A Novel Transmission System using Broadband Fiber Optic link for Remote Antenna

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Abstract

Worldwide Interoperability for Microwave Access (WiMAX) is a broadband wireless data communications technology based on the IEEE 802.16 standard for providing high speed data over a wide area. This wireless network, when based on radio-over-fiber (RoF) technology, provides the most useful solution to the ever increasing demand for larger transmission bandwidth. In this paper, a novel transmission system for seamless integration of RoF with centralized lightwave Orthogonal Frequency Division Multiplexing (OFDM) for Next-Generation Passive Optical Network (NG-PON) based on an integrated external modulator is demonstrated. Here we have investigated the performance limitation when transmitting WiMAX signal over RoF/PON, the change in Signal-to-Noise Ratio (SNR) with the receiver power when varying fiber length with splitter ratio, and the number of Base Stations (BSs) that can be supported at a particular distance in a PON. The result shows that RIN has negative effects by limiting the SNR of the subcarriers.

Keywords: WiMAX, RoF, OFDM, PON, SNR, BSs, RIN.

1. Introduction

In the past, Digital Subscriber Line (DSL) technologies require telephone/cable lines to be laid over long distances to serve customers. The potential for broadband access is extremely high, taking into account the trend of Internet requirements. However, the penetration of DSL/cable is not as high, mainly due to lack of reliable infrastructure, cables or backbone switching equipment.

Thus, the emergence of WiMAX technology was able to replace the cable infrastructure provided for DSL, and also promises to offer high data rate which is able to serve the customers [1].

In addition, WiMAX can achieve data rates up to 75Mbps and a theoretical 30 mile reach. WiMAX is also an essential technology for the provision of unlimited access to broadband wireless communications in a range of applications including last mile solutions, extension of existing radio coverage and capacity, and backhaul is the RoF technology. The RoF technology was developed to meet the increasing demand for wireless access with greater bandwidth and longer reach. This was achieved through the integration of wireless and optical links whereby radio signals are transmitted over high capacity fibers. Executing this technology directly as it was designed is quite difficult and expensive because for every BS in a cellular network, a length of fiber will be dedicated to it.

Moreover, there are other networks that have been developed and deployed in various places using fiber cables. One of such network is the passive optical networks (PONs). This network has an increasing penetration into user's premises. It connects a service provider's central office (CO) also called optical line termination (OLT) to various users called optical network units (ONUs) using two multiplexing schemes: time division multiplexing (TDM) and wavelength division multiplexing (WDM). The integration of PON and Mobile WiMAX architecture will support differentiated bandwidth allocation to end users in order to provide more network capacity at a reduced operational cost as compared to other existing technologies [2].

However, this paper investigate the performance limitation of WiMAX signal transmission over fiber link, the changes in SNR with the receiver power when varying fiber length with splitter ratio, and the number of BSs that can be supported at a particular distance in a PON .The investigation was performed in three stages with the help of Optisystem 10. The first stage involves using two-tone test. A carrier generator was used to generate two (2) sub-carriers at a frequency of 500MHz, spacing of 50MHz and amplitude of 0.1a.u are set to be transmitted over the optical link. These sub-carriers were then used to modulate the optical carrier (main-carrier) externally with the aid of Mach-Zehnder modulator (MZM is used for controlling the amplitude of an optical wave). Because of

the common challenge of signal impairments in the transmission of analogue radio signal over fiber such as Relative Intensity Noise (RIN describes the fluctuations in the optical power of a laser), nonlinear characteristics of the optoelectronic conversion process and the chromatic dispersion. This paper however investigates the effect of RIN and the non-linearity when the fiber length and the splitting ratio were varied simultaneously to achieve SNR of 20dB at the receiver power in order to test their performances. The second stage was performed to integrate the OFDM modulation technique of the WiMAX signal into RoF system networks. Because of the advantages of the OFDM to distribute data over a large number of carriers that are spaced apart at precise frequencies with overlapping bands and RoF to use high capacity of optical networks along with the mobility of wireless networks. Thus, integrating OFDM along with RoF can be used for both short distances as well as long-haul transmission at a very high data rate of 100Mbps [3]. Finally, the number of sub-carriers that can be supported in WiMAX air interface of 20MHz was investigated.

2. System design

OFDM based PON plays a leading role in next-generation access network. It offers bandwidth flexibility between applications such as mix of digital, analog, circuit and packet-switched, legacy and emerging applications in figure 1. Integrating PON with WiMAX might be an efficient solution to broadband network access that can take advantage of the bandwidth benefit of fiber communications, and the mobile and non-line-of-sight features of wireless communications [4]. PON based backhauls also achieve low cost-effective transformation to next generation (NG) Mobile WiMAX networks.

In OFDM-PON system, sub-carriers becomes transparent pipes for delivery of arbitrary signals like Ethernet, Radio Frequency (RF), T1/E1, mobile backhaul, VPN, IPTV, etc. Therefore bandwidth is dynamically assigned to different services or different users are assigned different OFDM subcarrier within one OFDM band of total N subcarriers [5]. In this section, a simple block diagram showing the flow of data signals in the downlink direction of RoF over PON network is presented in figure 1 followed by a detailed description of each component block of the design. And finally, the impairments that affect the quality of the signal expected at the receiver end is discussed as well.

From the discussion above, the principle of OFDM is to split high-rate data streams into lower rate streams, before they are transmitted simultaneously over several subcarriers [6]. In the same manner, this illustration is demonstrated in Figure 1. In this report, the OFDM system were modeled for application based on WiMAX standard which is using frequency carrier between 2GHz and 6GHz,bandwidth channel of 20MHz, the data rate of the system is 100Mbps and modulation type is 16 QAM/ 4 bit per symbol [7]. The Length of the fiber for

transmission link is 20Km. The splitter is also fixed initially at a ratio of 1:4. But for the purpose of the investigation, the fiber length and the splitter were latter varied to obtain SNR of 20dBm.

At the central office (CO), the digital data input would first be split into parallel streams data by OFDM transmitter, then this data would be carried onto the optical fiber link. In the optical link, the laser (CW laser) would emit a continuous beam or a train of short pulses of a laser. Also in the MZM, the electrical wave signals from OFDM transmitter are combined with the continuous wave light from the CW laser. These two waves are then modulated by MZM to form optical signal which is sent through the optical fiber. Here the OFDM signal can either be modulated directly or externally. From the illustration in the Figure 2, the dotted lines show the alternate means of modulating the lasers which can also be called transmitters. It should be noted that each of the OFDM signals generated at different frequencies between 2GHz and 6GHz are combined before they are modulated directly or externally.

