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Optical Remote Measurement Using Loop-Mirror Sensing Fibers

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ABSTRACT The use of a fused-tapered single mode optical fiber known as loop-mirrors for remote measurement device was investigated. The optical field is input into a delivery fiber then traveling into the tapered region of the sensing device and evanescent into the air-glass boundary region which affects the optical coupling power. In applications, loop mirrors device was fabricated and connected to the one end of the sensor system, where the reflected coupling power was detected by using the optical time domain reflectometer (OTDR). The relationship between the change of the reflected output power may be related to the change of the surrounding environmental parameters. Results obtained have shown the relatively change between the reflected output power and the environmental or external surrounding environments which can be tested and detected. The constructed device characteristics have shown the feasibility of using incorporating with the remote measurement system.

KEYWORDS: laser applications, remote sensor, fiber optic sensor.

INTRODUCTION

Fiber optic sensors have become the popular subject in the field of the optical sensor technology.[1] The advantages of such devices are small size, light weight, good sensitivity and widely used for sensor applications. The use of fused single mode fiber couplers both in theory and experiment for sensor applications was investigated.[2-5] Results have shown the implication of using such devices for optical sensing applications. The study of a single mode tapered fiber characteristics was reported by Ref [6] and Ref [7], where the device output coupling power was satisfactorily closed to the theoretical prediction. Such a device was also investigated by [8], where the device was connected into the optical system using loop mirrors. The reflected light was detected by using the OTDR, where the measurement was performed. The constructed tapered single mode fiber was employed in this work by connecting to one end of the delivery fiber in the sensor system. The device characteristics in term of coupling power were investigated, and the use of the device for sensor applications was discussed. The use of such a system for remote sensing and network sensors were also investigated and discussed. Results have shown the potential of using such a system for fiber optic remote measurement extending to a loop for networking sensors.

OPERATING PRINCIPLES

The tapered fiber drawing unit is used to draw the loop mirror as shown in Fig 1, the splitting ratio of coupling power was relatively controlled by the device soft zone length.[9] The comparison data between numerical results and fabricated data was demonstrated with less than 10 percent difference. In next section, the use of fabricated loop-mirrors is employed and investigated for remote sensing applications. The different surrounding material environment or refractive indices is employed to the air-glass boundary region, to implement the sensor system for remote measurement scheme.

When light from source *ie* He Ne laser enters into each sensing element, then the coupled light from one port of the sensing fibers is transmitted, the other is reflected into the launching source. The reflected light beam is used for the require measurement interpretation, the reflected optical output power, P_r, is expressed as[6]

$$P_r = \sin^2[2\int_0^z c(z)dz] \quad (1)$$

The coupling coefficient from equation (1) is given as

$$C(z) = 3.26\, \delta^{1/2}/a(z)[V(z)]^{5/2} \quad (2)$$
$$V(z) = a(z)\, k\, (n_1^2-n_2^2)^{1/2} \quad (3)$$
$$\delta = 1-(n_2/n_1)^2 \quad (4)$$

and $k = 2\pi/\lambda$

where a is the coupling fiber radius, n_1 and n_2 are core and cladding refractive indices of the coupling fibers, respectively. λ is light source wavelength.

Experiment Set-Up and Results

A slowly varying composite waveguide was constructed as a single or a series of sensing devices, using single mode fiber as shown in Fig 1 and 2 (a). Light from a linearly polarized single mode HeNe laser with wavelength of 632.8 nm was launched into an input port of the fiber into one end of a tapered single mode fiber, then both of the output ends were connected to the light detectors. The principles of the sensor system is that the coupling light at the sensing device is occurred due to the change of the surrounding environment. The relationship between the change of the environmental parameters and the detected output intensity of the reflected light is observed by using OTDR. The measurement technique is that when change of light from the OTDR source enters into the sensor system then the optical power is transmitted and reflected into the OTDR receiver. When the sensing environment is changed, the change of the reflected light intensity is occurred and detected, the light intensity may be relatively changed by the coupling power, i.e. coupling fiber length.

Fig 2(a) shows the sensing element as a series configurations. Where a series of sensing devices may be connected to employ for the case of multiplexed sensors. Each sensing fiber is located 60 meters and 10 kilometers away from each other respectively, the input light is launched into one fiber end. Generally, the coupling light at the tapered region is reflected to OTDR relatively to the change of tapered length or refractive index, resulting the change of optical peak power intensity. The change of peak power intensity varies with the change of the surrounding refractive index due to the surrounding environment such as air and water pollution, which means measurement. Fig. 2(b) shows the remote measurement system employed with the sensing device control and signal detection part. Where light from OTDR was launched into the sensing system, the reflected light was detected and analyses. The use of the surrounding material such as water, alcohol and glycerin were used at the device tapered region to implement the measurement.

