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TIME-DIVISION MULTIPLEXING OF FIBRE OPTIC INTERFEROMETRIC SENSORS USING A FREQUENCY MODULATED LASER DIODE

Indexing terms: Optical fibres, Optical sensors, Lasers and laser applications, Interferometers

A multiplexed sensing system based on a frequency modulated laser diode is demonstrated, where a time addressing technique is used to identify signals from different interferometers. It is shown that sensor interferometers with the same path differences can be deployed in the system and crosstalk between different interferometers is avoidable.

Recently three methods for multiplexing sensor arrays have been discussed. Coherence multiplexing of the fibre interferometric sensors has been realised using a short coherence length source with an array of interferometers in the receiver.[1] The receiving interferometers are paired with sensing interferometers; therefore interference occurs for each matched pair. A frequency division technique has been used for a system made up of unbalanced interferometers where the path imbalances are different and are restricted by certain constraints.[2,3] Consequently a heterodyne carrier is created for each interferometer. Time division multiplexing of fibre sensors has also been discussed for both multimode fibre sensing systems[4] and single-mode hydrophone arrays.[5]

In this letter we present a time-domain addressing scheme based on a linearly modulated laser diode with a gated sawtooth current. Delay lines between the fibre interferometers can be deployed to generate time delays (at least) corresponding to the time duration of the ramp applied to the laser. Fig. 1 shows schematically a multiplexed system based on this time-division technique using a frequency modulated laser diode. Each oval symbol represents the interference fringes corresponding to a specific interferometer which depend on the path imbalance in that interferometer and also the change in frequency of the laser when the injected current is linearly modulated. The photodiode output can be gated such that all the independent interferometric outputs are separated. For a change $\Delta\nu$ in the frequency of the laser the phase of an interferometer changes as

$$\Delta\phi = Kl\,\Delta\nu$$

where $K = 2n\pi/C$ (or $4n\pi/C$ in reflective configuration), l is the path imbalance of the interferometer and n is the effective refractive index of the fibre.

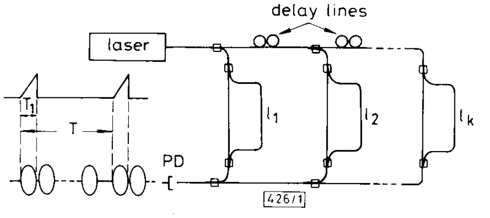

Fig. 1 *Schematic of a parallel configuration for a time division multiplexed sensing system when the laser injection current is modulated with a gated ramp*

PD, photodiode

A phase modulation $\Delta\phi$ of $2m\pi$ is required to give a carrier output without amplitude modulation,[6] where m is an integer. For the proposed sensor arrays this imposes the condition

$$\frac{l_k}{l_{min}} = k$$

where l_k is the path imbalance of the kth interferometer and l_{min} is the minimum path imbalance in the system. Because demultiplexing is achieved in the time domain, it is clear that no mutual constraint between the interferometers is required; i.e. sensors with exactly the same path imbalances can be deployed in a system. This is an advantage over previously presented coherence multiplexed localised sensors with approximately equal lengths[7] and also frequency division based multiplexed systems.[8] One further condition to be satisfied is that

$$T_1 \leq \Delta T \leq T$$

where T is the time between two successive ramps, ΔT is the maximum time delay between any two interferometers and T_1 is the period of the applied ramp. This condition limits the maximum number of sensors which can be time division multiplexed to

$$N = T/T_1$$

In our experiment two Mach–Zehnder interferometers with path imbalances of approximately 15 and 30 cm with a delay line of 1 km were used (Fig. 2). The effective time delay is nL/C which corresponds to 5 μs, where L is the length of the delay fibre. This requires a maximum ramp time of 5 μs. We gated the saw-tooth waveform with an 'on time' of 5 μs (Fig. 3*a*) and adjusted the amplitude of modulation to drive the interferometers over one and two periods of their transfer functions. The multiplexed output with the two successive interferometer

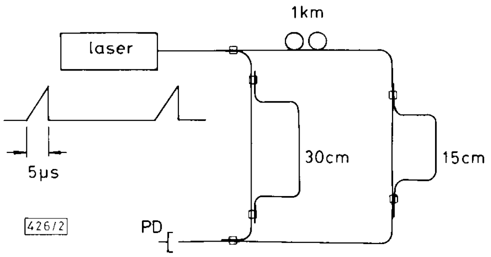

Fig. 2 *Experimental arrangement for two all fibre Mach–Zehnder interferometers*

outputs corresponding to a single applied ramp is shown in Fig. 3*b*. The output was gated twice such that the outputs of the individual interferometers were separated (Figs. 3*c*, *d*). It is clear that by bandpass filtering each output a pseudo-heterodyne carrier is created, so that the phase information of each interferometer can be recovered. Alternatively the laser injection current can be modulated by a gated sinusoidal waveform; then the method described by Lewin *et al.*[9] may be used to generate the pseudo-heterodyne carriers.

