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Research Article

AMPLIFIER ANALYSIS OF RADIO OVER FIBER COMMUNICATION SYSTEMS

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ABSTRACT

This study focuses on radio communication systems over fiber (ROF). In the design of these systems, optical source, pulse generator, modulator, optical fiber, optical add-drop multiplexer (OADM), amplifier, filter were used. The amplifiers were examined and their performance analyses were done on the OptiSystem 7.0 simulation software. Radio over fiber system is modeled with different types of amplifiers. Effects of optical amplifiers on the system were analyzed. The amplifiers were compared to determine the most suitable amplifier for the radio over fiber.
Keywords: Communication technologies, optical communications, ROF, amplifier, optical fiber, EDFA.

1. INTRODUCTION

Nowadays, wireless communications have progressed in many areas from sending simple messages to application services and multimedia sharing with larger data capacity. To perform future services Optical communications technology can be an appropriate solution due to its low attenuation loss, wider bandwidth, safety, and less impact on electromagnetic fields and minor interference [1]. Fiber optic technology is seen as a promising technology for future networks and is trusted by users. Optical communications technology uses fiber optic cables to transmits data over long distances. This technology can reduce the adverse effects of various wireless networks and can contribute to environmental protection and facilitate sustainable management of diminishing resources. The ability to transmit data over long distances with reduced energy consumption and cost provides significant value for networks such as mobile phones, wireless systems, and broadband. The demand and use of optical fibers has increased considerably over the recent years. Application areas of optical fibers range from global networks to desktop computers [2].

In optical communication systems, the most important factor which limits the transmission distance is fiber losses. In optimizing these losses, optical amplifiers are preferred for high gain, low noise, high bandwidth and high output power characteristics. The optical amplifiers amplify

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the light with excited radiation and provide an optical gain based on the frequency and wavelength of the input signal by means of a laser mechanism without feedback. In the design process of the amplifiers these parameters, namely frequency and wavelength of the input signal, significantly affect the gain and noise spectrum of the amplifiers. Therefore, in gain optimization studies system design parameters are important for the transmission of the optical signal over long distances [3].

2. RADIO OVER FIBER (ROF)

Radio over Fiber (RoF) is a technology in which light is modulated by radio frequency signals and transmitted via optical fiber to facilitate wireless access and transmission [4]. This technique is also used for cable TV networks and satellite stations. Modulation PSK (Phase Shift keying) can be analog or digital, such as QAM (Quadrature Amplitude Modulation). After modulation, these signals are transmitted via fiber [1].

The modulated signal is carried over the fiber using distributed antenna systems in cellular and micro-cellular radio networks. In each cell, radio signals are transmitted to and received by mobile users by means of a separate small box connected to the base station through the fiber station. The cells were subdivided into micro cells to increase the rate of reuse and to support an increasing number of mobile users. The introduction of micro-cells has several advantages: First, micro-cells can meet increasing bandwidth demands; secondly, small size cells reduce power consumption and the size of telephone devices. The high-power base station antenna is replaced by a split antenna system connected to the base station via optical fiber. RoF (radio over fiber) is widely used in wireless access. RoF networks operate in mm-wave bands, which require additional attenuation in particular around 193.1 THz due to limitation of the transmission range in the external environment by oxygen absorption.

Compared to microwave bands such as 2.4 GHz or 5 GHz, which require various BS (base stations) to support a wide range of service areas, the mm-wave band needs small cells. Networks working with a large number of small cells can overcome difficulties in cost and mobility management. There are several advantages of RoF (radio communication over fiber) systems such as low attenuation, wide bandwidth and immunity to radio frequency interference, operational flexibility, less power consumption and long signal transmission distance and reliability [5].

The RoF (Radio over Fiber) network typically consists of a Central Station from which all switching, routing, Media Access Control (MAC) and frequency management functions are performed, a number of Base Stations (remote antenna units) which enable wireless signal delivery by means of connections between these base stations and an optical fiber network. The main function of the base station is to convert the optical signal into a wireless one, and vice versa. Figure 1 shows a basic RoF system. The RF signal appears to be used to directly modulate the laser diode in the central area (headend). The resulting density modulated optical signal is then transmitted to the BSU (RAU-remote antenna unit) along the fiber. In RAU, the transmitted RF signal is recovered by direct detection in the PIN photo-detector. The signal is then amplified and emitted by the antenna. The uplink signal from the MU (Mobile Unit) is transmitted in the same way as from the RAU to the header. The method of transmitting RF signals through fiber is called Density Modulation by Direct Detection (DM-DD) and is the simplest form of RoF connection [6].

