Journal of Engineering Technology Vol. 2(1): 47-53, 2012
ISSN 2231-8798

Photo Parametric Amplifier Configuration for Optical Wireless Transmission

M.F.L Abdullah & M.F.M. Elbireki
Department of Communication Engineeirng
Faculty Electrical & Electronic Engineeirng
Universiti Tun Hussein Onn Malaysia

Corresponding email: faiz@uthm.edu.my

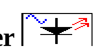
Abstract: An optical receiver design fundamental requirement has two very important features in getting reliable system, which are the achievement of high sensitivity and broad bandwidth. This paper presents a receiver circuit based on Photo Parametric Amplifier (PPA), which is one of the alternatives for receiver detection and amplification techniques. The PPA mode of operation involves optical detection and amplification within a single device where it is able to provide selectivity and sensitivity at the same time, as required for wireless optical communications. The most common problem for any communication system might face is the noise which must be eliminated or reduce to its minimum. Therefore, in order to reduce the noise, filters have been implemented before the signal is passes through an amplifier. This paper describes how an Up converter has been placed at the transmitter circuit in order to obtain high frequency, while at the receiving end, filters has been placed with Down converter to obtain the desired frequency. Photodetection is achieved using a PIN photodiode to detect any incoming signal at the receiver circuit. Simulated results showed that the output signal has been improved; achieving more strength power and noise reduction which showed that PPA is more reliable and suitable to be used in an optical wireless communication system. The transmitted signal gain detected at the photodiode, equals 37dBm at the frequency of 193.4THz while the gain obtained after the PPA is 45.60dBm for the same frequency. Therefore, the desired strength signal has been achieved after the signal passes through the amplifier with desired frequency value.

Keywords: Downconverter, PPA, receiver and transmission amplifier, upconverter

1.0 INTRODUCTION

Photoparametric amplifier is a device similar to electrical parametric amplifiers with the distinction that they use a photodiode instead of a varactor to perform photodetection and parametric amplification simultaneously. This paper provides an overview of literature review and full understanding of the optical receiver components, characteristics and design considerations. Literature review concerning the photo parametric amplification technique is used as the basic, where the work has been discussed in [1, 3, 5, 7, 10]. For conventional PPA circuit at high sensitivity circuits, the total input source Pump (LO) can severely limit the available bandwidth from the circuit. Therefore, the best way to permit the full gain bandwidth characteristic of an op-amplifier to be fully exploited is by using Photo Parametric Amplifier technique. Therefore, a PPA circuit simulated using Optiwave will be studied and analyzed theoretically, especially the effects of wavelength and low responsively of the photo detectors.

2.0 THEORY OF TRANSMITTER AND RECEIVER COMPONENTS

2.1 CW laser 

This component is to generates a continuous wave (CW) optical signal**.** In the CW case, the average output power is a parameter that can be specify by user. Laser phase noise is modeled using the probability density function:

$$f(\Delta\varphi) = \frac{1}{2\pi\sqrt{\Delta f\, dt}} \cdot e^{-\frac{\Delta\varphi^2}{4\pi f dt}} \ldots\ldots\ldots\ldots (1)$$

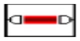
where $\Delta\varphi$ is the phase difference between two successive time instants and dt is the time discretization. A Gaussian random variable for the phase difference between two successive time instants with zero mean and a variance equal to $2\pi\sqrt{\Delta f}$ has been assumed, with Δf as the laser Line width. The output is multiplied with a complex vector considering the state of polarization.

$$\begin{pmatrix} E_X(t) \\ E_Y(t) \end{pmatrix} = \begin{pmatrix} \sqrt{1-K} \\ \sqrt{K e^{j\theta}} \end{pmatrix} \cdot \sqrt{P(t)} \ldots\ldots\ldots\ldots (2)$$

where the power splitting k and the phase difference θ are related to the parameters Azimuth α and Elasticity ϵ as follows:

$$\tan(2\alpha) = \frac{2\sqrt{K(1-K)\cos(\theta)}}{1-2.K} \ldots\ldots\ldots (3)$$

