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Technical Memorandum

REMOTE PASSIVE PHASE SENSOR

Date: 1 March 1985

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14. ABSTRACT

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ABSTRACT

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ADMINISTRATIVE INFORMATION

This technical memorandum documents a presentation to the Third International Conference on Optical Fiber Sensors, OFS '85 San Diego, CA, Feb. 13-14, 1985. A short summary is published in the proceedings of that conference. This work was supported by the NUSC Independent Exploratory Development Program, Project No. B-50031, Task Area ZF66112001, Program Element 62766N, Sponsoring Activity, NAVMAT 05D, Principal Investigator, E.L. Green, Code 3321.

We wish to measure modulation of the phase of light in one or more single mode fiber sensors. These sensors are deployed remotely by means of optical fiber leads; apart from the light which they modulate, they are unpowered and passive. In the past, we have considered several approaches to remote deployment of Mach-Zehnder (two-path) interferometers. We shall now discuss an extension of two-path interferometry, that is adaptable to serial multiplexing of significant numbers of remote phase sensors, and present some preliminary laboratory results. The new approach has the particular advantages that only fiber sensor elements are remotely deployed, not the reference elements, and that stabilization-demodulation techniques, that were previously developed for Mach-Zehnder interferometry, are applicable. (ref 1, ref 2)

SLIDE 1

This is our preferred approach to a remotely deployed fiber phase sensor. Light is transmitted by a single mode fiber lead, that is butt-coupled to the sensor. The fiber sensor is coated at its junction to the fiber lead to partially reflect incident light; its termination may be fully reflecting. The initial mutual coherence of the two reflected beams of light re-entering the fiber lead is low; a time delay is introduced between the beams by the double pass through the sensor. Light from the phase sensor is returned by means of the fiber lead through a 3 dB junction to an interferometer, the two paths of which are made unequal in length, so that the path difference compensates the time delay between the two back-reflected beams. Although the remote sensor is a Fabry-Perot configuration, the compensator is of Mach-Zehnder form. This arrangement facilitates the recombination of two beams from the remote sensor so as to create the equivalent of one extended equal path two-beam interferometer. The light source either is continuous of low intrinsic coherence length or is pulsed. In the latter case, the pulse length must be less than the path difference between the two beams returned from the interferometer. For each pulse transmission the initially received return pulse from the partial reflector via the short compensator path provides an intensity reference to light that enters the sensor element. The second received pulse is the coherent summation of the two reflected beams. A third intensity pulse is received from the full reflector via the long compensation path. Either feedback-homodyne or heterodyne detection is possible.

SLIDE 2

The basic interferometric technique that utilizes a compensating Mach-Zehnder interferometer in conjunction with a remote sensor element can be applied in various ways. This is a diagram of an alternative that we implemented with discrete optical components in our initial exploration of the compensating interferometer. Linearly polarized light was obtained from an He-Ne laser operating at .63 um. By polarization means we achieve low mutual coherence and efficient recombination of reflected beams from the continuous light source. The path difference between reflections from partially and totally reflecting mirrors of the remote cavity was 4 meters; orthogonally polarized beams from initial and terminating reflectors of the remote cavity (that incorporates a quarter-wave plate) are directed by a polarizing beam splitter respectively to long and short paths of the compensator. A half-wave plate in the long path restores a common polarization to the beams prior to detection. Signals from the remote cavity were observed by means of a spectrum analyzer in DC to 1000 Hz. The typical threshold system noise level was -100 dB/$\sqrt{Hz}$ (10^{-5} radian). Implementation in fibers would require maintenance of the two orthogonal polarization modes.

SLIDE 3

This is the diagram of an all fiber remote cavity implementation that we now are investigating in the laboratory. The light source is, a He-Ne laser. The fiber is a single mode at .63 μm, with 4 μm core diameter and .12 numerical aperture. The length, L_1, of the fiber sensor is 50 meters. The light detector is an RCA APD. A low frequency feedback signal may be applied to the second PZT in the compensator to stabilize the interferometer in quadrature. In our initial laboratory study of the basic interferometer - compensator phenomenon, the partial reflecting junction was replaced by a 3 dB coupler, and the end of the fiber lead was silver coated to create a Michelson configuration. The path difference between front and rear mirrors remains 50 meters.

SLIDE 4

This is an oscilloscope display of the three discrete pulses returned from the remote sensor to the light detector via the compensating interferometer. The time scale is 200 ns/div. It is a direct output, bypassing the boxcar. The 100 ns pulses are separated by 500 ns (transit time through 100 meters of fiber). The outer pulses are returns from front and back reflectors of the remote sensor. The middle fuzzy pulse, a time average over one second, shows interference between pulses from front and back reflectors.

SLIDE 5

The time scale here is increased to 250 ns/div. The pulse width now is 500 ns, closing the gap between the three received pulses. Again notice the blurred second pulse, showing interference between the two reflected beams.

