

16-QAM Modulation Based on Quad-Parallel Mach-Zehnder Modulator Dedicated for Radio-over-Fiber System

Kamal Ghoumid, Slimane Mekaoui, Ali El Moussati, and Jamal Zaidouni

Abstract—A In this paper the authors have theoretically investigated the transmission performance of the optical millimeter (mm)-wave generated by a structure of optical modulation dedicated to Radio-over-Fiber (RoF) system. This configuration generates optical 16-QAM signals in a quad-parallel structure of Mach-Zehnder modulators (MZMs) producing the 60 GHz mm-wave after passing through the bandpass filter centered on this frequency. The millimeter-wave is obtained with optical frequency multiplication. Clear eye opening was achieved at 20 Gbaud with on-off-keying, in order to prove that the evidence that the 60 GHz RoF structure suggested is successful. Such a system can be appropriate for the proposed coherent optical/wireless seamless network.

Index Terms—16-QAM modulation, radio-over-fiber (RoF), mach zehnder modulator, optical communications, wireless access.

I. INTRODUCTION

Millimeter-wave radio-over-fiber (RoF) is a technology that has been widely investigated in the recent years due to its high capacity, flexibility and cost-effectiveness. It refers to a technology whereby light is modulated by a radio signal and transmitted over an optical fiber link to facilitate wireless access. Although radio transmission over fiber is used for multiple purposes, such as in cable television networks and in satellite base stations, the RoF systems is usually applied when this is done for wireless access with broadband communication systems [1]-[3]. In RoF systems, wireless signals are transported in optical form between a central station (CS) and a set of base stations (BS) before being radiated through the airwave. The generation of wireless signals, based on the radio-over-fiber (RoF) technology, is expected to be suitable for high-frequency wireless transmissions as well as in applications involving an optical/wireless seamless network.

A combination of the simple RoF generation and the versatile digital receiver technique is suitable with this type

of networks. A combination of the simple RoF generation and the versatile digital receiver technique is suitable for the proposed coherent optical/wireless seamless network.

Among the main axes of these systems is photonic generation of millimeter-wave carrier and electric modulation. In optical communication, many advanced modulation techniques developed in the field of wireless communication, such as differential phase shift keying (DPSK), differential quadrature phase-shift-keying (DQPSK) on-off-keying (OOK) with carving techniques [4], [5], frequency-shift-keying (FSK) [6], single sideband (SSB) modulation techniques [7] etc, were investigated to obtain enhanced spectral efficiency. Orthogonal modulation techniques with OOK and FSK or OOK and DPSK are also attractive for optical labeling in packet systems [8], [9].

Multilevel modulations signal generating optical are recommended for this type of system, this can be achieved eg by coherent superposition of several binary phase-shift keying(BPSK) signals which only requires binary electric signals easily obtained from conventional electronics. Otherwise, by another more effective technique based on series and/or parallel Mach-Zehnder optical modulator which is suitable for the realization of this type of modulation at multiple levels.

This type of modulation based on MZOM is highly recommended for achieving high spectral efficiency by use of the amplitude and phase of light wave for superposing data. Experiments employing this scheme have demonstrated the generation and transmission of microwave carriers up to 60 GHz, carrying 16- and 64-QAM radio signal up to 40 Mbaud total symbol rate over multimode fiber [10]. In addition to the use of M-QAM modulation associated with multicarrier OFDM spectral efficiency has a higher level than the NRZ, it also helps to combat fiber dispersion and higher bit rates [11], [12]. However, in this type of component signal delay between the optical modulators should be controlled precisely for stable operation. This type of modulator has been widely used in the RoF systems, such as signal generation method integrated on a monolithic LiNbO₃ substrate which is useful for optical 16-QAM signal generation. Another system QPSK/16QAM modulation scheme utilizing only one fiber for Millimeterwave RoF systems is proposed [13], [14], [15], [16].

In this paper, we first describe the 16-QAM-RoF system used to obtain the frequency 60 GHz, and then we will use numerical simulations in order to evaluate the performances system by viewing and analyzing its constellation and its eye diagram together with its power spectral density.

Manuscript received September 15, 2012; revised November 5, 2012.

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II. SYSTEM ARCHITECTURE

The architecture of the 16-QAM modulation based on quad-parallel Mach-Zehnder modulator studied and dedicated for Radio-over-Fiber system is given in Fig. 1.