$$\sin(2\epsilon) = 2\sqrt{K(1-K)\sin(\theta)} \ldots\ldots\ldots (4)$$

2.2 OWC channel 

This component model represents the optical wireless communication (OWC) channel. It is a subsystem of two telescopes and the wireless communication channel between them. This component allows the simulation of free space optical links [2, 6]. The optical signal received at the receiver is given by:

$$P_R = P_T \eta_T \eta_R \left(\frac{\lambda}{4\pi Z}\right)^2 G_T G_R L_T L_R \ldots\ldots (5)$$

where P_T is the transmitter optical power; η_T is the optics efficiency of the transmitter; η_R is the optics efficiency of the receiver; λ is the wavelength; Z is the distance between the transmitter and the receiver, given by the parameter range; G_T is the transmitter telescope gain; G_R is the receiver telescope gain; and, are L_T, L_R the transmitter and the receiver pointing loss factor, respectively. The term in parentheses is the free-space loss and it can be removed from the equation if the parameter free space path loss is disabled. Parameter Geometrical gain defines whether the user will enter the value of transmitter and receiver gain directly or estimate the gain for a diffraction-limited beam. The gain that can be expressed by:

$$G_T \approx \left(\frac{\pi D_T}{\lambda}\right)^2 \ldots\ldots\ldots (6)$$

where D_T is the transmitter telescope diameter. Similarly, the receiver telescope gain that can be expressed by:

$$G_T \approx \left(\frac{\pi D_R}{\lambda}\right)^2 \ldots\ldots\ldots (7)$$

where D_R is the receiver telescope diameter.

Most of the system uses a narrow-beam-divergence angle laser transmitter and narrow field of view receiver; hence small misprinting can cause signal loss. The approximation transmitter pointing loss factor is given by:

$$L_T = \exp\left(-G_T \theta_T^2\right) \ldots\ldots\ldots (8)$$

where θ_T is transmitter azimuth pointing error angle, and the approximation receiver pointing loss factor by:

$$L_R = \exp\left(-R\theta_R^2\right) \ldots\ldots\ldots (9)$$

where θ_R is receiver azimuth pointing error angle. Additional losses due to scintillation, misprinting, and others are specified by the parameter. Additional losses Parameter Propagation delay allows for calculation of the delay between transmitter and receiver.
If the parameter intensity scintillation is enabled, a Gamma-Gamma distribution [4, 8,9] is used to model atmospheric fading. In this case the probability of a given intensity I is:

$$P(I) = \frac{2(\alpha\beta)^{(\alpha+\beta)/2}}{\Gamma(\alpha)\Gamma(\beta)} I^{(\alpha+\beta)/2-1} K_{\alpha+\beta}\, 2\sqrt{\alpha\beta I} \ldots\ldots (10)$$

where 1 / α and 1 / β are the variances of the small and large scale eddies, respectively.[9] Γ (…) is the Gamma function and $K_{\alpha-\beta}$ (…) is the modified Bessel function of the second kind.

$$\alpha = \exp\left[\frac{0.49\sigma_R^2}{\left(1+1.11\sigma_R^{12/5}\right)^{5/6}}\right] - 1 \ldots\ldots\ldots (11)$$

$$\beta = \exp\left[\frac{0.51\sigma_R^2}{\left(1+0.69\sigma_R^{12/5}\right)^{5/6}}\right] - 1 \ldots\ldots\ldots (12)$$

The Rytov variance is calculated from:

$$\sigma_R^2 = 1.23\, C_n^2 K^{7/6} Z^{11/6} \ldots\ldots\ldots (13)$$

where C_n^2 is the parameter Index refraction structure, k is the optical wave number and z is the parameter range. Channel time variations are considered according to the theoretical quasi-static model, also known as the frozen channel model. This model, channel fading is considered to be constant over the duration of a frame of symbols (Coherence time), therefore changing to a new independent value from one frame to next.

2.3 Photo detector PIN 

The incoming optical signal and noise bins are filtered by an ideal rectangle filter to reduce the number of samples in the electrical signal. The new sample rate is defined by the parameter sample rate. The center frequency can be defined, or it can be calculated automatically by centering the filter at the optical channel with the maximum power.

