PROJECT COMPLETION REPORT

FOR

(SHORT TERM) RESEARCH GRANT

UPLINK RADIO ACCESS POINT WITH RADIO OVER FIBER TECHNOLOGY FOR PICOCELL SYSTEM

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Project Code No.: PJP/2011/FTK(7A)/S00957

Report Submission Date : 6 May 2013

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ABSTRACT

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(*Keywords: RoF, access point, uplink, picocell*)

The purpose of this project is to design the uplink radio access point (RAP) for radio over fiber (RoF). RoF is the technology whereby radio signal modulated the light then it's transmitted over an optical fiber link to facilitate wireless access. It also will be applying picocell technology as well. The RAP has 2 types of modulator which direct and external modulator but in this project will be focus on direct modulator. The uplink RAP design consists of BPF (optional), LNA and amplifier which operating at 2.4GHz band and also included a laser. The RAP is located after the antenna and before optical fiber. The execution of design is based on Optisystem software from Optiwave System. It is used to perform the simulation of the uplink RAP. In the simulation, the analysis of constellation and EVM diagram are concerned which it's presenting the receive signal at the central base station (CBS). The design optimization needs in order to enhance the signal receive performance. At the end of the design, the best simulation result was given by combination of LNA, amplifier and laser. With this arrangement, the receive signal at CBS is almost similar to the transmit signal from end user. Towards the end, this combination is proposed as uplink RAP for RoF system which operating at WLAN 2.4GHz band.

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1. INTRODUCTION

1.1 Introduction of the project

Wireless operations permits services, such as long range communications, that are impossible or impractical to implement with the use of wires. The term is commonly used in the telecommunications industry to refer to telecommunications systems (e.g. radio transmitters and receivers, remote controls, computer networks, network terminals, etc.) which use some form of energy (e.g. radio frequency (RF), infrared light, laser light, visible light, acoustic energy, etc.) to transfer information without the use of wires. Information is transferred in this manner over both short and long distances.

2. BACKGROUND

2.1 Project Background

The propagation of mobile and other wireless devices coupled with increased demand for broadband services are putting pressure on wireless systems to increase capacity. Wireless systems must have increased feeder network capacity, operate at higher carrier frequencies, and cope with increased user population densities in order to achieve the propagation of mobile and other wireless devices. Nevertheless, raising the carrier frequency and thus reducing the radio cell size leads to costly radio systems while the high installation and maintenance costs associated with high-bandwidth silica fiber render it economically impractical for in-home and office environments (Ng'oma, 2007).

Fiber optics can be categorized in 3 current technologies which are analogue transmission over fiber or known as RF over fiber or IF over fiber. The other approaches are digital transmission over fiber for Analogue-to-Digital/Digital-to-Analogue conversion and also analogue transmission over hybrid fiber-coaxial (HFC) network for subcarrier multiplexed (SCM) technology.

Radio over Fiber technology (RoF) is an integration of wireless and fiber optic networks, is an essential technology for the provision of untethered access to broadband wireless communications in a range of applications including last mile solutions, extension of existing radio coverage and capacity, and backhaul. The advantages of optical fiber as a transmission medium such as low loss, light weight, large bandwidth characteristics, small size and low cable cost make it the ideal and most flexible solution for efficiently transporting radio signals to remotely located antenna sites in a wireless network. In addition to its transmission properties, the insensitivity of fiber optic cables to electromagnetic radiation is a key benefit in their implementation as the backbone of a wireless network.

This technology has been proposed to provide functionally simple base station or radio access point (RAP) that are interconnected to switching center or otherwise known as Central Base Station (CBS) via an optical fiber. Radio-over-fiber (RoF) technology has emerged as a cost effective approach for reducing radio system costs because it simplifies the remote antenna sites and enhances the sharing of expensive radio equipment located at appropriately sited CBS. First RoF systems were mainly used to transport microwave signals, and to achieve mobility functions in the sited CBS. That is, modulated microwave signals had to be available at the input end of the RoF system, which subsequently transported them over a distance to the RAP in the form of optical signals. At the RAP the microwave signals are regenerated and radiated by antennas.

