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SUPPRESSION OF NONLINEARITY INDUCED DISTORTIONS IN RADIO OVER FIBER LINKS

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ABSTRACT

Radio over fiber is an analog-optical link proposed as a promising cost-effective solution to meet the explosive demand for broadband, interactive and multimedia services over wireless media. RoF provides functionally simple base stations that are interconnected to a control station through an optical fiber, exhibiting the exciting features of transparency to bandwidth, modulation techniques, centralized sharing of resources, multiuser-multiservice operation and immunity to electromagnetic interference. But harmonic and intermodulation distortions in laser diode and semiconductor optical amplifier affect the signal quality to a greater extent. So necessary actions must be taken to improve the signal to noise ratio. For linearizing the laser diode, a suitable predistorter circuit topology is modeled using sinusoidal and QPSK input. Similarly, the nonlinearities in SOA can be suppressed by the introduction of feedforward technique. The individual effect of predistortion in laser and feedforward in SOA are investigated and the combined effect is also investigated in this paper.

Keywords: Radio over Fiber, Feedforward Linearization, Intermodulation distortion, Harmonic Distortion.

I. INTRODUCTION

The proliferation of wireless communication services has been quite remarkable. Allied to the inherent mobility feature, wireless services are providing large bandwidth per user end. This trend is expected to be intensified, meeting the bandwidth hungry and sophiscated services.[1] The consequent need for wireless services to cope with the increasing bandwidth, demands a cost effective manner making changes in the system architecture. The support of more users at higher data rates require the use of higher radio frequencies resulting in small radio cells, due to the increased propagation losses and line of sight restrictions [2]. Due to the radio cell reduction at higher frequencies, more and more antenna sites are needed to cover a certain area. A radio base station is located within each of these sites to process and generate radio signals. Alternatively, the radio signals may be provided from a central head-end site, thereby sufficiently reducing the complexity and cost of antenna sites. In this way all signal processing functions can be consolidated at the head-end site. This allows an easier upgrade to support a new wireless standard. Due to the inherent broadband and low-loss characteristics, the optic fiber is considered to be a suitable transmission medium for transporting radio signals [3]. This innovation is said to be Radio over Fiber Technology.

Radio over fiber is an analog optical link transmitting modulating RF signals. A Radio over Fiber link consists of three stations: central station, base station and mobile station. In between central station and base station there exist optical link since the RF signals are transmitted through optic fibers. Radio signals are transmitted between base station and mobile station [3]. A Radio over Fiber consists of the entire network required to impose RF signal on an optic carrier and the network required to recover RF signal from the carrier. The modulated signal is detected by a photodiode. The photocurrent undergoes transimepedance amplification to yield a voltage which is in turn used to excite the antenna. The basic block diagram of Radio over Fiber is shown in Fig 1.

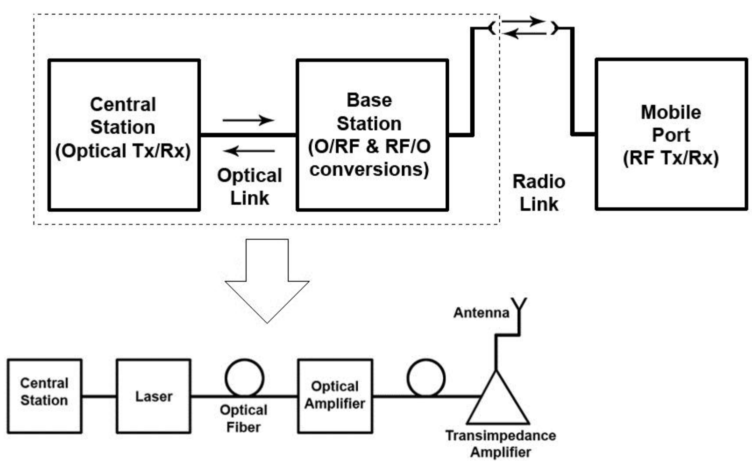


Fig. 1.1: Basic block diagram of Radio over Fiber System

Three different methods exist for the transmission of RF signals over optical fiber: a) direct modulation, where input current of laser is modulated by the information bearing RF signals (b)external modulation and (c)remote heterodyning. The simplest method for optically distributing RF signals is simply to directly modulate the intensity of the light source with the RF signal itself and then to use direct detection at the photodetector to recover the RF signal. This method falls under the IM-DD, as well as the RFoF categories. There are two ways of modulating the light source. One way is to let the RF signal directly modulate the laser diode's current. The second option is to operate the laser in continuous wave (CW) mode and then use an external modulator such as the Mach-Zehnder Modulator (MZM), to modulate the intensity of the light. The two options are shown in Figure 2.1. In both cases, the modulating signal is the actual RF signal to be distributed. The RF signal must be appropriately pre-modulated with data prior to transmission. Thus RoF requires costly high-frequency electro-optic equipment at the headend.

