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Ecological Research Series

INSTRUMENTATION TO MONITOR LOCATION OF FISH CONTINUOUSLY IN EXPERIMENTAL CHANNELS

Environmental Research Laboratory
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U.S. Environmental Protection Agency
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INSTRUMENTATION TO MONITOR LOCATION OF FISH CONTINUOUSLY IN EXPERIMENTAL CHANNELS

by

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Contract No. 68-01-0752

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FOREWORD

Our nation's freshwaters are vital for all animals and plants, yet our diverse uses of water---for recreation, food, energy, transportation, and industry---physically and chemically alter lakes, rivers, and streams. Such alterations threaten terrestrial organisms, as well as those living in water. The Environmental Research Laboratory in Duluth, Minnesota develops methods, conducts laboratory and field studies, and extrapolates research findings

--to determine how physical and chemical pollution affects aquatic life

--to assess the effects of ecosystems on pollutants

--to predict effects of pollutants on large lakes through the use of models

--to measure bioaccumulation of pollutants in aquatic organisms that are consumed by other animals, including man.

This report describes development of an ultrasonic tracking system used to monitor position and temperature history of a mobile fish population in an experimental stream channel, and discusses design problems and solutions associated with operations near a nuclear power electrical generating facility.

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ABSTRACT

This study resulted in the development and construction of equipment to monitor continuously the position and the temperature of up to 20 fish in a water channel 486 meters long, 3 meters wide, and 1 meter deep. The system utilized miniature sonic transmitters (tags) operating in the 51 kHz to 366 kHz frequency range which were implanted in 500 gram or heavier fish. The battery operated tags were pulse modulated and designed for over 1 year operational life. A temperature sensitive thermistor controlled the repetition rate of the tag providing the temperature of the fish to an accuracy of 1 degree C. The nominal range of the polyurethane encapsulated tage was several hundred feet. Nominal tag size was 16 mm OD x 32 mm long (4.6 - 5.4 g in water). Sixteen hydrophones were located at 30.5 meter intervals in the water channel. A control console contained a manually-operated, frequency-stepped receiver which could select any individual hydrophone, thus locating the fish to within ± 15.25 meters. Up to 20 individual fish could be monitored. Automatic operation and recording of the data was considered in the design of the system for future equipment.

Severe radio frequency interference problems were encountered, requiring extensive precautions and modification of the channel equipment and wiring.

Also investigated were passive fish monitoring and tracking of small fish fry. An experimental system was completed for limited monitoring applications.

This report was submitted in fulfillment of Contract Number 68-01-0752, by Bayshore Systems Corporation under the sponsorship of the Environmental Protection Agency. Work was completed as of October 1974.

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ACKNOWLEDGEMENTS

This program was completed based on a team relationship between the EPA, Monticello Ecological Research Station as directed by Dr. Kenneth Hokanson, and his assistant, Mr. Charles Kleiner, and Bayshore Systems Corporation (BSC). The many contributors at BSC were Don Anderson, Fred Gagnon, Homer Guerra, Francis Sherwood, Robert Greenwell, Richard Rockwell and Joseph R. Jahoda. Their contributions include advances in the state-of-the-art in low current and high efficiency ultrasonic transmitters, RF interference elimination, tag potting techniques, step tuned sensitive rf receiver, hydrophone preamplifier development, temperature A/D decoders, and light emitting diode displays. Note must be made of the days of working in cold/hot weather side-by-side with EPA personnel installing the equipment.

SECTION I

INTRODUCTION

To solve some of the more complex ecological problems concerning the discharge of waste heat into the nation's surface waters, the Environmental Research Laboratory-Duluth constructed a field station at Monticello, Minnesota. Eight (8) identical experimental stream channels, each about 486 meters (1,600 feet) long were constructed at the Monticello test site (Figure 1). Each channel is composed of alternating riffle and pool areas. Each channel contains a total of eight (8) riffle areas of 2.4 meters (8 feet) wide and .3 meters (1 foot) deep and eight (8) pools of 3.7 meters (12 feet) wide and .92 meter (3 feet) deep; each about 30.5 meters (100 feet) long. To date, one channel was instrumented, channel number 1, and placed into operation. A small laboratory provides office space, sample processing areas, and houses the control and monitoring equipment (Figure 2).

Raw Mississippi River water is used for the water supply. This water is heated to the desired temperature in a heat exchanger using the heated condenser water of Northern State Power (NSP) nuclear power plant. The condenser water is returned to the NSP discharge where it is monitored against state water-quality standards. The rate of flow of water in channel number 1 was .028 cubic meters per second (1 cubic foot per second) with mean velocity less than .03 meters per second (0.1 foot per second).

Four different annual temperature regimes in duplicate will be programmed and controlled at the upstream end of the channels. Thermal gradients will develop in these channels except for one pair which will follow ambient Mississippi River temperatures. Temperatures will vary diurnally and seasonally along thermal gradients. It is intended to monitor water temperature and other water quality and meteorological parameters in some detail to accurately describe conditions in each channel.

Figure 1. Test channel at Monticello Ecological Research Station.

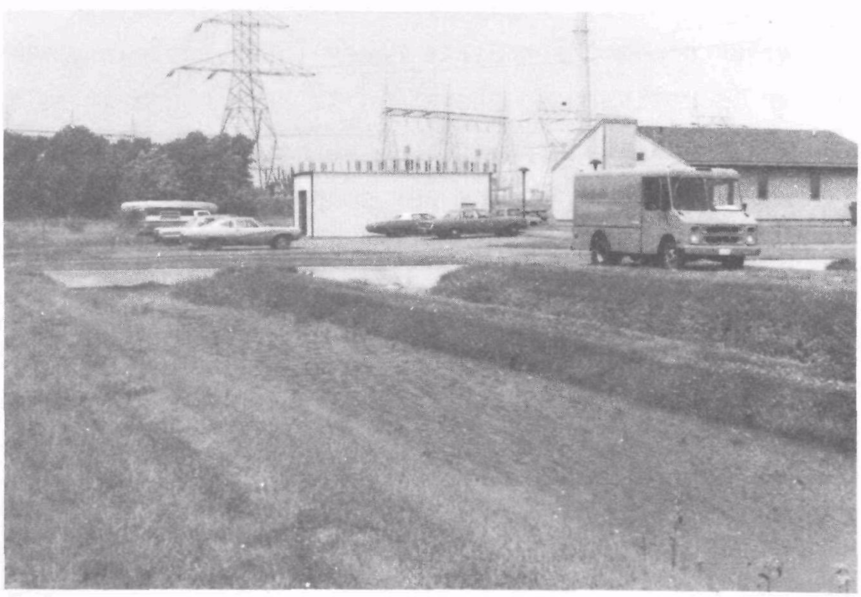

Figure 2. Monticello Ecological Research Station test site. Building to the right is the laboratory, the building in the center is a garage and storage building.

Natural river plankton and insect fauna are expected to colonize all of the experimental channels. Once an abundance of food organisms is present, one fish species will be stocked at natural densities. The distribution of fish is known to be strongly influenced by the environmental temperature and varies with the different age groups. Young fish can thrive at higher temperatures than adult fish. Larval fish will most likely be found near the surface in pools and in areas of low current velocity. Juvenile and adult fish may have a wider distribution and may be found on the riffles near the substrate. Recognizing the problem of monitoring temperature of mobile organisms, this contract was awarded on 30 June 1972 to develop the instrumentation to monitor the location of large fish on a continuous basis in the experimental channels. This instrumentation is necessary to permit determination of the thermal experience of each fish in the channel so that the effects of temperature can be properly assessed. In addition, a small fish monitor system, required to monitor continually the location of small fish fry, was demonstrated. The large fish monitor system was completed and delivered by October 1974.

As part of the overall program other items which were delivered included Instruction and Maintenance Manual and Engineering Drawings of System Prototype.

LARGE FISH MONITOR SYSTEM

A system was required by the EPA to monitor instantaneous positions and temperature of fish in the water channels. The system requirements included a temperature monitoring transmitter (tag) which would be affixed to fish and measure the temperature of the fish or the surrounding water to the nearest 1 C. Further, the tag must have a minimum life of 1 year and be small enough to be placed on, or in, a 25.4 cm (10 inch) fish without significantly interferring with growth or survival. Each fish position and temperature should be recorded once an hour. The tags will require a minimum range of 30 to 150 meters (100 to 500 feet). Either different frequencies or pulse rates should be used for each fish to permit distinguishing 10 to 20 individual fish in each channel. The final system design must be capable of interfacing with a real-time, digital recording system at a later date.

An additional factor which must be considered in the final design of the system is the presence of two high voltage overhead transmission lines (345 and 230 kilovolts) which cross the channels and will unquestionably cause radio frequency interference (RFI) problems (see Appendix A for details).

During the early phases of the program several system approaches were considered. They all utilized the basic concept of attaching a small transmitter to the fish and thereby transmitting the location and internal temperature to pick-up units on shore. Several variations were possible and accordingly considered.

Radio Frequency System

A significant amount of research has been done in related military and wildlife programs for developing rf tags[1 and 2] for use in fresh water. Ranges of over 500 meters have been reported. The use of rf tags would have required rf receivers, multiple frequencies (to identify individual fish), elaborate direction finding antenna systems (to locate each fish), and means to eliminate the effects of rf signals present from local and distant transmitters and interference from the overhead power line. These problems would prove insurmountable and the rf system was dropped from consideration early in the program.

Sonic System

The use of sonic tags has been used for well over 25 years for fish/manual location,[3 to 24], temperature monitoring,[25 and 26], and other fish/mammal/water parameter monitoring,[27 to 33]. All of the efforts to date had concentrated on manual tracking over relatively short periods of time, usually 2 to 4 weeks. The ranges usually involved 100 to 500 meters (110 to 550 yards).

Early in the program it became evident that to meet the one year operating life requirement of the tag in a compact unit, a highly efficient tag would have to be developed. Since long range was not required in the experimental channels, a system was designed which would decrease the range requirement of the tags to 40 meters (132 feet) and thereby considerably reduce size and increase battery life[34].

The minimum fish size of 25.4 cm (10 inches) dictated the use of internally mounted tags with lengths of less than 3.2 cm (1.26 inches) and outside diameters of less than 1.6 cm (.63 inches). This size limitation was arrived at by researching the literature,[9, 35], discussions with fish biologists, and experimentation at the Monticello EPA laboratory.

All of these requirements imposed severe restrictions on the final tag design. Factors considered were:

(a) Long term (over one year) waterproof sealing.
(b) Ultra-miniature packaging.
(c) Circuitry stabilization to minimize frequency drift as a function of short and long terms and temperature.
(d) Non-toxic outer coating.
(e) Long life batteries.
(f) Minimum weight (in water).

Passive System

The use of passive systems has found very little application in fish tracking systems[2]. The approach basically utilizes sonic or magnetic energy beamed to a remote location (fish tag) from a shore station. This energy is converted to dc and used to power a transmitter which then responds with an appropriate signal. The limiting factor is the range between the tag and shore location. After considerable effort, a maximum range of only 3 meters (9.9 feet) was accomplished. By utilizing larger power levels at the shore based transmitters this range could be increased. However, after considering all factors, this system was deemed economically unfeasible (see Appendix B for details).

SMALL FISH MONITOR SYSTEM

Initially, the EPA required the counting and/or location within the water channels of freeswimming offspring from natural reproduction in relation to temprature recording stations. A remote sensing device was required to locate and/or count (i.e. ± 10%) larval and juvenile fish (i.e. 4 to 40 mm total length) at fixed stations. Fish count or position recordings were to be made once an hour at each station. Relative abundance indices at each station were required, rather than a total fish count in each channel. Such a means of detection would not require handling or tagging individuals. A design goal was to discriminate different size fish so that large and small fish could be counted as individuals regardless of their direction of movement. The system was to have the design capability of interfacing with a real time, digital recording system at a later date.

There is very little precedent for a system of this type which concerns itself with a female fish spawning 15,000 to 40,000 eggs in the channel bottom. Initially, the survival rate is 60% to 70% and one should be prepared to monitor several thousand 4 to 12 mm (.16 to .47 inches) fish fry. In the early stages the fry may school together or assume a uniform distribution. As they approach 10 mm (0.4 inches) they start to school, covering an area of approximately one cubic meter (1.31 cubic yards).

The following are typical of the methods proposed and/or actually utilized by researchers, fisheries, universities, commercial fisherman and industrial, NASA, military and non-profit agencies for tracking schools of fish:

1. Passive - acoustic

   a. Swimming noise.
   b. Vocal sounds.
   c. Strumming, beating or scratching noises.
   d. Noise produced by contact with external objects.

2. Passive - general

   a. Water-color spectrometer - color/luminescence.
   b. Luminescing fish detection.
   c. Fish oil slick detection.
   d. Infra-red detection of fish swimming near the water surfaces.
   e. Visual-by air and shipborne observers.
   f. Photographic - IR and color.
   g. RF signal emmissions from fish.

3. Active

   a. Sonar - transmission and reception of acoustic signals.
   b. Laser - transmission and reception of coherent light.
   c. Microwave/millimeter radiometers.

After considering all of these techniques, those which offered promise for locating fish fry in the narrow channels were sonar, laser, and infra-red.

Sonar

This is probably the most often taken approach. Sonar systems for fish location have been built over the frequency range of 10 kHz to 600 kHz. They have been used to: count salmon going upstream, measuring biomass (kilograms) of fish in rivers, lakes, and portions of the ocean, etc. with some success. However, the transmission of an acoustic signal in a small narrow channel offers additional problems. These are due to such factors as multiple reverberations, pickup from the main and side lobes of the transducers, unpredictable variation in reflection from the fish as a function of its position, reflection from the water surface and irregular contours, the unpredictable variation in signal strength returned from fish of different sizes, and doppler shifts due to rapidly moving fish. Many techniques have been proposed or attempted to obviate these disadvantages. Such factors as swim bladder, vertebral column and body tissue resonances can be used to isolate fish acoustically,[36 to 47], especially small fish, from others of different sizes. To properly utilize resonance effects would require transducers operating at multi-frequencies. The problem of reflections, echos, false responses, etc., can be solved by time gating, FM techniques and multiple transducers. One could use specially built sonar arrays, funnels, baffles, etc., to assist the sonar system, however, the small size of the fish and the desire to avoid unusual mechanical intrusions into the water further complicate the use of sonar techniques. The final system chosen, after careful consideration of all factors and extensive experimentation, utilized a modified multi-frequency sonar technique, see Appendix C for system details.

Laser

This would prove expensive due to the complexity of the ancillary equipment required. In addition, the data processing would prove too complex and expensive and it would suffer from shading effects from fishes nearest the laser. The same comments would apply to the use of similar techniques based on light source sonar.

Infra-Red

Limited to fish at surfaces of the water. Shading effects and difficulty of implementation prevented serious consideration.

SECTION II

CONCLUSIONS

The final system, which accomplished this objective was composed of 16 hydrophone/preamplifiers, sonic fish tags, shielding cabling and conduits, and a receiver/decoder console. The 16 hydrophone/preamplifiers were located at 30.5 meter (100-foot) intervals along the channel. The operator can select the operating frequency of the desired tag (unique frequency in the 51 kHz to 366 kHz range for each fish) and the appropriate hydrophone which has the strongest response. Knowing which hydrophone received the strongest signal would locate the fish to within an accuracy of $\pm$ 15.25 meters (50 feet). The decoder converted the repetition rate to a numeric display of the fish temperature.

The extrapolated life of the tag meets the one (1) year objective. With the advent of the new lithium battery, the life can be further increased by almost a factor of two.

The seriousness of the radio frequency interference (RFI) from the overhead high voltage power lines cannot be overstated. Signals were present at unpredictable times on frequencies very close to those being used. At times, the frequencies in use had to be changed. Based on the RFI difficulties experienced with one instrumented channel, additional shielding, filtering and isolation will be required for the instrumentation to be installed in the future for the remaining 7 channels. This is mandatory because the RFI problem can be expected to be cumulative in its impact.

Monitoring of the small fish fry was a most difficult task. Their small size and their physical properties, being very similar to that of water, precluded the use of conventional sonar, laser, and infra-red techniques to monitor their presence. Drifting algae also presented background interference problems during the initial system development. After considerable experimentation a modified sonar technique (utilizing critical frequencies and the transmission of sonic energy through a mass of material having characteristics different from that of the water) was developed which was capable of monitoring small fish fry under conditions of limited floating algae and in areas of minimum turbulence.

SECTION III

RECOMMENDATIONS

Based on the data and results of this program, recommendations for future effort and system expansion are;

(a) The availability of advanced shielding material, improved coupling and balancing circuits, and a more selective phase-lock receiver will greatly improve system operation. The RF interference problem, which inherently is unpredictable, will necessitate these modifications. In particular, the use of a phase-lock receiver should be stressed, since it will permit automatic frequency lock-on to each tag. Thus, should the tag frequency drift or the fish be successful in hiding behind growth for a short time, the equipment would not require manual retuning and loss of data would not result. Specifically, the following should be implemented during the next program phase:

(1) Hydrophone Preamplifiers - Modify output circuitry to provide improved sensitivity and decrease ground loop and RF interference from power station.

(2) Improved shielding of console and receiver.

(3) Automatic phase lock receiver modification.

(4) Improved tags, through the use of temperature compensated components, to minimize frequency drift.

(5) As additional instrumentation is added for the remaining 7 channels, extreme care must be exercised in proper utilization of interference filters, isolation and shielding to avoid mutual interference problems.

(b) The present receiver-decoder system control panel is manually operated. This greatly limits the data available to the normal working hours of available personnel and increases the system operating costs. The present design was predicated upon ease of conversion to automatic operation with a computer and recorder. This should be implemented after the initial phases of system check-out are completed and the biological experiment is satisfactorily structured.

(c) Lithium batteries should be used when they become available. They will permit as much as a 10% decrease in length and weight for the same life expectancy or a longer life expectancy for the same size.

(d) It is recommended that a small fish fry detector be implemented in biologically critical areas of the channel. An efficient and simplified system can be completed and calibrated especially with the availability of fish fry on site. They were not available during much of the original experimentation. As a minimum such a system would provide position location and approximate volume of the fish fry school.

(e) Initiate a small program to study the impact of the projected automated system on the computer software requirements. A computer with sufficient capacity will be required and a study made of the specific details of modifying the fish location system. Specifically, it is important that the computer have sufficient capacity to handle the data from eight channels. Typical of the critical factors which need to be considered is the switching rate of the receiver and hydrophones. This will be limited by reverberation rate of the channels, time required to locate each fish, etc.. This effort will interface with the biological work in progress at the Monticello test site and paragraph (a) above.

SECTION IV

DESCRIPTION OF THE LARGE FISH TRACKING SYSTEM

The large fish tracking system installed at the Monticello Field Station consists of a number of component equipments arranged as shown in Figure 3. The system is comprised of three main sub-systems/components; a number of ultrasonic temperature transmitters (tags, inserted within the fish), an array of hydrophones, and a receiver-decoder control console.

Ultrasonic temperature transmitters (or fish tags), transmit a pulsed, acoustical signal through the water (Figure 4). The repetition rate at which the tags transmit is determined by a temperature sensor within the tag. At cold temperatures the repetition rate is slow and for warm temperatures the repetition rate is faster. This form of transmission is called pulse interval modulation (PIM). This type of modulation permits location and temperature monitoring with minimum hardware. Complex telemetry modulation techniques would have required more electronics in the tags as well as in the receiver. As an additional advantage, the system is much less susceptible to reverberation effects than multi-carrier, phase or constant wave modulation techniques. The tags are designed to be pulsed on for a relatively short interval of time in order to obtain a low duty cycle which minimizes the drain on the internal batteries and increases the effective life of the tag.

The hydrophones are used to pick up pulsed acoustical signals transmitted by the tags and convert them to electrical signals that can be detected by a receiver. A total of 16 hydrophones, located at 30.5 m (100 ft) intervals are used. By observing which of the hydrophones receives the strongest signal, one can determine the location of the fish within ± 15.75 m (50 ft). Due to the wide range of frequencies covered by the tags, 51 to 366 kHz, a special wide-band hydrophone was designed with special filters and preamplifiers. Due to the extremely high radio frequency interference level, rf shielding was used in the hydrophones/preamplifiers and at all junctions and conduits. Each preamplifier was

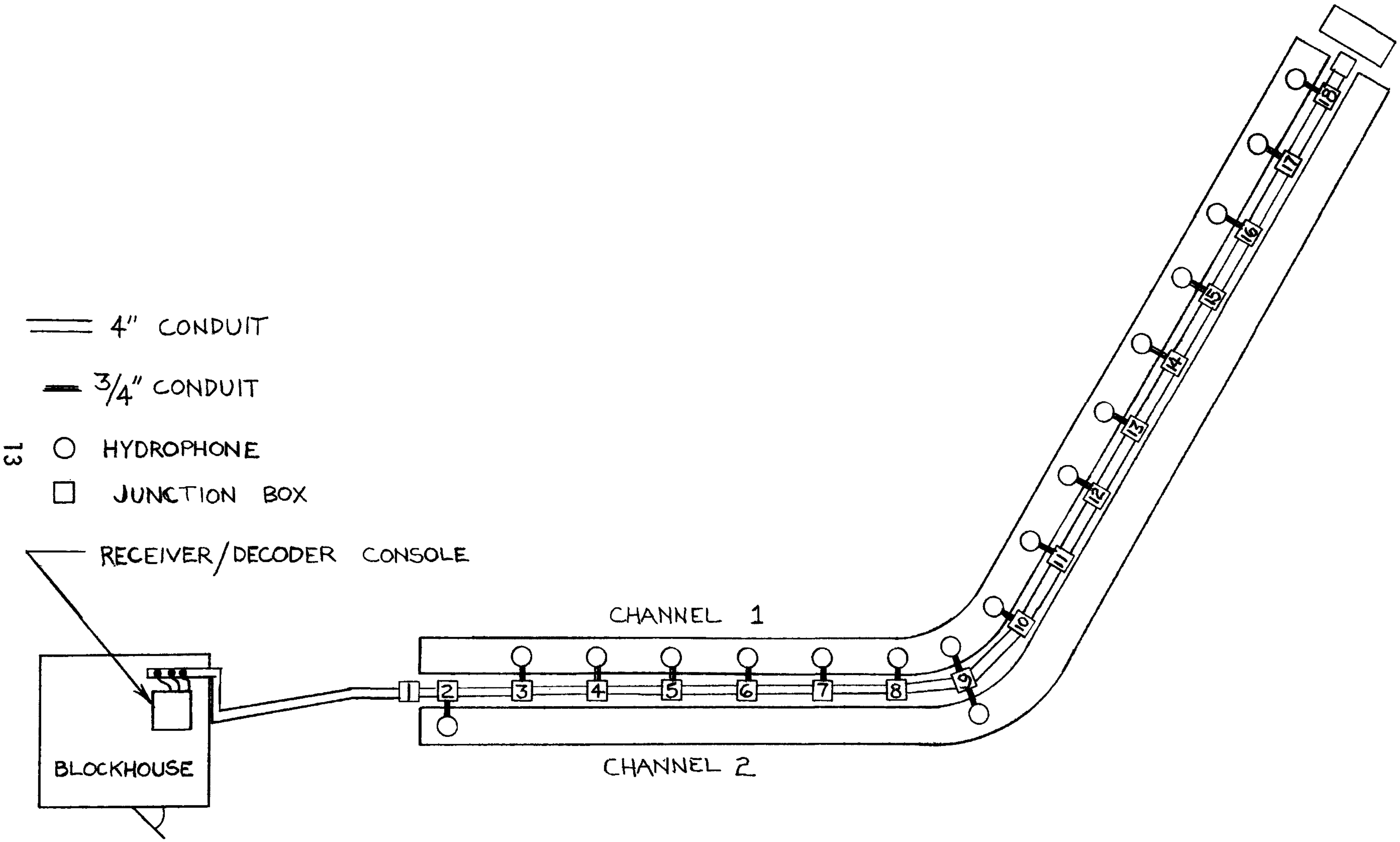

Figure 3. Large fish tracking system, hydrophone and channel conduit layout.

Figure 4. Ultrasonic temperature transmitters.

protected against high rf levels and high induced voltage from electro-fishing instruments and possible lighting discharges by the use of diodes at their inputs.

The receiver selects the one desired frequency from among the 20 present frequencies at the output of the hydrophone/preamplifier and converts the pulsed electrical ultrasonic signals to a low frequency pulsed signal to the decoder. The decoder then measures the time between pulses and gives a corresponding readout of temperature on a digital display meter.

Technical specifications of each of the major subsystems are as follows: The value of the parameters are average or nominal values. All tags delivered were within 10% to 15% of these values. The dimensions varied more widely since at the higher frequencies smaller ceramic elements were used. Specific specifications are discussed in greater detail in Section V.

(1) Ultrasonic Transmitters

Frequency:	51 to 366 kHz (18 Tags)
Pulse Width:	2.5 milliseconds
Power Output:	+40 dB re 1 μbar/meter
Repetition Rate:	0.8 pps at 0 C
	1.6 pps at 30 C
Duty Cycle:	.2% at 0 C
	.4% at 30 C
Expected Life:	450 days at 0 C
	275 days at 30 C
Size:	(OD) 15 to 17 mm
	(L) 30 to 39 mm
Weight:	(Air) 10.7 to 12.6 grams
	(Water) 4.6 to 5.4 grams
Frequency Stability:	0. 15% (0 C to 30 C)

(2) Hydrophone/Preamplifier (16 per channel)

Frequency:	51 to 366 kHz
Gain:	20 dB (Minimum)
Output Impedance:	10 ohms (Maximum)
Input Power:	12 V DC
Shielding:	
(RF)	Special Housing/Cable
(Electrostatic)	Coating for Sonic Window
Beamwidth: (Each Section)	180° Horizontal
	40° Vertical
Sensitivity:	-88 dB re 1 μbar/meter

(3) Receiver (Located in Receiver/Decoder Console)

Frequency:	51 to 366 kHz (20 steps)
Sensitivity:	0.1 microvolts (S/S+N = 1)
IF Bandwidth (3dB):	1.2 kHz or 4.0 kHz
Input Impedance:	400 ohms

(4) Receiver/Decoder Control Console

Temperature Readout:	0 to 30 C
VCO Readout:	Voltage to VCO (Frequency analog voltage)
Controls:	Audio Gain
	RF Gain
	Tag Selector (20 Frequencies)
	Freq. Adj. Fine Tuning (20 Frequencies)
	Temp. Calibration (20 tags)
	Hydrophone Selector (16 stations)
Jacks:	Oscilloscope Output
	Audio Output
	AGC Level
Meter:	Signal Strength

SECTION V

LARGE FISH TRACKING SUB-SYSTEMS

ULTRASONIC TEMPERATURE TRANSMITTERS (TAGS)

Oscillator Circuits

During the design phase of the contract three oscillator circuits were selected to be evaluated: squegging, modified Colpitts and Hartley. These oscillators were designed to serve dual purposes: frequency generator and transmitter, in order to reduce the number of components used in the transmitter circuit. The size of the tag was of primary concern, therefore emphasis was placed on the use of minimum parts along with the selection of miniature sized components. Since the electronics would only occupy less than 25% of the final tag (the battery and ceramic element are the largest size contributor and cannot readily be miniaturized), the possible size and weight saving on the final tag of using microcircuitry do not justify their high cost and accordingly were not considered.

The squegging or blocking oscillator was found to be the simplest circuit as far as the number of components used (Figure 5). However, the circuit was very unstable with changes in battery voltage and resulted in a 25% change in repetition rate over the life of the battery. A small tag was assembled, potted and evaluated. The size of the tag was 10 mm in diameter and 20 mm in length. Test results showed an interaction between the repetition rate and pulse width with load changes in the oscillator circuit. As the tag was lowered into the water the repetition rate would increase and the pulse width would decrease. This circuit, although simple and small, could not be used for accurately determining temperature of the water due to large changes in the repetition rate with battery voltage decay and water loading.

The modified Colpitts oscillator (Figure 6) was breadboarded and evaluated. The circuit had good frequency stability with changes in battery voltage (1.4 to 1.0 volts), less than 0.15% frequency drift

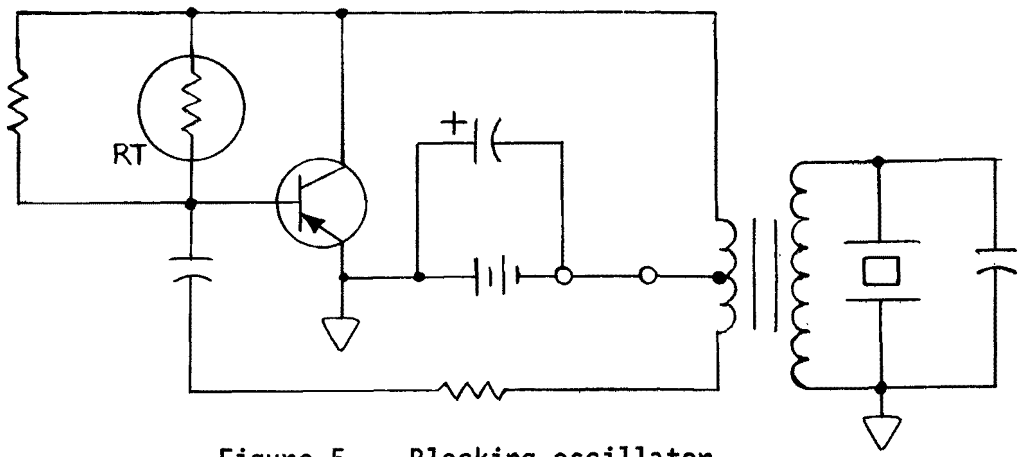

Figure 5. Blocking oscillator.

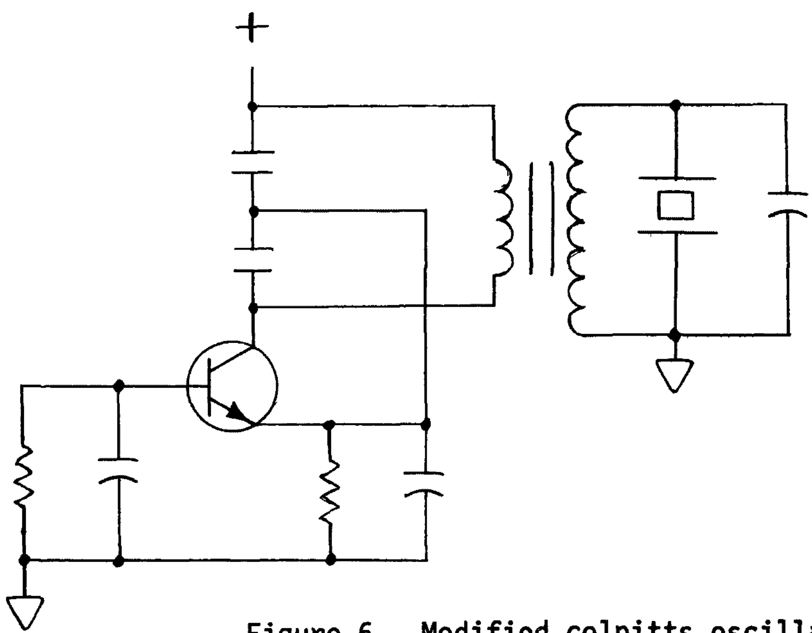

Figure 6. Modified colpitts oscillator.

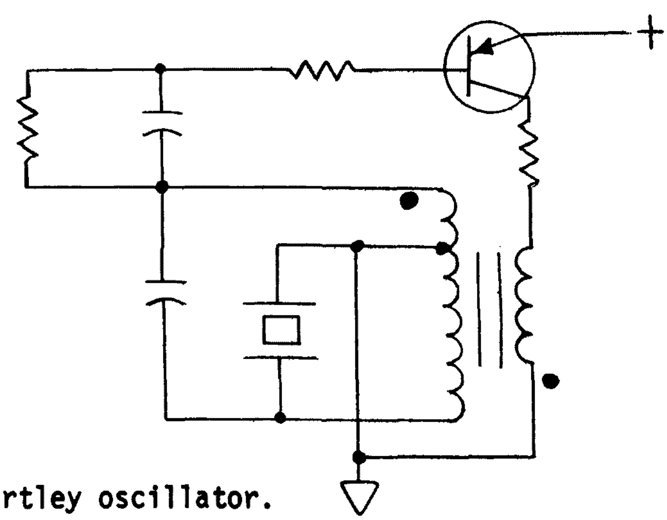

Figure 7. Hartley oscillator.

resulted. The tuning of the circuit was critical because the ratio of the two feedback capacitors had to be changed with different frequencies. The circuit required four capacitors to tune to the operating frequency and two of the four were large value capacitors which required larger sized components. The power output of the Colpitts oscillator was limited due to the required emitter resistor in the oscillator circuit.

The Hartley oscillator (figure 7) was breadboarded and evaluated. The frequency stability of the circuit was less than 0.12% with the change in battery voltage. The frequency of the oscillator could be changed by changing the value of a single capacitor. The voltage required across the cylinder could be varied by changing the turns ratio of the transformer. The power output of the oscillator could be adjusted by inserting a low value resistor in series with the emitter of the oscillator transistor. Because of the simple circuit with few components the Hartley oscillator was chosen to be used as the transmitter in the tags.

