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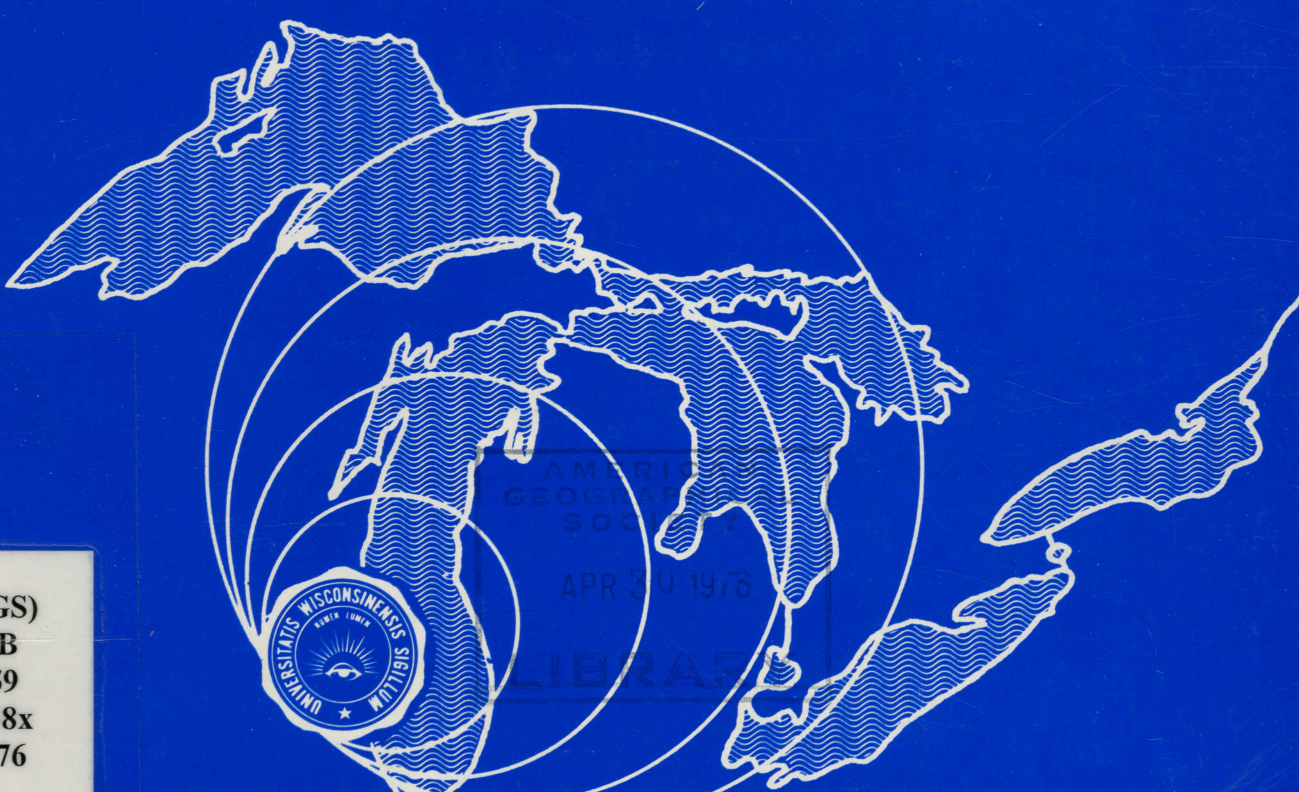

MILWAUKEE, WISCONSIN 53201 U.S.A.

SPECIAL REPORT NO. 26

An Underwater Temperature-Depth Data Collection Device

by

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ABSTRACT

An underwater probe has been constructed which, when towed by a vessel, transmits temperature and pressure (depth) information to a receiver and recorder on deck. A carrier signal, which is frequency modulated by temperature and pressure, is sent up the towing cable which also is used to conduct power to the probe. The on-deck receiver records the modulated carrier signal on a low-cost cassette tape recorder. The temperature and pressure information are demodulated and can be monitored or recorded as voltage analog outputs.

AN UNDERWATER TEMPERATURE-DEPTH DATA COLLECTION DEVICE

INTRODUCTION

During the period of 1969-1971, under a U.S. Army Corps of Engineers Contract (Mortimer 1972), a towed submerged temperature-depth profiling system was developed. It was designed as a low-cost, semi-portable data collection device with a small, streamlined body that could be towed at speeds up to 16 mph. A one-eighth inch diameter, counter spiral wound armoured cable with a single center conductor was used to carry the probe power and data. To equip the system with record and playback capabilities would have increased the system cost and complexity considerably. Therefore the system was designed with digital telemetry and digital data recording with record-only capabilities and no provision for on-station checking of recorded data quality.

This first generation system was used during September through November of 1971 to gather temperature structure data of the cross section of Lake Michigan from Milwaukee, Wisconsin, to Ludington, Michigan. The equipment was installed aboard the Grand Trunk Railroad car ferry S.S. MADISON. Fifteen transects were made and an isotherm depth plot was constructed for each transect (Mortimer 1972).

During the International Field Year for the Great Lakes Program of 1972, a second version of the system was used for the investigations of the internal temperature structure of Lake Ontario. The equipment was installed aboard the NOAA ship RESEARCHER, and during three separate five-day cruises, a total of 75 transects were made. Analysis of this large body of data is in progress (Mortimer and Cutchin 1974).

A third version of the system considerably modified by the author, described here, uses the same winch, cable, and sensor body, but employs frequency modulated carrier signals to transmit continuous data from the submerged sensor to the on-deck electronics. Demodulated voltage analog outputs from the on-deck unit can be used to drive X-Y plotters or strip chart recorders. The recovered frequencies can be recorded and played back using an inexpensive cassette tape recorder. Accurate reproduction of the recorded data is achieved by recording a reference frequency to permit compensation for tape speed variations during playback. The recorded analog data can also be played back under laboratory conditions and digitized for computer analysis.

A method of recording identification numbers in the reference channel has been incorporated in the design. This is useful for correlating the playback with time-of-day and logbook entries.

The probe circuit and housing, the on-deck console, the winch and other mechanical equipment are shown in Appendix B. This report describes the probe and on-deck electronics only. The mechanical equipment, probe dynamics, and operating procedures have been fully described in an earlier report (Mortimer 1972).

SUBMERGED PROBE

Probe circuitry is divided into the following parts (Fig. 1):

1. a voltage regulator to condition and regulate the raw power being carried by the cable;

2. two voltage controlled oscillators to convert the two voltage analog channels to frequency among channels;

3. a bead thermistor and a bridge amplifier for temperature sensing;

4. a pressure transducer and amplifier for depth sensing; and

5. a signal mixer and amplifier for transmission of frequencies along the towing cable.

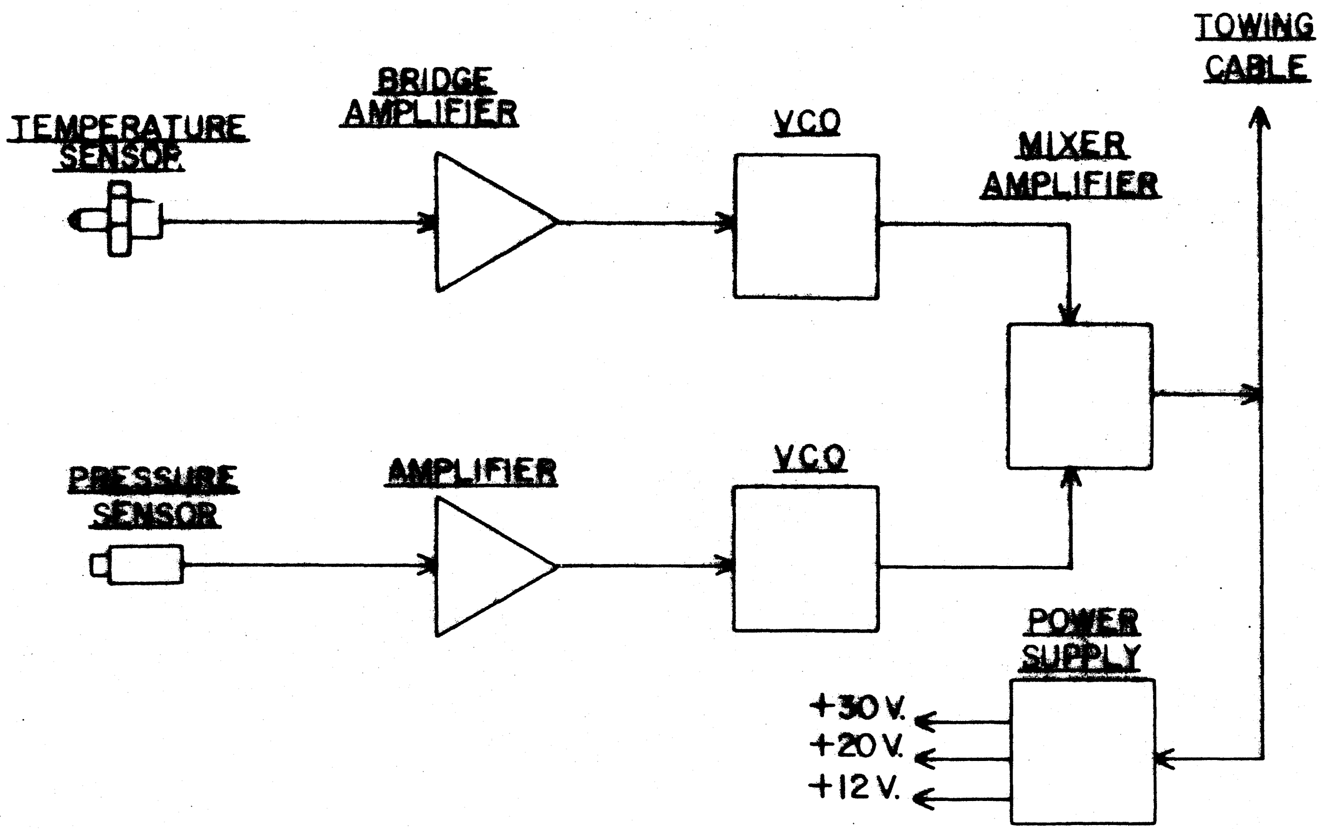


FIGURE I. SUBMERGED PROBE BLOCK DIAGRAM

Probe Voltage Regulator

The voltage regulator receives 35 to 50 volts, 50 ma, power from the towing cable. From this it generates regulated voltages of +30 volts for the pressure transducer, +20 volts for the signal mixer and amplifier, and +12 volts for the bridge amplifiers and oscillators. Protection against component failure and overvoltage is incorporated in the design. The primary 30 volt regulator of D2, Q2, Q1, and Q3 in Figure 2 limits the total output current to 50 milliamps. If for any reason Q3 becomes short circuited, a 30 volt zener diode D3 would clamp the primary voltage to 31 volts with the input current being limited by the internal resistance of L1, an 8 ohm resistor, and the cable resistance of 75 ohms. The inclusion of L1 gives the 30 volt regulator a high input impedance at the telemetry frequencies and prevents loading of the signal mixer and amplifier.