Since RoF utilizes analog modulation and transmission of light, it is basically an analogue transmission system. Therefore, signal disturbances, such as noise and interference, which are important in analog communications systems, are also of precedence in RoF systems. These distortions influence Noise Figure (NF) and Dynamic Range (DR) of RoF connections [7]. DR is a very important parameter for mobile communications systems because the power received from MUs varies greatly. Namely, the RF power from an MU close to the BS may be much higher than that received from an MU located within the same cell, but a few kilometers away from the BS.

In the RoF system shown in Figure 1, the RF signal is transmitted from the central station to the base station or vice versa. The central station performs most of the signal processing operations. Since this station contains heavy and expensive equipment, the cost of the base stations is reduced. The base station or radio distribution point, which is the remote antenna unit, performs only simple functions which are small in size and have a low cost [4]. This is why most of the scattered antenna systems perform radio communications over fiber [1].

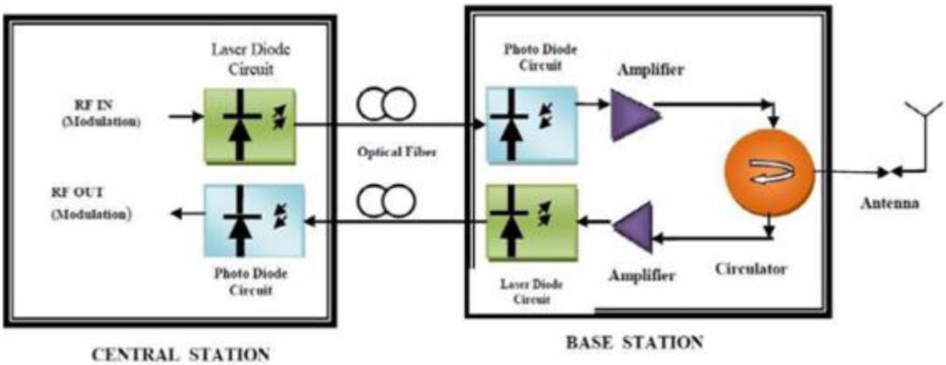


Figure 1. Basic principle of Radio over fiber (RoF) [8]

3. OPTICAL AMPLIFIERS

Fiber losses are a factor that significantly limits transmission distance in fiber optic communication systems. Optical amplifiers directly amplify the optical signal without transferring it to an electrical medium. Optical amplifiers are preferred because of their high gains, high bandwidths, high output power characteristics and low noise levels. There are three types of amplifiers: Erbium doped amplifiers, ytterbium doped amplifiers and Raman amplifiers.

Optical gain, which is the main parameter in optical amplifiers, depends on the wavelength of the incoming signal and the local beam intensity at any point within the amplifier. Wavelength and density parameters are directly related to the reinforcing medium and material [9]. Optical amplifiers are manufactured by doping various elements in order to amplify a signal with a wide spectrum ranging from visible light to infrared wavelengths, approximately 450-750 nm interval. The most commonly used doping elements are erbium and ytterbium. The type and amount of additives used in manufacturing the optical fiber determine the wavelength dependent amplifier gain characteristic [10].

The EDFA and YDFA optical amplifier systems consist essentially of an optical signal source, pump laser, and a doped fiber, which carry information. In order to initiate the process of density inversion in an amplifier, the erbium and ytterbium ions are stimulated to an upper energy level, thereby strengthening the process. Optical gain achieved depends on the wavelength of the non-feedback laser signal.

3.1. Erbium Doped Fiber Amplifier (EDFA)

The EDFA amplifier prevents cross-gain saturation and facilitates amplification of individual channels in WDM systems. In silica fibers, the life of the spontaneous carrier is relatively long, which results in a high gain for a weak signal with low NF (noise figure). Due to the low NF, the difference in the signal to noise ratio at the input and output of the device is taken into account. This is the main reason why EDFAs are very popular in the field of optical amplification.

The EDFAs are also insensitive to polarization and have negligible noise for inter-channel cross talk and minimum matching losses, therefore require less pumping power. In addition, EDFA provides high bit rate transmission over long distances. It has a lower peak at 1550 nm and a narrow peak at 1532 nm and a high peak with versatility, high pumping efficiency, useful gain bandwidth and low internal noise. The gain obtained by the EDFAs is in the 1530-1560 nm wavelength band. At these wavelengths, the energy emitted by erbium ions is greater than the energy absorbed and the gain bandwidth is narrow. The highest gain with EDFA is obtained around 1550 nm wavelength [10].