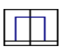
Optical noise bins are converted to Gaussian noise inside the signal bandwidth. The combined optical field is then converted to optical power. If the option Numerical - Convert Noise Bins is selected, the output noise and signal are combined. This means that the user cannot see the separate contributions of the noise. However, if user selects Numerical only, the signal and noise are separated and user can select the different contributions of the noise.

2.4 Combiner 2x1 

This component combines evenly two input signals into a single output port. The s-parameters for the combiner are:

$$s_{o_{1I_i}} = [-3dB - \alpha]\angle 0^{\circ} \text{.........}(14)$$

where α is the parameter insertion loss (dB), N is the number of input ports and it is the input port index.

2.5 Filter 

Pass is an adjective that describes a type of filter or filtering process; it is frequently confused with pass band, which refers to the actual portion of affected spectrum. Otherwise Optical filter with a rectangle frequency transfer function.The filter transfer function is:

$$f_c - B/2 < f < f_c + B/2 \text{ Otherwise } \quad H(f)=\{ \begin{matrix} \alpha, \\ d, \text{ ... ... } \end{matrix} \text{(15)}$$

where H(*f*) is the filter transfer function, α is the parameter insertion loss, d is the parameter depth, fc is the filter center frequency defined by the parameter frequency, B is the parameter bandwidth, and f is the frequency.

2.6 Trans-impedance amplifier 

This component is an electrical trans-impedance amplifier with user defined noise Fig.. It has linear gain and additive thermal noise. This component amplifies the input electrical signal and adds thermal noise to the signal output. The value of the thermal noise is calculated from the input SNR and the user can defined the parameter noise Fig.. Since Optiwave system can have noiseless electrical signals, the parameter input noise density assures a minimum value for the noise floor at the input signal.

3.0 PROPOSED PPA TECHNIQUE

Fig. 1 and Fig. 2 illustrated the proposed PPA circuit. The proposed PPA consisted of a laser source, pump laser source, two high OBPF, a photodiode and an amplifier.

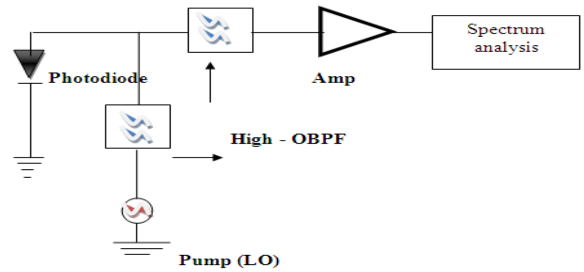


Fig. 1 Block diagram of PPA at the receiver

The proposed transmitter circuit is shown in Fig. 2, where the laser source generate the trasnmitted signal; the generated signal will pass through the OWC channel. During its travel, energy is dissipated through the OWC channel, the signal will lose its power. Therefore, in order to increase the power again, pump source will generate another signal, where the signal will be compared with the initial signal by the Up converter. The Up converter will then choose the signal with the highest amplitude to be transmitted. At the receiver circuit as shown in Fig. 1 the incoming signal will bedetected by the photo diode. The incoming signal is weak due to losses along the OWC and additional noise, therefore, the pump source and filter at the receiver side is used to increase the power and to filter noise of the incoming signal. Down converter is proposed before the signal passes through the filter in order to reduce the noise. When the signal passes through the amplifier, the signal strength will increase with minimum noise.

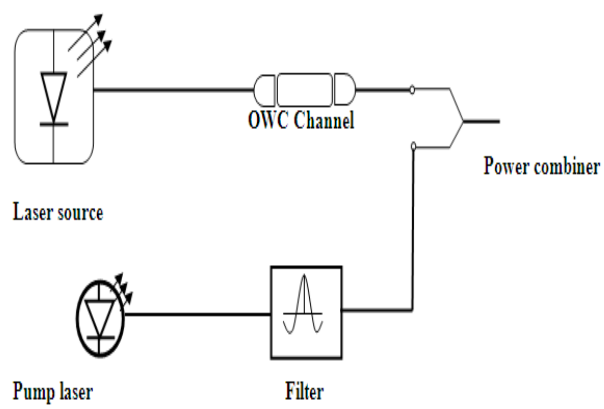


Fig. 2 Block diagram of PPA at the transmitter

4.0 OPERATING OF THE TRANSMITTER AND RECEIVER CIRCUITS

4.1 Transmitter circuit

When the CW laser source generate a signal, the signal is passed through the OWC channel and Up converter. This converter receives two signals, the first signal from the OWC channel and the second signal from the pump laser. The Up converter then regulates both of these signals and pushes them up to the limited frequency where it will be sent to the receiver circuit.

