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Full Duplex Radio over Fiber System with Carrier Recovery and Reuse in Base Station and in Mobile Unit

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Abstract**: *A novel full duplex Radio over Fiber (RoF) system extending from the central office (CO) to the mobile unit using a single continuous wave laser in the central station is proposed. Mobile unit is designed without a high frequency local oscillator. An optical frequency comb is generated in which one frequency is used as carrier for modulating data. The frequency for uplink is obtained from other comb signal. A large number of comb lines can be utilized along with the data comb line. Thus the frequency of operation of the base station can be selected by switching to different comb lines. The modulation scheme QAM accounts for greater spectral efficiency for the system. The proposed system is viable for high bandwidth communication and cost effective.***

Index Terms**: *Full duplex, Optical comb, RoF***

I. INTRODUCTION

Radio over fiber (RoF) is a promising solution to wireless access with the integration of optical techniques and wireless methods. RoF technique results in low loss and extremely wide bandwidth [1]. Optical fiber is used to carry RF signals from the central office (CO) to various base stations (BS) in the RoF technology.

Lightwave centralized systems need to be designed such that the base stations have to be as simple. The carrier recovery and reuse (CRR) in Base stations [2-6] results in reusing lightwave that are generated after modulation with an external modulator[7]. Carrier reuse is also accomplished by using polarisation[8]. A high frequency local oscillator is needed to be used in the mobile units for modulating the uplink data.

A novel full duplex RoF system in which only a single laser source is used at the CO is proposed. Comb lines with frequency separation of 10 GHz is generated. 193.49 THz is taken as the carrier for modulating the QAM data signal. Another comb of frequency 193.44 THz is optically coupled and send to the base station via a single mode fiber (SMF). In the BS 193.44 THz is separated and reserved for the uplink. By beating comb of frequency 193.44 THz and the data comb of frequency 193.49 THz using a PIN photodiode, we get an RF carrier of 50 GHz and data in lower side band (LSB) and also in upper side bands (USB).We suppress the lower side band data and only the carrier at 50 GHz and USB data are transmitted to the mobile units using RF antennas. In the mobile unit data transmitted from the CO is obtained by demodulation. The RF carrier is also separated from the downlink signals which is used as carrier for uplink.

The uplink QAM data to be transmitted back to central station is modulated on this RF carrier and only the lower sideband signal is transmitted to the BS via antenna (uplink). In BS, the uplinked lower side band data from the mobile unit is received and modulated on the reserved comb of frequency 193.44 THz obtained and transmitted to the CO via another fiber.

In this proposed method, we can change the frequency of operation of a base station by the selection of the second comb signal. Additional combs (f3,f4 etc.) can be selected to optically combined with data comb(f1) to operate at frequency of (f3-f1). BS will obtain the RF carrier of frequency (f3-f1) for uplink. Hence, no local oscillator is needed and a wide range of RF frequencies can be used in mobile units.

II. PRINCIPLE OF GENERATION OF COMB LINES FOR TRANSMISSION

The schematic diagram for comb generation is given in Fig. 1. A laser with frequency of 193.4 THz and a radio frequency (RF) source of frequency 10 GHz generates comb lines with 10 GHz spacing centered at 193.4 THz. Electro absorption modulator (EAM) and phase modulator (PM) generates comb signals of 0.2 dB flatness[6]

The RF signal is fed to the EAM and an output spectra of 10 GHz spacing is obtained as in Fig. 2.

It is then passed to the phase modulator(PM) where RF signal is fed after passing through an electrical amplifier (EA) for boosting the input signal. The optical signals at the output of the PM can be expressed as in Eqn.1

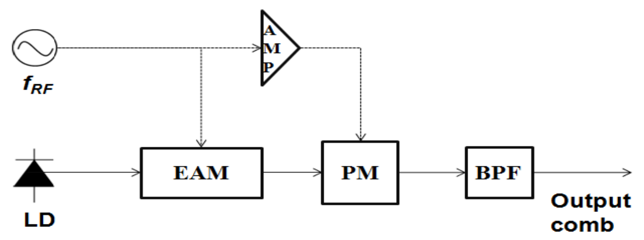

Fig.1 Generation of comb, LD: laser diode; EAM: Electro Absorption Modulator; AMP: Electrical Amplifier; PM: Phase Modulator.

