Chapter 3

Research Designs and Methods

First, PD frequency response measurement system based on the MZM technique has been set up and performed at NTC Telecommunications Research Laboratory, Department of electrical engineering, Faculty of engineering, Chiang Mai University. A standard MZM is used for generating the two-tone stimulus signal instead of a high-extinction ratio MZM as originally proposed [1]. Moreover, an optical coupler is used to direct the two-tone stimulus signal for difference measurements. This modified measurement system has been proposed [20].

In this work, we use an EDFA to control the two-tone optical signal power. There are two approaches to accomplish this. The first approach is by pre-amplifying the light before MZM and the second approach is by amplifying the light after MZM modulation. The goal of optical amplifier is to increase the signal to noise ratio of the converted RF signal of the photodiode at high frequencies as the pointed out.

3.1 PD Frequency Response Measurement Setup without Using EDFA [20]

The proposed PD frequency response measurement system is shown in figure 3.1. A commercially available MZM (JDSU Microwave modulator AM-150) with standard extinction ratio performance is used to generate a two-tone light signal whose frequency separation is twice the modulating RF frequency ($2\omega_{RF}$). The optical carrier is generated by a tunable DFB laser at wavelength 1550nm. The RF frequency is generated by an Agilent N5182A synthesized CW generator in frequency range from 100kHz to 6GHz and then, is amplified by a wideband amplifier (SHF 115 BP). The polarization controller is used to adjust the polarization of the carrier to obtain low transmission loss through the MZM. The optical carrier ω_0 is suppressed by biasing the MZM at null point ($\phi_B = \pi$) using a programmable Agilent E3632A power supply. The bias voltage is controlled by computer by considering the different RF frequency components to achieve the optical two-tone signal. The on-off extinction ratio of the MZM is approximately 30dB. The previous study shows that this is sufficiently large for acceptable frequency response error [5]. Optical couplers are used to direct the two-tone signal to either the optical power meter (Anritsu ML9001A), the photodiode (DUT) or the RF spectrum analyzer. From the 90:10 fiber coupler, 10% of light is directed to the optical power sensor for the measurement of the two-tone light power. Another 9% of the remaining power is used for setting the MZM bias by an RF spectrum analyzer. Therefore, approximately 81% of two-tone light power is used to stimulate the PD. The use of couplers should enable faster automated measurement, where it takes shorter time to obtain stable readings as the modulation frequency is swept. The measured insertion losses due to fiber couplers through different port pairs are considered, where L_{A90}, L_{B90} and L_{A10} denote the insertion losses in coupler A and B of the 90% and 10% ports as indicated. The tested photodiodes consist of a Picometrix PD model P-18A (responsivity 0.9 A/W) having approximately 19 GHz bandwidth and a Picometrix PD model PT-15C (responsivity 1.0 A/W) having approximately 15 GHz bandwidth. The RF power sensor is an Agilent N1913A wideband thermal sensor that has bandwidth 18 GHz and measurement noise level of 10 nW (-50 dBm). The RF spectrum analyzer is an Agilent 8593E that has bandwidth 22 GHz. Therefore, PD frequency response values combined with optical coupler insertion loss is obtained,

$$\kappa[dBe] = 10\log P_{RF} - 20\log(5P_{opt}) - 2(L_{A10} + L_{B90} - L_{A90}), \qquad (3.1)$$

where L_{A90}, L_{B90} and L_{A10} are the measured insertion losses as shown in table 3.1.

Table 3.1 Insertion losses of the optical couplers

Optical coupler ports	Insertion loss (dB)
L_{A10}	-10.62
L_{A90}	-1.42
L_{B10}	-10.64
L_{B90}	-1.58

To obtain the frequency response of the PD across broad frequency range, the frequency of the RF signal generator is swept from 0 to 6 GHz with the step of 50 MHz step or smaller. At each frequency the optical power before entering the PD is measured, and the RF power after the PD conversion is also measured. The frequency response is calculated using equation (3.1).

