ANL/ES-108

ANL/ES-108

AN AUTOMATIC UNDERWATER RADIOTELEMETRY SYSTEM TO MONITOR TEMPERATURE RESPONSES OF FISH IN A FRESHWATER ENVIRONMENT

by

W. Prepejchal, M. M. Thommes,
S. A. Spigarelli, J. R. Haumann,
and P. E. Hess

ARGONNE
NATIONAL
LABORATORY

ARGONNE NATIONAL LABORATORY, ARGONNE, ILLINOIS

Prepared for the U. S. DEPARTMENT OF ENERGY
under Contract W-31-109-Eng-38

Printed in the United States of America
Available from
National Technical Information Service
U. S. Department of Commerce
5285 Port Royal Road
Springfield, VA 22161

NTIS price codes
Printed copy: A05
Microfiche copy: A01

Distribution Category:
Environmental Control Technology
and Earth Sciences (UC-11)

ANL/ES-108

ARGONNE NATIONAL LABORATORY
9700 South Cass Avenue
Argonne, Illinois 60439

AN AUTOMATIC UNDERWATER RADIOTELEMETRY SYSTEM TO MONITOR TEMPERATURE RESPONSES OF FISH IN A FRESHWATER ENVIRONMENT

by

W. Prepejchal, M. M. Thommes, S. A. Spigarelli
Ecological Sciences Section
Radiological and Environmental Research Division

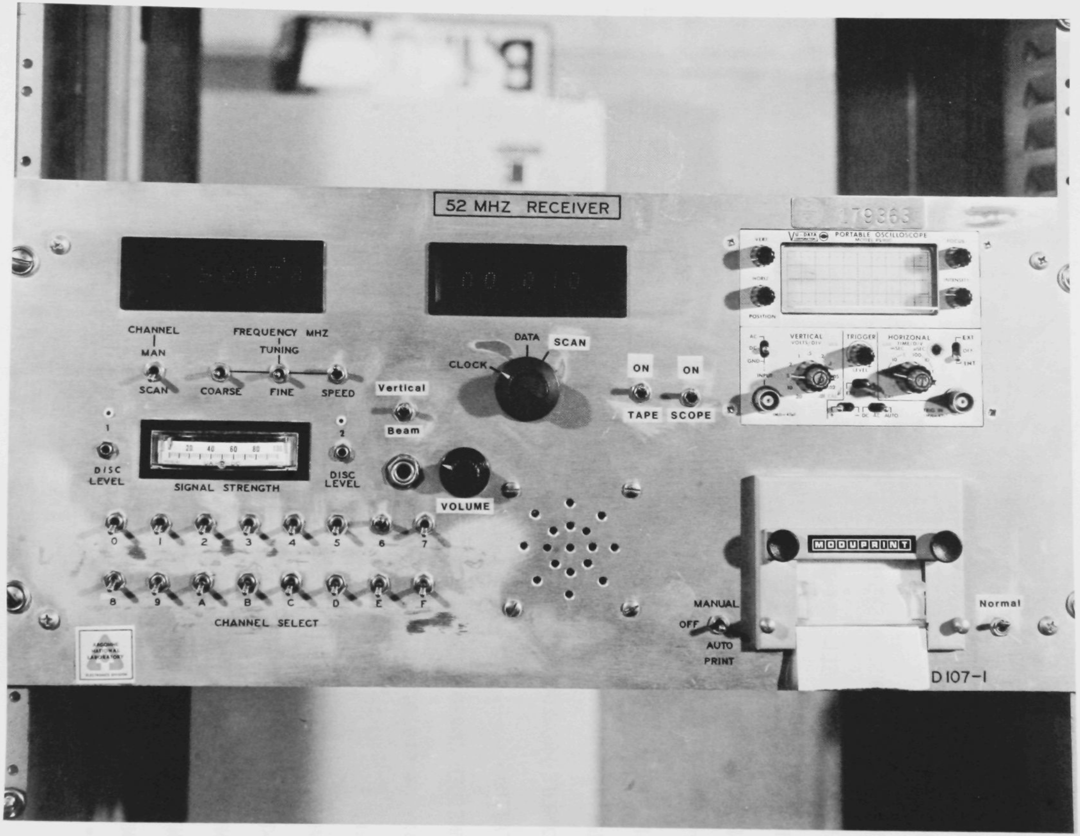
J. R. Haumann
Electronics Division

and

P. E. Hess
Atmospheric Physics Section
Radiological and Environmental Research Division

November 1980

TABLE OF CONTENTS



ANL-built automatic scanning receiver used for underwater radiotelemetry (ANL Neg. 149-80-132).

ABSTRACT

An automated radiotelemetry system developed at Argonne National Laboratory to monitor body and water temperature of free-swimming fish is described. The receiving and data acquisition unit can be programmed to monitor as many as 16 transmitters (fish); each transmitter can time-multiply data from up to 9 resistive transducers. A typical transmitter with saddle-type attachment, suitable for fish weighing 1 to over 10 kg, has a submerged weight of less than 10 g. The typical range is 2700 m for fish 1 m below the surface.

Complete schematics and operational logic are provided for the receiver and data processing printed circuit boards, for 3 types of fish transmitters, and for an environmental parameter monitor. Construction methods, calibration and tagging procedures, and the required computer programs are detailed.

This system was in operation for 3 years at the Point Beach Nuclear Power Plant, Two Creeks, Wisconsin. Of the 89 fish tagged, 77 fish provided useable body and water temperature information with tracking times ranging from 0.5 to 505 hours. Modifications which would further improve the system's reliability are discussed.

INTRODUCTION

A number of techniques have been developed and used by Argonne National Laboratory to evaluate the effects of warm-water discharges on Lake Michigan fishes. These have ranged from the use of echo locators combined with simultaneous water temperature mapping (1), to the use of string tags (2), and temperature integrating tags (3,4) which yield long-term movement and temperature exposure information. However, these techniques yield almost no specific temperature or short-term movement information. Such data can best be obtained by telemetric devices which allow continuous tracking of individual fish while monitoring important parameters such as water temperature and fish body temperature.

Telemetry systems utilizing either ultrasonic or radio-frequency transmitters have been used by other workers in monitoring aquatic animals (e.g., 5-7), but ultrasonic devices have proven to be of limited value in turbulent water (8) and in regions of strong thermal gradients (9); both of these conditions prevail in the plume regions of warm-water discharges. In addition, the potential for rapid multiparameter data transmission is somewhat restricted with ultrasonic devices because of bandwidth limitations. For these reasons, we elected to begin research on and development of an automated radiotelemetry system that would allow unattended continuous monitoring of a variety of parameters associated with fish residence in or near thermal plumes.

System Requirements

Since our investigation involved the study of fish interaction with heated discharge water, the required range of the system had to be such that reliable data signals were provided over the expected range of the plume. In order to determine the minimum coverage required, data from fish distribution/temperature studies at the Point Beach Nuclear Plant (10) were analyzed to establish plume configurations, i.e., depth and distance of heated water from the receiver location. The shaded envelope shown in Figure 1 represents the greatest ranges and depths of heated water (1°C above ambient lake temperatures) observed during past studies. Included in this plot are observed maximum transmitter ranges (usable signals) established through field measurements at various depths and distances within the local region.

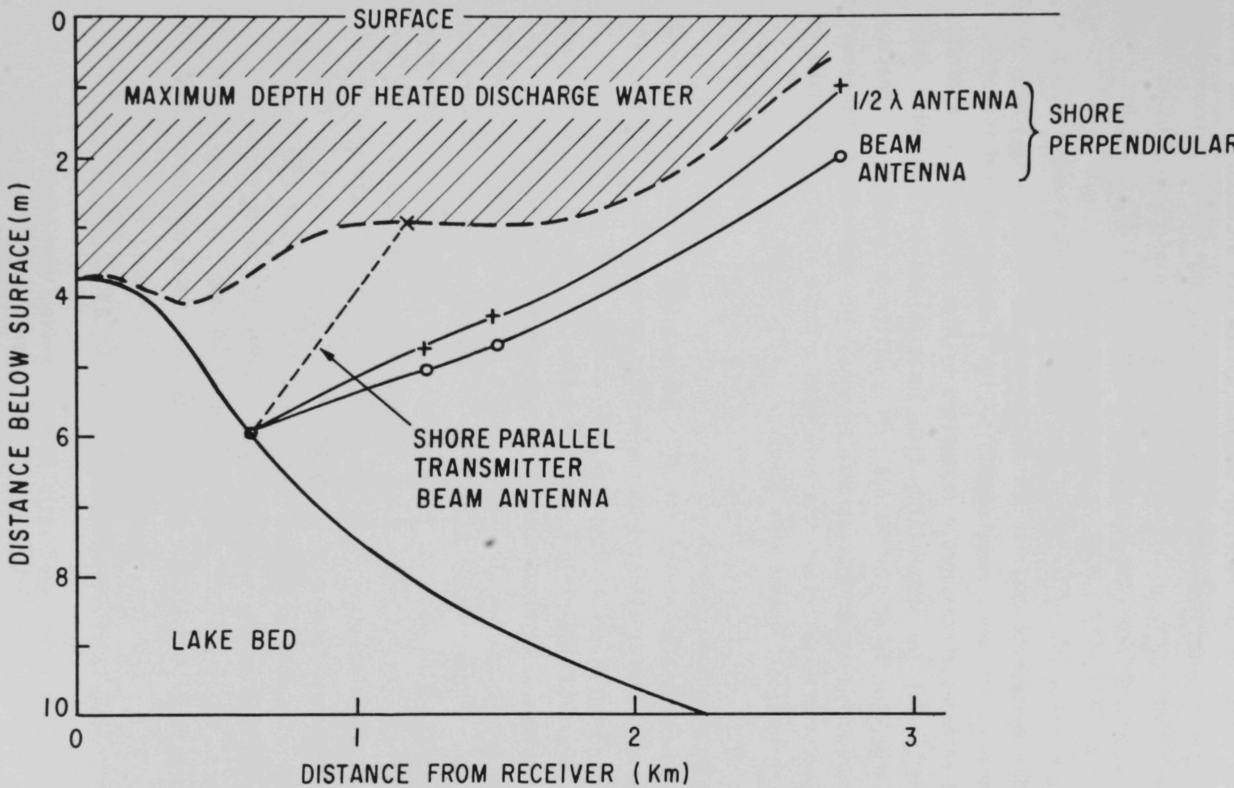


Fig. 1. Maximum usable transmitter depth (Mark I), Point Beach Power Plant, October 1975.

The selection of the receiver antenna system was dictated by the polarization of the transmitted signal, antenna gain, and the requirements for directional resolution. Diffraction at the air-water interface of the transmitted signal from the horizontally polarized (fish mounted) antenna results in a vertically polarized emergent radio wave (11,12). Low natural and man-made noise levels at the 50 MHz frequency (12) allows the use of high gain antenna systems to optimize transmitter range, life, and size by minimizing the transmitter power requirements. High gain is achieved in vertically polarized antennas of reasonable dimensions by high directivity. A directive antenna is useful for determining fish location and for acquiring data at maximum range, but is of limited use during unattended operation. Unattended operation requires an omnidirectional antenna. To accommodate both requirements, a vertically polarized rotatable beam antenna as well as a fixed omnidirectional vertical antenna were used.

Site Description

The research site chosen for this project was the Point Beach Nuclear Power Plant (Figure 2) situated on the western shore of Lake Michigan near Two Rivers, Wisconsin. Data from previous studies of fish responses to this discharge provided invaluable background information needed to design a useful telemetry system. The plant consists of two pressurized water reactors of ~500 MWe capacity each. The water intake for both units is located 533 m offshore and is constructed as a circular rock-lined crib (offshore porous dike type). Cooling water is drawn directly from Lake Michigan at a maximum flow rate of about 45 m^3/sec and is returned to the lake via two surface discharge flumes extending 46 m offshore. Discharge velocities at the end of the flumes range between 0.33 m/sec and 0.93 m/sec (14). The maximum temperature rise (ΔT) in the cooling water is 10.5°C except during winter when warmed cooling water is recirculated back to the intake to maintain an intake temperature of 4.4°C to prevent ice formation. Total plume areas (circumscribed by the 1°C ΔT isotherm) typically are on the order of 10-100 hectares.

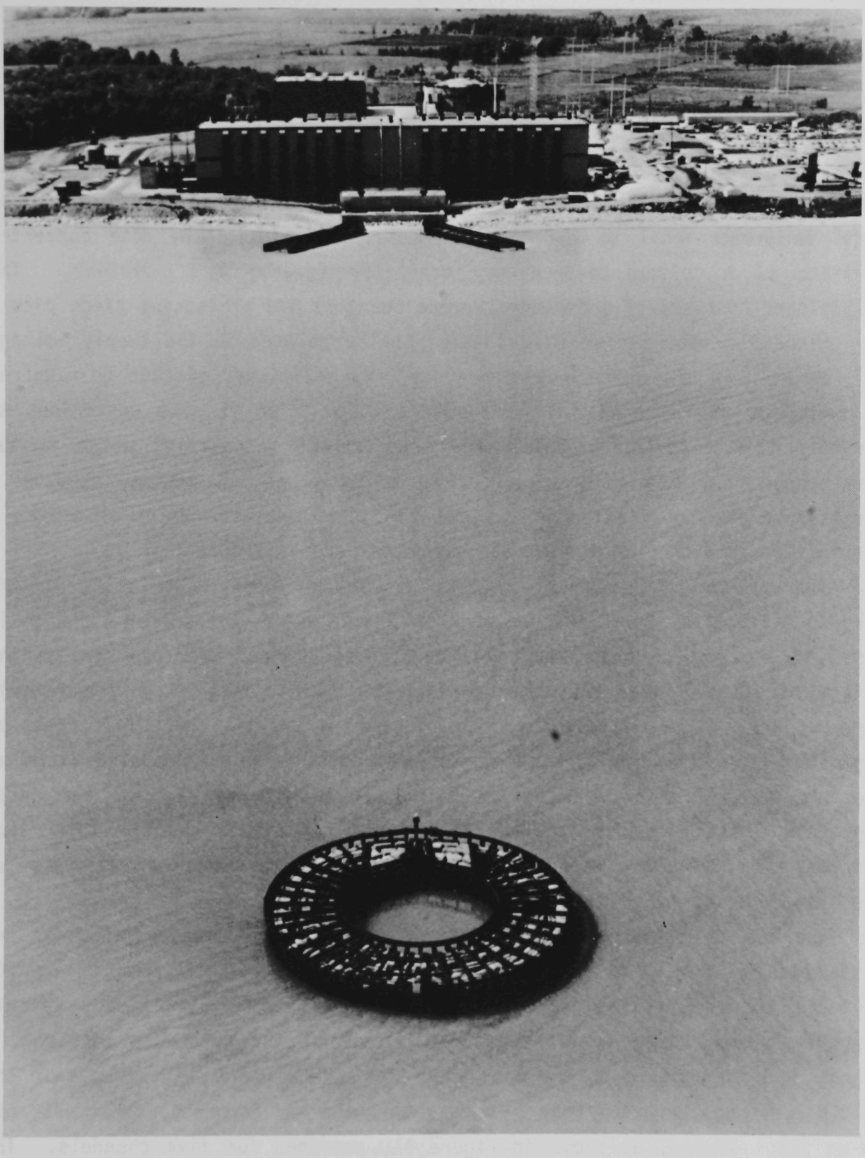


Fig. 2. Aerial photo overlooking research site, Point Beach Nuclear Power Plant, Two Rivers, Wisconsin (ANL Neg. 190-492).

UNDERWATER TRANSMITTERS

Transmitter Logic

The multi-channel transmitter (Figure 3) consists of three basic elements: an analog data converter, a data multiplexer, and a blocking oscillator-type radio-frequency generator. The data converter transforms a resistance value to a time period (P) which controls the transmitter such that the time interval from the end of one tone burst to the end of the next tone burst is proportional to the sampled resistance value. The data converter consists of a current-to-frequency converter feeding a 2^7 divider. The multiplexer consists of a decoder (decade counter) and a blocking diode pack.

Since the time period (P) is functionally related to the supply voltage (E), as well as transducer resistance (R_T), an additional circuit is required to normalize for changes in the supply voltage. It is also convenient to identify this normalizing signal and thus provide a starting point in the time-sequenced multiplexed signal. These functions are accomplished by a temperature stable resistance (R_r) and the tone modulator which generates a distinctive reference tone (higher-than-normal audio-frequency).

The current-to-frequency converter is composed of IC1A, IC1B, and T_1 (Figure A1). IC1A integrates the current input from R_T and stores a charge in its 0.47 μF feedback capacitor, thus developing a linear voltage ramp at the output of IC1A. This ramp, when applied to IC1B (acting as a comparator), turns on T_1 at a predetermined level and discharges the IC1A feedback capacitor. Discharging this capacitor produces a ramp of opposite slope at the output of IC1A. At a preset point, IC1B shuts off T_1 and the cycle repeats. These ramps are applied to a seven stage CMOS counter (IC2); its outputs, Q_2 and Q_3, are diode "anded" to produce a "transmitter on" signal at the base of T_2.

The time multiplexing is accomplished by the decade counter (IC3) and the diode pack (IC4). The trailing edge of the pulse output from Q_3 on IC2 advances IC3 and applies power to the next transducer. IC4 blocks reverse current through the transducers. In the case of the reference resistor, a signal is also applied to the tone modulator. The number of channels in the multiplexer can be varied from 2 to 9 by changing the jumper to the reset, pin 15 on IC3. Wiring, as shown in Figure A1, provides for five channels. The transmitter duty cycle will be approximately 25% with the components shown.

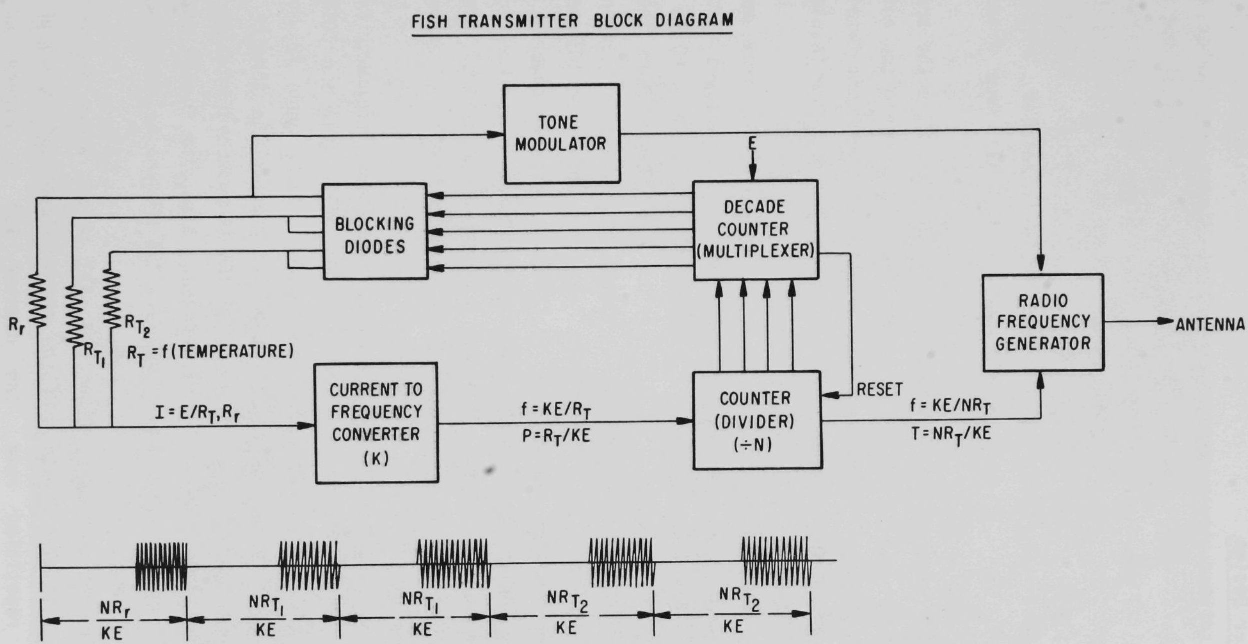


Fig. 3. Block diagram of typical underwater fish transmitter.

Transmitter Design

The transmitter is a crystal-controlled Pierce oscillator with the collector tuned to resonate at the third overtone of the crystal and is biased such that it operates in a blocking mode, i.e., bursts of radio-frequency are produced at an audio rate (tone modulator, Figure A1). This rate is determined by the charging rate of C_1, the 0.47 μF capacitor. During the time interval at which the reference resistor is being sampled, this charging current is approximately doubled and thus, the audio tone frequency is doubled.

Final tuning of the potted transmitter must be done while the transmitter package is submerged in water, and is accomplished by trimming the antenna for maximum signal. The antenna, a 40-cm length of flexible 300 ohm twin-lead, is initially cut longer than needed. After trimming, the ends are insulated from the water.

Components for the Mark I transmitter (Figures 4, A1) were mounted on flexible printed circuit board material which was wrapped around the battery. The completed assembly was then potted in a 25 mm x 40 mm snap-cap vial (7 dram, Cole-Parmer No. 6102-20). The water temperature thermistor, switch leads, fish temperature thermistor leads and antenna all extended from one end. The material used for potting was Shell Epon type 815 resin well mixed with Celanese type 855 hardener (2:1 mixture). When powered by a 7 V mercury battery (Union Carbide, Eveready No. 2175) with a service capacity of 160 mAh, expected transmitter life was 7.5 days. A typical transmitter package, including saddle, weighed 53 g and displaced 34 cc of water. Thus, the submerged weight was 19 g.

In order to reduce cost and increase transmitter lifetime, two design changes were made for the Mark II model (Figure A2). IC1A and IC1B (Figure A1) were replaced with a CMOS Schmitt Trigger, IC1A (Figure A2). In this circuit the 0.33 μF capacitor charges until it reaches the Schmitt level of IC1A, whereupon the 10K resistor at pin 8 of IC4 is switched into the feedback loop of IC1A and the capacitor is discharged. Also, the decade counter IC3 (Figure A1) was replaced by a decade decoder, IC3 (Figure A2) which was available in a smaller package.

