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DETECTION AND MAPPING OF INSOLUBLE SINKING POLLUTANTS

by

Raymond A. Meyer
Milton Kirsch
Larry F. Marx
Rockwell International
Newbury Park, California 91320

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Project Officer

John E. Brugger
Oil & Hazardous Materials Spills Branch
Solid & Hazardous Waste Research Division
Municipal Environmental Research Laboratory - Cincinnati
Edison, New Jersey 08837

MUNICIPAL ENVIRONMENTAL RESEARCH LABORATORY
OFFICE OF RESEARCH AND DEVELOPMENT
U.S. ENVIRONMENTAL PROTECTION AGENCY
CINCINNATI, OHIO 45268

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FIGURES (continued)

TABLES

ABBREVIATIONS

AC	alternating current
ANSI	American National Standards Institute
Ar	argon
C	speed of sound
°C	degrees Celsius
CCl_4	carbon tetrachloride
cm	centimeter
CO_2	carbon dioxide
cos	cosine
dB	decibel
dB/km	decibels per kilometer
f	frequency
°F	degrees Fahrenheit
ft	feet
g	gram
gm/cm	grams per centimeter
Hz	Hertz
ID	inside diameter
in.	inch
kg	kilogram
kHz	kilohertz

kPa	kilopascal
kt	knot
lb	pounds
LIDAR	light detection and ranging
LED	light emitting diode
m	meter
m/sec	meters per second
m^3	cubic meter
m^3/d	cubic meters per day
mhos cm^{-1}	micromhos per centimeter
MHz	megahertz
ml	milliliter
ml/day	milliliters per day
ml/min	milliliters per minute
mm	millimeter
ms	millisecond
mv	millivolt
Pi	incident wave
Pr	reflected wave
psi	pounds per square inch
psig	pounds per square inch gauge
Pt	penetrating wave
SCUBA	self-contained underwater breathing apparatus
STP	standard temperature and pressure
TCE	trichloroethylene
W	watt
μsec	microsecond

θ_i	angle of incident wave
θ_r	angle of reflected wave
θ_t	angle of penetrating wave

SECTION 1

INTRODUCTION

Spills or releases of hazardous materials into rivers, streams, or lakes cause severe environmental impact that could result in massive fish kills or contamination to municipal water supplies. Many of these hazardous materials are immiscible and denser than water. These insoluble sinking pollutants must be detected immediately and mapped to initiate cleanup operations that will minimize health and environmental impacts.

This class of pollutants may sink rapidly to the bottom, forming localized pools, or if turbulence is great enough, they will remain suspended in the water column until they reach a quiescent area of the watercourse where they may settle out. Very often the nature and existence of the spill is known, but mapping the location and movement of the pollutant pools is necessary to direct cleanup techniques and avoid widespread environmental damage.

This report focuses on both facets of the problem by reporting on the development of a continuous bottom-deployed submersible monitor and the investigation of a pollutant pool mapping technique.

SECTION 2

CONCLUSIONS

MONITOR SYSTEM

The concept of monitoring electrical conductivity to detect the presence of sinking insoluble pollutants in watercourses has been proven viable. A purged conductivity cell has been conceived, developed, tested, and is ready for inclusion into a monitor design. Proposed design concepts for a submersible monitor and shore station have been developed and the program awaits the decision to start construction of the prototype.

MAPPING SYSTEM

The applicability of ultrasonic echo study to the location of pollutant pools has been tested both in the laboratory and in the field. An automated system has been constructed to take 16-mm motion pictures of an oscilloscope face while it is showing the voltage excursions of an echo return. The great majority of the 50,000 echoes captured on film from actual field studies in lake and watercourse environments show no precursor signals that would interfere with observation of pollutant pool echoes. A technique for digitizing and processing the photographic data has been developed and used to test a data management concept. The concept appears viable. Both a minimum-cost system and a complex, computer-operated, multidetector system have been conceived and are reported under Section 3, Recommendations.

SECTION 3

RECOMMENDATIONS

This report discusses concepts for monitoring and for mapping pollution caused by watercourse spills of insoluble sinking materials such as halocarbons. Both of the concepts have been developed through successful laboratory and preliminary field testing. Additional work is required to complete the transformation into field-ready equipment. The monitoring and mapping concepts are discussed separately.

MONITOR SYSTEM

The designs of the submersible monitor and associated shore station seem well established. The only experimental work left undone is selection of the optimum cell purge gas volume. Once this factor is known, discussion with concerned and knowledgable individuals will establish the other operating parameters and construction of the prototype system will begin. The prototype design will include provision for altering the timing and data reporting functions. It will be tested over several 1-month periods under different bottom stability conditions in the Rockwell test tank. Additional studies will be performed in a local fresh-water lake to study the effect of algal buildup on the conductivity cell and transmitting transducer, vertical movement into a soft bottom, the effect of the possible intrusion of bottom material into the sensor, and any unexpected aberrations caused by a real environment. Shore station operation will be verified during the field test.

MAPPING SYSTEM

The development discussed in this report has shown that ultrasonic echoes from the surface of pollutant pools can be resolved from echoes off the bottom of watercourses. A return signal study technique has been developed and used to test the feasibility of a proposed microcomputer-based system. These studies were performed with modified commercial depth-sounding equipment using a 200-kHz transducer. Several important parameters must be investigated before an optimum system can be designed.

Frequency

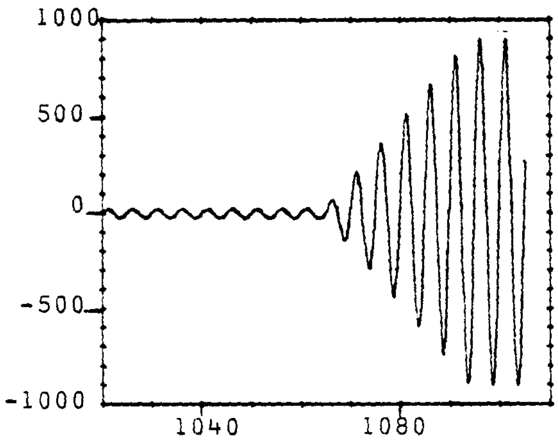
Frequencies used in the field of applied ultrasonics cover the wide range from less than 115 Hz to more than 10 MHz. The low-frequency range is important because of its ability to penetrate long distances and/or lack of reflection from density discontinuities such as thermoclines. While these parameters are very useful if the goal is submarine location, they are of negative value in pollutant mapping. On the other hand, while the higher frequencies will reflect better from density discontinuities, their attenuation by water is higher. Data from Urick (4) fits equation 1, which relates sound absorption in fresh water to frequency.

$$\text{absorption (db/m)} = 2.63 \times 10^{-7} \text{ (frequency [kHz])}^{1.994} \qquad (1)$$

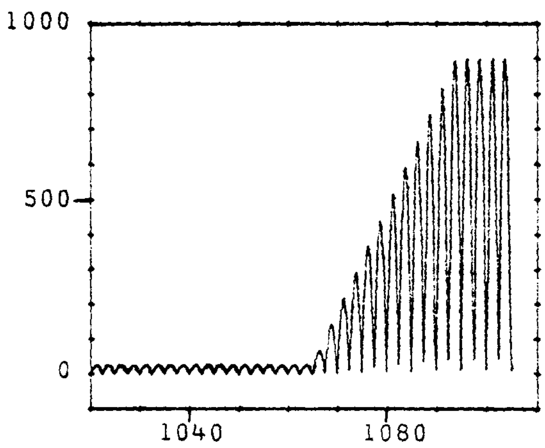
A study of manufacturer's transducer literature indicates that a 1-MHz signal may be effective in 33 meters of water. This is in excess of the 15-meter design depth and will provide some allowance for the effect of turbidity on signal absorption. Accordingly, a 1-MHz system will be assembled and tested both in the Rockwell test tank with actual pollutant layers and in the field with the oscilloscope-photographic system. This represents a large change in transducer frequency and, based on the data from the test, one or two intermediate frequencies may be tested to determine the optimum frequency.

Rectifier Addition

After the completion of the experimental work of this investigation, it became apparent that only the positive voltage excursions of the echo signal were used. However, if a precision full-wave rectifier were incorporated into the receive amplifier, the rectifier would convert the negative excursions into positive and fold them in between the actual positive voltage excursions. This simple addition would double both the time resolution and the dynamic range of the oscilloscope. The change will be simple and will have no effect on the rest of the electronics. The normal and proposed oscilloscope traces are diagrammed below.



Normal return signal



Full-wave rectified return signal

Power

Once the optimum frequency has been determined, the system will be test at locations having maximum suspended solids to optimize the signal power level. The power must be sufficient to result in satisfactory return echoes but excess power places an unneeded load on the portable power supplies.

Beam Form

The ultrasonic beam of the system used in the reported study was circular with -3 dB at 9°. Another transducer is in house that has a 2° beam. The return signals from both transducers will be evaluated in an effort to determine the optimum beamwidth. The Edo Western 1-MHz transducer tentatively selected for the next test has a -3 dB beamwidth of 1.5° and a maximum power rating at 10% duty of 100 W. Its theoretical maximum effective depth is rated at 33 m (100 ft).

Pollutant Density Study

Carbon tetrachloride has been used in all testing up to this point. The EPA list of priority pollutants will be studied and a group of several other materials will be selected and their surface echoes characterized. Emphasis will be placed on selecting a wide density range of materials.

Once the optimum frequency beamwidth and power level have been determined, the design of the transducer-receiver system will be fixed. At this point the development may continue along one of two divergent paths. The first is directed toward development of the technique into a computerized, multidetector system capable of sweeping a wide path of the watercourse. The computer will make pollution location decisions and relate the location to micro-navigational data. The net result would be a watercourse map showing pollutant pools. The second path is directed toward a minimum-cost system. This system would consist of a single detector-oscilloscope combination and employ an observer to monitor the oscilloscope pattern. The two systems will be discussed separately.

Multidetector-Computer System

A single detector unit will be constructed in its final form. The implementation of the data management concept will proceed through the usual steps of breadboard, prototype, and final production. Once the breadboard is functional, a few field trips will gather the large amounts of data required to formulate the data processing algorithms. At the present stage of the development, reduction of the photographic data to digital data requires 1 minute for each 0.1 second of data-taking, or a ratio of 600:1. This precludes the reduction of large amounts of data. The photographic record, however, is very useful for subjective evaluation by viewing the projected film. Photography will continue and be used as a second data source that can be correlated with the data from the multi-voltage level comparator-counter system. It is premature to attempt to describe the algorithm to be used in detecting pollutant echoes. Some requirements are obvious:

1. Adaptable to rapidly changing depths

2. Must ignore weeds and submerged objects

3. Not affected by changing bottom conditions, e.g., mud, rock, etc.

4. Unaffected by thermoclines, internal waves, and water turbulence, both surface and bottom

5. Not affected by turbidity

The subjective evaluation of photographs gathered during the preliminary field trips indicates that the major problem area will be detection of pollution layers on a weed-covered bottom. Satisfaction of the remaining requirements seems well within the realm of possibility.

Final Design and System Deployment

Multi-sensor boom deployment techniques have been developed for hydrographic survey work. One such system is described in literature from Ross Laboratories, Seattle, Washington. The literature indicates the portability of the sensor deployment system. It is anticipated that a similar system may be used to deploy the sensors in the final design. Several alternate techniques for use of the data have been suggested. They range from an on-board audio alarm signalling the operator to throw an anchor buoy overboard to a sophisticated recording system involving the generation and recording of precise navigational data to accompany the sensor return data. The sophisticated system could generate an actual map of the pollutant pools by subsequent processing of the recorded data. The simple system should be implemented and used before passing on to the more elaborate system. When the system detects a pollutant pool, a light on the particular detecting transducer flashes and the operator could then throw an anchored buoy at that light to mark the area. In a second operation, a boat equipped with a single transducer system and weighted conductivity probe searches the buoyed areas to define the pool.

The deployment boat or, even better, a lead boat should be equipped with standard depth-sounders to locate the deepest part of the watercourse where the pollutant pools would be expected to lie. The sensor boat could then sweep that area.

Single-Detector System

The single-detector system development is directed toward construction of a field-usable device at a minimum cost. In this embodiment, the proposed computer data management system development will be shelved in favor of a trained operator observing the echo return patterns on an oscilloscope.

The ultimate purpose of this development will be to construct and deliver a suitcase-sized, battery-operated apparatus for locating sunken pollutant pools. A training film and instruction manual will be included to allow operation by untrained personnel. The system will be designed for passenger aircraft transportation as part of the spill response team luggage for deployment from a 14-foot or larger rental fishing skiff. An inflatable boat such as an Avon or Zodiac and an outboard motor may be included in the package for complete independence from local facilities.

The great majority of the development work is completed. However, the past study was limited to a single frequency -- 200 kHz. This is the frequency favored for depth-sounder use because of its penetration abilities. Long-distance penetration is not a requirement for pollutant pool location, and a higher frequency that reflects better from density discontinuities would be preferred. Frequencies between 200 kHz and 1 MHz may be tested to determine the optimal frequency. It is anticipated that the higher frequency system will give superior results.

When the optimal transducer selection has been made, a suitcase-sized spill response system will be constructed mainly from existing materials. It will be battery-operated, light in weight, and capable of deployment from small fishing craft. The system will consist of the ultrasonic electronics and will read out on a battery-operated oscilloscope. A line-deployed, battery-operated conductivity measurement system will be included in the kit to verify the presence of the pollutant pool. The electrical conductivity of the halogenated hydrocarbon is near zero and easily distinguished from that of a watercourse ambient. The system will be tested in a local lake under simulated emergency spill response conditions. If deemed desirable, spill response team personnel may be included during the testing.

The frequency study and system testing will generate motion picture film of the oscilloscope face taken during field operation. These photographs of actual bottom return signals will be incorporated into a short training film to show potential operators what to expect. An instruction manual will be written to explain the deployment theory and the electronic circuitry of the system. Upon completion of the reduction to practice, the possibility of a system patent will be investigated.

Spills of this nature are infrequent and very difficult to simulate for testing. It may prove desirable to include one of the system development team in the first spill response operation. A post-response critique could result in suggestions for improved deployment efficiency or system improvement.

SECTION 4

SUBMERSIBLE MONITOR

INTRODUCTION

To treat spills of hazardous materials effectively, the spill must be detected and identified rapidly. Rapid detection makes it possible to reduce damage from a spill by discovering it before it becomes widespread and by expediting means of localized impoundment, treatment, and removal. A wide range of chemical and physical phenomena have been explored as a possible means of detecting sinking, insoluble pollutants. Automated gas chromatography, LIDAR, optical energy absorption, etc. were considered as techniques for detecting sinking pollutants. All were judged impractical because of cost, complexity, or performance when compared with the simple electrical conductivity cell.

The electrolytic conductance is a measure of the ability of a solution to carry an electric current, and it is a summation of contributions from all the ions present. The specific conductance or conductivity depends on the number of ions per unit volume of solution and on the velocity with which each ion moves under the influence of the applied electromotive force. As a solution of an electrolyte is diluted, it decreases, since fewer ions are present to carry the electric current in a given volume. The electrical conductivity of representative halogenated hydrocarbons that are typical candidates for spill pollution appear in Table 1. Without exception, the conductivity of these materials is less than 0.001% of that of the common waterway fluid. The large difference in conductivity permits application of simple go/no-go testing.

INITIAL LABORATORY TESTING

Trichloroethylene was selected as typical of the insoluble sinking pollutants because of its reported (1) 1.5 specific gravity and 0.1-part-per-100 solubility. Measurements showed that the conductivity of Newbury Park tap water was 700×10^{-6} mhos cm^{-1}, whereas the trichloroethylene had a conductivity below the measurement capability of a Markson portable conductivity meter, less than 2×10^{-8} mhos cm^{-1}.

The first laboratory evaluation consisted of flowthrough experiments with a Markson conductivity cell in the horizontal position. The conductivity cell consisted of a 0.4-cm-ID tube 15 cm long with two annular gold rings at the exit end. Gravity-induced flow of tap water through the conductivity cell (maximum rate of 190 ml/min or 0.5 kt linear or watercourse flow velocity) and an injection septum for the addition of the pollutant with a hypodermic syringe completed the experimental apparatus. Many injections of varying amounts of

TABLE 1. ELECTRICAL CONDUCTIVITY OF SOME SUBSTANCES

Chemical	Conductivity ($mho\ cm^{-1}$)
Chloroform	$<2 \times 10^{-8}$
Carbon Tetrachloride	$<2 \times 10^{-8}$
Trichloroethylene	$<2 \times 10^{-8}$
Freon TF	$<2 \times 10^{-8}$
Newbury Park Tap Water	7×10^{-4}
Laboratory Deionized Water	1×10^{-6}
Northern Sacramento River Delta	1 to 3×10^{-4}

trichloroethylene were made into the flowing stream of tap water. To avoid possible residual effects building up in the cell, 1 ml of air bubbles was injected periodically into the flowing water. Several simulated watercourse flowrates were tested.

All tests, irrespective of watercourse flowrate and pollutant injection amount or rate, resulted in a measurable decrease in conductivity. Figure 1 shows that significant decreases in conductivity occurred as higher amounts of the pollutant, trichloroethylene, were added. Figure 2 indicates that the period of the pollutant injection is directly reflected in the conductivity cell output. These results show that the Markson portable conductivity meter is capable of rapid response to the intrusion of even microscopic volumes of pollutant.

FINAL DESIGN AND TESTING

During prior laboratory testing, the conductivity sensor was deployed in the horizontal position. Water flowing by gravity forced the sample through the cell. In natural watercourses, the energy available along the bottom is predicted to be insufficient for good sampling, and plugging of the cell due to river material may cause problems in long-term deployment. To avoid these difficulties, a new deployment concept was initiated with the conductivity cell oriented vertically in the water column and utilizing a cyclic gas burst purging system.

Figure 3 shows a laboratory system to test this arrangement. In operation, a timing circuit switched the three-way valve for 10 seconds every minute or more, depending upon the desired sampling frequency. When the three-way valve switches, the pressurized contents of the purge volume are dumped into a

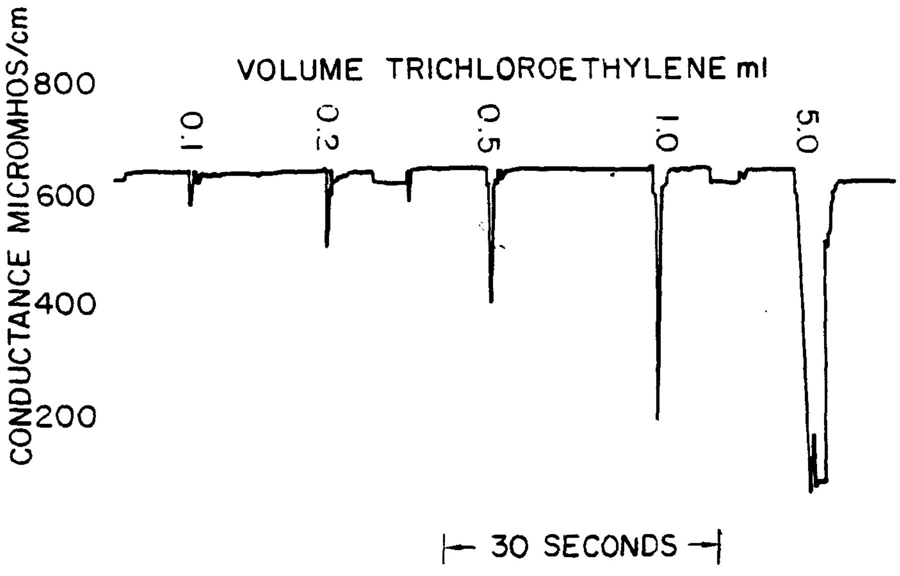


Figure 1. Five different volumes of trichloroethylene each injected over a 2-second interval into a 3.2-ml/min water stream.

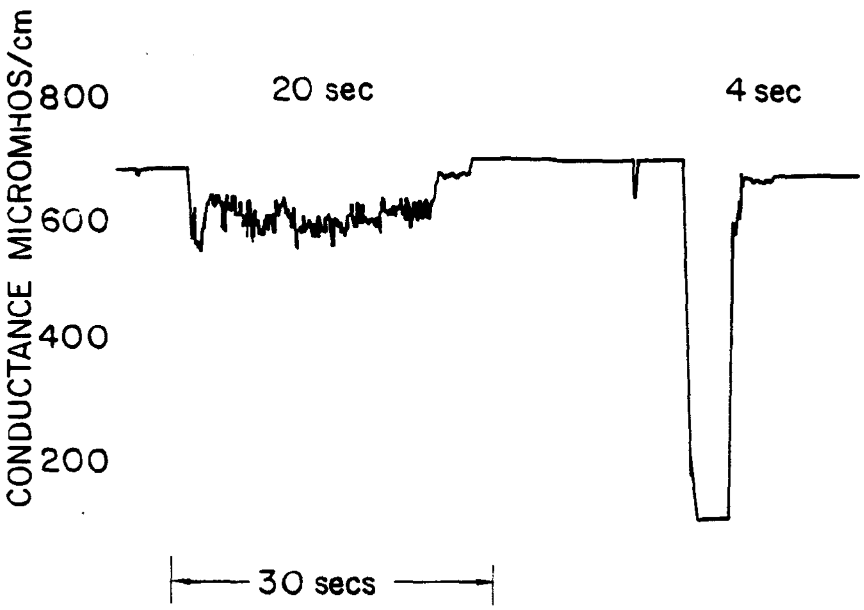


Figure 2. 10 ml trichloroethylene injected into water flowing at 0.26 m/sec (0.5 kt) (two injection rates [sec]).

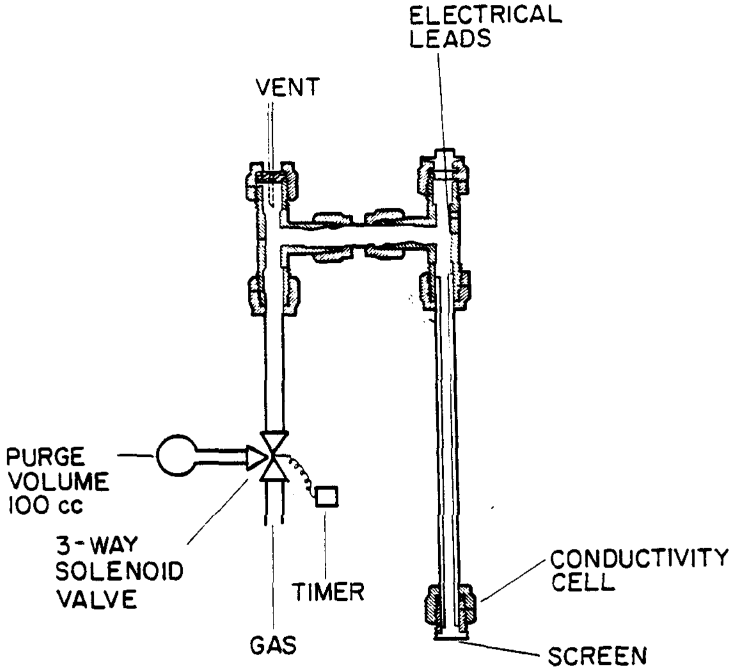


Figure 3. Test System.

line leading to the cell. Some of the gas escapes through the vent but the majority rushes downward through the cell, displacing the old sample and clearing the inlet screen. When the purge gas volume is exhausted, a new sample of bottom water enters the cell, displacing the air through the vent. This system allows a fresh sample from the bottom of a watercourse to be reliably taken at any desired time interval.

Figure 4 is the recording made during testing which involved the addition of trichloroethylene to a depth of 2 cm above the surface of a sand bottom. The screened end of the cell was buried to a 2-cm depth in the sand during the test to simulate a system in which bottom material (sand, silt, clay, etc.) covers the cell opening. The first four cycles after the trichloroethylene was added did not show intrusion of the pollutant, but upon the fifth cycle (Figure 4 [1]), the trichloroethylene entered the cell and the conductivity dropped significantly. Although not shown in this figure, the conductivity remained near zero for 100 more cycles.

The laboratory test system was operated continuously for 2 months without failure. Power for the system was supplied from an automobile battery that was recharged as required. The gas supply system was laboratory compressed air at 584 kPa (70 psig).

Thus, this embodiment of the concept of a vertically oriented, cyclically purged conductivity cell was proven to perform satisfactorily. It was also proven operable even when the cell opening was buried in sand.

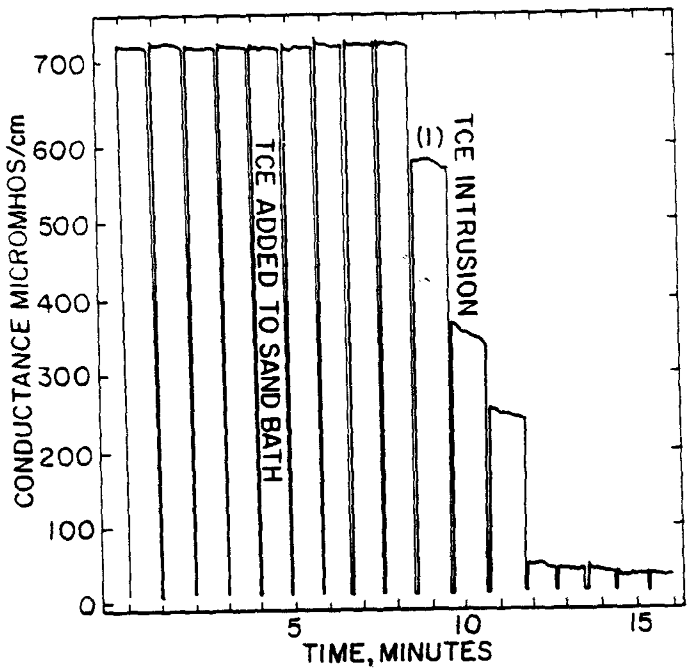


Figure 4. Sand-covered sensor.

SUBMERSIBLE MONITOR AND SHORE STATION DESIGN

The preliminary design of a submersible monitor for detecting sinking pollutants employing the vertically oriented conductivity cell has been completed. The design criteria are:

1. Operation without restrictions caused by turbidity, salinity, depth, and flowrate of the watercourse
2. Operation without restriction to bottom type or substratum
3. Ability to be self-contained, requiring no pipe or electrical connection to shore
4. Unattended operating time of at least 365 days
5. Deployment from small craft without diver assistance
6. External design to minimize damage by anchor snagging, net or trawl disturbance, or impact of submerged objects

The basic concept of the submersible monitor is that of a battery-operated, electronically controlled cylinder gas purged cell unit with ultrasonic data transmission to shore. The system must be weighted and durable enough to remain in position on the bottom and covered with a smooth and sturdy fairing to deflect waterborne objects and boat anchors. The conductivity cell must be immune to clogging and be able to receive a fresh sample from the bottom of the watercourse.

The supply consumption calculations and, therefore, the unattended life of the proposed system are based on a 10-minute cell purge frequency, a depth of 15.2 meters (50 ft), and a water temperature of 4°C (39°F). The cell purge volume was established at 10 ml.

