CABLELESS ELECTRONIC SURVEYING SYSTEMS FOR HORIZONTAL HOLES

prepared for

UNITED STATES DEPARTMENT OF THE INTERIOR
BUREAU OF MINES

by

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EARTH SCIENCES and SYSTEMS DIVISION
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ENSCO, INC.

Final Report

on Contract H0177069
CABLELESS ELECTRONIC SURVEYING SYSTEM
FOR HORIZONTAL HOLES

March, 1981

CABLELESS ELECTRONIC SURVEYING SYSTEM FOR HORIZONTAL HOLES

FINAL REPORT

Prepared for:

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16. Abstract (Limit: 200 words)

This report contains a description of the contract activities performed by ENSCO, Inc. under contract No. H0178069. The purpose of this project was to enhance the Bureau of Mine's Cableless Electronic Survey System use to aid in the drilling of long (approx. 2000 feet) boreholes in coal. This drilling is performed as part of the methane drainage program. The system that was ultimately developed was field tested and demonstrated in actual in-mine drilling activities. The significance of this system as compared to previous drill survey systems is the fact that it surveys without having to be inserted and removed for each survey point. It is so designed that it can withstand the shock and vibration experience by the drill string during drilling. This means an increased productivity is now possible in that drill operators can determine drill bit positioning in a near real-time environment.

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This report was prepared by ENSCO, Inc., Earth Sciences and Systems Division, Springfield, Virginia under USBM Number H0177069. It was administered under the technical direction of the Bureau of Mines with Dr. H. Sacks and Merle Bowser acting as Technical Project Officer. A. G. Young was the contract administrator for the Bureau of Mines. This report is a summary of the work recently completed as part of this contract during the period September 30, 1977 to February 29, 1980.

DISCLAIMER

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1. EXECUTIVE SUMMARY

Throughout the history of coal mining, the dangers associated with elevated levels of methane gas within the mine environment has posed serious hazards. It has been directly responsible for the distruction of many mines as well as the death of many miners. In response to this, the United States government through the Bureau of Mines has undertaken many research projects whose purpose have been and are to develop methods by which the measurement of the level of this deadly mine hazard as well as the control of the level can be accomplished.

One of the control techniques which has been developed is the use of long horizontal boreholes being placed along a coal seam. Coal which is beneath the earth's surface tends to contain gas, much as a sponge will hold water. Research as well as industry practice shows that by the drilling of the boreholes in the coal seam permit the coal to release large amounts of the gas through the hole where it can be safely vented out of the mine. This technique is particularly beneficial because methane drainage can be done well ahead of the actual mining of the coal seam. Since modern mining methods and equipment expose virgin coal at such a rapid rate, the prerelease of entrapped gas almost becomes a requirement to keep methane levels below the danger point.

The drilling of these long (approx. 2000 feet) boreholes, however, is not without problems. Specifically, maintaining the drill within the coal seam during drilling coupled with the desire to know where the drill is located geographically are problems faced by the drill operator. Until recently, the most widely used technique for surveying during the drilling operation was the use of the Sperry Sun Multi-Shot tool. This tool is used by pumping it down the center of the drill string until it gets to the drill bit. Then a photo of the internal compass and pendulum position is taken and the tool retrieved. After development of the photo, it is read and the drill operator is given the heading (bearing) and inclination of the drill position. The process is repeated at increments, such as when additional lengths of pipe are added, thereby providing a history and current location of the drill string. Each shot takes approximately 30 minutes to complete from the time the drill stops until drilling resumes.

In the early 70's the Bureau of Mines developed a system that would give the driller information within minutes. If featured radio communication between the drill and the driller, and the use of a computer on the surface to analyze the data and inform the driller of the results. This system provides information in less time than the earlier techniques. However, it did have operational disadvantages, as the computer operators on the surface had to phone the results to the driller in the mine.

With the development of microprocessors in the mid-70's, it became possible to develop a computer small enough to go into the mine, and designed for the driller to operate it. The Bureau of Mines then awarded a contract to ENSCO, Inc. to develop that computer and to enhance the downhole unit that transmits information. This report contains the results of this research project along with conclusions and recommendations for the continued operation and enhancement of the Cableless Survey System (CSS).

The resulting CSS tells the driller where his drill is very quickly following the stopping of the drill. Figure 1 shows the operational setup of the CSS. Time is saved over previous survey techniques in that CSS remains "downhole" in the horizontal borehole during drilling operations. It is rugged enough to withstand the shock and vibration resulting from the drilling operation.

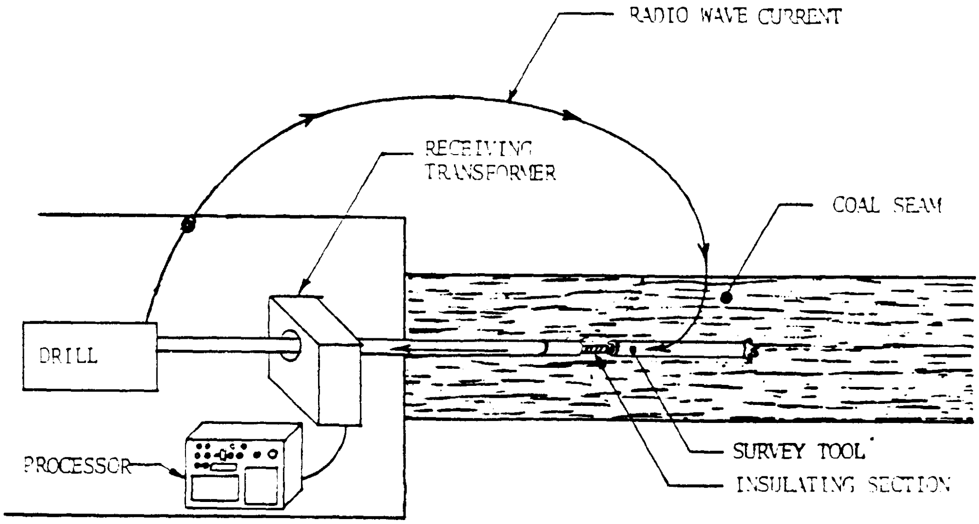


Figure 1. Cableless Survey System

The CSS works by measuring with its on-board sensors the position of the earths magnetic and gravitational vectors. It then relays that data by induction of an electric current through the drill and the surrounding coal material to the "uphole" receiver/processor. The processor then computes the current position of the tool with respect to the vectors mentioned above and displays the results to the driller. In addition, the processor then adds the new data point to the survey as drill rods are added, thus giving survey information such as vertical and horizontal deviations from a straight line based on initial headings and inclinations at the beginning of the borehole.

Figure 2 is a photograph of the front panel drillers display of the CSS Processor. The keyboards are used to key in initial conditions as well as control the survey operations. Under a hinged panel on the right hand side is located a thermal printer where survey results are printed for reference and records the entire survey. As designed, the entire receiver, processor, display and printer are intrinsically safe. This now permits the driller to have all aspects of the survey system located at the drill site.

This research project which started in October of 1977, was conducted in three phases. A detailed description of the work accomplished in each phase is contained in this report. The three phases are as follows:

Phase I: Repair and Evaluation of Existing System
Phase II: Design and Fabrication of a Portable Display and Processing Unit
Phase III: Field Test and Upgraded System

During Phase I the initial downhole tool and receiver was repaired and field tested in the Mariana Mines to determine its capability. Results of this testing was the decision to upgrade and enhance the downhole tool to make it more reliable and operationally efficient. Additionally, sensors were added to improve system measurement capability.

Activities under Phase II were the design and fabrication of a portable, intrinsically safe receiver processor. Hardware was designed, developed and tested. Initial field calibration tests were conducted which indicated that the system worked within expected limits. Bearing and inclination errors were within the $\pm 0.5^\circ$ and $\pm 0.01^\circ$ respectively.