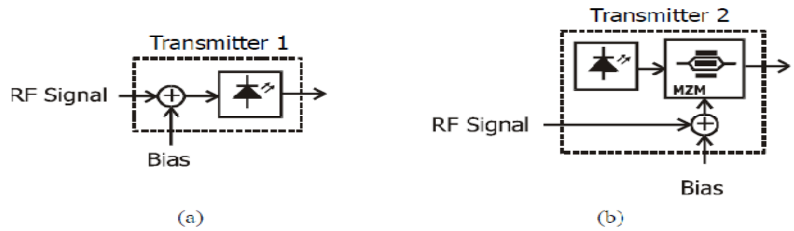


Figure 2.1: Generating RF Signals by Direct Intensity Modulation (a) of the Laser, (b) Using an External Modulator

After transmission through the fibre and direct detection on a photodiode, the photocurrent is a replica of the modulating RF signal applied either directly to the laser or to the external modulator at the headend. The photocurrent undergoes transimpedance amplification to yield a voltage that is in turn used to excite the antenna. If the RF signal used to modulate the transmitter is itself modulated with data, then the detected RF signal at the receiver will be carrying the same data. The modulation format of the data is preserved. Most RoF systems, including IM-DD RoF systems, use SMFs for distribution. However, the use of the IM-DD RoF technique to transport RF signals over multimode fibre, by utilising the higher order transmission passbands, has also been demonstrated for WLAN signals below 6 GHz [19], [20], [26].

The advantage of this method is that it is simple. Secondly, if low dispersion fibre is used together with a (linearised) external modulator, the system becomes linear.Consequently, the optical link acts only as an amplifier or attenuator and is therefore transparent to the modulation format of the RF signal [25]. That is to say that both Amplitude Modulation (AM) and multi-level modulation formats such as xQAM may be transported. Such a system needs little or no upgrade whenever changes in the modulation format of the RF signal occur. Sub-Carrier Multiplexing (SCM) can also be used in such systems. Furthermore, unlike direct laser bias modulation, external modulators such as the Mach Zehnder Modulator (MZM) can be modulated with mmwave signals approaching 100 GHz, though this comes at a huge cost regarding power efficiency [9], [11], and linearization requirements.

Due to the simplicity direct modulation is commonly used in Radio over Fiber system. There exist nonlinear relationship between input current and output power of laser resulting in distortions. While linearity is an important constraint in the design of analog light-wave transmission system, it is mandatory to keep the distortion below a certain level. To meet this stringent requirement, two techniques are used in this paper: Predistortion in laser and feedforward in SOA. By introducing a predistortion circuitry before the laser, we can create direct proportionality between input current and output power. The operation of feedforward circuit is based on the subtraction of two equal signals with subsequent cancellation of error signal.

II. PREDISTORTION TECHNIQUE IN LASER

The most useful type of a laser for optical networks is the semiconductor diode laser. The simplest implementation of a semiconductor laser is the bulk laser diode, which is a p.n junction with mirrored edges perpendicular to the junction (see Fig. 3.6). In semiconductor materials, electrons may occupy either the valence band or the conduction band. The valence band and conduction band are analogous to the ground state and excited state of an electron mentioned above. The valence band corresponds to an energy level at which an electron is not free from an atom. The conduction band corresponds to an energy level at which an electron has become a free electron and may move freely to create current flow. The region of energy between the valence band and the conduction band is known as the band gap.