Timer Circuits

Due to the limited battery power the tag should operate at the minimum duty cycle consistent with satisfactory reception at the receiver. The duty cycle is merely the ratio of transmitter "ON" (drawing battery power) to transmitter "OFF" (drawing no battery power). To obtain low duty cycles the transmitter must be turned ON and OFF at certain periods of time. To do this a timer circuit is used that required little current drain from the battery. Two timer circuits were evaluated; astable multivibrator and a complementary astable multivibrator.

The astable multivibrator is a two transistor oscillator that periodically produces a square or rectangular pulse at its output. The frequency at which this pulse is produced can be controlled by changing the value of a resistor in one of the transistor stages. By using a thermistor, which is a device that has a negative temperature coefficient, in place of the resistor, large changes in resistance occur with changes in temperature. This provided a means of turning the transmitter ON and OFF at different time intervals that corresponded with the temperature of the thermistor. The astable circuit proved to be stable with voltage changes with less than a 5% change in the repetition rate over the life of a single battery. The use of two batteries reduced the change in repetition rate to 2.5%. The one disadvantage of the astable multivibrator was that at all times one of the two stages was in an ON condition, thereby continually drawing current from the battery. The average current drawn was reduced to less than 20 micro-amps but this was considerable as the total average current for both the transmitter and timer had to be kept below 25 micro-amps to obtain a one year life. This is based on an available battery capacity of .18 amperes hours. A year has almost 9000 hours, thus at 20 microamperes (or 20×10^{-6} amperes) consumption per hour, the battery would require a capacity of $9000 \times 20 \times 10^{-6}$ or 0.18 ampere hours.

The complementary astable multivibrator uses a complementary pair of transistors (Q1 and Q2, Figure 8) so that both transistors are either ON or OFF at the same time. The only time current is drawn from the battery is during the pulse on time which is in the order of a few milliseconds. With the use of high beta transistors and high value resistors the average current can be kept below two micro-amps for the timer circuit. This circuit was selected for the timer because of its good stability (less than 5% variation in repetition rate over the voltage variation which results over the life of the battery), low power consumption and the simplicity of the circuit. It should be noted that an integrated circuit (IC) commercially available version of the complementary astable was also evaluated and found to have excellent stability, less than 1% change in repetition rate with 20% changes in battery voltage. The IC required a minimum of 3.0 volts for its operation and its overall size was larger than that of the discrete components. Because of the additional batteries required and the larger size, the IC was not selected as the timer in the final design.

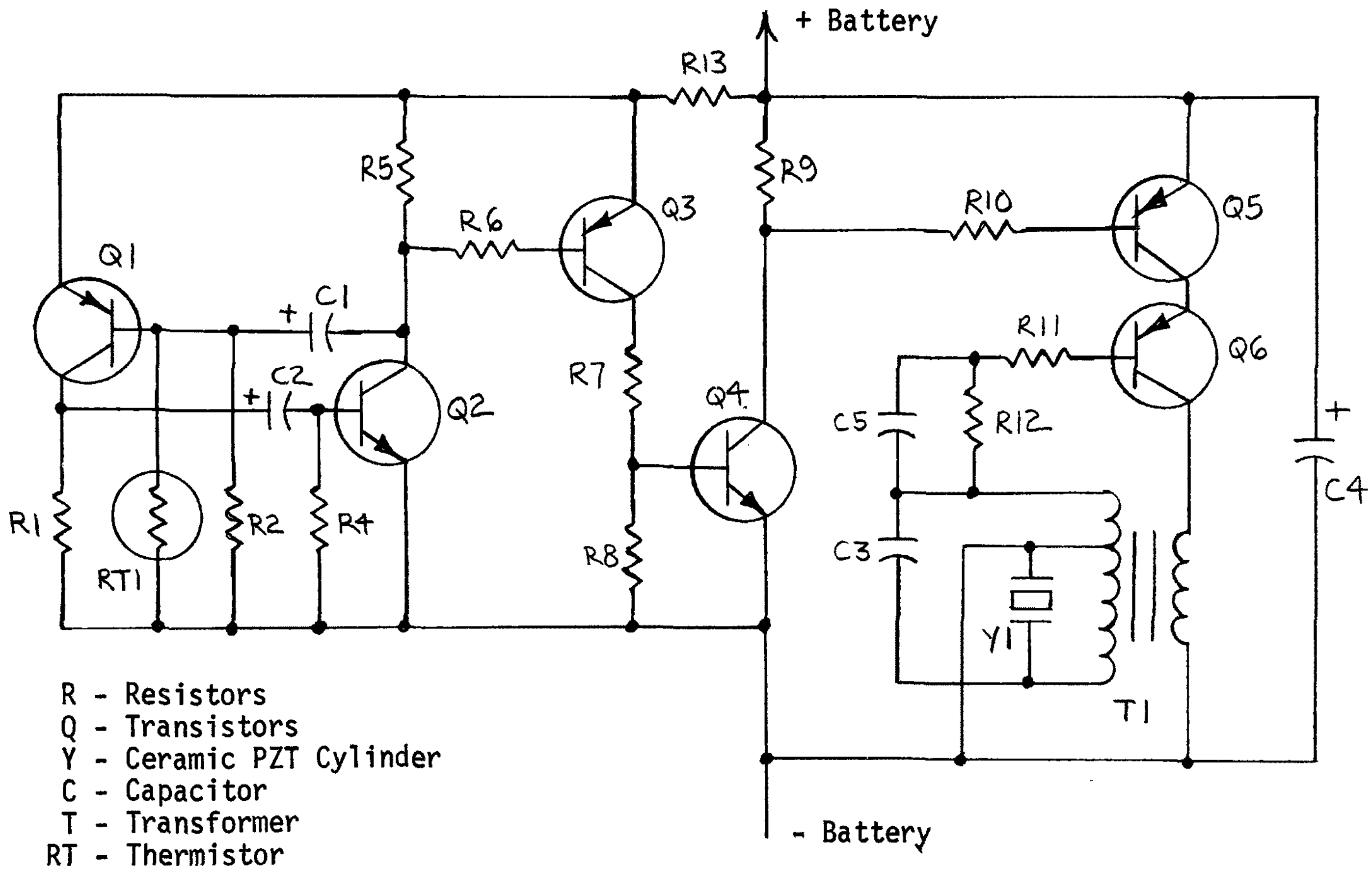

Figure 8. Acoustic temperature transmitter schematic.

Transmitting and Receiving Elements

The transmission and reception of underwater sonic signals is made possible by piezoelectric devices. They have the property of vibrating mechanically when a voltage is applied to them. Piezoelectric cylinders and discs were evaluated to be used as acoustic transmitters and receivers for the tags and the land-mounted hydrophones. The requirements of the receiving hydrophone were that it be directional to reduce noise pickup and be highly sensitive so as to reduce the power output requirements of the acoustic transmitters. As an example, since the water is shallow, there is no need to have the hydrophone receive signals from the bottom and top of the channel. Rather it should be most sensitive up and down stream. Thus extraneous signals and noises coming from the top of the channel would not be received strongly and would not interfere with the desired (tag) signals. Lead zirconate titanate (PZT) discs were selected as the receiving elements because of their directional capabilities and their high sensitivities.

Three PZT cylinders of different dimensions were selected as the acoustic transmitters. Initially, one size of cylinder was used. However, the sensitivity of the unit was poor at the low and high frequencies. This is due to a quality of resonance which all cylinders have. The cylinder vibrates best at its resonance and this is primarily due to its size and shape. To cover the large frequency range several units with different resonant frequencies were required. The size of the cylinders and their resonant frequencies are as stated below. Note that the highest frequency is 185 kHz. Since this unit operated satisfactorily up to 365 kHz, higher resonant frequency cylinders were not necessary. This is fortunate since higher frequency units are not readily available and are fragile.

(1) 12.9 mm OD x 6.4 mm L and 11.4 mm ID
Frequency-Circumference Mode 80 kHz.

(2) 9.6 mm OD x 6.4 mm L and 8.0 mm ID
Frequency-Circumference Mode 125 kHz.

(3) 6.4 mm OD x 6.4 mm L and 4.8 mm ID
Frequency-Circumference Mode 185 kHz.

Thermistor Element

In order to monitor the temperature of the tag environment a small temperature sensitive element (thermistor) was used in the tag. Its resistance varies with the temperature. Thus, by using the thermistor element in a circuit whose repetition rate varies with the variation in the thermistors,[25 and 26], its temperature can be monitored at a remote location by measuring the repetition rate of the received signal.

The thermistor has a resistance of one megohm with a tolerance of ± 20%. With a ± 20% tolerance the resistance variation is 800K ohms to 1.2 megohms. Such a wide range will result in wide variation from tag to tag. To compensate for the different repetition rates to be expected, a gain and slope adjustment was required in the decoder unit which converts repetition rate to temperature.

Final Design Circuit

The schematic of the final tag circuit is shown in Figure 8. The timer circuit consists of transistors Q1 and Q2 and their associated components. Transistors Q3, Q4 and Q5 act as switches and buffer amplifiers. The oscillator and transmitter circuit is transistor Q6 and its components. The PZT cylinder is represented by the symbol Y1 and the thermistor by the symbol RT1. The frequency determining components are the PZT cylinder Y1, capacitor C3 and the secondary inductance of T1. Thus for each tag, these 3 parameters must be carefully evaluated to assure that the correct final operating frequency results. The thermistor RT1 along with capacitor C1 determine the repetition rate of the transmitter, with the thermistor being the variable with temperature changes. The operating frequencies of the transmitters were selected so as to maintain a minimum of 6.5 kHz ± 2% of the frequency between each transmitter (Table 1).

Table 1. TRANSMITTER (TAG) FREQUENCIES
(kHz)

Tag number	Fundamental frequency	2nd Harmonic	3rd Harmonic	4th Harmonic
1	50.0	100.0	150.0	200.0
2	59.35	118.7	178.05	237.4
3	69.2	138.4	207.6	276.8
4	77.2	154.4	231.6	308.8
5	88.2	176.4	264.6	352.8
6	102.0	204.0	306.0	
7	113.6	227.2	340.8	
8	123.9	247.8		
9	133.0	266.0		
10	143.0	286.0		
11	160.25	320.5		
12	170.2	340.4		
13	184.1	368.2		
14	194.4			
15	218.4			
16	239.7			
17	365.0			
20	345.0			

The pulsing ON and OFF of the transmitter creates harmonically related spurious signals that are of sufficient power levels to interfere with certain selected operating frequencies. Therefore the second, third and forth harmonics of each transmitting frequency must be considered when selecting the operating frequencies, in order that they are different from the fundamental frequency of all of the tags. This is particularly important in selecting the lower frequencies. These will have harmonics which could fall in the range of higher frequency tags. See Table 1, and note the final selection of frequencies and how the harmonics are different from all of the fundamental frequencies.

Another factor in determining the operating frequency is the cylinder. Each cylinder has three modes of operation: Circumference, length and thickness; each mode resonates at a different frequency. At these mode frequencies large changes in cylinder impedance occurs, resulting in critical tuning at, or near these frequencies. These frequencies must also be omitted in the final section of operating frequencies.

Another consideration for the selecton of the tag frequencies, and one which was not considered until the problem surfaced during final systems testing at Monticello, was interference from signals being transmitted through the overhead high voltage wires. These signals are unusually strong and are picked up through the water and into the hydrophones, at the junction boxes and cables, and at the blockhouse in the receiver.

The frequency stability of the oscillator at a constant temperature is determined by the aging process of the ceramic material used in the manufacture of the cylinder. After the manufacture of the cylinder a continuing change in the dielectric constant occurs for a period of several weeks. This dielectric change results in a change in the capacitance of the cylinder which results in a change in the oscillator frequency. The aging rate decreases with time and can be accelerated by placing the ceramic in a heated oven for a period of time.

The frequency drift of the oscillator with changes in temperature is caused by the temperature coefficients of the cylinder, the transformer and the tuning capacitor. This change in frequency over temperature was compensated in the final tags to a marked degree with temperature compensating capacitors. They are larger in size than the miniature tuning capacitors used in the present tags but do not affect the final size significantly.

The acoustic power output of the tags average 1 milliwatt with an average of 7 milliwatts input power for an efficiency of approximately 14%. The range of most tags exceeded 46 meters (150 feet) in clear stable water, with the design goal set for a minimum of 15.25 meters (50 feet).

The temperature sensing thermistor was placed inside the tag to reduce external leads. External leads were kept to a minimum to prevent any weak points in the tag that might be susceptible to water leakage.

Directional patterns of an 82 kHz tag are shown in Figures 9 and 10. The horizontal pattern, Figure 9, clearly indicates that maximum power is radiated from the sides of the cylinder, as expected. The vertical pattern, Figure 10, is symmetrical and virtually omnidirectional. All of the tags will exhibit similar patterns.

Batteries

The mercury and the silver oxide batteries are at this time the only available miniature high capacity batteries on the market, with a relatively constant voltage over the life of the battery (Table 2). The silver oxide battery MS76 has an initial voltage of 1.5 v and a maximum capacity of 160 milliampere hour for the required size used in the present tags, 11.4 mm OD, 5.2 mm long, and a weight of 2.8 grams. The mercury battery MP675 was selected for the tags because of its higher capacity of 220 milliampere hour. Its size is 11.4 mm OD, 5.1 mm long, and it weighs 2.8 grams.

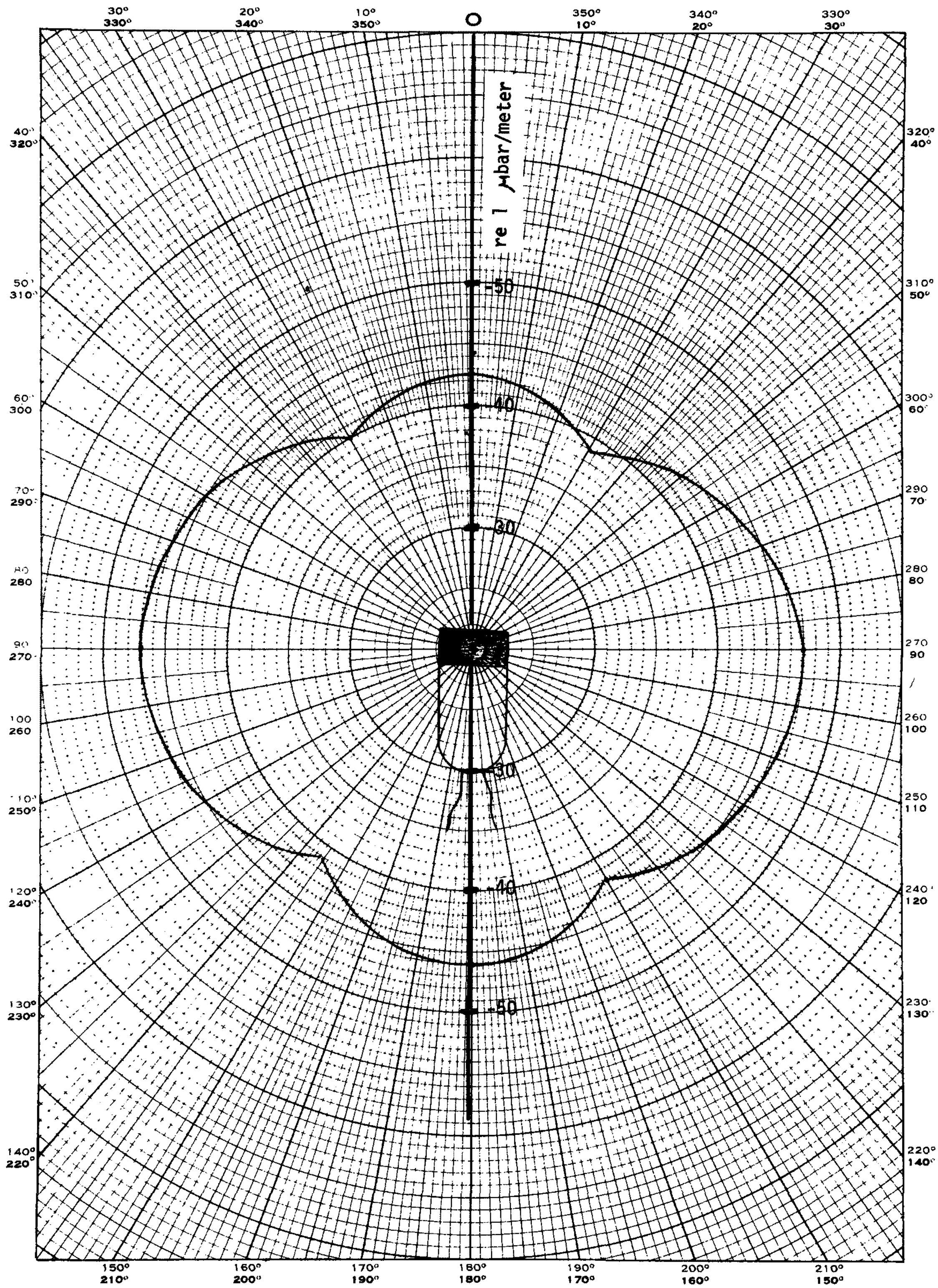

Figure 9. Beam pattern-tag frequency: 82 kHz, horizontal mounting.

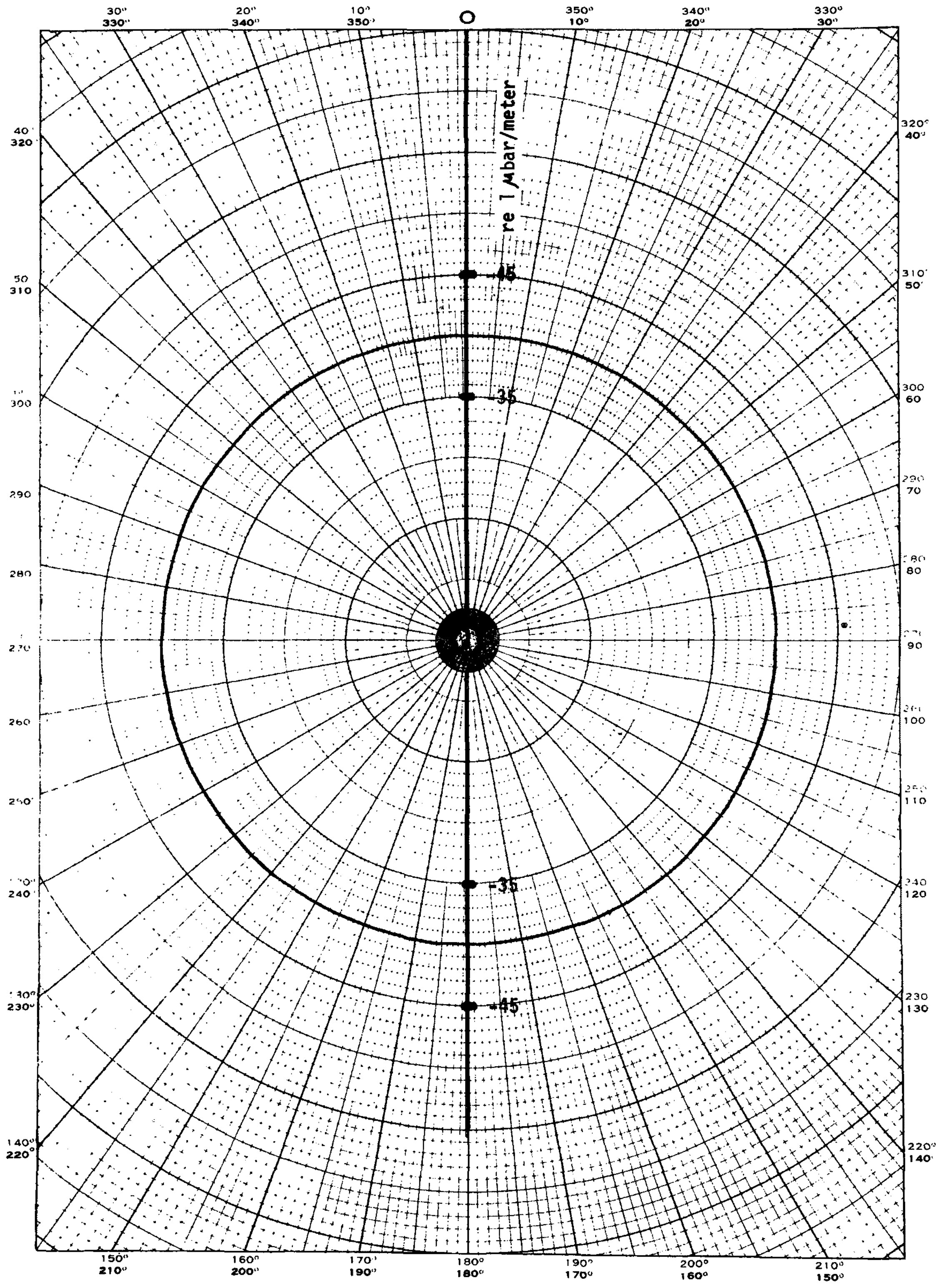

Figure 10. Beam pattern-tag frequency: 83 kHz, vertical mounting.

Table 2. COMMERCIALLY AVAILABLE MERCURY CELLS

Type[a]	Chemistry	Voltage, volts	Service capacity, ma-hour	Weight, grams	Diameter/ height, cm
RM 212	Mercury	1.4	16	0.5	0.33/0.55
RM 312 E 312 Hg 312	Mercury	1.4	36	0.64	0.36/0.79
W-1	Mercury	1.4	36	0.64	0.36/0.79
Mallory RM13GH	Mercury	1.4	60	0.98	0.535/0.79
MS13H	Silver Oxide	1.5	60	0.98	0.535/0.79
RM 400 E 400 Hg 400	Mercury	1.4	80	1.15	0.345/1.16

[a]Letter prefixes in "type" show mfgr. RM, Ms Mallory; e, Everready; Hg Burgess

The battery is the major limiting factor in the life of the tags. The capacity of the batteries vary depending on when they were manufactured and where they have been stored since their manufacturing date.

Batteries of the same type but made by different manufacturers vary in their capacity. The batteries used in the present tags were made by Mallory because of their higher capacity rating 220 ma/hr as compared to Everready with 210 ma/hr and Burgess with a rating of 180 ma/hr. Batteries purchased from Mallory were ordered directly from the manufacturer and were placed in plastic bags and put into a refrigerator when received. The temperature of the refrigerator was maintained at approximately 5 C.

A higher capacity lithium battery has been developed and is being manufactured in the larger battery sizes. The lithium battery has approximately twice the capacity of an equivalent volume mercury battery. There are several manufacturers of the lithium battery, however, at this time there are no miniature batteries of this type being sold. They should be considered for future tags, however.

Tag Assembly

The tag as shown in Figure 11 is assembled in four steps. First, the printed circuit board containing the timer is assembled and tested for operation. The oscillator circuit is next assembled on the back side of the printed circuit board.

The second step of assembly is the glueing (Eastman 910 Glue) of the transformer pot core with the cylinder. The pot core is an iron core upon which the transformer is wound, providing an efficient and smaller transformer than if an air core were used. With the use of the 125 mm (0.5 inch) OD cylinders the pot core is inserted into the cylinder to reduce the length. With the smaller high frequency cylinders the pot core is attached to the end of the cylinders.

The third step glues the cylinder and pot core to the printed circuit board. At this point the tag can be tested for operation and

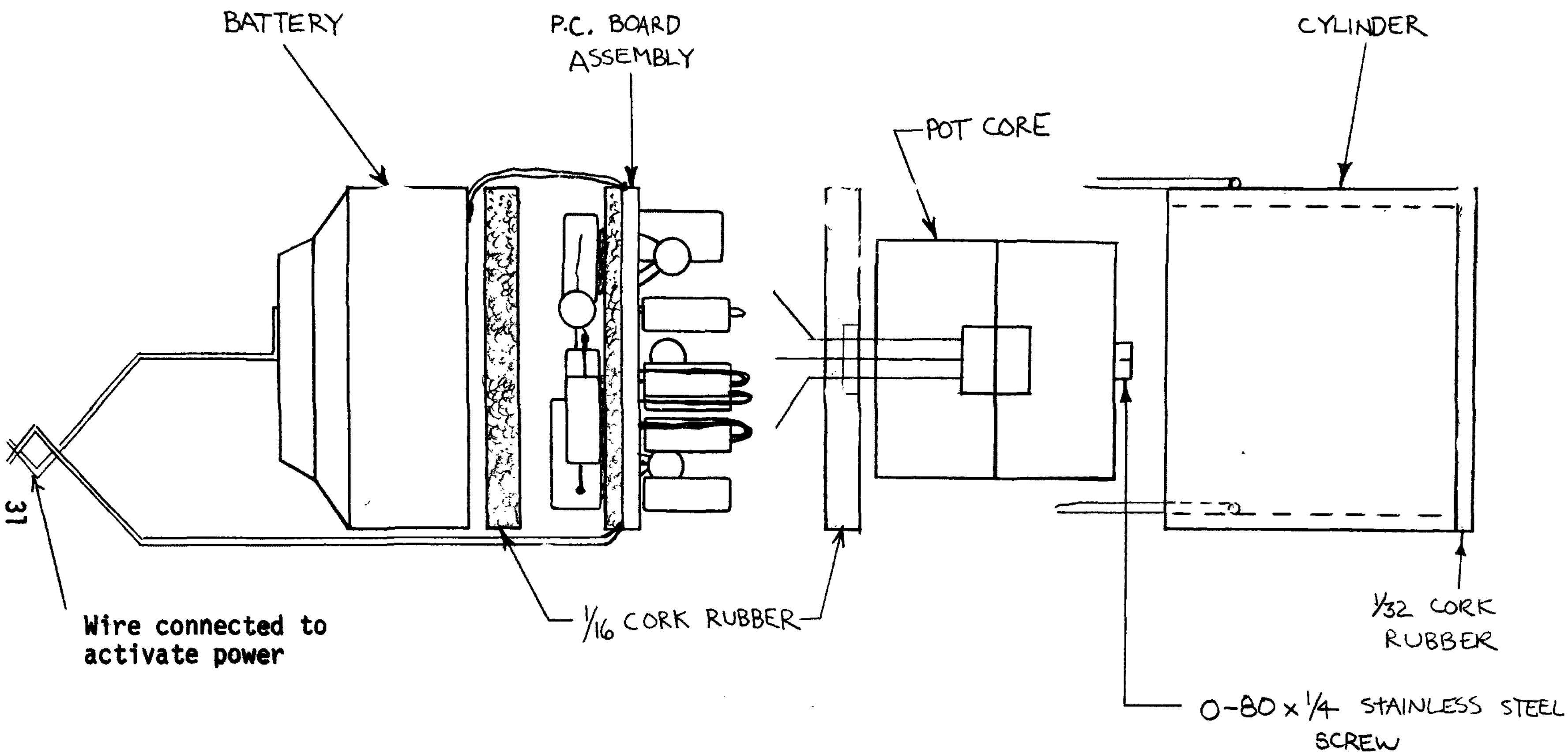

Figure 11. Acoustic temperature transmitter (tag) assembly.

can be tuned to its operating frequency. This involves changing the value of capacitor C3 until the desired frequency is achieved. The last step consists of attaching the battery, applying epoxy to all components except the cylinder and the potting of the completed tag.

Potting Compounds and Molds

Potting compounds from several manufacturers (Dupont and Products Research and Chemical Corporation) were evaluated. The compounds evaluated were epoxy resins, silicone rubber, and urethane rubber. Parameters used in the evaluation were: Workability, presence of air bubbles, odor, hardness, fish toxicity, and moisture absorption.

The two-part epoxy resins tested had a durometer hardness of 35 to 80 on the Shore D scale. The moisture absorption rate of the resins was dependant to an extent on the hardness of the cured epoxy. The harder the epoxy the lower the absorption rate. The moisture absorption rate varied from .1% to 1.2% after ten days with a relative humidity of 96% as quoted by the manufacturers.

The silicone rubber tested had a durometer hardness of 20 to 35 on the Shore A scale and was very susceptible to water absorption. This single part room temperature curing, Silicone Rubber Sealant (RTV) compound was available in tubes and when squeezed from the tube was in a thin paste form. Two or more coatings of RTV were required to prevent water leakage into the test circuits.

The urethane rubber, a two-part compound, required an evacuation process to remove trapped air bubbles from the compound. With a durometer hardness of between 50 to 80 on the Shore A scale, the urethane rubber proved to be satisfactory for the potting of the tags. The semi-flexible urethane adhered well to the cylinders and presented a good acoustical match between the cylinder and the water.

The manufacturer of the urethane selected was Products Research and Chemical Corporation (PRC). The PRC number of the first urethane used was PR 1524. This compound was used for over one year before it was known that it contained a cancer suspect agent, 4, 4'-methylene-bis-(2-chloroaniline) or "Moca" as named by Dupont. At that time PRC came out with a "Moca" free compound PR 1564. This new compound was used in the potting of the tags and the hydrophones delivered to EPA.

Plastic molds were used initially for the potting of the tags. With the use of the higher viscosity compound PR 1524, trapped air bubbles remained at the bottom of the mold after evacuation. This resulted in weak spots in the cured compound which made the tags susceptible to water leakage. Attempts were made to dip the tags in the potting compounds, but resulted in an uneven coating around the tags which after a short period of time in water resulted in water leakage into the tags.

With the use of the lower viscosity compound PR 1564 and the use of the teflon molds the majority of the trapped air could be removed by evacuation for about 30 minutes. This resulted in a uniform coating around the tag with less chance of water leakage.

Several types of molds were evaluated. The final mold used was a "split" mold made from 2 sheets of Teflon (each 2.54 cm x 12 cm x 8 cm) held together in a vise to form a 5.08 cm x 12 cm x 8 cm sandwich. A 1.5 cm diameter hole was drilled at the joint between the 2 sheets. The depth of the holes was approximately 6 cm. After the potting was completed the tags were easily removed by separating the teflon sheets.

Tables 3, 4, and 5 summarize the individual tag overall dimensions, weight, volume, repetition rate, pulse width, cylinder dimensions, and coil winding information. Section IV also provides technical specifications for the tags.

HYDROPHONE/PREAMPLIFIER

Piezoelectric Elements

Three different sized PZT disc were selected for use in the receiving hydrophone to construct a wide band hydrophone with good sensitivity. The radial and thickness resonances are used to obtain overlapping frequency

Table 3. OVERALL DIMENSIONS, WEIGHT AND VOLUME OF EACH TAG

Tag number	Length, mm	Diameter, mm	Weight in water, g	Weight in air, g	Volume mg/l
2	32.4	15.5	4.77	11.08	6.3
4	36.4	17.4	4.72	12.58	7.8
5	34.6	15.7	4.64	11.50	6.8
6	33.3	15.5	5.12	11.71	6.7
6*	32.5	16.1	5.17	11.68	6.4
7	33.7	15.5	5.47	11.98	6.4
8	30.4	16.1	4.98	11.05	6.1
10	30.8	16.2	4.69	10.67	5.9
12	32.4	15.4	4.84	11.18	6.3
13	31.8	15.3	4.91	11.17	6.2
14	38.9	16.2	4.77	12.44	7.7
15	37.0	16.1	4.60	12.01	7.4
16	38.8	15.8	4.79	12.62	7.9

*No longer in use.

Table 4. TAG REPETITION RATE AND PULSE WIDTH CHARACTERISTICS

Tag number	Repetition rate, pps	Pulse width, msec	Frequency, (kHz) air	water
1	.75	2.5	49	51
2	.74	2.6	58.5	62
3	.74	2.8	68.4	69
4	.87	2.6	78.5	80
5	.84	2.6	89.2	91
6	.75	2.6	103	96
7	.77	2.8	108	110
8	.78	2.8	123	122
9	.80	3.0	133	134
10	.80	2.8	145	145
11	.78	3.0	161	162
12	.76	2.6	171	173
13	.84	3.5	184	183
14	.78	2.4	195	198
15	.84	3.0	219	221
16	.84	2.6	242	236
17	.82	3.4	365	366
20	.74	2.0	340	341

Table 5. TAG CYLINDER AND COIL SPECIFICATIONS

Tag number	Cylinder diameter x length cm	Coil (number of turns) primary	secondary	tap	Nominal frequency in water, kHz
1	1.3 x .64	15	90	20	51
2	1.3 x .64	15	81	20	62
3	.97 x .64	15	80	20	69
4	.97 x .64	15	64	18	80
5	.97 x .64	15	90	18	91
6	1.3 x .64	13	80	18	96
7	1.3 x .64	13	71	18	110
8	1.3 x .64	13	64	18	122
9	1.3 x .64	13	62	18	134
10	1.3 x .64	11	60	15	145
11	1.3 x .64	11	50	15	162
12	1.3 x .64	11	45	15	173
13	1.3 x .64	10	40	15	183
14	.97 x .64	8	45	15	198
15	.97 x .64	8	40	15	221
16	.64 x .64	8	50	15	236
17	.64 x .64	8	45	15	366
20	.64 x .64	8	30	15	341

ranges to cover the frequency range of 51 to 366 kHz.

