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PHOTONIC ANTENNA FOR LONG RANGE WIRELESS COMMUNICATION

Razali Ngah
Teguh Prakoso
Tharek Abd Rahman
Mohd Amin Mualif

4.1 INTRODUCTION

Wireless access network is a very popular and famous technology in today's communication world. Wireless access, either fixed or mobile is regarded as an excellent way to achieve good broadband services. The future generation of cellular networks will need much smaller cells than present generation networks and Radio over Fiber (RoF) technology and photonic antenna are introduced for this application. However, photonic antennas proposed in some publications generally are intended for short range communication. This chapter presents design and simulation of photonic antenna for longer range application. The antenna is designed for 5.8 GHz, as the operating frequency is commonly used for long range, WLAN backhaul network. Overview on RoF technology and photonic antenna are also presented in this chapter.

4.2 RADIO OVER FIBER TECHNOLOGY

Radio-over-Fiber (RoF) technology entails the use of optical fiber links to distribute RF signals from a central location (headend) or central base station (CBS) to remote antenna units (RAUs) or radio access points (RAPs). In narrowband communication systems and WLANs, RF signal processing functions such as frequency up conversion, carrier modulation, and multiplexing are performed at the RAU or RAP, and immediately fed into the antenna. RoF makes it possible to centralize the RF signal processing functions in one shared location (headed or CBS), and then to use optical fiber, which offers low signal loss (0.3 dB/km for 1550 nm, and 0.5 dB/km for 1310 nm wavelengths) to distribute the RF signals to the RAUs, as shown in Figure 4.1. By using this technique, RAUs are simplified significantly, as they only need to perform optoelectronic conversion and amplification functions.

The centralization of RF signal processing functions enables equipment sharing, dynamic allocation of resources, and simplified system operation and maintenance. These benefits can translate into major system installation and operational savings, especially in wide-coverage broadband wireless communication systems, where a high density of BS/RAUs is needed.

There are some other advantages and benefits of the RoF technology compared to conventional electronic signal or radio frequency distribution. They are low attenuation loss, large bandwidth, immunity to radio frequency interference, easy installation and maintenance, reduced power consumption, multi-operator and multi service operation, and dynamic resource allocation.

One of the pioneer RoF system implementations is depicted in Figure 4.1. The system can be used to distribute GSM signals. The RF signal is used to directly modulate the laser diode in the headed or CBS. The resulting intensity modulated optical signal is then transported over the length of the fiber to the RAU or RAP. At the RAU, the transmitted RF signal is recovered by direct detection in the PIN photodetector. The signal is then amplified and radiated by the antenna. The uplink signal from the mobile unit (MU) is transported from the RAU to the headed in the same way. This method of transporting RF signals over the fiber is called Intensity Modulation with Direct Detection (IM-DD), and is the simplest form of the RoF link as shown in Figure 4.2.