Fig 3 shows the schematic diagram of the experimental system, using a loop-mirrors as a sensing element. HeNe laser was used to make initial alignment for the sensing device fabrication unit, the device was drawn and controlled to obtain the required coupling length. The sensing device was connected to a 1-km delivery fiber. Light from OTDR *eg* laser diode (LD) or light emitting diode (LED) was launched into a sensor system, then coupled into taper region and reflected back to the OTDR receiver then displayed on the screen. The magnitude of the peak power intensity was measured related to the change of the surrounding refractive indices. The reflected power was shown as a loop or periodic signals according to the coupling power obtained from the loop of the traveling signal entering into a loop-mirror, which was observed on OTDR screen and printed out.

Discussion

Fig 4 shows graphs of the results obtaining from the returned/reflected signals form the sensor system using loop-mirrors with difference refractive indices, where the vertical and the horizontal lines represented the detected optical peak power and

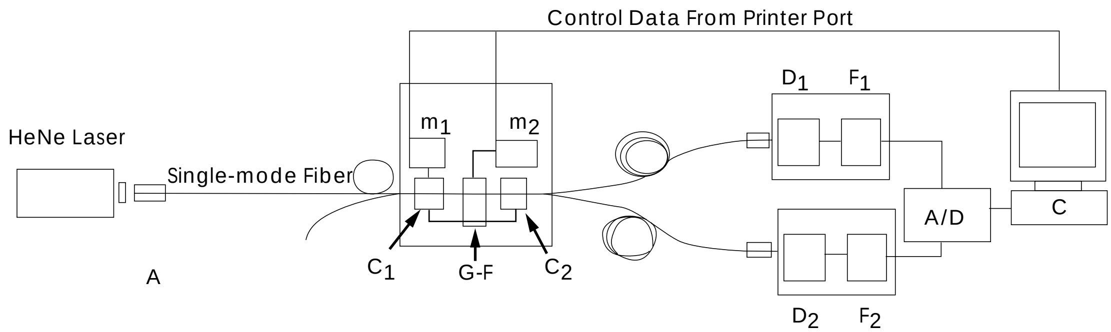


Fig 1. Illustrates diagram of a fabricated sensing element using in the sensor system. A: Launching Unit, ms : Motors, Ds: Detectors, Fs: Filters, Cs : Control Unit, C : Computer, A/D : Analog to Digital Converter, G-F : Heat Source.

