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Analysis of OFDM based V-band RoF Millimeter Wave System with Wireless AWGN Channel

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***Abstract*: As technology advances, the bandwidth requirement is increasing day by day. These growing needs push the RF carrier frequencies towards the millimeter wavebands. A radio over fiber link schemes with Quadrature Amplitude Modulation (QAM) with 5 Gbps data rate in OFDM format is presented in this paper. The 60 GHz millimeter wave is generated by implementing Frequency Quadrupling techniques. Optical generation method is adopted in this paper. The central office to base station link as well as the base station to mobile station links is analysed with the help of simulation software.**

Index Terms: OFDM, Radio over Fiber, Full duplex, RF down conversion

I. INTRODUCTION

The last few decades can be considered as an era of development in wireless communication techniques. The requirement of broadband access is one of the ever increasing needs in the present scenario. The researchers face a major challenge to satisfy this increased bandwidth need of the users [1]. One of the efficient solutions to this problem is to move towards the millimeter wave bands. The designation given by International Telecommunication Union to this band is Extremely High Frequency Band (EHF). The electromagnetic spectrum varies from 30-300 GHz in this band.

High atmospheric attenuation is one of the main problems occur to the signals in the EHF frequency band. This attenuation result in a reduced range of about 1 Km for the terrestrial communication. This makes the practical implementation of wireless communication in this band difficult. But backing up this wireless network with a wee structured optical network helps in solving this problem. This is what the Radio over Fiber (RoF) technology deals with.

RoF is the technique by which the optical and wireless communication is seamlessly integrated. The optical fiber provides almost unlimited bandwidth and has no attenuation. Optical fiber also has the immunity towards electromagnetic inference. Even though the initial cost for the implementation of the optical fiber network is high, the ease of maintenance makes the technology makes it one of the promising candidates for long haul communication.

The millimeter waves in optical domain can be easily transmitted between the central office and the remote station. The central office controls the entire signal processing functions and transmits signals to the remote station through the fiber network. The remote station only needs to convert the optical signals to electrical signals and transmit it wirelessly.

The generation of millimeter wave carrier is another important problem faced during the practical implementation of millimeter wave systems. As the frequency of operation is very high, the local oscillators which are to be designed must have high frequency capabilities. Also, the generation of millimeter waves in electrical domain is very difficult. The frequency limit of common electronic devices is the main reason for this. Hence optical generation is the feasible way[2]. Among many techniques used, optical heterodyning is an attractive method for generating optical carrier frequencies. This method can be called as Optical Frequency Multiplication (OFM). OFM is the process in which a low frequency RF is upconverted to a much higher microwave signal through optical signal processing. Frequency multiplication techniques based on non-linear modulation of Mach Zehnder modulator is used in this paper. This technique makes system more reliable and cheap to implement[3].

QAM being a popular vector digital modulation format is selected as the modulation scheme. Orthogonal Frequency Division Multiplexing (OFDM) technique is also used to provide high spectral efficiency and to achieve high level of spectral shaping[4]. OFDM allows the allocation of narrow guard bands to be reserved for each sides of the carrier.

The OFDM signal in the EHF band is wirelessly transmitted from the remote station to the mobile units. This wireless link is modeled as an AWGN channel for the analysis. The performance of this OFDM system is studied both in optical fiber and AWGN channel.

This paper is organized as follows. Section II describes the system model. The principle of operation of whole system is explained in section III. The details of the experiment done and the results are explained in section IV and finally the paper is concluded in section V.

II. SYSTEM MODEL

The whole system is modeled as shown in fig. 1. The transmission system is divided into three stages.

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i. Central Office
ii. Remote station
iii. Mobile unit

The central office and the remote station are connected via an optical fiber link and the interconnection between the remote station and mobile station is wireless.

A. *Central office*

The central office is where all the signal processing functions are carried out. A random binary sequence is taken as the message signal. The binary sequence is fed to a quadrature amplitude modulator where the message bits are mapped to a 16-QAM signal. The 16-QAM signal is again modulated by an OFDM modulator. This OFDM modulated QAM signal serves as the RF signal to be transmitted over the fiber network. A continuous wave laser diode is used as the light source for the optical network. The OFDM signal is modulated on to the light waves with the help of electro absorption modulator. The modulation procedure is carefully designed so that the frequency up-conversion requirement is also satisfied. The optical signals carrying the millimeter waves are transmitted to the remote station through optical fiber.

