Analyze and mitigation of Interference in Free space optical communication systems

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***Abstract*-Free space optical communication systems have special privileges in comparison with radio transceivers in last-mile connections. Some of These features are high security, low power consumption, extremely high bandwidth and low interference. The fact that the interference free systems are one of the nowadays challenges, as well as the stems and sources of interference were investigated in this research and cost-effective optical solutions were proposed.**

***Index Terms*-Free space optics, interference, bandwidth limiter**

I. INTRODUCTION

Today, with the rise of requests of using higher bandwidth wireless services and constrains of obtaining new frequency licenses, it became a new challenge to use interference-free technique in order to enhance the quality of service between users and stations.

Different types of interference can produce undesired signals for a receiver. Noise reduces the S/N [1] ratio which yields higher BER [2] for a communication link. Therefore it is essential to design efficient structure to increase the quality of service. In this research we probe into radio and fiber optics interference sources and compare them with free space optics technology. Each condition supported with experimental results. Finally, Polaroid filters were used to enhance the quality of service and noise filtering.

II. INTERFERENCE

Electromagnetic waves are the main carriers of signal in both optical and radio communication systems, whereas the major difference in their propagation is due to their wavelengths. In another word, longer wavelengths have less interaction with smaller particles in their radiation path. In contrast, visible light attenuates by scattering in atmospheric channel. Shorter wavelengths can travel without multi-surface-reflections. Accordingly, there is less possibility of signal being destructively interfered in optical communication.

A. Co-Channel interference

Co-channel interference occurs when two or more carrier frequencies interact with each other in space. In optical communication systems, it is expected to have a same behavior when two equal lasers pointed to a same path in space. In some cases multi-reception is the major source of co-channel interference in radio telecommunications.

Sometimes a transmitter bandwidth overlaps with another's in the receiver location which causes interference. The reason is the wide radiation pattern of radio transmitters. In free space optical communication there is a stable central frequency or laser wavelength which convey data stream easily by firing on or off correspondence optical pulses. Therefore Co-channel interference occurs when two or more same-polarized transmitters locate close to each other sending their beam in a same path. It is rational to assume these beams interfering destructively or instructively at the receiver location. Our experiment launched with two 650nm laser beams interfering each other producing figure 1 with 158 KHz and 31.7 KHz repetition rate on/off keying.

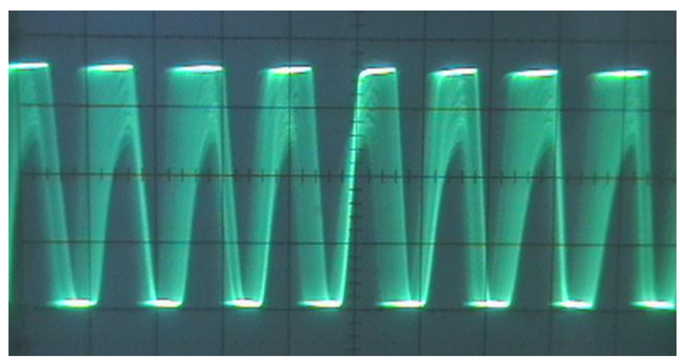


Figure 1. Interfered signal of two 650nm lasers with 158 KHz and 31.7 KHz frequencies.

For free space optics there are strict conditions of interference. In another word small radiation pattern of laser sources confine the possibility of signal being interfere in space.

B. Intermodulation Interference

When signal amplifies in non-linear components, new frequencies create. For a radio transmitter, it is essential to use proper filters in order to enhance the quality of service [2], [3]. Free space optical transmitters are completely different from radio transmitters owning the fact that, the carrier frequency never produced in the circuit resulting higher immunity to Intermodulation interference.

[1] Signal to noise
[2] Bit error rate

C. *NEFE interference*[3]

NEFE interference occurs when two transmitters locates in counter side of their particular receivers in space. With this arrangement the power level of unwanted signal receives higher than the main transmitter. Therefore signal to noise ratio decrease causing phenomenon called signal fading. This is a common problem in radio communications. [3], [8]

We used to lasers which were adjusted to 31.7 KHz and 3.17 KHz switching frequencies with 100mW and 5mW optical powers like figure 2. When detector tuned to 31.7 KHz high power laser figure (3) shows results displayed on the oscilloscope.

