COMMAND AND DATA SYSTEM FOR AN UNDERSEA DREDGE

THOMAS E. LINDERS
Senior Staff Engineer
Lockheed Missiles & Space Co.

Summary. By the use of commercial equipment whose original purpose was to provide alarm monitoring (fire and burglar) over telephone lines, a command and data system was constructed to control an undersea dredge. The system was designed around the Larse Corporation Data Communicators (trademark), and only a PAM multiplexer and a digital demultiplexer were added to make the system perform. The system requirements were analyzed, and only after the candidate design was agreed upon were the ideas put to paper. The system was designed in modules, with the various components grouped according to their function, to simplify interconnecting and test/checkout. The system has performed well, no component failures have occurred to date, and all data and command functions have worked as expected.

Introduction. "Design a stepper-switch command and data system for an undersea dredge" – those simple words introduced the problem, which was not quite that simple. The system was to function from depths of 1000 feet (for test dives) down to several miles. A hollow pipe and cable were to connect the dredge to the ship. Because of the high interest in the dredging operations and the desire to protect the uniqueness of the mechanical and hydraulic designs, only the electrical portion of the design will be discussed. The data link system was to be of simple design, involve minimum cost, and be repairable in minimum time.

Design Requirements. In order to implement a design, a set of requirements (and "desirements") was established:

System Requirements:

Commands	About 32 (plus spares)/1 time per second
Data	About 32 (plus spares)/1 time per second
Power (primary)	115 V, 60 Hz, single phase
Load current	As needed
Command types	Discrete; switch closure
Data range	0 to 5. 1 V (20 mV steps)
Command constraint	Reject rather than execute false commands
Cable	Two twisted pair shielded

System Desirements:

Simple system (one or two men to operate)
Fast repair time (less than 1 hour)
On-line monitoring of all functions (considerable diagnostics)
Easily obtained parts
No design frills
Use of existing designs where possible

The requirements and desirements, not excessively strict in magnitude, left considerable latitude in the means of finding the best system. Normally, requirements are originated by a systems organization, but on this project our systems organization consisted of one man to handle the paperwork, myself, and one or two other mechanical designers.

Systems Considered. Several systems were considered for both the command and data functions, each within a price constraint of $10,000 to $20,000. The pros and cons of each system, as follows, were listed and evaluated:

1. Command Function:
    a. Stepper Switch Command System: This system, shown in Fig. 1, is simple and inexpensive, but -
        (1) The system operates slowly.
        (2) More than one twisted pair shielded is required.
        (3) The monitoring of a large number of commands is difficult.
        (4) The stepper requires that a high pulse current be sent down the cable.
        (5) The system requires that each action be done in sequence.
    b. Touch Tone Command System: The touch tone system, as used on a telephone, requires very little equipment and is inexpensive. The system, shown in Fig. 2, overcame the major disadvantages of the stepper switch system in that it required only one twisted pair shielded and produced no major cable transients, but -
        (1) The system operation is slow.
        (2) Each action must be done in sequence.
    c. Digital Command System: This system, shown in Fig. 3, was the system selected, for the following reasons -
        (1) It is fast.
        (2) It has no series actions.
        (3) It is inexpensive.
        (4) It is simple to implement.
        (5) It is easy to maintain.

This system is described later, under System Design.

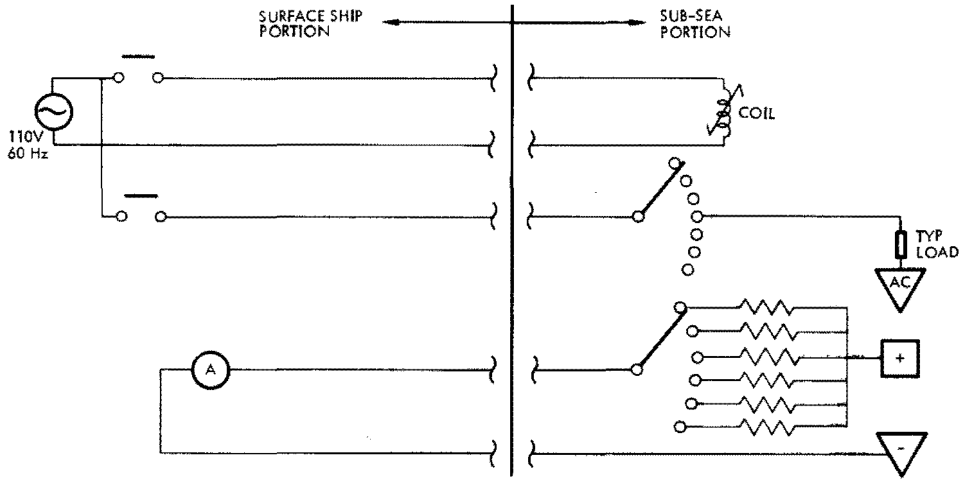

Fig. 1 - Stepper Switch Command System.