Voltage Controlled Oscillator (VCO)

The voltage controlled oscillator used is an Intersil ICL 8038 AC oscillator. It offers high stability against changes in temperature and supply voltage (30 PPM/°C, and 500 PPM/V_s). The FM linearity is 0.1% over a 1000:1 frequency range (Intersil 1972).

A unique feature of this oscillator is that the voltage thresholds of the internal comparators are a function of supply voltage. If the sweep input voltage is also a function of supply voltage, then the generator frequency becomes independent of supply voltage variations. The temperature oscillator is set for IRIG subcarrier channel 9 (3900 Hz ± 7.5%) and the pressure oscillator is set for channel 7 (2300 Hz ± 7.5%).

Temperature Sensing

The temperature sensor is a Fenwall GC32SM2 thermistor probe fixed to a Marsh-Marine watertight connector. The thermistor bridge (Fig. 3) is designed to give a linear output to within 0.5°C of the actual value at any

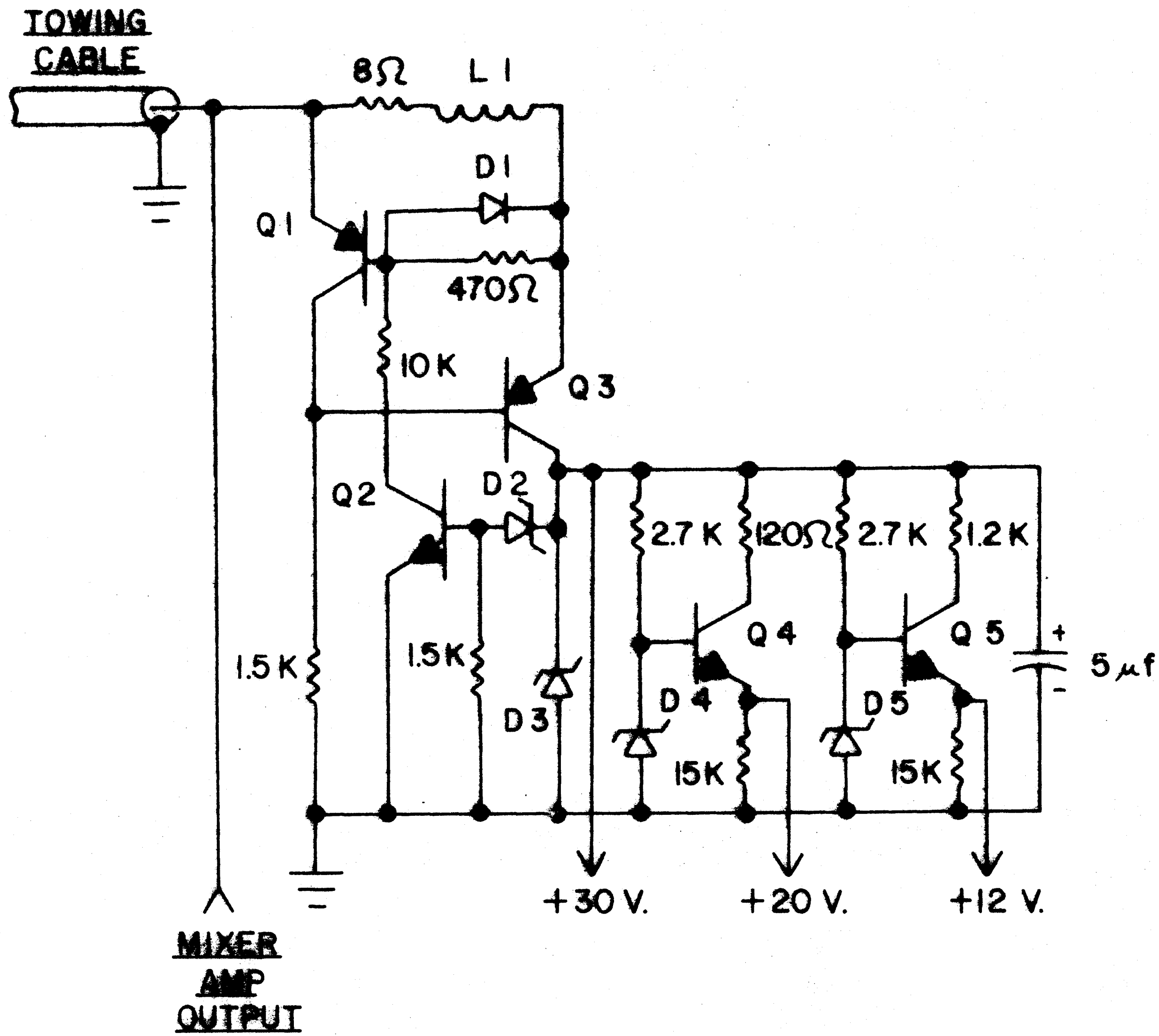


FIGURE 2. [redacted] VOLTAGE REGULATOR

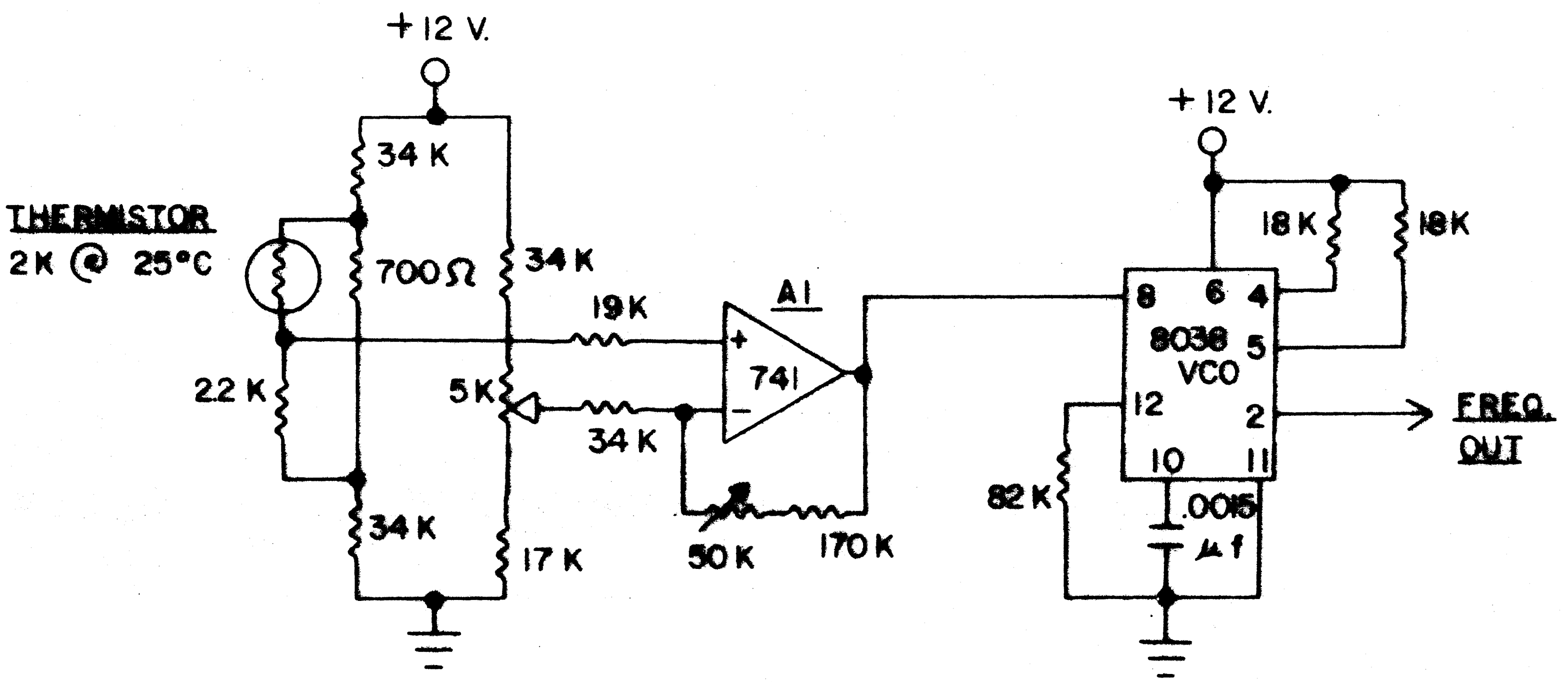


FIGURE 3. TEMPERATURE TO FREQUENCY CONVERTER.

point within the 0°C to 25°C temperature range. The entire temperature channel response to known temperatures can be measured and plotted if higher accuracy is needed. The time constant of the thermistor and connector assembly is approximately 50 milliseconds.

Since the bridge output is also affected by supply voltage, the input to the VCO is partially a function of supply voltage as required for good oscillator stability (see section on Voltage Controlled Oscillator).

Span and offset adjustments are provided to adjust the VCO full range frequencies to within the channel 9 bandwidth.

Pressure Sensing

The pressure transducer is a Statham Industries Model PA505-200. A full range pressure input of 0-200 psia corresponds to 0-5 volts D.C. The specifications of this transducer are given in Appendix A.