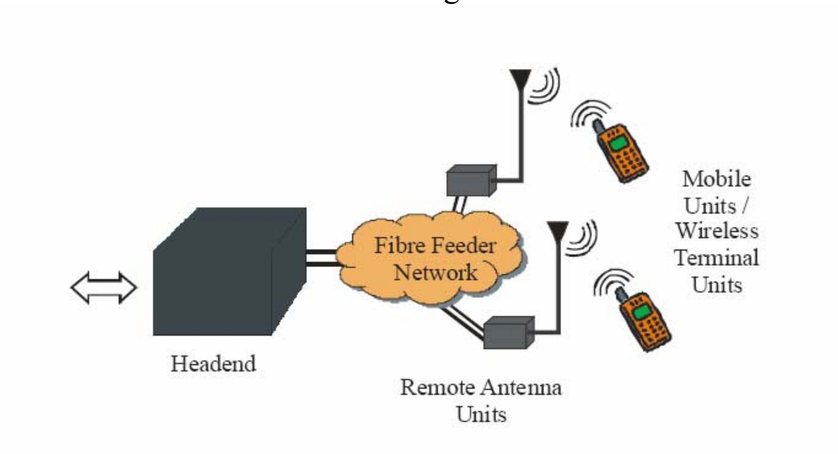


Figure 4.1 Radio over fiber system concept

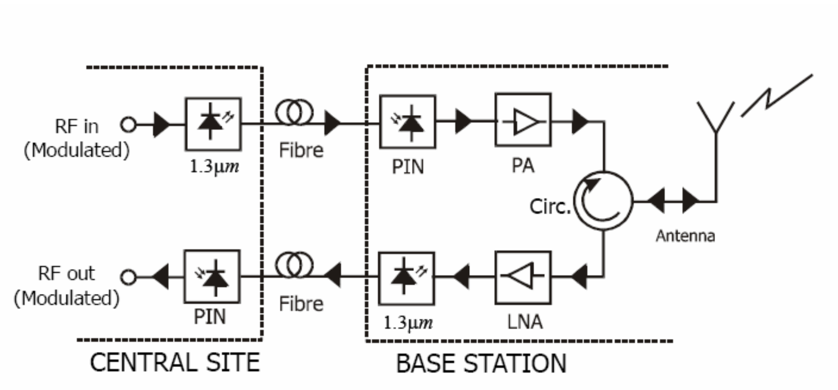


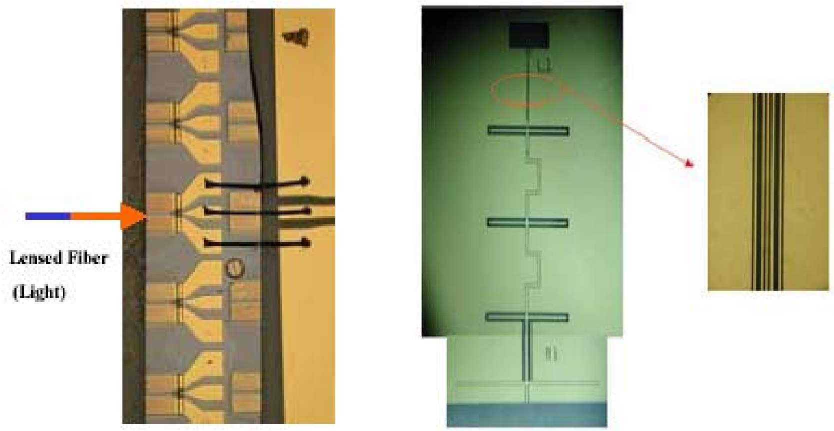
Figure 4.2 Fiber radio system

4.3 PHOTONIC ANTENNA

There are three main steps in the growth of RF/Photonics systems for wireless communications [4]. The *first step* is to use photonic components such as photodetector to gradually replace conventional RF components, such as the coax interconnecting the antenna to the electronics since optical fibers provide a better medium for broadband RF communication systems. The lightweight property of fibers, low loss and its immunity to other signal interference make them ideal in the development of future RF distribution systems. The *second step* is integration of photonic components and RF wireless circuits in the form of Optoelectronic Integrated Circuits (OEIC's). Fiber-optic technologies have reached the stage where insertions into various commercial RF systems are practical. In the *third step*, the aim is to reduce cost by eliminating the need of local oscillators, mixers, amplifiers and a host of other parts by directly feeding an antenna through a fiber.

The third step is called passive integrated antenna or simply photonic antenna. The existence of connector at optoelectronics interface to antenna introduces loss. Removing the connector, the problems can be overcome and some other increases in performance can be obtained too, such as diplexing, filtering, beamforming, impedance matching, more compact and lightweight [5]. The notion began with integration of waveguide photodetector to microstrip antenna via coplanar waveguide.

Yu *et al*. integrated printed slot antenna with high power photodiode (PD). Integration began with simple circuit model of photonic antenna (PD-matching circuit-slot antenna), then minimizing loss resistance of antenna to obtain better efficiency. Because PD and slot antenna grown on different substrate, they were connected with gold bond wire. The selected antenna was three element folded slot for ease of tuning. With this configuration, achieved antenna gain was 3 dBi and radiation pattern was semi hemisphere. Figure 4.3 shows the antenna-PD integration.



(a) (b)

Figure 4.3 Photodiode integrated with slot antenna; (a) integration (b) slot antenna

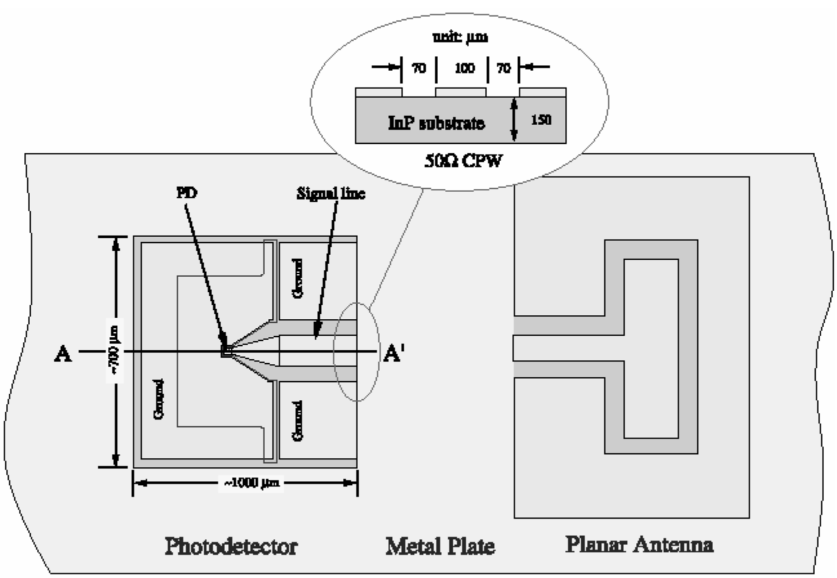


Figure 4.4 Configuration of planar antenna and photodetector to be integrated

Effort to integrate planar antenna with high power photo diode also was done by Li and Izutsu. Uni-travelling carrier photodiode (UTC-PD) was integrated to coplanar patch antenna (CPA) with ground plane. They were able to characterize slot antenna which behave like microstrip antenna. CPA had 3.4% bandwidth and gain of 7.8 dBi, and if the antenna configured in array of two elements, its gain was 10.5 dBi. RF output of PD was more than 10 dBm with incident optical power of 13 dBm. Figure 4.4 shows the integrated PD-CPA.

Increase in radiated power of AFPM based passive integrated picocell is being investigated by integrating AFPM with photonic bandgap (PBG) planar antenna. For integration purpose, AFPM is developed using new semiconductor material. Figure 4.5 shows proposed antenna. Dual rectangular patches tuned to Tx/Rx band and built above uni-planar compact PBG with different periodicities to provide isolation between the Transmit and Receive feed to the AFPM. This ensures that the output RF signal from the AFPM is efficiently diverted to the Transmit antenna and sees a good match. Similarly the incoming RF optimally excites the RX patch and thus channels the available power efficiently to the AFPM.