The single low frequency disc 31.75 mm OD x 15.4 mm thick has a radial resonance of 70 kHz and a thickness resonance of 150 kHz. The single medium frequency disc 19.1 mm OD x 6.35 mm thick has a radial resonance of 125 kHz and a thickness resonance of 300 kHz. The three high frequency discs (10.7 mm OD x 4.7 mm thick) have a radial resonance of 220 kHz and a thickness resonance of 400 kHz.

Preamplifier

The dual sided receiving hydrophone (Figure 12), consists of three sets of PZT discs on each side with each set of discs having its own bandpass filter and buffer amplifier to isolate the different sets of discs from each other to prevent interaction between the discs. The acoustic signals received by the discs are filtered by the bandpass filters (L1 L2/C1C7 and L3L4/C8C14,....etc.) and are sent to the buffer amplifiers (Q1, Q2, Q3...Q6) (Figure 13) The signals from each of the buffer amplifiers are added together and amplified by the low output impedance power amplifier. The output of the power amplifier (Q12 and

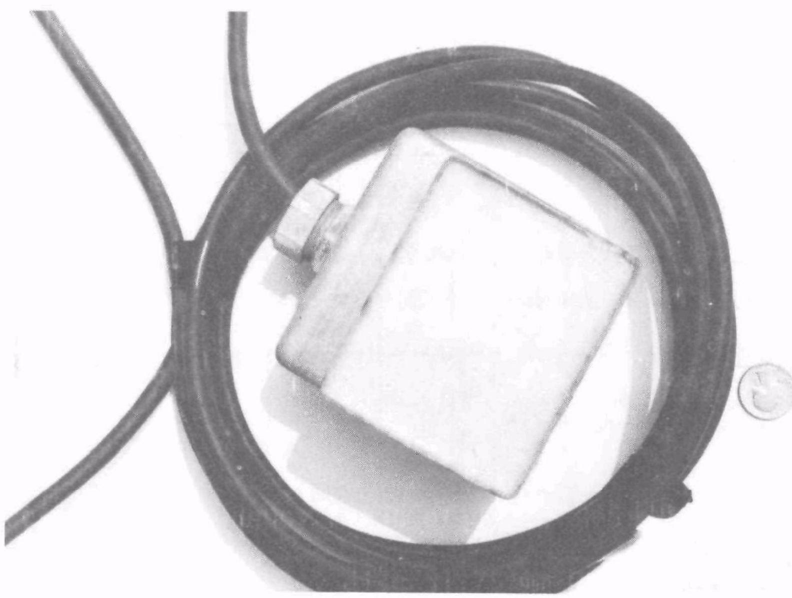

Figure 12. Dual sided receiving hydrophone.

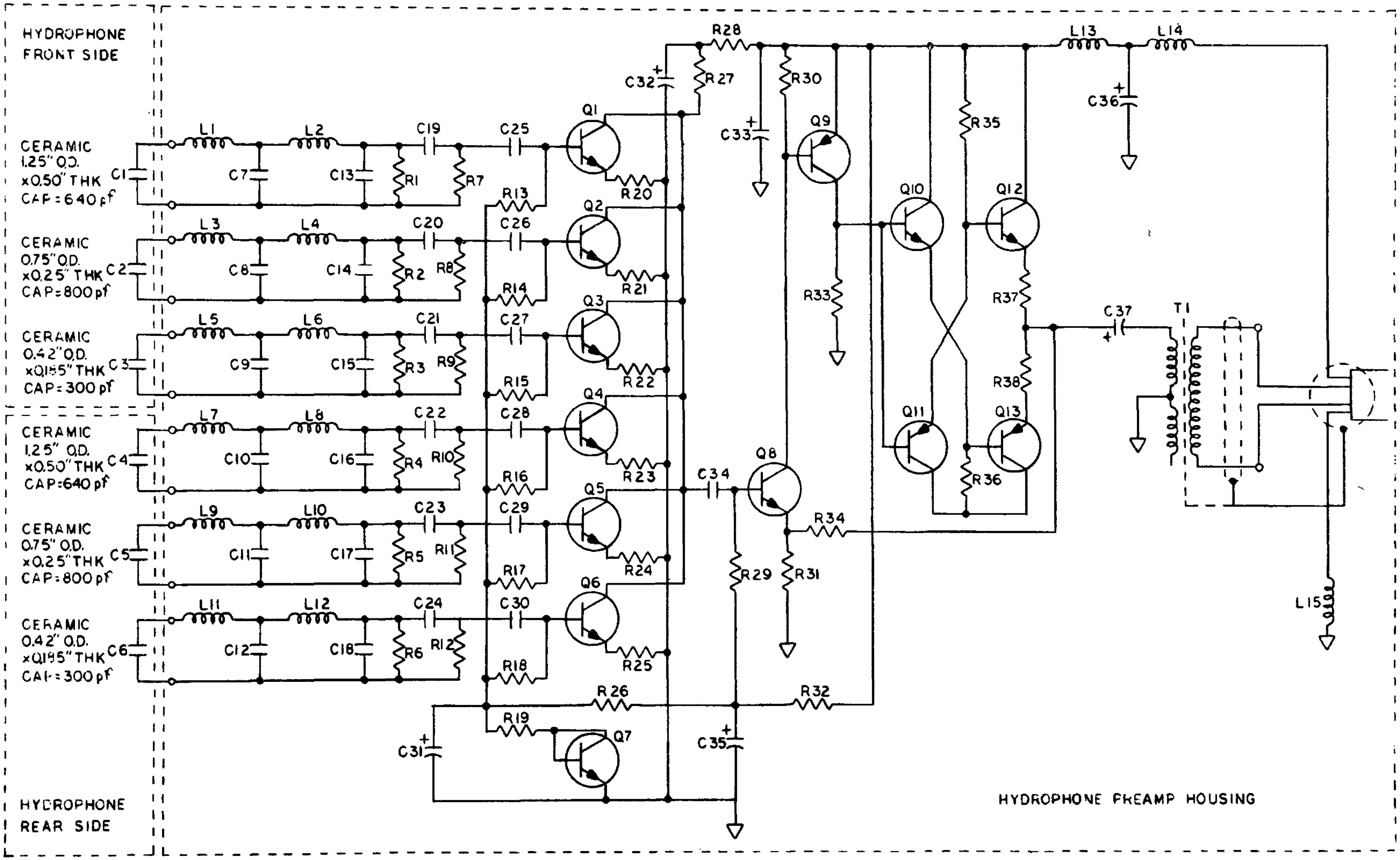

Figure 13. Hydrophone preamplifier schematic.

Q13) is coupled into a low impedance balanced transformer (T1). The output of the balanced transformer is connected to the signal cable through contacts of a relay located inside the junction box at the selected station.

Power to the preamplifier and the relay is obtained from the hydrophone selector switch on the receiver-decoder console. The necessary dc power supply is included in the console.

Hydrophone Assembly

The hydrophone consists of two aluminum housings bolted together as shown in Figure 14 and Figure 15.

The rear housing contains three sets of discs mounted on rubber spacers to insure their vertical centering within the housing. Cork rubber is glued to the bottom and the side of the discs.

The front housing contains the preamplifier printed circuit board and three sets of discs that are also mounted on rubber spacers to provide centering.

The two housings are filled, one at a time, with a urethane potting compound to within 3 mm of the top edge of each housing. The housing is placed in an evacuation chamber for 60 minutes to remove air bubbles from the urethane compound. The urethane is allowed to cure for approximately 24 hours.

Special care was taken to protect against rf interference (RFI). Any rf signal present in the vicinity of the channel will be picked up by the hydrophone assembly. Some signals will of course be picked up more readily than others; such factors as wavelength, power level, depth of the hydrophone under water, direction from which the signal is generated, etc., will determine the final intensity of the signal which is received. Thus, to eliminate false readings or even mask the signals from the fish tags, the RFI must be greatly diminished.

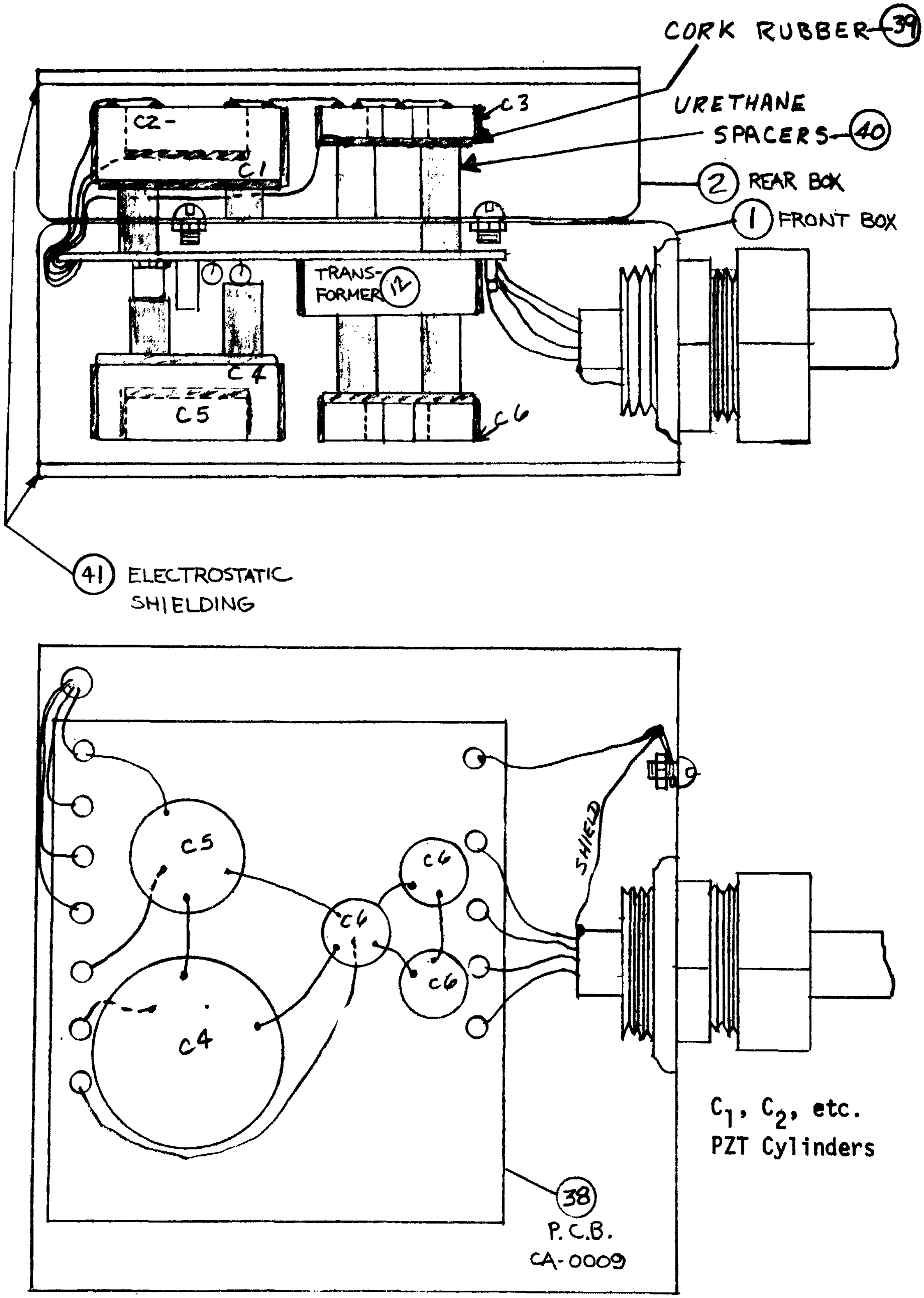

Figure 14. Hydrophone assembly.

Since the hydrophone ceramic elements must be exposed to the sonic signals, a solid metal shield cannot be used to eliminate the RFI. What is required is a material which will inhibit RF signals and allow sonic signals to pass unattenuated. Screen materials (20 x 20 mm to 100 x 100 mm meshes) have been used with varying success to solve similar problems associated with military sonar systems. Unfortunately, when tried on the present hydrophones, the attenuation to power line frequencies and the RF signals present on them, was not sufficient to prevent masking of several tag signals. The final solution to most of the RFI was the use of liquid silver paint (Acheson-Electrodag # 5041) which was brushed on the outer surface of the hydrophone (Figure 14).

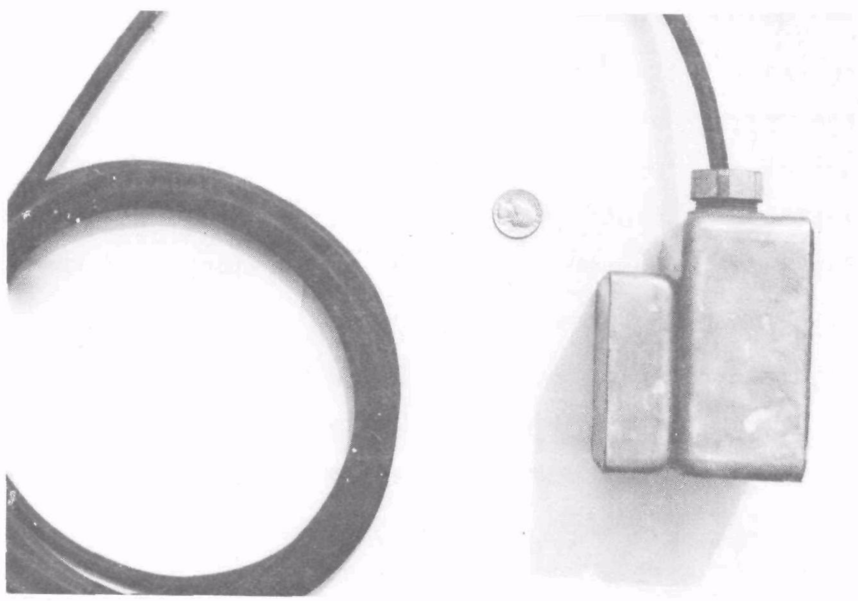

Figure 15. Hydrophone assembly.

RECEIVER

General

The sonic receiver is designed to monitor various sonic sources within a frequency range of 50-365 kHz. It is a sensitive and selective receiver using super heterodyne circuitry built around modern integrated circuits and discrete components. Tuning is accomplished by varying the voltage controlled local oscillator thus giving the receiver the feature of optional remote control tuning. The modification for EPA application provides a 20 step frequency selection feature with vernier adjustment for each step, rather than continuous tuning and a mechanical mounting arrangement which is compatible with the other units of the entire EPA fish tracking system. The final receiver is mounted in the console.

Description

The selected signal source (described elsewhere in this document) is connected to the 600 ohm winding of the input transformer (Figure 16).

A band pass filter consisting of capacitors C1, C2, C3, and C4 and inductors L1, L2 and L3 is included to reject signals outside the tuning range of the receiver. The signal input level to the first mixer, Y1, is adjustable by front panel control R1 - RF Gain. The output of Y1 is the difference frequency between the input signal and the local oscillator, Y6.

The local oscillator frequency range is determined by the components, C13, C15, L4 and the voltage across CR1, the tuning diode. The diode tuning controls are connected to pin 9 on the PC board. Rotating TAG SELECTOR switch connects resistor networks to the tuning diode which sets the receiver channel frequencies. Each channel frequency may be adjusted over a limited range by the TAG TUNING CONTROLS.

The dual outputs of the mixer are connected to two band pass filters at the IF frequency, 455 kHz. These filters establish the selectivity

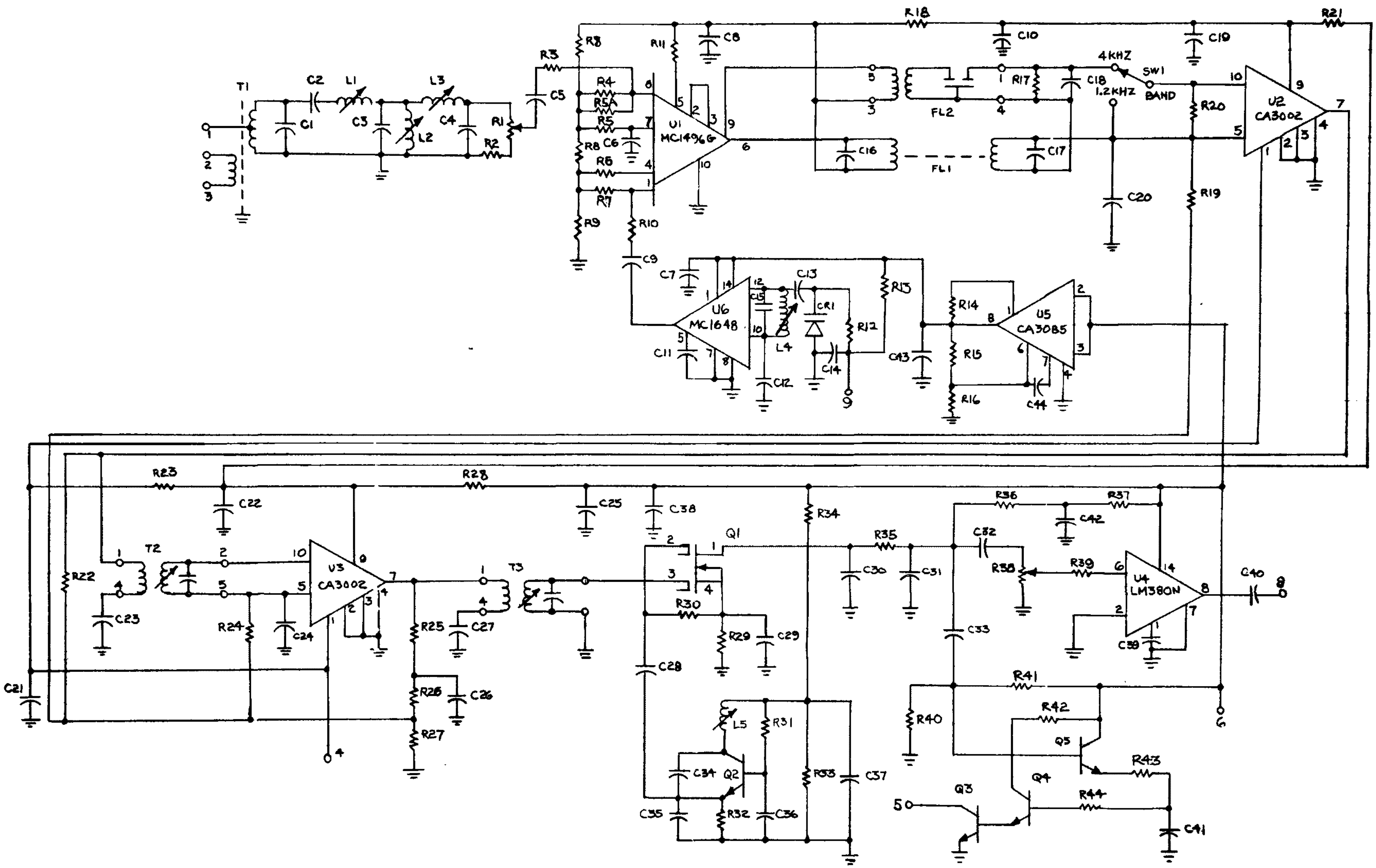

Figure 16. Receiver schematic.

characteristics of the receiver. The choice of bandwidths is made by selector switch BANDWIDTH. The 455 kHz signal is amplified by two transformer coupled integrated circuit amplifiers, Y2 and Y3.

Signal detection occurs by the product mixer action of Q1, a dual gate transistor. Transistor Q2 and its associated circuitry form a beat frequency oscillator (BFO). The output signal of the product detector is the difference frequency between the IF frequency and the BFO frequency. The BFO is adjusted for approximtely 100 Hz.

The audio signal is amplified to earphone level and speaker level by 1C U4. The audio level is adjustable by the AUDIO GAIN control (AGC).

The output of the product detector is also fed into the AGC amplifier consisting of transistors Q3, Q4, and Q5. The AGC output, pin 5, is connected to the IF amplifiers, integrated components (IC) U2 and U3, pin 4, through the SIGNAL STRENGTH meter.

Jacks are provided on the front panel for earphone, loudspeaker, and oscilloscope monitoring of the audio signal and a jack is provided to monitor the AGC level.

Operation

The receiver is made operative by applying power to the system. To monitor a specific tag, rotate TAG SELECTOR switch to the desired channel. Controls AUDIO GAIN, RF GAIN and the appropriate control of the TAG TUNING CONTROLS group may be adjusted to produce a satisfactory signal. The relative signal strength of the received tag signal may be observed by the deflection on the SIGNAL STRENGTH meter. This is a relative reading only, any deflection above the steady state level can be compared with other signals.

Adjustments

There are only two adjustments to be made on the receiver, the local oscillator and the beat frequency oscillator (BFO) frequencies. These adjustments are to be found on the back of the enclosure holding the receiver electronics. There are two access holes in the compartment cover, marked LO level oscillators and BFO beat frequency oscillator. To adjust the local oxcillator, rotate the TAG SELECTOR switch to Tag 1, and set the Tag Tuning Control to mid scale, and the BANDWIDTH switch to 1.5 kHz position. Connect a signal generator to the input of the receiver and adjust its frequency to 50 kHz. Using an insulated hexigon alignment tool, adjust the case of L4, maximum signal strength, as indicated in the SIGNAL STRENGTH meter. The output level of the signal generator should be about 11 microvolt for this adjustment. The beat oscillator may be adjusted to produce a beat of about 1000 Hz.

TEMPERATURE DECODER

The fish tags used in this system produce a continuous series of energy bursts whose period varies as a function of temperature. The temperature information is contained in the period of the tag, and the temperature decoder extracts this information by measuring the time between the signals from the tag and applying to that quantity a multiplication constant.

The measurement of time is accomplished by counting internally generated clock pulses during the interval between tag signals. From this point the decoding process involves a scaling operation which is performed by first converting the contents of the counter to an analog voltage and then modifying that voltage by means of two operational amplifiers whose function it is to compensate for the variations in the period-versus temperature characteristics of the tags. The output of the operational amplifiers is then displayed as temperature on a digital (voltmeter) display on the front panel.

Operation

The temperature decoder operates as follows: A timing module (U3), shown in Figure 17, is used as a source of clock pulses (approximately 900 Hertz) which are accumulated in a counter (U4). Each time a signal

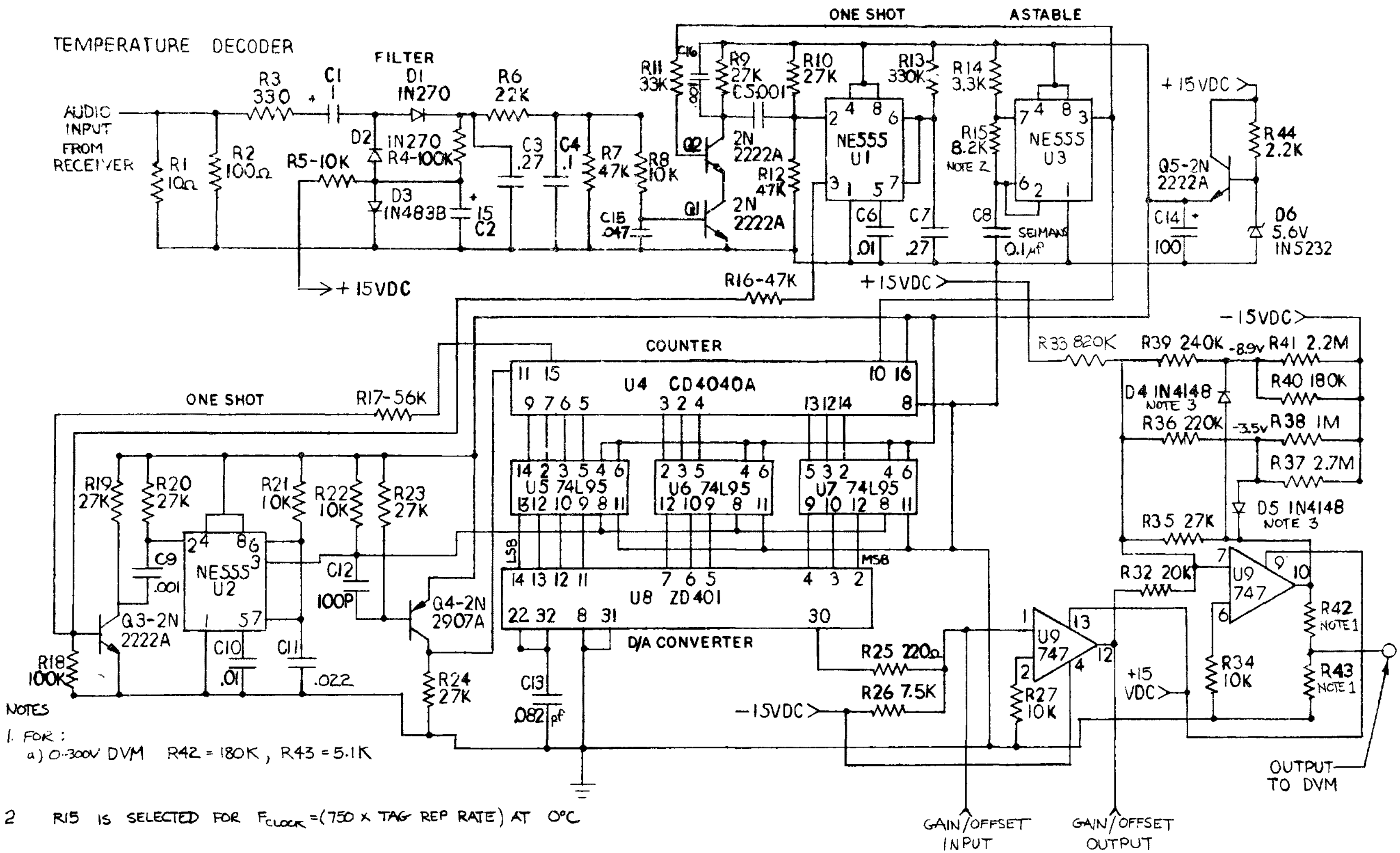

Figure 17. Temperature decoder.

is received by the decoder, the contents of the counter are loaded into a shift register, (U5, U6 and U7), and the counter is reset. This is shown in Figure 18. Immediately after the counter is reset, it begins a new counting cycle which continues until the subsequent audio pulse is received. If another pulse is not received, the counter will accumulate to maximum capacity and load "all ones" into the registers, corresponding to "minimum"temperature.

Monostable U1, which is triggered by the initial signal from the receiver, has a pulse width long enough to prevent the monostable from being re-triggered by echo pulses of the tag-generated acoustic signal. The signal which loads the register and resets the counter is generated by the monostable U2 which was fired by the leading edge of a pulse generated by the monostable U1 (Figure 18).

A digital to analog converter, U8, provides an output voltage which is proportional to the contents of the register. The resistance versus temperature curve of the fish tags are to a large extent linear. Non-linearities occur, however, at the higher and lower temperature extremes. These nonlinearities are corrected by the Op Amp U9 and the feedback circuitry composed of R39, R40, R41, and D4 at one extreme and by R36, R37, R38 and D5 at the other extreme. Offset and gain adjustments of the Op Amp translate into calibration of 0°C and at 25°C. These are performed by potentiometers on the temperature decoder unit which are accessed through holes in the front panel. Each tag has a corresponding set of potentiometers for high and low temperature calibration.

Calibration

Calibration is performed as follows: The TAG SELECTOR is set to select the desired tag. The tag is immersed in a water bath at 0° C for about 10 minutes, allowing it to stabilize. A portable hydrophone is also inserted in the water and connected to the hydrophone input on the rear of the console. The potentiometer, identified under the zero degree column by the appropriate tag number, is adjusted until

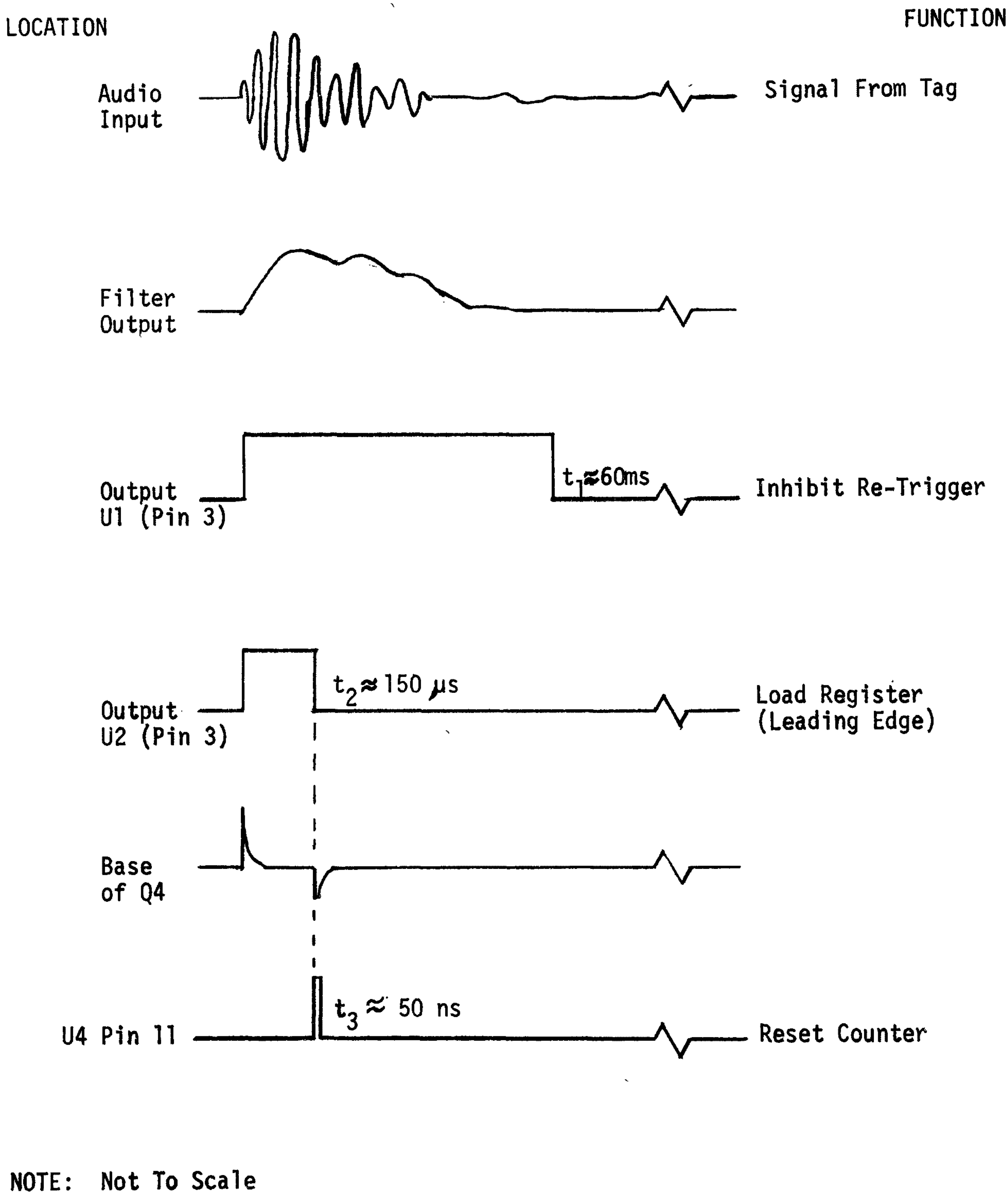

Figure 18. Signal descriptions of temperature decoder.

the temperature display meter indicates zero. The tag is then immersed in water at 25 C for 10 minutes and the corresponding potentiometer in the 25 C column is adjusted until the display reads 25 C.

Ordinarily there is very little inter-relationship between the zero and 25 degree potentiometers; however, it is recommended that the cycle be repeated at least once.

RECEIVER-TEMPERATURE DECODER CONSOLE

The receiver-temperature decoder console provides the controls and displays by means of which fish are located in a channel and their temperature is determined. The console contains three elemental assemblies. They are: The receiver, the temperature decoder and the power supply.

Operation

Up to a maximum of twenty tags may be addressed using the TAG SELECTOR switch on the panel of the console (Figure 19). Each tag is individually selected by one of 20 TAG TUNING CONTROLS. A separate selector, VCO VOLTAGE switch, is available to display the VCO voltage associated with each tag. The VCO voltage is directly related to frequency. This is an excellent check on the tag selected for temperature monitoring. This feature was readily available due to the circuitry chosen to tune the receiver. By using voltage tuned diodes to accomplish frequency tuning, one need only read the voltage on the tuning diode to have a frequency analog. By using the digital display on the panel to indicate VCO voltage, a precise analog measurement of frequency is available. This measurement is representative of the frequency to which the receiver is tuned and can be recorded for reference purposes.