Next in the block is the splitting device that splits the optical signal into ratios of equal power. Finally the data would be received first by the photodetector (or base station). This photodetector then converts the incoming photonic stream back into a stream of electrons, so the optical signals are converted back into electrical signals [8]. The signal then would recombine again in the OFDM receiver to get the original data back. This Unit is called the Optical Network Unit (ONU).

The main idea of this study is to investigate the performance limitation of analogue radio signal transmission over fiber link, and to know the number of base stations that can be supported at a particular distance in a Passive optical network (PON). The investigation was performed in three stages with the help of Optisystem. The first stage involves using two-tone test. A carrier generator was used to generate two (2) sub-carriers at a frequency of 500MHz, spacing of 50MHz and amplitude of 0.1a.u are set to be transmitted over the optical link. These sub-carriers are then used to modulate the optical carrier (main-carrier) externally using MZM. As a result of signal impairments in the transmission of analogue radio signal over fiber such as Relative intensity noise (RIN), nonlinear characteristics of the optoelectronic conversion process and the chromatic dispersion. This study also investigates the effect of RIN and the non-linearities when the fiber length and the splitting ratio were varied simultaneously to achieve a signal-to-noise ratio (SNR) of 20dB at the receiver power in order to test their performance. The second stage was performed to integrate the OFDM modulation technique of the WiMAX signal into RoF system networks.
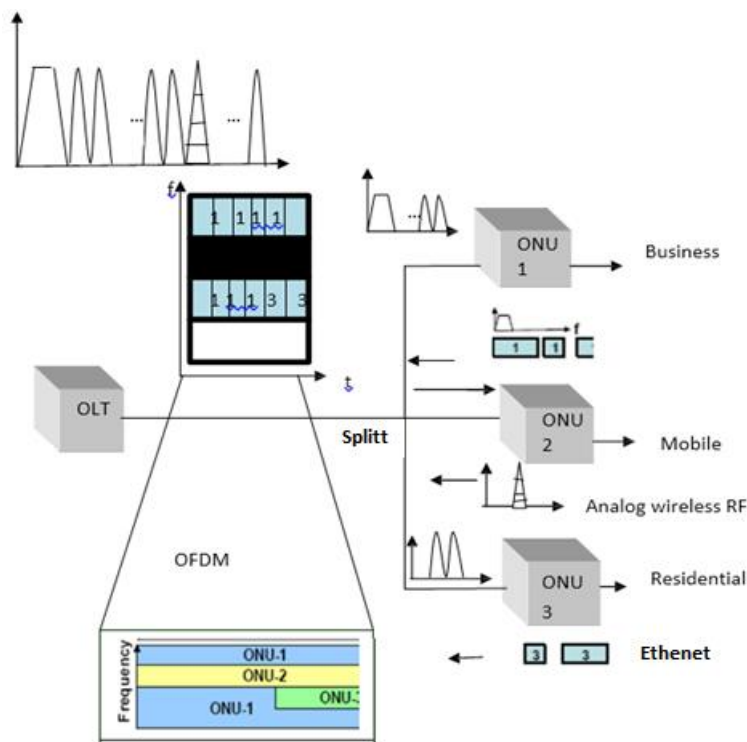
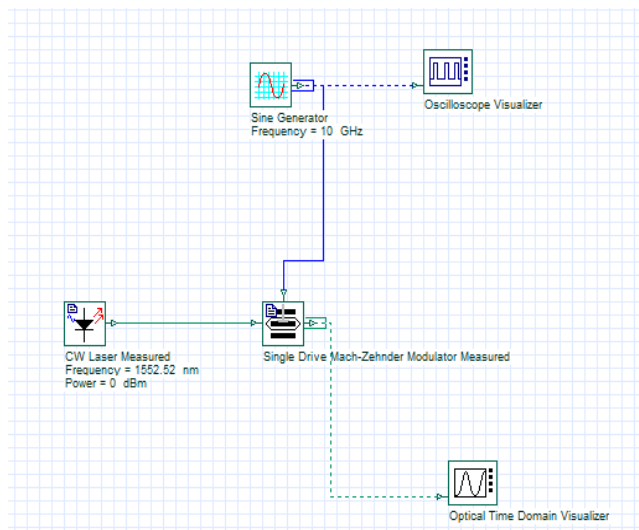**Fig. 1** Block diagram of a simple OFDM based PON system

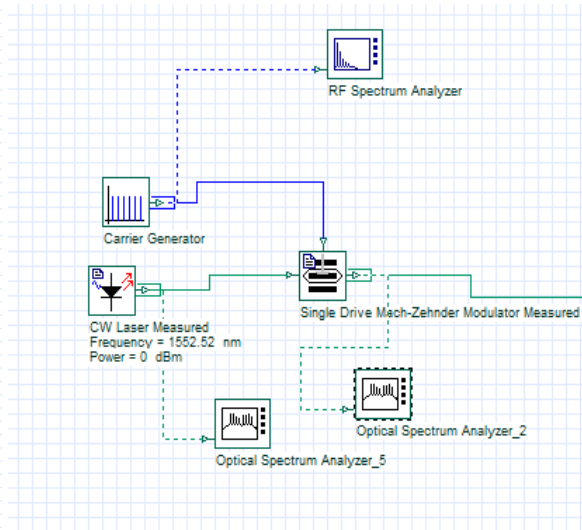**Fig. 2** Biasing MZ modulator

Fig. 3 OLT Design

OFDM has the advantage to distribute data over a large number of carriers that are spaced apart at precise frequencies with overlapping bands and RoF to use high capacity of optical networks along with the mobility of wireless networks. Thus, integrating OFDM along with RoF can be used for both short distance as well as long-haul transmission at a very high data rate of 100Mbps. Finally, the number of sub-carriers that can be supported in WiMAX air interface of 20MHz was investigated. This report was designed and simulated by a commercial software package called Optisystem. This software was used for this investigation because it offers a comprehensive design suite that allows one to plan, test and simulate at the transmission layer current and next

generation of optical networks [9]. This was made available at the University's Radio Communication Lab.

The RoF based OFDM-PON model employed in this study are the External Optical Modulation (EOM) and direct Optical Modulation (DOM). From figure 2, a carrier generator was used to create two sub-carriers which are modulated by External Optical Modulator called single drive MZM. In this design the external modulator was biased properly so as to obtain the MZ bias point. At this point, modulating the MZ will produce an optical modulated signal devoid of distortion. This point is normally around 0 volts but in practice around few hundred millivolts [10]. Having biased the MZ, the OLT design was carried out as shown in Figure 3 above.

