Optical communication system based on intensity modulation in plastic optical fibres

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Abstract - **Over the past decades the importance of technology in our daily life as increased. The applicability of technology has become a fulcrum point not only in our work environment, but also at our homes and automobiles. With a constant growth of services provided to the users, especially in residential environments and automobiles, it appeared the necessity of improvement of the pre-existing communication systems. The upgrade of these systems involves increasing the bandwidth as well as the transmission capacity.**

In this context, the job of perfecting these communication systems involves the substitution of the traditional coaxial cables for the plastic optical fibres. This simple change will suffice the decrease of the systems 'price and it will allow larger bandwidths as well as bit rates.

Keywords - Fibre-optics communication system, amplitude modulation, direct detection, plastic optical fibre

I. INTRODUCTION

Plastic optical fibre is becoming an alternative to the traditional coaxial cables as well as for glass optical fibres in same applications. The lower installation cost of plastic optical fibres make them an appropriate and desired solution for home networks as well as for automobiles and airplanes.

In home networks the flexibility of these fibres allow users the possibility of concealing there existence because they are easily disguised [1]. Other advantage comes from the fact that these fibres are immune to electromagnetic interference [2] which is an upgrading compared to coaxial cables. Regarding the automobile industry the continuous addition of digital devices in cars led to the necessity of implementing a higher capacity network which has been possible with plastic optical fibres. Another advantage as important to the automobile industry as to the aviation is the light weight of these fibres.

The work that was developed intends to inquire the feasibility and viability of an optical communication system using plastic optical fibres.

II. THEORETICAL FUNDAMENTS

Primarily before starting the implementation of the optical communication system it is necessary to understand the modulation which is going to be used, as well as the intrinsic characteristics of the plastic optical fibres.

A. *ASK Modulation*

The digital modulation that it will be used is the ASK modulation, which means that the binary sequence, also called binary message, will only modify the amplitude parameter of the carrier [3].

The carrier is given by a sinusoidal function, with a determined frequency, fc, and amplitude, A:

$$c(t) = Asen(2\pi fct) \qquad (1)$$

During the modulation process the amplitude of the carrier signal changes accordingly to the value of the bits given by the binary message, as represented in figure 1.

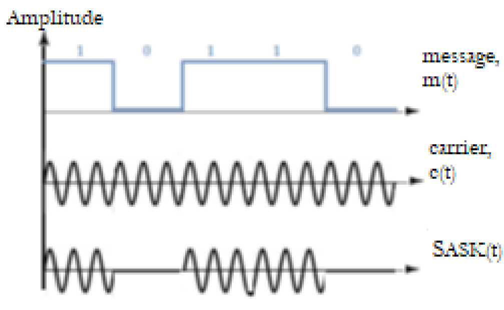

Figure 1. ASK modulation.

B. *Plastic Optical Fibres*

There are two characteristics that can strongly affect the performance of the step-index plastic optical fibre which are attenuation and dispersion.

1. *Attenuation:*

Attenuation has been a recurrent issue in the history of the plastic optical fibres. They started extremely high, around 1000 dB/km, which only made their application viable to illumination and sensors. As the years went on those values of losses started to decrease which made the application of these fibres worthwhile to the automobile industry as well as home networks. The drastic reduction in values of attenuation was due to the discovery of impurities introduced in the fabrication process of these fibres.

In the figure 2 is represented the evolution of the values of attenuation on the step-index and gradual-index plastic optical fibres.

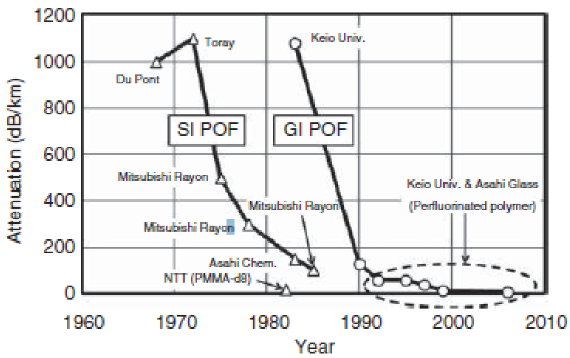

Figure 2. Evolution of the attenuation values in plastic optical fibres [source: extracted from [4]].