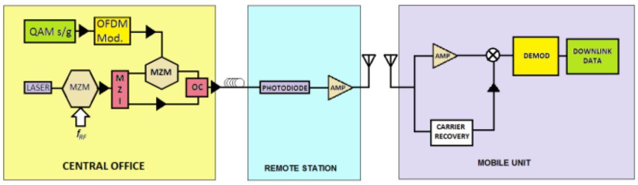

Fig. 1 System model

A. *Remote Station*

The remote station serves as the transmitter for the wireless communication link. The optical millimeter waves have to be converted to electrical signals for wireless transmission. As the power loss in the optical fiber link is low, the need for an RF amplifier can be avoided if sufficient power is provided by the central office itself. High speed photo diodes are used for the conversion of optical millimeter wave to electrical signal and this signal is abstracted by using appropriate electrical filter. The RF millimeter wave is then fed to the antenna for further transmission. The wireless channel between the remote station and mobile unit is modeled as an AWGN channel.

B. *Mobile Unit*

The mobile unit receives the millimeter wave signals with the help of in built antennas. As the operating frequency is in the order of Gigahertz, the size of the antenna required will be very small as antenna height and frequency are inversely proportional. The requirement for high frequency oscillators for demodulation can be avoided by the implementation of self homodyning or by extracting the carrier by narrow band filters and reusing the same. The OFDM and the QAM modulated signals are demodulated using corresponding demodulators and the input message sequence is obtained.

III. PRINCIPLES OF OPERATION

A. *Optical Frequency Multiplication*

In this technique, a low frequency RF is upconverted to a much higher microwave signal through optical signal processing. The mathematical formulation of the frequency upconversion process is expressed as follows. In this paper we assume that the laser diode has a central frequency

$$f_c = 2\pi/\omega_c \tag{1}$$

The light wave with central frequency f_c can be expressed as

$$E_c(t)=E_c exp(j\omega_c t) \tag{2}$$

Using a Mach Zehnder Modulator (MZM), the optical carrier wave $E_c(t)$ is intensity modulated in accordance with the RF carrier signal. Let the RF signal be expressed as:

$$V_{RF}(t)= V_{RF} sin(2\pi f_{RF} t) \tag{3}$$

The modulation process results in a spectrum where the the central carrier along with a number of side bands separated by a frequency gap of f_{RF}. For obtaining frequency multiplication, the modulation index is enhanced in such a way that the optical carrier and the first order side bands are completely suppressed. The output of the modulator should only have prominent positive and negative second order side bands. This can be obtained for a modulation index $m= 2.405$[2,3]. The output of the MZM which serves as the carrier for the RF message signal can be expressed as:

$$\begin{aligned} E_{OC}(t) &=(\alpha/2)\, E_c exp(j\omega_c t)[exp\{j(\pi/V_\pi)\, V_{RF} sin(2\pi f_{RF} t)\} \\ &\quad +exp\{-j(\pi/V_\pi)\, V_{RF} sin(2\pi f_{RF} t)\}] \\ &=\alpha\, E_c\, J_2(m)[\, expj(\omega_c-2\,\omega_{RF})t- expj(\omega_c+2\,\omega_{RF})t] \end{aligned} \tag{4}$$

where α is the MZM insertion loss and J_2 is the second order Bessel function. Also modulation index m is given by

$$m= \pi V_{RF}/V_\pi \tag{5}$$

Now the two side bands are separated by a frequency gap of $4f_{RF.}$ Using Mach Zehnder Interferometer or other filter structures, the positive and negative sidebands are separated and the positive side band is modulated with OFDM signal. The expressions for the same are as follows.

$$E_{OC-}(t)= \alpha\, E_c\, J_2(m)\, \{expj(\omega_c-2\,\omega_{RF})t\} \tag{6}$$

for the negative side band and

$$\begin{aligned} E_{OC+}(t)= \alpha\, E_c\, J_2(m)\, [&expj(\omega_c+2\,\omega_{RF})t\ + \\ &(\pi/V_\pi)\{S(t)\, expj(\omega_c+2\,\omega_{RF} + \omega_{IF})t\} + \\ &(\pi/V_\pi)\{S(t)\, expj(\omega_c+2\,\omega_{RF} - \omega_{IF})t\}] \end{aligned} \tag{7}$$

for the modulated positive sideband, where S(t)is the modulating signal.