It was realized with a CW laser module, MZ modulator and a carrier generator. The CW laser is set at a frequency of 1552.52nm and power of 0dBm. With the carrier generator, two (2) channels (sub-carriers) at a frequency of 500MHz, spacing of 50MHz and amplitude of 0.1a.u are set to be transmitted over the optical channel.
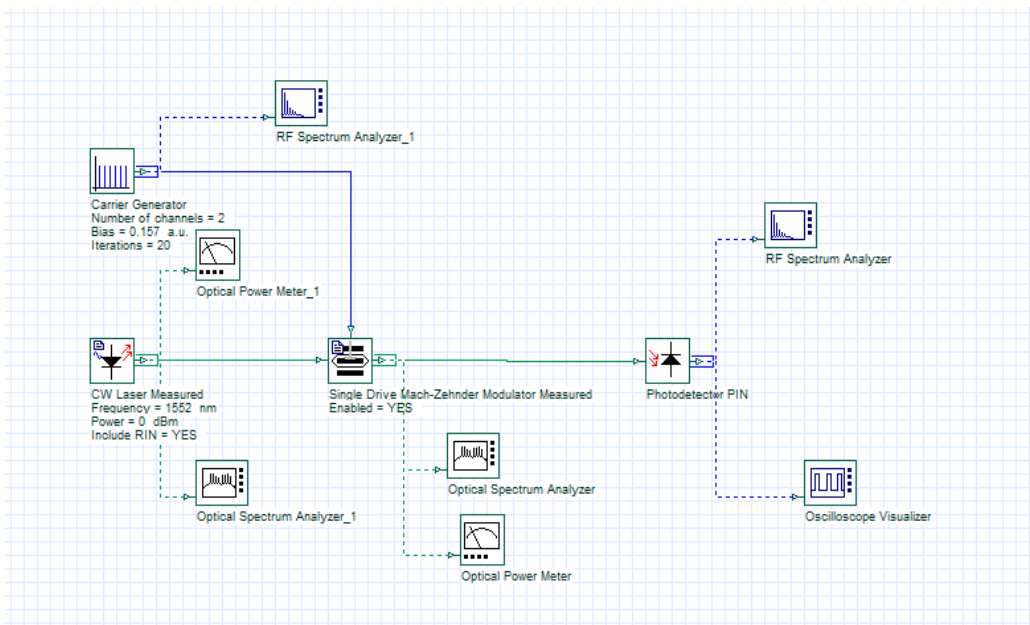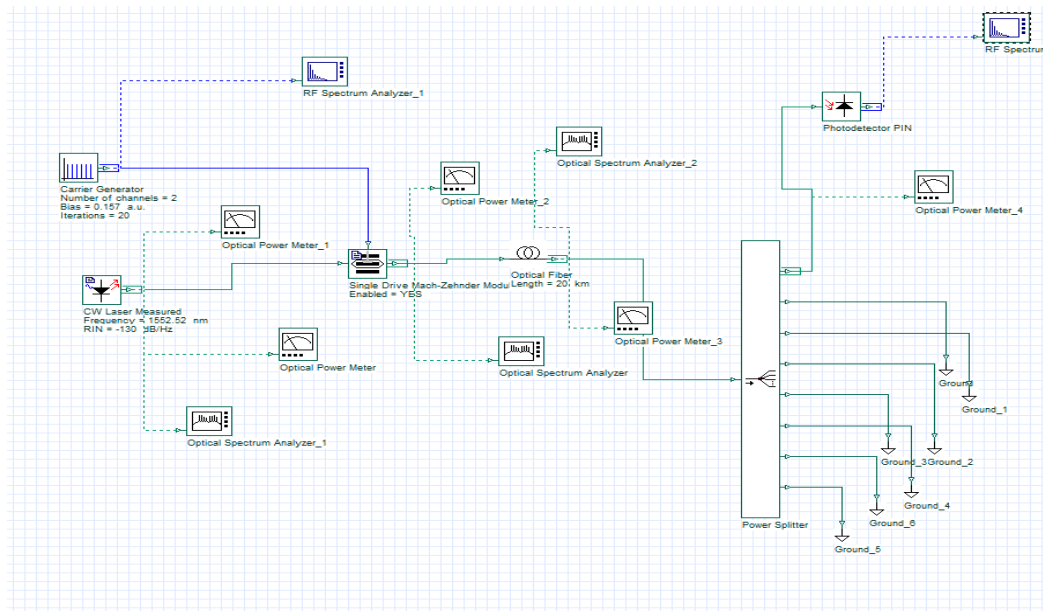

Fig. 4 Back –to- Back Connection

Fig. 5 Complete design with various visualizers

From figure 4, the back-to-back connection from the OLT directly to the photo detector PIN diode without the fiber was meant to observe the corresponding output of the carrier generator to the photodiode at different amplitude of 0.01, 0.05, and 0.1 a.u. This will then lead to the complete optical network component as shown in figure 5 below. This component includes the optical fiber and passive optical splitter together with the photodiode at the receiver end. The various visualizers are placed accordingly based on the signal output from each component block and connections done appropriately.

