The MIT Marine Industry Collegium
Opportunity Brief #19

A New Underwater Communication System

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A NEW UNDERWATER COMMUNICATION SYSTEM

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PREFACE

This Opportunity Brief and the accompanying Workshop (held on February 13, 1980) were presented as a part of the MIT/Marine Industry Collegium program, which is supported by the NOAA Office of Sea Grant, by MIT and by the more than 110 corporations and government agencies who are members of the Collegium. The underlying studies were carried out under the leadership of Professor Arthur Baggeroer, but the author remains responsible for the assertions and conclusions presented herein.

Through Opportunity Briefs, Workshops, Symposia, and other interactions the Collegium provides a means for technology transfer among academia, industry and government for mutual profit. For more information, contact the Marine Industry Advisory Services, MIT Sea Grant, at 617/253-4434.

Norman Doelling

July 7, 1980

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1.0 Business Perspectives

Although the ocean environment greatly limits underwater communication, this limitation has previously had only a relatively minor impact on underwater operations. Since the most common instrument systems and unmanned vehicles were tethered, the tethering cable could also serve as an electrical communication link.

However, as microprocessor technology has advanced, it has become feasible to develop underwater instruments and vehicles that can operate on their own power, untethered and untended, for long periods. Such untethered systems offer potential benefits for carrying out tasks in which cables may become entangled--around the foundations of offshore platforms, for example. In addition, untethered systems provide attractive operational and economic benefits since they remove the requirement for large vessels, crew, and cable handling equipment needed to work with cables. Finally, mobility is enhanced in untethered systems as drag forces on tethering cables are eliminated.

If an operator at the surface could rely on acoustic channels to interrogate cable-free systems and to receive transmitted data from them, it would provide the basis for a new generation of instrumentation and semi-autonomous vehicles with a greatly enhanced range of useful underwater applications.

Under MIT Sea Grant sponsorship, a team of investigators from MIT's Ocean Engineering Department and Electrical Engineering and Computer Science Department, and from Woods Hole Oceanographic Institution have been working on new underwater communication systems. The systems are designed for use in near vertical paths and to operate at maximum data rates consistent with the limitations of the ocean environment. The systems exploit algorithms developed in modern communication theory using microprocessor implementations. This project is an adaptation to the ocean environment of modern techniques which have been applied for the communication of data over hard wires or through the troposphere, to satellites and other forms of electromagnetic wave communication.

A prototype communication system has been developed and partially tested. Preliminary analysis indicates that data rates on the order of one to four kilobits per second can be achieved over ranges of one to two kilometers. Such capabilities point toward potential opportunities and applications for a wide range of oceanographic monitoring tasks, platform inspections, and deployment of submersibles from tenders. Instrument manufacturers, oceanographic research organizations, and the offshore industry may stand to profit from successful further development and implementation of the techniques described in this Brief.

An important feature of these systems is that because of the microprocessor implementation they can be adapted through programmable software changes to satisfy a wide variety of systems which may require differing tradeoffs among the key parameters of data rate, range, and error rates.

At the Workshop on February 13, 1980 at MIT the current system was displayed and discussed and its flexibility and potential adaptations were reviewed. Potential users are encouraged to contact the author or Professor Arthur Baggeroer.

2.0 BACKGROUND

The use of acoustic signals to transmit data underwater has been well known since the advent of sound ranging (sonar) in World War II. The difficulties of transmitting data at high rates in an ocean medium is also well known. Absorption of sound energy in the ocean prohibits long-range propagation at the high frequencies required for high data rates. In addition, inhomogeneities in the sea create multiple communication paths and "reverberation." The reverberation phenomenon is particularly vexatious for horizontal signaling.

Figure 1 indicates a categorization of undersea tasks on the basis of communication paths and range requirements. Horizontal, long-range communication is not addressed in this Brief, although it is obviously important for certain defense missions. We are primarily concerned with near vertical, short-range transmissions to a maximum depth of perhaps a kilometer and with a horizontal, short-range transmission of up to about three kilometers.

The studies we report here use a direct acoustic link such as that shown in Figure 2a. For deep applications, systems like that suggested in Figure 2b are being developed. Such a system would consist of an acoustic link and a coaxial or fiberoptic cable stretching from a deep receiving station to the surface. This combined system may provide an effective way of communicating with very deep (on the order of a 20,000 feet) submergance vehicles.

