A fiber optic digital uplink for ocean-floor experimentation

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Abstract

A fiber optic data link has been implemented to carry data from an ocean-floor geomagnetic data collection system to a surface telemetry buoy. The battery-powered link was designed to operate at depths of up to 100 meters although the system margin would allow depths in excess of 1.5 km. Pulse-code modulated data is obtained from sampled analog data, organized into frames, preceded by a synchronizing code word, and applied to the optical transmitter. Data rates of up to 250 kb/s were achieved. Commercial transmitters and receivers were incorporated into waterproof housings with bulkhead penetrators of local design used to provide fiber access. Fiber optic cable with Kevlar strength members was used for the link. A nonmagnetic deployment apparatus was fashioned to to allow for deployment and recovery of the experiment from an oceanographic research vessel. The experiment was sucessfully deployed, operated, and recovered in Monterey Bay on three separate occasions.

Introduction

The Geophysics Research Group of the Naval Postgraduate School has had a long-time interest in the measurement of the spectral distribution of the fluctuations of the background geomagnetic fields. The project[1] seeks to measure the magnetic fields in the 0.01 Hz to 100 Hz region of the spectrum. Both landbased and undersea data are being collected in this investigation. Since background magnetic fields were to be measured, it was important that no contaminaing electromagnetic fields be introduced by the telemetry system. Since it was feared that a coaxial cable or other conducting medium used in the data uplink might also provide a source of downward-coupled interference signals, it was decided to use a fiberoptic link as part of the data link to provide dielectric isolation from the electromagnetic fields that might exist at the water's surface. Data was collected from a two-axis magnetometer that provided a preamplified analog data signal for each axis. The goal of the project was to digitize the data, time-division multiplex the digital data, transform the data from an electronic signal to an optical signal transmitted through a fiber uplink, detect the data stream, and feed the digital data to a radio transmitter located in a spar buoy. All devices had to be enclosed in nonmagnetic waterproof housings that could operate sucessfully at desired depths down to 100 meters.

The block digram of the system is shown in Fig. 1. The location of the devices is shown in Fig. 2. The sensor subsystem is located on the ocean floor with a coaxial lead to the instrumentation section located approximately 25 m above it. The instrumentation was located away from the sensor to avoid electromagnetic interference with the antenna coil sensors. The fiber uplink was approximately 30 m long. It was decided that the fiber cable would not have to be used to recover the experiment, since one inch polypropylene line could easily be incorporated into the design for use in deployment and recovery. A short electrical cable fed the detected data stream to the spar buoy that contained a radio telemetry link to the shore-based recording station. All components were to be operated from batteries co-located with the subsystems.

Sensor subsystem

The sensors were two coil-wound antennas of copper magnet wire. Each coil weighed approximately 45 kg (out-of-water). The preamplifiers were low-noise ELF (extra-low frequency) preamps of commercial design. A cutoff frequency of 20 Hz was used to avoid any contamination by 60 Hz power sources, although no penetration was really expected to the depths of operation of the system. Careful shielding was done to prevent the preamps from effecting the measured fields. The sensors and preamps were mounted in two Benthos spheres (one for each channel). Power was provided by two 12 volt batteries mounted in nearby PVC sections with the power coupled into the spheres through keyed Jones connectors. A mounting platform was constructed of ABS pipe sections and weighted to provide negative buoyancy. Nonmetallic platform material was required to avoid electro-chemically induced currents at the interface between the material and the seawater. The coaxial uplink connection was made to coaxial penetrators in the Benthos spheres. A magnetically activated reed switch was incorporated in the power supply to allow activation from the outside without opening the sealed units.