The RF spectrum Analyzer is used to analyze the frequency spectrum, Optical spectrum analyzer (OSA) is used to measure the Optical Power as a function of Wavelength or frequency and the Optical power meter is the essential tool for measuring optical power within a fiber optic link. Figure 5 shows the varying parameters from fiber length to splitting ratios. The fiber length was kept fixed at 20 km while varying splitter ratio for 1:4, 1:8, 1:16, 1:32 and 1:64. With the RIN enabled and thermal noise of 1e-009 A/Hz^5 at the photodiode, the effect of the varying parameters was observed and recorded.
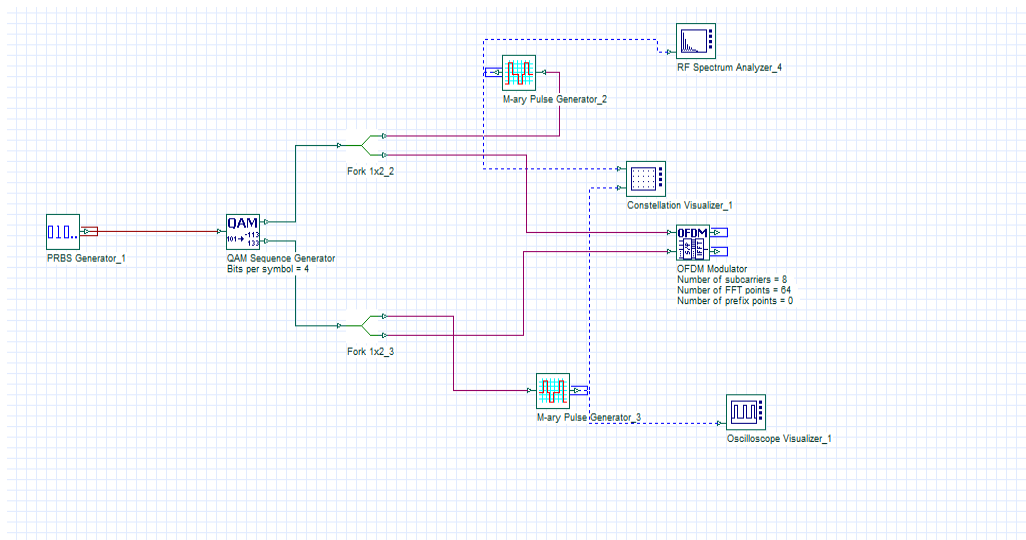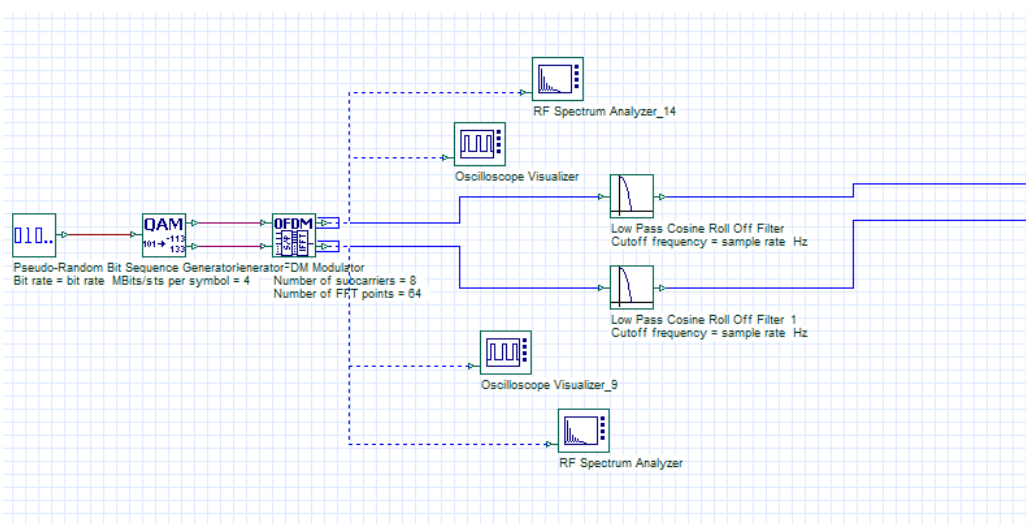
Fig. 6 A Typical 16 QAM Design

Fig. 7 OFDM transmitter Design

In the figure 6 above, a PRBS (Pseudo Random Binary Sequence) generator is used to generate a binary sequence at the OLT. But for the purpose of this study, the digital sequence from the PRBS needs to be converted to an electrical signal and hence a QAM (quadrature amplitude modulator) pulse generator is used to generate two M-ary (16-QAM) electrical signal output from the binary sequence output of the PBRS. The M-ary QAM constellation is responsible for mapping the bit stream into complex symbols [11]. The output of the QAM modulation is then received by the IFFT block.

In figure 7, the OFDM block contain some parameters which is represented graphically. The dots on x-axis represents the number of IFFT points which is '32' in numbers while the y-axis represents the corresponding values. Eight dots on the x-axis have corresponding values of '1's on the y-axis while the rest of the values are '0's. Which means that number of subcarriers = 8 [12]. The position array is calculated as (position = number of IFFT/2) + 1 [12]. The design of the OFDM at the receiving end is displayed in the Figure 8 below. This design also

follows the OFDM block diagram in Figure 1. The low pass cosine Roll off filter is been used in the design because of its ability to reduce Inter-Symbol interference (ISI). Also the OFDM demodulator block contains some parameters.

Then the QAM sequence decoder detects the electrical signals using an M-ary threshold detector to recover the original QAM sequence and then decode the sequence into the original binary signal. Hence, a complete system design of the OFDM-PON showing the fiber link and the splitter is shown in Figure 9 below. This comprises of the WiMAX transmitter (OFDM transmitter, Quadrature modulator and bandpass Gaussian filter), the external modulator (MZM), the fiber link, the splitter, the photodetector, electrical amplifier, Quadrature demodulator and then the WiMAX receiver. Both the OFDM transmitters and the receivers are located at the OLT and ONU respectively. And the parameters also follows the WiMAX standards such as data rate of 100Mbps, frequency band of 2.5GHz and the channel bandwidth of 20MHz[4,5].
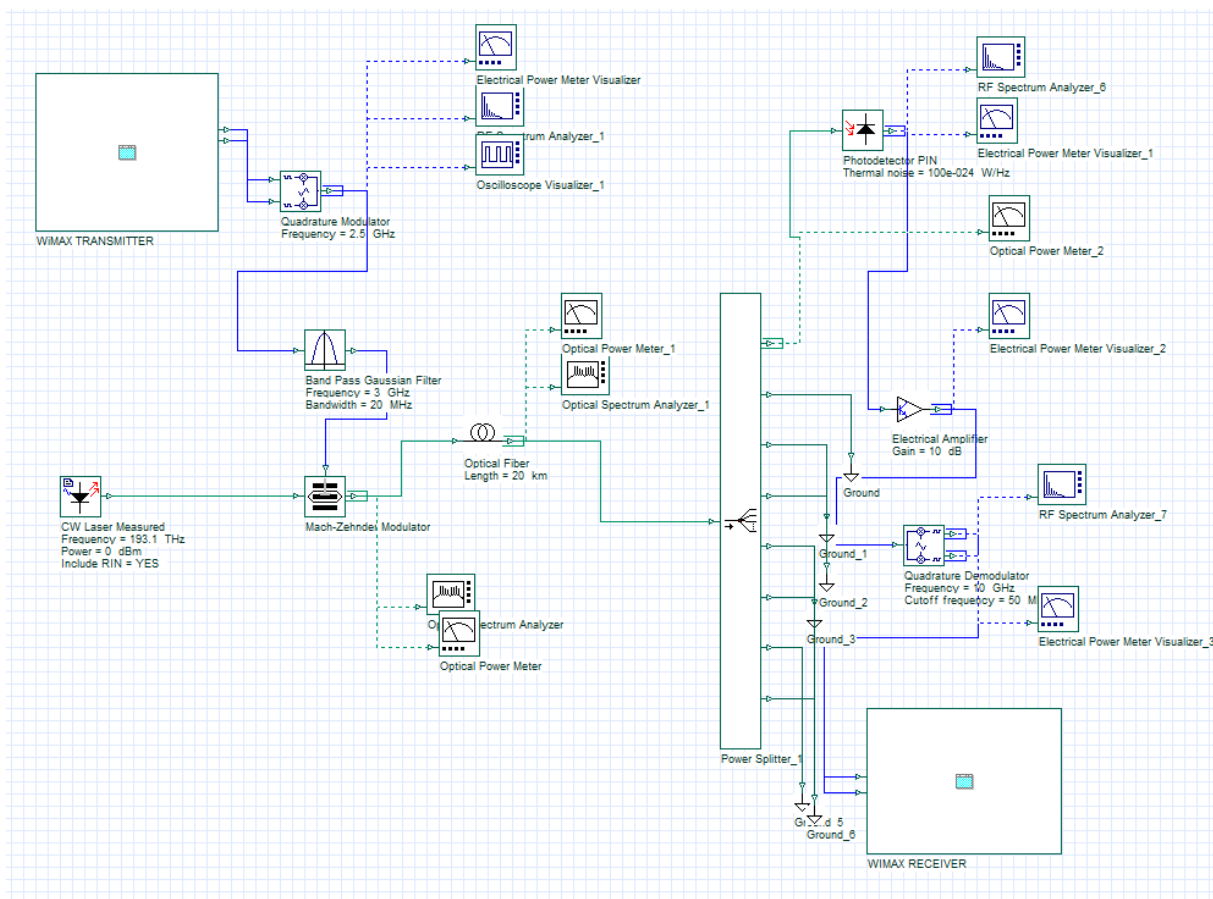
Fig. 9 Complete system design of RoF based OFDM-PON

