decay time-constant exhibits the value of 0.41 ±0.05eV, in the temperature range 200–500°C. The decay time-constant at 15°C can be obtained by extrapolation as $\tau = (2.34 \pm 0.07) \times 10^7$ s or ~280 days. To confirm this value, we measured the decay process of the induced SHG at 15°C, and the result at 15°C was $(2.48 \pm 0.08) \times 10^7$s, in excellent agreement with the extrapolation.

In conclusion, we report quantitative decay measurements of SHG induced in a UV-poled GeO_2-SiO_2 glass. Single-exponential decays were observed in the temperature range 200–500°C. The activation energy of the induced SHG is 0.41 ±0.05eV, and the decay time-constant at 15°C is ~280 days.

Acknowlegments: The authors are grateful to K. Saito of Toyota Technological Institute for fruitful discussions. This work was partially supported by the Science Research Promotion Fund of the Japan Private School Promotion Foundation.

27 March 1997
Electronics Letters Online No: 19970622

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References

1 FUJIWARA, T., WONG, D., ZHAO, Y., FLEMING, S., POOLE, S., and SCEATS, M.: 'Electro-optic modulation in germanosilicate fibre with UV-excited poling', *Electron. Lett.*, 1995, **31**, (7), pp. 573–575

2 FUJIWARA, T., TAKAHASHI, M., and IKUSHIMA, A.J.: 'Second-harmonic generation in germanosilicate glass poled with UV-irradiation', submitted to *Appl. Phys. Lett.*, 1997

3 MYERS, R.A., MUKHERJEE, N., and BRUECK, S.R.J.: 'Large second-order nonlinearity in poled fused silica', *Opt. Lett.*, 1991, **16**, (22), pp. 1732–1734

4 KAZANSKY, P.G., DONG, L., and RUSSELL, P. ST. J.: 'High second-order nonlinearities in poled silicate fibres', *Opt. Lett.*, 1994, **19**, (10), pp. 701–703

5 FUJIWARA, T., WONG, D., ZHAO, Y., FLEMING, S., GRISHINA, V., and POOLE, S.: 'UV-excited poling and electrically tunable Bragg gratings in a germanosilicate fibre'. Tech. Dig. OFC, 1995, **PD-6**,

Error reduction of referenced intensity-based optical fibre sensor by adaptive noise canceller

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Indexing terms: Fibre optic sensors, Optical noise

A strategy for suppressing the perturbations of an intensity-based optical fibre sensor is presented by introducing an adaptive noise cancelling method. The time-varying offset between the sensing fibre arm and the reference fibre arm can be significantly reduced by the proposed strategy compared to direct subtraction. Experimental results are provided to demonstrate the performance of the perturbation suppression.

Introduction: Intensity-based optical fibre sensors, such as microbending structures, have been widely studied for their potential use in the detection of pressure signals. However, the sensitivity of the sensor suffers from optical attenuation and noise while the signals propagate through the components of the sensor system. The developed reference-based optical fibre sensor can minimise these noise factors through the cancellation of the common-mode variations [1]. However, the cancellation of analogue signals is highly susceptible to environmental conditions. The environmental perturbations cannot be eradicated from these optical fibre sensor systems due to fibre vibration, fibre temperature changes, light source fluctuations, mode volume variations caused by the selective coupling component, responsitivity variations of the photodetectors, and the mismatched characteristics between sensing path and reference path, etc. This will cause an output perturbation which is not easy to correct, unless we independently monitor the sensor temperature and add the correct offset to the output signal [2].

To design an accurate sensor system, the influence of environmental perturbations must be minimised as much as possible. The adaptive noise canceller (ANC) [4] is capable of performing satisfactory results without a complete knowledge of the relevant signal characteristics. In a nonstationary environment, the ANC is capable of tracking the time-variation data if the variations are slow; yet in a stationary environment, the adaptive filter in the ANC is capable of converging to the optimun Wiener solution in a statistical sense. In this Letter, an adaptive noise canceller is employed in a referenced intensity-based optical fibre sensor system to improve the performance of error reduction without information about the precise frequency of the interference added in the sensor. Experimental results are included to demonstrate the feasibility of the proposed strategy in the application of optical fibre sensors.