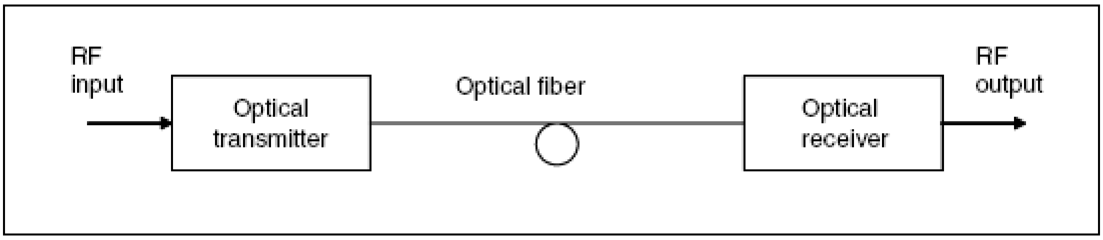

Figure 2.1: Block diagram of a generic fiber-optic link.

Figure 2.1 is showing the basic block diagram of the fiber optic link. Traditionally, the optical transmitter uses intensity modulation of a laser source to impress a microwave signal onto an optical carrier frequency. The optical transmitter is also known as CBS. The modulated light is then transmitted over a low-loss fiber-optic cable and detected by a high-speed photodetector in optical receiver or also known as RAP. The intensity modulation may be done by directly modulating the current of a semiconductor laser or by externally modulating a continuous-wave (CW) semiconductor or solid-state laser source with an RF signal. Common external modulators include the Mach-Zehnder modulator (MZM) and the electro-absorption modulator (EAM) which located in RAP (Jemison & Paolella, 2008).

2.2 RoF Technology

RoF technology is a technology by which microwave (electrical) signals are distributed by means of optical components and techniques. A RoF system consists of a CBS and a Remote Site (RS) connected by an optical fiber link or network. For the GSM network application, Mobile Switching Centre (MSC) as a CBS while the RS is the base station (BS) as in shown in Figure 2.1. The CBS wireless Local Area Networks (WLANs) of would be the headend while the RAP would act as the RS.

The frequencies of the radio signals distributed by RoF systems span a wide range (usually in the GHz region) and depend on the nature of the applications. In this report, the terms microwave and RF are used interchangeably when referring to all the electrical signals generated at the RS of the RoF system. Thus high frequency millimeter waves (mm-waves), microwaves, and lower frequency signals are all loosely referred to as microwave or RF signals in the report (Ng'oma, 2007).

RoF transmission systems are usually classified into two main categories shown in Figure 2.2 (RF-over-Fiber; IF-over-Fiber) depending on the frequency range of the radio signal to be transported. In RF-over-Fiber architecture, RF signal carried by a data with a high frequency (usually greater than 10 GHz) is imposed on a light wave signal before being transported over the optical link. Therefore, wireless signals are optically distributed to base stations directly at high frequencies and at the base stations, it's converted to from optical to electrical domain before being amplified and radiated by an antenna. As a result, no frequency up/down conversion is required at the various base station, thereby resulting in simple and rather cost-effective implementation is enabled at the base stations. Then, for IF-over-Fiber architecture, an IF (Intermediate Frequency) radio signal with a lower frequency (less than 10 GHz) is used for modulating light before being transported over the optical link. Therefore, wireless signals are transported at intermediate frequency over the optical.

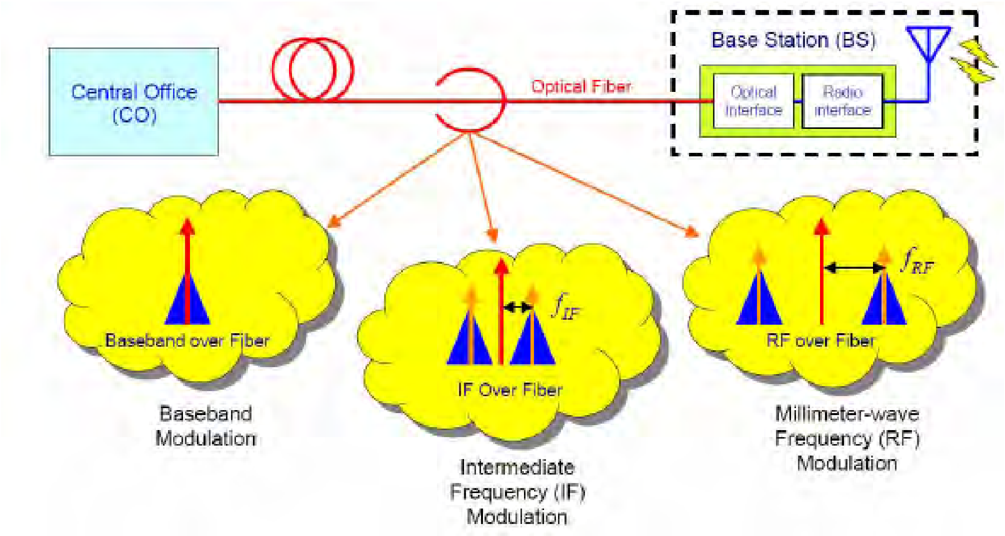

Figure 2.2: Radio signal transport schemes for RoF systems (D.Opatic).