4.2 Receiver circuit

The photo diode detects any coming signal and converts it from an optical signal to an electrical signal. The converted signal is then combined with the sin generator signal. Both of these signals will be compared using the down converter. Then the converter down signal will pass through the filter which accepts only the desired signals.

5.0 PARAMETRIC AMPLIFIER COMPONENTS

5.1 Up converter

This is a unilateral, stable device with greater bandwidth than the negative resistance amplifier, which is rather limited, since it is dependent on the ratio of output to input frequencies. Therefore the Up converter circuit is used to obtain the higher signal between the incoming signals into the circuit.

5.2 Down converter

Photo Parametric Down converters could considerably simplify the receiver end of microwave subcarrier systems where it can perform photo detection amplification and down conversion simultaneously. Since a number of investigators have indicated that the tunnel diode is capable of operation as a low noise mixer with gain, directed toward evaluating various Down converter circuit arrangements as a substitute for the more conventional approach of an RF amplifier and resistive mixer. Therefore, Down converter in this work is use to obtain the lower signal between the incoming signals.

6.0 PROPOSED PPA DESIGN SIMULATED USING OPTIWAVE

The circuit shown in Fig. 3 (a), Fig. 3 (b) is transmitter design and Fig. 3 (c), Fig. 3(d) is the receiver design simulated using the Optiwave software:

