TEST REPORT
EVALUATING A DISCRETE FREQUENCY AIR ACOUSTIC WATER LEVEL SENSOR

SUBMITTED TO
NATIONAL OCEAN SURVEY

NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION
U.S. DEPARTMENT OF COMMERCE
6010 EXECUTIVE BOULEVARD
ROCKVILLE, MD 20852

1 OCTOBER 1981

WORK PERFORMED UNDER
CONTRACT NA-80-SAC-00619

RAYTHEON

OCEAN
SYSTEMS
COMPANY
PORTSMOUTH, R I

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1.0 Introduction and Objectives

This report documents testing of a discrete frequency air acoustic water level sensor conducted by Raytheon Ocean Systems Company under Contract No. NA-80-SAC-00619. The objective of the experiment is to determine if a discrete frequency air acoustic sensor can provide an accurate indication of water level in an enclosed pipe.

Of secondary interest is whether it can do so in an open configuration, simply directed at the water surface, in the presence of waves. Concern in both cases is regarding the characteristics of returned signals. In an enclosed pipe, signals may be returned from points other than the water's surface such as fouling, welds or joints in the pipe and via reflected paths other than direct. In both cases, the characteristics of the returned signals are investigated and an assessment made regarding the accuracy of reported data.

A power requirements analysis has also been performed in order to determine duty cycling necessary if the device is to be utilized in an energy limited application.

2.0 Description of Experiment

A National Sonics Sensall sensor was borrowed and set up in four configurations: 1) in a four inch PVC pipe in the laboratory, 2) in an open configuration in the laboratory viewing a simulated wave surface, 3) in an open configuration in the presence of ocean waves and, 4) in a four inch PVC pipe in the presence of ocean waves. Signals were observed at the receiver before and after conditioning using a camera equipped oscilloscope and at the analog output of the device after signal processing. Figure 1 depicts the experimental setup.

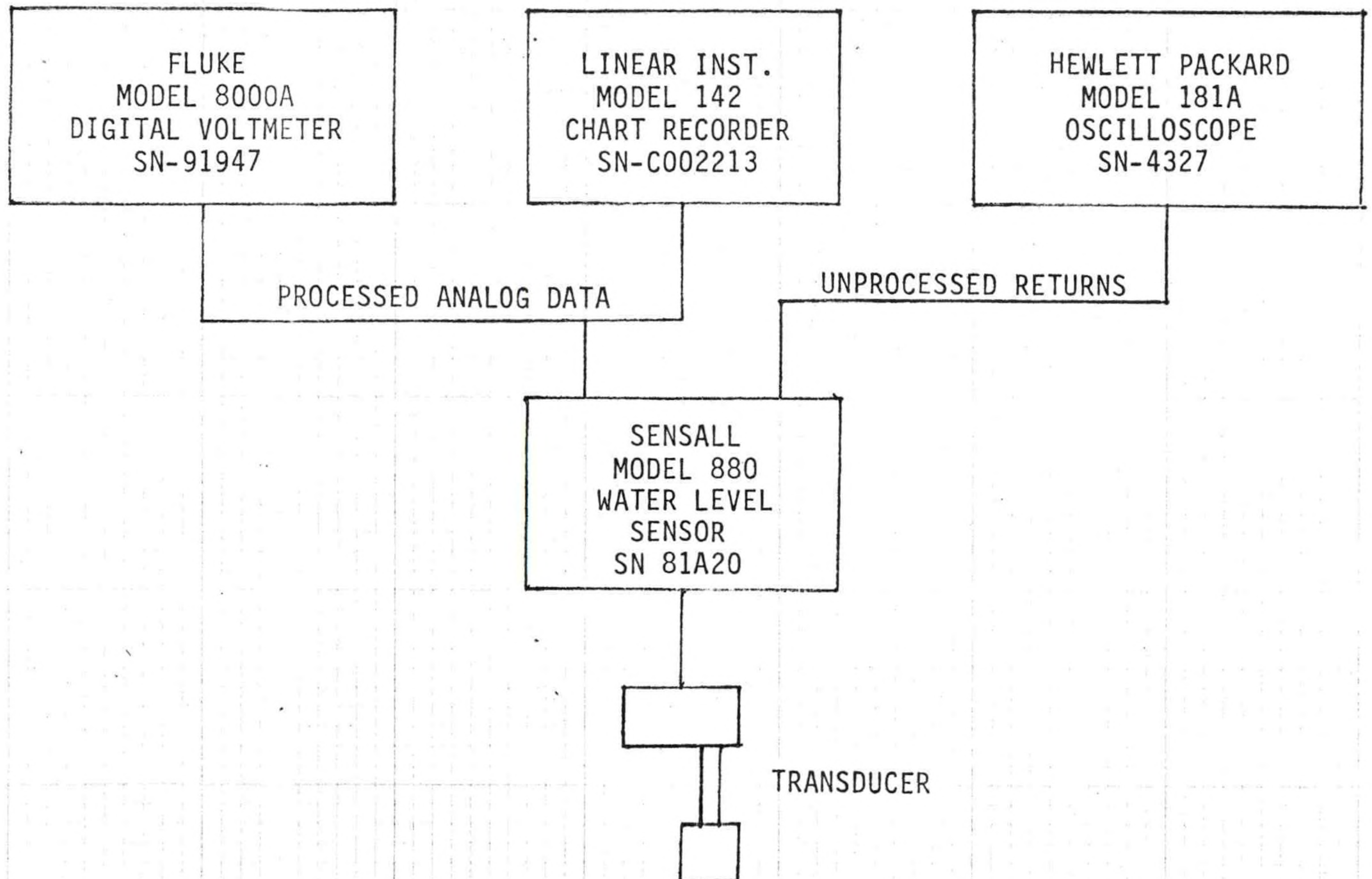


Figure 1

Experimental Setup

3.0 Device Description

The device used in these experiments is a Sensall Model 880 Continuous Level Transmitter manufactured by National Sonics, 250 Marcus Boulevard, Hauppauge, N.Y. 11787. It was provided free of charge by the manufacturer for this experiment.

3.1 General Description

The Sensall Model 880 Continuous Liquid Level Transmitter is normally used to detect and control the level of a liquid in a vessel over a 5 or 10 foot range (maximum). The system consists of a microcomputer-based control unit and an ultrasonic sensor assembly. The control unit electronics are housed in a NEMA-4 enclosure. HIGH and LOW ALARM, OPERATE, NEAR ZONE (liquid level closer than 10" standard). FAR ZONE (liquid level beyond 127.5" standard), LOST ECHO indicators and the front panel indicating meter are provided in the enclosure. A 4-20mA DC output signal is standard. Two SPDT setpoint relays are provided for external control of pumps, solenoid valves and/or audible or visual alarms. Additional relays for Far Zone and Near Zone modes are optional. The sensor assembly consists of a CPVC or optional Kynar sensor mounted on a cast aluminum NEMA-4/NEMA-7 Junction box.

The Model 880 may be set for Height and Distance Mode operation. The Height Mode provides direct acting outputs: output increases as the liquid level rises. Distance Mode provides reverse acting outputs.

Optional equipment includes Near and Far Zone relays, control unit heater assembly (for ambients down to -40^{o}F), digital meter, explosion-proof enclosure, multi-sensor switching assembly and flanged sensor fittings.

The following factory bulletin depicts the Model 880 unit and presents its specifications.

3.2 Principles of Operation

The Sensall Model 880 consists of three principal elements - a sensor, an analog transmitter/processor and a microcomputer - plus associated binary coded decimal (BCD) switches, temperature compensation, isolated output and output driver circuitry.