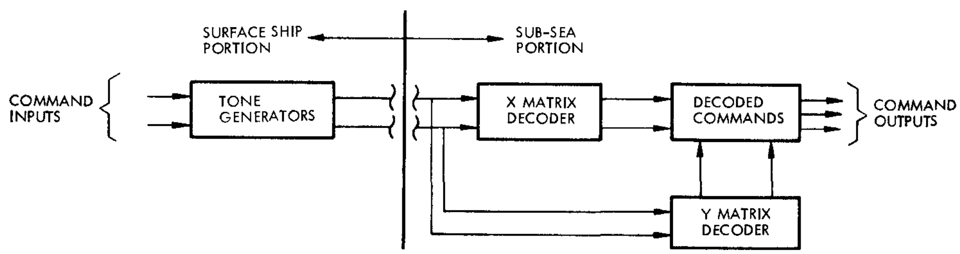

Fig. 2 - Touch Tone Command System.

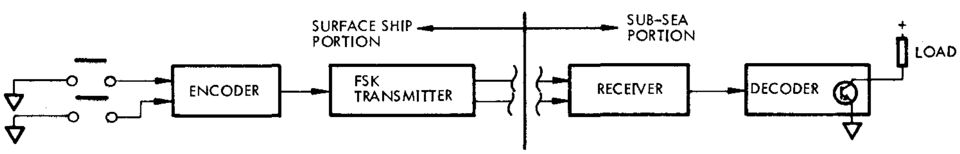

Fig. 3 - Digital Command System.

2. Data Function: Several alternatives were also considered for the data function:
   a. Stepper Switch Data System: A stepper switch data system, Fig. 4, is configured similar to its command system counterpart. This system, although simple and inexpensive, has several drawbacks:
      (1) It requires more than one twisted pair shielded.
      (2) High cable transients exist.
      (3) The cable AC voltage would interfere with the system.
      (4) Operation is slow.
      (5) Only one data point exists at one time.

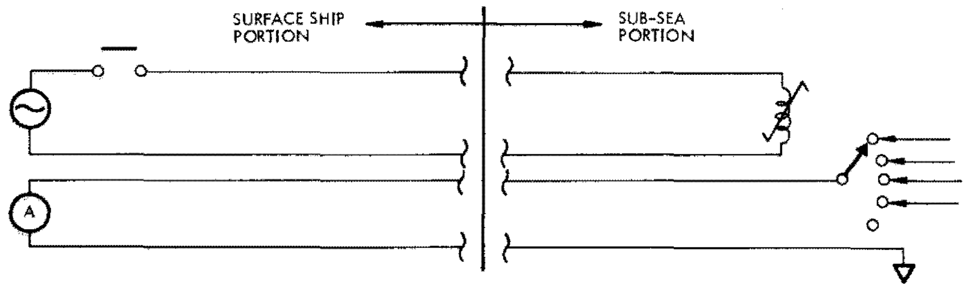

Fig. 4 - Stepper Switch Data stem.

b. PAM Data System: This system, Fig. 5, is a slight modification of the stepper switch data system, and has eliminated all of its drawbacks. However, the PAM data system is a DC system; and with the 60 Hz power on, the cable would offer interference.

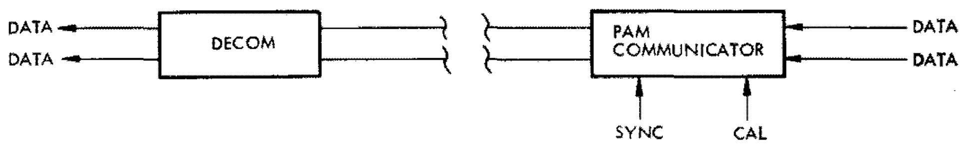

Fig. 5 - PAM Data System.

c. Digital Data System: This system, Fig. 6, is the exact opposite to the command system shown in Fig. 3. Since it uses the same parts as the command system, which simplifies the spares problem, and it meets all system requirements and desirements, it was selected.

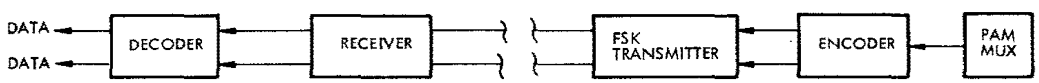

Fig. 6 - Digital Data System.

System Design. With the selection of an FSK digital system for the command and data function, it was a simple matter to select the major system components (Fig. 7). Larse Corporation in Palo Alto supplied the basic parts of the data system, as their equipment was available off-the-shelf, required no modifications, and had a good history. The heart of their system is a Data Communicator. This unit takes 16 inputs and, at the other end, supplies 16 outputs. The data multiplexer was supplied by LMSC; it has been used on several space programs with excellent results.