An alternative (Mark III, Figures 5, A3) to the above design was also used. By increasing the capacity of the storage capacitor to 4.7 μF and thus reducing the repetition rate, the counter IC2 in Figure A2 can be

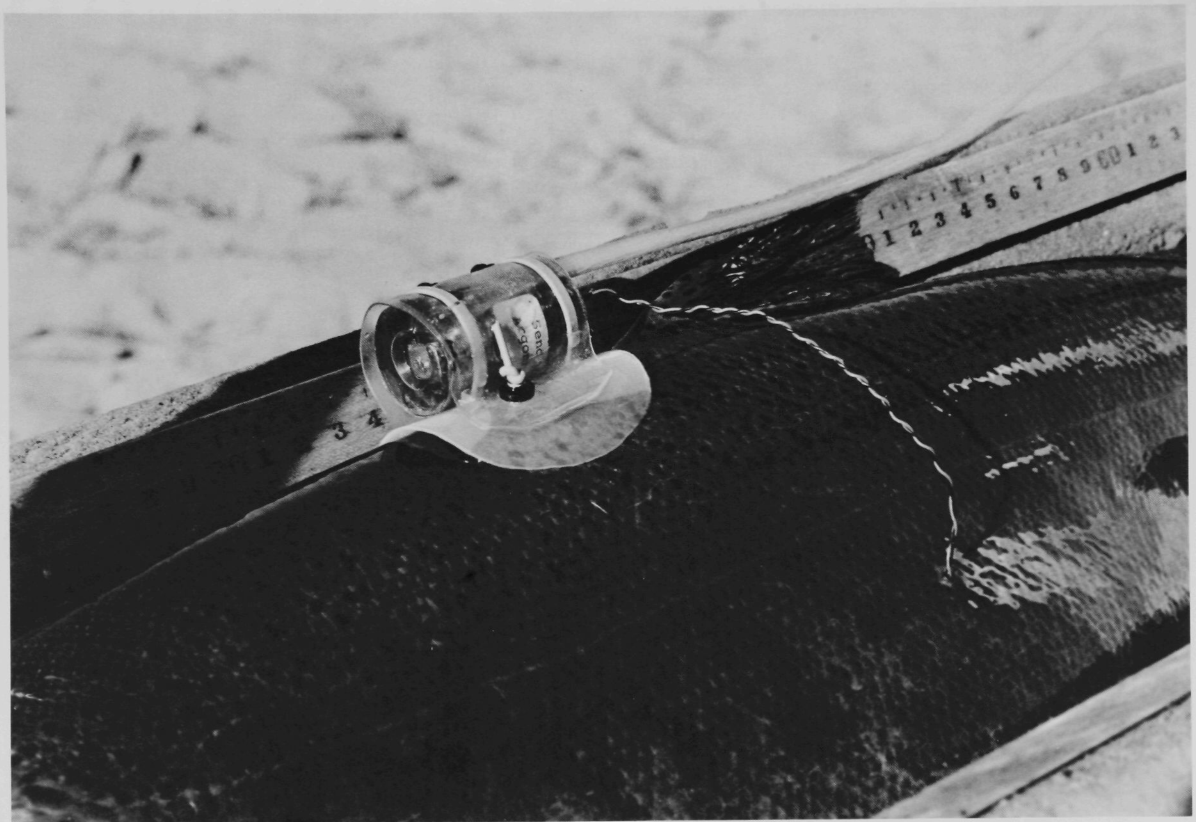


Fig. 4. Mark I fish transmitter showing insertion location of body temperature probe (ANL Neg. 301-76-28 #15).

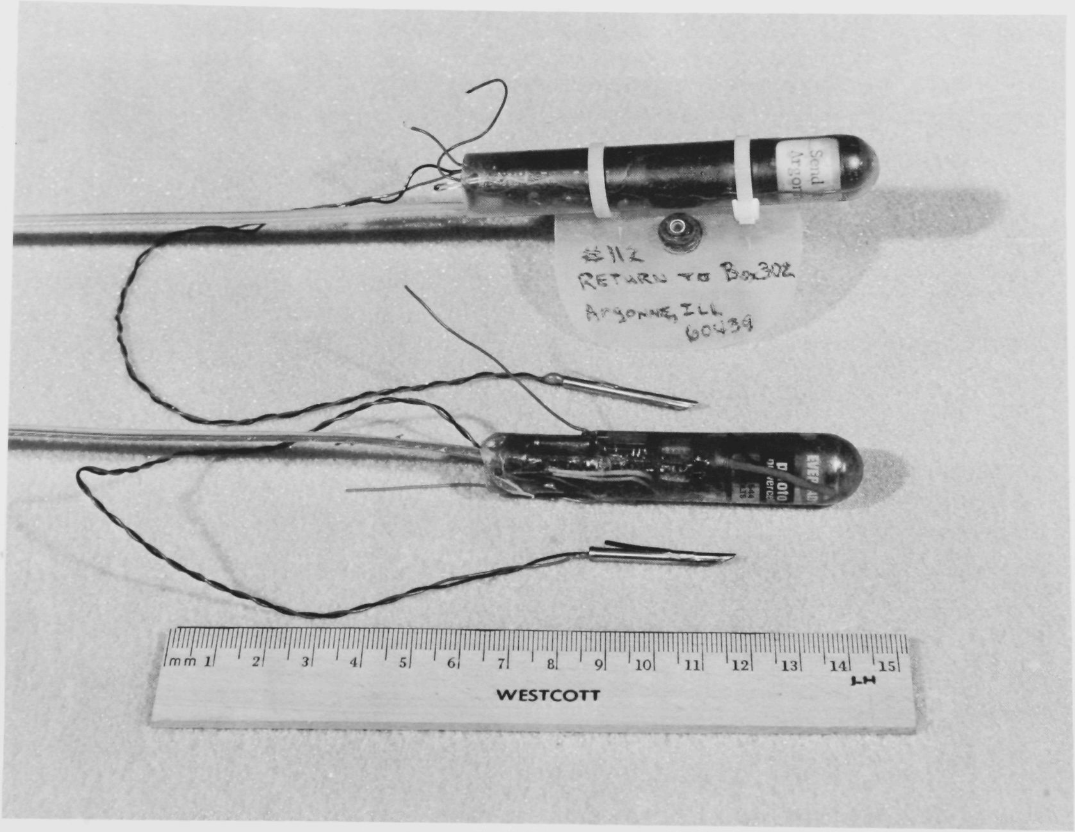


Fig. 5. Mark III fish transmitter with saddle attachment and body temperature probe (ANL Neg. 149-80-133).

eliminated. This leaves the decade counter IC2 in Figure A3 as the multiplexer. In this system, the duty cycle of the transmitter is controlled by the feedback resistor in IC1A.

Components of the Mark II/III transmitters were assembled on a rigid circuit board and potted in a 15 mL round-bottomed polypropylene test tube, 16 mm x 116 mm (Cole-Parmer No. 6330-32). If a tagged fish was recaptured, a separation between battery and circuit allowed for the replacement of the battery by cutting off the old battery section, replacing the battery and repotting. This circuit was powered with either a silver oxide battery (Union Carbide, Eveready No. 544) giving a service life of 8.7 days, or two lithium batteries (Power Conversion, Inc. No. 400-5) giving a service life of 24 days. Included in each transmitter were instructions for return if found. Transmitters of this type, including saddles, weigh 39 g with 30 cc water displacement (lithium battery version) and 37.5 g with 25 cc water displacement (silver oxide battery version).

Modifications for Monitoring Water Temperatures

Environmental temperatures, or other information which can be measured with resistive transducers, can readily be included in the data logged by this system. Remote monitoring is limited only by antenna line-of-sight distances and/or power available. Such a system was used during our research to continuously monitor water temperature in the power plant discharges and intake (Figure 6).

A slightly modified version of the fish transmitter (Figure A1) was used and is shown in Figure A4. This circuit, built on a conventional printed circuit board, was powered by six "D" cells and housed in an aluminum minibox. In this circuit two fixed resistors (1 reference, 1 dummy) and three thermistors were used. This results in five channels as in the fish transmitters. However, unlike the fish units, temperature data are not repeated during each transmission.

Because of the turbulence in the discharge structures and wide fluctuations in air and water temperatures, mechanical integrity and water-tight seals were extremely important to the life of the sensors. Thermistors were encased in 1 m lengths of 3/8" O.D. x 1/4" I.D. type 304 stainless steel tubing, weld-sealed at the lower end and partially filled with an insulating oil (Heraeus-Engelhard, HE-400) having a specific gravity of 1.45. A

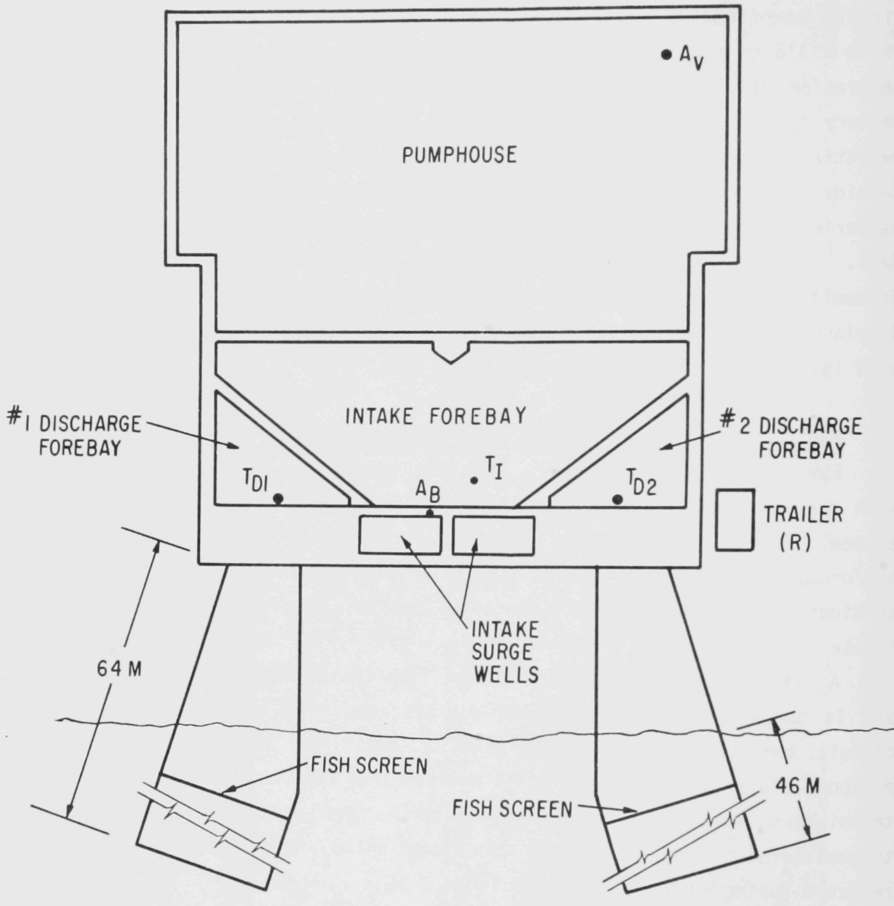


Fig. 6. Location of receiver and plant transmitter probes. A_B - beam antenna; A_V - 1/2 λ vertical antenna; R - receiver; T_{D1} - Unit 1 discharge temperature probe; T_{D2} - Unit 2 discharge temperature probe; T_I - intake temperature probe.

vulcanized top seal at the junction between the neoprene-covered signal cable and the stainless steel tubing was made with a portable molding press (Hotsplicer Co., Model 301). Temperature changes in the discharge and intake cause pressure changes within the probes and result in air flow to and from the probe through the voids in the connecting cables. The high enviromental humidity encountered in these locations thus leads to condensation within the probe enclosure. In addition to serving as a heat conductor, the high density oil effectively excludes any water from the region of electrical connections between the thermistor bead and the cable. Since these thermistors are high resistance devices, any leakage would result in erroneous temperature data. Epoxy, as employed in the construction of transmitters, was not used for this application; even though it is acceptable for short duration use (a few weeks), constant exposure to moisture over the long-term results in degradation of the coating and eventual failure.

ANTENNA SYSTEMS

Two antenna systems were used at the Point Beach field site. A six element vertically-polarized Yagi-type antenna (Cush-Craft No. A50-6)(Figure 7), having a gain of 9.3 db (with respect to 1/2 λ dipole antenna), was mounted 12 m above lake level, and was equipped with a rotator (Cornell-Dubilier Electronics, Model Ham M). A preamplifier having a 2.5 db noise figure (Janel Labs, Model PB) was located at the antenna to minimize the effects of spurious signal pickup and attenuation of the transmission line. In addition, a half-wave length vertical antenna with a gain of 3.75 db (with respect to 1/4 λ ground plane antenna)(Cush-Craft No. AR-6) was mounted with its base 20 m above lake level. This antenna also included a preamplifier (Figure A5) to reduce the effect of transmission line-related noise. Coaxial antenna cable used for both systems was RG58U (Alpha Wire Corp., No. 9058).

In spite of the lower gain of the 1/2 λ antenna, it was useful during periods of unattended operation of the field station, since the horizontal pattern could be counted upon to fully cover the region of the lake under direct influence of the heated discharge water. The higher gain beam antenna (achieved by a rather narrow horizontal pattern), while producing stronger signals for distant or deep fish, would not provide adequate signal strength in all directions during unattended operation.

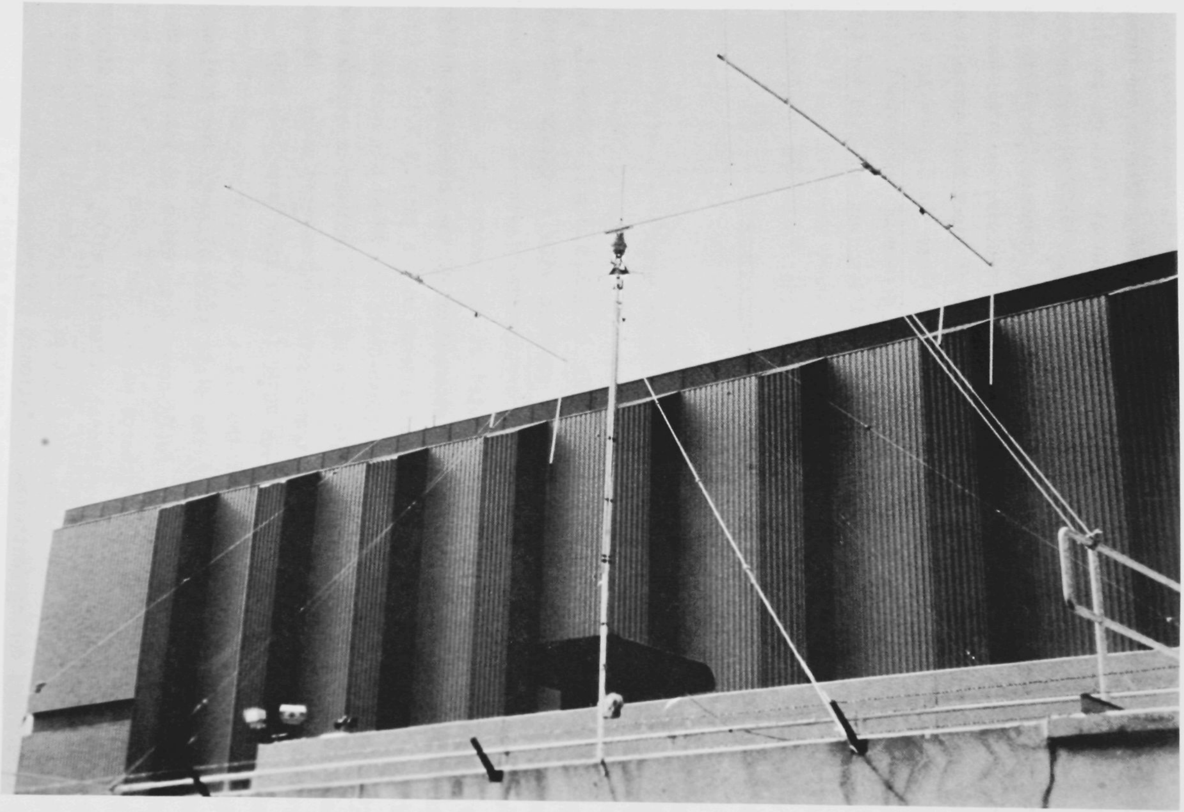


Fig. 7. Dual six element Yagi-type beam antennas located near intake surge wells.

Vertical Antenna Preamplifier

A conventional FET low noise RF preamplifier was used in conjunction with the vertical antenna (Figure A5). The preamplifier noise figure using the 3N159 FET in this circuit is 2.5 db with a bandwidth of 2 MHz centered on 51.7 MHz. Diode protection is provided in the input network to prevent damage to the FET. The input and output circuits, designed to match 50 Ω, are tuned for maximum gain consistent with bandwidth requirements. The circuit is housed in a water-tight enclosure and operating power is provided by the receiver power supply.

RECEIVER/DATA PROCESSOR SYSTEM

The receiver/data processing system is a modular assembly of circuit boards and display devices. Individual circuits as shown in the block diagram (Figure 8) can be easily removed for service or replaced with spares to maintain continuity of service. The schematic flow of control and information signals between the various elements is shown in this diagram. The following is a brief description of the logic and methods for each circuit element.

Main Receiver and Valid Signal Discriminator

Integrated circuits are used throughout the main receiver thus simplifying design and construction. This circuit (Figure A6) is a double conversion super-heterodyne receiver having I.F. frequencies of 10.7 MHz and 455 MHz. A programmable frequency synthesizer generates the local oscillator signal for the first balanced mixer (converter). Following the first I.F. amplifier (10.7 MHz) a second double balanced mixer and crystal-controlled local oscillator produce a 455 KHz signal which is further conditioned by a ceramic filter. The following amplitude modulation detector, a phase locked loop, outputs to a 150 Hz RC low pass filter and amplifier. A buffered signal is provided for a panel mounted tuning meter and an audio signal is provided for the valid signal detector, loud-speaker and oscilloscope.

The valid signal detector consists of a 311 comparator which, in conjunction with a front panel potentiometer, functions as a minimum-signal-settable discriminator. The network formed by the dual retriggerable monostables (74123), the 4017 counter and the 7408 ("and" gate) make up the valid signal discriminator. The function of this circuit is to discriminate between spurious noise pulses and the desired data signal. The 120 msec

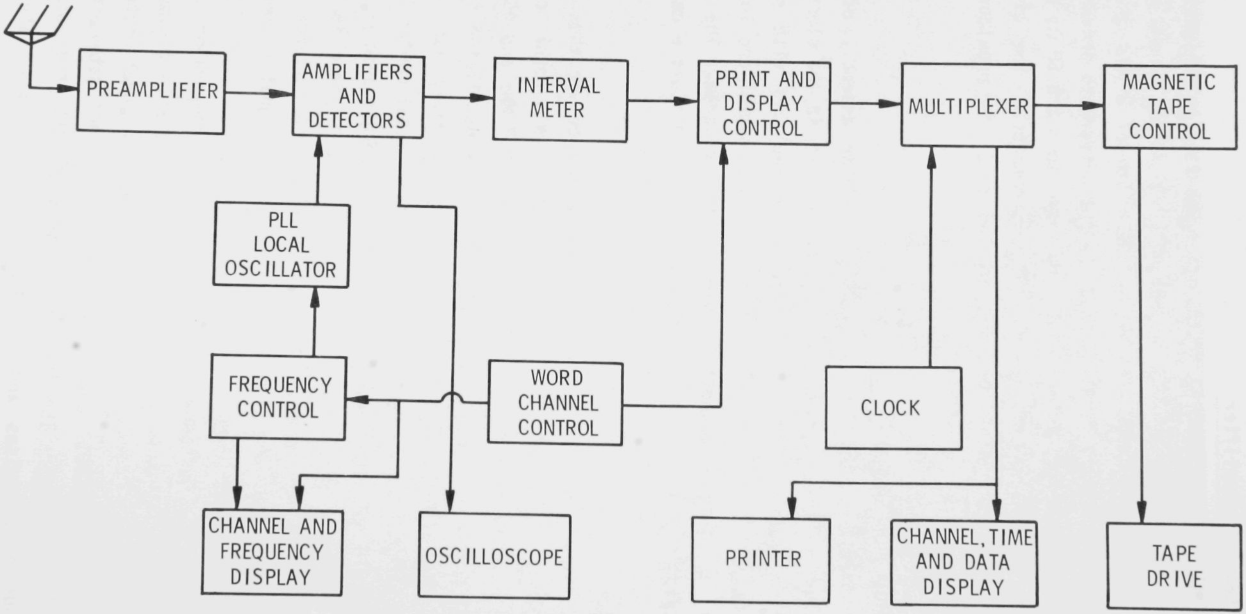


Fig. 8. Block diagram of receiver-data processing system.

monostable resets the counter if no pulses are received during its "on" period, and the 1 msec monostable is simply a pulse shaper for the data signals. When a signal is received, both monostables are triggered, releasing the reset on the counter. If a subsequent signal (R.F. burst) is received within the 120 msec time constant, a count is registered in the counter. Another R.F. burst within the allotted time latches the counter and the "and gate" is opened allowing the third and all following bursts to be delivered to the remainder of the data processing system. Failure of a signal burst to occur within the expected time frame resets the system and the process is repeated. Spurious signals are thus suppressed and defective data burst sequences result in restart of this circuit. The overall system bandwidth is approximately 150 Hz resulting in satisfactory detection of signals down to 0.1 μV.

First Local Oscillator

Receiver tuning is controlled by the first local oscillator (Figure A7), a programmable phase lock loop indirect frequency synthesizer, capable of covering the frequency of 50.7 to 52.7 MHz. A fixed divider string is used to count down a 4 MHz crystal oscillator frequency to a 1 KHz reference signal. The divide ratio of the presettable divider string is controlled by a digital input number such that the selected output frequency will yield a 1 KHz signal. These signals are compared and the generated error signal is filtered and applied to a varactor which controls the transistor LC oscillator. Further shaping and buffering stages provide an output signal of 40 to 42 MHz.

Since the minimum step in frequency is limited to 1 KHz, an additional circuit is included to allow fine tuning within any 1 KHz step. In this circuit, digital input numbers are converted to an analog voltage. This voltage is applied to the varactor in the reference oscillator circuit which "pulls" the generated reference frequency sufficiently to fine tune over the 1 KHz steps.

Frequency Control and Display

The digital input numbers which control the local oscillator phase-locked loop are generated, stored and selected by this circuit (Figure A8). These numbers are complements of the desired local oscillator frequency in the form of binary coded decimals. A circuit is included to translate the coded input numbers to the corresponding receiver tuning frequencies.

The tuning rate, or that rate at which the memories can be loaded, is selectable over a range of three decades (coarse, medium, fine). The input signals are derived from sub-multiples of the clock frequency. One-half of the 4013 provides synchronization and controls the direction of the frequency scan, up or down, for the binary counters and dividers (4029). A selected BCD number, N, is stored in the 7489 memories. The storage address within the memories is selected by the hexidecimal channel number inputs. Since the memories output the inverse of N, or 16 - N, and since the variable divider on the PLL local oscillator requires the 10's complement of N, or 10 - N, adding 10 in the 4008 parallel adders results in 26 - N with 16 overflowing, thus leaving the required 10 - N as an output.

