# First Demonstration of Symmetric 10-Gb/s Access Networks Architecture based on Silicon Microring Single Sideband Modulation for Efficient Upstream Signal Re-modulation

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**Abstract:** We demonstrate an optical access network utilizing downstream silicon microring single-sideband modulation and upstream phase-remodulation of a centrally distributed carrier. Rayleigh-backscattering is suppressed by using the destructive port of the delay-interferometer demodulating the upstream signal.
**OCIS codes: (**060.2330) Fiber optics communications; (130.3120) Integrated optics devices

## Introduction:

New bandwidth-intensive services in optical access networks have driven the deployment of wavelength-division multiplexing (WDM) in passive optical networks (PON). Reducing the cost of WDM PON is a key challenge toward realizing broad deployment. In these network configurations, the employment of colorless optical network units (ONUs) enables the re-modulation of downstream signals for upstream transmission, thus reducing the overall cost and management of remote ONUs [1]. Single-sideband (SSB) modulation can provide a continuous wave (CW) carrier distributed from the central office for upstream remodulation [2] as well as reduce the dispersion influence on transmission of the optical millimeter-wave signal [3]. However, the generation methods of SSB modulation are typically complicated [4]. Compact, low-energy silicon microring modulators have been shown to be feasible for medium- and long-haul optical communications [5]. Their compatibility with existing complementary metal-oxide-semiconductor (CMOS) fabrication processes allows them to meet the stringent cost requirements of WDM PON. In this paper, we demonstrate an architecture based on SSB modulation using silicon microring modulators for downstream transmission and remodulation of the CW-like sideband for upstream transmission with mitigated Rayleigh backscattering influence.

## Working Principle and Device Characterization:

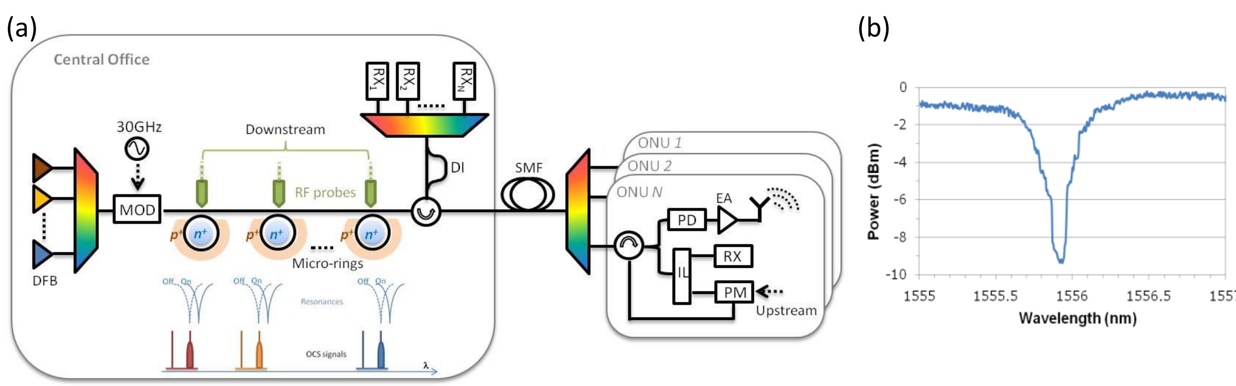


Fig. 1 (a) Architecture of wired and wireless networks using single sideband modulation with colorless ONU. Inset: conceptual diagram of single sideband modulation. (b) Spectrum of the microring in its passive state.