The power supplies were commercial units. A central system was used for the surface ship and another identical unit for the undersea portion. The analog demultiplexer and the test/monitor function were designed to fit the system.

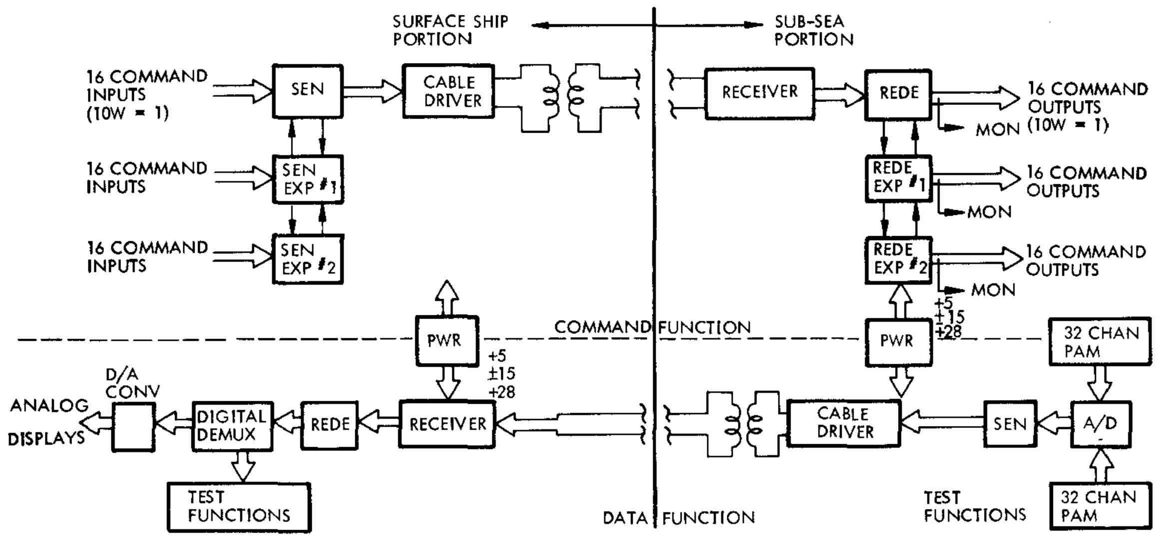

Fig. 7 - Selected System Design.

a. Cable Transmitters: The output of the SEN (scanning encoding) is 1V peak-to-peak FSK, with an output impedance of ≈600 ohm. Since the cable is a twisted-pair shield (AWG 16) with Z_o = 89 ohms, it was necessary to provide an impedance matching device to properly drive the cable (Fig. 8). One of these units was provided for the data portion (sub-sea) and one for the command (surface ship) portion.

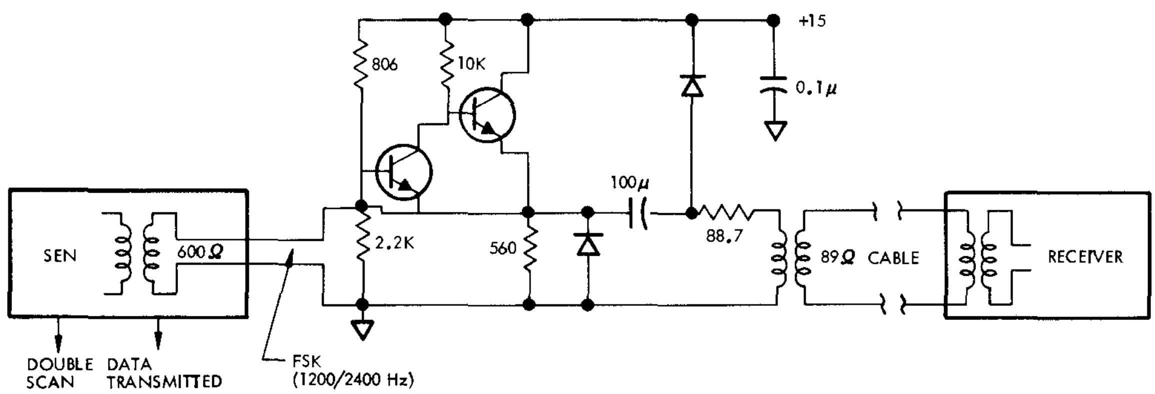

Fig. 8 - Cable Driver Receiver.