The frequency bandwidth of the receiver may be set to either 1.5 kHz or to 4 kHz by a selector switch located on the panel. The 4 kHz bandwidth permits a broader spectrum of signals to be monitored by the receiver, while the 1.5 kHz bandwidth restricts the reception to a smaller spectrum of frequency and at the same time reducing the amount of noise picked up by the receiver. This has the effect of increasing the signal-

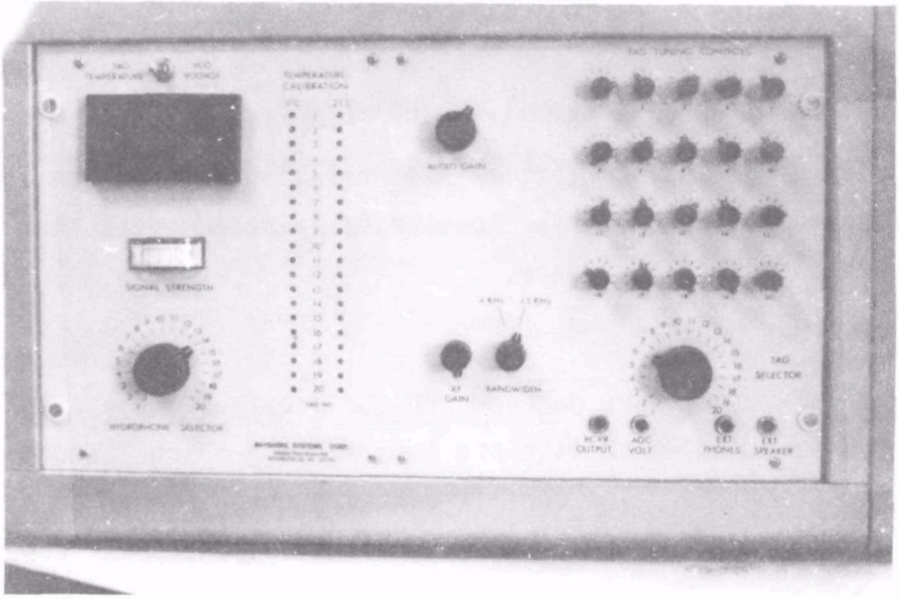

Figure 19. Receiver decoder console.

to-noise ratio of the reception by approximately the ratio of the bandwidths. Thus, by switching from 4 kHz to 1.5 kHz the signal reception is improved by approximately 2.6. This is an approximately 50% increase in reception range.

The panel contains controls for adjusting both the RF and audio gains of the receiver. It also provides a meter to monitor signal strength, and phone jacks for additional monitoring of the receiver output and AGC voltage and for connecting external phones or an external speaker. Since the tag temperature and tag tuning parameters can be represented as analog voltages, it has been convenient to display both on the same display. In order to do this the appropriate scaling circuitry has been designed into both the temperature decoder and the receiver. The display is, in fact, a digital voltmeter. The desired parameter may be displayed by selectively throwing a toggle switch.

Calibration

Calibration of the temperature tags is performed at 0 C and at 25 C. Twenty sets of calibration potentiometers are provided on the console panel for this purpose. These are related to the "TAG TUNING

CONTROLS so that a tag is selected by the TAG SELECTOR, the appropriate set of calibration pots is applied to the temperature decoder.

The power assembly is located in the console and is attached to the bottom frame. The assembly houses two commercial power supplies, and a terminal strip. A New Jersey Electronics Model RL 1-5 provides 3 amps at 5 volts. The plus and minus 15 volt source may be either of the following units: Zeltex Model Z 15AT100DP, Analog Devices Model 902, or Semiconductor Circuits Model P741-1015.

INSTALLATION

System installation was completed during the period of 25 to 28 June 1974 at the Monticello Ecological Research Station (Figure 1). The receiver-decoder console was located inside the blockhouse adjacent to the conduit box provided for the cable runs to the channels. A ground strap was connected from the console to the conduit.

The power and signal cables from the console to the junction boxes at the channels were run through a 10.2 cm (4 inch) steel conduit (Figure 20) to provide additional shielding from the power lines. The conduit is strapped to each junction box along the channel to insure that a low resistance path is provided for better shielding of the cables from the power lines. Both ends of the conduit were connected to 4 meter rods driven completely into the ground. A cable inter-connecting box was installed within the junction boxes at each station to provide additional shielding and to protect the exposed cable wires from moisture (Figure 21). These grounding and shielding precautions are all essential to minimize ground loop currents within the overall hydrophone, preamplifier, cables and console system.

The inter-connecting boxes have romex connectors mounted on them for the entry of the signal and power cables. The boxes contain a terminal strip, provided for the inter-connection of the cable wires, and a relay. This relay is used to activate the appropriately selected preamplifier.

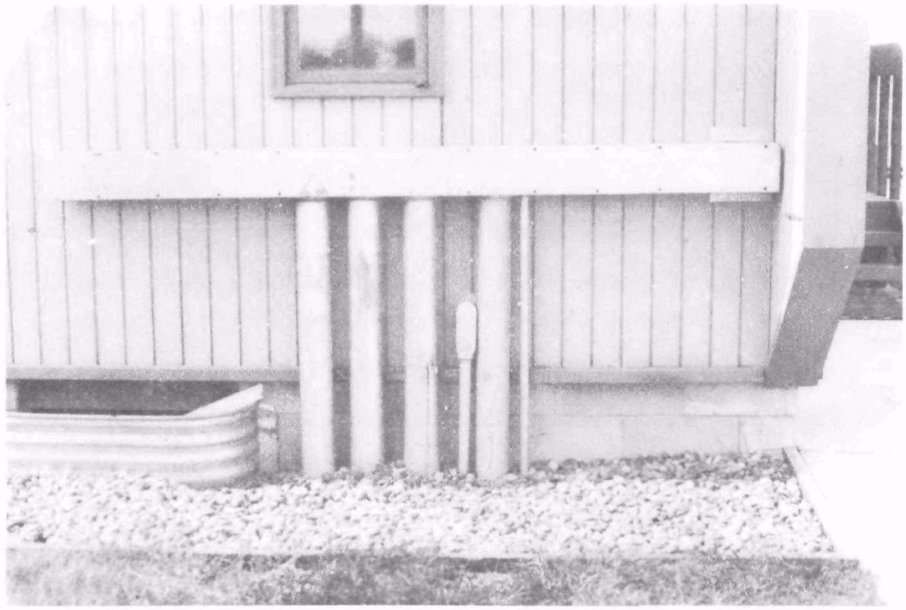

Figure 20. Steel conduit runs from blockhouse.

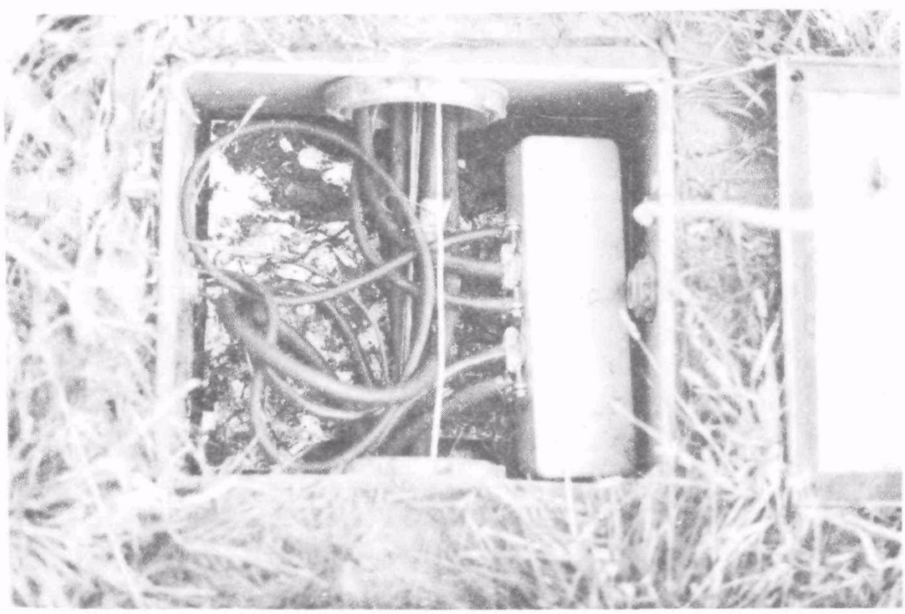

Figure 21. Juction box.

The shield of each power and signal cable entering the box is connected to the box by an adjustable clamp on the romex connector (Figure 22). The shields are connected together again on the terminal strip.

The output cable from each hydrophone is run through a 19 mm (3/4 in.) conduit to the junction boxes. The conduit is connected to the hydrophone housing by a compression type connector that is mounted through one wall of the hydrophone housing (Figure 23).

Figure 22. Interconnecting box.

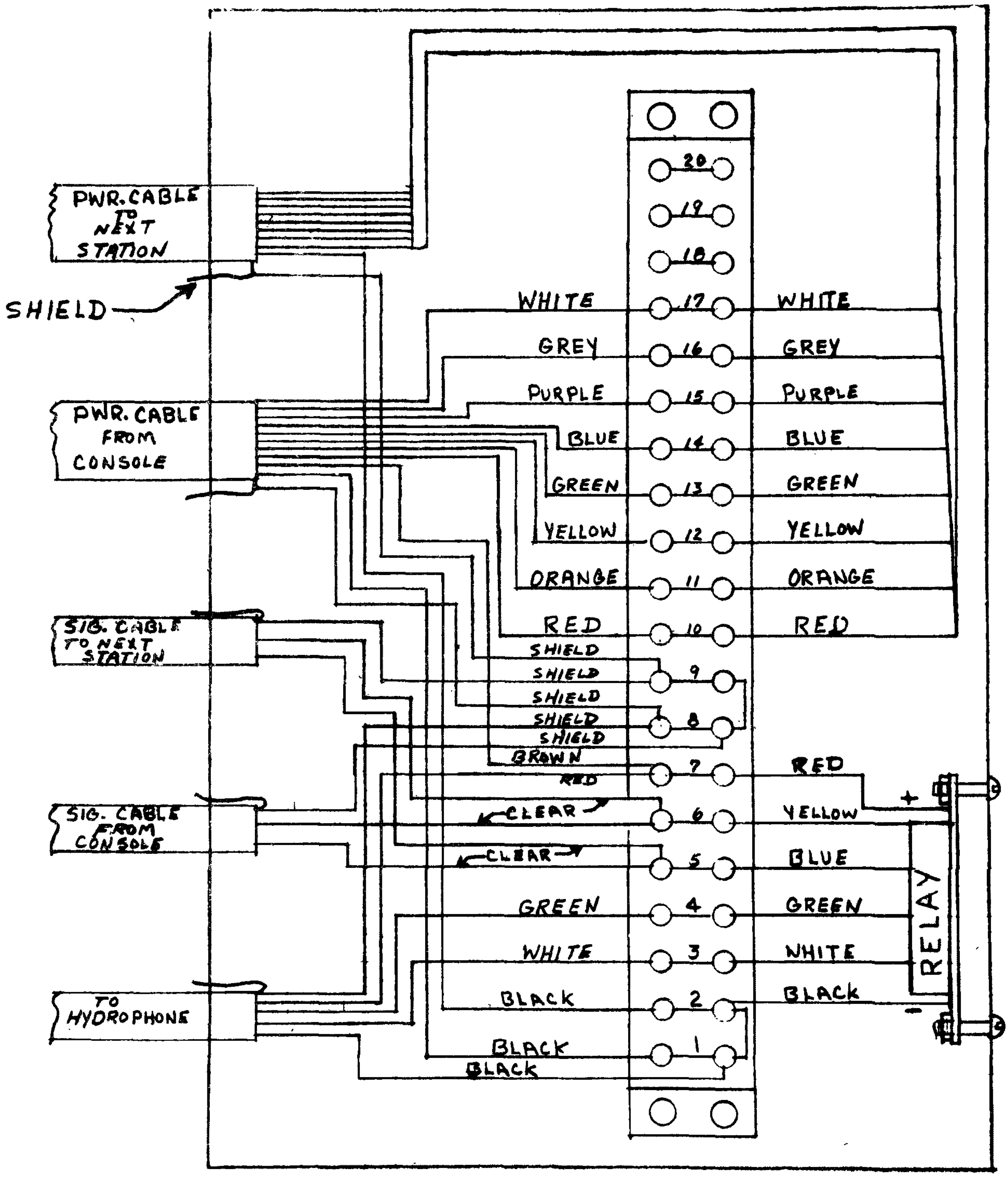

Figure 23. Interconnecting box wiring diagram.

NOTE: Each cable feeds through 1.27 cm (1/2 inch) romex electrical connector mounted through side of box.

SECTION VI

PROBLEMS AND SOLUTIONS

Tests conducted at the Monticello Ecological Research Station revealed two interference problems that resulted in loss of reception of signals transmitted by ultrasonic transmitters.

The two problems were electromagnetic interference (EMI) and radio frequency interference (RFI), both of which were being generated by the overhead power lines.

RADIO FREQUENCY INTERFERENCE

During the early phases of the program an RFI evaluation of the area was made, see Appendix A, over the frequency range of DC to 50 kHz. A quick search at higher frequency was also made; however, no signals were evident up to, and beyond, 200 kHz. The signal frequencies below 50 kHz appeared to be of a level which would not cause serious RFI problems. Subsequently, the power companies started to transmit signals which are now causing problems. Telemetry signals used for relay switching are transmitted along the power lines. The frequency of the signals 105 kHz, 146 kHz, and 192 kHz fall within the receiving bandwidth of the ultrasonic receiver, and are close to the frequencies of tags numbers 6, 10, and 14. These signals were being picked up at low levels by the signal and power cables and at higher levels by the hydrophones. The signals and, to some extent, their harmonics, could also be detected at low levels within the blockhouse. The level of these signals were two or three times higher with the hydrophone located in channel 1 as compared to the hydrophone being located in channel 2.

Testing of electrostatic shielding was conducted to determine to what degree the interference could be reduced. Shielding materials consisting of mu-metal, aluminum screen and steel screen, were evaluated for their attenuation properties. A frequency generator was used to produce the RFI signals. The use of aluminum screen placed over the hydrophone and connected to the housing resulted in attenuation of RFI signals by 40 dB where as the steel screen resulted in an attenuation of only 27 dB.

A solid mu-metal shield placed over the hydrophone and connected to the hydrophone housing resulted in an attenuation of 58 dB of the RFI signals. Additional testing using silver paint resulted in RFI attenuation of 67 dB. Two hydrophones were built and shielded with the silver paint. These hydrophones were tested at the test site and resulted in the attenuation of the RFI signals to a near acceptable level, that is one can reasonably isolate and recognize tag and RFI signals.

Additional attenuation of the undesired RFI signals was gained when the hydrophone cable was inserted in the 19 mm (3/4 in.) conduit and when the signal and power cables were connected inside the inter-connecting box within the junction boxes. Further attenuation was noticed when the front panel of the receiver was cleaned on the inside with steel wool allowing better contact of the front panel to the receiver housing.

The RFI signals at this point had been reduced to an acceptable level and resulted in little, if any, interference with the reception of the tag signals.

ELECTROMAGNETIC INTERFERENCE

The EMI signals were picked up by the signal and power cables and were induced into the receiver at levels high enough to block the reception of the lower level acoustical signals. A common mode interference problem resulted due to these high level signals that required changes to be made in the hydrophone preamplifiers and the receiver. To reduce the common mode interference, a balanced transformer was placed at the receiver input and at the hydrophone preamplifier output. With the addition of the balanced transformers and additional filtering within the preamplifier circuits the EMI problem was reduced to an acceptable level. See Appendix A on electromagnetic testing for additional detailed information.

STABILITY OF EQUIPMENT

The reciever-decoder components were designed to be operated within a controlled temperature environment. Temperature variations of more than a few degrees centigrade will cause variations in the frequency of the local oscillator within the receiver. This oscillator has to be capable of being continuously tuned over a wide frequency range. Crystals could not be used in the receiver unless the tags also contained crystals to maintain a constant frequency at each of the tag frequencies.

The hydrophone preamplifiers were designed to operate over a wide temperature range due to their location within the channels. The operation of the preamplifiers is constant over the temperature range of 0 C to 40 C and over a voltage range of 10 to 18 volts.

TAG LEAKAGE AND AGING

Some problems were experienced with water leaking into the electronics of the tags. The problem was solved by covering the external 2 wires which are used to activate the tag with GE Silicone Rubber Sealant, RTV-102. To minimize aging effects of tags, all units were stored under refrigeration.

ACOUSTIC ATTENUATION PROBLEMS

Serious tag signal attenuation was observed which severely limited the system range. Under some conditions, the range was limited to 3 meters. The problem was caused by vegetation, drifting algae, and, in some cases, bubbles in the vicinity (within a 3 meter area) of the channel inlet. To solve the bubble problem, the area was screened off and the fish were excluded from the inlet area.

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APPENDIX A

ELECTROMAGNETIC FIELD MEASUREMENTS

TEST OBJECTIVES

The objectives of these tests are to determine the design criteria for the instrumentation system with respect to the possibility of interference from the power lines that are located overhead or from the power generators themselves.

TEST SPECIFICATIONS

The electromagnetic fields present at the experimental channels will be measured at various points along the channels in order to establish a profile of the field at the site.

In order to relate the on-site test to a known set of conditions a set of measurements will be made in Virginia on power lines of similar construction and power capacity. By comparing the two sets of data the on-site radiation contributed by the generators may be determined.

A third set of measurements will be made in the Bayshore Systems laboratory area where the fish tanks are located and where the in-house experimental work is undertaken. The level of interference in the lab can then be compared to that at the actual site and establish a bench marker to work from in the design of the instrumentation.

The above mentioned tests are to be conducted in the frequency range of from DC to 50 kHz, with equipment having a sensitivity of 1 microvolt, a sensitivity equal to, or better than, that of the proposed test instrumentation. A search from 50 kHz to 200 kHz will also be made to observe possible spurious signals.

TEST RESULTS

The electromagnetic radiation tests were run at the EPA test channel at the Monticello Nuclear Generating Plant at Monticello, Minnesota on October 5, 1972.

The Monticello test site is 40 miles northwest of Minneapolis on the Mississippi River. The soil condition at the site is that of sandy loam to the channel bottom level. The overall site is flat and 8 to 10 feet above the river level.

Conditions of the test were with heavy fog during the first half of the day and heavy overcast during the afternoon. The temperature was in the high 40's and low 50's. Some water was evident on the ground with surface mud indicating a rainfall earlier in the week.

The power plant was in operation during the test. Two or more pieces of construction equipment were in operation during most of the test. During the noon break of the construction equipment a test was run to establish the effect of the equipment. There was no apparent effect, with the radiation from the power line masking out any of the interference from the construction equipment.

The map in Figure 24 illustrates the positions of each of the tests that were run.

CONCLUSIONS

From the test results, Figures 25 to 37, it is evident that the signal levels present on the site, resulting from power line radiation, is of a magnitude that will cause interference to the fish tracking systems. The tests have indicated that the design of any system instrumentation to be used on this site must be designed for operation in a high noise level environment.

From the various tests that were run, both on site and local, the radiation originates from the power lines rather than from the power generating equipment or the nearby distribution station. This point

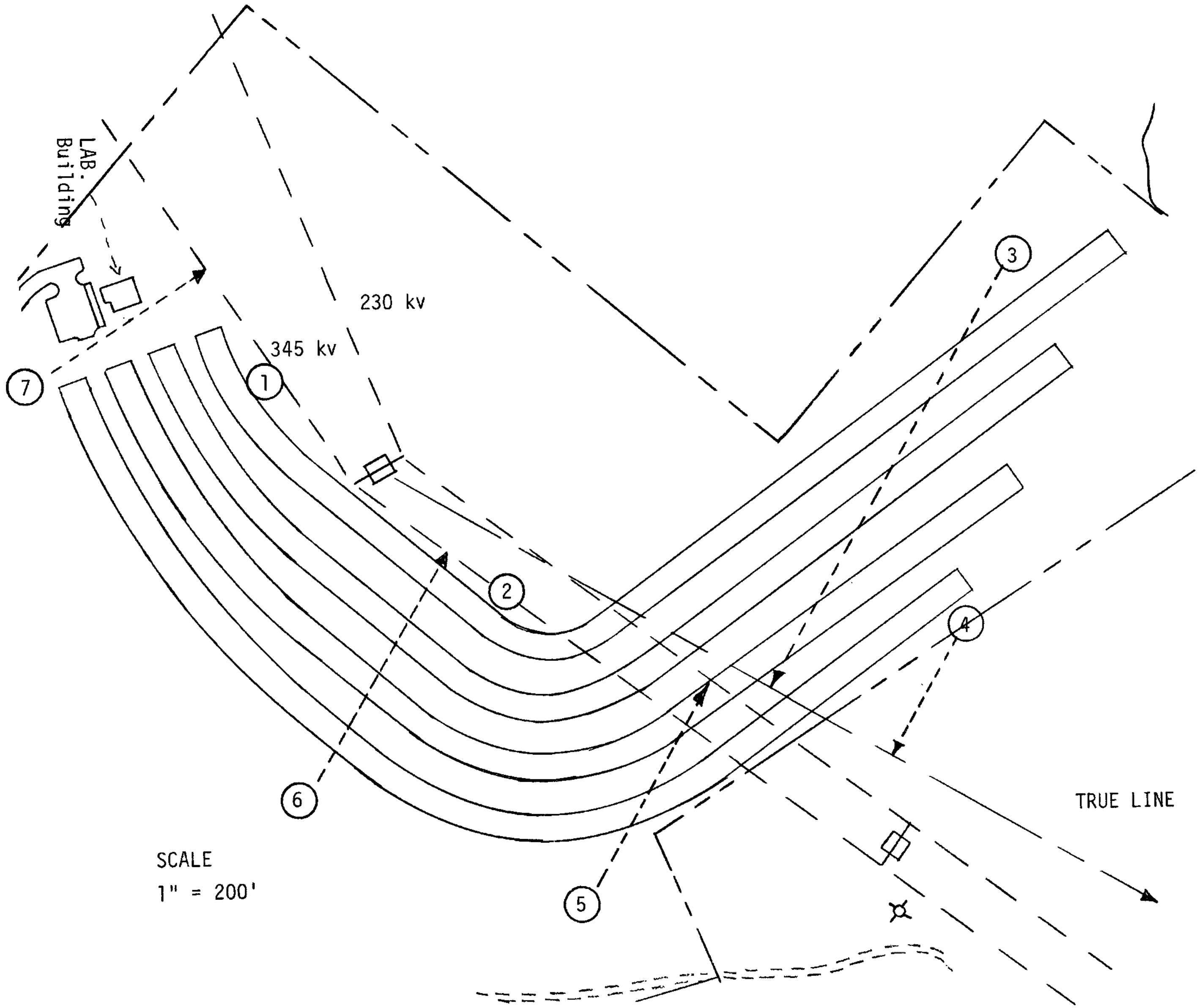


Figure 24. Electromagnetic test sites - Monticello Ecological Research Station channels, Monticello, Minnesota.

TEST LOCATION: MONTICELLO

TEST DATE: 10/5/72

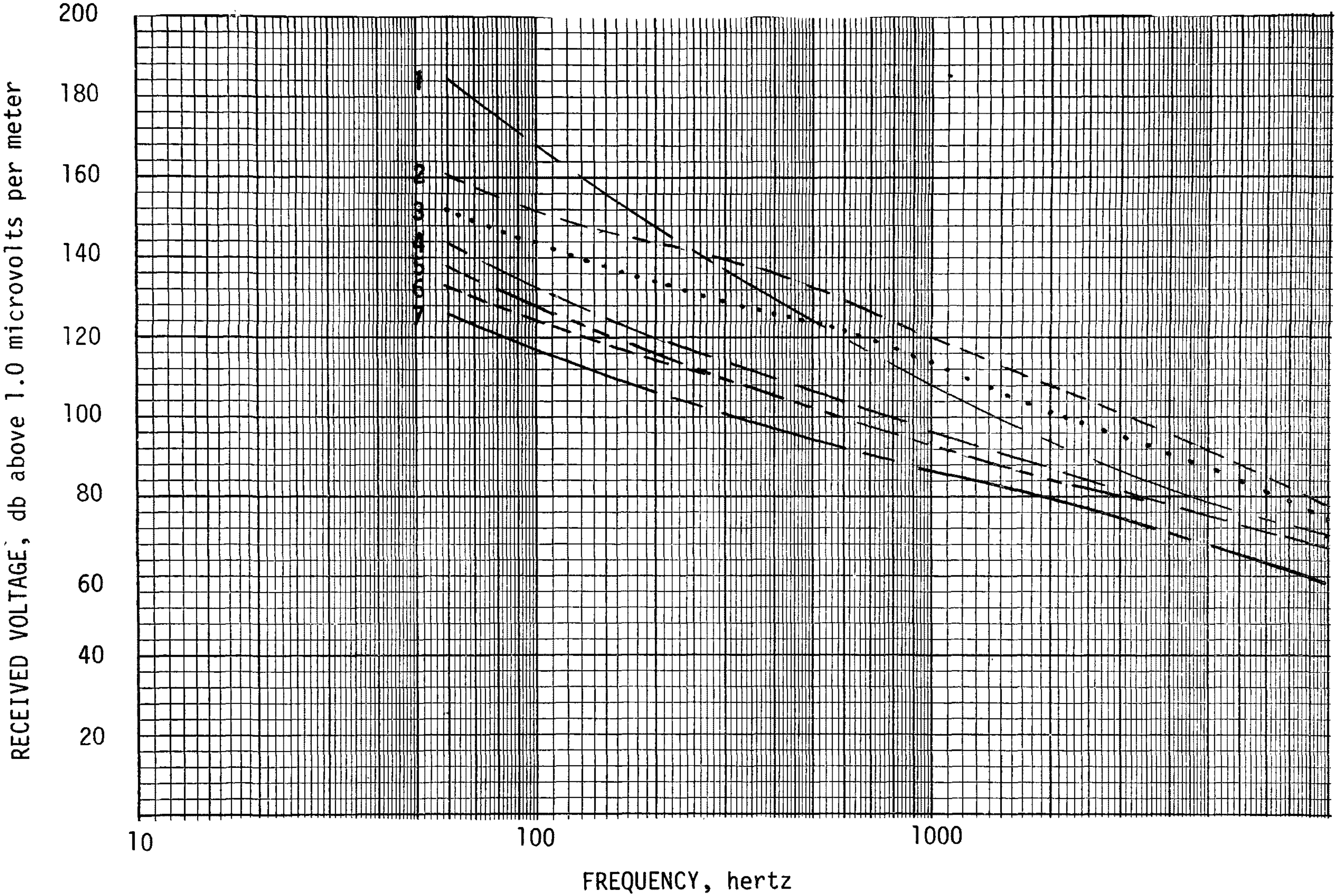


Figure 25. Electromagnetic field measurements - composite tests.

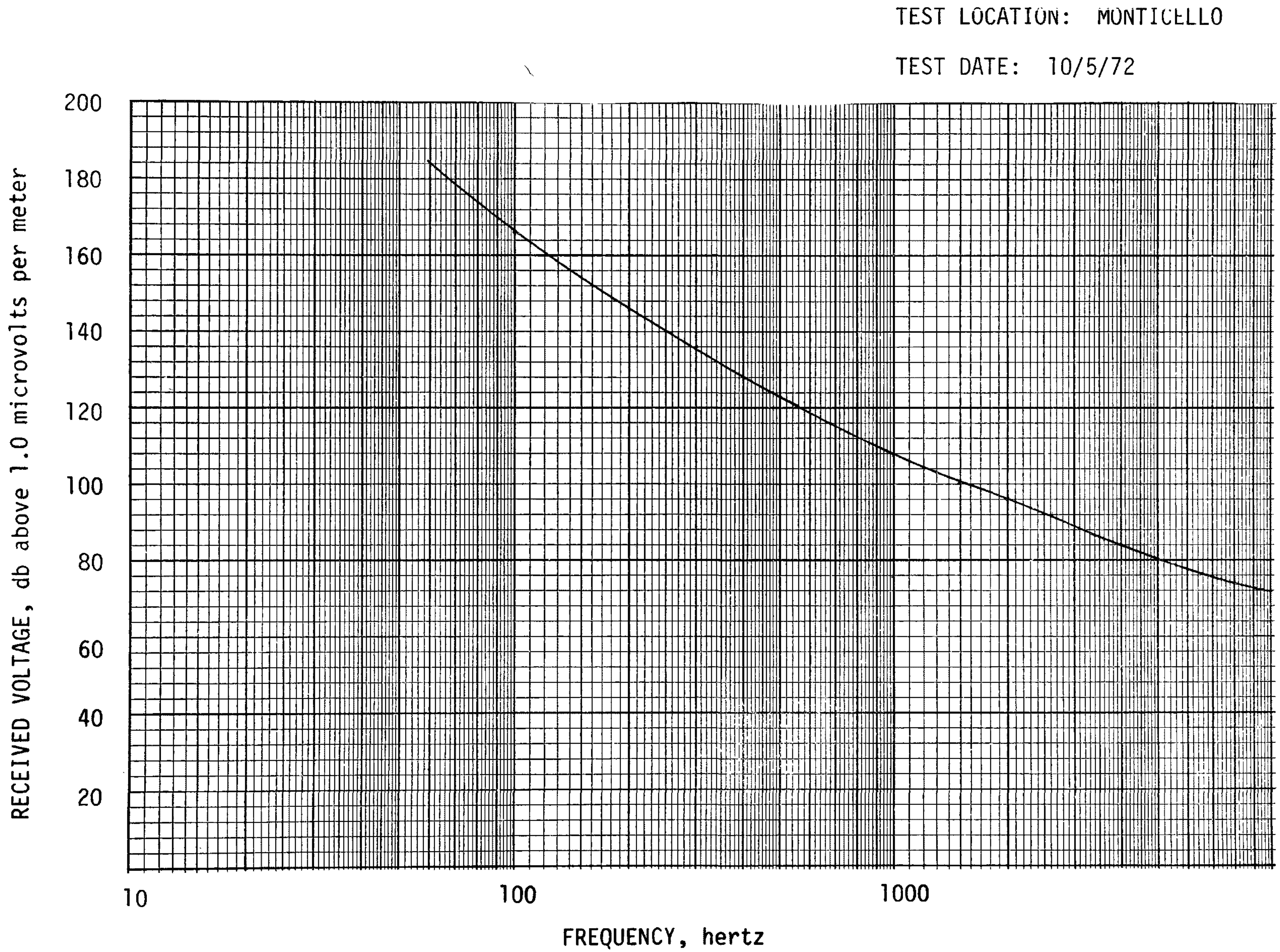


Figure 26. Electromagnetic field measurements - test number 1.

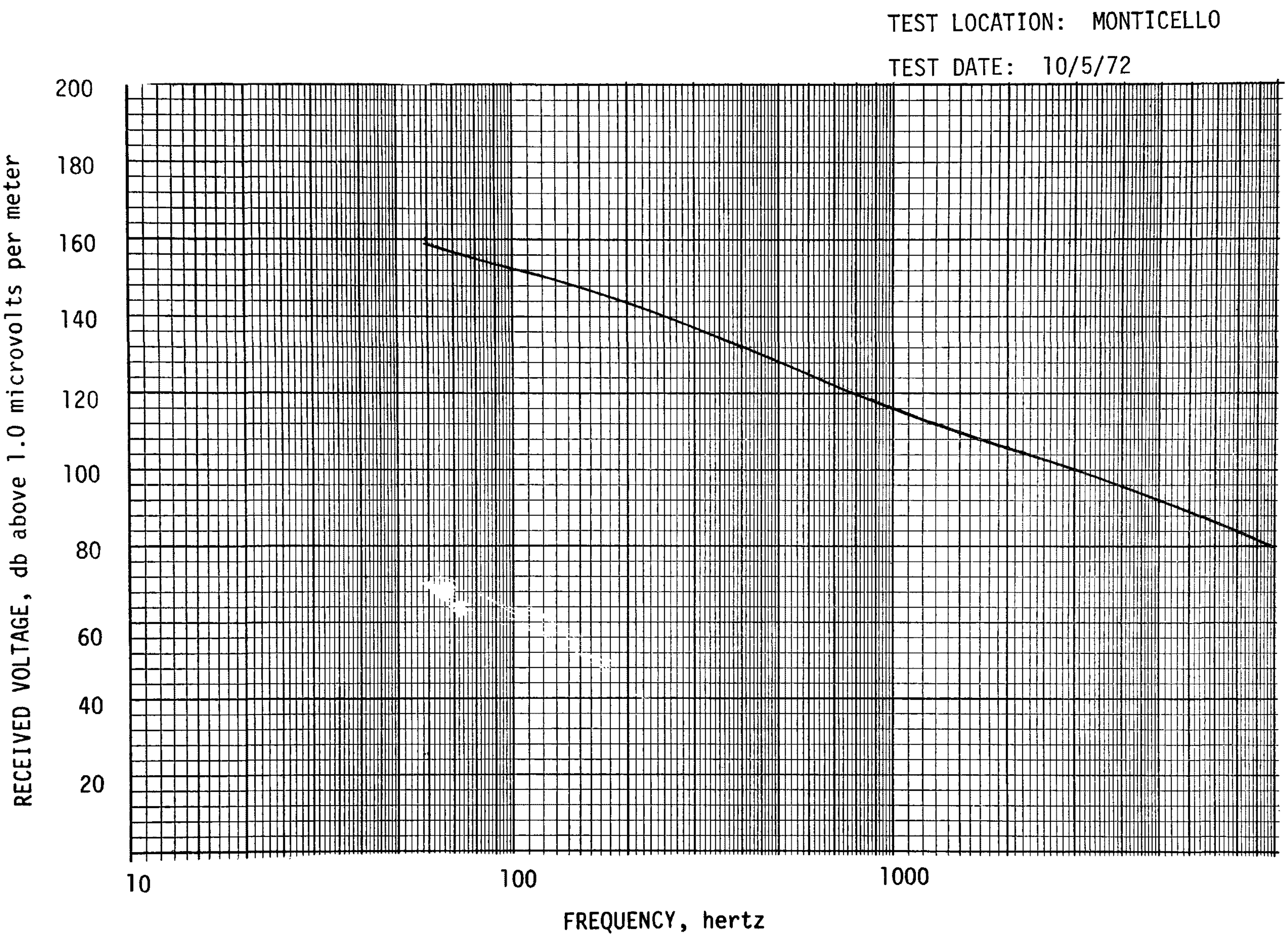


Figure 27. Electromagnetic field measurements - test number 2.

