Bandwidth measurement in POF based on general purpose equipment

J. Mateo *, M. A. Losada *, J. J. Martínez-Muro *, I. Garcés *, J. Zubia #

* Universidad de Zaragoza, Zaragoza, Spain
# Universidad del País Vasco, Bilbao, Spain

C.P.S. Universidad de Zaragoza, Maria de Luna 1, 50018 Zaragoza, Spain
Tel: +34 976 762360. Fax: +34 976 762111. E-mail: jmateo@unizar.es

Abstract

We present two different methods to obtain the bandwidth of step index plastic optical fibres (SI-POF). First, bandwidth is obtained by sweeping the frequency of sinusoidal waveforms and measuring their attenuation. Second, bandwidth is calculated by estimating the step response from the fibre response to a train of pulses. For the experimental implementation of both approaches, we used conventional equipment controlled by computer through the GPIB. The maximum measurable bandwidth using our system is 1GHz for a maximum allowed fibre attenuation of 30dB.

I. Introduction

Although the bandwidth of step index plastic optical fibres (SI-POF) has been measured by different methods [1-3] and analysed from different points of view, such as its relationship with the launching conditions [4], the use of scramblers to enhance it [5-7] or the bandwidth behaviour of aged or stressed fibres [8], its behaviour remains attracting attention and even now, new results and models are being published [9-10].

The aim of this paper is to show two reliable methods to measure the bandwidth by using general purpose equipment such as a signal generator and an oscilloscope. Both methods are based on the Japanese standard JIS [11]. The first one consists on measuring the attenuation of a pure sinusoidal waveform by sweeping its frequency. The second approach uses a pulse as the input signal and analyses the output pulse to obtain the fibre bandwidth. This method is essentially different to those ones that obtain bandwidth from the broadening of extremely narrow pulses because ours are much wider which reduces the cost and complexity of the system.

The extent of the measurement range depends on the quality of the electronic equipment, and naturally, it could be improved using more expensive equipment. Our aim here is to emphasize some processing tips that have been useful to us to extend our measurements beyond the limits of our material and can be applied to similar systems. By the computer-aided control of the devices, we have managed a friendly, intuitive and reliable bandwidth measurement system based on two different approaches. With these systems, we can measure the useful length range of a standard SI-POF, being limited on the one hand by the maximum measurable bandwidth of 1 GHz in spite that our receiver has a 3dB optical bandwidth of only 200MHz and on the other hand, by a maximum allowed fibre attenuation of 30dB, obtaining accurate measurements even when the signal to noise ratio (SNR) was less than one.

Both methods have proved to be equivalent but present particularities depending on the provided information or the time needed to reach an accurate measure.

II. Experimental Set-up

Figure 1 shows the schematic of the experimental set-up. The devices are fully controlled and data is acquired by the computer through the GPIB and processed using

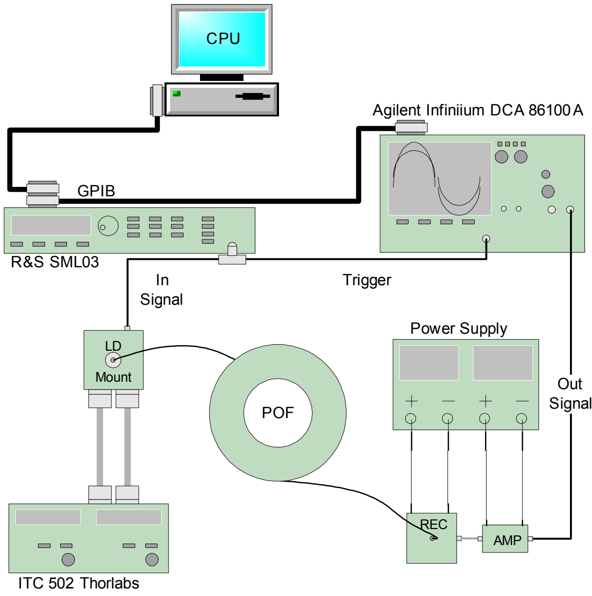


Fig. 1. Schematic of the experimental set-up shared by the two implemented methods to obtain bandwidth in POFs.