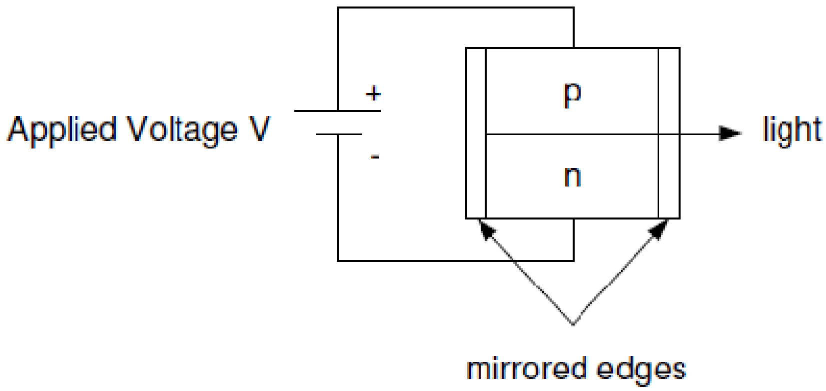


Figure 3.6: Structure of a semiconductor laser diode

An electron may not occupy any energy levels in the bandgap region. When an electron moves from the valence band to the conduction band, it leaves a vacancy, or hole, in the valence band. When the electron moves from the conduction band to the valence band, it recombines with the hole and may produce the spontaneous emission of a photon. The frequency of the photon is given by Eq. (3.1), where Ei Ef is the band-gap energy. A semiconductor may be doped with impurities to increase either the number of electrons or the number of holes. An n-type semiconductor is doped with impurities that provide extra electrons. These electrons will remain in the conduction band. A p-type semiconductor is doped with impurities that increase the number of holes in the valence band. A p-n junction is formed by layering p-type semiconductor material over n-type semiconductor material. In order to produce stimulated emission, voltage is applied across the p-n junction to forward bias the device and cause electrons in the .n. region to combine with holes in the .p. region, resulting in light energy being released at a frequency related to the band gap of the device. By using different types of semiconductor materials, light with various ranges of frequencies may be released. The actual frequency of light emitted by the laser is determined by the length of the cavity formed by mirrored edges perpendicular to the p-n junction.

The important causes of nonlinearity in laser diode are operating bias point, temperature variations, inhomogenities in active region, nonlinear energy exchanges and leakage current. Operating bias point must be chosen in a linear region for precise RF signal transfer into optical domain. In other words, modulation must take place in linear region for analog signals. If the bias point is not set properly, the modulating RF signal's optical output might get clipped at the bottom or compressed at the top, producing distorted output signal. As the temperature is increased, there is an increase in threshold current, causing a reduction in output power. Active region is the light emitting region of laser diode. The size of active region is very small ranging from few micrometers to few nanometers. Therefore, high precision is needed for the fabrication of active region. This may probably leads to inhomogenities in active region, resulting in nonlinearity in laser diode.

The nonlinear distortion of laser reflects on amplitude and phase of modulated information. Predistortion is an effective solution to linearize laser diode. This linearization method predistorts the input signal such that the amplitude and phase nonlinearity of laser diode are compensated [4]. The predistorter circuitry is introduced before the laser diode to generate frequency components which are equal in amplitude, but opposite in phase to the undesired frequencies caused by laser diode nonlinearity. The predistorter has a transfer function with gain expansion that is inverse of laser diode compression, and a phase rotation that is negative of laser diode phase rotation. The LD predistorter should be integrated with RoF transmitter in order to reduce the complexity as low as possible. This predistorter is applied to the laser diode model simulating the entire system. The nonlinearity in LD generate distortion of harmonic and intermodulation in the RF signals. The proposed digital predistortion method can be used to linearize the device.

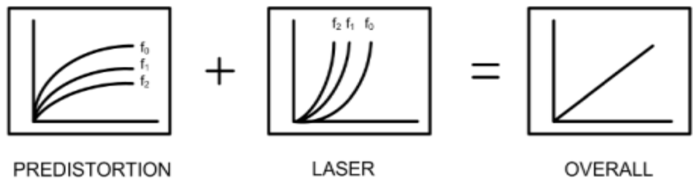


Fig.2: Laser Predistortion Principle

To reiterate, the principle of predistortion is to create direct proportionality between input signal and optical output. The figure shows the basic principle [4]. The basic principle is that when an expansive block is cascaded with compressive block, the overall nonlinearity of the laser can be reduced to an unpredictable amount. This is shown in fig 2. For different frequencies, the nonlinear behaviour also changes. Therefore predistortion transfer function should be adjusted for different frequencies. The block diagram of Laser predistortion is shown in fig 3. The signal as such is passed through the top path with a small time delay. X, X^2, X^3 blocks provide linear, second order and third order paths. The frequency profile shaping filters adjust each term to achieve the desired rate of compression.