For EDFA, 980 nm wavelength pump laser is preferred. The 1480 nm pump wavelength is also used. Efficient pumping is possible at both wavelengths. Stimulated erbium ions have a semi-stable life of about 10 ms [10].

3.2. Raman Amplifier

In a Raman amplifier, the signal is amplified by a process called stimulated Raman scattering (SRS) in which light is distributed among atoms up to a wavelength which is higher than the lower wavelength of the pump. When there is sufficient pumping power at the lower wavelength, there may be excited scattering where a signal having a high wavelength is amplified by Raman scattering caused by the pump signal. The SRS is a nonlinear interaction between the signal (higher wavelength) and the pump (lower wavelength) and may be included in any optical fiber. The efficiency of the SRS process is low in most fibers, which means that high pump power (typically above 1 W) is required to obtain useful signal gain, so in most cases Raman amplifiers cannot compete effectively with EDFAs.

The main advantage of the Raman amplifier is that the gain spectrum is quite large (up to 10 nm), which can be altered by changing the number of pumps and pump wavelengths, while at the same time making the relatively low NF more efficient. These two features can be used to expand and equalize the Raman amplifiers, the gain spectrum of a given amplifier, and constitute the main elements of the optical systems by adding little noise to the amplified signal. Optical gain of SRS can be combined with that of EDFAs to expand the flattened bandwidth.

The disadvantages of Raman amplifiers are the poor pumping efficiency at low signal strength and use of high-cost lasers capable of delivering large powers to single-mode fibers. DWDM and RAs are also preferred because of their negligible noise, negligible coupling loss, and more efficient cross-channel cross-talk characteristics [11].

There are two types of Raman amplifiers:

The distributed Raman amplifier (DRA) is a system in which the transmission fiber, which is generally quite long (~ 100 km), is used as gain media by multiplexing a pump wavelength with signal wavelength.

The discrete Raman amplifier uses a special, shorter fiber length (~ 20km) to provide amplification. A highly non-linear fiber with a small core which increases the interaction between signal and pump wavelengths renders shorter fiber lengths possible.

In discrete amplifiers, the amplification takes place at a single point at the end of the connection and occurs in the DRA through the amplification fiber, thereby avoiding low power at the end of the connection and/or allowing low energy at the beginning of the connection [11].

3.3. Ytterbium Doped Fiber Amplifier (YDFA)

Ytterbium doped fiber lasers provide a very wide wavelength range between 975 and 1200 nm to provide amplification and are expected to increase interest in the future [12].

YDFA also offers high output power and excellent power conversion efficiency, and many of the well-known complications from erbium-doped fiber amplifiers such as excitation state absorption and interionic energy transfer and concentration quenching (due to Erbium's high concentration doping) are discarded. By avoiding concentration quenching, high levels of doping are possible, resulting in high yields of a short fiber length [13].

The wide bandwidth allows for better amplification of very short pulses and high saturation flux makes high impact energies possible. It also allows for various pumping schemes, since wide pump wavelength range (860 nm to 1064 nm) is achievable. The application areas of YDFAs include power amplification, such as small-wavelength amplifiers in fiber sensing applications, free-field laser communications, and hopping pulse amplification of very short pulses, at specific wavelengths (e.g. 1083 nm required for spectroscopic measurements).

Based on the laser power of the pump, the doped fiber length and wavelength of the YDFA input signal exhibits a maximum gain of 62 dB in the neighborhood of about 1030 nm with 975 nm pump wavelength, for a pump power of 5 Watt and YDF length of 8 m [14].

4. RADIO OVER FIBER COMMUNICATIONS SYSTEM DESIGN AND AMPLIFIER ANALYSIS

In the design cycle of a radio over fiber communication system, OptiSystem 7.0 simulation software was used to determine the effect of fundamental parameters on system performance.