At the central office (Fig. 1a), CW carriers are first modulated with a Mach-Zehnder modulator (MOD). By tuning the DC bias of the MOD appropriately, double-sideband carrier suppressed optical modulation is achieved, with the output of the MOD having first-order sidebands. The MOD is followed by cascaded silicon microrings, each microring having its radius tuned to correspond to a particular CW carrier. To produce SSB modulation, one sideband of each generated double sideband signal is aligned with the resonance of microring (Fig. 1a inset), taking advantage of the microring's wavelength selectivity. The spacing of 60 GHz between sidebands ensures that there is no modulation crosstalk on the unmodulated sideband from the microring [6]. Power level and polarization optimization are not necessary between the modulated and unmodulated sidebands. The signals are sent from the central office to the ONUs through a single-mode fiber (SMF). At the ONU, a data-modulated mm-wave carrier is created for wireless service by heterodyne detection using a high-speed photodetector (PD). In parallel, an interleaver separates the two sidebands. The data carried by the modulated sideband is detected for downstream wired service while the CW-like unmodulated sideband is remodulated with differential-phase-shift keying (DPSK) for upstream transmission. At the central office, a delay-interferometer (DI) is used to demodulate the upstream DPSK signal. The notch-filter like destructive port of the DI considerably suppresses any Rayleigh-backscattering from the downstream signals.

The microring device used in this experiment, fabricated at the Cornell Nanofabrication Facility, has a 6-μm microring radius with waveguide dimensions of 450 nm x 260 nm. It was fabricated by patterning the SOI substrate using electron-beam lithography and reactive-ion etching, followed by doping using ion implantation. The spectrum of the microring is shown in Fig. 1b in its passive state.

**Experiment and Results:**

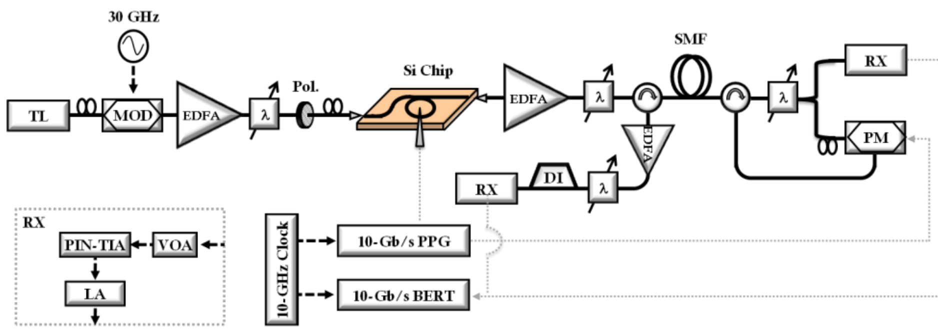


Fig. 2 Experimental setup. Inset: optical receiver.

The experimental setup is shown in Fig. 2. A CW signal from a tunable laser (TL) is modulated by a $LiNbO_3$-based intensity modulator, which is electrically driven with a 30-GHz sinusoidal RF signal and biased at transmission minimum. The generated signal (Fig. 3a) has a 60-GHz spacing between two first order sidebands. The signal is then amplified, filtered and set to a TE polarization before being launched from a tapered fiber into the waveguide. The sideband whose wavelength overlaps with the resonance is modulated with 10-Gb/s non-return to zero (NRZ) $2^7$-1 pseudo-random bit sequence (PRBS) using a pattern generator (PPG) and a microring modulator. The microring modulator is driven electrically with a 0.85-V voltage bias and 2.1-Vpp electrical signal. The neighboring wavelength will not suffer from intermodulation crosstalk for sufficiently large wavelength spacing [6]. The optical signal egressing from the waveguide (Fig.3b) is amplified and filtered before propagating in 25-km of SMF. Fig.3c shows the spectrum and respective time domain waveform by filtering each sideband using 0.22-nm (3-dB bandwidth) filters. The unmodulated sideband retains a CW characteristic while the modulated sideband shows a clean eye-diagram (Fig. 3c).