SLIDE 6

The time scale here is 500 ns/div. The pulse length (approximately 700 ns) now is greater than the time delay in the sensor or in the compensator. Consequently we observe the following complex interference phenomenon comprised of interference of each reflected pulse with itself through the two paths of the compensator, and cross interference of the two reflected pulses from the sensor, as in the previous displays. Proceeding from the left we have the intensity of the pulse from the first reflection via the short path in the compensator. We then have (narrow fuzzy peak) the superposition of the first pulse via the short compensator path, the first pulse via the long compensator path, and the pulse from the second reflection via the short compensator path. In the center we have, as before, interference of the first pulse via long path and second pulse via short path. We then have another narrow fuzzy peak, the superposition of first pulse via long path, second pulse via short path, and second pulse via long path. On the right is the intensity of the second pulse transmitted through the compensator via the long path.

SLIDE 7

The time scale is now 500 nsec/div. The pulse width is just less than 500 nsec. The interval between pulses is 1500 nsec.

SLIDE 8

This is a spectrum analyzer display of a .5 radian, 400 Hz, signal. No stabilization was applied. Noise level was in the 10^{-3} to 10^{-4} radian range. Signal/Noise ratio was limited by available light in this preliminary work.

SLIDE 9

We show here the application of the compensating interferometer to a serial array of fiber phase sensors. The phase modulation attributable to the interval between successive junctions is measured. The reflection of pulses from the initial junction, Jo, provides a reference to intensity modulation by the lead (assuming a stable light source). The function of the electronic box labeled "demodulate" is to provide serial-to-parallel switching, averaging over several pulses, and demodulation by the heterodyne means.

