DESIGN AND TESTING OF A SIMPLE OPTICAL FIBER TELEMETRY LINK FOR USE IN RUGGED ENVIRONMENTS

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ABSTRACT

The design and testing of an optical fiber telemetry link for use in rugged environments is described. Several potential applications for this cost effective telemetry link built from readily available components are given. The results of testing the simple telemetry link for vibrations up to 20g and temperatures up to 150^0 C are reported.

KEY WORDS

Optical fiber telemetry link, rugged environments, vibration testing, temperature testing.

INTRODUCTION

Environmental conditions sometimes complicate the implementation of telemetry. For example, the presence of large amounts of electromagnetic interference can hinder transmission by RF and microwave signals or unshielded wire cables. Where difficult environmental conditions hinder the use of more traditional telemetry; optical fiber cable can sometimes be used. Crossley et al. report on an optical fiber telemetry system for use in rugged environments [1].

An example of such an application is in the field of coiled-tubing earth drilling. While drilling a well, sensitive devices can measure physical and geological parameters and transmit the data to the operators on the surface. This measurement-while-drilling process can help the operators drill more efficiently. However, because of the high temperature, high shock and vibration levels, and electromagnetic interference, communication by means of RF, microwave or wire/cable connections is difficult. The method used currently for subsurface telemetry is the mud/air pulse [2]. While this method works well, it is limited to data rates less than 10 bits per second. Certain applications, like drill bit steering, require much higher data rates. A novel optical fiber telemetry link for use in measurement-while-drilling has been developed using modulated fiber Bragg gratings downhole. The telemetry system survived at temperatures up to 150^0 C and survived drilling, reaming, and rotating in a test well [3]. While the subsurface telemetry system is quite promising, it allows only one way communication, from measurement device to surface. An inexpensive telemetry system allowing two-way communication would have an application in this area.

Another area where optical fiber telemetry links have been used is in undersea measurement and communication. Several hybrid cables containing electrical and optical fiber cables have already been developed for use as telemetry links for ROVs [4]. A cheaper optical fiber telemetry link without electrical cables might find an application as a link between a subsurface measurement device and a receiving station.

The goal of this work was to develop a simple, cost-effective optical fiber telemetry link built with readily available components for use in rugged environments. The essential components to such a link are the receiver, the optical fiber cable, and the transmitter. The three components were tested for operability at elevated temperatures up to 150^0 C and under vibration levels near 20g.

DESIGN CONSIDERATIONS

OPTICAL FIBER

The optical fiber portion of the telemetry link must meet certain requirements to function in a rugged environment. A complete set of requirements depends on the desired application for such a link, but several requirements are applicable for most potential applications: vibration and shock survivability, immersion survivability, and operability at elevated temperatures.

Temperature effects can seriously influence optical fibers. For conventional plastic optical fibers, such as those made from polymethyl methacrylate (PMMA), temperatures much above 110^0 C cause changes in the polymers chemical structure that lead to increased attenuation. Certain plastic optical fibers have been developed for long-term use at temperatures above 100^0 C, but these fibers sacrifice transparency, resulting in increased attenuation [5]. Silica optical fibers can withstand much higher temperatures but commonly used buffer, coating, and jacketing materials begin to fail at temperatures above 150^0 C, decreasing the fiber's resistance to other environmental factors. Specially designed optical fiber cables for use in rugged environments can withstand temperatures above 350^0 C, but are relatively expensive.

To keep the design cost effective, only those commercially available fibers capable of temperatures up to 150^0 C were considered for the design. The 150^0 C temperature limit also coincides with the availability of electronic components able to operate at this temperature and for potential uses for such a system (automotive, aerospace, well drilling) [6].

The survivability of an optical fiber in high shock/vibration environments or applications depends mostly on the jacketing and protection materials used to cover the fiber core and cladding. Carbon coatings and metal armor/strength members can help protect an optical fiber from damage. However, these methods of protection are relatively expensive and were not considered for use in this design. The buffer material chosen must provide sufficient protection against impact, abrasion, and shock at temperatures up to 150^0 C and be commercially available.

The type of environment surrounding the optical fiber can greatly affect the performance of the fiber. Certain coatings permit the migration of H_2 into the core resulting in increased attenuation [7]. Chemicals can destroy the jacketing and buffer materials, decreasing the amount of protection for the core, which can lead to microbending and increased attenuation.