The heart of the system is the SEN units. These units accept 16 bits on the input in several different circuit configurations. The configuration selected was to use mechanical switch (or open collector) closures. This configuration was selected because it appeared to be the most versatile and required no signal conditioning outside of the unit (Fig. 9). The switch closure configuration was used in the surface ship to allow the operator to input to the SEN unit by merely closing a switch. The open collector inputs were used on the sub-sea data function, as it was the easiest to implement.

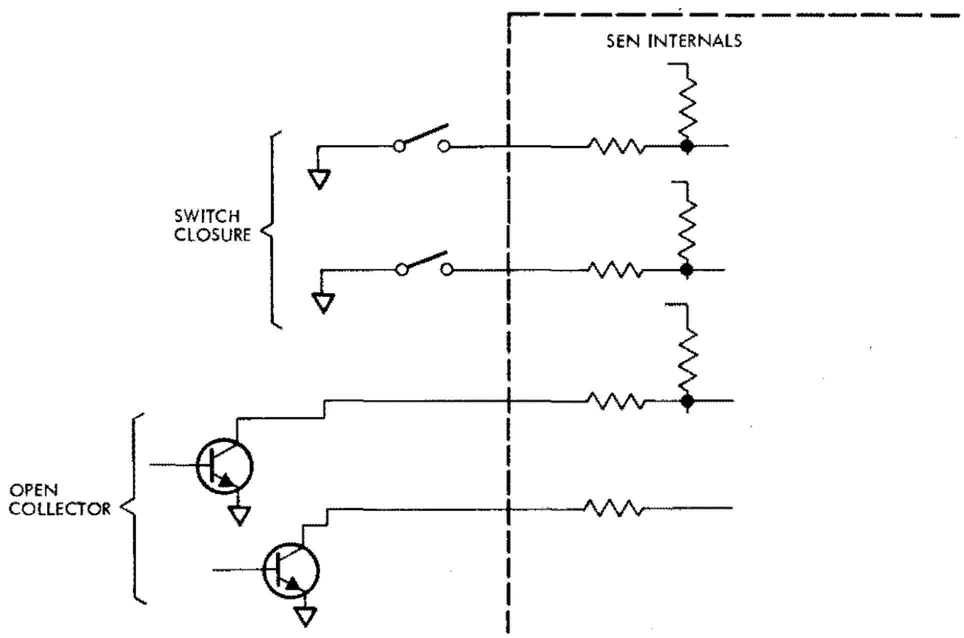

Fig. 9 - SEN Input Circuit Configurations.

The SEN unit takes the 16 data inputs, multiplexes them with 18 clock pulse, and outputs 34-bit Larse code. This code (Fig. 10) assures that the system will not lose sync. The SEN unit thus transmits 16/34 = 47.1% of the number of bits; thus for every 1200 bits sent per second, 564.706 are "usable" for data. A summary of the system usefulness capability appears on Fig. 11.

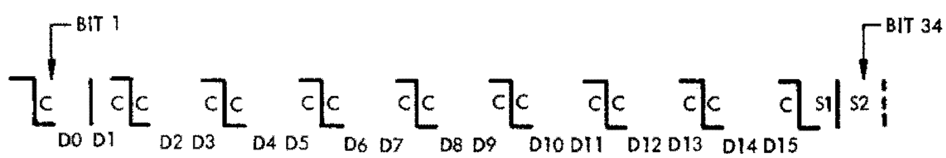

Fig. 10 - Larse Code.

B/S TOTAL	WORD EFF	USEFUL B/S	NO. OF 16 BIT WORDS PER SEC 1 SCAN	NO. OF 16 BIT WORDS PER SEC 2 SCAN	TIME* FOR 1 DOUBLE SCAN	TIME FOR 3 DOUBLE SCANS	CMDS PER SEC	DATA WORDS PER SEC
1200	16/34 = 47%	564.71	35.29	17.65	57mS	170mS	5.88	35.29

Fig. 11 - System Usefulness (1200 B/S).

Several features of the SEN unit were used in the system design. For instance, the unit puts out a timing signal during the 34th bit to indicate that a group of data has been transmitted; this pulse was used in the data system to "step" the analog multiplexer to its next position. This and other features are described in the command and data sections following.

The SEN unit output is a frequency shift-keyed signal. This signal, obtained from an internal oscillator, is 1200 Hz for a data “0” (input open) and 2400 Hz for a data “1”. Since the data rate is 1200 b/s, a “0” has one transition and a “1” has two transitions.

b. Cable Receiver: The receiving systems consist of a cable receiver and a REDE (receiving decoding) system. The receiver accepts the cable output (in this case ≈ 100 MV peak-to-peak), performs an AGC function, conducts a sensitivity check, and presents “cleaned up” FSK data to the REDE unit.

