Remote Photonic Frequency-Upconversion using a Semiconductor Optical Amplifier for WDM / Broadband Radio-on-Fiber Links

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Abstract

We present a novel remote photonic frequency-upconversion scheme based on SOA cross-gain modulation. Using the scheme, we successfully demonstrated 60GHz radio-on-fiber distribution of 2× 622 Mbps WDM channels.

Key Words: Remote photonic frequency-upconversion, semiconductor optical amplifier, cross-gain modulation, radio-on-fiber applications

I. Introduction

The fiber-optic transmission of millimeter-wave (MMW) signals has attracted much attention for broadband radio access system applications, such as local multipoint distribution services [1], indoor wireless LAN [2], intelligent transportation systems [3] and radio astronomy [4]. The broadband radio access requires a large number of base stations due to the small cell size. The base-stations should be compact and simple in implementation. A simple approach to transmit MMW signals over fiber-optic links is to employ the high-speed external modulators, which result in periodic signal power suppression due to fiber chromatic dispersion [5]. In order to avoid dispersion-induced penalties, various heterodyne schemes for optical generation and fiber-optic distribution of MMW signals have been studied and demonstrated [6]. But, it is difficult to link optical heterodyne technologies to the existing wavelength division multiplexing (WDM) networks.

One alternative approach is to send baseband or intermediate frequency (IF) data that are frequency-upconverted at base-stations. This approach is not only insensitive to fiber chromatic dispersion but also able to utilize WDM networks easily. But, it will make the base-stations more complex and expensive in design and implementation because high-frequency electrical mixers and local oscillator (LO) sources are required for frequency-upcoversions.

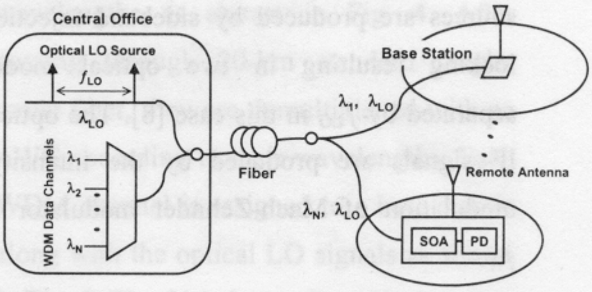


Fig. 1. Radio-on-fiber architecture for WDM data channels sharing one optical heterodyne LO source.

We have proposed and experimentally demonstrated an efficient photonic frequency-upconversion scheme using cross-gain modulation in a semiconductor optical amplifier (SOA) [7]. Fig. 1 shows a radio-on-fiber architecture under our consideration, where WDM data channels are wavelength-selectively distributed to base-stations and one optical heterodyne LO source is shared among base-stations. The optical LO source has two optical modes separated by the desired LO frequency (f_{LO}) to avoid the dispersion-induced signal suppression. At base-stations, photonic frequency-upconversions of WDM data signal with optical LO sources occur to eliminate the needs of high-speed electrical mixers and LO sources. In addition, it will be potentially cost-effective since SOA and PD can be monolithically integrated using multi-electrode semiconductor fabrication [8].

II. Photonic Frequency-Upconversion

Fig. 2 shows the experimental configuration under our investigation, where optical IF signals at 1 GHz (f_{IF}) is frequency-upconverted with the optical heterodyne LO sources at 25 GHz (f_{LO}). The optical LO sources are produced by sideband injection locking resulting in two optical modes separated by f_{LO} in this case [8]. The optical IF signals are produced by the intensity-modulation of Mach-Zehnder modulator at f_{IF}.