One final consideration for the optical fiber deals with the core size of the fiber. A large multimode core size decreases the required coupling tolerances, making it easier to couple light into and out of the fiber. The relative ease of coupling light into multimode fiber makes it attractive for field applications. The larger silica multimode fibers usually cost less due less strict tolerances in manufacturing. Although the larger cores are attractive for field applications, the data rate is limited by intermodal dispersion.

ELECTRONICS

For simple multimode point-to-point telemetry links light emitting diodes (LEDs) serve as optical sources and photodiodes serve as optical detectors. LEDs and photodiodes that can operate at elevated temperatures are readily available from commercial suppliers.

Other electronic components are required for signal generation and processing. Due to the increasing number of designs that must operate at elevated temperatures, passive elements like capacitors and active elements like operational amplifiers with operating temperatures up to 150^0 C are commercially available.

Proper shielding and housing of the electronics portion of the telemetry link can prevent damage from shock and immersion.

TESTING

Potential link components were first tested individually for operability at elevated temperatures up to 150^0 C. Components with superior elevated temperature performance were selected and a prototype link fabricated. The prototype was then subjected to forced sinusoidal vibration excitation below 3g and broadband vibration excitation up to 20g.

TEMPERATURE TESTING

Figure 1 below depicts the setup used in testing the operation of the prototype telemetry link at 150^0 C over a period of several hours. The same setup was used to test the individual link components with only the component under test inside the oven.

The modulator/driver circuit produced a 131 Hz periodic pulse wave that was coupled to the LED under test inside the oven by high temperature wire. The LED was coupled to the optical fiber using standard ST connectors. The other end of the fiber was coupled to the detector. The detected electrical signal was coupled out of the oven by high temperature wire. The signal was captured by the oscilloscope and displayed. Using a GPIB connection, the oscilloscope signal was sent to a computer running a LabView VI (program) that recorded and stored the signal. The signal from the telemetry link was recorded once every hour while the link was at 150^0 C. A thermocouple connected to a multimeter displayed the actual temperature in the oven.

The recorded output signal from the telemetry link at 150^0 C was compared to the initial output signal recorded at room temperature. The hourly-recorded signals were analyzed for distortion of the waveforms and decreased amplitudes. Decreases in signal amplitude were expected since the LEDs and photodiodes were operating at elevated temperatures [8]. The amplitude loss can be corrected by post amplification methods. However, a distorted waveform may irreversibly corrupt the data.

