Dual-modulation of a novel Integrated Laser-modulator for Radio-over-Fiber Systems

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ABSTRACT

We present the first demonstration of a monolithic electro-absorption modulator-laser (EML) device for single sideband (SSB) modulation. Suppression of upper or lower sidebands is observed when synchronous dual push-push analog continuous wave (CW) modulation of the laser and the modulator is performed. Such 10 GHz CW carrier can transport digital format data for Radio-over-Fiber (RoF) transmission systems. A 50 mega symbol transmission of a 16-QAM signal has been achieved over 150 km of SMF fiber. Constellations, eye diagrams and error vector magnitude (EVM) measurements are presented, all of which are temperature independent up to 45°C. The demonstrated SSB modulation capability, which allows for signal transmission with uniform signal strength over entire length of the optical fiber, makes the device ideal for use in optical metropolitan and access networks. These results establish this dual-EML SSB transmitter as a serious candidate for optical-wireless network convergence and future OFDM systems.

Keywords: Radio-over-Fiber, Electro-absorption Modulated Laser, Optical Access Network, Dual-EML, Single Side-Band Modulation, QAM Modulation.

1. INTRODUCTION

Hybrid-Fiber Radio (HFR) systems employing radio-over-fiber (RoF) technology for distributing broadband multimedia signals are an attractive choice for future telecommunications services providers. More so because hybridized overlay multiservice optical networks are fast clustering all service rings and network layers into single optical infrastructure[1] thus bringing radio-over-fiber technologies to center-stage. But one of the major issues these RoF technologies face today is signal fading during transmission in optical fibers, which are by very nature highly dispersive towards millimeter-wave signals[2]. Optical single side-band modulation is an effective means of resolving this issue. Where double sideband (DSB) modulated RoF signals suffer from chromatic dispersion-induced destructive interference at the receiver, the single sideband (SSB) modulated signal successfully escapes this problem. More so an SSB signal has only half the spectral width of a DSB signal thus making it twice bandwidth efficient[3]. In this paper we propose a transmission system that takes advantage of the properties of SSB signals for RoF technology while using a novel single-chip integrated EML unit to reduce deployment costs and unit size.

1.1 Broad-band and Narrow-band Access Networks

Challenges faced by broadband wireless access networks include spectrum efficiency, deployment, maintenance and scalability costs, operational reliability and bit-rate asymmetry. In a typical broadband access network, blocks of subscribers are served by base stations (BS) which are connected to a Central Office (CO). The CO processes call routing and switching, while the BSs act as radio interfaces for the Mobile Units (MU) or Customer Premises Equipment (CPE). CO may be linked to BS either through analog microwave links or digital fiber optic links. The baseband signals received at the BS are processed and modulated onto the appropriate carrier which is then diffused into the coverage area of the BS, also known as the cell. Within a cell the MUs and the CPEs share the radio frequency spectrum. It is here that wireless access systems that operate at lower frequencies are in general restricted to low bandwidth. The networks using such systems, also known as narrowband access networks (NBAN), can only offer a limited capacity. For instance, the second generation (2G) mobile technologies such as global system for mobile communication (GSM), which operates at frequencies around 900 or 1800 MHz, only allows for a 200 kHz channel[4]. While a third generation (3G) universal

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mobile telecommunications system (UMTS) operating at 2 GHz frequency band allows for a 4 MHz allocated bandwidth[5] and gets a step closer to the implementation of broadband access networks (BBAN). Here, it must be noted that as the carrier frequency goes higher, the competition for frequency spectrum among professional, governmental and utility wireless communication systems using those frequencies also becomes stiffer, especially between 900 MHz and 6 GHz. On the other hand, there are certain significant advantages associated with systems operating at lower frequencies as well, such as low power consumption and larger cell sizes, due to increased efficiency of active devices at lower frequencies[6] and longer reach of radio waves.

1.2 Capacity vs. complexity dilemma for optical-wireless access networks

While larger cells enable high user mobility, they do lead to poor spectrum efficiency and decreased system capacity since the spectrum is shared by all MUs/CPEs operating in the cell[5]. One method of increasing user capacity in NBANs, as seen above, is to increase the carrier frequencies. This helps avoid the congested ISM band frequencies. Higher carrier frequencies offer greater modulation bandwidth, but then they lead to increased costs of radio front-ends in both the BS and the MU/CPE. The other method of increasing the capacity is to form smaller cells, also referred to as micro- and pico-cells. This may be achieved by reducing the radiated power at the antenna. Pico-cells are relatively easier to create inside buildings, where high losses induced by building walls help limit cell sizes[7].