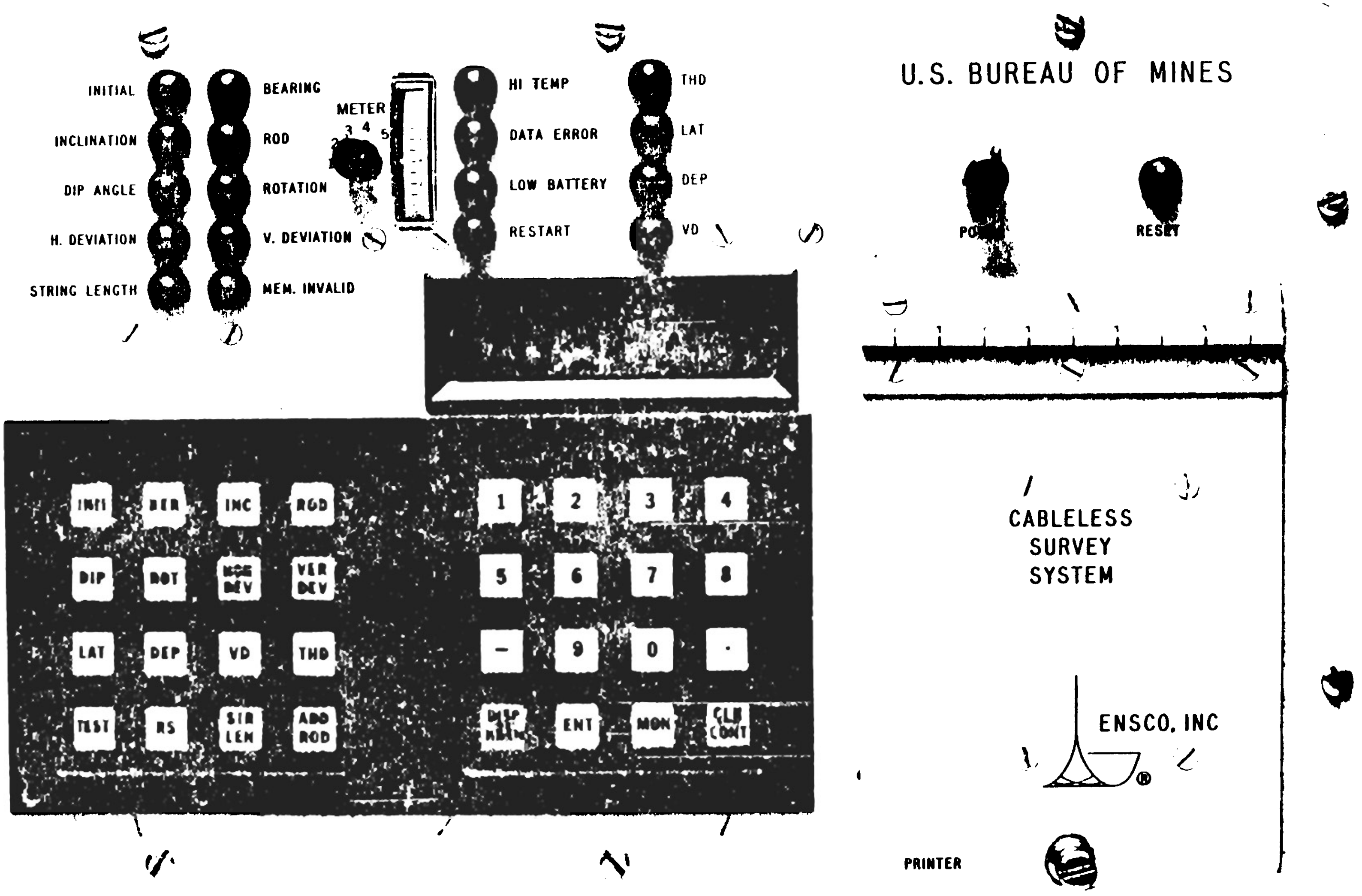


Figure 2. Front Panel of the Cableless Survey System Processor

Phase III work covered the in mine drilling tests and demonstrations. During this phase, the CSS was used during actual drilling operation in two different coal mines. Although, holes that were surveyed totaled slightly over 800 feet, the tool was in place for many redrilling and reaming operations which subjected it to a significant number of drilling hours. Operational problems were encountered during drilling. Most of the problems were associated with battery packs and connections. All were repaired but system availability was hampered by these problems. Other operational problems were in the area of the size and weight of the tool and its effects on drill guidance.

In conclusion, the newly enhanced and upgraded CSS provides critical survey information in a timely and efficient manner to the drill operator. The development of the permissible microprocessor subsystem has provided a system that can be tailored for future expansion of the CSS as well as other research applications requiring data acquisition and processing on site in the hazardous mine environment. The operational problems discovered during actual field use should be further examined and incorporated in future design. The research project has provided the industry with the capability of increased productivity in degassing operations.

2. PROGRAM ACTIVITIES

The objective of this program was to recondition the United States Bureau of Mines (USBM) cableless surveying system (CSS) and imporve its operational capability. The program was divided into three separate phases. They are as follows:

- Phase I: Repair and Evaluate Existing System
- Phase II: Design and Fabricate a Portable Display and Processing Unit
- Phase III: Field Test of Upgraded System

Phase I

Phase I of the program started in October 1977 and culminated in May of 1978 with the submission of the Phase I report. During this phase, work consisted of the repair of the downhole unit to make it operational, field testing and an evaluation of its capability.

The repair of the downhole unit involved both mechanical and electrical aspects of the device. Some of the repair work actually involved minor modifications to improve previous known difficulties. The centralizers which support the inner canister in the outer driller collar as originally designed failed during previous testing. In addition, these centralizers did not properly support the inner unit which permitted it to flex and disturb proper sensor alignment. New centralizers were designed and fabricated by molding urethane to form a collar with spacers which fit around the inner canister. This later proved to be very successful. The new pieces slipped on and off with no direct attachment and could be easily replaced and spaced along the entire length of the canister.

Another activity that went beyond what would normally be considered as repair was a modification that permitted the batteries to be recharged without disassembly of the downhole unit as previously required. Circuitry was added to the power control circuit boards which permitted a modified audio power oscillator to be connected to the downhole transducer in a fresh air environment. This technique fully recharges the batteries in about sixteen hours and eliminates the requirement for disassembly of the tool.

Once the downhole unit was considered operational, it was subjected to pressure tests to ensure that the integrety of the explosion proof canister still met permissability requirements. The inner canister was subjected to a minimum pressure of 1500 psi over a 10 hour period. During the test a peak pressure of 1700 psi was experienced. After testing the unit was operated and then disassembled to determine if any leakage had occurred. The unit operated satisfactorly and no leaks had occurred.

Following the above repair and rehabilitation the CSS was taken to the mine for field testing and data acquisition. The mine chosen for the field testing was Marianna #58 in Pennsylvania. During the field tests the downhole unit operated satisfactorily when exposed to more than 25 hours of drilling operations including several hours of hole reaming activities. Only minor problems were encountered during this testing. They involved thermally induced drift of the system receiver, operational difficulties associated with mounting the up-hole toroid and excessive water pressure required to trigger the downhole unit. All of these problems were expected prior to testing and steps were already planned for Phase II that would correct them.

The data from the field test was tabulated and returned to ENSCO, Inc. for detailed analysis. In addition, survey data from the Sperry-Sun survey tool used to survey the same hole was gathered for comparison. Results of the comparison indicated that the CSS closely matched the survey results obtained with the Sperry Sun. For example, in a survey of a 830 foot hole, the two survey tools differed by approximately 2.3 feet in vertical deviation and less than 1 foot in lateral deviation. Further lab testing indicated that certain instrument biases associated with sensor mechanical alignment and electrical offsets did exist in the CSS. Also, an error analysis was done by feeding simulated data into a computer which indicated significant errors could exist with the CSS when it is directed along a northerly or southerly heading. It was determined that by adding two additional sensors to the downhole unit, there errors would be greatly reduced.

A report for Phase I which gives the details of all Phase I activities was prepared and submitted to the USBM. Results of the computer analysis are contained in Appendix A of this report.

Phase II

Program activities that were accomplished during Phase II of the contract were the modification and upgrade of the downhole tool, and the design and development of a new portable uphole receiver-processor.

As a result of Phase I activities, as well as previous drilling experience, a number of deficiencies with the downhole survey tool were outlined. They were as follows:

- Water pressure required for triggering downhole tool too high,
- Excessive errors caused by sensor ambiguities when operated along a northerly or southerly heading,

- Electronic components included originally which were no longer available,

- Transmit clock instability which prohibited receive tracking on a reliable basis.

The downhole tool was designed to send a transmission sequence when the water pressure in the drill collar is raised to a level greater than 100 psi. In actual field test operation this pressure was difficult to obtain. A number of factors were responsible such as too small or defective pump, lack of enough water volume, debris clogging the water way, etc. Since the pressure problem was still evident in Phase I of this program, it was decided to install a lower pressure trigger switch. An identical switch with a lower range which now activates the downhole tool with approximately 70 psi water pressure was installed.

In order to correct the anomallies associated with the north-south problem, it was decided to add two additional sensors. These sensors consisted of biaxial accelerometers oriented to detect the gravatational vector along the planes from side to side and top to bottom of the sensor canister. A single package was procurred that contained both accelerometers mechanically aligned 90° apart from each other.

The addition of the new sensors required that the sensor canister be made longer. In order to make room for this extension while maintaining the original overall package length forced the repackaging of the electronics to provide the additional space. The requirement for repackaging also provided the opportunity to improve several other known deficiencies.

In the original design, the survey tool clock was controlled by resistor-capacitor timing. This proved to be unstable in the drilling environment and therefore required wide bandwidths in the receiver tracking circuits. The increased bandwidth also increases the suseptability to noise problems. Therefore, a crystal controlled clock was installed in the survey tool. This will permit narrow bandwidths to be used in the telemetry receiver.

During the rehabilitation of the downhole package done in Phase I the A/D converter was found to be inoperative. Attempts to replace the unit led to the discovery that the particular part was no longer manufactured. Fortunately, one was found and installed for testing, but no spare units for future repair would be available.