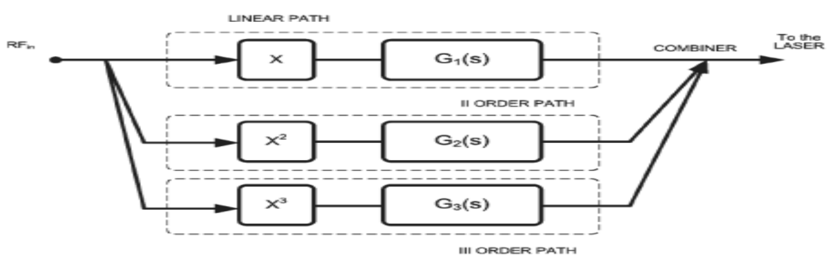
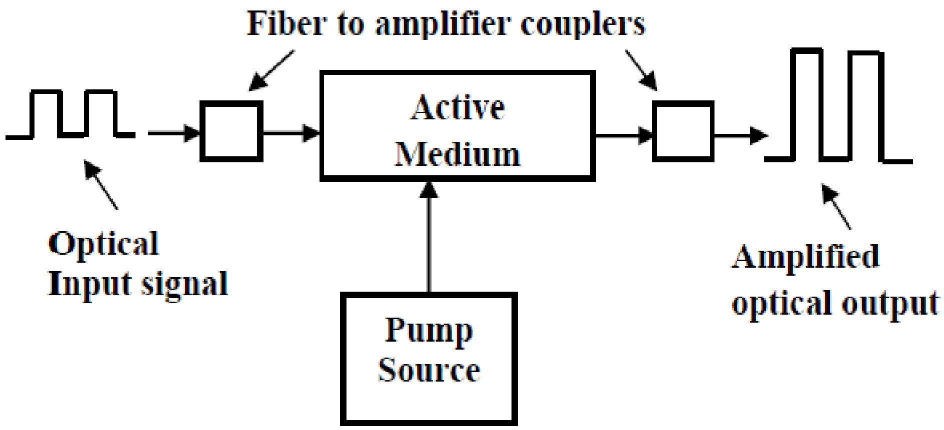


Fig.3: Block diagram of Laser Predistortion

III. FEEDFORWARD TECHNIQUE IN SOA

Semiconductor optical amplifiers increase the power level of incident light through a stimulated emission process. The mechanism to create population inversion that is needed for stimulated emission to occur is same as is used in laser diodes. Although the structure of optical amplifier is similar to that of laser, it does not have the optical feedback mechanism that is necessary for lasing to take place. Thus, optical amplifier can boost incoming signal levels, but it cannot generate a coherent optical output by itself. The basic operation is shown in figure 3.6. Here, the device absorbs energy supplied from an external source called the pump. The pump supplies energy to the electrons in an active medium, which raises them to a higher energy level to produce a population inversion. An incoming photon will trigger these excited electrons to drop to lower levels through a stimulated emission process, thereby producing an amplified signal. Alloys of semiconductor elements from groups III and V (eg: phosphorous, gallium, indium and arsenic) make up the active medium in SOAs. The attractiveness of SOAs is that they work in both the 1300-nm and 1550-nm low attenuation windows, they can easily be integrated on the same substrate as other optical devices and circuits, and compared with DFA they consume less power, have fewer components and more compact. The SOAs have a more rapid gain response, which is of the order of

1 ps to 0.1 ns. This results in both advantages and limitations. The advantage is that SOAs can be implemented when both switching and signal processing are called for in optical networks. The limitation is that rapid carrier response causes the gain at a particular wavelength to fluctuate with the signal rate for bit rates up to several Gb/s. Since this affects the overall gain, the signal gain at other wavelengths also fluctuates, which give rise to crosstalk effects when a broad spectrum of wavelength must be amplified.



Nonlinearity in SOA originates from carrier depletion at high input power, lack of proper biasing, increased bias current, optical reflection and high input impedance. As the input signal level is increased excess carriers are depleted from the active region. Any further increase in input signal will no longer provide appreciable change in output power since there are not enough excited carriers to provide stimulated emission. The harmonic and intermodulation distortions in SOA are given by

$$HD = \frac{-0.5 m x_s[\exp(G)-1](1+j2\Omega\tau_c)\{1+x_s/2[\exp(G)+1]+j\Omega\tau_c\}}{(1+x_s+j\Omega\tau_c)[1+x_s\exp(G)+j\Omega\tau_c][1+x_s\exp(G)+j2\Omega\tau_c]}$$

