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PROGRESS REPORT
TO
OFFICE OF NAVAL RESEARCH

FOR CONTRACT NO: N00014-90-C-0123

TITLE: Development of an Expendable Particle Sensor

ITEM NO: 0001AF

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PROGRESS REPORT:

Development of an Expendable Particle Sensor

Sea Tech Inc.

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INTRODUCTION:

This report addresses progress on the Phase II Development of the Expendable Particle Sensor (EPS) over the time period of August through September 1992. A design review meeting was held at Sparton in early August of 1992. During this meeting it was obvious that XOTD development progress was not on schedule at Sparton. It was also obvious that Sparton had not accounted for a significant amount of engineering time on this project. The design review meeting can best be summarized by stating that Sparton has not performed well with regard to the development of the AXOTD or XOTD. Sparton has assured Sea Tech that these problems will be resolved in the future.

Design Review:

Four technical problems were outlined during the design review meeting at Sparton:

1.) A decision needed to be made regarding the location of the scattering sensor in the XOTD.
2.) A sea water switch needs to be designed for the dual battery supply used in the XOTD.
3.) A temperature sensor needs to be designed for the XOTD.
4.) A battery must be selected to power the AXOTD and XOTD.

These four problems have been resolved by Sea Tech as follows:

Location of the Scattering Sensor in the Expendable Probe Body

Much discussion has taken place between Sparton, Sea Tech and Dr. Katz at Johns Hopkins University, and we all believe that the present XBT expendable probe design is unstable based on the tow test video and more recently the drop tests done at Santa Catalina Island. We know this instability will effect probe drop rate but we question whether it will have any effect on the performance of the light scattering sensor since the probe does not wobble as it falls through the water column. Considering all this, Dr. Katz feels that placing the scattering sensor as close to the nose cone as possible in the present expendable probe design will minimize flow separation problems which could cause errors in the measurement of light scattering. Based on this, Sea Tech has instructed Sparton that they should proceed with the mechanical design of the AXOTD and XOTD expendable probes and place the scattering sensor in the probe body as close to the nose cone as is practical.

Verbal approval for a hydrodynamic study of the existing expendable probe design to be used to house the AXOTD and XOTD has been given by NRL. Because of limited funds it has been suggested by both ONR and NRL that this study be limited to the determination of the boundary layer and flow separation of the expendable probes. Everyone recognizes that this ignores the problem with the stability of the probe as it drops through the water column; however, we must concentrate on our main objective with this project, which is to develop an expendable light scattering sensor. If hydrodynamic problems remain they can be addressed at a later date.

The hydrodynamic study is planned to begin at Johns Hopkins University on October 1, 1992. Sea Tech and Sparton cannot wait for the results of this study and must proceed with the design of the expendable probes if we are to maintain our scheduled progress. The funding agencies should be well aware of the potential problems that this approach may cause. Since neither Sparton nor Sea Tech designed the expendable probe body that will be used to house the

AXOTD and XOTD, we both should probably disclaim any responsibility for the hydrodynamic stability of the expendable probe body.

Sea Water Switch Design for the AXOTD and XOTD:

The design of a simple sea water switch and temperature probe for the AXOTD and XOTD has been completed at Sea Tech.

The sea water switch design for the AXOTD & XOTD dual battery power supplies is shown in Figure 1. The field effect transistors are SuperTex VN01 and VP01. These devices will switch greater than 100 milliamps of current and have an on resistance of less than 10 Ω. The resistance from source to gate can be used to set the sensitivity of the switch. Gate threshold voltage is between 1 and 3 volts. With the resistance values shown between source and gate the switch functions very well in natural fresh water. Lower values of source to gate resistance would be used if only salt water applications are desired.