software specifically designed. Although the approaches underlying the two methods implemented are very different, the equipment used is the same: A signal generator Rohde & Schwartz SML03 is used to generate both, sinusoidal signals and 20ns FWHM pulses, using different outputs. In both cases, the signal is fed to the transmitter which is based on an AlGaInP laser diode (LD SANYO DL-3147-021) emitting a maximum of 5mW at 645nm and with a typical divergence of 30º in the perpendicular plane, and of 7.5º in the parallel plane. The LD is mounted onto a Thorlabs TCLDM9-TEC LD mount with a band-pass from 100 KHz to 1GHz. The bias and temperature of the LD are controlled by a Thorlabs ITC-502 controller to guarantee its stability. The receptor system consists on a custom circuit based on a 1mm diameter photodiode (FDS010) with a 50Ω load resistance. Its output is amplified using a 40dB amplifier (Mini-Circuits ZKL-1R5) with a band-pass from 10MHz to 1.5GHz. A wideband Infinium DCA 86100A oscilloscope from Agilent is connected to the output of the amplifier and is externally triggered from the same signal fed to the transmitter but conveniently attenuated.

To compare results from the two approaches, we have tested a step-index fibre from Toray PGU-CD1001-22E (PMMA core, 1mm-diameter). It is an upper-grade fibre with a numerical aperture of 0.5 and a relatively low attenuation (0.15dB/m).

III. METHODS

A. *Frequency sweeping method*

The frequency method implemented here is based on the JIS for the measurement of bandwidth [11]. It consists on sweeping the frequency of a pure sinusoidal waveform that is fed to the LD. The oscilloscope captures the received signal whose amplitude is directly related with the frequency response of the system. We capture 4096 points of the output sine-waves with a sampling frequency of 2.048GHz, being the observation time of 2μs and thus, the spectral resolution is 500 KHz. We calculate the FFT of the acquired signal to measure the amplitude at the generated frequency and also, to estimate the SNR. A Hanning window is used to diminish the power leakage due to the finite observation time. For high frequencies or large fibre lengths, the output sinusoids have very small SNR and the measure of amplitude signal has been found to be very weak. For this reason, when the SNR is smaller than a threshold, the oscilloscope automatically begins to average a number of these sinusoids until the SNR is above the threshold, and then, the measure is taken. This particular feature makes our method more robust and permits to extend the fibre estimated bandwidth far above the system bandwidth.

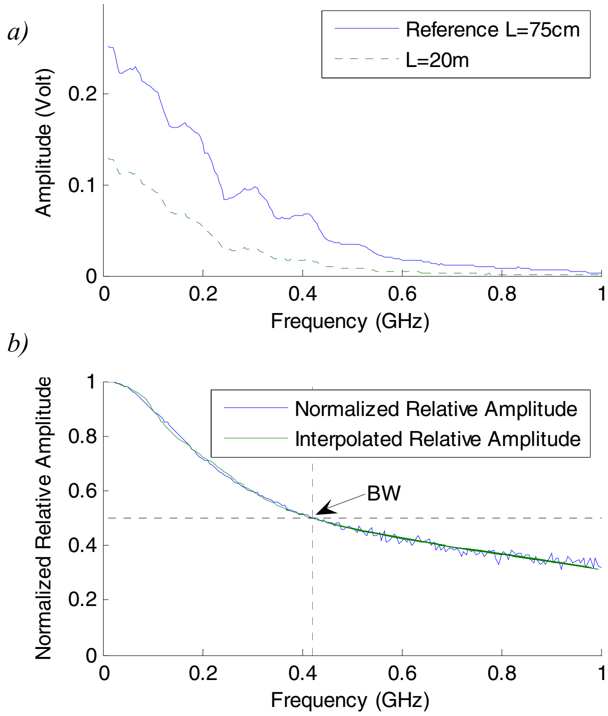


Fig. 2. Frequency responses obtained by the frequency sweeping method. a) Whole system response for a 20m fibre length (dashed line) and for the reference (solid line). b) Fibre response obtained as the normalized ratio of the two curves above.

At the beginning of a measurement session, the frequency response of a short segment of fibre (75cm) is obtained to characterize the electrical system (solid line in Fig. 2a). This measure is used as a reference to determine the frequency response for the fibre only. Subsequent measurements for other fibre lengths (dashed line in Fig. 2a) are divided by the reference curve to eliminate the effect of the system electrical components (Fig. 2b).