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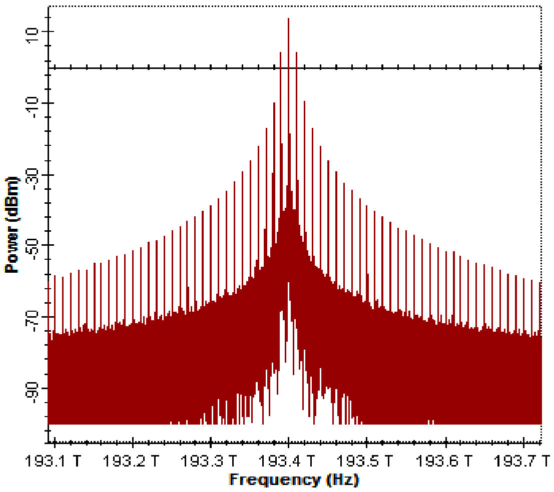

Fig 2: Output waveform of Electro Absorption Modulator.

$$E_{PM}(t) = E_{in}(t)exp[j.\pi.m_{PM}.\cos(\omega_{RF}t)]$$

$$= E_0\exp(j\omega_0 t).exp[j.\pi.m_{PM}.\cos(\omega_{RF}t)]$$

$$m_{PM} = \frac{V_{PM}}{V_{\pi PM}} \quad (1)$$

$$E_{PM}(t) = E_0.\sum_{n=-\infty}^{n=+\infty} J_n(\pi.m_{PM})\exp[j(\omega_0 + n\omega_{RF})t]$$

where m_{PM} is the modulation index of phase modulator, J_n is the first kind Bessel function of order n . E_0 and ω_0 are the magnitude and frequency of the optical field and ω_{RF} is the angular frequency of the RF signal. Here ω_0 =193.4 THz and ω_{RF} =10 GHz. The spectra of PM is given in Fig. 3

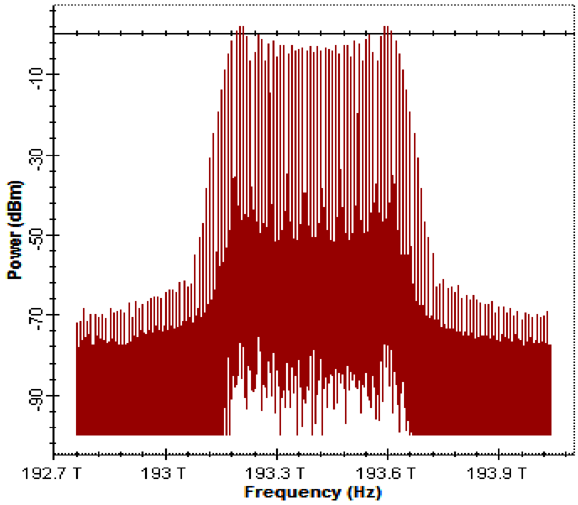

Fig 3: Output of Phase Modulator

A Mach-Zehnder Intensity Modulator can be used to increase the flatness of the comb signals [6] and passed through a band pass filter (BPF) to get only the desired number of comb lines. The spectra at the output of the band pass filter is given in Fig. 4

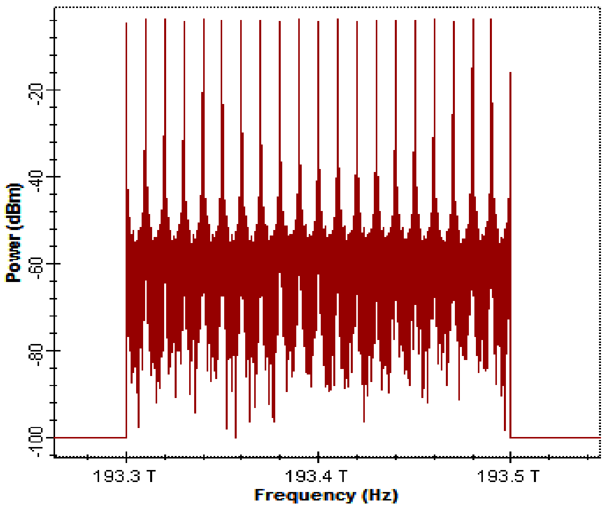

Fig 4: Output of Band Pass Filter.