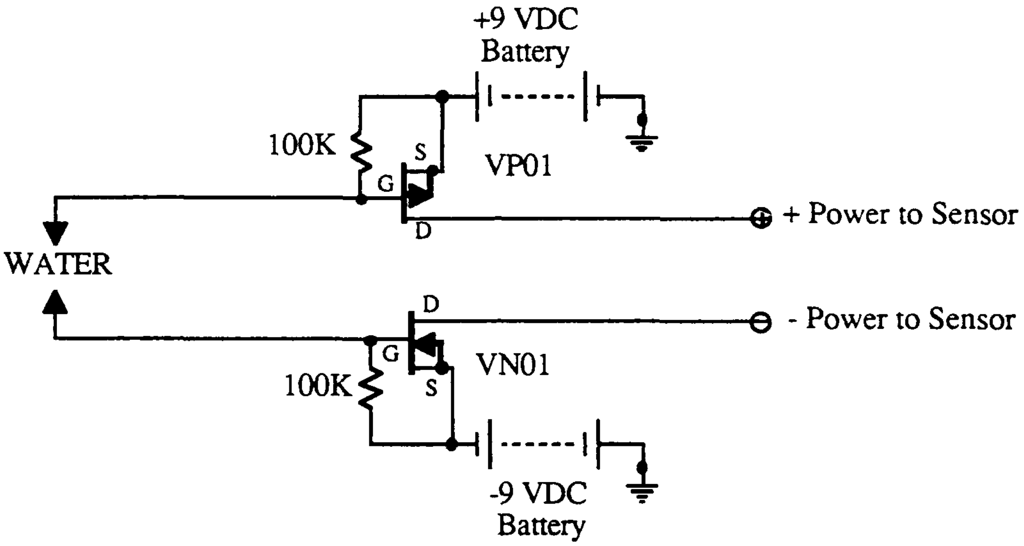


Figure 1 Sea Water Switch Schematic

Temperature sensor design for the AXOTD and XOTD probes:

The temperature sensor, shown in Figure 2, has been designed to use the same thermistor as in Sparton's XBT, a Betatherm Corp. 5K3A1.

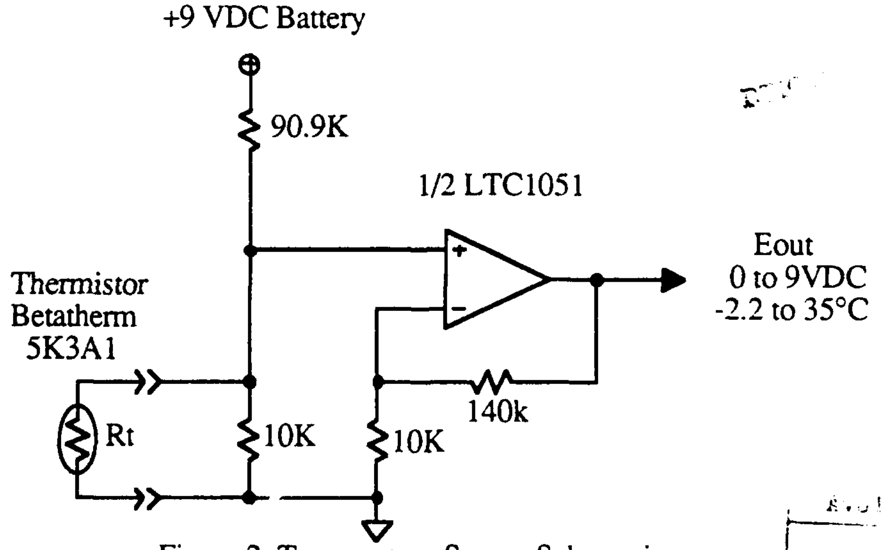


Figure 2 Temperature Sensor Schematic

Table 1 contains the temperature sensor design data. The design goals and/or specifications for this sensor are, accuracy +/- 0.1°C, time constant 100 milliseconds and temperature range -2.2 to 35 °C.

Temperature measurement resolution for this sensor will be limited by the AXOTD and XOTD telemetry system. For the purpose of design the telemetry system resolution is assumed to be close to that measured for the prototype XOTD sensor in the laboratory, 0.05% of full scale. Since full scale is 9 VDC and telemetry measurement resolution is 0.05% the minimum signal we can measure with the telemetry system is approximately 0.005 volts. A measurement resolution of 0.005 volts yields a best case resolution for this sensor of 0.03°C at a temperature of -2°C and a worst case resolution of 0.05°C at a temperature of 35°C.