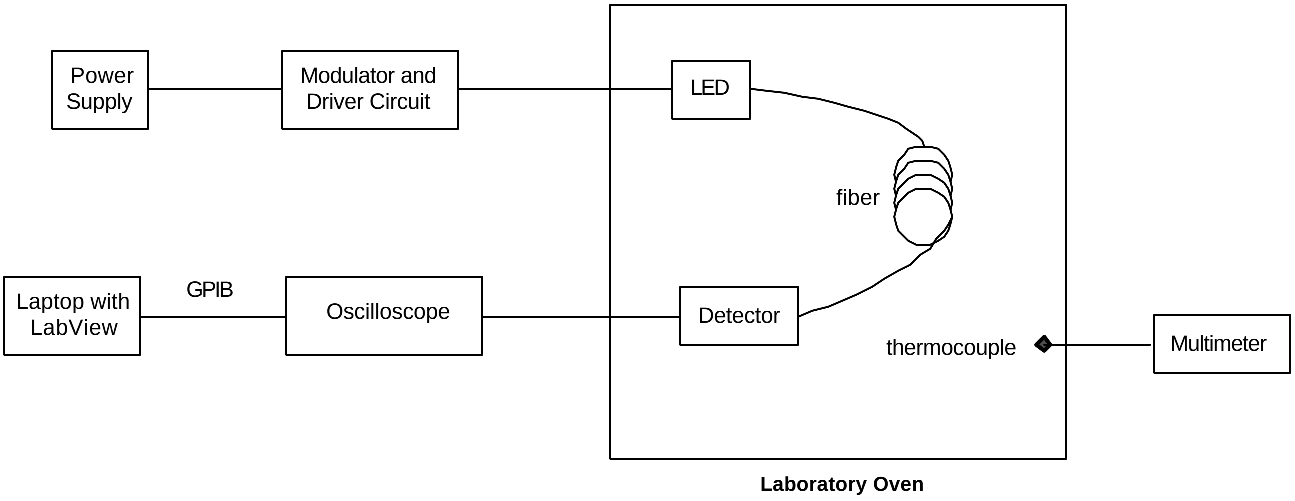

Figure1 - Diagram of temperature testing system

For the LED portion of the transmitter link an AlGaAs LED operating at 850 nm worked well. It exhibited a 15 % relative decrease in signal amplitude and no distortion of the waveform occurred at 150^0 C. For the detector part of the link, a silicon PIN photodiode worked well up to 150^0 C. Although temperature effects caused a relative decrease in signal amplitude of about 85 %, no waveform distortion occurred. Both the LED and PIN photodiode tested were housed in a standard TO – 18 cans mounted inside ST connector receptacles which helped ease coupling to the optical fiber.

Of the optical fibers that underwent temperature testing, none exhibited increased attenuation above 5 % due to elevated temperatures. Therefore, other considerations were used to select a fiber type for further vibration testing. A plastic clad silica (PCS) multimode fiber preformed well during temperature tests. With a core size of 200 microns and a numerical aperture of 0.40, light was easily coupled into and out of the fiber. A cladding of silicone and buffer of Tefzel help protect the fiber from abrasion and damage. The PCS fiber was also very inexpensive and has minimum bend radius between 4 and 13 mm. While other fibers had higher temperature limits or stronger buffers, they usually proved more expensive or less flexible. Figure 2 compares the signal from the prototype link, consisting of the AlGaAs LED, the Si PIN photodiode and the PCS optical fiber, at room temperature to the output signal after seven hours at 150^0 C. The main difference between the two is the decrease in signal amplitude. No waveform distortion occurred at the low frequency data rate used in the test.