1.3 Radio-over-fiber and Single-sideband Modulation

Keeping in sight the trade-offs of the above mentioned methods for increasing the capacity of wireless access networks, there are two solutions that are of importance. The first is the Radio-over-Fibre (RoF) technology which achieves the simplification of the base station through consolidation of radio system functionalities at a centralized headed, which are then shared by multiple remote antenna units (RAUs). In addition to the employment of RoF, the second solution is the choice of Single Side-band (SSB) modulation which offers improved spectral efficiency and protection against distance-dependant transmission attenuation for a given modulation frequency (as shown in fig. 1).

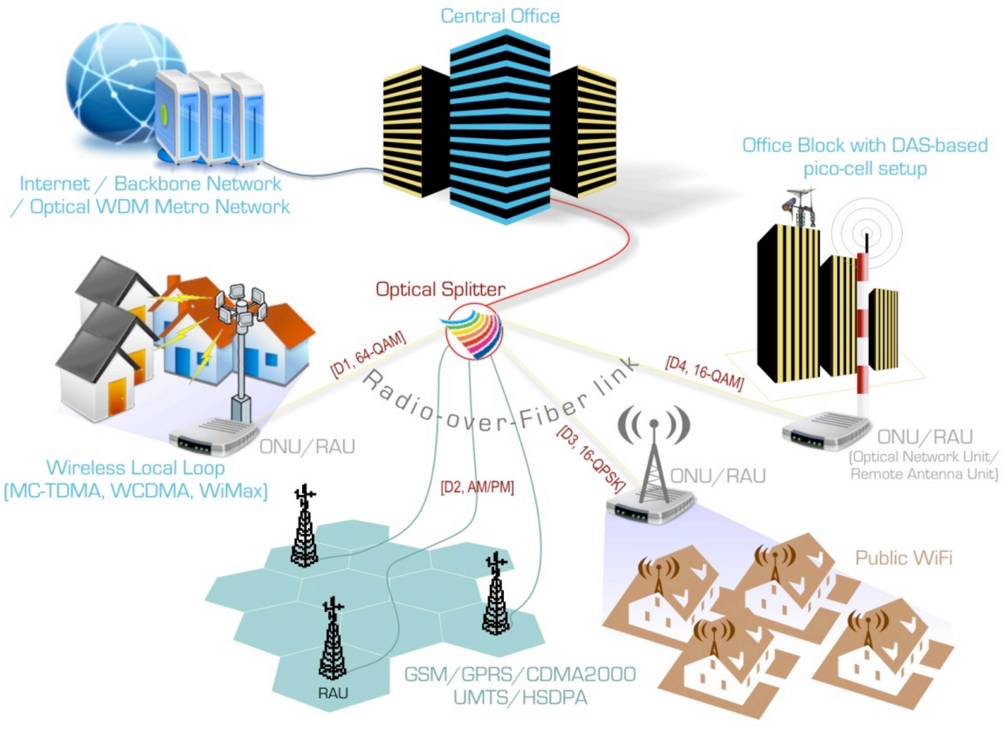

Figure 1. Radio-over-Fiber SSB advantage for various transmission distances [Dn] and modulation formats depending on the distribution standard involved.

2. OPTICAL SSB MODULATION USING DUAL-EML TRANSMITTER

Single Side-Band modulation decreases the spectral occupancy of the modulated signal, but for RoF systems that is not the critical parameter, since only one RF carrier is used at a time. It is, however, critical for deployment of coarse-WDM for optical access networks, but there, at the time of the writing of this article, SSB isn't achieved yet. SSB modulation can be implemented via various methods including, but not limited to, employing a Mach-Zehnder modulator or an optical filter to eliminate a harmonic on one side of the principal signal peak. The solution that we have chosen is based on an integrated electro-absorption modulated laser (EML) device. This solution is easier to implement and is less expensive as compared to the two solutions cited above, since a single integrated device is performing the two functions of laser emission and modulation. More so, the device not only consumes less energy but is robust to temperature variations and performs in a temperature-independent manner.

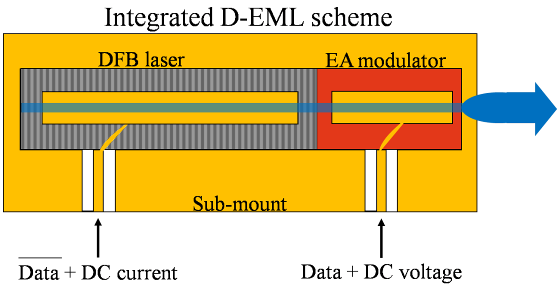

Figure 2.1 Scheme of the integrated Dual-EML devise with double RF coplanar access.