Gas Supply

Under the design conditions, each cell purge discharges 81.4 ml of gas at STP. Since the cell is purged 144 times per 24 hours, gas is consumed at a rate of 1.172×10^4 ml/day, or 0.0117 m^3 per day. Table 2 relates the type of cell purge gas, the volume in a typical cylinder, and the life span of such a cylinder. Carbon dioxide releases more gas per cylinder than any other except the 41,000-kPa (6000-psi) cylinders of compressed gas. All the standard cylinders are 23 x 152 cm (9 x 52 in.) cylinders. Additionally, CO_2 is available in a 20 x 69 cm (8 x 27 in.) cylinder that holds 109 kg (24 lb) of liquefied gas. Each such cylinder will purge the cell 70,000 times, or 144 times per day for 1.3 years.

Power Supply

Power will be supplied to the entire system with lead-acid truck batteries or gel cells. One such truck battery will deliver 25 amperes for 440 minutes or a conservative 185 ampere-hours. This battery weighs approximately 662 kg (146 lb). Once the electronic control package design has been completed, the power demand will be calculated and a suitable number of batteries will be installed. At least two, and perhaps four batteries will be used in a switching string so that each battery is discharged in turn. A fully charged battery

TABLE 2. COMMON CYLINDER GAS SUPPLY DATA

Gas	Volume in Typical Cylinder, m^3	Days at 0.0117 m^3/day
Ar	9.5 - 16.3	811 - 1391
CO_2	12.4 - 14.9	1055 - 1270
Helium 2640	8.2 - 14.8	703 - 1266
Methane	8.5 - 14.4	725 - 1231
Nitrogen 2200	6.4 - 14.0	546 - 1193
Air	6.2 - 14.0	531 - 1193
Freon 13	3.5	295
CO_2	5.9 (Matheson #2 cylinder)	507

has a lower self-discharge rate and thus longer shelf life. The lowered capacity of a battery at watercourse temperatures will be considered in the final design. All batteries will be given two or more charge-discharge cycles before installation to eliminate defective units. The batteries will be contained in pressurized waterproof compartments.

Data Transmission

Data will be transmitted to the shore station with a pulse-modulated ultrasonic signal. The transducer frequency will be selected on the basis of non-interference from other similar signals. For example, the 200-kHz range will not be considered because of possible interference from depth-sounders and fish-finders. Off-the-shelf system components will be thoroughly evaluated before development effort is expended. Low frequencies will be preferred for their penetration of soft mud in case the system sinks into a soft bottom.

Shore Station

The present shore station concept includes an ultrasonic receiver, electronics to decode the signals, signal test circuitry with an adjustable "normal signal" window, a stripchart recorder output and a dial-up alarm system to notify a remote oeprator of abnormal conductivity caused by a pollution alert or system malfunction. Provisions will be made for routine dial-up and data transmission each 24 hours as a means of quality assurance. Additionally, the station telephone may be called and the data tone will be transmitted as it is received. Both of these operations may be disabled with ease. Several monitors may be serviced by a single shore station. The ultrasonic data signal will be coded to eliminate shore station response to spurious signals from non-monitor sources such as boat motors, depth-sounders, and fish-finders.

MONITOR DESIGN

The previous paragraphs prove that it is practical to construct a submersible monitor meeting the design criteria. The next task is to weigh the various operating parameters such as purge gas volume, cycle time, reporting frequency, reporting resolution, and self-check features against the power and gas supply budget. One of these parameters, purge gas volume, requires further study to develop an optimum amount. The rest must be decided by the ultimate user. For the purposes of this report, it will be assumed that 10 ml of gas at 100 psig, which is 21 cell volumes, will be sufficient to purge the cell, the cycle time will be established at 10 minutes, and the conductivity signal will generate a frequency-coded signal used to modulate the ultrasonic transmission signal. Data to be transmitted for 30 seconds out of every 10 minutes will be the conductivity of the cell immediately prior to the purge cycle. Figure 5 indicates the electrical control cycle. The proposed design will have an operational life of one year. It is shown conceptually in Figures 6, 7, and 8. The proposed system will be weighted with concrete, probably a few hundred pounds. However, study of the various forces occurring along the watercourse bottom will give the necessary information to determine optimal weighting and support of the system.

Figure 8 indicates the use of anchor pins that would be suitable for hard bottoms, but other supports such as spread footings or inverted eliptical pads

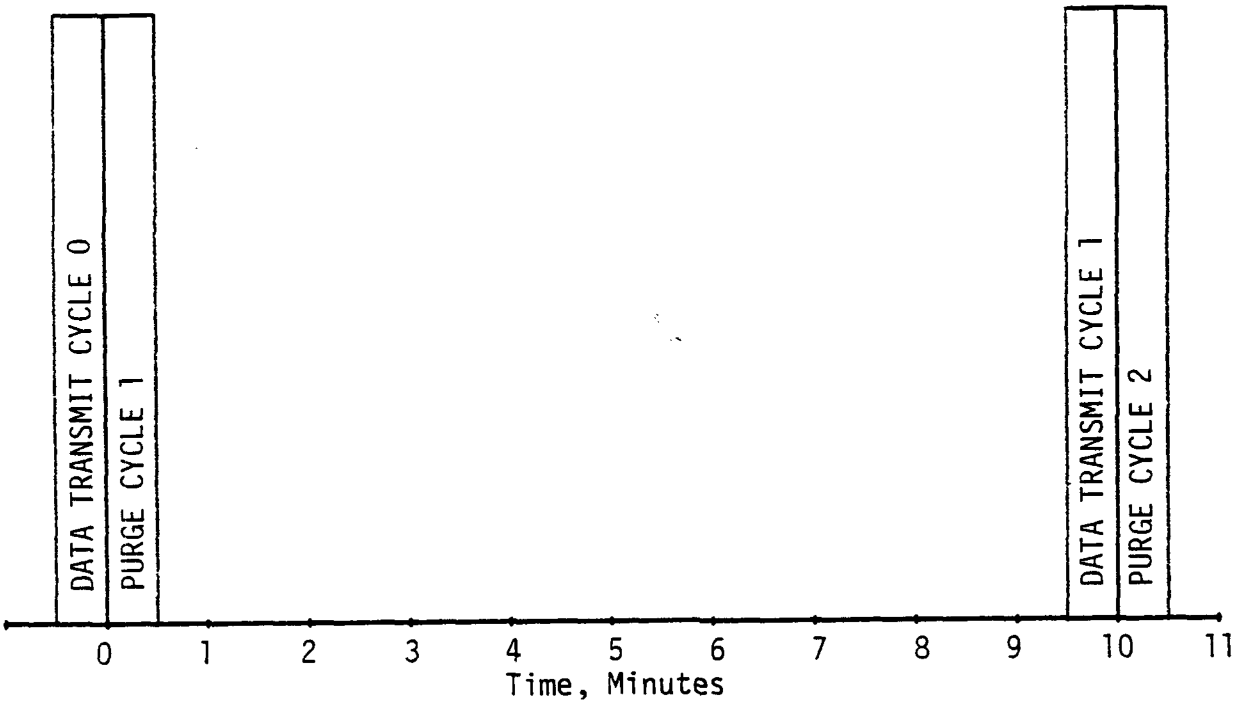


Figure 5. Submersible electrical control cycle.

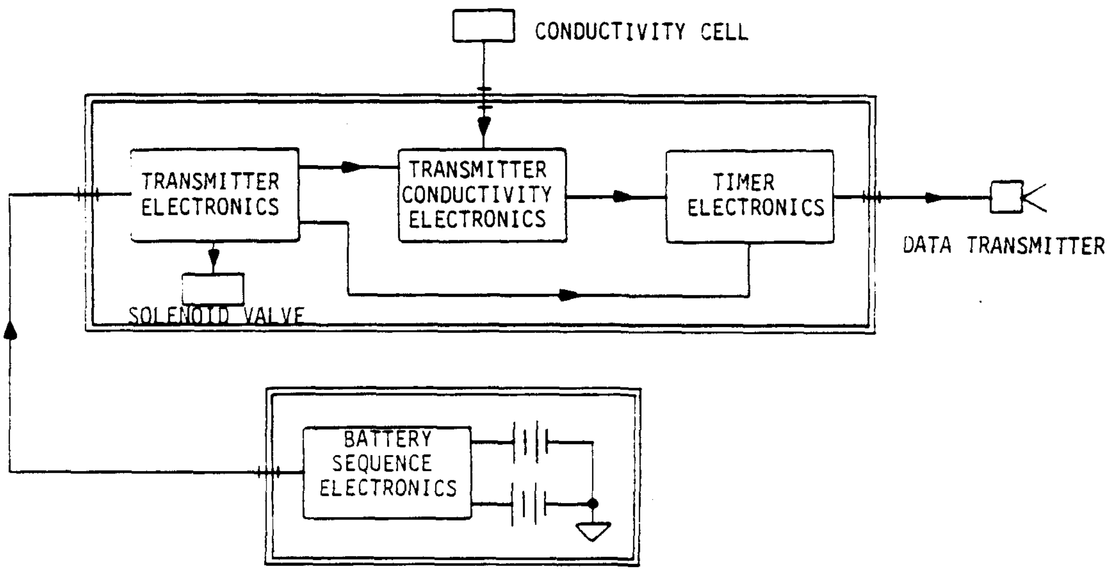


Figure 6. Submersible electronic block diagram.

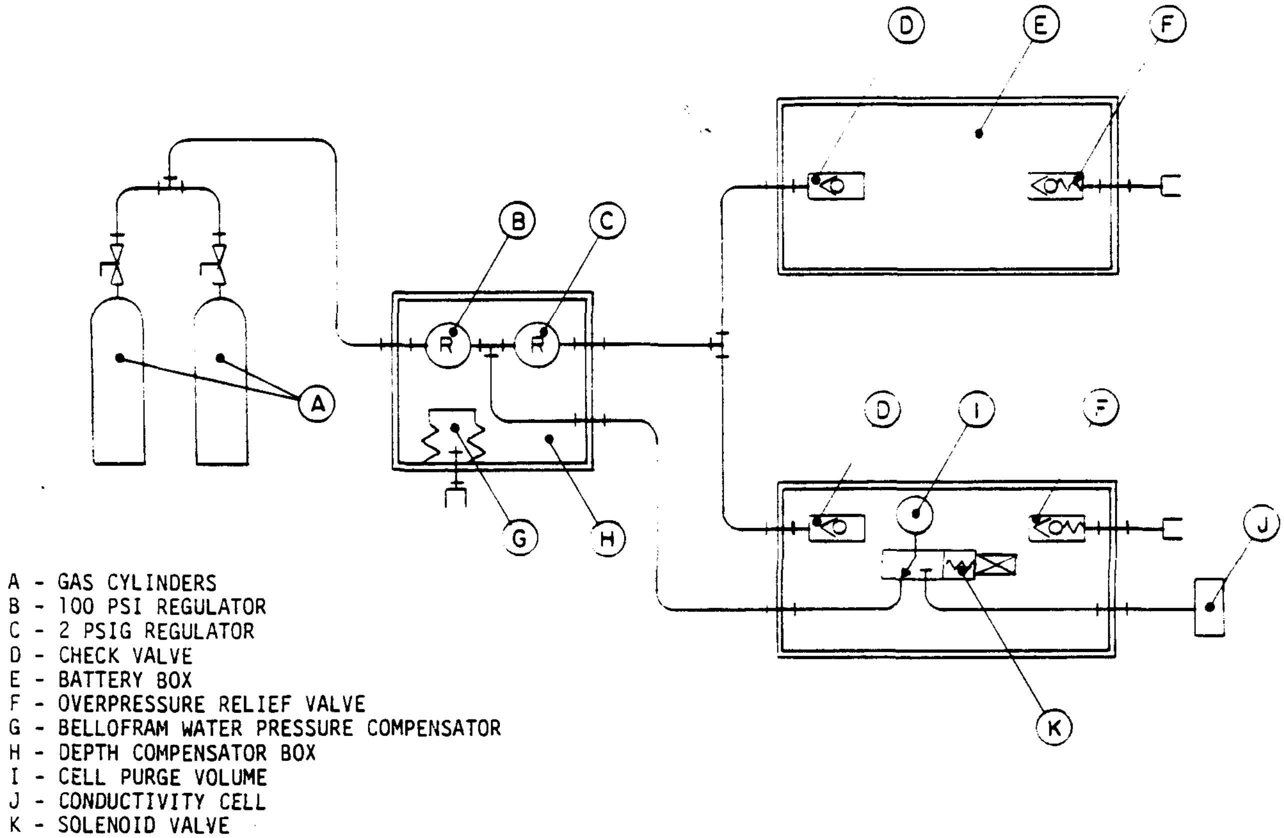


Figure 7. Gas flow schematic for submersible.

may be more suitable for softer bottoms. The design provides for an interchangeable support system. It can be deployed from a small boat and positioning adjusted if required by a SCUBA diver and lift bag (buoyancy compensator). The design may be such that recovery is not cost-effective but, since the position will be triangulated from shore when it is placed, a diver with a metal locator should be able to locate it with ease.

The monitor will be placed on the thalweg line (maximum depth) of the watercourse. A hydrographical study will be made to select an area where there is a minimum shift of the thalweg line due to changes in watercourse flow velocity. This is typically in an area between the meandering currents, where the flow is fairly directional and smooth for a distance. It is anticipated that the monitor may settle as much as 50 cm into a soft bottom, but

A - LIFTING RING
B - DATA TRANSMITTER
C - ELECTRONICS BOX
D - BATTERY BOX
E - DEPTH COMPENSATOR
F - CONDUCTIVITY CELL
G - REMOVABLE BOTTOM
ANCHOR PINS
H - GAS CYLINDERS
I - WEIGHTED FRAME
J - OUTER SHELL

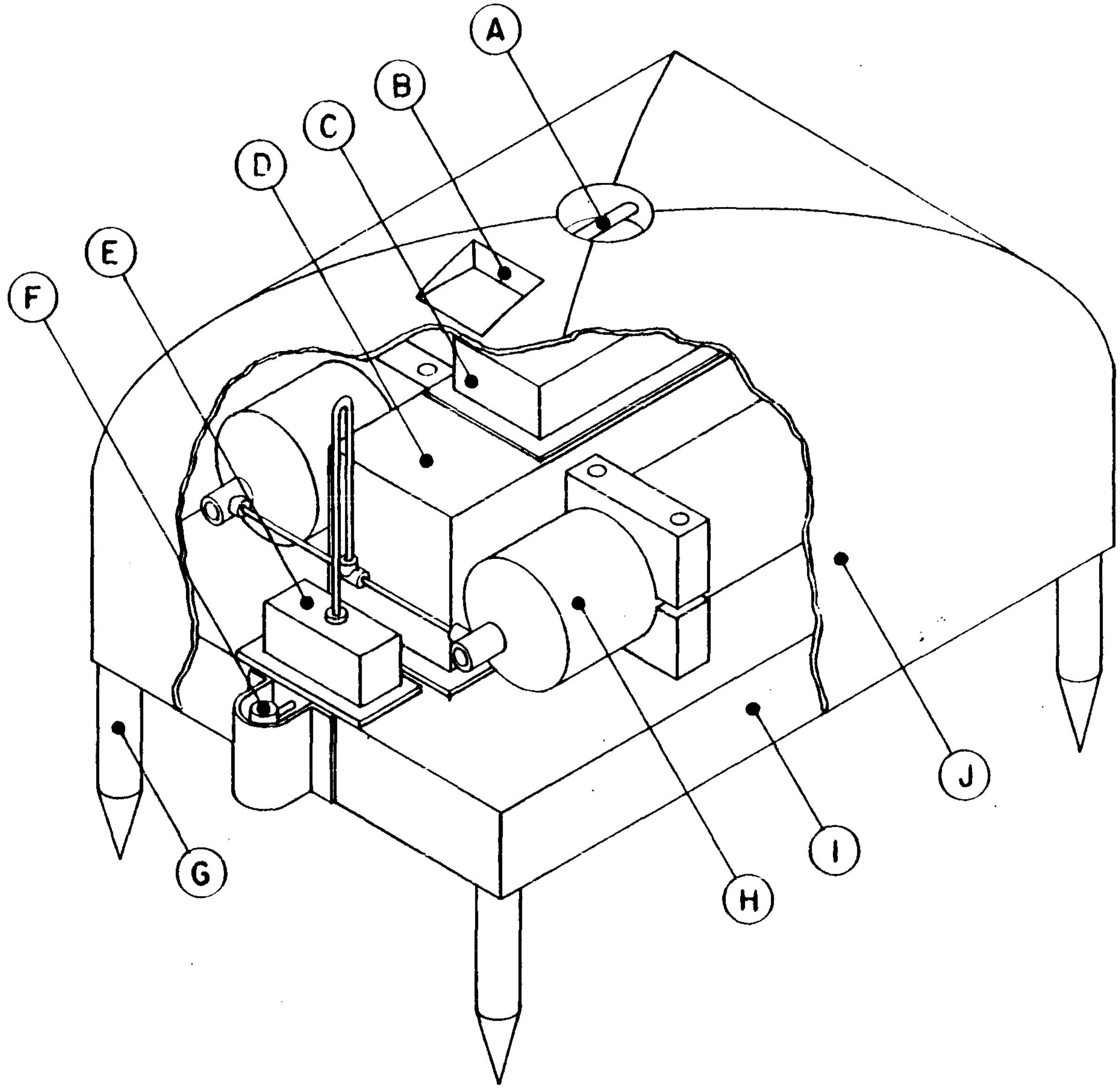


Figure 8. Submersible monitor.

laboratory experiments have shown that the cell is capable of operation when buried in sand and mud. The purge gas opens a large hole to the surface of the bottom and the cell is filled with liquid from the bottom of the watercourse. Extremely soft bottoms, such as reported by Saxona and Smirnoff (2), may preclude use of the monitor. The final design will be well tested in a large tank presently located at the Rockwell facility. Various bottom types will be generated using material from actual watercourses. Other considerations to be studied are discussed in the Recommendations section.

SECTION 5

POLLUTANT MAPPING TECHNIQUE

INTRODUCTION

The continuous submersible monitor that will be located on the watercourse bottom will provide a new technique to rapidly detect the occurrence of a hazardous material spill. Laboratory experiments have shown (3) that the material may travel great distances down a channelized river bottom, accumulate as pools filling up the valleys of undulating watercourse bottoms, or form as random globs and pools whose size and movement are dependent upon the hydrodynamic and physical characteristics of the watercourse. A pollutant mapping technique is needed to locate the hazardous material along the watercourse and direct rapid cleanup operations to minimize widespread biological and environmental impact.

This mapping system will be transported to spill locaions and deployed with speed of response as a major factor in its design. It therefore must be modular in construction and light in weight to permit air transport, even by small charter aircraft, to remote locations. Ideally, it should be capable of deployment from rental outboard-powered fishing boats or inflatable boats (i.e., Avon or Zodiac) carried as part of the package. The system must have low power requirements and be battery operable. An example of such a power supply would be typical 12-volt gel-cells.

Watercourse bottoms are characterized by nonuniformity of depth, substrate, currents, turbidity, etc., and a wide range of man-introduced material. These typical bottom parameters impose severe design constraints upon sensors or probes such as conductivity cells that would be submerged and towed through the watercourse or contact with the bottom. This leads to another requirement that the sensing technique function from on or just below the surface of the watercourse.

The design, construction, and application of the selected technique should be compatible with field deployment and eventual operation by nontechnical personnel.

CANDIDATE TECHNIQUES

Gas Chromatography

Halogenated hydrocarbons dissolved in water can be detected and measured by gas chromatography, especially if a semi-specific detector, such as electron capture, is used. This technique would be applied by analyzing a series of samples withdrawn from the watercourse for halogen content. The flow characteristics of the watercourse would then be integrated into the sample data base and the position of the polluted pools calculated. The halogen content would be very low throughout most of the water column, which would impose severe sensitivity requirements. One of the largest problems in the application of the gas chromatographic technique would be defining the watercourse flow and mixing pattern with sufficient accuracy to calculate the position of the source. Other problems with this technique involve sampling, time, and power requirements.

LIDAR (Light Detection and Ranging)

LIDAR is a technique where laser energy is injected into the watercourse. It penetrates the water to the bottom where it excites the atoms of the pollutant to photo-emission. The weak emitted light then travels to the surface, where it is measured. The wavelength of this light is a function of the atomic structure of the pollutant and may be used to characterize the material, as well as locate it.

LIDAR has been used to locate temperature microstructure in the water column, but has been applied only to moderate depths of clear ocean water. Both the incident laser beam and the weak returning Raman spectra would be severely attenuated by passage through 15 meters of typical flowing turbid watercourse media. The system could be towed near the bottom of the watercourse; however, this increases the risk of snagging and damaging and possibly loss of the submerged part of the system. Additionally, the technique deals with very low energy levels, which necessitates delicate and costly electronics. The technique was discarded since it did not seem to be responsive to the objectives of the program.

Ultrasonics

Of all forms of energy known to man, sound travels through water the best. In turbid, rough water conditions, both light (optical methods) and radio waves are attenuated to a far greater degree than is sound. Because of its relative ease of propagation, underwater sound systems are being used for depth-range recording, fish-finding, environmental monitoring, biomedical research, metallurgy applications, as well as exploration of seas, rivers, and lakes, and forms the framework for the pollutant mapping technique.

Theory of Echo-Sounding and Ultrasonics--

Catacoustics is defined as that part of acoustics that deals with reflected sounds, or echoes. It is this portion of underwater acoustics that forms the basis of the pollutant mapping technique.

Based on Huygen's Principle (4, 5) that an acoustic wave front expands radially until it encounters either a medium having a different sound speed or an object, Figure 9 shows a sound wave propagating from fresh water above, into a pool of dense, low-soluble hazardous material (i.e., CCl_4 density = 1.595 g/cm^3) below. The incident wave, traveling in the direction of the arrow labeled p_i, impinges on a surface, its angle θ_i measured from the normal to the surface. The reflected wave, p_r, leaves the surface at angle θ_r. When $\theta_i = \theta_r$, the reflection is termed specular, in that the reflection has a waveform that is a duplicate of the incident waveform and can be perfectly correlated with it. Some of the sound penetrates the material, setting up waves in that medium. The penetrating or transmitted ray, p_t (Figure 9), travels in a direction θ_t which is determined by Snell's Law (4, 6),

$$(\cos \theta_i / C_o) = (\cos \theta_t / C_1)$$

for acoustic waves. This penetrating wave, p_t, will be reflected off the next boundary layer, which in the case of the pollutant mapping technique will be the watercourse bottom, and travel back through both mediums to the transducer.

Figure 10 shows the expected video mode display of an echo-sounding system for a two-layered, liquid-liquid medium. The initial echo return time (from the CCl_4 interface) is composed of twice the water depth transit time. The bottom echo return time is composed of twice the water depth time plus twice the transit time in the pollutant layer. Pollutant depth measurements are thus based on the time difference between the return echoes from the pollutant-water interface and the bottom.

When traveling through a medium other than water, the speed of sound, c, is dependent on the adiabatic compressibility and density of the medium (4).

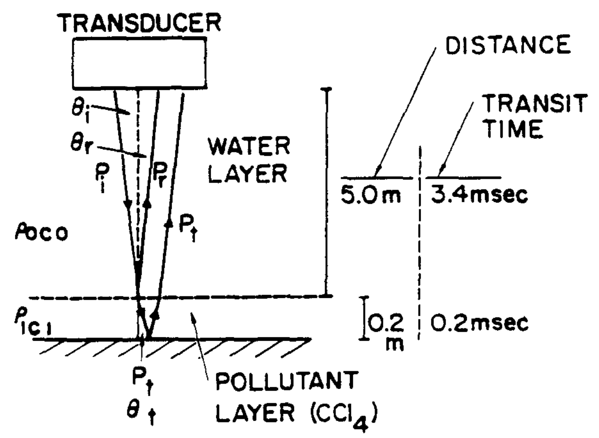


Figure 9. Ray diagram depicting the incident, reflected and refracted acoustic waves generated at a liquid-liquid interface. Refracted wave shown for $\rho_0 c_0$ (fresh water) $< \rho_1 c_1$ (CCl_4).

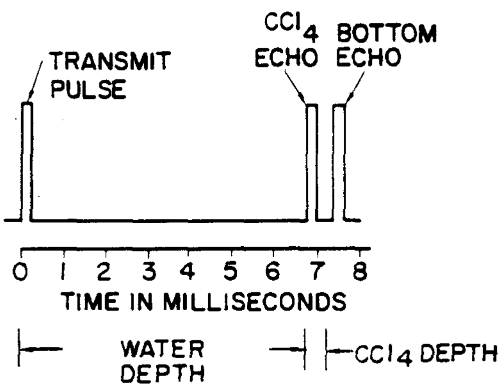


Figure 10. Expected video mode display for conditions shown in Figure 9. Return echo time composed of twice the travel time (transmit down, echo return up).

The speed of sound in the pollutant carbon tetrachloride, for example, is only 63% of that in fresh water. This causes the sound to slow down and increases the depth resolution. In order to differentiate the return signals, the pulse width of the transmit signal must be short enough that the return signals do not overlap in time and combine to form only one return signal. Figure 10 illustrates a resolvable set of echoes with the transmit pulse being 60 microseconds long.

The echo-sounding technique measures the time for a sonic signal to go from the transducer face to a reflective interface (watercourse bottom or liquid-liquid boundary layer) and back to the boat. The known sound speed in the traveling medium is then used to convert the travel time to acoustic depth. In order to have an efficient echo-sounding system, two parameters that need to be defined are the desired depth of penetration and the resolution required.

The depth of penetration of sound signals is dependent upon the frequency of the signal and the absorption coefficient of the medium. The absorption of sound in water increases dramatically as the acoustic frequency is increased (see Table 3) (4, 5).

Resolution of a sonar system is a complex relationship involving beamwidth, bandwidth, and most importantly, pulsewidth (5). The beamwidth, defined as the angle from half power to half power of the main acoustic beam, is dependent on the internal design of the transducer. In general, the narrower (i.e., more directive) the beam pattern, the greater the resolution (decreases the insonified area). Greater resolution can also occur by utilizing a deep towed array. Acoustic energy in the ultrasonic frequency range is known to reflect from layers of slightly different density such as thermoclines. The knowledge developed from the depth-sounder application proved that usable bottom echo signals could be recovered from depths of several hundred feet. This knowledge, when coupled with the well-developed portable sporting equipment, indicated that ultrasonic reflection studies were the best candidate for continued investigation.

ULTRASONIC POLLUTION MAPPING DEVELOPMENT

Phase 1 - Screening Test

The initial laboratory test was designed to test the feasibility of the acoustic mapping technique. The test was conducted using a 1-liter beaker with a 1-MHz transducer powered by a Budd Instrument 725 Immerscope in the video mode display. The beaker contained a 1.3-cm layer of CCl_4 on the bottom and a 6.3-cm layer of fresh water from the transducer face to the top of the CCl_4 layer.

The results (see Figure 11) indicate that acoustic signals reflect from the CCl_4 layer, as well as transmit through the layer and reflect back from the bottom. The CCl_4 depth is shown to be approximately 1.9 cm, but this is slightly over-estimated, since the display on the Immerscope was calibrated against the speed of sound in fresh water, not CCl_4.