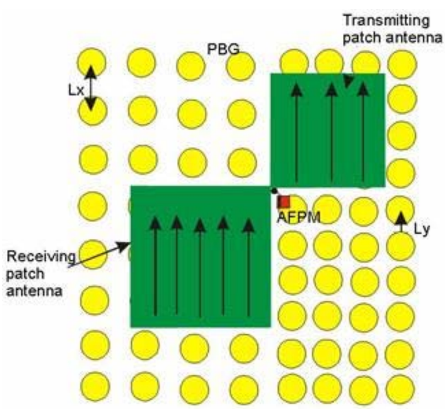


Figure 4.5 Proposed self-diplexing PBG antenna with integrated AFPM.

Despite the fact that the integration of photonics with antennas has recently gained momentum the issue of controlling the output power in photonic antennas has not yet been considered. A framework for developing faster, adaptive wireless communication using arrays of smart antennas. The antenna and the optical fiber are interfaced through a photodetector, and the hybrid integration with the antenna increases bandwidth and communication capacity. The power control system (implemented in software) uses RF noise power measurements to adaptively regulate the bias voltage of the photodetector. Through the bias voltage, the transmission power of the antenna can be adjusted. In this way, the required signal-to-noise ratio for slowly varying noise levels and control the capacity of the channel at the same time was achieve. Since parallel nodes in a wireless network introduce noise, nodes must transmit at the minimum possible energy level. An array of RF modulator/ photodetectors integrated directly to an array of antennas can combine the advantages of both fiber optics and wireless channels. Used with a transmission power control system, this new RF/photonic antenna array can form a smart system that enhances network capacity and coverage. A large number of such RF/Photonic antenna elements could be networked together into a star configuration, feeding in and out of a radio hub.

Phased array photonic antennas are being considered for military communication systems. For these systems to be cost effective, the integration of photonics and millimeter wave components into a single module that can operate up to Q/V-Band is required. As the operating frequency of phased array systems approaches 20 GHz, the antenna size and spacing approaches the size of the MMIC circuit itself. Because of this, single layer planar techniques cannot be implemented due to the large module footprint. The most advantageous way to maintain a footprint compatible with Ka band and higher frequency systems is to reduce the size of the module using a multilevel approach. A module design and assembly process that includes optical components, millimeter wave components, optical fiber interfaces, and an integrated planar antenna to form a module capable of meeting military requirements at 40 GHz was designed.

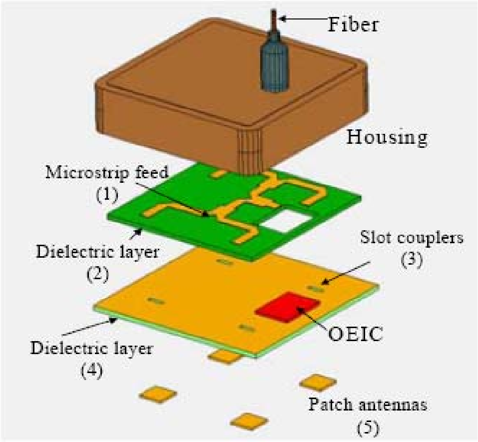


Figure 4.6 Millimeter wave photonic antenna modules

The planar antenna is part of the module package eliminating the need to attach or secure an additional antenna component on the phased array antenna. A multi-level photonic module for a phased array antenna operating at millimeter wave frequencies was successfully developed. The module comprises of photonic and millimeter wave circuits integrated with planar antenna sub-array that forms a complete transmitter element. The module performance matched the simulation demonstrating a 7.5 dBm EIRP at 40 GHz. This was the first attempt to develop low cost, high volume products using commercially available batch processing of photonic and millimeter wave components into a single multi-level package for phased array antennas.

4.5 DESIGN AND SIMULATION

The implementation of photonic antenna could be simplified as described in the block diagram at Figure 4.7. The first is optical part that will be simulated and optimized using optical communication software, namely Optisystem. The second part is antenna, will be designed and simulated using Agilent ADS software. Finally, the antenna is included in the Optisystem simulation to evaluate the photonic antenna system performance.

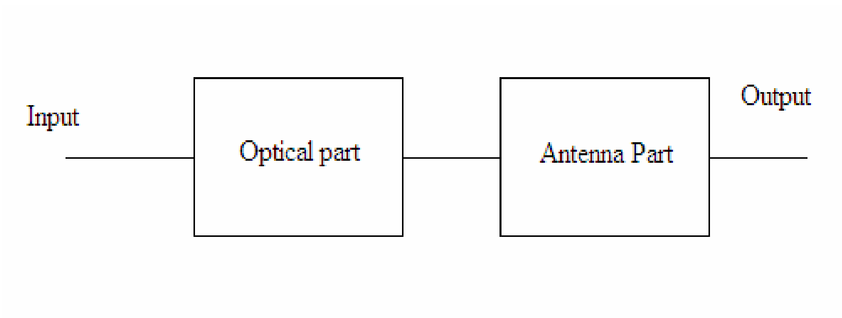


Figure 4.7 Implementation block diagram

4.5.1 Microstrip Antenna Design

The photonic antenna is designed to be used for longer range application, therefore the antenna must have high gain for the bridging application. An array antenna will be design for this purpose. The first step in the design is to specify the dimensions of a single microstrip patch antenna. The equation below will be used to determine the value of W and L of the patch antenna.

