IJCRT.ORG ISSN : 2320-2882

INTERNATIONAL JOURNAL OF CREATIVE RESEARCH THOUGHTS (IJCRT)
An International Open Access, Peer-reviewed, Refereed Journal

DESIGN AND ANALYSIS OF OPTICAL FREQUENCY MULTIPLICATIONTHROUGH RoF USING ANALOG AND DIGITAL MODULATION TECHNIQUES

[1]**R.Meenakshi,P.G scholar, Department of ECE, Alagappa Chettiar Government College Of Engineering And Technology, Karaikudi, Tamilnadu, India.**

[2]**G.Dhevanandhini,Assistant professor, Department of ECE, Alagappa Chettiar Government College Of Engineering And Technology, Karaikudi, Tamilnadu, India.**

Abstract: Radio over fiber (RoF) or RF over fiber (RFoF) refers to a technology whereby light is modulated by a radio frequency signal and transmitted over an optical fiber linkOptical frequency multiplication enables the utilization of only low frequency electro-optical components at the headend. This helps to cut back the RoF system costs, while providing high-frequency operation at the RAU. Optical Frequency Multiplication employing a FabryParot Interferometer (FPI), is demonstrated with Optisystem for generating micro/ millimeter signals optically and distributed to many remote located base stations. The simulation results show that the relative strength and frequency of the harmonics is strongly hooked in to sweep frequency, FSR, Frequency Deviation and FM index. it's observed that optical uplifting of FM radio signals to 19, 30 and 50 GHz frequencies admire 4th, 6th and 8th harmonic after transmission in optical downlink with the facility level of 10 dbm, -10 dbm and -20 dbm respectively. Similarly, PSK data is recovered from the 4th harmonic of 12 GHz. Hence, the OFM system is employed successfully for multiple functions concurrently, like high-frequency-carrier-generation, optical signal transportation, frequency up-conversion, and bi-directional data transmission through generated harmonics.

Keywords - Optical Frequency Multiplication, Fabry Parot Interferometer, FSR, modulation techniques.

1.INTRODUCTION

The fundamental principle of radio over fiber transmission is that it involves the transport of analog radio radiations through an glass fibre link; the radio signal is employed to modulate the sunshine wave, not a baseband digital signal as is common in most optical communication links. RoF transmission systems are usually classified into two main categories (RF-over-Fiber; IF-over-Fiber) reckoning on the frequency range of the radio wave to be transported. For first one is RF-over-Fiber architecture, a data-carrying RF (Radio Frequency) signal with a high frequency (usually greater than 10 GHz) is imposed on a light-weight wave signal before being transported over the optical link. Therefore, wireless signals are optically distributed to base stations directly at high frequencies and converted from the optical to electrical domain at the bottom stations before being amplified and radiated by an antenna. As a result, no frequency up/down conversion is required at the assorted base stations, thereby leading to simple and rather cost-effective implementation is enabled at the bottom stations. For other is IF-over-Fiber architecture, an IF (Intermediate Frequency) radio radiation with a lower frequency (less than 10 GHz) is employed for modulating light before being transported over the optical link. Therefore, before radiation through the air, the signal must be up-converted to RF at the bottom station. The RoF transmission mainly consists of three sections namely, Central Station (CS), Base Station (BS) and Optical Distribution Network (ODN) or fiber Network (OFN). The concept of ROF refers to the merging use of two conventional technology worlds frequence (RF) for wireless and fiber for wired transmission. Long-range metro or wide-area access links are provided by optical fibre and links to finish users are accomplished by RF wireless. A typical RoF system consists of a CO, fibre network, remote passive node, and an oversized number of base stations 2 (BSs). RoF systems perform all switching, multiplexing, signal generation and processing at the CO. An optical fibre network is employed to transparently deliver the radio signals to multiple Remote Nodes (RN) so to antenna BSs and end users.

1.1 MODULATION TECHNIQUE

Modulation is employed by singers and other vocalists to switch characteristics of their voices, like loudness or pitch. Modulation is additionally a technical term to specific the multiplication of the first signal by another, usually periodic, signal. In electronics andtelecommunications, modulation is that the process of varying one or more properties of a periodic waveform, called the carrier signal, with a separate signal that typically contains information to be transmitted. The term analog or digital modulation is employed when the modulating signal is analog or digital, respectively. Most radio systems within the 20th century used analog modulation techniques: modulation (FM) or modulation (AM) for broadcast. Most, if not all, modern transmission systems use QAM (Quadrature Amplitude Modulation) which changes the amplitude and phase of the (digital) carrier signal. The aim of analog modulation is to transfer an analog baseband (or lowpass) signal, as an example an audio signal or TV signal, over an analog bandpass channel at a distinct frequency, as an example over a limited frequence band or a cable TV network channel. The aim of digital modulation is to transfer a digital bit stream over an analog communicating, for instance over the general public switched telephone network (where a bandpass filter limits the frequency range to 300–3400 Hz) or over a limited frequency band. Analog and digital modulation facilitate frequency division multiplexing (FDM), where several low pass information signals are transferred simultaneously over the identical shared physical medium, using separate passband channels (several different carrier frequencies). The aim of digital baseband modulation methods, also called line coding, is to transfer a digital bit stream over a baseband channel, typically a non-filtered copper wire like a serial bus or a wired local area network. The aim of modulation methods is to transfer a narrowband analog signal, as an example, a call over a wideband baseband channel or, in a number of the schemes, as a touch stream over another digital transmission.