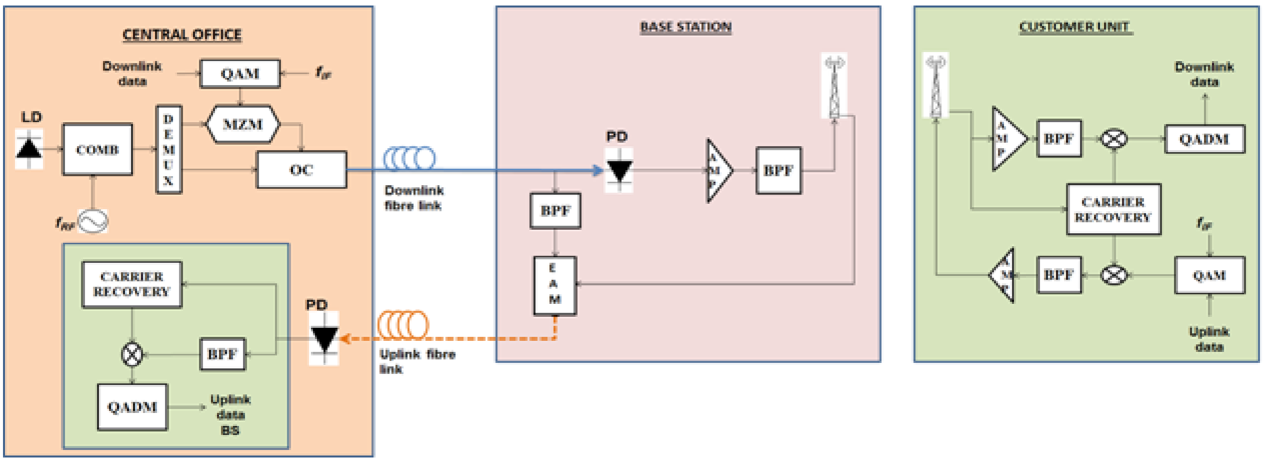

Fig 5: Schematic diagram of the proposed system

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III. SYSTEM DESIGN

The schematic diagram of the proposed RoF system is given in Fig. 5. The system is simulated by using Opt system 13 software.

The comb lines are separated from the generated comb signal by passing through a WDM demultiplexer and the first comb line $E1(t)$ with frequency of 193.49 THz and 2 Gb/s QAM data $S(t)$ are selected and modulated onto this optical carrier and double side band output centered at 193.49 THz is obtained. Another comb line $E2(t)$ at 50 GHz from the first comb and having a frequency of 193.44 THz is optically combined using an optical combiner (OC) .The combined signals are send to the BS for the generation of RF carrier of frequency 50GHz (193.44 THz-193.49 THz) at the base station. Band pass filter is used to separate 193.44 THz carrier in base station and is used as the carrier for modulating the uplink data. The transmitted spectra of modulated data centered at 193.49 THz along with reserved carrier at 193.44 THz is given in Fig. 6. The carrier at 193.49 THz can be expressed as in Eqn.2

$$E_1(t) = \gamma E_0 J_9(\pi m_{PM}) \exp(j(\omega_0 + 9\omega_{RF})t) \quad (2)$$

where γ is the insertion loss of Mach Zehnder Modulator (MZM)

Similarly, the comb line at 193.44 THz can be expressed as given in Eqn.3

$$E_2(t) = \gamma E_0 J_4(\pi m_{PM}) \exp(j(\omega_0 + 4\omega_{RF})t) \quad (3)$$

The carrier at 193.49 THz modulated with QAM signal can be expressed as given in Eqn.4. The output of optical coupler is given by the sum of the above two signals and can be expressed as in Eqn.5

$$E_3(t) = \gamma E_0 J_9(\pi m_{PM})\{\exp(j(n\omega_0 + 9\omega_{RF})t + \frac{\pi}{V_\pi}[S(t)\, exp(j(\omega_0 + 9\omega_{RF} + \omega_{IF})t] + \frac{\pi}{V_\pi}[S(t)\exp(j(\omega_0 + 9\omega_{RF} - \omega_{IF})t] \quad (4)$$

$$E(t) = E_2(t) + E_3(t) \quad (5)$$

In the base station, the PIN photodiode is used for detection. The detector output RF signal spectra is given in Fig. 7.

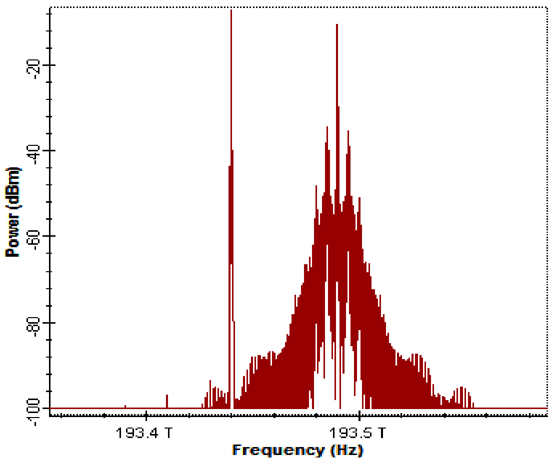

Fig 6: Spectrum of modulated data centered at 193.49 THz along with reserved comb at 193.44 THz