The resistor bridge and A2 (Fig. 4) ensure that the input to the VCO is related to the supply voltage for good oscillator stability.

Span and offset adjustments are provided to adjust the VCO full range frequencies to within the channel 7 bandwidth.

Signal Transmission

The frequency outputs from the VCO's are summed by amplifier A3 (Fig. 5) and transmitted up the towing cable. The amplifier uses a separate supply voltage to isolate the signal conditioning circuits from any electrical noise that may be present in the towing cable.

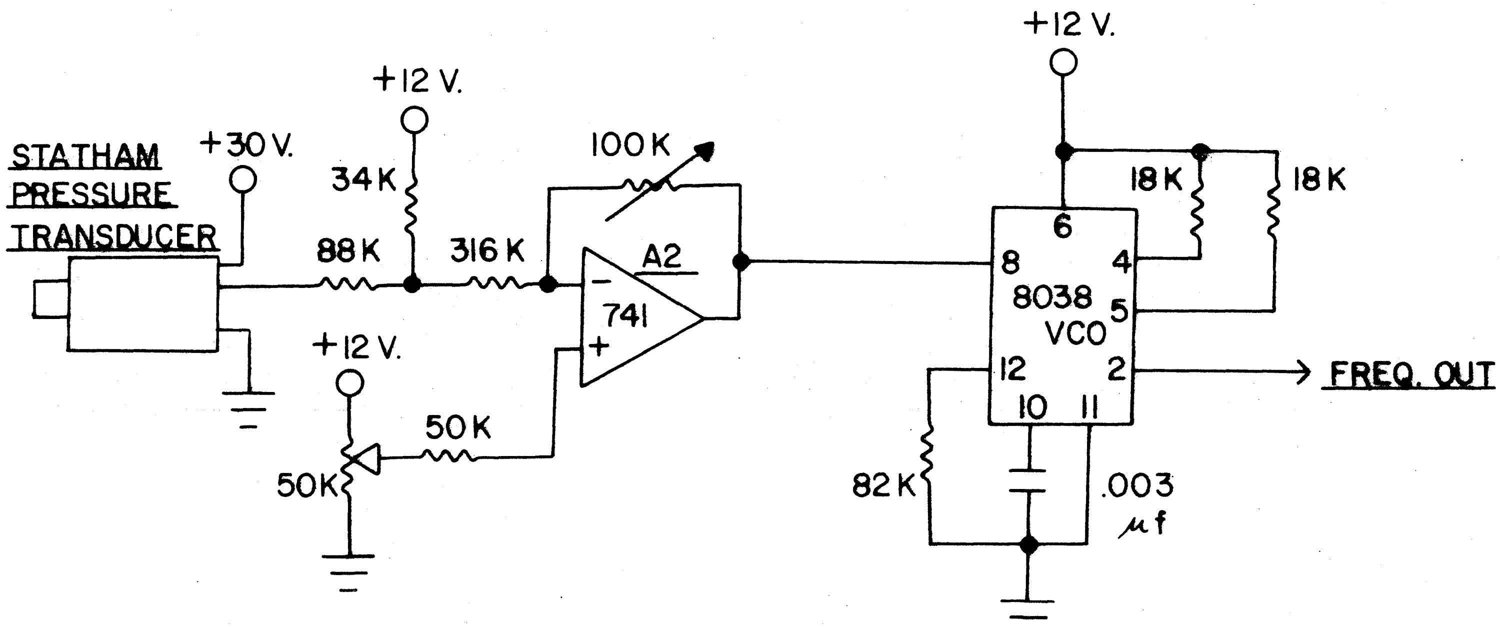


FIGURE 4. PRESSURE TO FREQUENCY CONVERTER

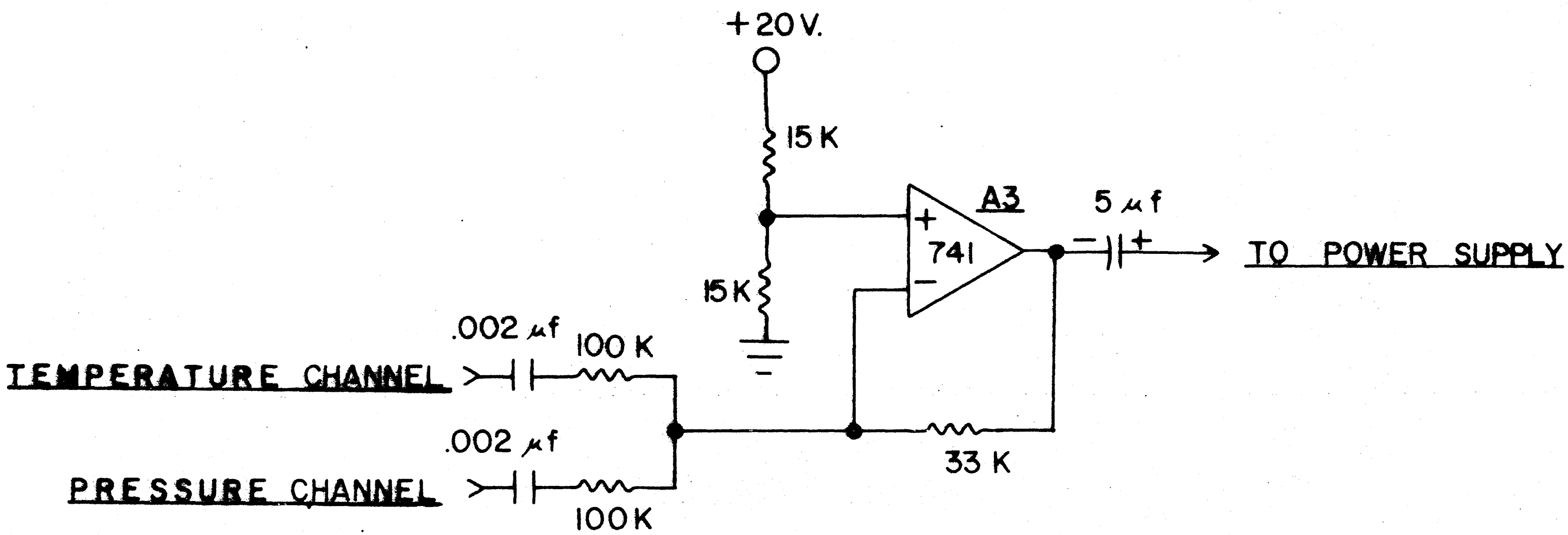


FIGURE 5. MIXER AMPLIFIER

ON-DECK CIRCUITS

After the modulated signals have traveled through a typically 3000 foot length of cable, considerable signal attenuation and addition of electrical noise has occurred.

The on-deck circuits (Fig. 6) receive and regenerate the weak and noisy carrier frequencies which were transmitted through the cable by the submerged probe circuitry. The regenerated frequencies are demodulated and the voltage analogs are available to drive display meters and strip chart or X-Y recorders. The regenerated frequencies can also be recorded on one track of a low-cost cassette stereo tape recorder with no loss of accuracy, because a reference frequency is recorded on the other track. During playback the reference frequency is used to remove the tape speed fluctuation errors from the demodulated data. The circuit used to demodulate the real time data is also used to demodulate the playback data.

The on-deck electronic package also records operator-selectable, three-digit identification (ID) numbers on the tape, using the reference signal as an amplitude-modulated carrier. During playback, as each ID number is encountered, a digital display is updated with that new number.

Power Supply

The power supplies in Figure 7 produce the following voltages and currents:

1. +5 V.D.C. @ 750 ma supplied by a Standard Power SPS30-5 supply;

2. +12 V.D.C. @ 70 ma and -12 V.D.C. @ 50 ma supplied by a Standard Power SPS30 ±15 supply; and

3. 45 V.D.C. @ 35 ma supplied by T1 and bridge rectifier.