Attenuation can be summarized as a parameter within an optical fibre which limits the distance between the transmitter and the receptor of any given signal. In other words this losses diminish the optical power of the signal which is being transmitted through the fibre until it reaches a lower value than the minimum necessary at the receptor.

The coefficient of attenuation, α, is expressed in dB/km and it is given by:

$$\alpha = \frac{10}{L} \log_{10} \frac{P_{in}}{P_{out}} \qquad (2)$$

The effect of attenuation is illustrated in the following figure.

Figure 3. Effects of attenuation in any given signal. [Source: adapted from [5]]

2. *Dispersion:*

Dispersion is a phenomenon which occurs in an optical fibre when a pulse is being propagated through it and suffers a broadening in time due to imperfections and properties of the material. When this broadening causes an overlap between pulses it appears an intersymbol interference, ISI, which can lead to a higher bit error rate, BER.

Dispersion limits the bit rate at which the information is transmitted through the optical fibre since it also restricts the bandwidth [5] [6].

There are to different types of dispersion: intramodal and intermodal. While intermodal only exists in multimode fibres which is the case of the step-index optical fibre, intramodal dispersion exists in single-mode and multimode fibres.

Intramodal dispersion, also entitled as chromatic dispersion, causes a delay among the different spectral components within the same mode. This is caused by the different propagation velocities of the spectral components which provoke a signal broadening at the output of the fibre.

In the figure 4 it is showed the effect of chromatic dispersion.

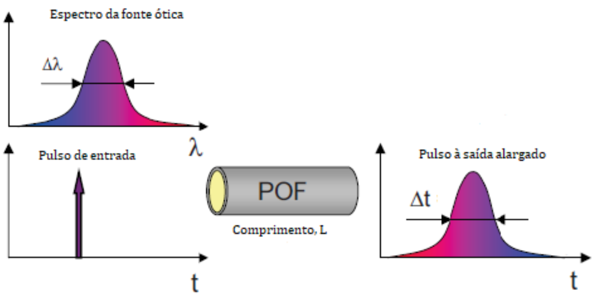

Figure 4. Effect of intramodal dispersion. [Source: adapted from [7]]

An estimation of the capacity of the fibre in terms of bit rate-distance when this dispersion is presented is:

$$R_B.L \leq \frac{1}{|D_\lambda|.\Delta\lambda} \qquad (3)$$

Although intramodal dispersion exists in step-index plastic optical fibres, SI-POF, it is not the one which limits the most the performance of the optical communication system formed with these fibres. Intermodal dispersion is the main type of dispersion which strongly effect these system's performance. This results from the fact that each mode propagates through different trajectories in the fibre which means that they will arrive at various instants at fibre's output.

In figure 5 it is showed how intermodal dispersion affects the signal depending on the type of plastic optical fibre.

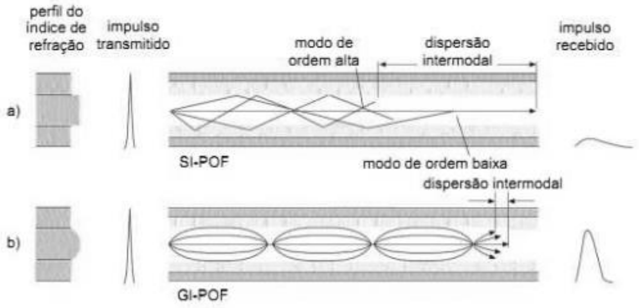

Figure 5. Effects of intermodal dispersion. [Source: extracted from [8]]

The capacity's system given the existence of intermodal dispersion when using the SI-POF can be calculated as:

$$R_B.L \leq \frac{n_2.c}{n_1^2.\Delta} \qquad (4)$$

III. NUMERICAL IMPLEMENTATION

In this section it is intended to explain how it was simulated a theoretical optical communication system for two supposed different fibre's lengths, L=5 m and L= 40 m.