2.3 Picocell System

Picocell is a wireless base station with extremely low output power designed to cover an extremely small area, such as one floor of an office building or more recently in-aircraft. Picocell systems have been proposed to meet the growing demands of high data rate and high carrier frequency in wireless communications. In cellular networks, picocells are typically used to extend coverage to indoor areas where outdoor signals do not reach well, or to add network capacity in areas with very dense phone usage, such as train stations, airports or shopping malls. A picocell is analogous to a WiFi access point.

It's tend to have a longer range than femtocells which are designed to cover a user's home or small office rather than an office floor or street corner. Picocells are normally installed and maintained directly by the network operator, who would pay for site rental, power and fixed network connections back their switching centre. Picocell is configured with neighbour lists, so that mobile phones can switch over to an appropriate nearby cell and continue their conversation without interruption. One way to establish a picocell is to provide a picocell base station that operates within a relatively limited range within the coverage area of a macrocell.

3. PROBLEM STATEMENT

3.1 Problem Statement

The RoF technology is a technology by which microwave (electrical) signals are distributed by means of optical components and techniques. A RoF system consists of a CBS and a Remote Site (RS) connected by an optical fiber link or network. The base station has some limitation such as high cost, high power and harder installation. In order to overcome these limitations, picocell system has been introduced where it is a wireless base station with extremely low output power designed to cover an extremely small area, such as one floor of an office building.

In a RoF system, it has 2 types of modulation in RAP whether using the direct modulator such as filter, laser and amplifier or using external modulator such as Mach-Zehnder modulator (MZM) and the electro-absorption modulator (EAM). The modulator is needed because it’s the transceiver where it can covert the optical signal to the electrical signal or vice versa. This project is designing the direct modulator for reducing the costing of the design. It would cover only on the design simulation of the uplink transmission system using the specific software.

4. APPROACH

4.1 Methodology

Figure 4.1 shows the research methodology of uplink RAP for RoF system. As a beginning of the project, just design a simple transmitter section and uplink system for simple evaluation and better understanding. Then proceed to the single patch antenna design by using the CST Microwave Studio software. The antenna that has been designed is a narrow band that transmitted at frequency 2.44GHz. BPF has been designed for passes frequency within certain range. The BPF has simulated by using the AWR software.

After the antenna and BPF had designed, they had implemented into the Optisystem for transmitter section and uplink transmission simulation. The uplink transmission had been designed stage by stage in order to gather the required results. After that analysis on the parametric performance of the design and finally, after the simulation completed analysis the results obtain.