$$W = \frac{C}{2f_0}\left[\frac{2}{\varepsilon_r + 1}\right]^{1/2} \tag{4.1}$$

$$\varepsilon_{r_{eff}} = \frac{\varepsilon_r + 1}{2} + \frac{\varepsilon_r - 1}{2}\left[1 + 12\, h/w\right]^{1/2} \tag{4.2}$$

where h = 1.6mm and ε_r = 4.7

$$\Delta L/_{h} = 0.412\left[\frac{\left[\left(\varepsilon_{r_{eff}} + 0.3\right)\left(^{w}/_{h} + 0.264\right)\right]}{\left[\left(\varepsilon_{r_{eff}} - 0.258\right)\left(^{w}/_{h} + 0.8\right)\right]}\right] \quad (4.3)$$

$$L = \frac{C}{2f_{o}\sqrt{\varepsilon_r}} - 2\Delta L \quad (4.4)$$

For the feeding technique, the transmission line is design to matching at 50Ω. The equation below will be used to determine the value of *w* and ℓ of the transmission line.

$$\frac{W}{d} = \frac{8e^{A}}{e^{2A} - 2} \quad \text{for } \frac{W}{d} \leq 2 \quad (4.5)$$

$$A = \frac{Z_o}{60}\sqrt{\frac{\varepsilon_r + 1}{2}} + \frac{\varepsilon_r + 1}{(\varepsilon_r - 1)\left(0.23 + \frac{0.11}{\varepsilon_r}\right)} \quad (4.6)$$

$$k_o = \frac{2\pi f}{C} \quad (4.7)$$

$$\ell = \frac{90^{o}\left(\frac{\pi}{180^{o}}\right)}{\sqrt{(\varepsilon_{r_{eff}})(k_0)}} \quad (4.8)$$

Its characteristic parameters are the length L and width W for the antenna and, the width *w*, and length ℓ for the transmission line matching network as shown in Figure 4.8.

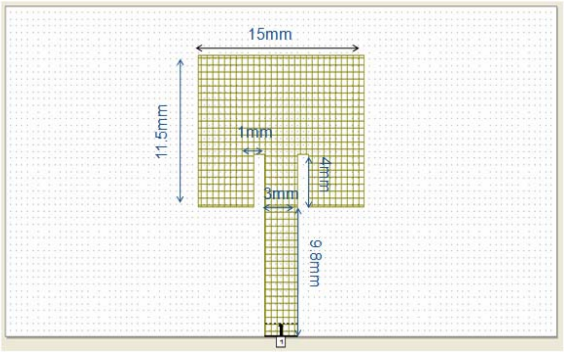


Figure 4.8 The accuracy of binary classification

For the two-element array antenna, the power divider transmission line matching technique had been designed. By using the equation above, taking the Z_0 equal to 50Ω, 70.7Ω, and 100 Ω, the result is shown in Figure 4.9.

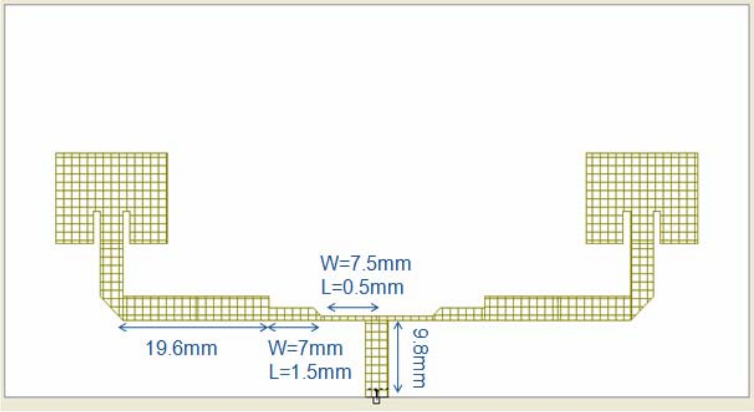


Figure 4.9 Two element array antennas

The design of the antenna will be until 4 element array. The design of the 4 element array antenna is shown in Figure 4.10.

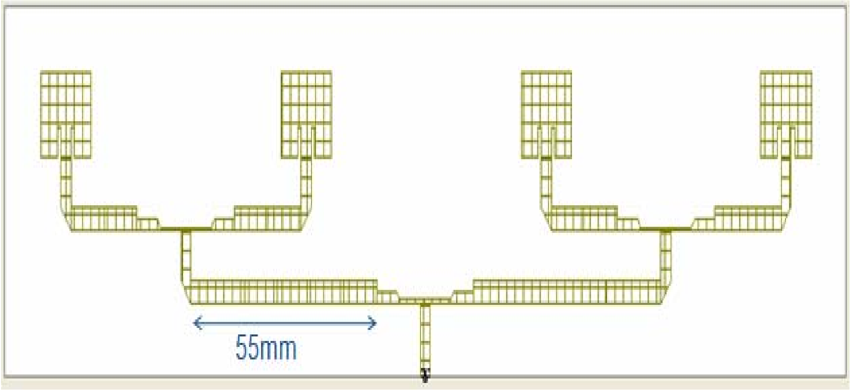


Figure 4.10 4 element array antennas

The value for the transmission line matching feeding antenna is not fixed. Approximate technique can be used to get a very good return loss for the antenna.