50 GHz carrier and QAM data are obtained in the output of detector. In the QAM data, we get both the upper side band centered at 55 GHz and lower side band centered at 45 GHz. The resulting signal is amplified and the lower side band is removed by filtering. The millimeter wave $I_{mmw}(t)$ which corresponds to the upper sideband (USB) QAM data obtained by filtering can be expressed as in Eqn 6.

$$I_{mmw}(t) = \mu\gamma^2 \frac{\pi}{V_\pi} E_0^2 J_9(\pi m_{PM}) J_4(\pi m_{PM}) * [I(t)]\cos(5\omega_{RF} + \omega_{IF})t + Q(t)\sin(5\omega_{RF} + \omega_{IF})t \quad (6)$$

where $I(t)$ and $Q(t)$ are in phase and quadrature components and μ is the sensitivity of the photodiode used. The carrier and upper side band data are transmitted from the base station to the mobile unit in wireless manner. The reserved optical carrier at 193.44 THz for uplink transmission is also separated at the base station using narrow band filtering and the filtered carrier acts as the uplink optical carrier signal.

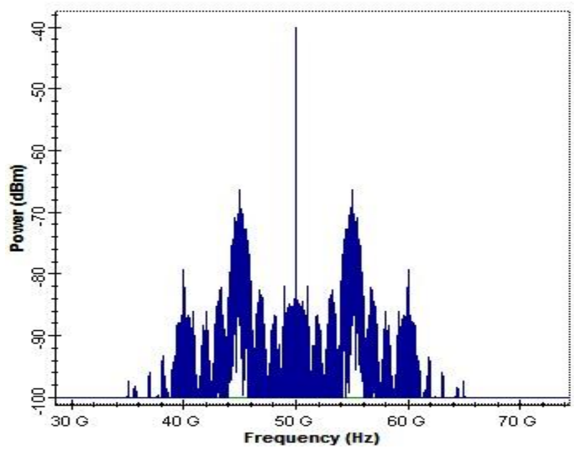

Fig 7: RF signal obtained from PIN photodiode

At the customer mobile unit, the 50 GHz pure millimeter wave is extracted for uplink transmission and the 55 GHz millimeter wave signal is filtered out for demodulation[8]. The extracted 50 GHz carrier is multiplied with the received signal using a mixer.

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The resulting signal will have dc component, QAM modulated signal at 5 GHz (f_{IF}) and its harmonic components. The downlink QAM signal is demodulated using coherent detection by beating it with the f_{IF} generated by the oscillator.

Thus the need of a 50 GHz oscillator at the mobile unit for down conversion is eliminated here. The constellation diagram of the received signal at the mobile unit is plotted and is given in Fig. 8. The eye diagrams of obtained and are given in Fig. 9. We can see a wide opening in both the eye diagrams.