In light of all of the above it was decided that the downhole survey tool electronics would be upgraded throughout with commercially available components. Further, the existing explosion proof canister would be retained unaltered so as to retain permissibility.

Appendix B gives the resulting mechanical layout of the upgraded tool along with its output specifications and sensors specifications.

The second aspect of the Phase II activity was the design and development of a permissible portable uphole receiver and processor. A system design was submitted that called for the use of low power CMOS circuitry. It was felt that the use of this low power integrated circuit technology would simplify the permissibility process because power requirements would fall within the intrinsically safe levels. Figure 2 shows the front panel of the resulting receiver/processor.

A detailed description of the system design is included in Section 3 of this report.

The final activity of Phase II was the testing and alignment of the system. Since this device uses the earth's magnetic field as its input and this field is disturbed in the proximity of magnetic materials, i.e., buildings, cars, pipes, etc., the system was taken to an open land area. The field tests consisted of rotating the package around each axis and plotting the output from each sensor to determine exact scale factor and offset. After exact scale factor and offsets for each sensor channel were determined new alogirthm coefficients were calculated and incorporated in the processor programmable memory. The rotational tests were then repeated for verification.

It should be noted that vertical rotation of the package was not accomplished. This was due to the fact that the package was very long and heavy and would require a complicated and costly fixture to support the unit while providing precise alignment.

Following the alignment tests, the system was subjected to a simulated trajectory test. This was done by placing a pattern of nine holes in a board in the following arrangement.

●2	●3	●4
●9	●1	●5
●8	●7	●6

The coordinate distance between each hole was such that movement between any two adjacent holes vertically or horizontally repositioned the tool by 1° in bearing for horizontal and 1° in inclinations vertically. The simulated survey was performed by entering the initial conditions for hole #1 at an initial string length of 20 feet. Then a survey of the first hole position was done and an assumed 10 foot drill rod added. The tool was then positioned sequentially in each hole and a survey done adding 10 foot rod sections for each hole until hole #1 was repeated. This resulted in a total simulated survey of 120 feet of string length. Figure 3A shows a comparison of calculated bearings versus tool measurements. Figure 3B gives the same comparison for inclination. Figure 3C compares the theoretical survey path to the computer results provided by the cableless survey system. As seen in Figures 3A and 3B the bearing and inclination readout fall very close to the expected accuracies for the tranducers, i.e., ±0.5° for the magnetometer and ±0.1° for the accelerometers. Some of the inclination errors are slightly outside of the expected variance. This has been attributed to two factors. First, a buildup of tolerance and secondly a slight play in the interface of the holes in the target and the positioning pin. In addition, errors in the absolute position of the hole were not corrected or compensated.

The errors associated with sensor relative alignments were examined by repeating the simulated trajectory test twice. First, two readings separated by a 180° rotation were average for each hole and then repeated taking four readings separated by 90° rotations for each hole. The results of these tests are:

	2 Readings Per Hole	4 Readings Per Hole
Bearing errors: mean	0.149°	0.145°
Standard Deviation	1.12°	0.078°
Variance	1.20°	0.006°
Inclination errors:		
mean	0.008°	0.006°
Standand Deviation	0.084°	0.07°
Variance	0.007°	0.005°

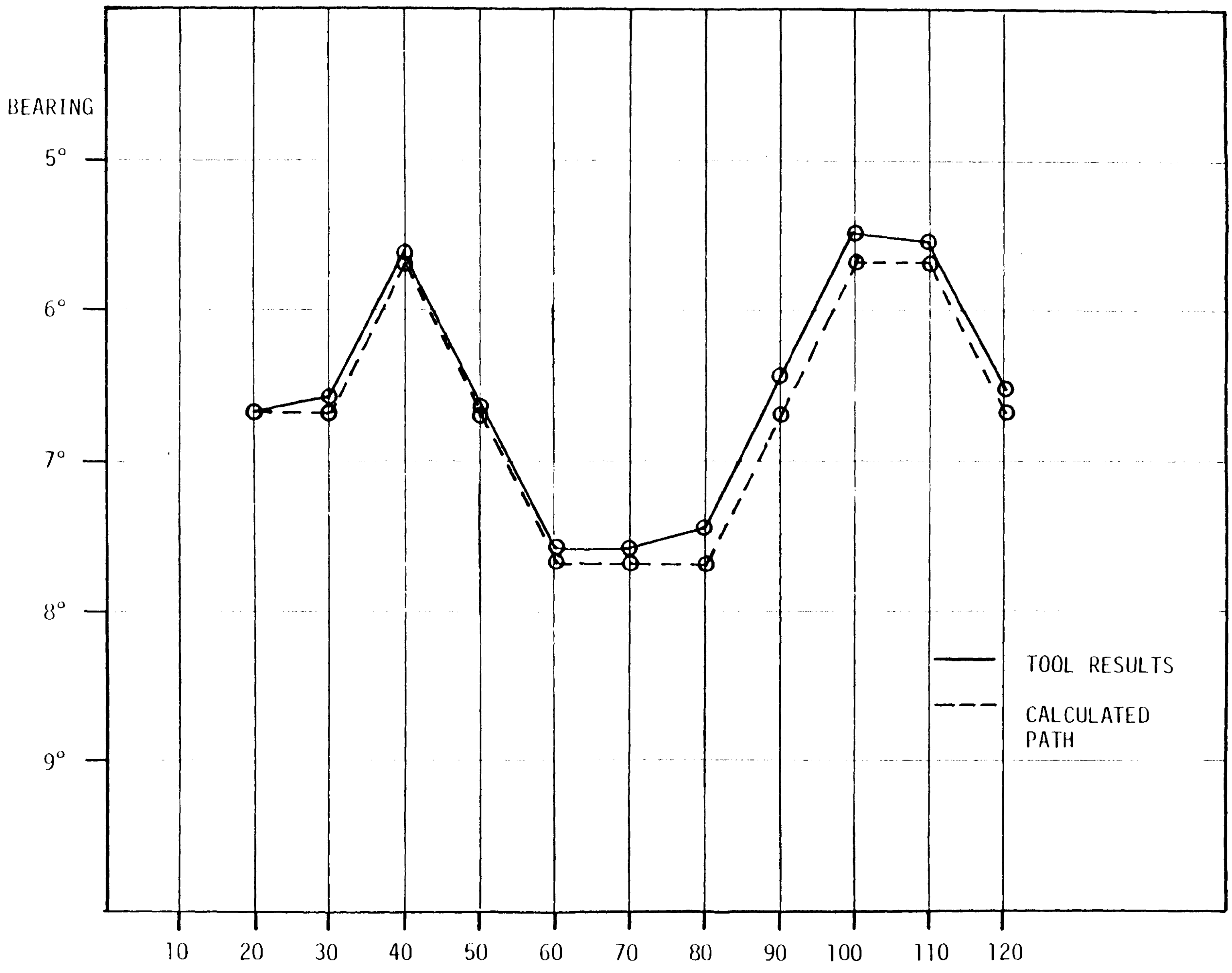


Figure 3A. Comparison of Calculated Survey Path vs. Measured Bearings for Simulated Trajectory Test