RANGE	Vertical Communication Paths	Horizontal Communication Paths
Short (Shallow)	1) Inspection of offshore platforms 2) Submersibles deployed from tenders	1) Command/control from wellheads 2) Pipeline inspections
Long (Deep)	1) Deep sea mining and resource recovery 2) Current and thermister sensors 3) Hydrophone, geophone and seismometer sensors 4) Deep submersibles	1) Command/control communication among naval submarines

Figure 1: Categorization of Undersea Tasks on the Basis of Communication Path and Range Requirement

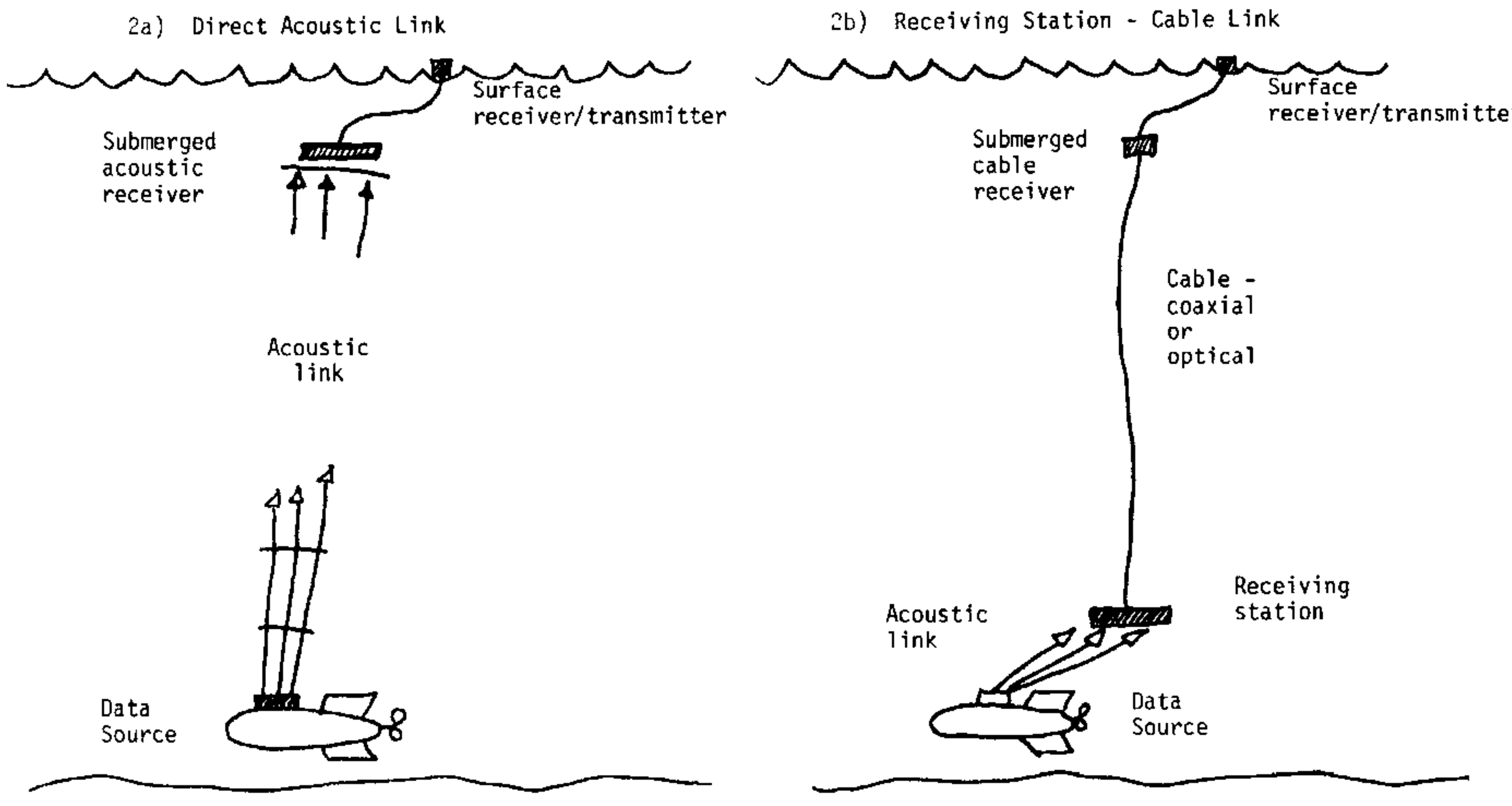


Figure 2: Proposed Communication Systems

3.0 THE UNDERWATER COMMUNICATIONS SYSTEM

A canonical communication system is pictured in Figure 3. For the current system consider the data source to be an instrument of some sort - a compass for example. The data source, the encoding and the modulation hardware, and the transmitting hardware would be located in a remote untethered vehicle or in a self-contained, self-powered instrument package. The communication channel, in this case, is the ocean. The receiver and demodulating and decoding hardware are assumed to be on the surface. To minimize energy storage requirements on the remote self-powered systems, the general design philosophy has been to use encoding and transmitting systems that minimize the use of electric power and, thus, computational complexity.

Receivers or demodulators are assumed to be located at the surface where power and space requirements are less restrictive and need not limit computational sophistication.

3.1 Data Sources

We are concerned here with command and control data or read-out of stored data from a remote instrument package. Data rates for these applications can be relatively low, from perhaps 10 bits per second to as much as a 1000 bits per second. In the case of a robot vehicle, where data communication may be important to the survival of the vehicle itself, error rates must be very low and system reliability must be very high. In general, the lower the data rate, the lower the error rate that can be achieved for any given communication system..