ENVIROTECH

SENSALL® 880 ULTRASONIC NON-CONTACT CONTINUOUS LEVEL TRANSMITTER

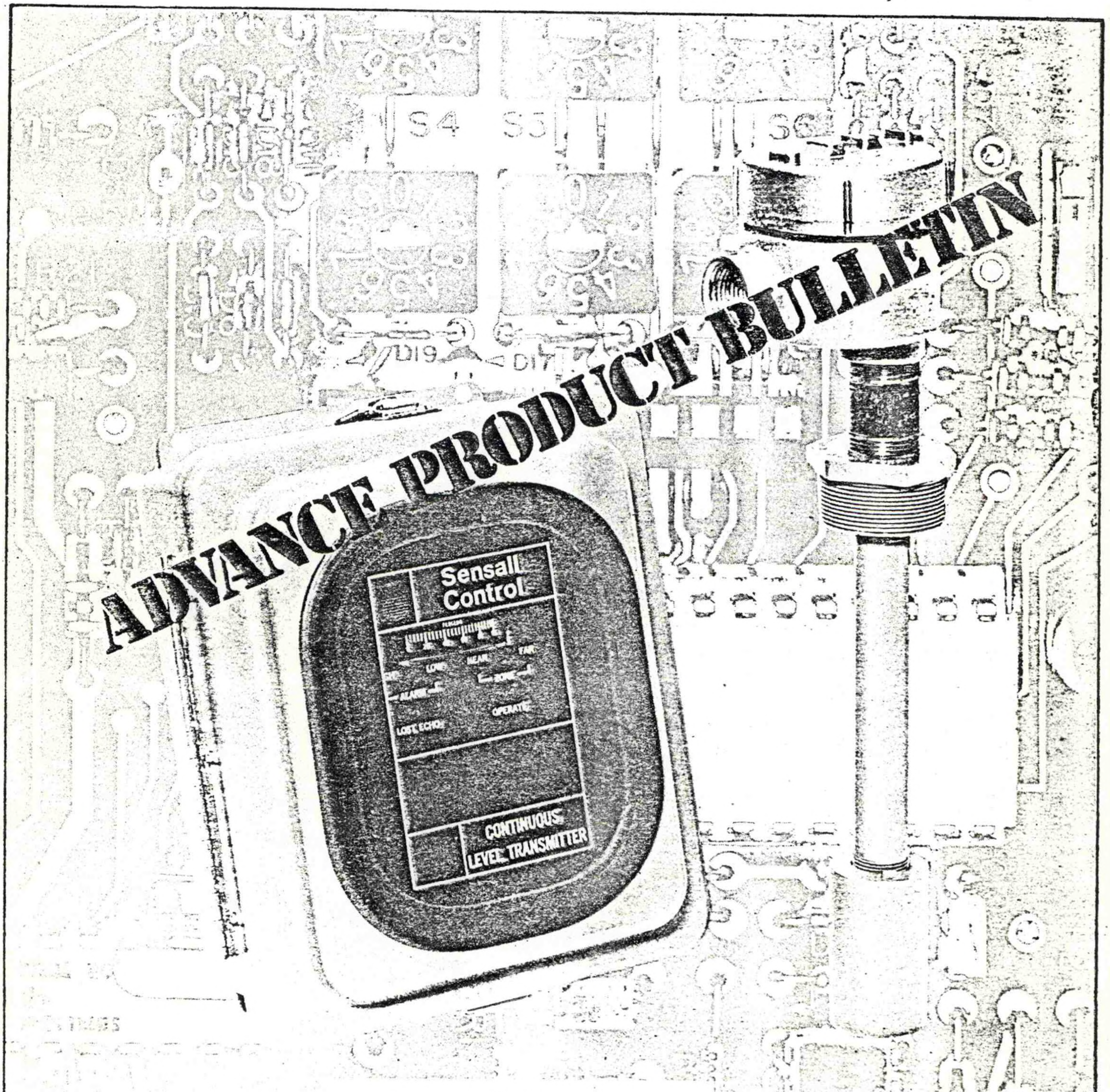


Figure 2 (a)

NOW, NATIONAL SONICS BRINGS THE BENEFITS OF MICROPROCESSOR TECHNOLOGY TO NON-CONTACT CONTINUOUS LEVEL SENSING

Introducing the Sensall Model 880 Continuous Level Transmitter, the low cost alternative to level measurement problems. Based on proven ultrasonic technology and incorporating microprocessor based electronics, the Sensall Model 880 provides highly accurate level indications continuously over a 10 foot range.

The Model 880 measures levels accurately from 10" to 127.5". Pulsed signals are transmitted from the transducer to the liquid and are received back as echoes. The elapsed time between the transmission and received echo is proportional to the distance. This information is processed by the electronics and converted to highly accurate level indications that can be used in various switching operations. A non-linear digital filter and employment of a moving average technique (programmed into the microprocessor) rejects noise and atmospheric interference, providing accurate measurements despite turbulence, agitation, or foam.

Two sets of binary coded decimal (BCD) switches are employed to set the ranges desired and the relay set-points. The Model 880 may be set for Hi and Lo operation, Automatic Fill, Automatic Empty or optional High Level Fail-safe operation. A continuous 4-20 mA or 0-10V DC output is provided. Level indication of the liquid in the tank is displayed on the front panel indicating meter. Indicators for High, Low, Operate, Near Zone, Far Zone and Lost Echo are also provided on the front panel.

Features

- Microprocessor Control
- Dual-point operation (Two additional points optional)
- Switchable modes
- Simple calibration
- Fail-safe operation
- Built-in diagnostic program
- Choice of mounting configuration
- Highly accurate and reliable measurements
- Continuous 4-20 mA or 0-10V DC output

Applications

- Petroleum Processing
- Chemical Processing
- Food Processing
- Pharmaceuticals and cosmetics
- Marine Operations

Specifications

Range
10" to 127.5" (25.4 cm to 323.9 cm) from sensor face

Repeatability
1/8" (.3 cm) typical

Accuracy (Analog Output)
1/2% of full scale

Span Limits
Adjustable over a 3:1 range

Response Time
Factory set fixed at 1/2 second standard, others available

Temperature Compensation
Automatic over full range

Ultrasonic Frequency
50K Hz

Beam Angle
Conical 12^o (typical)

Output Signal
4-20 mA DC (isolated) into 0-1000 ohms or 0-10 V DC into minimum load of 1000 ohms

Set Point Operational Modes
Height Mode - High, Low, Auto Fill, Auto Empty and High Level Fail-safe
Distance Mode - High and Low

Enclosure Type
Control unit - NEMA-4 Fiberglass, (1) 1/2" Conduit hub and (1) 1" conduit hub
Sensor - NEMA-4, Cast Aluminum

Sensor Construction
CPVC; Kynar (optional)

Sensor Mounting
2" NPT process connection; 2" flange, 3" NPT and 3" flange (optional); 1" NPT electrical connection

Operating Power
117 VAC, 50/60 Hz ±10%; 24 V DC, 4 watts approx. optional

Extension Cable
10 feet dual coaxial cable terminated in spade lugs standard
Up to 50 feet maximum (optional)

Pressure Rating
Up to +50 PSIG (3.52 kg/cm^2) operating

Temperature Range
Sensor - -22^o to +158^{o}F (-30^o to +70^{o}C)
Electronics - +32^o to +158^{o}F (0^o to +70^{o}C)

Relay Contacts
2 SPDT Independent, 5 amps at 24 V DC and 117 VAC (non-inductive) standard; 2 SPDT independent, 5 amps at 24 V DC and 117 VAC (non-inductive) for Near Zone, and Far Zone or High Level Fail-safe optional

Weight
Sensor - 3 lbs. (1.4 kg) approximate
Electronics - 8 lbs. (3.6 kg) approximate

ENVIROTECH

National Sonics Division
Envirotech Corporation
250 Marcus Boulevard
Hauppauge, N.Y. 11787
Telephone: 516/273-6600
Telex: 14-4545

Figure 2 (b)

Litho U.S.A.

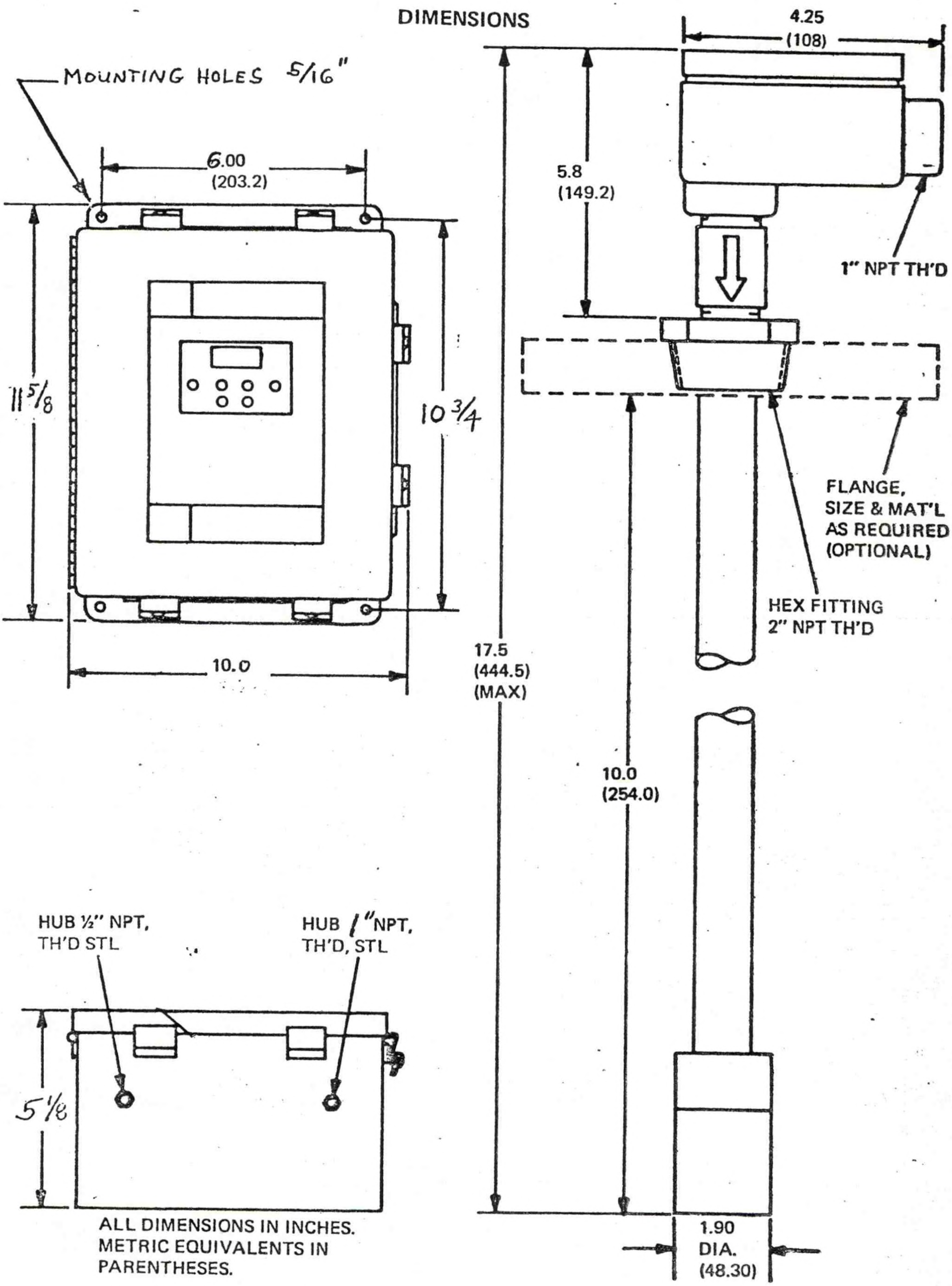

DIMENSIONS
MOUNTING HOLES 5/16"
6.00
(203.2)
11 5/8
10 3/4
10.0
HUB ½" NPT,
TH'D STL
HUB 1" NPT,
TH'D, STL
5 1/8
ALL DIMENSIONS IN INCHES.
METRIC EQUIVALENTS IN
PARENTHESES.
4.25
(108)
5.8
(149.2)
1" NPT TH'D
FLANGE,
SIZE & MAT'L
AS REQUIRED
(OPTIONAL)
HEX FITTING
2" NPT TH'D
17.5
(444.5)
(MAX)
10.0
(254.0)
1.90
DIA.
(48.30)

Figure 2 (c)

In operation, the microcomputer's software program generates a series of transmit pulses and a transmit gate signal which are routed through the transmit electronics to the ultrasonic sensor. The sensor transmits an ultrasonic beam with a conical 12° (typical) angle to the surface level. Returning echos from this surface are detected, amplified and converted to a digital representation of the distance between sensor and reflecting surface. This information is used for valid detection of received return signals.

