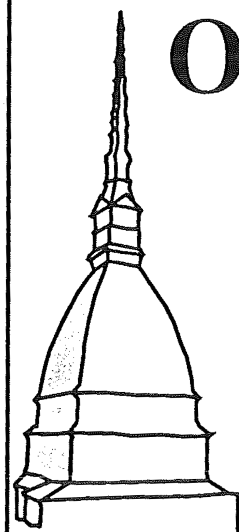
TECHNICAL DIGEST



OFMC '93

TORINO
Italy

September 21-22, 1993

2nd OPTICAL FIBRE MEASUREMENT CONFERENCE

Sponsored by:

CSELT - Centro Studi e Laboratori Telecomunicazioni
European Project COST 241 - Characterisation of advanced optical fibres for the new photonic network

Organised by:

IIC - Istituto Internazionale delle Comunicazioni

PREFACE

The second Optical Fibre Measurement Conference (OFMC '93), follows the first analogous event held in York (UK) on 17 & 18 September 1991. It is a two-days topical meeting devoted to the subject of measurements of optical fibres and related components. The objective of the meeting is that of providing an opportunity for disseminating the latest results in the field of optical fibre measurements and a forum for the discussion of topical issues in the field.

The OFMC '93 Chairman of the Organising Committee would like to thank CSELT and COST 241 for technical and organising support, the Commission of the European Community for contribution to the financial expediture of the Conference and the members of the Technical Committee, in particular Dr. S. Pollitt, for high technical and scientific support.

TECHNICAL COMMITTE

S. Pollitt (Chairman of the Technical Committee)	NPL (United Kingdom) (*)
M. Artiglia	CSELT (Italy)
C. Boisrobert	France Telecom-CNET (France)
D. Bonnedal	Telia Research (Sweden) (*)
G.W. Day	NIST (USA)
G. De Marchis	FUB (Italy)
E.M. Dianov	Russian Academy of Sciences (Russia)
P. Di Vita (Chairman of the Organising Committee)	CSELT (Italy) (*)
W. Dultz	DBP-FTZ (Germany)
W. Frank	DBP-FTZ (Germany)
H. Gilgen	Swiss PTT (Switzerland) (*)
F. Kapron	Bellcore (USA)
G. Kuyt	Philips Optical Fibre (The Netherlands)
M. Leppihalme	VTT (Finland) (*)
C. Millar	BT (United Kingdom)
Y. Namihira	KDD (Japan)
H. Okamura	NTT (Japan)
J. Pelayo	University of Zaragoza (Spain) (*)
A. Rossaro (Secretary of the Technical Committee)	CSELT (Italy)

(*) Members of the Organising Committee

Low-coherence Interferometric Measurement of Group Transit Times in Precision Optical Fiber Delay Lines

B. L. Danielson

National Institute of Standards and Technology, Boulder CO

Abstract

We describe a low-coherence interferometric method for measuring the transit time in optical fiber delay lines as long as 1.5 km. Group delays in 100 m standard reference fibers can be determined with an expanded uncertainty of about 4 ps (1 mm) and a resolution of 0.15 ps (0.03 mm). The principal limitations of this approach are identified and discussed.

Introduction

We report here on a new experimental method which uses low-coherence interferometry along with a bootstrap process to measure the group delay of kilometer-length fibers. The precision optical fiber delay lines were developed for the purpose of calibrating high-resolution optical time-domain reflectometers. Reference test fibers with well-characterized group delay (along with a given value of group index) can be used as a convenient and accurate means for evaluating distance measuring accuracy in these devices [1].

Group delay can be measured by a number of techniques including the optical pulse time-of-flight method [2] and amplitude or phase modulation [3]. Albares [4] was the first to demonstrate that the group delay could be determined interferometrically; the present work is an extention of this approach.