The most significant digit of the frequency display, which is always 5, is hard-wired. A programmable read-only memory (8223) translates the BCD code for the local oscillator to the BCD display number. The fourth and fifth most significant digits are derived from the memory outputs by the 4009 inverters. This is the actual tuned frequency. No provisions were made to display the fine tuning offset. The auto-manual selector (spring return to off from manual) allows for automatic channel advance via the word/channel control or manual channel advance by momentary closure.

Word/Channel Control

The function of the word/channel control (Figure A9) is to sequentially advance the receiver tuning through the preselected transmitter frequencies. Either of two requirements (a filled data set or failure of a data burst to occur during a preset time) will result in the receiver tuning being advanced. In the scan or automatic mode, "channel advance" is high and thus "data word" increments the 4017 data word counter. When this counter is filled to a preset level, as selected by the data group size switch, the 7474 flip-flop is enabled. A 1 KHz clock pulse then triggers the 7474 allowing the channel number counter to advance to the next selected channel, resetting the sequence counter and, thus, the data word counter.

Since "data word" is generated at the beginning of a data burst, the last data period being measured by the interval meter has yet to be recorded. Following reset of the sequence counter, the two second period of "$\overline{\text{read data}}$" provides the required time to transfer this last bit of data.

Two additional seconds of settling time are then provided for acquisition of the next selected transmitter channel followed by the "read channel", "read clock", and "$\overline{\text{read data}}$" which continues until the next reset.

In the event that no data transmission is received within 10 sec, "data word" will be low and in the absence of reset, the delay counter will clear the 7474 flip-flop and thus advance the channel number counter to the next selected channel. This feature prevents locking of the receiver on a dead channel.

Interval Meter

The function of the interval meter (Figure A10) is to detect the reference tone burst and to measure and digitalize the period between tone bursts. The operation of the reference signal detector can best be understood by referring to the timing diagram (Figure 9). The detector output is a train of pulses which are 1 msec in duration, separated by more than 2 msec and lasting longer than 100 msec. The first positive edge triggers the 50 and 100 msec monostables (14258). The negative edges trigger the "A" monostable (14258) which re-shapes these pulses. Capacitor C_1 thus charges to a level determined by the burst frequency and the time constants determined by R_1, R_2, and C_1. High burst frequencies, as during the reference transmission, result in a higher acquired voltage than would be generated from a data burst. At the end of the 100 msec integration period, determined by the 100 msec monostable, the voltage on C_1 is transferred to C_2 by the "B" monostable and the 4016 switch. Note that the voltage that is stored on C_2 was that which had been developed on C_1 during the previous tone burst. In a reference tone burst, C_1 will be at a higher voltage than C_2. The 3130 comparator output will be high, enabling the "B" flip-flop which, when clocked by the end of the 100 msec pulse, sets Q on the "B" flip-flop high. Thus, pin 14 of the 80C97 will be high and when it is enabled, the reference line (pin 13 of the 80C97) will be high. This condition, which in effect results in the addition of a preset cueing number (N_Q) to the recorded data signal, is recognized by the computer program to signify a reference channel.

Since the order in which the transducer inputs are sampled is known with respect to the reference channel, individual transducers, as well as the reference channel, are identified within the computer program.

The Q output of the 50 msec retriggerable monostable generates "data

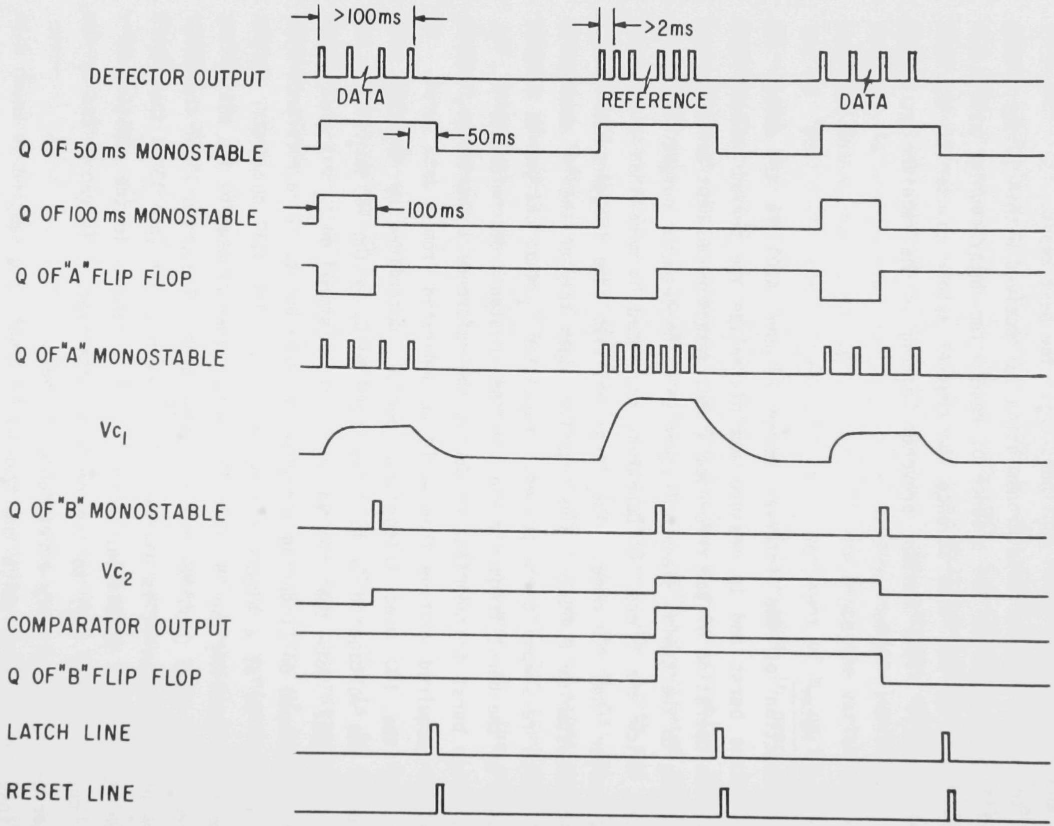


Fig. 9. Interval meter timing diagram.

word" (the digitized time period). The trailing edges of the $\overline{Q}$ output is differentiated and shaped to generate a latch pulse for the synchronous counter-latch and multiplex circuit (85L52 BCD counters). The trailing edge of the latch pulse generates within the "C" flip-flop a 5 μsec pulse which resets the synchronous counters, at which time a new count begins. (The clock frequency is 1 KHz; thus, the precision of period measurement is ±1 msec.) The latched count, which is the time interval between the end of the current and previous tone burst, is strobed to the displays and recorders when "$\overline{\text{interval}}$" and "$\overline{\text{read data}}$" or "$\overline{\text{scan}}$" are both high.

Print and Display Control

The selection and control of displayed and recorded information is accomplished within this circuit (Figure A11). The three-position mode switch allows the display of clock only (used in setting clock time), data only (for initial transmitter checking) or scan (for full information storage and/or display). In "data only" mode, autoscan is locked out to allow continual observation of one channel. The printer control switch (spring return to off from manual) selects a continuous printed record in auto position or a single line when held briefly in the manual position.

"Read clock", "read channel" or the trailing edge of "data word" generates a "record" pulse for the magnetic tape control circuit and also enables the printer. Current requirements of the printer are such that transistor buffering of "read data" is required to block the two most significant digits when printing data (4 digits long).

Clock

A precision 10 KHz crystal oscillator and six dual binary counters (Figure A12) generate all the required timing frequencies and the date/time information. Pulse rates of 1, 10, 100, and 1000 Hz are derived through four (divide by 10) counter sections. Two additional sections (divide by 60) generate a pulse rate of one per minute, which input into six additional counter sections to produce minute, hour and day outputs. Resolution is, thus, one minute. The maximum day number of 39 (at which point date resets to zero) is a limitation imposed by the maximum allowable record size. The hour and minute counters are presettable at a rate of 1 Hz via switches on the clock circuit. The day is reset to zero when the clock is being set.

Multiplexer

Clock signals and channel numbers are strobed onto the data bus by this circuit (Figure A13). In the scan mode, "scan" is high and "read clock", a one second pulse, transfers date and time to the data bus. In clock only mode, "$\overline{\text{clock}}$" is low resulting in continuous date/time to the data bus and thus a continuous display. This mode is utilized only for the initial set-up of date and time.

Magnetic Tape Control

All information destined for storage exists on the data bus as parallel information. The function of this circuit (Figure A14) is to strobe this information, in a byte serial format, to the incremental recorder. The sequence in which information is recorded on magnetic tape is channel number, date/time, and then data. The channel entry is six digits in length, the first two of which are channel number; the last four digits, reserved for other applications, are zeros. The date/time entry is six digits, two each for day, hour and minute. Our data entries (5 normally) are four digits long. A complete transmitter record is thus 32 digits (6 + 6 + 20).

Considering the date/time operation first, the following occurs: A "record" pulse resets the 4017 counter and starts the timing generator. The first timing pulse enables the 1×10^4 through 8×10^5 multiplexer section, and if the "read clock" is high, generates a "step and record". Subsequent timing pulses repeat this procedure for the 1×10^2 through 8×10^3 and 1×10^0 through 8×10^1 multiplexer sections after which the timing generator is stopped. When recording channel number, "read channel" replaces "read clock" and the same sequence follows.

When recording data entries (4 digits), "step and record" is generated only on the second and third timing pulse. Since both "read channel" and "read clock" are low, the first timing pulse is blocked and therefore, the first two most significant digits are not outputed. The 9-track recorder (8 data plus 1 parity) record two digits per "step and record" command; thus, sixteen entries (32/2) constitute a complete transmitter record. Seven "record" pulses are required for the sixteen entries. The record counter (14528) generates an inter-record gap after 256 "record" pulses. A "record" pulse can result in three "step and record" commands when in date/time or channel mode, or only two "step and record" commands when in the data mode.

Each tape record will have 252 (7 x 36) complete transmitter records plus four extra record pulses. If these pulses initiate data information, eight additional entries result. If the two (3 "step and record") commands are initiated, a maximum of ten additional entries result. Consequently, tape record lengths will vary between 4040 ((16 x 252) + 8) and 4042 ((16 x 252) + 10) entries.

Displays and Recorders

The channel number and frequency display is composed of one Hewlett-Packard 5082-7340 Hexidecimal Display Module for channel numbers 1-F (1-15) and five Hewlett-Packard 5082-7300 BCD Display Modules for the tuned frequency. The most significant digit is hard-wired at 5 for frequency as is a decimal point between the second and third most significant digit. Channel number inputs are provided by the word/channel control and frequency inputs by the frequency control.

Inputs for the channel, time and data display are all generated by the multiplexer. The hexidecimal channel number is converted to BCD and displayed on the first of the six Hewlett-Packard display modules during the "read channel" time period. During the "read clock" period the first two blocks display the day number and final four blocks display the hour and minute. In "read data" mode, the first two blocks are blank and only the four digit data is displayed.

Hard copy (Figure 10) is produced on a Moduprint Model CMMP-6A (Practical Automation, Inc.) 6-digit parallel printer. Input is from the multiplexer and is of the same sequence as the displays.

Data storage controls and inputs for the 9-track tapewriter (Cipher Data Products, Model 85H-9) are provided by the magnetic tape storage control. The sequence and format is the same as for the hard copy. Since the rate at which the data is strobed into the tapewriter is well below the maximum capacity of the tape unit, "busy/ready" feedback is not required.

Oscilloscope

A compact oscilloscope (Vu-Data, Model PS-9000) displays the detected audio signal. Its use facilitates setting the discriminator level such that the weakest usable signal can be accepted while normal noise levels are rejected, and permits the evaluation of transmitter performance before fish

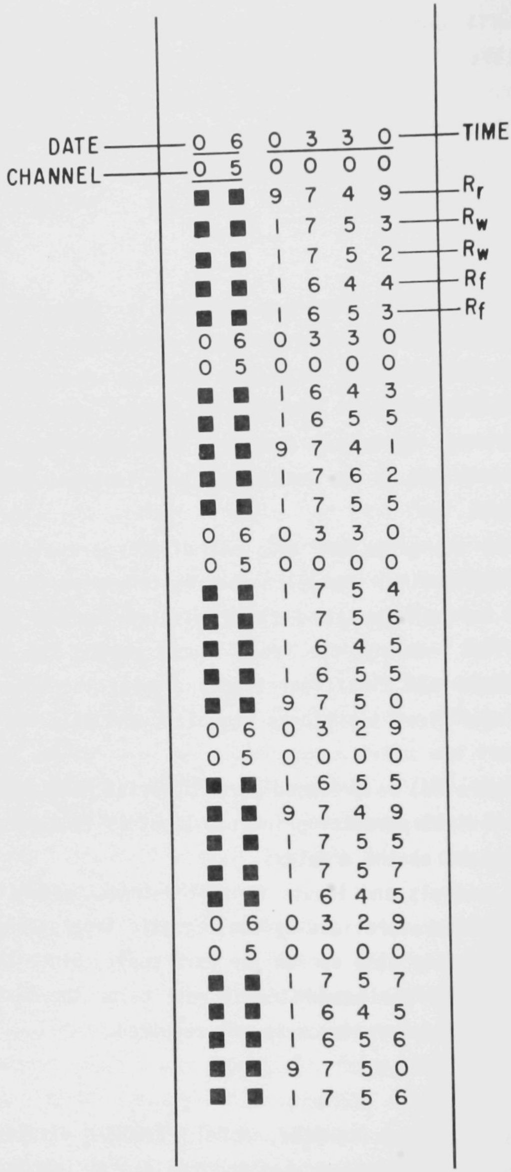


Fig. 10. Printer output showing date, time, channel number, reference (R_r), and data (R_w, R_f).

are released. The transmitted pulse train can be readily inspected to detect temperature probe damage occasioned during the tagging operation.

Power Supplies

All operating voltages were provided by a regulated, dual output (±5, ±15 V) power supply (Electrostatics Inc., Model 301). A standby power supply for the 7489 memories in the frequency control and display circuit is required to prevent loss of preselected frequency information during short-term power interruptions. This is provided by a type GRC 6060 CDF charger (Globe-Union Co.) and a 6 V gel cell battery (Globe-Union Inc.).

ASSOCIATED TRANSMITTER COMPONENTS

Body Temperature Probe

The thermistor probe used in determining fish body temperature (Figure 11) is constructed in the following manner. Soldered connections between the thermistor and phono cable are made by inserting the leads from the thermistor into the stripped-end wires of the cable and quickly soldering (so as not to melt tubing "C"). Tubing "B", which was well back on the phono cable, can then be slipped down over tubing "C".

Epoxy, the same as used for transmitter potting, is applied on all joints as well as the last inch of phono cable containing the thermistor bead. The coated assembly is then pulled into the needle such that the bead is just protected by the needle tip and any voids on either end of the needle are filled with epoxy and allowed to cure for 48 hours. The thermistor probes are then tested for electrical leakage (thermistor to water) by monitoring the probe's insulation resistance with an ohmmeter during a 48 hour water exposure test.

Saddle Construction

To minimize stress during attachment and after release, we have developed an easily attached saddle (Figure 11) which secures and positions the transmitter package to the fish. The body of the saddle is cut from a 4 oz. polyethylene bottle (Cole-Palmer No. 6033-30); edges are rounded to minimize abrasion and attachment holes are reinforced with aluminum rivets (W. W. Grainger, Inc., No. 4X641) and fiber spacing washers (Allied Radio Corporation, No. 2153). In installing these rivets, the attaching nail is

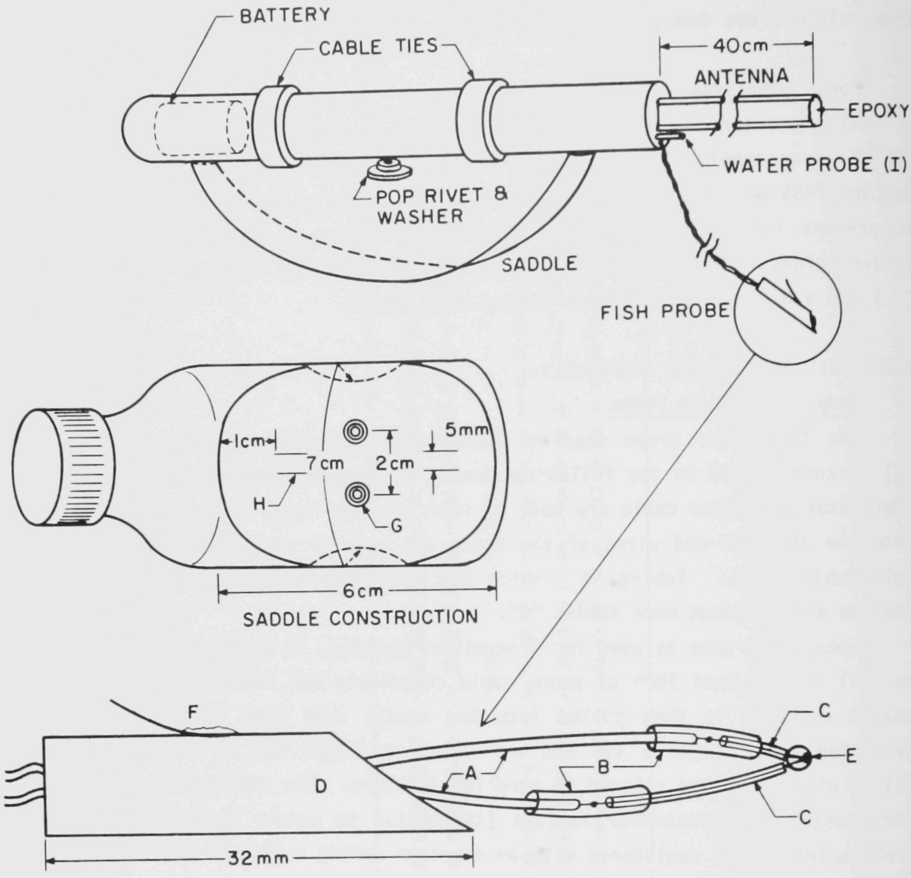


Fig. 11. Construction of transmitter saddle and body temperature probe. (A) 20 cm, 28 G twisted pair phono pickup arm cable, Belden #8430-250. (B) Intramedic polyethylene tubing, 12.7 mm O.D., 0.86 mm I.D., Clay-Adams PE-90. (C) Tygon microbone tubing, 0.76 mm O.D., 0.25 mm I.D., Cole-Parmer #6418-01. (D) 32 mm stainless steel tubing, 11 G, 3.05 mm O.D., 2.39 mm I.D. (E) Thermistor, glass bead, 200 k, Fenwal type GA52J2, Allied Radio Corp. #791-0412. (F) Barb, 19 mm x 4.8 mm x 0.15 mm shim stock, soft soldered in place. (G) Aluminum rivet, W. W. Granger Inc. #4X641, with fiber spacing washer, Allied Radio Corp. #2153. (H) Insert slots for cable ties, Thomas and Betts #TY25. (I) Thermistor, glass probe, 200 k, Fenwal type GA52P2, Allied Radio Corp. #791-0415.

pulled only far enough to expand the rivet and then driven back out, leaving a hole through the rivet for the attaching wire. The saddle is slotted to accommodate two self-clinching cable ties (Thomas and Betts, No. TY25) which hold the transmitter package on the saddle. The lacing needle constructed from 16 cm of 16 G SS tubing sharpened at one end, with a length of wire (No. 20 AWG stranded Belden 8502 vinyl insulated) soldered into the other end, is used to attach the transmitter package to the fish. The natural concave surface of the saddle conforms to the fish's contour and minimizes motion between the fish and transmitter package.

TRANSMITTER CALIBRATION

The transmitters are placed in a continuously stirred bath, initially cooled to ≈0°C and allowed to stablize. Five transmitter cycles are then recorded while simultaneously measuring bath temperature with a StoLab Model 911L electronic thermometer (±0.05°C). This procedure was repeated at ≈3°C intervals up to 30.0°C.

For every transmitter, pulses for each of the data channels (R_0) were normalized using the measured internal reference pulse (R_r) minus the preset queing number (N_Q) for that cycle using the equation:

$$R = R_0/(R_r - N_Q).$$

The normalized values for each data channel were averaged over the five cycles. These averaged values (R_{avg}) were then regressed against the measured absolute temperatures in the bath (T_k) using the equation:

$$R_{avg} = K_2/(\log_e(T_k) + K_6).$$

This equation is based on the theoretical expression which relates the resistance and the absolute temperature of a thermistor:

$$\frac{R_0(T_1)}{R_0(T_2)} = \varepsilon^{\beta}\left(\frac{1}{T_1} - \frac{1}{T_2}\right)$$

where:

$R_0(T_1)$ = resistance at absolute temperature T_1.

$R_0(T_2)$ = resistance at absolute temperature T_2.

e = 2.718.

β = constant which depends on the material used to make the thermistor (15).

The operating equation is derived in the following manner:

(1) $$\frac{R_{T1}}{R_{T2}} = e^{\beta\left(\frac{1}{T_1} - \frac{1}{T_2}\right)}$$

(2) at some particular temperature T_2: $R_{T2} = K_1$, $\beta = K_2$, $1/T_2 = K_3$ so that

$$\frac{R_{T1}}{K_1} = e^{K_2\left(\frac{1}{T_1} - K_3\right)}$$

(3) $$\log_e(R_{T1}) - \log_e(K_1) = K_2\left(\frac{1}{T_1} - K_3\right)$$

(4) $$\log_e(R_{T1}) - K_4 = \frac{K_2}{T_1} - K_5$$

(5) $$\log_e(R_{T1}) = \frac{K_2}{T_1} + K_6$$

(6) $$R_{T1} = K_2/(\log_e(T_1) + K_6.$$

Regressions were run utilizing FATAL (16), a non-linear weighted least-squares fitting routine and then plotted (Figure 12). The calculated parameter values (K_2, K_6), with appropriate identifying characters, are then inserted into a database (Figure 13) which is accessed by the main PL/1 computer program (FISH).