TABLE 3. THE EFFECT OF FREQUENCY UPON ABSORPTION COEFFICIENT AND SINGLE PULSE WIDTH[a]

f (kHz)	Minimum Single Pulse Width (μsec)	Absorption Coefficient (dB/km)(4,5)
1	1000.0	2.20×10^{-4}
10	100.0	2.20×10^{-2}
50	20.0	1.84×10^{-1}
100	10.0	2.20
200	5.0	8.79
300	3.3	19.78
400	2.5	35.17
500	2.0	54.95
700	1.4	107.71
1000	1.0	219.82

a - All calculations are referenced to sound speed in fresh water (1463 m/sec).

Phase 2 - Depth-Sounder Tests in Cylindrical Container

The 1-MHz laboratory test unit operated at high frequency compared with the 200 kHz used in commercial depth-sounders and fish-finders. Penetration of water is a function of frequency, so this 1-MHz unit seemed not to be optimal for testing in deeper water. It also had low power capabilities. A Heathkit Model 1030-2 depth-sounder kit, operating at 200 kHz, was purchased and assembled. The Heathkit was chosen over the many depth-sounders in the commercial market for its superior documentation of the electronic circuitry and theory. The Heathkit circuit appears as Figures 12 and 13, which are shown for general information only. (For component identification, please refer to the Heath Company, Benton Harbor, Michigan.) Pulse repetition rate is controlled by the motor speed through a magnet on the spinning disk. In depth-sounder operation, each time the magnet passes over a switch it causes a pulse of ultrasonic energy to be emitted from the transducer. The echo from the bottom is detected by the transducer (acting now as a receiver),

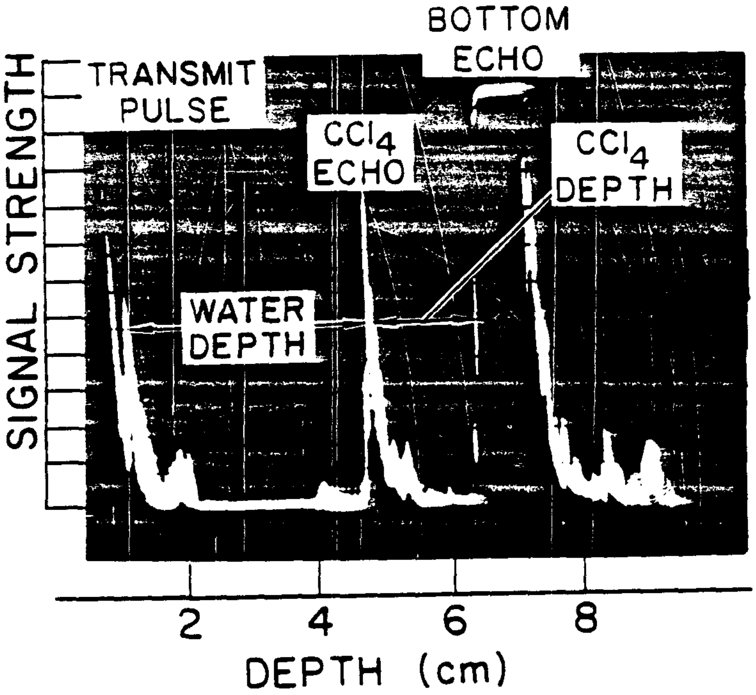
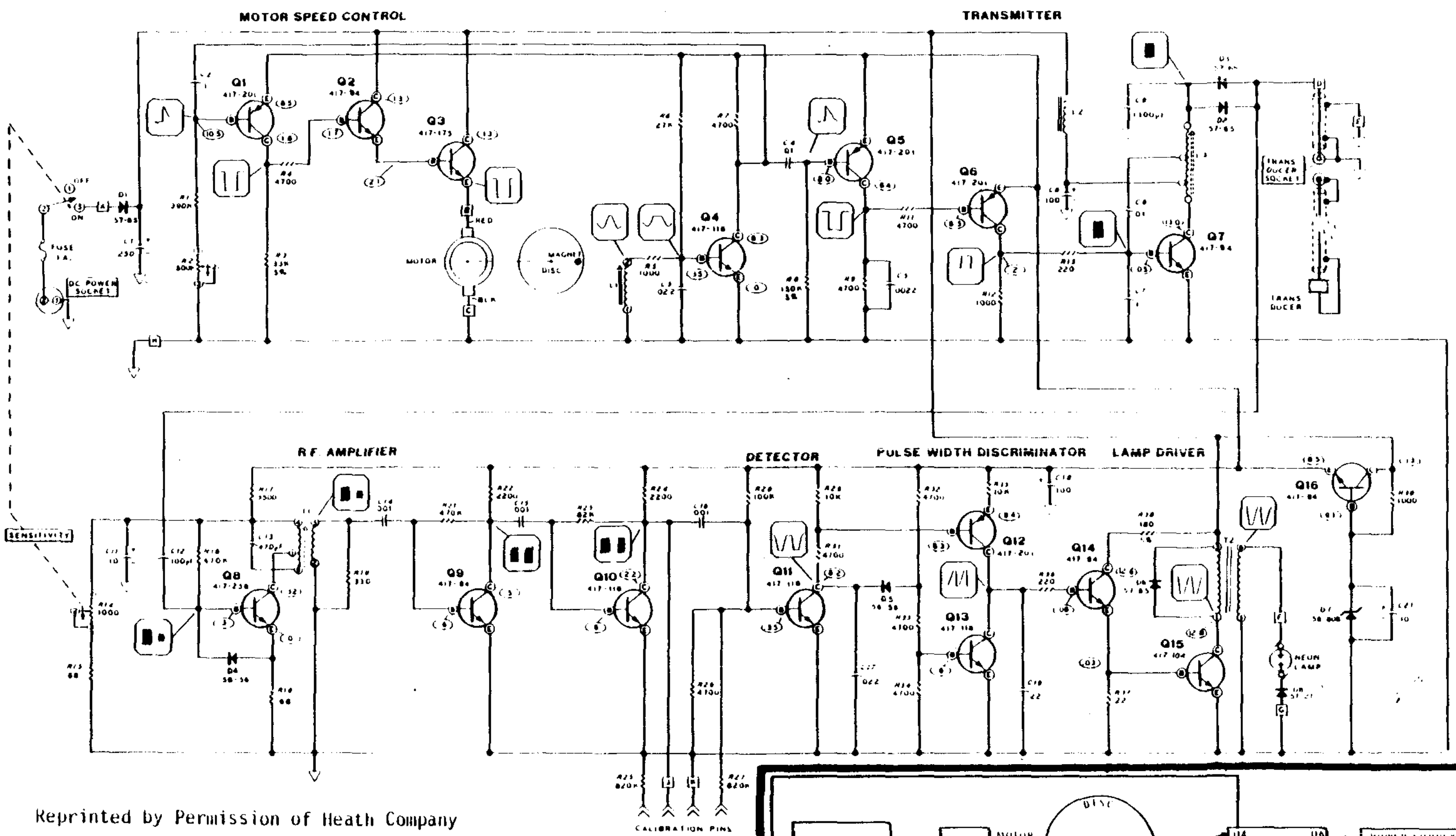


Figure 11. Detection of carbon tetrachloride layer at the bottom of a beaker full of water.

amplified, and the signal causes a neon light on the spinning disk to flash. The angular location of the echo flash is used as the depth indicator. If a large body such as a school of fish is interposed in the beam, two flashes occur. The first is the echo from the fish and the second from the bottom.

The system as assembled had an ultrasonic pulse width of 1.4 ms and a repetition rate of 20 Hz. The typical sounder propagation rate in fresh water is 1480 m/sec (in salt water at 21°C it is 1520 m/sec) (4). Thus during the 1.4-ms pulse width, the sound travels 2.07 m. This is diagrammed in Figure 14, which shows the sound travel paths for the bottom and pollutant surface return echoes. The acoustic signals are actually superimposed but have been offset for clarity. Figure 15 shows a synthesized signal based on a theoretical square-wave 1.4-ms pulse envelope. Note that the echo returns from a 10-cm-deep pollutant pool and the bottom superimpose because of the pulse length.

The superposition of the pool and bottom echoes may be minimized by shortening the transmit pulse length. In addition, the receiver amplifier of the depth-sounder was designed to perform the neon lamp control function and not to reproduce the echo signal. Accordingly, the electronics were redesigned to optimize return amplification and to permit adjustment of both pulse length and repetition rate. The receiver amplifier was replaced by a new amplifier, as shown in Figure 16.



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SCHEMATIC OF THE HEATHKIT DEPTH SOUNDER MODEL MI-1030

SCHEMATIC NOTES

1. ALL RESISTORS ARE 1/2 WATT UNLESS MARKED OTHERWISE. RESISTOR VALUES ARE IN OHMS (K = 1000, M = 1,000,000).
2. ALL RESISTORS ARE 10% UNLESS MARKED OTHERWISE.
3. ALL CAPACITOR VALUES ARE IN µF UNLESS MARKED OTHERWISE.
4. REFER TO THE CIRCUIT BOARD X-RAY VIEW FOR THE PHYSICAL LOCATION OF PARTS.
5. ▽ THIS SYMBOL INDICATES A GROUND CONNECTION.
6. ( ) THIS SYMBOL INDICATES A DC VOLTAGE MEASUREMENT TAKEN WITH A HIGH IMPEDANCE VOLTMETER. ALL VOLTAGE MEASUREMENTS WERE TAKEN WITH ONLY A "ZERO FLASH" (NO RETURN FLASH) ON THE DIAL, THE SENSITIVITY CONTROL AT MINIMUM, AND WITH AN INPUT SUPPLY VOLTAGE OF 13.8 VDC. VOLTAGES MAY VARY ±20%.
7. THIS SYMBOL INDICATES THE APPROXIMATE WAVEFORM TO BE SEEN WITH AN OSCILLOSCOPE AT THE POINT INDICATED.
8. THIS SYMBOL INDICATES CLOCKWISE ROTATION OF A CONTROL WHEN VIEWED FROM THE KNOB.
9. - - - THIS LINE REPRESENTS A MECHANICAL CONNECTION BETWEEN THE POINTS INDICATED.
10. THIS SYMBOL INDICATES A LETTERED CIRCUIT BOARD CONNECTION POINT.

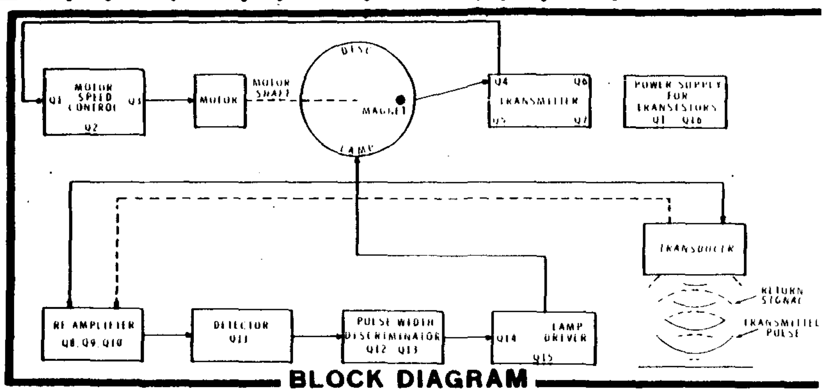
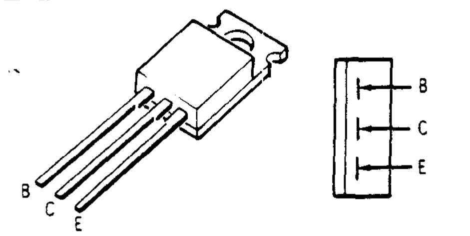
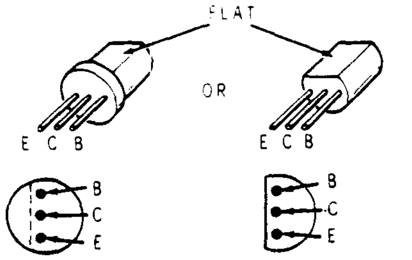
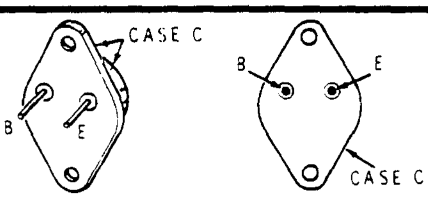


Figure 12. Heathkit electronics.

TRANSISTORS

COMPONENT NO. (Q NO.)	HEATH TYPE NO.	PART NO.	BASE DIAGRAM
3	417-175	2N5294	
2, 7, 9, 14, 16	417-94	2N3416	
4, 10, 11, 13	417-118	2N3393	
1, 5, 6, 12	417-201	X29A829	
8	417-258	TIS87	
15	417-104	37436	

DIODES

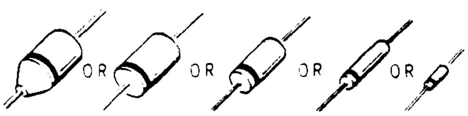
COMPONENT NO.	HEATH PART NO.	TYPE NO.	IDENTIFICATION
1, 2, 3, 6	57-65	1N4002	HEATH PART NUMBERS ARE STAMPED ON MOST DIODES 
4, 5	56-56	1N4149	
7	56-608	1N4739A, 9.1V ZENER	
8	57-27	1N2071	

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Figure 13. Identification chart.

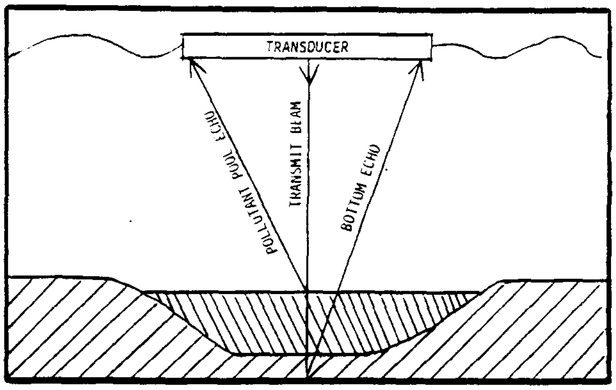


Figure 14. Sound path diagram (superimposed signals are separated for clarity).

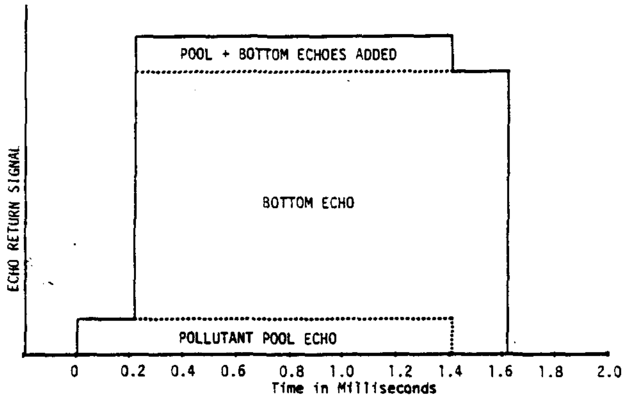


Figure 15. Return signal from a 1.4-ms square-wave pulse envelope.

The system was adjusted to a pulse length of 30 microseconds and a repetition rate of 16 Hz and used to study the return echoes from a water-filled metal container 580 mm in diameter and 880 mm deep. The test container was a standard 189-liter (55-gallon) drum with the top removed. The face of the transducer was located a nominal 1 cm below the surface of the water. The transducer was treated and wiped free of any surface bubbles that can cause signal attenuation and masked echo returns.

Figure 17 is a photograph of the oscilloscope screen with the horizontal sweep set at 0.2 ms per division and the vertical amplifier set at 500 mv per division. The start of the transmit pulse was used to trigger the sweep of the oscilloscope. The bottom return echo arrives at the transducer 1049 microseconds after the start of the transmit pulse. Using the literature value (4) for the speed of sound in water at 19°C (1483 m/sec), one calculates a two-way distance of 1555 mm, or a depth of 778 mm. This is within 1.6% of the 765 mm measured with a scale.

The intensity of the return echo from the surface of a CCl_4 pool is only 2.9% of that from the hard bottom of the metal container. This necessitates a dynamic range expansion to study both return signals in detail. Additionally, the time separation caused by a 23-mm depth of CCl_4 is only 48 microseconds, which requires time expansion to obtain readable changes of the oscilloscope pattern (sound speed in CCl_4 = 938 m/sec). The time expansion was easily obtained by use of the sweep/time delay feature of the oscilloscope. Figure 18 shows the return echo with the sweep speed increased to 20 microseconds per division and the start of the sweep delayed 952 microseconds. The dynamic range requirement is satisfied by use of the two-channel feature of the oscilloscope.

The sensitivity of the second channel was set at 50 mv/division, which is 10 times that of the first channel. Figure 19 shows the oscilloscope trace under these conditions. Figure 20 shows the combination of the two traces in one photograph obtained by parallel feeding of both channels from the amplifier

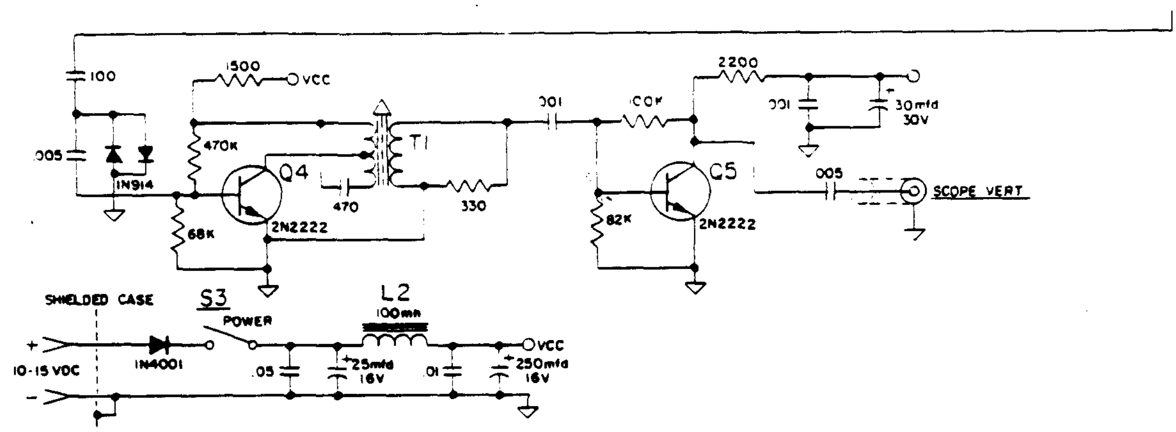
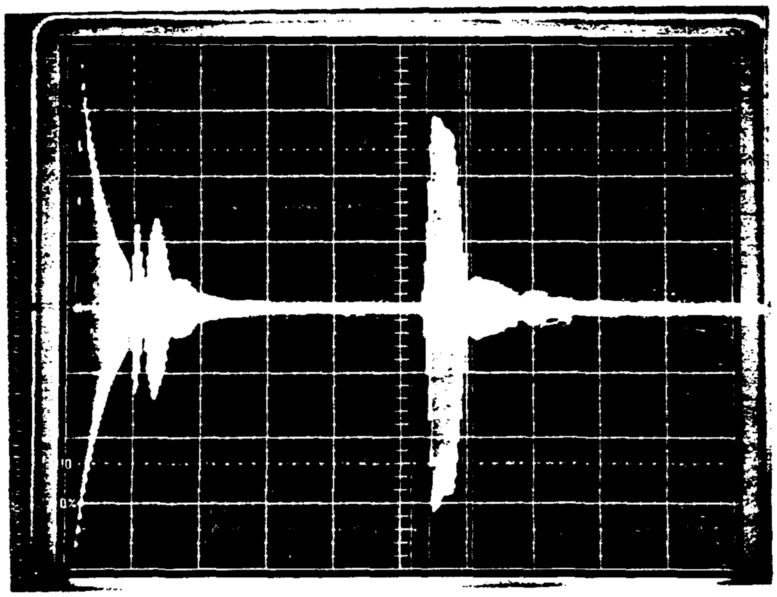


Figure 16. Receiver amplifier.

Signal, 500 mv per division



Time, 2 microseconds per division

Figure 17. Return echo from 765-mm-deep water column.

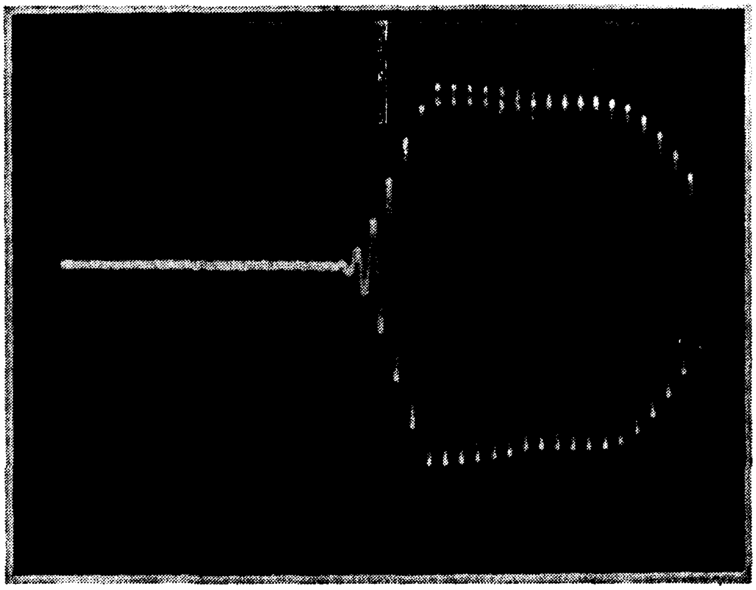


Figure 18. Expanded echo return.

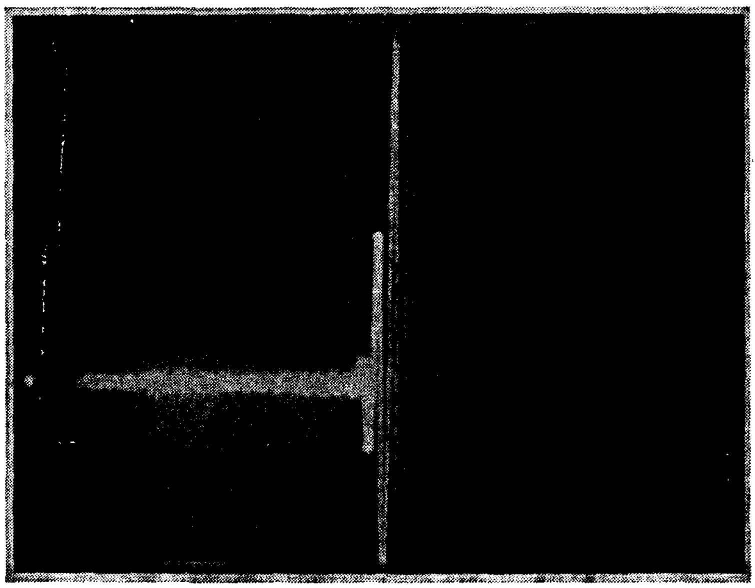


Figure 19. Expanded return echo with tenfold sensitivity increase.

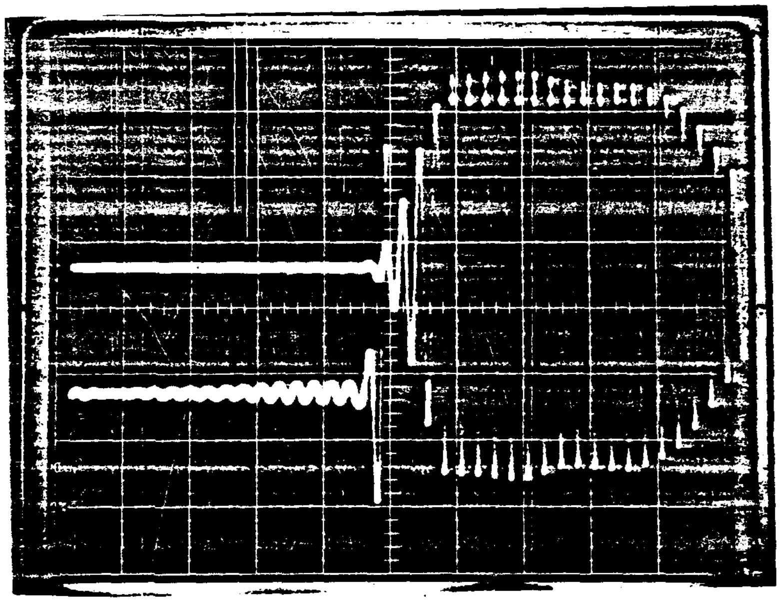


Figure 20. Combined echo returns, both high and low sensitivity, clean bottom.

output and use of the alternate sweep feature of the oscilloscope. The rapid and offscale images of the number 2 channel disappear because of photographic emulsion limitations. This results in an oscilloscope pattern where the leading portion of the bottom return echo may be studied in detail and still retain the entire bottom echo for study.

Figure 20 shows the bottom return echo when there is no pollutant pool, and Figure 21 shows the change caused by addition of a 21-mm-deep pool of CCl_4. The advantage of the time and range scale expansion is clearly demonstrated in these photographs. The bottom return echo has been delayed 49 microseconds by the CCl_4 pool.

Literature values for the speed of sound in water and CCl_4 at 19°C are 1483 and 938 m/sec, respectively (5). In the test depicted in Figure 20, the sound traveled through 765 mm of water to the bottom and returned for a total path length of 1530 mm and a calculated travel time of 1022 microseconds. In the figure, a 21-mm pool of CCl_4 was interposed, shortening the water travel to 1488 mm (time = 994 microseconds) and adding travel along a 42-mm path in CCl_4 (time = 45 microseconds). Thus the total time for the sound signal's round trip should be 1039 microseconds, or 17 microseconds longer than without the pollutant pool. The validity of this calculation is demonstrated experimentally by comparing the position of the bottom return echoes in Figures 20 and 21. The echo is seen to have moved one division, 20 microseconds, lenghtening the return time, as expected.

The echo from the surface of the pollutant pool should arrive 28 microseconds before the bottom echo when there is no pollutant, since the travel

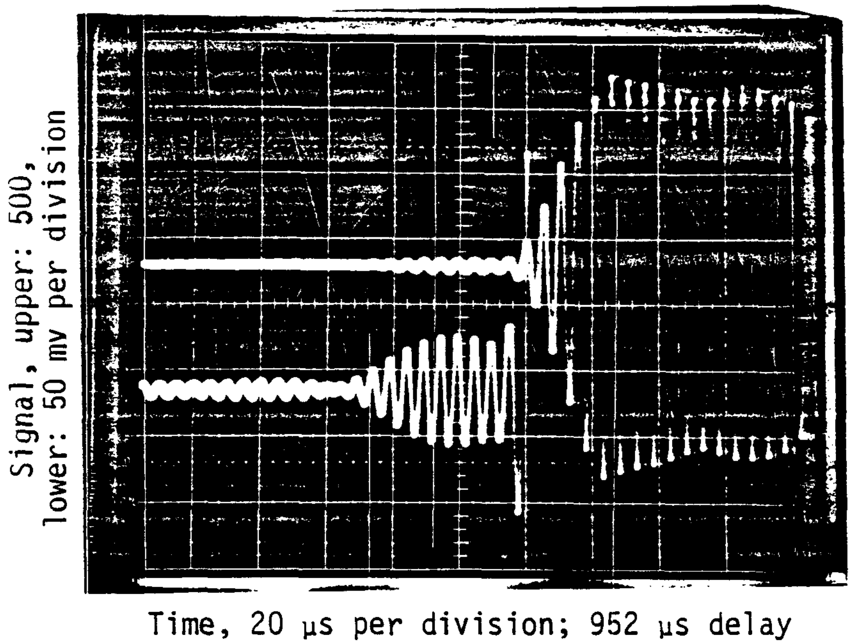


Figure 21. Combined echo return, 21-mm-deep CCl_4 bottom layer.

time through the water is 994 microseconds, not 1022. The high sensitivity (lower trace, Figure 21) supports this expectation. It has therefore been shown that all phases of the theory are substantiated, and that a detectable echo signal may be recovered and resolved from the surface of a 21-mm CCl_4 pool. Similar testing has been performed in tanks with sand and mud bottoms. In all cases, a 1-cm or thicker layer of CCl_4 produced a detectable change in the bottom return echo.