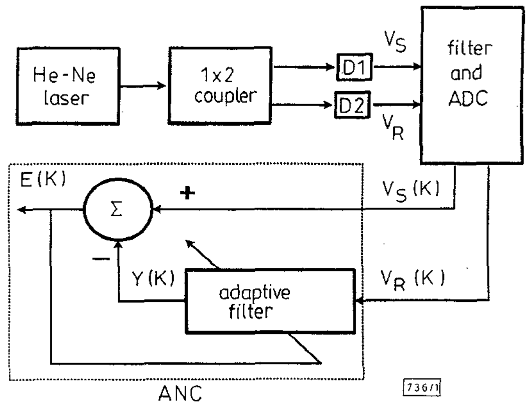

Fig. 1 *Schematic diagram of experimental sensor system*
D1, D2: photodetectors

Description of experimental sensor system: A schematic diagram of the system is depicted in Fig. 1. The light output from an He-Ne laser is divided into two by a 3dB 1×2 coupler and is then coupled into two multimode optical fibres: the sensing fibre arm and the reference fibre arm. The light output from these two fibres is converted into two electrical voltages, V_R and V_S, through the dual photodetectors (OPT 202 [3]); they are each filtered by the bandpass filter (0.001 Hz to 150Hz) and then digitised with a sampling rate of 400Hz. The voltage $V_R(k)$ should ideally be equal to $V_S(k)$.

The ANC is implemented by the LMS algorithm for its simplicity: it requires neither measurements of the pertinent correlation functions, nor matrix inversion. If the noise and signal in V_S are uncorrelated, and the noise in V_R is correlated with that in V_S, the tap weight is updated iteratively by the following equations:

$$Y(k) = \sum_{i=0}^{M-1} W_i(k) V_R(k-i)$$

$$E(k) = V_S(k) - Y(k)$$

$$W_i(k+1) = W_i(k) + \mu V_R(k-i) E(k) \quad i = 0, 1, ..., M-1$$

where W_i is the ith tap-weight, M is the total number of tap-weights in the adaptive filter, and μ is the step-size parameter. After proper filtering and subtraction, the noise in V_S can be suppressed significantly.

Experimental results: The fluctuation signals of the sensing fibre arm (V_S) and the reference fibre arm (V_R) are shown in Fig. 2. Both $V_S(k)$ and $V_R(k)$ have been normalised into the interval [–1, 1] with zero mean. A comparison of the error reduction between direct subtraction ($V_S(k)$–$V_R(k)$) and the ANC ($E(k)$) is shown in Fig. 3. The step-size μ = 0.01 and the tap-weight number M is chosen to be 30. It is evident that $E(k)$ is closer to zero for most time intervals and has smaller variations compared to the subtraction results of $V_S(K)$–$V_R(K)$. Thus, the time-varying error fluctuations of the optical fibre sensor can be well compensated for by the ANC. The experimental results demonstrate that the SNR of the intensity-based optical fibre sensor could be significantly improved by the ANC method.

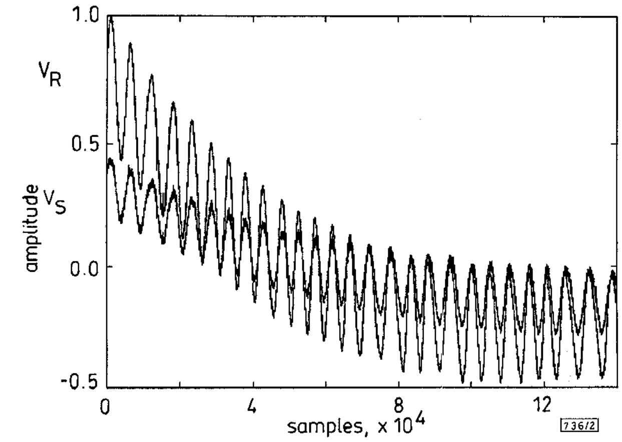

Fig. 2 *Fluctuation signals of sensing fibre arm and reference fibre arm*

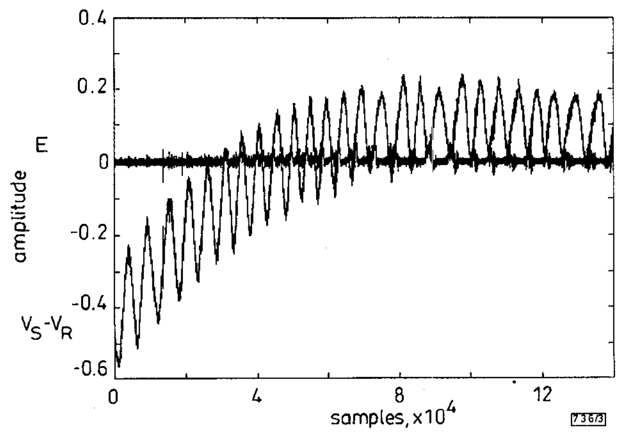

Fig. 3 *Comparison of error reduction between adaptive noise canceller (E) and direct subtraction (V_S-V_R)*

Conclusions: The error reduction of the referenced intensity-based optical fibre sensor is presented by introducing an adaptive noise cancelling method. The experimental results demonstrate the feasibility of the proposed strategy for applications of optical fibre sensors.