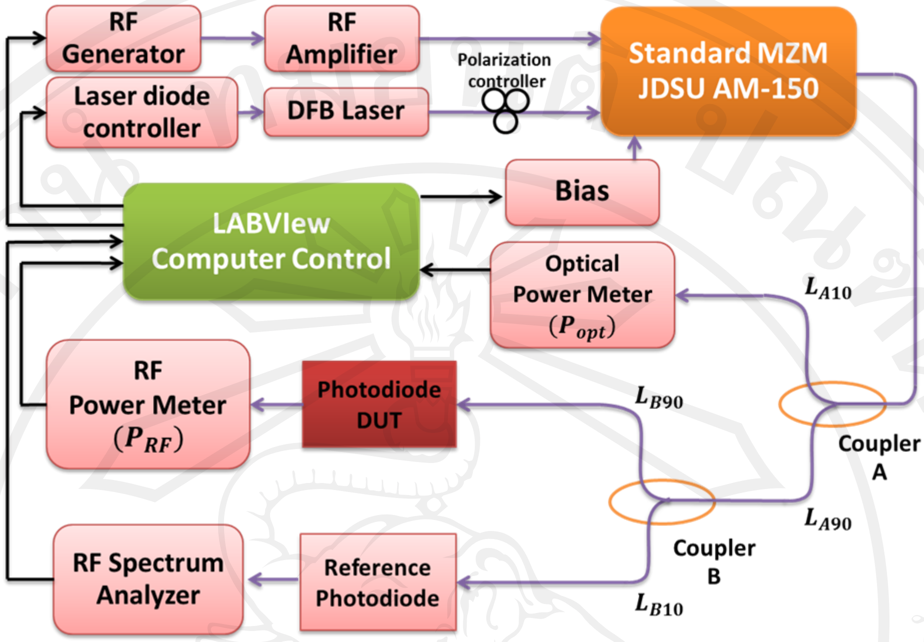

Figure 3.1 PD frequency response measurements system

The devices in the system are automatically controlled by a computer using LabVIEW programming via the GPIB port which has developed in our laboratory. This enables precisely and faster control. The front panel of the program is shown in figure 3.2, consisting of frequency response result and the space for entering the setting values for measuring compliance with the requirements including frequency start, frequency stop, frequency step-size, RF power, initial MZM bias, optical couplers insertion loss. When the measurement process complete, the measurement results are saved in a text file format for easy to calculations and analysis.