After aligning polarizations, the two signals $E_{OC-}(t)$ and $E_{OC+}(t)$ are combined using optical coupler and transmitted. The transmitted signal $E_T(t)$ is given by:

$$\begin{aligned} E_T(t)&=E_{OC-}(t)+E_{OC+}(t) \\ &=\alpha\, E_c\, J_2(m)\, [expj(\omega_c+2\omega_{RF})t\ + expj(\omega_c-2\omega_{RF})t\ + \\ &\quad (\pi/V_\pi)\{S(t)\, expj(\omega_c+2\,\omega_{RF} + \omega_{IF})t\} + \\ &\quad (\pi/V_\pi)\{S(t)\, expj(\omega_c+2\,\omega_{RF} - \omega_{IF})t\}] \end{aligned} \tag{8}$$

At the remote station, with the help of a high speed PIN photo diode, the optical signal is converted to electrical signal. The photo current includes a dc, high frequency RF signal at $4\omega_{RF} + \omega_{IF}$ and $4\omega_{RF} - \omega_{IF}$, the modulating signal at ω_{IF} and carrier signal at $4\omega_{RF.}$ Either of the two millimeter wave signals at $4\omega_{RF} + \omega_{IF}$ or $4\omega_{RF} - \omega_{IF}$ can be used for wireless transmission, and the expression for the millimeter wave at $4\omega_{RF} - \omega_{IF}$ is obtained as:

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$$I_{mmw}(t)=2\mu\alpha^2(\pi/V_\pi)E_c^2J_2^2(m)[I(t)\cos(4\omega_{RF}-\omega_{IF})t + Q(t)\sin(4\omega_{RF} - \omega_{IF})t] \quad (9)$$

where I and Q are the in phase and quadrature components of the of the modulating signal respectively. From the equation, it can be inferred that the RF carrier frequency ω_{RF} becomes four times the original value. Hence we can say that by supplying a low frequency signal, high frequency carrier can be optically generated by careful design.

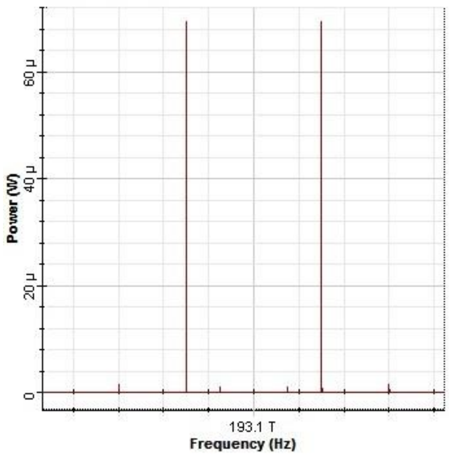

Fig.2 carrier suppression

B. RF Down Conversion

RF down conversion can be done using several methods. Two effective methods that can be used without the use of an external oscillator are self homodyning and carrier extraction and reuse method.

i. Self Homodyning

The method of extracting information encoded as modulation of an oscillating signal by comparing the same with a standard oscillation that would be identical to the signal itself is called homodyne detection. In optical interferometry, the reference radiation is derived from the same source as the signal before the demodulation process signifies homodyning[5].

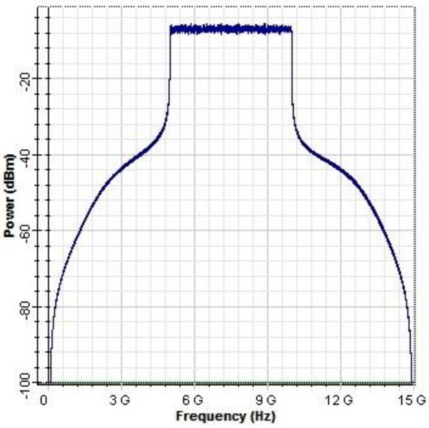

Fig.3 OFDM spectrum

ii. Carrier Extraction and Re-use

The carrier extraction and re-use is an RF technique where the high frequency RF carrier is extracted using narrow band filtering and reused by mixing it with the wide band data for down conversion. This procedure is carried out by first splitting the high frequency RF signal using a power splitter and at one of the power splitter's output, the RF carrier is filtered by narrow band filter. This filtered output serves as the local oscillator carrier signal which is mixed with high frequency received signal to the base-band signal.

These two methods provide cheap and efficient detection of the message signal at the receiver{5].

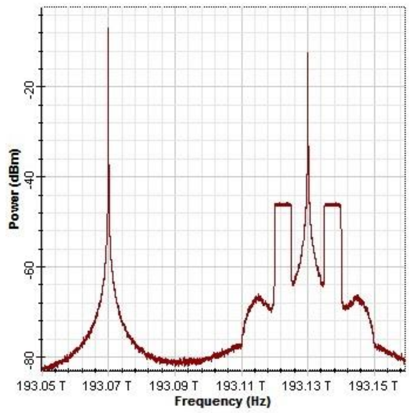

Fig. 4 Transmitted signal(spectrum)

IV. EXPERIMENTATION AND RESULTS

The optical link is built on opti-system platform. The central frequency of the continuous wave laser is selected as 193.1 THz. As the analysis in this paper is based on the V-band (40 – 75 GHz), let's take the wireless link is operating at 60 GHz. For the generation of 60 GHz signal based on the OFM, the F_{RF} is taken as 15 GHz. This 15 GHz RF signal is fed to the MZM to obtain the two second order side bands at 193.13 THz and 193.07 THz. By enhancing the modulation index, the carrier as well as other side bands is suppressed completely as shown in fig.2. The Mach Zehnder Interferometer is used for splitting the two side bands and the upper side band is modulated with the OFDM signal.