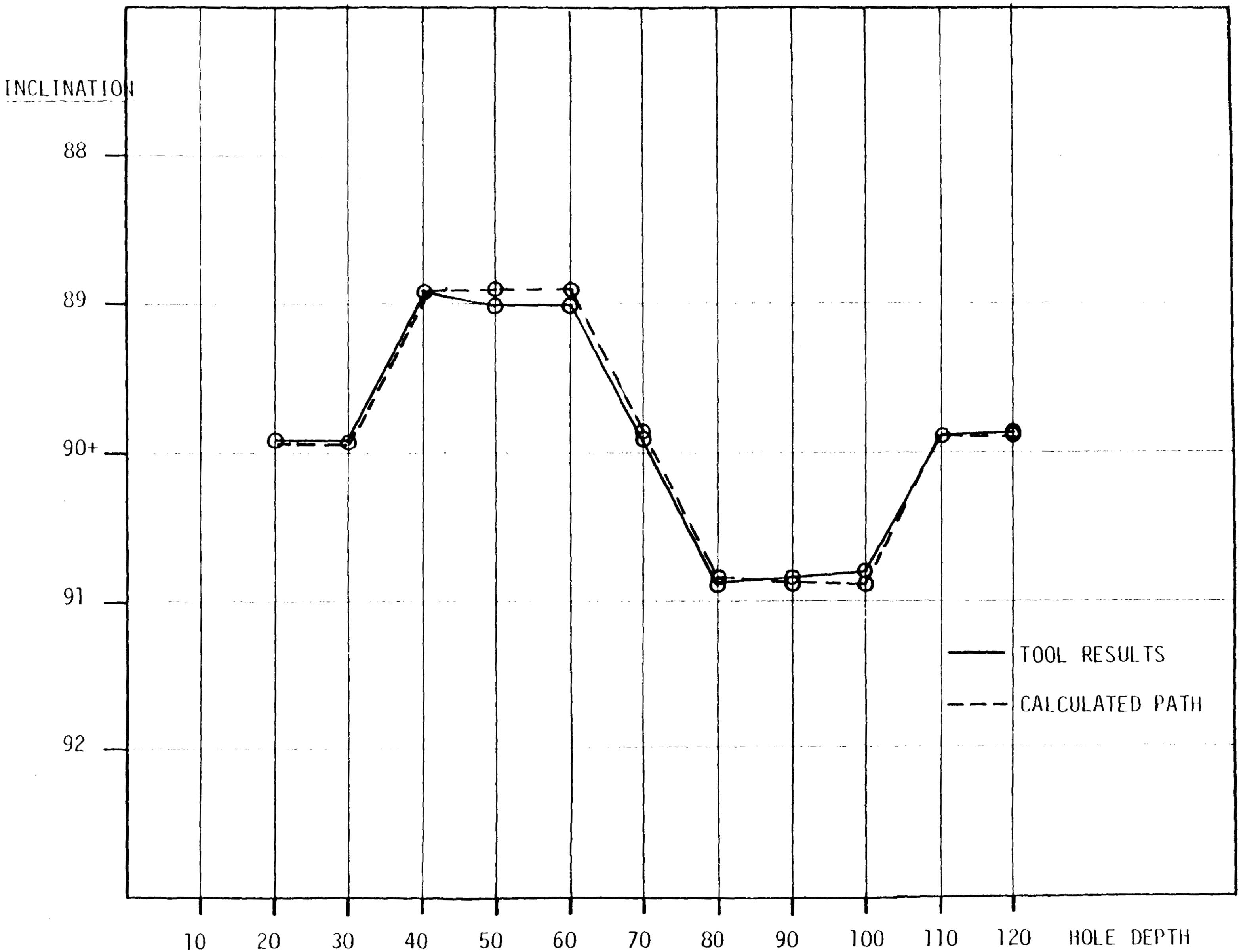


Figure 3B. Comparison of Calculated Survey Path vs. Measured Inclination for Simulated Trajectory Test

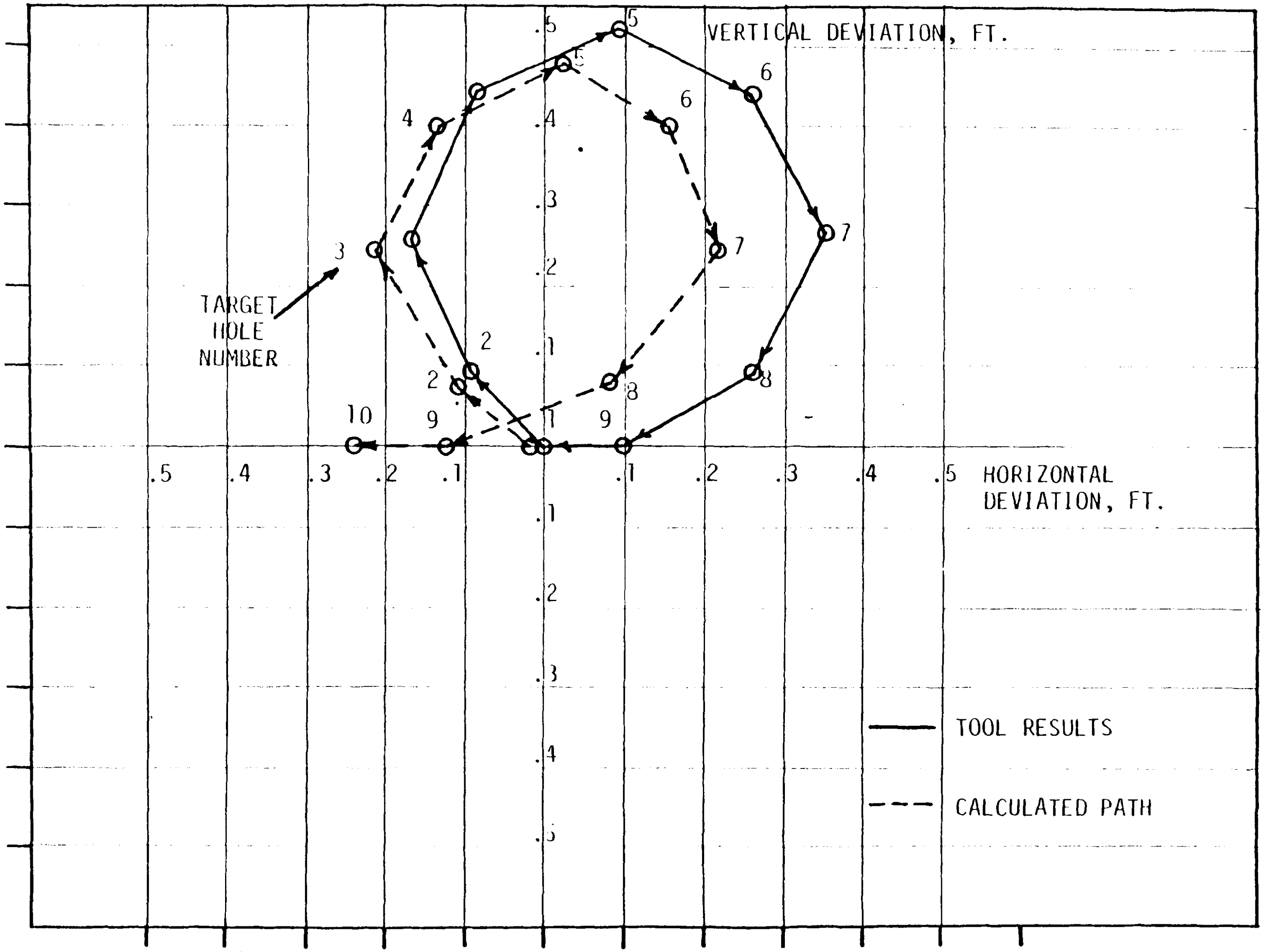


Figure 3C. Comparison of Calculated Survey Path vs. Measured Survey Path for Simulated Trajectory Test

These results are interesting in that the errors associated with the accelerometers are fairly consistent in both cases and are well within the expected ranges. The bearing calculation is the result of combining the outputs of three orthagonally oriented magnetometers. The inclination is the result of a single accelerometer oriented axially within the package. Therefore, the bearing includes the combination of three independent errors whereas the inclination error is the result of a single transducer and thus the larger bearing errors and the statistical improvement with four readings.

Phase III

Phase III began in July of 1979 with the first in-mine drilling test of the upgraded system. Testing began in Eastern Coal Company's Federal #1 mine near Fairmont West Vigrinia. A series of problems with the drilling operation caused a one month delay in the field test activities. The problems were primarily associated with the drill motor itself and the water pump used.

Upon return to Federal #1 in mid August the USBM had installed a new drill motor and water pump system. The CSS was installed and drilling was begun. During the testing phase the only problem encountered with the CSS centered around two areas.

First was the batteries. In both the downhole tool as well as the uphole tool battery life seemed to be much less than the theoretical life should be. Later examination of the batteries revealed failed cells in the positive side of the downhole battery pak and failed cells in the receive side of the uphole processor. Batteries were replaced prior to future drilling operations.

The second problem deals with an intermittent contact on the downhole torid connections. This was fairly a fairly severe problem in that the toriod connection is buried deep within the potted transducer. The connection was reconditioned and future drilling activities were accomplished without problems in this area. Another aspect with this same connector was discovered during this test series was the problem of debris in the water supply lodging against the connector and the result blockage of sufficient water flow and pressure. It was realized that a water supply filter must be used when the CSS is used to restrict particles greater than 1/16 inch from being pumped into the drill string.

Even with the above problems, the CSS was used successfully diring actual drilling operation to survey from 35 feet to 320 feet in the hole. In addition, the Sperry Sun Tool was used to survey the same hole. Figure 4 shows a comparison of the CSS results and the Sperry Sun for vertical depth of the hole. The difference between the two surveys falls primarily in an initial reported offset. Although no specific reason for the difference was determined, the basic output of the two tool results does correlate.

A record of automatic receiver gain settings was kept and is given in Figure 5. As shown as string length increased, received gain also increased. This is especially true out to about 290 feet. Beyond 290 feet receiver gain started to decrease. This was due to an abandoned drill string which was seized in an adjacent hole. In fact the drill bit eventually hit the adjacent drill steel at 329 feet. Note that the readings taken while the two drill strings were in contact were 34dB and 10dB. These very low gain readings were due to the excellent conductivity of the return signal path provided by the seized drill string.