1.2 ANALOG MODULATION METHODS

In analog modulation, the modulation is applied continuously in response to the analog information signal. Common analog modulation techniques include:

1.AM (AM) could be a modulation technique employed in transmission, most typically for transmitting messages with a radio radio wave. In AM, the amplitude (signal strength) of the radio emission is varied in proportion to it of the message signal, like an audio signal. this method contrasts with angle modulation, during which either the frequency of the carrier is varied as in FM, or its phase, as in modulation.

2. FMmodulation (FM) is that the encoding of data during a radio emission by varying the instantaneous frequency of the wave. The technology is employed in telecommunications, radio broadcasting, signal processing, and computing. In analog FM, like radio broadcasting, of an audio signal representing voice or music, the instantaneous frequency deviation, i.e. the difference between the frequency of the carrier and its center frequency, contains a functional relevance the modulating signal amplitude.

3. PM Modulation (PM) could be a modulation pattern for conditioning communication signals for transmission. It encodes a message signal as variations within the instantaneous phase of a carrier. PM is one among the 2 principal sorts of angle modulation, along with FM.

1.3 DIGITAL MODULATION METHODS

In digital modulation, an analog carrier signal is modulated by a discrete signal. Digital modulation methods will be considered as digital-to-analog conversion and also the corresponding demodulation or detection as analog-to-digital conversion.

1. **Amplitude shift keying**

Amplitude-shift keying (ASK) could be a sort of AM that represents digital data as variations within the amplitude of a radio wave. In an ASK system, the binary symbol d-amplitude radio radiation and glued frequency for a small amount duration of T seconds. If the signal value is 1 then the carrier signal are transmitted; otherwise, a proof value of 0 are going to be transmitted.

2. **Frequency shift keying**

Frequency-shift keying (FSK) could be a modulation scheme within which digital information is transmitted through discrete frequency changes of a carrier signal.[1] The technology is employed for communication systems like telemetry, weather balloon radiosondes, caller ID, garage door openers, and low frequency radio transmission within the VLF and ELF bands. the only FSK

is binary FSK (BFSK). BFSK uses a pair of discrete frequencies to transmit binary (0s and 1s) information.] With this scheme, the 1 is termed the mark frequency and also the 0 is termed the space. communication systems like telemetry, weather

balloon radiosondes, caller ID, garage door openers, and low frequency radio transmission within the VLF and ELF bands. the best FSK is binary FSK (BFSK). BFSK uses a pair of discrete frequencies to transmit binary (0s and 1s).

3. **Phase shift keying**

Phase-shift keying (PSK) may be a digital modulation process which conveys data by changing (modulating) the phase of a relentless frequency reference signal (the carrier wave). The modulation is accomplished by varying the sine and cosine inputs at a precisetime. it's widely used for wireless LANs, RFID and Bluetooth communication.

2.METHODOLOGY

Next-generation wireless networks must provide high broadband access, which may be possible by integrating the 2 different technologies, the fiber optics and wireless communication. The bandwidth requirements of consumers are increasing tremendously that's motivated by bandwidth hungry applications including High-Definition TV (HDTV), IP Television (IPTV), Video-Conferencing, Video on Demand (VoD), Live-Streaming, Telemedicine, phonation IP (VoIP) and plenty of more.

They require very high-speed data transmission to meet such styles of demand of the consumers. It will be possible only by providing the glass fibre closer to the buyer premises that provides enormous bandwidth. additionally, this increasing demand for more and more bandwidth must be provided via wireless access networks. RoF (Radio-over-Fiber) technology is an appropriate means to construct a hybrid network of fiber optics and wireless access that allows seamless integration of both kinds of infrastructures. The growing data rates, emerging new services and advanced multiple wireless standards are putting up pressure on RoF to face the new challenges and opportunities presenting by a replacement era of technologies.

