

FIBER OPTIC DIGITAL TELEMETRY FOR DEEP SEA SUBMERSIBLES

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ABSTRACT

The telemetry electronics for an optical fiber data link in a small unmanned underwater vehicle are reported. The Miniature Optical Stereo Evaluation System (MOSES)* vehicle transmits two monochrome television channels to the surface for use in a stereo display. Each video channel is digitally encoded into four bits using Multi-Level Delta Modulator (MLDM) encoders. The resultant data rate is 120 Mb/s NRZ, and is transmitted over the optical fiber at a wavelength of 1.25 μm . Command and control are transmitted to the vehicle at 2.0 Kb/s and at a wavelength of 0.83 μm . Optical duplexers permit simultaneous two-way transmission of data over a single optical fiber. Transmission distances of 8.2 kilometers have been demonstrated using graded index, multi-mode fibers.

INTRODUCTION

Coaxial telemetry systems for use in underwater vehicles suffer from three serious problems; (1) cable size-to-bandwidth tradeoffs, (2) interference from power transmission and (3) interference between data channels. Fiber optic telemetry can eliminate power transmission interference due to its inherent immunity to EMI. Also, optical fiber bandwidths are almost independent of cable size, and offer very large length-bandwidth products (approximately 10 GHz-km). In fact, analog fiber optic telemetry systems for use in the undersea environment already have been demonstrated. The FOCUS vehicle is an example of a two-TV-channel, FM system built at the Hawaii Laboratory of the Naval Ocean Systems Center.¹ However, high carrier-to-noise (CNR) ratios are required in all analog telemetry systems, which severely limits transmission distances. Analog modulation formats which try to reduce this have been investigated but still require ~ 20 dB CNR.^(2,3)

Use of digital telemetry permits much lower SNR's (peak signal-to-RMS-noise ratio of 6 required for 10^{-9} BER), and thus much longer transmission distances. The 1.3- μm region is particularly attractive due to the lower attenuation and minimal

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dispersion compared to performance at shorter wavelengths. Data rates in excess of 100's of Mb/s can be transmitted easily from the ocean bottom.

The MOSES system is being developed to demonstrate the impact of digital fiber optic telemetry on the design of deep sea submersibles. MOSES is a miniature, downward looking, inspection system, and is equipped with two TV cameras (configured as a stereo pair). Its telemetry operates full duplex over a single optical fiber.

REQUIREMENTS FOR A FIBER-OPTIC-TETHERED, DEEP SEA SUBMERSIBLE

In the design of a tethered system, the diameter of the support cable has a major impact on the usefulness and portability of the vehicle. Therefore, it is desirable to utilize a single optical fiber, along with a power conductor (if needed) and strength members, in order to minimize the tether cable size. An additional fiber would probably add serious operational problems due to microbends, fiber curvature and increased cable size and complexity. Typical telemetry requirements for this hypothetical system are listed below.

1. Command/control data link.
2. Instrumentation channel to monitor vehicle functions.
3. Full duplex operation over a single optical fiber.
4. Stereo TV for monitoring tasks.
5. Sonar (about 0.5 MHz bandwidth) and a single TV for maneuvering.
6. High-resolution TV for close inspection.

Requirements 4, 5 and 6 need not be required simultaneously. Figure 1 shows a block diagram of the digital telemetry requirements.

DIGITAL FORMAT

Using a ten-bit digital word (assuming one bit for synchronization and nine data bits/word), the above requirements can be met as shown in figure 2. An eight- or nine-bit PCM can be used for the high-resolution TV channel. The four-bit encoders can be used to provide a lower resolution video for use