The REDE unit accepts the FSK data, demodulates it, checks for single or dual scan, and outputs the 16 bits of data. Immediately after the data have been outputted, a “here it is” timing pulse is present. This pulse is used on the surface ship to steer the data. The data output from the REDE unit is an open collector transistor - low if the data output is a “1” and high if a “0” - exactly the same as the input to the SEN units.

c. Command Function: Input of the SEN units in the command system is switch closures to the SEN unit return. A requirement of the command system is that the system not execute a false command; it is preferable that no command be executed rather than a wrong one. This operation is handled in the command system by sending every 34-bit message two times prior to “moving on.” Since it was desired to have about 32 commands plus spares in the system, the system was designed with 48 discrete inputs arranged in 3 groups of 16 each. This was mechanized by using one SEN unit as the primary unit and two SEN expanders. This configuration can be further expanded so that as many groups of 16 commands as desired can be wired into the system. If, in the future, it is desired to go beyond 48 commands, it will be a simple task to wire in additional units.

Each of the three REDE units is wired for a double-scan mode. Each unit is scanned two times, and then the next unit is addressed and the process repeated. Each unit is scanned two times in 68/1200 second (57 ms), with the whole cycle for the 48 commands taking 204/1200 second (170 ms). If a command is changed in the middle of a scan, it will be rejected at the receiving end and picked up in the next cycle (170 ms later).

The receiver, the REDE unit, and the two REDE expanders are at the receiving end of the command system. They are wired to perform the inverse of the SEN and SEN expanders. They take the Larse code, investigate it to ensure correctness, scan the message two times and, if identical, dump the message to the output. The last two bits of the message are checked to see if more than one unit is being used; if it is, the next unit is gated on for the following message. Each unit checks each of its messages two times and passes the message along.

The SEN unit outputs are open collector transistors that can accommodate ≈ 25 mA from a 28 V source (Fig. 12). Each of the 48 outputs has a Hewlett-Packard resistor LED on the output so that the command link can be checked. A push-to-test switch is installed, and the 5 V to the LEDs is switched to reduce the power being drawn after the unit is sealed.

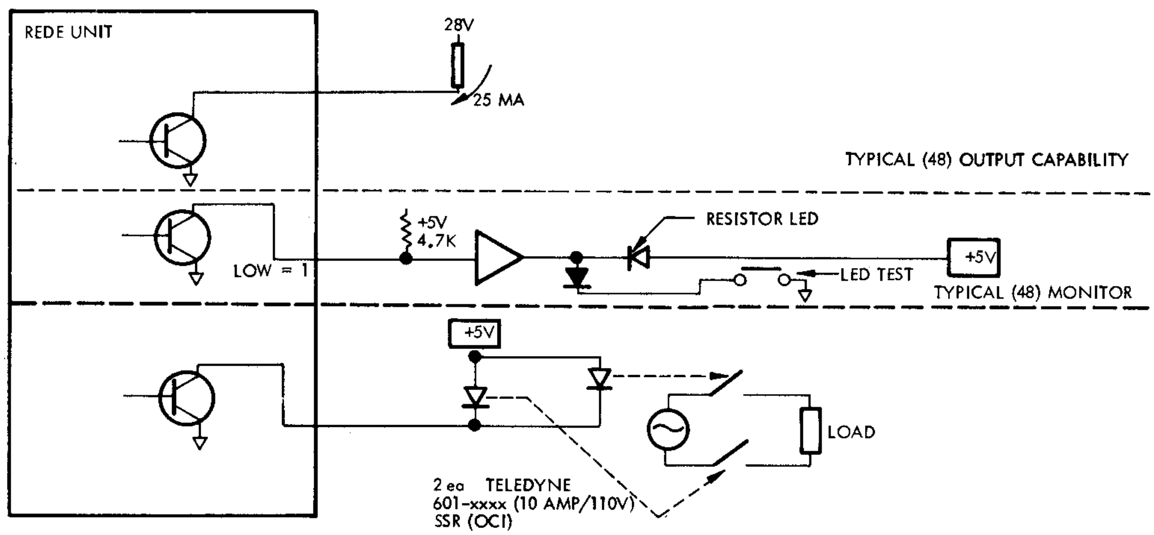

Fig. 12 - REDE (Command) Unit Outputs.

Resistor LEDs, test points, and controls are also installed in the following places as health and status indicators.