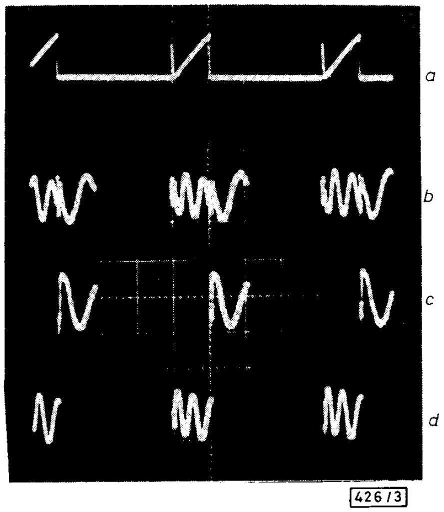

Fig. 3 *The signals in the time domain*

a Laser injection current
b Photodiode output
c Gated photodiode output corresponding to first interferometer
d Gated photodiode output corresponding to second interferometer
x axis; 5 μs/division

A new technique in multiplexing all-fibre interferometric sensors has been described. Two interferometers were used in a system where the laser injection current was modulated by a gated saw-tooth and consequently the output was demultiplexed in the time domain. The resultant demultiplexed outputs were thus two independent pseudo-heterodyne carriers.

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TWO YEAR REFRACTIVITY STATISTICS FOR MERSA MATRUH, EGYPT

Indexing terms: Tropospheric propagation, Refraction, Atmospheric propagation

Surface refractivity and refractivity gradient statistics are presented for Mersa Matruh, Egypt. Seasonal, monthly and day and night variations are investigated. The results indicate that this region suffers from nonstandard propagation conditions, even during daytime, particularly in summer months.

Introduction: In the lower troposphere, the trajectories of electromagnetic waves are influenced by the atmospheric refractive index, n, and its variations. A semi-empirical formula relating n to the total atmospheric pressure p (mbar), the temperature T (K) and the partial water vapour pressure e (mbar) is given by

$$\begin{aligned} N &= (n - 1) \times 10^6 \\ &= 77{\cdot}6p/T + 3{\cdot}73 \times 10^5 e/T^2 \qquad N\text{-units} \quad (1) \end{aligned}$$

where N is termed the refractivity. The right hand side of eqn. 1 is divided into two terms: the dry term ($DT = 77{\cdot}6p/T$) and the wet term ($WT = 3{\cdot}73 \times 10^5 e/T^2$). In hot and humid coastal areas, large variations in the WT cause both temporal and spatial fluctuations in the refractivity. Mersa Matruh is a good example of such areas. It is bounded from the south by the desert and from the north by the Mediterranean Sea.

Our study of the refractivity in this region is based on radiosonde data gathered by a weather station for a period of two years from August 1980 until August 1982, with the data of August 1981 missing. A total of 722 midday and 715 midnight balloon ascents are investigated combined and separately, in order to emphasise the presence of abnormal propagation conditions at midday.

Numerical results: Inspection of the refractivity profiles shows the presence of inversion layers and subrefraction conditions, even during the day time, particularly in the summer months.

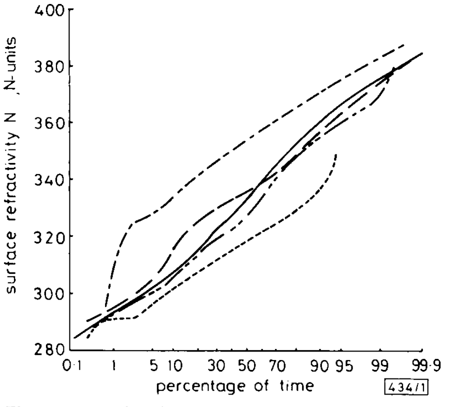

Fig. 1 *Seasonal and yearly cumulative distributions of the surface refractivity* N_s

– – – – winter
—   — spring
— – — summer
—---— autumn
——— yearly distribution