Acoustic instruments such as side-scan sonars may require data rates on

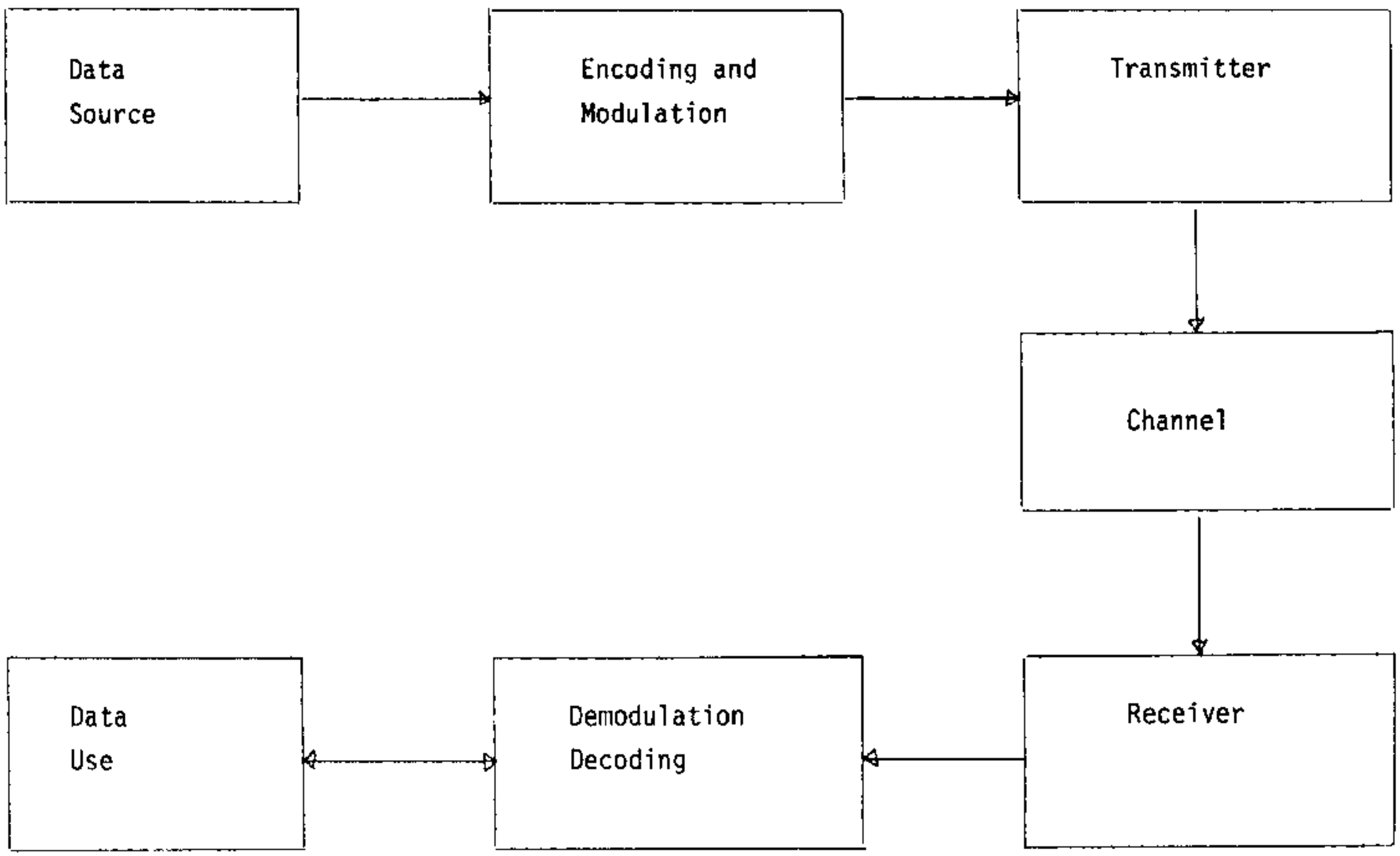


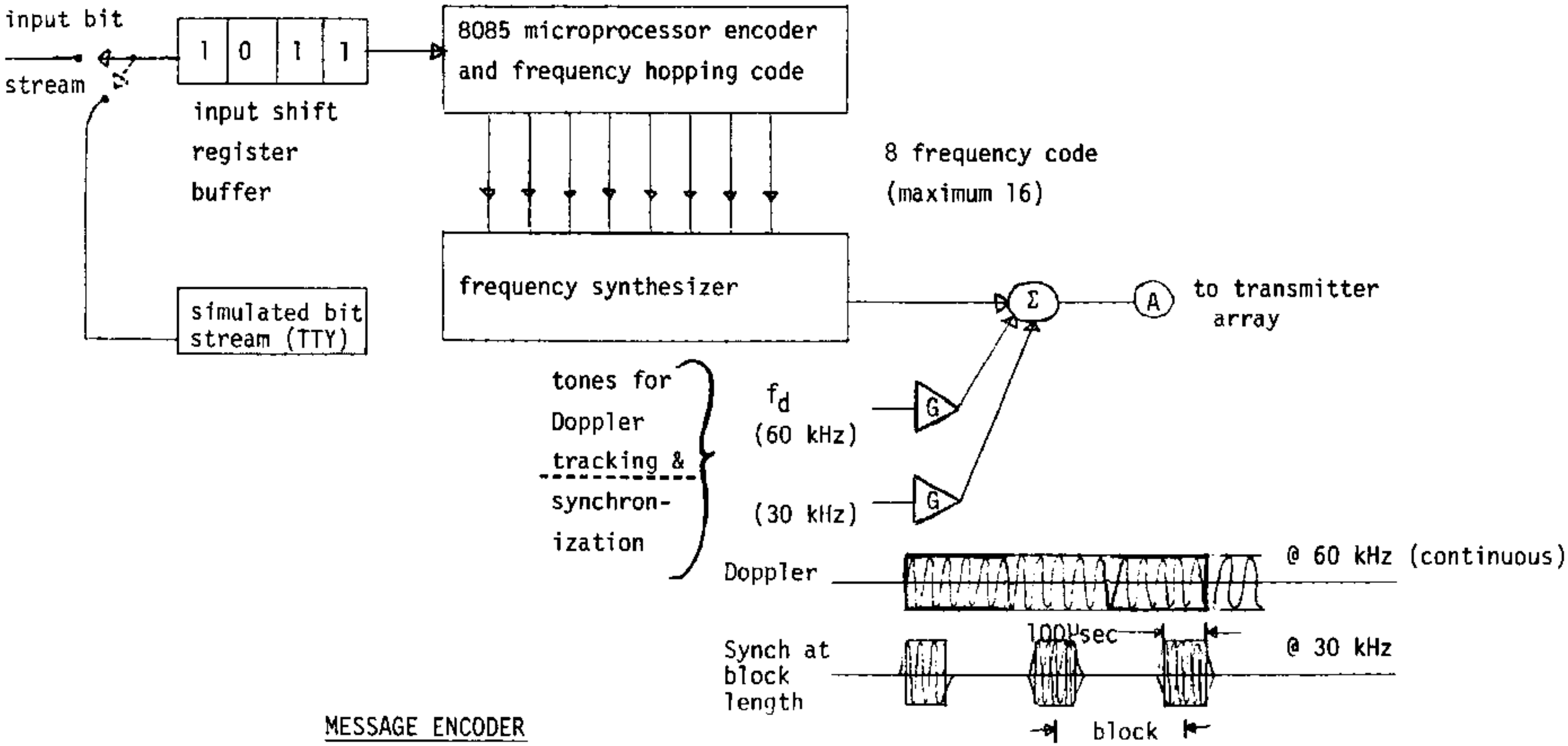
Figure 3: Communication System Components

the order of .1 to 10 kilobits per second. Video images require the greatest amount of information and data rates on the order of 10 to 100 kilobits per second are required to obtain one picture about every 10 seconds. The current system is designed for maximum data rates of up to a few kilobits per second. The maximum data rate is determined by the range over which information must be sent, the acoustical characteristics of the particular ocean environment, and the error rate that can be tolerated. The system can be used at lower data rates with correspondingly lower error rates if needed. In general, the higher the data rate, the greater the probability of error.

3.2 Encoding and Modulation

Since digital data cannot be transmitted directly, it is first encoded and then modulated for acoustic transmission through the ocean medium. In the encoding and modulation procedures, the microprocessor with its low power consumption is essential. The literature on information theory includes extensive studies of coding methods and a large number of algorithms have been developed. However, until the advent of microcomputers these techniques could not even be considered for remote underwater use because of the large electric power requirement and the large size of the computers needed.

A block diagram of the encoding/modulation system is shown in Figure 4. Data are transferred to an Intel 8085 microprocessor in four bit blocks. The 8085 accepts 4 bits of data and puts out 8 to 16 bits, which drive a frequency synthesizer, which in turn generates bursts of chords having up to 8 tones. The presence or absence of each of the 8 tones permits up to 256K possible output codes (2 to the 8th power). The 4 bit input represents only



Examples:
1) 2 msec/4 bit block → 2 kbit/sec
8 tones → 8 kHz total bandwidth with +/- shift (bandwidth expansion = 4)

2) 1 msec/4 bit block → 4 kbit/sec
8 tones → 8 kHz total bandwidth with 1/0 keying (bandwidth expansion = 2)

3) 4 msec/4 bit block → 1 kbit/sec
8 tones → 8 kHz total bandwidth with +/- shift and frequency hopping 4 kHz/block

Figure 4: Data Encoding and Modulation System

16 possible messages, so there is redundancy in the output. This additional redundancy can be used to improve system performance by use of error correcting codes and diversity techniques. The correspondence between input and output (the encoding scheme) is an important software variable available to the user.