DATA DESCRIPTION

Telemetered data is recorded on 9-track unlabelled tape at a density of 800 bits per inch. Physical record length is nominally 585 or 586 bytes but actually varied from less than 16 bytes to over 700 bytes due to idiosyncrasies of the electronic recording system. Early tracking tapes suffered from this inconsistent physical record length and from the number of FF record delimiters due to an open ground return between the magnetic tape storage control and the Cipher tape drive. Each physical record is composed of 16-byte logical records, and each 16-byte record contains 32 hexadecimal digits (nibbles) packed two per byte. Two additional anomolies exist in the manner in which input records from different transmitters are mixed together on the tape and the manner in which temperature inputs within each record are

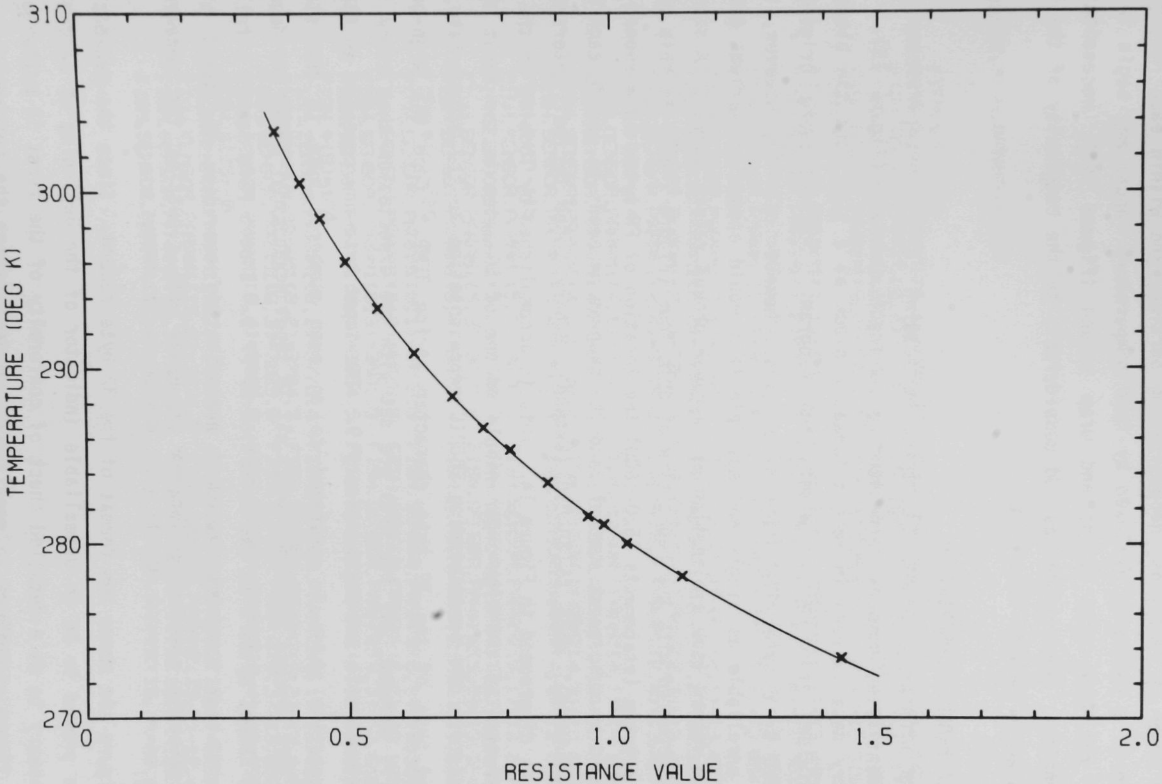


Fig. 12. Typical calibration curve produced utilizing FATAL fitting routine.

sequenced. Specifically, any one of 16 transmitter channels is recorded on tape in order of reception, necessitating sorting, and within each record the sequence of a reference followed by four temperature inputs may begin in any one of the five data fields and wrap around (Figure 14b), necessitating resequencing. These anomalies add considerably to the complexity of the PL/1 program which reduces this data.

COMPUTER PROGRAM DESCRIPTION

The program (Appendix B) begins by reading calibration parameters and fish identifying numbers corresponding to input channels (Figure 13). The telemetry data is read in record format a block at a time, and the block is then divided into records within the program. Records were originally delimited by a byte with all bits on (i.e., hexadecimal FF); however, this proved unreliable as single and multiple FF's would appear at various places within a record (see explanation of improper ground return above). A similar problem occurred with the repetition of byte four (Figure 14a). At this point in the program (statements 1520-1600) the location of FF bytes in a record are determined by subsequent removal, and the program proceeds to decode each byte from hexadecimal code to EBCDIC (Extended Binary Coded Decimal Interchange Code), as diagrammed in Figure 14. This is accomplished by looking at the bit configuration of the high-order nibble of one of 16 bytes in the input block and assigning the corresponding EBCDIC representation to the appropriate odd numbered byte of the 32 byte character string TEMP. Once the high-order nibble is decoded, all its bits are set with the expectation that every low-order nibble will not exceed binary 9. The input byte now contains an EBCDIC representation which is assigned to an even numbered byte in the string TEMP. This process continues until all 16 input hexadecimal bytes are decoded into 32 EBCDIC bytes with the exception of FF's. Should FF's occur, a full 32 bytes will not have been decoded, necessitating rereading the input block while skipping previously located FF bytes and repeating the conversion process.

Figure 14c shows the format of the 32 byte record. Since the hexadecimal FF byte proved to be an unrealiable indicator of the beginning of record, it is necessary to do a detailed check of conformity of the first 12 bytes to the record format. Failure to meet the above test causes the program to search forward to the beginning of the record a character at a time. Finding a "C"

```
INPUT.FISH.DATA(R14451)

        FISH.#(0)=120
        FISH.SENSOR.PARAM1(0,1)=3726.5  FISH.SENSOR.PARAM2(0,1)=13.540
        FISH.SENSOR.PARAM1(0,2)=3718.4  FISH.SENSOR.PARAM2(0,2)=13.517
        FISH.SENSOR.PARAM1(0,3)=3728.4  FISH.SENSOR.PARAM2(0,3)=13.515
        FISH.SENSOR.PARAM1(0,4)=3728.9  FISH.SENSOR.PARAM2(0,4)=13.515
        FISH.#(1)=105
        FISH.SENSOR.PARAM1(1,1)=3758.0  FISH.SENSOR.PARAM2(1,1)=13.459
        FISH.SENSOR.PARAM1(1,2)=3711.0  FISH.SENSOR.PARAM2(1,2)=13.303
        FISH.SENSOR.PARAM1(1,3)=3627.7  FISH.SENSOR.PARAM2(1,3)=13.104
        FISH.SENSOR.PARAM1(1,4)=3616.4  FISH.SENSOR.PARAM2(1,4)=13.064
        FISH.#(2)=125
        FISH.SENSOR.PARAM1(2,1)=3762.3  FISH.SENSOR.PARAM2(2,1)=13.422
        FISH.SENSOR.PARAM1(2,2)=3730.1  FISH.SENSOR.PARAM2(2,2)=13.312
        FISH.SENSOR.PARAM1(2,3)=3750.0  FISH.SENSOR.PARAM2(2,3)=13.466
        FISH.SENSOR.PARAM1(2,4)=3753.0  FISH.SENSOR.PARAM2(2,4)=13.477
        FISH.#(4)=114
        FISH.SENSOR.PARAM1(4,1)=3607.3  FISH.SENSOR.PARAM2(4,1)=13.190
        FISH.SENSOR.PARAM1(4,2)=3575.7  FISH.SENSOR.PARAM2(4,2)=13.081
        FISH.SENSOR.PARAM1(4,3)=3604.2  FISH.SENSOR.PARAM2(4,3)=13.083
        FISH.SENSOR.PARAM1(4,4)=3602.3  FISH.SENSOR.PARAM2(4,4)=13.073
        FISH.#(5)=115
        FISH.SENSOR.PARAM1(5,1)=3678.9  FISH.SENSOR.PARAM2(5,1)=13.257
        FISH.SENSOR.PARAM1(5,2)=3646.8  FISH.SENSOR.PARAM2(5,2)=13.149
        FISH.SENSOR.PARAM1(5,3)=3669.4  FISH.SENSOR.PARAM2(5,3)=13.314
        FISH.SENSOR.PARAM1(5,4)=3690.3  FISH.SENSOR.PARAM2(5,4)=13.386
        FISH.#(6)=126
        FISH.SENSOR.PARAM1(6,1)=3752.8  FISH.SENSOR.PARAM2(6,1)=13.301
        FISH.SENSOR.PARAM1(6,2)=3723.5  FISH.SENSOR.PARAM2(6,2)=13.202
        FISH.SENSOR.PARAM1(6,3)=3601.5  FISH.SENSOR.PARAM2(6,3)=13.060
        FISH.SENSOR.PARAM1(6,4)=3604.9  FISH.SENSOR.PARAM2(6,4)=13.071
        FISH.#(8)=124
        FISH.SENSOR.PARAM1(8,1)=3778.4  FISH.SENSOR.PARAM2(8,1)=13.462
        FISH.SENSOR.PARAM1(8,2)=3784.7  FISH.SENSOR.PARAM2(8,2)=13.487
        FISH.SENSOR.PARAM1(8,3)=3829.0  FISH.SENSOR.PARAM2(8,3)=13.800
        FISH.SENSOR.PARAM1(8,4)=3825.8  FISH.SENSOR.PARAM2(8,4)=13.790
        FISH.#(15)=0
        FISH.SENSOR.PARAM1(15,1)=3480.5  FISH.SENSOR.PARAM2(15,1)=12.514
        FISH.SENSOR.PARAM1(15,2)=3531.0  FISH.SENSOR.PARAM2(15,2)=12.452
        FISH.SENSOR.PARAM1(15,3)=3458.1  FISH.SENSOR.PARAM2(15,3)=12.321
        FISH.SENSOR.PARAM1(15,4)=0000.0  FISH.SENSOR.PARAM2(15,4)=00.000;
```

Fig. 13. Typical data base containing calibration coefficients calculated from least-squares fitting routine.

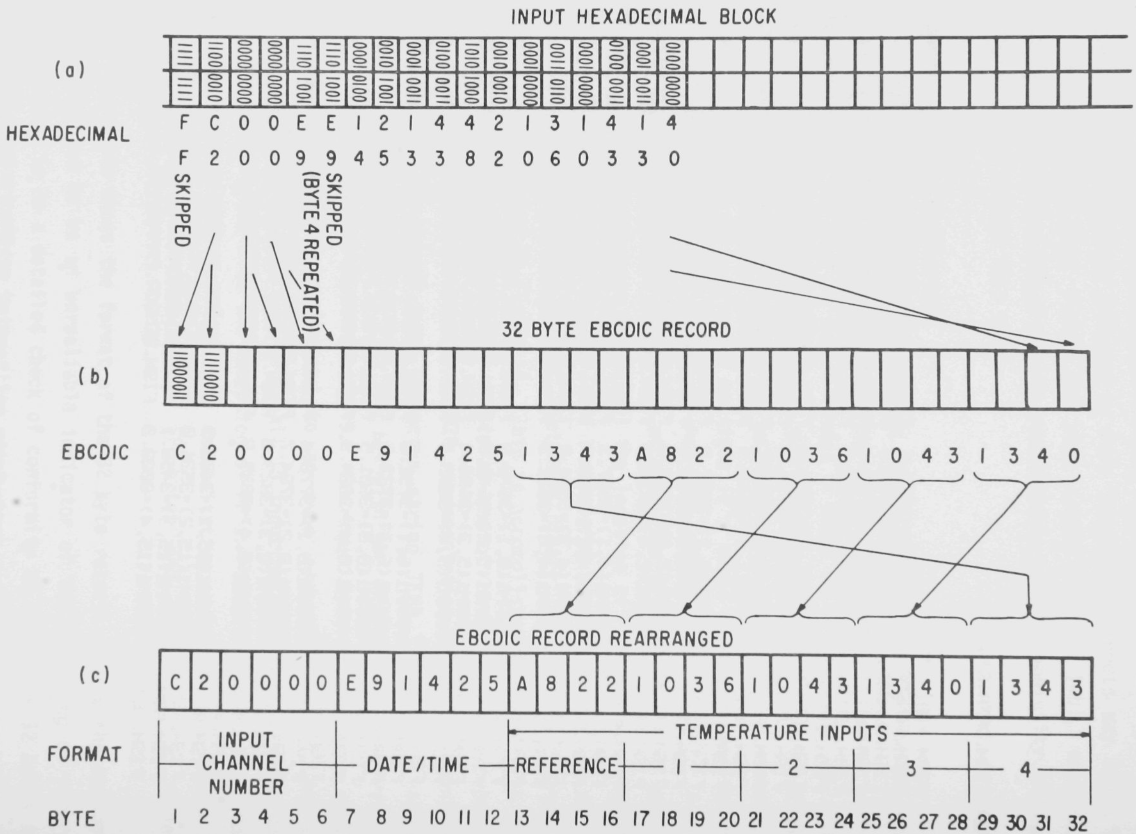


Fig. 14. Data transformation from hexadecimal format to EBCDIC and subsequent rearrangement to proper sequence.

or a "D" sets the byte location in the input block for the beginning of the next record. The erroneous data is printed on the sysprint file and the decoding process is repeated beginning with the reading of a new record starting at the new byte location.

In the event the first 12 bytes of the record satisfy the tests, a rearranging and calibration process is initiated on the remaining 20 bytes of the record. The 20 bytes represent five four-digit decimal integers corresponding to a reference (the leading reference digit may be hexadecimal), two water temperatures, and two fish temperatures. The reference is the first of the sequence but may be positioned in any one of the five data fields. The program looks at the 32 bit string representation of each field searching for the reference (reference value plus cueing number) which lies between the values 8000 and 9999 or A000 and B999. Fields between C000 and C900 or D000 and D900 cause printing on the sysprint file and record resequencing. Multiple references also cause the record to be discarded and printed on sysprint. References beginning with A or B are converted to decimal representation. Once an acceptable reference number has been found, the numbers are rearranged with the reference positioned in the first field; temperature fields are then converted to floating point numbers and calibrated.

All error-free records are sorted into print (and optionally plot) files whose DD (Data Definition) names (Appendix C) correspond to the fish channel number (first six bytes of the record). If a file corresponding to the channel number does not exist, one is opened. Blocks shorter than 16 bytes, records not conforming to the record format (Figure 14c), resequencing records, records with multiple references, records with no reference, and records with invalid characters are all printed on the sysprint file with appropriate flags.

Appendix C is a listing of the job control statements (JCL) used to batch process the telemetry data at Argonne's Central Computing Facility. Appendix D is a listing of the TSO (Time Sharing Option) command procedure used to modify and submit the JCL in Appendix C for the appropriate magnetic tape input. The keyword PRNTALL causes all records to be written on tape file sysprint for subsequent listing on microfiche. Keyword LIBRARY allows substitution of a library tape for the standard private input tape. Since both these data sets are straightforward, no further comment is necessary.

DATA REDUCTION

From the individual sysprint files, observations are manually screened for defective data (usually due to spurious noise interference) by comparison between thermistor pair values. Data points are taken every five minutes except in the case of a temperature excursion exceeding 2.0°C between adjacent observations in which case data points are taken every 1-2 minutes. This time interval was chosen based on a previous study dealing with the kinetics of fish body temperature change (17). The reduced data were then used as input to the SAS (Statistical Analysis System)(18) for data analyses and to the PLOTIN/MYPLOT (19) graphical routines for visual scanning of recurring activity patterns.

CAPTURE METHODS

Experimental fish were captured by one of two methods. The first employed a 305 m long x 3.7 m deep shore seine deployed on either side of the discharge flumes. The second method utilized lift nets attached to fish barrier screens located within each of the discharge flumes. Salmonids entering the discharge flumes were captured when they passed over the submerged nets. Fish in the size range of 1-10 kg were effectively tagged with the transmitters.

ATTACHMENT PROCEDURE

A fish selected for tagging was placed in a wet trough (Figure 15) which was padded with polyurethane foam. Morphological characteristics (e.g., weight, length, etc.) were measured and the trough with fish was suspended in water such that the trough was partially filled. The fish was easily held immobile at this point. The attaching needle (far end of wire knotted) was threaded through the first hollow pop rivet, through the adipose tissue under the skin (above the epaxial muscle mass) and out the remaining pop rivet. A knot at the exit point completed the attachment.

The body temperature probe was inserted above the pelvic fin, about one inch below the lateral line through the lateral musculature, slanting down and back into the body cavity. To facilitate insertion, the skin was first perforated with a sharpened stainless steel rod (1/8" diameter) having a stop that prevents penetration beyond 1/4".

The tagged fish was then returned to the holding tank for approximately

Fig. 15. Attachment procedure utilizing weighing trough (ANL Neg. 301-76-28 #20).

one-half hour. The holding tank was continuously flushed with water of the same temperature as that from which the fish was captured. This period allowed time to check proper operation of the transmitter, to check for possible adverse reaction of the fish to the tagging and to permit the fish to equilibrate to the transmitter package. Although no specific studies were done to determine the effects of the attachment procedure or the transmitter itself on the behavior of tagged fish, a number of observations indicated minimal effects. Most fish suffered no apparent losses of equilibrium after transmitter attachment. Tagged fish were frequently seen swimming in the discharge flumes (.93-1.50 m/sec current velocity) and many of the tagged fish were recaptured by sport fishermen in the vicinity of the release site and at remote locations.

LIMITATIONS

Signal levels as received onshore can be quite variable. This variability can be attributed to lake conditions (wave height) and/or orientation of the transmitting antenna. Strong wave action can cause rapid fluctuations in signal levels such that sections of the data bursts are lost, which results in a defective record. The alignment of the transmitter antenna relative to the wave direction appears to be important since strong wave action does not always preclude good data reception. Another source of signal loss is due to transmitter antenna orientation with respect to the receiver location. The strength of the radiated signal is greatest along a line through the transmitting antenna; thus, optimum conditions require that the fish be oriented shore-perpendicular. Signal attenuation for shore-parallel orientation (Figure 1) appears to increase more rapidly with distance than that for shore-perpendicular orientation; however, our tracking records indicate that normal (random) fish movement allows nearly continuous coverage in the plume region.

The hydrodynamics of typical canal (flume) discharges of warmed water are such that plume depth decreases with increasing distance from the point of discharge. The depth from which reliable information is transmitted/received likewise decreases from the receiver location (Figure 1). Thus, in our application, a compensation exists which provides coverage throughout that region where a fish could encounter heated water. Other research sites and applications might not provide such a serendipitous compensation.

RECOMMENDED IMPROVEMENTS

Occasional transmitter failures occurred after the tagging operation both before and after release of the fish into the lake. These failures were probably caused by electrical leakage in the temperature probes. Two possible leakage paths are suggested. The first is from the epoxy-sealed antenna ends (one at supply voltage, the other at ground potential). The second is from the "power on" connection: negative battery lead and ground were only soldered together, making no provisions for insulation from the water.

The inclusion of blocking capacitors in both antenna lines would eliminate the antenna leakage path; a reed relay "power on" switch sealed inside the transmitter would eliminate leakage from that source. Both of these modifications would not significantly affect the package size but would improve transmitter reliability. Both lines to any one sensor would have to be faulty to disable the transmitter and even then, only the faulty channel would be lost. Whereas, with the unprotected system, leakage at any of the probe ends going to the current-to-frequency converter render the entire package inoperable.

While temperature is the only parameter we have monitored thus far, any transducer capable of modulating a current could be used. For example, pressure transducers could be used for measuring depth, or in a differential configuration for determining swimming speed. Since the point of origin of the transmitted signal represents a fish's location, a phase-sensitive system such as that offered by the Adcock antenna (20) with suitable processing circuitry could generate spatial information.

SUMMARY OF RADIOTRACKING DATA

A list of trout tagged with transmitters and released at Point Beach is given in Table 1. Track periods ranged from 0 (transmitter failure) to 505 total hours. As indicated in Figure 16, tracks include time spent by fish in plume and ambient waters and total hours tracked include intermittent periods while fish were "out of range". Track periods ended with the last usable data received from each transmitter.

Three patterns of fish behavior were observed in these studies: (1) the first represents fish that left the study site and receiving range of the tracking system almost immediately after release; (2) a large number of tagged fish remained at the site for a day or less after tagging and then left the

Table 1. List of all trout tagged with underwater radiotransmitters and track periods at the Point Beach Nuclear Plant, Two Rivers, Wisconsin (* indicates transmitter failure).

Species	Sex	Weight (kg)	Length (cm)	Start track date (hr)	End track date (hr)	Total Hours
Brown trout	F	3.18	62	01 Oct 75 (1232)	03 Oct 75 (0958)	45.5
	F	2.95	61	01 Oct 75 (1600)	*	0
	F	2.49	57	01 Oct 75 (1805)	02 Oct 75 (1502)	21
	M	3.40	63	02 Oct 75 (1055)	02 Oct 75 (1541)	5
	M	2.31	54	09 Oct 75 (0911)	13 Oct 75 (0312)	90
	M	2.77	54	09 Oct 75 (0914)	*	0
	F	4.76	67	09 Oct 75 (1317)	09 Oct 75 (1341)	0.5
	M	3.86	65	13 Oct 75 (1700)	14 Oct 75 (1258)	20
	M	2.27	57	14 Oct 75 (1053)	15 Oct 75 (1531)	4.5
	F	2.72	57	14 Oct 75 (1332)	15 Oct 75 (0408)	14.5
	F	3.63	67	14 Oct 75 (1606)	*	0
	F	4.08	56	22 Oct 75 (1527)	27 Oct 75 (1008)	114.5
	F	4.08	53	22 Oct 75 (1538)	24 Oct 75 (2250)	55
	F	3.40	61	23 Oct 75 (1016)	26 Oct 75 (2131)	83
	M	4.08	65	23 Oct 75 (1055)	23 Oct 75 (1643)	6
	F	1.59	50	05 Nov 75 (1400)	10 Nov 75 (1032)	116.5
	M	1.81	54	05 Nov 75 (1401)	05 Nov 75 (1500)	1
	M	1.59	54	10 Dec 75 (1202)	11 Dec 75 (1111)	23
	F	0.79	47	11 Dec 75 (0949)	12 Dec 75 (1026)	24.5
	F	1.93	48	11 Dec 75 (1035)	14 Dec 75 (1804)	79.5
	F	0.91	45	11 Dec 75 (1357)	12 Dec 75 (0352)	14
	F	1.59	46	20 Apr 76 (0947)	*	0
	M	4.08	64	20 Apr 76 (1214)	20 Apr 76 (2141)	9.5
	F	1.59	48	20 Apr 76 (1216)	*	0
	F	5.44	65	23 Jun 76 (1733)	24 Jun 76 (0540)	12
	M	4.31	69	23 Jun 76 (1734)	24 Jun 76 (0839)	15
	M	3.40	57	23 Jun 76 (1743)	27 Jun 76 (1905)	97.5
	M	3.18	54	23 Jun 76 (1833)	*	0
	F	5.90	70	24 Jun 76 (1628)	25 Jun 76 (0115)	10
	F	5.44	69	24 Jun 76 (1630)	25 Jun 76 (1849)	26.5
	F	3.33	63	12 Oct 76 (1452)	13 Oct 76 (0100)	10
	F	3.18	60	12 Oct 76 (1704)	12 Oct 76 (1820)	1
	F	2.27	52	12 Oct 76 (1806)	12 Oct 76 (2337)	5.5
	F	2.95	57	14 Oct 76 (1125)	14 Oct 76 (1428)	3
	M	2.38	55	14 Oct 76 (1200)	16 Oct 76 (0945)	46
	F	4.08	63	02 Nov 76 (1600)	03 Nov 76 (2050)	29
	F	5.22	69	03 Nov 76 (0955)	03 Nov 76 (1359)	4
	M	2.84	58	03 Nov 76 (0955)	04 Nov 76 (0902)	23
	F	1.13	45	09 Feb 77 (1508)	10 Feb 77 (0745)	17
	M	1.36	47	09 Feb 77 (1509)	03 Mar 77 (0124)	514
	F	1.59	48	09 Feb 77 (1532)	18 Feb 77 (1933)	196
	F	0.91	45	09 Feb 77 (1558)	14 Feb 77 (0959)	114
	F	3.40	69	10 Feb 77 (1312)	13 Feb 77 (0720)	66
	F	1.59	49	10 Feb 77 (1312)	14 Feb 77 (0646)	89.5

Table 1. Continued.