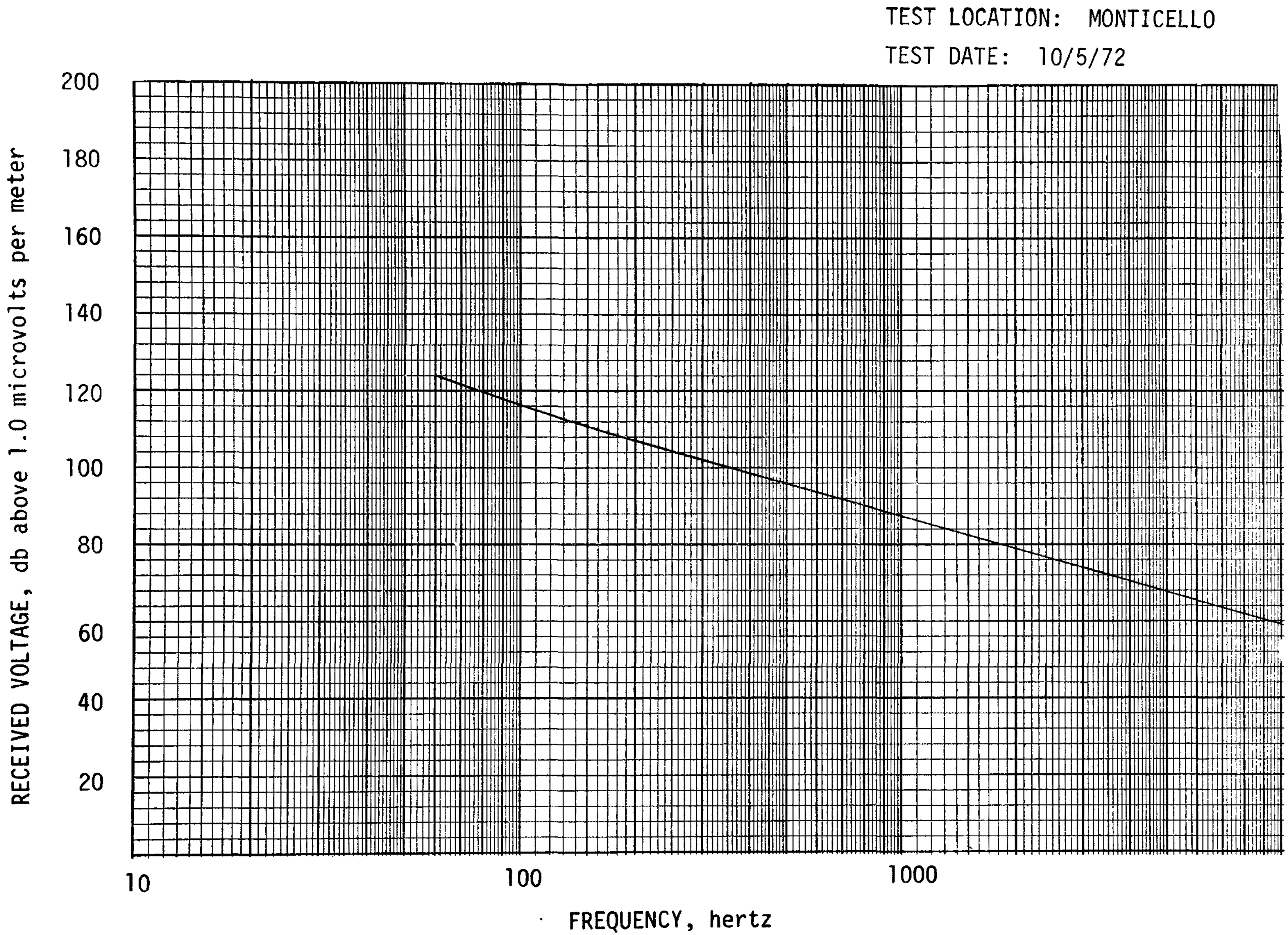


Figure 28. Electromagnetic field measurements - test number 3.

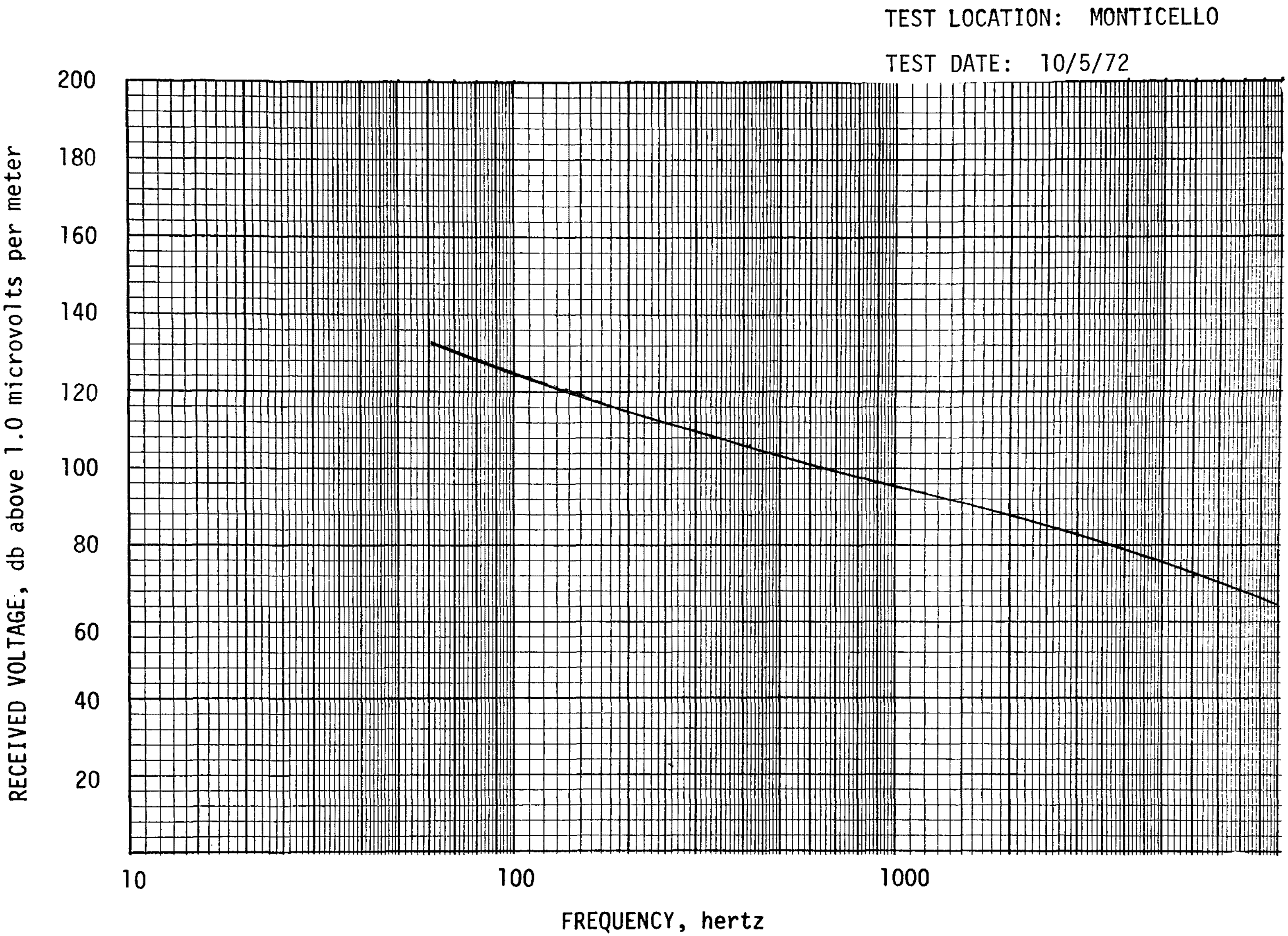


Figure 29. Electromagnetic field measurements - test number 4.

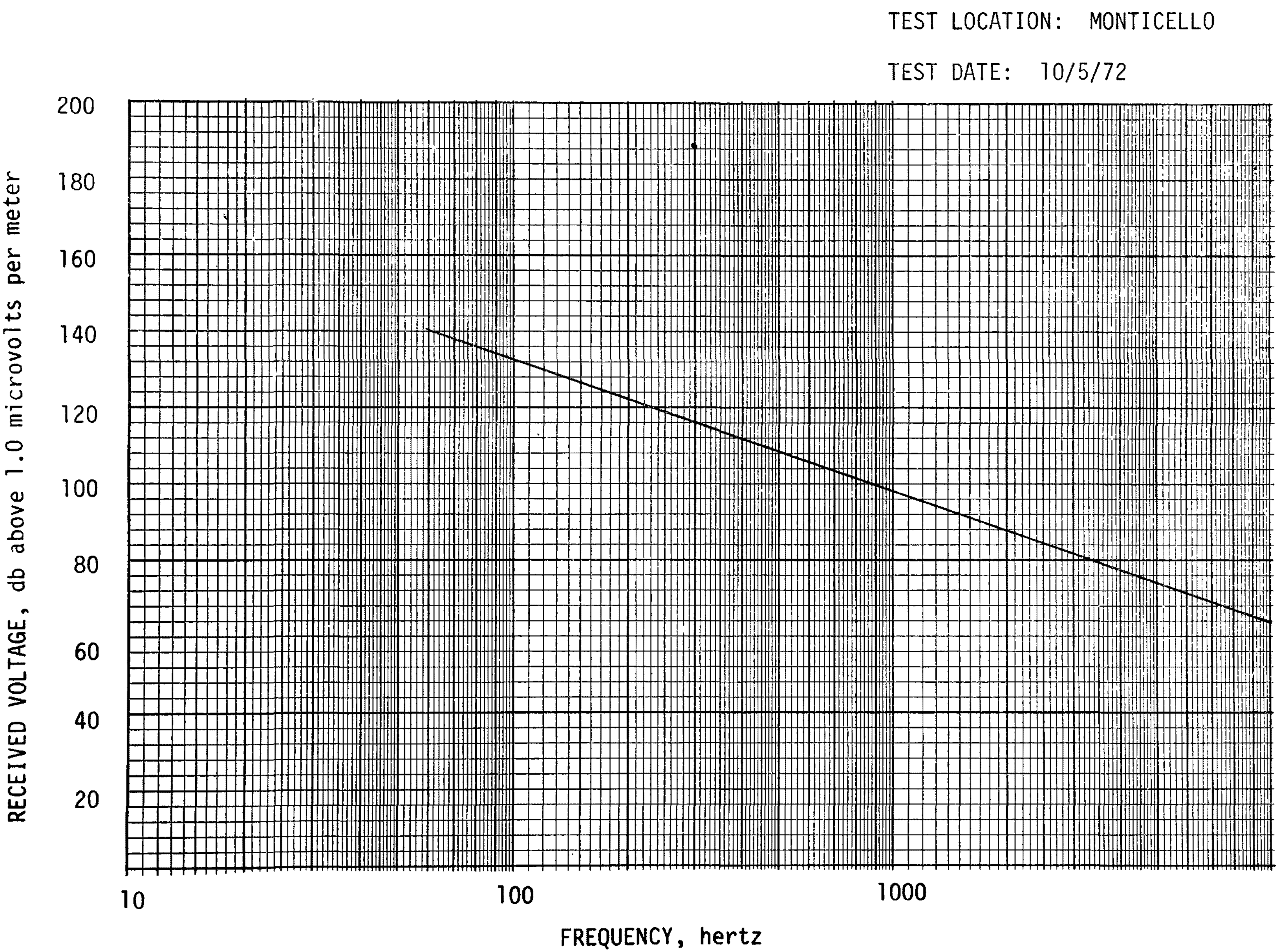


Figure 30. Electromagnetic field measurements - test number 5.

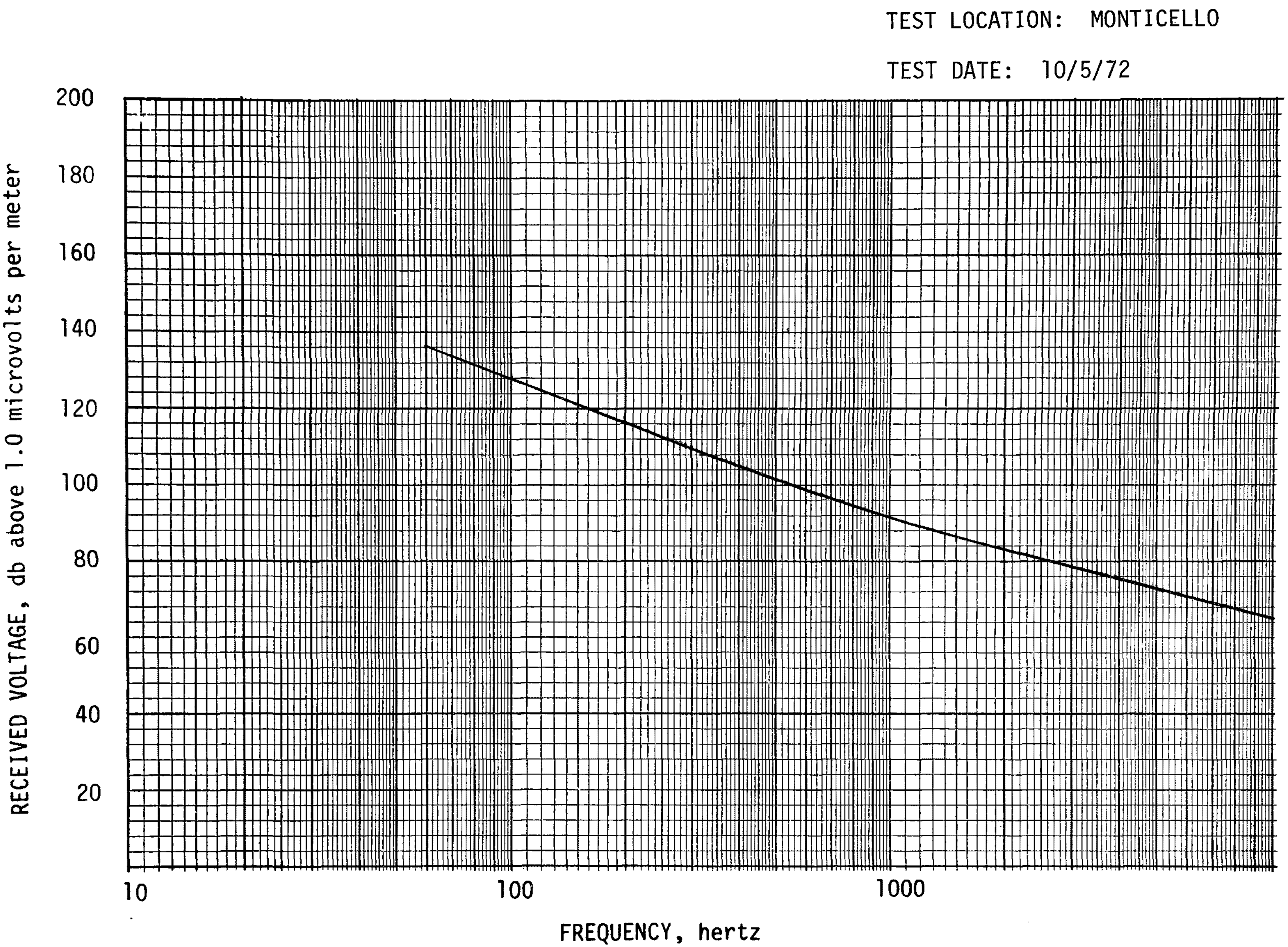


Figure 31. Electromagnetic field measurements - test number 6.

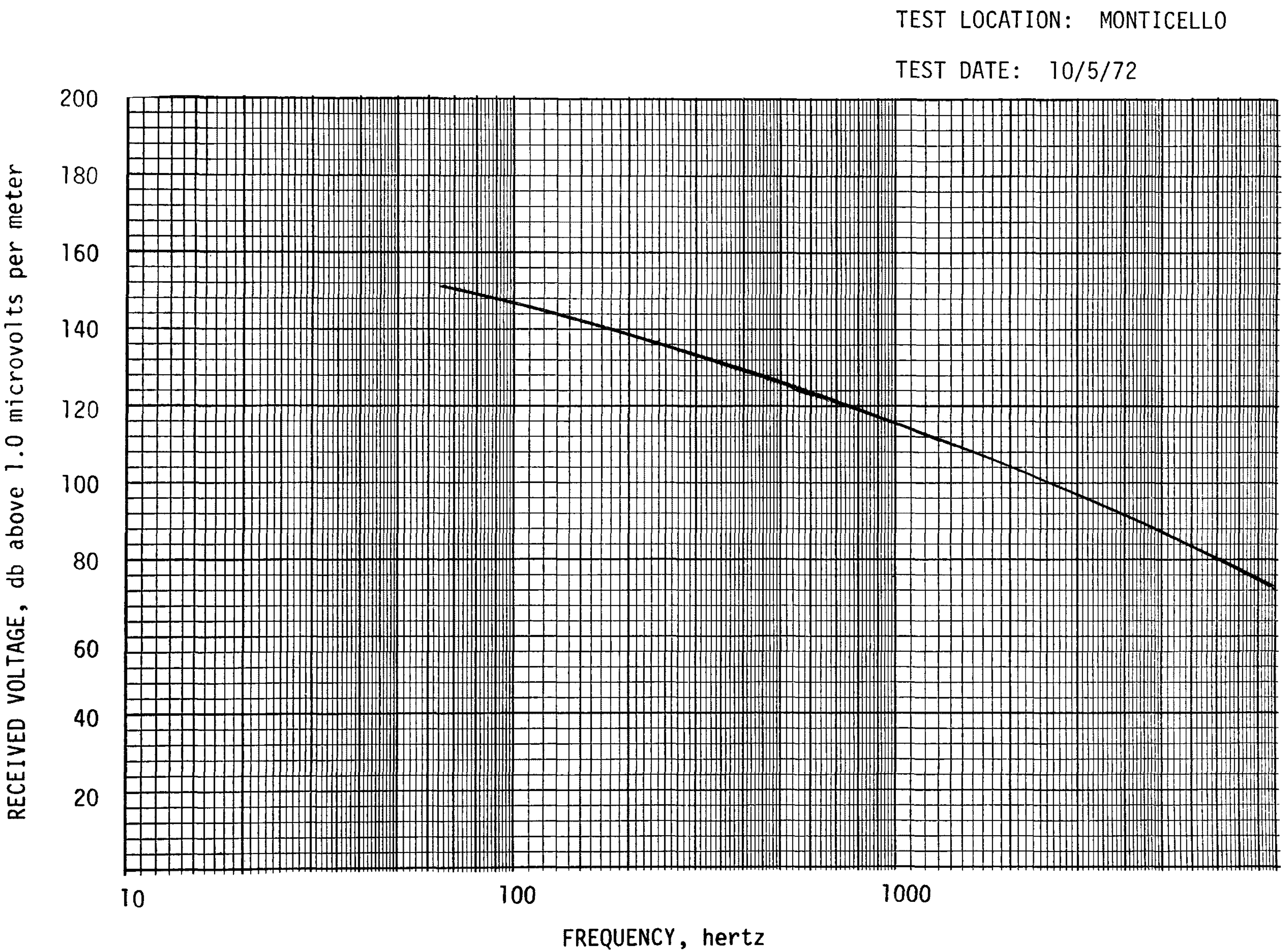


Figure 32. Electromagnetic field measurements - test number 7.

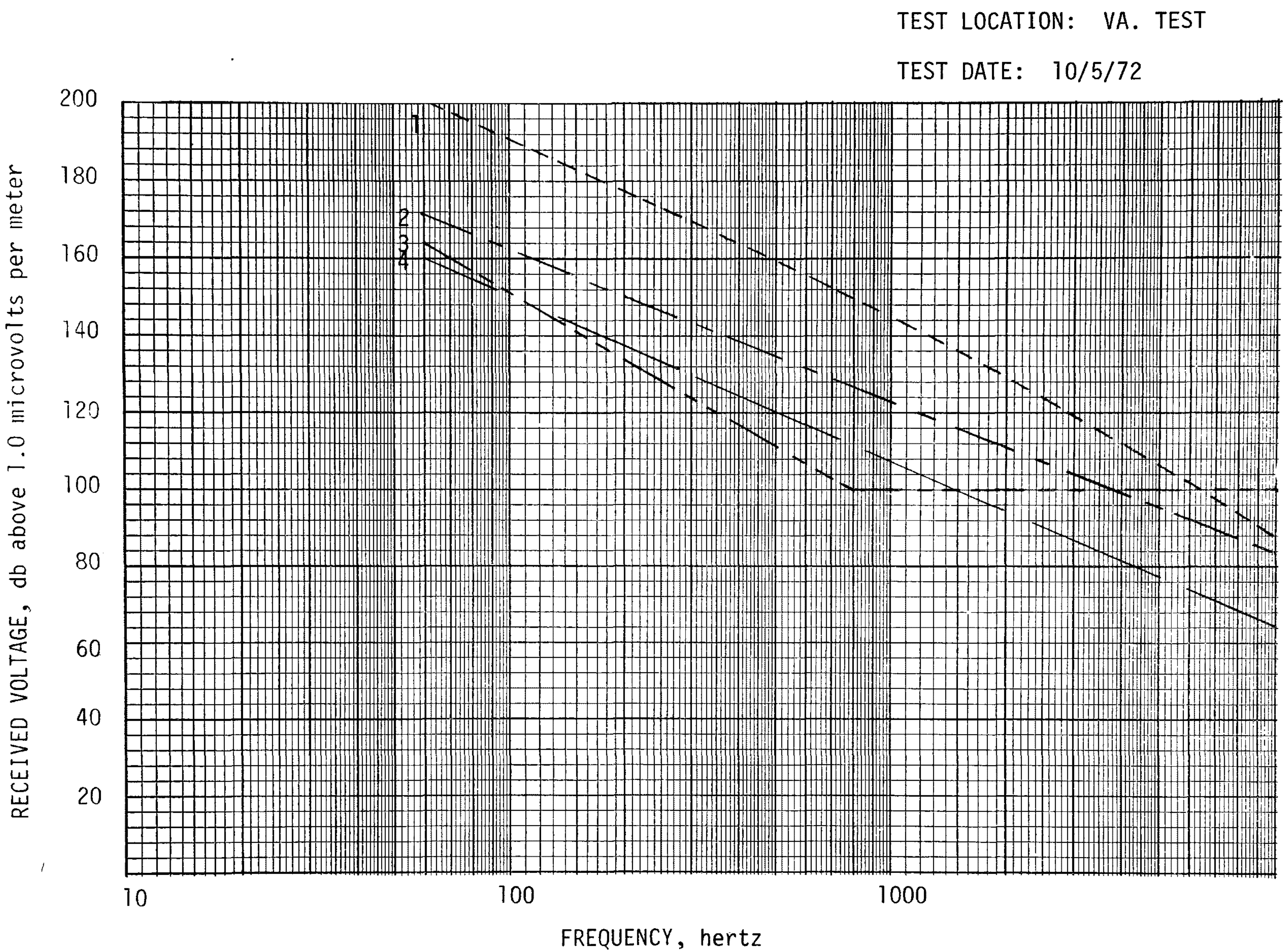


Figure 33. Electromagnetic field measurements - composite tests.

TEST LOCATION: FAUQUIER COUNTY, VIRGINIA

TEST DATE: 9/15/72

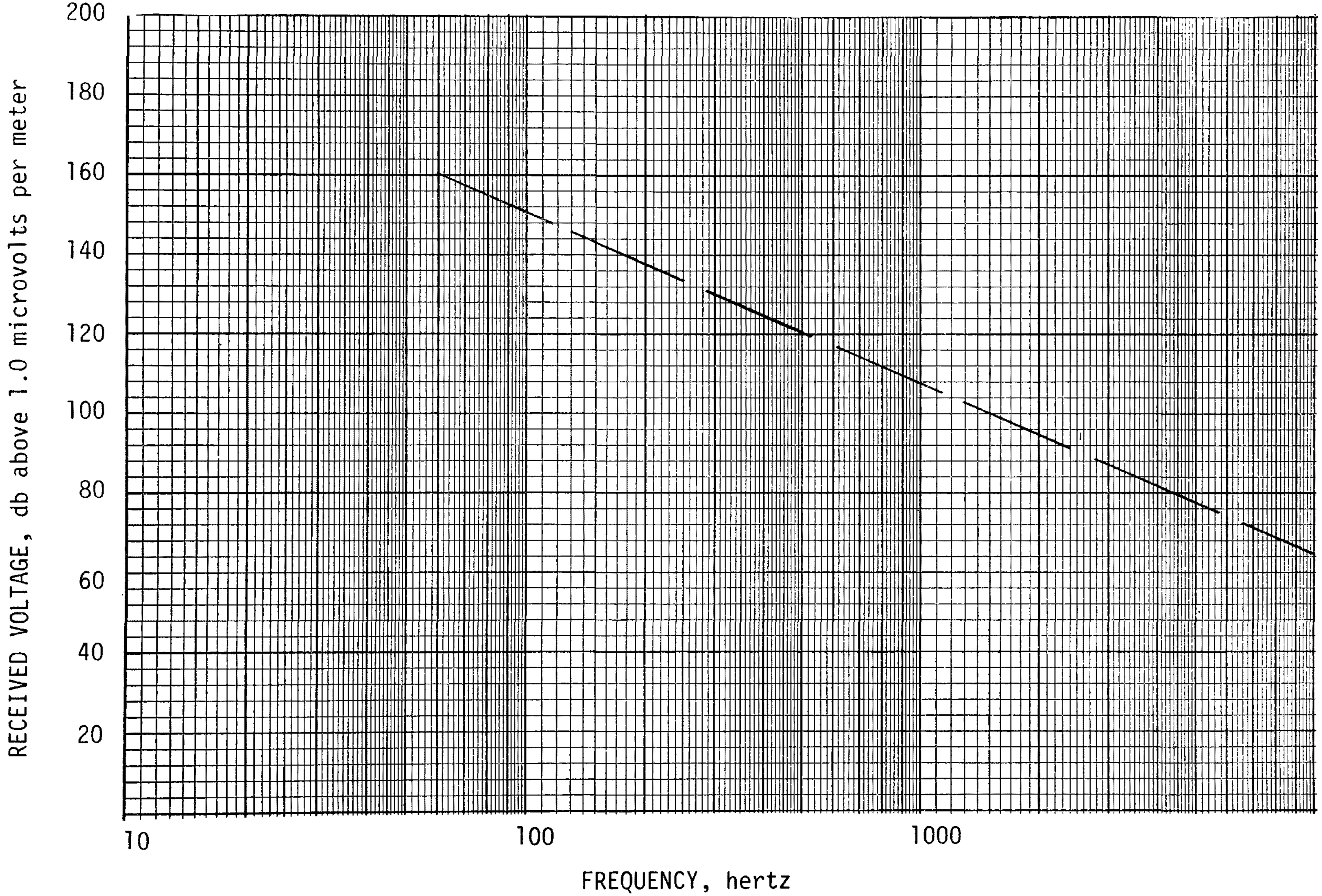


Figure 34. Electromagnetic field measurements - test number 1.

TEST LOCATION: FAUQUIER COUNTY, VIRGINIA

TEST DATE: 9/15/72

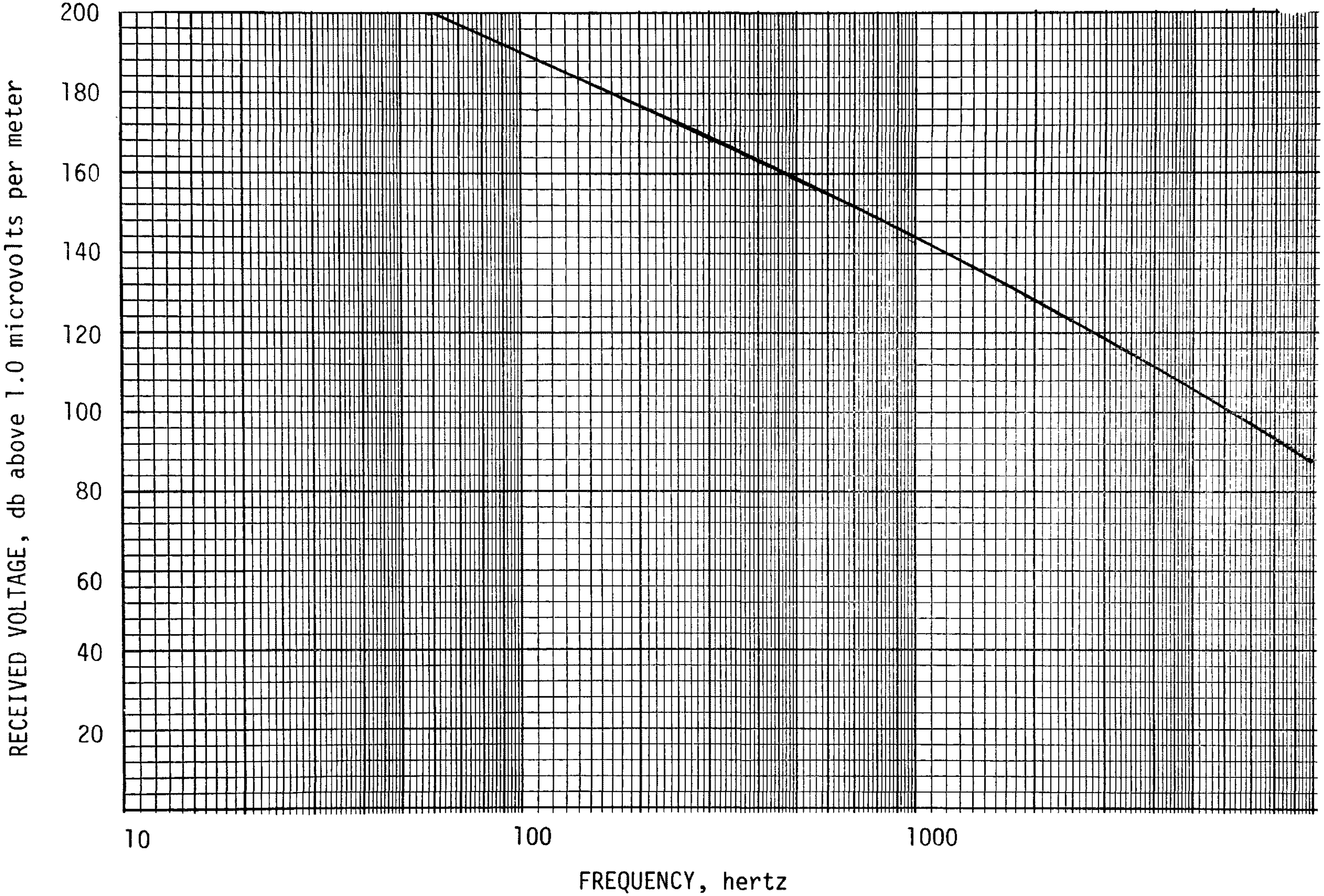


Figure 35. Electromagnetic field measurements - test number 2.

