J. Opt. Commun. 11 (1990) 1, 22–25

Journal of
Optical Communications

Spectral Attenuation Measurements of Optical Fibers: Design of an Instrument based on a Pulsed-light Source

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Summary

For the measurements of spectral attenuation of optical fibers in the range 800–1 600 nm, an instrument based on a halogen-tungsten lamp pulsed at a few Hz has been designed and developed. This approach is shown to have substanstial advantages over the usual chopped-light technique. With a low-noise front-end photodiode preamplifier (− 110 dBm sensitivity), the instrument offers a > 40 dB dynamic range of attenuation measurement in monomode fibers and can operate in analog as well as digital mode.

1 Introduction

Commonly, a spectral-attenuation instrument for measurements of optical fibers based on the well-known cutback technique [1] is built around a broadband source, a monochromator, and a low noise photodetector. The broadband source is usually a high-radiance, halogen-tungsten lamp, operated at the highest possible color temperature that will ensure a reasonable life, and modulated at audio frequency to shift the detection away from mains interference and 1/f preamplifier noise. Light modulation is commonly achieved by a mechanical chopper, such as a rotating wheel or a vibrating tuning-fork. This approach results in a fairly complex mechanical layout, since the coupling of vibrations to the optics shall be carefully avoided and an electrical reference signal shall be somehow generated for the subsequent lock-in amplifier processing.

In this paper, we show that the direct electrical modulation of the halogen lamp can be used instead of the chopper, resulting in a greatly simplified layout of the instrument and an improved overall optical efficiency. Also, the lifetime of the pulsed lamp is found substantially unchanged respect to dc operation.

In the instrument (Fig. 1), we use a two-stage standard monochromator (2 × Oriel 7240) to ensure rejection of stray light better than 40 dB, along with standard conjugating and launching optics. The detection unit contains the measurement channel and a reference channel which picks up a fraction of the monochromator output power by a multimode fiber. Both detectors are low-noise

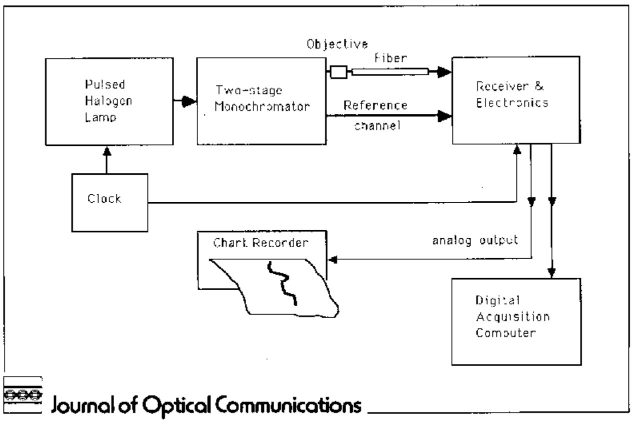

Fig. 1: Block scheme of the spectral-attenuation instrument

InGaAs photodiodes with useful spectral range 800–1 650 nm. After the low-noise preamplifier and lock-in detector, the output signals are converted into their logarithms by precision op-amp analog converters. Then, the reference is subtracted to the measurement channel, so as to yield an attenuation signal compensated (at first order) for the wavelength dependence of the optical chain. Thus, the baseline or zero-attenuation signal as measured with a short piece of fiber is almost constant with wavelength, instead of showing a large drift. By performing the cut-back measurement, the difference of two wavelength-runs yield the spectral attenuation, either directly on a chart-recorder or through computer acquisition and display.

2 The light source

A tungsten-halogen lamp (Osram 64425) rated at 20 W nominal power was selected. The lamp was driven with a

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Received 31 July 1989

low frequency square wave, the amplitude of which was adjusted so as to keep constant the peak temperature as the drive frequency was varied. A typical waveform of collected power is shown in Fig. 2. Obviously, as frequency decreases the modulation depth increases, but at too low frequencies the halogen cycle can be disturbed and life is shortened [2]; also, the 1/f noise of the photodetector worsens. At the opposite, by increasing the drive frequency, the modulation depth falls off. Therefore, one can find an optimum working point by measuring, on a spectrum analyzer, the amplitude of the fundamental-frequency component supplied by the lamp and comparing it to the noise spectral distribution of the receiver (photodiode and preamplifier). Figure 3 shows this result, from which one should select 3.5 Hz as the highest frequency that maximizes the S/N ratio. However, at this frequency the temperature swing is fairly high, from 3350 K to 1200 K, and the lamp life is shortened (6 h measured). Thus, we chose to work at 7 Hz where the temperature swings from 3350 K to 2900 K and, with a little S/N penalty, a long lifetime is obtained (80 h measured).