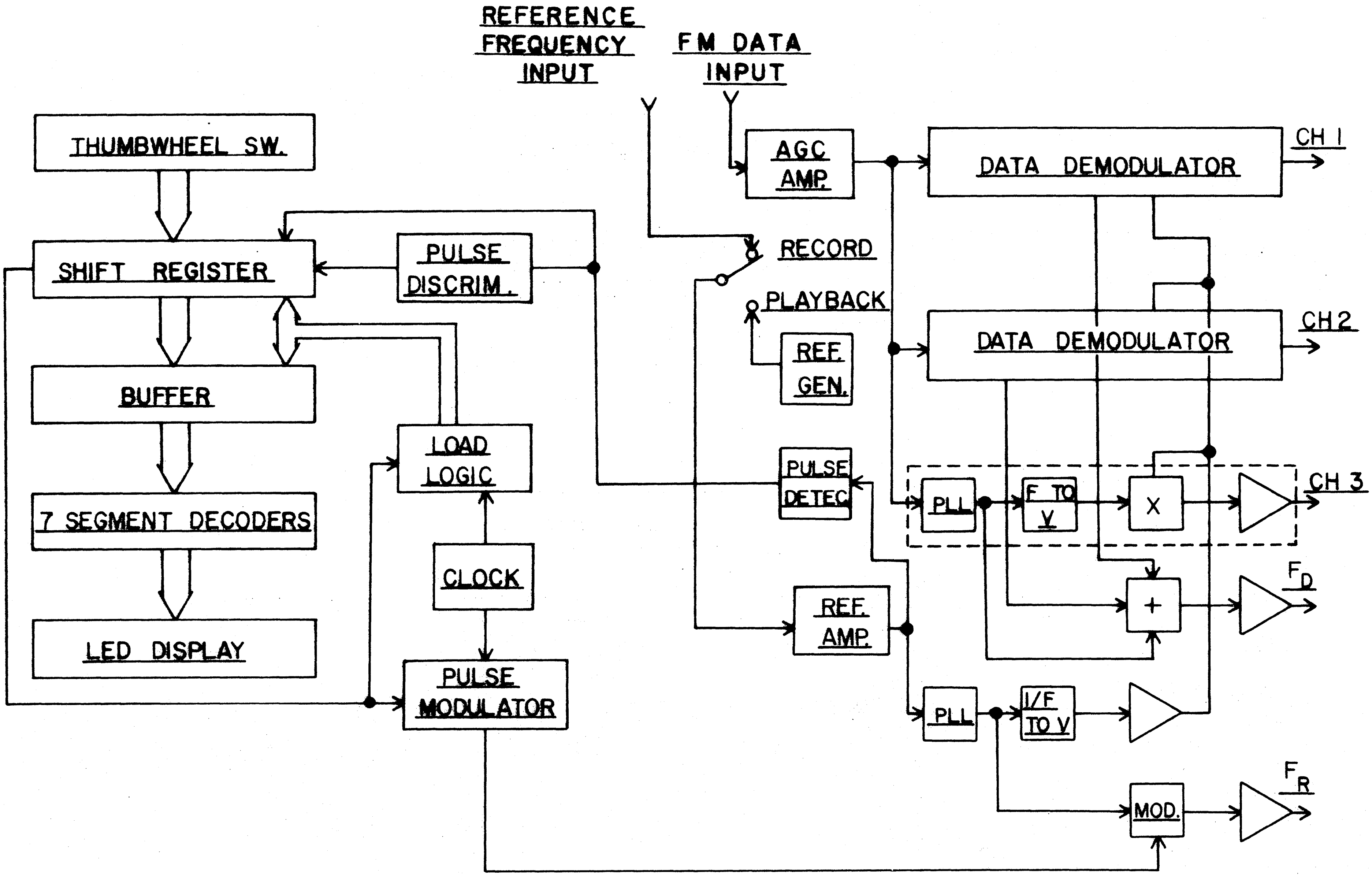


FIGURE 6. ON-DECK SYSTEM DIAGRAM

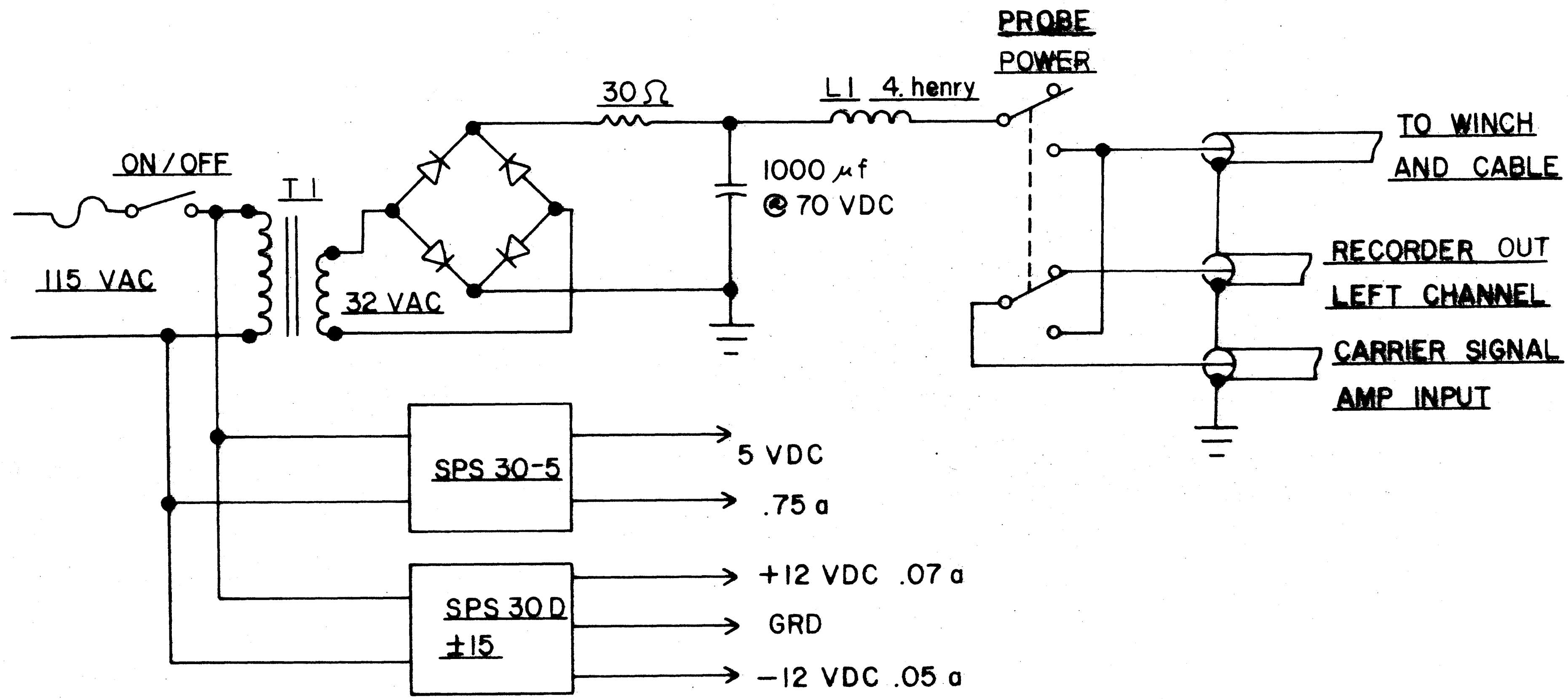


FIGURE 7. ON-DECK POWER SUPPLY

The impedance of inductor L1 is 5000 ohms at the carrier frequencies. The data signal is developed across this impedance and is sensed by the data signal amplifier. The secondary contacts of the probe power switch are wired to route real-time sensor data to the data signal amplifier when the probe power is turned on. With the probe power off, the input to the data signal amplifier comes from the tape playback output.

Frequency Modulated Data Recovery

The circuits for recovery of the frequency-modulated data consists of the following parts:

1. a data signal amplifier with automatic gain control;
2. a reference signal amplifier and limiter;
3. a reference generator;
4. an A.M. detector for ID number pulse data recovery;
5. a frequency selective reference period demodulator and reference signal amplitude modulator; and
6. three frequency selective demodulators and reference multipliers.

Data and Reference Signal Conditioning

The data signal from the submerged probe or tape recorder playback is amplified by A1 in Figure 8. The rectified, filtered, and amplified output of A2 drives Q1 to adjust the closed loop gain of A1 to maintain the output of A1 at a nominal 1 volt RMS. This constant level signal is distributed to the three frequency selective data demodulators. Amplifier A2 also drives light-emitting diode LED 1 for a visual indication of signal acquisition.

The reference frequency generator, DC1, provides a stable 5500 Hz signal in the IRIG subcarrier band 10.

The reference signal input to A3 comes, as selected by the record/ playback switch, either from the reference frequency generator or from the tape playback output. The reference signal is amplified and limited by A3 to 1.2 volts peak-to-peak and is distributed to the frequency-selective reference period demodulator and the reference signal A.M. pulse detector.