1. *Modulation:*

Firstly, it was generated a random binary message with a bit period of 0.1 ms which corresponds to a bit rate of 10 kbps. The simulation window was set to 0.5 s and the sampling frequency to 1000 kHz. As a consequence there were simulated 5000 bits which corresponds to 500000 samples or 100 samples per bit period. The digital message was used to modulate the sinusoidal signal so that it could be transmitted over the channel. The frequency of the sinusoidal carrier was fixed to 250 kHz.

Both binary messages and modulated signals are illustrated in the following figures.

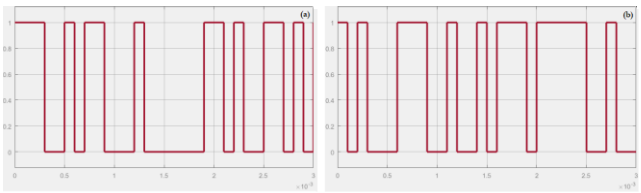

Figure 6. Sample of the first 30 bits of the binary message (a) L= 5 m; (b) L=40 m;

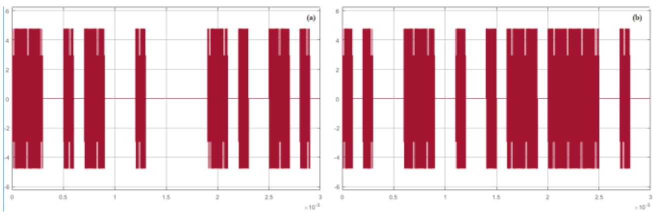

Figure 7. ASK modulated signal (a) L=5 m; (b) L=40 m;

2. *Propagation:*

After obtaining the modulated signal, this will be transmitted over the propagation channel which intends to represent an approximation to the real plastic optical fibre. To do so it was required to create noise, attenuation and dispersion.

Noise was simulated by introducing additive white gaussian noise.

Attenuation as previously mentioned is a loss in the power of the transmitted signal and it depends on the fibre length. In the experimental implementation it will be used a SI-POF from Broadcom which possesses an attenuation of 0.22 dB/m at the red region of the electromagnetic spectrum which is the region that it is going to be used to simulate the experimental system. This means that the attenuation constant value for each length is -1.1 dB for L=5 m and -8.8 dB for L=40 m.

Dispersion is a much harder parameter to consider in this simulation. As it was formerly stated the dispersion which had the strongest impact on the performance of these optical communication systems is intermodal dispersion. However, this type of dispersion can not be replicated because in the theoretical implementation there is not any way to distinguish modes. So, instead it was made an approximation. It was only considered the use of intramodal dispersion. To simulate this dispersion there are two coefficients needed: β_1 which represents group delay and β_2 which stands for the group velocity dispersion [9] [10]. In the fibre datasheet is only given the group delay coefficient, so it will be the only one considered. In figure 8 it is presented a scheme that explains how the dispersion was tested.

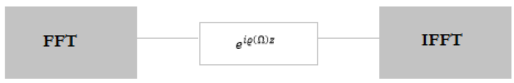

Figure 8. Intramodal dispersion.

3. *Demodulation:*

When the signal reaches the output of the transmitted channel it is necessary to reconstruct the binary message. In figure 9 the scheme represents the demodulation process.

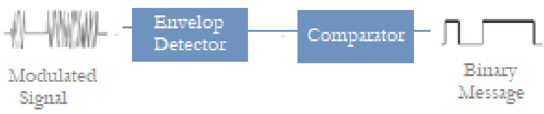

Figure 9. Demodulation Scheme.

The envelope detector is formed by one half wave rectifier and low pass filter. The rectifier is simply used to remove the negative values of amplitude of the signal. And the low pass filter is used to remove higher frequencies such as the frequency of the sinusoidal signal.

In figure 10 are showed the results of the signal after propagation and at the output of the envelope detector.