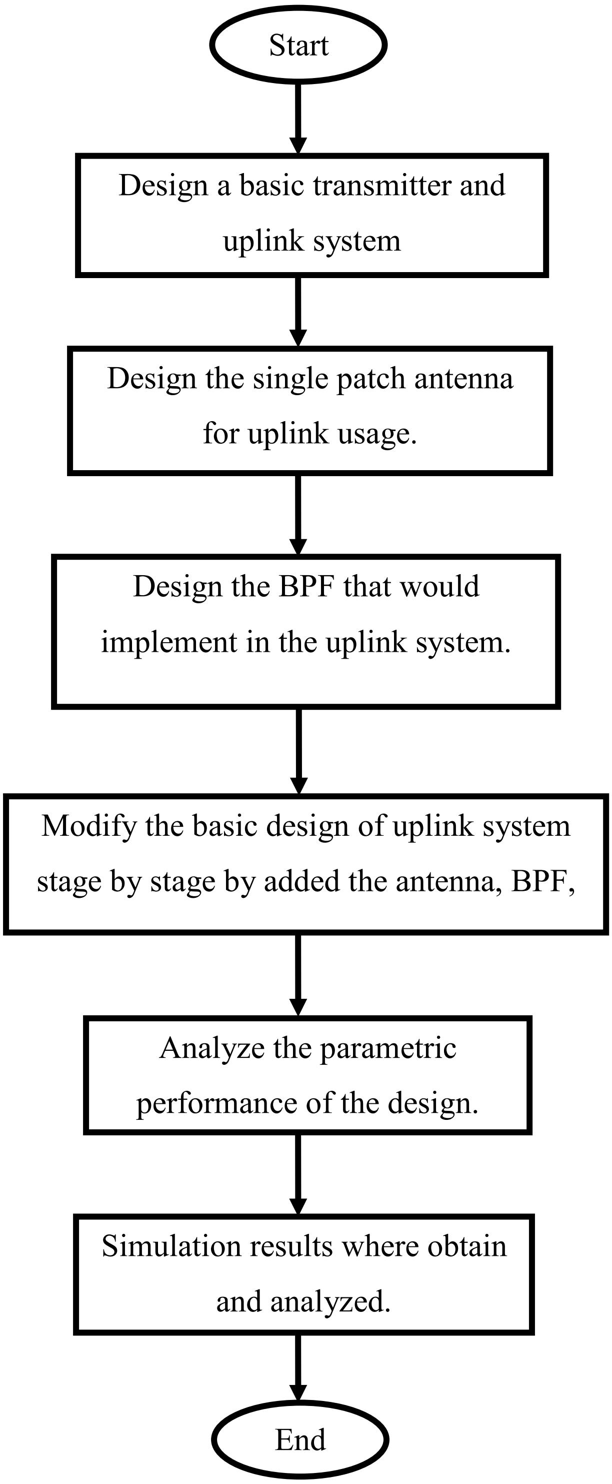

Figure 4.1: Flowchart of uplink transmission design for RoF system

4.2 Antenna Design

A patch antenna is a narrowband, wide-beam antenna fabricated by etching the antenna element pattern in metal trace bonded to an insulating dielectric substrate with a continuous metal layer bonded to the opposite side of the substrate which forms a ground plane. Common microstrip antenna radiator shapes are square, rectangular, circular and elliptical, but any continuous shape is possible. The most commonly employed microstrip antenna is a rectangular patch.

4.2.1 Antenna Specifications

The process of the antenna design starts with choosing on antenna specifications such as frequency range, return loss (S_{11}), transmitted power, bandwidth, antenna types, materials and matching impedances as shown in Table 4.1. The antenna type chosen to be used the microstrip patch because it can produce the directional.

Table 4.1: Antenna Specifications

Antenna Specifications	**Values**
Frequency	2.44 GHz
Return Loss, S_{11}	< - 10dB
Transmitted Power	> 90%
Bandwidth	Narrowband
f_2/f_1	< 2
Antenna Types	Microstrip Patch
FR4 dielectric constant	4.7
FR4 thickness	1.6 mm
Matching Impedance	50Ω

The required parameters should be calculated in order to design the single patch antenna are the patch width, patch length, width and length of 50Ω transmission line and also the inset length. Below is the calculation for the desired antenna parameters design.

Patch width, $\omega_{patch} = \dfrac{c}{2f\sqrt{\dfrac{\varepsilon_r + 1}{2}}}$

$$= \frac{3x10^8}{2(2.44 \times 10^9)\sqrt{\dfrac{4.7+1}{2}}}$$

= 36.415mm

Parameters calculated in order to calculate the patch length:

$$\varepsilon_{eff} = \frac{\varepsilon_r + 1}{2} + \frac{\varepsilon_r - 1}{2}\left[1 + 12\left(\frac{h}{w}\right)\right]^{-1/2}$$

$$= \frac{4.7+1}{2} + \frac{4.7-1}{2}\left[1 + 12\left(\frac{1.6 \times 10^{-3}}{36.415 \times 10^{-3}}\right)\right]^{-1/2}$$

= 4.347

$$\Delta\ell = \frac{0.412h(\varepsilon_{eff} + 0.3)\left(\dfrac{w}{h} + 0.264\right)}{\left(\varepsilon_{eff} - 0.258\right)\left(\dfrac{w}{h} + 0.8\right)}$$

$$= \frac{0.412(1.6 \times 10^{-3})(4.351 + 0.3)\left(\dfrac{36.415}{1.6} + 0.264\right)}{(4.351 - 0.258)\left(\dfrac{36.415}{1.6} + 0.8\right)}$$

= $7.3204x10^{-4}$

Patch length, $\ell_{patch} = \dfrac{c}{2f\sqrt{\varepsilon_{eff}}} - 2\Delta\ell$

$$= \frac{3 \times 10^8}{2(2.44 \times 10^9)\sqrt{4.351}} - 2(7.3204 \times 10^{-4})$$

= 28.02mm

Inset length, y_o calculation:

Where;

n = 120π

$$\lambda_o = \frac{c}{f} = \frac{3\times10^8}{2.44\times10^9} = 0.123$$

$$k = \frac{2\pi}{\lambda_o} = 51.089$$

$$G = \frac{\pi\omega}{n\lambda_o}\left[1 - \frac{(kh)^2}{24}\right]$$

$$= \frac{\pi(36.415\times10^{-3})}{120\pi(0.123)}\left[1 - \frac{(51.089\times1.6\times10^{-3})^2}{24}\right]$$

$$= 2.466\text{x}10^{-3}$$

Input resistance, $R_{in}(y=0) = R_e = \frac{1}{2G}$

$= 202.76\Omega$

Therefore, the inset length is $y_o = \frac{L}{\pi}\sin^{-1}\left(\frac{50}{R_{in}(y=0)}\right)^{1/4}$

$$= \frac{28.02\times10^{-3}}{180}\sin^{-1}\left(\frac{50}{202.76}\right)^{1/4}$$

$= 6.975\text{mm}$

Knows that z = 50Ω,

Therefore, to calculate the width and length of 50Ω transmission line,

$$H' = \frac{z_o\sqrt{2(\varepsilon_r+1)}}{119.9} + \frac{1}{2}\left(\frac{\varepsilon_r-1}{\varepsilon_r+1}\right)\left(\ln\frac{\pi}{2} + \frac{1}{\varepsilon_r}\ln\frac{4}{\pi}\right)$$

$$= \frac{50\sqrt{2(4.7+1)}}{119.9} + \frac{1}{2}\left(\frac{4.7-1}{4.7+1}\right)\left(\ln\frac{3.142}{2} + \frac{1}{4.7}\ln\frac{4}{3.142}\right)$$

$= 1.5712$

$$\frac{\omega_{50}}{h} = \left(\frac{\exp H^{'}}{8} - \frac{1}{4\exp H^{'}} \right)^{-1}$$

= 1.8195

50Ω transmission line width, ω_{50} = 1.8195 x 1.6 x 10^{-3}

= 2.9112mm

$$\frac{\omega_{50}}{2} = 1.4556mm$$

$$\varepsilon_{eff} = \frac{\varepsilon_r + 1}{2} + \frac{\varepsilon_r - 1}{2}\left[1 + 12\left(\frac{h}{w_{50}}\right)\right]^{-1/2}$$

$$= \frac{4.7+1}{2} + \frac{4.7-1}{2}\left[1 + 12\left(\frac{1.6\times10^{-3}}{2.9115\times10^{-3}}\right)\right]^{-1/2}$$

= 3.5213

$$\lambda_g = \frac{c/f}{\sqrt{\varepsilon_{eff}}}$$

$$= \frac{3\times10^{8}/2.44\times10^{9}}{\sqrt{3.5213}}$$

= 65.52 x 10^{-3}

50Ω transmission line length, $\ell_{50} = \frac{\lambda_g}{4} = \frac{65.52\times10^{-3}}{4}$

=16.38 x 10^{-3}

4.2.2 Optimization

Firstly, the antenna dimension in the CST software is according to the calculation above. Then running the simulation and Figure out the return loss of the antenna is not really good. Consequently, the certain parametric is needed to be optimized. The aim of optimization is to improve the performance of antenna such as the gain and return loss. The dimension of the antenna in Figure 4.2 is after optimization. In order to obtain the best return loss, the dimension of the propose antenna has been optimized.