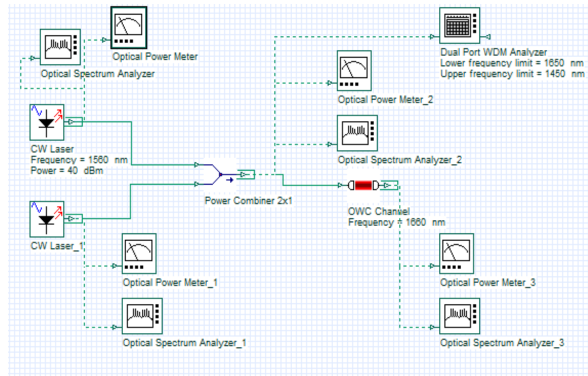


Fig. 3 (a) Part 1 of transmitter

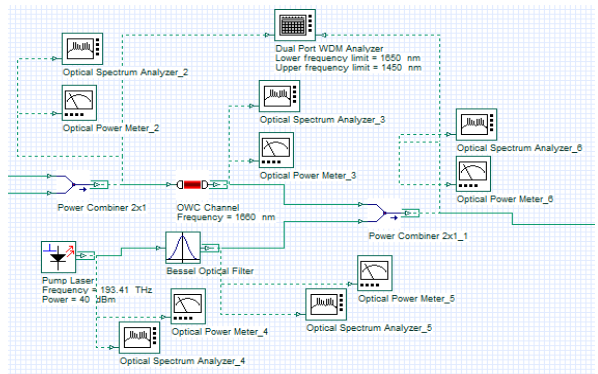


Fig. 3 (b) Part 2 of transmitter

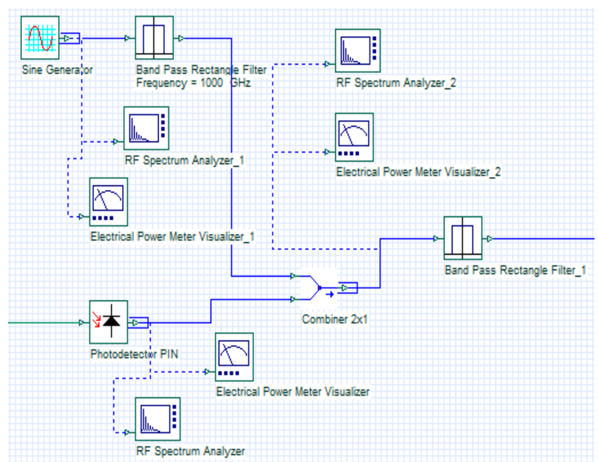


Fig. 3 (c) Part 1 from receiver

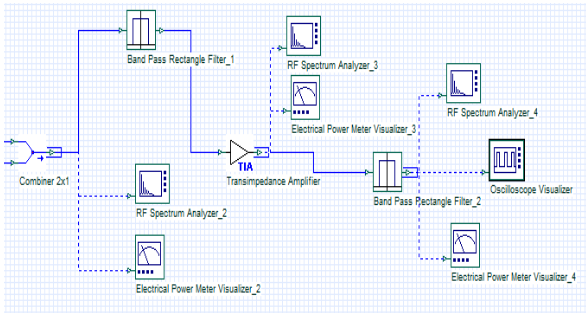


Fig. 3 (d) Part 2 from receiver

7.0 SIMULATION RESULTS AND ANALYSIS

7.1 Signals at CW laser source output

The result obtained from the simulation of optiwave is shown in Fig. 4, where, the input frequency is 193.4THz and the input power is 40dBm. The width of the signal is between 185THz to 211THz including noise.

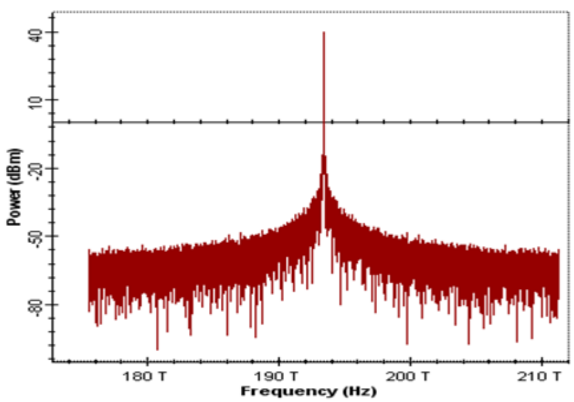


Fig. 4 Laser source output

7.2 Signal after OWC channel

The display signal in Fig. 5 shows that, the value after the signal passed the OWC channel has the same bandwidth value as the transmitted signal but the power is less than before because power losses due to fading effect. The power's value is only15.118dBm.

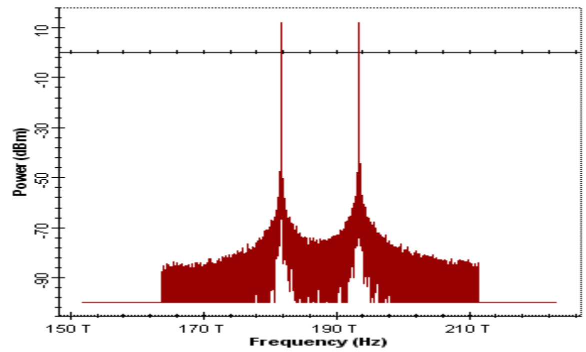


Fig. 5 Signal after passing the OWC channel

7.3 Pump source characteristics

Fig. 6 shows the output of the pump source before the combination of the input signal in order for the pump power to be stronger. The pump signal occurred at the frequency equals to 193.4THz, the bandwidth is between 192.4THz to 194.4THz and the power value is 40dBm.

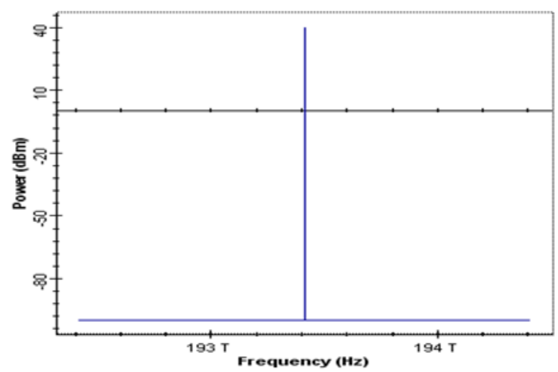


Fig. 6 Pump Source Signal

7.4 Signal after the combiner

Fig. 7 shows the input signal after the combiner, where it is noticed that the pump source, the input source power is stronger than before passing through the pump source, the value of the power is 37dBm and the bandwidth value is still the same.