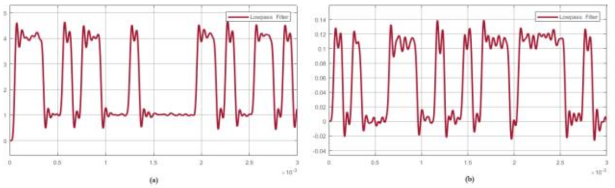

Figure 10. Signal at the output of the low pass filter (a) L=5 m; (b) L=40 m;

Finally the signal goes through the comparator which compares each sample to a threshold value. The values higher than the threshold will originate bit 1, and lower values will create bit 0. Subsequently BER calculation is made by comparing the obtained binary message to the original binary message.

In this particular case the results of BER calculation were quite identical. For L=5 m it was attained a null bit error rate. For L= 40 m it was obtained an error of 0.04% which can be disregarded. In any case this shows that it was able to reconstruct the original binary message after the propagation through the channel.

Figure 11 shows eye diagrams for either one of the cases studied.

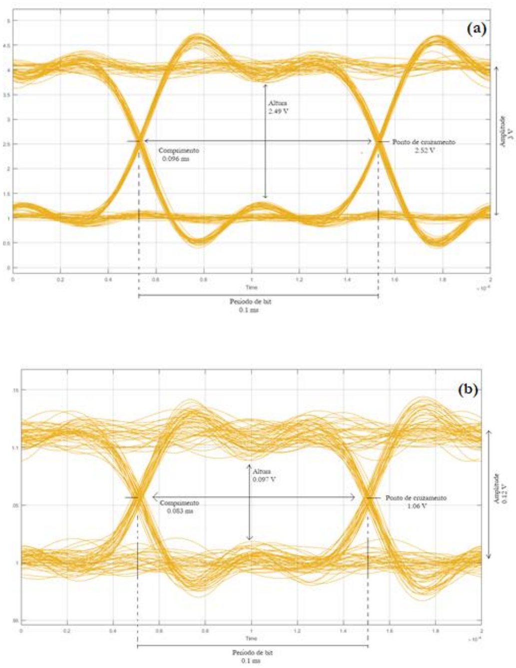

Figure 11. Eye diagrams (a) L=5 m; (b) L=40 m;

IV. EXPERIMENTAL IMPLEMENTATION

To develop an optical communication system it is required the use of a LED, as transmitter, a SI-POF, as a wave guide, and photodiode as receptor. Besides these components, it was also required the use of an analog device, ADALM1000. This device has a sampling frequency of 100 kHz and is only able to acquire signals within the range of [0; 5] V [11].

Before proceeding to the results, it is important to study the behaviour of the LED. With the support of figure 12 it can be concluded that the best window transmission is from [2.4; 5] V.

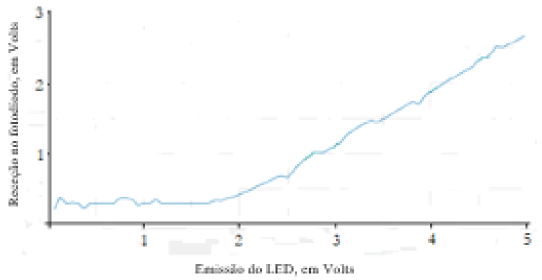

Figure 12. Optical power emitted by the LED in function of tension polarization.

The implementation of this system can be seen in figure 13.

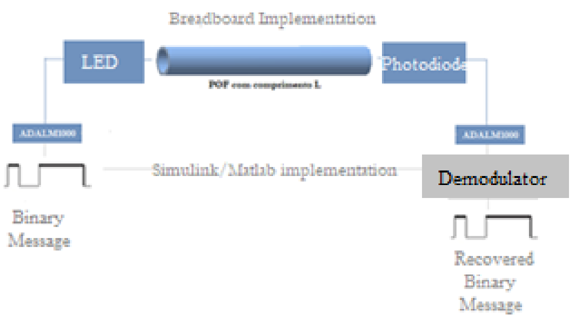

Figure 13. Experimental implementation;

Firstly, it is generated a binary message (figure 14) with the same bit period as in the numerical implementation. Then, this message is send through ADALM1000 to the chosen LED which will modulate directly the signal before heading to the plastic optical fibre.