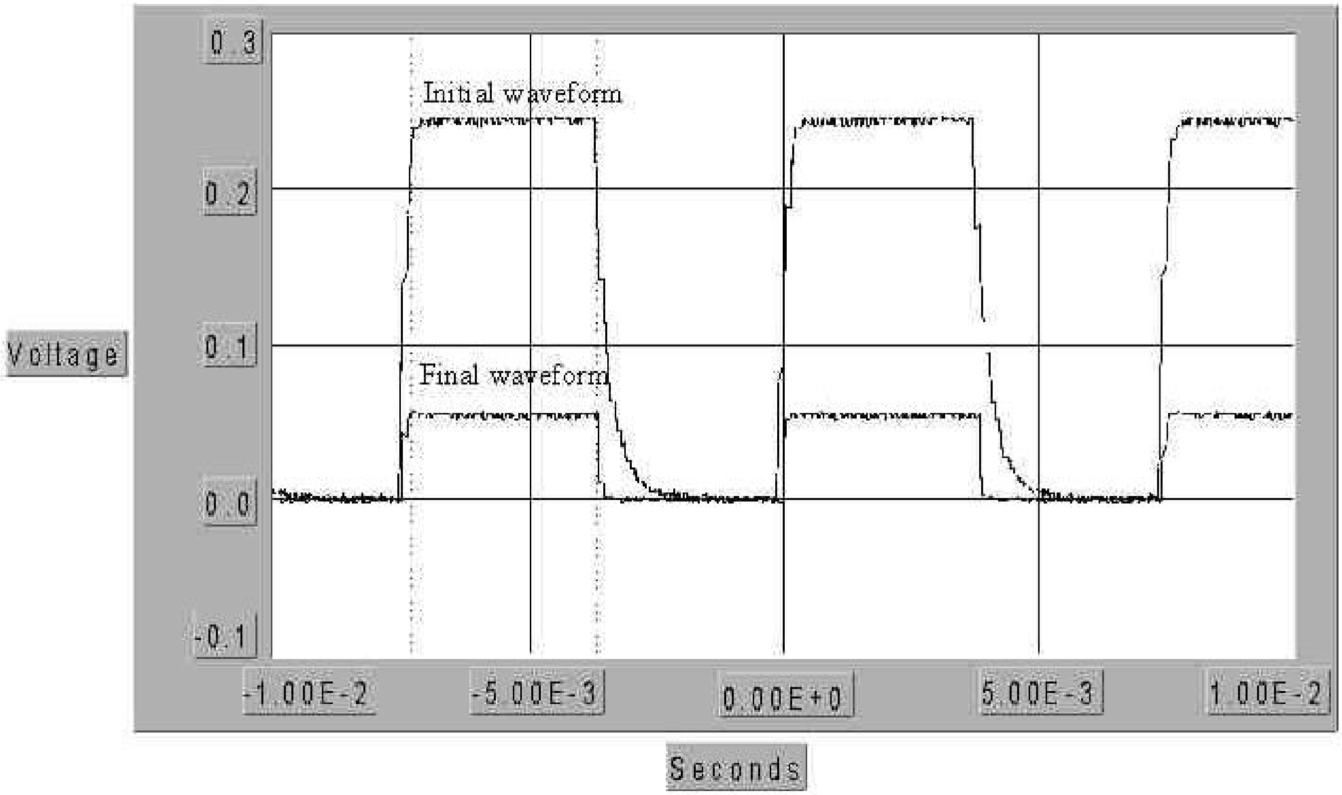

Figure 2 - Comparison of telemetry link output signal at room temperature and output after 7 hours at 150^0 C

VIBRATION TESTING

The vibration portion of testing of the prototype link consisted of two parts: a sinusoidal forced vibration at moderate excitation levels and a broadband vibration excitation at relatively high g levels. The sinusoidal vibration test (10 Hz to 2 kHz) was used to identify any harmful effects caused by particular frequencies of vibration. The high g level test was used to simulate vibration in an actual operating environment.

To subject the link components to sinusoidal vibration, the components, along with a PZ accelerometer, were mounted inside a small stainless steel cylindrical container and secured to the armature of a 98 N shaker. A 131 Hz periodic pulse wave was applied to the LED connected to approximately 6 meters of optical fiber inside the container. The resultant signal from the detector inside the container was connected to an oscilloscope and displayed. A swept sine test was then performed on the link at a rate of one octave per minute from 10 Hz to 2 kHz and at g levels ranging from 3g to 0.75g. A LabView VI (program) recorded the signal from the oscilloscope and determined if any problems with the signal occurred during the sweep. Figure 3 below shows the setup for the forced sinusoidal vibration testing.

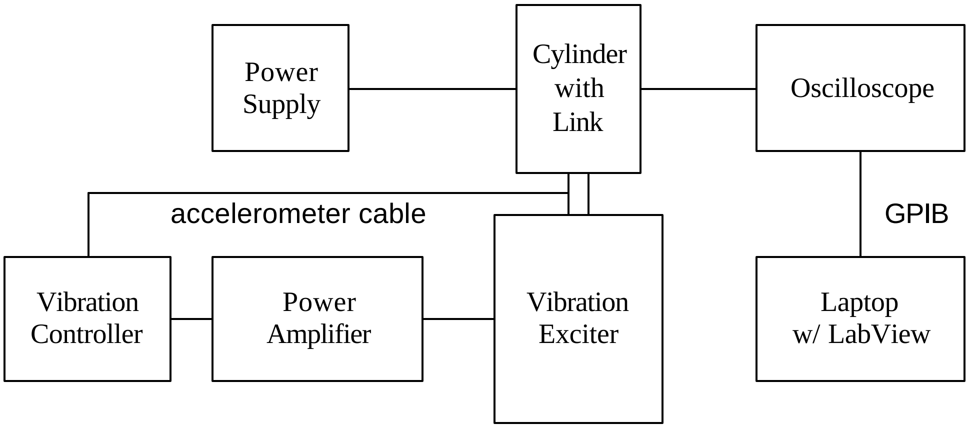

Figure 3 – Diagram of swept sine test

No detrimental effects due to the repeated sinusoidal vibration testing were evident. The signal remained at the same amplitude and was undistorted, leading to the conclusion that forced vibration of the link components within the swept frequency range had no effect.

To test the link components under broadband vibration levels, the link components and an accelerometer were mounted inside a one gallon paint can and secured to a paint can shaker. The LED and photodiode were secured to the bottom of the can while the fiber was loosely coiled inside. After connecting the accelerometer output to a spectral analyzer, displays of the vibration levels of the paint can shaker were captured during operation. The prototype link was shaken for 40 minutes. By comparing the link's output electrical signal from the detector before and after the vibration testing, the influence of the testing on the link was easily determined. A diagram of the test setup is shown below (Figure 4).