For certain acoustic environments it may be useful or necessary to use frequency hopping techniques through which successive messages are encoded on slightly different frequencies. The frequency hopping code must be included in the signal sent out so the receiving system can be told about the encoding technique. For the system being implemented, the frequency band used for data transmission extends from 45 kHz to 55 kHz.

Two additional signals are also transmitted with each signal. A 60 kHz tone is generated and transmitted as a reference tone. Any deviation in frequency of this tone at the receiver indicates a Doppler shift resulting from relative motion between the source and receiver. The appropriate percentage Doppler shift is used to generate a calibration signal for the entire demodulator/decoder system. In addition, a 30 kHz signal is transmitted as 100 microsecond tone bursts to provide a timing indicator for the beginning of each four bit block.

3.3 Transmitter Systems

A most efficient method for reducing power requirements and at the same time decreasing multipath effects is to use a directional data transmission system. Since the remote vehicle and the surface ship will move with respect to one another, it is essential to be able to control the direction of maximum transmission. Borrowing from sonar and radar technology, the MIT team has designed a steered array. As indicated in Figure 5, the array of small transmitters is made directional by introducing prescribed signal time delays between the individual elements of the array. A four by eight element array has been chosen, with a beam width of about 15 degrees by 7 and 1/2 degrees at the 50 kHz center frequency. This size provides an engineering balance between signal gain and the possibility of pointing errors, i.e. missing the signal because it is very narrow and not pointed directly at the receiver.

A transmitter on board ship transmits two command signals to the remote vehicle for pointing the array. The control input is envisioned as a joy stick type of control. One direction will correspond to "north/south" pointing and an orthogonal one will correspond to "east/west". The operator generates a FM signal centered at 9.5 kHz for the "north/south" indication and a signal at 10.5 kHz for the "east/west" signal. These signals will be received and tracked through filters and phase-locked loops for steering. The output of the phase-locked loops is two signals, one corresponding to a north/south component and the other to an east/west component. These two signal components provide inputs to voltage controlled oscillators that are incorporated in the microprocessor computer system. The 8085 microprocessor computes the required thirty-two steering delays that are then generated through charge-coupled-device (CCD) shift registers.