Species	Sex	Weight (kg)	Length (cm)	Start track date (hr)	End track date (hr)	Total Hours
	M	2.04	53	10 Feb 77 (1314)	12 Feb 77 (2350)	58
	M	1.81	50	13 Apr 77 (1407)	16 Apr 77 (0616)	64
	M	1.93	55	13 Apr 77 (1654)	*	0
	M	1.25	46	13 Apr 77 (1655)	*	0
	M	2.72	60	13 Apr 77 (1655)	23 Apr 77 (1348)	236.5
	M	2.95	55	26 May 77 (1447)	31 May 77 (0556)	111
	M	2.38	52	26 May 77 (1500)	27 May 77 (1248)	22
	M	2.49	50	26 May 77 (1645)	27 May 77 (0813)	15.5
	F	2.72	52	26 May 77 (1706)	30 May 77 (1129)	90.5
	M	4.76	62	26 May 77 (1706)	27 May 77 (0708)	14
	?	2.49	54	26 May 77 (1720)	27 May 77 (0512)	12
	F	2.72	55	29 Jun 77 (1419)	29 Jun 77 (1835)	4
	F	2.27	51	29 Jun 77 (1422)	*	0
	F	1.81	47	29 Jun 77 (1423)	29 Jun 77 (1749)	3.5
	M	7.26	70	29 Jun 77 (1425)	29 Jun 77 (2035)	6
	F	3.93	63	16 Aug 77 (1441)	29 Aug 77 (0938)	307
	M	2.27	55	16 Aug 77 (1445)	*	0
	M	3.63	63	16 Aug 77 (1446)	17 Aug 77 (1052)	20
	M	7.48	73	16 Aug 77 (1458)	23 Aug 77 (0645)	160
	F	3.41	56	16 Aug 77 (1614)	29 Aug 77 (0940)	305.5
	M	3.86	63	16 Aug 77 (1617)	17 Aug 77 (0305)	11
	F	2.86	58	21 Sep 77 (1442)	21 Sep 77 (1810)	3.5
	M	2.72	59	21 Sep 77 (1443)	21 Sep 77 (1546)	1
	M	2.27	56	19 Oct 77 (1106)	26 Oct 77 (0217)	159
	F	2.04	52	19 Oct 77 (1159)	23 Oct 77 (0626)	90.5
	M	2.04	52	19 Oct 77 (1159)	22 Oct 77 (0600)	66
	F	2.27	50	19 Oct 77 (1413)	28 Oct 77 (2014)	222
Rainbow trout	M	3.13	65	09 Oct 75 (1032)	*	0
	M	6.35	76	13 Oct 75 (1853)	14 Oct 75 (0350)	9
	F	2.49	64	05 Nov 75 (1415)	06 Nov 75 (1810)	28
	M	3.18	63	05 Nov 75 (1615)	06 Nov 75 (0500)	13
	F	1.81	54	03 Dec 75 (1815)	04 Dec 75 (1405)	20
	M	2.27	53	03 Dec 75 (1815)	03 Dec 75 (2007)	2
	M	4.20	70	03 Dec 75 (1816)	04 Dec 75 (1040)	16.5
	M	1.13	48	10 Dec 75 (1202)	12 Dec 75 (2105)	57
	M	3.18	65	20 Apr 76 (0943)	20 Apr 76 (1955)	10
	M	3.18	62	12 Oct 76 (1730)	12 Oct 76 (1758)	0.5
	F	2.27	57	13 Oct 76 (1511)	13 Oct 76 (1540)	0.5
	M	2.72	65	02 Nov 76 (1602)	03 Nov 76 (0622)	14.5
	F	4.54	63	02 Nov 76 (1724)	02 Nov 76 (2327)	6
	F	1.70	55	13 Apr 77 (1407)	13 Apr 77 (1439)	0.5
	?	2.04	57	21 Sep 77 (1204)	22 Sep 77 (2322)	35.5
	?	1.59	53	21 Sep 77 (1205)	21 Sep 77 (1234)	0.5
	M	2.50	58	21 Sep 77 (1216)	*	0
	F	2.50	56	21 Sep 77 (1223)	21 Sep 77 (1303)	0.5

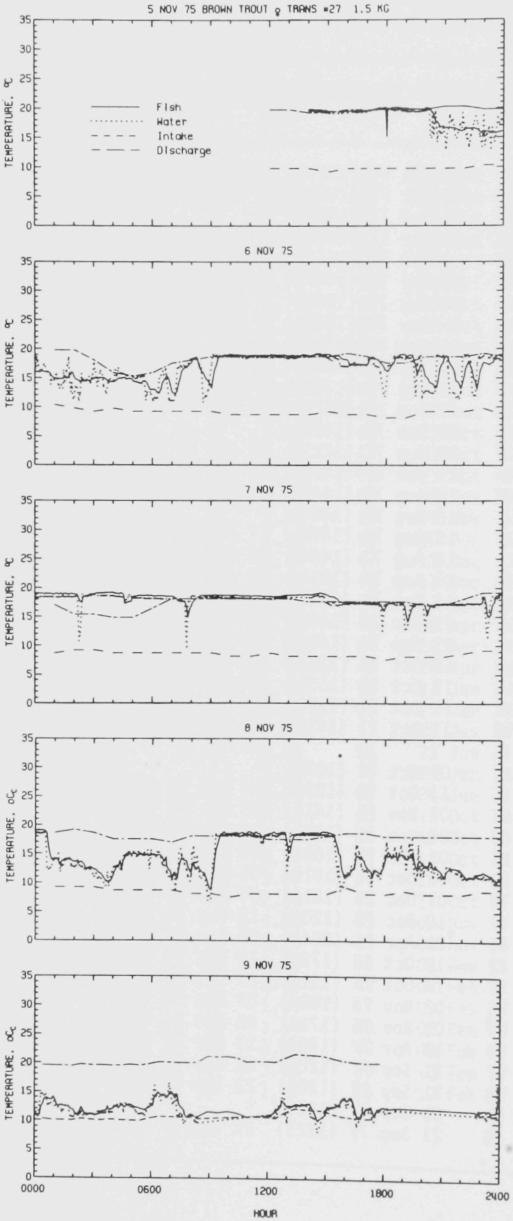


Fig. 16. Continuous 5-day temperature track of 1.5 kg brown trout showing excursions between intake and discharge temperatures
(ANL Neg. 149-77-341)

area; (3) some fish remained in the area for more than a week, moving "in and out of range" of the system. Continuous plume residence periods of 1-2 days were common during summer and fall, while longer continuous periods of plume residence were common during winter and spring.

The results of this study are now being reduced and analyzed to describe thermoregulatory behavior of brown trout and rainbow trout that frequent thermal discharges to Lake Michigan. Time-at-temperature histories are being summarized to estimate seasonal selected temperatures and energetic demands on plume-resident fishes. Experiments designed to estimate the effects of observed temperature selection/exposure are being conducted using the telemetry data as a basis for temperature exposure simulation.

REFERENCES

1. S. A. Spigarelli, G. P. Romberg, and R. E. Thorne, A technique for simultaneous echo-location of fish and thermal plume mapping. Trans. Amer. Fish. Soc. 102, 462-466 (1973).
2. G. P. Romberg, S. A. Spigarelli, W. Prepejchal, and M. M. Thommes, Migratory behavior of fish tagged at a nuclear power plant discharge into Lake Michigan. Proc. 17th Conf. Great Lakes Res., pp. 68-77 (1974).
3. G. P. Romberg, W. Prepejchal, and S. A. Spigarelli, Temperature exposure measured by the use of thermoluminescence. Science 197, 1364-1365 (1977).
4. G. P. Romberg and W. Prepejchal, Thermoluminescence dosimeters (TLDs) used to monitor temperature exposure. Proc. 15th Int. Conf. Luminescence Dosimetry, Sao Paulo, Brazil, 14-17 February 1977, pp. 387-392.
5. J. D. Winter, V. B. Kuechle, and D. B. Siniff, An underwater radiotracking system. Underwater Telemetry Newsletter 3, 1 (1973).
6. H. R. Henderson, A. D. Hasler, and G. G. Chipman, An ultrasonic transmitter for use in studies of movements of fishes. Trans. Amer. Fish. Soc. 95, 350-363 (1966).
7. J. R. M. Kelso, Diel movement of walleye *Stizostedion vitreum vitreum*, in West Blue Lake, Manitoba, as determined by ultrasonic tracking, J. Fish. Res. Board Can. 33, 3070-3072 (1976).
8. K. Schiefer and G. Power, Tracking in a turbulent river. Underwater Telemetry Newsletter 2, 14-15 (1972).

9. E. S. Gardella and A. B. Stasko, A linear-array hydrophone for determining the swimming depth of a transmitter-equipped fish. Underwater Telemetry Newsletter 2, 6-7 (1972).
10. W. Prepejchal, G. P. Romberg, and S. A. Spigarelli, Effects of season, locations, and discharge type on fish distribution and density in thermal plumes. Radiological and Environmental Research Division Annual Report, January-December 1974, ANL-75-3, Part III, pp. 150-154.
11. R. K. Moore, Radio communications in the sea. IEEE Spectrum 4, 42-51 (1967).
12. R. Gabillard, P. Degauque, and J. R. Wart, Subsurface electromagnetic telecommunication - a review. IEEE Trans. Commun. Technol. COM-19(6), 1217-1228 (1971).
13. Anonymous, CCIR Report 322, 10th Plenary Assembly, Geneva, Switzerland, in: Reference Data for Radio Engineers (1963).
14. A. A. Frigo and D. E. Frye, Physical measurements of thermal discharges into Lake Michigan: 1971. Special Report, Argonne National Laboratory, ANL/ES-16 (1972).
15. Thermistor Manual (EMC-6), Fenwal Electronics, Farmingham, Massachusetts (1974).
16. L. Salmon and D. V. Booker, FATAL - a general purpose computer program for fitting experimental data to any required function. AERE-R-7129, London, HMSO (1972).
17. S. A. Spigarelli, M. M. Thommes, and T. L. Beitinger, The influence of body weight on heating and cooling of selected Lake Michigan fishes. Comp. Biochem. Physiol. 56A, 51-57 (1977).
18. Statistical Analysis System (SAS), User's Guide, SAS Institute Inc., P. O. Box 10066, Raleigh, N.C. 27605 (1979).
19. R. E. Toohey, J. Rundo, and T. J. Kotek, A user's guide to PLOTIN/MYPLOT, a general purpose plotting routine for use with AMD graphics. Special Report ANL/RER-78-3 (1978).
20. F. E. Terman, Radio Engineering, pp. 727-728, McGraw-Hill Book Co., New York (1937).

APPENDIX A:

Electronic Component Schematics

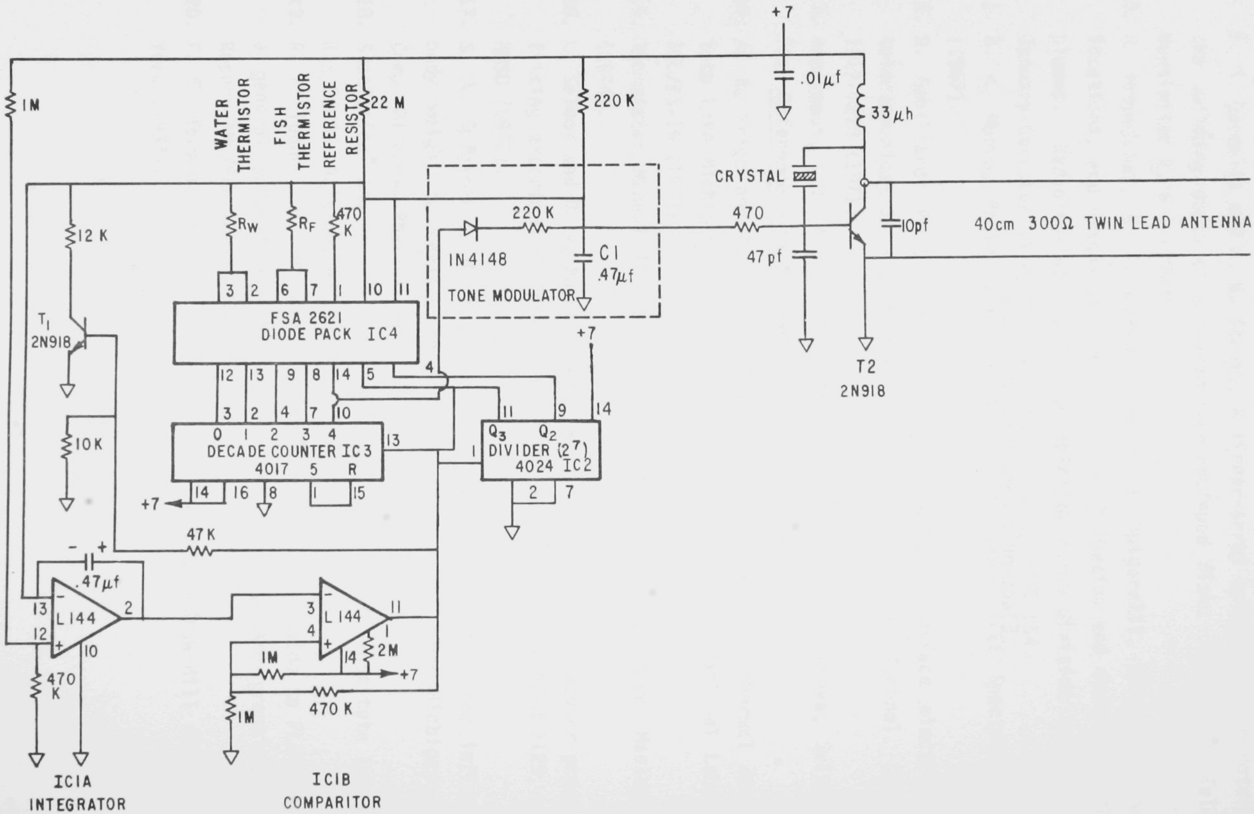


Fig. A1. Mark I fish transmitter.

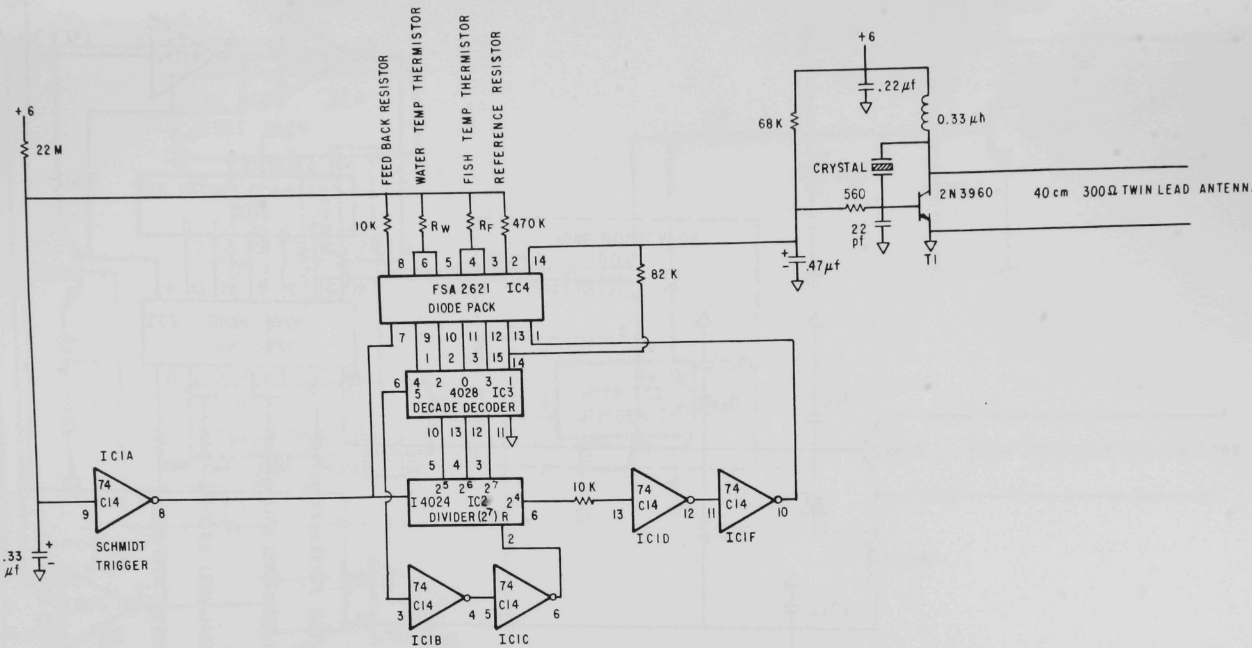


Fig. A2. Mark II fish transmitter.

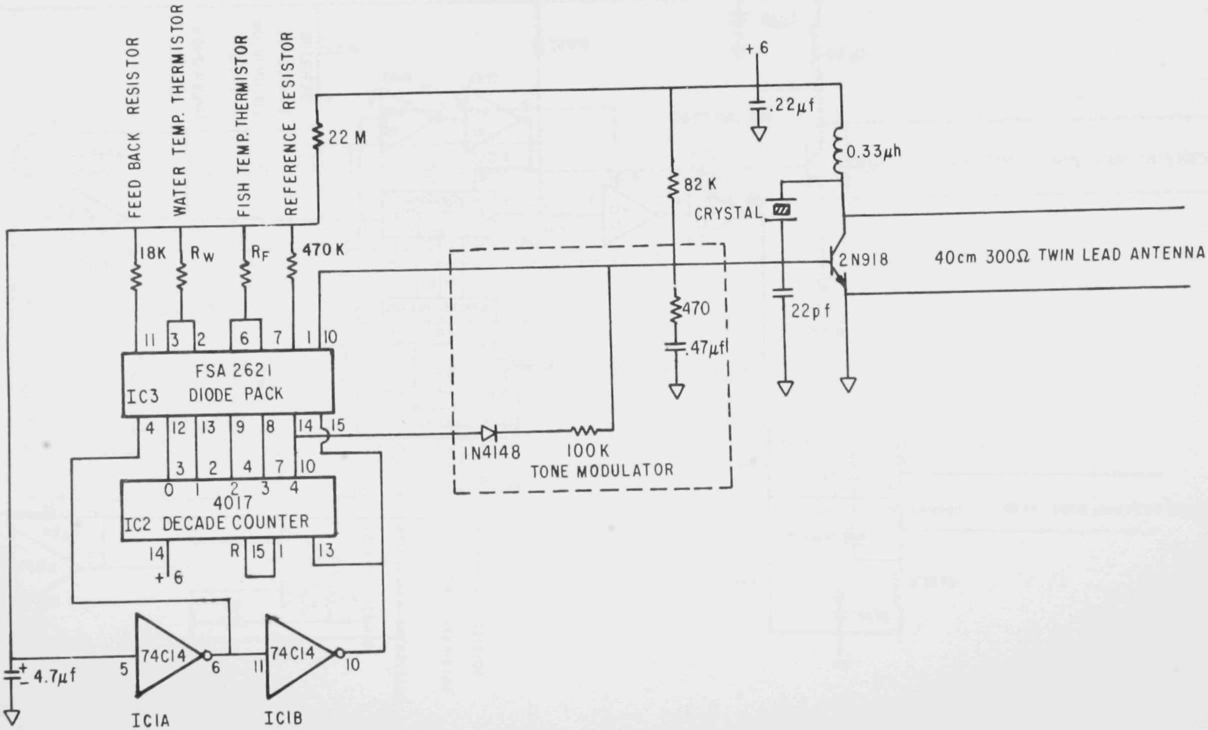


Fig. A3. Mark III fish transmitter.

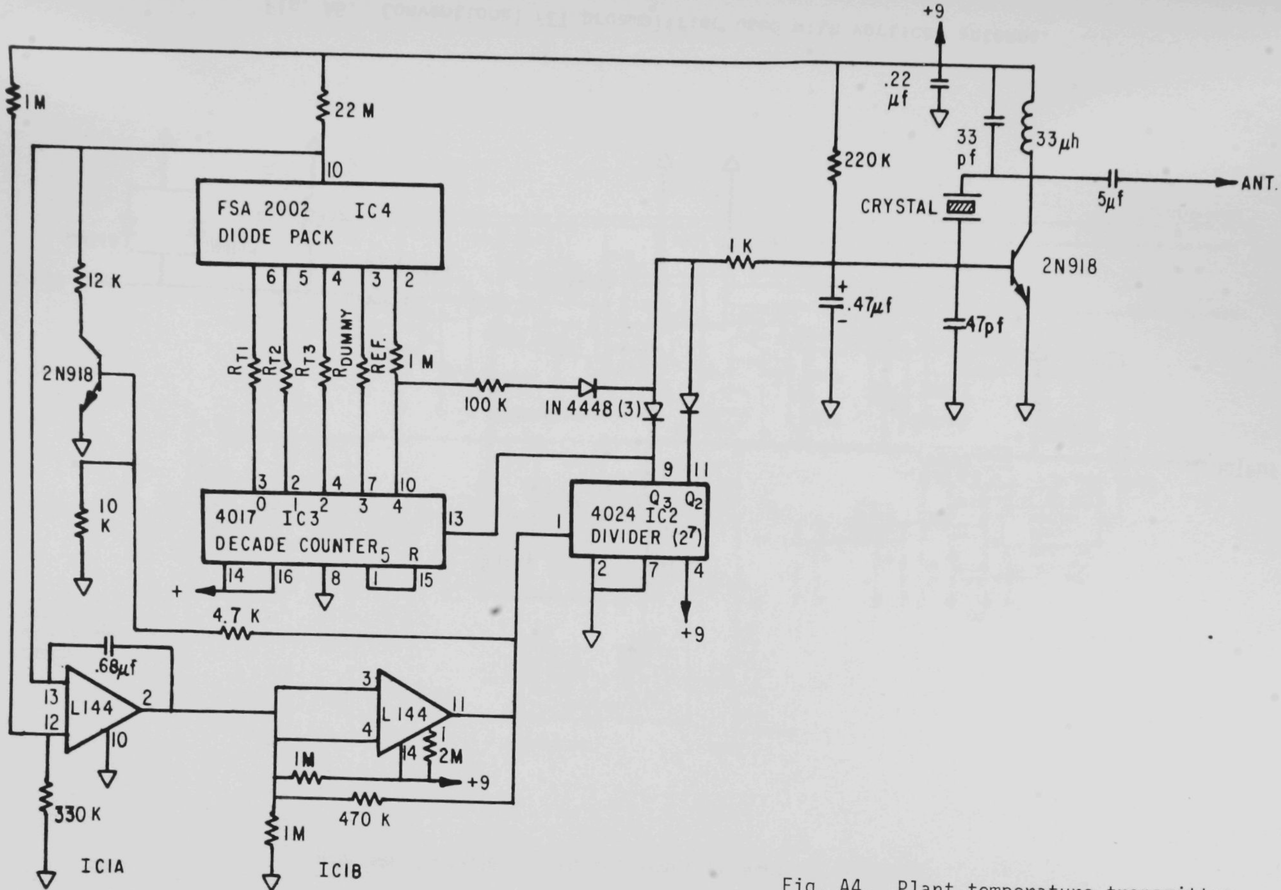


Fig. A4. Plant temperature transmitter.