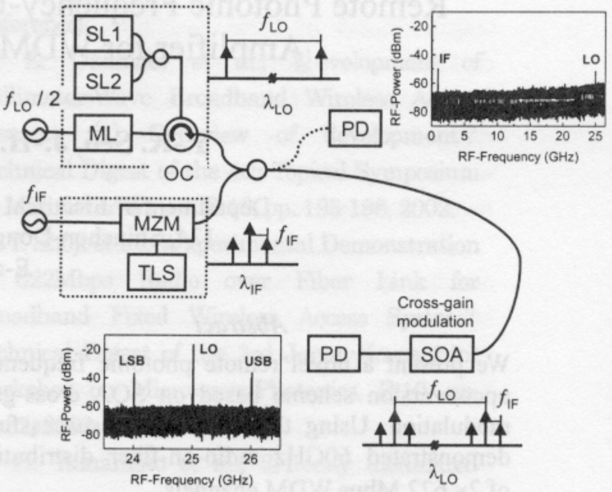


Fig. 2. Photonic frequency-upconversion scheme based on SOA cross-gain modulation. ML: master laser, SL: slave laser, OC: optical circulator, TLS: tunable light source, MZM: Mach-Zehnder modulator.

When optical IF and LO signals co-propagate through an SOA and are detected by a PD, photonic frequency-upconversion of f_{IF} to lower sideband (LSB, f_{LO} - f_{IF}) and upper sideband (USB, f_{LO} + f_{IF}) is achieved with SOA cross-gain modulation and square-law photo-detection. Two insets in Fig. 2 show photo-detected RF-spectra measured before and after SOA, where f_{LO} of 25GHz and f_{IF} of 1 GHz are used. The post-conversion LSB and USB signal powers are larger than the pre-conversion IF signal power indicating conversion gain.

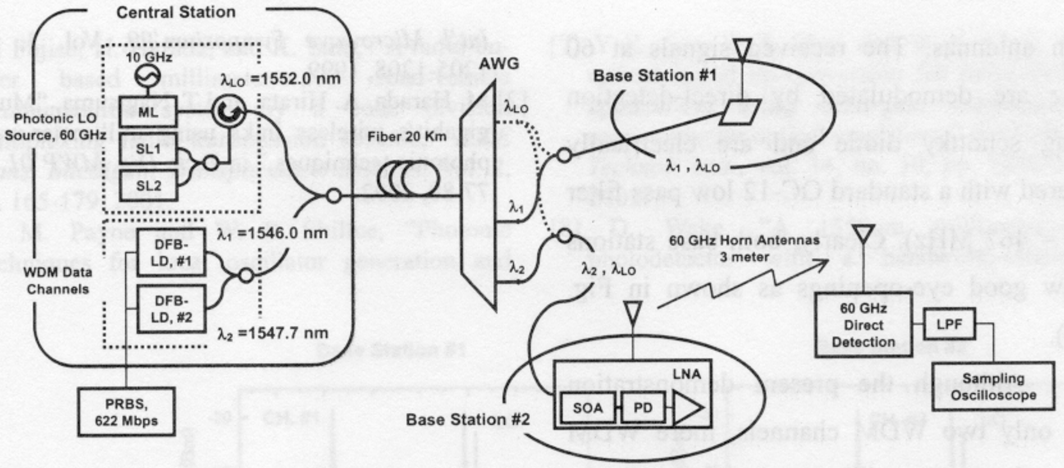
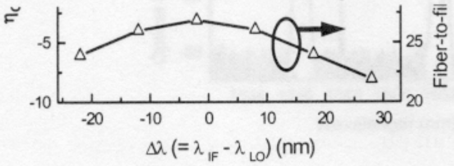


Fig. 4. WDM / Broadband RoF distribution using remote frequency-upconversion with an SOA.



(b)

Fig. 3 Frequency-upconversion efficiencies (η_C) for optical LO powers (a) and wavelength-detunings between optical IF and LO signals (b). The optical IF signal power is fixed at –10.9 dBm.

In order to investigate the characteristics of conversion efficiencies, the up-converted USB RF-powers are measured as function of various SOA bias currents, optical LO powers and wavelength detunings between optical IF and LO signals. The results are shown in Fig. 3. The conversion efficiency (η_C) is defined as the ratio of the up-converted USB RF-power to the IF RF-power, measured from the photo-detected currents with and without SOA, respectively. Fig. 3 shows that the frequency-upconversion efficiencies are directly attributed by the SOA optical gain and can be optimized by either controlling the optical LO power or selecting the optical IF and LO wavelengths within the SOA optical gain bandwidth. One should note that the upper limit for f_{LO} is