Dakin and his coworkers at Plessey have demonstrated such an array of sensors accessed by two mutually coherent pulses. (ref 3) The proposed technique should be much less sensitive to phase noise of the laser, since the two beams of the interferometer are matched in optical path length. We learned after submitting the summary of this paper that they suggested a technique of compensation similar to ours at the Stuttgart meeting last September, (ref. 4) as an improvement over their original double pulse device; however, they did not have laboratory results.

SLIDE 10

The sensor architecture may consist alternatively of discrete sensors, with time delay differentials between sensors provided by progressively increasing lengths of fiber leads from the sensor to a junction; at the junction the discrete leads connect to one fiber, into which signals are serially multiplexed. Both serial and parallel configurations, in principle, may be implemented either with broadband continuous source or with a pulsed source. By dichroic filtering within the sensor arrays, multiplexing by wavelength of light rather than by time could be achieved. Separation into parallel channels would be done after time delay compensation, and before light detection.

SLIDE 11

We have described a versatile technique, time delay compensation, for measuring phase modulation in remote phase sensors, and have discussed our prelimenary laboratory investigation. The light source may be continuous or pulsed. The sensors may be acoustic, static pressure, temperature, magnetic, or combinations of these, all operated from one central location. Potentially, large numbers of phase sensors, powered from one or more light sources may be accessed serially and/or by multiple parallel leads.

References

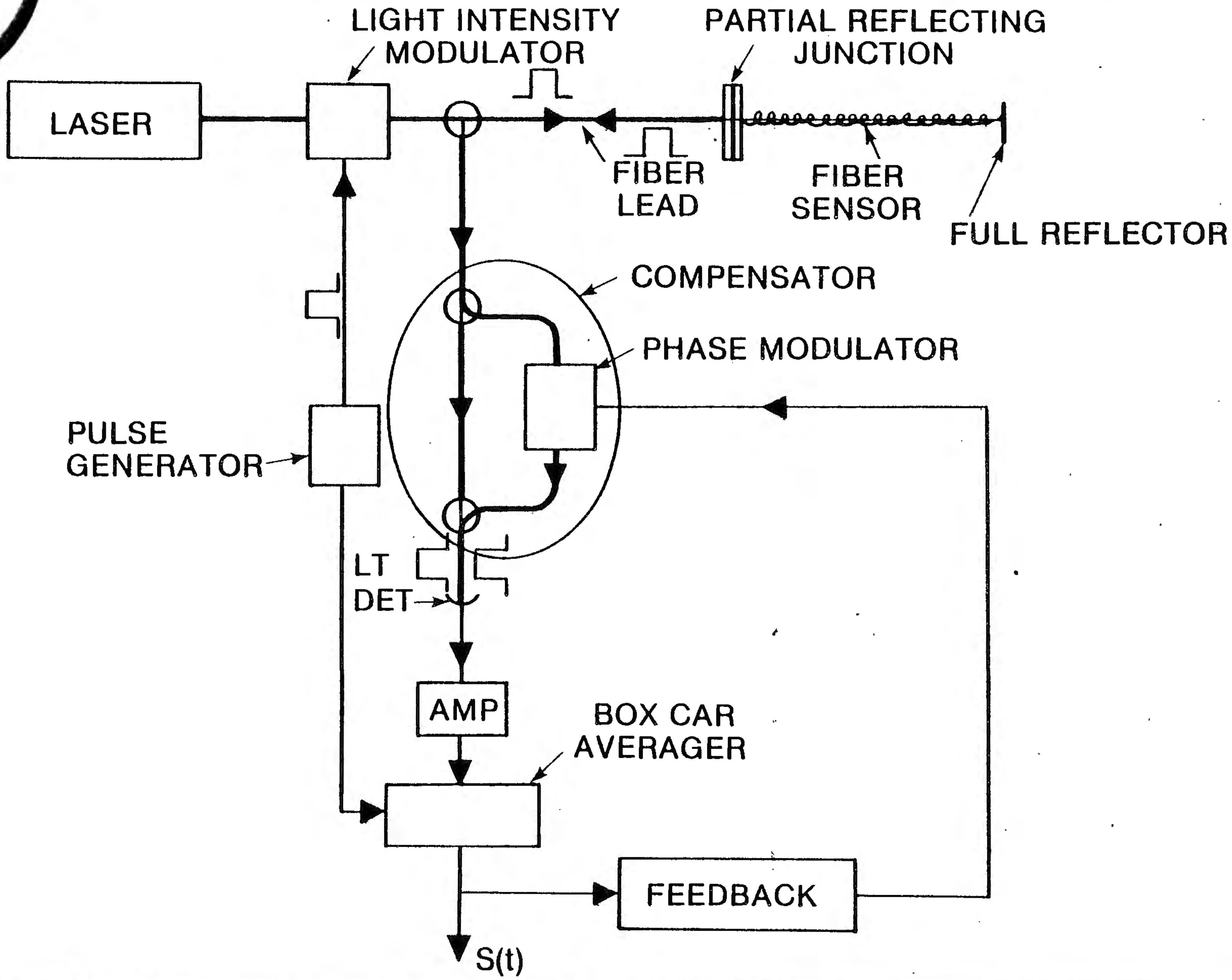
(1) E.L. Green and P.G. Cable, "Passive Demodulation of Optical Interferometric Sensors", IEEE Journal of Quantum Electronics, Vol. QE-18, 1982, pp 1639-1644.