The radio over fiber (ROF) communications system consists of two parts: CS (central station) and BS (base station). Two NRZ (non-return-to-zero) pulse generators, CW (continuous wave) laser and MZM (Mach-Zender modulator) and WDM (wavelength division multiplexing) were used in the CS (central station) on the transmitter side of the design. The CW optical sources in the 193.1 and 193.2 THz frequencies are 0.1 dBm. Both the light signal from the CW laser and the electrical signal from the NRZ pulse generator are modulated in the MZM (MachZender modulator). The modulated signals from both channels are multiplexed in WDM (wavelength division multiplexing) and the multiplexed signal is transmitted through a singlemode optical fiber of 10 km length. After the signal reaches the base station, the signal at frequency 193.1 THz is reduced in the OADM multiplexer. The weakened signal is first amplified by 10 dB in the optical amplifier and then converted from optical to electrical signal using a PIN detector, passed through a 10 GHz bandwidth Bessel filter and finally fed to a BER analyzer for analysis of the BER of the downlink. The amplified signal having the THz frequency is transmitted to CS through a 10 km long single mode optical fiber which has an attenuation rate of 0.2 dB/km, with a power of 15 dBm of 193.1 THz uplink data added from BS. At the central station the signal is demultiplexed and the signals at two different frequencies are passed through the Bessel filter and the photodetector PIN elements to complete the design. The BER analyzer element is used to examine the BER and Q factor values and the results of the eye diagram.

In the radio over fiber (ROF) communications system, the optical amplifier analysis is used to amplify the weakened signal and examine it. Analyses of the signal outputs of the base station and the central stations of the system were carried out using EDFA (Erbium Doped Fiber Amplifier), Raman Amplifier and YDFA (Ytterbium Doped Fiber Amplifier).

In Figure 2, a 5 m long EDFA amplifier was used to amplify the weakening signal. In Figure 3 and Figure 4, 5 km long Raman and 5 m long YDFA amplifiers were used. In Table 1, Table 2 and Table 3, the BER analyzer results of the base station and the central stations of the systems designed with EDFA, Raman and YDFA amplifiers were compared. In Table 4, the quality factors of EDFA, Raman and YDFA amplifiers were compared.