A software program in the microprocessor processes the returned and conditimed signals and stores the range value, using a non-linear digital filter and moving average technique to reject spurious signals and noise. Details of this algorithm are proprietary.

The continuous measurement is displayed on the front panel meter with an analog output signal provided. Resolution of the system is eight bits over the 10 foot operating range or 0.47 inchs (1.2cm). If there is a loss of signal for more than 8 seconds (Lost Echo condition), the analog outputs will go to full scale. For liquid levels closer than 10" (Near Zone) or beyond 127.5" (Far Zone), the system will not track the level but will maintain the last valid indication.

4.0 Test Descriptions

The following sections describe the various tests conducted. Data from each test is provided along with photographs of signals and other information. Observations and discussion are included in the material covering each test.

4.1 Air Calibration

Objective: To verify the linearity and accuracy of the Sensall unit in an open air configuration.

Procedure: The transducer was placed in a horizontal position, at least 3 feet from any adjacent planes on a movable platform A steel tape was used for measuring distances from a perpendicular reflective surface (wall) to the transducer face. Output was read using a 4 digit DVM. Data was collected at 6" increments by moving the transducer away from the reflector over the full specified operating range of 10" to 120".

Data: The following data resulted.

Distance (inches)	Output (ma)	Distance (inches)	Output (ma)
10	19.90	78	10.13
14	19.31	84	9.25
18	18.73	90	8.36
24	17.91	96	7.43
30	17.02	100	6.59
36	16.14	108	5.71
42	15.32	114	4.89
46	14.35	120	4.01
54	13.55	126	3.12
60	12.66	12	19.89
66	11.83	14	19.31
72	10.95		

Analysis: A plot of the above data is shown in Figure 3. A linear regression of the data set shows a slope of -0.14455 ma/inch with an intercept of 21.35 ma. In plotting the deviation of the experimental data from the regression equation, maximum deviation of 0.4262 inches was found (see Figure 4) which is within the 0.5% FS (0.6") accuracy stated in the Sensall specifications.

Observations: The Sensall unit digitizes data to an 8 bit resolution, i.e., 1 part in 256 over the full scale range of 120 inches. One least significant bit is then 0.469 inches. Thus, the non-linearity seen here is of the order of 1 LSB, and may be implied to be beyond the resolution of the device as designed.

4.2 Stilling Pipe Calibration

Objective: To investigate the linearity and accuracy of the Sensall unit in a protective well.

Procedure: The transducer was mounted in a fixture allowing it to be attached to the top of a vertical 4" diameter plastic pipe. A drain was installed in the lower portion of the pipe, which was filled with water. Water level was changed by filling and draining. The distance from the transducer face to the water surface was measured using a steel tape mounted adjacent to a manometer type water level indicator. See Figure 5 for pipe calibration setup.