$$IMD = \frac{-0.25 m^2 x_s^2[\exp(G)-1](1+j3\Omega\tau_c)}{[1+x_s\exp(G)+j\Omega\tau_c][1+x_s\exp(G)+j3\Omega\tau_c]} \times \left(\frac{\exp(G)\{1+0.5x_s[\exp(G)+1]+j\Omega\tau_c\}}{[1+x_s\exp(G)+j\Omega\tau_c][1+x_s\exp(G)+j2\Omega\tau_c]} + \frac{0.5[\exp(G)-1]}{(1+x_s+j\Omega\tau_c)}\right)$$

where τ_c is the SOA carrier lifetime, G is the saturated SOA gain in neipers, m is the optical modulation index an x_s is the input signal [8].

The most important necessities of modern society are higher bandwidth, higher data rate, increased signal quality without information loss, higher secrecy and low power requirement. This leads to the deployment of Radio over Fiber system. Nonlinearity in SOA degrade the performance of the system. In order to reduce this, feedforward technique is used in SOA since there is a strong demand for a linearizer that has a simple optical circuit configuration, a minimal control circuit and large improvement in the reduction of harmonic and intermodulation distortion [5].

The fig.4 shows the basic block diagram of feedforward technique. The optical signal at the input of SOA is split into two identical paths. The signal at the top path is amplified by the main power amplifier. Because of the nonlinearities present in the main power amplifier, harmonic and intermodulation distortions are being added to the original signal. The block diagram that is shown in fig. reveals the model of RoF system which utilizes feed forward technique at the SOA in order to linearize its output. The nonlinearities present in SOA results in harmonic and intermodulation distortions.

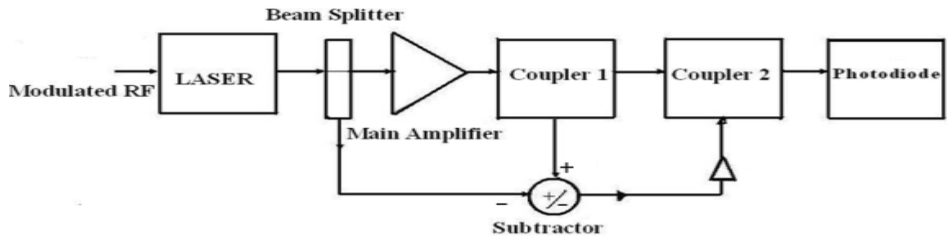


Fig.4: Block diagram of Feedforward Technique

The first directional coupler (C1) permits the distorted signal to reach the substractor. The other end of substractor is fed by the input signal of SOA which is referred to as reference signal that comes from the beam splitter that is placed before the semiconductor optical amplifier. The output of the substractor will be the distortion caused due to the nonlinearity in SOA, which is referred to as error signal. This error signal is amplified by means of an error amplifier and fed to the second coupler. The signal from the top end after a time delay, reaches the other end of the coupler so that the distortion products are cancelled at the output of the second coupler. The main path signal through coupler 1 is time delayed by an amount equal to the time delay through error amplifier and fed to the output coupler. The amplified error signal is fed in antiphase to the original input signal, so that amplified original input signal will be the result. The optical feed forward linearization system is made up two loops: error-determination loop and distortion-cancellation loop. The unwanted distortion signals add in anti-phase, resulting in an output with suppressed distortion products. Both error determination and distortion-cancellation loops need amplitude and phase for cancellation of the distorted signal at the optical coupler.

IV. COMBINED EFFECT OF PREDISTORTION AND FEEDFORWARD TECHNIQUE

In Radio over Fiber systems, laser and SOA are nonlinear devices. Both of these introduce distortions in the system. By suitable shaping in a given frequency range, predistorter circuitry compensates both harmonic and intermodulation distortions in laser while feedforward technique in SOA. The combined effect reduces the overall nonlinearity to a greater extent.

V. RESULTS AND DISCUSSION

A. Predistortion in Laser

The predistorter is applied to the laser model simulating the entire system. A suitable predistorter circuit topology is made by choosing a configuration characterized by two independent nonlinear channels that generate second and third order correction signal. These are subsequently combined with the delayed transmit signal to intensity modulate the LD. Here simulations are carried out with a QPSK modulated RF signal of 2 GHz frequency, modulating the laser. It can be extended for higher frequencies also. The fig 5 shows the result when a simple sinusoidal signal is used as the input to laser. There is an improvement of 40% to second order distortion and 30% to third order distortion. The fig. 6 shows the result when a QPSK signal is used as the input to laser. There is an improvement of 30% to second order distortion and 20% to third order distortion.