In RoF, to scale back the complexity and price of the bottom Station (BS), electrical and optical components which are used for the various processing functions namely RF generation, multiplexing, coding and modulation, are to be shifted to the Central Station (CS), jointly shared by an outsized number of Base Stations (BS) [2-3]. Today, a range of methods will be wont to generate and transmit frequence signals optically, but, IM/DD is extensively used thanks to its inherent easiness. during this technique, the frequence signal modulates the sunshine source directly and transmitted to the BS through optical fibre media. CW-LD either modulated directly or by employing an external modulator (Electro-Absorption Modulator/ Mach-Zehnder Modulator). The optical generation of frequence signals in micro-millimetre range is that the hot topic that demands added attention of the research scholars today. the 2 most well-liked ways to get optical microwave carrier are Remote Heterodyne Detection (RHD) and therefore the generation of harmonics optically. basics of RHD is coherent mixing of two carries within the photo detector for generating the RF signal [4] and also the frequency drift between these two carriers generated by master-slave Laser Diodes produces the wanted frequence signal. the straightforward configuration, the likelihood of generation of carrier of very high-frequency with low RF signal, insensitive to chromatic dispersion and in particular low cost are the most advantages of this method. The limited bandwidth of the PD, the necessity of complex optical filters, and unstable carrier due to variable laser phase noise are the bottlenecks to the opposite side. To cater of these bottlenecks, the extra mechanism to manage phases like Optical Injection Locking (OIL) and Optical Phase Locked Loops (OPLL), are required to achieve prime quality and highly stable carrier that increases the complexity of the system.

2.1 Generation Of Microwave Signals

an occasional phase noise and frequency-tunable microwave or millimeter-wave (mm-wave) source is desirable for several applications like in radar, wireless communications, software defined radio, and modern instrumentation. Conventionally, a microwave or mm-wave signal is generated supported electronic circuitry with many stages of frequency multiplication to realize the required frequency. The system is complicated and expensive. additionally, for several applications, the generated microwave or mmwave signal should be distributed to an overseas site. The distribution of a microwave or mm-wave signal within the electrical domain isn'tpractical because of the high loss related to electrical distribution lines, like line. due to the extremely broad bandwidth and low loss of the state-of-the-art optical fibers, the distribution of a microwave or mm-wave signal over optical fibre is a perfect solution to satisfy this task. Therefore, the flexibility to get a microwave or mm-wave signal within the optical domain would allow the distribution of the signal over an fibre from a home office to a distant site, greatly simplifying the equipment requirement. Numerous techniques are proposed and demonstrated within the previous couple of years to come up with lowphase-noise microwave or mm wave signals with the 2 or mm wave signals with the 2 optical waves being locked in phase. These techniques will be classified into four categories: 1) Optical injection locking, 2) Optical phase-lock loop (OPLL), 3) Microwave generation using externalmodulation, and 4) Dual-wavelength laser source.

2.2 Microwave Generation supported External Modulation

High-quality microwave signals may be generated supported external modulation .A method to get an mm-wave signal using an external optical modulation technique was first proposed in 1992. A frequency-doubled electrical signal was optically generated by biasing the Mach–Zehnder modulator to suppress the even-order optical sidebands. A 36-GHz mm-wave signal was generated when the Mach- Zehnder modulator (MZM) was driven by an 18-GHz microwave signal. In 1994, another method was proposed to come up with a frequency-quadrupled electrical signal. rather than biasing the Mach–Zehnder modulator to suppress the even-order optical sidebands, the tactic was supported the quadratic response of an optical intensity modulator. The optical carrier and therefore the first and thirdorder optical sidebands were suppressed by adjusting the drive amplitude. A 60-GHz millimeter-wave signal was generated when a 15-GHz drive signal was applied to the Mach– Zehnder modulator. However, to confirm a clean spectrum at the output of a photodetector, an imbalanced Mach-Zehnder filter with a free spectral range (FSR) up to the spacing of the 2 secondorder optical sidebands are accustomed suppress the unwanted optical components. Recently, an approach using an optical phase modulator to come up with a frequency-quadrupled electrical signal was proposed. during this approach, a Fabry-Perot filter was wont to select the 2 second-order optical sidebands. An electrical signal that has fourfold the frequency of the electrical drive signal was generated by beating the second-order sidebands at a photodetector. A keyadvantage of those approaches in is that an optical modulator with a maximum operating frequency of 15 GHz can generate a millimeter-wave signal up to 60 GHz.