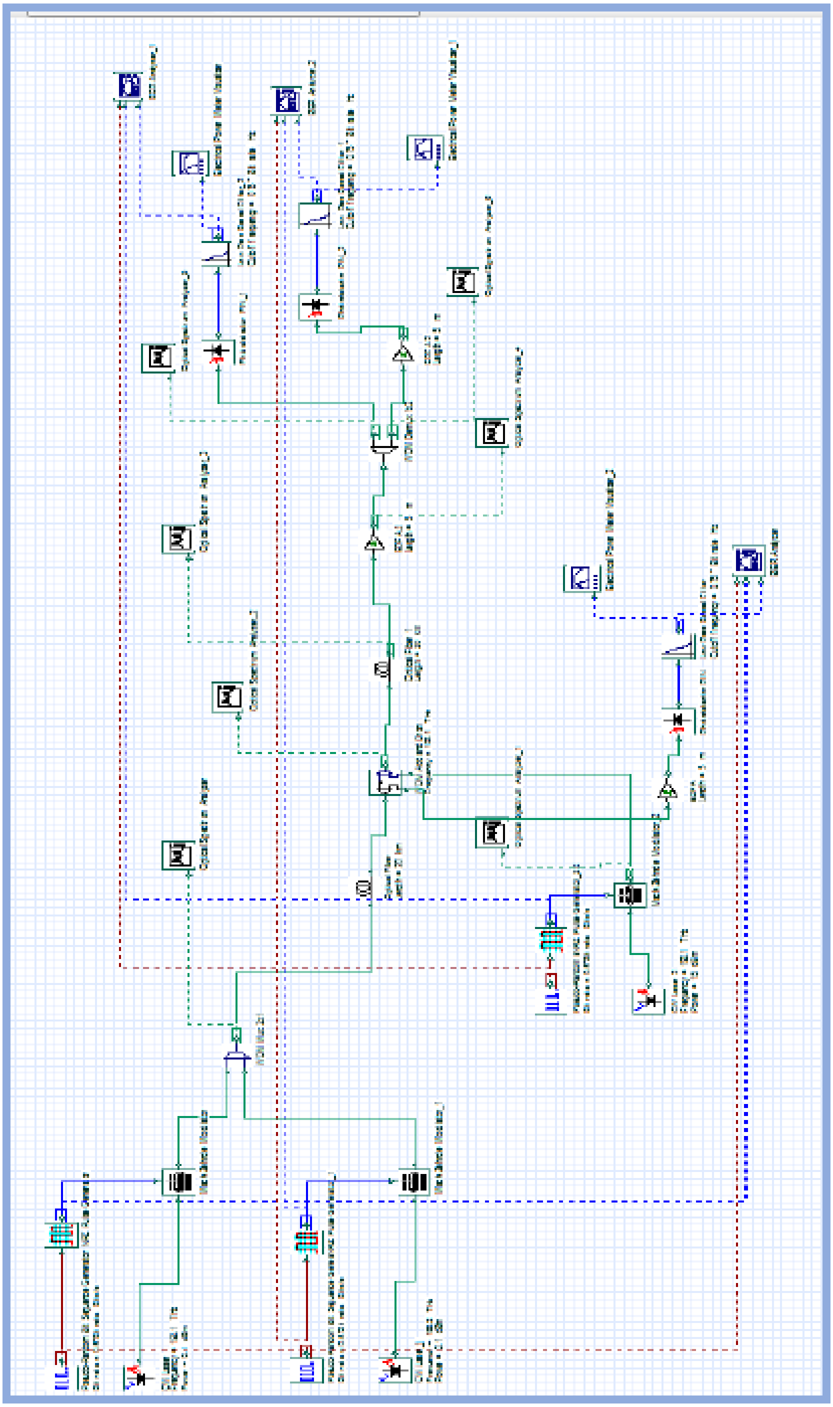


Figure 2. Radio over fiber system designed with EDFA amplifier

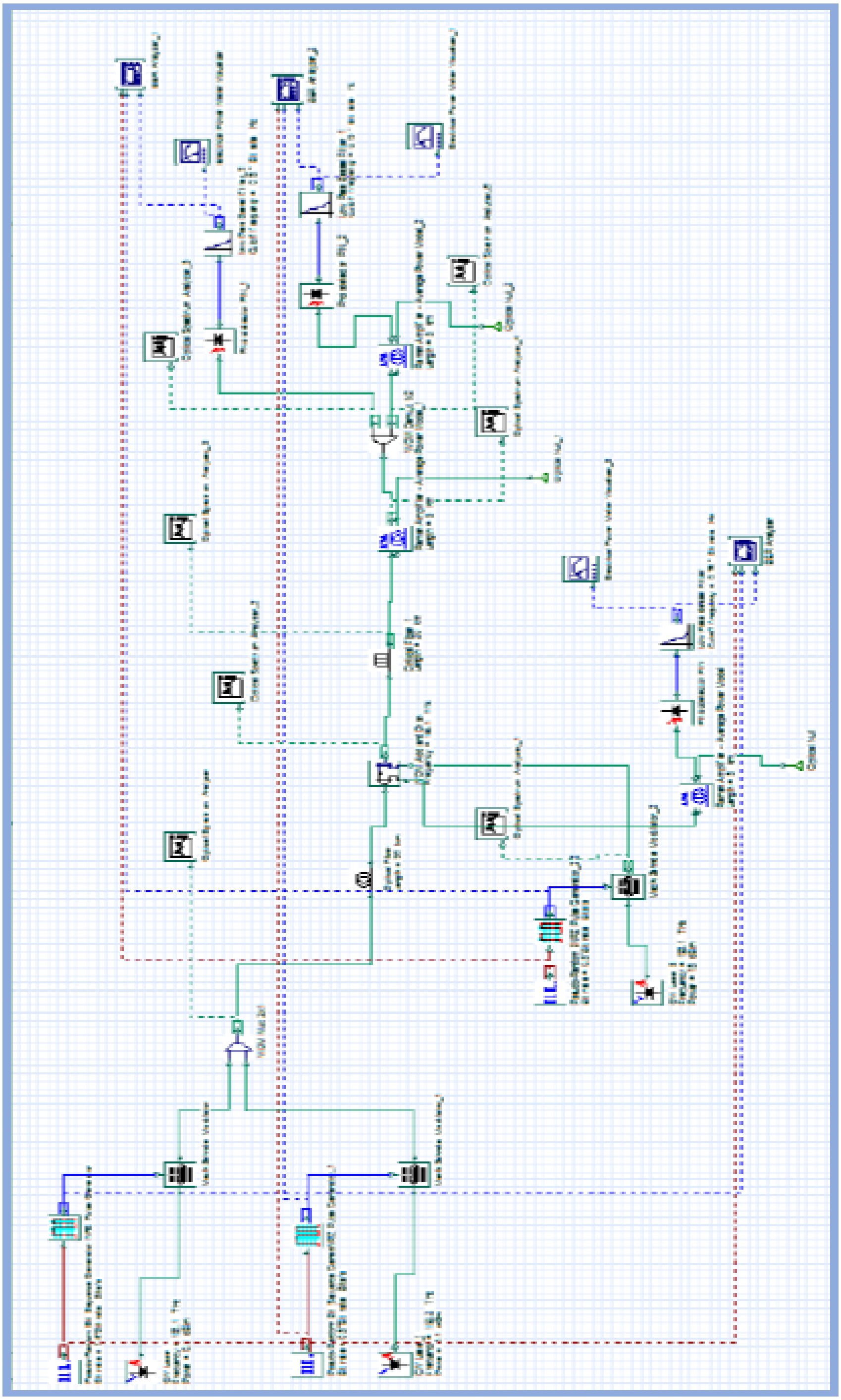