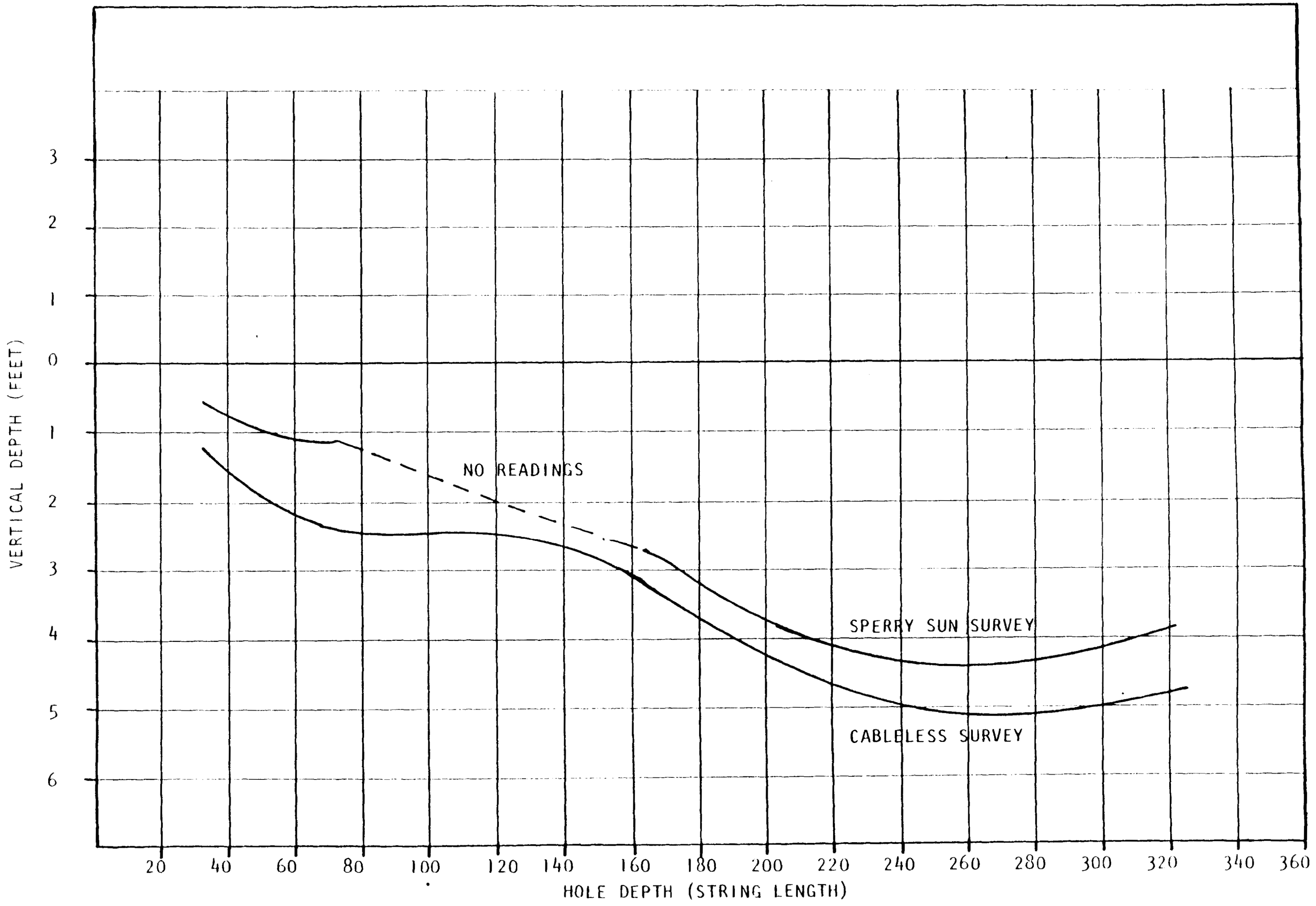


Figure 4. Vertical Survey of Horizontal Drill Hole Using Sperry Sun Tool and CSS

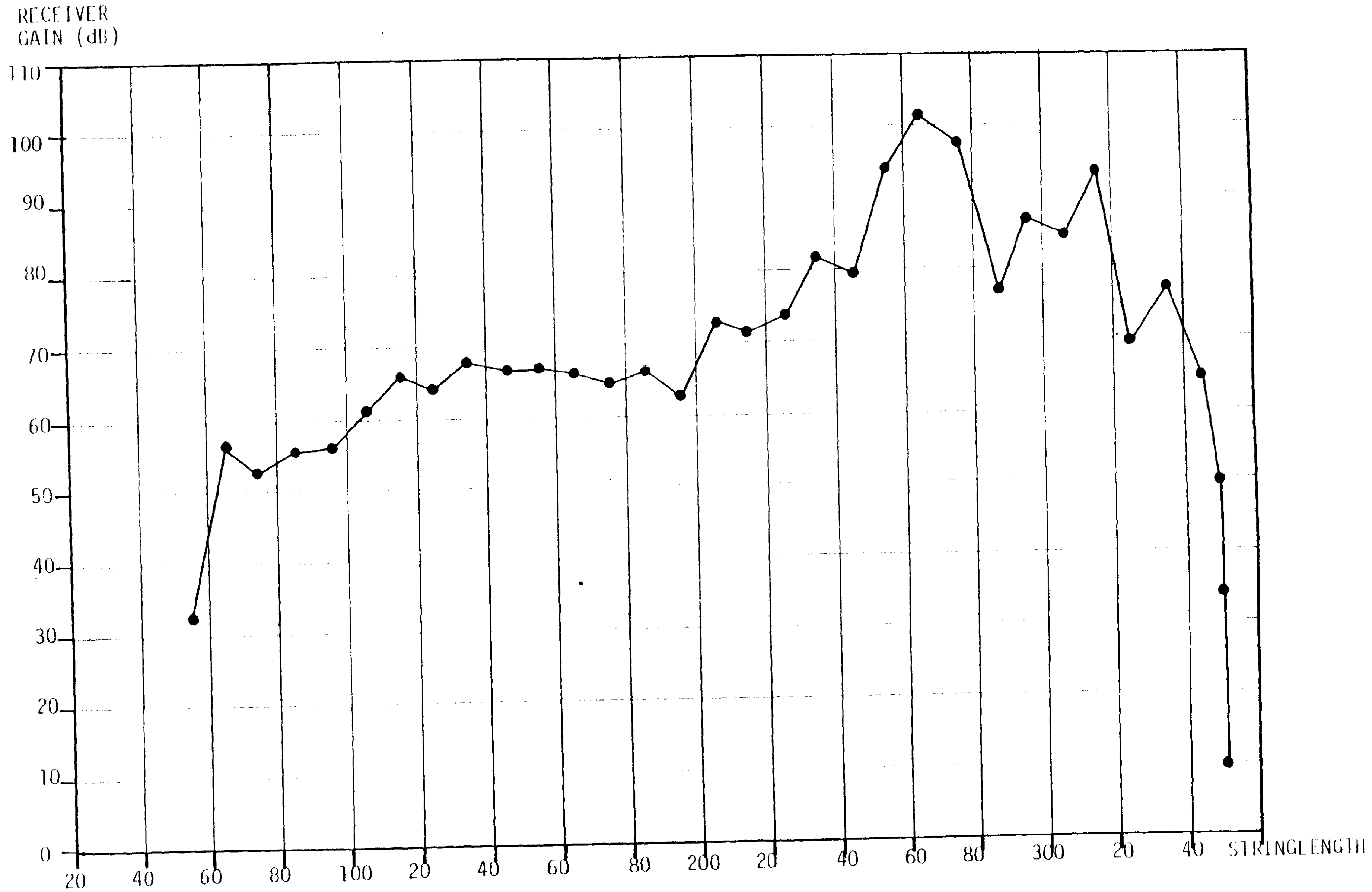


Figure 5 . Receiver Gain vs. String Length

The readings which were taken out at 245 feet and 255 feet were higher than expected and were actually getting close to the limit of the receive capability. Later testing showed that these high readings were the result of the "dirty" hole. For example, in hole depths on the order of 400 to 500 feet receiver gains of 40 to 50dB were common provided the hole had been washed clean of cuttings prior to the transmission.

Hole #2 was abandoned after several attempts to redirect the drill had failed. A third hole was started but had to be abandoned when the drill could not be kept in the hole. Therefore, no other survey tests were conducted at Federal Mine #1.

The tool was returned to ENSCO while the next drilling site was being prepared. While at ENSCO, adjustments were made to improve the operational characteristics of the system. These improvements were based on experience gained during the Federal #1 mine drillings. These changes occurred primarily in the area of monitoring capability and operating signalling via the front panel to indicate what operation the system is performing. These changes were most beneficial in removing the "mystery" of the electronic survey system.

The next drilling activity occurred in December of 1979 at the Mariana #58 Mine in Pennsylvania. During the drilling program the CSS was successfully used to survey the drilling operation to a depth of 490 feet.

While drilling at the Mariana Mine the survey system worked fairly well. On several occasions when the survey indicated that drilling was approaching regions known to contain slate binder layers within the coal seam, cuttings indicated that the layers were hit within 3 feet along the drill path. This was at a string length of 454 feet. Records of the receiver gains attained in this field trial indicated that with a clean hole, good ground and good bit to coal thrust pressure, numbers on the order of 40 to 60dB of gain were common through this drilling from 55 feet to 490 feet.

As with the previous testing exercise, batteries continued to be less than adequate. The problem was traced to be the interconnections within the battery cansiter and the relays used to activate the system. These items were all repaired and no further debilitating problems occurred. Another less serious problem that occurred throughout the testing was the triggering of the down hole unit. This is done by raising the water pressure to at least 70 psi and then permitting it to fall below 60 psi. The various pumps used and available water supplies were often not capable of not delivering the required levels unless orifices were installed in the bit to restrict flow.