Conclusively, the two complete systems designs; the two-tone test and the RoF based OFDM-PON design are set to WiMAX standard parameters. The two-tone test was used in order to characterize the non-linearity of RF components both active and passive. The results of performances achieved were shown in figures 10, 11, 12, 13 and 14 respectively. Also, the OFDM-PON design was used to describe the performance of WiMAX signals using OFDM as it were achieved in a real life case. The results obtained are shown in figures 15,16,17,18 and 19 respectively using the SNR to test their performances.

3. Performance analysis results

The results obtained in this section are also based on the three stages of simulation employed under system design. For the result analysis, the consideration is focused on minimum SNR of 20dB from the received signal which is considered as SNR for WiMAX.

Stage 1

Having established the necessary parameters and their values, the simulation was run and the results obtained from the various analyzers were presented in figures 10,11,12,13 and 14 respectively.
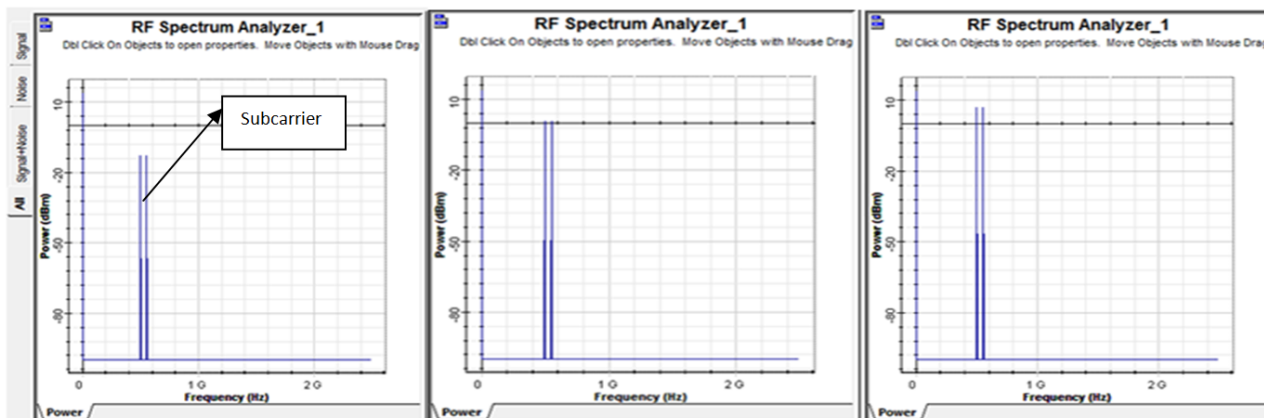

Fig. 10 Output of the Carrier generator when connected back-to-back at different amplitude of 0.01, 0.05 and 0.10 a.u.
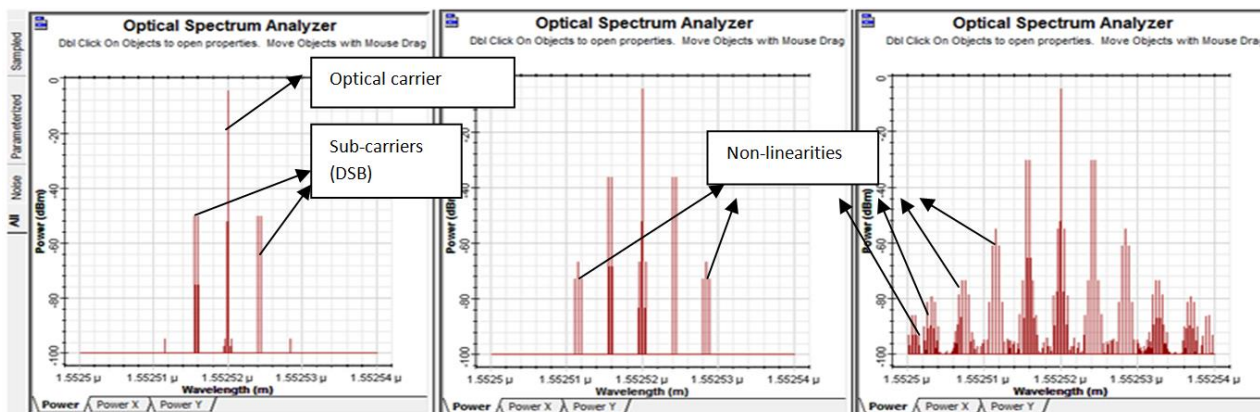
Fig. 11 Optical Output from the MZM when connected back-to-back at different amplitude of 0.01, 0.05 and 0.1 a.u.

From the above Figure 10, increasing the amplitude of the subcarriers by (0.01, 0.05 and 0.10 a.u) will increase the power level of the subcarriers from -13dBm, 0dBm and 7dBm respectively. This also affects the output from MZM as shown in Figure 11.

The Figure 11 above shows the output from the MZM after external modulation has taken place. The optical carrier at 0dBm has been reduced to -16dBm due to insertion loss of -4dBm present in the MZM. The Optical carrier could be seen in between double side bands (DSB)

containing the subcarriers at a power of -50dBm, -36dBm, and -30dBm respectively. Increasing the amplitude of the subcarriers will create impairments.