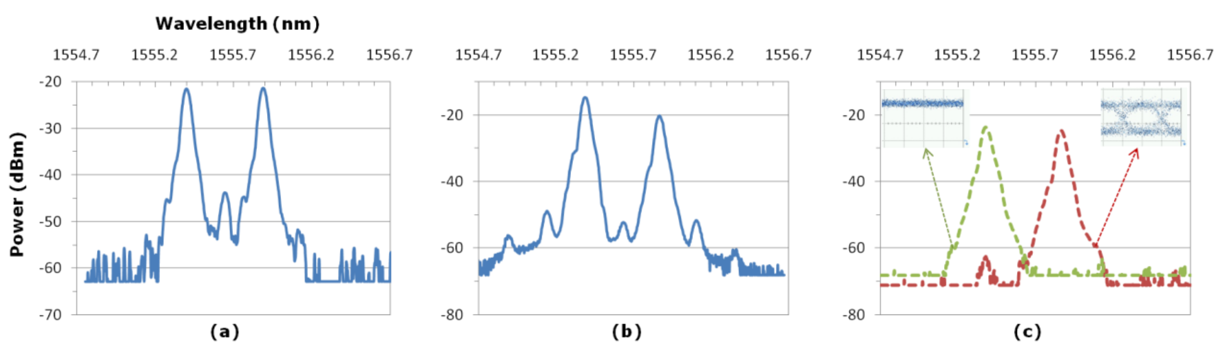


Fig. 3 spectrum of (a) before the silicon chip (b) after the chip (c) filtered sideband. Inset: waveform of the sideband in time domain.

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At the ONU, the double sideband signals are separated using filters instead of an interleaver for proof-of-principle demonstration. The upstream signal is modulated by a phase modulator (PM) driven with a 10-Gb/s $2^{31}$-1 PRBS and launched to the same fiber via an optical circulator. At the central office, the upstream DPSK signal is amplified and filtered before demodulation using a 100-ps DI. Both downstream and upstream signals are detected using a variable optical attenuator (VOA), a photodetector (PIN-TIA) followed by a limiting amplifier (LA), and examined on a BER tester (BERT). We record BERs and eye-diagrams for downstream NRZ signals and upstream DPSK signals as shown in Fig. 4. Power penalties of 2.5 dB for downstream NRZ signal and 1.5 dB for upstream DPSK signal are experimentally obtained with error free operation in a single fiber scheme.

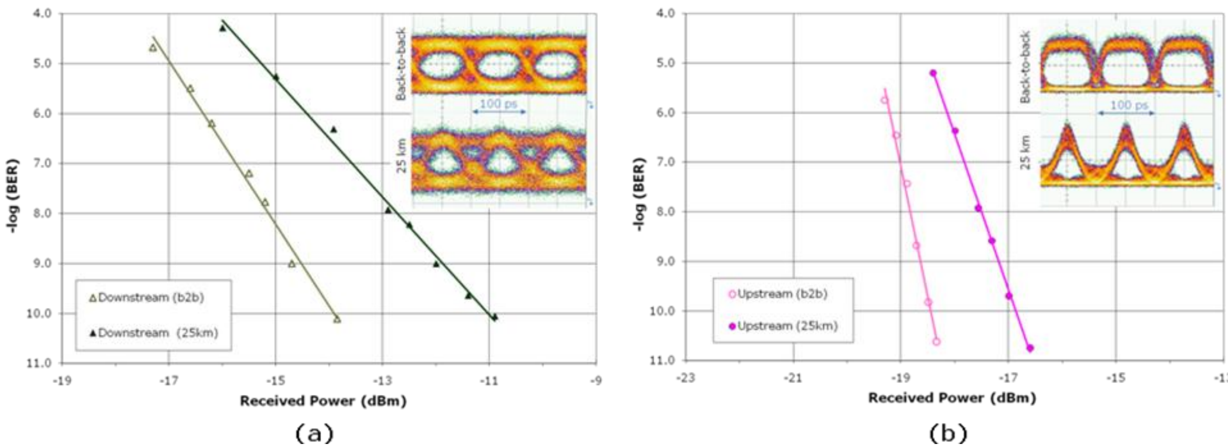


Fig. 4 BER measurement of (a) downstream NRZ signals (b) upstream DPSK signals. Inset: respective eye diagrams.

## Conclusion:

We have demonstrated a silicon microring modulator enabled SSB modulation scheme with colorless ONUs for access networks. The scheme can provide wireless and wired downstream signals, provide a CW carrier for upstream remodulation, and mitigate the impairment from RBS effect. The CMOS compatibility of the silicon microrings adheres to the stringent cost requirements of WDM PON.

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