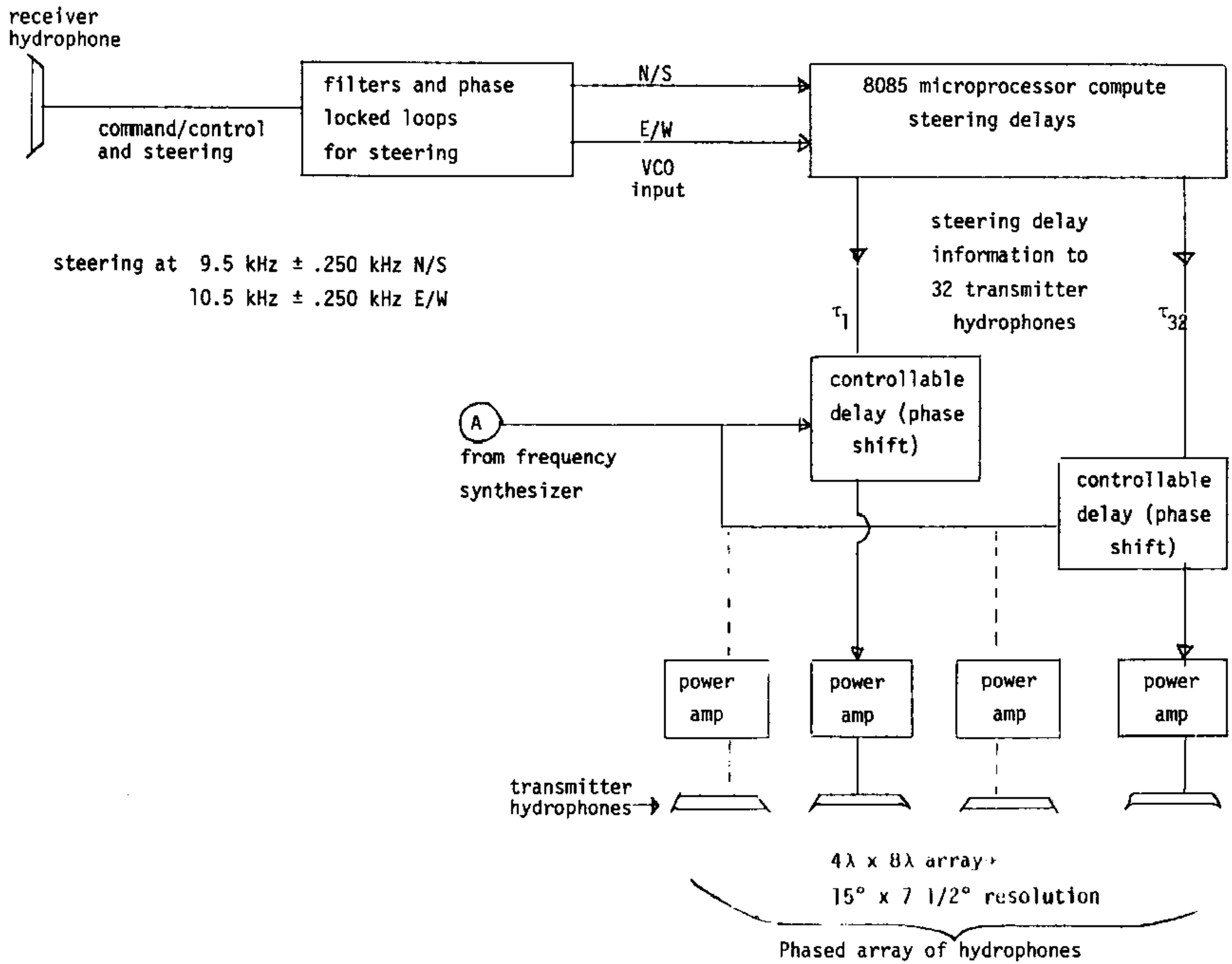


Figure 5: Transmitter Phased Array Steering System

3.4 Receiver Demodulator and Decoder

The receiver hydrophone is assumed to be on board ship and, for our development purposes, is considered to be an omni directional system. It could also be a steered array, if multipath problems or other signal-to-noise ratio problems are severe. The front end of the receiver system is indicated in Figure 6. The incoming data signals, the Doppler signals and the synchronization signal are separated by filtering techniques. The Doppler shift signal is used to modify the nominal 50 kHz center frequency of the quadrature demodulator. The quadrature demodulator operates on the data signal frequency band in order to shift it to a nominal plus or minus 5 kHz signal so that the analogue-to-digital conversion and the subsequent processing can take place at lower data rates The decoder system shown in Figure 7 utilizes an HP 2100 with an attached array processor to perform a complex, fast fourier transform (FFT) of the demodulated signals. The hardware indicated in the block diagram in Figure 7 is more powerful than required in an absolute sense and is being used as a matter of convenience and immediate availability. A microprocessor/array processor (or FFT chip) will be used at a later date.

The signal flow used to accomplish a complex fast Fourier transform (FFT) on the data signals and to decode the signals is indicated in Figure 8. The signal spectrum is obtained from the FFT and then decoded by using an inverse of the previous encoding algorithm. Depending upon the encoding algorithm, various error correction or error detection schemes may be incorporated in the decoding process. The symbol output is the binary 4 bit signal that was originally the input.