These impairments arise as a result of the nonlinear characteristics of the optoelectronic conversion process at the laser transmitter which leads to increased inter-modulation distortion (noise). In order to minimize the nonlinear distortions, the amplitude of the subcarriers has to be reduced greatly to 0.01 a.u as shown in Figure 11.
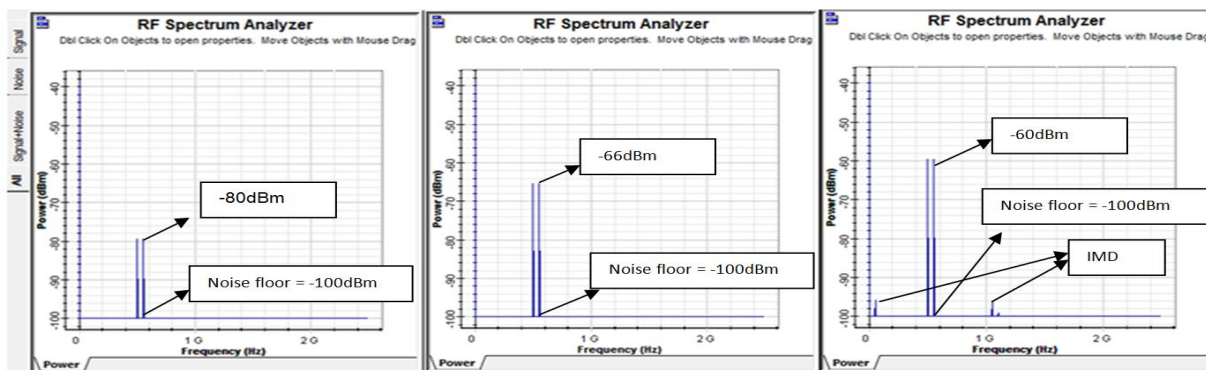

Fig. 12 Output of the photodiode when connected back-to-back at different amplitude of 0.01, 0.05 and 0.1 a.u.

The Figure 12 shows the results obtained from the output of the photodiode for back-to-back connection. It will be observed that as the output power level of the subcarriers increases, the intermodulation distortion (IMD) also increases and the SNR increases also. The SNR is calculated as follows ;(-80-(-100)) dB, (-66-(-100)) dB and (-60-(-100)) dB which are 20dB, subcarriers will lead to increased SNR which will consequently results into distortions (IMD) or noise as shown in Figure 12. Now when the RIN was enabled at the laser, the following are the results obtained from the photodiode.

Figure 13 shows the effect of Relative intensity noise (RIN) on the subcarriers. It could be observed that the noise level was increased from -100dBm to -92dBm. The SNR was calculated as follows; (-80-(-92)) dB, (-66-(-92)) dB and (-60-(92)) dB which are 12dB, 26dB and 32dB

respectively. The SNR decreases relative to the one displayed in Figure 12 by 8dB because of RIN. Next is to vary the laser power, fiber length and power splitter after completing the system design, then the corresponding SNR and the receiver power were recorded respectively. The results obtained when the laser power is fixed at 0dBm, fiber length is fixed at 20km and the power splitter is been varied for 1:4, 1:8, 1:16, 1:32 and 1:64 are displayed below.

The laser power was latter increased to 5dBm, while the fiber length remains at 20km and the power splitter was varied. It was observed that, increasing the power of the laser will only end up driving the laser to its non-linear region thereby resulting into numerous distortion (IMD) products. The same experiment was performed for 40km length of fiber at varying splitting ratios and then the laser power was finally increased to 8dBm.The results is displayed in the Tables 1,2,3 and 4.
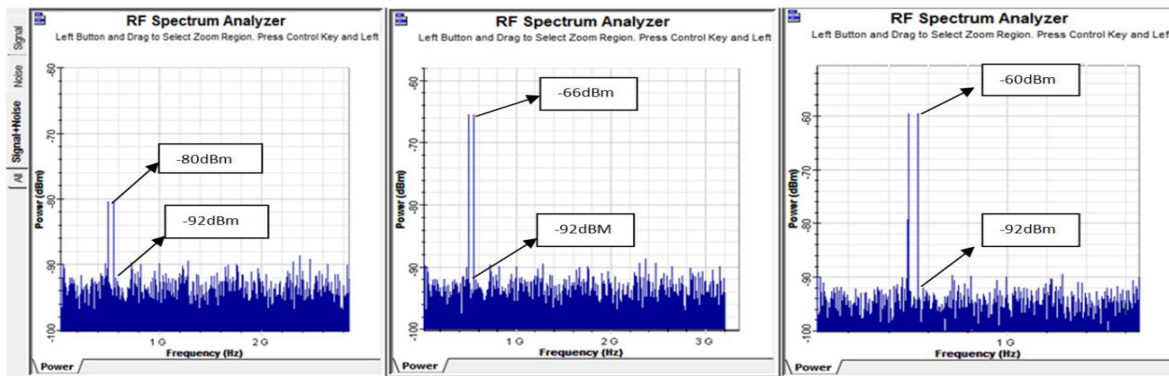
Fig. 13 Output of the photodiode when connected back-to-back at different amplitude of 0.01, 0.05 and 0.1 a.u.
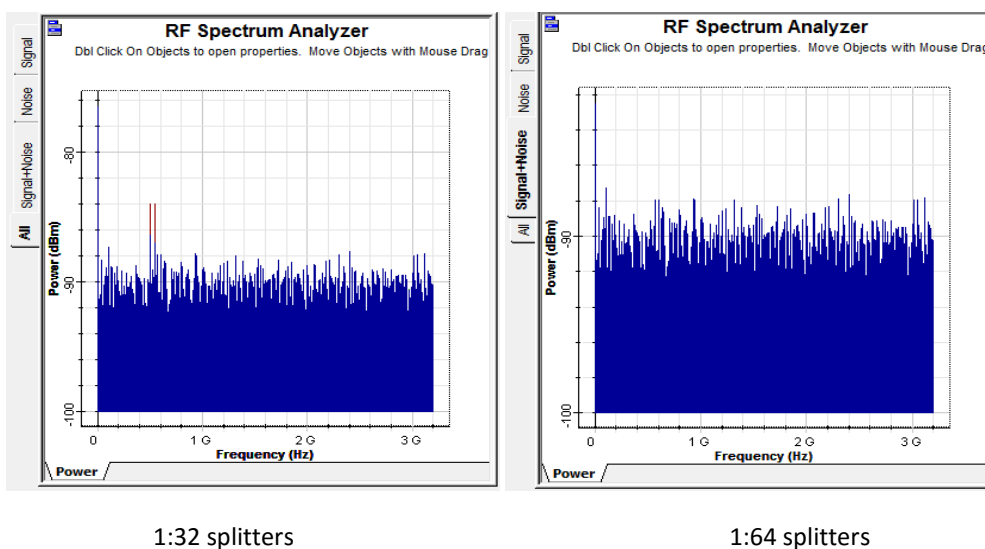