Figure 3. Radio over fiber system designed with Raman amplifier

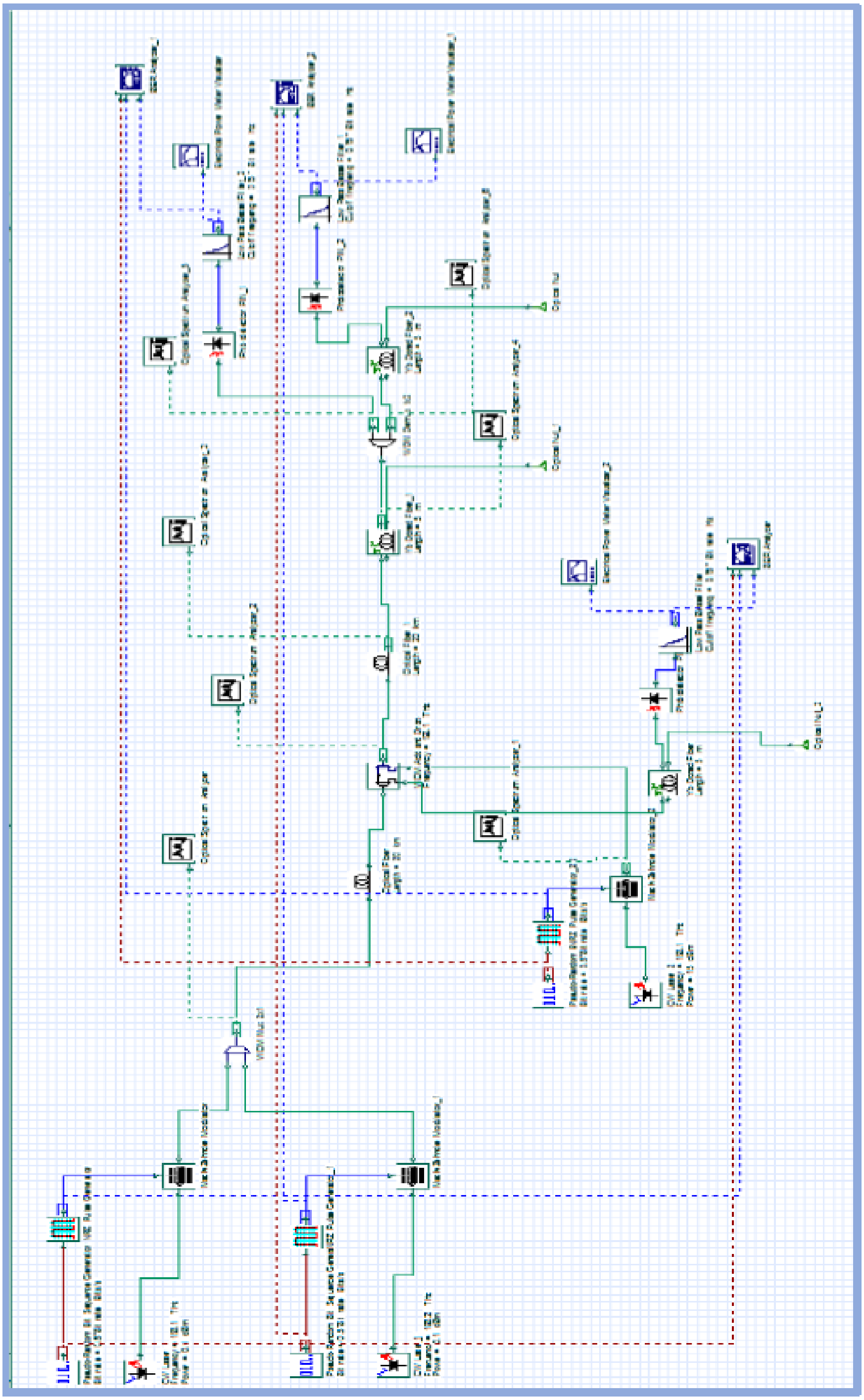
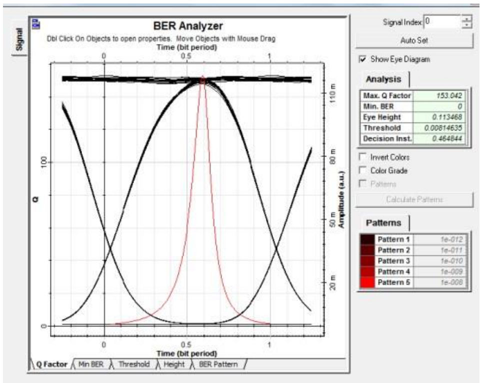