The temperature sensor circuit must have highly stable, tight tolerance components if it is to meet the goal for accuracy. Given the specification of +/- 0.1°C accuracy for the 5K3A1 thermistor supplied by Betatherm Corp. and a design goal of +/-0.1°C accuracy for this temperature sensor it is apparent that thermistors will have to be selected to achieve this higher accuracy. In addition, precision resistors with very tight tolerances and very low temperature coefficients will be necessary. Since Sparton is charged with the manufacture of this temperature sensor and has significant experience with the 5K3A1 thermistor, they will be responsible for choosing the necessary components, as well as addressing the concerns that appear below, so that the goal of +/- 0.1°C temperature accuracy is met.

The dissipation constant of the thermistor must be determined with an XOTD in water to evaluate self heating temperature errors for this sensor. The manufacturer of the thermistor specifies a dissipation constant of 1 milliwatt per °C in air and 7 milliwatt in water. This however is significantly changed by both thermistor mounting and water flow across the thermistor and needs to be evaluated.

The time constant of the sensor needs to be determined and is best done at sea by dropping the sensor through a large known temperature gradient and measuring the sensor output. The manufacturer's time constant for the thermistor cannot be used to specify sensor time constant, mainly because when the thermistor is packaged in the expendable probe body, the water flow rate across the thermistor is unknown.

Temperature measurement error caused by the change in ambient water temperature flowing across the thermistor due to the large thermal mass, (steel nose cone), being in close proximity to the thermistor needs to be evaluated as well.

During the design of this temperature sensor errors were discovered in the Betatherm Corp., 5K3A1 thermistor resistance versus temperature, R-T data. To prevent design errors based on incorrect design data the original calibration data was obtained from the manufacturer. The R-T data, Table 2, was then calculated and compared with the manufacturer published R-T data.

The manufacturer's calibration data for the 5K3A1 thermistor are:

0°C = 16325.28 Ω
25°C = 5000 Ω
70°C = 875.8077 Ω

The following equation was used to calculate thermistor resistance after the constants A0 through A4 were determined from the three point calibration data.

Thermistor resistance, R = EXP(A0+A1/°K+A2/°K^2+A3/°K^3)

A0=-5.68118628676
A1=4425.05894459049
A2=-14869.2085626441
A3=-12618425.356930

The manufacturer R-T data compares very well with the calculated R-T values as shown by R-Rc column in Table 2. The calculated R-T data gives us confidence that accurate input data was used for the design and analysis of the temperature circuit.