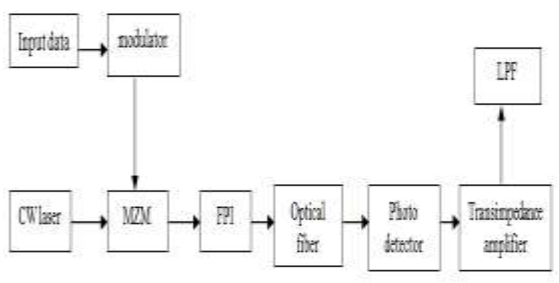


Fig.:1 Bidirectional RoF link employing OFM

Optical Frequency Multiplication (OFM) for high-frequency carrier generation. This describes the sensible implementation of a RoF downlink employing the principle of OFM. The results of in depth system experiments are used not only to validate the theoretical OFM models, but also to work out the sensible challenges that accompany the OFM system approach. Furthermore, the power of the OFM system to distribute RF signals with different modulation formats via different fibre infrastructure is additionally experimentally investigated. The OFM-system comprises a headend, and a distant Antenna Unit (RAU) as described When used as a mere oscillator (LO) generator, no fibre link between the headend and therefore the RAU is required. However, to deliver RF signals from the headend to a RAU, a fibre link in between is required. Both SMF and MMF links of various lengths were investigated.

2.2.1 CW LASER

endless wave or continuous waveform (CW) is an radiation of constant amplitude and frequency, typically a undulation, that for mathematical analysis is taken into account to be of infinite duration. Continuous wave is additionally

the name given to an early method of radio transmission, during which a sinusoidal radio wave is switched on and off. Information is carried within the varying duration of the on and off periods of the signal, as an example by code in early radio. In early wireless telegraphy radio transmission, CW waves were also called "undamped waves", to tell apart this method from damped wave signals produced by earlier spark gap type transmitters.

2.2.2 MACH-ZEHNDER MODULATOR

The Mach-Zehnder modulator (MZM) is an interferometric structure made of a cloth with strong electro-optic effect (such as LiNbO3, GaAs, InP). Applying electric fields to the arms changes optical path lengths leading to PM. Combining two arms with different PM converts modulation into intensity modulation.

2.2.3 heterodyne oscillator

In electronics, an area oscillator (LO) is an electronic oscillator used with a mixer to alter the frequency of an indication. This frequency conversion process, also called heterodyning, produces the sum and difference frequencies from the frequency of the oscillator and frequency of the signaling. Processing an indication at a set frequency gives a receiver improved performance. In many receivers, the function of oscillator and mixer is combined in one stage called a "converter" - this reduces the space, cost, and power consumption by combining both functions into one active device.

2.2.4 FABRY PEROT INTERFEROMETER

In optics, a Fabry Pérot interferometer (FPI) or etalon is an optical cavity made of two parallel reflecting surfaces . Optical waves can submit to the optical cavity only if they're in resonance with it.

2.2.5 PHOTO DETECTOR

Photodetectors, also called photosensors, are sensors of sunshine or other nonparticulate radiation. a photograph detector includes a p–n junction that converts light photons into current. The absorbed photons make electron–hole pairs within the depletion region. Photodiodes and photo transistors are some samples of photo detectors. Solar cells convert a number of the sunshine energy absorbed into current.

3. OPTICAL FREQUENCY MULTIPLICATION

The OFM system is employed to perform an outsized number of functions namely generation of the high-frequency carrier, optical signal transportation, frequency up-conversion, and bi-directional data transmission through generated harmonics.

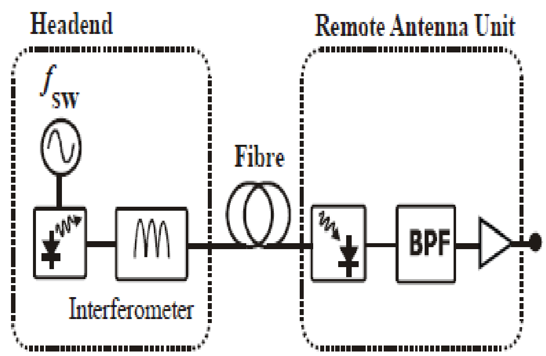


Fig:2OFMDownlink

The OFM could be a method by which a coffee frequency RF signal is up-converted to a way higher microwave frequency through optical signal processing. this is often achieved by periodic filtering and photodetection of an optical signal whose wavelength is continuously swept by the low-frequency RF signal, OFM generates several frequency components, which are harmonics of the sweep signal. Therefore, the selection of the sweep signal depends on the specified carrier frequency, which should be a multiple of the sweep signal. In general, the generation of high order harmonic components requires a greater FM index. Thus, for very high multiplication factors, the OFM system may well be less efficient spectrally, compared to another optical methods for transporting high frequency signals. The Optical Frequency Multiplication technique is employed for down-conversion and to avoid the RAU hardware complexities. rather than using the separate oscillator at RAU, the OFM generated harmonic is employed as LO. Thus OFM can help reduce system costs in next-generation dense high frequency broadband wireless systems, where numerous radioaccess units must be deployed. OFM requires a frequency-tunable source to get a swept optical signal. Such a source may well be an