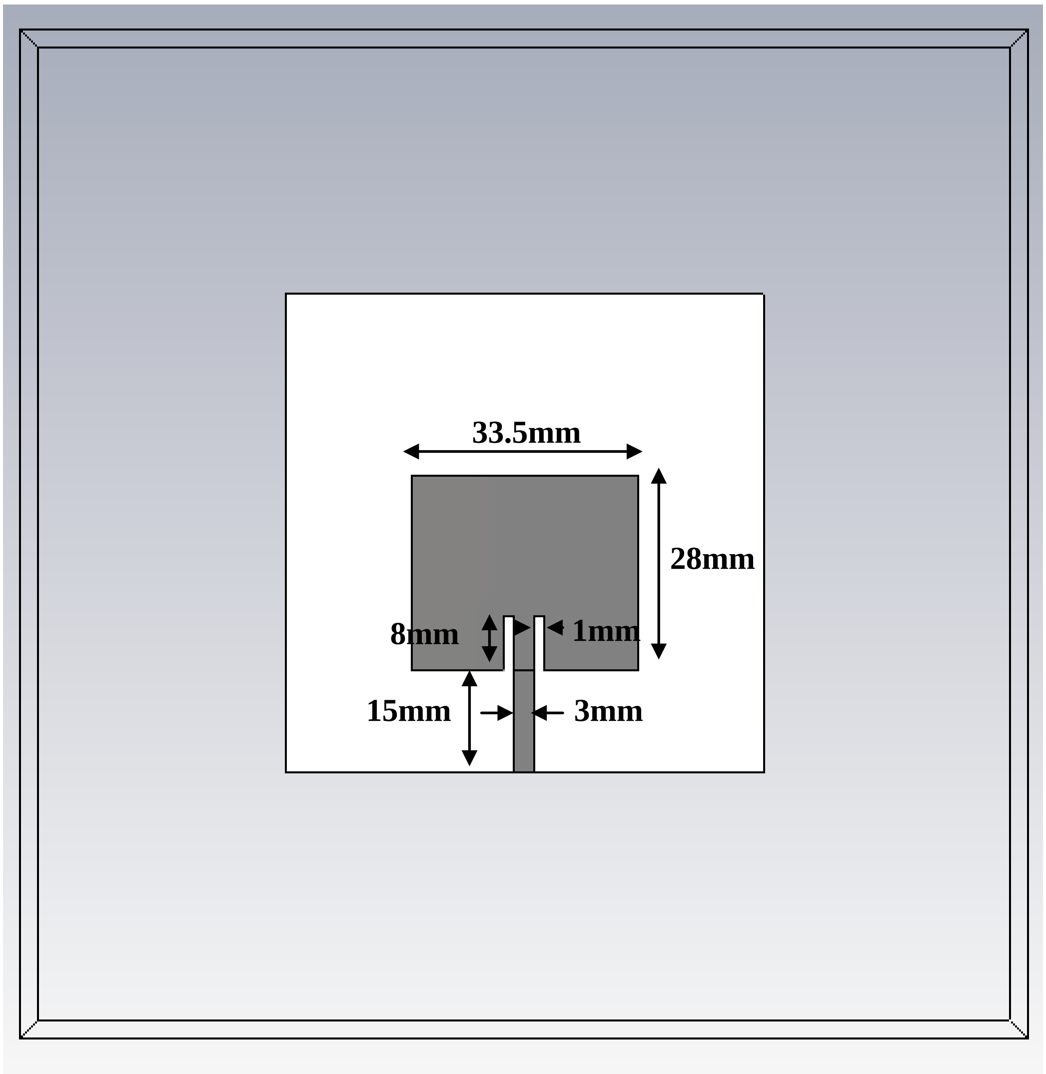

Figure 4.2: Final antenna dimension for operated frequency 2.44GHz.

4.3 BPF Design

Basically, the design of BPF is based on insertion loss method. The perfect filter would have zero insertion loss in the passband, infinite attenuation in the stopband and a linear phase response to avoid signal distortion in the passband. This method allows filter performance to be improved in a straightforward manner, at the expense of a higher order filter.

4.3.1 BPF Specifications

The procedure of the filter design starts with deciding on filter specifications such as frequency range, bandwidth, stopband attenuation and frequencies, input and output impedances as shown in Table 4.2. The chosen frequency is operated in ISM frequency band for WLAN (IEEE 802.11b standard) and also unlicensed band. Then, the Chebyshev would satisfy a requirement for the sharpest cutoff compared to others response of filter.

Table 4.2: Band Pass Filter Specifications

Filter Specifications	**Values**
Center Frequency, f_c	2.44 GHz
Upper cutoff Frequency, f_2	2.5 GHz
Lower cutoff Frequency, f_1	2.38 GHz
Bandwidth	0.12 GHz (4.92%)
Response	Chebyshev (0.5 ripple)
Min. Stopband Attenuation	-50dB at 2.28 GHz (100 MHz from f_1)
Input / Output Impedance	50Ω

4.4 Radio over Fiber (RoF) system design

The transmission design uplink is using Optisystem software. Figure 4.3 shows the block diagram of uplink transmission design for RoF system. The end user and transmitter antenna are a part of the transmitter section. For this path, just need a simple design that can be transmitted the signal to the receiver path.

The receiver path, need to be concentrate more on the design. The RAP consists of BPF, LNA, Amplifier and optical modulator. For optical modulator, can be used a laser as an electrical – optical converter. For the picocell technology, Fabry-Perot (FB) laser is recommended. This is because from FB characteristics, it's economical and suitable for the short range. For the CBS, photodector be using as optical receiver that can be translate the optical to electrical. The specifications to choose the photodetector are the current, responsivity and the noise-equivalent power.