SURROGATE POLLUTANT

Some effort was directed toward development of a surrogate pollutant material. This material, such as a large sheet of plastic, could then be mounted on the bottom of a watercourse to simulate a pollutant pool. The study was a brief one and was unsuccessful. The problem of deploying such a material on the bottom of a watercourse, coupled with the lack of suitable material, indicated that the effort could be better directed elsewhere.

FIELD TEST SYSTEM

The goal of the field test system was to capture the actual bottom return echoes from the field for laboratory and computer study. Oscilloscope trace photography and digitization of the photographs, as was done for the laboratory studies, seemed to be the most cost-effective solution to the problem. A 16-mm motion picture camera was modified by placing a light source and detector straddling the shutter. As the shutter exposed the film to the lens, the detector was exposed to the light source and thus generated a trigger signal. Figure 22 shows the depth-sounder electronics as modified to use this signal. Appendix A contains a technical description of the circuitry. Switch S1 allows either an internal oscillator or the camera trigger to control the

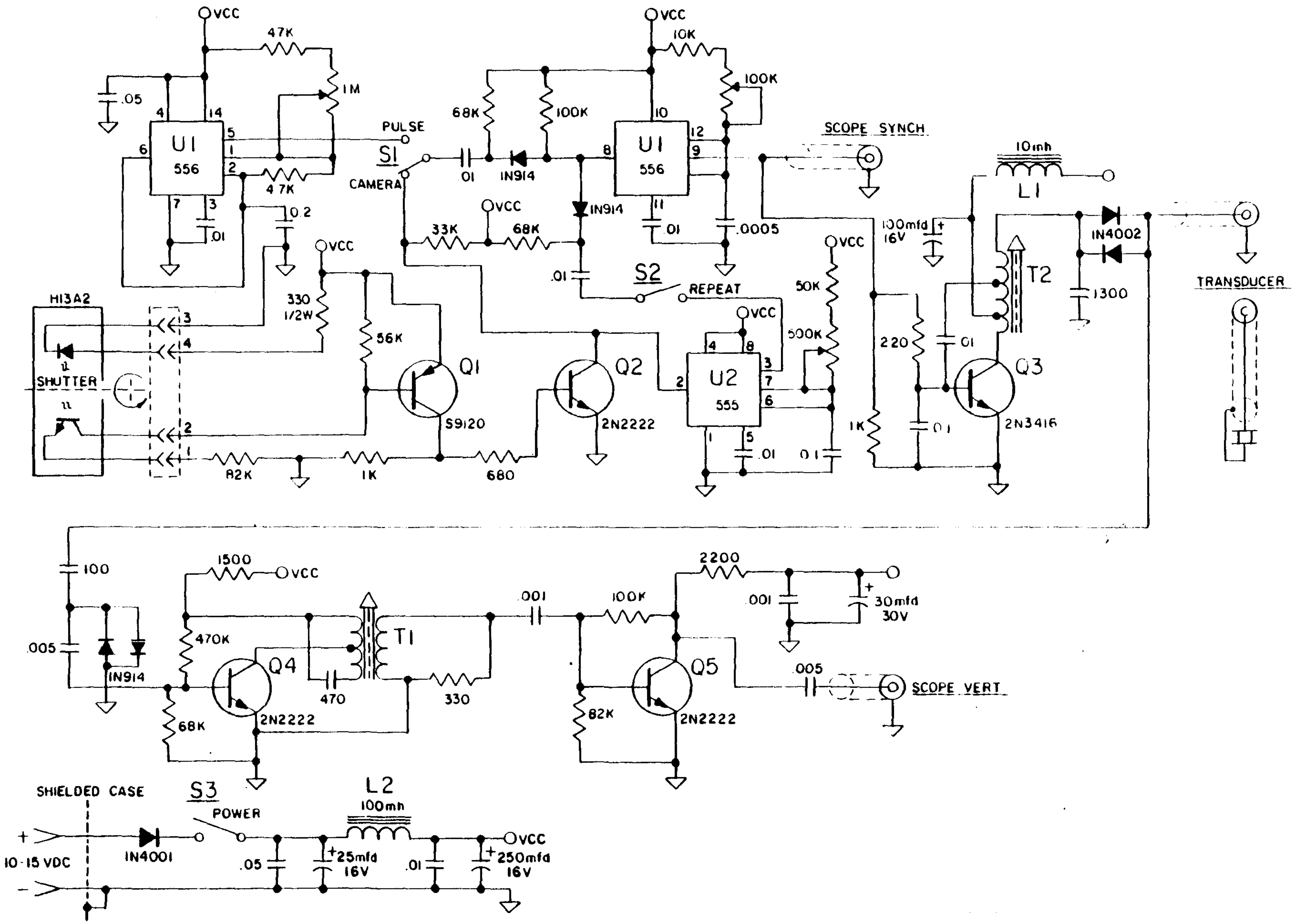


Figure 22. Electronic circuitry used in field studies.

sounder pulse generation. The two-sounder-pulse-per-camera-pulse feature is required to retain the desired dynamic range extension. It is controlled by switch S2.

This system allows the investigator to photograph a continuous stream of bottom return echoes for later study either subjectively by typical motion picture projection or objectively by digitization and computer data treatment. Two techniques for utilization of the ultrasonic system will be presented later. The basic one uses subjective evaluation of the oscilloscope trace in an on-board mode. The other involves the digital computer evaluation of the data.

This system and an earlier single-range system have been used to study the watercourse bottom return echoes from a variety of sources. The most used site was Lake Casitas, a local fresh-water recreational lake. There, a 3- x 5.5-meter pontoon boat was rented and used as a deployment vehicle. Figures 23 and 24 show the boat and the equipment in use. (The lower oscilloscope is not part of the system and was used for generator evaluation.) During a trip arranged for other purposes, the system was operated on a houseboat cruise in the San Francisco, California, middle delta region. Here, bottom echoes were photographed in tidal brackish water sloughs and watercourses. Figure 25 shows sections from nautical charts 18662 and 18661 locating the areas of Meadows Slough and the South Mokelumne River that were studied. Depths ranged from 1.8 m (6 ft) to 13.7 m (45 ft). Bottom conditions ranged from smooth to weedy and submerged-brush-covered. In all cases, the bottom return echoes were similar to those observed at Lake Casitas.

Each 100-foot roll of 16-mm Super XX negative motion picture film was processed on board the study boat as soon as it was completed. Thus the instrument's function could be immediately verified. Figure 26 shows the processing in an Arkay reel-to-reel film-developing tank. After washing, the film was dried between hooks on the boat, as shown in Figure 27.

More than 1000 feet of 16-mm film taken during the field studies has been subjectively evaluated by slow-motion projection. There were many short transient areas of film where the leading edge of the echo return was very complex because of submerged weeds and brush, but in most of the film the precursor echo of a pollutant pool would have been visible. Transient precursor echoes at various depths were observed and attributed to fish and gas bubbles.

In some cases a large echo was seen to originate at the bottom and rise through the next several frames. These observations were attributed to the decomposing material on the lake bottom releasing gas in large bubbles. Echoes from these gas bubbles were seen to separate from the bottom and rise at 23 cm/sec. Bubbles of air generated in the laboratory had a rise rate range of 25 to 32 cm/sec. The echo magnitude reached 15 mv in some cases and varied between 0.5 mv and 5 mv between movie frames. The echo return magnitude was quite variable as would be expected from the random variations in bubble surface. Some lake areas generated large amounts of gas and others were free of gas.

In all cases, these transient echoes were easily recognized and would not have interfered with pool location.

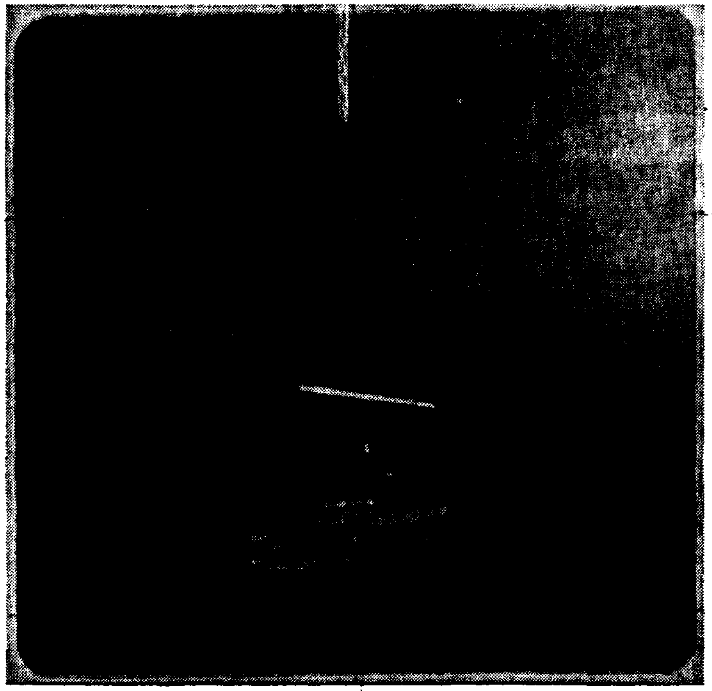
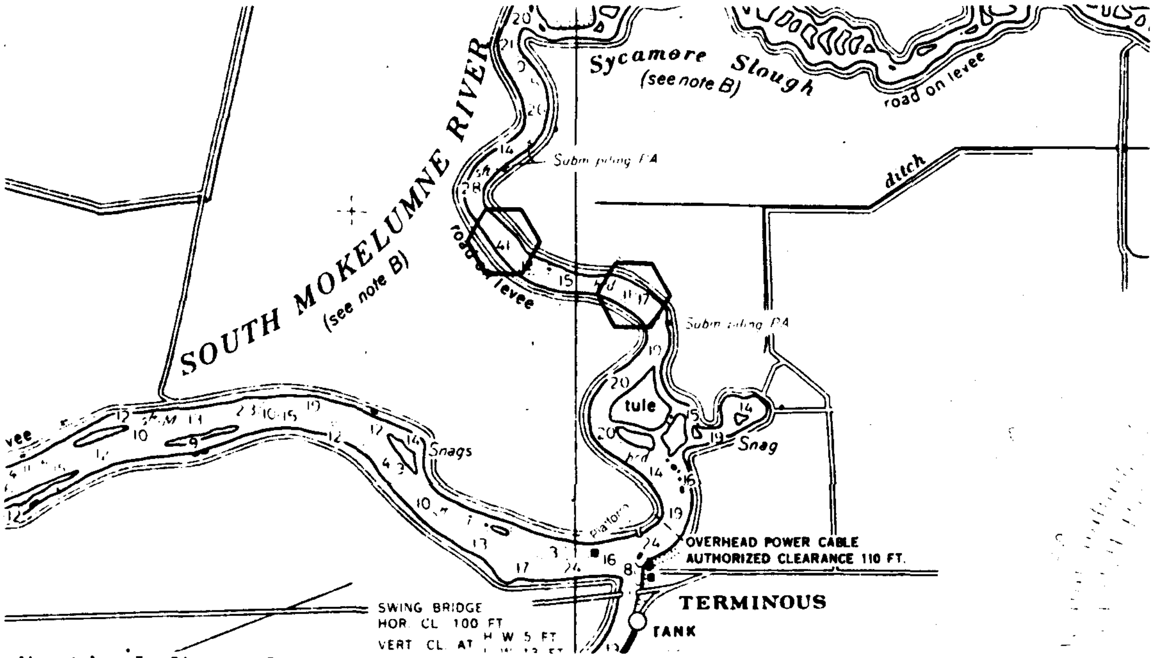
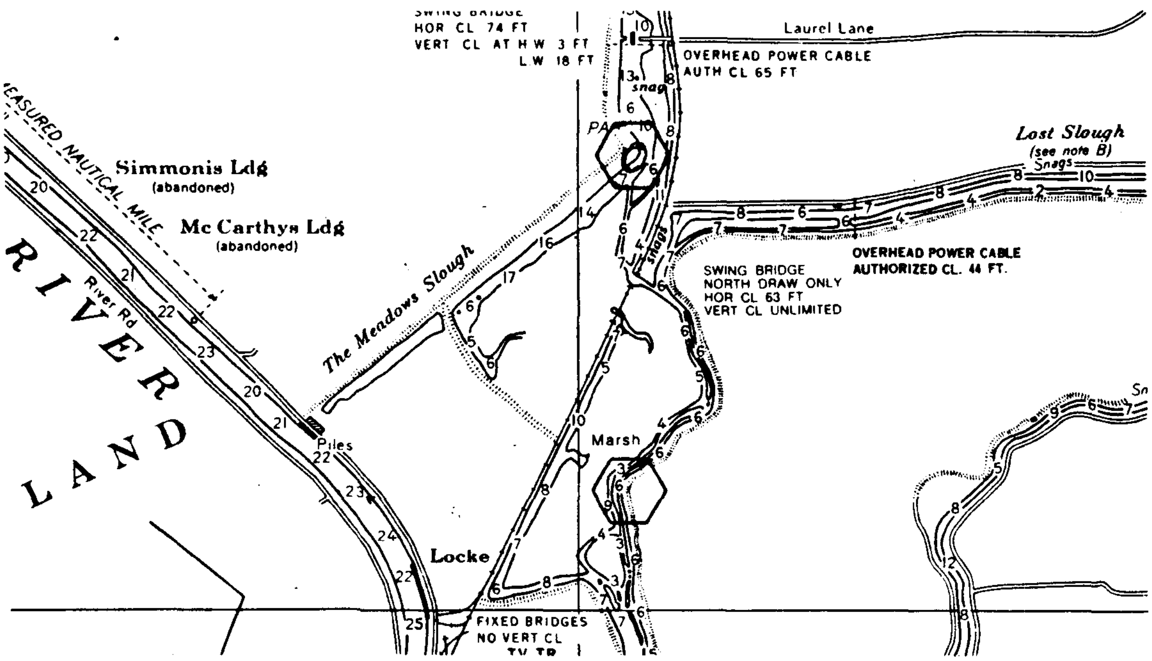


Figure 23. Pontoon boat used in Lake Casitas study.

Figure 24. Lake Casitas study instrumentation.



Nautical Chart 18661



Nautical Chart 18662

Figure 25. Delta Region study areas.

(⬡ indicates areas studied)

Figure 26. Developing 16-mm film.

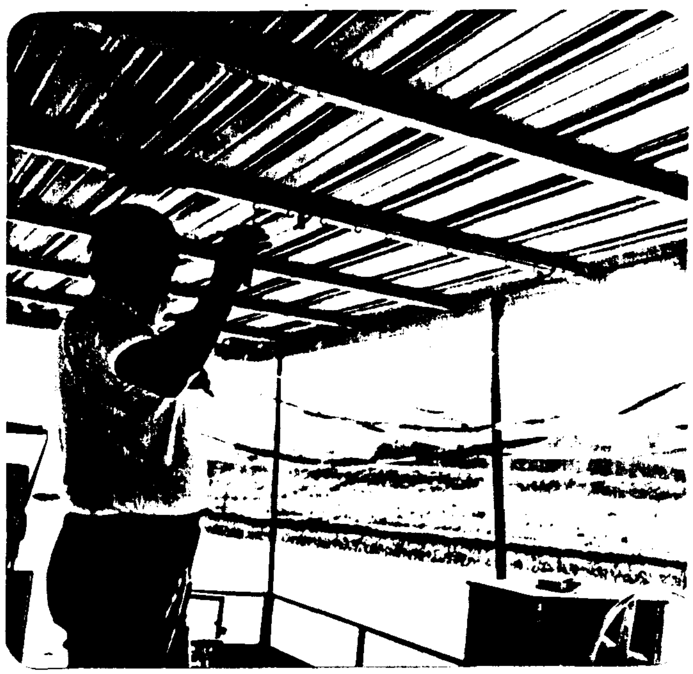


Figure 27. Drying film.

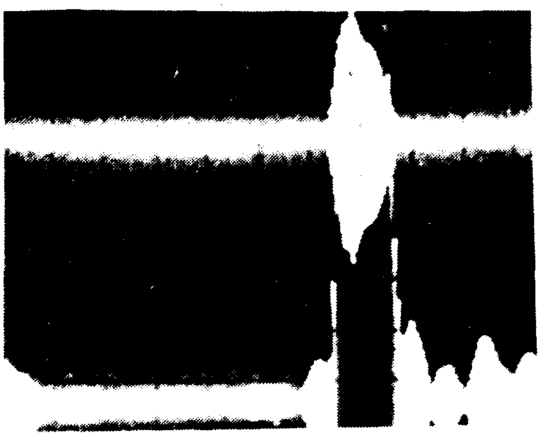
Eighteen representative frames from the laboratory and field studies are shown in Figures 28 through 30.

The experience gained during observation of the oscilloscope during the field studies indicates that an observer should be able to detect the occurrence of a pollutant pool in most watercourse areas. In some weed-covered areas a computer may make better decisions because of its large data storage capabilities.

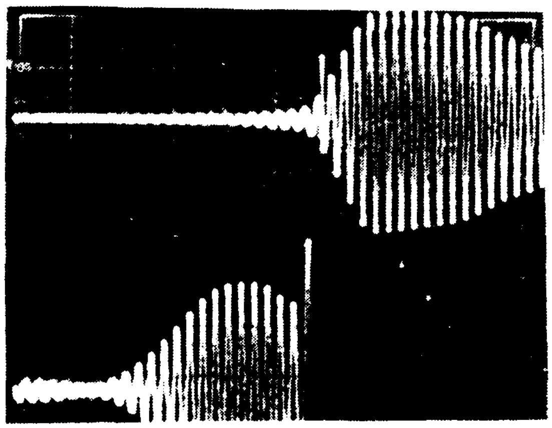
COMPUTERIZED DATA MANAGEMENT

The static laboratory testing has indicated that discernible echoes reflect from the water-CCl_4 interface at the top of a pollutant pool. The field testing results indicate that most of the time there are no precursor bottom echoes that would preclude recognition of pollutant pool echoes. Thus an operator could be trained to continuosuly observe the oscilloscope and sound an alarm when pools are located. This operation would be very labor-intensive since at least two operators would be required to relieve each other. Additionally, only a single detector could be observed, which limits the swath covered by a boat path. This system is, however, recommended as a cost- and time-effective method of implementing the technique.

The search swath could be greatly increased by employing multiple sensors mounted on a boom. In this case the labor required to monitor the multiple signals would become overpowering and attention must be directed to computerized data management.

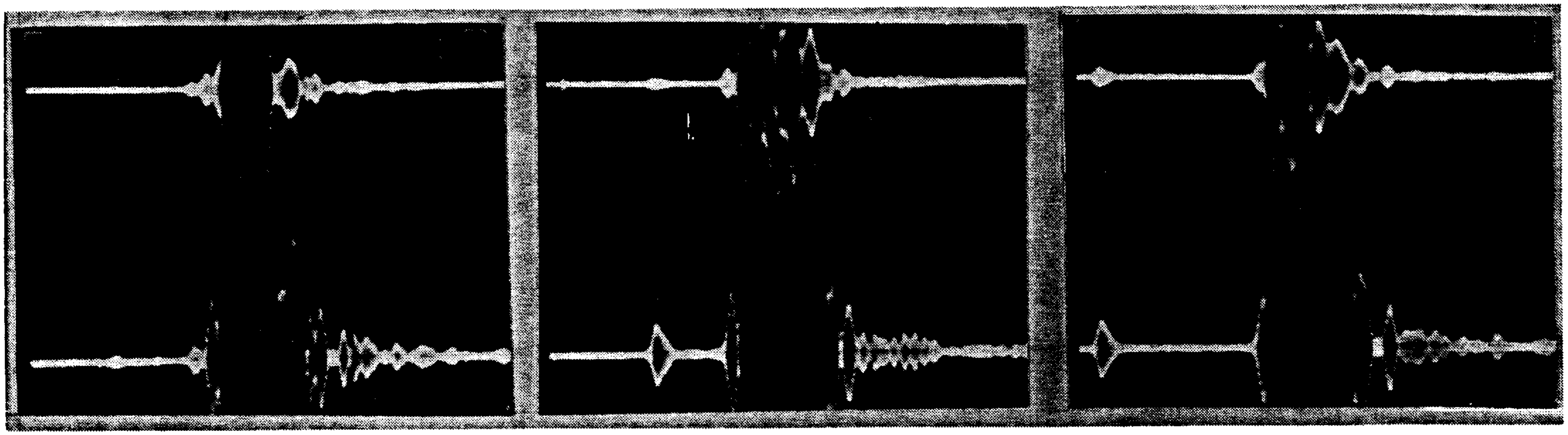


Dual-sensitivity 16-mm photograph showing uncomplicated bottom return echo from metal tank bottom



Dual-sensitivity, time-expanded 16-mm photograph showing both pollutant pool echo (lower, high-sensitivity trace) and metal tank bottom echo (low-sensitivity, upper trace)

Figure 28. Laboratory experiment photographs.

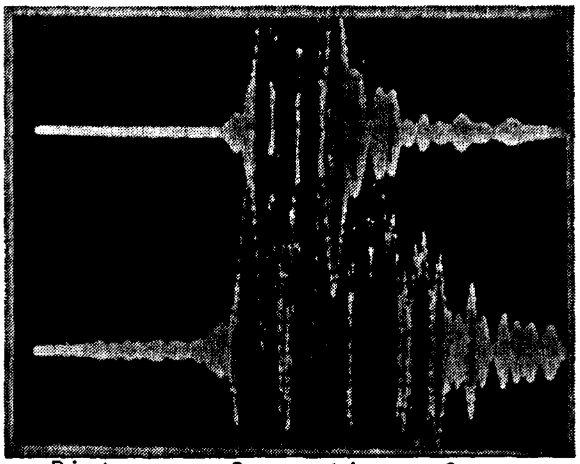


A	B	C

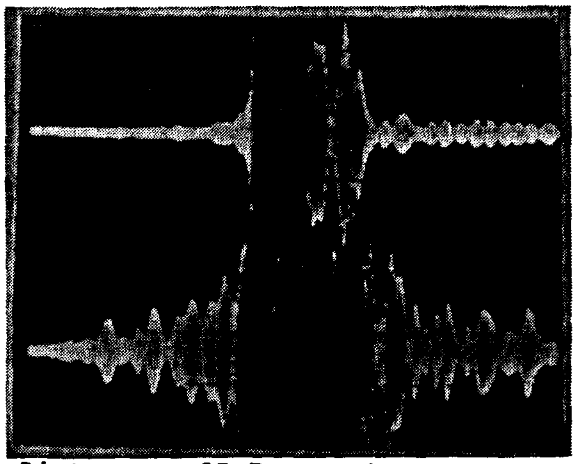
A	B	C
First 16-mm frame showing bubble echo separating from the bottom.	7th frame taken 0.8 sec later. The bubble has now moved toward the surface and its echo is well separated from the bottom.	17th frame taken 1.9 sec after A. The bubble, rising at 23 cm/sec, is about to escape from the time-expanded trace.

Upper trace 20 mv/division; lower trace 5 mv/division. Time increasing to the right at 20 microseconds/division with 14-ms delay.

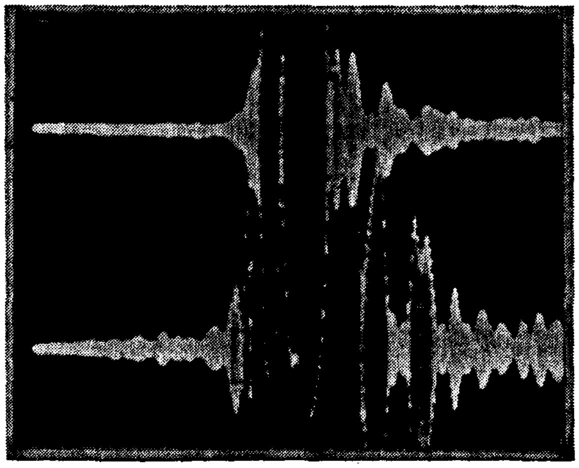
Figure 29. Field study photographs showing rising gas bubble.



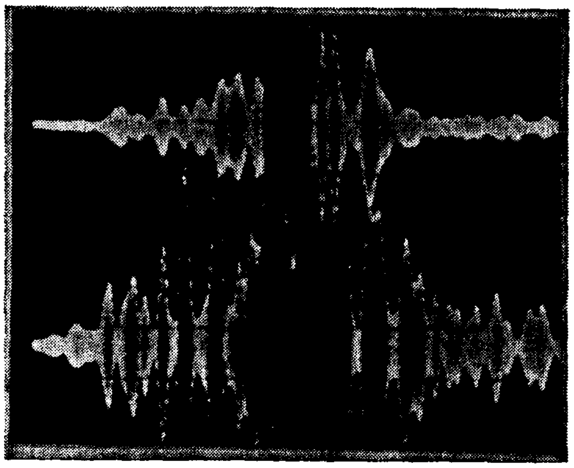
Distance = 0 cm, time = 0 sec



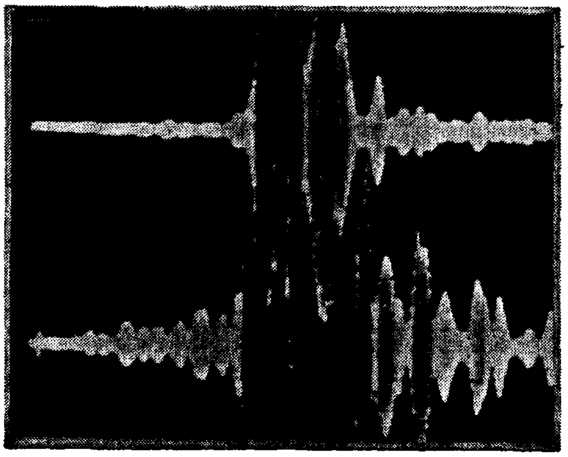
Distance - 25.7 cm, time = 1.0 sec



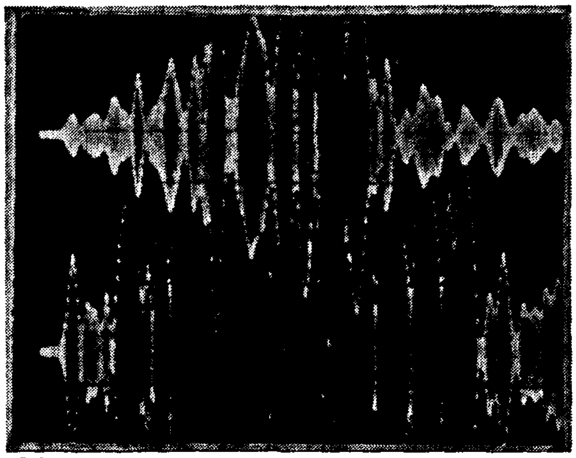
Distance = 8.6 cm, time = 0.3 sec



Distance = 34.3 cm, time = 1.3 sec



Distance ≈ 17.2 cm, time = 0.7 sec



Distance = 42.9 cm, time = 1.7 sec

Expanded - dual-sensitivity 16-mm photographs taken in transit from a smooth-hard bottom area to a weedy bottom area. Time increases to the right in all photographs; at 20 μs/div., 8 ms delay; upper trace = 20 mv/div., lower trace = 5 mv/div.