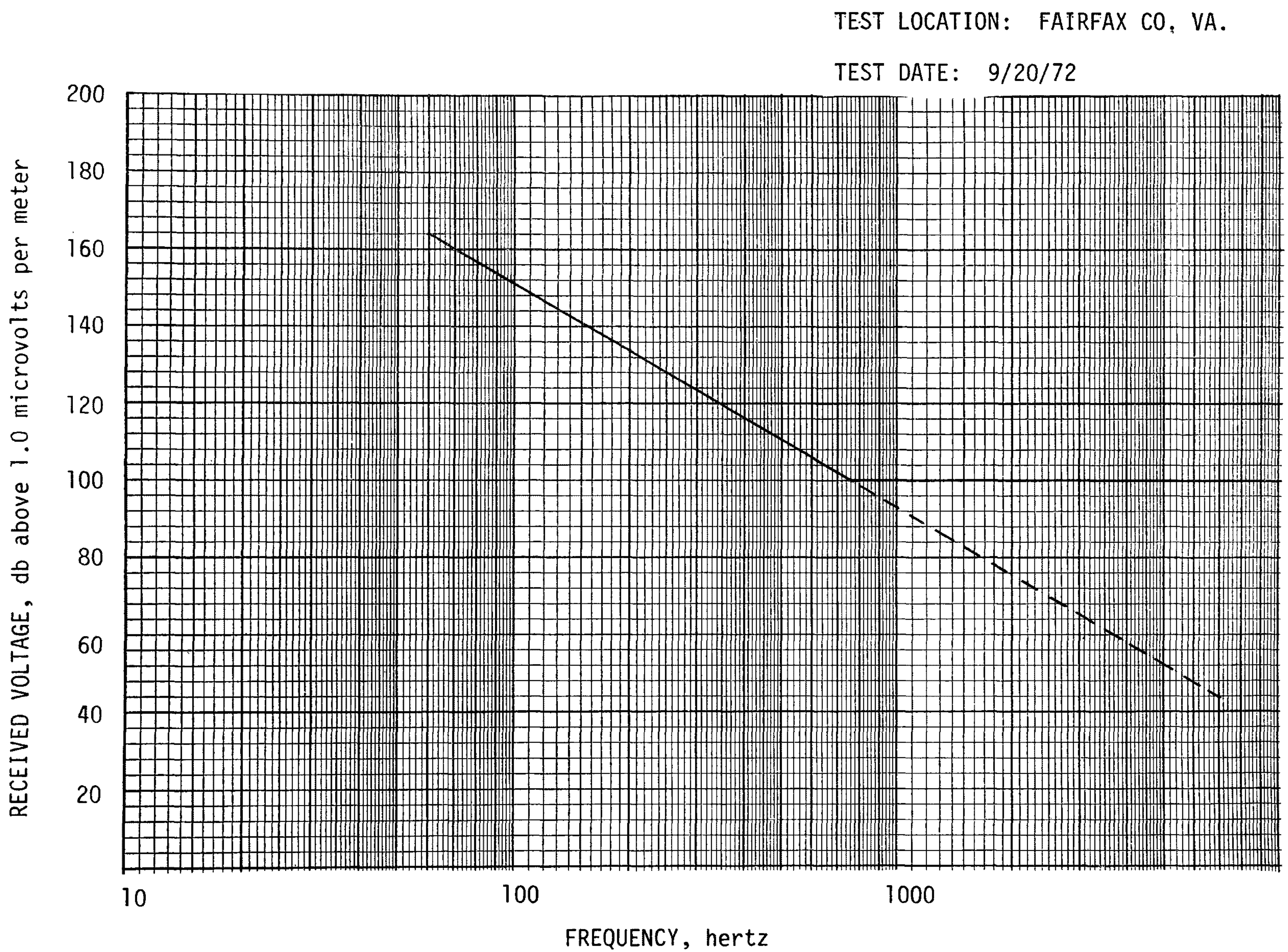


Figure 36. Electromagnetic field measurements - test number 3.

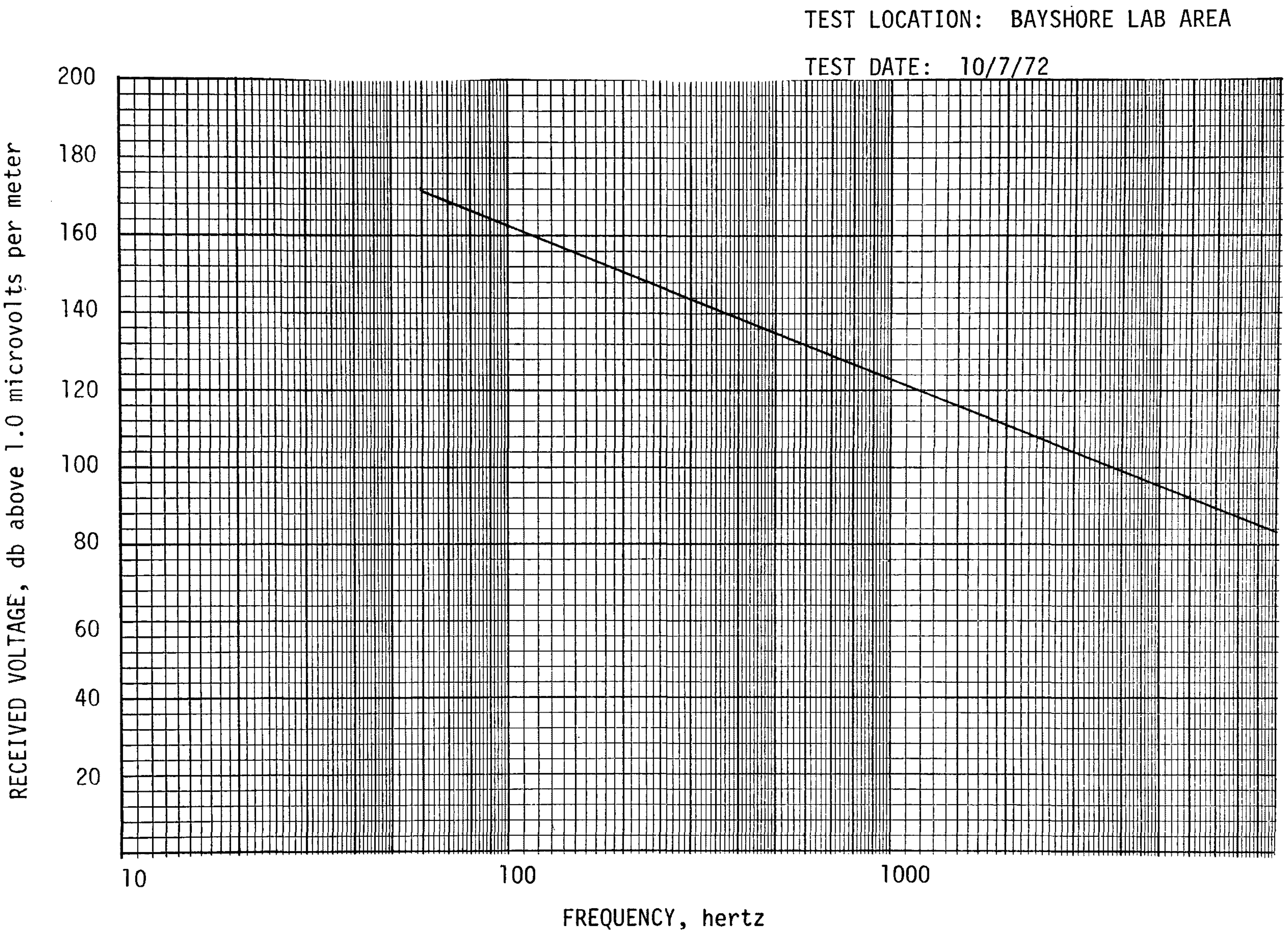


Figure 37. Electromagnetic field measurements - test number 1.

is made obvious when matching the curves from the different test locations.

There are two distinct areas of interference:

1. Those of power lines related frequencies up to about 10 kilohertz generating levels that will interfere with the sensor signals.

2. Above 10 kilohertz there are those carriers that are imposed on the power lines. The carriers are used for the relaying of switching and distribution information by the Northern States Power Company. These signals usually fall in the range from 14 to 50 kHz.
   It should be noted that none of these type of signals were detected. It is anticipated that when the power plant is fully operational their presence will be apparent. Normally, the measured level of the signals are not as high as the power line frequencies but are well above the ambient noise level on site. Since the signals are in the range of the sensor information they are not easily filtered out of the system.

As expected the signal levels vary over the site and are directly related to the distance from the power lines. The area of high test levels are those that are directly under and run parallel to the power lines. Unfortunately the laboratory building itself is set in a high level area.

The most severe problem to face the system designer is the poor ground that is present on the site.

The soil condition at the pond is a fairly high grade of sand, with the top 15 - 25 cm mixed with an organic base. The sandy soil, which showed good drainage characteristics during the test, will not hold moisture to any great extent. This point is also illustrated by the need of an additional sealer on the bottom of the channel to prevent leakage and errosion.

The problem presented by the sand is similar to many instrumentation and communication systems installed on islands or in soil that does not exhibit good ground characteristics. Although ground conductivity tests were not made, a good earth ground should be present at the water table, which in this soil should be at the river level, about 3.0 - 3.7 meters below the surface. This would place the reference ground at about 2.4 meters below the bottom of the pond. In order to maintain a reliable earth/ground the ground plane should be somewhat below this in order to compensate for a shift in the water table. It is conceivable that the ground level may be somewhat higher if there are deposits of minerals. In observing the soil in the channels this does not seem the case.

As stated the sandy soil will present a variable ground condition to the system designer. During or after a rainfall the ground conditions will be good with a low ground resistance. When the soil dries out, the ground resistance becomes higher, the sand becomes an insulator and the so-called ground is now above the earth/ground reference and a resistance is presented between the instrumentation and the ground reference.

The sketch in Figure 38 illustrates the channel in the sand base and the ground resistance (Rg). As shown, the channel when full of water is a rather large, long electrical conductor.

As shown in the site plan the four channels are located parallel to a power line for a distance of about 183 meters. The four channels are spaced out from the power lines to a distance of about 45.7 meters (150 feet).

As shown in Figure 39, the channels act as four isolated conductors spaced progressively away from the 345KV power line. The channels, like any other conductor under the same conditions, will act as the secondary of a transformer with a voltage generated in the channels due to the coupling to the power lines. Where the instrumentation lines are run above electrical ground, a voltage will also be induced into the conductors. A greater problem will exist where a sensor is "grounded"

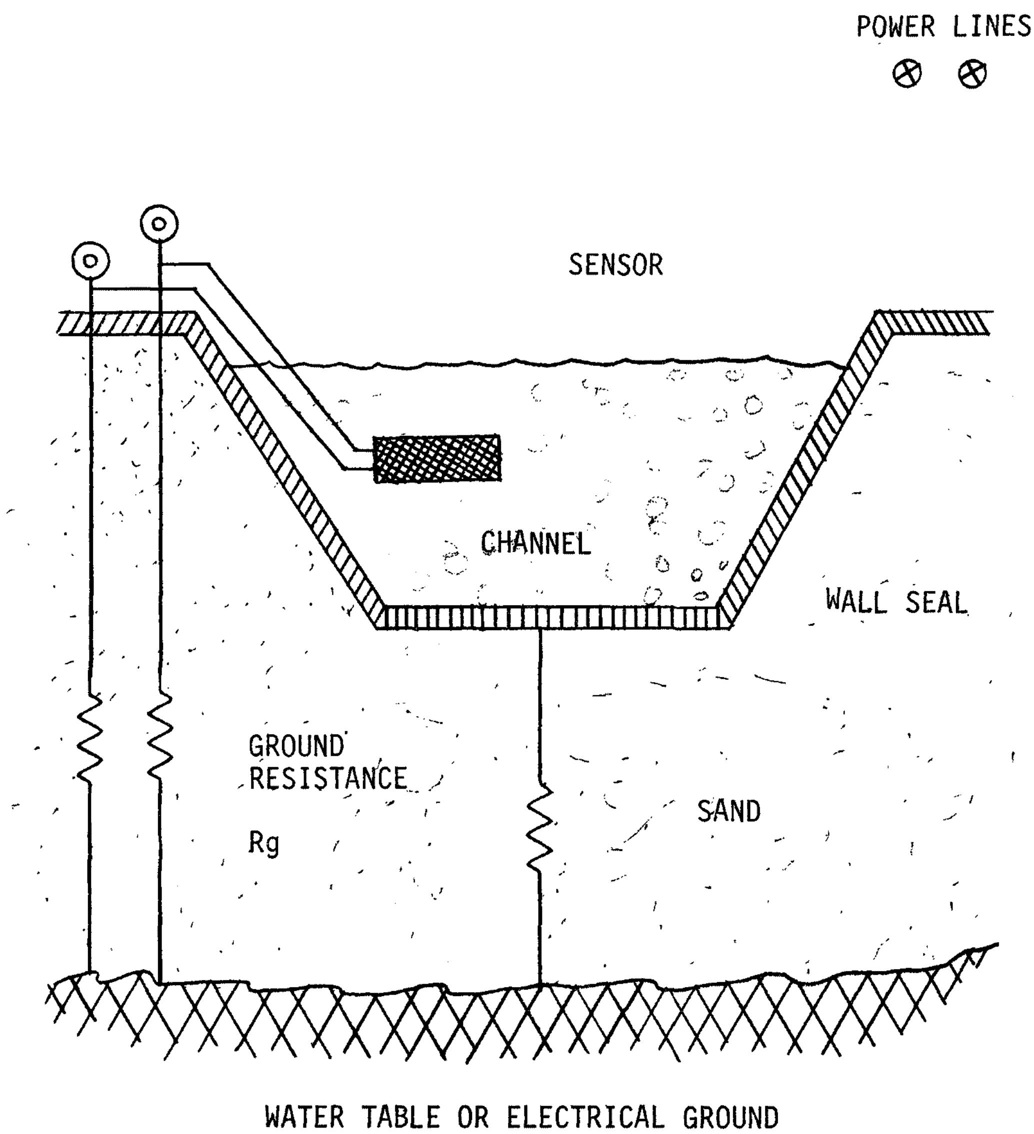


Figure 38. Ground conditions at the Monticello Ecological Research Station.

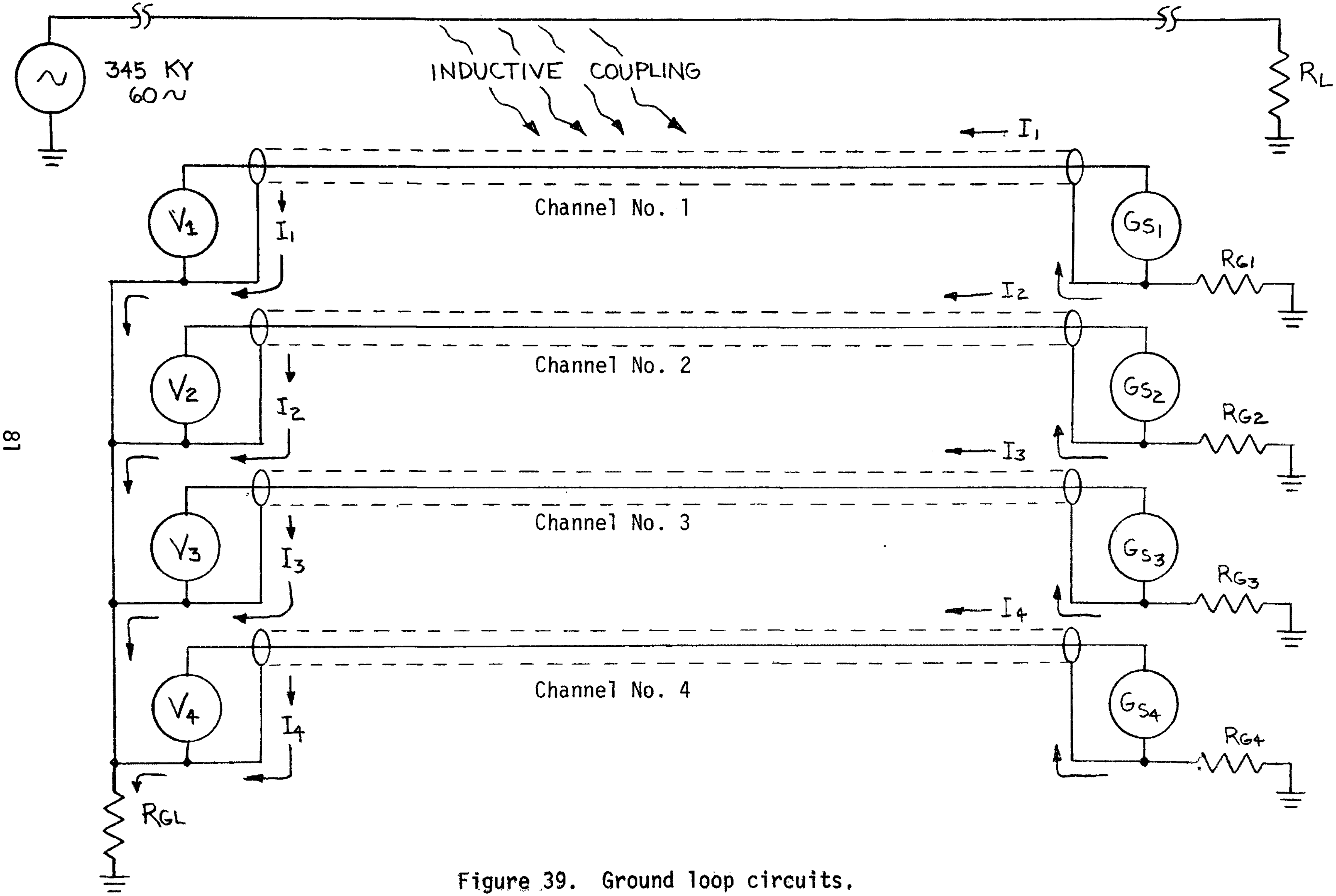


Figure 39. Ground loop circuits.

at the channel but will actually conduct the channel voltage (V_p) back to the instrumentation at the laboratory.

Figure 40, illustrates the methods in which the various interferring voltages are introduced into the system. There are sources of interferring voltage on both the sensor end and the load end of the system. On the sensor end a voltage is generated when the induced current from the shield flows through the ground resistance (Rg) with a voltage drop I Rg. An addition to the ground loss is the voltage developed from the signal current in the sensor. Since the two generators are in series both of the voltages will be present on the center conductor of the line. In the case of the channels nearest the power lines, the voltage induced may be greater than the voltage generated by the sensor. The induced voltage (or noise) from the power line may be of such a magnitude that makes the detection of the sensor signal impossible. Some relief from the ground loop may be had by using twin conductor cables with a floating ground (common) to the sensor. Using the two conductor cables will keep the line induced signal off the signal line but will not protect against the noise from being induced on the shield, and conducted back to the load end.

On the load end there are two possible sources of ground loop voltages. One of the sources is the same as in the sensor end where the loop voltage is developed across the ground resistance which is in series with the load. Again, like the sensor this condition may be relieved if two conductor cable are used. If the two conductor cable or balanced system is used then some type of transformer or other balanced type of transducer input circuitry must be used such as differential amplifiers. In the case of the balanced input the ground loop components will be dependent upon the balance of the system, at best the ability to hold balance is not better than about 0.1%. In the differential amplifiers or op amps this is referred to as common mode rejection.

Another problem associated with a poor ground system is cross talk that is generated by the common sensor signal currents flowing

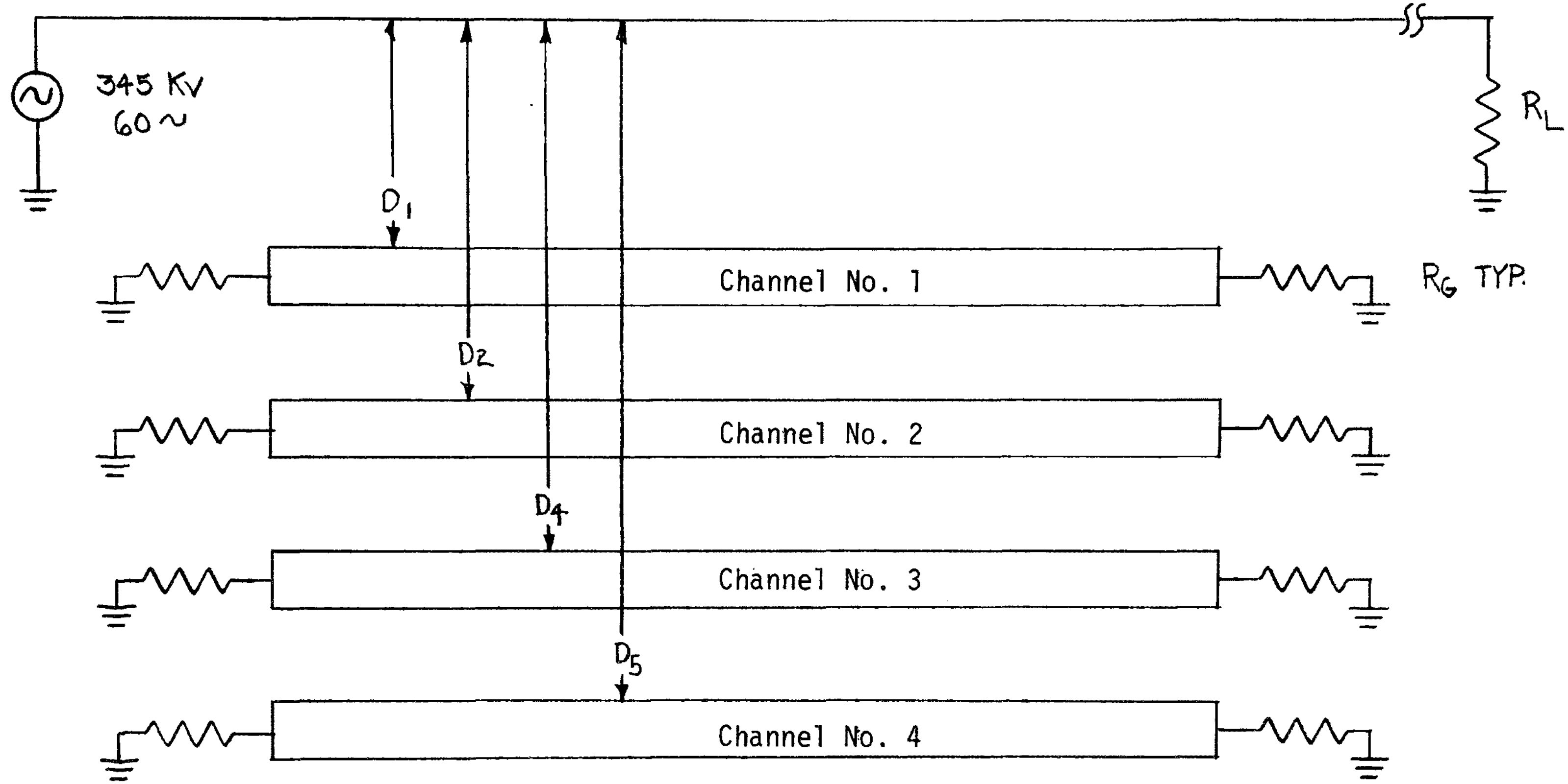


Figure 40. Induction coupling into pool conductor.

through a common ground resistance. In this case a portion of each of the sensors will show up at the input of every other sensor load. This means that in every channel there will be the desired signal and three undesired signals at various levels. In some cases this can drastically reduce the value of the received information causing a low signal/noise ratio.

A serious problem can also arise from a poor ground with lightning or similar phenomena. With the channels setting above ground it is conceivable that the channel could build up a high potential through the various discharge phenomena. For this reason alone the channels should be well grounded, in the same way that a building or other structure is grounded.

RECOMMENDATIONS

As a result of the test the following recommendations are made:

a. Receiver Sensitivity:
The sensor receiver sensitivity should be maintained as high as possible (insensitivity) while retaining the necessary system performance. A receiver with high sensitivity will be prone to over load (blocking) and generation of intermodulation products and spurious outputs.

b. Frequency Selection:
The operating frequencies of the system should be maintained as high as possible while retaining the other performance factors. By all means the operating frequency should be above 50 kHz.

c. Signal Levels:
The signal level present in all areas of the system must be maintained at a relatively high level with high signal to noise ratios. The use of local preamplifiers

c. Signal Levels: (Continued)
at the output of the sensors and intermediate amplifiers along the line is recommended.

d. Shielding:
Shielded two conductor cables should be used for all signal lines. In addition to the braided shield on the cable, the cables should be routed through conduit. The conduit should be of a type affording magnetic shielding (cold rolled or drawn steel). At all joints the conduit should be bonded with straps or welded. Each of the sensor inputs should be terminated in a shielded box. The termination boxes should be located along the line and like the conduit should be well bonded to the conduit itself. In addition to the shielding capability the boxes should be weatherproof.

e. Filtering:
High pass filters will have to be incorporated into the design of the sensor and the receiver. The cutoff of the filters should be as close to the operating frequency as possible, preferably near 50 kHz. The filters at the sensor end of the system may have to reject the line frequencies as much as 40 to 50 dB which will require 5 or 6 section filter.

f. Earth/Ground:
The grounding problem that is present on the site must be surmounted. The twin conductor will help. For the purpose of instrumentation the channel should be paired, the lines running up the dike between the channels or ponds. By pairing, a common ground can be established for the ponds. A series of ground rods must be driven into the dikes to a level that will provide

f. Earth/Ground: (Continued)

a good ground system. At this time it is not known to what depth or at what intervals the rod will be set. An estimate would be that the rods should be driven not less than 3.7 meters (12-feet) deep and should be spaced every 15.2 meters (50-feet) along the line or at each of the junction boxes. At best this will require a great number of ground rods to be installed. The rods should be one inch in diameter and made of copper clad steel. The junction boxes should be bonded to the rod or better yet mounted on the rods themselves.

APPENDIX B

INVESTIGATION OF INDUCTIVELY COUPLED CIRCUITS FOR USE IN FISH TAGS

Magnetically coupled transmitters and receivers are not new[1]. Contemporary portable broadcast receivers use a Ferrite antenna rod which uniquely responds to the magnetic field of electromagnetic radiation. As shown in Figure 41, a typical vertical antenna radiates electric flux lines vertically with closed horizontal magnetic flux lines. Hence, the electrical line is vertical and at right angles to the magnetic lines. Since magnetic lines generate an electromagnetic field when they cut electrical conductors, a multi-turned inductor resonant at the transmitted signal generates voltage at points a and b. The unique sensitivity of the inductor to the magnetic field alone, causes the broadcast portable receiver to be directional. Maximum signal is received when the Ferrite rod is orthogonal to the radius line from the transmitter and minimum when the end of the rod is pointed at the station.

The expression for E_i, the induced electromagnetic field (emf) is:

$$E_i = wn\,HA\sqrt{M_r} = n\,d\phi/dt$$

(The generator equation)

where H = received magnetic field intensity,
A = cross sectional area of the rod,
M_r = effective rod permeability,

The actual output voltage is a function of the electrical loss parameters of the tuned circuit. "Q" is used to express these losses. Generally, "Q" is expressed as a bandwidth function, that is $f/\Delta f$. But Δf is actually constrained due to the losses. In an air core coil these losses are due to fringe effects, parasitic capacitances and leakage

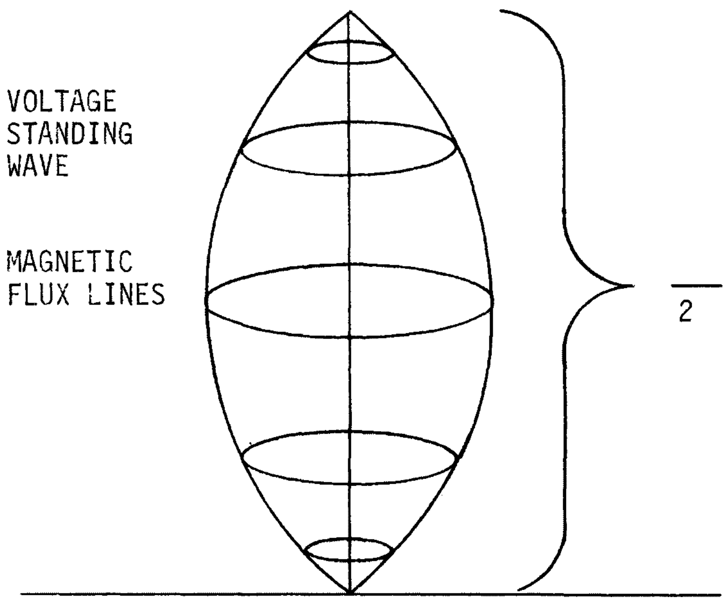


Figure 41. Electric and magnetic fields around a half wave vertical antenna.

flux. For a cored inductor the fringe effects, parasitic capacitances, eddy losses and frequency constraints (loss tangents) of the core material are the significant loss factors. Leakage flux is significant in the reduction of "Q" in air core inductors and certain ferrites reduce this leakage and thereby, significantly increase the "Q".

Therefore, the significant requirements for a miniaturized induction link system may be generalized. First, it should be noted that the general electromagnetic radiation equation show the electromagnetic field radiation is reduced as the inverse of the distance squared ($1/r^2$), and the induction, or near field, falls off as the inverse of the cube of the distance ($1/r^3$) for distances greater than 10 coil diameters. The range of the induction field communication is limited then to very short distances. The exact distances are ultimately dependent of the size of the transmitter and receiver inductance loops, although specific coil parameters seriously affect the received signal strength. The coil parameters must be developed empirically, and the range must be experimentally determined. For these reasons, it is extremely difficult to calculate many of the performance characteristics. Hence, when the receiving loop size is constrained, various inductors must be made within these constraints and measured electrically. From these data trends may be shown, trends which lead to the final design figures. Such data are described in the next section.

EXPERIMENTAL DATA

Several experiments conducted to evaluate the qualities of solonoid inductors are discussed in the following section. For these inductors, selected core materials representing optimal choices from off-the-shelf components were used. Various sizes of litz wire were used. These results are shown in Figures 42, 43, and 44. Once having tabulated the basic properties of these inductors with regard to core material, core size, wire and inductance, further tests evaluting their performance as receiver and transmitters were conducted. The data shown in these curves evaluate the "Q" against frequency for Indiana General's Q-1 and H material. The

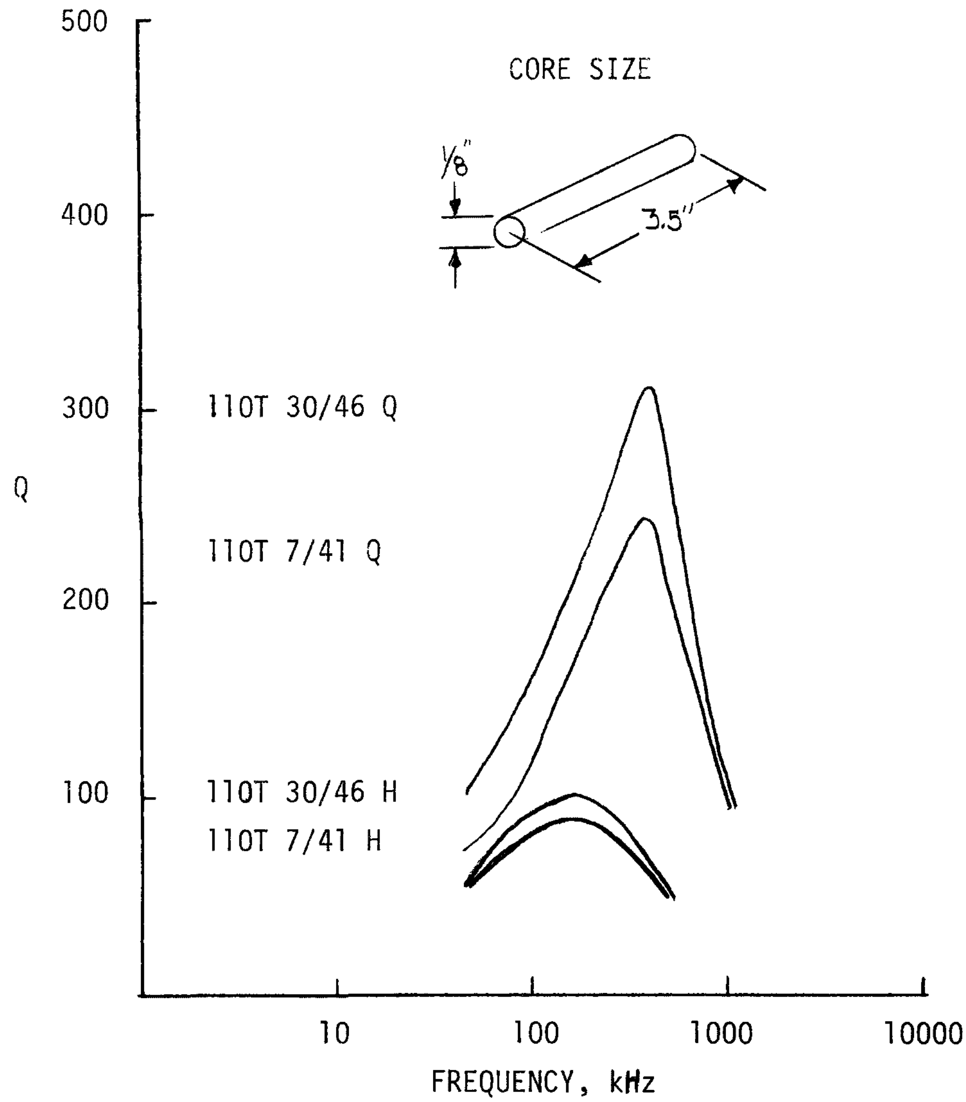


Figure 42. Variations of Q against frequency for various litz wound solonoid inductors. Core size as shown.