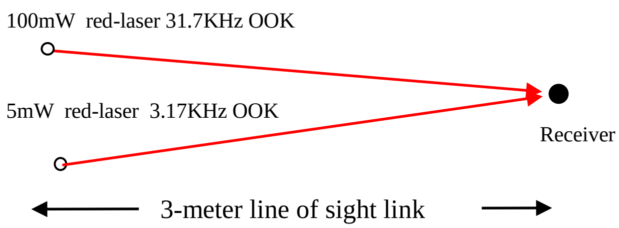


Figure 2. location of each transmitters and the receiver

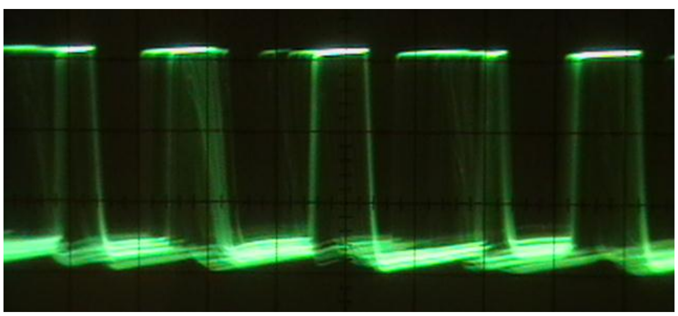


Figure 3. receiver output while high power noise transmitter interfered to low power laser beam at the receiver location

Another important notice about free space laser communication is that the transmitters with any wavelength will not affect each other while travelling in different paths. This fact was proved by our experimental results. We have used two separate laser beams pointed to their receivers, crossing each other in space. The junction angle varied between 30 to 180 in 5 degrees steps. But there were no distortion recorded even when beams traveled in parallel with each other but in an opposite directions. Likewise, no bit error will occur for high speed (Gbps) links. [6]

D. *Inter-symbol interference (ISI)*

In I/Q modulation techniques like QPSK, this phenomenon appears when eye-diagram degenerated with overlapping 1s and 0s bits which produces unstable locations in I/Q constellation. In optical communications jitter has the same behavior to ISI interference, which is the main cause of limitations in fiber- communication bandwidth and the link-margin.

In multimode fiber there are limitless paths for laser beam to reach the receiver. Some reflection angles are much high that make enough delay for a pulse to receive with the next signal simultaneously. Again the real signal will fade in the transmission channel. For saving the communication link, transmitter should reduce its bandwidth for longer time frames. [5]

Communication channel in free space optics technology is unstable and unpredictable. Raindrops and heavy fog can detour the laser beam as well as scintillation. Consequently, longer paths overlap with direct radiations at the receiver, called multipath interference (MPI). Although, this is not the main reason of link limitations but its intensity increases by raising the channel attenuation coefficient. Regulator filters could be used in the receiver to mitigate the system deficiency. [2], [7]

On the other hand, circuit components have frequency restrictions that can confine the transmission bandwidth. If transmitter or receiver overloads, jitter occurs. This effect will increase bit error ratio at the receiver output. Statistically the RMS and maximum normalized ISI can be defined according to equations (1) and (2).

$$ISI_{\max\_normalized} = \frac{\sum_{n=-\infty, n\neq 0}^{\infty} |h(nT_b)|}{h(0)} = \frac{\sum_{n=-N/2, n\neq 0}^{N/2} |h(nT_b)|}{h(0)} \qquad (1)$$

$$ISI_{\mathrm{RMS}\_normalized} = \frac{\sqrt{\sum_{n=-\infty, n\neq 0}^{\infty} |h(nT_b)|^2}}{h(0)} = \frac{\sqrt{\sum_{n=-N/2, n\neq 0}^{N/2} |h(nT_b)|^2}}{h(0)} \qquad (2)$$

Where

N is the number of bits that interfere with the bit at time *t*=0
Tb is the bit period, which is equal to 1/*B*
B is bit rate.
h(*t*) is the impulse response of the system assuming that *h*(0) is maximum
of *h*(*t*) for the bit at time *t* = 0.

[3] Near End Far End interference

Regardless of channel attenuations in a constant bandwidth, simulation results for normalized ISI interference were shown in figure (4) and (5). It is supposed to have less bit error when using one tenth of components maximum bandwidth, which is a logical conclusion. Therefore it is essential to use high speed devices in both optical transmitters and receivers.