The optical bandwidth of the fibre is calculated as the frequency when the amplitude decays to half of its maximum value after interpolating the frequency response to improve the accuracy beyond the frequency resolution. This process is illustrated in Fig. 2b for 20m of fibre length.

B. *Pulse method*

The method implemented in the temporal domain represents a new approach that, to our knowledge, has not been used before in POFs. In the proposed method, the frequency response of the system is obtained by estimating the step response from the measurement of the output of a train of broad pulses. The impulse response of the system can be obtained as the derivative of the step response, and its Fourier Transform is directly the system frequency response.

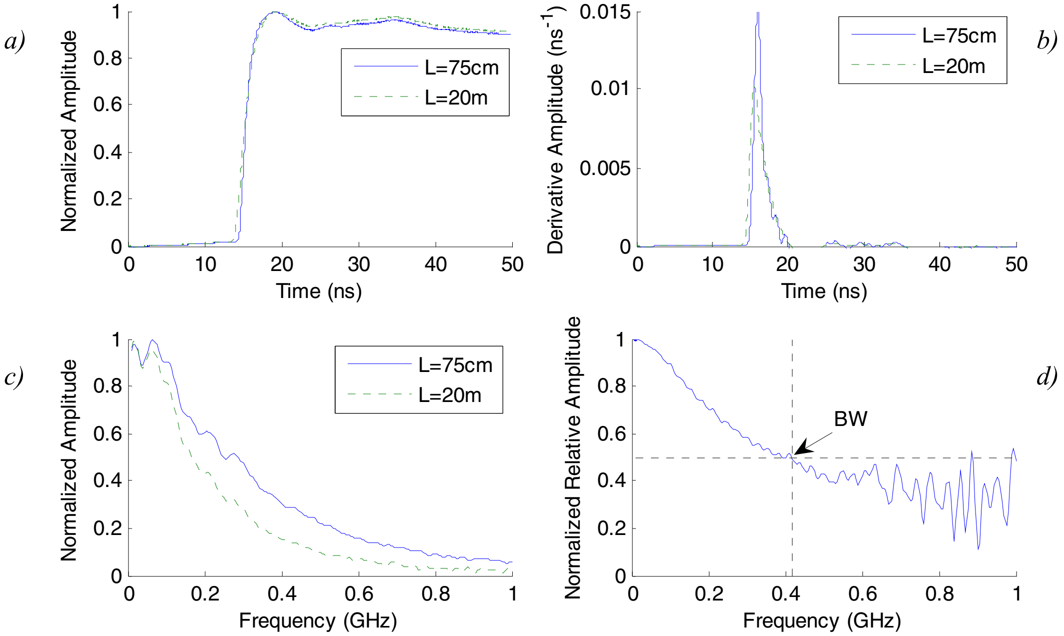


Fig. 3. Pulse method applied to the reference (75cm) and to a 20m fibre length. a) Normalized rising edge of output pulses. b) Impulse response estimated by taking the derivative of the pulses. c) Frequency response for a 20m fibre length (dashed line) and for the reference (solid line). d) Fibre response obtained as the normalized ratio between the fibre of 20m length curve and the reference curve.

Figure 3 describes our procedure for this method. We feed the LD with a train of broad pulses, although only the neighbourhood of the rising edge of the output pulses is used in our approach. Figure 3a shows the rising edge of the normalized output pulse acquired for a 20m fibre (solid line) and for a 75cm segment used as a reference (dashed line). Figure 3b shows the derivative for the same pulses. It can be seen that the slope for the 20m fibre is smoother than that for the reference. Consequently, the reference impulse response is narrower. We take the Discrete-Time Fourier Transform (DTFT) of the impulse response to obtain the frequency response of the whole system, shown in Figure 3c. As in the frequency sweeping method, the response for the fibre alone is calculated as the ratio of the whole system response and the reference (Figure 3d).