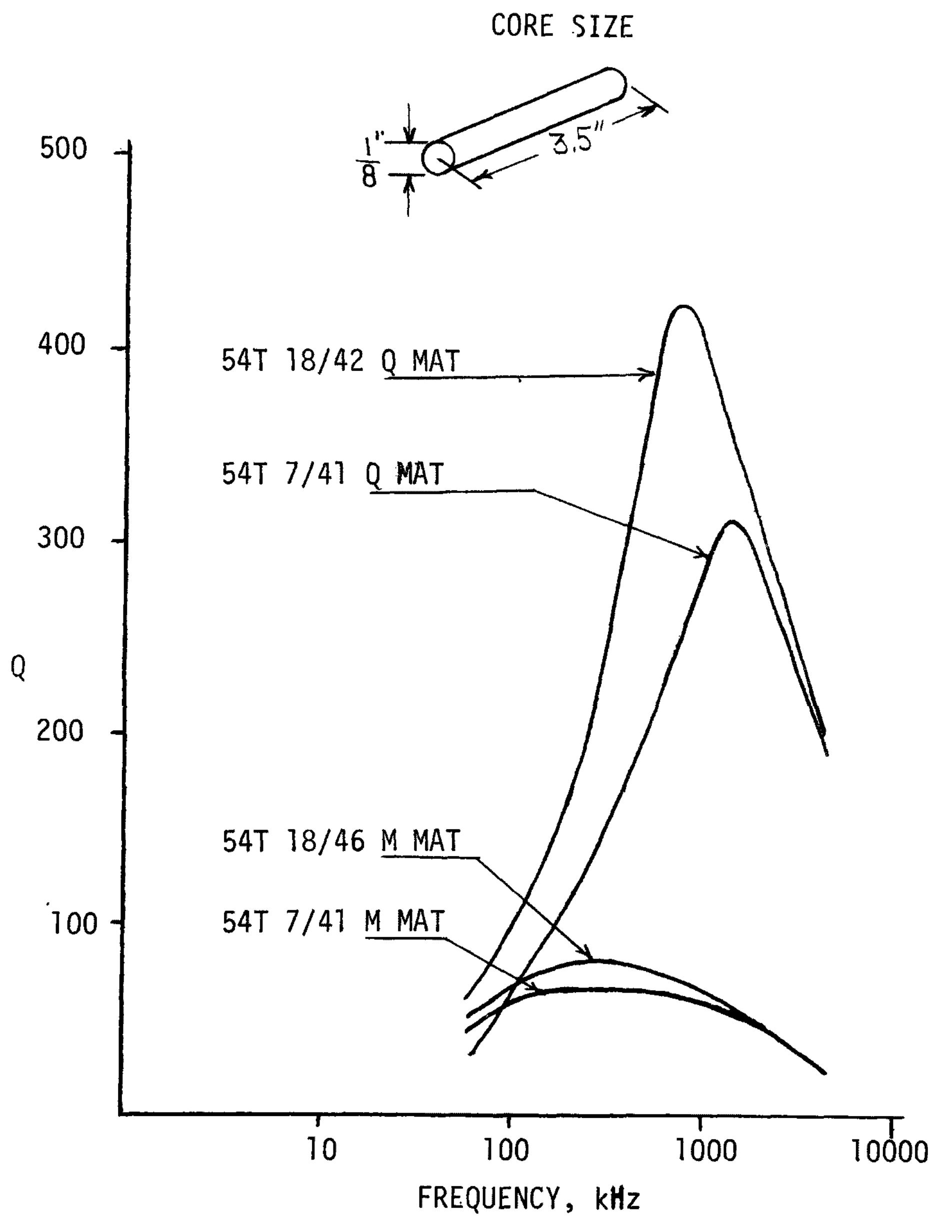


Figure 43. Variations of Q against frequency for various litz wound solonoid inductors. Core size as shown.

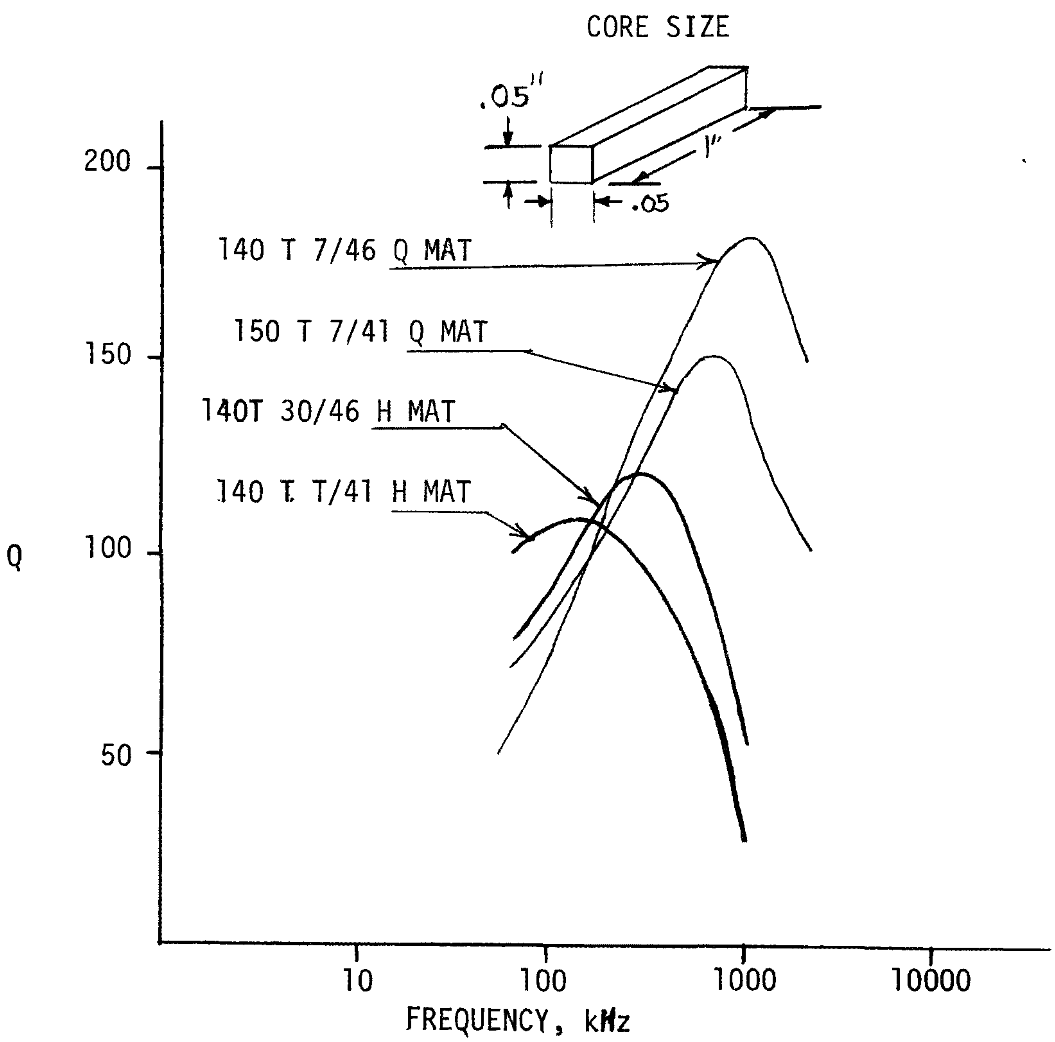


Figure 44. Variations of Q against frequency for various litz wound solonoid inductors. Core shape and size as shown.

litz wire size is shown. Since the highest output voltage is a function of figure of merit "Q", then the higher "Q" values are desirable. Note that "Q" is variable with material, number of windings, and wire type. "Q" peaking is at various frequencies and is possible through judicious selection of core material and wire type. "Q" was measured with a Boonton Model 260 A Q-meter. It should be noted that the Boonton "Q" meter measures "Q" with 8 ma. rms through the inductor at a scale multiplication of 1. It does not measure the actual "Q" at low signal levels such as would be experienced when the inductors are used in receiving systems as antennas. In these cases, performance can only be measured and, in general, curves are a good rational fit with the "Q" data.

For the actual use data, the test setup in Figure 45 was used for the accompanying data in both Figure 46 and Figure 47. Power into the transmitting inductor is provided by a current source with a maximum output voltage of 25 volts rms. Since litz wire is not easily available in larger sizes, some data is shown which obviously conceals some of the I^2R losses in the transmitter inductance. Additional data for higher powered sources was obtained by using a larger solid copper wire. The "Q" of the transmitter coil is not especially important. Lower "Q" coils merely require more voltage to drive the same amount of current as would be obtained by a higher "Q" coil. This does not affect transmitter efficiency, an efficiency which is not important for these tests. As stated before, a high "Q" for the receiver inductor is essential as the signal varies directly as the "Q".

EXTERNALLY POWERED AND EXTERNALLY TRIGGERED TAGS

To externally power or trigger a tag requires adequate energy to be transmitted to the tag receiver to either be rectified and hence provide power to the tag, Figure 48; or to be applied to a sensitive

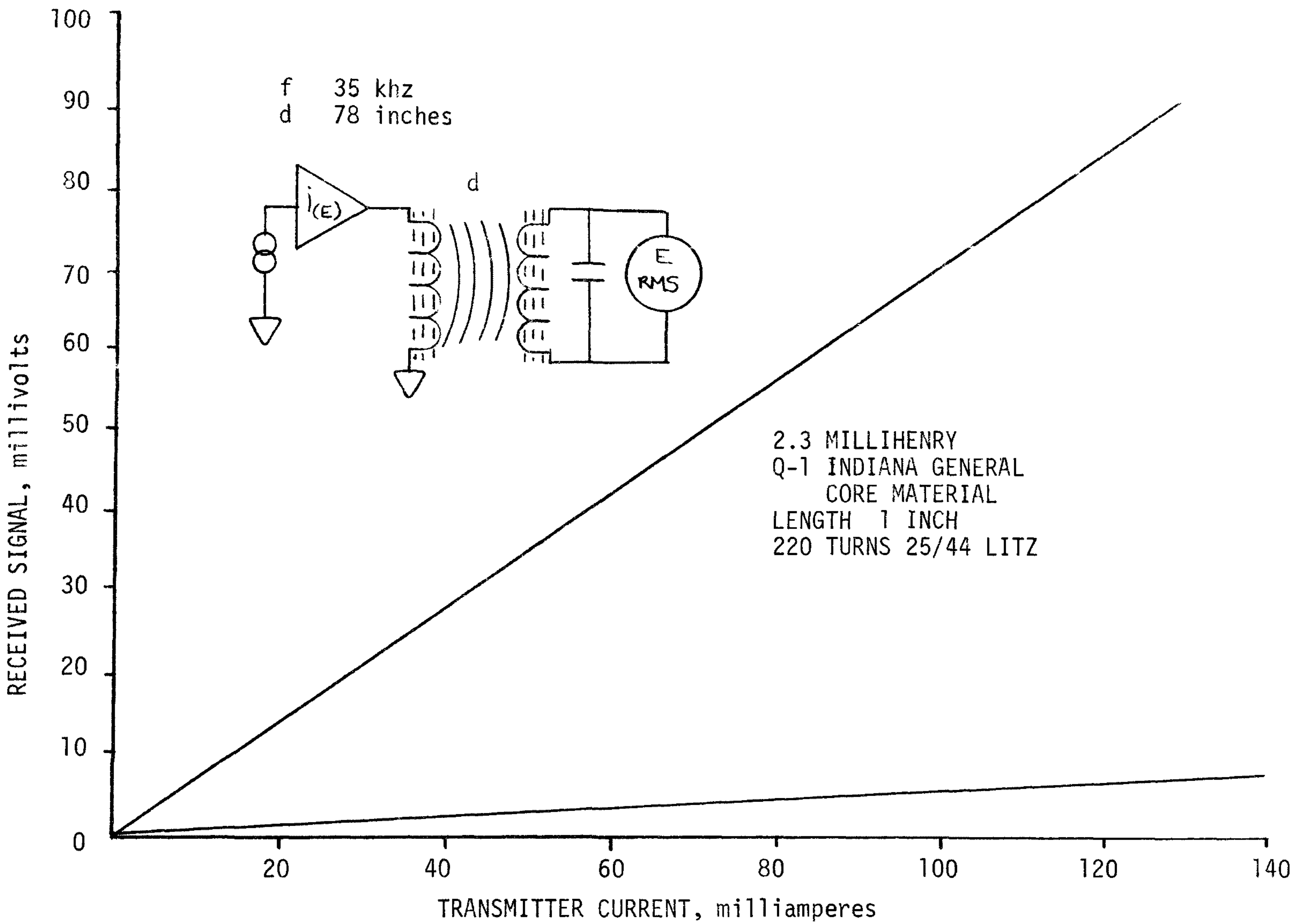


Figure 45. Curves showing the relative received energies for a varying source energy for Q-1 and H type core materials.

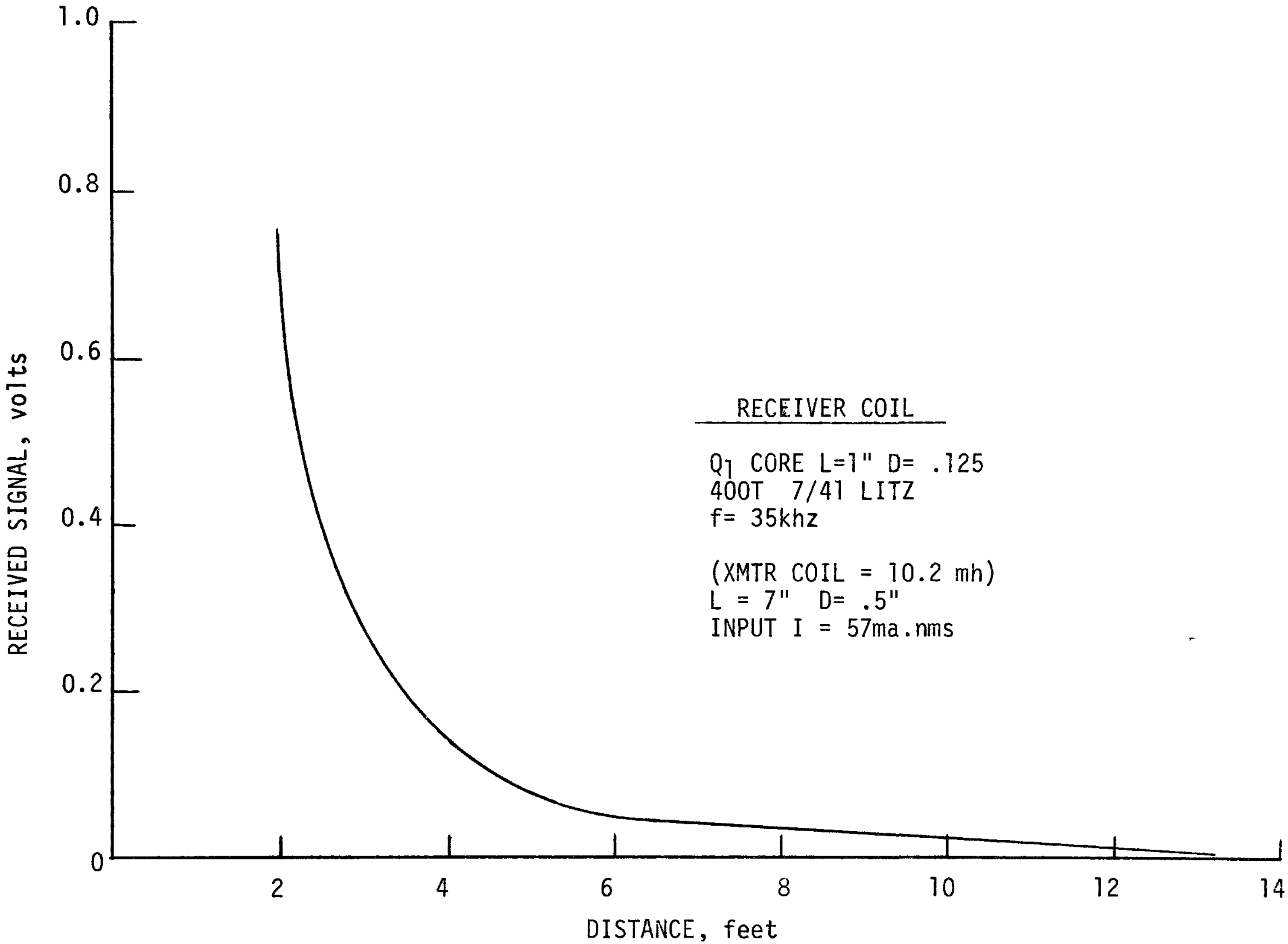


Figure 46. Curve showing the relative received energy for constant source energy.

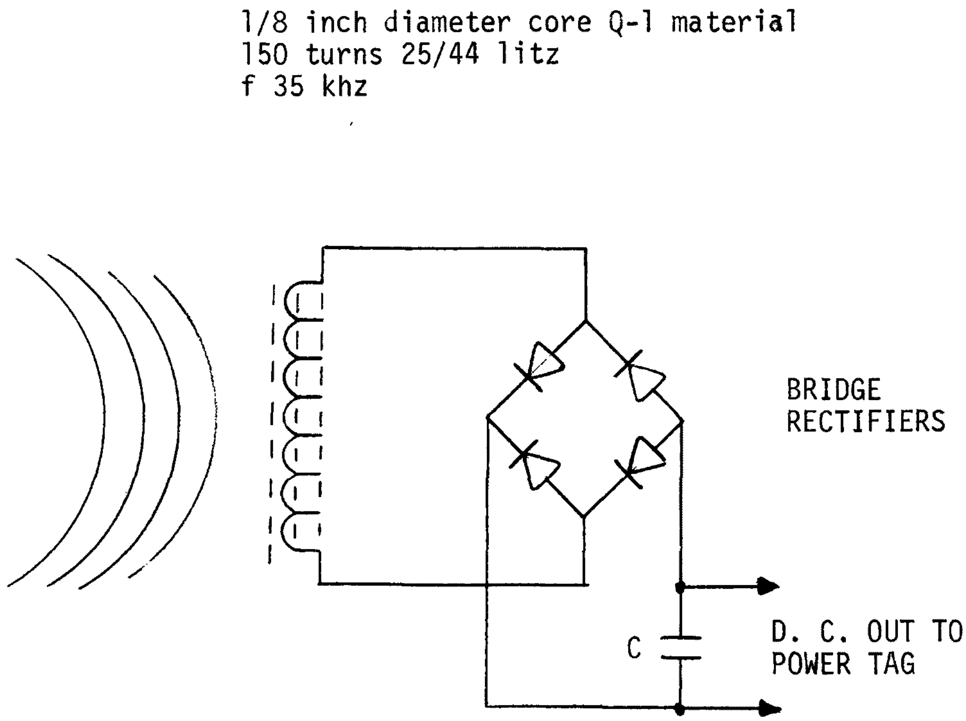


Figure 47. Schematic showing the configuration of a power pickup and converter for use as a power source for an ultrasonic tag.

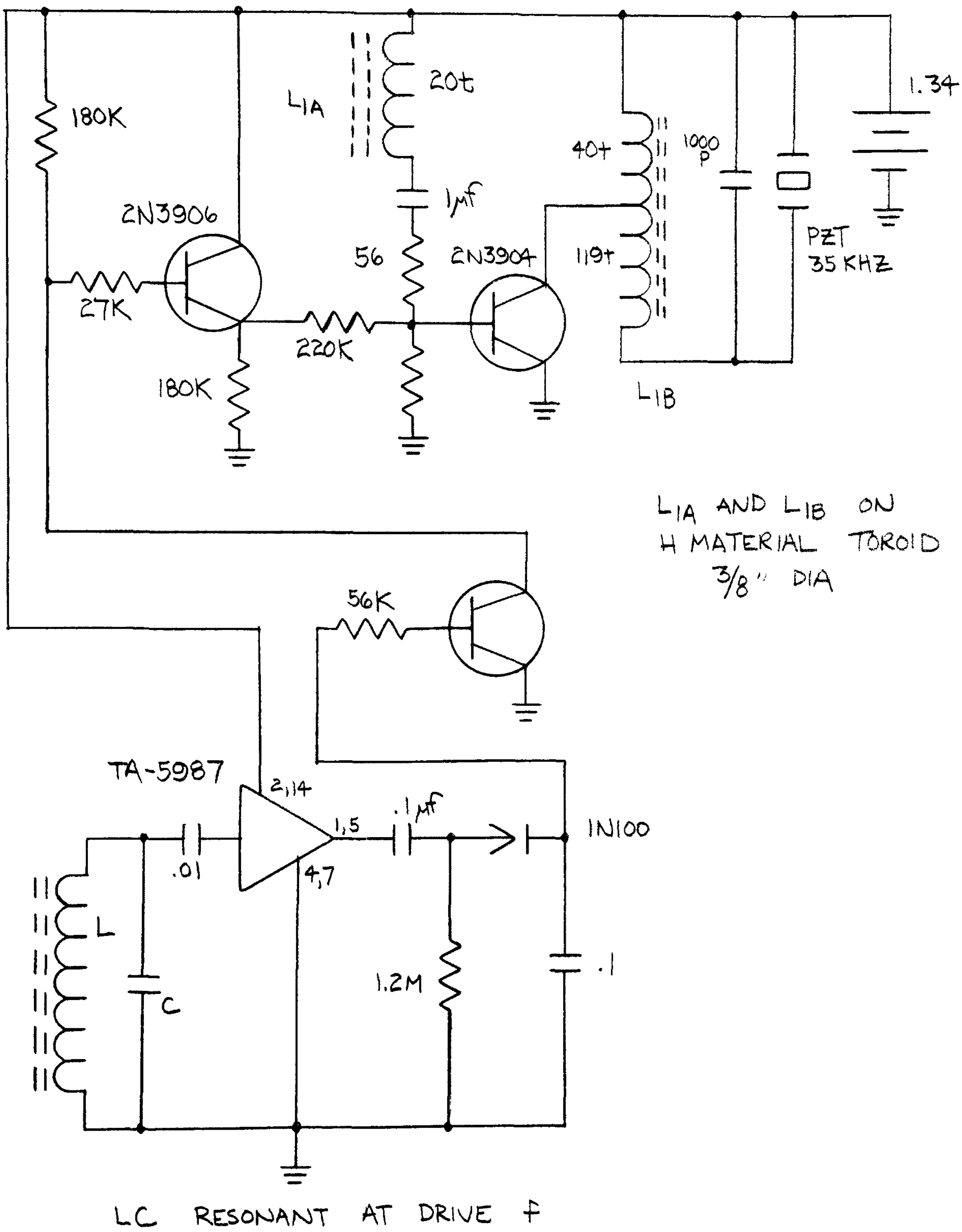


Figure 48. Externally triggered, battery operated ultrasonic tag.

switch which would turn-on a battery powered tag, see Figure 48, and thereby save battery life. Each of these choices required an evaluation of the useable power one could transmit to the tag and over what kind of distances this was practical. To externally trigger a battery operated on, 100 millivolts rms had to be available at the output of the tag receiver antenna and power (standby) for the switch activation is all that is required during off times. Since bridge rectifiers are used, the forward drop of the diodes is lost and this contributes to the inefficiency of an externally powered tag. In addition, the signal being pulled off the receiving inductor must be developed across a resistance and this spoils the circuit "Q"; therefore, the current that can be drawn from the antenna is limited. The load of the rectifiers and filter can be approximated by a 1000 ohm load. Any configuration can be evaluated for sufficient voltage by this technique. Germamium diodes, if available in miniature form, have a forward drop of 0.3 volts. For the two used in the bridge circuit, 0.6 V is lost. Earlier tests at less than 100 ma drive on the transmitting antenna indicated that higher drive currents would be required to reach the necessary voltage. Initial estimates were approximately 500 ma.

Preliminary experiments with higher power were discouraging. With the early transmitting inductors which were with litz wire, losses became excessive above 100 ma. rms. Increasing the drive power provided little increase in inductor current. The effect seemed to be due to the limited current handling ability of the small litz wire. When another inductor was wound with #21 enamel wire, the current limit effect was not observed and the inductor coil could be driven to the limit of the power amplifier.

The test set-up is illustrated in Figure 49. The operating frequency is determined by the signal genertor, an Hp 3310B. This signal is fed to a power amplifier, an Hp 467A,which in turn drives the inductor. The

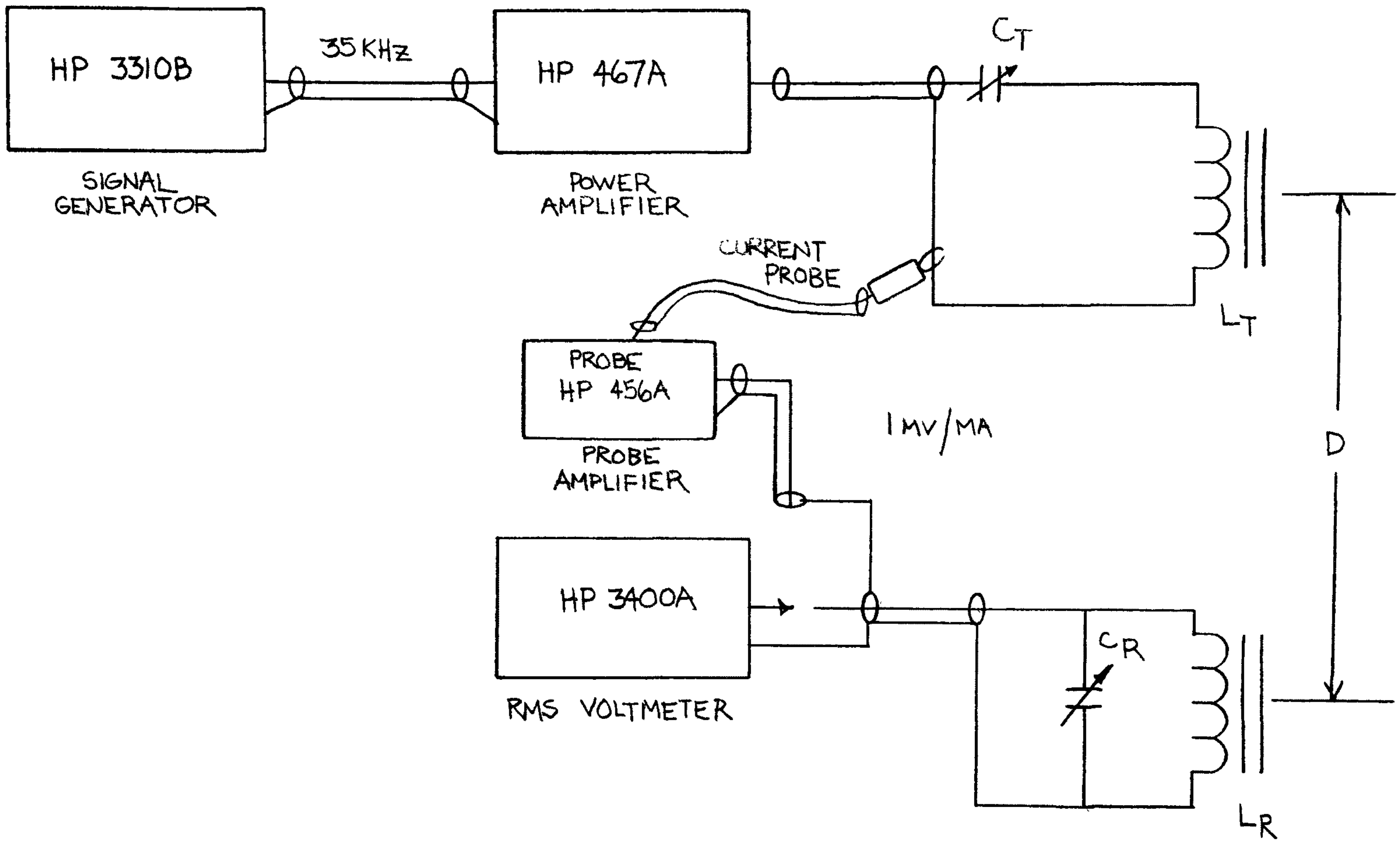


Figure 49. Test equipment configuration for the evaluation of high current inductive field sources and receivers.

inductor is series resonated at the generator frequency with a variable capacitor. A current probe, Hp 456A, was connected around one of the leads from the power amplifier to the inductor. The inductor consisted of 80 turns of #21 Formwar insulated wire on a 1.27 cm (0.5 in.) diameter by 17.7 cm (7 in.) long Indiana General Q-1 ferrite rod. The inductor and capacitor were mounted on a non-metallic stand which allowed a variety of positions and angular adjustments.

The receiver inductor was wound with a 25/44 litz wire on a 3.2 mm (1/8 in.) diameter ferrite rod of Indiana General Q-1 ferrite rod 2.54 cm (1 in.) long. It was parallel resonant with a capacitor at the transmitter frequency. The voltage across the resonant circuit was carried by coax to a switch which allowed the drive current and received signal to alternately be measured with a Hp 3400A rms voltmeter.

The received signal versus drive current and distances are shown in Figures 50 and 51, respectively. Since the ultra-sonic tag requires 1.2 volts for minimum operation, over 2 volts rms must be generated by the receiver inductor. From the earlier data showing the received signal strength, Figure 50, over 10 amps must be driven through the transmitter inductor to effectively be operational over a distance of 2.125 M (five ft). The ultrasonic tag used for this test was optimized for low voltage low current operation (Figure 52). Some frequency and pulse duration instabilities exist because of the variable voltages generated at the receiver due to distance and angle variations. When the antenna is nearly orthogonal, the signals are so low that the tag will not be activated. These are statistically small occurrences and should not seriously ramify the application.

ULTRASONIC RECIEVER

To receive the ultrasonic signal in a laboratory environment a versatile receiver is required. Such a receiver was fabricated for this

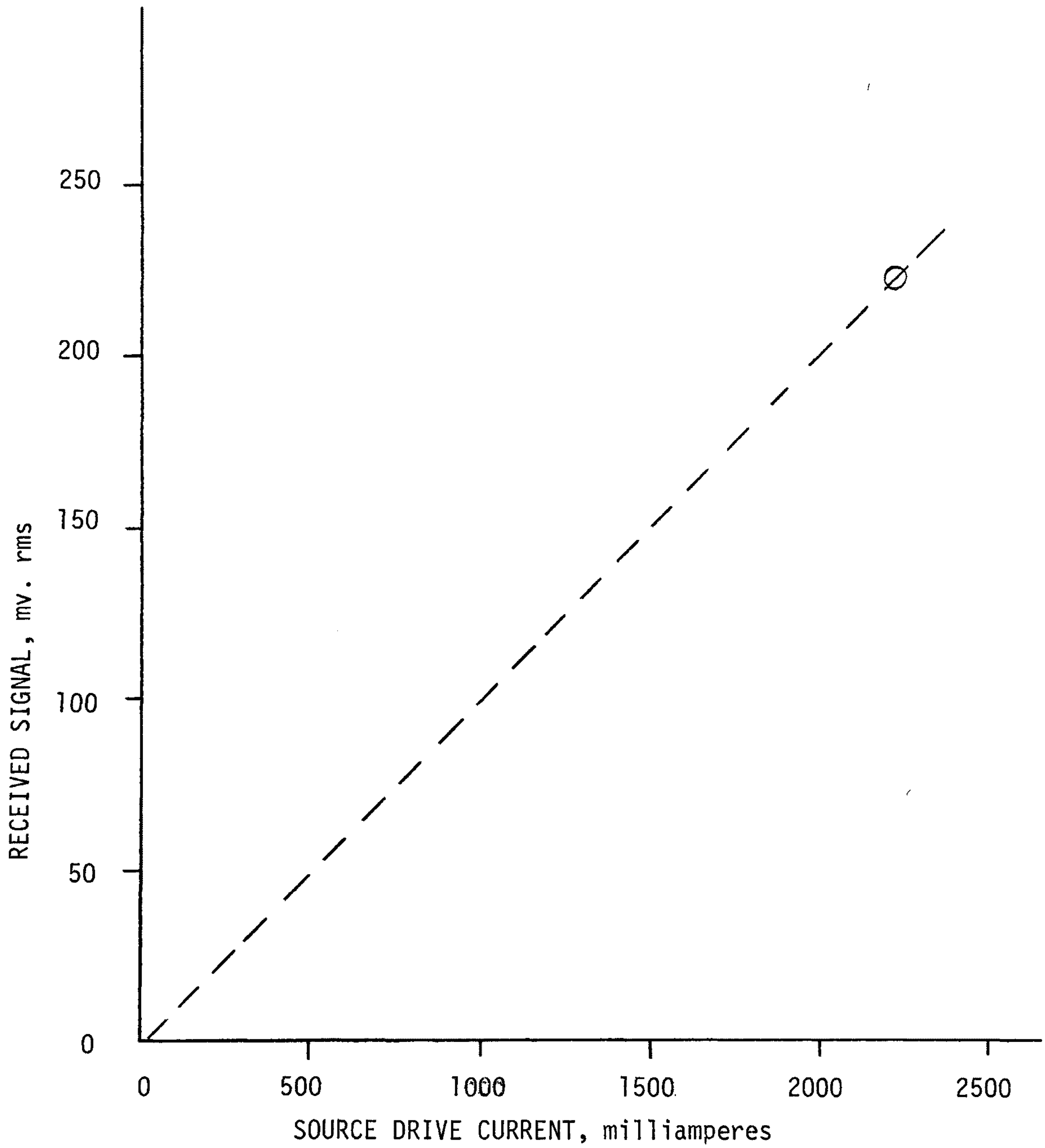


Figure 50. High power test data showing received signal as a function of drive current at a distance of 1.82 meters (6 feet).