4. SIMULATION DESIGN

Optisystem is an optical communication system simulation package for the planning, testing, and optimization of virtually any sort of optical link within the physical layer of a broad spectrum of optical networks, from analog video broadcasting systems to intercontinental backbones. A system level simulator supported the realistic modelling of fiber-optic communication systems, Optisystem possesses a robust simulation environment and a really hierarchical definition of components and systems. Its capabilities are often easily expanded with the addition of user components and seamless interfaces to a spread of widely used tools. Opti System is compatible with Opti wave's, Opti Amplifier and Opti BPM design tools. Optisystem serves a good range of applications, from CATV/WDM network design and SONET/SDH ring design to map design and transmitter, channel, amplifier, and receiver design. It Used for computer aided design of optical communication system. Application like FSO, optical interconnects, soliton transmission, coherent optical communication system.

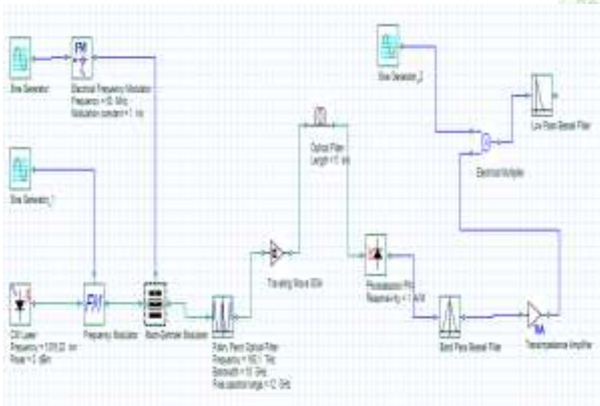


Fig:.3 downlink with FM

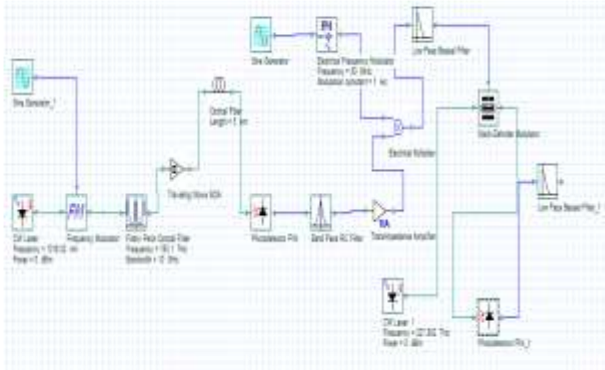


Fig.:4 uplink with FM

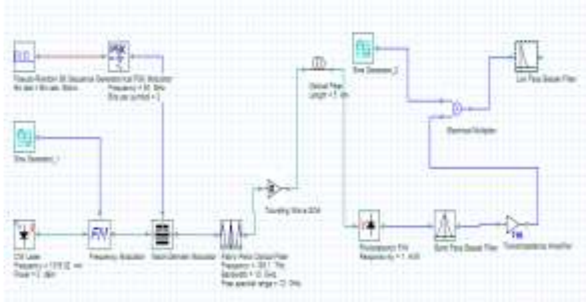


Fig.:5 PSK data modulation

An external modulator of MZM type is placed just after the Frequency modulator in this experiment, but it can also be put up in front of the FM modulator. It means that the functions of FM and IM are mutually changeable. The DFB laser output set at 1316.02206302 nm to achieve the frequency of 227.802 THz to align properly with the FPI filter that has the FSR of 12 GHz. The power and line-width of the laser is 0dbm and 2 MHz respectively. The swept signal frequency is 3 GHz and the peak to peak frequency deviation of the FM modulator is set to 24 GHz to achieve the multiplication factor of four. The responsivity of the photo detector is 0.9A/W. The 200 MHz modulated carrier with 20MHz modulating signal is fed to the MZM modulator. It is confirmed that high-frequency microwave signals can be generated and transmitted to remote antenna unit by using OFM technique successfully through a media of optical fiber. It may be single mode or multimode. The recovered microwave harmonics have outstanding quality with low phase noise. Therefore, these microwave harmonics signals may also be used for uplink transmission in a novel and economic way. Any harmonic component may be chosen with the help of an adequate bandpass filter which can be used as a LO to down-convert the uplink signal coming from the wireless terminal to an IF frequency. Because of this down-converted low frequency IF signal, the cost of the LED and FP lasers decreases tremendously for uplink resulting in simple and cost-effective RAU. Besides the generation and transportation of simple modulation formats, the complex modulation formats like BPSK, DPSK, QPSK, and QAM are also possible to transmit with OFM. This type of data transmission required a longer simulation time window (enough data points), which could not be achieved due toinsufficient computation resources.