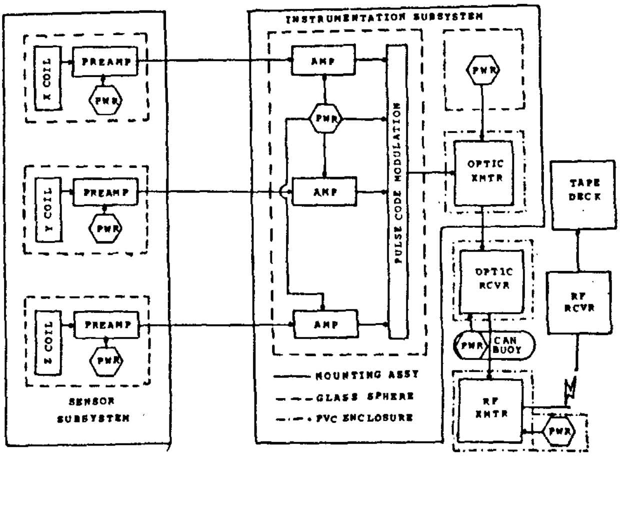


Figure 1 System block diagram

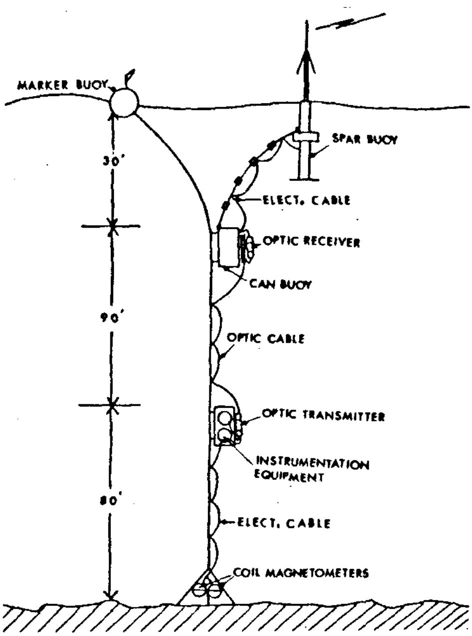


Figure 2 Deployed system

Instrumentation subsystem

The instrumentation subsystem was designed to: amplify and condition the analog data from the sensor subsystem, sample and digitize the analog signals, multiplex the digital data streams into a single stream, and drive the optical transmitter. The signal conditioner amplified the analog data by 30 dB and limited the data to a peak amplitude of 7.5 volts. The pulse-code-modulation system was a commercial system that can handle up to 15 analog channels with a selectable sample rate. To utilize the channel capacity of the board, the analog signals were fed to every third channel to increase the effective sample rate. (One set of five channels was reserved for upgrading the sensors to a three-axis system.) With a selected sample rate of 32 samples per second on each channel, the effective sample rate on an analog channel was 160 samples/s. At 12 bits per sample digitization, the overall data rate per analog channel was 1920 b/s. Since there are three analog channels (i.e., the two sensor channels and the spare channel), the overall bit rate of the output was 5790 b/s. All circuitry was CMOS to reduce power consumption. The output from the board was a bi-phase encoded TTL compatible signal. The data stream is organized into frames. A sync word (used in decoding) is first in the frame, followed by the data words from each channel in sequence. The optical transmitter was TTL-compatible and will be described separately in the optical link section. Power for the instrumentation subsystem was obtained from rechargeable batteries with the same magnetic activation circuitry previously described. The batteries were mounted in the same Bathos sphere as the instrumention subsystem.

Optical link

The optical link consisted of an optical transmitter and receiver housed in two separate environmental enclosures connected by the fiber optic cable. During deployment the fiber cable was stored and dispensed from a 20 inch radius reel fashioned from a plastic bicycle wheel rim. The transmitter-receiver pair (operating at 660 nm) were a Burr-Brown 3713T and 3713R unit, respectively. When connected to a suitable cable the units are rated as capaple of providing a data rate-distance product in excess of 400 kb/s-km. The transmitter converts TTL input data (up to 2 Mb/s in NRZ (nonreturn-to-zero) format) into optical pulses. The phasing of the transmitter is pin programmable. The LED can be ON when the data is high (called "theta-0" phasing) or when the data input is low (called "theta-180" phasing). The system operated under the theta-0 phasing (i.e., in-phase). (The theta-180 phasing is useful for an optical continuity check when long strings of zero data are expected.) The output power from the LED is controllable by the use of a resistor applied to the "power adjust" pin of the transmitter.