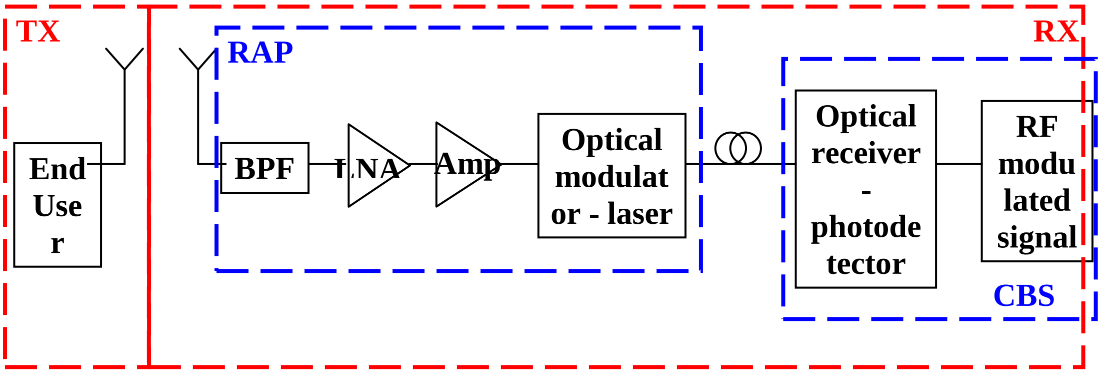

Figure 4.3: Uplink transmission block diagram

4.4.1 Basic transmitter

The design for RoF system started with the end user. For this section, just needed the end user and transmit antenna in the design. This simple transmitter section is used for the signal transmitted from the end user and it will be receiving at the uplink transmission system. Whichever the signal transmitted from here, the receiver need to deliver the receive signal as per transmitter.

Figure 4.4 shows the simple transmitter section system for RoF. The 1st dotted square is the end user that using the QAM. The 2nd dotted square is the transmitter antenna that has been designed before at the beginning of the design stage.

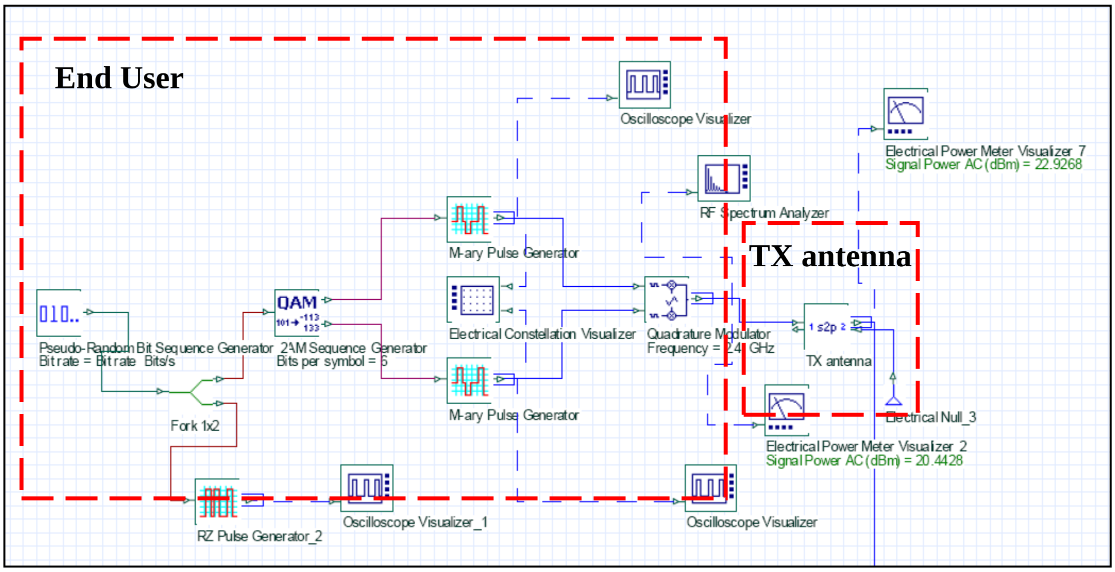

Figure 4.4: Transmitter section from end user

4.4.2 Basic uplink

Basic uplink design shows as per Figure 4.5. The path loss chosen is depending on the area need to be cover or distance between transmitter and receiver. It's showing by the 1st dotted square below. The receiver antenna was produced previously at the early stage of the design.