B. Feedforward Technique In SOA

Path with equal amplitude and opposite phase can completely cancel the distortion over an enlarged bandwidth. But in practical RoF system, accurate matching of matching and phase cannot be achieved so that it limits the amount of distortion reduction. There is an improvement of 20 dBc to second order distortion and 30 dBc to third order distortion as shown in fig.7 .

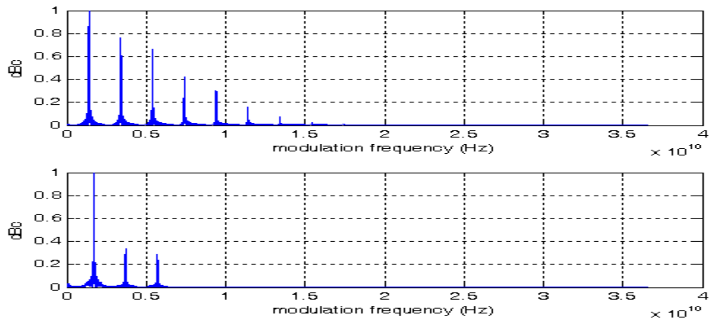


Fig.5: Simulation of Predistortion principle using sinusoidal input

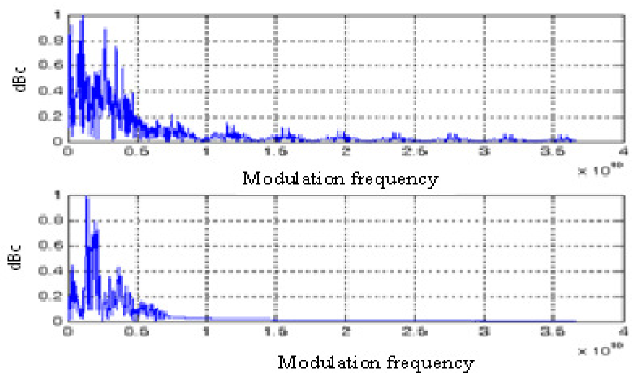


Fig.6: Simulation of Predistortion principle using QPSK input

C. Combined Effect Of Both The Techniques

The fig. 8and fig. 9 shows the combined effect of both the techniques. There is an improvement of 25% to second order distortion and 15% to third order distortion.

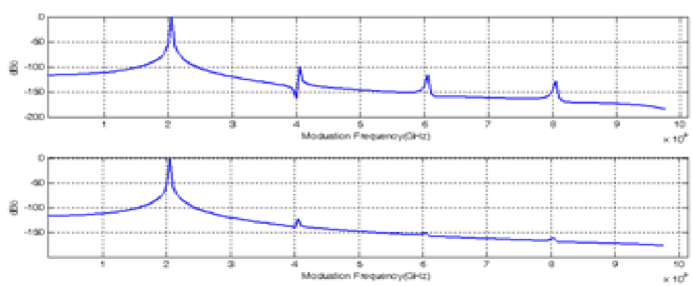


Fig.7: Simulation of feedforward technique in SOA using sinusoidal input

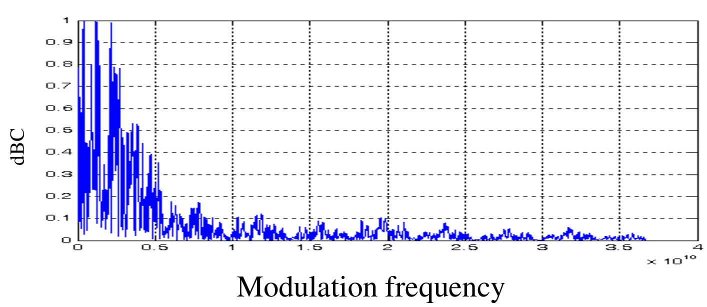
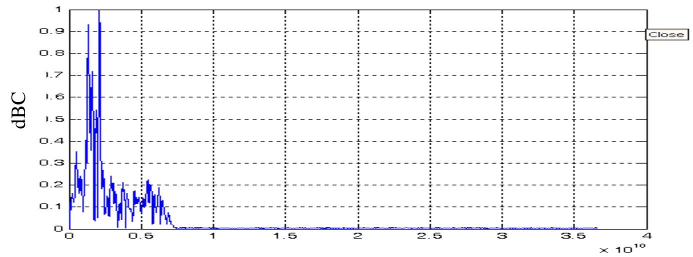