Figure 4. Radio over fiber system designed with YDFA amplifier

Table 1. Eye diagrams for the system designed using EDFA amplifier.

<table>
<tr><th>Type of Amplifier</th><th>EDFA Amplifier</th></tr>
<tr><td>BER analysis of base station output</td><td>
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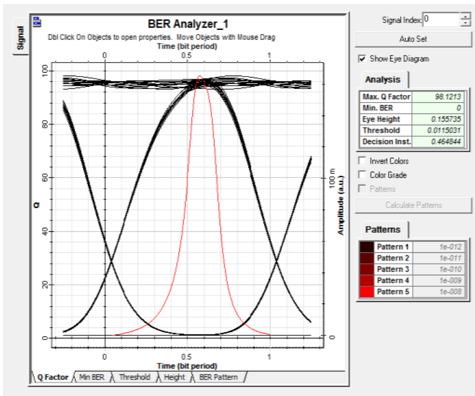
<tr><td>BER analysis of center station I output</td><td>
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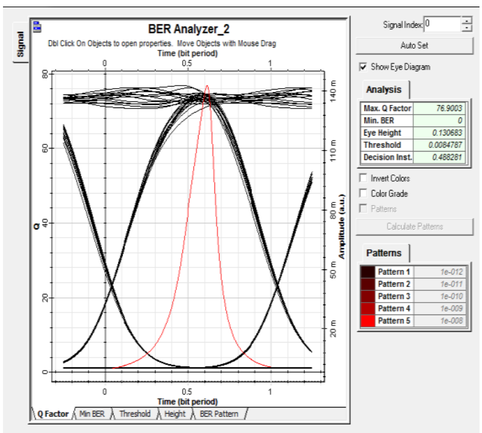
<tr><td>BER analysis of center station II output</td><td>
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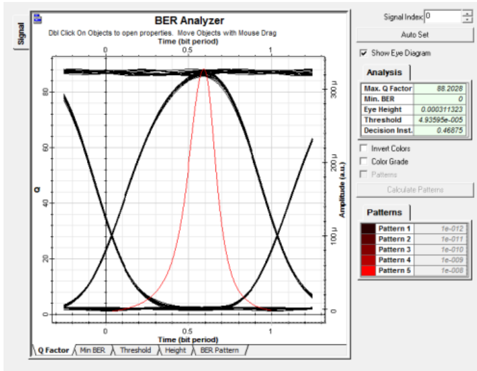
Table 2. Eye diagrams for the system designed using Raman amplifier.

