated in Fig. 2. The NRZ data signal is isolated with about 21 dB at 6.4 GHz from the clock signal port. Figure 5(b) illustrates the measured non-filtered electrical three-level signal from the signal mixer at 10 Gbps and the output amplitude of about 200 mV. The measured eye diagram implies a waveform characteristic with the simulated eye diagram of the wideband signal mixer at 10 Gbps.

## III. Measurement of CSRZ Signal Generator Performance

The performance of the EB-CSRZ signal generator including the fabricated wideband CMOS signal mixer was demonstrated with the experimental setup shown in Fig. 6. Optical spectrum analysis and eye-diagram measurement were performed using the ANDO AQ6317 optical spectrum analyzer, Agilent 86100A digital oscilloscope, Agilent E4438C vector signal generator, and Anritsu MP1764A pulse pattern generator (PPG).

The EB-CSRZ signal generation with the fabricated CMOS signal mixer is as carried out as follows. First, the wideband signal mixer makes a clear three-level waveform with an amplitude of about 200 mV, when 10 Gbps NRZ data with PRBS $2^{31}$–1 pattern length and a clock signal of 5 GHz are applied. Then, the modulator driver sufficiently amplifies the output swing of the wideband signal mixer up to $2V_\pi$ (approximately 12 $V_{p\text{-}p}$ in this work) to drive the single-arm MZ intensity modulator. The 0.6B LPF (cut-off frequency = 6 GHz at 10 Gbps) is located between the modulator driver and the MZ modulator in this work. The MZ modulator is biased at the null point of the transfer-function curve, which corresponds to its minimum output optical power.

Figure 7 shows the measured optical spectra for CSRZ signal with and without 0.6B LPF for the EB-CSRZ signal generation procedure. The resolution in the optical spectrum analyzer was set to 0.01 nm. The optical carrier wavelength was 1551.957 nm (carrier frequency = 193.304 THz). The optical spectral width of the CSRZ signal with 0.6B LPF is narrower than that of CSRZ signal without the LPF, and the carrier component is suppressed in both cases. The CSRZ signal with 0.6B LPF shows spectral narrowing of about 40% at the modulation frequency of 15 GHz.

Figure 8 shows the measured eye diagrams from the CSRZ signal generator with and without 0.6B LPF at a 10 Gbps data rate. The eye diagram from the CSRZ signal with 0.6B LPF has some waveform distortion compared to the CSRZ signal without the 0.6B LPF.

The measured results shown in Figs. 7 and 8, demonstrate that the proposed CSRZ signal generator employing the newly fabricated wideband CMOS signal mixer creates a waveform of the optical CSRZ signal. Moreover, optical spectral narrowing of the CSRZ signal is achieved by the bandwidth limitation of the LPF. However, signal distortion due to overband limitation should be avoided by selecting the optimum cut-off frequency of the LPF considering a trade-off

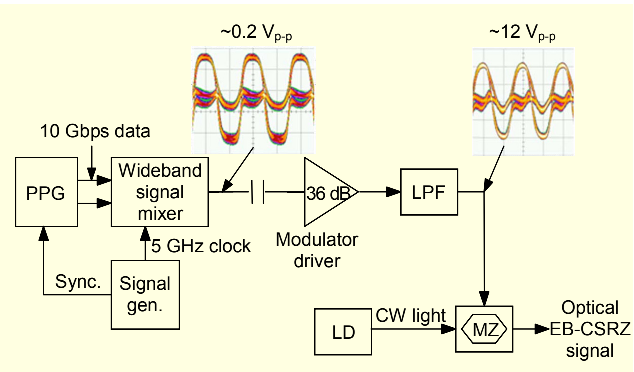


Fig. 6. Experimental setup for EB-CSRZ signal generation using the wideband CMOS signal mixer.

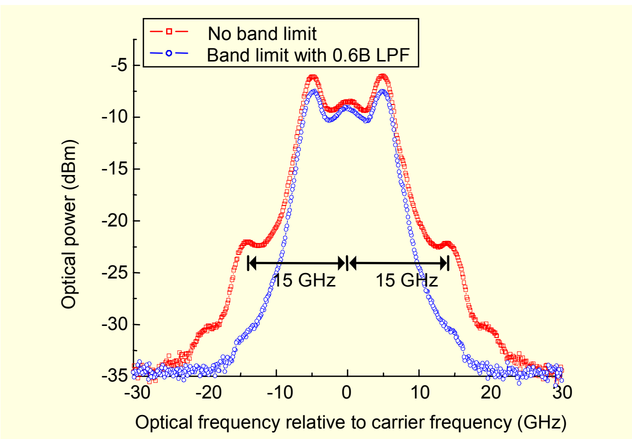


Fig. 7. Measured optical spectra of the optical CSRZ signal generator with and without 0.6B LPF.