Experimental Methods

The experimental arrangement is illustrated in Fig. 1. The system incorporates two mechanically coupled interferometers. The first is part of a commercial fringe-counting (632.8 nm) distance meter which measures the travel of the carriage on which is also mounted a cat's eye retroreflector for the 1310 nm fiber Michelson interferometer. The low-coherence source is a LED with a spectral width of approximately 60 nm FWHM. The carriage has an extension in air of about 1 m. All test fibers have connectors at each end so that they can be concatenated. Interferograms are generated by scanning the carriage around the point of equal optical path lengths (OPLs) in the two arms (Fig. 2). The Fresnel reflection from the distal end of the fiber in the test arm gives an adequate signal-to-noise ratio even for the longest samples. Direct detection (for fibers < 100 m) yields the entire fringe pattern as shown in Figs. 2(a) and 2(b). Envelope detection, Fig. 2(c), is more convenient for the longer lengths. Coarse adjustments of the carriage position are made manually and with a micrometer; the fine scan is produced by a calibrated PZT transducer. The group delay T is then obtained from the relation $T=NL/c$, where L is the measured travel on the distance meter, c is the velocity of light, and N is the group index of air at the center wavelength of the LED spectrum [5]. The bootstrap process comes into play for delay lines > 1 m. Previously measured fibers are added to the scan arm to increase the delay by a known amount so that a longer fiber can then be measured in the test arm. The zero, or no-sample, point must be redetermined for every measurement. Each iteration of this kind doubles the length of the test fiber which can be evaluated. Starting with the shortest fiber of OPL L_1, a chain of n-1 iterations (and n total fibers) can accommodate a test fiber of length L_n according to the relation $\log(L_n/L_1)=(n-1)\log(2)$. A minimum of 12 fibers is required to reach 2048 m. The contacting connectors allow the test fibers to be joined with no air gap.

Experimental Results

Most high-resolution OTDR applications involve distances less than about 200 m. However, in order to properly evaluate the present techniques, we have looked at a somewhat wider range of fiber lengths, up to around 1.5 km. Group delays were measured in two independent chains of 12 fibers each. An estimate of measurement uncertainties may be obtained by an examination of delay differences between corresponding samples in the companion chains.

As an additional check on the transit-time results, we have compared the group delays with the measurements obtained from a conventional optical-pulse time-of-flight system shown in Fig. 3. A typical delay uncertainty for this latter system is approximately 0.04 m. Here the top of the calibration chain is the precision quartz oscillator in the time interval counter, while the corresponding reference in the interferometer method is the wavelength of the He-Ne laser in the distance meter. Thus we have two entirely different basis standards for comparison. In Fig. 4 we have plotted the measured differences (time-of-flight value minus interferometer value expressed in millimeters) for various delay lines. The expanded uncertainty represented by the error bar is approximately the same for all the points, and is due almost entirely to the pulse system. We conclude that the two approaches agree within their stated uncertainties.

Sources of Uncertainty

We follow ISO guidelines [6] in expressing the measurement uncertainties. The absolute errors of the concatenated links are cumulative and increase at a rate which is proportional to the total number of links. In this case the most appropriate representation for group delay uncertainties is as a fraction of the total delay, and this is approximately the same for all of the delay lines. The most important uncertainties and estimates of their magnitude are listed below.

1. Location of signature peak. Under ideal conditions the central fringe of the signature occurs at the visibility maximum. This location will be obscured by distortions arising from polarization mode dispersion, differential chromatic dispersion, and second-order dispersion due to the finite source spectral width. There are strategies for dealing with all of these problems. Signature broadening also defines the

measurement resolution (Fig. 5).

2. Environmental effects. Although the reference fibers were kept in a temperature-controlled box, the fiber scanning interferometer was exposed to the effects of laboratory air temperature fluctuations; this caused poor run-to-run repeatability. These environmental instabilities constituted the largest single source of uncertainty and had estimated value of about 7 ppm.

3. Fiber temperature. The temperature stability of reference test fibers will present the ultimate limit on measurement uncertainty for group delay. The thermal coefficient for the present fibers was measured to be about 5.8 ppm/K. In our case, this results in an uncertainty of about 0.6 ppm.

4. Scanning interferometers. Both 632.8 and 1310 nm interferometers have length measurement uncertainties < 1 ppm if corrections are made for atmospheric pressure, humidity, air temperature, and misalignment ("cosine error"). In addition, the PZT displacement must be calibrated carefully.

Discussion and Conclusions

We have described and analyzed an interferometric method for measuring the transit time in optical fiber delay lines at the zero-dispersion wavelength. This technique is based on a bootstrap process in a low-coherence scanning fiber Michelson interferometer. The expanded (approximately two standard deviations) delay uncertainty associated with this approach is about 7 ppm and is dominated in the present study by ambient temperature fluctuations. The accuracy can be improved considerably by better thermal control of the interferometers and possibly also by management of the geometry and composition of the constituent fibers [7]. The interferometric method described here can be used to measure the group delay of any length of fiber, but is most attractive for relatively short delay lines (< 1 km). Well-characterized reference fiber delay lines find application in the calibration of distance measuring accuracy of very high-resolution optical time-domain reflectometers.