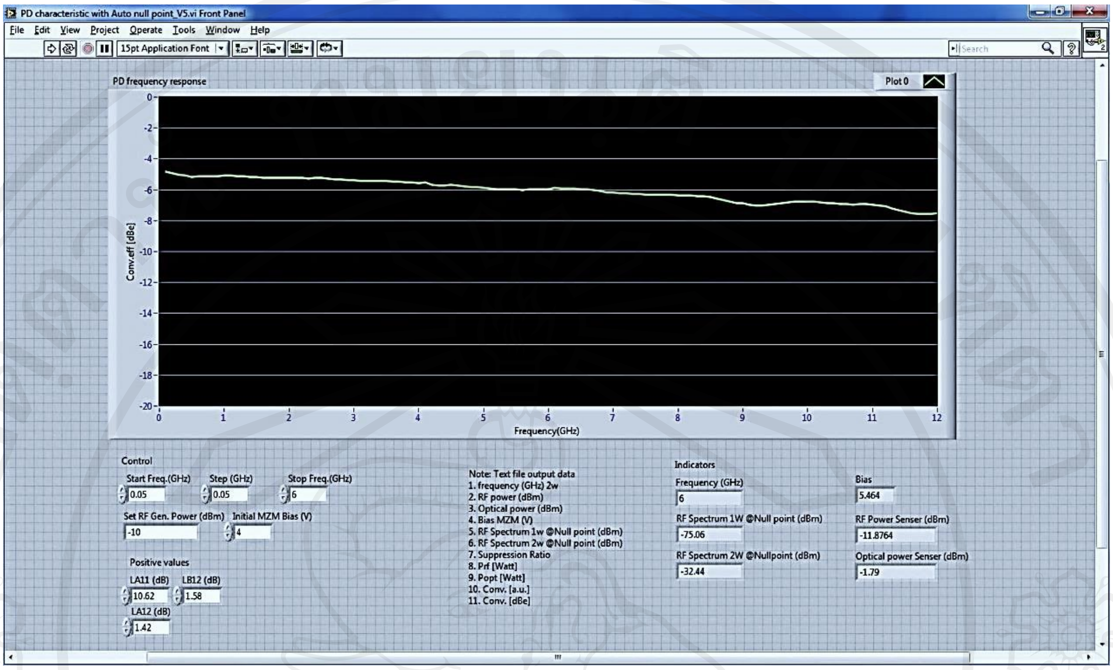

Figure 3.2 LabVIEW front panel

3.2 PD Frequency Response Measurement Setup Using EDFA

3.2.1 EDFA is used as a Pre-amp before the Laser Output is Modulated by an MZM

Setup the measurement system by the same as in previous section. Then, the EDFA is set as a pre-amp before the light carrier is modulated by an MZM as shown in figure 3.3. A tunable optical band pass filter is required to reduce ASE noise in frequency outside 1 nm band.

The goal of using EDFA as a pre-amp is to amplify the light carrier to difference power level before being launched into the MZM. The maximum amplifier gain of the EDFA is 25dB. Since the MZM has maximum input power level at 23dBm. We therefore vary the input power level from its maximum level to the lower level while the converted RF extinction ratio is considered. Nevertheless, the use of an EDFA in high input power regions resulting in the gain saturation where the maximum output power from the EDFA as high as only 13dBm can be reached. Moreover, the tunable DFB laser can generate the maximum optical carrier power as high as only 13.5dB. By the two factors above, the maximum light carrier power about 13.5dBm can be provided.

Therefore, using EDFA as a pre-amp is ignored. The experimental setup for this pre-amplifying case is the same as in figure 3.1. To determine the best input optical power for the MZM, the input power levels is varied from 13.5dBm to the lower level as much as possible by using only a DFB laser as a light source. In each varied input optical power level, the frequency is swept from 100MHz to 12GHz by the step of 100MHz. In each test frequency, the 1st, 2nd and 3rd harmonics values are recorded from the RF spectrum analyzer. The converted RF extinction ratio which is the ratio between the 1st and 2nd harmonics from the RF spectrum analyzer is calculated. The best input optical power level is considered by looking for the highest converted RF extinction ratio over the tested frequency range.