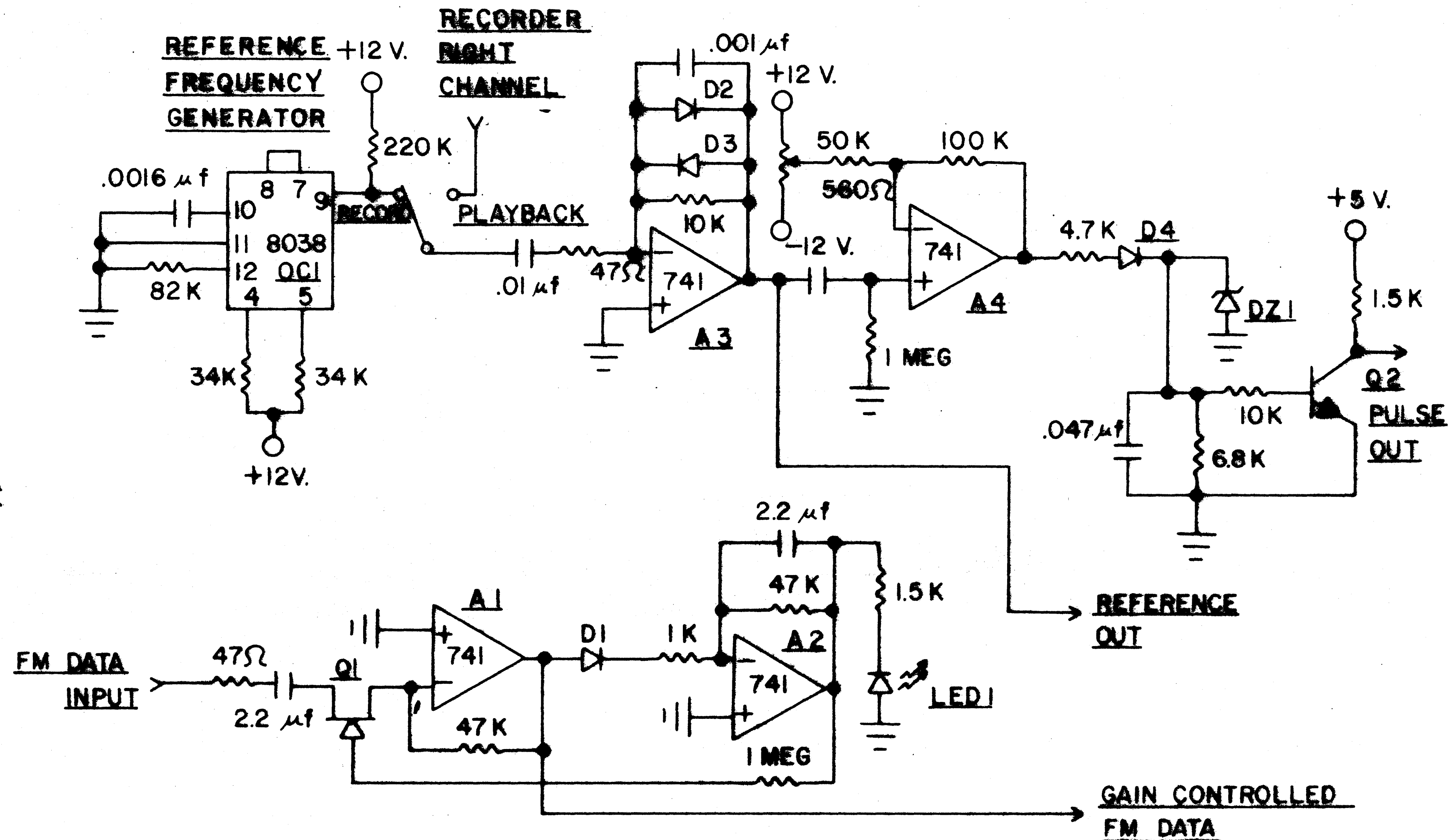


FIGURE 8. DATA AND REFERENCE AMPLIFIERS

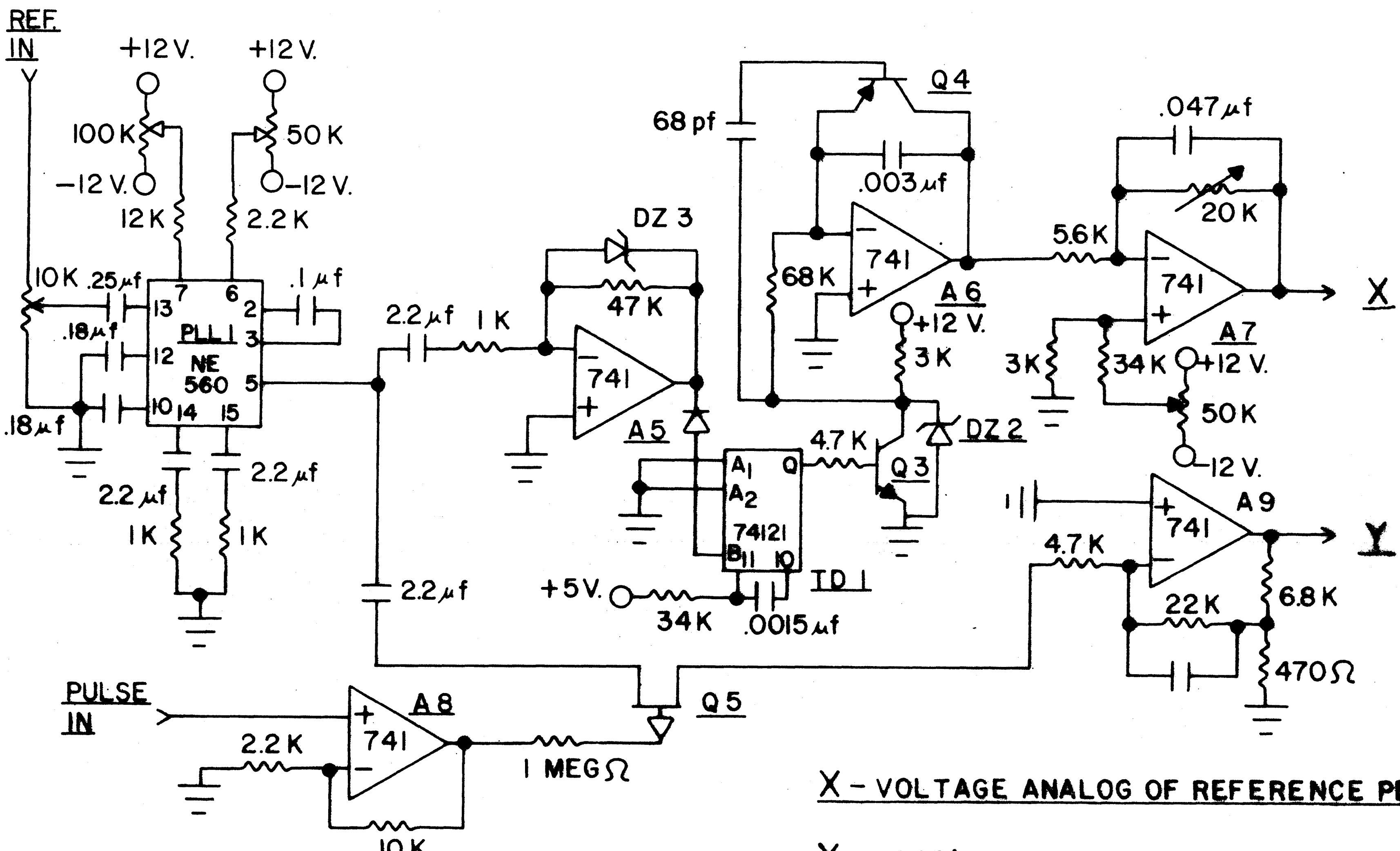
The conditioned reference signal is further amplified by A4, and the A.M. ID data pulses are detected and shaped by D4, DZ1, and Q2. The pulse data is then distributed to the digital logic which processes the pulse information.

Reference Period Demodulation

A Signetics NE560B phase locked loop (PLL) is used to selectively regenerate the reference signal. The design objectives are determined by the flutter and wow characteristics of the cassette tape recorder used. Using procedures outlined in the National Semiconductor Applications Note AN-46 (National Semiconductor 1972), PLL1 in Figure 9 was set up to provide a 33° loss-of-lock phase noise margin with a full-scale frequency response of 14 Hz and a damping factor of 0.707. The tracking range is ±10% of the center frequency of 5400 Hz with a capture range of ±7.5%. This is compatible with an expected maximum tape flutter frequency of 10 Hz and a 2% maximum excursion of the center frequency.

The regenerated frequency is amplified by A5 and triggers the monostable multivibrator TD1. The combination of TD1, Q3, and DZ2, generate a waveform of a variable period between pulses of precisely determined widths as shown in Figure 10. From this waveform, A6 and Q4 generate a linear sawtooth waveform with the amplitude, and therefore RMS value, proportional to the period of the driving frequency. The sawtooth wave is then amplified and filtered by A7 to provide a smooth D.C. voltage that is proportional to the period of the reference frequency.

The regenerated frequency from PLL1 is also passed through Q5 and amplified by A9 for the right channel input of the tape recorder. Pulse width modulated ID data is amplified by A8 which turns Q5 off and on. The result is 100% modulation of the reference signal being recorded on magnetic tape.



X – VOLTAGE ANALOG OF REFERENCE PERIOD

Y – REGENERATED REFERENCE SIGNAL WITH DATA MODULATION

FIGURE 9. REFERENCE PERIOD DEMODULATOR

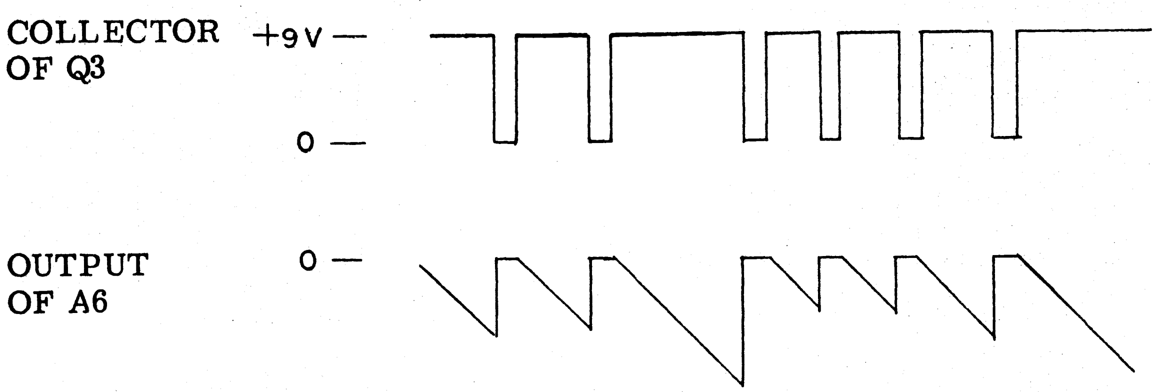


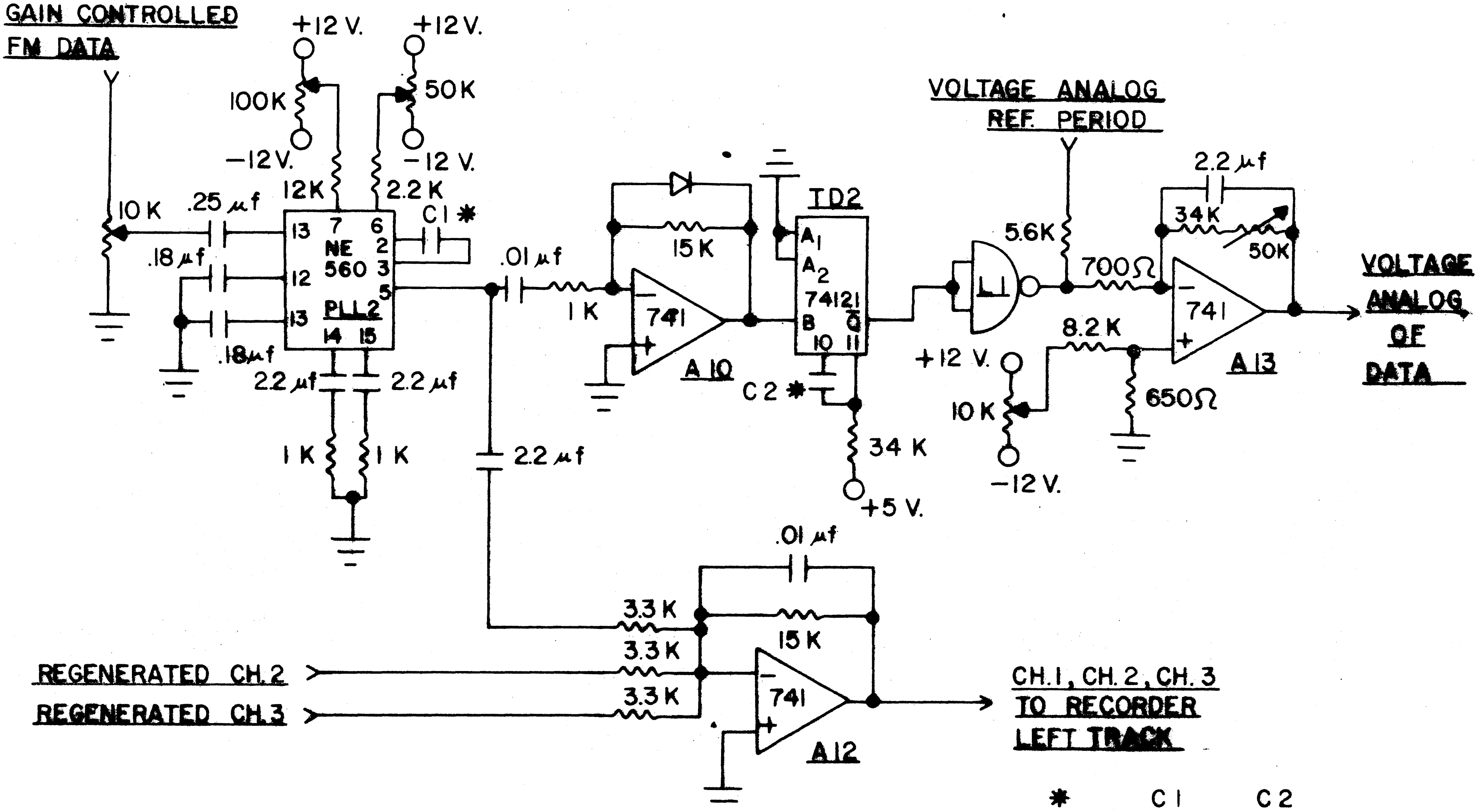
Figure 10. Reference period demodulator waveforms.