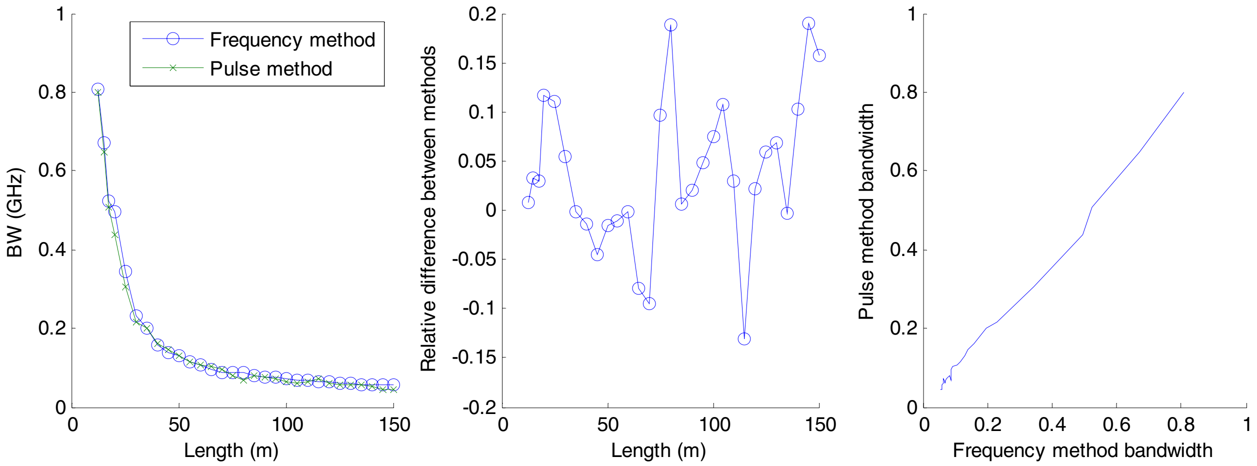
We use a processing time window of 50ns and a sampling frequency of 40.96GHz. For long fibres, the output signal has very poor SNR. Thus, a time-domain average of several pulses is taken to improve the SNR, hardly increasing the processing time.

IV. RESULTS AND DISCUSSION

We have obtained the bandwidth versus length for a fibre PGU-CD1001-22E from TORAY starting from a 150m fibre length by cutting 2.5m segments down to 12.5m with both proposed methods. The shorter length we tested is set by the maximum measurable bandwidth (1GHz), which is the same for both approaches, because it is set by the equipment (in fact, by the transmitter bandwidth). The longer length should be limited by the fibre attenuation and for this fibre, could have been extended beyond the 150m, but we did not intend to measure longer fibres as the bandwidth changes are not very significant.

Figure 4a compares the bandwidth versus length obtained from a train of pulses (crosses) and from the frequency sweeping approach (empty circles) methods. Data show a good agreement throughout the whole measured range. Relative differences between the results from the two methods, shown in Figure 4b, represent less than the 20% of the value and are not biased. Figure 4c shows the relationship between the two methods and the correlation has been found to be 0.9981.

We found that the sweeping frequency method is the more robust: Here, the test signals are pure tones and the processing has been tailored to detect peak amplitude for each particular case. High frequencies suffer high attenuation and their SNR is quite low, so a large number of them are averaged to obtain a reliable measurement. On the other hand, as the pulses are broadband, it is difficult to reduce the effects of the stronger attenuation of the higher frequencies, which makes the ratio between the measurement and the reference noisier and less reliable. However, the pulse method has the advantage of requiring less acquisition time, because it is not a sweeping process. Thus, we propose the pulse method for short fibres with better SNR while for longer fibres the



a) *b)* *c)*

Fig. 4. Comparison of bandwidth versus length: a) Actual data obtained by the frequency sweep method (empty circles) and by the pulse method (crosses). b) Relative differences between methods as a function of length. c) Bandwidth from the frequency sweeping method versus bandwidth from the pulse method.

frequency sweeping method is preferable since it is more suitable for noisy signals. In addition, for these long fibres, having narrower bandwidths, the sweeping process time can be reduced.

V. CONCLUSION

We present a novel method based on the measurement of a train of pulses to obtain bandwidth for POFs. This method produces results comparable to the standard frequency sweeping method and has the advantage of requiring less processing time, although the latter has been proved to be more robust. The maximum bandwidth measurable with our experimental set-up is 1GHz for both approaches. This bandwidth has been extended beyond the limits of our devices by processing the acquired data. These approaches can be applied to systems based on similar equipment.

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