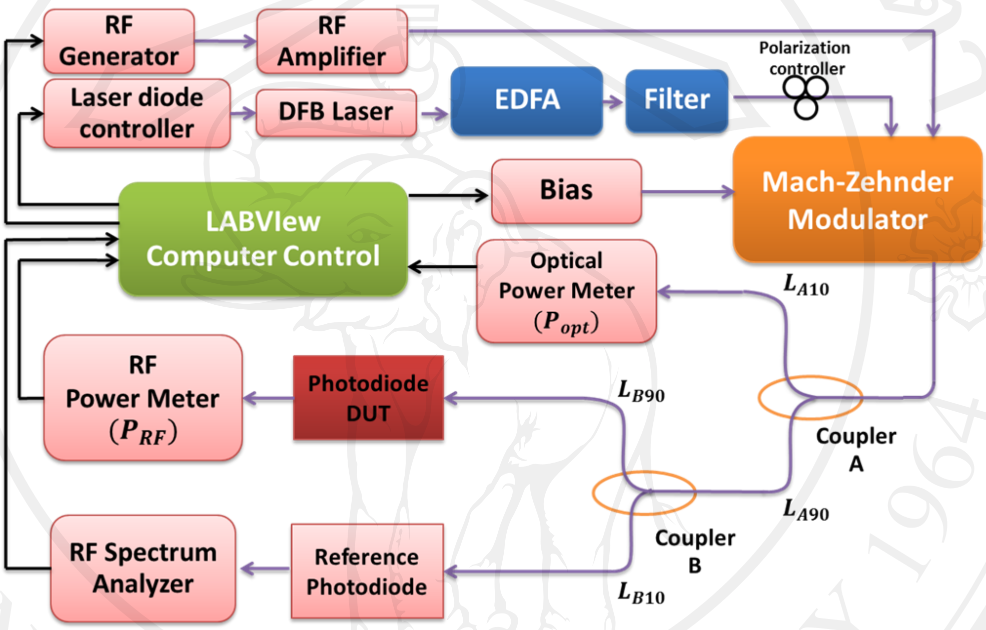

Figure 3.3 PD frequency response measurements using EDFA as a pre-amp

3.2.2 EDFA is used as a Post-amp for the Two-tone Signal Modulated by an MZM

Setup the measurement system the same as in previous section. Then, the EDFA is set as a post-amp to amplify the modulated two-tone lightwave from the MZM as shown in figure 3.4 with constant output power mode referred as "gain-controlled EDFA". A tunable optical band pass filter is also required to reduce ASE noise in frequency outside band of 1 nm. The best input optical power level for the MZM which obtained in previous section is used. Since the goal of using EDFA as a post-amp is to make the constant two-tone stimulus signal level to improve the signal to noise ratio of the converted RF signal. EDFA gain is tunable, where the maximum gain is 25dB. It should be note that the MZM has the insertion loss about 5dB [21]. Therefore, to determine the best constant two-tone optical power level, the EDFA operating mode is set to the constant output power mode which output power level varied from 1mW to 13mW can be adjusted in 1mW step. In each varied constant optical power level, the frequency is swept from 100MHz to 12GHz by the step of 100MHz. In each test frequency, the 1st, 2nd and 3rd harmonics values are recorded from the RF spectrum analyzer. The converted RF extinction ratio is calculated. The best constant two-tone optical power level is also considered by looking for the highest converted RF extinction ratio over the tested frequency range. In this post-amplifying case, the issue of power imbalance of the two-tone light must be considered since both EDFA and optical filter may cause the unequal gains of the light of different wavelengths.