Figure 30. Photo series in transit from smooth-hard to weedy bottom.

One obvious technique would be the digitization of the amplified bottom return echo and tape- or disk-record it for later processing. It is assumed that positional information will be added to the system at a later stage. This subject has been discussed in some detail in the Recommendations section. The very large data base generated by this simplistic approach and the high-frequency response required to digitize the echo signals limited the value of this technique. Several other techniques of data processing were similarly evaluated and discarded.

One technique seemed to meet the requirements for rapid, on-board data management. Proposed computer algorithms for evaluation of bottom return echoes require echo voltage-time input. This may be expressed as the question: "When, in the time frame of a single pulse and return, did the return signal reach certain voltages?" The following comparator-counter electronics were designed to extract the required data from the echo return signal.

A 3302 integrated circuit contains four independent voltage comparator circuits. The reference voltages are set by external adjustable voltage sources. When the signal input voltage reaches or exceeds the reference voltage, the comparator circuitry executes a switching action. This is shown in Figure 31 where the interaction between a voltage ramp and a comparator circuit is diagrammed. The signal voltage ramp is constant at zero for the first 50 microseconds and then rises monotonically to 10 volts over the next 50 microseconds. The reference voltage of the comparator was set at 5 volts. After 73 microseconds the signal voltage reached 5 volts and the comparator caused a switching action. If a microsecond timer were started at the start of the ramp generation and the comparator used to stop the timer, the timer would read 73 microseconds. This is the time from the start of the cycle to the point where the signal voltage reached the comparator reference voltage.

The same result could be obtained by connecting a counter to a 1-MHz oscillator at the start of the cycle and using the comparator to disconnect it when the reference voltage was reached. As before, the counter would read 73 counts of the oscillator frequency at 1 MHz, equivalent to 73 microseconds.

The application of this technique to a synthesized echo return signal is diagrammed in Figure 32. The application of four comparator-counter pairs with reference voltages set at 10, 20, 40, and 100 mv, is shown. The synthetic echo return signal is patterned after Figure 21 and shows a precursor pollutant pool echo followed by the strong bottom echo. The first counter is stopped at 955 microseconds when the echo return voltage reached the 10-mv reference voltage of the first comparator. The second counter was stopped at 960 microseconds by the second, 20-mv, comparator, etc. Thus the digital data available for computer study would be the times 955, 960, 970, and 1015 microseconds and provide the answer to the question, "When, in the time frame of a single pulse and return, did the return signal reach 10, 20, 40, and 100 mv?"

This comparator-counter technique is proposed for the data management portion of the pollutant mapping system. The system consists of a stable, continuously operating 1-MHz oscillator, a series of counters, and the same number of voltage comparators. The start of the transmit pulse zeroes all counters and connects them to the 1-MHz oscillator. After an adjustable time

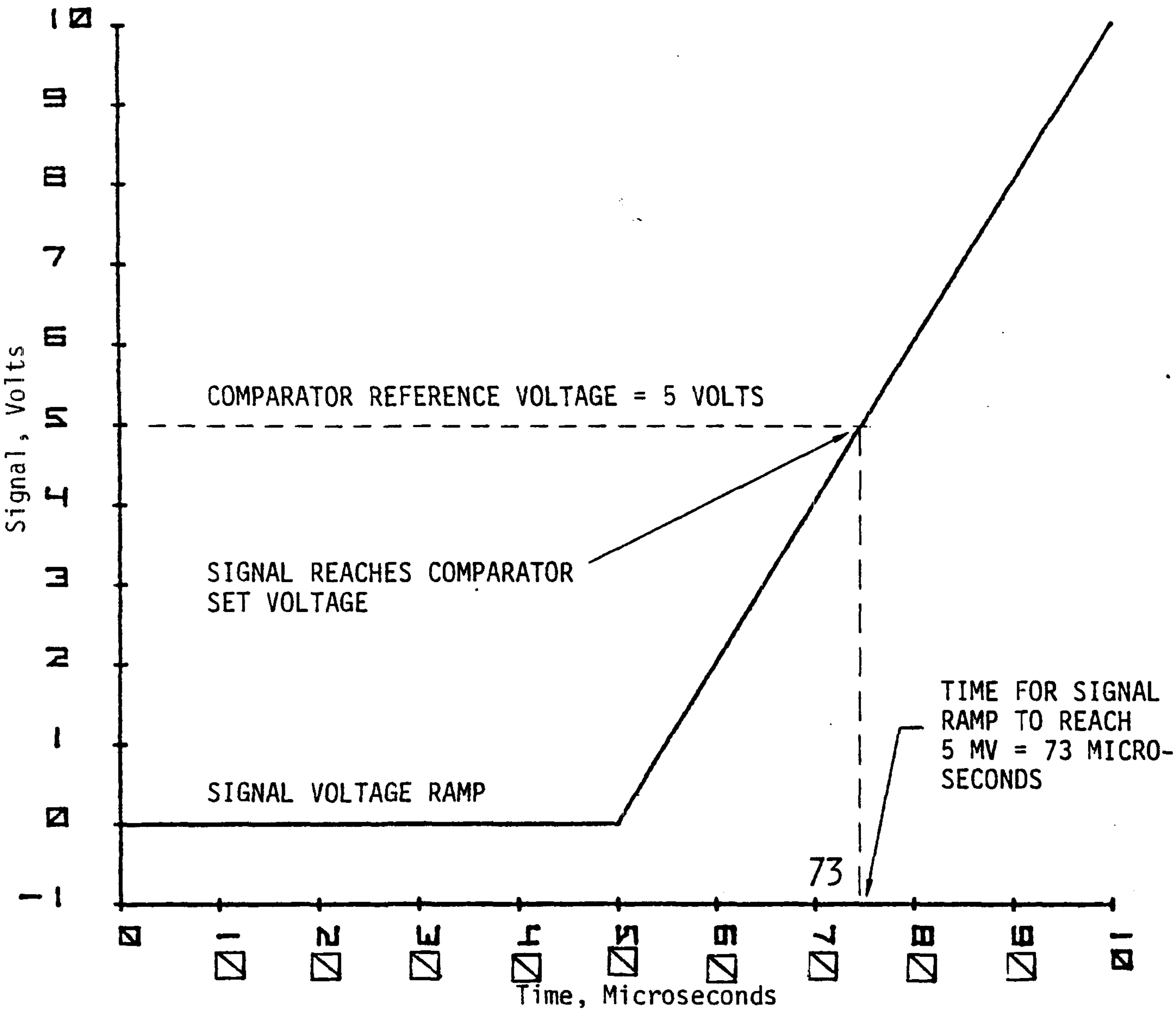


Figure 31. Voltage comparator example.

delay to allow the transmit signal to decay to zero, each counter is turned off when the echo signal reaches the reference voltage set in its associated voltage comparator. This system discussion continues based on six such counter-comparator pairs. (The choice of six is for convenience; the actual number will be chosen on the basis of field evaluation.)

The oscilloscope photographs previously discussed as Figures 20 and 21 were digitized by measuring the positive excursions of the trace referenced against time in microseconds. These digital data appear in Table 4. Visual examination of Figure 21 indicates that the oscillations at 1020 and 1025 microseconds after the start of the transmission pulse are the first returns from the surface of the pollutant pool. If the operator were to set the six comparator levels as shown in Table 5, the microprocessor would have the

TABLE 4. DIGITIZED BOTTOM ECHO DATA, TANK TEST

Time	Figure 20, Clean (mv)	Figure 21, Polluted (mv)
975	1	9
980	1	11
985	0	12
990	0	11
995	1	11
1000	2	11
1005	2	8
1010	3	8
1015	5	11
1020	5	19
1025	3	28
1030	3	34
1035	3	42
1040	28	45
1045	182	46
1050	432	43
1055	834	40
1060	1174	56
1065	1328	185
1070	1344	216
1075	1344	479
1080	1359	803
1085	1375	1112
1090	1375	1313
1095	1344	1467
1100	1328	1421
1105	1282	1390
1110	1266	1375
1115	1266	1313
1120	1297	1266
1125	1282	1282
1130	1236	1297
1135	1174	1313
1140	1066	1313
1145	958	1313
1150	788	1266
1155	602	

TABLE 5. TIME TO REACH SIX REFERENCE VOLTAGES
(digital data from Figures 20 and 21)

Comparator	Voltage (mv)	Fig. 20; clean Time (μs)	Fig. 21; polluted Time (μs)
1	15	1040	1020
2	25	1040	1025
3	50	1045	1060
4	200	1050	1070
5	500	1055	1080
6	1000	1060	1085

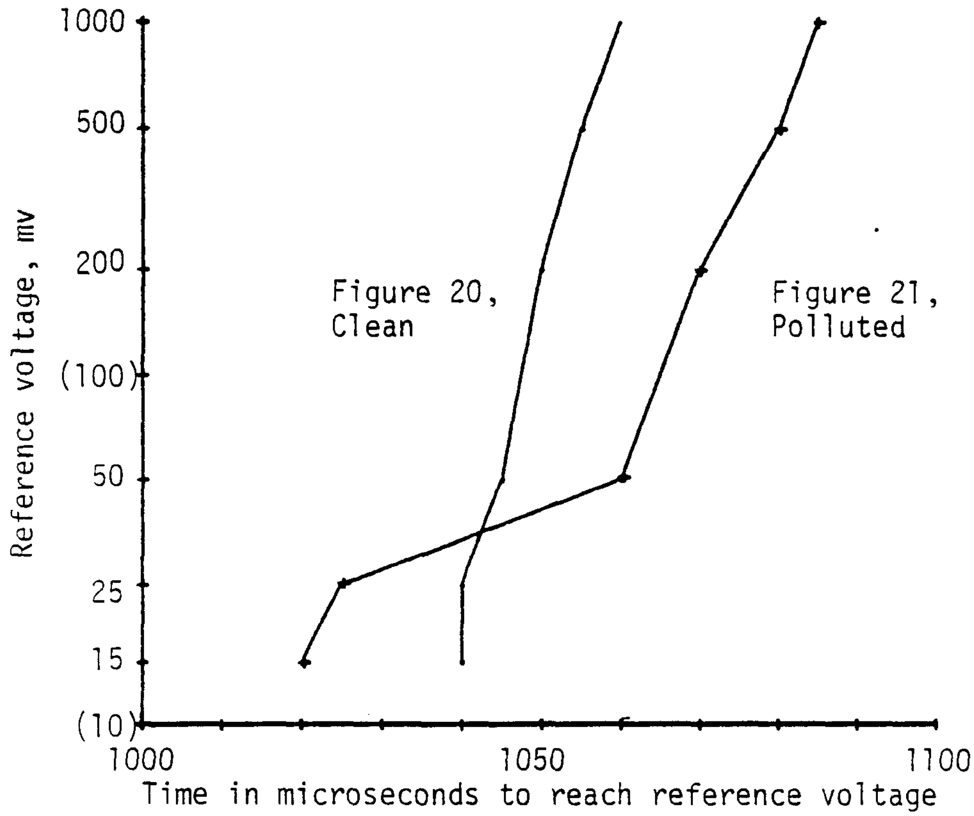


Figure 33. Comparator-time data from Figures 20 and 21.

irregularities, rocks, changes in consistency of the bottom, weeds, fish, etc. could complicate the leading edge of the return signal to a point where detection of the precursor pollutant surface echo may be quite difficult. The creation of a controlled spill in field conditions would be very costly, if it could even be approved. However, the echo from the pollutant pool should be the same whether from the laboratory or the field. Thus if the actual bottom echoes could be measured in detail in the field, mathematical addition of pollutant echoes can be made and the composite signal used to test the computer algorithm.

Selected 16-mm motion picture photographs from the field studies have been digitized for computer study and algorithm evaluation. The digitization was performed by projecting an individual frame on the digitizer platen and following the positive oscillation envelope with the cursor. The Fortran program and running instructions are in Appendix B. The digitization of each motion picture frame results in a file of data relating time to millivolts of return echo signal.

The present program provides for recording up to 160 voltage-time pairs from 200 traces. These limits may be altered in 15 minutes by recompiling the program. The first five voltage-time locations are reserved for the inclusion of synthetic pollution pool echoes.

The present data processing program will recover a selected data file and allow the options of complete printout, determination of the time to reach each of six reference voltages, or alteration of any datum. The reference voltages are input by the operator at run time. After the times to reach the reference voltages are located and stored for printing, the program calculates the water depth determined by the echo return time using 1483 m/sec as the speed of sound in the water and stores that data. All trace pairs (photographs) are treated in turn. The program then returns to "option" and allows the entry of six more voltage comparator levels or the stop command.

Data from the digitization of 45 movie frames, each containing a low and high sensitivity sweep, appear in Appendix C.

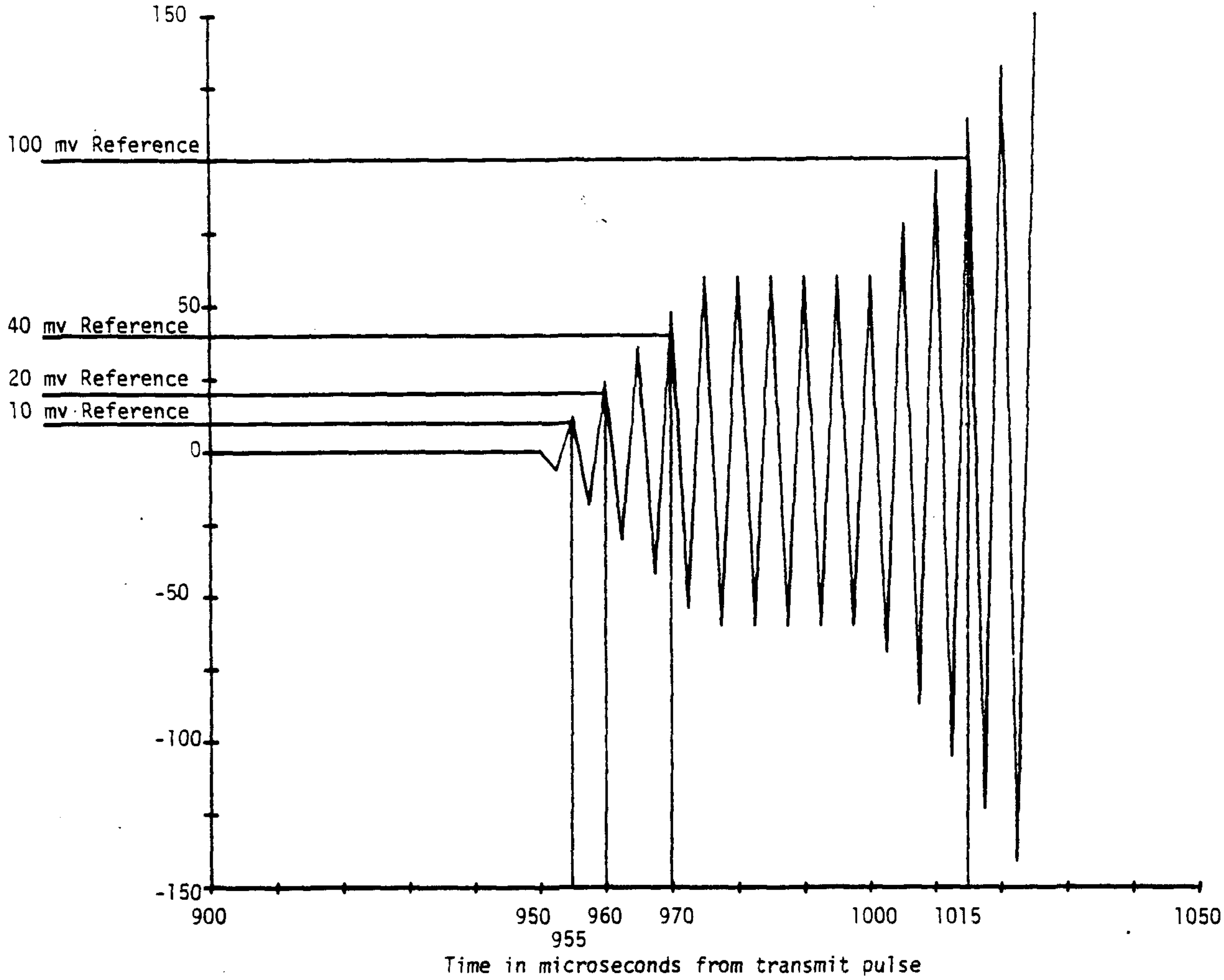


Figure 32. Multiple comparator-timer example.

indicated time data to evaluate in its search for a pool.

A semi-log plot of the data (Table 5) is shown in Figure 33. The forms of these two lines are quite different and a microprocessor algorithm to differentiate between them should not be overly complex. In field use, the bottom echo will be significantly weaker due to the poorer reflection from soft mud bottom compared with the hard metal bottom tank in the laboratory test. The pollutant echo would not change and would be a larger fraction of the total signal. This should simplify the detection of the pollutant layer. The ultrasonic frequency of 200 kHz has been used throughout the study because of its water penetration and its success in depth-sounder use. A higher frequency should be tested in an effort to optimize all parameters for pollutant mapping (see the Recommendations section).

Actual watercourse bottom echoes would be expected to be much more complex than laboratory-produced signals. Such factors as slope, depth

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APPENDIX A

ELECTRONIC CONTROL MODULE

The module is composed of five functional sections: (see Figure 22)

1. Camera shutter position sensor and signal conditioner
2. Repetitive pulse generator and rate control
3. Pulse shaper and repeat pulse generator
4. Transducer oscillator
5. Echo amplifier

CAMERA SHUTTER SENSOR

The Bolex H16 movie camera has been modified with an LED/photo-transistor sensor (H13A2) with the light path bisected by the rotary shutter disc. After uncovering the film gate, the shutter allows an optical coupling in the sensor, which puts a bias on the base of transistor Q1, which in turn applies a bias to the base of transistor Q2. Q2 is driven into saturation, producing a negative-going squarewave output, with a duration corresponding to approximately 60% of the shutter rotation period.

REPETITIVE PULSE GENERATOR

Integrated circuit U1, section 1, is a free-running oscillator with a positive-going squarewave output. The squarewave is approximately 1 ms wide, and the repetition rate may be varied from 20 to 300 pulses per second (3 to 50 ms).

PULSE SHAPER

Integrated circuit U1, section 2, is a single-shot oscillator with a positive-going squarewave output. The output pulse width may be varied from 10 to 50 microseconds. Pulse initiation is selected by switch S1, which connects the input to either the pulse generator or the camera shutter circuit. The trailing edge of the selected pulse grounds the input capacitor, which generates a fast, negative-going spike at the input of the IC, initiating the output pulse.

When switch S1 is in the camera position, a repeat pulse may be generated within 5 to 50 milliseconds by closing switch S2. Integrated circuit U2 is a single-shot oscillator that is triggered by the negative-going edge of the camera pulse, and outputs a positive-going square wave with an adjustable width of 5 to 50 milliseconds. The negative-going edge of the pulse is connected via switch S2 to an input capacitor on the pulse shaper U1-2, triggering the additional pulse.

TRANSDUCER OSCILLATOR

Transistor Q3 is biased on by the positive pulse from the pulse shaper, U1-2, and oscillates at the frequency determined by the adjustable transformer T2. T2 matches the oscillator to the characteristic line impedance of the transmission line and the piezoelectric transducer.

The transducer output is a squarewave envelope of ultrasonic oscillations (approximately 200 kHz), with selectable pulse width and repetition rate.

ECHO AMPLIFIER

The amplifier is coupled to the transducer circuit through a capacitive voltage divider, which incorporates a diode voltage clipper to limit the amplitude of the input signals.

The echo return pulse is amplified by a tuned circuit composed of transistor Q4 and adjustable transformer T1, then capacitively coupled to transistor Q5 for additional amplification.

The output of Q5 provides an AC output, for observation on an oscilloscope, where the horizontal sweep is synchronized with the transmitted pulse from the sync output of the pulse shaper U1-2.

CONSTRUCTION

The module is enclosed in a metal box to provide electrostatic shielding. All signal lines are coaxial, shielded capsules.

The input power lines are polarity protected by a steering diode and are filtered to eliminate any spurious signals from adjacent electrical noise sources.

APPENDIX B

FORTRAN PROGRAMS

These two programs were developed to extract digital data from a series of photographs of the oscilloscope screen. The data processing program, PRO10, allows printout of all data, testing with series of six voltage comparator values and alteration of any datum. Their operation should be easily understood by a programmer. Any questions should be referred to the programmer, Raymond A. Meyer, of Rockwell.

The programs were developed to run on a DEC PDP 11-40 with 128,000 words of memory. The multiple user operating system, RSX 11M, version 3.2, was in use. Programs were compiled with the ANSI Fortran IV version 1.8 compiler.

NON-FORTRAN SUBROUTINE

Tab -- CALL TAB (NX, NY, MENU)

This subroutine interfaces with the Sumagraphics digitizer platen. When the stylus is touched to the platen the subroutine returns the x, y coordinates in integer nibs. There are 39.4 nibs per cm (100 per inch). The upper 6 cm of the platen are reserved and called "MENU." This area is usable for program control. Thus the Fortran programs expect either two I4 numbers representing x-y location, or a number representing MENU.

TSK10.FTN

```
C     TO DIGITIZE FRAMES OF 2 SENSITIVITY RECORDINGS.
C     PROJECT FRAME WITH TIME INCREASING UP.
C     FULL=LOW SENS,EXP= HIGH.  OUTPUT FILE
C     "TSK XX .DAP" CAN HAVE DATA FOR 49 MOVIE FRAMES.
C     EACH PHOTO GENERATES DATA FOR 2 TRACES THE ODD
C     NUMBERED ARE LOW SENS AND EVEN HIGH.  THE
C     FINAL(200) TRACE 1-IR, RUN NUMBER;2-NF,TRACES
C     3-INCHES FOR FULL SCALE VOLTS;4-SAME TIME
C     5- MV FULL SCALE LOW SENS; 6-SAME
C     EXPANDED SCALE; 7-MICROSEC FULL SCALE
C     8-START TIME IN MICROSEC.  WITHIN A TRACE
C     ODD UMBERS ARE MV, EVEN MICROSEC.
      BYTE FNAME(20)
      DIMENSION I(120),NNN(200)
      TYPE 101
101   FORMAT ('$ I2 RUN NUMBER IS')
      ACCEPT 100, IR
      CALL FILS(FNAME,'TSK',IR,'DAP')
      CALL ASSIGN (2,FNAME)
      DEFINE FILE2(200,120,U,IV)
      DO 1 N=1,120
      I(N)=0
1     CONTINUE
      TYPE 225
225   FORMAT(  ' TOUCH TOP LEFT AND WAIT')
      DO 2 NN=1,200
      WRITE (2'NN)I
2     CONTINUE
      CALL CLOSE (2)
      CALL ASSIGN (2,FNAME)
      DEFINE FILE 2(200,120,U,IV)
102   FORMAT(' TOUCH ,BL,BR')
      TYPE 102
      CALL TAB (NX1,NY1,MENU)
      IF (MENU) GO TO 900
      CALL TAB (NX2,NY2,MENU)
      IF (MENU) GO TO 900
      CALL TAB (NX3,NY3,MENU)
      IF (MENU) GO TO 900
103   FORMAT('$ I5 X RANGE IN MV FULL SCALE= FULL/EXP')
      TYPE 103
      ACCEPT 100,NXFR
      ACCEPT 100, NXER
104   FORMAT(F10.5)
105   FORMAT('$ I5 30K MAX Y RANGE IN MICRO S FULL SCALE= ')
```

```
150  TYPE 105
     ACCEPT 100,NYR
108  FORMAT('$ I5  Y START TIME MICROSEC 30K MAX')
     TYPE 108
     ACCEPT 100, NYST
     NY=NYST+NYR
     IF(NY.GT.30000) GO TO 150
     NXS=(NX3-NX2)
     NYS=(NY1-NY2)
106  FORMAT(' START TRACE TOUCH START POINT OF CENTER LINE ODD=FULL')
     TYPE 106
     DO 22 NF=1,200
100  FORMAT(I5)
10   TYPE 100,NF
     DO 11,N=1,120
     I(N)=0
11   CONTINUE
     IF(IN.EQ.2) GO TO 160
     CALL TAB (NXA,NYA,MENU)
     IF (MENU) GO TO 900
160  DO 20 N=11,120,2
     CALL TAB (NX3,NY3,MENU)
     IF (MENU) GO TO 21
     I(N)=(NXA-NX3)
     IF(I(N).LT.0)I(N)=NX3-NXA
     I(N+1)=NY3-NYA
     IF (IN.EQ.1) GO TO 20
     IF(N.GT.100) GO TO 200
20   CONTINUE
21   WRITE (2'NF)I
     IF(N.GT.119) GO TO 210
     IN=0
22   CONTINUE
210  TYPE 211
     TYPE 211
     TYPE 211
211  FORMAT(  '  OVER LIMIT INTO NEXT TRACE')
     IN=2
     GO TO 22
900  TYPE 107
107  FORMAT('  IF YOU WANT TO END TYPE 33')
     ACCEPT 100,IN
     IF(IN.EQ.33)GOTO 910
     GO TO 10
200  TYPE 201
     TYPE 201
     TYPE 201
201  FORMAT ( ' WARNING OVER LIMIT IN 10')
     IN=1
     GO TO 20
```

```
910   I(1)=IR
      I(2)=NF-1
      I(3)=NXS
      I(4)=NYS
      I(5)=NXFR
      I(6)=NXER
      I(7)=NYR
      I(8)=NYST
      WRITE (2'200)I
      END
```