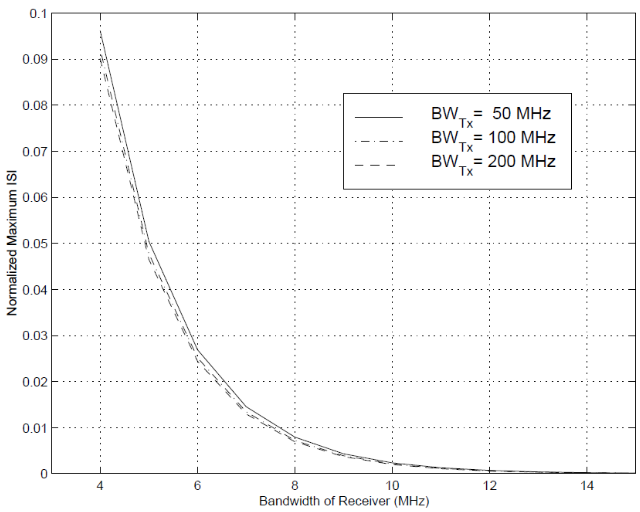


Figure 4. The normalized maximum ISI versus the receiver bandwidth. [4]

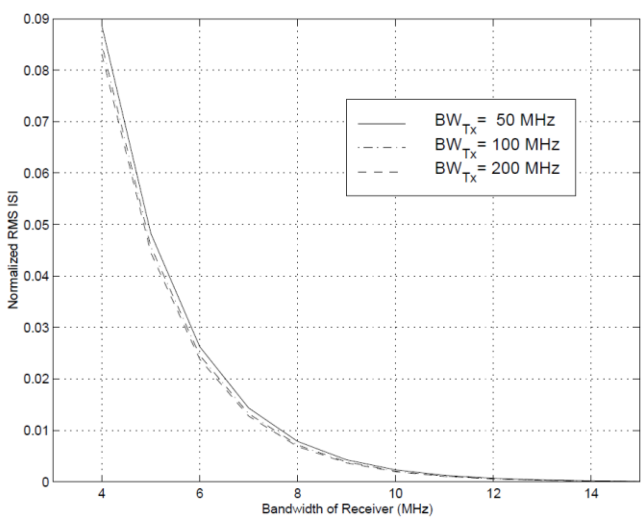


Figure 5. The normalized RMS ISI versus the receiver bandwidth. [4]

Likewise, there is a similar behavior while working with a low speed laser. Figure (6) shows analytical simulation for a constant bit rate communication link versus transmitter bandwidths. According to figure (7) a real experiment shows how zeros and ones extend over each other when the laser's transition time is higher than signal repetition ratio.

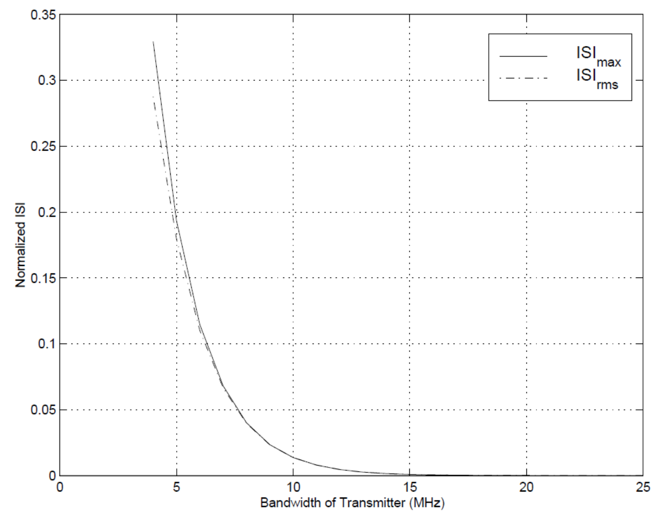


Figure 6. The normalized maximum ISI and normalized RMS ISI versus the ratio of transmitter bandwidth to the bit rate: assuming BWTx=BWRx. [4]

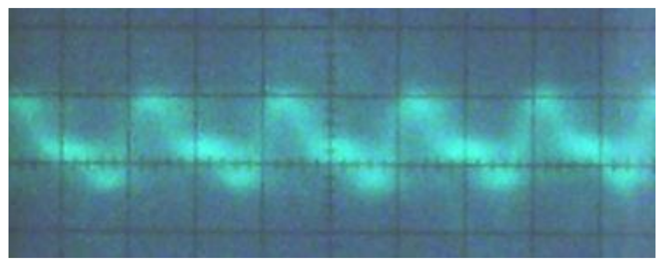


Figure 7. Receiver output signal at 10MHz when transmitter laser was driven with 20 times of its nominal switching frequency.