References

1. "Calibration of optical time-domain reflectometers," IEC TC86/WG4/SWG2. International Electrotechnical Commission, Geneva, Switzerland (1992), draft document.
2. A.H. Hartog, A.J. Conduit, and D.N. Payne, Opt. Quantum Electron. 11, 265-273 (1979).
3. A.J. Barlow, IEEE J. Lightwave Technol. LT-7, 1264-1269 (1989).
4. D.J. Albares, Technical Digest CLEO (1984), p. 98.
5. B. Edlen, Metrologia 2, 71-80 (1966).
6. International Organization for Standardization, Guide to the Expression of Uncertainty in Measurement, ISO TAG4, WG3, to be published (1993).
7. N. Lagakos, and J.A. Bucaro, Appl. Opt. 20, 3276-3278 (1981).

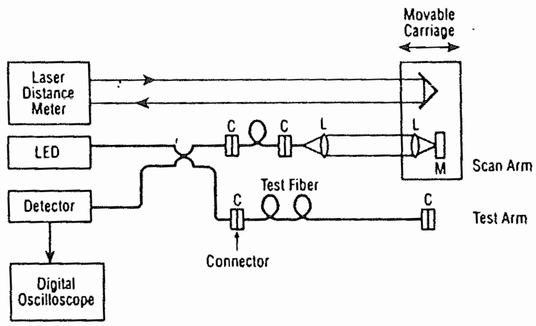


Figure 1. Block diagram of the low-coherence fiber interferometer.

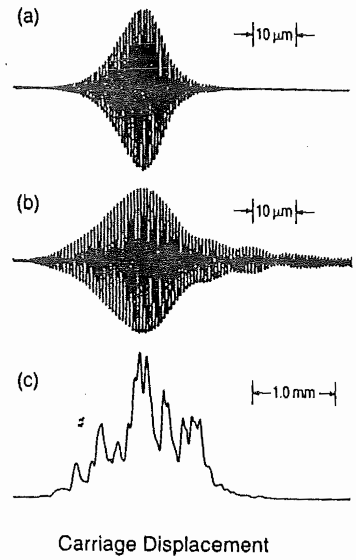


Figure 2. Experimental interferograms.
2(a) no sample.
2(b) 0.6 m test fiber.
2(c) 1.5 km test fiber.

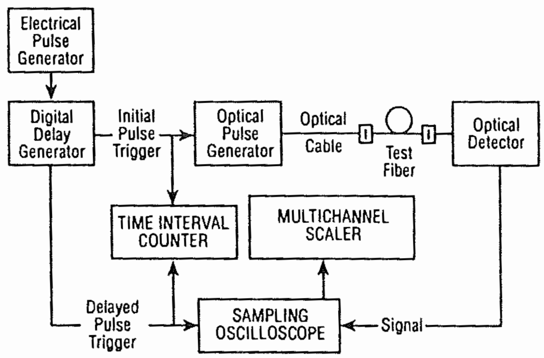


Figure 3. Block diagram, time-of-flight system.

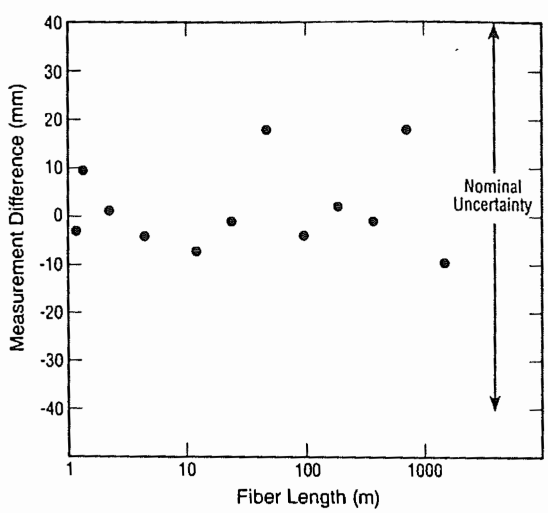


Figure 4. Difference in measured group delay values using two techniques.

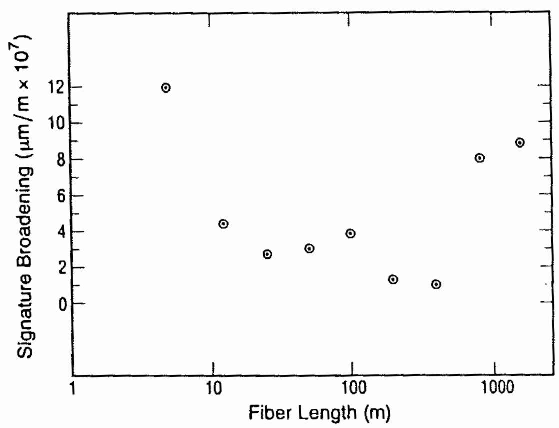


Figure 5. Typical values of observed signature broadening (FWHM).