The final aspect of Phase III was the development of an O&M Manual and a classroom training session given at the Bruceton Research Center. Personnel from the Bureau and from the independent drilling contractor were trained in this operation and maintenance of the system.

3. SYSTEM DESCRIPTION

The Cableless Survey System (CSS) is designed to provide near real time data during degasing operations in coal mines. Degasing is performed by drilling long (up to 2000 feet) horizontal boreholes into a virgin coal seam. The survey or downhole tool is attached directly behind the drill bit. This is shown in Figure 6 below.

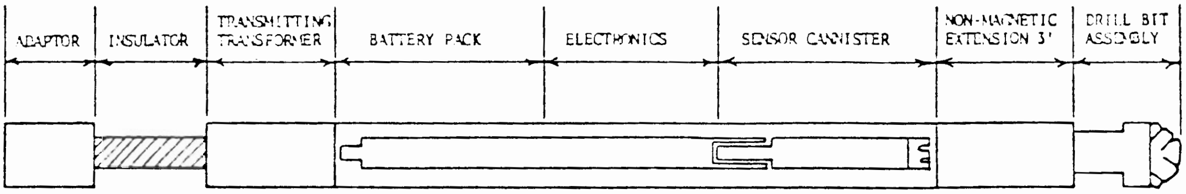


Figure 6. Survey Tool and Drill Bit

In the survey tool, the transmitter and battery are separate assemblies which join together in a pressure-tight tube. The sensors are in a separate pressure-tight tube which joins to the first. This pressure tube assembly is then enclosed in an outer tube with an annular space between them for water passage. The transmitting transformer joins the main package with a water-tight electrical fitting and has a hole through its center for water flow. A short non-magnetic extension of the same size as the outer tube is added at the sensor end of the unit to isolate the effects of magnetism which might exist in the drill bits and subs. The downhole unit mounts close behind the drill bit. Figure 7 is a block diagram of the survey tool electronics.

The sensor outputs are sampled in a time division multiplex technique in which each sample is converted from analog to digital form and used to modulate the phase shift transmitter.

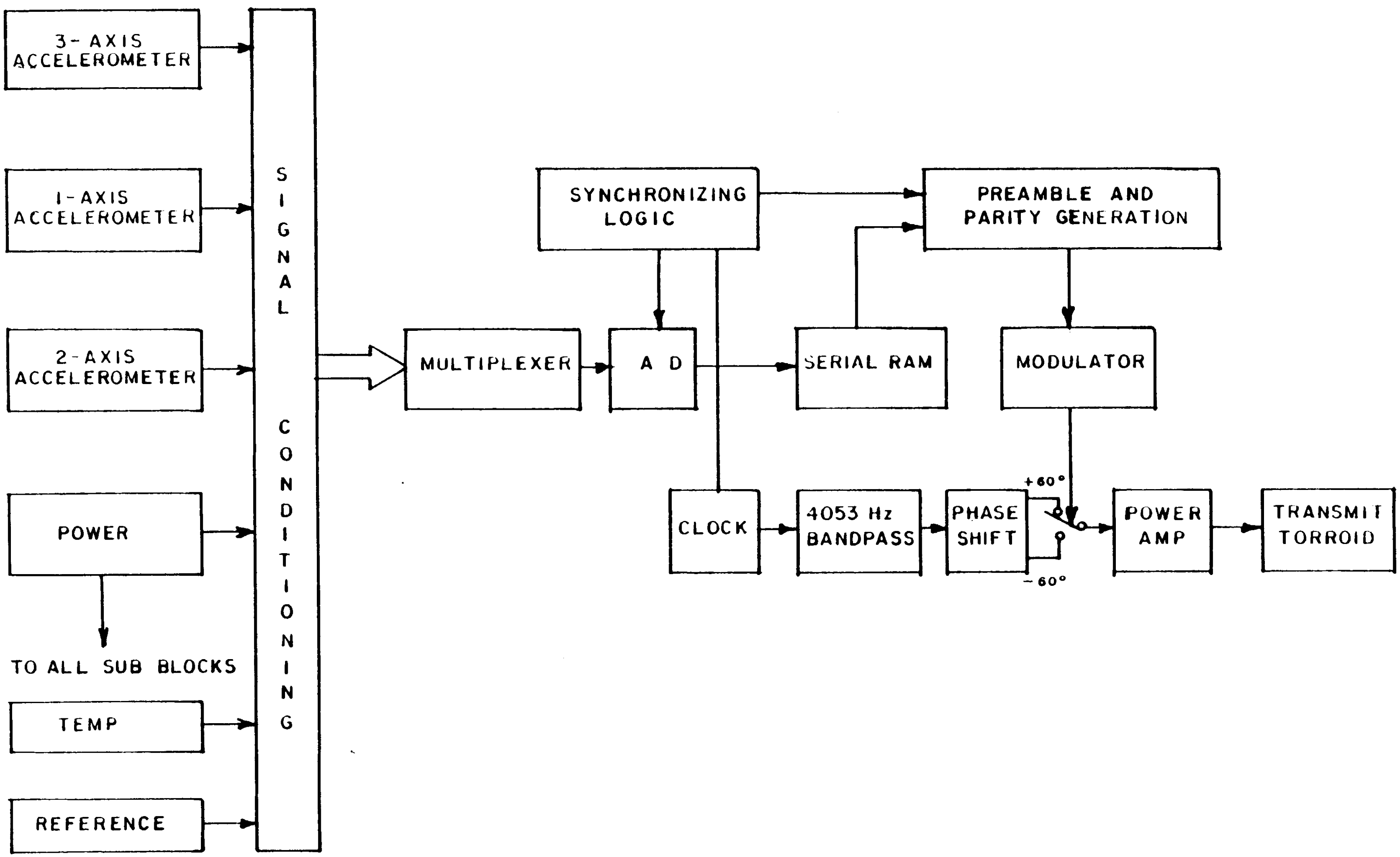


Figure 7. Block Diagram of Downhole Survey Tool

The sensor data transmission is preceeded by a long pulse of the carrier followed by a fixed message for receiving synchronization. The exact message and data format of the survey tool are contained in Appendix B. The transmitter output is efficiently coupled to the drill string by the transmitting transformer. The transmitting transformer is oriented such that it induces a true electric field into the drill string. The return path for the electric current is through the surrounding coal.

The signal on the drill string is picked up at the surface by the Receiving Transformer, Figure 8, and then passed via the toriod cable.

The receiving Transformer is mounted on the drill rig at the surface so that the drill pipe passes through it. The Processor, which includes the computer and receiver, is adjacent to the drill rig.

As mentioned before the survey tool contains a triaxial magnetometer, a biaxial accelerometer, and a single axis accelerometer. These sensors are used to measure the vector relationship in each axis to the earth's magnetic field and the earth's gravitation vector. Figure 9 shows graphically the directions of the earth's vector.

The Processor utilizes an automatic gain ranging, variable bandwidth phase lock technique for maximum separation of the signal from the noise. The Processor then calculates the bearing and inclination of the downhole unit.

When given the length of drill pipe sections, the Processor calculates the location of the bit and its deviation from the desired course.