	Device	Purpose
Surface Ship	Norm/Reset Switch	Forces All Commands to "0"
	Transmit LED	Visual Indicator of System Status
	SEN Sync Test Point	Scope Sync for Trouble-shooting
	SEN EXP 1 Code LED	Visual Indicator of EXP Status
	SEN EXP 2 Code LED	
	SEN EXP Code Test Point	
	SEN EXP Code Test Point	Test Point for Troubleshooting
Sub-Sea Portion	Carrier Present LED	Visual Indicator of Data Present
	REDE Code LED	Visual Indicator of Binary Data Present
	REDE Sync Test Point	Scope Sync for Troubleshooting
	REDE Code Test Point	Test Point for Troubleshooting
	Norm/Reset Switch	Forces all Command Outputs to "0"

d. Data Function: The data function was implemented with the Larse SEN, receiver, and REDE units, just as was the command function; but the input to the system was 8-bit PCM data, obtained from two 32-channel PAM multiplexer boards through an analog-to-digital converter (Fig. 13). One board, in addition to the multiplexer, also contained the timing circuits and an ADC-10Z analog-to-digital converter. The output from this converter, as well as the six timing outputs (F0 through F5), was delivered to a signal conditioner board prior to being transmitted link.

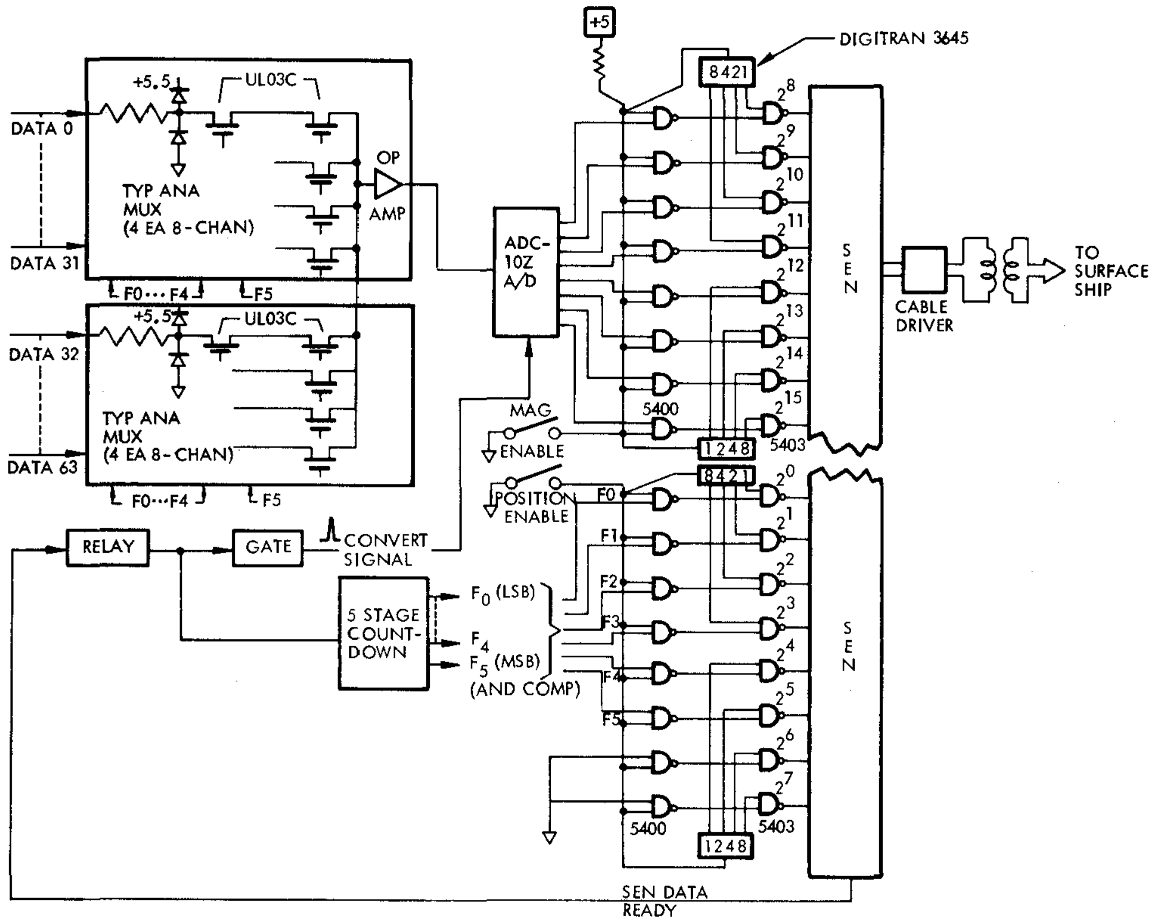

Fig. 13 - Data Function, Sub-Sea.

A PCM telemetry system is not difficult to design, but in this instance one was desired that required no synchronization word insertion and the inherent demultiplexer problem. Also, ease of maintenance and test was a desirable feature. Since the system only needed to "see" each data point every 1 or 2 seconds, it seemed natural to use the entire 16-bit word that was being transmitted. In the first 8 bits were inserted two 0s and F0 through F5 (the count of the analog multiplexer being sampled). In the last 8 bits was the analog-to-digital converter 8-bit output. This simple method allowed one to nearly look at F0 - F5 on the surface ship and use those 6 bits to steer the 8-bit digital data. The demultiplexer was implemented by using parallel in/parallel out shift registers with individual, inexpensive 6-bit digital-to-analog converters on the output. The outputs drove analog meters directly. Figures 13 and 14 shows the data function.