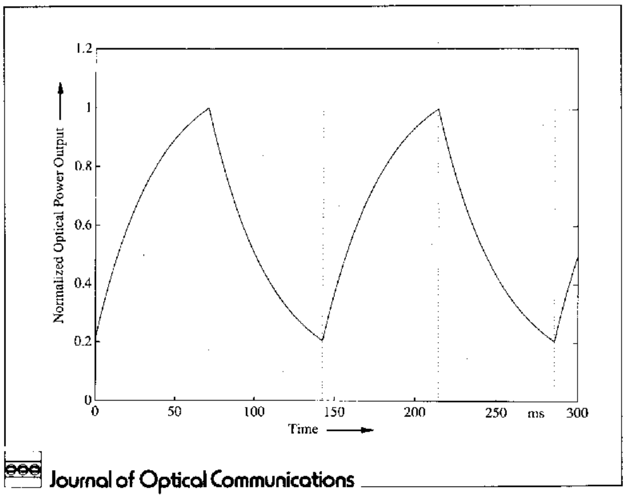

Fig. 2: Waveforms of the drive (square wave) and of lamp emitted power (f = 7 Hz)

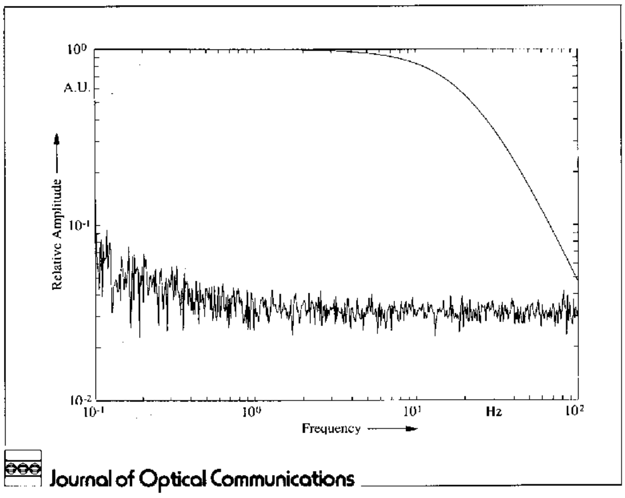

Fig. 3: Relative frequency response (fundamental component) of the pulsed lamp (top) and spectral noise density of the photodiode receiver (bottom)

To evaluate the optical power which can be launched in the fiber [3], one shall start with the (averaged) spectral radiance of the lamp, and multiply by the wavelength interval $\Delta\lambda$, the fiber acceptance, the diffraction efficiency of the monochromator and the transmission efficiency of the optics. Doing so, we have obtained the diagram of Fig. 4 which shows, as a function of wavelength, the power in dBm in a typical monomode fiber (Pirelli SM-01) for $\Delta\lambda = 6$ nm. The data of Fig. 4 are in agreement with the measured ones within $\pm 5\%$.

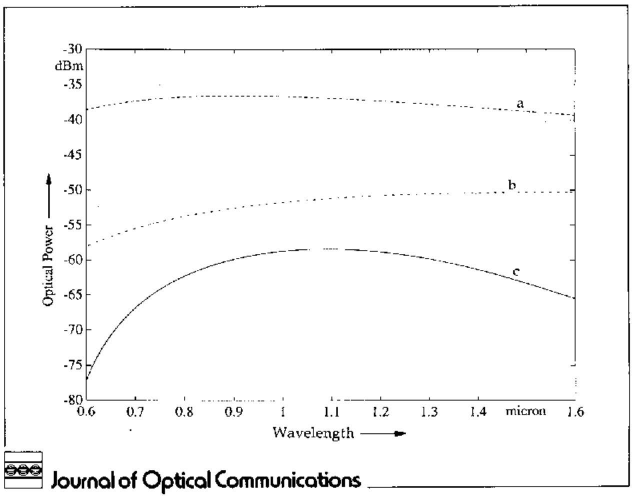

Fig. 4: Power available at fiber input (a); power launched into the fiber (b); power launched into the fiber through the two-stage monochromator (c); temperature of the source: 3200 K; spectral width for all curves: $\Delta\lambda = 6$ nm

As compared to the use of a chopper, the electrical modulation allows an overdrive of the lamp which compensates for the decreased modulation depth. At the same lifetime as in dc, the waveform at 7 Hz of Fig. 2 has been measured to contain a rms amplitude of the component at the fundamental frequency 2.7 dB lower than the theoretical value for an ideal 100% amplitude modulation. Considered that a chopper modulation achieves practically the same efficiency, electrical modulation is a viable technique wich greatly simplifyies the optomechanical design.