5. RESULTS AND DISCUSSION

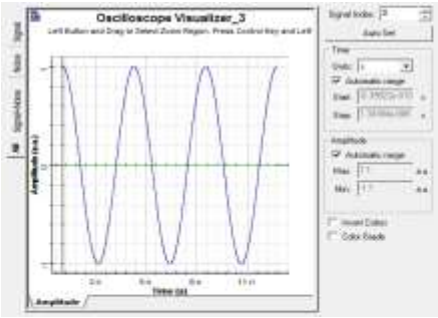


Fig.:6 Frequency modulated signal

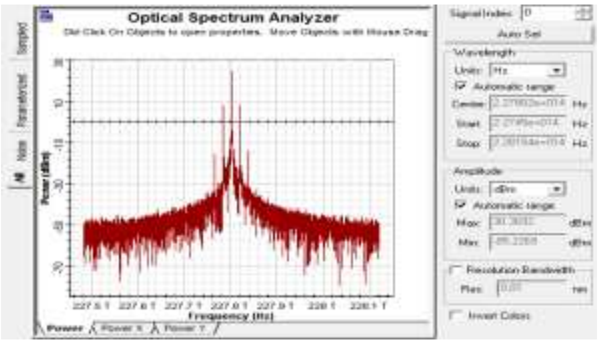


Fig.:7Spectrum of MZM output

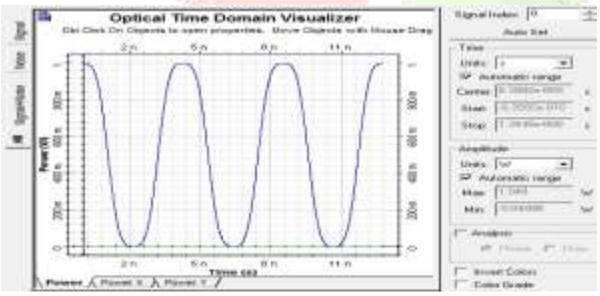


Fig.:8 FM signal at MZM output

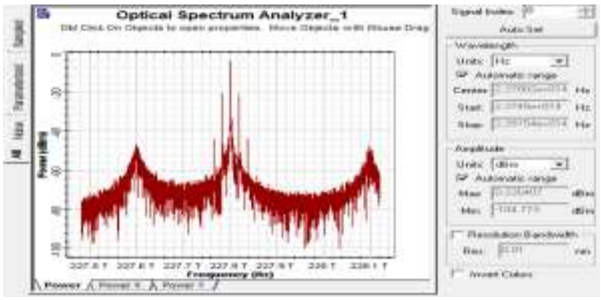
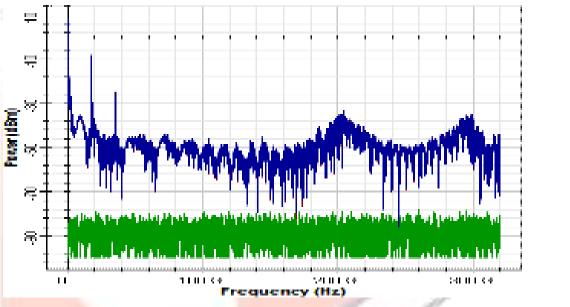