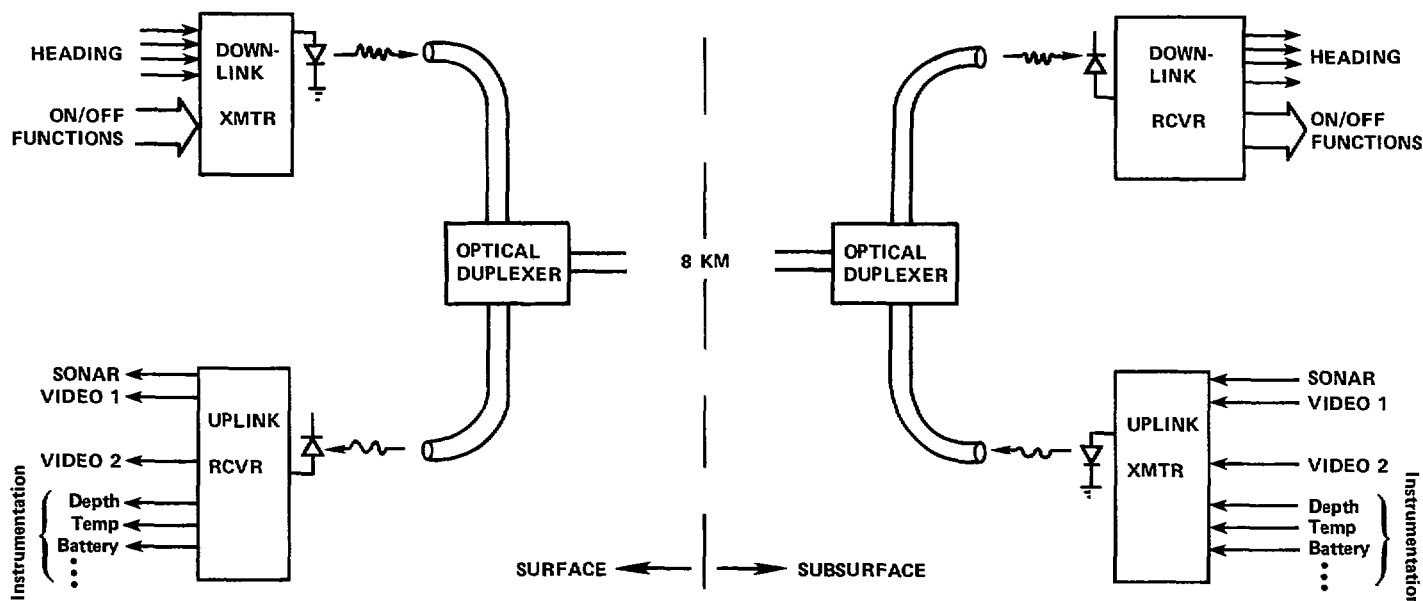


Figure 1. Typical Telemetry Requirements For A Tethered Submersible

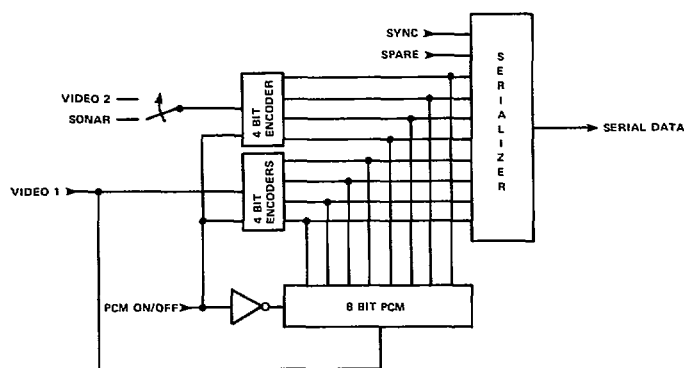


Figure 2. Digital Telemetry

by the stereo TV and sonar. Since the instrumentation channel will provide low-repetition-rate data, it can be placed on one of the video channels. Placing the data on an unused raster-scan line during the vertical blanking interval does not degrade video performance.

Use of a digital format easily meets the above requirements. Also, using digital telemetry, cross-talk and intermodulation problems associated with analog systems are eliminated. Since there is no interference due to power transmission, the design of the system is much simpler and hardware requirements are less stringent. As an example, the Remote Unmanned Work System (RUWS)⁴ required costly and bulky filters to separate the 60-Hz power from the RF signals.

MOSES TETHER CABLE

The MOSES tether cable⁵ is shown in figure 3. The 8.7-km optical fiber was manufactured by ITT-EOPD (Roanoke, VA), and was "ruggedized" by Air Logistics Corp. (Pasadena, CA). Final jacketing was performed by South Bay Cable (Idyllwild, CA).

This cabling process was accomplished with no measurable increase in attenuation. The ruggedness of the MOSES cable is demonstrated by the fact that it uniformly survives 3,000,000 flexure cycles (5-cm-radius sheave, $\pm 28^\circ$, at 30% of its ultimate loading). Additional cable properties are shown below.

1. Ultimate Strength	103 Kg (226 lb)
2. Ultimate Strain	2.10%
3. Stress/Strain	Linear to Break
4. Cable Weight	1.48 Kg/km (0.993 lb/1000')
5. Specific Gravity	1.166

The tether cable's functions have been limited to data transmission and strength. There is no power transmission since the vehicle will have its own energy source. The vehicle will be suspended from the end of the cable, and will carry propulsors for (X-Y) maneuvering and rotation.