III. Interference Mitigation with Polaroid Filters

Since laser transmitters emit polarized waves, it is viable to assuming two clusters for laser radiations, vertically and horizontally polarized beams. Owning the fact that the FSO modules (two sets per link) usually installed without polarization considerations, PIN or APD photo-diodes can detect Omni-polarized waves. That means the better results using precisely tuned Polaroid filters at the receiver location.

In our experiments two transmitters were used according to figure (8) arraignment while their polarization had 135° phase differences. Nevertheless, signal filtering was thoroughly attainable. Figure (9-b) shows the low power laser signal which was extracted from its 20 times stronger noise transmitter using a proper filter which was accurately fixed to the polarization of desired transmitter. Figure (10-a) depicts how our 157 KHz signal affected by 31.7 KHz powerful laser without using any optical filter.

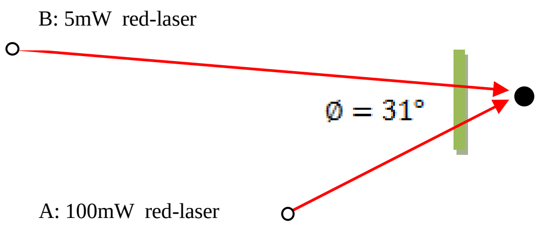
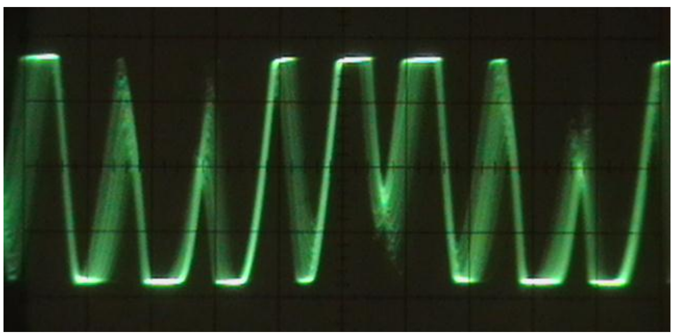
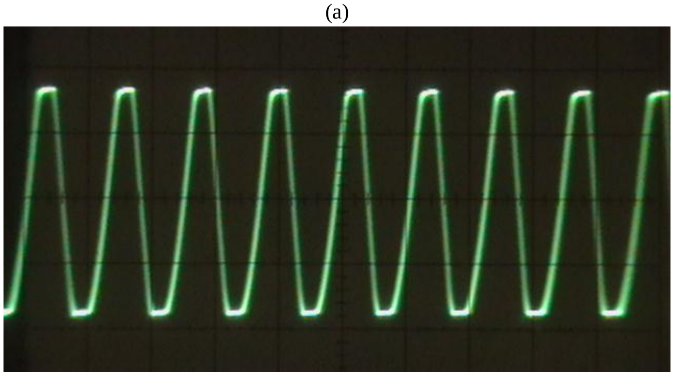


Figure 8. The arraignment of laser transmitters and the Polaroid filter at the receiver location



(a)



(b)

Figure 9. Output signal of the receiver where transmitters interfered on PIN photo-detector's surface a) without filter b) when receiver was shielded with a tuned Polaroid filter

Overall, it is reasonable to have precise polarization division for each receiver according to its transmitter. It is supposed to have high quality results even when using four beams with 45° polarization differences and tough filters.

IV. CONCLUSION

Free space optics has special privileges in comparison with other communication methods. Results reveal that this technology has higher immunity between radio telecommunication systems against interference. Only frequency limitations of its components are the main cause of signal jitter. Another important point about FSO in comparison with radio communication is the facts that, the connection will remains errorless even If two or more beams intersect each other in space while other side receivers can detect signals individually. Concurrently, small radiation divergence in laser transmitters restricts the possibility of interference in FSO communication systems. Meanwhile, optical filters are cost-effective solution for mitigating deficiencies. Polaroid filters as a case in point have shown proficient ability to select desired signal between four directionally polarized beams at the receiver location.

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