Fig.:9Spectrum at the output of FPI



S

Fig.:10Photo diode output specturm with FM

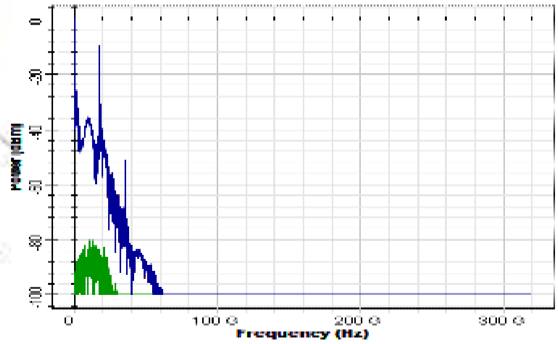


Fig.:11 BPF output with FM

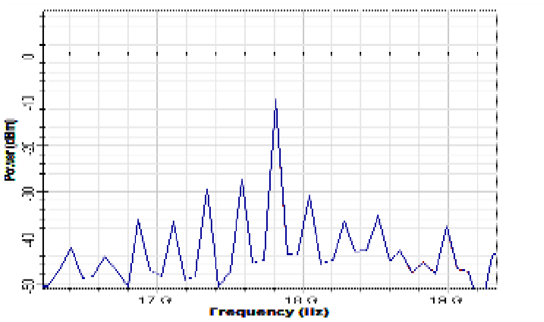


Fig.:12 FM spectrum recovered from 4th harmonic

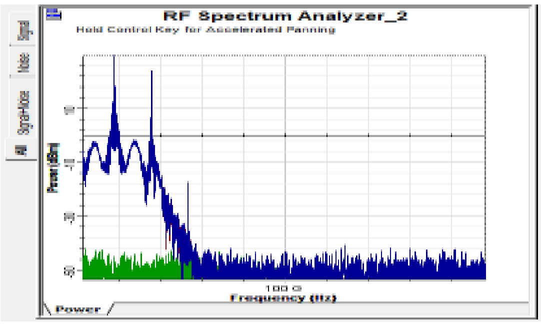


Fig.:13

4th harmonic of 19.5 GHz with FM

The outputs of all the components used in the system set up at the Central Station. the amplitude modulated signal and their spectrum at the output of electrical FM modulator..

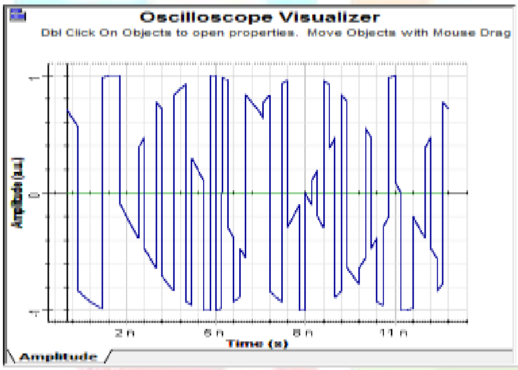


Fig.:14PSK data modulation

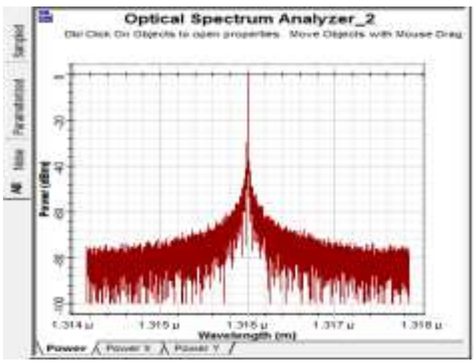


Fig.:16 1316nm laser output spectrum

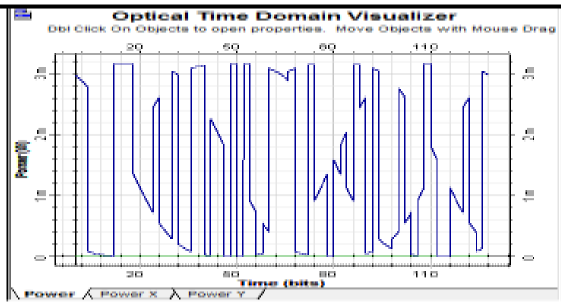


Fig.:15MZM modulator output with OTDR

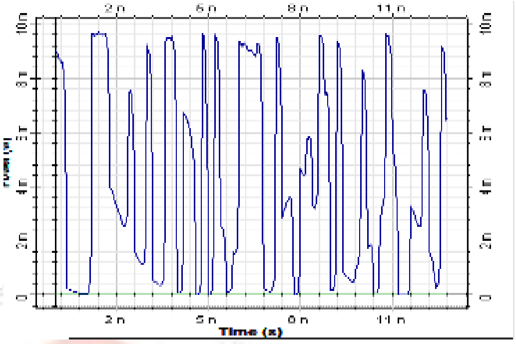


Fig.:17 FPI filter output with OTDR

At the RAU, photodiode converts the optical carrier into an electrical signal. At the output of the photodiode, the basic fundamental frequency and their harmonics are available with FM signal. Now, it is our choice that from which harmonic FM signal will be recovered.