Fig.8: Distorted signal without any effect



Modulation frequency

Fig.9: Corrected signal using combined effect

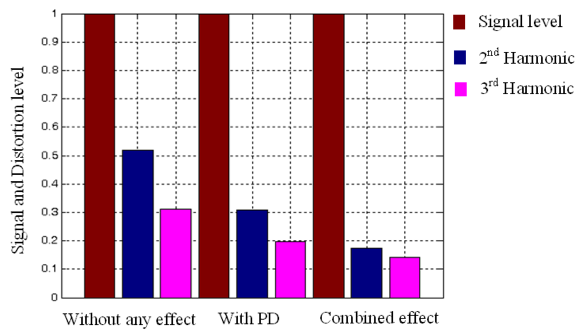


Fig.10: Comparison of the used Techniques

VI. CONCLUSION

The individual effect of predistortion in laser and feedforward in semiconductor optical amplifier used in Radio over Fiber system has been investigated. With predistortion alone, there is an improvement of more than 50 dBc. The simulation result verified the feedforward technique for single tone as well as for multi tone signals .There is an improvement of better than dBc for single tone signal .A performance enhancement of more than 25% has been observed for second order distortions and 20% for third order distortions by the combined effect of both of these techniques. The fig. 10 shows the comparison of the tehniqus which came to the conclusion that combined technique is most suitable. Future works may include GSM, and WLAN systems.

IV. REFERENCES

[1] Eszter Udvary , Tibor Berceli , Marek Chacinski , Richard Schatz , Pierre-Yves Fonjallaz, "Reduction of Dispersion Induced Distortions in Radio over Fibre links", Proceedings of the 38th European Microwave Conference, October 2008

[2] P Shen,A. Nkansah., " Multilevel Modulated Signal Transmission for Millimeter-Wave Radio over Fiber System " University of Kent,UK,2008 IEEE

[3] Pardeep Kaur, R.S.Kaler, "Radio over Fiber Networks,"Proceeding of National Conference & Opportunities in Information Technology (COIT-2007), March 23, 2007

[4] M.Gadheri,S.Kumar,D.E.dodds, "Adaptive predistortion linearizer using polynomial functions, "IEEE Proc.Common .,vol.141,no .2,April 1994

[5] P.B.Kenington, "High linearity RF Amplifier Design"Norwood,MA:Artech House,2000

[6] A.H.Coskun and S.Demir, "A mathematical characterization and analysis of a feedforward circuit for CDMA applications," IEEE Trans. Microw. Theory Tech.,vol.14,no.3,pp.767-777,Mar.2003.

[7] N.Pothencary, "Feedforward Linear Power Amplifier,"Norwood,MA:Artech House,2000.

[8] Javier Harrera, Francisco Ramos, and Javier Marti, "Nonlinear distortion generated by semiconductor optical amplifier booster in analog optical systems" OPTICS LETTERS / Vol.28,No.13/July 1, 2003.

[9] Venkatesh Kumar.N, Raghavendra.N, Subash Kumar T.G and Manoj Kumar.K, "Improving the Global Parameter Signal to Distortion Value in Music Signals using Panning Technique and Discrete Wavelet Transforms", International Journal of Electronics and Communication Engineering & Technology (IJECET), Volume 4, Issue 1, 2013, pp. 1 - 10, ISSN Print: 0976- 6464, ISSN Online: 0976 –6472.

[10] Srijibendu Bagchi, "Cognitive Radio: Spectrum Sensing and Performance Evaluation of Energy Detector under Consideration of Rayleigh Distribution of the Received Signal", International Journal of Electronics and Communication Engineering & Technology (IJECET), Volume 2, Issue 1, 2011, pp. 17 - 23, ISSN Print: 0976- 6464, ISSN Online: 0976 –6472.

[11] Mohammed Arifuddin Sohel, Dr. K. Chennakeshava Reddy and Dr. Syed Abdul Sattar, "Linearity Enhancement of Operational Transconductance Amplifier using Source Degeneration", International Journal of Advanced Research in Engineering & Technology (IJARET), Volume 4, Issue 3, 2013, pp. 257 - 263, ISSN Print: 0976-6480, ISSN Online: 0976-6499.

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