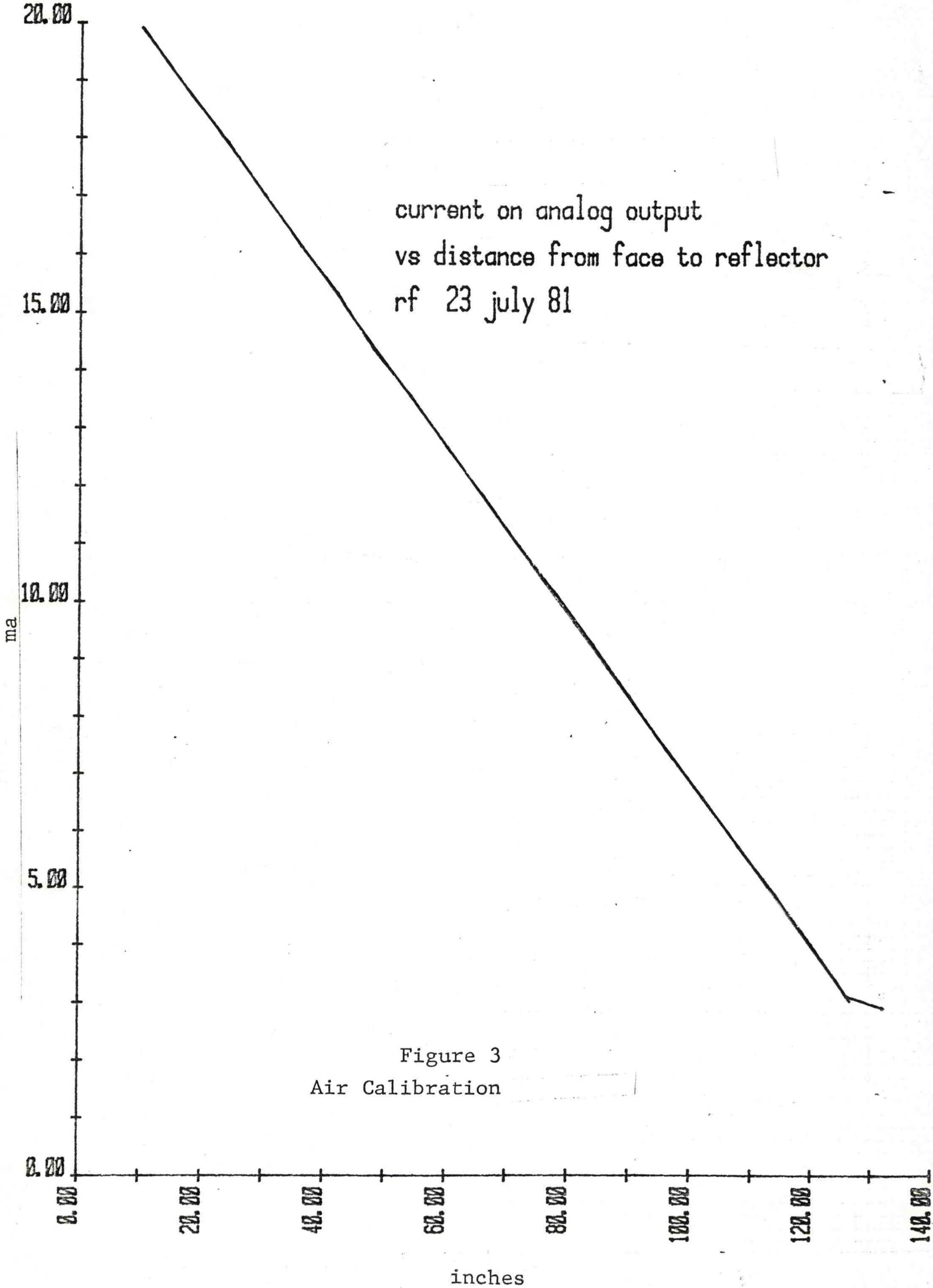


Figure 3
Air Calibration

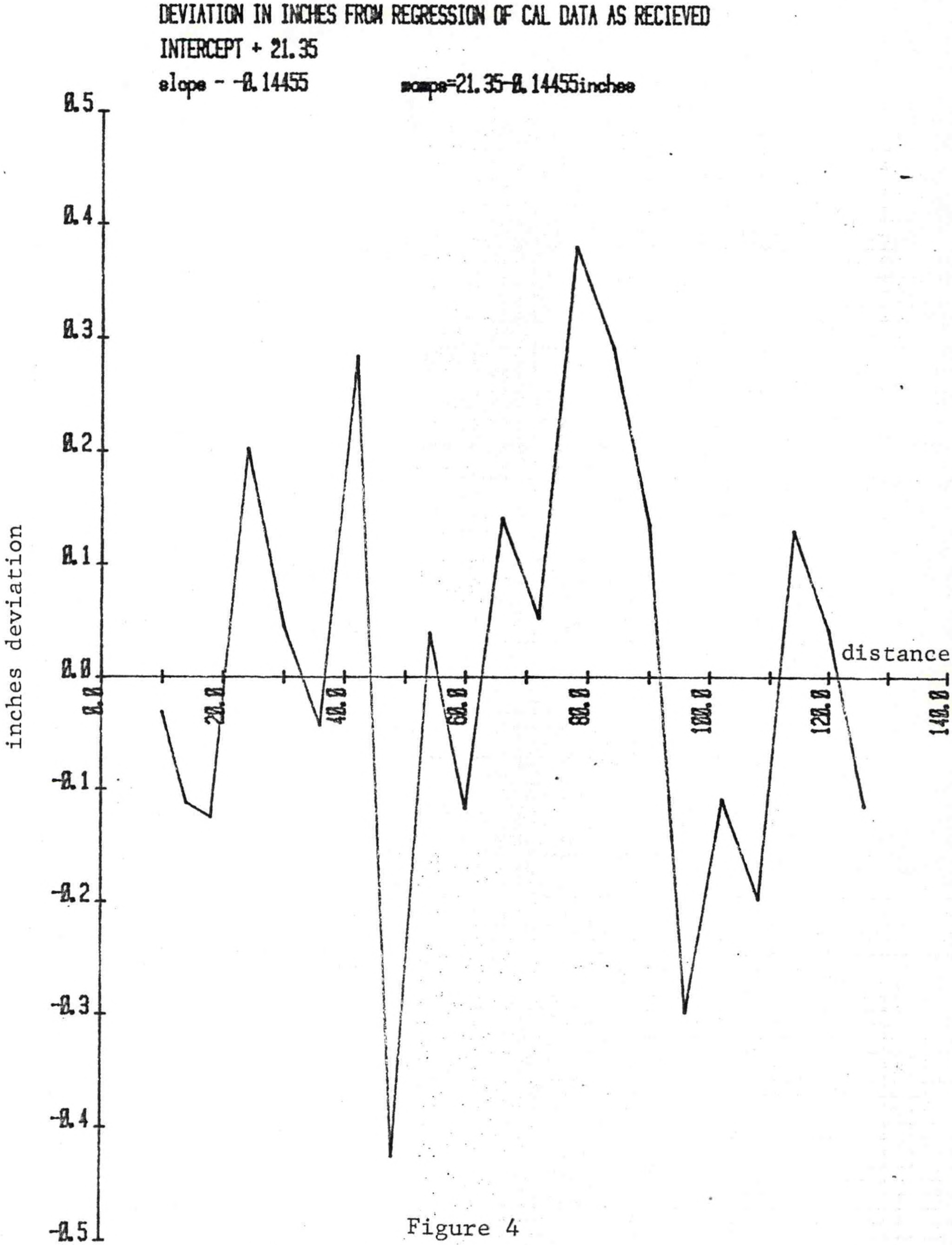


Figure 4
Air Regression Deviation

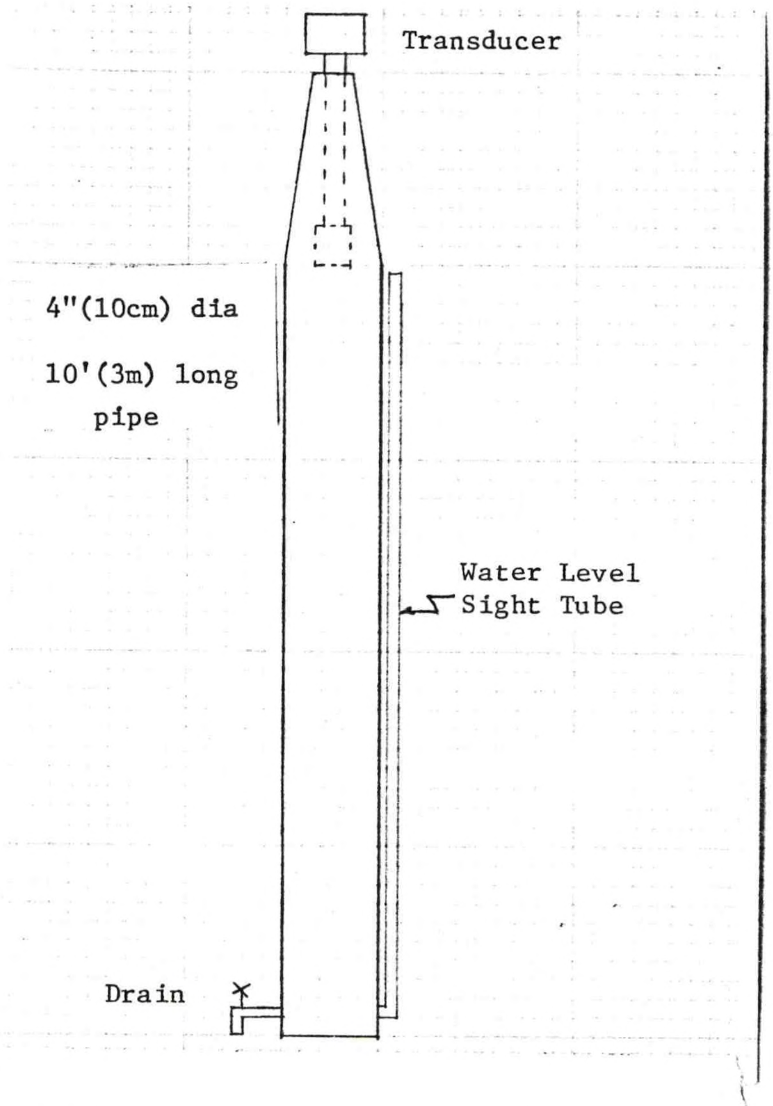


Figure 5

Pipe Calibration Setup

The water level was lowered at approximately 6" intervals over the range of the Sensall device, and data was taken using a 4 digit DVM.

Data: The following represents the data set collected.

Distance (inches)	Output (ma)	Distance (inches)	Output (ma)
12.00	19.65	72.06	10.87
18.19	18.77	78.06	10.06
24.00	17.87	84.00	9.18
30.38	16.90	90.00	8.29
36.00	16.16	96.00	7.39
42.50	15.19	102.19	6.51
48.06	14.37	108.00	5.70
53.88	13.56	114.00	4.81
60.00	12.67	118.06	4.22
66.00	11.76		

Analysis: A plot of the data set is shown in Figure 6. A linear regression of the data yields a slope of -0.1453 ma/in with an intercept at 21.37 ma. Comparison of the regression equation (Figure 7) with the actual data shows a maximum deviation of about 0.38" which is beyond the resolution of the Sensall as designed. The device then is linear when operated in the 4" well, and is within the stated specifications.

Observations: Although the intercept is about the same as that in open air, there is a slight difference in the slope of about 0.5%, again in the order of the resolution of the instrument.