Temp °C	Thermistor R	V input	V output	Resolution °C	Measured °C	T-Tm
-2.000	18091.4	0.595	8.932		-1.993	-0.007
-1.000	17183.1	0.585	8.778	0.032	-0.993	-0.007
0.000	16325.4	0.575	8.622	0.032	0.006	-0.006
1.000	15515.2	0.564	8.465	0.032	1.006	-0.006
2.000	14750.0	0.554	8.306	0.032	2.006	-0.006
3.000	14027.1	0.543	8.147	0.031	3.005	-0.005
4.000	13343.8	0.532	7.987	0.031	4.005	-0.005
5.000	12697.8	0.522	7.827	0.031	5.004	-0.004
6.000	12086.3	0.511	7.666	0.031	6.004	-0.004
7.000	11508.0	0.500	7.505	0.031	7.004	-0.004
8.000	10960.8	0.490	7.344	0.031	8.004	-0.004
9.000	10442.6	0.479	7.183	0.031	9.004	-0.004
10.000	9951.8	0.468	7.022	0.031	10.005	-0.005
11.000	9486.8	0.458	6.863	0.031	11.005	-0.005
12.000	9046.3	0.447	6.704	0.031	12.005	-0.005
13.000	8628.7	0.436	6.546	0.032	13.005	-0.005
14.000	8232.5	0.426	6.389	0.032	14.005	-0.005
15.000	7857.0	0.416	6.233	0.032	15.005	-0.005
16.000	7500.6	0.405	6.079	0.032	16.004	-0.004
17.000	7162.3	0.395	5.926	0.033	17.004	-0.004
18.000	6841.3	0.385	5.775	0.033	18.003	-0.003
19.000	6536.4	0.375	5.626	0.034	19.002	-0.002
20.000	6246.8	0.365	5.479	0.034	20.002	-0.002
21.000	5971.6	0.356	5.333	0.034	21.001	-0.001
22.000	5710.0	0.346	5.190	0.035	22.001	-0.001
23.000	5461.3	0.337	5.050	0.036	23.001	-0.001
24.000	5225.0	0.327	4.911	0.036	24.000	0.000
25.000	5000.0	0.318	4.775	0.037	25.001	-0.001
26.000	4786.0	0.309	4.642	0.037	26.001	-0.001
27.000	4582.4	0.301	4.511	0.038	27.001	-0.001
28.000	4388.5	0.292	4.383	0.039	28.002	-0.002
29.000	4203.9	0.284	4.257	0.040	29.002	-0.002
30.000	4028.0	0.276	4.134	0.041	30.003	-0.003
31.000	3860.5	0.268	4.014	0.042	31.004	-0.004
32.000	3700.8	0.260	3.896	0.042	32.004	-0.004
33.000	3548.6	0.252	3.781	0.043	33.003	-0.003
34.000	3403.5	0.245	3.669	0.045	34.002	-0.002
35.000	3265.1	0.237	3.559	0.046	34.999	0.001

Table 1 Temperature Sensor Design Data

Temperature °C	Mfg. Data Sheet R value	Temperature °K	Calculated Resistance	R-Rc
-2.000	18091.40	271.150	18091.74	-0.34
-1.000	17183.10	272.150	17183.08	0.02
0.000	16325.40	273.150	16325.30	0.10
1.000	15515.20	274.150	15515.29	-0.09
2.000	14750.00	275.150	14750.13	-0.13
3.000	14027.10	276.150	14027.10	0.00
4.000	13343.80	277.150	13343.65	0.15
5.000	12697.80	278.150	12697.41	0.39
6.000	12086.30	279.150	12086.16	0.14
7.000	11508.00	280.150	11507.83	0.17
8.000	10960.80	281.150	10960.45	0.35
9.000	10442.60	282.150	10442.22	0.38
10.000	9951.80	283.150	9951.43	0.37
11.000	9486.80	284.150	9486.49	0.31
12.000	9046.30	285.150	9045.89	0.41
13.000	8628.70	286.150	8628.24	0.46
14.000	8232.50	287.150	8232.23	0.27
15.000	7857.00	288.150	7856.61	0.39
16.000	7500.60	289.150	7500.24	0.36
17.000	7162.30	290.150	7162.03	0.27
18.000	6841.30	291.150	6840.95	0.35
19.000	6536.40	292.150	6536.06	0.34
20.000	6246.80	293.150	6246.46	0.34
21.000	5971.60	294.150	5971.29	0.31
22.000	5710.00	295.150	5709.77	0.23
23.000	5461.30	296.150	5461.15	0.15
24.000	5225.00	297.150	5224.73	0.27
25.000	5000.00	298.150	4999.84	0.16
26.000	4786.00	299.150	4785.87	0.13
27.000	4582.40	300.150	4582.23	0.17
28.000	4388.50	301.150	4388.37	0.13
29.000	4203.90	302.150	4203.78	0.12
30.000	4028.00	303.150	4027.95	0.05
31.000	3860.50	304.150	3860.44	0.06
32.000	3700.80	305.150	3700.80	0.00
33.000	3548.60	306.150	3548.63	-0.03
34.000	3403.50	307.150	3403.54	-0.04
35.000	3265.10	308.150	3265.16	-0.06

Table 2 R-T Data, Betatherm Corp. 5K3A1 Thermistor

Batteries to Power the AXOTD and XOTD:

Sea Tech tested an XOTD board with positive and negative 9 volt alkaline transistor batteries to determine how long we could transmit and receive accurate data. A full report on this test is included in Appendix A. The test showed that these batteries were able to provide adequate power so that the XOTD could accurately transmit data for over seven hours. It is apparent that these batteries have much more capacity than what is required for the XOTD. Also, the size of this battery is too large to fit into the expendable probe body with room left over for a center flow chamber needed to allow water flow across the temperature sensor.