Data Demodulation

The on-deck electronics has the capacity for three data channels, two of which are used for temperature and pressure and one spare. Figure 11 shows the demodulation circuitry for the pressure (depth) channel. The other two channels are identical except for different values of timing capacitors C1 and C2 which determine the operating frequency of PLL1 and TD2.

A phase-locked loop, PLL2, is used to regenerate and track a data modulated frequency within the loop's bandwidth. The PLL's of all three channels have a tracking range of $\pm 10\%$ of center frequency and a capture range of $\pm 7.5\%$. Each PLL has a 33° loss-of-lock phase noise margin and a damping factor of 0.707, but with different frequency responses. The 33° phase noise margin occurs at a bandwidth of 18 Hz for the temperature channel. The pressure (depth) channel has the 33° phase noise margin at a bandwidth of 28 Hz. Even though the submerged probe data channels have frequency responses of 5 Hz or less, the wider frequency response of the demodulators is needed to track the tape speed flutter described in Section 3.22.

The regenerated frequency is amplified by A10 and triggers the monostable multivibrator TD2. The open collector SN7403 Quad nand gate L1 is turned on and off by TD2. Since the voltage supplied to the 5600 ohm collector



✱	C 1	C 2
CH. 1	.10 μf	.01 μf
CH. 2	.13 μf	.006 μf
CH. 3	.20 μf	.0034 μf

FIGURE 11. DATA CHANNEL DEMODULATOR

load resistor is the voltage analog of the reference period, the result is a variable duty cycle variable pulse height multiplier with the output being filtered and amplified by A13. During tape playback, the data and reference frequencies are modulated simultaneously by the tape speed flutter. The multiplication of the flutter-modulated data frequency by the inverse of the flutter modulated-reference frequency cancels the tape flutter components of the two frequencies. The voltage analog data output is then free of errors caused by tape speed flutter and long-term speed changes.

The regenerated data frequency from PLL2 is mixed with data frequencies from the other two channels and then amplified by A12; which drives the left track input of the tape recorder.

Identification Number Processor

The identification number processor transmits and receives a three character binary coded decimal (BCD) number in the form of a pulse width coded serial pulse train. The data word consists of a start bit, twelve data bits, and two stop bits as shown in Figure 12. Components of the ID processor are:

1. a shift register for receiving and transmitting serial data;
2. a display storage and seven segment decoder to drive the LED character display;
3. a gated system clock generator;
4. a pulse-width modulator;
5. a pulse-width discriminator; and
6. logic to control the register load, clear and shift functions.

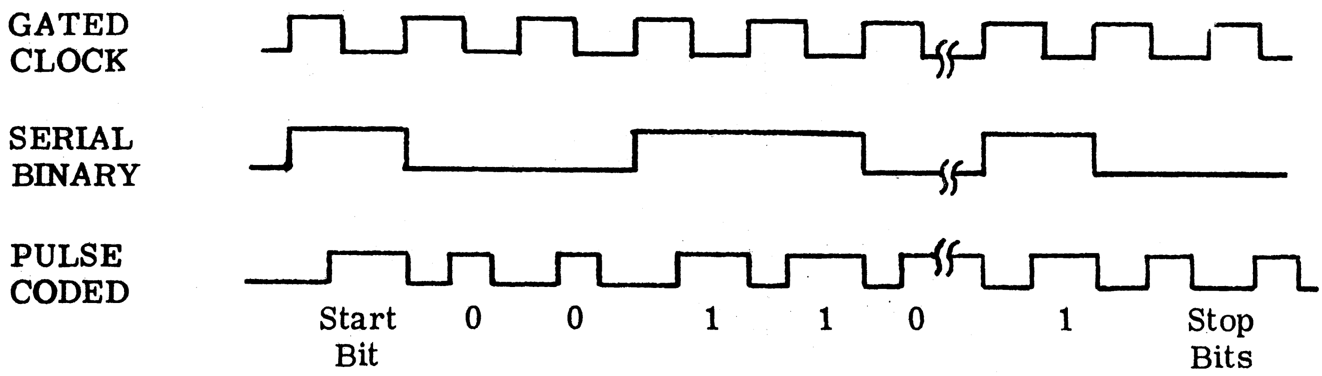


Figure 12. Pulse width modulator waveforms.

ID In/Out Registers

The fifteen-bit shift register (SR1, SR2, and SR3 combined in Fig. 13) receives parallel BCD data from thumbwheel switches mounted on the front panel. The twelve-bit latch, B1, B2, and B3 combined, receives and stores BCD data from the shift register and drives the seven segment decoder and LED display.

As the binary bits are shifted out of the end of SR3, one of the two monostables, TD5 and TD6, is enabled depending upon whether the particular binary bit is one or zero. A one-bit pulse is 8 milliseconds wide and a zero-bit pulse is 2 milliseconds wide. The gated clock triggers the enabled monostable, and the result is a train of variable width pulses representing the BCD data being shifted out of the shift register. The control inputs to the In/Out register block are generated by the control logic of Figure 14.

Table 1. Control Inputs.

Originating Logic Gate	Input Name
L3	SRL, shift register load
L4	SRC, shift register clock
L8	SRR, shift register reset
L9	DBL, display buffer load
L10	GBS, gated system clock
Record/Playback Switch	SBL, start bit load
L1	SD, serial data