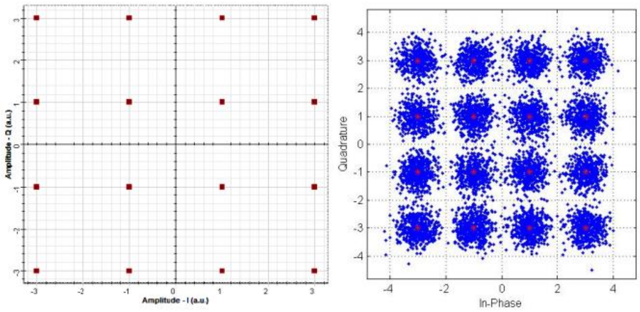

Fig. 5 constellation diagrams (transmitted and received)

A pseudo random binary sequence generator which produces bit sequences is taken as the information signal. The bit rate is taken to be 5 Gbps. The QAM modulator maps the bit sequence into a 16 QAM vector modulated signal. The in-phase and quadrature components are fed to an OFDM modulator having 512 sub-carriers. A block length of 1024 is taken for IFFT operation. 7.5 GHz intermediate frequency carrier is used to modulate the signal and the spectrum is shown in fig. 3. This OFDM modulated 7.5 GHz signal is modulated on to the positive second order side band at 193.13 THz and is then optically combined with the side band at 193.07 THz. The spectrum of the combined signal is shown in fig. 4.

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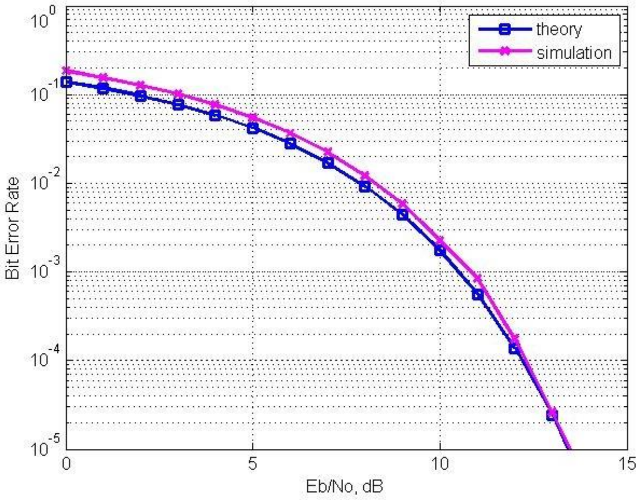

Fig. 6 BER versus SNR

The signal is transmitted to the remote station through standard single mode fiber with following standards. Chromatic dispersion = 17 ps/nmKm and power attenuation of 0.2 dB/Km. The photo diode converts the optical signals to millimeter wave electrical signals as shown in equation (9). The photo current consists of 60 GHz pure millimeter wave carrier, 67.5 GHz and 52.5 GHz OFDM modulated RF signals, 7.5 GHz original OFDM signal and dc component. In this simulation, the millimeter wave at 52.5 GHz and the millimeter carrier at 60 GHz are wirelessly transmitted. The channel for the wireless transmission is modeled as AWGN channel and is simulated by introducing MATLAB component in opti-system. Carrier extraction and reuse method is used for the down conversion and are demodulated to get the QAM signal back. The constellation diagram of both transmitted and received QAM signal is shown in fig. 5.

The constellation diagram shows that the signal points maintain sufficient distance between other signal points so that the probability of false detection remains low. The noise due to laser diode and photo diode also affects the system performance. Fig. 6 shows the BER plot of the received signal. It is seen that the bit error rates are below the forward error correction limit and also the theoretical and simulation results maintain satisfactory performance.

V. CONCLUSION

In this paper, the performance of both optical and wireless links in an OFDM based RoF system is studied. The optical frequency multiplication and the carrier extraction and reuse procedures provide cheap and reliable implementation of RoF networks and also maintain good performance not only in optical fiber but also in wireless AWGN channels. Carrier recovery and reuse in the mobile unit makes RoF systems simple and cost effective.

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