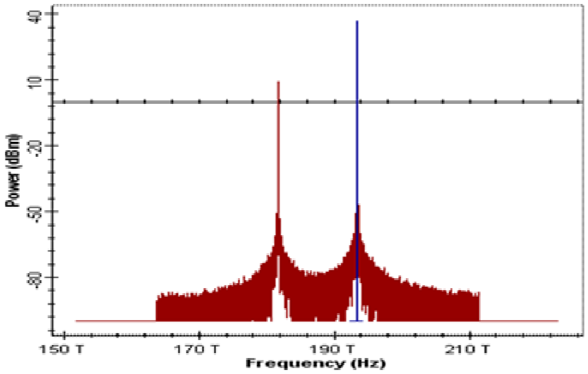


Fig. 7 Signal after the combiner (up converter)

7.5 Signals at the photodiode

Fig. 8 shows that the detected signal at the photo diode produce a value equals to 35.977dBm at the same frequency. It is noticed that the optical signal is changed to electrical signal using the photo diode.

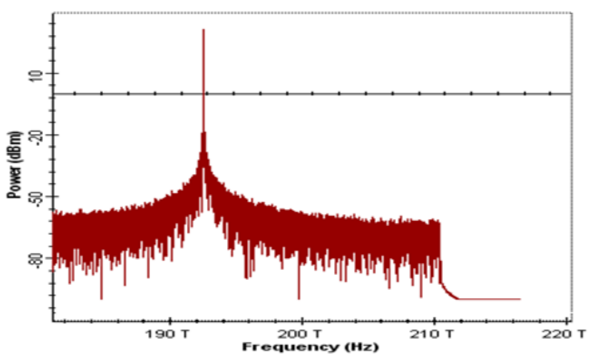


Fig. 8 Detected signals at the photodiode

7.6 Pump source at the receiver

The power source generates a signal that has a value of power which is, 40dBm and the frequency obtained is equal with the optiwave simulation value which is 193.4THz. The bandwidth is between 191.8THz to 193.8THz.

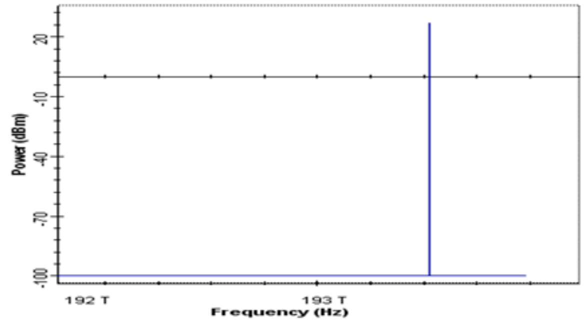


Fig. 9 Pump Source signal at the receiver end

7.7 Signal after the combiner at the receiver

The combiner combined the signal from the photo diode and other signal from the pump source at the receiver end. The power value here is equal to 33.665dBm.

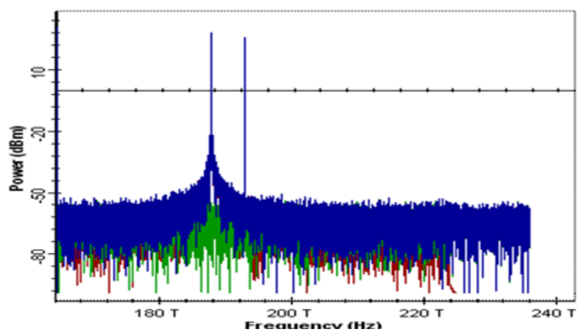


Fig. 10 Signal before the filter (with noise)

7.8 The amplifier signal

Fig. 11 shows the output signal generated using optiwave software. After the signal pass through the amplifier, it is noticed that the value of the amplitude and power increased as well. The value of the power at that moment is 45.604dBm.