4.5.2 Photonic Antenna Design

The objective of the optical design is to generate modulated RF signal with optical carrier (laser) and the result from both signals will be modulated and fed to an optical fiber as a transmission line. The output from the fiber will fed through the optical detector (photodetector) and finally fed to antenna that had been designed. The schematic of the optical design is shown in Figure 4.11.

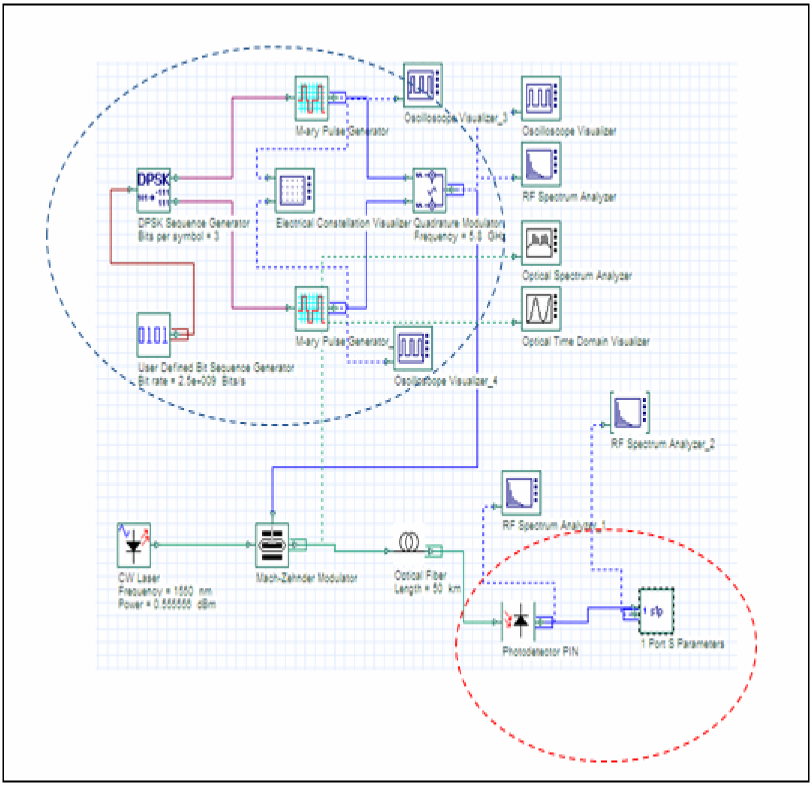


Figure 4.11 Schematic of the optical design

The data rate from bit sequence generator is assumed about 2.5 GB/s which possibly are a good estimation for the RAU capacity. Then, the Duo-binary Phase Shift Keying (DPSK) modulated scheme was used to increase the spectral efficiency of the system. The signals coming from the DPSK modulator was converted to M-ray pulse by using M-ray pulse generator and then were modulated using 5.8 GHz RF carriers. RAU is simply modeled by doing this step as shown in the blue circle in Figure 4.11.

The output from RAU will modulated with optical carrier (laser) and fed to optical fiber. The laser diode is radiating in the range of 1550 nm for low loss of optical frequency band. For the optical fiber, the length is set up to 50 km as a default value. At the receiver part, PIN photodetector was used by take the value of responsitivity = 1A/W and dark current = 10 nA as a default value. Then, the results from antenna will exports to 1 port S parameters component as the antenna model. The implementation for the photonic antenna is done as shown in Figure 4.11.

4.6 RESULTS AND DISCUSSIONS

There are two major results that will be discussed in this section. The first is the micostrip antenna part and the second is photonic part. For the antenna, it will operate at 5.8 GHz which means the return loss will drop at 5.8 GHz. The antenna must have high power gain due to the point to point transmitting signals while the main objective for the photonic part is to generate modulated RF signals with optical carrier (laser). This signals will fed to antenna and the result the result will be discussed.

4.6.1 Microstrip Antenna Results

From the previous section, all the equation to design an antenna will be used. There are several parameter of the antenna will be discussed which is the return loss and the gain of the antenna.

4.6.1.1 Single Patch Microstrip Antenna

The magnitude of S_{11} versus frequency (return loss) is shown in Figure 4.12. It shows that the rectangular single patch antenna is indeed resonating at 5.8 GHz with a return loss of -20 dB. These results show that the single patch microstrip antenna will operate well at 5.8 GHz. Magnitude of the gain of this antenna is shown in Figure 4.13. It shows that the maximum gain is at 6.48 dB. This result is not satisfying the objective of this project due to the high power gain. So, the design will continue with two element microstrip patch antenna.

