Maximizing Throughput of Free Space Optics Communication link with Array of Receivers

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Received 21 April 2015; revised 27 January 2016; accepted 24 August 2016

This paper analyse the integration of optical amplifiers and optical filters with free space optics link (FSO) for improving its performance. These components play a crucial role for enhancing and conserving pulse shape of transmitted signal. Different amplifiers and filters are critically investigated to improve the optical wireless link output. The high quality link is analysed to increase its acceptability in terms of bit error rate, Q factor and height of eye diagram. Further, the optimal combination of an amplifier and a filter is chosen so as to give the best output for a particular application of FSO. To further enhance the versatility of the designed optical link the performance of FSO link has also been analysed using array of receivers and under different weather conditions. After simulations it is found that the usage of specific filter – amplifier combination significantly improves the performance of FSO link.

Keywords: Erbium Doped Fiber Amplifier (EDFA), Semiconductor Optical Amplifier (SOA), Butterworth Filter, Chebyshev Filter, Bessel Filter, Free Space Optics (FSO).

Introduction

In communication systems, the reduction of Inter symbol Interference (ISI) and enhancement of power of band limited channels due to multipath reflections are two most important aspects. For accomplishment of these aspects filters and amplifiers play an important role in the optical wireless link. Filters are the components that are used for signal processing and for removal of unwanted components or features from a signal. They remove all frequencies above or below a set of frequency allowing only desired frequency to pass. The applications of filters give wide range of opportunities to the designer of wireless link for implementing a system according to his needs under adverse conditions. From several types of filter responses, it is seen that if it is employed at transmitter end along with modulator it acts as anti-aliasing component and if employed at receiver end, it acts as detector. Generally low pass filters are preferably used in communication systems. Popularly used filters in these areas are Butterworth, Chebyshev and Bessel filter. All of these have their own advantages and disadvantages. Butterworth filter has no ripples in the pass band or stop band. Chebyshev has more roll off than Butterworth but ripples are present in the pass band. Bessel filter has least roll off in stop band but constant group delay as compared to other filters. Amplifiers are the electronic components that enhance the power of the signal taking energy from the power supply. These components control the output signal by matching it with input signal but with increased amplitude. The most recommended amplifiers are SOA and EDFA. The structure of SOA is same as semiconductor laser but the resonant cavity is not present. This amplifier can be designed for specific frequencies. Whereas, EDFA operate at wavelengths closer to 1550 nm. As EDFA is built with optical fiber, so it can be easily connected to other sections of optical fiber. EDFA are not sensitive to polarisation and are relatively stable under environmental changes as compared to SOA. One of the major applications of wireless communication that deploys these components is FSO. The technology is having combined features of wireless communication and fiber optics. Its potential of high data rates and secure communication has proved its worth in emerging as well as already existing wireless technologies. However, as the signal is transmitted in free space, it is highly affected by atmospheric turbulences and weather conditions. Such conditions, degrades the signal to noise ratio as well.

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as the quality of the signal by adding noise making
the light beam ambient at the receiver end. Also, the
use of 1550 nm wavelength in FSO is necessary to get
output safe for human eyes. Due to high intensity of
radiated emission, the output light gets diffused. This
issue can be resolved with optimum utilization of
Amplifier-filter pair. With little added cost, these
affects of ambient light can be reduced and the signal
strength can be enhanced. As the Signal to Noise
Ratio (SNR) of the link is inversely proportional to
ambient power $^5$, so reducing it will enhance the SNR
of communication signal.

$$SNR_{link} = \frac{P_{signal}}{P_{noise}}$$

$$= \frac{1}{2(i^2 ctrc) + 2qRP(R_p + P_{amb})B_{eff}}$$

Where,
- $P_{signal}$ = Signal power
- $P_{noise}$ = Power of noise
- $R_p$ = DC component of received photocurrent
- $\bar{P}_r$ = Average power at the receiver side
- $i_{circ}$ = noise power due to pre amplifier
- $q$ = electric charge
- $B_{eff}$ = equivalent noise bandwidth of system
- $P_{amb}$ = Power of ambient light