(2) A. Dandridge, A.B. Tveten, and T.G. Giallorenzi, "Homodyne Demodulation Scheme for Fiber Optic Sensors Using Phase Generated Carrier", IEEE Journal of Quantum Electronics, Vol. QE-18, 1982, pp 1647-1653.

(3) J.P. Dakin, C.A. Wade, and M. Henning, "Novel Optical Fibre Hydrophone Array Using a Single Laser Source and Detector", Electronics Letters, Vol. 20, 1984, pp 53-54.

(4) J.P. Dakin, C.A. Wade, "Optical Fibre Hydrophone Array - Recent Progress", Proceedings, Second International Conference on Fiber Optic Sensors, OFS '84, Stuttgart, FRG, Sept. 1984.

REMOTE PASSIVE PHASE SENSOR



LIGHT INTENSITY MODULATOR

PARTIAL REFLECTING JUNCTION

LASER

FIBER LEAD

FIBER SENSOR

FULL REFLECTOR

COMPENSATOR

PHASE MODULATOR

PULSE GENERATOR

LT DET

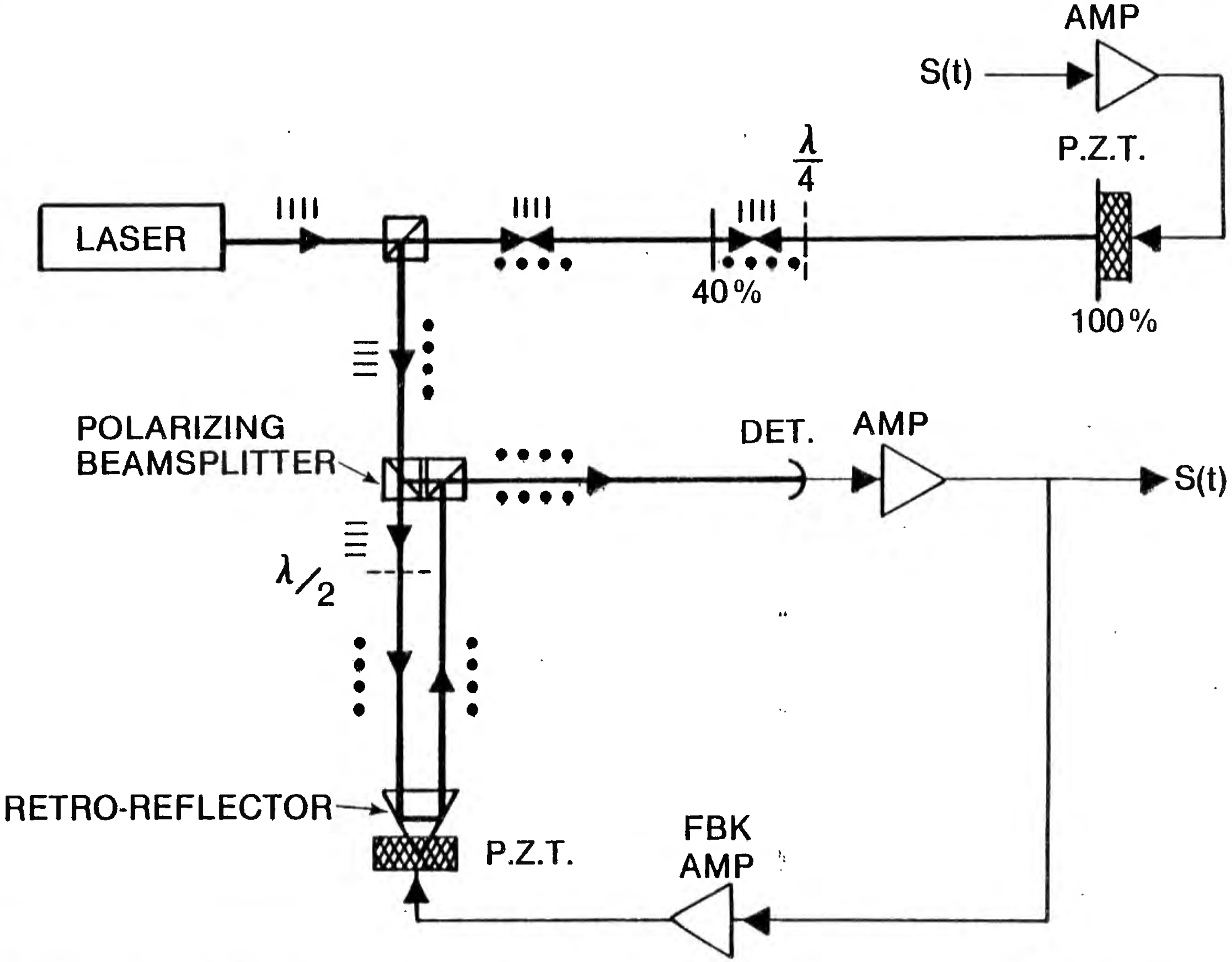
AMP

BOX CAR AVERAGER

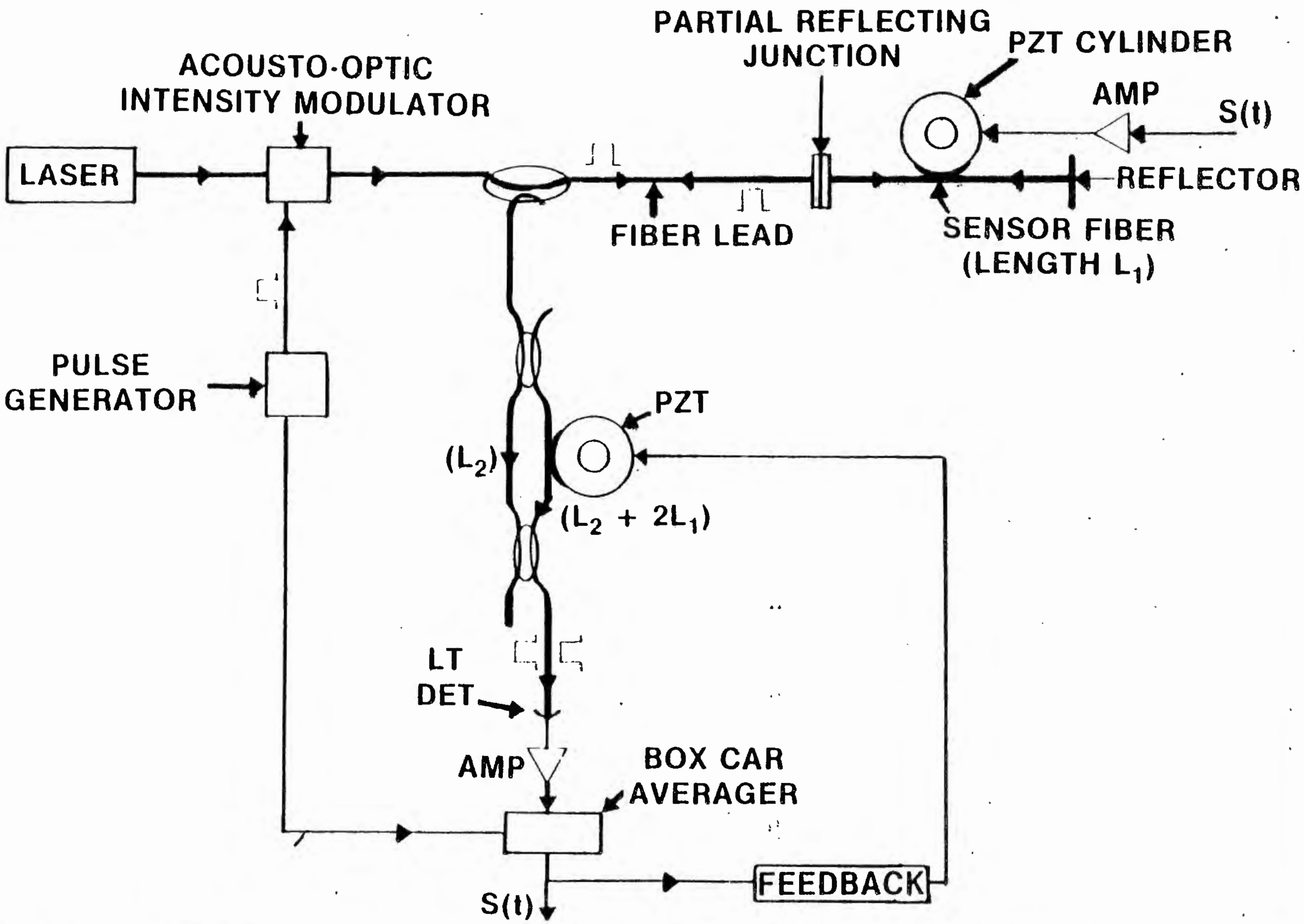
FEEDBACK

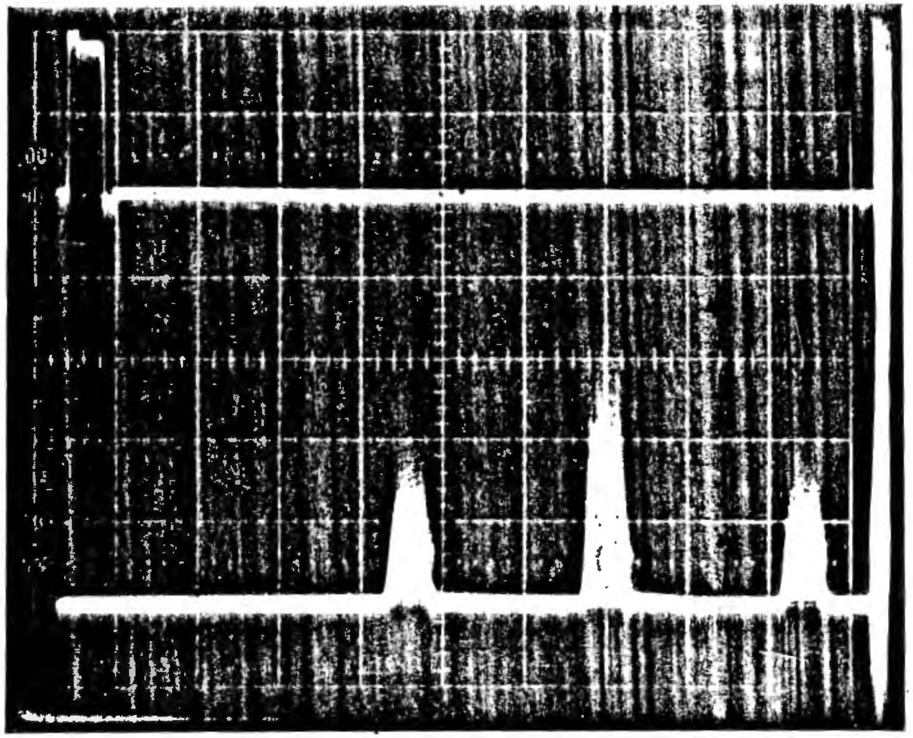
S(t)