MOSES DIGITAL TELEMETRY

The MOSES telemetry uses optical duplexers developed by the Ocean Systems Division of NOSC.⁵ The duplexers have a throughput loss (at each end) of less than 2 dB, and have a cross-channel discrimination better than 50 dB. The command/control channel operates at an optical wavelength of 0.83 μm and at a data rate of 2 Kb/s. A standard data acquisition system is used for both the command/control- and instrumentation channels.

The uplink channel and its digital format are shown in figure 4. A single-mode, 1.25- μm injection laser diode (ILD) is used as the source. Pre-biasing minimizes the laser's turn-on delay. The bit rate is 120 Mb/s (10 bits x 12 MHz), nonreturn to zero (NRZ).

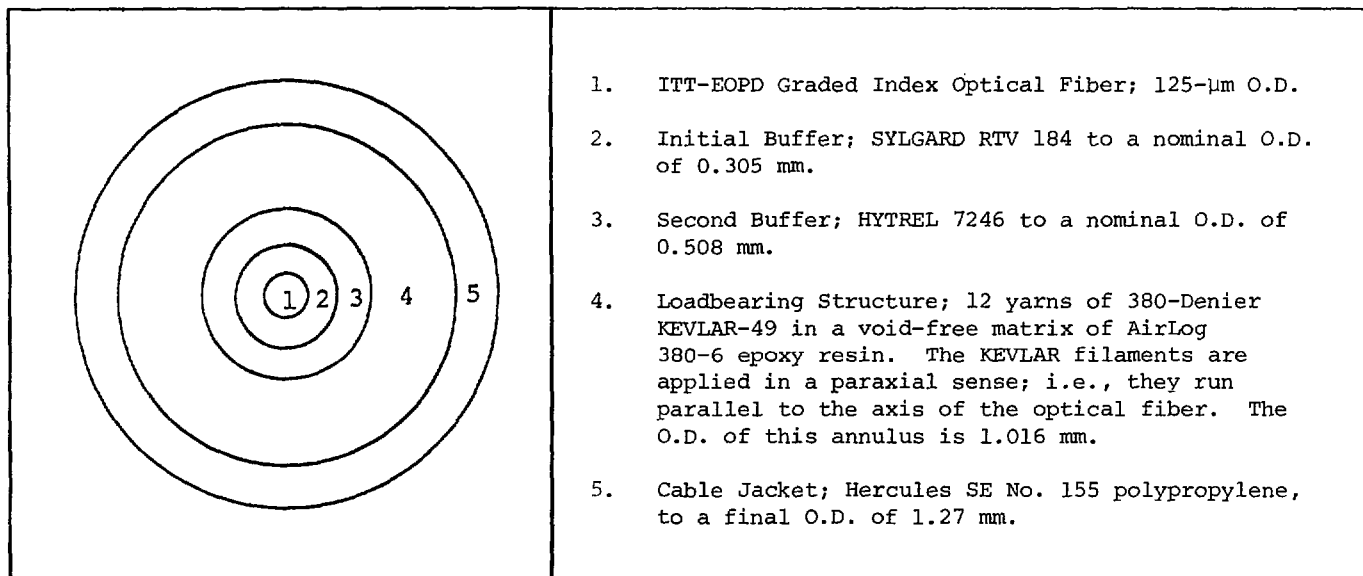


Figure 3. MOSES Optical Cable

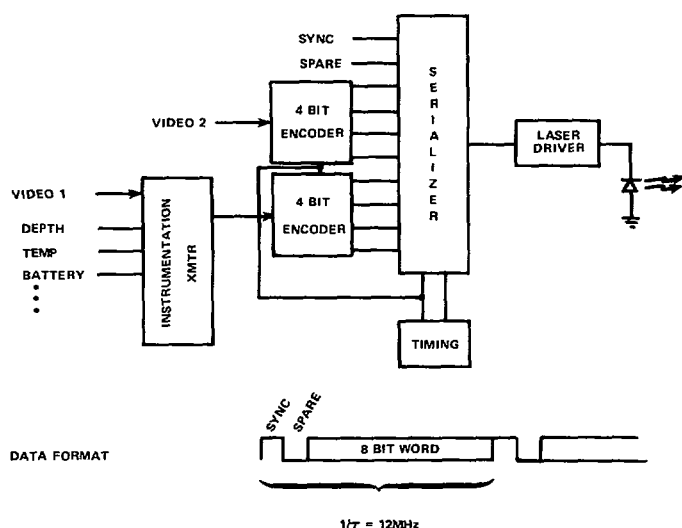


Figure 4. MOSES Digital Telemetry

The four-bit encoders are multi-level delta modulators (MLDM) which use encoding techniques similar to differential pulse code modulation (DPCM).⁶ Video quality is comparable to standard broadcast quality, except with reduced resolution. The spare data bit presently is not used.