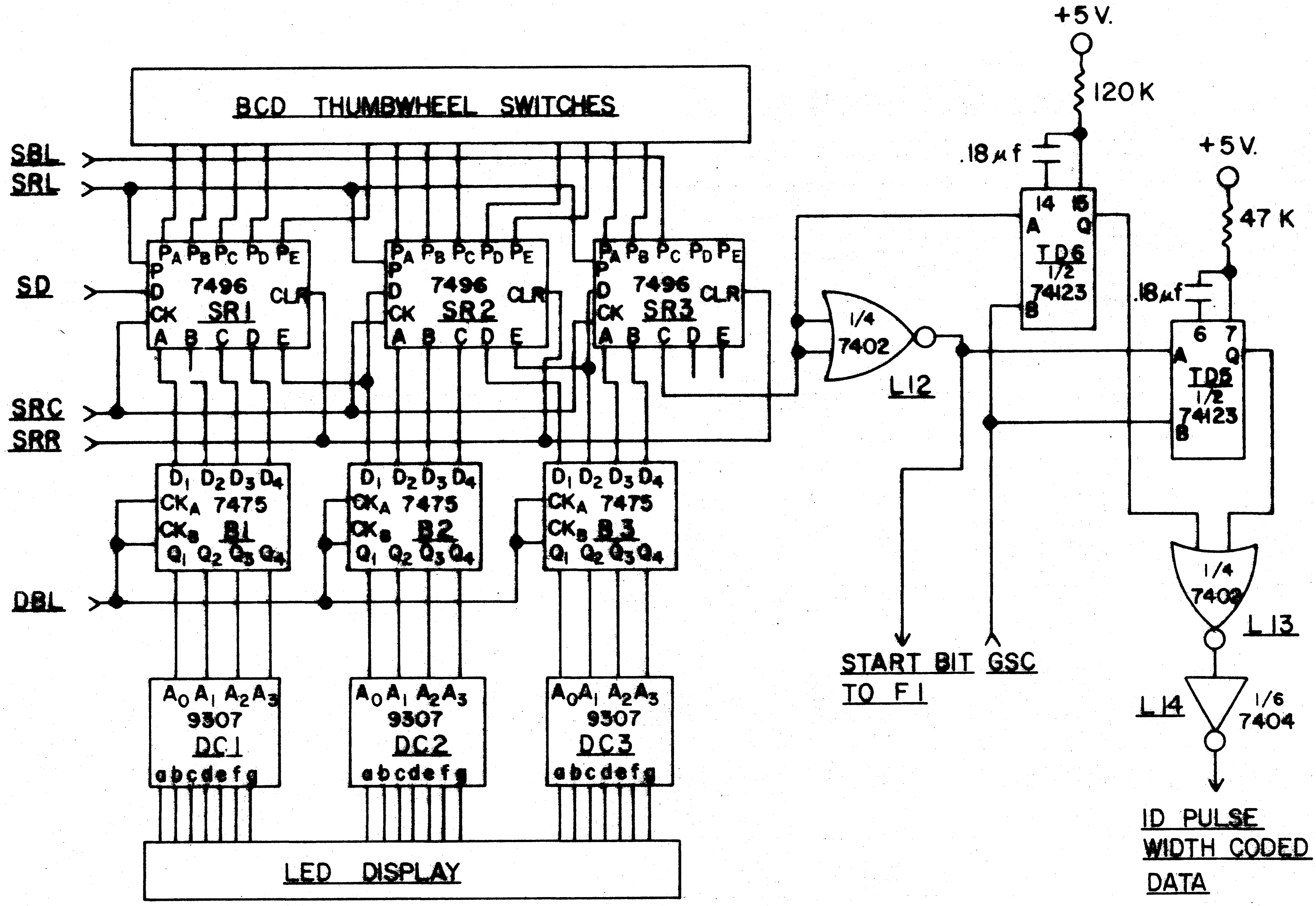


FIGURE 13. ID IN/OUT REGISTERS

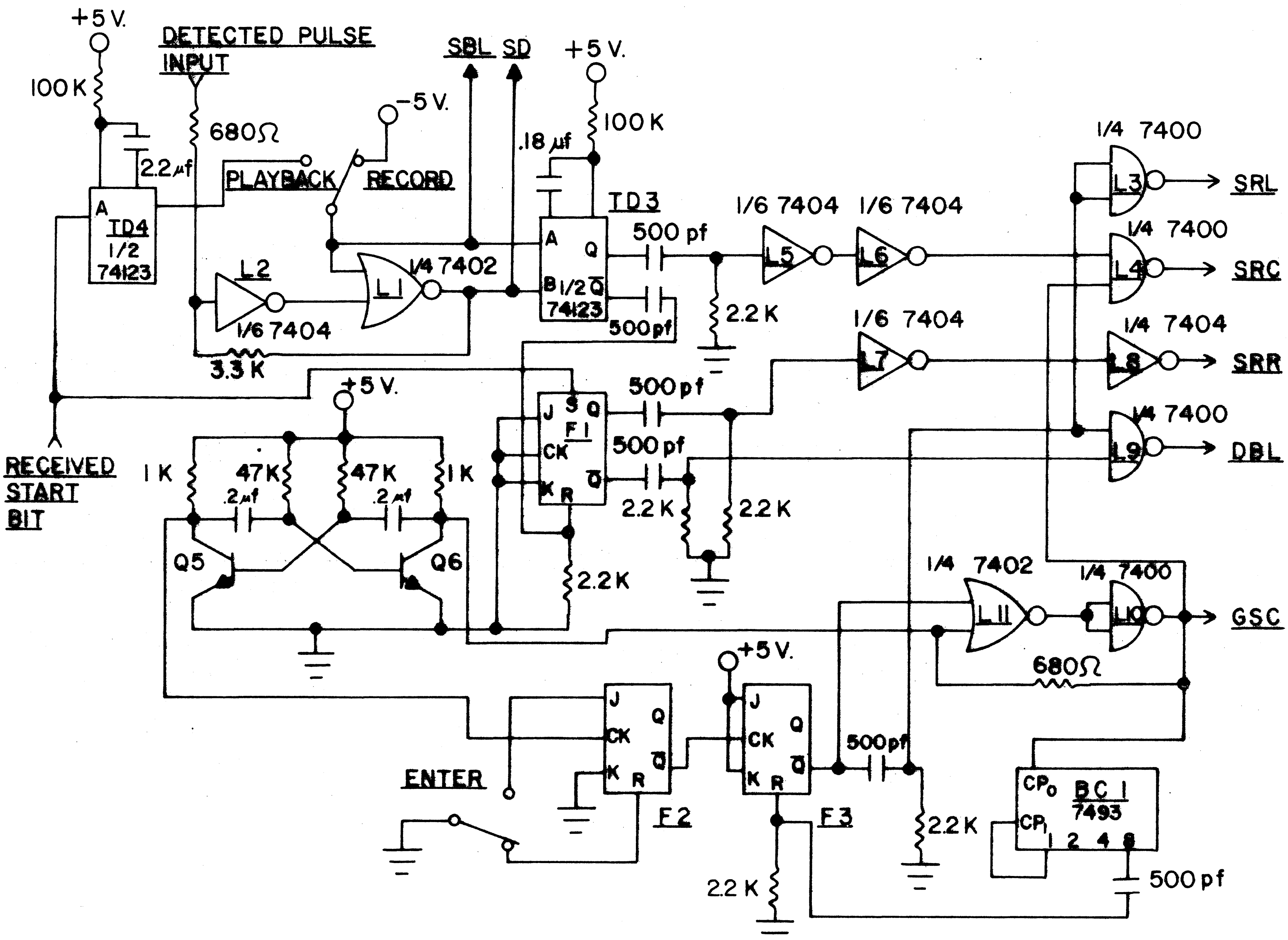


FIGURE 14. ID CONTROL LOGIC

ID Control Logic

The inputs to the control logic are the detected ID data pulses, the received start bit, the enter switch, and the record/playback switch.

In the "record" position the record/playback switch disables the pulse-width discriminator and puts a "1" on the start bit output (SBL). An "enter" command from the enter switch is synchronized with the system clock by F2, and F3 is toggled to the set condition. This transition causes a SRL and a DBL output to be given by L3 and L9. The three digit ID number is loaded into the shift register and the display buffer from the thumbwheel switches. Schmitt trigger L11 and L10 is enabled and the gated clock, which operates at a rate of 50 pulses per second, generates SRC through L4 and shifts binary bits out of the shift register; while the bit counter BC1 and the pulse-width modulator are being clocked. After the thirteen bits have been shifted out of the shift register, BC1 allows two stop bits to be generated before it resets F3 and stops the gated clock. The transmitting logic is now ready for another word transmission.

When the record/playback switch is in the playback position, the Schmitt trigger L2 and L1 is enabled. During playback of a recorded ID number the detected pulses are shaped and used to trigger monostable TD3. The pulse discriminator operates as shown in Figure 15.

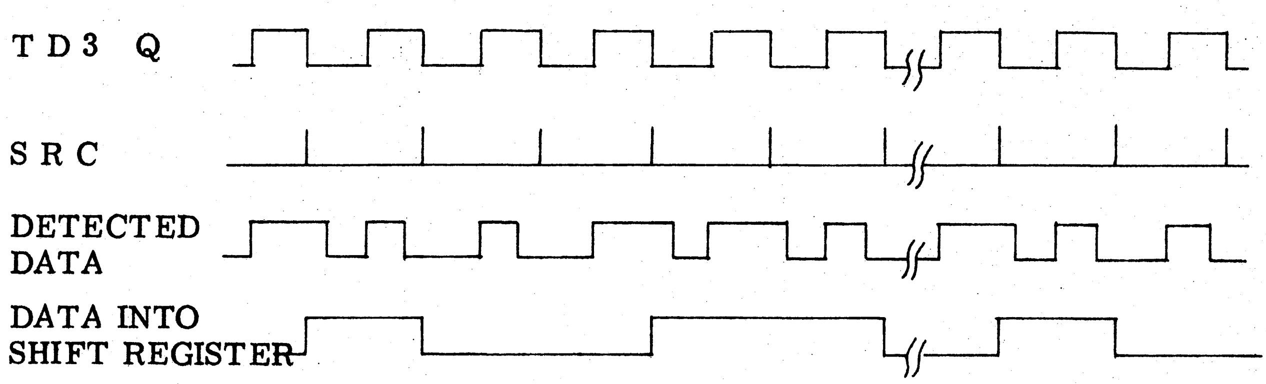


Figure 15. Pulse width discriminator waveforms.

When TD3 is triggered by the detected start pulse, Q of TD3 resets F1 which causes SSR to be generated and the shift register to be cleared. The start bit propagates through the shift register to bit 13 where it is sensed by L12 and causes F1 to be set. The transition cuases DBL to be generated and the display buffer is loaded with the newly received ID number. The start pulse also triggers TD4 which disables the pulse-width discriminator and prevents the system from receiving data for 0.5 sec. After this time delay the discriminator is again enabled and ready for the next ID number update.

Tape Recorder

The tape recorder used at present is a Panasonic RS-264S portable stereo cassette recorder. The tape drive motor of the RS-264S has an electromechanical governor speed control and is associated with a 2% 10 Hz tape speed flutter. Any tape recorder could be used as long as the tape speed flutter does not exceed the demodulator bandwidths described in Sections 3.22 and 3.23 and as long as the record and the playback electronics have a frequency response of 7000 Hz or more.

CIRCUIT STABILITY ANALYSIS

The probe and on-deck packages were subjected to a number of tests to determine which errors existed and the magnitude and causes of these errors. The probe package in its housing was immersed in water baths of different temperatures to measure component drift with temperature. The on-deck package was subjected to ambient air at several temperatures and the demodulated data output monitored for drift. The sensitivity to power line fluctuations was also measured. The repeatability of the playback circuits was tested by replaying a recorded test tape twice daily over a period of a month.

The stability parameters measured are:

Probe

Pressure channel drift	200 PPM/°C
Temperature channel drift	90 PPM/°C

On-Deck Package

Demodulated data drift (15°C to 27°C)	200 PPM/°C
Demodulated data sensitivity to power line voltage changes	0.4%/volt
Playback stability	4.0% maximum error
Playback speed flutter rejection	>35 db

In the probe most of the pressure channel drift can be attributed to the Statham pressure transducer, with the VCO and the signal conditioning amplifier bias drifts contributing the remainder of the error. The temperature channel drift is caused by bias drifts of the VCO and signal conditioning amplifier. These drifts are a combination of internal leakage currents and external offset voltage changes caused by regulated voltage level changes. The drift rates of the pressure and temperature sensors are within the design limits, and no attempt was made to improve them.

In the on-deck portion of the system, the demodulated data drift is caused in part by the bias current drifts of the reference oscillator and data amplifier. The most significant contribution to error is the temperature drift of the plus and minus power supply which alters the offset settings of the data amplifiers. The on-deck electronics package is forced-air cooled by an internal blower, so no improvement is contemplated, beyond replacing the power supplies.

The power supplies also show poor line-voltage regulation (typically .25% per a 10% line-voltage change) which causes a .4%/volt change in the demodulated data output. Replacing the power supplies with those having .075% line/load regulation is expected to greatly improve the line-voltage sensitivity.