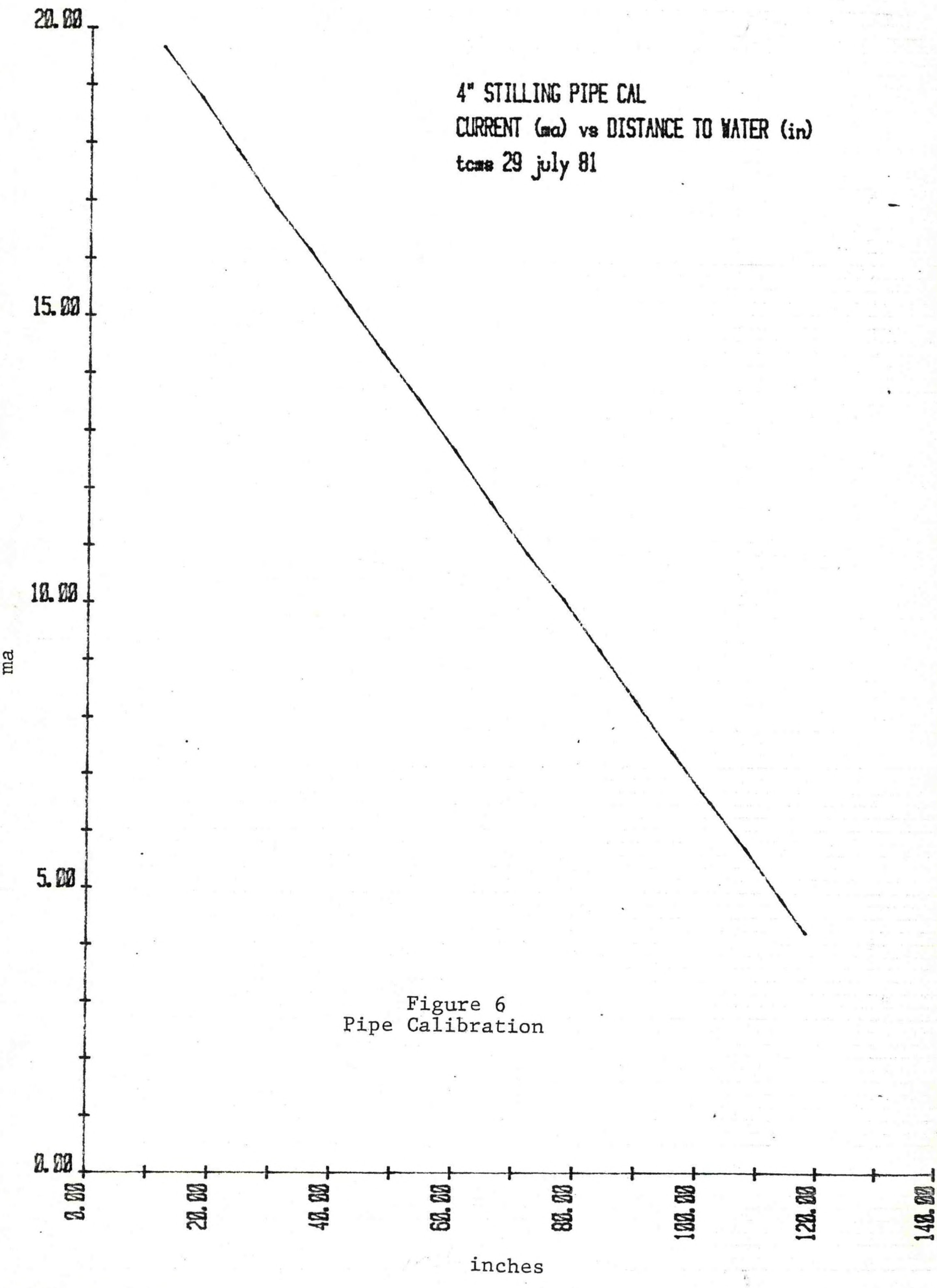


Figure 6
Pipe Calibration

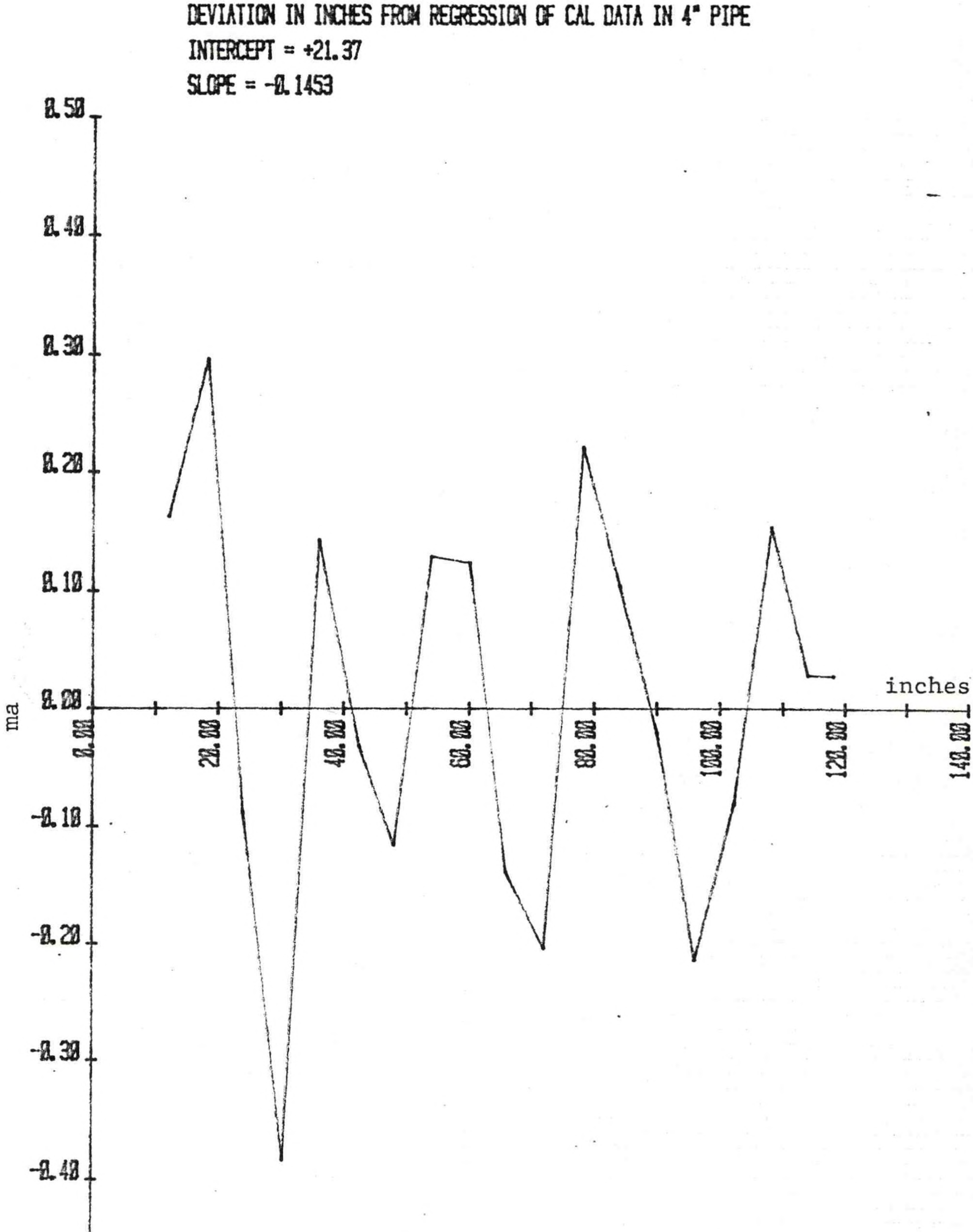


Figure 7
Pipe Regression Deviation

4.3 Non-perpendicular Reflector in Open Air

Object: To investigate the response of the system to a non-perpendicular reflector such as that created when a wave passes beneath the transducer.

Procedure: The transducer was mounted in a vertical track above a sheet of ABS plastic material having a smooth surface. As the plastic sheet was moved from a perpendicular position, the echo was lost at a very small angle. A new reflector with a slightly roughened surface was used and the angle was found to increase slightly. A third reflector was constructed in an attempt to simulate a surface roughness similar to what might be encountered in actual practice. The reflector was covered with plastic bubble wrap packing material having 3/8" diameter hemispheres on 1/2" centers. The material presented more perpendicular surface when tilted at an angle and thus the Sensall was able to maintain a lock on the returned signal. Calibration checks were conducted with the reflector at angles of 0^o, 5^o, 9^o and 13^o.

Data: The following data set was collected:

Angle = 0^o

Distance (inches)	Output (ma)
45.25	19.84
52.00	13.86
56.50	13.14
63.00	12.17
69.00	11.37
76.00	10.30
84.00	9.12

Angle = 5^o

Distance (inches)	Output (ma)
44.50	14.92
51.00	14.05
55.25	13.36
62.00	12.39
67.50	11.56
74.00	10.60
82.75	9.34

Angle = 9^o

Distance (inches)	Output (ma)
45.50	15.21
54.50	13.51
67.00	11.78
82.00	9.56

Angle = 13.1^o

Distance (inches)	Output (ma)
42.00	15.36
53.00	13.80
65.50	12.01
72.50	11.12
74.50	10.89

Analysis: Linear regressions were performed on each of the sets of data with the follow results:

Angle	Intercept	Slope	$r^2 \times 10^3$
0^o	20.97	-0.1401	997
5^o	21.48	-0.147	997
9^o	21.99	-0.152	997
13^o	21.14	-0.138	994

The 13^o series, which shows a poorer fit, exhibited some loss of echo, and therefore is a questionable data set. The 0^o, 5^o, and 9^o data show a progression in both intercept and slope. Analysis shows that that the data sets fall within the 0.5 - 1% of FS range, some of which is attributed to the experimental error in measuring the actual distance to an approximated centerpoint of the illuminated area.

Observations: The "experimental error" noted above highlights a problem with determining the "water level" of an irregular surface and how it relates to the return spectrum of the acoustic signal.

4.4 Response In a Pipe With a Sloped Water Surface

Objective: Investigate the characteristics of the return signal in a 4" pipe with a slanted reflecting surface.

Procedure: The transducer was mounted in the top of a 4" diameter pipe containing water. The analog output was read using a 4 digit DVM. An oscilloscope was connected to monitor the Sensall at a point in the receive circuitry to allow monitoring of the signal return. The pipe was tilted with respect to vertical to simulate the tilted surface which might be realized as a wave passed by a water level gage.

Data: The following data set was observed:

Tilt degrees	Analog ma	Photo (Figure 8)
0	12.78	A
5	12.68	B
10	12.61	C
15	12.61	D

Using a scale factor of 0.1445 ma/inch, the apparent change in reported value between 0^o tilt and 10^o tilt is 1.17 inches (2.99cm).