1:32 splitters   1:64 splitters

Fig. 14 Output of the photodiode when laser power was fixed at 0dBm, fiber length of 20km and the power splitter is varied above

Table 1: 20km fiber length at 0dBm   **Table 2:** 20km fiber length at 5dBm

Splitter	SNR (dB)	Receiver Power (dBm)
4	24	-14.246
8	18	-17.257
16	12	-20.267
32	6	-23.277
64	0	-26.288

Splitter	SNR (dB)	Receiver Power (dBm)
4	32	-9.348
8	26	-12.359
16	20	-15.369
32	14	-18.379
64	8	-21.388

Table 3: 40km fiber length at 5dBm   **Table 4:** 40km fiber length at 8dBm

Splitter	SNR (dB)	Receiver Power (dBm)
4	26	-13.246
8	20	-16.257
16	14	-19.267
32	8	-22.277
64	2	-25.288

Splitter	SNR (dB)	Receiver Power (dBm)
4	30	-10.348
8	24	-13.359
16	18	-16.369
32	12	-19.379
64	6	-22.388
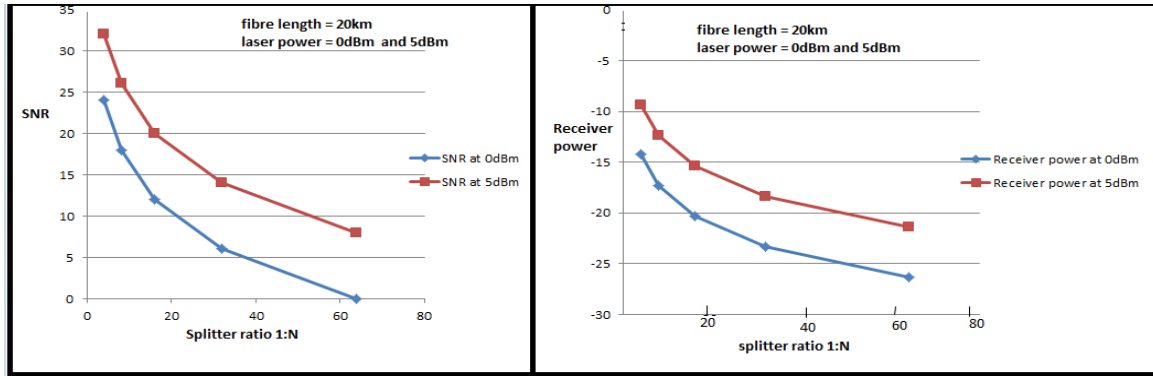
Graph 2 40km fiber length at 5dBm and 8dBm with SNR and Receiver power
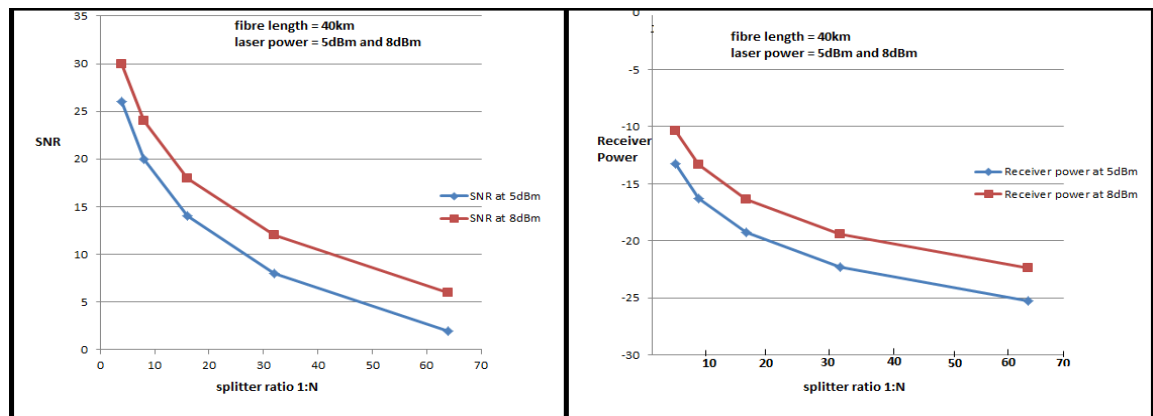
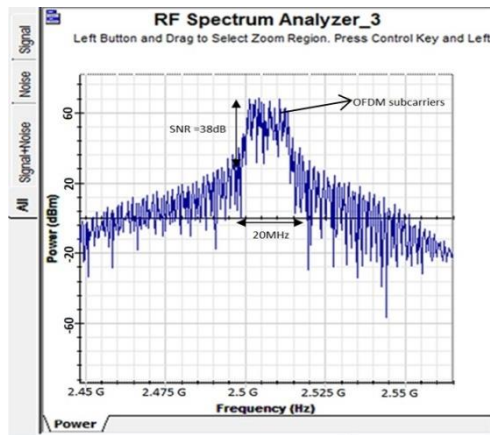**Graph 2** 40km fiber length at 5dBm and 8dBm with SNR and Receiver power

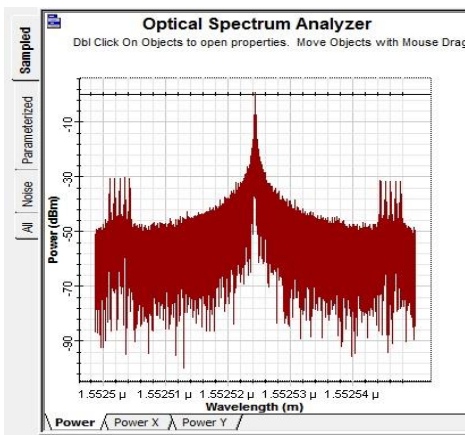**Fig. 15** OFDM signal from transmitter

Fig. 16 OFDM optically modulated by MZM

The Graph1 plotted shows the variation of change in the SNR and the receiver power when the splitter ratio is increased for 1:4, 1:8, 1:16, 1:32 and 1:64. The fiber length is kept constant as the laser power was increased from 0dBm to 5dBm. It was observed that when the laser power was increased, the signal to noise ratio was also increased as the receiver power increases. Then the length of the fiber was increased further by 20km which is shown in Graph 2.