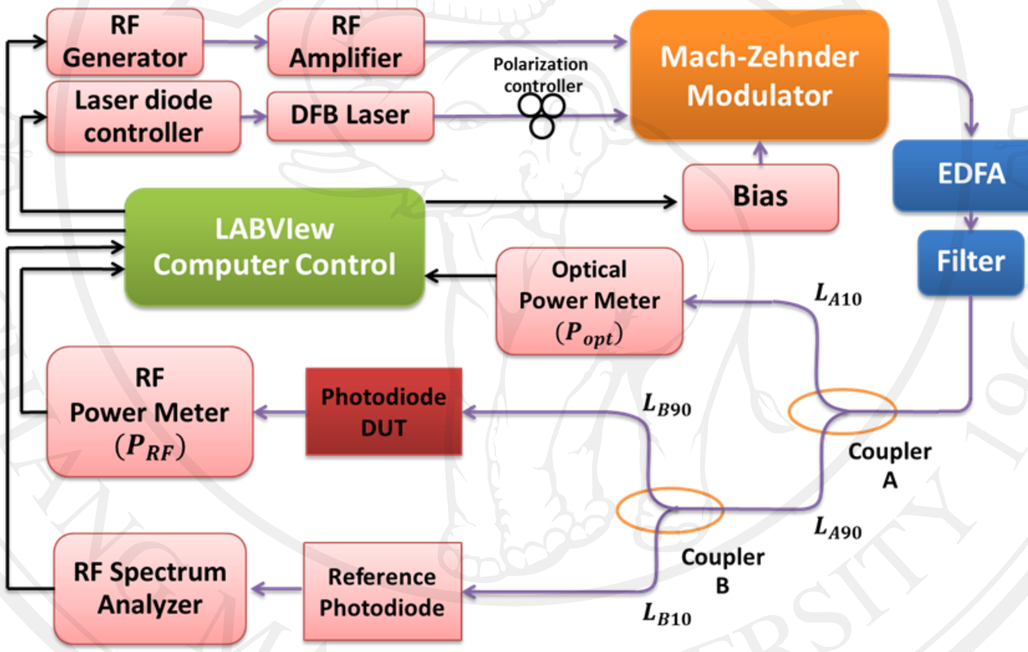

Figure 3.4 PD frequency response measurements using EDFA as a post-amp

3.3 EDFA Characterization

When the EDFA is used, there are some fundamental characteristics that we should know such as Noise figure, Gain saturation and Gain spectrum. The measurement results can be applied to the two-tone amplification in this work appropriately.

The system components are shown in figure 3.5. A DFB tunable laser (FITEL-FRL-15TCWA) is used as a light source controlled by a laser diode controller (LDC-3724C). The wavelength can be tuned from about 1525 to 1560nm. An EDFA (AEDFA-PA-25) is used to amplify the two-tone signal as a DUT in this experiment.

An optical power meter (Anritsu ML9001A) is used to measures the input optical power. An optical Spectrum Analyzer (Agilent 86142B) is used to analyze the output optical spectrum from the EDFA. An optical coupler is used, insertion loss in each port pair is considered. The LabVIEW computer controller is used to control both the optical wavelength and optical power via the laser diode controller by changing current biasing and controlling temperature control. The measured data are recorded by computer. These recorded data are the input optical power and the output optical spectrum. After that these will be used for gain calculation and ASE noise estimation.

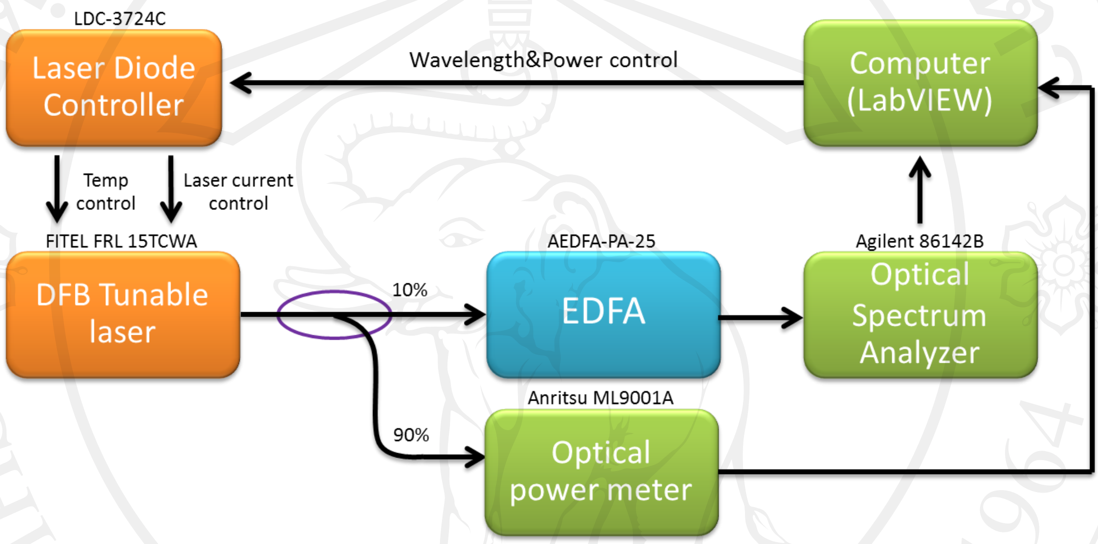

Figure 3.5 EDFA characterization measurement system

3.3.1 Noise Figure

Noise figure is one of the most important parameters to indicate the noise performance of an EDFA. The noise figure can be calculated as follow,

$$F = \frac{SNR_{in}}{SNR_{out}}, \tag{3.2}$$

which is the formulated ratio of input signal to noise and output signal to noise ratio. From this equation, if the noise figure value is too high, the noise performance is too worse. For simple calculation, the noise figure can also be determined by this equation,