Sea Tech is now considering the A76 button type 1.5 Volt Alkaline cell manufactured by the Union Carbide Everyready division for powering the XOTD. These cells have approximately 20% of the capacity of the transistor batteries, which should be more than adequate. Battery life rated by the manfacturer is five years, the actual battery capacity is reduced by 1% to 2% per year so battery life should be much longer in this application. A battery pack containing 12 of these cells will provide +/- 9VDC and will easily fit into the expendable probe body.

APPENDIX B

9 VDC Transistor Battery Life Test

Two Duracell 9 Volt alkaline transistor type batteries were used to supply positive and negative power to an XOTD board. The XOTD board was modified for this test. Two voltage dividers replaced the scattering and temperature sensors, as shown in Figure 1. Thus, Channels 1 and 2 were 2/3 and 1/3 of the 9 Volts from the positive supply. To simulate the current drawn by the scattering sensor, a transistor was switched on and off so that about 100 mA at 50% duty cycle was drained from the positive supply, as shown below.

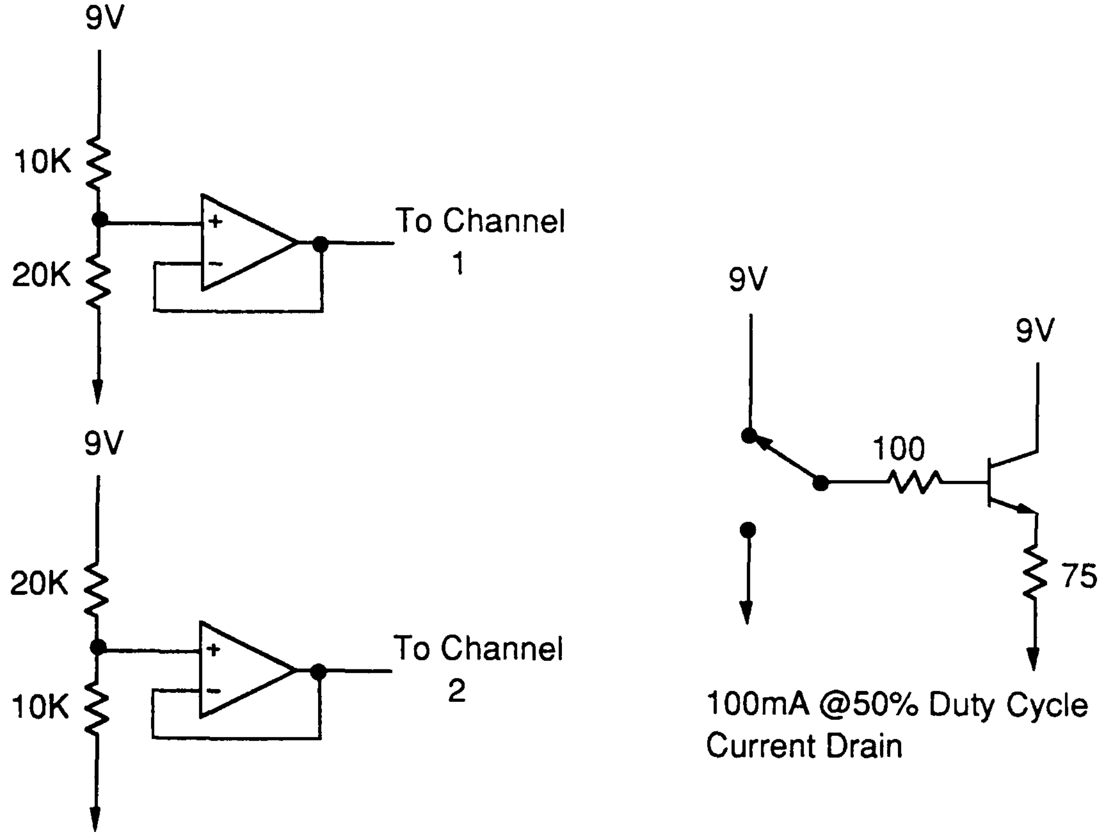


Figure 1 Modifications to XOTD Board for Battery Life Test

As the batteries discharged during their powering of the modified XOTD board, their voltages were recorded manually. A plot of the voltages versus time is shown in Figure 2. The received VCO frequencies and the voltage ratio computed from these frequencies were recorded using the XOTD receiver card and software. The received frequencies plotted versus time are shown in Figure 3. The computed voltage ratios plotted versus time are shown in Figures 4 and 5.