Fig. 4 shows an experimental configuration, where the optical heterodyne 60 GHz LO source is produced by the sideband injection locking. For experimental demonstrations, two WDM channels are realized by directly modulating two DFB lasers with 622 Mbps NRZ pseudo-random bit sequence (2^{15}-1 bits) and multiplexed with the optical 60 GHz LO source having different wavelengths as shown in Fig. 4. After passing through 20-km standard single-mode fiber, they are demultiplexed with an AWG according to their wavelengths. Each WDM channel is assigned to a base station along with the optical LO signals as shown in Fig. 5. Fig. 5(a) shows the optical spectra of the WDM channels and optical LO signals at two base stations. Remotely at base stations, photonic frequency upconversion of WDM signals with optical 60 GHz LO signals is performed in SOA and PD. The frequency-upconverted signal at 60 GHz is electrically amplified with low-noise amplifiers and transmitted over 3-meter wireless distance using 60 GHz horn antennas. The received signals at 60 GHz are demodulated by direct-detection using schottky diode and are electrically filtered with a standard OC-12 low pass filter (f_C = 467 MHz). Clearly, both base stations show good eye-openings as shown in Fig. 5(b).

Although the present demonstration has only two WDM channels, more WDM channels are possible as long as all the optical wavelengths are within the optical gain wavelength bandwidth of SOA used.

IV. Conclusion

We have demonstrated the novel remote photonic frequency up-conversion of WDM data channels with optical heterodyne 60 GHz LO signals. It is achieved with SOA cross-gain modulation and PD square-law photo-detection. This frequency-upconversion process is limited by PD photo-detection bandwidth only. It is potentially cost-effective since one optical LO source can be shared among multiple base-stations and the monolithic integration of SOA and PD is possible. In addition, the high conversion gain can be obtained over the wide wavelength separation between the optical WDM data and LO signals.

Using these features, we have experimentally demonstrated 60 GHz radio-on-fiber distribution of 2×622Mbps WDM data channels.

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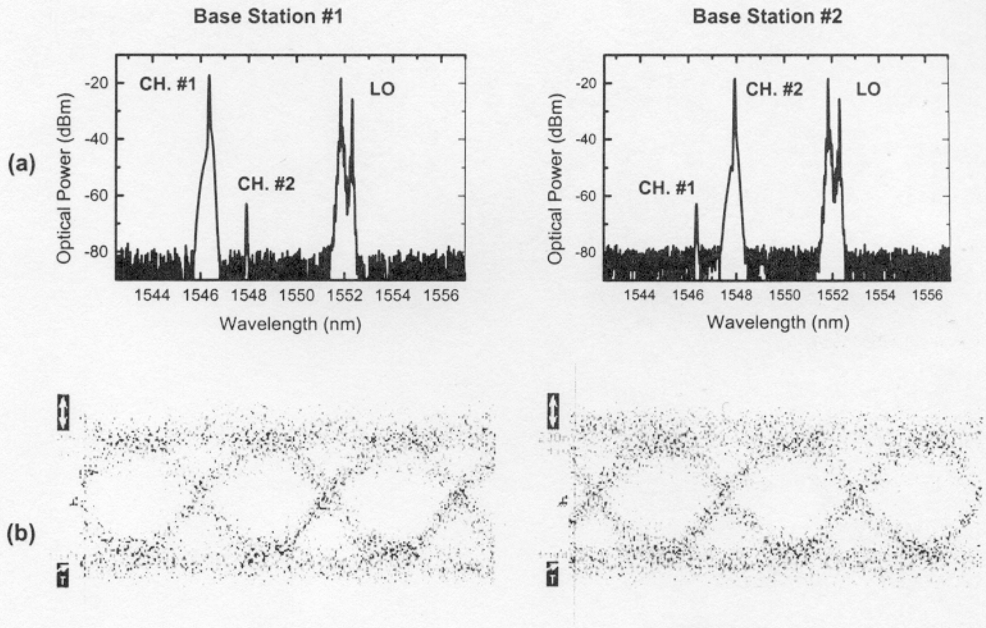

Fig. 5. Measured optical spectra at base-stations after 20-km fiber-optic link (a) and eye-diagrams of recovered 622Mbps NRZ data after 3-meter wireless link (b).

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