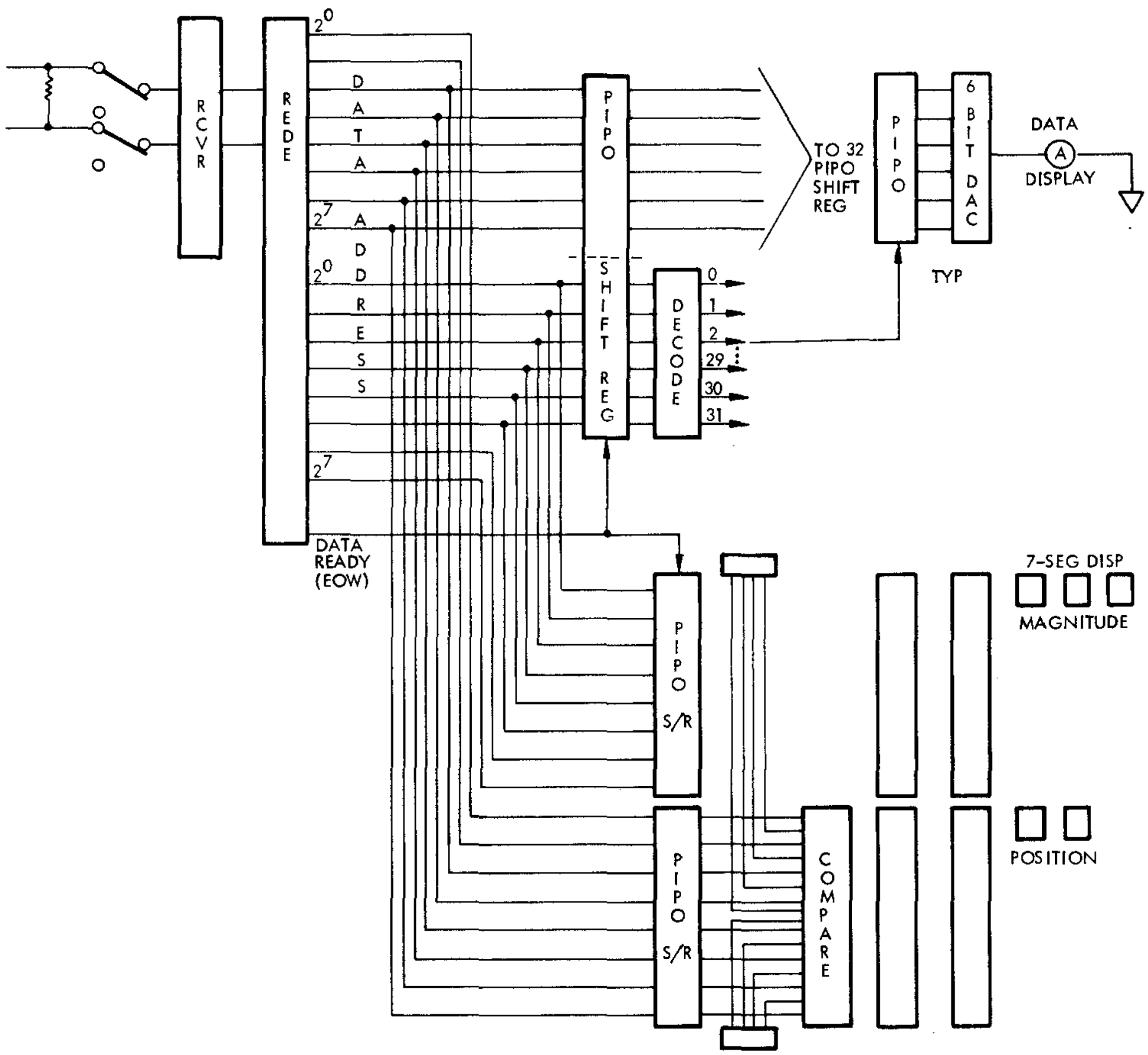

Fig. 14 - Data Function, Surface Ship.

The system works as follows: Upon sampling the data, the SEN unit generates a pulse to indicate end of word (EOW). This pulse is counter one position. Since the SEN unit sequentially samples the input data, there is plenty of time for the counter to settle. After the counter settles, the desired PAM multiplexer gate is opened and the data are sampled by the analog-to-digital converter. The output of the converter as well as F0 - F5 (the timing signals) are run through two 5400 (NAND) gates. The data can be inhibited by one of two switches so that the contents of two and/or four Digitran switches can be transmitted uplink in place of the data and timing signals. This feature allows the insertion of either fixed data or timing bits to aid in fast troubleshooting of the system.