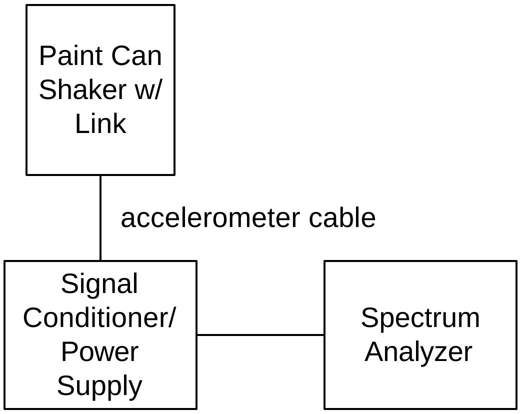

Figure 4 - Diagram of broadband vibration test

After subjecting the link to 40 minutes of broadband vibration ranging from 6 to 20g, a comparison of the link’s performance before and after the test indicated that the link components were not damaged by the test. Figure 5 shows the signal from the link before and after the testing being essentially the same.

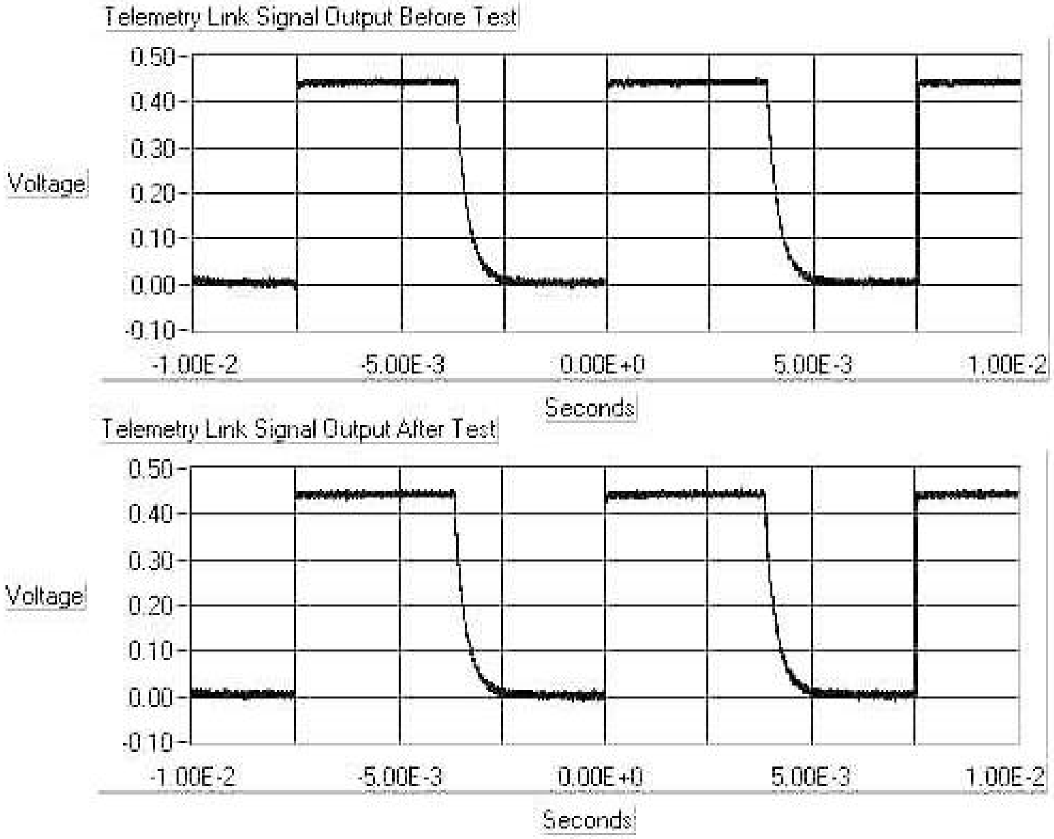

Figure 5 – Comparison of telemetry link signal output before and after broadband vibration testing

The telemetry link's excellent performance under forced vibration and relatively high g levels indicates that it should function well under similar environmental conditions in actual applications.

CONCLUSION

The design of an inexpensive, simple optical fiber telemetry link for use in rugged environments has been presented. Potential applications for such a link were discussed. Considerations governing the design: elevated temperature operation, vibration/shock survivability, and immersion survivability, and descriptions of the testing procedures used for component selection and evaluation were presented. The results of the temperature testing and vibration testing indicate that properly housed AlGaAs LEDs, silicon PIN photodiodes, and PCS optical fiber would work well for a simple, inexpensive optical fiber telemetry link.

Further testing of the telemetry link will consist of simultaneous temperature and vibration testing and analysis of component lifetimes.

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