3 Photodiode preamplifier and electronic processing

In the front-end receiver, we used a low dark current InGaAs pin photodiode (Fujitsu FID13Y32WS) operating at zero bias and a FET-input op-amp (LF 357) in the transresistance configuration. Since the shunt-resistance of the photodiode is 9.2 GΩ, the reverse saturation current is 2.5 pA, and the input bias op-amp current is 20 pA (measured values), we selected a feedback resistor R = 10 GΩ. By compounding the noise contributions associated with these currents and resistances [4], values very close to those obtained experimentally were found.

In Fig. 5 we report the noise-equivalent current density of the front-end, with and without the photodiode; note that the 1/f corner frequency is lower than 1 Hz. With a typical spectral responsivity of 1 A/W at 1.55 mm, the receiver has a noise-equivalent power of 4.96 ± 10^{-15} W/$\sqrt{}$Hz.

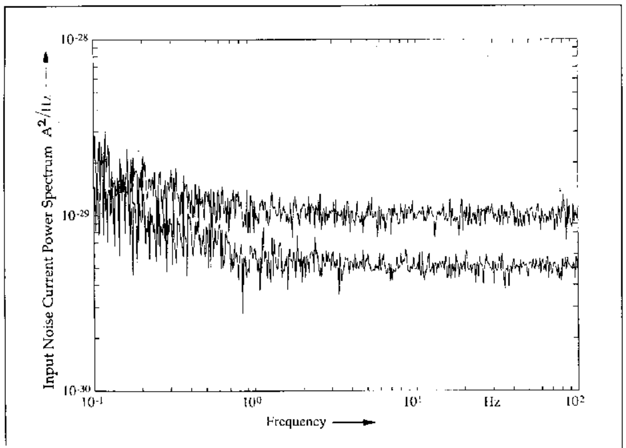

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Fig. 5: Noise spectral density of the receiver circuit without the photodiode (lower trace) and with the photodiode at dark (upper trace)

In the processing circuits (see Fig. 6), after a lock-in detection performed with the aid of the 7 Hz lamp-driver waveform properly delayed, the signal is filtered and becomes available for acquisition in a digital processor. Also, it is log-converted by a precision analog converter built around a μA 726 thermal-stabilized transistor pair, yielding a linearity better than 1% over 4 decades of input amplitude, and is finally subtracted to the similarly processed signal of the reference channel. Thus, an analog output is available which is proportional to the logarithm of collected power, and is compensated for the wavelength-dependence of optics transmission, spectral radiance of the lamp, and responsivity of the photodiode. Except for the dependence from the launching condition, this signal gives the attenuation of the interposed fiber. Yet before baseline subtraction, the attenuation trend of a fiber is clearly evident right in the first long-distance measurement of the cut-back procedure.

4 Performances

The sensitivity performance of the instrument at different attenuation levels is reported in Fig. 7. Here, the baseline chart recording of the analog output is shown for a short piece of fiber, while in the optical path neutral optical density filter of increasing attenuation are progressively inserted. Even at 33 dB (lower trace) the attenuation is still measurable. From the result of several runs, the accuracy of the attenuation measurement has been evaluated in 0.2 dB and the repeatibility in 0.5 dB in the range 900 to 1 500 nm. With a little degradation of noise and dynamic range, the working wavelength range is 800 to 1 600 nm.

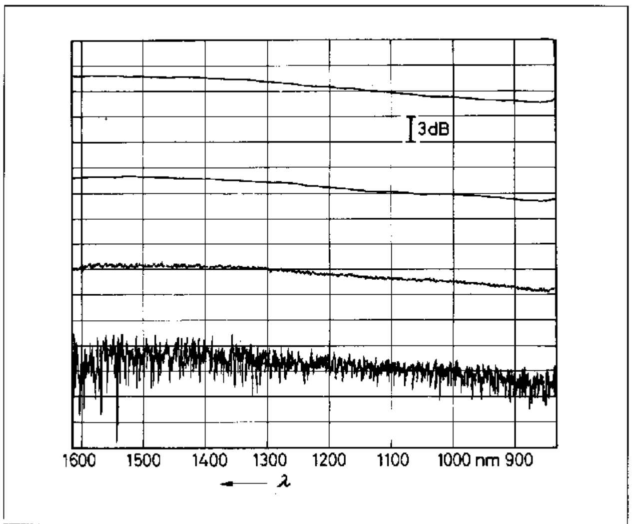

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Fig. 7: Baseline of the instrument vs. wavelength for various attenuations; from top to bottom: 0, 12, 21 and 33 dB

Figure 8 shows a typical attenuation measurement performed in the analog mode on a monomode fiber (Pirelli SM-01, 5 μm core): the bottom line is the 0-dB short-length attenuation and the top curve is for a 1.4 km length. The fiber attenuation is given by the difference of the two curves.