The optical receiver converts optical pulses into TTL compatible signals at a data rate up to 250 kb/s. There is a comparator in the receiver that decides when the signal exceeds threshold. For maximum noise immunity it is desirable to have the threshold automatically adjust to a position halfway between the maximum signal and the noise floor of the receiver. The 3713R includes a peak detector automatic threshold circuit. The light level of a logical "1" is stored in the circuit's capacitive memory and divided in half for providing the comparator threshold setting. In this way the receiver adaptively adjusts for changes in the transmitter output power due either to environmental effects or to designed changes in the power through the "power adjust" pin of the transmitter. The memory of the circuit lasts about 0.5 s before losing the information due to voltage decay. With a data rate of appproximately 6 kb/s, there was little chance of losing the threshold in a properly operating link. The "analog output" pin of the receiver permits observation of the raw received data before post-amplification and detection at the comparator. This serves as a useful test of the proper operation of the optical link, allows estimation of the fiber losses, and provides an opportunity to examine the noise performance of the detector and preamp combination. In the designed link the output signal could be taken directly from the analog output pin since the signal-to-noise ratio was high enough in this low data rate-distance link. The output level of 200 to 240 millivolts at this terminal was utilized to drive the RF transmitter modulation input without overdriving.

The fiber optic cable was avilable in the laboratory and was a graded index multimode fiber. The fiber had a 125 micrometer outer diameter with a 50 micrometer diameter core. The fiber is centered in a cable with Kevlar strength members surrounding it. The outer cable diameter is nominally 1 mm. The rated breaking strength of the cable is 1000 Nt (225 lbs). The cable attenuation was rated as 7 db/km. This cable type has previously been tested and characterized by the Naval Ocean Systems Center, Hawaii. Although the fiber core size was smaller than the 200 micrometer core suggested by the transmitter/receiver spec sheets, the availability of a rugged tested cable dictated the choice. The transmitter specification sheet indicated that about 0.9 microwatts (-30.5 dBm) of power would be launched into a fiber core of this fiber.

In calculating the system margin, the receiver specification gave a minimum power of 30 nW (-45.2 dBm) to meet a BER=10^{-9} specification. For this power the source-receiver power difference is 14.7 dB. Since 100 m of cable would require only 0.7 dB of cable loss, there was more than adequate power performance in the system design. For such a short distance link one must avoid saturating the detector with too much power, thereby degrading the receiver performance below its specifications. The maximum power into the receiver is specified as 1 microwatt. Since the power in the fiber is below this rated value, the system was in no danger of saturation at maximum current. (With a bigger core fiber, the drive current of the source would have been reduced to a level sufficient to provide the minimum required power, but not sufficient to saturate the receiver.)

The connectors at the transmitter were AMP Optimate plastic ferrule connectors. The cable size was built up slightly to fit in the available ferrules. With measured losses of 1 dB per connector, the presence of four connectors in the link would degrade the margin by 4 dB. This degradation is not sufficient to require a change in source, receiver or fiber. (In fact, the remaining 10.7 dB of margin would allow for a maximum transmission distance of 1.5 km with this cable.)

Environmental enclosures

The fiber transmitter and receiver were mounted in enclosures as shown in Fig. 3. The enclosure was manufactured from PVC pipe with an inside diameter of 15 cm (6 inches). One