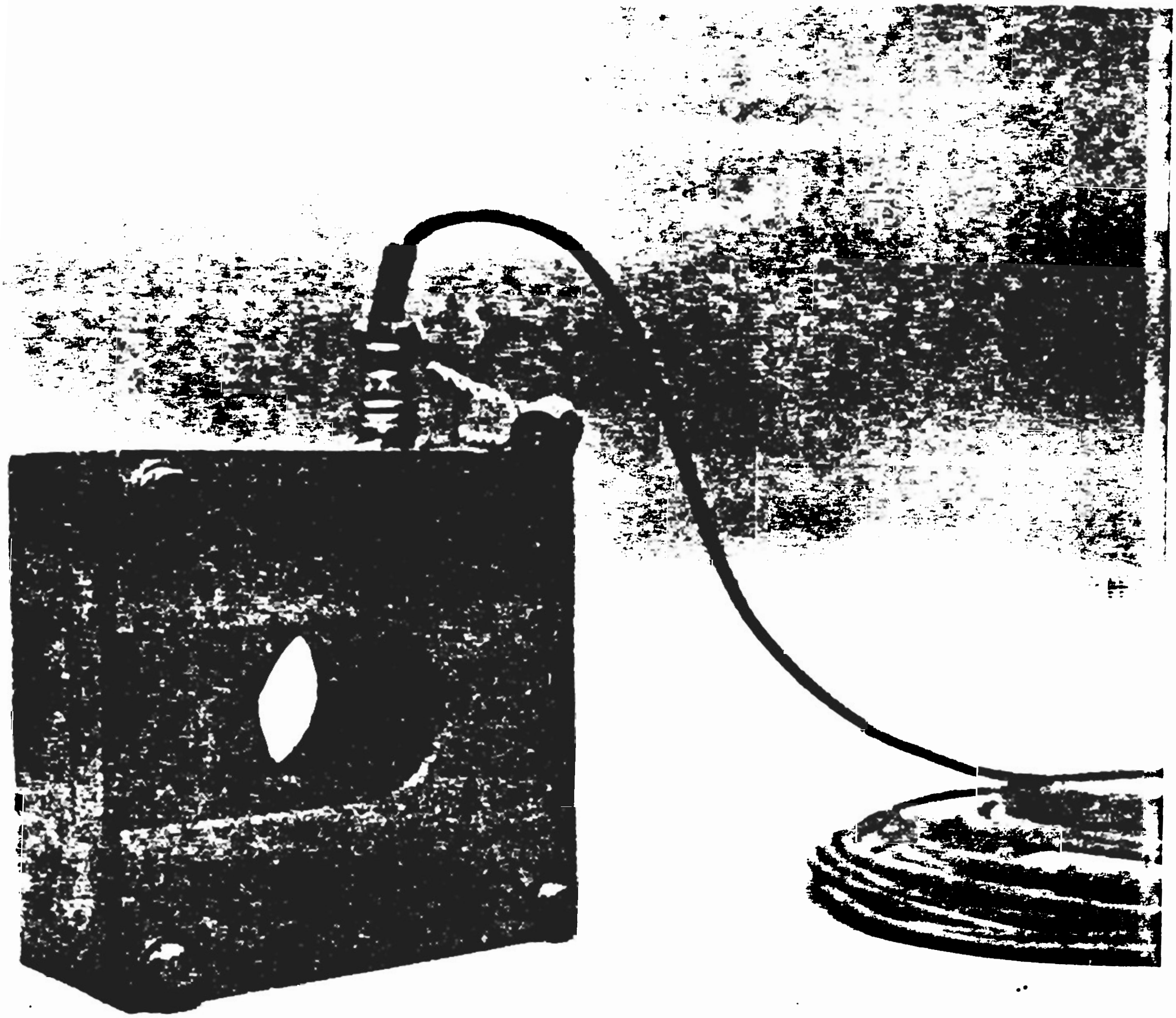


Figure 8. Receiving Transformer

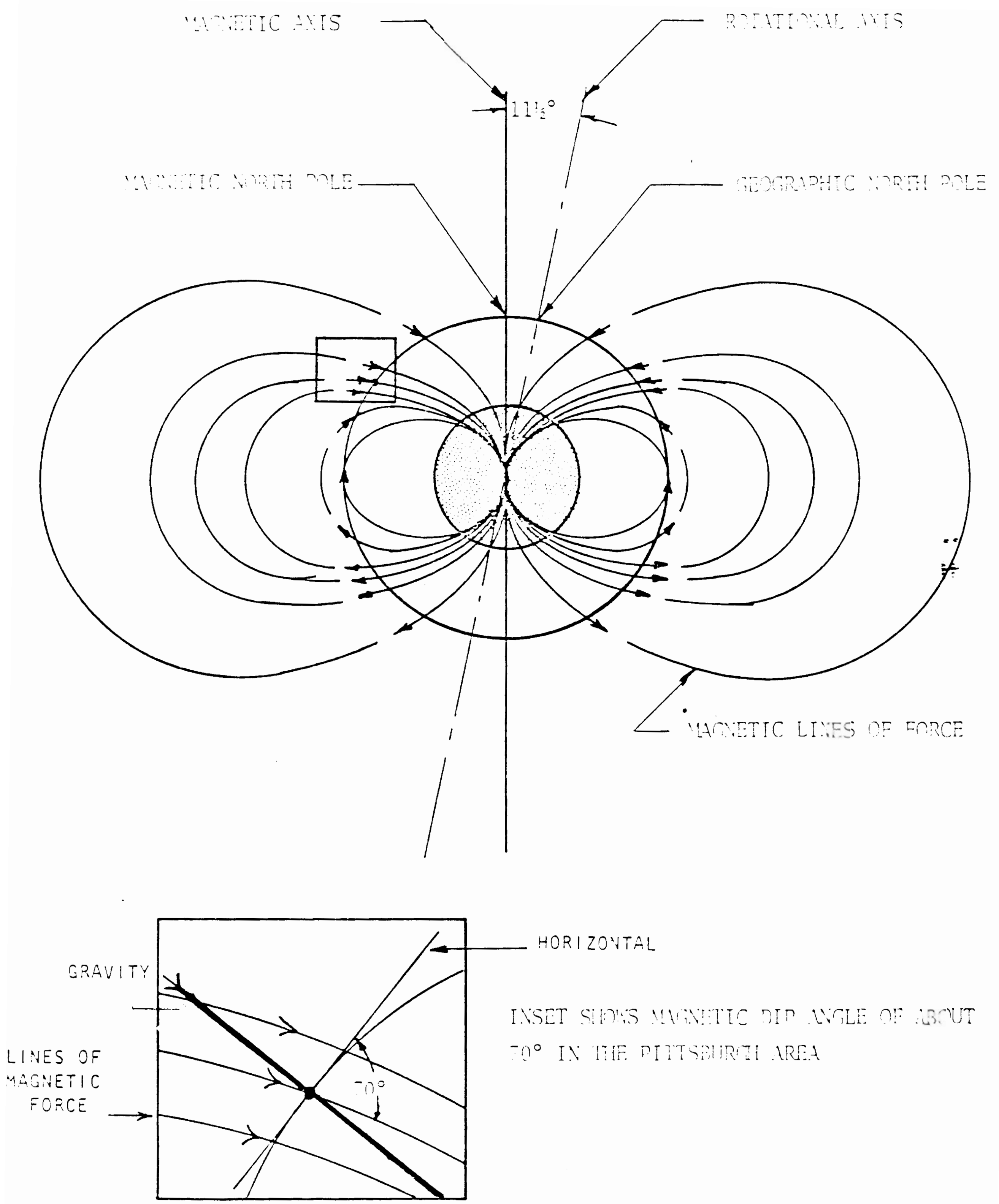


Figure 9. Direction of Earth's Magnetic and Gravatational Vectors

Figure 10 is a block diagram of the system receiver. Figure 11 is a block diagram of the microprocessor based processor and display unit.

When the processor receives data from the system receiver it performs several functions. First, it does data error testing by examining that data parity is correct and that the raw data values are within reasonable limits. Following the data checking, the processor then processes the received data to calculate the necessary parameters for the survey. Finally, the processor displays on its front panel those parameters that the drill operator needs to know such that he can initiate drill actions to guide the drill within the coal seam. Appendix D contains the detailed schematics of the survey tool, receiver and processor. Also includes are the software program listings employed by the processor. Appendix E contains a discussion of the computer algorithms that are employed by the processor.