A laser source is emitting at wavelengths around $\lambda = 1310$ nm which is frequency modulated by a sweep frequency $f_s = 6.5$ GHz with a phase modulator (PM). This Laser source generates an optical spectrum broadening of around 50 GHz. The radio data signal 16-QAM at symbol rate is $R_s = 20$ Mbaud on a low frequency subcarrier $f_c = 1.5$ GHz which modulates the intensity of the optical FM with a chirp-free Mach-Zehnder intensity modulator (IM). The resulting optical signal is passed through a Mach-Zehnder interferometer (MZI) whose free spectral range (FSR) is 10 GHz. This optical signal is then amplified by an erbium-doped fiber amplifiers (EDFA) and transmitted over a downlink fiber to beat at photo-detector (PD) in base station (BS), generating many electrical harmonics signal. These harmonics are amplified by an Low-noise amplifier (LNA) and pass through a band pass filter (BPF) in order to capture the specific narrowband of 60 GHz followed by an amplifier before being radiated in the air by an antenna.

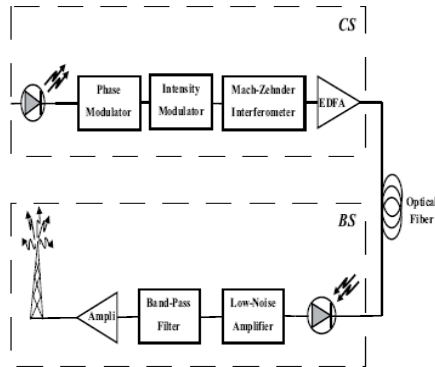


Fig. 1. Structure and components of RoF system studied.

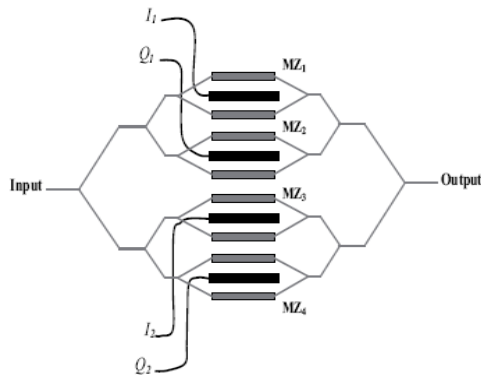


Fig. 2. Schematic of 16-QAM modulation using DPMZM.

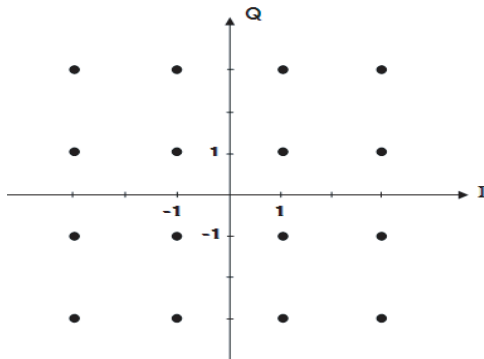


Fig. 3. 16-QAM constellation following the structure DPMZM.

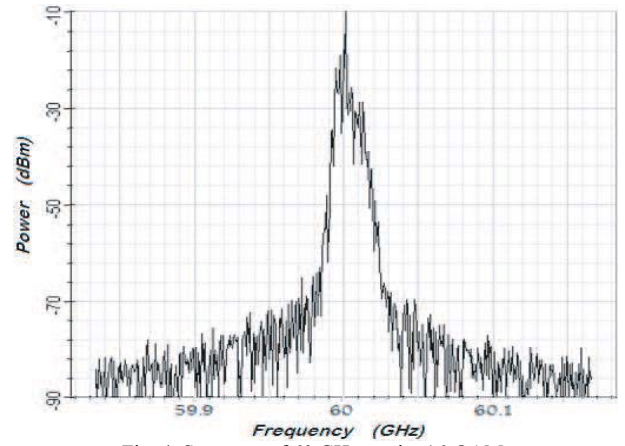


Fig. 4. Spectrum of 60 GHz carrier 16-QAM.