It has been observed in the literature $^6,7$ that various
methods are employed in optical communication to
reduce the effects of ambient light and degradation of
signal. According to Beer’s Lambert law, the light
travelling through the distance gets attenuated due to
absorption and dispersion. So, it is a function of distance
between the transmitter and the receiver end $^13$.

$$L_{atm} = 10log_{10}\left[\frac{dB}{km}\right]$$

Where
- $\tau = \exp(-\gamma L)$
- $\gamma$ = attenuation coefficient
- L = link distance

To minimize these effects, researchers come up
with various techniques like aperture averaging,
spatial diversity like multiple input multiple output
(MIMO) etc $^{14,17}$. The technique of spatial diversity
using array of receivers instead of single receiver at
the end has shown tremendous results in weak, moderate
and strong weather conditions $^{17}$. Extending the same
work $^{17}$, the aim of the paper is to employ application of
filter and amplifier on the link using array of receivers.

It can further make link robust in adverse conditions,
having large value of attenuation and interference in
transmitted signal. The paper is organised as follows:
After the introduction of filters and amplifiers and their
requirement in wireless communication in section 1,
the methodology followed for analysis of components
in the wireless link is illustrated in section 2. The
detailed description of available amplifiers and their
results after applying them on the link are discussed in
section 3. The detailed description of available filters
and their results after applying them on the link are
discussed in section 4. The combination of best chosen
pair of amplifier and filter and their simulated
parameters are plotted in section 5. Finally, the
conclusions are drawn in section 6.

Preliminaries and Methodology Used

In this section, some preliminaries of the amplifiers
and filters are introduced. The main requirements of
these components are generated as:

- Even though the problem of multipath fading is
not a major hindrance to wireless optical links but
temporal dispersion of the received signal due to
multipath propagation remains a problem. This
dispersion is often modelled as a linear time
invariant system since the channel properties
change slowly over many symbol periods.

- Along with specifications regarding the frequency
and distortion performance, the noise sources of a
wireless optical link are critical factors in
determining performance. Various atmospheric
and artificial noises degrade the quality of
transmitted signal.

- The interaction between successive transmitted
pulses is also very important factor taken into
consideration in case of wireless communications.
In dispersive channels, transmitted pulses are
received at the receiver end after matched
filtering but with some ISI. This ISI is also major
cause of communication barrier in the link.

- The wireless optical intensity channel imposes
amplitude constraints on all transmitted signals.
Specifically, all emitted signals must be non-
negative since optical intensity modulators and
direct detection receivers are employed. Additionally,
the average amplitude must also be
constrained due to eye and skin safety requirements.
So, amplifiers serve an important purpose in
improving the amplitude of received signal.
Keeping in view some of these important factors the link is simulated and analysed with the use of filter and amplifier. To chose the most appropriate combination for a particular chosen link following methodology is followed. First of all, FSO link with array of receivers operating at 0 dBm power, 1550 nm wavelength and 3.5 km range having data rates up to 10 Gbps is simulated. Then, the link is tested deploying various amplifiers and the amplifier giving best output is chosen. After that the model is simulated deploying various filters in the link. Among these filters, the one giving output with maximum accuracy is chosen. The most appropriate combination of amplifier and filter is deployed in the link and the value of desired simulation parameters is calculated. At the end, the designed model is simulated for various weather conditions and the output is plotted on characteristic curves.

Different types of Amplifiers and their Results for FSO link

According to optical transmission Regenerator Section (RS) section, systems can be dispersion-limited or attenuation limited. However, by introducing optical amplifiers in the link the loss limitation of the system can be partially reduced. A Free space optics link with range 3.5 km, operating wavelength 1550 nm, transmitter power 0 dBm, receiver aperture diameter 2.9 cm and eight photo detectors is analysed for improving its performance.

Figure 1 is illustrating the output of the BER analyser for the link without the use of any amplifier or filter. Two most commonly used amplifiers travelling wave tube SOA and EDFA are introduced and analysed according to the output behaviour of the link.

- **SOA**: The semiconductor optical amplifier is an electrically pumped amplifier which is of small size. It is potentially less costly than the EDFA. This amplifier can be used by integrating it with semiconductor lasers, modulators, etc. But its performance is not equivalent to EDFA. The SOA has moderate polarization dependence, higher noise, high nonlinearity and lower gain with fast transient time.