REMOTE CAVITY INTERFEROMETER

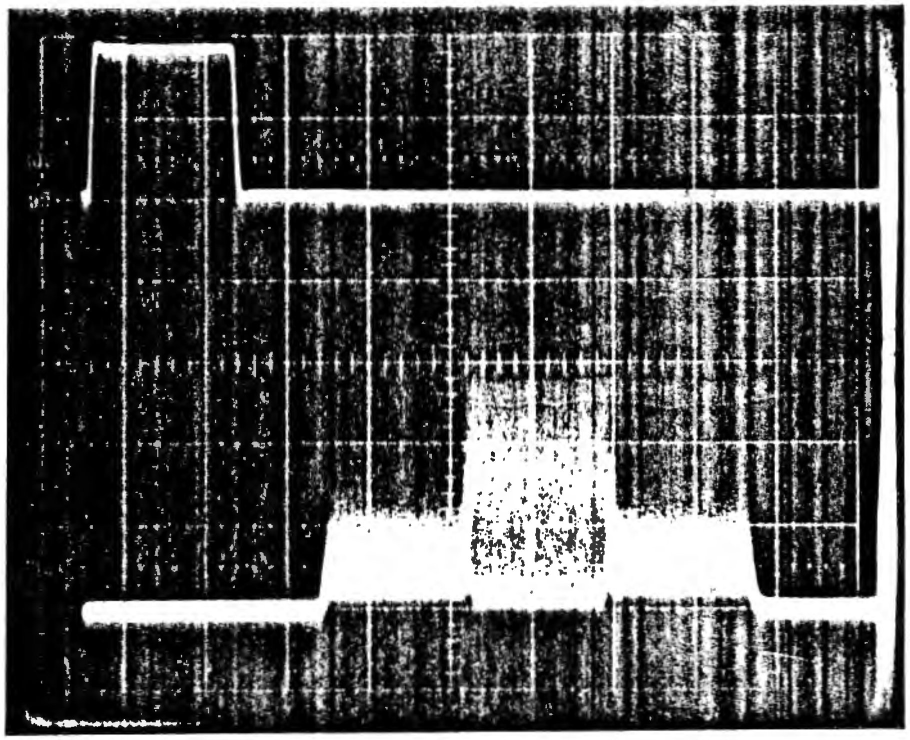


ALL FIBER REMOTE CAVITY

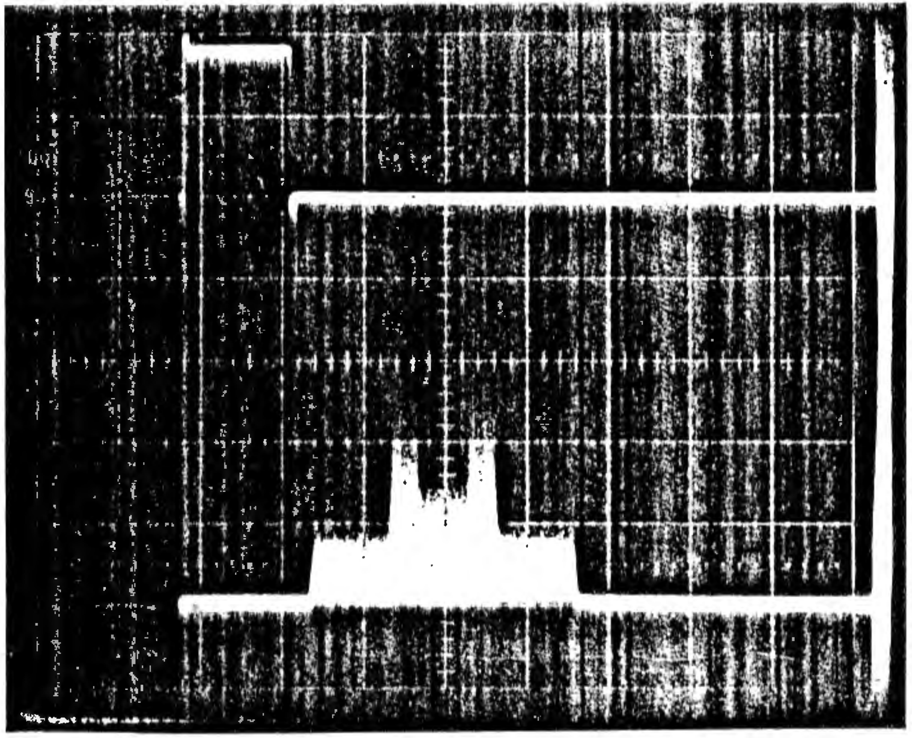




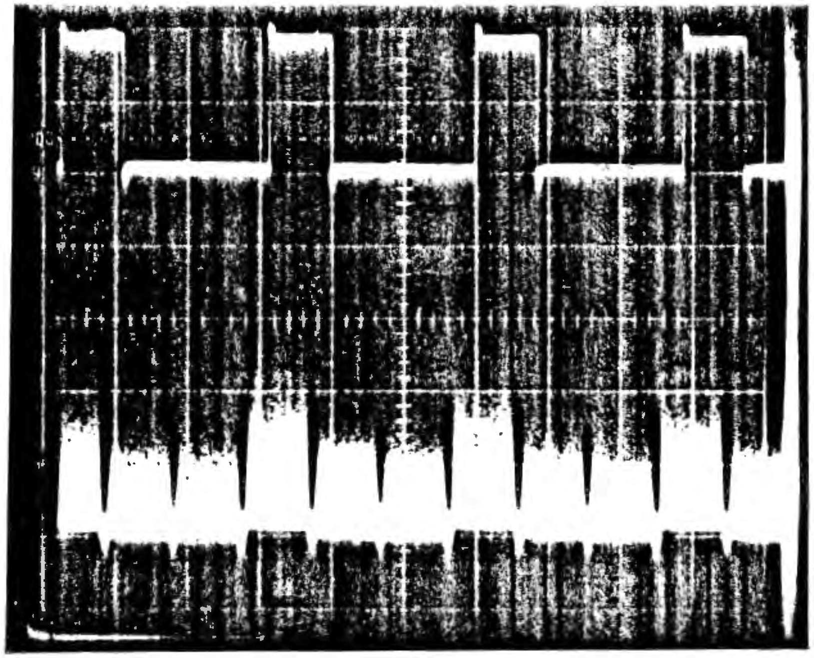
PULSE WIDTH: 100 ns (200 ns/div)