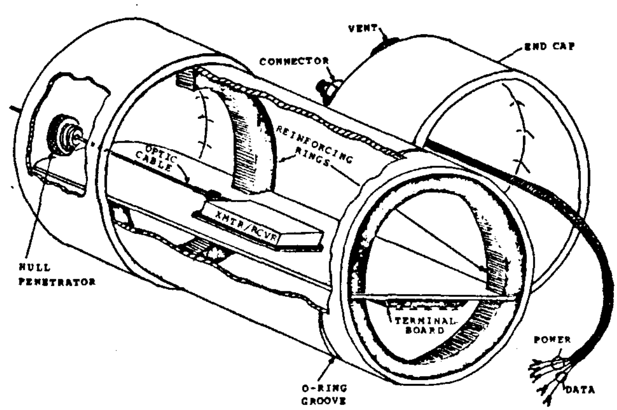


Figure 3 Transmitter and receiver enclosures

end of the pipe and the associated endcap were machined into a true round with tolerances of +/-0.003 inches on the pipe and +/-0.015 inches on the cap. An O-ring groove, 0.16 inches wide and 0.093 inches deep was machined 0.75 inches from end of the pipe. Reinforcing rings of 0.75 inch PVC were inserted into the pipe and supported the circuit board in slots cut into them. The machined endcap was fitted with two Brantner connectors and a vent hole. The other endcap was fitted with a penetrator to support the fiber optic cable. The penetrator design was developed in conjunction with another project[2,3] and has been successfully tested at depths down to 2000 feet for prolonged periods. The endcap with the penetrator was mounted and secured with PVC cement. The fiber cable passing through the penetrator was initially secured with cyanoacrylic glue and then permanently secured with epoxy. Testing showed that the fiber was likely to break at the penetrator location due to bends in the cable, so the final design incorporated a bend limiter consisting of 3 layers of heat shrink tubing placed around the cable with each layer shorter than it predecessor. Power was provided through one set of connectors from rechargeable batteries located in an adjacent Benthos sphere. Signal information was coupled into the transmitter enclosure through the other connector on the endcap.

The receiver was placed in a similar container and mounted on a can buoy (along with the bicycle wheel cable reel). The receiver batteries were placed in the can buoy.

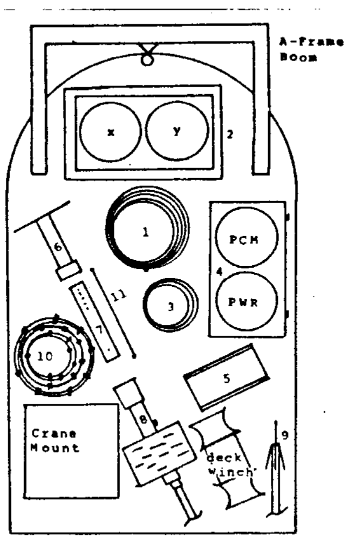
Spar buoy and shore-based subsystems

The spar buoy contained battery power, a free-flooding section for stabiliy, the radio transmitter for data relay, cabling, and the antenna. The buoy was designed in association with a previous experiment[4]. It is demountable for easy transportability and is assembled as the unit is deployed over the side of the ship. The shore system is a radio receiving set, an instrumentation tape recorder for data recording, and an oscilloscope for checking transmission effectiveness. Additional equipment is used to perform the digital-to-analog data conversion and spectral analysis.

System performance

Once the link design had been debugged, a laboratory test of the system was performed by inserting sine waves of known frequencies and amplitude at the PCM board on the instrumentation board subsection. The data was sucessfully sampled, encoded, optically transmited and received, broadcast and received through the radio link, recorded, decoded, and reconstructed at the output, providing a checkout of the electronics and the fiber optic link.

A deployment scenario was designed and rehearsed using dummy subsystem units. Deck space assignment was optimized (Fig. 4) and sequences for the deployment were improved.



(a)

1. Main support line
2. Sensor subsytem
3. Cable (sensor to transmitter)
4. Instrumentation subsystem
5. Can buoy, receiver, fiber cable
6. Spar buoy power section
7. Spar buoy flooded section
8. Spar buoy transmitter section
9. Spar buoy antenna
10. Cable (receiver to spar buoy)
11. Cable (spar buoy power to spar buoy transmitter)

(b)

Figure 4 (a) Deck layout of system
(b) Layout list

The system was sucessfully deployed on three different occasions in the Summer of 1982 for periods of approximately four hours, 22 hours and 24 hours. Simultaneously data was collected from a landbased location for comparison of undersea fields and land fields. Fifty hours and 30 minutes of data was sucessfully collected for subsequent analysis and modelling efforts.

Summary

A fiber optic digital uplink was sucessfully designed and deployed in an ocean floor experiment in depths of 70 meters. The dielectric isolation of the fiber portion of the link was critical to the measurements being taken. Analog data was digitized and time-multiplexed before optical transmission. The digital data was sucessfully transmitted and received with ample margin for links up to ten times the distance of this design.

Acknowledgements

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