From the Graph 2 plotted above, the variation of change in the SNR and the receiver power when the splitter ratio was increased for 1:4,1:8,1:16,1:32 and 1:64 can be shown. At this point, the fiber length has been

increased to 40km while the laser power was increased from 5dBm to 8dBm. It was also observed here that, increasing the laser power will not only increase the SNR or receiver power but it also drives the Laser to its non-linear region thereby resulting into numerous distortion (IMD) products. At a time, the output was almost drowned by distortions (IMDs) or noise.

Stage 2

This stage presents the result of the OFDM transmitter before been transmitted over the fiber link. The result shown in the Figure 15 is derived from OFDM signal with

8 subcarriers that have been multiplexed before optically modulated. We could see from the figure that the signal power is about 68dBm, frequency carrier of the signal is 2.5 GHz, the channel bandwidth is 20MHz and the SNR is 38dB.

Stage 3

This stage presents the results of the entire system. Starting from the point when the OFDM signal is fed into the Band pass Gaussian filter with frequency of 3GHz to the point where the signal is recovered at the photodetector. The electrical band-pass Gaussian filter is used to minimize the electrical signal noise and group delay becomes constant for all the frequencies.

This will allow signals within a selected range of frequencies (2.5GHz, 2.6GHz, 2.7GHz, 2.8GHz and 2.9GHz) to be encoded while preventing signals at unwanted frequencies from getting through the center frequency. Next is to modulate the OFDM signal by MZM. The result from the transmission link after OFDM signal is optically modulated by MZM are shown in the Figures 16 and 17 respectively. After been optically modulated, the signal is then transmitted through the fiber optic link transmission as seen in Figure 17.
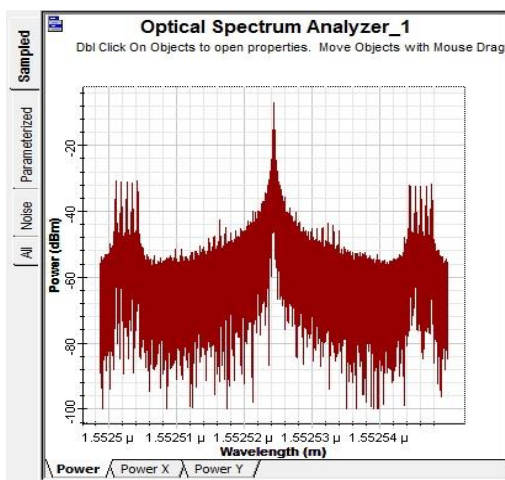

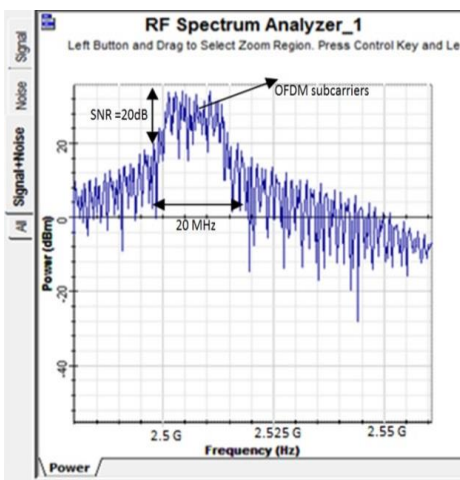**Fig. 17** OFDM signal after through optical

Fig. 18 OFDM signal from photodetector

From figures 16 and 17, we could see that the wavelength is 1552.52 nm, but the power from both signal are different. The power of the signal after been transmitted through optical fiber was decreased from 0dBm to -8dBm because of attenuation of 0.2dBm/km present in the fiber. Because the fiber length is 40km, then 0.2dBm/km of 40km gives 8dBm loss. After the OFDM signal has been optically modulated and being transmitted over the fiber link transmission and the splitter, the optical domain signal is then converted back into electrical domain signal by the photodetector. The photodetector used in this simulation has responsivity of 1A/W. The OFDM signal is then converted and retrieved back in the receiver part as shown in Figure 18. In figure 18, it was observed that the signal power level is decreased from 68dBm to 28dBm because of the fiber loss and also the splitter loss. This also causes the SNR to change from 38dB to 20dB. Then the varying of the fiber length with respect to the splitter by increasing it further also degrades the signal power level thereby decreasing the SNR. Thus, the laser power was increased to 5dBm. It was justified that increasing the laser power does not only increase the SNR but also drives the laser to its non-linear region to create distortions and noise. This signal is then amplified with gain of 10dB by the electrical amplifier, before been demodulated back to get the original data that has been sent from the transmitter.
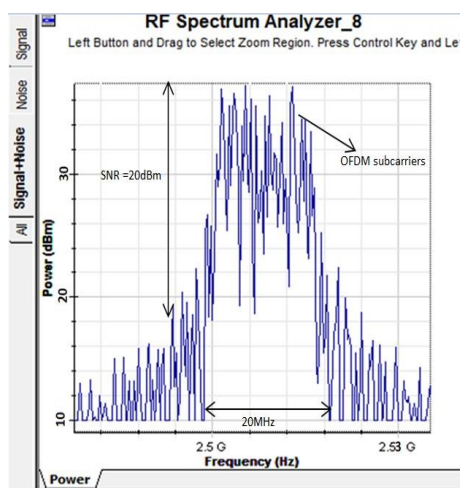

Fig. 19 OFDM signal after amplified

Conclusion

As a result of the advantages of using OFDM in transmitting WiMAX signals, the integration of OFDM modulation technique with RoF over PON technology was investigated in this study. In addition, the present and future implementation of this optical communication technology was also explored. And with the combination of RoF based OFDM-PON, the system can be used for both short distances as well as long-haul transmission at a

very high data rate for access network. Thus, the simulation of two-tone test and modelling of the OFDM scheme for RoF/PON system was completely performed with the aid of commercial software called optisystem 10. The WiMAX transmission parameters were considered in the system design in order to meet the applicable design in practical application. The system model has been designed to accommodate data rate of 100Mbps over frequency carrier of 2.5GHz and channel bandwidth of 20MHz. This paper demonstrate that the performance of the system setup when transmitting WiMAX signal over RoF/PON is limited by some impairments such as RIN. When the fiber length increased from 20km to 40km with the splitter ratio of 1:4, 1:8, 1:16, 1:32 and 1:64, the SNR decreases with the receiver power. It was also shown that increasing the power of the laser from 0dBm to 8dBm will not only increase the SNR but also drives the laser to its non-linear region.

In conclusion, after modeling the OFDM with 8 subcarriers at 64 FFT point with the same experiment when the fiber length was increased for different splitter the laser power also increased to 5dBm. With respect to SNR of 20dB obtained at 20km fiber length and 4 splitter, it will be concluded that with the data rate of 100MHz, four base stations will support 8 subcarriers each at 20km fiber length.

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