The playback error magnitudes appeared to be randomly distributed throughout the 30-day period and appeared to be caused by power-line voltage fluctuations.

The degree of playback speed-flutter rejection is difficult to estimate, but in all cases it is greater than 35 db and could possibly be improved by closer calibration of the reference circuit.

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APPENDIX A

SPECIFICATIONS: Model PA505-200 Pressure Transducer, Statham Instruments, Inc.

1.1 Typical Pressure Ranges, Natural Frequency, and Static Acceleration Response. (The acceleration response quoted represents the output of the transducer due to stimulus applied in the sensitive axis, including vibration at frequencies up to approximately 20% of the natural frequency. Above this frequency, the response will increase in accordance with the behavior of an undamped single-degree-of-freedom system.)

1.2 Maximum Overload: 200% of rated range through 500 psia range; 150% for 1000 psia and above.

1.3 Pressure Media: Fluids compatible with Types 17-4 PH and 17-7 PH stainless steel.

1.4 Transduction: Resistive, balanced, fully active strain gage bridge.

1.5 Power Requirements:

1.5.1. Voltage: 28 ± 4V DC.

1.5.2. Current: 25 mA nominal at 28V DC.

1.6 Output Voltage: 0.1 to 5V DC nominal into an open circuit.

1.7 Output Impedance: 2000 nominal (25 k minimum load).

1.8 Output Isolation: Current isolation (negative excitation and negative output leads are common).

1.9 Output Noise: Less than 5 mV rms.

1.10 Regulation: 0.15% FS/V from 24 to 32V.

1.11 Resolution: Infinitesimal.

1.12 Non-linearity and Hysteresis: Less than ± 0.75% FS terminal-based.

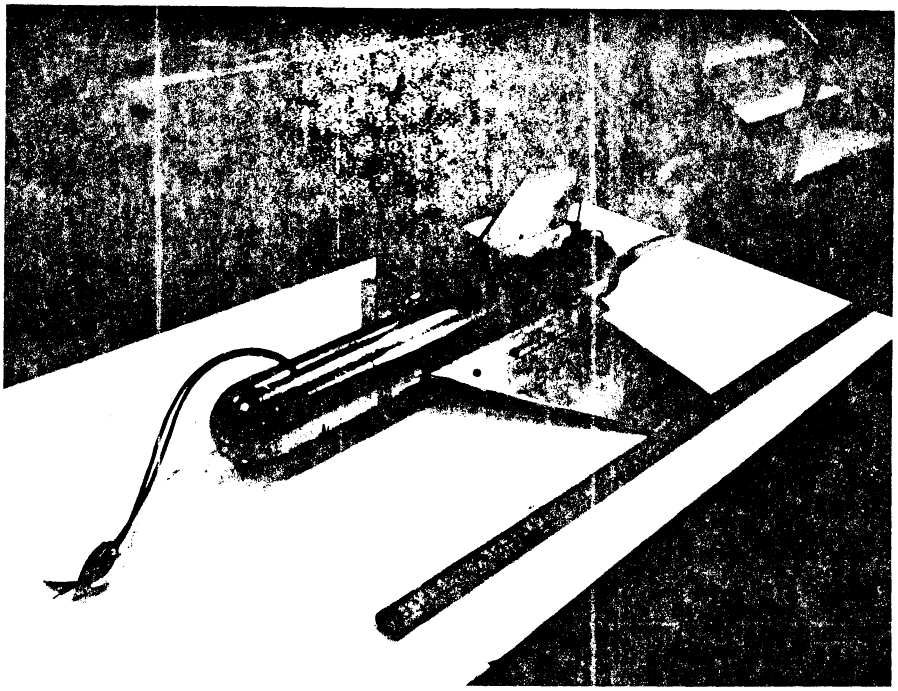
1.13 Compensated Temperature Range: 0 to 150°F.

1.14 Thermal Sensitivity Shift: Less than 0.015%/^{o}F.

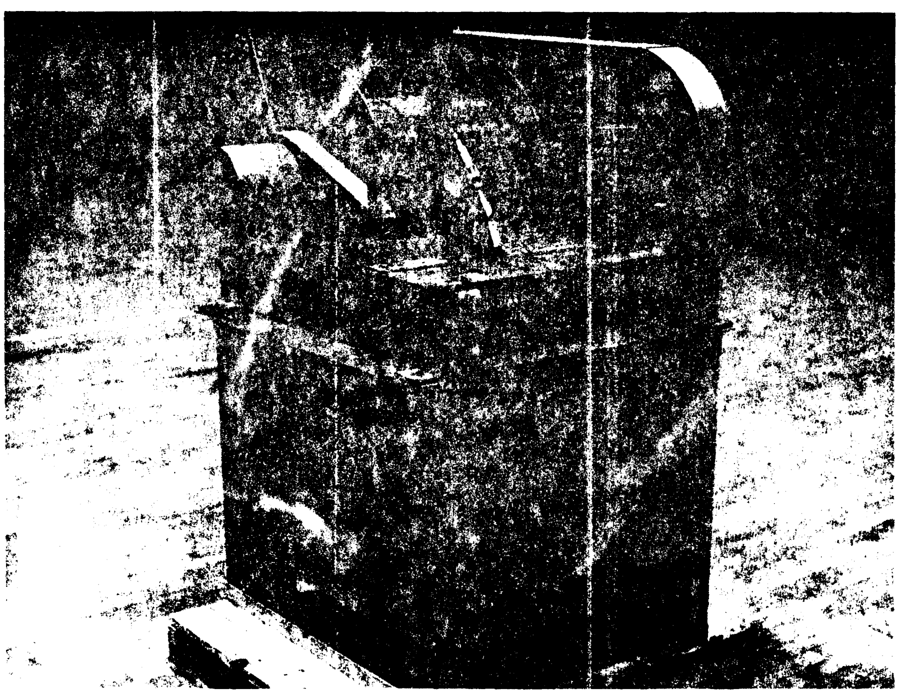
1.15 Thermal Zero Shift: Less than 0.015% FS/^{o}F.

1.16 Pressure Connection: 7/16-20 external fitting per MS33656-E4.

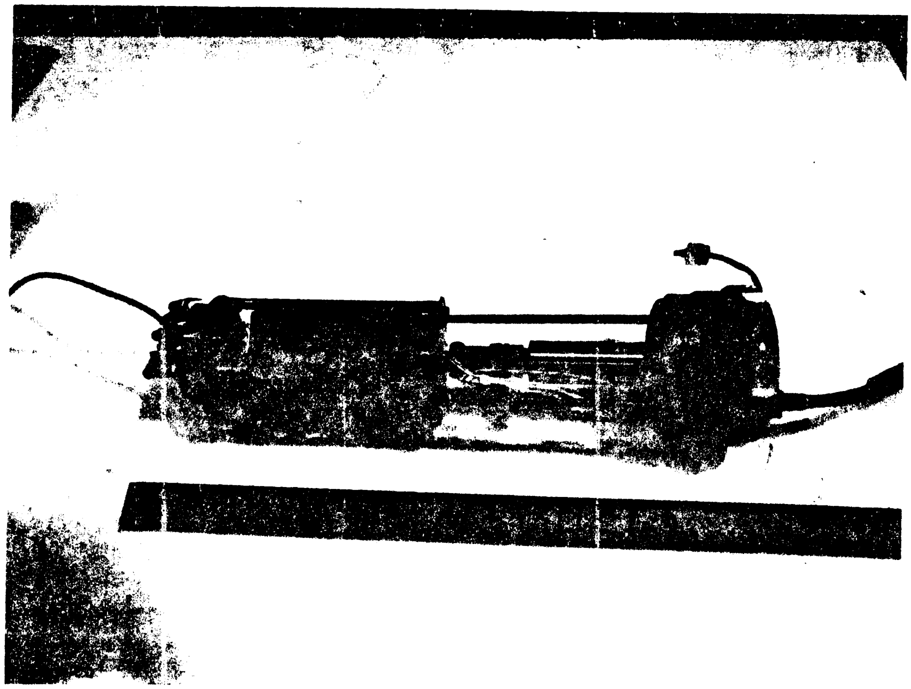
1.17 Electrical Connection: Case-mounted electrical receptacle to mate with PT06-10-6S.



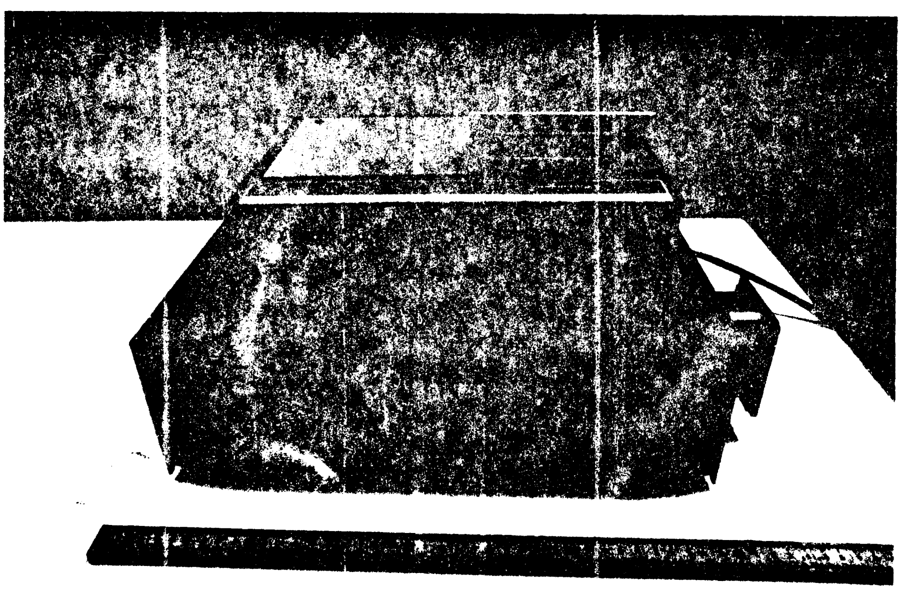
Probe Body



Modified HydroProducts HR60 Winch



Probe Circuitry



On-deck Electronics Package