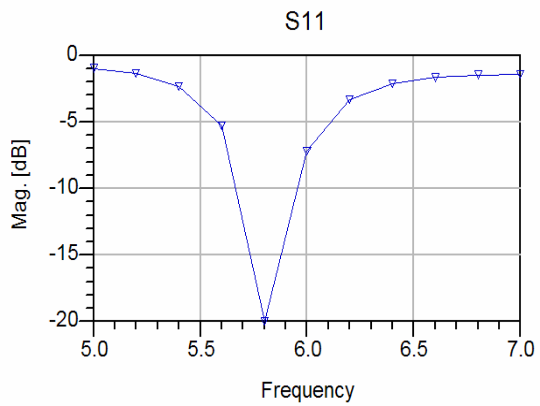


Figure 4.12 Return loss for single element antenna

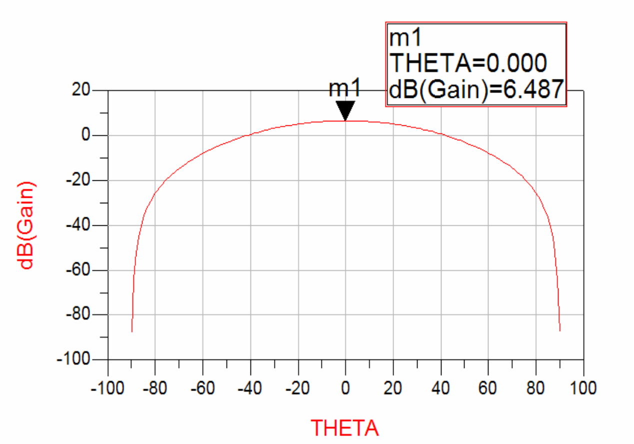


Figure 4.13 Gain for two elements antenna

4.6.1.2 Two-Element Microstrip Array Antenna

For two element microstrip array antenna, the return loss is shown in Figure 4.14. It shows that the two element microstrip array antenna is indeed resonating at 5.8GHz with a return loss of -12dB.

These results show that the single patch microstrip antenna will operate well at 5.8GHz. Magnitude of the gain of this antenna is shown in Figure 4.15. It shows that the maximum gain is at 11.76 dB. This result is not satisfying the objective of this project due to the high power gain. So, the design will continue with four element microstrip patch antenna

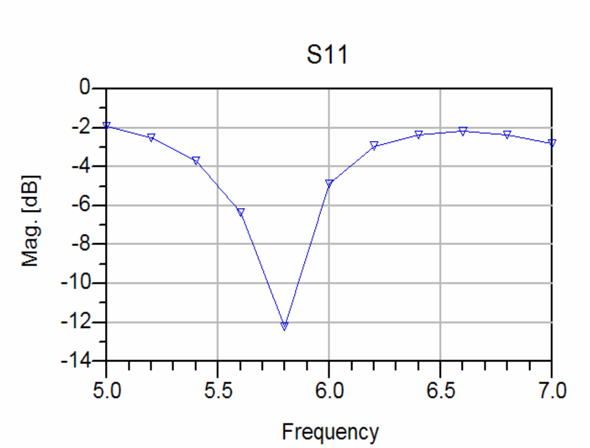


Figure 4.14 Return loss for two elements antenna

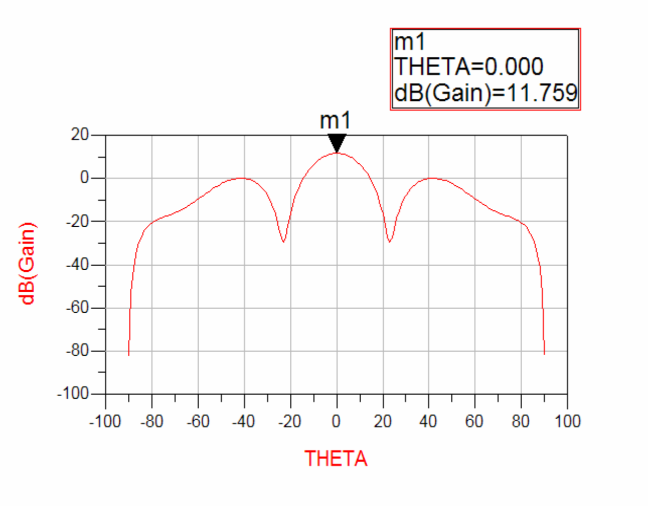


Figure 4.15 Gain for two elements antenna

4.6.1.3 Four Element Microstrip Array Antenna

Four-element microstrip array antenna's return loss is shown in Figure 4.16. It shows that the four-element microstrip array antenna is indeed resonating at 5.8 GHz with a return loss of -12 dB. These results show that the single patch microstrip antenna will operate well at 5.8 GHz. Magnitude of the gain of this antenna is shown in Figure 4.17. It shows that the maximum gain is at 15.01 dB. This result shows that the four element array has the highest maximum gain. Due to the project objective, this antenna will be taken for the input at the photonic antenna design.

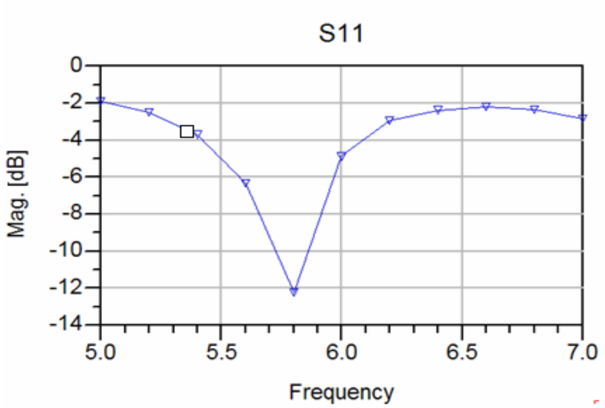


Figure 4.16 Return loss for four elements antenna

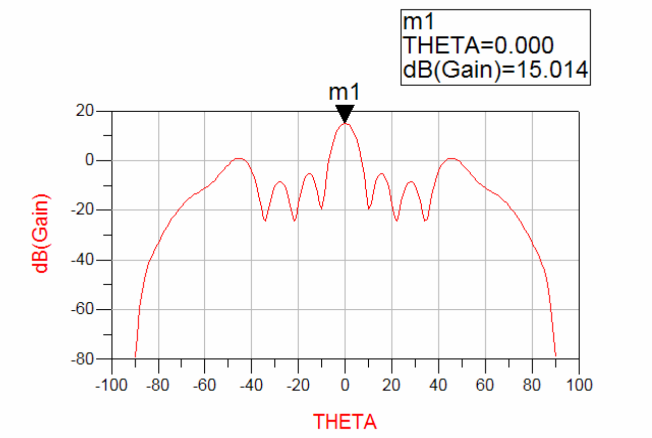


Figure 4.17 Gain for four elements antenna

4.6.2 Photonic Antenna Results

Figure 4.18 shows the input signals that will be fed into the photodetector through optical fiber. The signal power at 5.8 GHz is about 18 dBm and this signal will be modulated with optical carrier (laser). The output from the photodetector is shown in Figure 4.19. The signal power at the output of photodetector at 5.8