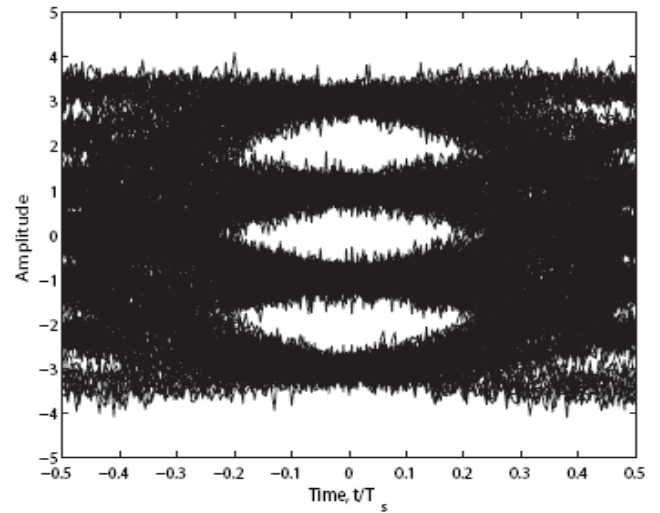


Fig. 5. I/Q channel eye diagram: amplitude versus to the time normalized to time symbol T_s .

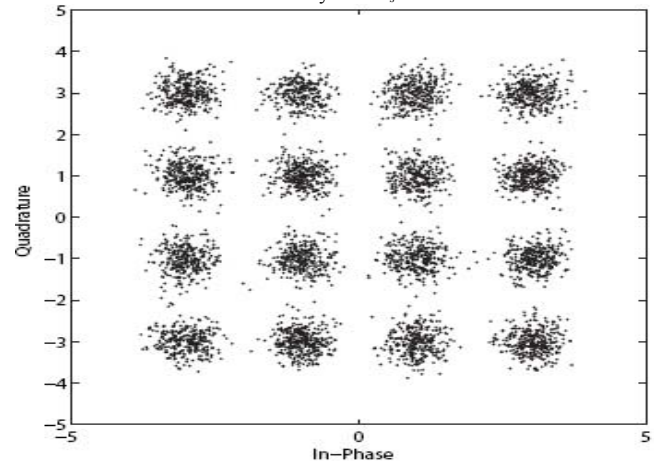


Fig. 6. 16-QAM constellation signal obtained after the passage by band-pass filter (BPF).

III. QUAD-PARALLEL MACH-ZEHNDER MODULATOR FOR HIGH DATA RATE SIGNAL GENERATION

Quad-parallel MZ modulator consists of four sub MZIs embedded in a main MZI, as shown in Figure 2, where a pair of two-bit codes for in-phase (I_1 ; I_2) and for quadrature (Q_1 ; Q_2) components are fed to four sub MZIs used with electrodes direct current (DC) biases of the I-Q modulator at appropriate values. It should be noted that in general a parallel MZM with N sub MZIs can generate a signal in which each symbol consists of N bits. Thereby, this

component generates a 4 bit/symbol from four binary data streams and the bit rate R_b to a value greater than twice the symbol rate $R_s = R_b/2$ (for parallel MZM with N sub MZIs, we have $R_s = R_b/N$).

The optical signal obtained at the output of the modulator is characterized by the 16-QAM constellation given in Fig. 3.

IV. THEORETICAL ANALYSIS AND RESULTS DISCUSSION

When a low frequency subcarrier $f_c = 1.5$ GHz modulates the intensity of the optical FM signal, it becomes up converted double-sided along with the harmonics of f_{sw} according to the equation:

$$f_{RF} = n f_s \pm f_c \quad (1)$$

where n is the n^{th} harmonic. Note also that harmonic generation of $f_s = 6.5$ GHz at the output of the photodiode is due to the conversion through the MZI. So in our case with ($f_s = 6.5$ GHz, $f_c = 1.5$ GHz, $n = 9$). It is worth noting that at this order the two harmonics are generated at frequencies 60 GHz and 56 GHz. Thus after passing through the band-pass filter, it remains that the sideband frequency of the 9^{th} order harmonic is 60 GHz. The spectrum of 16-QAM modulated signal at 60 GHz is shown in Fig.4. The Constellation of 16-QAM signal detected at the point after BPF and the baseband 16-QAM signals eye diagram is also shown in Fig. 5 and 6 respectively.

V. CONCLUSION

The structure 16-QAM modulator based of the DD-MZMs for photonic generation of millimeter-wave for the RoF system is proposed and demonstrated. High bit rate signals can be generated by this structure because modulation rate R and the number of MZIs N can be increased simultaneously. Clear eye opening was achieved at $R = 20$ Gbaud. The system has many advantages, such as stability, simplicity, interference immunity and is a competitive low cost system which does not need the use of other special optical devices.

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