2.1 Principle of Dual EML-based SSB modulation

We use a dual modulation of the laser and the modulator synchronously with several conditions. In fact the laser produce a phase modulation and the modulator produce an intensity modulation with the same RF signal input into the different arms of the EML but with a compromise between the RF signal intensity applied to the modulator, and a phase shift applied to the RF signal input to the laser access. There are phase and amplitude conditions describes by the Bessel functions that can be assumed to the first order.

Extinction of the lower or the upper side depends on the difference of the phase between the laser and the modulator, in phase or in opposite phase respectively. The amplitude condition between the laser and the modulator can be resumed by:

$$\mathrm{m} \cdot \mathrm{A} \cdot \mathrm{J}_0(h) = A \cdot J_1(h) \tag{1}$$

With $h=A\beta/\omega_m$ is the relation between the index β of the laser frequency modulation (FM), the amplitude of the modulation signal A at the angular frequency of the signal modulation ω_m. The index of amplitude modulation (AM) of the EA modulator m can be simplified as $m=2\ \beta/\omega_m$. J_0 and J_1 are the fundamental and the first order of the functions of Bessel which development at the first order applied for this SSB EML-based technique is exposed in [8].

SSB modulation spectrum is show in figure 3.1 for an 21dB extinction of the lower side band before and after the optical transmission line. The extinction of the upper side band has produced also but with minus extinction, in fact, in [8] it's concluded this is due of a smaller AM modulation of EML total output signal. The figure 2.2 show eye diagrams for different IQ modulation formats.

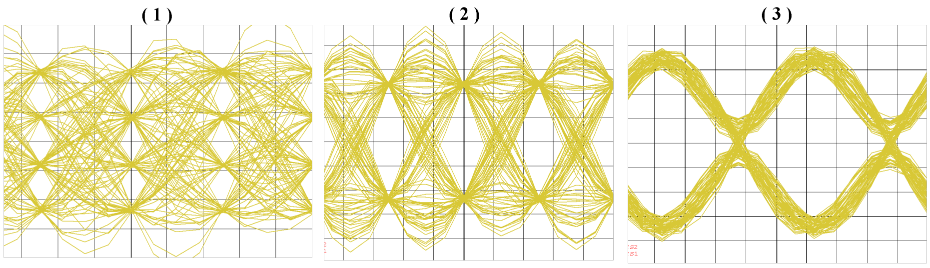

Figure 2.2 Eye Diagrams of 16-QAM (1), QPSK (2), and MSK (3) after 65 km SMF fiber for 7 MSymb/s rate.

2.2 Single Side-Band Transmission in Optical Fiber

It's proved that the CW signal transmitted on the optical carrier has RF power extinction for specified fibers length which corresponds at one frequency. We can see that by an inverse approach if we consider a fixed distance of the fiber and it's the frequency of the CW signal changes for simulate different sub-frequency carriers. This phenomena is describes in [3]. This is due of the different velocity group of the spectral components, and with one side band format this effect disappears. The equation (2) deals with the phase-intensity factor α measurement but he permits also to know the f_u frequency of the RF signal extinction for a fixed fiber length[10].

$$f_u^2 \cdot L = \frac{c}{2\lambda^2 D}\left(1 + 2u - \frac{2}{\pi}\arctan(\alpha)\right) \quad (2)$$

One carrier and one harmonic using the modulation of the laser.

2.3 Technology behind integrated EML

The EML used for the experiment is a sub-mount QW AlGaInAs device structure emitting at 1536 nm and developed in III-V labs [3]. The output power of the EML can reach 0dBm collected in the optical fiber. The device is not packaged for the experiment. However, in order to perform dual modulation, the RF access for both the laser and the modulator are connected to ceramic coplanar lines through microwave probes.

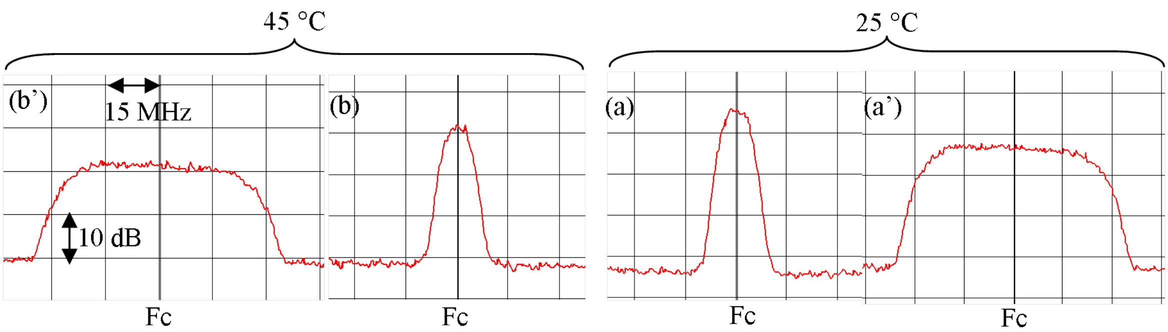

Figure 2.3 16-QAM Spectrums for 50 and 7 Msymb/s rate over 155 Km SMF fiber.