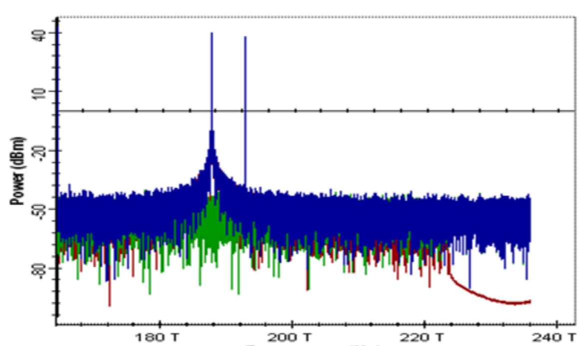


Fig. 11. Amplifier Output

8.0 CONCLUSION

Up converter has been used at the transmitter to send a high power signal and that was implemented using pump source signal because the laser source signal has lost its power after going through the OWC channel. The transmitted signal which is detected at the photodiode, power is equals 37dBm and frequency 193.4THz.

Down converter has been used at the receiver circuit, where the photo diode, PIN type is used to detect any incoming signal. Down converter circuit has been used to pass the lower signal and then the signal is passed through an amplifier. The signal after passing through the amplifier obtained more strength and the noise has been reduced. At the receiver end, the signal gain is 35.977dBm and the frequency is 193.4THz has been detected by the photodiode which converts the signal from optical signal into electrical signal. Before the signal pass through the amplifier the gain is 33.665dBm which is the same transmitted frequency value. When the signal passed through the amplifier, the signal obtained more strength where the gain is 45.604dBm and the frequency still remained the same value. The desired signal strength has been achieved after the signal passed through the amplifier with the desired transmitted frequency value.

The receiver circuit must be connected with resistance and inductance in order to reduce the noise of the incoming signal. When connecting the resistance and inductance, the signal will get more strength and the noise is reduced which is the main goal of this paper.

REFERENCES

[1] A.Khanifar and R.J.Green**, "**Photo parametric amplifiers for subcarrier multiplexed communication systems"**,** *IEE Proceedings Optoelectronics*, v146, n5, p223-229, (1999).

[2] A. Polishuk ,S.Arnon, "Optimization of a laser satellite communication system with an optical preamplifier", *J. Optical Society of America. Vol. 21, No. 7,*pp 1307-1315, July (2004).

[3] D.J.ROULSTON," Low-Noise Photo parametric Up Converter*", Journal Solid-state Circuit*, SC3, n4, p431-440, (1968) .

[4] Farid, A.A., Hranilovic, S," Outage Capacity Optimization for Free-Space Optical Links With Pointing Error*", Journal of Light wave Technology, vol. 25, no. 7*, pp. 1702-1710, July (2007).

[5] Khanifar and R. J. Green, "A. Photo-Parametric Amplifier /converter In Subcarrier Multiplexed Light wave Communication Systems*", Proceedings MTT-S Int. Microwave Symp, Albuquerque*, NM, USA, 761-764,(1992)

[6] S.Arnon, "Performance of a laser satellite network with an optical preamplifier", *J. Optical Society of America. Vol. 22, No. 4*, pp 708-715, April (2005)

[7] S. M. ldrus, R. J. Green and A. S. M. Supa'at," Nonlinear Analysis for Performance Characterization of a Photo parametric Amplifier", *APACE*2005, Johor Baharu, Malaysia, 301-305, (2005)

[8] Larry C. Andrews, Ronald L. Phillips, Cynthia Y. Hopen, "Laser Beam Scintillation with Applications*", SPIE PressBook*, (2001).

[9] Larry C. Andrews, Ronald L. Phillips," Laser Beam Propagation through Random Media*", 2nd edition, SPIE Press Book*, (2005).

[10] Mark S. Leeson, Roger J. Green, Matthew D. Higgins, "Photo parametric Amplifier Frequency Converters", *10th Anniversary International Conference on Transparent Optical Networks, ICTON* 2008 , *Athens, Greece, IEEE*, 197 – 200 (2008)