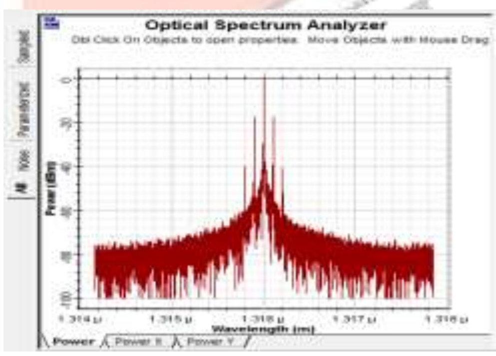


Fig.:18 3GHz swept FM output

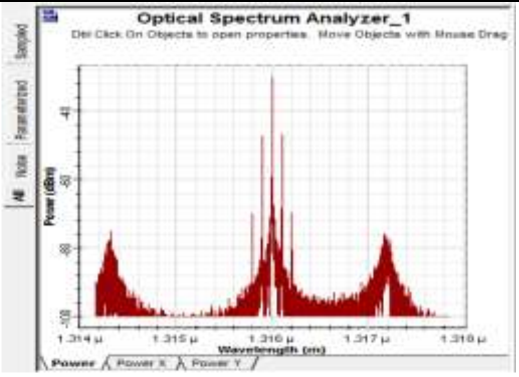


Fig.:19 FPI filter output spectrum

The output of the Electro-Optic FM modulator has the sidebands centered on the 1316 nm optical carrier at a spacing equal to the sweep signal frequency of 3GHz The sinusoidal swept optical carrier is modulated with AM signal at MZM optical modulatorThe spectrum of CW laser at 1316nm and is
applied to the FM modulator. The 3 GHz swept the optical spectrum. It shows the harmonics placed at 3GHz spacing. The optically multiplied spectrum produced by FPI.An optical transmission downlink consists of CW laser source, frequency modulator, MZM modulator, FPI and semiconductor amplifier at Central Station (CS) and a remote generation of LO at the Base Station (BS). In a similar way, RF uplink signals remotely down-converted for uplink transmission, in whichIntensity Modulation (IM) is used at the BS and detection of the light at the CS direct. The ensuing optical signal is then transmitted to the optical fiber and retrieved with the help of

6.CONCLUSION

In this dissertation work, with the simulation founded on OptiSystem, the principal of Optical Frequency Multiplication is demonstrated. the mixture of CW laser diode, the frequency modulator, an external MZM modulator with FPI periodic interferometer is successfully used as an optical source for generating the higher-order harmonics at high frequencies. The relative strength and frequency of the harmonics are strongly passionate about sweep frequency, FSR, frequency deviation, FM index and also the proper alignment between the laser and therefore the filter. the various info like PSK, and FM is transmitted in both direction downlink still as uplink successfully with the up-converted and down-converted carrier respectively. Hence, the OFM system is employed to perform an outsized number of functions namely generation of the high-frequency carrier, optical signal transportation, frequency up-conversion, and bi-directional data transmission through generated harmonics simultaneously. within the downlink, FM modulated signal at 200 MHz at the CS has beenrecovered from 4th, 6th and 8th harmonics, corresponding frequencies at 19 GHz, 30 GHz and 50 GHz at the bottom stations with the ability level of 0 dbm, -10 dbm and -20 dbm.

REFERENCES

1. Koonen A.M.J. Gracia M, Vegas Olmas J.J., Ng'oma A." Bi-directional ROF link employing OFM", IEEE photonics tech. Letter, Vol. 18, No. 1, 2006, pp 241-243.
2. M. Mohamed, B. Hraimel, X. Zhang, and K. Wu, "Efficient photonic generation of millimeter-waves using optical frequency multiplication in radio over fiber systems," Proceedings of IEEE Topic meeting on Microwave Photonics 2007, paper .
3. M. García Larrodé, Student Member, IEEE, A. M. J. Koonen, Fellow, IEEE, J. J. Vegas Olmos, Student Member, IEEE, and E. J. M. Verdurmen, Student Member, IEEE, "Microwave Signal Generation and Transmission Based on Optical Frequency Multiplication With a Polarization Interferometer", Journal Of Lightwave Technology, IEEE, Vol. 25, No. 6, June 2007.
4. M. Mohamed, X. Zhang, B. Hraimel and K. Wu, "Analysis of frequency quadrupling using a single Mach-Zehnder modulator for millimeter-wave generation and distribution over fiber systems", Opt. Express, vol. 16, no.14, Jul. 2008.
5. Haytham G. Bassiouny and Moustafa H. Aly, OSA Member, "Optical Frequency Multiplication for Up-Converting Frequencies of RF Signals for Radio over Fiber Applications", IEEE,May 2009.
6. Liwen, "Photonic Generation of Millimeter-Waves Using Two Cascaded Electro-Absorption Modulators in Radio-over Fiber Systems", August 2010.
7. Neelam Kumari and Parvin Kumar Kaushik, "A Review on Radio Over Fiber Technology", International Journal of Advance Research In Science And Engineering, February 2014, Vol. 3, Issue 2, pp. 167-179
8.K. Esakki Muthu and A. Sivanantha Raja, "Bidirectional MM-Wave Radio over Fiber transmission through frequency dual 16-tupling of RF local oscillator", Journal of the European Optical Society-Rapid Publications, 2016 12, pp. 24.
9.Badiaa Ait Ahmed, Otman Aghzout, Mounia Chakkour, Fahd Chaoui and Azzeddin Naghar, "Transmission Performance Analysis of WDM Radio over Fiber Technology for Next Generation Long-Haul Optical Networks", International Journal of Optics, 2 January 2019.

10. Bo Wang, Limei Peng and Pin-Han Ho, "Energy-efficient radio-over-fiber system for next-generation cloud radio access networks", EURASIP Journal of wireless communication and networking, 2019, Issue-118, pp. 2-8