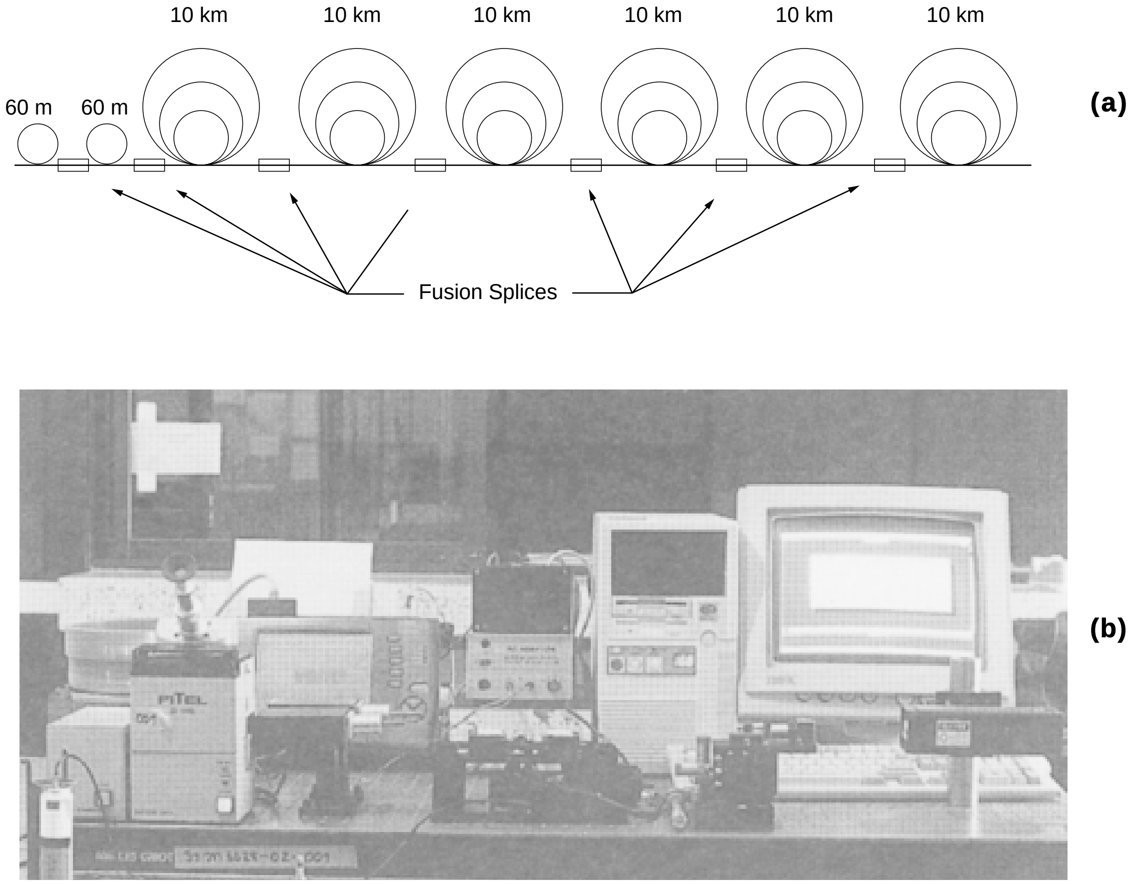


Fig 2. Illustration of a network sensor system. (a) A series of sensing heads and (b) Experimental set up.

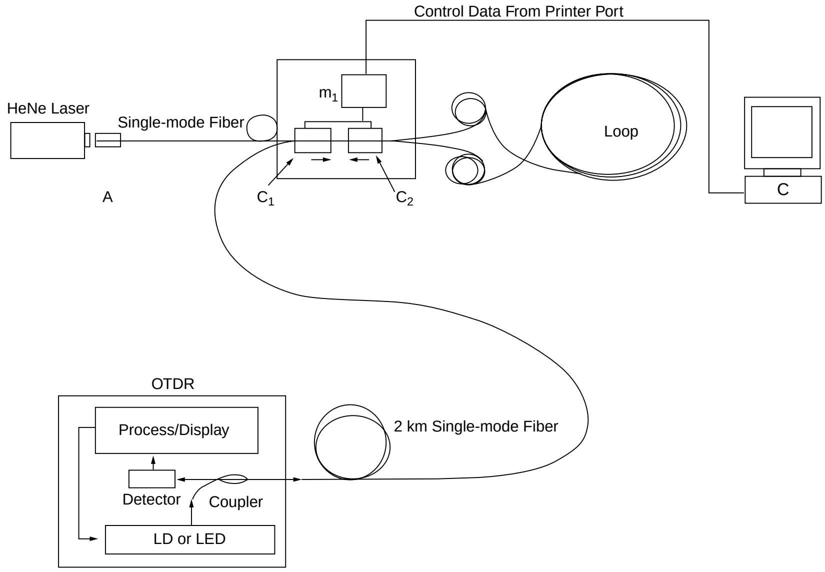
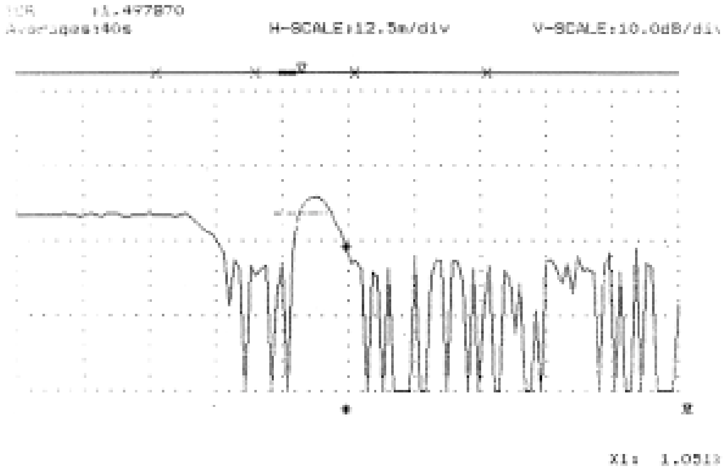
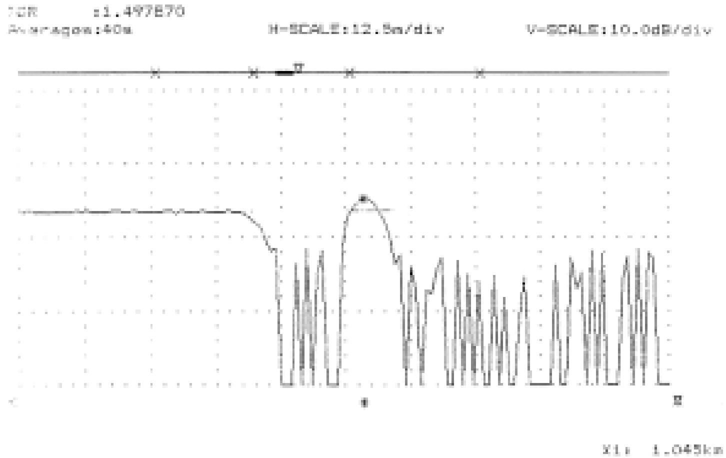


