how it works

IF YOU THINK MEGABIT-PER-SECOND DATA LINKS ARE TOUGH, TRY TO REACH 2400 BPS–UNDERWATER!

Underwater modem meets the challenge of a difficult channel—but slowly

By Bill Schweber, Executive Editor

FOR ALL OF YOU red-hot designers pushing data at gigabits per second through a pristine optical fiber or at tens of kilobits per second or megabits per second via a copper or wireless link, what would you do if your channel medium were water? With a physical channel that is hostile and variable and with constraints that differ from those of conventional fiber, copper, and wireless systems, most design ground rules you use become invalid with water.

However, the need exists for modems that transmit data among underwater locations without using a physical wire as the channel. For example, undersea data loggers that monitor seabed seismic motion or track water temperatures need to communicate with other underwater nodes or a ship-based node to upload data. Some of these sensor measurements are important for oil exploration, marine-animal research, and national-security surveillance.

Due to the absorption and consequent attenuation of electromagnetic energy by water, the only radio technique for undersea communication involves modulating a low-frequency carrier (less than 10 kHz), which suffers less loss in the ocean than higher frequencies. This method, however, requires megawatts of transmitter power and huge antenna arrays that spread over many acres and yields data rates around 100 bps. The Navy uses such a system to send messages to submarines on patrol, but the system is an expensive, one-way link.

For moderate distances, you can use an acoustic alternative. As long as you can accept a relatively modest data rate of 2400 bps or slower, you can have a bidirectional link that appears to your system as a conventional RS-232/RS-422 serial port. Benthos, Inc (North Falmouth, MA, www.benthos.com) makes several versions of these modems. Each version targets different applications and sea conditions.

For user access, you can disassemble the cylinder that houses the modem, but the cylinder must be sea-pressure-worthy when you reassemble it; the upper-left object is one of the available transducers.

The modem node at each side of the link comprises two separate units, including a modem module and an acoustic transducer, connected by a cable. Acoustic signals send signals through water by using a user-specified audio-frequency band. You can choose a low-frequency 9- to 14-kHz band, a medium-frequency 15- to 20-kHz band, or a high-frequency 25- to 30-kHz band and change them when operating conditions change. Your frequency choice depends on your expected ambient-noise sources (nearby ships, for example) and the distance you need to cover; lower frequencies better suit long-range communication.

You should also select a transducer-radiation field pattern that matches your situation. You can pick an omnidirectional transducer, which prevents you from aligning the receiving-transducer position with respect to the sourcing transducer; a directional transducer from which you can point to a complementary transducer; or a line array, which best suits horizontal propagation paths. As with conventional RF antennas, a more directional transducer enhances your apparent signal-output power and also improves received-signal SNR.

LOW-POWER OPERATION IS CRITICAL, BECAUSE THE MODEM MAY NEED TO CONTINUOUSLY RUN FOR A FEW DAYS OR INTERMITTENTLY RUN FOR AS LONG AS A YEAR.

The transmitted audio level at the transducer is relatively modest: 178 to 190 dB depending on the model. You might assume this level is deafening, because a 120-dB sound-pressure level in the conventional acoustic-measurement scale approximates the loudness of a jet taking off; this signal level is referenced to 1-μPa pressure at 1m. If you put your ear within a few meters of the transducer, you can hear the sound, but the sound level is tolerable.

The Benthos modem achieves 100 to 2400 bps at 2400 baud, using a combination of modulation and coding techniques supplemented by forward error correction. Hadamard coding is used for 100- to 1200-bps operation, along with noncoherent M-ary frequency-shift keying (M=1 to 4), which can achieve 2400 bps under good conditions, plus a significant amount of data redundancy, $^1/_2$ or $^1/_3$ rate-convolution coding, and Viterbi maximum-likelihood decoding. Although the maximum data rate of the modem is 2400 bps, the serial input port is buffered, so you can download data at a maximum rate of 9600 baud.

The efficiency factor, which relates the baud-signaling rate to the final data rate, is user-specified, but the modem adjusts the efficiency factor according to channel conditions and the uncorrected error rate that the modem determines for the received signal. In addition, the modem puts a guard period around each signaling interval to minimize the impact of multipath signals reaching the receiver, which vary with underwater-geography features and water conditions.

Two important and interrelated demands stress the modem design. First, low-power operation is critical, because the modem may need to continuously run for a few days or intermittently run for as long as a year. You also need an extraordinary amount of signal processing to implement the algorithms that encode the transmit-side signal and to extract, decode, and error-correct the received signal.

For this application, Benthos chose a Texas Instruments fixed-point DSP. Although a floating-point DSP makes coding algorithms easier, its power demands are too severe. The availability of relatively fast, low-power, fixed-point DSPs is one of the keys to the success of this project.

The Benthos ATM-875 subsea modem comes in an anodized aluminum package that measures approximately 30×3.5 in. (76×9 cm), weighs 24 lbs (11 kg), and is rated to a 2000m operating depth (**Figure 1**). (A slightly longer and heavier version is rated to 6000m.) The receiver portion operates from a 4 to 9V supply that a 6V/6-Ahr lithium battery provides and consumes 170 mA in active mode and 0.7 mA in standby mode.

The transmitter operates from a 14.8 to 48V-dc source and receives power from a 21V/18-Ahr battery; it consumes just 100 μA in standby mode, and the active-mode current consumption depends on the transducer you select. Note that if one end of your link is ship-based, you can purchase that modem in a rack-mount, 110/220V-ac-powered model. Transducers weigh 8.5 to 26 lbs (4 to 12 kg), and the largest transducer measures 18×4.5 in. (45×11 cm). To improve SNR, each transducer contains a 35-dB gain preamplifier for the receiver channel.

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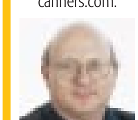

You are probably asking yourself: How far can such a modem communicate, and how much does the modem cost? In Buzzard's Bay in Cape Cod, MA, the modem reliably linked 3 to 5 km (1.8 to 3 miles); in the open ocean, Benthos achieved 7-km (4.4-mile) paths. The cost for a modem and its transducer varies with the transducer, but you can probably set up each end of the subsea acoustic modem for less than $10,000.□

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