- **EDFA**: Fiber amplifiers have an extremely high bandwidth as compared to electrical amplifiers. Erbium doped amplifiers are more important because they allow high amplification at relatively low pump powers. Apart from this advantage, they also have a flat gain profile at 1550 nm. At this wavelength quartz glass fiber has its least attenuation.

As illustrated in table 1, with the introduction of SOA in the link, the system is not able to give optimum performance. The value of Q factor falls to 4.5 which is less than minimum optimum value of Q factor required for smooth communication. The error

![Output of BER analyser for link not containing amplifier and filter](image-url)
rate is also very high in the transmitted signal. So, the use of SOA is not appropriate in this particular application as the performance is deteriorating with increasing distance. Whereas, the effects of using EDFA in the link are very remarkable. The value of Q factor boosts up to 298 that were 82 in conventional link. The bit error rate also reduced to negligible value with the introduction of this amplifier. It is improving the power of received signal thus enhancing the strength of the information signal.

**Different Types of Filters and their Results for FSO link**

The low pass filters mainly preferred in optical wireless communication are chosen to verify on designed FSO link. The detailed description of the filters and results of the BER analyser after using them in the link are as follows:

- **Butterworth Filter**: This filter has the flat frequency response in the pass band and the slower roll off than Chebyshev. So, it requires higher order to implement a desired stop band³.
- **Chebyshev Filter**: This filter has steeper roll-off but more pass band ripples as compared to Butterworth filter³.
- **Bessel Filter**: It is a type of analog linear filter that have maximum group delay when preserving the wave shape of the signals to be filtered. Though it is similar to Gaussian filter but has more flat phase delay & group delay and better shaping factor. The transfer function of Bessel filter is given by ¹⁰:

\[
H(s) = \frac{\theta_n(0)}{\theta_n \left(\frac{s}{\omega_0}\right)} \quad \text{... (3)}
\]

\[\omega_0 = \text{frequency chosen to give desired cut off}\]

\[\theta_n(\zeta) = \text{reverse Bessel polynomial}\]

\[\theta_n(0) = \lim_{\zeta \to 0} (\zeta), \text{indeterminate but removable singularity}\]

Table 2 is showing the output of BER analyser after employing these three filters in the link. Table is illustrating the fact of unsuitability of Butterworth filter in the particular link due to high degradation in the values of simulation parameters. The Q factor has reduced to 3 and BER has also become very high. So, this filter cannot be used in this link. Though the performance provided by after using chebyshev filter is within acceptable limits of wireless transmission, but if we compare it with previously simulated links then a large drop in the output can be clearly visualised. So, it is also not suitable for this particular application. The output of the link after using Bessel filter is showing tremendously good results. The Q factor has attained value of 421.659 and curve of Q factor has become very sharp thus showing the enormous quality of received signal. The wide opening of eye is also demonstrating the fact that there is negligible noise and jitter contents in the transmission signal.

**Characteristic Curve of Simulated Parameters with best chosen Combination**

A comprehensive value of simulation parameters has been presented in an organised manner at considered weather conditions in tabular form. Table 3 shows the values of simulation parameters at different levels of attenuation. The quality of received signal has improved to a large extent which can be justified from the output values of simulated parameters. The link is incorporated with EDFA and Bessel filter and analysed for most common weather conditions like clear air, drizzle, haze, light fog and moderate fog. The output shows that quality of the signal has improved to a large extend as compared to previous literature. Thus, the link can further be used in adverse weather conditions like heavy rain, dry snow, wet snow etc. The characteristic curves show the