$$F = \frac{2\rho_{ASE}}{Gh\nu}, \tag{3.3}$$

where ρ_{ASE} is the estimated ASE power within bandwidth 1Hz, G is the amplifier gain which will be mentioned next, h is the Planck's constant and v is the optical frequency. Noise figure measurement results with difference EDFA gain are plotted in figure 3.6. X-axis is the optical wavelength from 1535 to 1560nm and Y-axis is the measured noise figure in dB. We observe at higher EDFA gain, the noise figure performance is better. The average noise figure value is about 8dB at wavelength 1550nm which is used for two-tone amplification in this work.

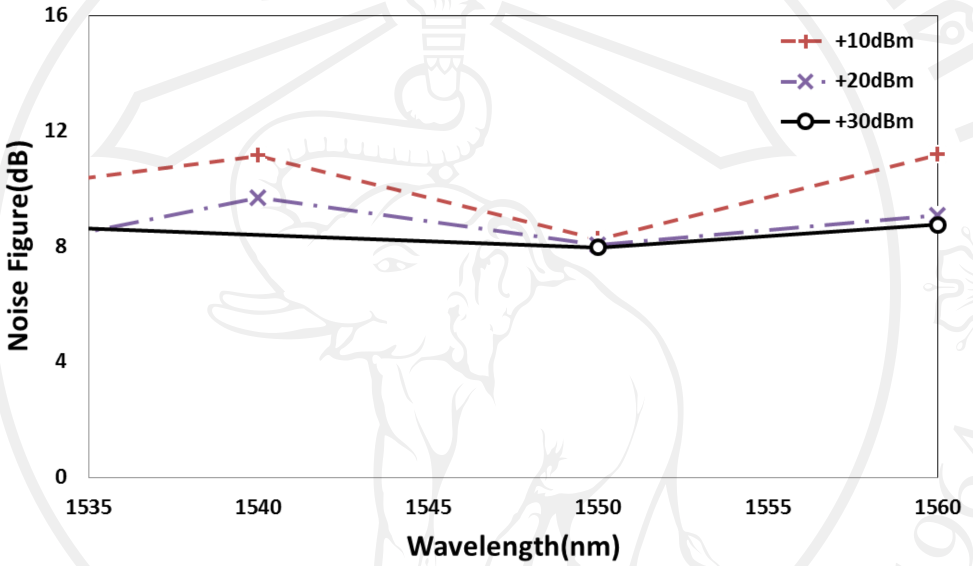

Figure 3.6 Noise figure as a function of optical wavelength

3.3.2 Gain Saturation

Due to the optical power level into the EDFA significantly affects to the EDFA-gain. If the input power level is too high, it results in to the saturation phenomena (Gain saturation), as mentioned earlier. Gain saturation characteristic will be measured which is the relationship between EDFA-gain to the input optical power level. The limit of the amplification by an EDFA should be known. The EDFA-gain can be calculated as follow,

$$G = \frac{P_{out} - P_{ASE}}{P_{in}}, \qquad (3.4)$$

where P_{out} is the output optical power reading by an OSA in Watt, P_{in} is the input optical power launched into an EDFA in watt. P_{ASE} is the estimated ASE noise power from the optical spectrum. The optical spectrum data measured by LabVIEW is in text file format. We use the MATLAB programming for ASE noise estimation and EDFA gain calculation. As for the ASE noise estimation, the averaged optical power level in both sides around the 1550 nm about 10 nm is used to estimate the ASE noise power at 1550nm. Figure 3.7 shows the ASE noise power estimation example where the ASE noise level is about -24.953dBm (cross symbol).