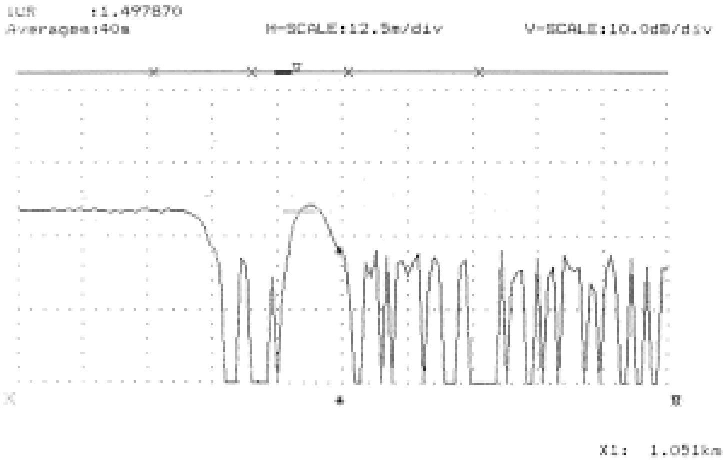
Fig 3. Illustrates the experimental system using loop-mirror sensing element. A: Launching Unit, m : Motor, Cs : Control Unit, C : Computer, LD : Laser Diode, LED:Light Emitting Diode.



(a)



(b)



(c)

Fig 4. Experimental results obtained from OTDR with environmental parameter variations. (a) Water, (b) Alcohol, and (c) Glycerin-99%

corresponding remote distance measurement respectively. The periodic signals obtained showing the effect of harmonic of the return signal from the sensing region detecting by OTDR. The sensing device was spliced into the delivery fiber locating by OTDR. Results of the one using glycerin have shown the larger change of the peak power than the results obtaining from water and alcohol, where the marking point was at distance of 1.05 kilometers.The peak power was lower level than the case of air-boundary region *ie* without any applied surrounding environment. The reason of this effect is the glycerin refractive index larger than water and alcohol. The reason is that the when the surrounding material index is closed to fiber optic index *ie* silica, then the system obtained more coupling power on the boundary between fiber core and the surrounding material than the one smaller index. The change of peak power intensity was measured relatively to the refractive index variation, where the change of intensity *ie* refractive index may be used to implement the measurement. The difference of the fiber core and surrounding indices was induced the difference coupling power returning to the detection instrument.

In application, the remote measurement using a series of sensor heads may be constructed using the technique called multiplexed sensors. However, the measurement limitations such as OTDR resolution, dynamic range and sensor sensitivity have to be considered. In this technique, the sensor head separation of 10 meters is the OTDR resolution with dynamic range of 200 kilometers. However, the signal to noise ratio (SNR) is significant detected signals *ie* signal to noise ratio of signal is more than 2, comparing to noise floor and OTDR resolution (dead zone). Dead zone is the detection limit of OTDR obtaining from the relation between input pulse width and the traveling time of the signal along the fiber.

The change of reflected light intensity obtained from sensing system as shown in Fig. 3 may be related to the change of the surrounding parameters. The sensing heads separation depend on the OTDR resolution and light source power. In applications, the idea of network sensors and remote measurement may be implemented using the extension dynamic range with the same structure and technique. The change of air-glass boundary refractive index may be affect the measured signal in term of modulation signals.

Conclusion

In conclusion, from the preliminary results of the reflected and transmitted powers obtained from the fused tapered sensing fibers showing the potential of using such a system for remote measurement applications. The network system may be implemented using a series of loop-mirrors as the sensing heads, where the networking signals may be observed. Preliminary results have shown the significant change of the optical intensity which may be related to the interested parameters. The environmental parameters such as air pollution may be monitored incorporated with the communication cables where the sensing fibers may be implemented being a sensor system, then the air pollution will be monitored and controlled by the central office. The environmental parameters such as pressure, temperature and moisture may be used this technique for monitoring, which may be the subject of our further investigations.

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