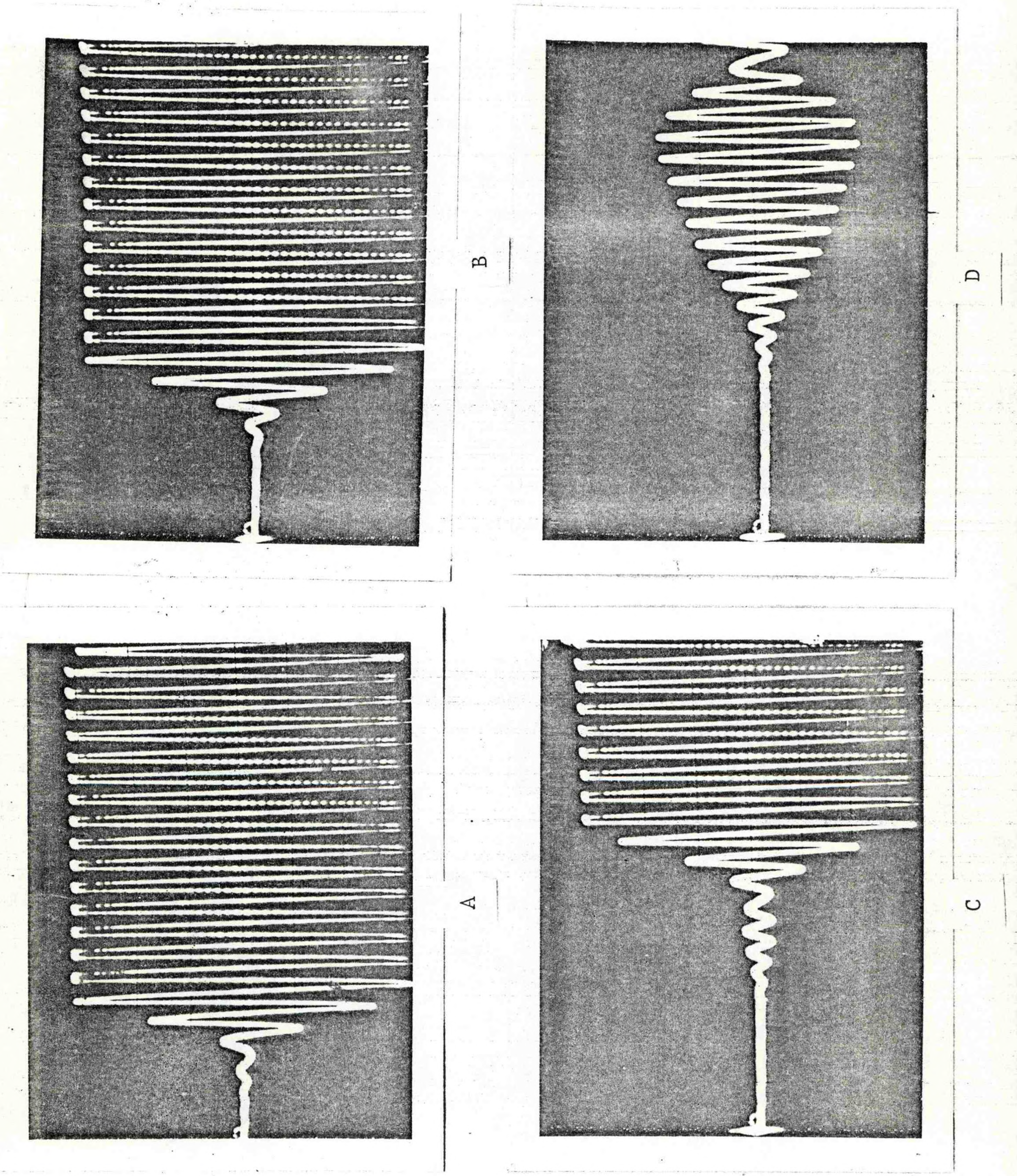


Figure 8
Response in a Tilted Pipe

Observations: It is clear that as the surface tilts, the apparent distance from the transducer increases. The first explanation is the increased time of travel of the pulse due to the sharper reflecting angle and consequently more bounces on the walls of the pipe. Additionally, a phase cancellation effect is apparent. Amplitude of the return is diminished as the angle is increased to the point of a classic example of phase cancellation beginning to develop in photo D.

4.5 Long Range Response

Objective: To determine the relative return amplitude as a function of distance in a 4" pipe.

Procedure: The transducer was placed in a 4" pipe with an oscilloscope viewing the returned signals in the receive circuitry. The reflector was varied in 5 foot steps from 40 to 10 feet and the peak amplitude of the return recorded.

Data:

Distance (feet)	Amplitude (volts)
>40'	∿0.1 (noise)
40	<0.2
35	0.2
30	0.25
25	0.65
20	1.6
15	6.2
10	7.0 (saturation)

Figure 9 shows the return at 30 feet (9 meters). The scale is 10 msec/cm horizontal and 0.5v/cm vertical. The rightmost return is the 30' reflector. The large return at left is the pipe joint at 10'. The pipe used had overlapped joints, and thus presented a reflection of the discontinuity.

Observations: The use of overlapped pipe joints does not appear satisfactory, as their reflection is quite large in the near field. The Sensall uses a linear gain over its range, and thus it gives an apparent weighting to the amplitude of the closer reflector. Use of thresholding and non-constant gain may decrease its susceptibility to pipe discontinuities.

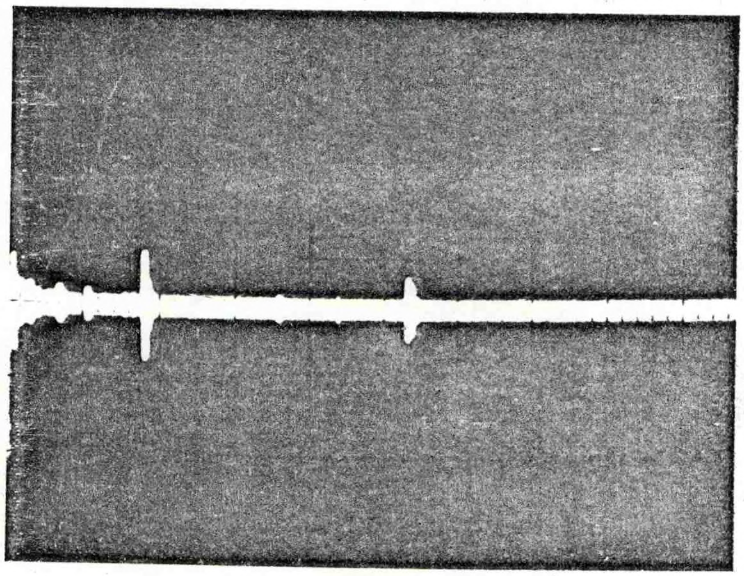


Figure 9

Long Range Response

4.6 Effects of Foreign Objects

Objective: To investigate the potential effect of barnacles and other fouling in the 4" pipe.

Procedure: With the transducer mounted in a 10 foot long 4" diameter pipe, a series of different sizes and geometrical shapes were moved along the edges of the pipe and the response was monitored in the receive circuitry. Several 0.625 inch diameter holes were drilled at 6" intervals from 4 to 8 feet from the transducer to allow insertion of objects to test the sensitivity across the axis of the beam.

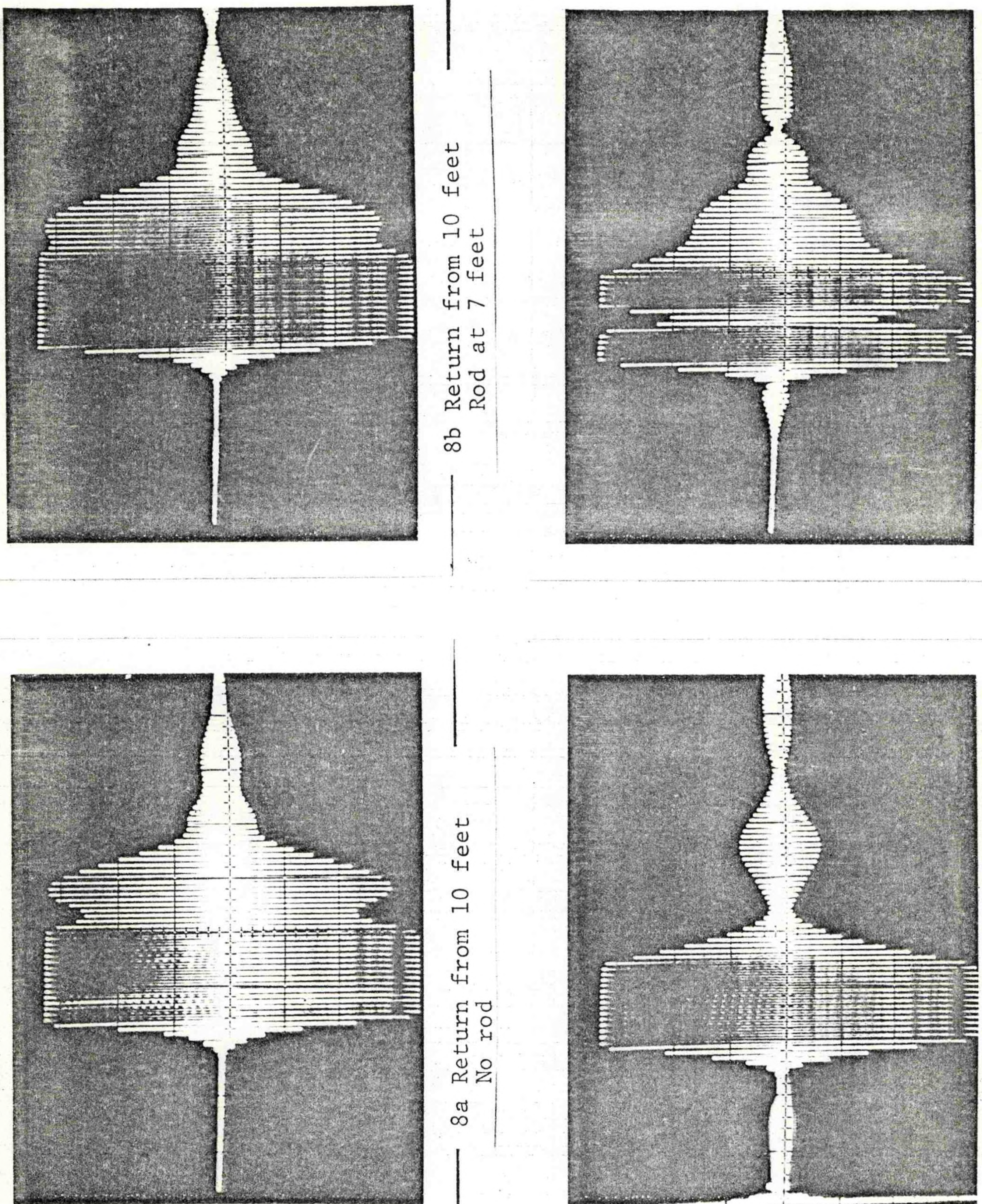
Observations: Figure 10 shows the effects on the return from the 10" reflector created by placing a ¼" rod across the diameter of the tube at intermediate points. In addition to generating a return of its own, the interfering object affected the latter portion of the return waveform. Effects on the leading edges are small until the object is placed 5 feet from the transducer.

The returns exhibited from the rod itself demonstrated somewhat predictable results. The return amplitude at each distance was a function of the penetration of the rod toward the center of the pipe, increasing in a logarithmic fashion. The implication being that biological fouling on the walls of the pipe is a problem only if it protrudes well into the center one inch of the pipe. The return amplitude as a function of distance from the transducer face was not linear. The return from the rod was apparently a function of where it was placed with respect to the bottom return, and whether the return signals added or canceled. The phase cancellation of the signal frequency source again appears influential.