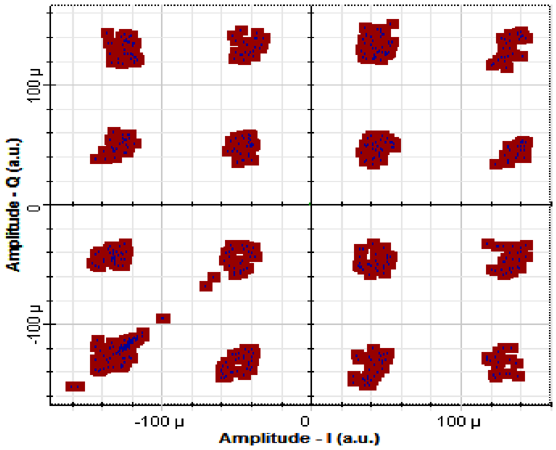

Fig 8: Constellation diagram of the received signal at the mobile unit

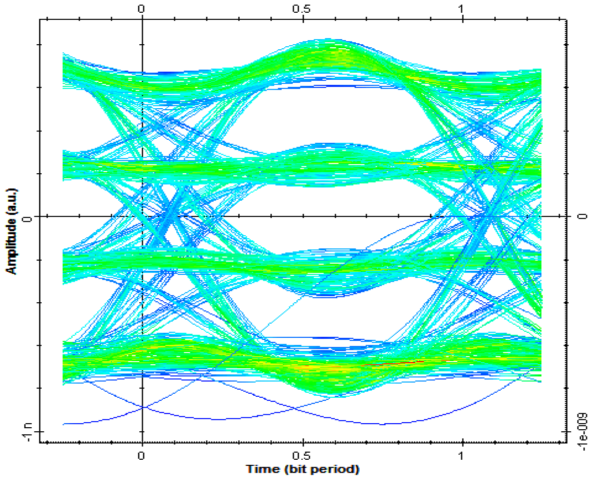

Fig 9: Received eye diagram of I branch of downlink data received

We generate a low frequency intermediate subcarrier of frequency f_{IF} in the customer mobile unit. The uplink data is modulated using QAM modulator and converted to the intermediate subcarrier frequency. We use 5 GHz as the intermediate frequency. The uplink QAM data in 5 GHz is modulated with 50 GHz extracted carrier and only the lower side band is transmitted to the base station by eliminating the upper side band. By this method we can ensure proper separation between wireless uplink and wireless down link signals.

The received RF signal from the antenna is converted to optical signal by modulating it with the extracted optical carrier at 193.44 THz in the base station using an Electro Absorption Modulator (EAM). The modulated signal spectrum is given in Fig. 10.

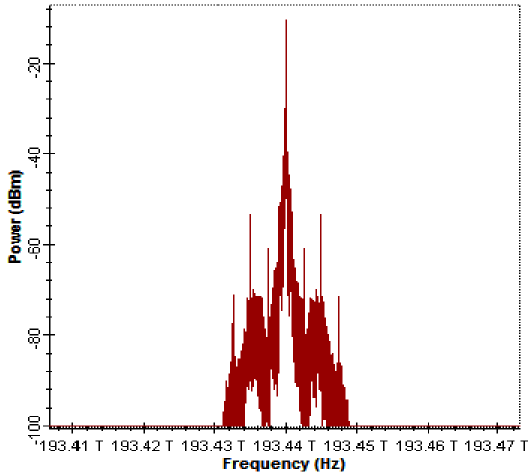

Fig 10: Modulated up link signal spectrum

This is transmitted to the central station via another single mode fiber where the signal is given to a PIN photo detector. The received signal at the output of the photo detector will be a 45 GHz RF millimeter wave signal. The carrier recovery circuit is used to extract 45 GHz RF carrier and the QAM signal at 45 GHz is coherently demodulated at the central station.

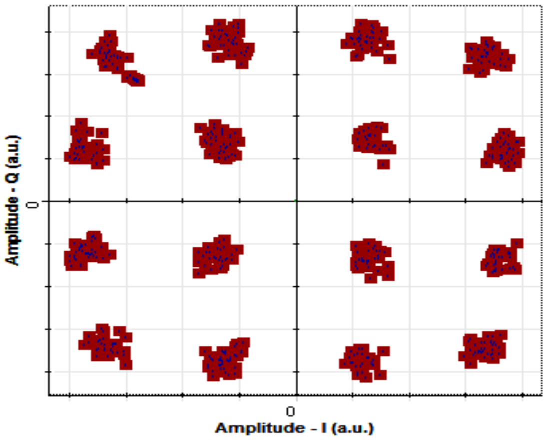

Fig 11: Received up link data constellation diagram

The constellation diagram of the received up link data is given in Fig. 11. The eye diagrams of the received signal at up link data are given in Fig. 12. The eye diagrams obtained are wide opened.

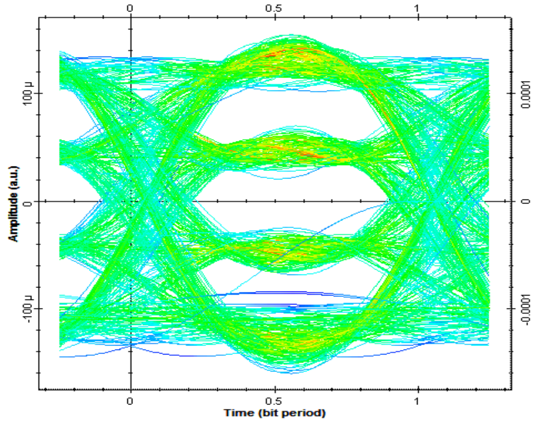

Fig 12: Received eye diagram of uplink data received

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IV. CONCLUSIONS

In summary, a novel full duplex RoF system using a single laser source is proposed. Satisfactory constellation diagrams obtained and Good eye opening for the uplink and downlink data has been observed. The frequency of operation of the base station can be changed by sending more comb lines along with the data comb line. The use of high frequency oscillator in customer mobile unit is avoided here.

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