PRO10.FTN

```
C     TO PROCESS DATA IN TSK XX.DAP FILES.
      BYTE FNAME (20)
      DIMENSION I(120),D(400),F(120),MA(200),MB(200),MC(200),MD(200),
      2MF(200),ME(200)
      TYPE 4
4     FORMAT('$ FILE TO ACCESS IS  ')
      ACCEPT 5,N, FNAME
5     FORMAT(Q,20A1)
      CALL ASSIGN (3,FNAME,N)
      DEFINE FILE 3(200,120,U,IV)
      CALL ASSIGN (2,'LS:TSK10.DMP')
220   READ (3'200)I
      TYPE 6,I(1),I(2),I(5),I(6),I(7),I(8)
      WRITE(2,6) I(1),I(2),I(5),I(6),I(7),I(8)
      G=I(8)
      C=I(3)
      DD=I(4)
      SXF=I(5)/C
      SXE=I(6)/C
      SY=I(7)/DD
C     SENSITIVITIES IN ENG UNITS PER NIB.
6     FORMAT(' RUN ',I2,' WITH',I3,'TRACES.
      2 MV FULL=',I5,' MV EXP=',I5,' US FS=',I5,' US START=',I5,/)
      TYPE 288,I(3),I(4)
      WRITE(2,288)I(3),I(4)
288   FORMAT( ' W NIBS ',I5,' H NIBS ',I5)
      TYPE 299,SXF,SXE,SY
      WRITE(2,299) SXF,SXE,SY
299   FORMAT( ' SENS--FMV/N ',F10.3,' EX MV/N ',F10.3,' US/N ',F10.3)
13    TYPE 7
7     FORMAT('$ PRINT=1,TEST=2,STOP=3,ALTER=99  ')
      ACCEPT 8,K
      IF(K.EQ.2) GO TO 100
      IF(K.EQ.3) GO TO 900
      IF(K.EQ.99) GO TO 210
      READ(3'200)I
```

```
      DO 10 N=1,I(2)
      READ (3'N)I
      WRITE(2,11) N
11    FORMAT(' TRACE NUMBER',I4, '        MV,MICROSEC')
      DO 405 M=1,120
      F(M)=0
405   CONTINUE
      DO 400 L=1,120,2
      IF (I(L).EQ.0) GO TO 400
      SXT=SXF
      IF(MOD(N,2).EQ.0)SXT=SXE
      F(L)=(I(L)*SXT)
      F(L+1)=(I(L+1)*SY)+G
400   CONTINUE
12    FORMAT(5(2F7.0,' '))
      WRITE (2,12) (F(NCT), NCT=1,20)
      DO 987 NXX=21,120,10
      IF( F(NXX).EQ.0) GO TO 10
      WRITE(2,12) (F(NCT), NCT=NXX,NXX+9)
987   CONTINUE
10    CONTINUE
      GO TO 13
100   TYPE 101
101   FORMAT(' SET CUT OFF LIMITS A,B,C,D,E,F')
      ACCEPT 8,LA,LB,LC,LD,LE,LF
8     FORMAT(I5)
      WRITE (2,144)
144   FORMAT( /,'  MICROSECONDS TO CUTOFF MILLIVOLTS')
      WRITE (2,143)LA,LB,LC,LD,LE,LF
143   format(6('      ',i5))
      READ(3'200)I
      NKF=I(2)
      DO 105 NF=1,NKF,2
      MA(NF)=0
      MB(NF)=0
      MC(NF)=0
      MD(NF)=0
      ME(NF)=0
      MF(NF)=0
      DO 530 N=1,119
      I(N)=0
      D(N)=0
530   CONTINUE
C     READ EXPANDED SCALE TRACE
      J=1
      READ (3'(NF+1))I
      SXT=SXE
      DO 500 N=1,119,2
      IF(I(N).EQ.0) GO TO 500
      D(J)=I(N)*SXT
```

```
      J=J+1
      D(J)=(I(N+1)*SY)+G
      J=J+1
500   CONTINUE
C     ADD FULL SCALE AFTER EXPANDED
      DO 505 N=1,119
      I(N)=0
505   CONTINUE
      READ(3'NF)I
      SXT=SXF
      DO 520 N=1,119,2
      IF(I(N).EQ.0) GO TO 520
      D(J)=I(N)*SXT
      J=J+1
      D(J)=(I(N+1)*SY)+G
      J=J+1
520   CONTINUE
C     SEARCH FOR VOLTAGES EXCEEDING
C     THOSE SET IN COMPARITORS.
      J=J-1
      DO 110 N=1,J,2
      IF(D(N).EQ.LA.OR.D(N).GT.LA) GO TO 120
110   CONTINUE
131   DO 130 N=1,J,2
      IF(D(N).EQ.LB.OR.D(N).GT.LB) GO TO 135
130   CONTINUE
141   DO 140 N=1,J,2
      IF(D(N).EQ.LC.OR.D(N).GT.LC) GO TO 145
140   CONTINUE
151   DO 150 N=1,J,2
      IF(D(N).EQ.LD.OR.D(N).GT.LD) GO TO 155
150   CONTINUE
160   DO 161 N=1,J,2
      IF(D(N).EQ.LE.OR.D(N).GT.LE)GO TO 162
161   CONTINUE
163   DO 164 N=1,J,2
      IF(D(N).EQ.LF.OR.D(N).GT.LF)GO TO 165
164   CONTINUE
      GO TO 105
120   MA(NF)=D(N+1)
      GO TO 131
135   MB(NF)=D(N+1)
      GO TO 141
145   MC(NF)=D(N+1)
      GO TO 151
155   MD(NF)=D(N+1)
162   ME(NF)=D(N+1)
      GO TO 163
165   MF(NF)=D(N+1)
105   CONTINUE
```

```
C     WRITE TIMES PHOTO BY PHOTO
      DO 300 NF=1,NKF,2
      A=MA(NF)
      B=MB(NF)
      C=MC(NF)
      DD=MD(NF)
      E=ME(NF)
      FF=MF(NF)
      WRITE (2,201)A,B,C,DD,E,FF
201   FORMAT(6F11.1)
300   CONTINUE
      WRITE (2,305)
305   FORMAT( /,/,'  CM WATER TO CUTOFF MILLIVOLTS')
C     CONVERT TIMES TO CM OF WATER
C     USING 1483 M/S AND WRITE.
      DO 301 NF=1,NKF,2
      A=MA(NF)*.07415
      B=MB(NF)*.07415
      C=MC(NF)*.07415
      DD=MD(NF)*.07415
      E=ME(NF)*.07415
      FF=MF(NF)*.07415
      WRITE (2,201)A,B,C,DD,E,FF
301   CONTINUE
      GO TO 13
210   TYPE 211
      ACCEPT 212,IFC
      ACCEPT 212,INC
211   FORMAT(  ' TRACE/NUMBER CHANGE 0=RETURN')
      IF (IFC.EQ.0) GO TO 220
      READ (3'IFC)I
      TYPE 8,I(INC)
      ACCEPT 8,ICN
212   FORMAT(I5)
      IF(ICN.EQ.0 ) GO TO 213
      I(INC)=ICN
      WRITE (3'IFC)I
213   CONTINUE
      GO TO 210
900   CONTINUE
      END
```

PRO10.CMD FOR TKB USE

```
PRO10/CP=PRO10,USH1,UERT,[1,54]AMC/LB,[1,1]FOROTS/LB
/
ASG=SG:1, TI:5
MAXBUF=400
//
```

TSK10.CMD FOR TKB USE

```
TSK10/CP=TSK10,[1,54]AMC/LB,[1,1]FOROTS/LB
/
ASG=SG:1, TI:5
MAXBUF=400
//
```

APPENDIX C

SAMPLE DATA PRINTOUT

These data are from the digitization and processing of a short section of motion picture film. The data are included to provide an example of the signals to be processed by computer algorithms for locating pollutant pools.

The photographs were taken during a field operation at Lake Casitas, a local fresh-water lake. The bottom was soft mud as evidenced by anchor penetration and mud upon the flukes of the anchor when it was raised. Nominal water depth was 725 cm (24 ft). The boat was drifting at a nominal 30 cm per second (0.7 mile per hour) during the photography at 9 frames per second. Thus the digitized 45-frame section of the film represents 150 cm travel across the bottom. The even-numbered traces are at the low sensitivity, 160 mv full scale to study the entire echo envelope and the odd-numbered traces are at 40 mv full scale to study the leading edge of the envelope in detail. During processing, the two traces are combined into a single data file. They are recorded separately to retain a maximum of visibility for possible detailed study. The data were processed and the times for the return signal to reach 2, 4, 8, 20, 40, and 80 mv were determined and converted to water depth to the reflecting surface. A large portion of the data scatter may be attributed to the digitization, since each millimeter on the digitizing platen is equivalent to 1.9 cm of water depth. The distance between the 8-mv surface and the 20- to 40-mv surface is related to penetration of the multi-layer soft bottom.

The comparator voltage values selected for this demonstration of the program represent only the first step in computer evaluation of the data. The values generated do provide a basis for continued optimism for the eventual success of the development. It should be re-emphasized that the oscilloscope photography is only a study tool and is not expected to be part of the final system.

The printout data is interpreted as follows:

Run 32: Arbitrary 2-digit number assigned during digitization

MV EXP: Millivolts full scale for the lower, high-sensitivity trace

MV FULL: Millivolts full scale for the upper, low-sensitivity trace

US FS: Microseconds full scale

US START: The start of the expanded time sweep

W NIBS: Image width in .25 mm nibs

H NIBS: Image height in .25 mm nibs

SENS--FMV/N: MV equivalent to .25 mm on platen (low-sensitivity trace)

EX MU/N: MV equivalent to .25 mm on platen (high-sensitivity trace)

US/N: Microseconds equivalent to .25 mm on platen

Trace Number: The odd-numbered traces are the low-sensitivity traces and the even are the high-sensitivity traces. Thus, traces 1 and 2 are generated by digitizing the first photograph, etc.

Data Table: The odd-numbered columns are millivolts and the even are the associated time in microseconds for each touch of the stylus. Thus, in trace 1, the 51st entry, "37," indicates that the signal reached 37 mv in 9934 microseconds after the transmit pulse.

After printout is complete the "test" data follow. The six columns contain the time in microseconds to reach each of the comparator reference voltages that were input during the running of PR 010. Each line in the table represents a separate photograph containing two traces. An entry of 0.0 indicates that the reference voltage was not reached.

In the last data table, the times from the preceding table are converted to water depth in cm.

```
RUN 32 WITH 90TRACES. MV FULL=  160 MV EXP=   40 US FS= 5000 US START= 6000

W NIBS   613 H NIBS   769
SENS--FMV/N      0.261 EX MV/N      0.065 US/N      6.502
TRACE NUMBER   1        MV,MICROSEC
    0.     0.       0.     0.       0.     0.       0.     0.       0.     0.
    0.  9817.       1.  9849.       5.  9869.       7.  9888.      11.  9901.
   13.  9901.      16.  9901.      17.  9908.      19.  9908.      21.  9914.
   24.  9914.      26.  9914.      28.  9921.      31.  9927.      34.  9927.
   37.  9934.      39.  9934.      42.  9940.      43.  9940.      43. 10090.
   47. 10096.      49. 10096.      52. 10096.      54. 10096.      57. 10096.
   60. 10103.      61. 10103.      64. 10109.      67. 10122.      68. 10129.
   70. 10129.      73. 10135.      75. 10148.      78. 10148.      81. 10148.
   83. 10155.      86. 10155.      86. 10155.       0.     0.       0.     0.
TRACE NUMBER   2        MV,MICROSEC
    0.     0.       0.     0.       0.     0.       0.     0.       0.     0.
    1.  7060.       1.  7066.       1.  7066.       1.  7086.       1.  9804.
    2.  9823.       3.  9843.       3.  9843.       4.  9836.       4.  9843.
    5.  9836.       6.  9836.       8.  9843.      10.  9843.      12.  9862.
   13.  9882.      15.  9875.      17.  9908.      20.  9901.      23.  9882.
   24.  9862.      27.  9862.      28.  9901.      30.  9895.       0.     0.
TRACE NUMBER   3        MV,MICROSEC
    0.     0.       0.     0.       0.     0.       0.     0.       0.     0.
    2.  9843.       0.  9869.       2.  9888.       2.  9914.       5.  9927.
    7.  9934.      12.  9921.      15.  9921.      18.  9921.      22.  9921.
   25.  9927.      27.  9934.      31.  9934.      36.  9934.      39.  9940.
   42.  9940.      44.  9953.      47.  9960.      50.  9966.      53.  9966.
   56.  9960.      59.  9966.      62.  9973.      64.  9973.      65.  9979.
   66.  9992.       0.     0.       0.     0.       0.     0.       0.     0.
TRACE NUMBER   4        MV,MICROSEC
    0.     0.       0.     0.       0.     0.       0.     0.       0.     0.
    1.  8789.       1.  8783.       2.  8789.       2.  8783.       2.  8789.
    2.  8822.       1.  9784.       1.  9791.       2.  9797.       3.  9836.
    4.  9830.       5.  9830.       6.  9836.       7.  9836.       8.  9830.
    9.  9817.       9.  9830.      11.  9849.      12.  9849.      14.  9862.
   15.  9849.      17.  9843.      18.  9843.      19.  9849.      20.  9843.
   20.  9836.      21.  9836.      22.  9836.      23.  9856.      24.  9856.
   25.  9862.      26.  9869.      27.  9869.      28.  9875.      29.  9875.
   31.  9836.      32.  9843.      33.  9823.      34.  9836.      34.  9836.
   35.  9849.      36.  9862.       0.     0.       0.     0.       0.     0.
TRACE NUMBER   5        MV,MICROSEC
    0.     0.       0.     0.       0.     0.       0.     0.       0.     0.
    1.  9830.       1.  9836.       2.  9849.       4.  9856.       7.  9869.
    9.  9869.      11.  9875.      12.  9875.      15.  9895.      18.  9908.
   21.  9921.      23.  9934.      25.  9934.      26.  9940.      27.  9947.
   27. 10109.      28. 10096.      29. 10096.      31. 10096.      31. 10142.
   32. 10174.      33. 10168.      35. 10168.      36. 10174.      37. 10181.
   38. 10252.      38. 10233.      40. 10246.      43. 10259.      45. 10272.
   47. 10272.      48. 10272.      50. 10285.      51. 10291.      52. 10291.
TRACE NUMBER   6        MV,MICROSEC
```

0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
0.	6163.	1.	6176.	1.	6202.	1.	6221.	1.	9804.
2.	9810.	2.	9817.	4.	9856.	5.	9849.	6.	9849.
7.	9849.	8.	9856.	8.	9862.	9.	9856.	10.	9856.
11.	9862.	12.	9862.	13.	9869.	14.	9875.	15.	9875.
17.	9869.	18.	9875.	19.	9869.	21.	9862.	22.	9862.
23.	9862.	23.	9862.	25.	9875.	26.	9875.	27.	9869.
28.	9856.	29.	9849.	30.	9849.	31.	9843.	32.	9843.
33.	9843.	34.	9836.	35.	9843.	36.	9843.	0.	0.

TRACE NUMBER 7 MV,MICROSEC

0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
0.	0.	3.	9836.	5.	9843.	7.	9849.	9.	9862.
10.	9869.	11.	9875.	15.	9888.	17.	9888.	19.	9901.
21.	9908.	23.	9921.	23.	9940.	25.	9953.	28.	9953.
30.	9966.	33.	9979.	35.	9992.	37.	9992.	39.	10012.
40.	10012.	41.	10031.	42.	10135.	43.	10129.	45.	10129.
46.	10129.	48.	10135.	50.	10148.	51.	10155.	51.	10155.

TRACE NUMBER 8 MV,MICROSEC

0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
1.	6117.	1.	6130.	1.	6143.	1.	6143.	1.	9778.
2.	9804.	3.	9797.	4.	9804.	5.	9817.	6.	9823.
8.	9830.	9.	9836.	10.	9817.	11.	9817.	12.	9836.
13.	9843.	14.	9849.	14.	9869.	14.	9882.	15.	9895.
15.	9888.	16.	9882.	17.	9888.	17.	9895.	18.	9882.
19.	9862.	20.	9875.	21.	9875.	22.	9862.	23.	9869.
25.	9856.	26.	9843.	28.	9836.	30.	9843.	32.	9856.
33.	9856.	34.	9849.	35.	9849.	0.	0.	0.	0.

TRACE NUMBER 9 MV,MICROSEC

0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
1.	9810.	3.	9817.	5.	9830.	7.	9830.	9.	9843.
9.	9869.	11.	9875.	12.	9895.	14.	9895.	16.	9895.
18.	9895.	21.	9888.	22.	9888.	23.	9888.	27.	9895.
29.	9901.	32.	9908.	34.	9914.	36.	9921.	39.	9934.
41.	9934.	43.	9940.	47.	9947.	52.	9934.	54.	9953.
55.	9960.	0.	0.	0.	0.	0.	0.	0.	0.

TRACE NUMBER 10 MV,MICROSEC

0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
1.	6072.	1.	6091.	1.	6104.	1.	9778.	1.	9804.
2.	9804.	3.	9804.	5.	9804.	6.	9823.	7.	9830.
7.	9830.	8.	9823.	8.	9823.	9.	9823.	10.	9823.
10.	9817.	12.	9817.	14.	9830.	14.	9830.	15.	9830.
16.	9830.	17.	9830.	17.	9843.	18.	9849.	18.	9869.
19.	9856.	21.	9843.	25.	9856.	27.	9856.	32.	9862.
34.	9869.	34.	9882.	0.	0.	0.	0.	0.	0.

TRACE NUMBER 11 MV,MICROSEC

0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
1.	9823.	5.	9836.	7.	9823.	10.	9823.	12.	9823.
14.	9823.	17.	9823.	19.	9817.	21.	9836.	22.	9843.
23.	9875.	23.	9888.	25.	9908.	27.	9908.	30.	9914.
31.	9927.	31.	9940.	31.	10070.	32.	10064.	33.	10057.
35.	10057.	37.	10064.	40.	10083.	42.	10077.	43.	10083.

43.	10096.	43.	10122.	43.	10155.	43.	10194.	44.	10194.
46.	10213.	47.	10207.	48.	10200.	49.	10200.	50.	10207.

TRACE NUMBER 12 MV,MICROSEC

0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
0.	6020.	1.	6026.	1.	6039.	1.	6046.	1.	6059.
1.	9804.	1.	9817.	1.	9836.	2.	9823.	3.	9817.
4.	9823.	5.	9830.	5.	9836.	6.	9836.	7.	9830.
8.	9836.	9.	9843.	10.	9843.	12.	9843.	13.	9836.
14.	9836.	15.	9836.	16.	9836.	16.	9849.	17.	9869.
17.	9888.	18.	9895.	19.	9895.	20.	9882.	21.	9875.
22.	9875.	23.	9875.	25.	9875.	26.	9869.	27.	9869.
28.	9869.	29.	9869.	31.	9869.	32.	9869.	32.	9875.
34.	9882.	34.	9888.	35.	9888.	35.	9882.	0.	0.

TRACE NUMBER 13 MV,MICROSEC

0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
1.	9830.	2.	9830.	4.	9830.	6.	9836.	8.	9843.
9.	9843.	12.	9856.	13.	9856.	16.	9862.	19.	9856.
21.	9856.	23.	9862.	25.	9862.	26.	9869.	26.	9888.
26.	9901.	27.	9914.	28.	9927.	30.	9934.	31.	9940.
33.	9934.	35.	9934.	37.	9940.	39.	9940.	42.	9947.
43.	9947.	44.	9953.	44.	9953.	0.	0.	0.	0.

TRACE NUMBER 14 MV,MICROSEC

0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
1.	9752.	3.	9771.	5.	9778.	6.	9784.	7.	9791.
7.	9797.	8.	9810.	8.	9836.	9.	9849.	10.	9849.
11.	9849.	13.	9843.	14.	9849.	16.	9836.	17.	9836.
19.	9843.	19.	9856.	19.	9875.	20.	9895.	21.	9901.
22.	9895.	23.	9888.	25.	9888.	26.	9895.	27.	9888.
29.	9882.	29.	9888.	0.	0.	0.	0.	0.	0.

TRACE NUMBER 15 MV,MICROSEC

0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
1.	8081.	1.	8081.	2.	8087.	2.	8107.	1.	9765.
2.	9771.	3.	9765.	4.	9784.	6.	9791.	7.	9797.
8.	9804.	9.	9817.	9.	9843.	9.	9862.	9.	9862.
9.	9901.	10.	9908.	12.	9914.	14.	9914.	15.	9914.
17.	9914.	19.	9914.	20.	9921.	22.	9934.	24.	9934.
26.	9927.	27.	9934.	30.	9934.	32.	9940.	33.	9947.
34.	9947.	35.	9953.	35.	9953.	36.	9973.	36.	10064.
42.	10064.	45.	10070.	48.	10083.	50.	10083.	54.	10090.
56.	10103.	59.	10103.	61.	10103.	63.	10109.	64.	10116.

TRACE NUMBER 16 MV,MICROSEC

0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
2.	9778.	3.	9771.	4.	9765.	5.	9771.	6.	9771.
7.	9758.	8.	9758.	9.	9765.	10.	9758.	11.	9752.
12.	9752.	13.	9752.	14.	9745.	15.	9745.	15.	9752.
15.	9765.	15.	9843.	16.	9843.	17.	9843.	19.	9836.
20.	9843.	22.	9849.	23.	9843.	24.	9830.	25.	9830.
27.	9843.	28.	9843.	29.	9843.	31.	9849.	32.	9836.
33.	9817.	34.	9810.	35.	9804.	36.	9804.	0.	0.

TRACE NUMBER 17 MV,MICROSEC

0.	0.	0.	0.	0.	0.	0.	0.	0.	0.

2.	9791.	1.	9797.	3.	9810.	5.	9817.	7.	9817.
7.	9817.	9.	9810.	10.	9817.	11.	9823.	12.	9836.
15.	9849.	20.	9862.	23.	9869.	26.	9875.	27.	9882.
27.	9888.	28.	9908.	33.	9927.	36.	9914.	40.	9934.
42.	9934.	43.	9940.	46.	9940.	47.	9940.	50.	9953.
50.	9953.	52.	9960.	53.	9960.	54.	9966.	54.	9966.
56.	9973.	56.	9979.	57.	10129.	59.	10129.	63.	10129.
64.	10142.	68.	10148.	69.	10168.	0.	0.	0.	0.

TRACE NUMBER 18 MV,MICROSEC

0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
2.	9726.	2.	9732.	3.	9752.	4.	9771.	6.	9778.
7.	9784.	8.	9784.	9.	9778.	11.	9765.	12.	9771.
13.	9830.	15.	9817.	16.	9804.	17.	9791.	18.	9784.
18.	9778.	19.	9791.	19.	9856.	20.	9752.	20.	9778.
22.	9778.	23.	9765.	24.	9765.	24.	9758.	25.	9758.
26.	9758.	26.	9778.	26.	9797.	27.	9791.	27.	9784.
29.	9765.	29.	9765.	31.	9778.	32.	9771.	33.	9778.
34.	9778.	35.	9778.	36.	9797.	0.	0.	0.	0.

TRACE NUMBER 19 MV,MICROSEC

0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
4.	9784.	2.	9778.	1.	9778.	3.	9791.	6.	9804.
8.	9817.	10.	9810.	12.	9817.	13.	9817.	14.	9830.
14.	9862.	15.	9888.	16.	9901.	19.	9901.	21.	9901.
24.	9908.	26.	9921.	29.	9927.	31.	9940.	32.	9947.
34.	9953.	37.	9960.	39.	9953.	42.	9966.	44.	9979.
44.	10031.	45.	10044.	48.	10051.	56.	10083.	60.	10103.
63.	10109.	66.	10116.	69.	10122.	73.	10129.	76.	10135.
79.	10155.	81.	10168.	82.	10174.	0.	0.	0.	0.

TRACE NUMBER 20 MV,MICROSEC

0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
2.	9739.	4.	9726.	5.	9726.	6.	9713.	7.	9706.
8.	9706.	9.	9706.	10.	9713.	12.	9719.	14.	9706.
16.	9732.	17.	9732.	18.	9732.	19.	9732.	20.	9719.
21.	9719.	22.	9706.	23.	9706.	23.	9706.	23.	9713.
24.	9778.	24.	9758.	26.	9758.	27.	9752.	28.	9745.
29.	9732.	30.	9745.	30.	9752.	31.	9752.	0.	0.

TRACE NUMBER 21 MV,MICROSEC

0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
4.	9758.	2.	9752.	4.	9773.	7.	9791.	10.	9810.
13.	9810.	16.	9804.	19.	9810.	21.	9817.	22.	9817.
27.	9817.	30.	9830.	33.	9836.	35.	9830.	38.	9836.
40.	9830.	42.	9849.	42.	10142.	46.	10116.	49.	10142.
52.	10142.	54.	10148.	56.	10155.	58.	10168.	60.	10168.
61.	10174.	64.	10168.	65.	10174.	0.	0.	0.	0.

TRACE NUMBER 22 MV,MICROSEC

0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
2.	9719.	5.	9765.	6.	9765.	7.	9758.	7.	9745.
8.	9739.	9.	9732.	10.	9732.	11.	9732.	12.	9719.
13.	9719.	14.	9713.	15.	9713.	15.	9706.	16.	9713.
17.	9693.	18.	9687.	18.	9674.	19.	9674.	20.	9667.
21.	9661.	23.	9648.	24.	9641.	25.	9641.	26.	9641.

26.	9641.	27.	9641.	28.	9635.	28.	9635.	29.	9635.
29.	9635.	30.	9641.	30.	9641.	31.	9641.	31.	9641.
32.	9635.	33.	9641.	33.	9635.	34.	9628.	34.	9628.
35.	9628.	35.	9622.	36.	9628.	0.	0.	0.	0.
TRACE NUMBER	23		MV,MICROSEC						
0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
4.	9765.	3.	9765.	1.	9765.	1.	9765.	2.	9771.
5.	9784.	7.	9804.	8.	9804.	9.	9810.	10.	9849.
10.	9875.	10.	9895.	11.	9888.	12.	9895.	13.	9895.
16.	9888.	17.	9895.	21.	9914.	22.	9914.	23.	9914.
25.	9921.	26.	9921.	26.	9927.	27.	9934.	27.	9940.
27.	9947.	0.	0.	0.	0.	0.	0.	0.	0.
TRACE NUMBER	24		MV,MICROSEC						
0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
2.	9732.	4.	9758.	5.	9765.	5.	9752.	6.	9745.
7.	9745.	8.	9739.	9.	9732.	10.	9732.	11.	9739.
12.	9739.	12.	9726.	13.	9713.	14.	9726.	15.	9726.
16.	9719.	17.	9706.	17.	9693.	18.	9693.	19.	9693.
19.	9693.	19.	9700.	20.	9700.	20.	9700.	20.	9700.
20.	9706.	21.	9765.	22.	9784.	23.	9765.	23.	9765.
24.	9765.	25.	9752.	26.	9745.	26.	9745.	27.	9752.
27.	9765.	27.	9771.	28.	9778.	28.	9778.	29.	9778.
29.	9771.	30.	9823.	0.	0.	0.	0.	0.	0.
TRACE NUMBER	25		MV,MICROSEC						
0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
5.	9804.	3.	9797.	1.	9810.	0.	9817.	1.	9823.
2.	9823.	3.	9830.	3.	9875.	3.	9888.	4.	9882.
5.	9895.	6.	9895.	7.	9901.	7.	9999.	7.	9999.
7.	9999.	10.	10005.	11.	10005.	13.	9999.	15.	9999.
16.	10005.	18.	10018.	19.	10018.	21.	10025.	23.	10012.
25.	10018.	26.	10025.	28.	10025.	29.	10031.	31.	10038.
33.	10031.	34.	10038.	36.	10044.	38.	10044.	40.	10057.
42.	10057.	43.	10057.	45.	10057.	46.	10057.	48.	10057.
48.	10070.	50.	10070.	51.	10083.	51.	10077.	52.	10077.
TRACE NUMBER	26		MV,MICROSEC						
0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
2.	7996.	2.	7996.	2.	7996.	2.	8016.	2.	9758.
2.	9771.	3.	9771.	4.	9771.	5.	9758.	6.	9771.
7.	9771.	8.	9778.	8.	9765.	9.	9765.	9.	9771.
10.	9771.	10.	9778.	11.	9784.	11.	9791.	11.	9817.
11.	9823.	12.	9823.	13.	9823.	13.	9823.	13.	9823.
14.	9830.	15.	9817.	16.	9817.	16.	9817.	17.	9810.
18.	9810.	19.	9810.	19.	9810.	20.	9804.	20.	9804.
20.	9804.	21.	9804.	22.	9797.	23.	9804.	25.	9836.
26.	9856.	26.	9849.	27.	9849.	27.	9843.	31.	9843.
TRACE NUMBER	27		MV,MICROSEC						
0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
0.	0.	4.	9765.	3.	9771.	3.	9784.	3.	9791.
3.	9784.	2.	9791.	2.	9797.	1.	9823.	1.	9823.
3.	9836.	6.	9843.	7.	9856.	8.	9849.	8.	9849.
10.	9849.	11.	9856.	11.	9856.	12.	9862.	13.	9901.