Fc is the 10 GHz RF carrier of the 16-QAM modulated signal applied. The temperature effect expended is not high because the SNR decreases minus 10 dB at 45°C if we compare with the spectrum at 25°C but the the error vector magnitude is quasi insensitive of this effect that this will explain in the next section of the article.

3. EXPERIMENTAL RoF TRANSMISSION BASED ON DUAL-EML

3.1 Experimental setup

The transmitter test platform (figure 3.1) consists in a 10GHz RF carrier modulated with IQ signal by the generator feeding both the laser and modulator inputs with the RF signal power at 10dBm minus 6dB due to the power divider, a manual electrical delay line for fine phase shift of the laser access, In order to control the balance between the FM and AM indexes modulation of both functions of the component and respect the several condition describes in equation 1 we use a variable electrical attenuator with 1 dB step and a total range of 10 dB. For transmission we use a fiber line consisting of standard SMF fiber with an EDFA booster and in line EDFA also for the 155km fiber length. The receiver includes a photodiode for quadratic detection of the 10 GHz RF signal and a signal analyzer for IQ demodulation. Static polarizations for the laser and the modulator are I_{Laser}= 36 mA bias current and V_{Mod} = -1.9 V bias voltage. The EML is temperature controlled at 25°C and 45°C.

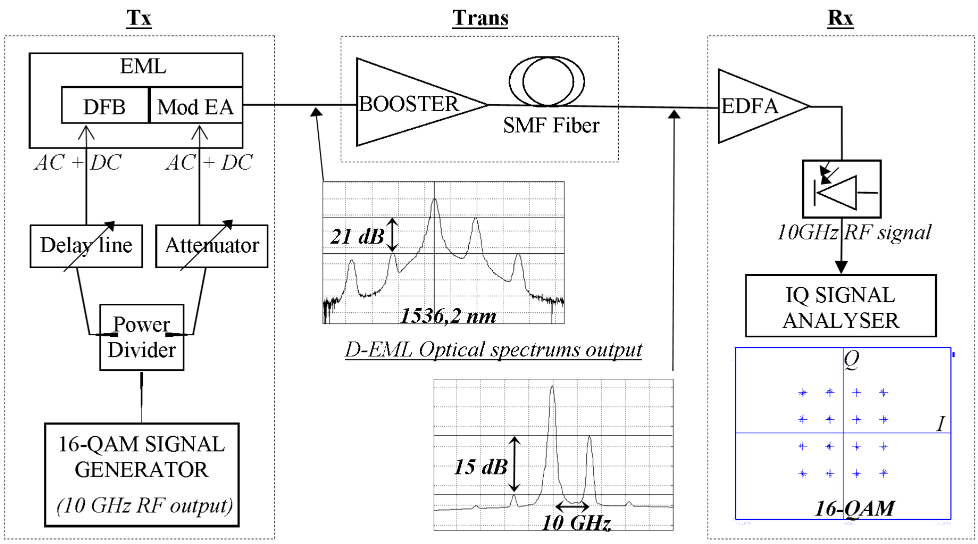

Figure 3.1 Experimental setup of D-EML SSB modulation and RoF transmission over 155 km.

About the RF signal integrity, when we use a 50 Msym/s 16-QAM modulation, the SNR=30 dB after 155 km of SMF fiber at 25 °C temperature operation of the device.
IQ demodulation has been applied with 7 MSym/s because the signal analyser used was limited at this time.
The table show the EVM performances for different lengths of fibers, temperatures operation and coherent modulations.

Distance	Measurement Parameter	Temperature	
		25°C	45°C
65 km	EVM	2,8 %	2,93 %
	OSNR	–	–
90 km	EVM	3,32 %	5,5 %
	OSNR	38 dB	27 dB
155 km	EVM	2,89 %	4,01 %
	OSNR	40 dB	32 dB

Table 1. Temperature dependences of EVM (%) and SNR (dB) of a 16-QAM signal transmitted over 3 fiber lengths.

4. CONCLUSION

4.1 Novelty

– First demonstration of SSB Radio-over-Fiber transmission using an integrated EML.

4.2 Perspectives

– Possible use in OFDM Radio-over-fiber transmission.

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