 24 March 1997
Electronics Letters Online No: 19970653

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References

1 MURTAZA, G., and SENIOR, J.M.: 'Referenced intensity-based optical fibre sensors', *Int. J. Optoelectron.*, 1994, **9**, pp. 339–348

2 BERTHOLD, J.W., GHERING, W.L., and VARSHNEYA, D.: 'Design and characterization of a high temperature fibre-optic pressure transducer', *J. Lightwave Technol.*, 1987, **5**, pp. 870–875

3 Burr-Brown IC Data Book, Linear Products, 1996/1997, p. 6.15

4 WIDROW, B., and STEARNS, S.D.: 'Adaptive signal processing', (Prentice-Hall, Englewood Cliffs, NJ, 1985)

Fibre dispersion or pulse spectrum measurement using a sampling oscilloscope

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Indexing terms: Optical fibre dispersion, Optical fibres, Optical modulation

A simple technique for measuring optical fibre dispersion (or pulse spectrum if fibre dispersion is known) is demonstrated. Ultra-short pulses are linearly dispersed in the fibre under test, thus mapping their spectrum to the time domain. The delay between two spikes in the dispersed pulse's temporal profile, corresponding to two spectral spikes, accurately gives the dispersion.

Introduction: The accurate measurement of optical fibre dispersion has recently attracted much renewed interest [1 – 3] owing to the need to accurately map out the fibre dispersion in long haul communication systems which use the silica fibre low loss window at a wavelength of ~1.55μm. Although many techniques have been developed [1 – 4] to measure optical fibre dispersion accurately, the new technique that we describe here offers the advantage of simplicity, and readily gives an accurate measure of the magnitude and sign of the dispersion in the wavelength range of interest for 1.55 μm optical communications.

Theory: The basic idea of the proposed technique is similar to the classic time of flight measurements [4]. However, our method does not need a monochromator to resolve the different spectral components of the pulse when measuring its time of flight. Instead, by using ultra-short pulses, the wavelength of the dispersed pulse will vary almost linearly with time, so that different spectral components of the pulse are automatically separated by their arrival times. The technique therefore simply involves passing low-power picosecond (or shorter) pulses, with a known broad optical spectrum, through a fibre with unknown dispersion and measuring the resultant temporal profile of the dispersed pulse. Provided the peak power of the pulses is low enough to ensure that dispersion is dominant over nonlinearities in the fibre under test, the output pulse profile will be purely dispersed, and if the input pulse is sufficiently short, the temporal profile of the dispersed pulse will trace out the input pulse spectrum. A point in the temporal profile at a time delay $\Delta\tau$ measured from an arbitrary reference point (e.g. the central peak), is mapped from a point that is $\Delta\lambda$ from the corresponding reference point (e.g. the central peak wavelength) in the spectrum and, to first order, $\Delta\tau = DL\Delta\lambda$ where L is the fibre length and D is the average dispersion of the fibre. Thus, a measurement of the time profile of the dispersed pulse and a measurement of the input optical spectrum will directly and accurately give both the sign and magnitude of the dispersion parameter D. A figure eight mode-locked erbium fibre laser [5] provides a very convenient and appropriate source of ultra-short pulses for measurements in the 1.55μm wavelength band, since its spectrum has a number of sharp side-bands (spikes), which can be used as accurate reference points for measurement of $\Delta\lambda$ and $\Delta\tau$. Alternatively, if fibre dispersion is known, the same setup is a convenient way of obtaining the relative spectral profile of ultrashort pulses using a sampling oscilloscope (offering the unique ability of resolving only the pulsed component of a spectrum which contains both pulse and CW components).

Experiment: The experiment setup is shown in Fig. 1. The ultrashort pulse source was a diode pumped erbium fibre laser, mode-locked using the figure eight configuration [5]. Fig. 2*a* shows the autocorrelation trace of the pulses from the erbium fibre laser. The autocorrelation trace has a full-width-half-maximum (FWHM) pulsewidth of 1.1ps (yielding a FWHM pulse width of 720fs, assuming a hyperbolic secant pulse profile). The input pulse profile, Fig. 2*b*, measured using a 25GHz photodiode and a 40GHz sampling oscilloscope, showed that the measurement system had a bandwidth-limited response of 16.5ps FWHM pulsewidth. A 10%:90% coupler was used to split the optical power into two portions: 90% of the power was sent to the fibre under test, while the remaining 10% was used to trigger the sampling oscilloscope. The dispersed pulses from the fibre under test