4.7 Operation in the Presence of Waves

Objective: To operate and evaluate the performance of the Sensall device in an actual wave affected situation.

Procedure: The device was installed in a 4" diameter open pipe mounted to a pile at Fort Adams State Park, Newport, R.I. The site was chosen for its exposure to wind waves and high incidence of wakes created by boat traffic. The system was set up with an oscilloscope to monitor return signals as well as a recorder on the analog output to record the processed signals.



8a Return from 10 feet
No rod

8b Return from 10 feet
Rod at 7 feet

8c Return from 10 feet
Rod at 6 feet

8d Return from 10 feet
Rod at 5 feet

Figure 10

Effects of Foreign Objects

Observations: The three conditions looked at were with the 4" well immersed 2.5 feet, 5 feet, and with no well. The 2.5' immersion situation tracked the wave conditions (2 sec period, 2 ft amplitude) extremely well, until a larger amplitude (3-4 ft) boat wake passed causing loss of tracking for 3-4 seconds. These losses may be attributed to the requirements that 5 of 7 return pulses must agree in order for a valid level to be reported. The pipe was then depressed to 5' immersion and the unit then tracked the attenuated waves almost flawlessly. Finally, the transducer was mounted outside the pipe, at a range of approximately 7 feet from the water surface. In this circumstance, the return amplitude was greatly diminished and the ability to track the surface quite poor. Figures 11 a, b, c present analog recordings taken for each of the above cases. These recordings are uncalibrated in amplitude but represent wave height maximums of 4 feet peak to trough. Flat portions of the traces represent periods during which the processor was unable to track the water surface.

Although limited by range, the Sensall appeared to operate quite well under real-world conditions. The sampling algorithm appears somewhat stringent, and phase cancellation was quite evident in the wave zone. The unit did seem to demonstrate quite well the ability to measure and track the moving surface in the well, once a more realistic immersion was used.

5.0 Power Requirements Analysis

5.1 Present System Power Requirements

The transmitter power requirement for this 3 meter system has been calculated to be 14 mwatts based on the voltage levels and duty cycling noted in Figure 12.

The impedance of the transducer is 1400 ohms

$$\text{Power} = \frac{(200\ \text{v}/1.414)^2}{1400} \quad \times \frac{1}{10^3} \text{ duty cycle}$$

$$= 14 \text{ mwatt}$$

This will increase as more power is required for longer ranges.

Receiver power for this system is calculated to be 675 mwatt using a nominal 15 ma @ 15 volt requirement for three operational amplifiers. These amplifiers were not selected with power requirement as a consideration. Optimizing of designs will cause this figure to reduce markedly.