13. 9908. 15. 9914. 16. 9921. 18. 9927. 22. 9927.
23. 9927. 24. 9940. 28. 9960. 28. 9953. 30. 9960.
32. 9960. 34. 9973. 35. 9979. 36. 9973. 37. 9979.
39. 9979. 40. 9986. 41. 9992. 42. 9992. 43. 9992.
43. 9992. 45. 10005. 45. 9999. 46. 9999. 46. 10005.
46. 10161. 48. 10168. 0. 0. 0. 0. 0. 0.
TRACE NUMBER 28 MV,MICROSEC
0. 0. 0. 0. 0. 0. 0. 0. 0. 0.
2. 9732. 3. 9752. 4. 9758. 5. 9752. 6. 9758.
7. 9752. 8. 9752. 8. 9752. 9. 9752. 10. 9745.
10. 9745. 12. 9745. 13. 9739. 13. 9745. 14. 9739.
15. 9745. 16. 9758. 17. 9752. 18. 9745. 18. 9745.
19. 9745. 20. 9739. 22. 9732. 22. 9719. 23. 9713.
24. 9713. 24. 9713. 26. 9713. 26. 9706. 27. 9706.
28. 9706. 28. 9700. 29. 9700. 30. 9700. 30. 9700.
31. 9700. 32. 9700. 32. 9700. 33. 9706. 33. 9706.
TRACE NUMBER 29 MV,MICROSEC
0. 0. 0. 0. 0. 0. 0. 0. 0. 0.
4. 9791. 2. 9797. 1. 9804. 1. 9823. 2. 9830.
4. 9849. 5. 9856. 7. 9856. 8. 9862. 10. 9869.
11. 9875. 13. 9875. 15. 9875. 16. 9869. 18. 9875.
19. 9888. 19. 9921. 20. 9934. 21. 9940. 22. 9940.
24. 9947. 25. 9953. 25. 9966. 25. 10018. 30. 10044.
31. 10038. 32. 10031. 34. 10038. 35. 10038. 37. 10051.
38. 10038. 39. 10038. 41. 10057. 42. 10051. 44. 10064.
45. 10064. 46. 10057. 47. 10057. 48. 10064. 49. 10064.
49. 10064. 50. 10070. 0. 0. 0. 0. 0. 0.
TRACE NUMBER 30 MV,MICROSEC
0. 0. 0. 0. 0. 0. 0. 0. 0. 0.
1. 7847. 2. 7847. 2. 7840. 2. 7840. 3. 7840.
3. 7853. 2. 9726. 3. 9726. 3. 9726. 4. 9739.
4. 9745. 5. 9752. 6. 9752. 6. 9745. 7. 9739.
8. 9745. 9. 9752. 10. 9752. 11. 9745. 12. 9752.
13. 9745. 14. 9745. 14. 9739. 15. 9739. 16. 9739.
18. 9726. 19. 9732. 19. 9732. 20. 9739. 21. 9739.
22. 9745. 23. 9726. 24. 9726. 24. 9719. 25. 9719.
26. 9719. 25. 9732. 26. 9719. 27. 9719. 27. 9732.
28. 9732. 29. 9726. 29. 9713. 30. 9706. 30. 9700.
31. 9700. 0. 0. 0. 0. 0. 0. 0. 0.
TRACE NUMBER 31 MV,MICROSEC
0. 0. 0. 0. 0. 0. 0. 0. 0. 0.
2. 8549. 1. 8568. 3. 9771. 1. 9784. 3. 9771.
7. 9771. 10. 9791. 13. 9791. 15. 9797. 17. 9791.
20. 9797. 24. 9804. 26. 9804. 28. 9810. 30. 9823.
32. 9823. 35. 9830. 37. 9830. 38. 9830. 41. 9843.
43. 9843. 44. 9849. 46. 9849. 49. 9862. 50. 9862.
52. 9856. 54. 9856. 56. 9862. 58. 9875. 59. 9875.
60. 9875. 62. 9875. 63. 9888. 63. 9888. 64. 9895.
TRACE NUMBER 32 MV,MICROSEC
0. 0. 0. 0. 0. 0. 0. 0. 0. 0.
1. 8159. 2. 8152. 2. 8152. 2. 8159. 3. 8152.

3.	8165.	3.	8178.	2.	8172.	2.	8178.	2.	9739.
3.	9745.	4.	9752.	5.	9732.	6.	9745.	7.	9745.
8.	9739.	9.	9739.	10.	9726.	11.	9719.	12.	9726.
13.	9739.	14.	9745.	15.	9758.	16.	9752.	17.	9739.
18.	9732.	19.	9732.	20.	9732.	21.	9726.	22.	9713.
23.	9706.	24.	9713.	25.	9713.	25.	9713.	27.	9713.
27.	9713.	28.	9700.	29.	9700.	30.	9700.	32.	9719.
TRACE NUMBER 33			MV,MICROSEC						
0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
3.	9732.	2.	9752.	0.	9758.	2.	9765.	4.	9771.
6.	9778.	7.	9778.	8.	9784.	9.	9823.	10.	9856.
13.	9862.	15.	9862.	16.	9869.	18.	9862.	20.	9869.
21.	9882.	22.	9882.	23.	9882.	23.	10031.	25.	10038.
27.	10051.	29.	10051.	32.	10051.	35.	10070.	36.	10064.
37.	10064.	39.	10070.	40.	10064.	41.	10077.	43.	10083.
45.	10083.	46.	10083.	48.	10090.	50.	10090.	51.	10083.
51.	10090.	52.	10103.	52.	10109.	0.	0.	0.	0.
TRACE NUMBER 34			MV,MICROSEC						
0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
1.	7177.	2.	9726.	3.	9739.	5.	9739.	6.	9758.
7.	9778.	8.	9778.	12.	9791.	13.	9784.	14.	9791.
15.	9784.	16.	9784.	17.	9791.	18.	9784.	19.	9784.
20.	9778.	21.	9778.	22.	9778.	22.	9771.	23.	9784.
23.	9797.	24.	9804.	24.	9823.	25.	9836.	26.	9843.
26.	9960.	27.	9953.	28.	9940.	29.	9934.	30.	9921.
31.	9908.	31.	9914.	32.	9927.	0.	0.	0.	0.
TRACE NUMBER 35			MV,MICROSEC						
0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
1.	9752.	0.	9758.	1.	9765.	3.	9778.	5.	9784.
6.	9791.	6.	9797.	7.	9823.	8.	9849.	10.	9849.
12.	9849.	13.	9862.	14.	9856.	16.	9862.	17.	9869.
18.	9875.	19.	9862.	19.	9882.	20.	9992.	21.	9986.
22.	9992.	23.	9992.	24.	9999.	25.	10005.	26.	10005.
27.	10005.	29.	9999.	29.	9999.	30.	10012.	31.	10109.
32.	10109.	35.	10103.	37.	10116.	39.	10116.	40.	10103.
42.	10109.	43.	10109.	44.	10109.	45.	10109.	47.	10116.
48.	10116.	49.	10109.	50.	10116.	51.	10207.	53.	10207.
55.	10207.	0.	0.	0.	0.	0.	0.	0.	0.
TRACE NUMBER 36			MV,MICROSEC						
0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
1.	6936.	2.	9693.	3.	9687.	3.	9700.	4.	9732.
4.	9732.	5.	9739.	6.	9752.	7.	9758.	8.	9758.
8.	9758.	9.	9758.	10.	9752.	11.	9752.	12.	9752.
13.	9745.	14.	9745.	15.	9732.	17.	9713.	18.	9713.
19.	9719.	21.	9713.	22.	9713.	24.	9706.	25.	9700.
27.	9693.	28.	9700.	29.	9700.	30.	9693.	31.	9687.
31.	9680.	32.	9687.	32.	9856.	33.	9849.	34.	9862.
35.	9875.	36.	9882.	0.	0.	0.	0.	0.	0.
TRACE NUMBER 37			MV,MICROSEC						
0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
4.	9687.	3.	9706.	1.	9752.	1.	9752.	3.	9758.

4.	9745.	7.	9752.	9.	9771.	11.	9778.	13.	9771.
15.	9778.	16.	9784.	19.	9784.	21.	9784.	23.	9797.
24.	9804.	26.	9810.	27.	9810.	28.	9810.	30.	9817.
30.	9934.	31.	9934.	34.	9934.	35.	9934.	37.	9940.
38.	9953.	40.	9947.	41.	9947.	42.	9953.	43.	9960.
44.	9966.	44.	9979.	0.	0.	0.	0.	0.	0.
TRACE NUMBER	38		MV,MICROSEC						
0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
1.	9706.	1.	9726.	1.	9732.	1.	9752.	2.	9771.
3.	9791.	3.	9797.	4.	9797.	5.	9810.	6.	9797.
6.	9791.	7.	9791.	8.	9778.	9.	9791.	9.	9791.
10.	9797.	11.	9797.	12.	9804.	13.	9810.	14.	9810.
14.	9817.	15.	9810.	16.	9804.	17.	9804.	18.	9797.
18.	9810.	19.	9810.	19.	9810.	19.	9843.	19.	9901.
20.	9908.	21.	9908.	21.	9914.	22.	9914.	23.	9927.
23.	9921.	24.	9921.	24.	9927.	24.	9947.	25.	9973.
25.	9960.	26.	9953.	27.	9953.	27.	9953.	28.	9953.
29.	9960.	0.	0.	0.	0.	0.	0.	0.	0.
TRACE NUMBER	39		MV,MICROSEC						
0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
2.	9713.	3.	9752.	5.	9765.	5.	9778.	7.	9784.
8.	9797.	9.	9810.	10.	9817.	10.	9817.	11.	9830.
11.	9882.	13.	9888.	14.	9888.	16.	9895.	17.	9895.
19.	9901.	20.	9901.	21.	9901.	22.	9908.	23.	9914.
24.	9927.	24.	9934.	25.	9953.	26.	9979.	27.	9979.
28.	9979.	29.	9979.	30.	9986.	31.	9992.	32.	9999.
34.	10005.	34.	10005.	35.	10025.	36.	10038.	36.	10038.
TRACE NUMBER	40		MV,MICROSEC						
0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
1.	7008.	1.	9062.	0.	9680.	1.	9706.	2.	9732.
2.	9745.	3.	9758.	3.	9765.	4.	9791.	5.	9797.
5.	9804.	6.	9804.	7.	9804.	8.	9810.	8.	9817.
9.	9817.	10.	9823.	11.	9830.	11.	9823.	11.	9830.
12.	9823.	13.	9830.	13.	9830.	14.	9817.	14.	9810.
15.	9817.	15.	9817.	16.	9804.	18.	9804.	19.	9804.
20.	9823.	20.	9823.	20.	9940.	21.	9973.	22.	9979.
24.	9960.	25.	9973.	26.	9973.	27.	9960.	28.	9966.
29.	9966.	29.	9979.	31.	9999.	31.	9999.	0.	0.
TRACE NUMBER	41		MV,MICROSEC						
0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
3.	9732.	3.	9739.	5.	9745.	6.	9752.	8.	9758.
9.	9765.	10.	9765.	10.	9778.	11.	9797.	13.	9810.
16.	9804.	17.	9804.	21.	9804.	22.	9810.	22.	9817.
24.	9817.	26.	9817.	28.	9823.	29.	9823.	30.	9830.
32.	9843.	34.	9849.	36.	9849.	37.	9856.	38.	9856.
39.	9856.	40.	9856.	41.	9862.	42.	9869.	43.	9888.
TRACE NUMBER	42		MV,MICROSEC						
0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
0.	6930.	1.	6943.	1.	6988.	0.	9706.	1.	9719.
2.	9719.	3.	9726.	4.	9739.	5.	9758.	6.	9765.
7.	9765.	8.	9771.	8.	9778.	9.	9778.	10.	9771.

11.	9778.	13.	9758.	14.	9752.	14.	9752.	15.	9758.
16.	9765.	17.	9771.	17.	9771.	18.	9778.	19.	9797.
20.	9804.	20.	9804.	22.	9797.	23.	9791.	24.	9797.
25.	9804.	25.	9804.	26.	9804.	26.	9804.	27.	9804.
28.	9804.	29.	9804.	30.	9804.	31.	9810.	32.	9810.
33.	9823.	34.	9830.	0.	0.	0.	0.	0.	0.

TRACE NUMBER 43 MV,MICROSEC

0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
2.	9706.	2.	9732.	3.	9752.	5.	9765.	7.	9771.
9.	9778.	11.	9778.	14.	9784.	16.	9797.	17.	9804.
17.	9823.	21.	9830.	24.	9830.	25.	9843.	27.	9849.
29.	9843.	30.	9843.	33.	9843.	34.	9843.	37.	9849.
38.	9849.	39.	9843.	41.	9849.	43.	9849.	44.	9843.
45.	9856.	45.	9862.	45.	10077.	46.	10090.	48.	10090.
47.	10122.	0.	0.	0.	0.	0.	0.	0.	0.

TRACE NUMBER 44 MV,MICROSEC

0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
1.	6910.	1.	8783.	1.	9674.	1.	9700.	2.	9713.
3.	9739.	4.	9752.	5.	9771.	7.	9778.	8.	9765.
9.	9758.	10.	9758.	11.	9758.	12.	9758.	13.	9752.
14.	9752.	14.	9765.	14.	9771.	15.	9817.	16.	9797.
17.	9804.	17.	9817.	18.	9830.	19.	9830.	20.	9823.
22.	9817.	23.	9810.	24.	9817.	24.	9830.	25.	9830.
26.	9830.	27.	9836.	28.	9843.	29.	9849.	29.	9849.
30.	9849.	30.	9843.	0.	0.	0.	0.	0.	0.

TRACE NUMBER 45 MV,MICROSEC

0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
3.	9700.	5.	9713.	8.	9719.	11.	9726.	13.	9732.
15.	9739.	17.	9752.	18.	9758.	19.	9797.	20.	9830.
22.	9836.	23.	9849.	27.	9862.	28.	9856.	29.	9862.
31.	9869.	33.	9882.	35.	9882.	36.	9882.	36.	9882.
40.	9999.	42.	9999.	44.	9992.	46.	9999.	49.	9999.
51.	9992.	53.	9999.	54.	10018.	54.	10057.	56.	10044.
59.	10051.	61.	10051.	63.	10044.	68.	10064.	70.	10064.
72.	10070.	74.	10077.	74.	10083.	0.	0.	0.	0.

TRACE NUMBER 46 MV,MICROSEC

0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
1.	6852.	1.	8399.	1.	9622.	1.	9648.	1.	9667.
1.	9687.	2.	9700.	3.	9700.	4.	9719.	7.	9719.
7.	9719.	8.	9732.	9.	9739.	10.	9745.	11.	9745.
12.	9758.	13.	9758.	13.	9758.	14.	9752.	14.	9758.
15.	9752.	16.	9745.	17.	9752.	17.	9758.	18.	9791.
19.	9784.	20.	9784.	22.	9784.	23.	9784.	24.	9778.
25.	9784.	26.	9797.	27.	9810.	29.	9804.	30.	9784.
31.	9778.	33.	9791.	0.	0.	0.	0.	0.	0.

TRACE NUMBER 47 MV,MICROSEC

0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
2.	9641.	4.	9687.	4.	9680.	6.	9719.	9.	9713.
12.	9706.	15.	9719.	17.	9719.	18.	9706.	20.	9706.
22.	9719.	24.	9719.	30.	9719.	31.	9732.	33.	9726.
34.	9732.	35.	9739.	35.	9739.	36.	9771.	38.	9778.

41.	9771.	43.	9778.	45.	9771.	47.	9771.	49.	9771.
50.	9765.	51.	9771.	53.	9791.	54.	9797.	0.	0.

TRACE NUMBER 48 MV,MICROSEC

0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
0.	9583.	1.	9635.	1.	9667.	3.	9674.	4.	9706.
5.	9706.	6.	9700.	7.	9700.	8.	9706.	9.	9713.
10.	9713.	11.	9713.	12.	9713.	13.	9713.	14.	9713.
15.	9719.	16.	9713.	17.	9719.	18.	9726.	19.	9719.
20.	9713.	21.	9719.	22.	9713.	22.	9713.	23.	9713.
24.	9719.	25.	9713.	26.	9706.	26.	9713.	26.	9719.
26.	9745.	26.	9862.	27.	9856.	28.	9856.	28.	9843.
29.	9843.	30.	9836.	30.	9843.	31.	9849.	32.	9849.
33.	9843.	33.	9843.	33.	9849.	0.	0.	0.	0.

TRACE NUMBER 49 MV,MICROSEC

0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
3.	9654.	4.	9693.	6.	9693.	10.	9693.	13.	9706.
16.	9713.	19.	9719.	21.	9719.	23.	9726.	25.	9713.
27.	9726.	28.	9719.	29.	9719.	30.	9726.	31.	9726.
32.	9732.	32.	9765.	34.	9771.	36.	9778.	37.	9778.
39.	9771.	39.	9778.	42.	9778.	42.	9778.	43.	9791.
44.	10005.	48.	10005.	51.	9999.	54.	10012.	57.	10018.
66.	10031.	67.	10018.	70.	10025.	73.	10025.	75.	10031.
78.	10031.	81.	10044.	0.	0.	0.	0.	0.	0.

TRACE NUMBER 50 MV,MICROSEC

0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
1.	9641.	2.	9648.	3.	9667.	4.	9674.	5.	9700.
8.	9700.	8.	9693.	9.	9700.	11.	9713.	12.	9713.
13.	9713.	14.	9706.	15.	9719.	16.	9719.	17.	9719.
20.	9713.	21.	9713.	22.	9706.	24.	9700.	25.	9706.
26.	9706.	26.	9713.	28.	9713.	29.	9713.	29.	9732.
31.	9739.	31.	9752.	33.	9745.	34.	9765.	34.	9765.

TRACE NUMBER 51 MV,MICROSEC

0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
3.	9687.	5.	9726.	9.	9739.	11.	9745.	14.	9758.
15.	9791.	18.	9810.	20.	9817.	25.	9843.	25.	9992.
27.	9999.	30.	9992.	34.	10005.	39.	10018.	47.	10038.
50.	10038.	53.	10044.	55.	10044.	59.	10051.	65.	10051.
67.	10051.	69.	10057.	71.	10051.	0.	0.	0.	0.

TRACE NUMBER 52 MV,MICROSEC

0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
1.	6741.	1.	9654.	1.	9674.	2.	9700.	5.	9706.
5.	9706.	7.	9713.	8.	9719.	8.	9732.	9.	9732.
11.	9726.	12.	9726.	14.	9726.	15.	9732.	16.	9739.
17.	9745.	18.	9739.	20.	9726.	21.	9726.	22.	9732.
23.	9732.	24.	9732.	25.	9739.	26.	9758.	27.	9778.
28.	9771.	29.	9778.	30.	9784.	30.	9778.	31.	9771.
32.	9771.	32.	9771.	33.	9771.	0.	0.	0.	0.

TRACE NUMBER 53 MV,MICROSEC

0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
3.	9726.	5.	9732.	8.	9732.	10.	9745.	11.	9758.
13.	9765.	16.	9758.	17.	9771.	20.	9778.	25.	9771.

27.	9778.	30.	9784.	33.	9784.	35.	9791.	37.	9804.
39.	9797.	40.	9804.	43.	9934.	45.	9953.	46.	10109.
48.	10103.	50.	10109.	54.	10122.	56.	10122.	58.	10129.
65.	10155.	67.	10155.	69.	10155.	71.	10161.	76.	10161.
78.	10161.	0.	0.	0.	0.	0.	0.	0.	0.
TRACE NUMBER	54		MV,MICROSEC						
0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
1.	7274.	0.	9583.	1.	9615.	1.	9700.	2.	9726.
3.	9745.	4.	9752.	5.	9758.	7.	9758.	8.	9758.
9.	9765.	11.	9758.	11.	9758.	12.	9765.	12.	9804.
14.	9797.	14.	9791.	16.	9784.	17.	9771.	19.	9784.
19.	9791.	20.	9797.	20.	9888.	21.	9901.	22.	9914.
23.	9921.	24.	9934.	25.	9940.	26.	9953.	26.	9960.
27.	9966.	28.	9973.	29.	9966.	29.	9966.	0.	0.
TRACE NUMBER	55		MV,MICROSEC						
0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
3.	9635.	4.	9661.	5.	9700.	6.	9713.	9.	9719.
10.	9726.	13.	9732.	15.	9745.	17.	9739.	20.	9745.
23.	9752.	25.	9758.	28.	9771.	31.	9771.	34.	9771.
36.	9778.	37.	9784.	38.	9784.	40.	9791.	42.	9791.
44.	9797.	47.	9804.	47.	9810.	48.	9810.	49.	10135.
51.	10142.	55.	10135.	57.	10135.	61.	10142.	63.	10142.
65.	10155.	66.	10155.	66.	10161.	0.	0.	0.	0.
TRACE NUMBER	56		MV,MICROSEC						
0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
1.	7437.	1.	9609.	2.	9654.	3.	9661.	4.	9667.
6.	9674.	7.	9667.	9.	9680.	10.	9700.	11.	9713.
12.	9713.	13.	9713.	14.	9713.	16.	9713.	17.	9713.
18.	9719.	19.	9732.	19.	9784.	22.	9771.	23.	9778.
24.	9784.	24.	9791.	25.	9791.	26.	9784.	27.	9791.
27.	9791.	27.	9849.	28.	9875.	0.	0.	0.	0.
TRACE NUMBER	57		MV,MICROSEC						
0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
3.	9641.	4.	9648.	6.	9661.	8.	9674.	9.	9680.
9.	9713.	10.	9713.	11.	9719.	13.	9719.	14.	9713.
16.	9719.	17.	9713.	18.	9706.	19.	9706.	20.	9706.
22.	9713.	23.	9719.	23.	9726.	24.	9895.	26.	9908.
25.	9992.	28.	9992.	31.	9992.	33.	9992.	35.	9999.
37.	9999.	39.	9999.	40.	10005.	42.	9999.	43.	9999.
44.	9999.	45.	10005.	45.	10012.	0.	0.	0.	0.
TRACE NUMBER	58		MV,MICROSEC						
0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
1.	9557.	1.	9635.	3.	9628.	4.	9635.	5.	9648.
5.	9654.	6.	9654.	7.	9654.	8.	9661.	9.	9654.
11.	9648.	12.	9667.	13.	9661.	14.	9674.	15.	9661.
16.	9661.	16.	9674.	16.	9739.	17.	9758.	18.	9771.
19.	9771.	21.	9771.	21.	9771.	21.	9797.	21.	9895.
22.	9875.	23.	9882.	24.	9882.	25.	9895.	26.	9895.
26.	9888.	27.	9888.	29.	9895.	30.	9908.	31.	9914.
32.	9908.	33.	9901.	33.	9901.	34.	9901.	34.	9901.
TRACE NUMBER	59		MV,MICROSEC						

0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
3.	9635.	4.	9635.	5.	9635.	7.	9641.	9.	9648.
11.	9661.	14.	9667.	16.	9674.	19.	9680.	21.	9687.
26.	9687.	28.	9693.	30.	9687.	32.	9700.	34.	9700.
35.	9706.	37.	9706.	38.	9719.	38.	9732.	39.	9843.
40.	9849.	43.	9856.	44.	9856.	46.	9856.	48.	9875.
48.	9875.	49.	9888.	49.	10135.	50.	10129.	52.	10135.
54.	10135.	56.	10155.	57.	10155.	59.	10161.	59.	10168.

TRACE NUMBER 60 MV,MICROSEC

0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
0.	9121.	1.	9134.	1.	9147.	1.	9166.	1.	9179.
1.	9628.	2.	9622.	2.	9628.	3.	9641.	3.	9648.
5.	9648.	5.	9648.	6.	9641.	7.	9641.	8.	9654.
9.	9661.	10.	9654.	10.	9674.	11.	9661.	13.	9674.
14.	9680.	14.	9687.	14.	9693.	15.	9713.	16.	9719.
17.	9719.	18.	9719.	20.	9713.	21.	9713.	21.	9719.
22.	9719.	23.	9719.	24.	9719.	25.	9726.	26.	9726.
27.	9732.	28.	9726.	29.	9732.	29.	9745.	30.	9739.
31.	9739.	32.	9739.	32.	9752.	33.	9758.	0.	0.

TRACE NUMBER 61 MV,MICROSEC

0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
3.	9199.	3.	9615.	5.	9628.	7.	9635.	8.	9648.
9.	9648.	11.	9654.	11.	9661.	13.	9661.	14.	9661.
15.	9667.	17.	9674.	19.	9674.	20.	9667.	21.	9680.
21.	9745.	22.	9817.	23.	9810.	25.	9823.	32.	9836.
35.	9836.	38.	9836.	41.	9836.	43.	9843.	46.	9849.
48.	9849.	49.	9849.	53.	9856.	54.	9856.	54.	9849.
56.	9888.	56.	9940.	57.	9927.	59.	9927.	60.	9934.

TRACE NUMBER 62 MV,MICROSEC

0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
1.	9212.	1.	9635.	2.	9680.	3.	9654.	4.	9687.
5.	9674.	6.	9680.	7.	9693.	7.	9706.	8.	9713.
9.	9713.	10.	9713.	11.	9719.	11.	9732.	12.	9758.
12.	9765.	13.	9765.	14.	9765.	16.	9765.	17.	9778.
18.	9784.	19.	9784.	20.	9791.	22.	9797.	22.	9804.
24.	9797.	25.	9804.	26.	9804.	27.	9817.	27.	9817.
28.	9823.	28.	9947.	28.	10064.	29.	10083.	30.	10096.
30.	10090.	31.	10083.	32.	10090.	33.	10077.	34.	10077.
35.	10070.	35.	10077.	0.	0.	0.	0.	0.	0.