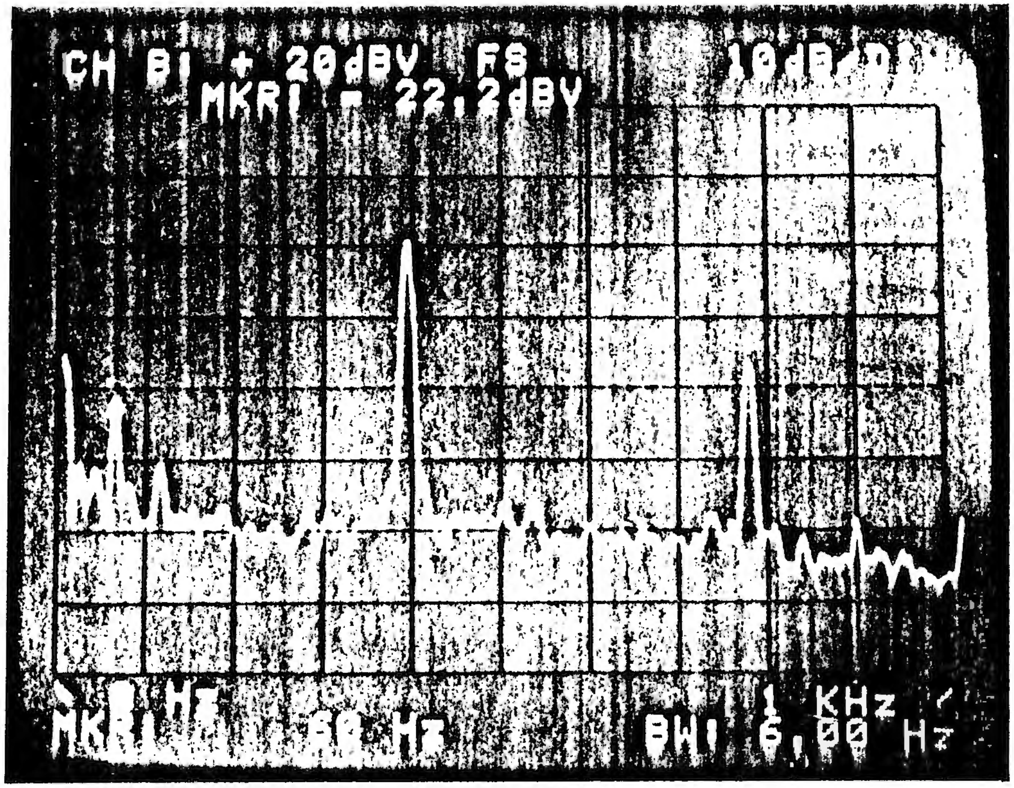
PULSE WIDTH: 500 ns (250 ns/div)



PULSE WIDTH: 700 ns (500 ns/div)

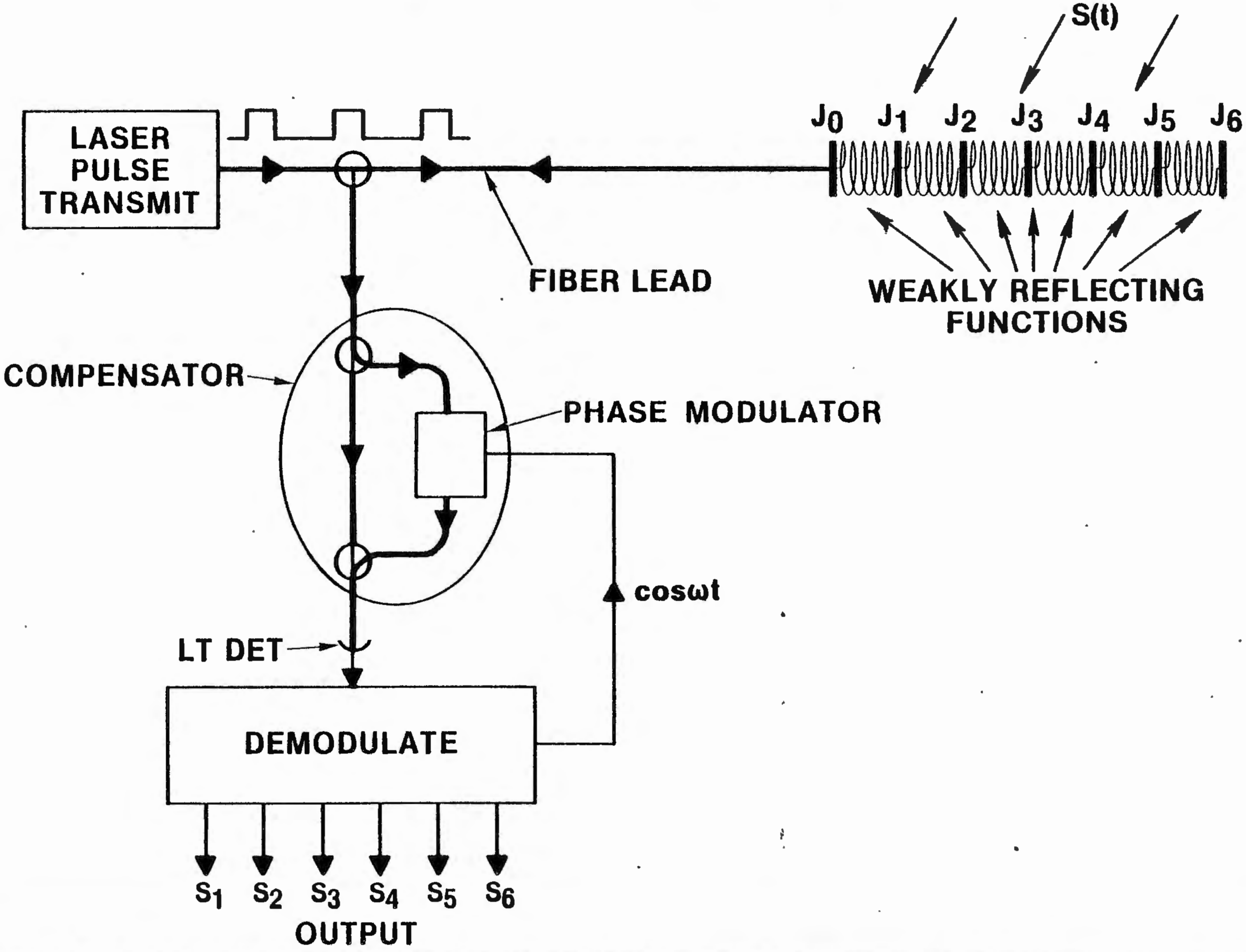


PULSE WIDTH: 500 ns (500 ns/div)