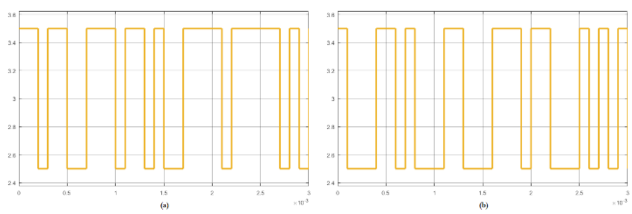

Figure 14. Binary Message (a) L=5 m; (b) L=40 m;

After receiving the binary message the signal needs to be processed using the same method described in the previous demodulation section. Figure 15 shows the results from the receiving binary message and low-pass filter.

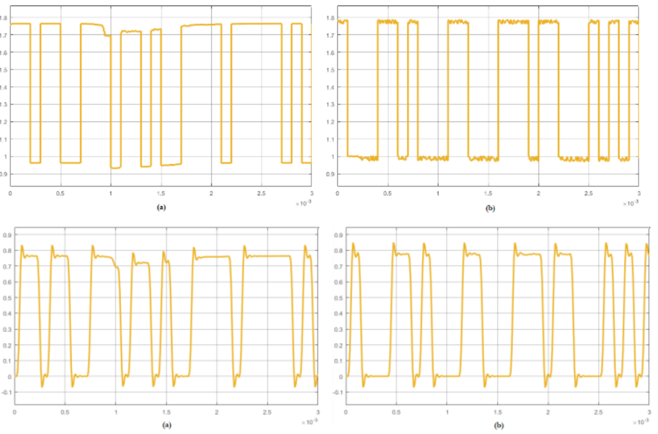

Figure 15. On top: binary message received from photodetector; below: low pass filter output signal (a) L=5 m; (b) L=40 m;

To address the feasibility and viability of this system is required to calculate the bit error rate, and to analyse the eye diagram's parameters.

In this particular case, in either POF length, the result of the BER is null. This means that for this bit rate, the characteristics of system did not have a negative impact on the performance of the system. Analysing the eye diagram from figure 16 it is possible to conclude that even though the results do not seen very different the major difference comes upon the calculation of Q-factor (done automatically using simulink). For L=5 m Q-factor was 34.12 and for L=40 m Q-factor was 20.86. This difference in result originates from the decreasing of signal-to-noise ratio when the fibre's length increases.

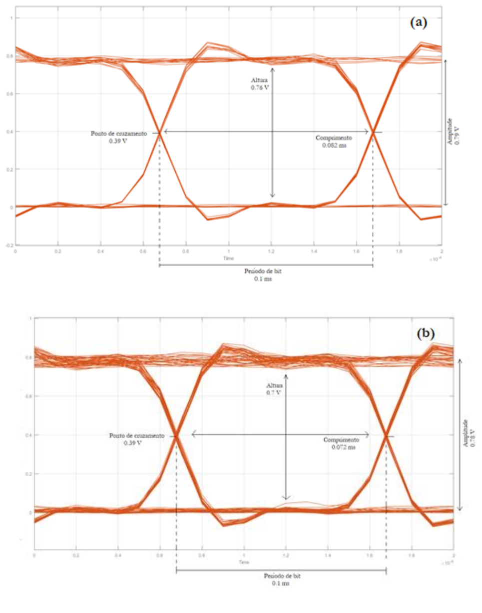

Figure 16. Eye diagram (a) L=5 m; (b) L=40 m;

V. CONCLUSIONS

To summarize it was proven for a bit rate of 10 kbps the optical communication system works perfectly without being disturbed by the subjacent characteristics of the plastic optical fibre.

The chosen bit rate was restricted by the analog device used upon the experimental simulation. Although the use of higher bit rates are desired in this case it was not possible practice them.

VI. REFERENCES

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