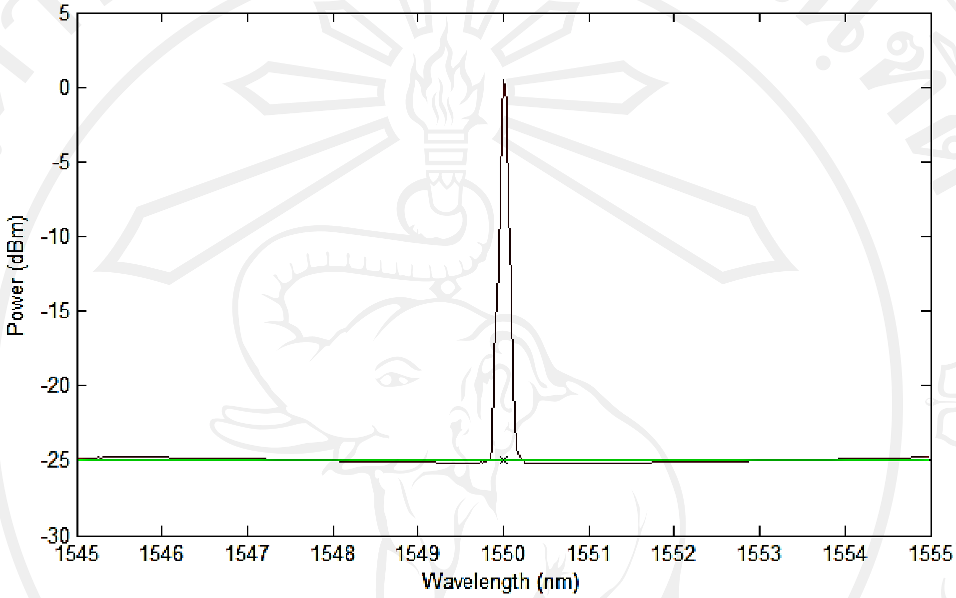

Figure 3.7 ASE noise estimation using MATLAB programming

Gain saturation measurement results are plotted in figure 3.8, where X-axis is the input optical power level from -30 to 0dBm and Y-axis is the output gain from an EDFA. The graph shows the measurement results for different pump currents consisting of 60mA, 90mA and 180mA. We observe that the gain is increased as the pump currents increases. However, the maximum pump current of the EDFA is limited at 180mA (diamond plot). At the input optical power of -30dBm, the EDFA gain can be extended up to 30dB. At the input optical power level of -1dBm, the EDFA gain is lower at about 12dB.