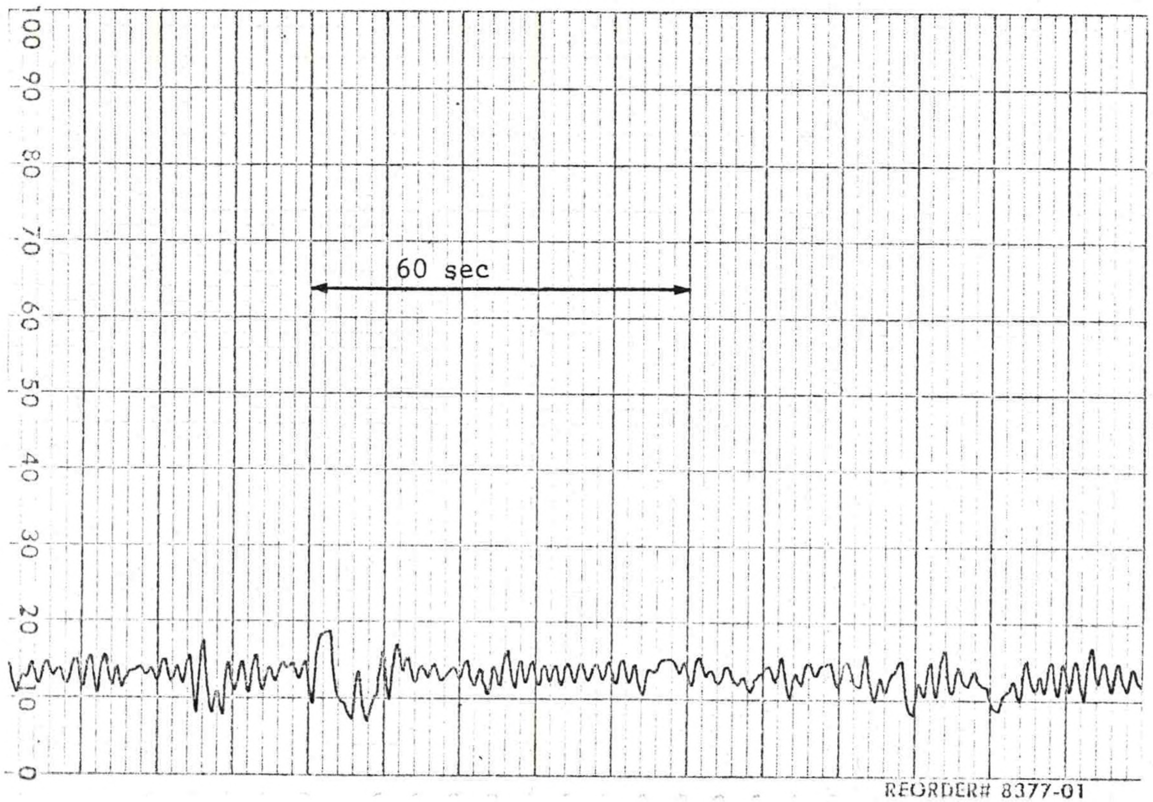


Figure 11 a
Operation in the presence
of waves with the pipe
submerged 2.5 feet

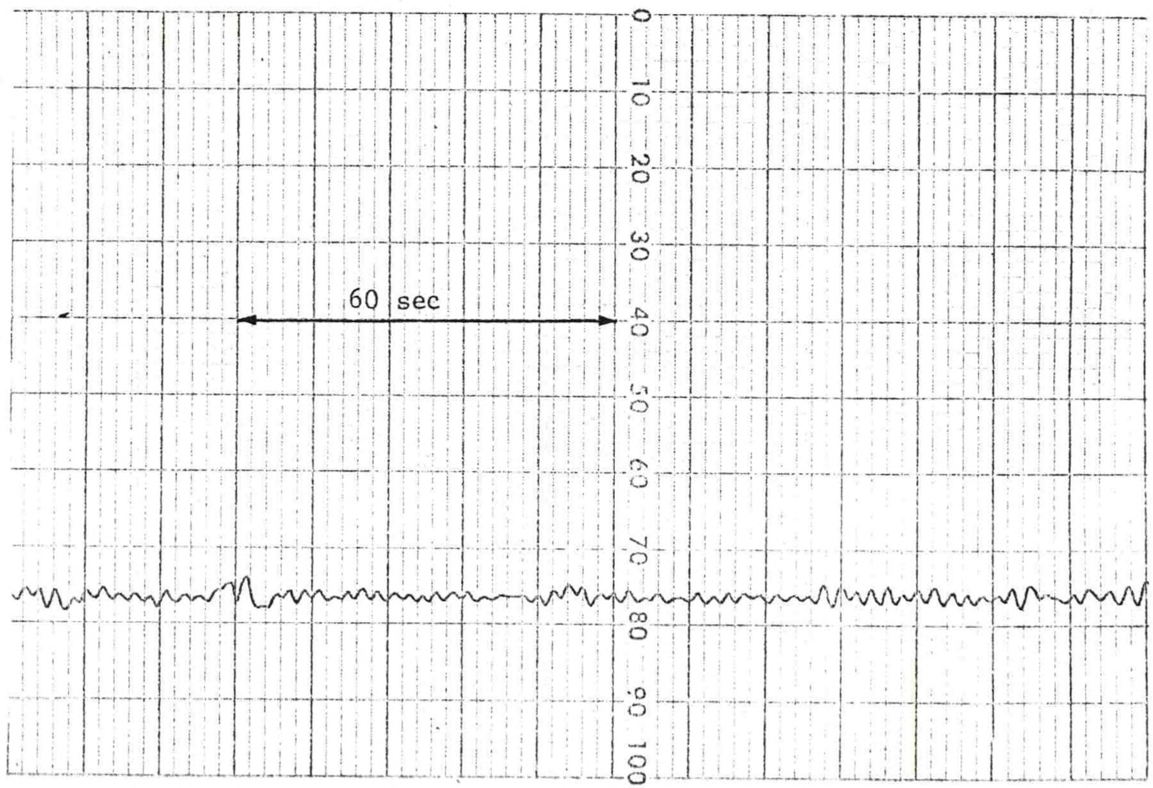


Figure 11 b
Operation in the presence
with the pipe submerged
5 feet

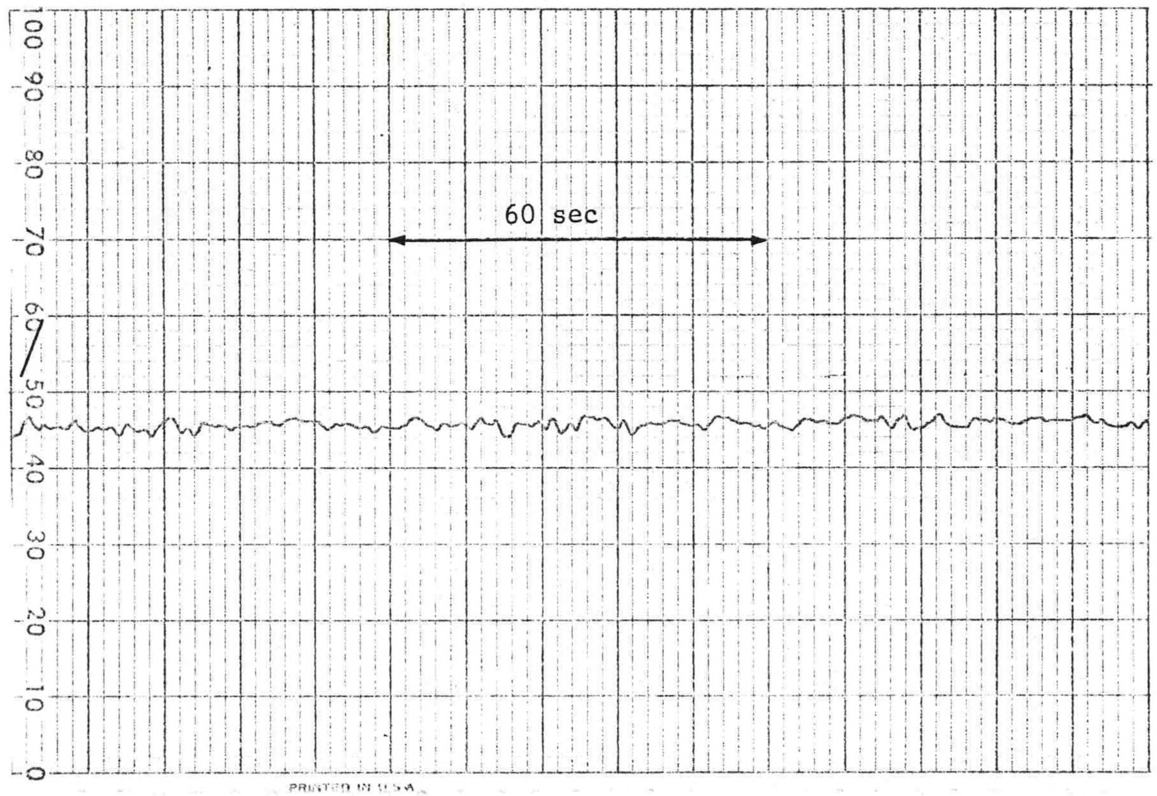


Figure 11 c
Operation in the presence
of waves without a pipe

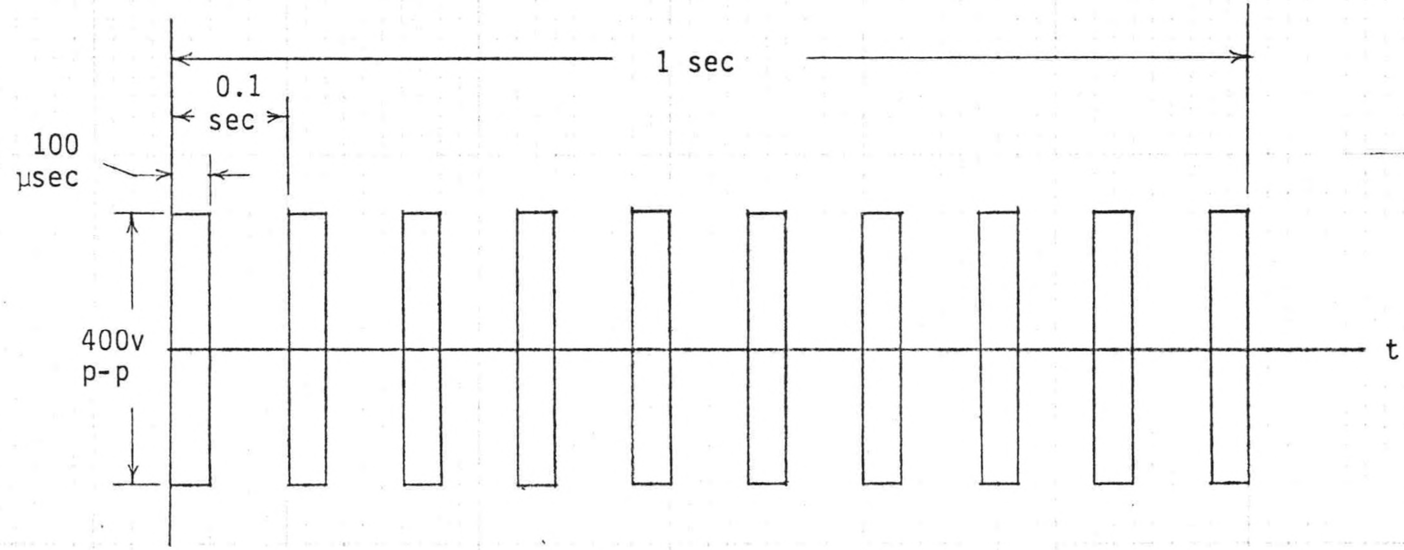


Figure 12
Transmit Duty Cycle

Logic and microprocessor power for this system is estimated at 4 watts. Again these components were not selected with low power being a requirement.

5.2 Future System Predicted Power Requirements

The optimizing of power usage for an air acoustic water level sensing system becomes a trade off between several areas and will require innovative design in selection of transmit power levels, pulse length, transmit frequency, duty cycle, receiver noise characteristics, sampling period, sampling interval and power strobing of the microprocessor.

The transmitter requirement of 14 mwatt is quite sufficient for 3 meters. Changing the values of voltage, pulse length and interval to result in an average power of 50 mwatt should easily result in useable data out to 7.5 meters. Beyond this point it is extremely difficult to predict requirements based on present information.

The receiver requirement of 675 mwatt is extremely high for this type of system. For instance, Raytheon utilizes a first stage acoustic receiver operational amplifier that requires only 0.8 mwatts of power. The signal presented to this amplifier however is a long tone burst and is easier to detect than that expected here. This becomes an area of trade off. The detection problem occurs only at the first stage. Following high gain stages can be reduced in power requirement. Our best engineering estimate is that total receiver power can be reduced to 150 mwatt, 50 mwatts for the high gain stages and 100 mwatts for the first stage.

Using a CMOS device for the microprocessor and logic elements will reduce power in this area to 250 mwatts. Power strobing will further reduce this value to an estimated 125 mwatts.

Typical power conversion efficiencies are 50 to 75 percent. Power conservative designs maximize the use of devices that do not require regulation or conversion to different levels. It is estimated that overall conversion efficiency can be improved to 85%.

For a 7.5 meter station using the above power values in the following total energy can be calculated for a 45-day period.

Transmitter	50 mwatt
Receiver	150 mwatt
Microprocessor	125 mwatt
	325 mwatt total

$$\frac{0.325 \text{ watt}}{0.85 \text{ eff}} \times 1080 \text{ hours} \times 0.5 \text{ duty cycle}$$

= 206.5 watt hours

= 17.2 Amp-Hours @12 volt
for a 7.5 m range, 45 days
and 50% duty cycle

This figure is considered nominal and achievable.

6.0 Summary and Conclusions

The testing conducted and discussed in this report has indicated that discrete frequency air acoustics is indeed a feasable technique for accurately measuring tide and water levels. The mechanical advantages of using a noncontact method far outweigh the increased electrical complexities of an air acoustic system.

The Sensall unit tested linear to within its 8 bit resolution (1.2 cm) and is presumably better. The most likely source of nonlinearity lies in the correction for the speed of sound variation due to temperature. This would only occur if the correction transfer function itself were nonlinear, i.e. the thermistor characteristic were not accurately modeled.

Signal levels noted during all phases of testing are strong and free from contaminating noise. Background noise levels are 0.1 to 0.15 volt. The unit is designed for a 3 meter range but signal levels at 9 meters were still quite significant. Little design is required to increase the range of this instrument easily to 10 meters and to 15-23 meters with a possible penalty in energy consumption.

Phase cancellation was noted in several tests where multipath returns occurred. Signal quality remained high however in all cases. This is a potential source of error and must be addressed in designs. Choice of frequency, pulse characteristics, receiver thresholds and processor algorithms are seen to eliminate this problem.

Foreign objects, pipe joints, fouling, etc in the 10 cm pipe were obvious in returns but at markedly lower levels compared to bottom returns; except at ranges well beyond that for which the unit was designed. Most extraneous sources of signal returns are poorer reflectors than the (nearly) horizontal water surface. The use of a relativley large (10 cm) pipe will reduce the effects of fouling.

A well will be required for use with a discrete frequency or other air acoustic technique. The columnation of air acoustic energy in the pipe allows lower transmit power levels, while smoothing of the water surface provides a better reflecting surface. Additional testing may identify certain applications where an open configuration is feasable.

The energy requirements analysis indicated that power levels can be brought down to acceptable levels for limited (but realistic) ranges. Our experience in the design of instruments for field use has shown that once low power has been identified as a design criteria, components are selected and duty cycling schemes devised such that power budgets are generally achievable.

The incorporation of a processor in the system allowing averaging or filtering, and discrimination against outliers not rejected in analog circuitry will further enhance the quality of data recorded.

Raytheon concludes then that the technique of measuring water level using a discrete frequency device is sound. This further substantiates the use of air acoustic techniques in general. The measurement of time is fundamental and takes place with great accuracy under processor control. The design and implementation of analog circuitry, such that the time intervals measured precisely represent distance to the water surface, involves relatively straight forward engineering techniques. This conclusion is based on Raytheon's extensive experience with acoustic systems far more complex than the one considered here. Engineering innovation will be required in the areas of signal detection, noise rejection, signal processing and energy consumption to achieve required specifications, but the goals are reachable within the current state-of-the-art of acoustic technology.