At the surface, a germanium avalanche photodiode (Ge-APD), followed by a transimpedance amplifier, converts the optical signal to an electrical signal. Clock extraction is performed, and the serial data are decoded into parallel bits and further decoded into video by the MLDM decoders. Presently, the APD is adjusted manually for optimum gain.

Receiver sensitivities of -40 dBm for a BER of 10^{-9} have been measured. For a source power of 0.0 dBm---and taking into account duplexer loss, splice loss and link margin---the maximum allowable cable attenuation is 29 dB.

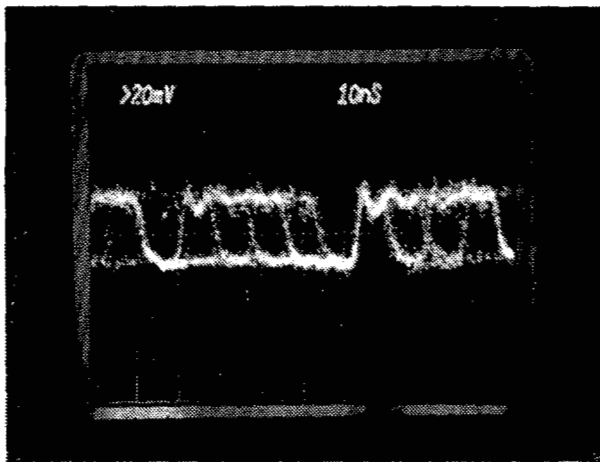
Laboratory demonstrations using graded index, multi-mode fibers designed for use at 0.85 μ m have achieved unidirectional transmission distances of 8.2 kilometers. Transmission distances have been limited by fiber attenuation rather than by dispersion (see figure 5 for received eye patterns). Use of low-loss fibers could result in transmission distances of at least 20 kilometers. Although not available at the onset of this program, a single-mode, 0.83- μ m laser with $\sim 10\text{\AA}$ spectral width could have been used. We have operated both 0.83- μ m and 1.25- μ m single-mode lasers over the 8.2-kilometer MOSES cable.

SUMMARY

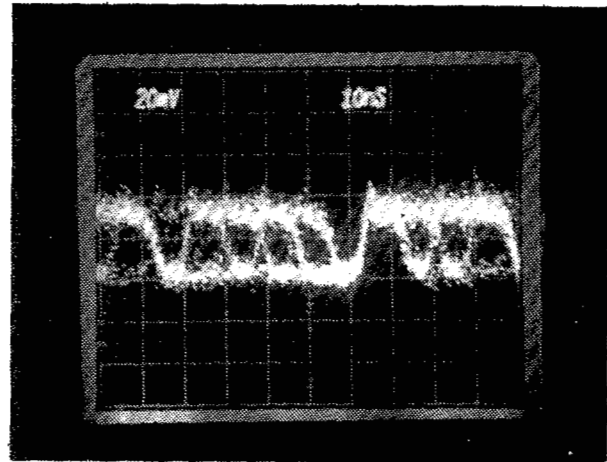
The MOSES telemetry has demonstrated that undersea vehicles can be optically tethered to reach the ocean bottom at 6-km depths. Additionally, the MOSES digital telemetry has demonstrated versatility in system configuration to meet specific tasks. For example, it could provide the following capabilities:

1. Stereo TV; one high-resolution TV channel (eight- or nine-bit PCM), or one TV and a sonar channel.
2. A continuous sonar display using delta modulation techniques and placing these data on the spare bit.
3. Using the spare bit to transmit digital data at 12 Mb/s; e.g., as an extra instrumentation channel.

In addition, the use of fiber optic telemetry allows complete separation of data- and power transmission. System design becomes much less cumbersome since careful filtering is not required.



(a) After 10M Fiber



(b) After 8.2 Km

Figure 5. Received Eye Patterns At 120 MB/S.

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