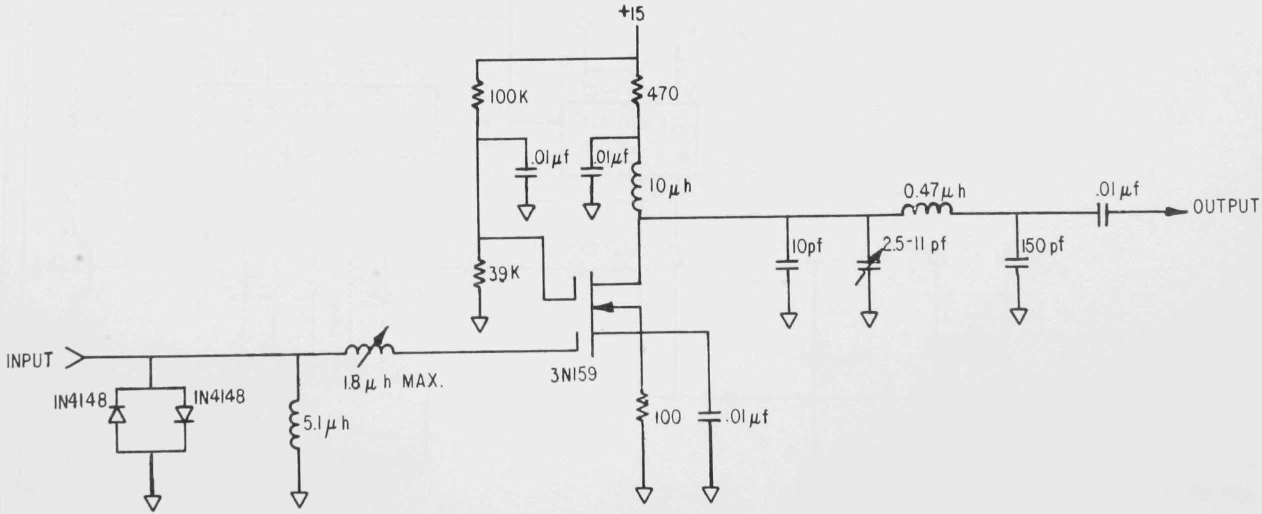


Fig. A5. Conventional FET preamplifier used with vertical antenna.

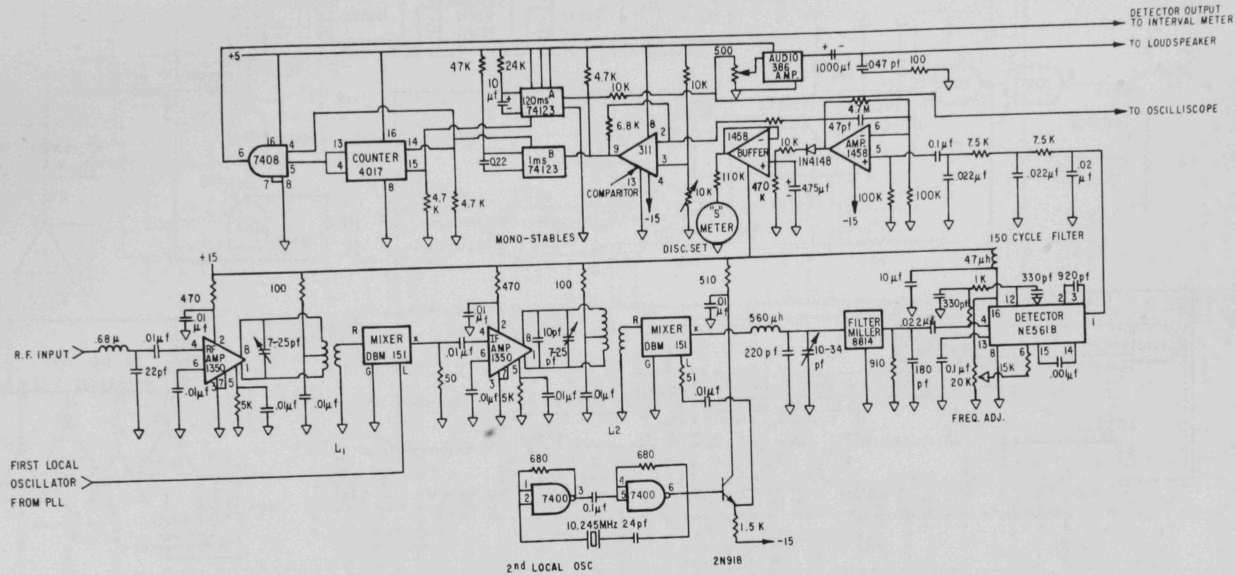


Fig. A6. Double conversion super-heterodyne receiver.

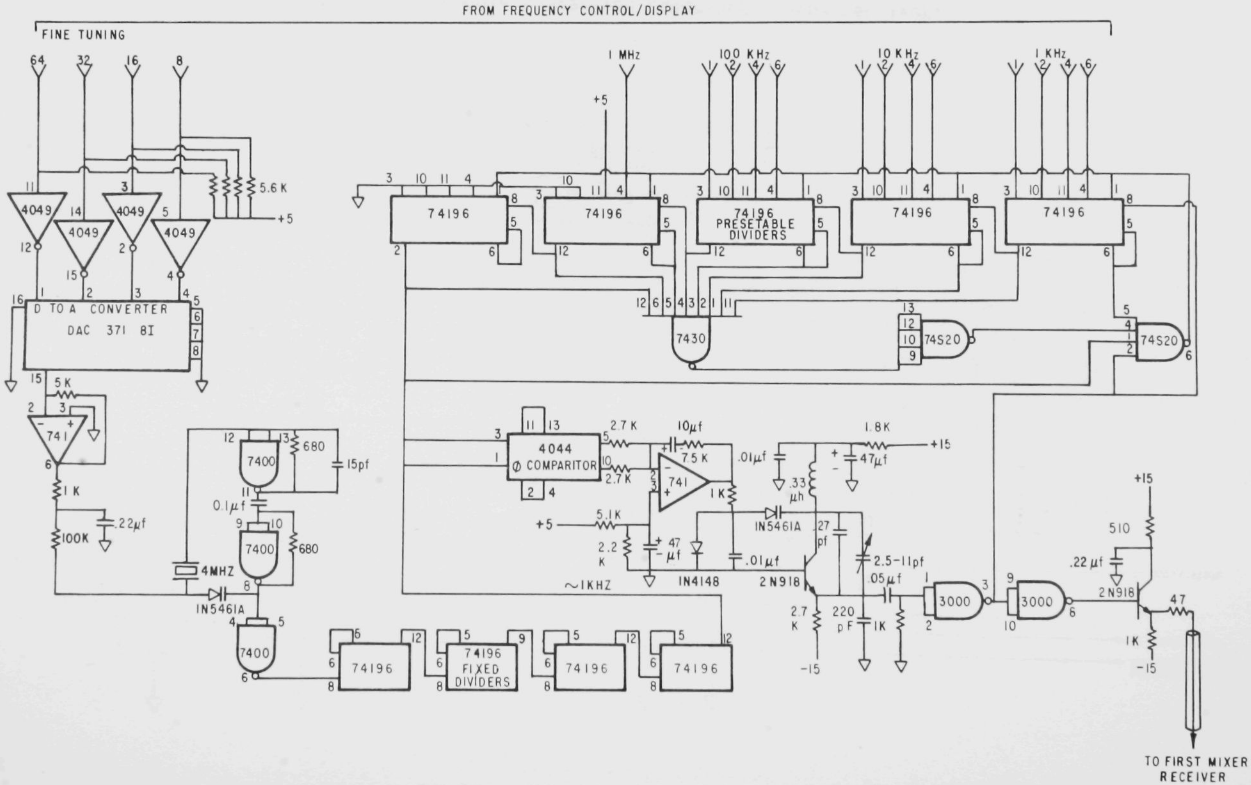


Fig. A7. First local oscillator.

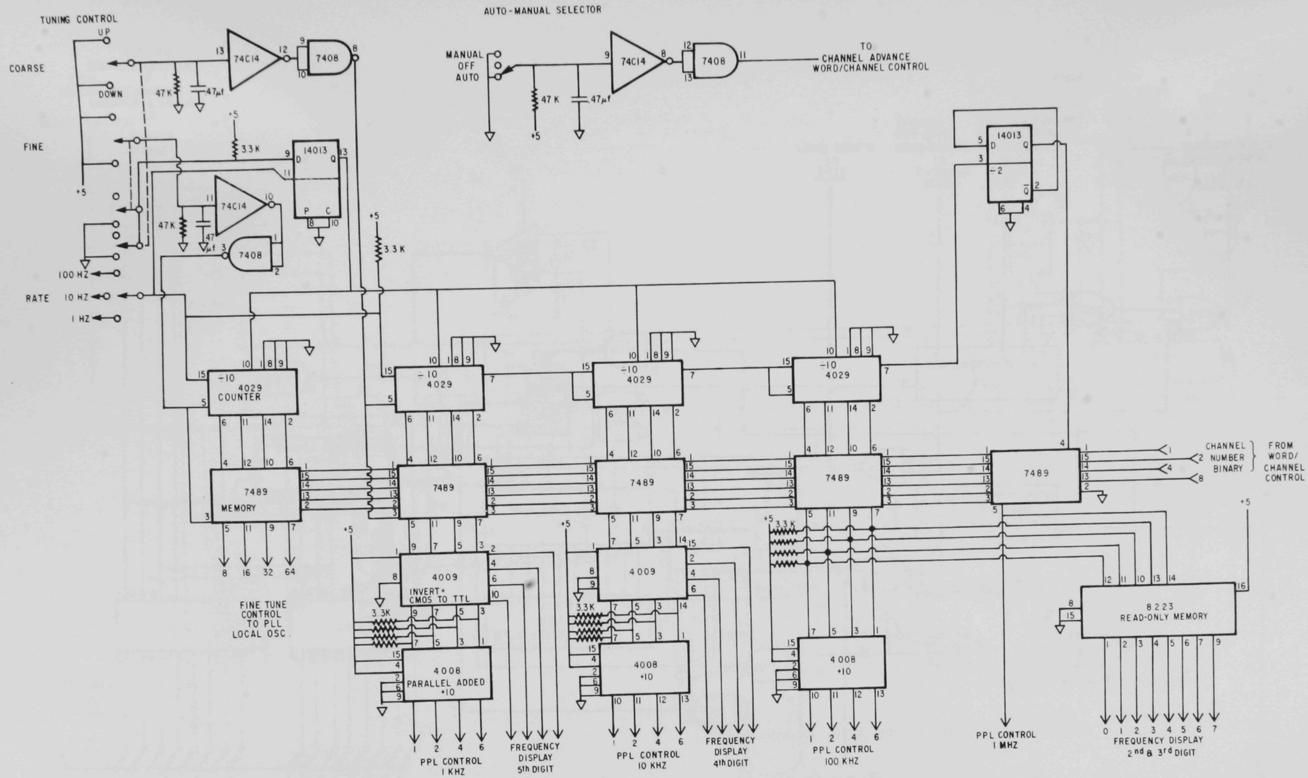


Fig. A8. Frequency controller and display.

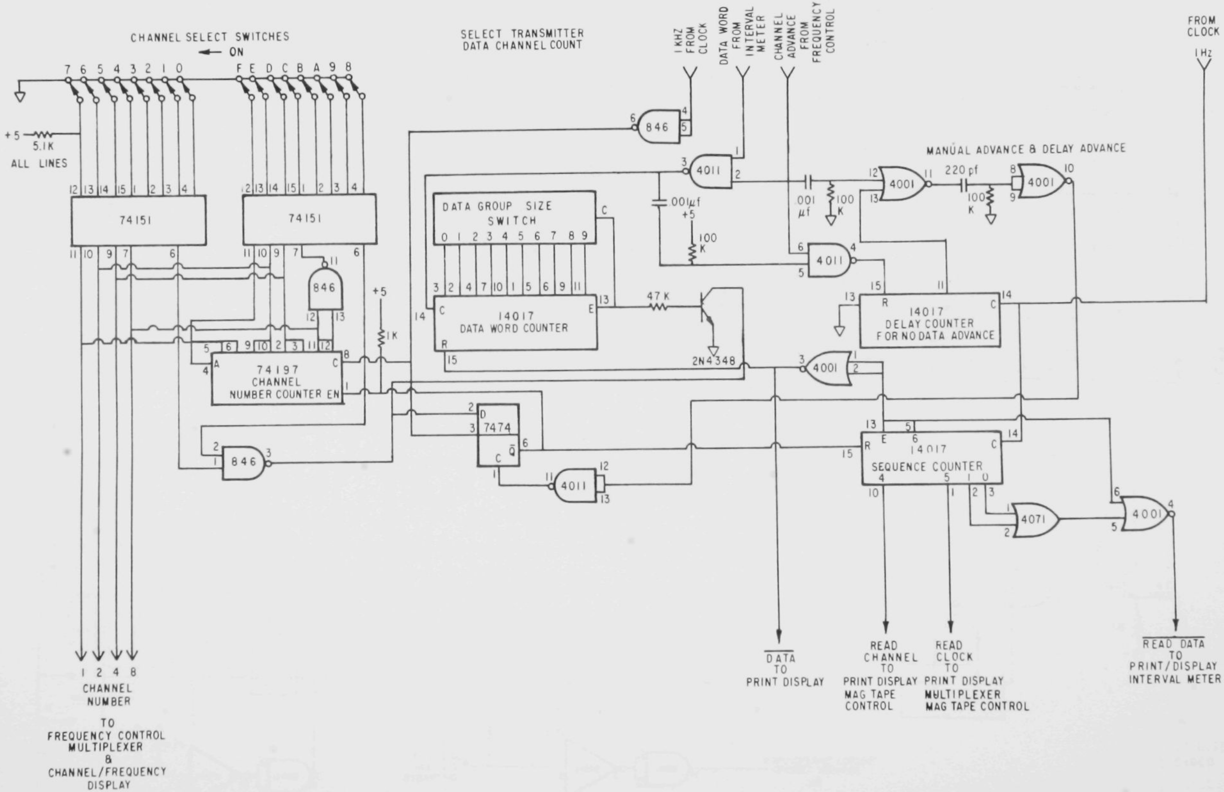


Fig. A9. Word/channel control.

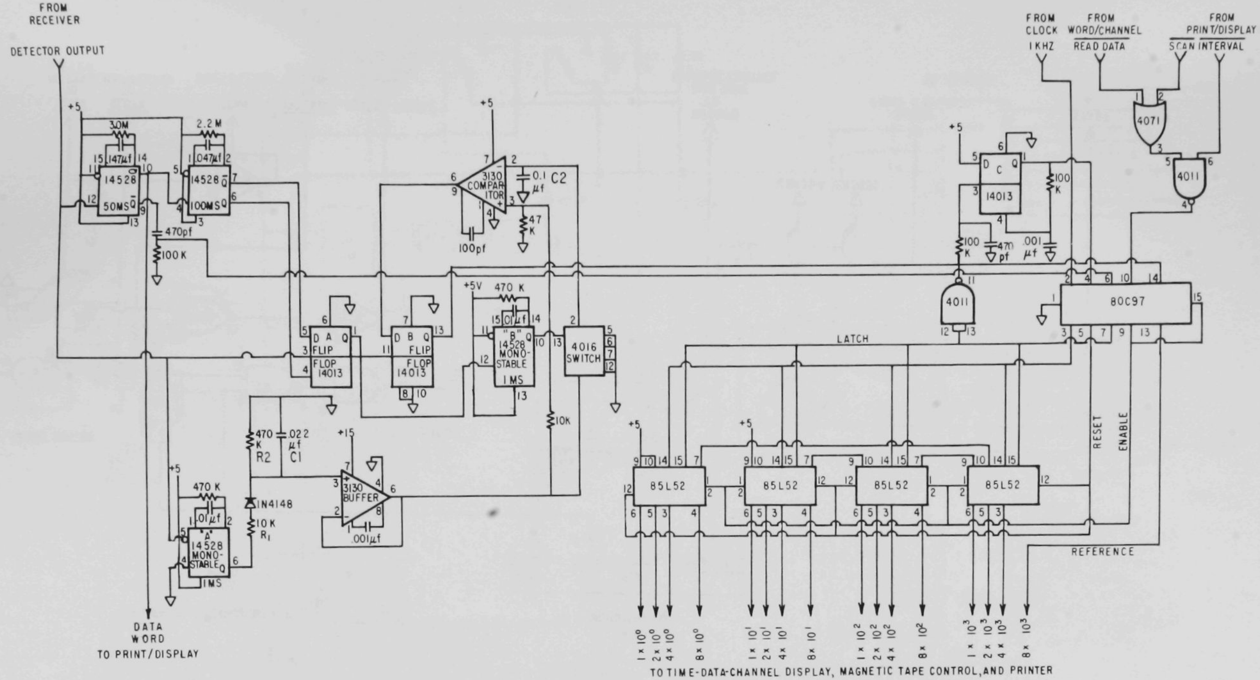


Fig. A10. Interval meter.

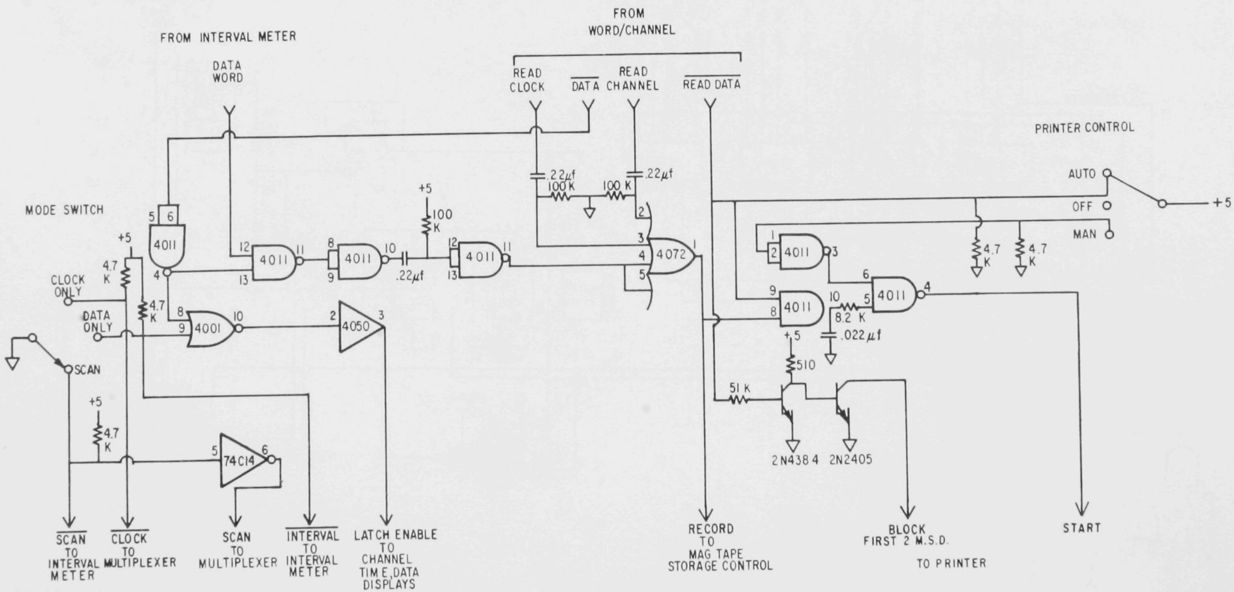


Fig. A11. Print and display controller.