GHz is drop to -68dBm due to the optical link loss and this signal will be fed into the antenna. The output signal from the antenna is drop again at 5.8GHz to -70dBm as shown in Figure 4.19. We can see there are some unwanted signals at the output from the antenna and the magnitude is very low. This can be overcome by adding a band pass filter and amplifier before the antenna as shown in Figure 4.20.

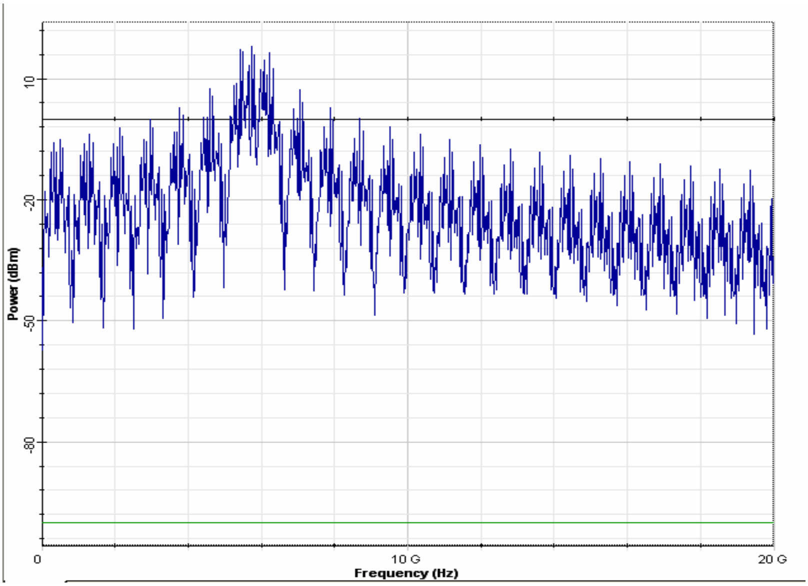


Figure 4.18 Modulated RF signal

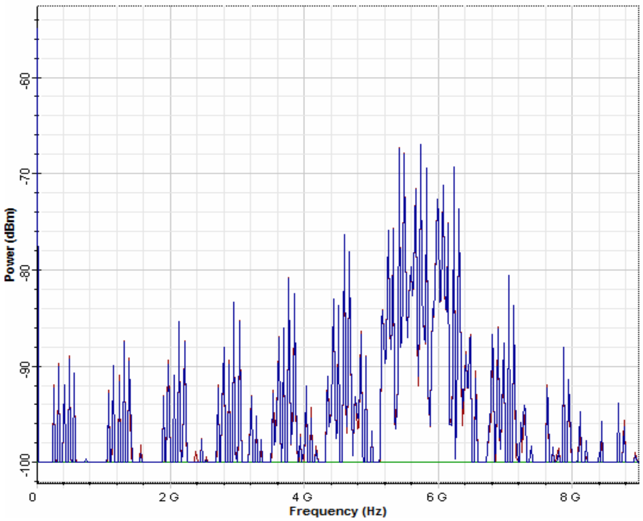


Figure 4.19 Signal at the output of the photodetector

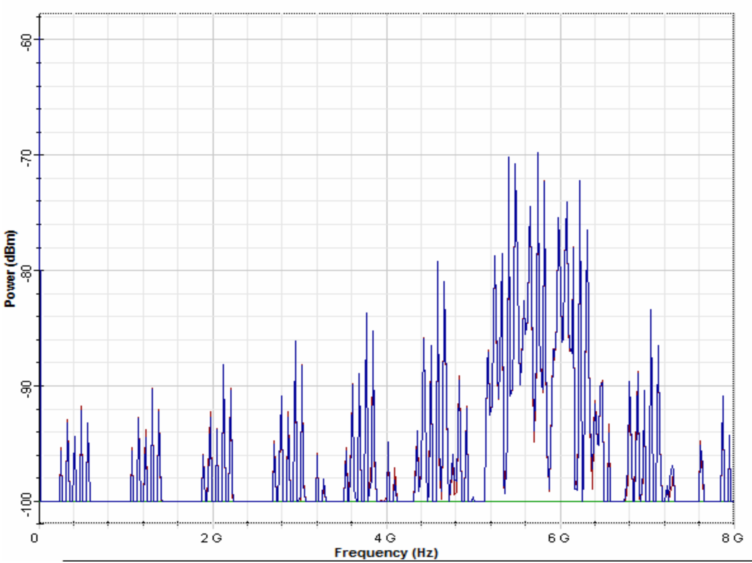


Figure 4.20 Signal at the output of the antenna

Let the cut off frequency of the filter is at 5.8GHz and the order of the filter is 5, the result after adding the bandpass filter is shown in Figure 4.21. From the result, we can see that all the noise was filtered out and the signal is only resonate at 5.8GHz. The magnitude of this signal is at -70dBm. It shows that the power transmitted from the antenna is very low. The transmitting power must be increased by applying an amplifier and the result after adding 10 dB gain amplifier is shown in Figure 4.22. It shows the maximum power is -60 dBm.