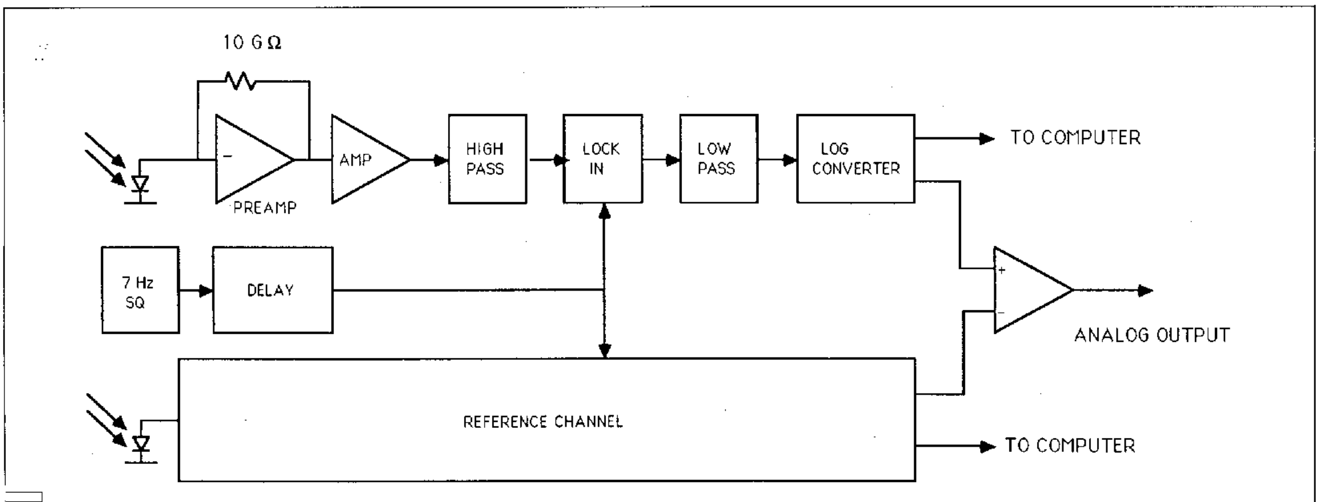

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Fig. 6: Processing circuits of the instrument

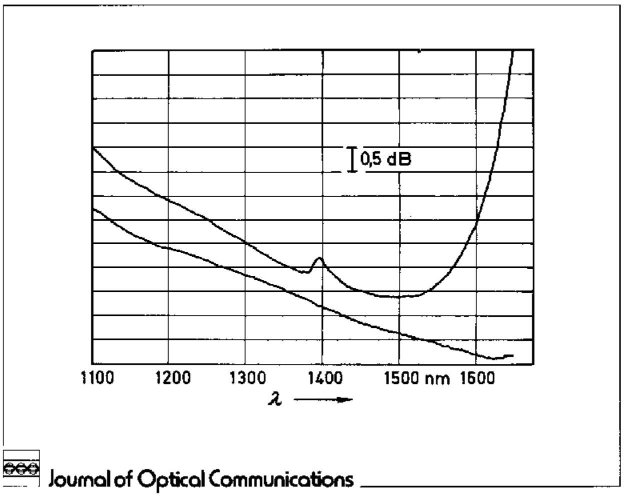

Fig. 8: Typical spectral attenuation measurement on a monomode fiber

As a final comment, let us note that for multimode fibers the performances of dynamic range and noise obviously improve (up to about +20 dB and a decade, respectively).

5 Conclusions

A spectral attenuation instrument based on a pulsed lamp source has been demonstrated, which is attractive in view of the obtained performances as well as for the simplification of the mechanical layout. Beside the usual computer-controlled mode, the instrument can operate in an analog mode with considerable saving of hardware in routine laboratory measurements.

6 Acknowledgements

Work performed under contract CNR Madess. The authors thank S. Bariani and G. Montiron for their lower case skillful help and D. Vaccarini for technical assistance.

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