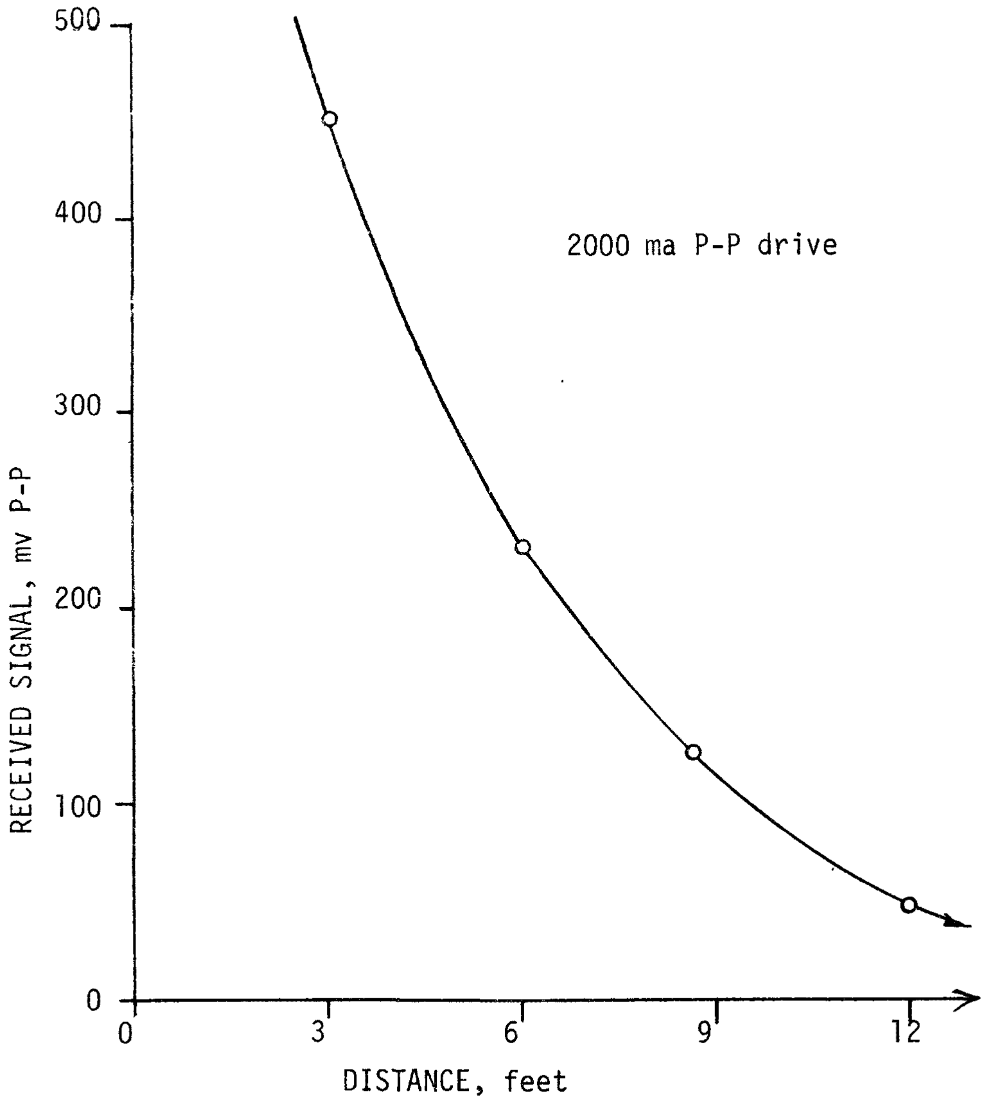


Figure 51. High power test data showing received signal as a function of distance from the transmitter. Transmitter inductor drive is held constant at 2000 ma P-P. Note the variation from $1/r^3$ loss hypothesis.

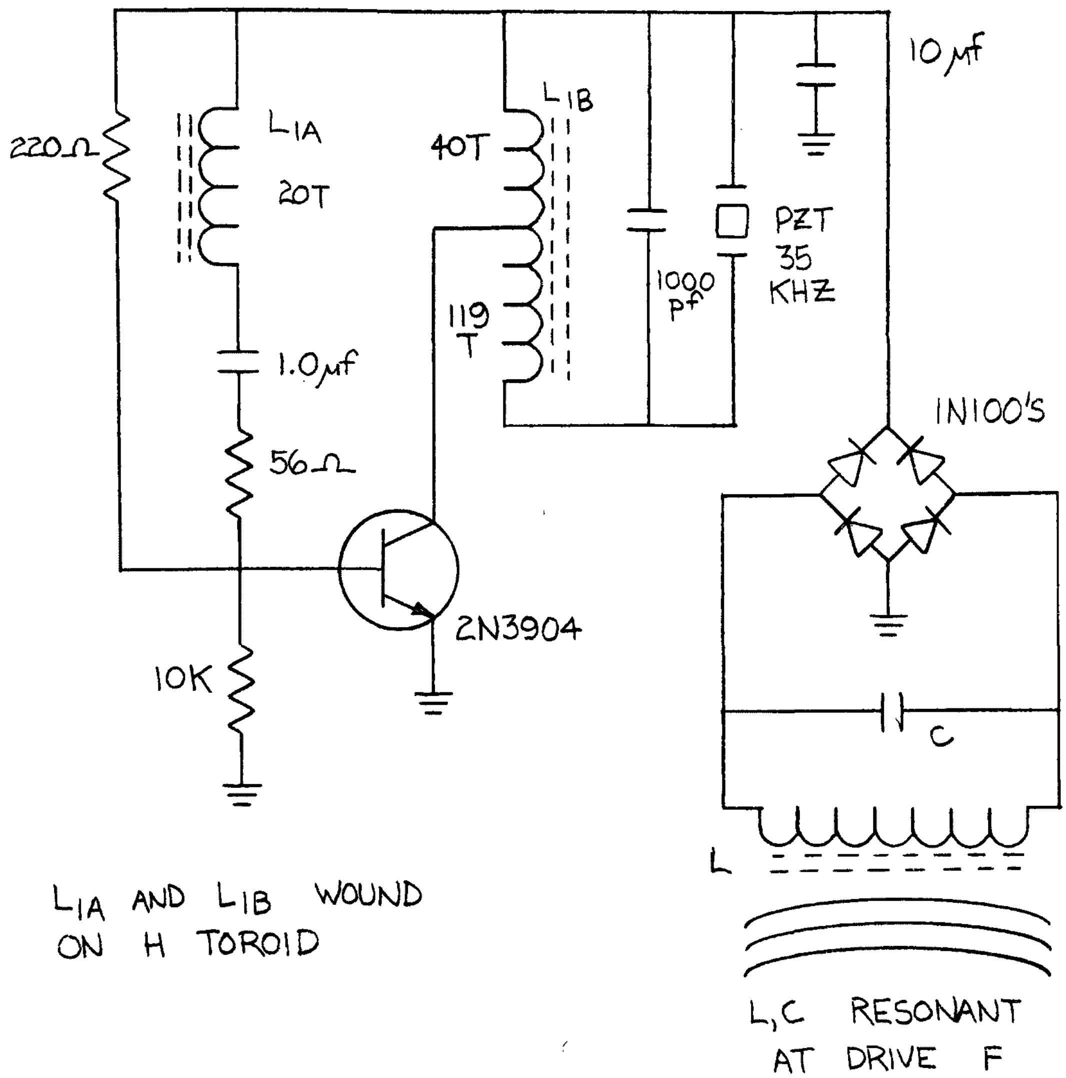


Figure 52. Schematic of externally powered ultrasonic tag.

program, and it is shown in Figure 53. It is similar to the receiver of Figure 16. The input is a PZT microphone. The received signal is amplified and hetrodyned down to video for audio detection. No attempt was made to filter out frequencies beyond the tuning range and should they be present, they will be heard as clicks in the loudspeaker. Basically, it is a tuned frequency receiver and uses one integrated circuit amplifier which serves also as the mixer for audio conversion

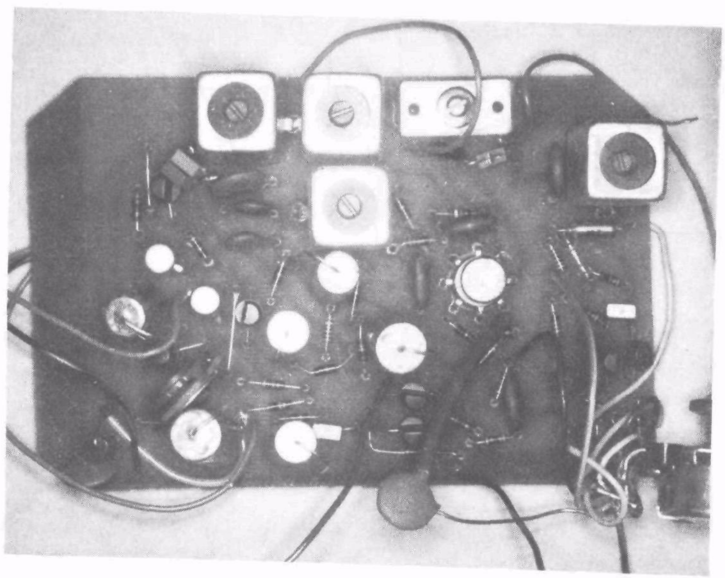


Figure 53. Photograph of ultrasonic receiver for reception of 35 kHz signals.

APPENDIX C

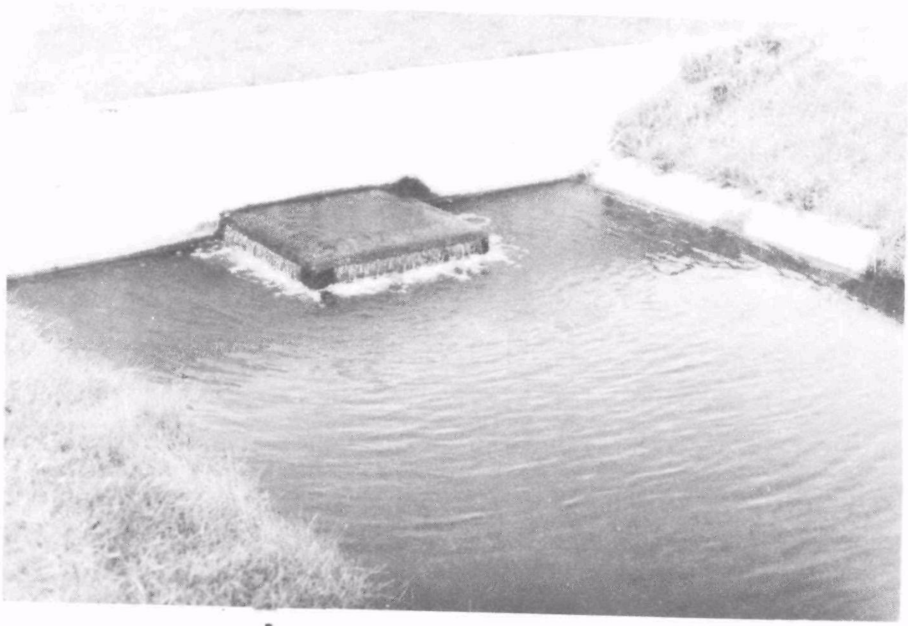
FRY DETECTION SYSTEM

GENERAL

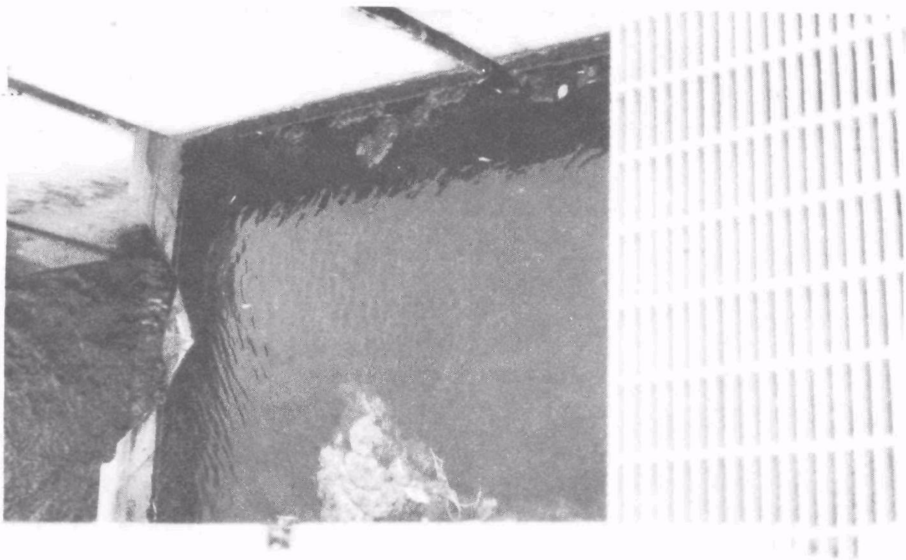
The investigation of thermal pollution effects at the Monticello Ecological Research Station requires a system to detect and count free-swimming fish fry entering and leaving a test channel. This condition must be monitored if meaningful results of fish production are to be measured. Consultation with fish hatcheries has provided a better understanding of the habits of fish fry, their size, quantity, physical characteristics and general behavior during the early stages of their life.

Basically, one is concerned with a fish spawning several thousand eggs in the river bottom. Initially, the survival rate is 60% to 70% and size varies from 4 to 12 mm long and 1 to 2 mm in diameter. In the early stages the young fish will be clumped together on the river bottom. As they approach a 100 mm size they start to school, covering an area of approximately one cubic meter. The schools range further afield as they grow and generally follow the flow of the current. Detection of single small fry would be exceedingly difficult but in schools the fry are detectable.

The physical layout of the Monticello test station provides a restricted area at both ends of each channel. River water is introduced at the head of each channel through a well 30.5 cm (1 ft) x 46 cm (18 in.) and at the lower end through a spillway with a V-notch weir gate (Figure 54). This means that a school of fry entering or leaving the test channel would be forced through a confined area providing an ideal point to establish a fry monitoring station.



Test channel entrance.



Exit gate.

Figure 54. Instrumentation sites for fry detection system.

BACKGROUND

Much effort has been expended over the last 30 years in attempts to locate, track, classify and count fish. A literature search was conducted to determine what methods had been tried and the results of research in the fish counting area. The following areas were found to be worthy of further development for our specific problem:

a. Magnetic field.

b. Impedance technique.

c. Electrostatic method.

d. Equilibrium potential electrodes.

e. Sonar pulsing.

The scope of investigation was limited to a detection method without consideration of target classification or data acquisition and processing.

INVESTIGATION OF FISH FRY DETECTION SYSTEMS

Magnetic Field Techniques

The detection of fry as a result of perturbation of an establish magnetic field was investigated using a series of flat wound coils bottom-mounted in the channel. The electrical Q of the coils could not be maintained in water and the system was insensitive to fry activity.

Impedance Techniques

The impedance of a section of the channel can be measured as a function of frequency. This impedance, $R \pm jX$, as a function of frequency would take into consideration the type of fish, its size, and quantity. After sufficient empirical data was obtained, extraneous objects, pollutants, etc., could be isolated due to their different composition. To increase the sensitivity of the method, the impedance would have to be normalized for varying temperatures. This will offer no problem since the temperature will be readily available for each channel section. Because this technique is parallel to the electrostatic method most effort was devoted to the capacitive approaches.

Electrostatic

The capacitance of a section of the channel can also be measured as a function of frequency. This method is similar to the impedance technique except it can be implemented more easily. An oscillator, using the capacity of the channel section as one element of the frequency determining LC network was investigated. A typical impedance or capacitance plate configuration to be used for either the capacitance or impedance techniques would in its simplest form be a 2.5 cm (1 in.) pipe laid on both sides of the channel and one on the channel bottom. The pipe would be composed of 3.05 m (10 ft) sections connected by a flexible insulated coupling. Inside the pipes each section would have an isolating electronic circuit to permit making the measurement at each section and allowing the data to be connected by relatively long wires to the on shore electronics and control center without these wires introducing stray impedances.

The use of pipe on the side and bottom of the channel allow more accurate measurements to be made on a school of small fishes located in the small depth areas near the shore.

Obviously, other impedance plate configurations are possible. Other plate configurations could be fiber glass mesh with silver painted surface, conventional wire mesh fence material, etc.. In all cases the metal surfaces must be covered to insulate the plates from the water.

Two types of plates were fabricated for this series of experiments. Aluminum plates 30.48 x 30.48 cm and type G10 copper-clad glass filled epoxy circuit board 15.24 cm x 30.48 cm were used. It was necessary to completely insulate the plates from the water and the G10 material with the copper clad sandwiched between glass insulators proved easiest to seal. The G10 boards were mounted on four wooden dowels separating the plates by 15.24 cm.

Direct current (dc) insulation resistance was checked with the plates in position in the filled fish tank and resistance was greater than 1 megohm. A 1.5 m (5 ft) long pair of test leads, separated by at least 15.24 measured 7 picofarads capacity. The complete system capacity with plates in air was 10 picofarads and the same system when placed in water exhibited a capacity of 1200 picofarads.

Because of the small variation in capacity expected as a result of fish located in the dielectric field, a second set of capacitor plates were constructed and placed in the water. The use of two sets of plates allows us to use a bridge circuit. The second set of plates are isolated from the fish and form the reference leg of the bridge. The capacity change caused by the fish is the differential capacity (AC) of the bridge circuit.

The passage of a 3.8 cm (1.5 in.) goldfish through the test area produces changes in capacity of 0.25 to 3.2 picofarad depending on the aspect of the fish during transit. Maximum capacity change occurs when the fishes length is perpendicular to the capacitor plates. Testing neo-tetras in place of goldfish under the same conditions produced variations of 2.5 to 3.0 picofarads capacity.

This system proved to be insensitive and adjustment very critical. Stray capacity due to lead dressing and shifting caused considerable problems in reproducing test results.

Equilibrium Potential Method

The equilibrium potential approach to fry detection was investigated following the outline of the paper presented by Spoor and Drummond of ERL-Duluth. Only one set of electrodes were used and one channel was recorded.

After the potentials in the test tank had stabilized and in the absence of electrical interference, which would affect the normal chemical equilibrium between electrodes, significant readings of repeatable data were recorded, using goldfish, as shown in Figure 55. Swimming movements could be identified, but no indication of breathing activity was observed. We seemed to be limited in ambient level due to AC power line pickup.

It was necessary for the fish to pass very close to the electrode for detection (2cm or less). Any activity in the tank other than fish movements produced responses similar to fish movement. It appears that a fairly elaborate electrode grid would be required to effectively monitor a small segment of the channel and would represent a definite impediment to the flow of large fish and debris.

Sonar Method

Since the simpler systems originally proposed did appear feasible from preliminary testing a sonar system concept was set up and tested at the Monticello facility. This is probably the most often taken approach. Sonar systems for fish location have been built over the frequency range of 10 kHz to 600 kHz. They have been used to: Count salmon going upstream, measuring the biomass (kilograms) of fish in rivers, lakes, and portions of the ocean, etc. with some success. However, the transmission of an acoustic signal in a small area (such as the narrow channel of the Monticello Ecological Research Station) presents many problems. This is due to such factors as multiple reverberations, side lobes of the transducers,

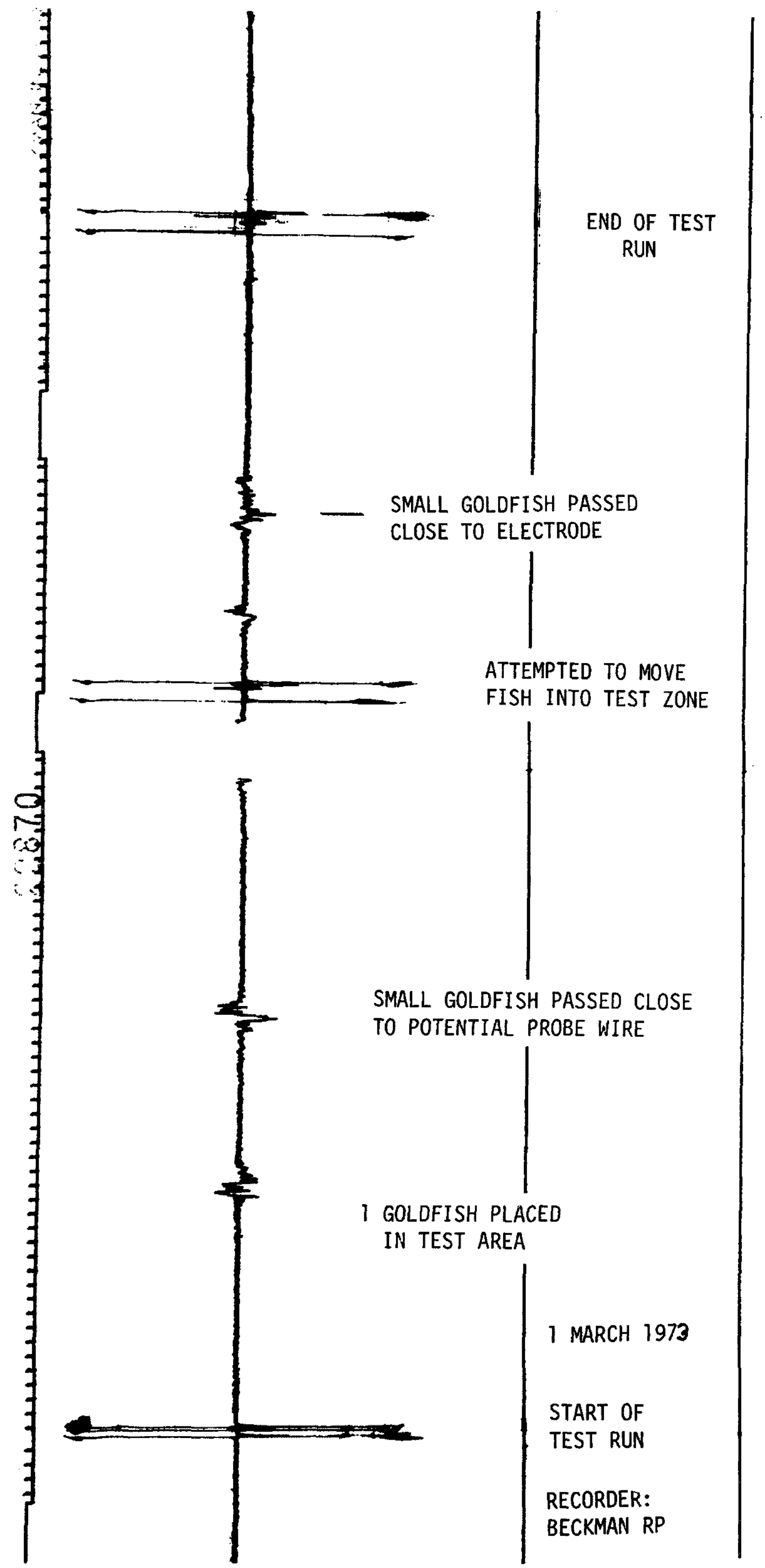


Figure 55. Sample test data, equilibrium potential system.

unpredictable variation in reflection from the fish as a function of its position (can vary as much as 30 dB), reflection from the water surface and irregular contours, the unpredictable variation in signal strength returned from fish of different sizes, and doppler shifts due to rapidly moving fish. Air in the water and plant life also add to the problem. Many techniques have been proposed or attempted to obviate these disadvantages, such factors as swim bladder, vertebral column and body tissue resonances can be used to isolate fish acoustically, especially small fish, from others of different sizes.

The sonar system tested at Monticello is shown in block diagram in Figure 56. A tone burst pulse generator provides the signal to the transmitting transducer at one side of the channel. The signal travels the acoustic path to two receiving transducers separated 15.24 cm on the receiving side of the channel, where the two receiver outputs are compared. A variation in either path is an indication of an abnormality present. The direction of movement can be determined from phase information. Target classification is possible by examination of the received waveform and period of perturbation.

DEMONSTRATION OF FRY SYSTEM AT MONTICELLO.

The fry detector system test program was conducted to demonstrate the feasibility of detecting small fry as they enter or leave the test channels at the Monticello Ecological Research Station, using an ultrasonic detector system.

The system will detect fry, and in addition, grass clippings, clumps of algae, and air bubbles. The system will not count the number of fry, but will indicate the time period fry are in the sonic beam allowing an estimate of the number of fry in the school. (There is

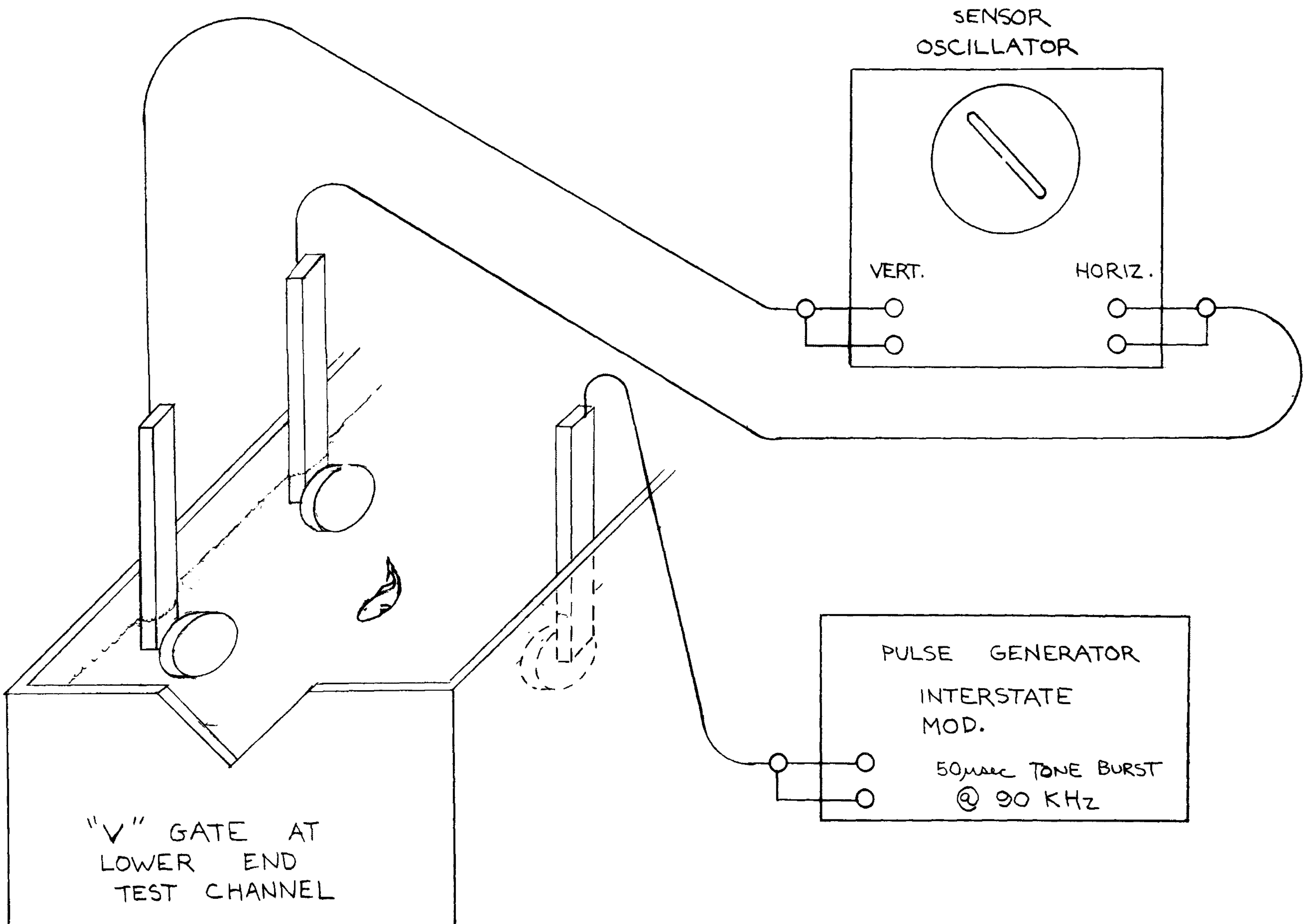


Figure 56. Acoustic fry detection system block diagram.

error here unless it is determined that the system is indeed looking at fry).

The detector transducers were placed in the outlet at the end of Channel No. 1 which is 92 cm (3 ft) wide with a water depth of 76 cm (30 in.). The sound field was established 46 cm (18 in.) upstream from the "V" slot weir and 38 cm (15 in.) below the water surface. There is a source transducer on one side of the channel and two receiving transducers on the opposite side. The signal received is applied to the plates of an oscilloscope and then differences in the scope pattern indicate one interruption of the sound field. Two receivers in a balanced configuration are the most sensitive to changes in the field.

A group of approximately 25 fry (identified as red horse, *Moxostoma* sp.) 20 to 40 mm in length were swimming in the current before the "V" notch weir in the end of the channel and would drift back and forth through the sound field. These transients were easily detectable in the oscilloscope display. There was considerable floating algae in the area and flowing through the sound field. Large clumps of algae extending a foot or more below the surface, disturbed the scope display in the same manner as the fry. Algae at the surface did not interfere with the system. Agitation of the surface of the water did not interfere with data displays.

The system was operated at frequencies from 40 kHz to 400 kHz and it was found that most satisfactory results were obtained at resonance of the transducers - 90 kHz. There was no indication of air bladder resonance or improved target acquisition as a function of frequency.

No attempt was made during this demonstration to optimize test zone acoustic path length, receiver spacing or acoustic window placement in relation to the bottom or distance from the "V" notch.

The tests demonstrated a viable sonic fry detection method, although further work would be required to properly implement a final system for enumerating fish fry without interference.

APPENDIX D

SUPPLEMENTARY MATERIALS

Oversize blueprints and other specific information of limited interest are available only from the project officer. Those materials are:

(1) Engineering blueprints
---System block diagram
---Receiver/temperature decoder
---Acoustic temperature transmitter assembly
---Interconnecting box wiring diagram
---Hydrophone assembly

(2) Parts lists for some of the five preceding components

(3) Instruction and Maintenance Manual for Large Fish Tracking System, 27 p.

Readers who want to review these materials may borrow them by writing to Ken Hokanson, Ph.D., Chief, Monticello Ecological Research Station, P.O. Box 500, Monticello MN 55362.

GLOSSARY OF ABBREVIATIONS

AGC	Automatic Gain Control
cm	Centimeters
cw	Constant Wave
dB	Decibels
dc	Direct Current
emf	Electromagnetic Field
IC	Integrated Circuits
ID	Inside Diameter
kHz	Kilohertz
mm	Millimeter
OD	Outside Diameter
pm	Pulse Modulation
pps	Pulses Per Second
PZT	Lead Zirconate Titanate
μbar	Microbar
rf	Radio Frequency
Shore A	Scale of Relative Hardness
Shore D	Scale of Relative Hardness
VCO	Voltage Controlled Oscillator

TECHNICAL REPORT DATA
(Please read Instructions on the reverse before completing)

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4. TITLE AND SUBTITLE Instrumentation to Monitor Location of Fish Continuously in Experimental Channels		5. REPORT DATE April 1977 issuing date
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7. AUTHOR(S) Joseph R. Jahoda		8. PERFORMING ORGANIZATION REPORT NO.
9. PERFORMING ORGANIZATION NAME AND ADDRESS Bayshore Systems Corporation, 5404 B Port Royal Road, Springfield VA 22151		10. PROGRAM ELEMENT NO. 1BA608
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15. SUPPLEMENTARY NOTES Only the large fish tracking unit was delivered and performed satisfactorily under field conditions. However, the technology was not continued as too costly. Supplementary materials, including blueprints and Maintenance and Instruction Manual, are available from the Project Officer.

16. ABSTRACT

This study resulted in the development and construction of equipment to continuously monitor the position and temperature of up to 20 fish in a water channel 486 meters long, 3 meters wide, and 1 meter deep. The system utilized miniature sonic transmitters (tags) operating in the 51 kHz to 366 kHz frequency range which were implanted in 500 gram or heavier fish. The battery operated tags were pulse modulated and designed for over 1 year operational life. A temperature sensitive thermistor controlled the repetition rate of the tag providing the temperature of the fish to an accuracy of 1 degree C. The nominal range of the polyurethane encapsulated tag was several hundred feet. Nominal tag size was 16 mm OD x 32 mm long (4.6 - 5.4 g in water). Sixteen hydrophones were located at 30.5 meter intervals in the water channel. A control console contained a manually-operated, frequency-stepped receiver which could select any individual hydrophone, thus locating the fish to within ± 15.25 meters. Up to 20 individual fish could be monitored. Automatic operation and recording of the data was considered in the design of the system for future equipment. Severe radio frequency interference problems were encountered, requiring extensive precautions and modification of the channel equipment and wiring. Also investigated were passive fish monitoring and tracking of small fish fry. An experimental system was completed for limited monitoring applications.

17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS	b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group
*Biotelemetry, *Temperature measuring instruments, *Acoustic receivers, *Monitors, *Electromagnetic noise, *Ultrasonic frequencies, *Pulse modulation, *Miniaturization, *Hydrophones, *Preamplifiers, *Sonar, *Inductive reactance, *Impedance	fish location, control console, polyurethane encapsulated, mercury batteries, temperature decoder, Hartley oscillator, complementary astable multivibrator	06B 09F

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