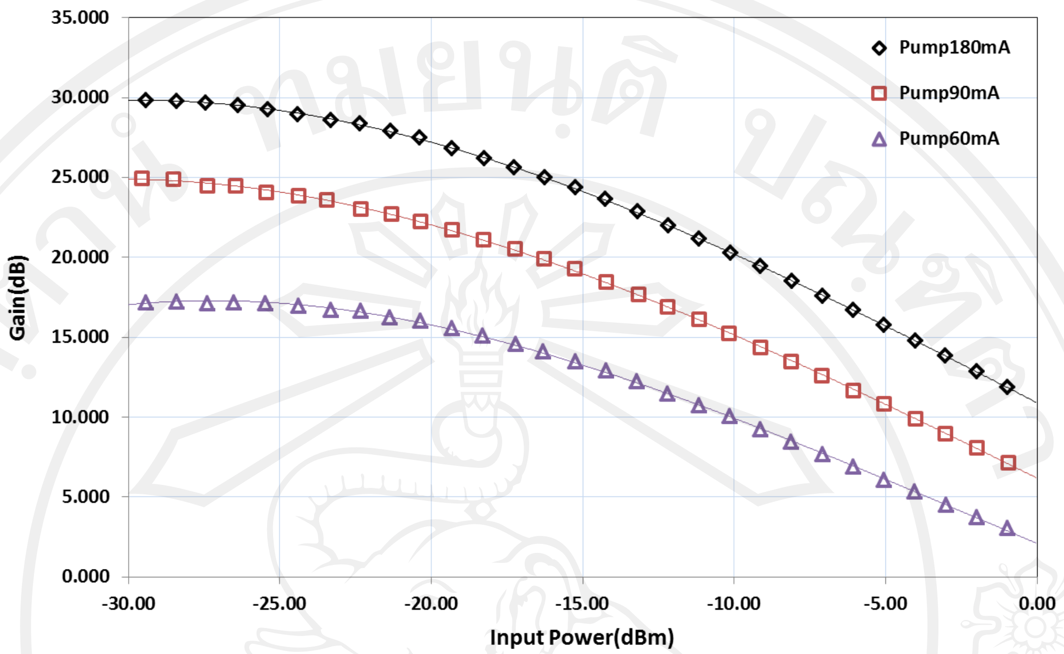

Figure 3.8 EDFA-gain as a function of input optical power

3.3.3 Gain Spectrum

The advantage of the EDFA is that it can amplify the broadband optical signal around 1525 to 1560nm simultaneously. However, the amplified power in each wavelength may not be equal which may affect to the two-tone generation in this work. We therefore study the EDFA gain spectrum characteristic to know how it affects to the two-tone generation referred to two-tone imbalance.

In experiments, the wavelength is swept in a 0.5nm step, where input optical power is kept constant at -5, -10 and -20dBm which is the range of the two-tone stimulus signal used in this work, the pump current of the EDFA is set to maximum level at 180mA. The EDFA gain values can also be calculated by equation 3.4 using MATLAB programming.

Gain spectrum measurement results are plotted in figure 3.9, where X-axis is the optical wavelength from 1545 to 1555nm and Y-axis is the output gain from an EDFA. The graph shows the measurement results for different optical input power level consisting of -20, -10 and -5dBm. We observe that at the higher gain the curve has more fluctuation, causing two-tone imbalance in the two-tone amplification. However, the maximum test frequency in the system is limited by RF generator at 12GHz. Therefore, the optical wavelength between two-tone is about 0.1 nm with center wavelength at 1550nm. We found that this wavelength range, the EDFA gain has some fluctuation average less than ±0.03dB that affects to the two-tone amplification.

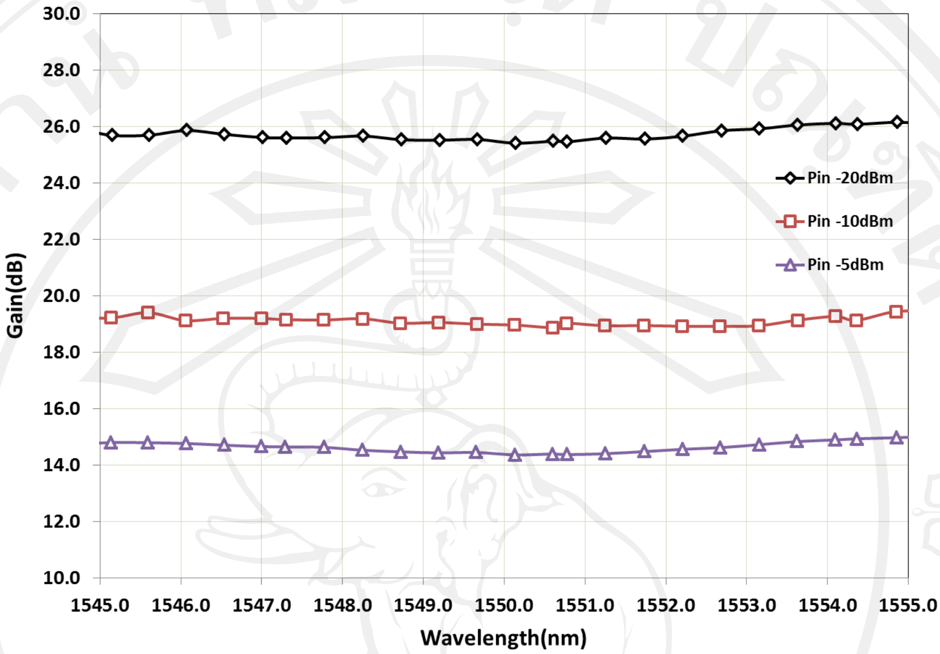

Figure 3.9 EDFA-gain as a function of optical wavelength