400 Hz SIGNAL

SERIAL SENSOR CONFIGURATION



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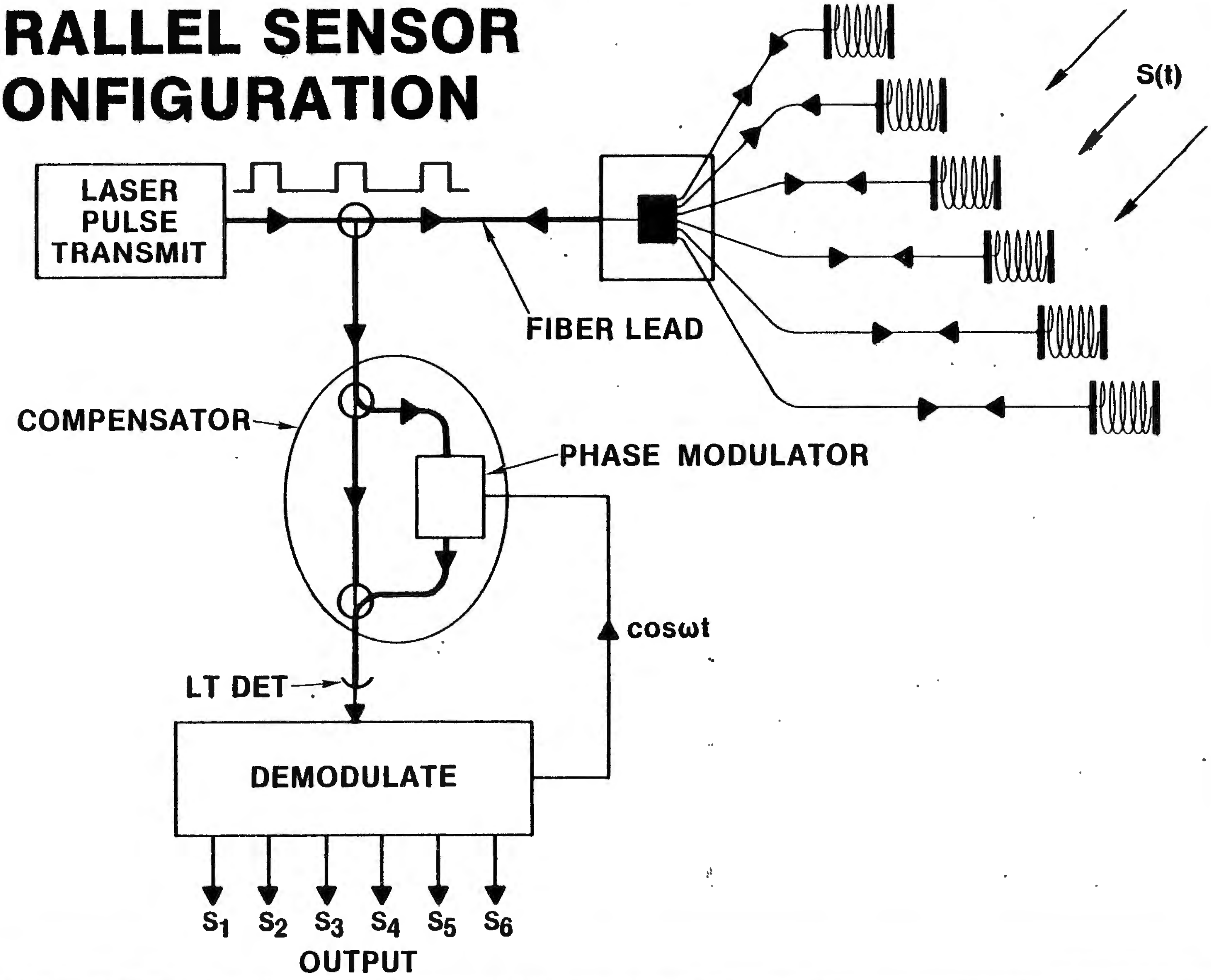
PARALLEL SENSOR CONFIGURATION



LASER PULSE TRANSMIT

FIBER LEAD

S(t)

COMPENSATOR

PHASE MODULATOR

cosωt

LT DET

DEMODULATE

S_1 S_2 S_3 S_4 S_5 S_6

OUTPUT

FEATURES OF THE COMPENSATOR TECHNIQUE

1. CENTRAL LOCATION OF ELECTRONICS
2. ALL DIELECTRIC CABLING AND SENSORS
3. SERIAL AND/OR PARALLEL SENSOR CONFIGURATIONS
4. PULSED OR CONTINUOUS LIGHT SOURCES

REMOTE PASSIVE PHASE SENSOR
E. L. Green
Code 3321
TM No. 841096
June 1984
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