At the top end of the cable, the REDE unit outputs the data and generates a dataready (or EOW) pulse. The data are split at the top side and diverted to two places - to a fixed decommutator and to a dial-up decommutator.

The fixed decommutator is hardwired to accept the six most significant bits of the magnitude data and the entire 8-bit position word. The EOW pulse is used to strobe the data into the decommutator boards, the position bits are then decoded, and a delayed EOW pulse strobes the data through a selected (by position bits) parallel in - parallel out shift register. The output of this shift register is hardwired to a 6-bit digital-to-analog converter (Mono DAC-01HS). The reason for continuing with a digital system was to eliminate the need for PAM data and the attendant sample and hold circuits. In our method the data remains in digital form to the very end. The 6-bit rather than the 8-bit DAC was selected because the cost of an 8-bit DAC is more than four times that of a 6-bit DAC and we only wanted to drive 1% meters. It is doubtful that the operator can see the difference (our least significant bit is 20 mV).

The other part of the decommutator is used for test only. It consists of a toggle switch and two 4-bit Digitran switches. The toggle switch allows the data display to either free run or freeze in a position. In the free-run state, the magnitude bits are strobed through and cause two seven-segment LEDs to continually count from 00 to the highest data channel used (31). Also displayed on three seven-segment LED displays is the value, in counts, that is in the data channel. In this mode the displays are continually active. In the freeze state, the display locks on a specific word until released or until the word number is changed.

Besides the on-line monitoring of the data, the following test, control, and monitoring capability is provided:

	Device	**Purpose**
Surface Ship	Record/Playback Switch	Select Data Source
	Cable Monitor Test Point	Monitor Cable at Receiver Input
	Carrier Present LED	Visual Indicator of System
	Receiver Code LED	Visual Indicator of Data
	Force OFF Switch	Forces All Data to “0”
Sub-Sea Portion	Force ON/OFF Switch	Forces All Data to “1” or “0”
	SEN Code LED	Visual Indicator of Data

e. Packaging: Both sections of the system were housed in 19-inch relay racks. The power supplies for the system were contained in separate sections; 110 V/ 60 Hz was the common input. The power outputs were +/-15 V, +5 V, and +28 V.

The Larse cards were the driving force for size; five were used in each section. These cards were 4-1/2 in. high by 9-1/4 in. long. Since the 32-channel analog multiplexer was an existing design, it was decided to use the existing art master and add the timing circuit and analog-to-digital converter. For the standalone multiplexer, only the multiplexer parts were added to the board. For the remaining cards, Cambion wirewrap boards were selected, with provisions for 64 16-pin display information processors.

For the individual digital circuits T^2L was used, even though it is much faster than required.

Since separate power supplies were used, each board had at least 100 µF of local decoupling on each voltage; also, a number of 0.1 µF decoupling capacitors were "sprinkled" about the boards. To ensure that there would be no problems with one shots, each one shot used had 0.1 µF capacitors from Vcc to ground across the back of the chip.

An illustration of the surface-ship panel is shown in Fig. 15.

The system has performed extremely well. In the year that it has been in operation, no false commands have been issued, no displays have had a case of "hiccups, " and none of the parts (all commercial) have failed.

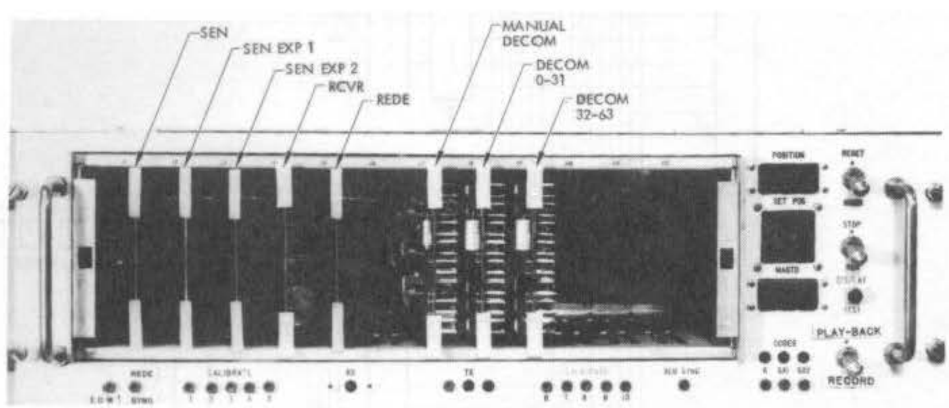

Fig. 15 - Surface Ship Panel.