The analogue optical link consists of the optical modulator, fiber optic and optical receiver. For optical modulator, already chose the laser as a converter from the electrical to optical before its pass through the fiber optic. PIN photodetector has been chose as the optical receiver. It's function as an adapter from the optical that transmitted from the fiber optic to the electrical signal only then proceeds to central station.

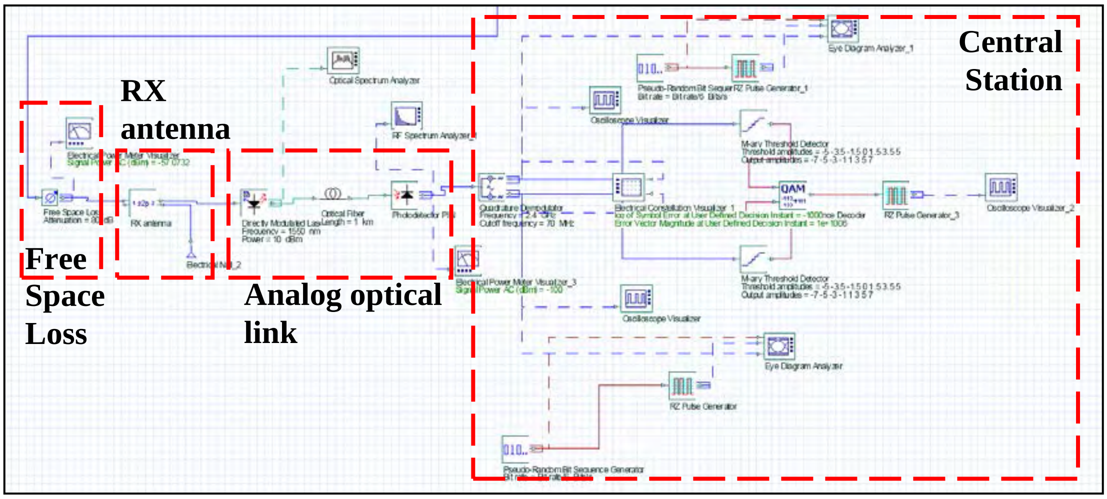

Figure 4.5: Basic uplink design as a 1st stage design

4.4.3 Embedded with LNA

From the previous design, it's simulated and Figure out the signal is very weak and need implementation on the current design to amplify the receive signal. In order to amplify, low noise amplifier (LNA) was added in the design. The LNA location is right after the receiver antenna as shown in Figure 4.6. LNA will reduce the noise and enhance a weak signal as well. The characteristic of LNA in order to use in the current design, it's must have high gain at the operated frequency. There's a lot of common LNA in the market. For this design, is decided to use the LNA from RFMD.

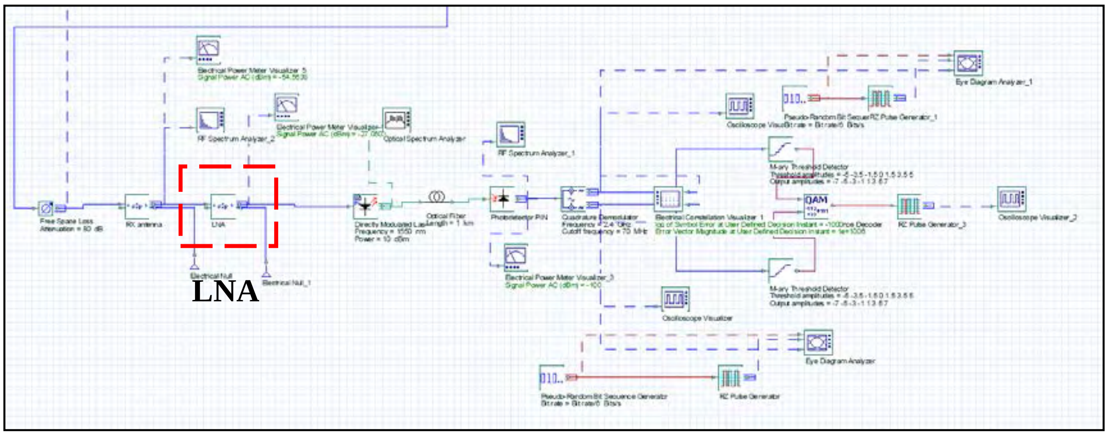

Figure 4.6: Improvement design by added LNA