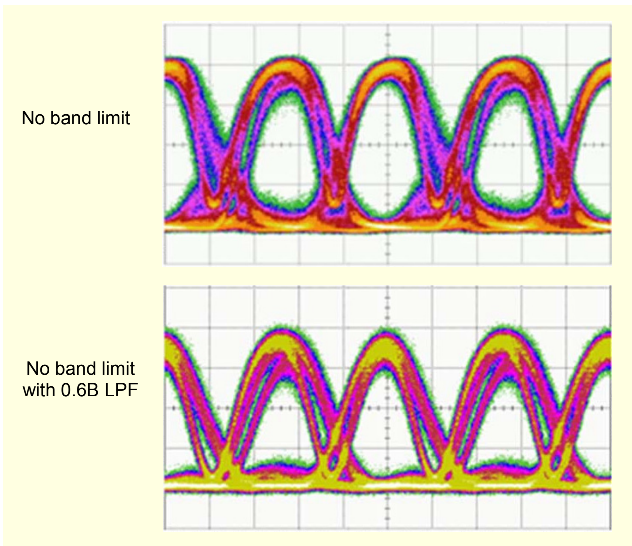


Fig. 8. Measurement eye diagram of the optical CSRZ signal generator with and without 0.6B LPF.

between optical spectrum width and signal distortion.

The dispersion tolerance of the band-limited CSRZ signal with 0.6B LPF in single-mode fiber as a transmission medium is demonstrated in the measurement eye diagram. The carrier wavelength of the optical signal was 1551.957 nm, and the chromatic dispersion of the used optical fiber was about 17 ps/nm/km at that wavelength. An optical amplifier was used to compensate fiber transmission loss (about 24 dB at 120 km transmission). Figures 9(a) and (b) show back-to-back eye diagrams after 120 km transmission through single-mode fiber for NRZ-modulated signal and electrically band-limited CSRZ signal at 10 Gbps. In the case of NRZ modulation, the signal waveform was collapsed by the fiber chromatic dispersion. On the other hand, the EB-CSRZ signal had a distorted signal waveform, but showed a clear region in the observed eye diagram after 120 km transmission. The dispersion tolerance of the EB-CSRZ modulation format with 0.6B LPF is superior to that of a NRZ modulation format.

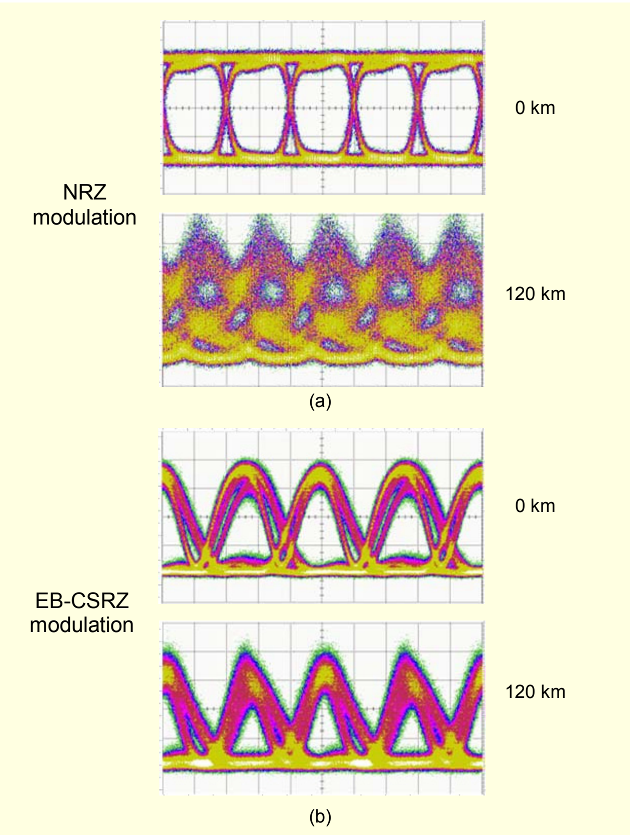


Fig. 9. Measured eye diagram before and after 120 km SMF transmission at 10 Gbps: (a) NRZ signal and (b) EB-CSRZ signal.

## IV. Conclusion

In this paper, we successfully demonstrated electrically band-limited CSRZ signal generation at data rates up to 10 Gbps using a single-stage Mach-Zehnder modulator and a newly designed wideband CMOS signal mixer. The signal mixer was fabricated using 0.13 µm CMOS technology. It operates from DC up to 6.4 GHz with power consumption of less than 15 mW. The dispersion-tolerance feature of CSRZ signal was confirmed experimentally through 120 km transmission. This successful experiment demonstrated the feasibility of implementing the EB-CSRZ modulation scheme and opens up an opportunity for low-cost, high-speed, and large-capacity communication systems.

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