TRACE NUMBER 63 MV,MICROSEC

0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
4.	9615.	5.	9648.	7.	9654.	8.	9680.	9.	9687.
14.	9687.	16.	9706.	20.	9719.	23.	9719.	25.	9719.
28.	9719.	29.	9719.	29.	9719.	31.	9732.	33.	9745.
35.	9739.	38.	9739.	39.	9752.	42.	9765.	43.	9778.
44.	9778.	45.	9784.	46.	9791.	46.	9953.	49.	9953.
50.	9960.	0.	0.	0.	0.	0.	0.	0.	0.

TRACE NUMBER 64 MV,MICROSEC

0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
1.	7378.	2.	8464.	1.	8627.	1.	9192.	1.	9609.
3.	9615.	4.	9635.	6.	9641.	7.	9641.	8.	9654.

10.	9654.	11.	9661.	11.	9661.	12.	9661.	13.	9667.
13.	9719.	14.	9706.	15.	9719.	16.	9726.	17.	9719.
18.	9719.	19.	9726.	20.	9752.	21.	9758.	22.	9765.
23.	9778.	23.	9765.	25.	9771.	25.	9765.	26.	9765.
27.	9765.	29.	9771.	30.	9765.	30.	9758.	0.	0.
TRACE NUMBER 65			MV,MICROSEC						
0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
4.	9225.	4.	9635.	6.	9628.	7.	9641.	8.	9648.
9.	9648.	11.	9648.	14.	9648.	15.	9648.	17.	9654.
18.	9661.	19.	9661.	20.	9667.	21.	9667.	22.	9674.
23.	9674.	23.	9687.	24.	9836.	25.	9888.	28.	9895.
29.	9895.	31.	9901.	31.	9921.	31.	9947.	31.	9986.
34.	9999.	37.	10012.	38.	10012.	38.	10031.	38.	10025.
39.	10051.	39.	10083.	40.	10077.	42.	10077.	42.	10077.
43.	10083.	45.	10083.	45.	10090.	46.	10096.	0.	0.
TRACE NUMBER 66			MV,MICROSEC						
0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
0.	9173.	1.	9179.	1.	9179.	1.	9192.	2.	9218.
0.	9459.	0.	9492.	1.	9498.	1.	9511.	1.	9531.
1.	9615.	2.	9654.	2.	9661.	4.	9654.	5.	9661.
5.	9667.	6.	9667.	7.	9667.	7.	9667.	8.	9667.
9.	9674.	10.	9680.	10.	9680.	11.	9680.	12.	9687.
13.	9693.	14.	9700.	15.	9706.	15.	9706.	16.	9719.
17.	9719.	18.	9732.	20.	9739.	20.	9745.	21.	9745.
22.	9745.	22.	9745.	23.	9745.	24.	9752.	25.	9752.
26.	9745.	26.	9752.	27.	9758.	28.	9765.	29.	9765.
29.	9765.	30.	9765.	31.	9765.	0.	0.	0.	0.
TRACE NUMBER 67			MV,MICROSEC						
0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
4.	9231.	4.	9628.	5.	9641.	7.	9641.	9.	9648.
10.	9654.	12.	9667.	14.	9674.	15.	9680.	16.	9693.
18.	9706.	19.	9719.	19.	9719.	20.	9732.	20.	9739.
22.	9739.	24.	9739.	25.	9752.	27.	9758.	28.	9758.
29.	9758.	32.	9765.	34.	9765.	35.	9771.	35.	9771.
36.	9830.	39.	9836.	42.	9836.	44.	9843.	45.	9843.
48.	9843.	49.	9843.	51.	9849.	51.	9849.	0.	0.
TRACE NUMBER 68			MV,MICROSEC						
0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
0.	9153.	0.	9166.	1.	9173.	1.	9212.	1.	9511.
1.	9602.	3.	9615.	4.	9641.	4.	9661.	5.	9680.
6.	9693.	7.	9680.	7.	9687.	9.	9680.	10.	9674.
12.	9693.	13.	9706.	13.	9713.	14.	9719.	15.	9719.
16.	9713.	17.	9732.	18.	9726.	19.	9745.	20.	9758.
21.	9758.	21.	9758.	22.	9758.	22.	9758.	23.	9758.
24.	9758.	25.	9758.	26.	9765.	26.	9778.	26.	9778.
27.	9830.	28.	9869.	28.	9856.	29.	9862.	29.	9856.
31.	9862.	31.	9862.	32.	9862.	32.	9856.	32.	9849.
32.	9849.	0.	0.	0.	0.	0.	0.	0.	0.
TRACE NUMBER 69			MV,MICROSEC						
0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
4.	9635.	7.	9635.	10.	9648.	10.	9648.	12.	9654.

16.	9654.	19.	9661.	20.	9667.	22.	9667.	23.	9674.
25.	9680.	25.	9862.	28.	9843.	31.	9856.	33.	9856.
35.	9856.	36.	9856.	38.	9856.	39.	9862.	40.	9862.
40.	9921.	43.	9927.	44.	9927.	45.	9934.	47.	9934.
47.	9940.	48.	9940.	49.	9966.	0.	0.	0.	0.
TRACE NUMBER		70	MV,MICROSEC						
0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
1.	9225.	1.	9296.	1.	9498.	1.	9576.	1.	9615.
2.	9615.	3.	9622.	4.	9628.	5.	9628.	6.	9628.
7.	9628.	8.	9628.	9.	9641.	9.	9648.	10.	9654.
11.	9661.	12.	9661.	13.	9667.	14.	9674.	14.	9680.
14.	9687.	15.	9693.	16.	9693.	18.	9693.	19.	9700.
20.	9700.	21.	9706.	22.	9706.	22.	9706.	23.	9700.
24.	9706.	25.	9706.	25.	9719.	25.	9726.	26.	9778.
26.	9849.	26.	9869.	27.	9862.	28.	9869.	29.	9875.
30.	9882.	30.	9895.	31.	9908.	32.	9914.	33.	9927.
34.	9921.	0.	0.	0.	0.	0.	0.	0.	0.
TRACE NUMBER		71	MV,MICROSEC						
0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
3.	9602.	6.	9615.	7.	9622.	9.	9622.	11.	9635.
12.	9641.	13.	9661.	13.	9706.	15.	9706.	16.	9719.
17.	9778.	20.	9771.	23.	9784.	25.	9784.	27.	9784.
30.	9797.	31.	9797.	33.	9797.	35.	9791.	37.	9791.
39.	9791.	42.	9804.	43.	9804.	45.	9810.	46.	9817.
47.	9817.	48.	9817.	49.	9817.	50.	9823.	50.	9830.
52.	9830.	53.	9843.	54.	9843.	55.	9849.	56.	9856.
56.	9862.	0.	0.	0.	0.	0.	0.	0.	0.
TRACE NUMBER		72	MV,MICROSEC						
0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
0.	9186.	0.	9205.	1.	9225.	1.	9257.	1.	9505.
1.	9544.	1.	9557.	2.	9589.	2.	9609.	3.	9628.
3.	9628.	4.	9628.	5.	9641.	6.	9648.	6.	9654.
7.	9661.	9.	9667.	9.	9674.	10.	9680.	11.	9726.
12.	9726.	12.	9732.	13.	9719.	14.	9739.	15.	9739.
15.	9732.	16.	9732.	17.	9726.	18.	9726.	19.	9732.
19.	9732.	19.	9732.	19.	9817.	20.	9830.	20.	9823.
21.	9823.	22.	9830.	23.	9830.	24.	9823.	24.	9823.
25.	9830.	26.	9836.	26.	9843.	27.	9836.	27.	9843.
28.	9843.	29.	9849.	0.	0.	0.	0.	0.	0.
TRACE NUMBER		73	MV,MICROSEC						
0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
4.	9244.	4.	9479.	4.	9524.	6.	9557.	7.	9615.
10.	9628.	13.	9628.	14.	9635.	15.	9641.	16.	9641.
18.	9700.	20.	9693.	21.	9687.	24.	9693.	27.	9700.
28.	9700.	29.	9700.	30.	9706.	31.	9700.	32.	9706.
33.	9706.	35.	9706.	36.	9706.	37.	9706.	38.	9706.
39.	9719.	40.	9719.	41.	9719.	42.	9719.	43.	9726.
44.	9719.	44.	9726.	45.	9719.	47.	9732.	49.	9739.
50.	9745.	0.	0.	0.	0.	0.	0.	0.	0.
TRACE NUMBER		74	MV,MICROSEC						
0.	0.	0.	0.	0.	0.	0.	0.	0.	0.

1.	8087.	0.	9225.	1.	9218.	1.	9231.	1.	9244.
2.	9270.	2.	9283.	1.	9518.	2.	9544.	2.	9557.
3.	9570.	3.	9609.	4.	9641.	6.	9641.	7.	9654.
9.	9648.	10.	9648.	12.	9654.	14.	9667.	15.	9667.
17.	9680.	18.	9680.	19.	9680.	21.	9680.	23.	9680.
25.	9680.	26.	9693.	27.	9687.	29.	9680.	30.	9674.
31.	9680.	33.	9680.	34.	9687.	0.	0.	0.	0.

TRACE NUMBER 75 MV,MICROSEC

0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
4.	9316.	4.	9498.	5.	9622.	10.	9635.	13.	9661.
16.	9661.	18.	9674.	21.	9674.	27.	9687.	29.	9687.
32.	9687.	34.	9680.	36.	9687.	38.	9693.	40.	9693.
41.	9700.	41.	9726.	44.	9719.	45.	9732.	48.	9739.
50.	9745.	51.	9745.	53.	9745.	55.	9752.	58.	9752.
61.	9765.	62.	9765.	63.	9771.	65.	9765.	66.	9778.
69.	9778.	70.	9784.	72.	9784.	73.	9784.	73.	9784.

TRACE NUMBER 76 MV,MICROSEC

0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
0.	9199.	1.	9231.	1.	9283.	1.	9303.	1.	9414.
1.	9446.	2.	9459.	3.	9453.	3.	9466.	4.	9459.
4.	9466.	4.	9466.	4.	9492.	4.	9628.	5.	9628.
7.	9622.	8.	9628.	9.	9648.	10.	9648.	11.	9661.
12.	9667.	13.	9680.	13.	9680.	15.	9680.	17.	9687.
19.	9693.	21.	9693.	23.	9693.	25.	9700.	28.	9700.
31.	9739.	32.	9745.	34.	9752.	36.	9758.	0.	0.

TRACE NUMBER 77 MV,MICROSEC

0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
3.	9375.	5.	9440.	5.	9440.	5.	9557.	6.	9635.
9.	9648.	10.	9654.	13.	9661.	16.	9674.	18.	9680.
19.	9680.	20.	9693.	20.	9726.	23.	9739.	25.	9732.
26.	9732.	30.	9739.	31.	9745.	32.	9745.	33.	9745.
34.	9758.	34.	9784.	36.	9778.	38.	9784.	39.	9784.
40.	9791.	42.	9791.	43.	9791.	46.	9797.	48.	9804.
48.	9804.	49.	9797.	49.	9804.	50.	9804.	51.	9804.

TRACE NUMBER 78 MV,MICROSEC

0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
0.	9218.	1.	9238.	1.	9251.	1.	9264.	1.	9296.
1.	9349.	2.	9362.	2.	9368.	3.	9375.	3.	9375.
4.	9381.	4.	9381.	4.	9388.	3.	9602.	4.	9609.
5.	9609.	6.	9615.	6.	9615.	7.	9622.	8.	9628.
9.	9635.	10.	9641.	11.	9641.	12.	9641.	14.	9654.
15.	9661.	15.	9667.	17.	9667.	18.	9674.	19.	9674.
20.	9680.	21.	9680.	21.	9680.	22.	9687.	23.	9687.
24.	9693.	25.	9700.	26.	9700.	27.	9693.	28.	9693.
28.	9752.	28.	9758.	29.	9752.	30.	9745.	30.	9745.
31.	9745.	32.	9752.	0.	0.	0.	0.	0.	0.

TRACE NUMBER 79 MV,MICROSEC

0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
5.	9466.	5.	9628.	7.	9641.	11.	9654.	12.	9648.
14.	9654.	16.	9654.	16.	9661.	17.	9700.	18.	9713.
19.	9713.	21.	9726.	22.	9719.	23.	9719.	25.	9732.

26.	9732.	27.	9732.	29.	9739.	29.	9817.	31.	9843.
32.	9869.	33.	9882.	34.	9882.	37.	9901.	39.	9901.
41.	9908.	42.	9908.	43.	9914.	44.	9908.	45.	9914.
46.	9914.	47.	9921.	48.	9927.	49.	9927.	0.	0.

TRACE NUMBER 80 MV,MICROSEC

0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
0.	6546.	1.	6546.	2.	6553.	3.	6566.	1.	6748.
0.	9212.	1.	9264.	2.	9270.	2.	9290.	4.	9296.
5.	9309.	6.	9316.	6.	9322.	7.	9342.	7.	9641.
8.	9648.	8.	9648.	9.	9641.	10.	9654.	11.	9667.
12.	9667.	13.	9661.	14.	9661.	15.	9661.	17.	9661.
18.	9661.	19.	9654.	20.	9674.	20.	9687.	20.	9687.
20.	9804.	21.	9810.	21.	9810.	21.	9817.	22.	9869.
22.	9888.	23.	9882.	24.	9875.	25.	9869.	25.	9882.
26.	9882.	27.	9895.	28.	9895.	0.	0.	0.	0.

TRACE NUMBER 81 MV,MICROSEC

0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
3.	6176.	3.	9257.	4.	9283.	6.	9296.	7.	9309.
8.	9309.	9.	9329.	8.	9667.	11.	9661.	14.	9661.
16.	9661.	17.	9661.	20.	9667.	23.	9674.	25.	9674.
28.	9680.	30.	9674.	32.	9667.	33.	9667.	35.	9674.
37.	9687.	39.	9687.	41.	9693.	43.	9687.	46.	9687.
48.	9693.	50.	9693.	52.	9700.	52.	9700.	54.	9706.
55.	9700.	57.	9700.	58.	9700.	60.	9706.	62.	9719.
63.	9745.	63.	10051.	68.	10025.	72.	10051.	75.	10044.
78.	10044.	80.	10057.	82.	10057.	84.	10057.	86.	10070.
88.	10070.	90.	10070.	0.	0.	0.	0.	0.	0.

TRACE NUMBER 82 MV,MICROSEC

0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
2.	6546.	1.	6709.	0.	9205.	1.	9218.	1.	9231.
2.	9257.	3.	9264.	3.	9270.	4.	9296.	5.	9296.
5.	9290.	5.	9290.	6.	9303.	5.	9680.	6.	9667.
7.	9667.	8.	9674.	9.	9680.	10.	9680.	11.	9687.
12.	9687.	13.	9687.	14.	9687.	15.	9687.	16.	9693.
16.	9700.	16.	9784.	17.	9791.	17.	9784.	18.	9791.
18.	9797.	18.	9882.	19.	9882.	20.	9875.	20.	9882.
22.	9921.	23.	9927.	24.	9934.	26.	9927.	26.	9927.
27.	9927.	28.	9914.	29.	9914.	30.	9901.	31.	9901.
32.	9908.	33.	9914.	0.	0.	0.	0.	0.	0.

TRACE NUMBER 83 MV,MICROSEC

0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
3.	9231.	4.	9238.	5.	9251.	6.	9270.	5.	9290.
5.	9648.	7.	9661.	9.	9687.	11.	9706.	13.	9706.
15.	9726.	16.	9726.	19.	9732.	21.	9732.	22.	9726.
23.	9732.	23.	9726.	25.	9726.	25.	9726.	26.	9719.
27.	9732.	28.	9765.	30.	9765.	31.	9771.	33.	9784.
34.	9784.	34.	9784.	34.	9817.	36.	9817.	38.	9817.
39.	9823.	40.	9823.	41.	9843.	42.	9836.	42.	9843.

TRACE NUMBER 84 MV,MICROSEC

0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
0.	9140.	1.	9153.	1.	9166.	2.	9173.	2.	9186.

3.	9199.	3.	9192.	4.	9192.	4.	9192.	4.	9199.
4.	9218.	4.	9602.	5.	9609.	6.	9622.	7.	9635.
8.	9654.	9.	9654.	10.	9667.	11.	9680.	12.	9680.
13.	9674.	14.	9667.	15.	9674.	16.	9680.	17.	9693.
19.	9713.	21.	9719.	21.	9732.	21.	9921.	23.	9927.
24.	9934.	26.	9934.	28.	9921.	30.	9927.	31.	9927.
33.	9914.	34.	9914.	35.	9927.	0.	0.	0.	0.

TRACE NUMBER 85 MV,MICROSEC

0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
3.	9153.	4.	9160.	5.	9173.	5.	9192.	5.	9205.
5.	9628.	7.	9667.	11.	9667.	15.	9674.	18.	9674.
22.	9667.	25.	9680.	26.	9687.	26.	9687.	31.	9706.
32.	9700.	32.	9706.	33.	9817.	35.	9823.	36.	9901.
39.	9908.	42.	9908.	43.	9927.	43.	10044.	45.	10044.
47.	10038.	49.	10031.	52.	10031.	54.	10031.	55.	10038.
57.	10038.	57.	10044.	58.	10051.	60.	10064.	0.	0.

TRACE NUMBER 86 MV,MICROSEC

0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
1.	9082.	2.	9095.	2.	9101.	2.	9108.	2.	9134.
2.	9160.	2.	9173.	3.	9192.	2.	9349.	3.	9349.
3.	9362.	4.	9368.	4.	9375.	4.	9381.	4.	9388.
4.	9563.	5.	9576.	5.	9563.	6.	9563.	7.	9563.
7.	9576.	7.	9589.	8.	9589.	8.	9589.	8.	9641.
9.	9622.	10.	9615.	10.	9622.	11.	9635.	12.	9641.
13.	9648.	13.	9648.	14.	9648.	15.	9654.	16.	9648.
17.	9648.	18.	9648.	19.	9648.	20.	9654.	20.	9648.
21.	9648.	22.	9654.	24.	9648.	26.	9641.	28.	9648.
29.	9641.	32.	9654.	33.	9778.	0.	0.	0.	0.

TRACE NUMBER 87 MV,MICROSEC

0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
1.	9082.	2.	9095.	3.	9101.	3.	9134.	2.	9420.
3.	9466.	4.	9492.	3.	9622.	5.	9654.	10.	9661.
14.	9661.	17.	9680.	21.	9693.	25.	9700.	27.	9713.
30.	9719.	32.	9732.	33.	9888.	38.	9895.	41.	9895.
44.	9901.	47.	9901.	50.	9908.	53.	9908.	55.	9914.
58.	9921.	62.	9934.	63.	9934.	66.	9940.	67.	9940.
70.	9973.	0.	0.	0.	0.	0.	0.	0.	0.

TRACE NUMBER 88 MV,MICROSEC

0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
1.	9049.	2.	9062.	3.	9082.	3.	9088.	4.	9082.
4.	9095.	5.	9108.	5.	9121.	6.	9121.	5.	9401.
6.	9394.	6.	9414.	6.	9440.	6.	9440.	7.	9453.
7.	9459.	7.	9472.	6.	9596.	7.	9609.	7.	9635.
7.	9635.	8.	9635.	9.	9641.	10.	9641.	12.	9641.
13.	9628.	14.	9628.	14.	9628.	15.	9641.	15.	9713.
16.	9700.	19.	9706.	21.	9713.	23.	9713.	25.	9706.
27.	9706.	29.	9706.	31.	9700.	33.	9700.	35.	9706.
37.	9726.	0.	0.	0.	0.	0.	0.	0.	0.

TRACE NUMBER 89 MV,MICROSEC

0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
0.	0.	1.	9062.	2.	9075.	2.	9342.	3.	9355.

4.	9362.	5.	9375.	5.	9394.	5.	9414.	5.	9635.
8.	9635.	10.	9667.	13.	9680.	14.	9700.	16.	9706.
17.	9706.	19.	9719.	20.	9726.	21.	9726.	22.	9726.
23.	9726.	24.	9732.	24.	9739.	25.	9739.	26.	9843.
28.	9843.	29.	9856.	32.	9862.	33.	9869.	35.	9869.
36.	9869.	37.	9869.	38.	9869.	39.	9875.	40.	9875.
41.	9882.	0.	0.	0.	0.	0.	0.	0.	0.

TRACE NUMBER 90 MV,MICROSEC

0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
1.	8952.	1.	8978.	2.	8978.	2.	8978.	2.	8991.
3.	8997.	3.	9010.	3.	9023.	3.	9030.	4.	9036.
4.	9043.	4.	9062.	4.	9322.	4.	9336.	4.	9349.
5.	9355.	5.	9362.	5.	9362.	6.	9375.	7.	9381.
7.	9388.	7.	9388.	8.	9388.	8.	9615.	9.	9622.
11.	9641.	12.	9628.	13.	9615.	14.	9609.	14.	9622.
15.	9635.	15.	9719.	15.	9804.	15.	9797.	15.	9830.
19.	9817.	19.	9823.	21.	9810.	23.	9804.	24.	9797.
27.	9823.	0.	0.	0.	0.	0.	0.	0.	0.

MICROSECONDS TO CUTOFF MILLIVOLTS

2	4	8	20	40	80
9842.0	9842.0	9842.0	9881.0	9881.0	10148.0
8782.0	9829.0	9816.0	9836.0	9836.0	0.0
9816.0	9849.0	9862.0	9862.0	9862.0	0.0
9797.0	9816.0	9836.0	9875.0	9875.0	0.0
9803.0	9803.0	9823.0	9842.0	9842.0	0.0
9816.0	9829.0	9836.0	9881.0	9881.0	0.0
9771.0	9777.0	9849.0	9901.0	9901.0	0.0
9777.0	9771.0	9764.0	9842.0	9842.0	0.0
9732.0	9771.0	9784.0	9777.0	9777.0	0.0
9738.0	9725.0	9706.0	9719.0	9719.0	10167.0
9719.0	9764.0	9738.0	9667.0	9667.0	0.0
9732.0	9764.0	9732.0	9699.0	9699.0	0.0
9771.0	9771.0	9764.0	9803.0	9803.0	0.0
9751.0	9758.0	9751.0	9732.0	9732.0	0.0
7840.0	9745.0	9745.0	9738.0	9738.0	0.0
8158.0	9732.0	9738.0	9725.0	9725.0	0.0
9738.0	9738.0	9777.0	9777.0	9777.0	0.0
9686.0	9732.0	9758.0	9712.0	9712.0	0.0
9790.0	9797.0	9790.0	9907.0	9907.0	0.0
9745.0	9797.0	9816.0	9823.0	9823.0	0.0
9719.0	9758.0	9777.0	9803.0	9803.0	0.0
9738.0	9771.0	9764.0	9823.0	9823.0	0.0
9699.0	9719.0	9732.0	9784.0	9784.0	0.0
9673.0	9706.0	9712.0	9719.0	9719.0	0.0
9667.0	9699.0	9693.0	9712.0	9712.0	10044.0
9699.0	9706.0	9732.0	9725.0	9725.0	0.0
9725.0	9751.0	9758.0	9901.0	9901.0	0.0
9660.0	9667.0	9680.0	9771.0	9771.0	0.0
9628.0	9647.0	9660.0	9771.0	9771.0	0.0
9628.0	9647.0	9660.0	9712.0	9712.0	0.0

9654.0	9686.0	9712.0	9790.0	9790.0	0.0
8464.0	9634.0	9654.0	9751.0	9751.0	0.0
9660.0	9654.0	9667.0	9745.0	9745.0	0.0
9615.0	9641.0	9680.0	9758.0	9758.0	0.0
9615.0	9628.0	9641.0	9706.0	9706.0	0.0
9608.0	9628.0	9667.0	9823.0	9823.0	0.0
9543.0	9641.0	9647.0	9680.0	9680.0	0.0
9459.0	9491.0	9647.0	9693.0	9693.0	0.0
9368.0	9387.0	9628.0	9680.0	9680.0	0.0
6552.0	9296.0	9647.0	9686.0	9686.0	0.0
6546.0	9296.0	9680.0	9881.0	9881.0	10057.0
9185.0	9608.0	9654.0	9719.0	9719.0	0.0
9159.0	9381.0	9641.0	9647.0	9647.0	0.0
9062.0	9094.0	9634.0	9712.0	9712.0	0.0
8977.0	9348.0	9621.0	9810.0	9810.0	0.0

CM WATER TO CUTOFF MILLIVOLTS

729.8	729.8	729.8	732.7	732.7	752.5
651.2	728.8	727.9	729.3	729.3	0.0
727.9	730.3	731.3	731.3	731.3	0.0
726.4	727.9	729.3	732.2	732.2	0.0
726.9	726.9	728.4	729.8	729.8	0.0
727.9	728.8	729.3	732.7	732.7	0.0
724.5	725.0	730.3	734.2	734.2	0.0
725.0	724.5	724.0	729.8	729.8	0.0
721.6	724.5	725.5	725.0	725.0	0.0
722.1	721.1	719.7	720.7	720.7	753.9
720.7	724.0	722.1	716.8	716.8	0.0
721.6	724.0	721.6	719.2	719.2	0.0
724.5	724.5	724.0	726.9	726.9	0.0
723.0	723.6	723.0	721.6	721.6	0.0
581.3	722.6	722.6	722.1	722.1	0.0
604.9	721.6	722.1	721.1	721.1	0.0
722.1	722.1	725.0	725.0	725.0	0.0
718.2	721.6	723.6	720.1	720.1	0.0
725.9	726.4	725.9	734.6	734.6	0.0
722.6	726.4	727.9	728.4	728.4	0.0
720.7	723.6	725.0	726.9	726.9	0.0
722.1	724.5	724.0	728.4	728.4	0.0
719.2	720.7	721.6	725.5	725.5	0.0
717.3	719.7	720.1	720.7	720.7	0.0
716.8	719.2	718.7	720.1	720.1	744.8
719.2	719.7	721.6	721.1	721.1	0.0
721.1	723.0	723.6	734.2	734.2	0.0
716.3	716.8	717.8	724.5	724.5	0.0
713.9	715.3	716.3	724.5	724.5	0.0
713.9	715.3	716.3	720.1	720.1	0.0
715.8	718.2	720.1	725.9	725.9	0.0
627.6	714.4	715.8	723.0	723.0	0.0
716.3	715.8	716.8	722.6	722.6	0.0

713.0	714.9	717.8	723.6	723.6	0.0
713.0	713.9	714.9	719.7	719.7	0.0
712.4	713.9	716.8	728.4	728.4	0.0
707.6	714.9	715.3	717.8	717.8	0.0
701.4	703.8	715.3	718.7	718.7	0.0
694.6	696.0	713.9	717.8	717.8	0.0
485.8	689.3	715.3	718.2	718.2	0.0
485.4	689.3	717.8	732.7	732.7	745.7
681.1	712.4	715.8	720.7	720.7	0.0
679.1	695.6	714.9	715.3	715.3	0.0
671.9	674.3	714.4	720.1	720.1	0.0
665.6	693.2	713.4	727.4	727.4	0.0