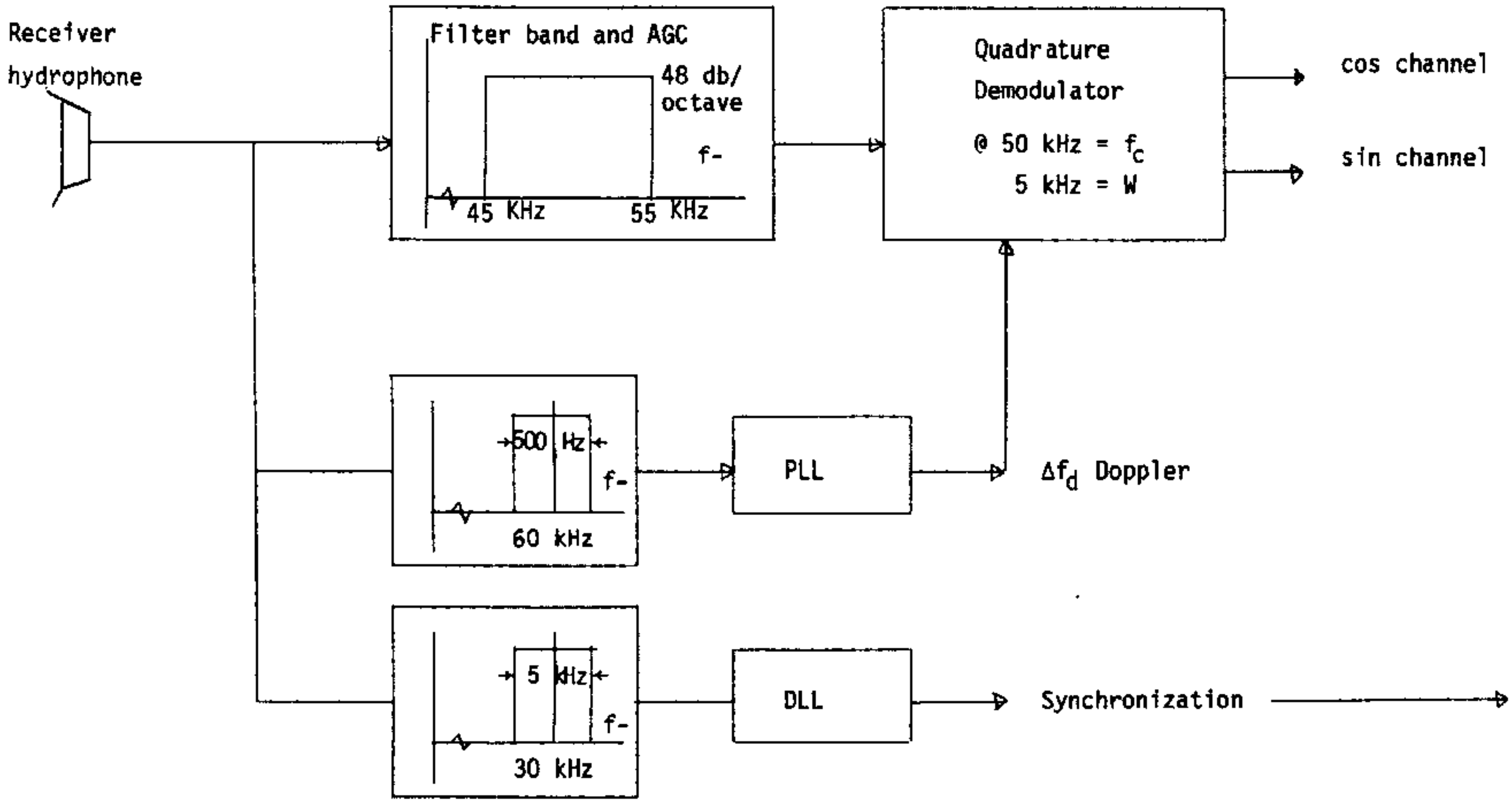


Figure 6: Receiver System Front End Block Diagram

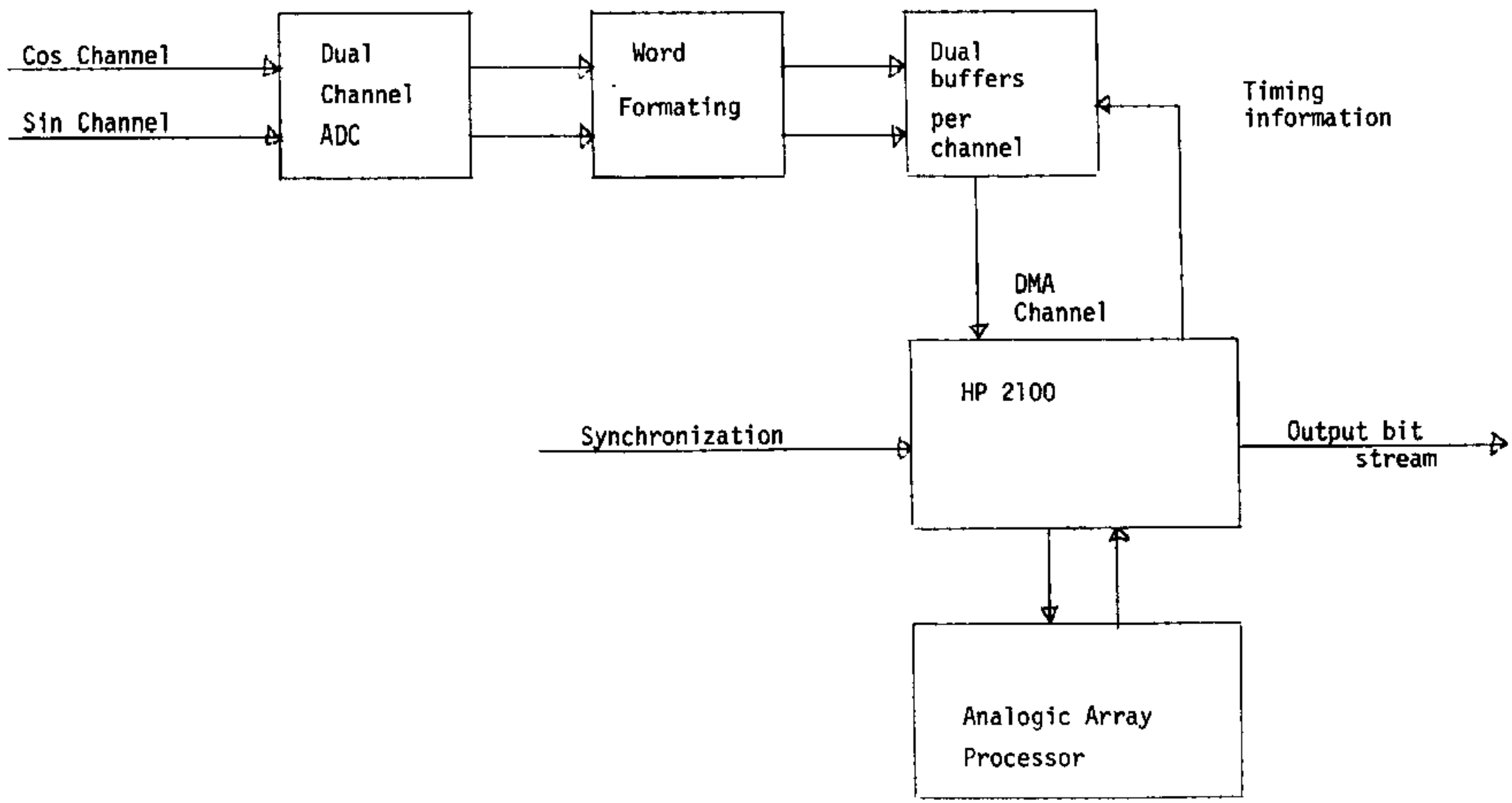


Figure 7: Decoding Hardware

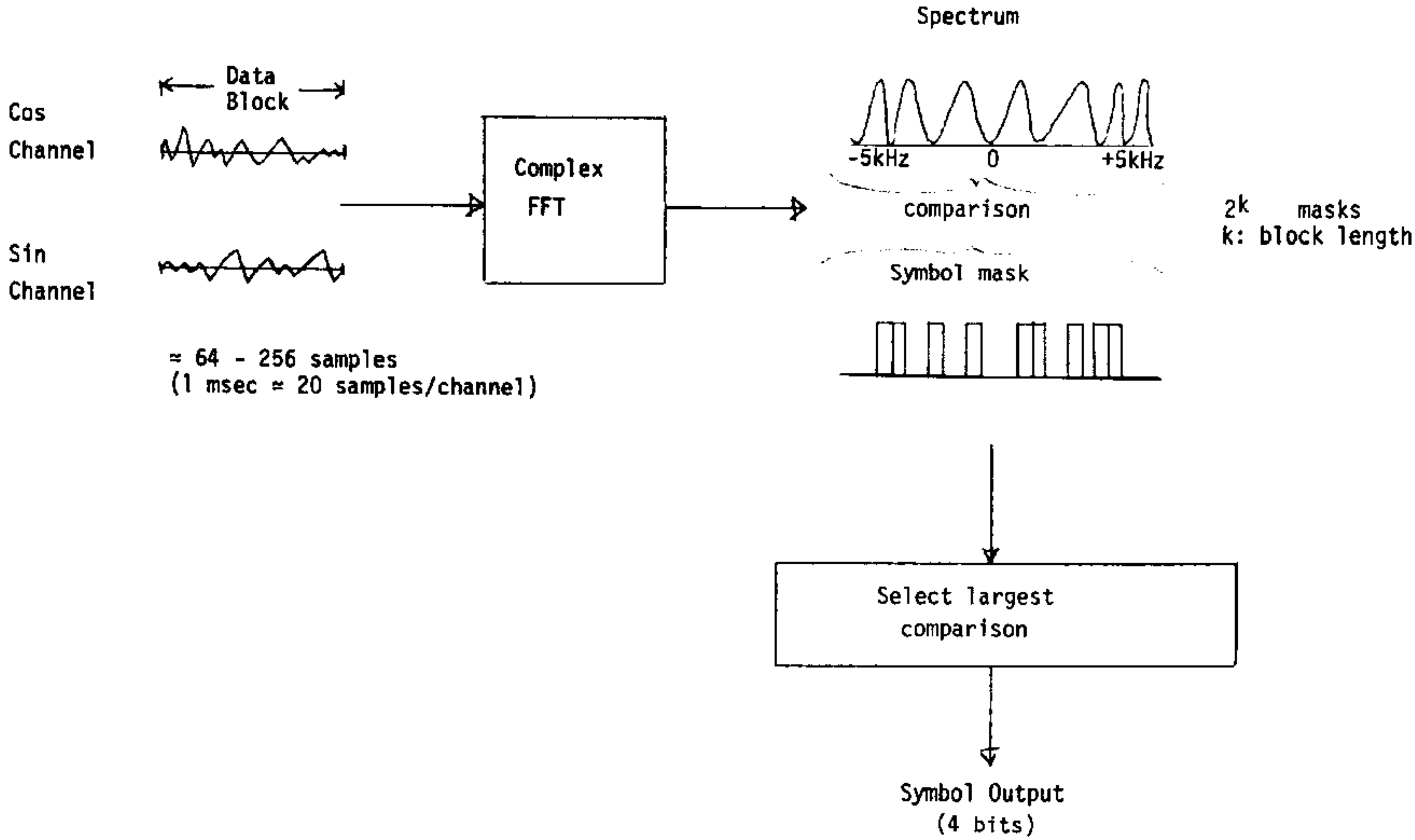


Figure 8: Signal Flow in the Decoder

4.0 SUMMARY

A functional prototype of a new "sonar modem" is undergoing preliminary testing. The leading edge technologies being used to implement the system allow programmable modifications of the system to suit a range of data communication needs. Since the development program is continuing for another year, comments and suggestions concerning user needs and applications are welcome.