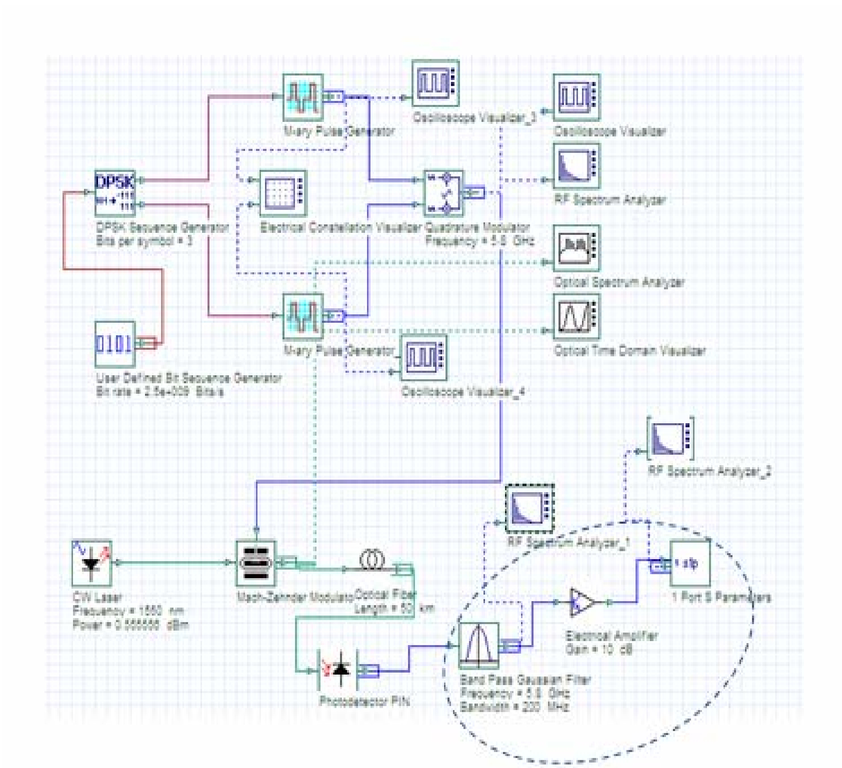


Figure 4.21 Integration of amplifier and bandpass filter with photonic antenna

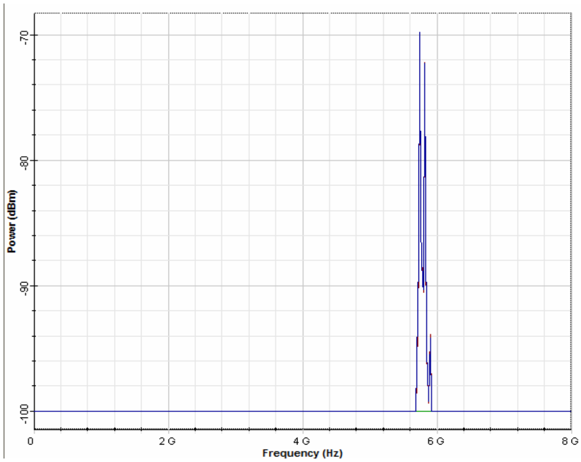


Figure 4.22 Output signal after adding bandpass filter

After adding power amplifier, the magnitude was increased to -60 dBm as shown in Figure 4.23. Base on this result, we can say that the input signals from RAU can get exactly same at the output of the antenna by increase the gain of the power amplifier.

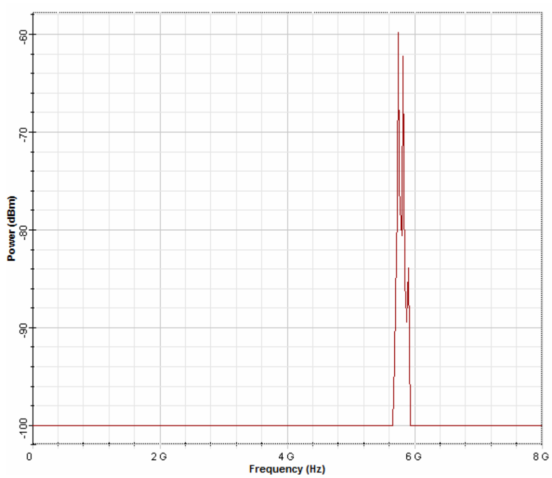


Figure 4.23 Output signal after adding power amplifier

4.7 CONCLUSION

ROF technology gives many benefits due to the development of optical fiber technology in wireless networks which provides great potential for increasing the capacity without largely occupying additional radio spectrum. This technology also helps to provide a cost effective, high performance solution for present and future high-speed fiber based wireless access systems.

From the simulation result, the photonic antenna is operating at 5.8GHz frequency and satisfies WLAN application (bridging) due to the high gain. This photonic antenna will be able to convert an optical wave to radio wave and then transmit at 5.8GHz frequency.

Photonic antenna can be implemented as a new hardware design base on the simulation had been done in this project. The results from this project will give a very good reference for future study on photonic antenna. This is a new technology that will make the wireless communication world becomes more challenging and interesting.

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