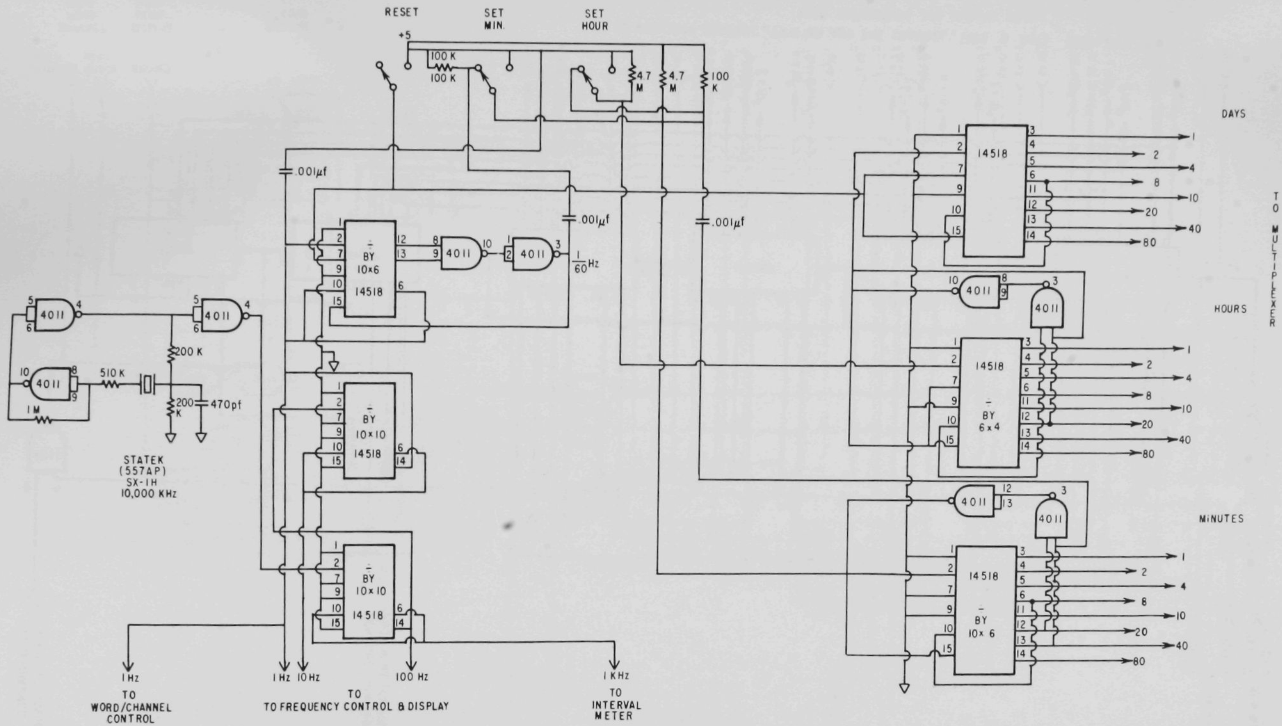


Fig. A12. Timing clock.

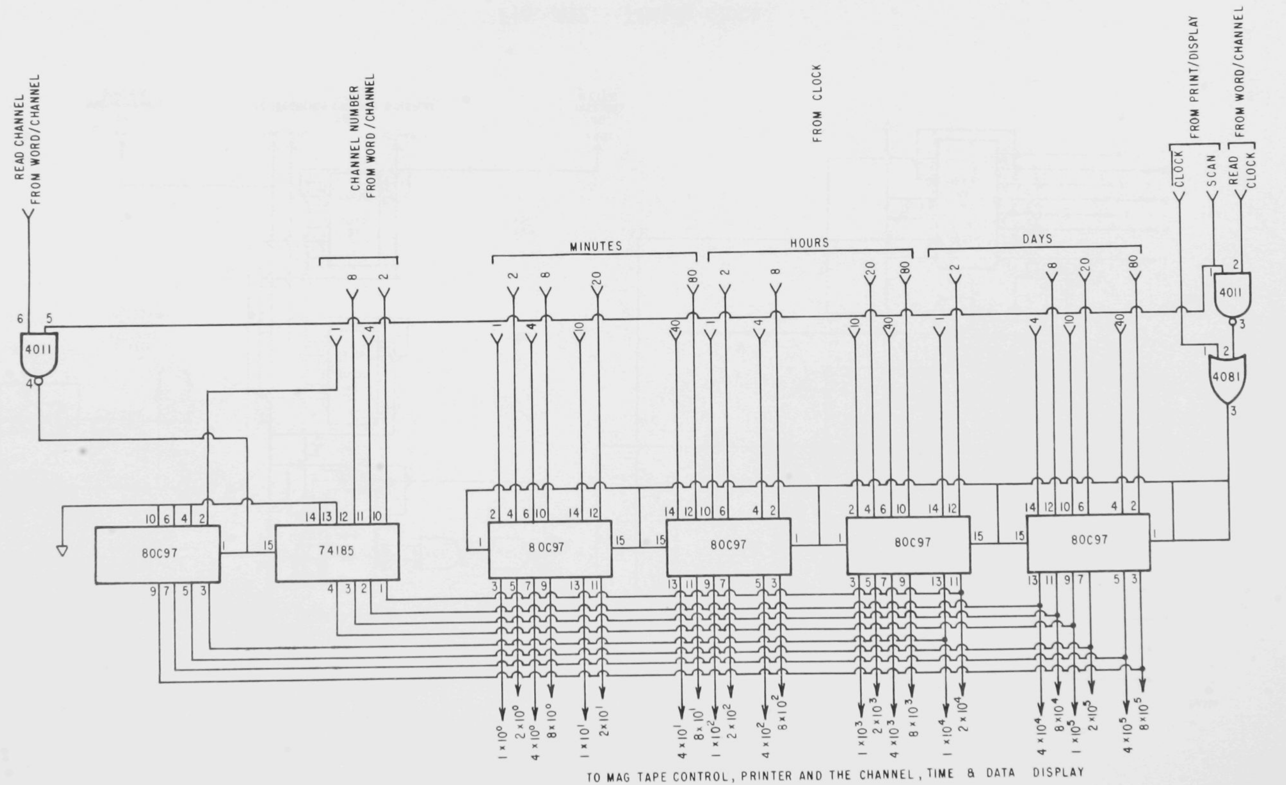


Fig. A13. Multiplexer

Fig. A13. Multiplexer

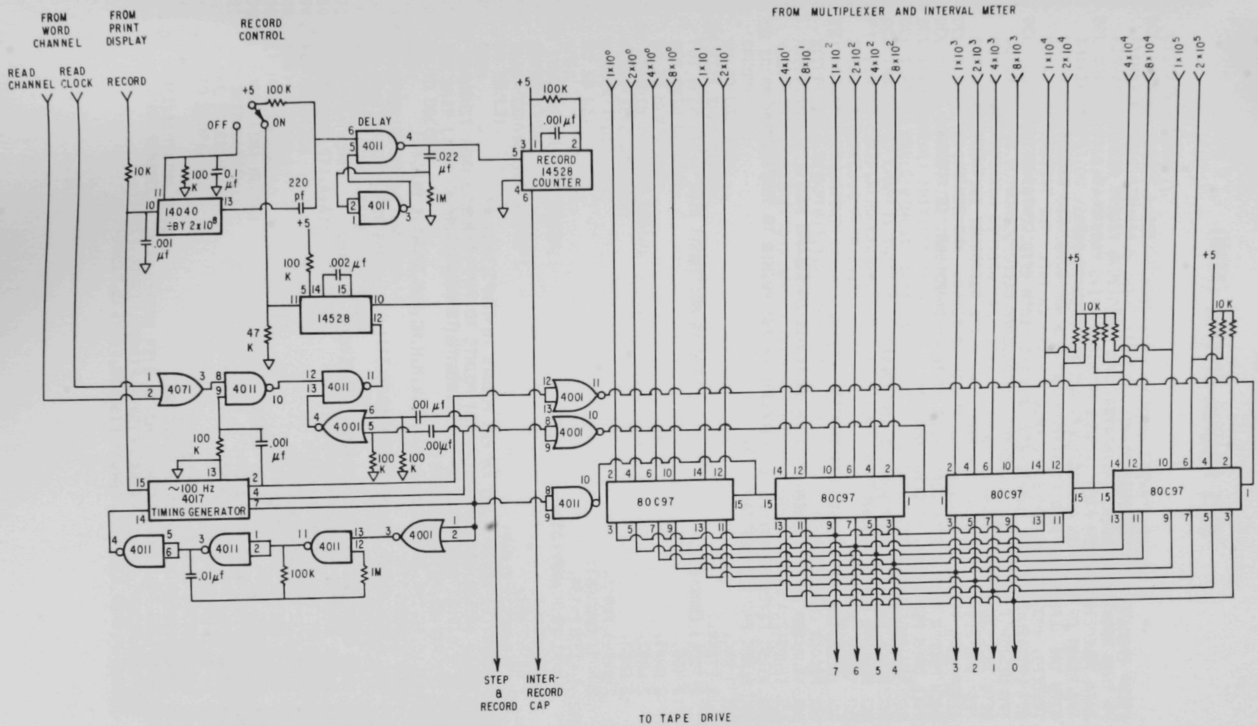


Fig. A14. Magnetic tape controller.

APPENDIX B:

PL/1 Program Listing (FISH)

```
FISH: PROCEDURE OPTIONS(MAIN);
/* THIS PROGRAM DECODES, CALIBRATES, AND SORTS INTO FILES,
DATA TELEMETERED FROM FISH IN LAKE MICHIGAN. FIVE VARIABLES,
THE FIRST OF WHICH IS A REFERENCE, ARE RECORDED ON TAPE
WITH THE REFERENCE FIELD POSITION FLOATING. NUMEROUS FISH MAY BE
TRACKED, AND THEIR RECORDS ARE FREELY MIXED ON TAPE. THE TAPE IS
NOT WRITTEN IN EBCDIC NOR IN HEX. INSTEAD, EACH BYTE CONTAINS
TWO DISTINCT HEXADECIMAL NUMBERS. THE PROGRAM DECODES EACH
BYTE INTO TWO EBCDIC CHARACTERS (I.E. BYTE 'C9' BECOMES HEXADECIMAL
'C3' AND 'F9'), REORDERS EACH RECORD WITH THE REFERENCE IN THE
FIRST DATA FIELD, CALIBRATES THE REMAINING FIELDS, AND SORTS
EACH RECORD INTO A FILE IDENTIFIED BY THE FISH NUMBER. IF SUCH A
FILE DOES NOT EXIST, IT OPENS ONE. */
DCL REMAINDER CHAR(32) VARYING;
DCL BLOCK CHAR(BLKLGTH) VARYING CONTROLLED;
DCL BLKLGTH FIXED BINARY(31);
DCL TEMP2 CHAR(16);
DCL TEMP3(16) CHAR(1) DEFINED(TEMP2);
DCL RECORD CHAR(32);
DCL TEMP(32) CHAR(1) BASED(PT); /* OVERLAYED ON RECORD */
DCL TEMP1(20) CHAR(1);
DCL ST(5) FIXED BINARY(31) BASED(PST); /* PST POINTS TO TEMP(13) */
DCL BLANK CHAR(8) INITIAL(' ');
DCL 1 REC,
  (2 FISH#,
   2 TIME) CHAR(6),
  (2 REF,
   2 CH#1,
   2 CH#2,
   2 CH#3,
   2 CH#4) FLOAT,
   2 BLNK CHAR(8);
DCL 1 FISH(0:15),
   2 # FIXED BINARY(31),
   2 SENSOR(4),
     (3 PARAM1,
      3 PARAM2) FLOAT;
DCL HEX BIT(4) BASED(PHX); /* PHX POINTS TO TEMP3(IXX) */
DCL BYTE1 BIT(8) BASED(PB1); /* PB1 POINTS TO TEMP(IX) */
DCL BYTE BIT(8) BASED(PB); /* PB POINTS TO TEMP3(IXX) */
DCL (PT,PHX,PB,PB1,PST) POINTER;
DCL (I,IC,IF,IFF,IX,IXX,J,JJ,JJJ,IJ,K,M,N,NC,BGN,START,I_OLD,F#)
  FIXED BINARY(31);
DCL (FILE_NOW,EIGHT,ZERO) FIXED BINARY(31);
DCL T(5) FLOAT;
DCL FLAG CHAR(20) VARYING INITIAL(' ');
DCL SHORT BIT(1) INITIAL('0'B);
DCL ERROR BIT(1) INITIAL('1'B);
DCL PLOT BIT(1) INITIAL('0'B);
DCL DEBUG BIT(1) INITIAL('0'B);
DCL PRINT_ALL BIT(1) INITIAL('0'B);
DCL REFA BIT(1) INITIAL('0'B);
DCL REF8 BIT(1) INITIAL('0'B);
DCL FF BIT(1) INIT('0'B);
DCL CONSECUTIVE BIT(1) INIT('0'B);
DCL (SUBSTR,ADDR,LOG,LENGTH) BUILTIN;
DCL PRINT(16) FILE VARIABLE
  INITIAL(FISH#1,FISH#2,FISH#3,FISH#4,FISH#5,FISH#6,FISH#7,
  FISH#8,FISH#9,FISH#10,FISH#11,FISH#12,FISH#13,FISH#14,
```

```
  FISH#15,FISH#16);
DCL (FISH#1,FISH#2,FISH#3,FISH#4,FISH#5,FISH#6,FISH#7,FISH#8,
  FISH#9,FISH#10,FISH#11,FISH#12,FISH#13,FISH#14,FISH#15,
  FISH#16) STREAM OUTPUT PRINT FILE INTERNAL;
DCL OUT(16) FILE VARIABLE
  INITIAL(OUT#1,OUT#2,OUT#3,OUT#4,OUT#5,OUT#6,OUT#7,
  OUT#8,OUT#9,OUT#10,OUT#11,OUT#12,OUT#13,OUT#14,
  OUT#15,OUT#16);
DCL (OUT#1,OUT#2,OUT#3,OUT#4,OUT#5,OUT#6,OUT#7,OUT#8,
  OUT#9,OUT#10,OUT#11,OUT#12,OUT#13,OUT#14,OUT#15,
  OUT#16)
  STREAM OUTPUT FILE INTERNAL;
DCL OLD_FISH#(16) CHAR(6);
DCL MONTH CHAR(8) INITIAL('SEPTEMBR');
DCL YEAR CHAR(4) INITIAL('1976');
DCL SKP(16) FIXED BIN(31) INIT((16) 0);
DCL TABLE(0:3) CHAR(1) INIT('8','9','A','B');
F1: FORMAT (SKIP,X(20-LENGTH(FLAG)),A,COLUMN(23),F(4),X(5),
  2 (A,X(3)),F(7),4 F(10,2),A);
F2: FORMAT (X(K),X(SKP(1)),A,X(SKP(2)),A,X(SKP(3)),A,X(SKP(4)),A,
  X(SKP(5)),A,X(SKP(6)),A,X(SKP(7)),A,X(SKP(8)),A,X(SKP(9)),A,
  X(SKP(10)),A,X(SKP(11)),A,X(SKP(12)),A,X(SKP(13)),A,X(SKP(14)),A,
  X(SKP(15)),A,X(SKP(16)),A); /* ALLOWS SKIPPING 'FF' */
ON ERROR BEGIN;
  ERROR='1'B;
  GO TO L3; END;
ON SIZE SNAP BEGIN;
  PUT SKIP LIST('SIZE CONDITION RAISED');
  PUT SKIP DATA(N);
  GO TO NEXT; END;
ON ZERODIVIDE SNAP BEGIN;
  FLAG='ZERO DIVIDE';
  ERROR='1'B;
  GO TO L3;
  END;
ON CONVERSION SNAP BEGIN;
  ERROR='1'B;
  FLAG='CONVERSION ERROR';
  GO TO L3;
  END;
ON TRANSMIT (IN) BEGIN;
  PUT SKIP LIST('TRANSMIT ERROR IN THIS BLOCK');
  GO TO DECODE;
  END;
ON ENDPAGE(SYSPRINT) BEGIN;
  IF START=1 THEN PUT PAGE;
  PUT EDIT(' FLAG RECD        FISH#      TIME        REF',
     '        CH#1       CH#2       CH#3       CH#4')
     (COLUMN(17),A,A);
  PUT SKIP(2);
  END;
FILE_NOW=1;
ON ENDFILE(IN) BEGIN;
  PUT SKIP DATA(N);
  CLOSE FILE(IN);
  GO TO STOP;
  END;
ON ENDFILE(SYSIN) BEGIN;
  PUT ('NO SEMICOLON TERMINATING FILE SYSIN') SKIP;
```

```
  GO TO L6; END;
START=0; BLKLGTH=5000;
SIGNAL ENDPAGE(SYSPRINT);
OLD_FISH#=' '; I_OLD=1; BLNK=' ';
FISH=0.; N=0; START=1; BGN=13; ZERO=0; PARAM2=0.1;
GET COPY DATA; /* READ INPUT PARAMETERS */
L6:
IF DEBUG THEN PUT SKIP DATA(FISH);
ALLOCATE BLOCK;
NEXT:      /* GET BLOCK OF HEXADECIMAL DATA */
  READ FILE(IN) INTO(BLOCK);
DECODE:
  IF SHORT THEN BLOCK=REMAINDER||BLOCK; /* SPAN BLOCKS */
  K=0; M=16; SHORT='0'B;
  I=LENGTH(BLOCK);
  IF I<16 THEN DO;
     FLAG='SHORT BLOCK';
     ERROR='1'B;
     GO TO L3;
     END;
  IF I=1056 THEN PUT SKIP;
  ELSE PUT SKIP LIST('LENGTH OF BLOCK =',I);
L2:      /* DIVIDE BLOCK INTO RECORDS */
  SKP=0; IF=0;
L8:
  GET STRING(BLOCK) EDIT(TEMP3)(R(F2));
  PT=ADDR(RECORD);
  IXX=0; FF='0'B;
  DO IX=1 TO 2*M BY 2;     /* DECODE HEXADECIMAL TO EBCDIC */
     IXX=IXX+1;
     PHX=ADDR(TEMP3(IXX)); /* HIGH-ORDER NIBBLE */
     PB=ADDR(TEMP3(IXX)); /* BIT REPRESENTATION OF UNDECODED BYTE */
     PB1=ADDR(TEMP(IX)); /* BIT REPRESENTATION OF DECODED BYTE */
     IF BYTE='11111111'B THEN DO;
        IF ¬CONSECUTIVE THEN IFF=IXX; /* SKIP SINGLE 'FF'S */
        /* IFF - BYTE # OF FIRST 'FF' OF A SERIES
           IF  - # OF 'FF'S IN A RECORD
           SKP(N) - N IS THE FORMAT LOCATION OF THE BYTE OR BYTES
              TO BE SKIPPED. THE VALUE OF SKP(N) GIVES THE # OF
              BYTES TO BE SKIPPED. */
        SKP(IFF)=SKP(IFF)+1; CONSECUTIVE='1'B;
        FF='1'B; FLAG='FF'; IF=IF+1; GO TO L5; END;
     CONSECUTIVE='0'B;
     IF HEX='1010'B THEN TEMP(IX)='A';
     ELSE IF HEX='1011'B THEN TEMP(IX)='B';
     ELSE IF HEX='1100'B THEN TEMP(IX)='C';
     ELSE IF HEX='1101'B THEN TEMP(IX)='D';
     ELSE IF HEX='1110'B THEN TEMP(IX)='E';
     ELSE IF HEX='1111'B THEN TEMP(IX)='F';
     ELSE BYTE1='1111'B||HEX; /* IF ITS NOT A LETTER ITS A NUMBER */
     IF DEBUG THEN PUT EDIT(BYTE)(SKIP,B(8));
     IF DEBUG THEN PUT EDIT(HEX)(SKIP,B(4));
     HEX='1111'B; /* SET UPPER-ORDER NIBBLE TO '1'S */
     IF DEBUG THEN PUT EDIT(BYTE)(SKIP,B(8));
     TEMP(IX+1)=TEMP3(IXX);
L5:  END;
L7:
  IF FF THEN DO;
     IF (K+M+IF)>I THEN DO;
```

```
         REMAINDER=SUBSTR(BLOCK,K+1,I-K);
         SHORT='1'B; GO TO NEXT; END;
      ELSE GO TO L8; END; /* GO BACK AND REMOVE 'FF'S */
   ERROR='1'B; NC=1; EIGHT=0; REFA,REF8='0'B;
   DO J=1 TO 2*M;       /* CHECK RECORD SEQUENCE */
      DO WHILE(J=1&(TEMP(1)='C'|TEMP(1)='D')&(TEMP(7)>='C'&
         TEMP(7)<='F')&TEMP(3)||TEMP(4)||TEMP(5)||TEMP(6)='0000');
         IF TEMP(7)||TEMP(8)=TEMP(9)||TEMP(10) THEN DO;
            /* IF BYTE 7 AND 8 ARE REPEATED, RESET SKP(4) AND
            REREAD RECORD. */
            SKP(4)=SKP(4)+1; IF=IF+1; FF='1'B;
            DO IX=5 TO 16; SKP(IX)=0; END;
            FLAG='REPEAT OF CHAR 7&8'; GO TO L7; END;
         IF ¬(TEMP(2)>='0'&TEMP(2)<='9') THEN GO TO L1;
         IF ¬(TEMP(8)>='0'&TEMP(8)<='9') THEN GO TO L1;
         IF ¬(TEMP(9)>='0'&TEMP(9)<='9') THEN GO TO L1;
         IF ¬(TEMP(10)>='0'&TEMP(10)<='9') THEN GO TO L1;
         IF ¬(TEMP(11)>='0'&TEMP(11)<='9') THEN GO TO L1;
         IF ¬(TEMP(12)>='0'&TEMP(12)<='9') THEN GO TO L1;
         ERROR='0'B;
         GO TO L1;
         END;
      IF J=13&¬ERROR THEN DO; /* REARRANGE DATA SEQUENCE */
         PST=ADDR(TEMP(13)); /* OVERLAY FIVE 32-BIT WORDS ON 20 BYTES OF TEMP STRING */
         DO JJ=1 TO 5;       /* LOOK FOR ONLY ONE REFERENCE */
            /* LOOK AT 20 DATA CHARACTERS IN FIELDS OF 4 */
            /* IGNORE STRINGS BETWEEN '0000' AND '7999' */
            IF ST(JJ)>='11111000111100001111000011110000'B
            |ST(JJ)<'11110000111100001111000011110000'B THEN DO;
               /* IF STRINGS ARE BETWEEN 'C000' AND C900' OR
                  BETWEEN 'D000' AND 'D900' INCLUSIVE, RESEQUENCE */
               IF (ST(JJ)>='11000011111100001111000011110000'B
                  &ST(JJ)<='11000011111110011111000011110000'B)
                  |(ST(JJ)>='11000100111100001111000011110000'B
                  &ST(JJ)<='11000100111110011111000011110000'B)
                  THEN DO;
                  M=16-(6-JJ)*2;
                  ERROR='1'B;
                  GO TO L3;
                  END;
               /* CONVERT REFERENCES BEGINNING WITH 'A' OR 'B' */
               ELSE IF (ST(JJ)>='11000001111100001111000011110000'B
                  &ST(JJ)<='11000001111110011111100111111001'B)
                  |(ST(JJ)>='11000010111100001111000011110000'B
                  &ST(JJ)<='11000010111110011111100111111001'B)
                  THEN DO;
                  IF EIGHT<1 THEN DO; /* EIGHT COUNTS THE # OF REFERENCES */
                  /* CONVERT MOST SIGNIFICANT HEXADECIMAL BYTE FROM
                  'A' OR 'B' TO EBCDIC '2' OR '3' FOR LATER ARITHMETIC
                  MANIPULATION */
                     ST(JJ)=ST(JJ)+
                     '00110001000000000000000000000000'B;
                     BGN=(JJ-1)*4+1;
                     REFA='1'B;
                     END;
                  EIGHT=EIGHT+1;
                  END;
               /* CONVERT REFERENCES BETWEEN '8000' AND '9999' */
               ELSE IF ST(JJ)>='11111000111100001111000011110000'B
```

```
            &ST(JJ)<='11111001111110011111100111111001'B
            THEN DO;
            IF EIGHT<1 THEN DO;
            /* CONVERT MOST SIGNIFICANT BYTE FROM EBCDIC '8' OR '9'
            '0' OR '1' FOR LATER ARITHMETIC MANIPULATION */
               ST(JJ)=ST(JJ)-
               '00001000000000000000000000000000'B;
               BGN=(JJ-1)*4+1;
               REF8='1'B;
               END;
            EIGHT=EIGHT+1;
            END;
         ELSE DO;
            ERROR='1'B; FLAG='INVALID CHARACTER';
            GO TO L1; END;
         END;
      END;
   IF EIGHT¬=1 THEN DO;
      IF EIGHT<1 THEN FLAG='NO REFERENCE';
      IF EIGHT>1 THEN FLAG='MULTIPLE REFERENCE';
      /* IF THERE IS MORE THAN ONE REFERENCE, RESTORE THE
      FIRST CONVERTED. */
      IF REFA THEN ST((BGN-1)/4+1)=ST((BGN-1)/4+1)-
         '00110001000000000000000000000000'B;
      IF REF8 THEN ST((BGN-1)/4+1)=ST((BGN-1)/4+1)+
         '00001000000000000000000000000000'B;
      ERROR='1'B;
      GO TO L1;
      END;
   IJ=0;
   /* REARRANGE T(1) THRU T(5) WITH REFERENCE IN T(1) */
   DO JJJ=1 TO 20; TEMP1(JJJ)=TEMP(12+JJJ); END;
   DO JJJ=BGN TO 20,1 TO BGN-1;
      TEMP(13+IJ)=TEMP1(JJJ);
      IJ=IJ+1;
      END;
   ON CONVERSION BEGIN;
      ON CONVERSION SNAP GO TO L3;
      ERROR='1'B; FLAG='CONVERSION ERROR';
      DO IC=0 TO 3;
      IF TEMP(13)=IC THEN TEMP(13)=TABLE(IC); END;
      GO TO L3; END;
   /* CONVERT REARRANGED STRING DATA STRINGS TO FLOATING POINT */
   GET STRING(RECORD) EDIT(REC.FISH#,REC.TIME,T(1),T(2),
      T(3),T(4),T(5))(2 A(6),5 F(4));
   /* RESTORE REFERENCE TO ORIGINAL FORM FOR PRINTING */
   IF REFA THEN ST(1)=ST(1)-
      '00110001000000000000000000000000'B;
   IF REF8 THEN ST(1)=ST(1)+
      '00001000000000000000000000000000'B;
   REF=T(1);
   T=T/REF; /* CALIBRATE 4 DATA INPUTS USING REFERENCE INPUT */
   /* F# IS THE DECIMAL REPRESENTATION OF THE FIRST TWO
   BYTES OF THE TELEMETRY CHANNEL ID, I.E., 'C00000' TO
   'D00000' - 16 NUMBERS. */
   F#=TEMP(2);
   IF TEMP(1)='D' THEN F#=F#+10;
   /* APPLY INPUT CALIBRATION PARAMETERS */
   IF T(2)=0. THEN CH#1=-273.;
```

```
        ELSE CH#1=PARAM1(F#,1)/(LOG(T(2))+PARAM2(F#,1))-273.;
        IF T(3)=0. THEN CH#2=-273.;
        ELSE CH#2=PARAM1(F#,2)/(LOG(T(3))+PARAM2(F#,2))-273.;
        IF T(4)=0. THEN CH#3=-273.;
        ELSE CH#3=PARAM1(F#,3)/(LOG(T(4))+PARAM2(F#,3))-273.;
        IF T(5)=0. THEN CH#4=-273.;
        ELSE CH#4=PARAM1(F#,4)/(LOG(T(5))+PARAM2(F#,4))-273.;
        REF=REF+8000;
        GO TO L3;
     END; /* END OF REARRANGE */
     IF DEBUG THEN PUT EDIT(BYTE)(SKIP,B(8));
     /* RESEQUENCE RECORD */
     IF (TEMP(J)='C'|TEMP(J)='D')&ERROR&NC=1 THEN DO;
        IF J=1 THEN K=K-15;
        ELSE K=K-(M-J/2);
        NC=NC+1;
        FLAG='SEQUENCE ERROR';
        END;
L1:  END;
L3:
  /* SORT RECORDS INTO FILES CORRESPONDING WITH FISH# */
  IF ¬ERROR THEN DO;
     N=N+1;
     DO IX=1 TO I_OLD;     /* PUT RECORD INTO EXISTING FILE */
        IF FISH#=OLD_FISH#(IX) THEN DO;
           FILE_NOW=IX;
           PUT FILE(PRINT(FILE_NOW)) EDIT(FLAG,N,REC)(R(F1));
           IF PLOT THEN PUT FILE(OUT(FILE_NOW)) EDIT(REC,N)
              (X(2),A,X(1),A,F(7),4 F(10,2),A,X(2),F(8));
           GO TO L4;
           END;
        END;
     /* NO FILE EXISTS FOR THIS FISH#. OPEN ONE. */
     OLD_FISH#(I_OLD)=FISH#;
     FILE_NOW=I_OLD;
     ON UNDF(PRINT(FILE_NOW)) BEGIN;
       FLAG='UNDEFINED FILE';
       ERROR='1'B;
       GO TO L3;
       END;
     IF PLOT THEN OPEN FILE(OUT(FILE_NOW)) TITLE('O'||FISH#);
     IF PLOT THEN PUT FILE(OUT(FILE_NOW))
        EDIT(FISH.#(F#),MONTH,YEAR,ZERO,REC,N)
        (F(2),X(1),A,X(1),A,COLUMN(73),F(8),SKIP,
        X(2),A,X(1),A,F(7),4 F(10,2),A,X(2),F(8));
     OPEN FILE(PRINT(FILE_NOW)) TITLE(FISH#);
     ON ENDPAGE(PRINT(FILE_NOW)) BEGIN;
        PUT FILE(PRINT(FILE_NOW)) PAGE;
        PUT FILE(PRINT(FILE_NOW))
           EDIT('FISH NUMBER',FISH.#(F#),'      DATE ',REC.TIME)
           (A,F(5),A,A);
        PUT FILE(PRINT(FILE_NOW)) EDIT(' FLAG RECD       FISH#       ',
           'TIME        REF       CH#1       CH#2       CH#3       CH#4')
           (COLUMN(17),A,A);
        PUT FILE(PRINT(FILE_NOW)) SKIP(2);
        END;
     SIGNAL ENDPAGE(PRINT(FILE_NOW));
     PUT FILE(PRINT(FILE_NOW)) EDIT(FLAG,N,REC)(R(F1));
     I_OLD=I_OLD+1;
```

```
L4:
      IF PRINT_ALL THEN PUT EDIT(FLAG,N,REC)(R(F1));
      END;
  ELSE IF PRINT_ALL THEN PUT EDIT(FLAG,(TEMP(IX) DO IX=1 TO 2*M))
      (SKIP,X(20-LENGTH(FLAG)),A,COLUMN(32),2 (6 A(1),X(3)),X(3),
      5 (4 A(1),X(6)));
  FLAG=' ';
  K=K+M;
  M=16;
  IF (I-K)<16&(I-K)>0 THEN DO;
      SHORT='1'B;
      REMAINDER=SUBSTR(BLOCK,K+1,I-K);
      GO TO NEXT;
      END;
  IF K<I THEN GO TO L2;
  GO TO NEXT;
STOP:
  CLOSE FILE(FISH#1),FILE(FISH#2),FILE(FISH#3),FILE(FISH#4),
      FILE(FISH#5),FILE(FISH#6),FILE(FISH#7),FILE(FISH#8),
      FILE(FISH#9),FILE(FISH#10),FILE(FISH#11),FILE(FISH#12),
      FILE(FISH#13),FILE(FISH#14),FILE(FISH#15),FILE(FISH#16),
      FILE(OUT#1),FILE(OUT#2),FILE(OUT#3),FILE(OUT#4),FILE(OUT#5),
      FILE(OUT#6),FILE(OUT#7),FILE(OUT#8),FILE(OUT#9),FILE(OUT#10),
      FILE(OUT#11),FILE(OUT#12),FILE(OUT#13),FILE(OUT#14),
      FILE(OUT#15),FILE(OUT#16);
  PUT SKIP LIST('END OF DATA');
END FISH;
```