<table>
<tr><th>Type of Amplifier</th><th>Raman Amplifier</th></tr>
<tr><td>BER analysis of base station output</td><td>
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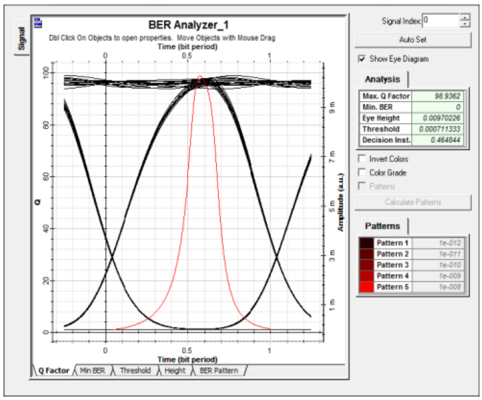
<tr><td>ER analysis of center station I output</td><td>
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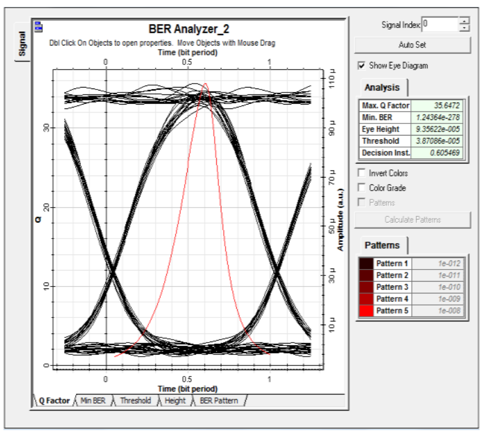
<tr><td>BER analysis of center station II output</td><td>
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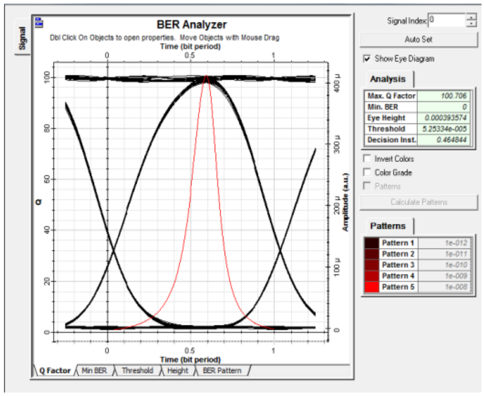
Table 3. Eye diagrams for the system designed using YDFA amplifier.

<table>
<tr><th>Type of Amplifier</th><th>YDFA Amplifier</th></tr>
<tr><td>BER analysis of base station output</td><td>


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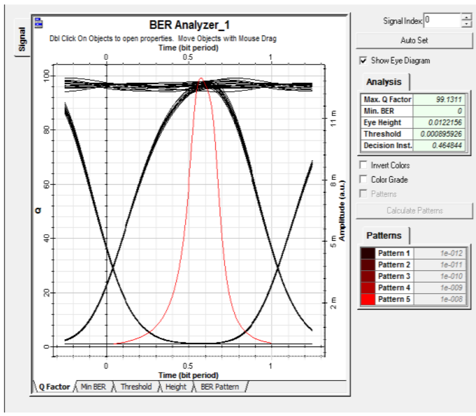
<tr><td>BER analysis of center station I output</td><td>


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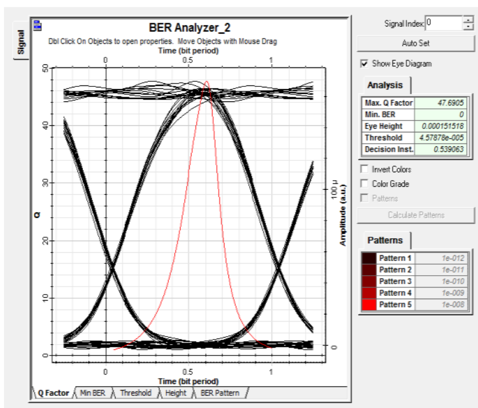
<tr><td>BER analysis of center station II output</td><td>


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Table 4. Table of Quality Factor values of output signals of base station and central stations obtained from BER analyzer for various types of optical amplifiers.

Type of Amplifier	**EDFA Amplifier**	**Raman Amplifier**	**YDFA Amplifier**
BER Analysis Q Factor (Quality Factor) Value on Base Station Output	153.04	88.20	100.706
BER Analysis Q Factor (Quality Factor) Value on Central Station I Output	98.12	98.93	99.131
BER Analysis Q Factor (Quality Factor) Value on Central Station II Output	76.90	35.64	47.69

5. CONCLUSIONS

In this study, radio communications over fiber were examined. OptiSystem 7.0 simulation program was used to design and analyze several radio communications over fiber systems. Performance of various types of amplifiers, which are among the elements used in radio communication systems, were evaluated based on the simulation results of this study.

When the ROF (radio over fiber) system analyses results with different optical amplifiers are examined, it is observed that in the eye diagrams of the base station and central stations outputs of the system which uses EDFA (Erbium Doped Fiber Amplifier) there is more pronounced disintegration of the signals than the systems where Raman and YDFA (Ytterbium Doped Fiber Amplifier) amplifiers are present. It was observed that the quality factor values of the base station and central station outputs were higher for the communication system with EDFA than those for the systems based on the Raman and YDFA amplifiers. In the systems evaluated according to the eye diagram and quality factor analysis, it was obtained that EDFA amplifier would be more suitable to use in optical communication systems because for EDFA amplifier higher quality factor values were achieved with lower losses as compared to the other amplifiers.

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