<table>
<thead>
<tr>
<th>Table 1 - Evaluation of FSO link using SOA &amp; EDFA amplifier in the link</th>
<th>Amplifiers</th>
<th>Q Factor</th>
<th>Min. BER</th>
<th>Eye height</th>
</tr>
</thead>
<tbody>
<tr>
<td>SOA</td>
<td>4.53626</td>
<td>1.2166e-006</td>
<td>12.2819</td>
<td></td>
</tr>
<tr>
<td>EDFA</td>
<td>298.63</td>
<td>0</td>
<td>1.14212</td>
<td></td>
</tr>
</tbody>
</table>

| Table 2 - Evaluation of FSO link using Butterworth, Chebyshev and Bessel filter in the link |
|------------------------------------------|----------|----------|----------|
| Filters                          | Q Factor | Min. BER | Eye height |
| Butterworth                       | 3.07502  | 0.00105243 | 4.15075e-005 |
| Chebyshev                         | 27.4877  | 1.2323e-166 | 0.00213129 |
| Bessel                            | 421.659  | 0         | 0.9277181 |

<table>
<thead>
<tr>
<th>Table 3 - Evaluation of FSO link under various weather conditions using EDFA &amp; Bessel filter in the FSO link</th>
<th>Quality factor</th>
<th>BER</th>
<th>Height of Eye</th>
</tr>
</thead>
<tbody>
<tr>
<td>Clear Air (0.06 dB/km)</td>
<td>1923</td>
<td>0</td>
<td>1.18627</td>
</tr>
<tr>
<td>Drizzle (0.22 dB/km)</td>
<td>1602</td>
<td>0</td>
<td>1.13728</td>
</tr>
<tr>
<td>Link Using Bessel Haze (0.73 dB/km)</td>
<td>1489</td>
<td>0</td>
<td>1.12149</td>
</tr>
<tr>
<td>Filter and EDFA Light fog (4.28 dB/km)</td>
<td>422</td>
<td>0</td>
<td>0.0927181</td>
</tr>
<tr>
<td>Moderate fog (25.5 dB/km)</td>
<td>10</td>
<td>2.6272e-023</td>
<td>0.0197556</td>
</tr>
</tbody>
</table>

\[w_0 = \text{frequency chosen to give desired cut off}\]

\[\theta_n(\zeta) = \text{reverse Bessel polynomial}\]

\[\theta_n(0) = \lim_{\zeta \to 0} (\zeta), \text{indeterminate but removable singularity}\]
output of the modelled link under various atmospheric weather conditions as mentioned in table 3. Fig. 2 shows the Q factor curve for the various values of attenuation. Here, the value of Q factor is very high in clear air conditions and information is transmitted with maximum accuracy. As the value of attenuation increases the value of Q factor reduces to 10 which is still more than minimum optimum value required of Q factor. It is clearly illustrating that even at very low power 0 dBm the optimum value of Q factor attained at 25.5 dB/km attenuation is due to the use of amplifier and filter in the link. For the case of analysing noise component in the received signal, the height of eye is considered at various weather conditions. The value is depicted in figure 3 for various values of attenuation. It can be visualised that with the introduction of EDFA and Bessel filter the noise and jitter contents are removed from the signal, thus enhancing the accuracy of the received bits. From the above results, it is clear that the application of amplifier and filter in FSO communication link have a great contribution in improving the quality and range of communication link.

**Conclusions**

In this paper, the usefulness of employing amplifier and filter in wireless communications is analysed. The effects of using these components on FSO link using array of receiver manifests itself as a reduction in the value of ISI. This application of amplifiers and filters in wireless systems has been brought with a different perspective in this work. The FSO link using array of receivers is considered, on which, this application has not been employed earlier. After extensive analysis of various optical filter-amplifier combinations on a specific FSO application, it is found that:

- Semiconductor optical amplifiers are not able to give good results at this range under high attenuation conditions.
- For the FSO link using array of receivers operating at attenuation of 25.5 dB/km, the most suitable combination of filter and amplifier is EDFA and Bessel filter.
- The link is also useful giving optimum value of simulation parameters even at 0 dBm transmitter power and 3.5 km range in foggy weather conditions.
- The value of BER in adverse weather conditions is improved to 10e-23 which was approximately 10e-6 in previously published work.
- FSO link with proposed combination of components can also be employed in regions with heavy atmospheric turbulences.

**References**


12 Vinayak N & Gupta A, Comparative analysis of WDM system using Cascaded amplifiers in Optical wireless channel over a distance of 10000 km, *SOP Trans on SP*, 1 (2014) 25-32.