APPENDIX C:

Job Control Language (JCL)

```
MEMBER NAME  FISH
//FISH JOB (F07175,50,0,10),'P.E.HESS',MSGLEVEL=(1,1),
//       REGION=250K,NOTIFY,CLASS=C
 HESS P      07175         66100-00149
//*NET ID=NFISH,RL=(TFISH)
//    EXEC PGM=FISH
//STEPLIB DD DSN=B07175.PROGRAM.LOAD,DISP=SHR
//SYSPRINT DD DCB=(RECFM=FBM,LRECL=133,BLKSIZE=1330),
//          DSN=B07175.TP.FISH.DATA,DISP=(NEW,CATLG),
//          UNIT=TAPE6250,VOL=(,RETAIN,SER=SCRTCH)
//C00000 DD SYSOUT=A,DCB=(RECFM=FBM,LRECL=133,BLKSIZE=1330)
//C10000 DD SYSOUT=A,DCB=(RECFM=FBM,LRECL=133,BLKSIZE=1330)
//C20000 DD SYSOUT=A,DCB=(RECFM=FBM,LRECL=133,BLKSIZE=1330)
//C30000 DD SYSOUT=A,DCB=(RECFM=FBM,LRECL=133,BLKSIZE=1330)
//C40000 DD SYSOUT=A,DCB=(RECFM=FBM,LRECL=133,BLKSIZE=1330)
//C50000 DD SYSOUT=A,DCB=(RECFM=FBM,LRECL=133,BLKSIZE=1330)
//C60000 DD SYSOUT=A,DCB=(RECFM=FBM,LRECL=133,BLKSIZE=1330)
//C70000 DD SYSOUT=A,DCB=(RECFM=FBM,LRECL=133,BLKSIZE=1330)
//C80000 DD SYSOUT=A,DCB=(RECFM=FBM,LRECL=133,BLKSIZE=1330)
//C90000 DD SYSOUT=A,DCB=(RECFM=FBM,LRECL=133,BLKSIZE=1330)
//D00000 DD SYSOUT=A,DCB=(RECFM=FBM,LRECL=133,BLKSIZE=1330)
//D10000 DD SYSOUT=A,DCB=(RECFM=FBM,LRECL=133,BLKSIZE=1330)
//D20000 DD SYSOUT=A,DCB=(RECFM=FBM,LRECL=133,BLKSIZE=1330)
//D30000 DD SYSOUT=A,DCB=(RECFM=FBM,LRECL=133,BLKSIZE=1330)
//D40000 DD SYSOUT=A,DCB=(RECFM=FBM,LRECL=133,BLKSIZE=1330)
//D50000 DD SYSOUT=A,DCB=(RECFM=FBM,LRECL=133,BLKSIZE=1330)
//OC00000 DD DSN=B07175.FISH.C00000.DATA,DISP=(NEW,CATLG),
//         DCB=(RECFM=FB,LRECL=80,BLKSIZE=3120),UNIT=SHRT7330,
//         SPACE=(TRK,(20,10),RLSE)
//OC10000 DD DSN=B07175.FISH.C10000.DATA,DISP=(NEW,CATLG),
//         DCB=(RECFM=FB,LRECL=80,BLKSIZE=3120),UNIT=SHRT7330,
//         SPACE=(TRK,(20,10),RLSE)
//OC20000 DD DSN=B07175.FISH.C20000.DATA,DISP=(NEW,CATLG),
//         DCB=(RECFM=FB,LRECL=80,BLKSIZE=3120),UNIT=SHRT7330,
//         SPACE=(TRK,(20,10),RLSE)
//OC30000 DD DSN=B07175.FISH.C30000.DATA,DISP=(NEW,CATLG),
//         DCB=(RECFM=FB,LRECL=80,BLKSIZE=3120),UNIT=SHRT7330,
//         SPACE=(TRK,(20,10),RLSE)
//OC40000 DD DSN=B07175.FISH.C40000.DATA,DISP=(NEW,CATLG),
//         DCB=(RECFM=FB,LRECL=80,BLKSIZE=3120),UNIT=SHRT7330,
//         SPACE=(TRK,(20,10),RLSE)
//OC50000 DD DSN=B07175.FISH.C50000.DATA,DISP=(NEW,CATLG),
//         DCB=(RECFM=FB,LRECL=80,BLKSIZE=3120),UNIT=SHRT7330,
//         SPACE=(TRK,(20,10),RLSE)
//OC60000 DD DSN=B07175.FISH.C60000.DATA,DISP=(NEW,CATLG),
//         DCB=(RECFM=FB,LRECL=80,BLKSIZE=3120),UNIT=SHRT7330,
//         SPACE=(TRK,(20,10),RLSE)
//OC70000 DD DSN=B07175.FISH.C70000.DATA,DISP=(NEW,CATLG),
//         DCB=(RECFM=FB,LRECL=80,BLKSIZE=3120),UNIT=SHRT7330,
//         SPACE=(TRK,(20,10),RLSE)
//OC80000 DD DSN=B07175.FISH.C80000.DATA,DISP=(NEW,CATLG),
//         DCB=(RECFM=FB,LRECL=80,BLKSIZE=3120),UNIT=SHRT7330,
//         SPACE=(TRK,(20,10),RLSE)
//OC90000 DD DSN=B07175.FISH.C90000.DATA,DISP=(NEW,CATLG),
//         DCB=(RECFM=FB,LRECL=80,BLKSIZE=3120),UNIT=SHRT7330,
//         SPACE=(TRK,(20,10),RLSE)
//OD00000 DD DSN=B07175.FISH.D00000.DATA,DISP=(NEW,CATLG),
//         DCB=(RECFM=FB,LRECL=80,BLKSIZE=3120),UNIT=SHRT7330,
//         SPACE=(TRK,(20,10),RLSE)
```

```
MEMBER NAME  FISH
//OD10000 DD DSN=B07175.FISH.D10000.DATA,DISP=(NEW,CATLG),
//           DCB=(RECFM=FB,LRECL=80,BLKSIZE=3120),UNIT=SHRT7330,
//           SPACE=(TRK,(20,10),RLSE)
//OD20000 DD DSN=B07175.FISH.D20000.DATA,DISP=(NEW,CATLG),
//           DCB=(RECFM=FB,LRECL=80,BLKSIZE=3120),UNIT=SHRT7330,
//           SPACE=(TRK,(20,10),RLSE)
//OD30000 DD DSN=B07175.FISH.D30000.DATA,DISP=(NEW,CATLG),
//           DCB=(RECFM=FB,LRECL=80,BLKSIZE=3120),UNIT=SHRT7330,
//           SPACE=(TRK,(20,10),RLSE)
//OD40000 DD DSN=B07175.FISH.D40000.DATA,DISP=(NEW,CATLG),
//           DCB=(RECFM=FB,LRECL=80,BLKSIZE=3120),UNIT=SHRT7330,
//           SPACE=(TRK,(20,10),RLSE)
//OD50000 DD DSN=B07175.FISH.D50000.DATA,DISP=(NEW,CATLG),
//           DCB=(RECFM=FB,LRECL=80,BLKSIZE=3120),UNIT=SHRT7330,
//           SPACE=(TRK,(20,10),RLSE)
//IN  DD UNIT=TAPE1600,DISP=OLD,
//    DCB=(DEN=2,BLKSIZE=5000,RECFM=U,OPTCD=Z),
//    VOLUME=SER=R09552,LABEL=(2,NL)
//PLIDUMP DD SYSOUT=A
//SYSIN DD DSN=B07175.INPUT.FISH.DATA,UNIT=DISK,DISP=OLD
```

APPENDIX D:

Time Share Option (TSO) Command Procedure

```
MEMBER NAME  FISH
PROC 1 TAPE PLOT(NO) TIME(10) LINES(50) REGION(250K) PRNTALL(NO)-
 LIBRARY(NO)
IF (&PLOT. EQ YES) -
D (FISH.C00000.DATA FISH.C10000.DATA FISH.C20000.DATA-
 FISH.C30000.DATA FISH.C40000.DATA FISH.C50000.DATA-
 FISH.C60000.DATA FISH.C70000.DATA FISH.C80000.DATA)
IF (&PLOT. EQ YES) -
D (FISH.C90000.DATA FISH.D00000.DATA FISH.D10000.DATA-
 FISH.D20000.DATA FISH.D30000.DATA FISH.D40000.DATA-
 FISH.D50000.DATA)
COPY JCL.CNTL(FISH) FISH.CNTL
EDIT FISH.CNTL
IF (&PLOT. EQ NO) D 230 700
C 10 31 %FISH%&TAPE.%ALL
C 61 %FISH%&TAPE.
C 10 %50,0,10%&LINES.,0,&TIME.
C 20 %250K%&REGION.
C 730 %R09552%&TAPE.
IF (&LIBRARY. EQ YES) C 730 %2,NL%1,NL
IF (&LIBRARY. EQ YES) C 730 %=L%=
C 750 %INPUT.FISH%&TAPE.
IF (&LINES. NE 50) GO TO LABEL 4
IF (&PRNTALL. EQ YES) GO TO LABEL 3
LABEL 4
D 31
D 61 62
C 60 %),%),SYSOUT=A
LABEL 3
SAVE
END
COPY INPUT.FISH.DATA(&TAPE.) &TAPE..DATA
IF (&PLOT. EQ YES) GO TO LABEL 2
IF (&PRNTALL. EQ YES) GO TO LABEL 2
GO TO LABEL 1
LABEL 2
TNOTE THE CONTROL DS(SYSIN) IS NOW BEING OPENED.
EDIT &TAPE..DATA NONUM
TOP
IF (&PLOT. EQ YES) TNOTE ENTER PLOT='1'B FOLLOWED BY 2 RETURNS
IF (&PLOT. EQ YES) I *
IF (&PRNTALL. EQ YES) TNOTE ENTER PRINT_ALL='1'B FOLLOWED BY 2 RETURNS
IF (&PRNTALL. EQ YES) I *
SAVE
END
LABEL 1
SUBMIT FISH
IF (&PRNTALL. EQ NO) GO TO LABEL 4
COPY JCL.CNTL(TPFISH) TPFISH.CNTL
QED TPFISH.CNTL NONUM
TOP
C * 10 %FISH%&TAPE.%ALL
SAVE
END
SUBMIT TPFISH
LABEL 4
END
```

APPENDIX E

Manufacturer's Directory

NOTICE

Argonne National Laboratory does not approve, recommend, or endorse any proprietary product or proprietary material mentioned in this publication. No reference shall be made to Argonne National Laboratory or to this publication furnished by Argonne National Laboratory in any advertising or sales promotion which would indicate or imply that Argonne National Laboratory approves, recommends, or endorses any proprietary product or proprietary material mentioned herein, or which has as its purpose an intent to cause directly or indirectly the advertised product to be used or purchased because of this publication.

Cole-Parmer Instrument Company, 7425 N. Oak Park Avenue, Chicago, IL 60648, (312) 647-7600.

Shell Chemical Company, One Shell Plaza, Houston, TX 77001, (713) 241-6161.

Celanese Corporation, 1211-T Avenue of the Americas, New York, NY 10036, (212) 764-7640.

Union Carbide Corporation, Battery Products Division, 270 Park Avenue, New York, NY 10017, (212) 551-3763.

Power Conversion, Inc., 70 MacQuesten Parkway S., Mt. Vernon, NY 10550, (914) 699-7333.

Leybold-Heraeus Vacuum Products, 200 Seco Road, Monroeville, PA 15146, (412) 856-9030.

Hotsplicer Company, 4606 Santa Fe Street, San Diego, CA 92109.

Cush-Craft Corporation, 48 Perimeter Road, P. O. Box 4680, Manchester, NH 03108, (603) 627-7877.

Cornell-Dubilier Electronics, 150 Avenue L, Newark, NJ 07101, (201) 589-7500.

Janel Labs, 33890 Eastgate Circle, Corvallis, OR 97330, (503) 757-1134.

Alpha Wire Corporation, 711 Lidgerwood Avenue, Elizabeth, NJ 07207, (201) 925-8000.

Hewlett-Packard, Corporate Division, 1501 Page Mill Road, Palo Alto, CA 94304, (415) 856-1501.

Practical Automation Incorporated, Trap Falls Road, Shelton, CT 06484, (203) 929-5381.

Cipher Data Products Incorporated, 5630 Kearny Mesa Road, San Diego, CA 92111, (714) 279-6550.

Vu-Data Corporation, 7170 Convoy Court, San Diego, CA 92111, (714) 279-6572.

Electrostatics Incorporated, 7718 Clairemont Mesa Boulevard, San Diego, CA 92111, (714) 279-1414.

Globe-Union Incorporated, Battery Division, 5757 Green Bay Avenue, Milwaukee, WI 53201, (414) 228-1200.

Belden Corporation, Electronics Division, P. O. Box 1327, Richmond, IN 47374, (317) 966-6661.

Clay-Adams, Division of Becton, Dickinson and Co., Parsippany, NJ 07054.

Fenwal Electronics, 63 Fountain, Farmington, MA 01701 (617) 872-8841.

W. W. Grainger, Inc., 20 Davis Drive, Bellwood, IL 60104, (312) 378-6834.

Allied Electronics Corporation, Division of Tandy Corp., 401 East 8th Street Fort Worth, TX 76102.

Thomas & Betts, 920 Route 202, Raritan, NJ 08869, (201) 685-1600.

Distribution for ANL/ES-108

Internal:

W. E. Massey
W. K. Sinclair
R. E. Rowland
P. F. Gustafson
E. J. Croke
P. T. Cunningham
P. Frenzen
R. H. Huebner
W. R. Penrose
M. M. Thommes (142)
M. Fieldhouse
ANL Contract File
ANL Libraries (2)
TIS Files (6)

External:

DOE-TIC (27)
Manager, Chicago Operations and Regional Office, DOE
Chief, Office of Patent Counsel, DOE-CORO
President, Argonne Universities Association
Radiological and Environmental Research Division Review Committee:
- A. K. Blackadar, Pennsylvania State U.
- A. W. Castleman, Jr., U. Colorado
- H. L. Friedell, Case Western Reserve University Hospitals
- R. E. Gordon, U. Notre Dame
- R. A. Hites, Indiana U.
- D. Kleppner, Massachusetts Inst. Technology
- G. M. Matanoski, Johns Hopkins U.
- D. W. Schindler, U. Manitoba
- W. H. Smith, Yale U.