Figure 2 + and - 9V XOTD Transistor Battery Voltage vs. Time

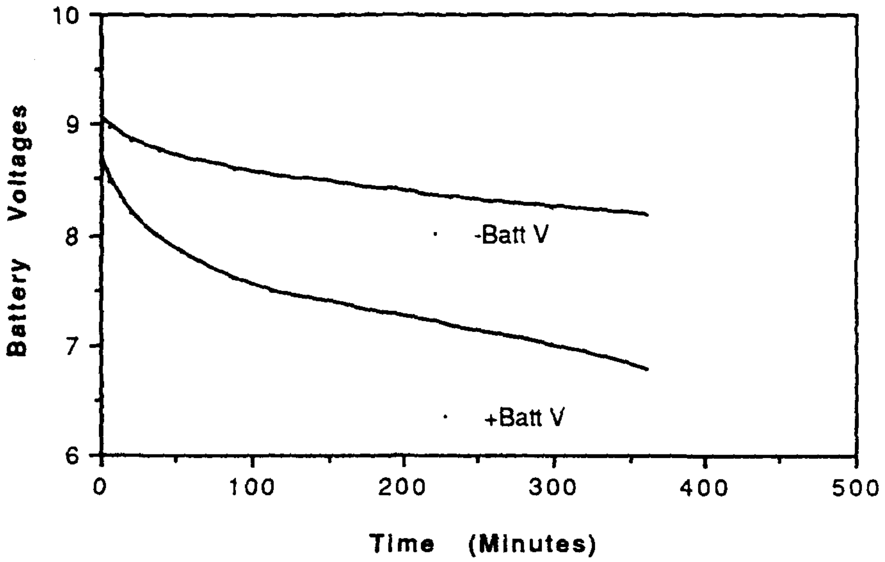


Figure 3 XOTD VCO Frequencies vs. Time

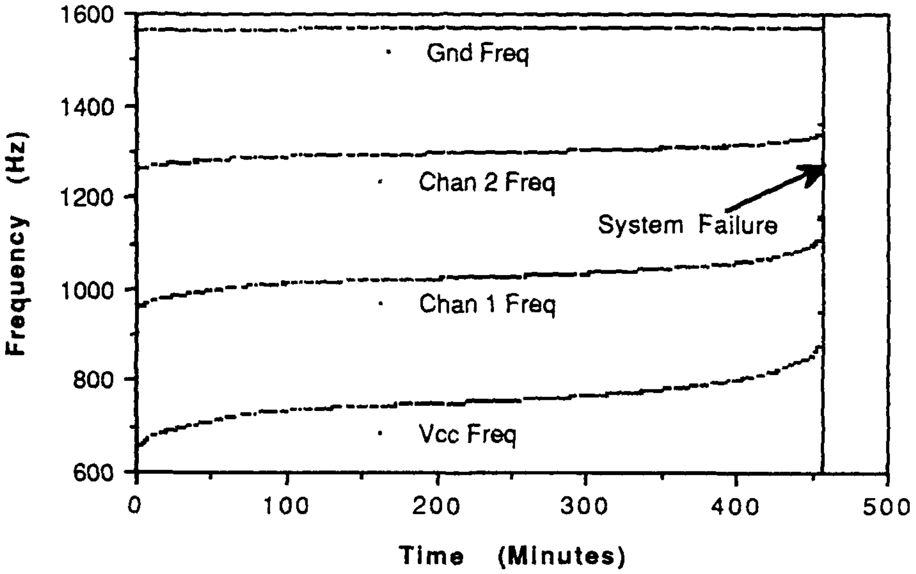


Figure 4 Channel 1 Voltage Ratio vs. Time

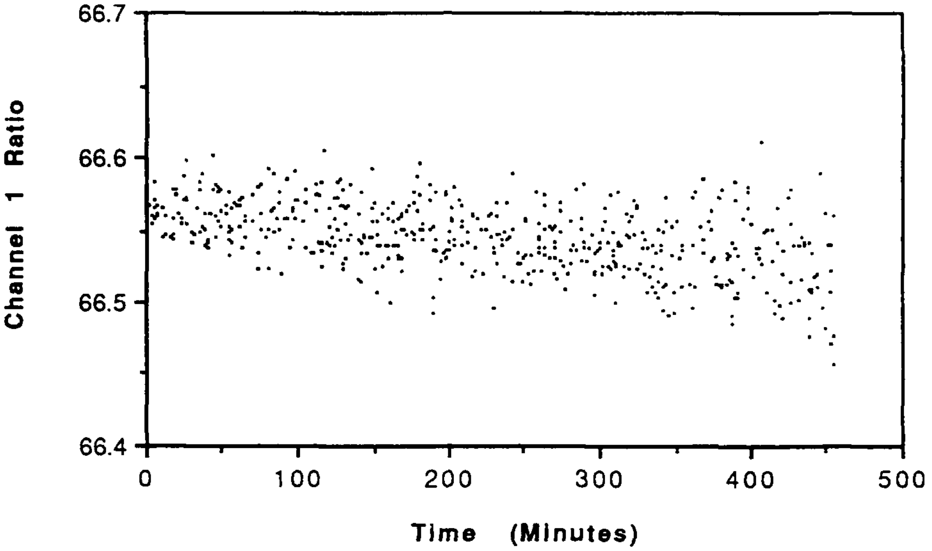
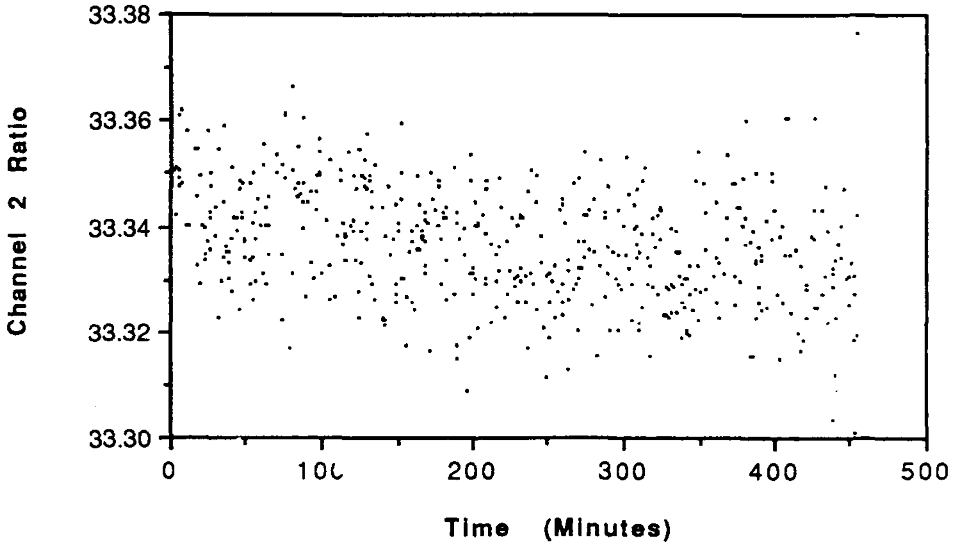


Figure 5 Channel 2 Voltage Ratio vs Time



Test Results:

The system operated for about 7 hours with these batteries before failure occurred. The positive battery supply voltage decreased more than the negative supply, the bandwidth decreased, and noise increased.