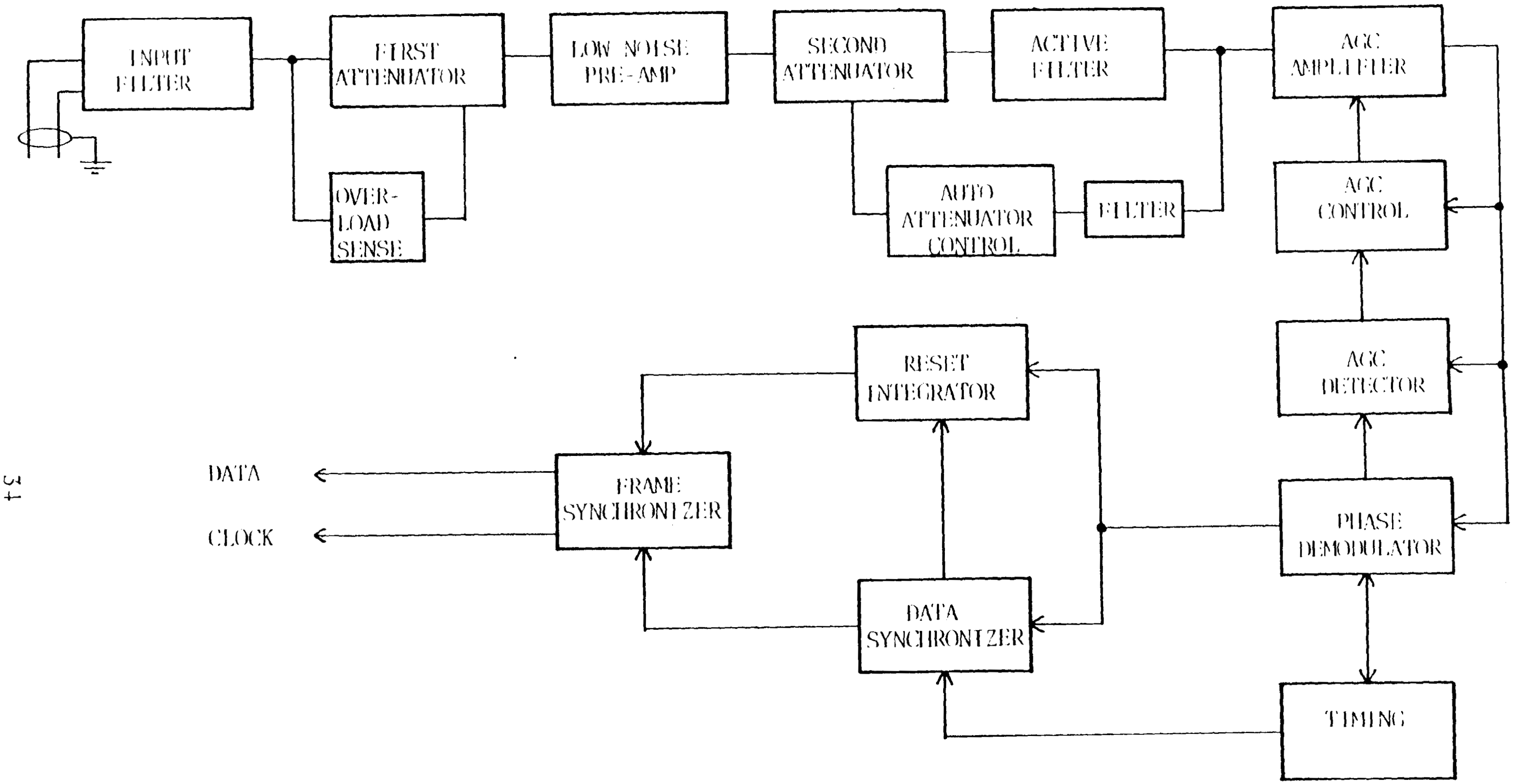


Figure 10. Telemetry Receiver Block Diagram

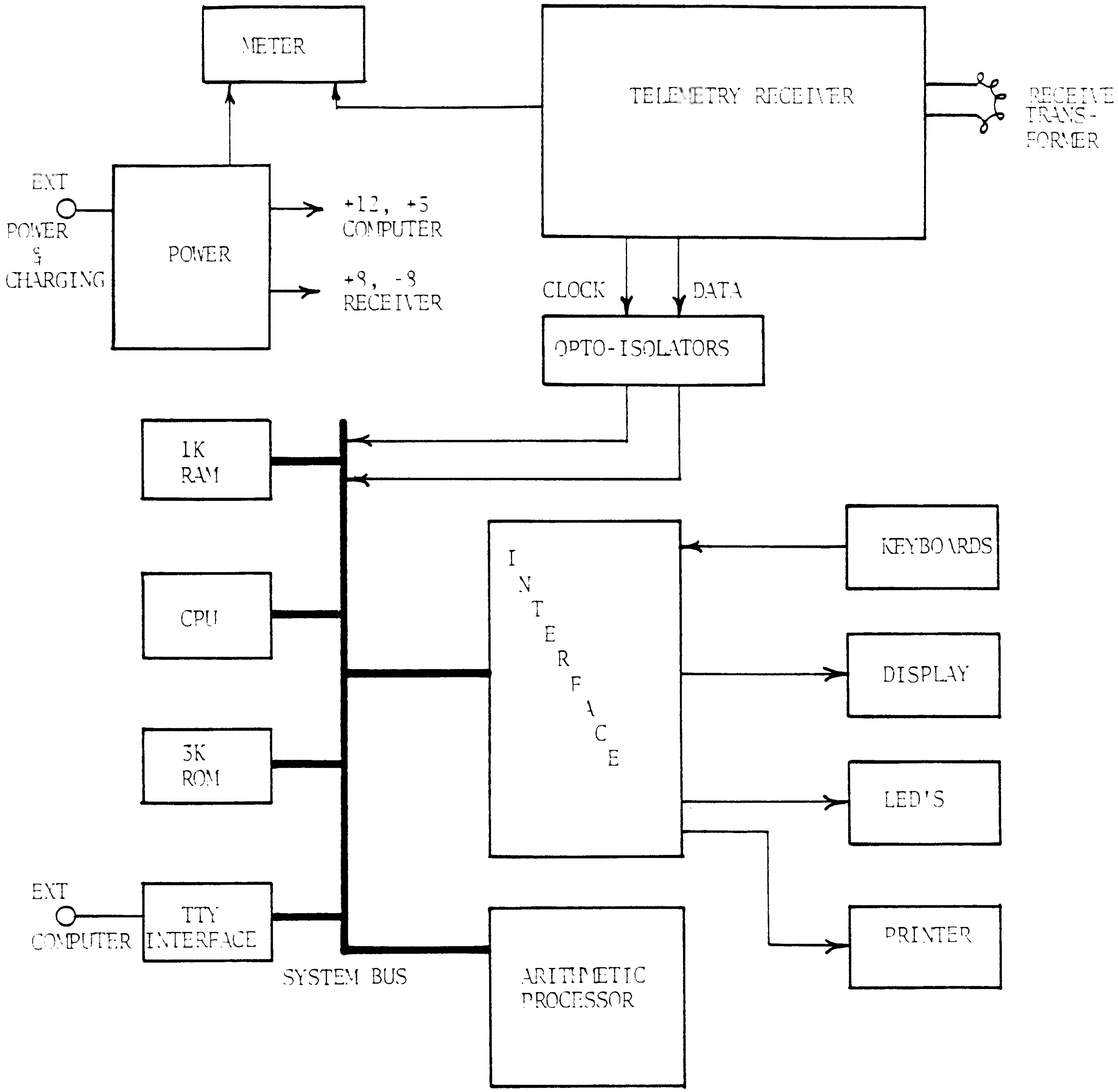


Figure 11. Block Diagram of Uphole Processor and Display Unit

4. CONCLUSIONS AND RECOMMENDATIONS

The Cableless Survey System developed in this project has proved that drilling efficiency can be enhanced when detailed drill bit position is made available to the drill operator in near real time environment. Field tests have shown the CSS is as accurate as previous methods for borehole surveying and saves time in that the survey tool can withstand the drilling shock and vibration. The uphole receiver processor has proven to be reliable and most importantly portable.

As with any project of this nature, looking back over the final design as it related to operational use there are, of course, some recommendations that ENSCO, Inc. feels would significantly enhance the tools operation. Efforts to further utilize, upgrade and improve the system should be continued.

The following is a list of recommendations by subsystem that should be explored in any further development.

<u>PROCESSOR</u>

- Access to the values of average inclination and bearing that the Processor uses for advancing the survey will allow projection of hypothetical surveys.
- Allow initial values for seam dip angle and vertical depth in the seam so the computer will read out (on demand) the current vertical seam depth.
- Extend the memory by 2K-4K to allow for program expansion.
- Change the batteries used to take advantage of recent improvements in sealed lead acid cells.

SURVEY TOOL

- Break the package about 10 feet back from the front end so a stabilizer can be put at a more effective distance from the front and to make the package more manageable.
- Change the batteries to lead acid. They are more durable and need fewer inter-cell connections.
- Use a pumpable battery pack or downhole water turbine generator (could also be used to measure water flow).
- Develop sensors to read thrust, RPM and torque.
- Lighten the inner canister.
- Operate the tool as radio source to get attenuation curves in coal and other media.
- Reduce the outside diameter of the downhole package to allow more drilling control.
- Provide two way radio communication to eliminate the need for water pressure triggering.
- Design a new means for lengthwise compensation of the inner sections. The existing rubber cushions take a set and are difficult to install.

APPENDIX A

Phase I - Computer Analysis of Survey Results

Error Analysis of Downhole Tool

SURVEY RESULTS

During Phase I the CSS was field tested by surveying a horizontal borehole. The hole was also surveyed with the Sperry-Sun device. The results of both surveys were fed into a computer and comparisons made between the two. Since the Sperry-Sun device is subject to reader interpretation, the films were interpreted by two readers and their results averaged.

An obvious discrepancy in survey depth between the Sperry-Sun and ENSCO surveys is evident in Figures 12a and 12b. Figure 12a compares the two surveys without a depth correction, while the comparison in Figure 12b includes a 10 ft. depth reduction in the ENSCO survey at the 200 ft. point. The greatly improved correlation between surveys in Figure12b indicates that an error in survey depth was made and comparison of the ENSCO and Driller's logs reveals that the first survey point on March 16 was taken at 200 ft. but was improperly entered in the ENSCO log as 210 ft., creating the 10 ft. offset. The depth correction was made before final survey data was processed in the computer and is included in the data used in the following discussion.

The inclinations of the two surveys are represented graphically in Figure 13 and the correlation between the surveys is excellent, especially when standard deviation of 1.134° between the two readers of the Sperry-Sun survey is considered. There does exist however a consistent negative bias between the ENSCO and the Sperry-Sun surveys. This bias becomes more apparent when the plots of vertical deviation for the two surveys are compared in Figure 14. The accompanying plot of the difference between the vertical deviation of the two surveys depicts an ENSCO survey bias of about +0.106°. Since the ENSCO procedure of taking two readings, separated in rotation at 180°, at each survey point would have removed any internal bias errors, the difference must be attributed to external factors such as the bit rise created by the use of only a front stabilizer or a sag in the non-magnetic extension between the bit

DEPTH CORRELATION COMPARISON

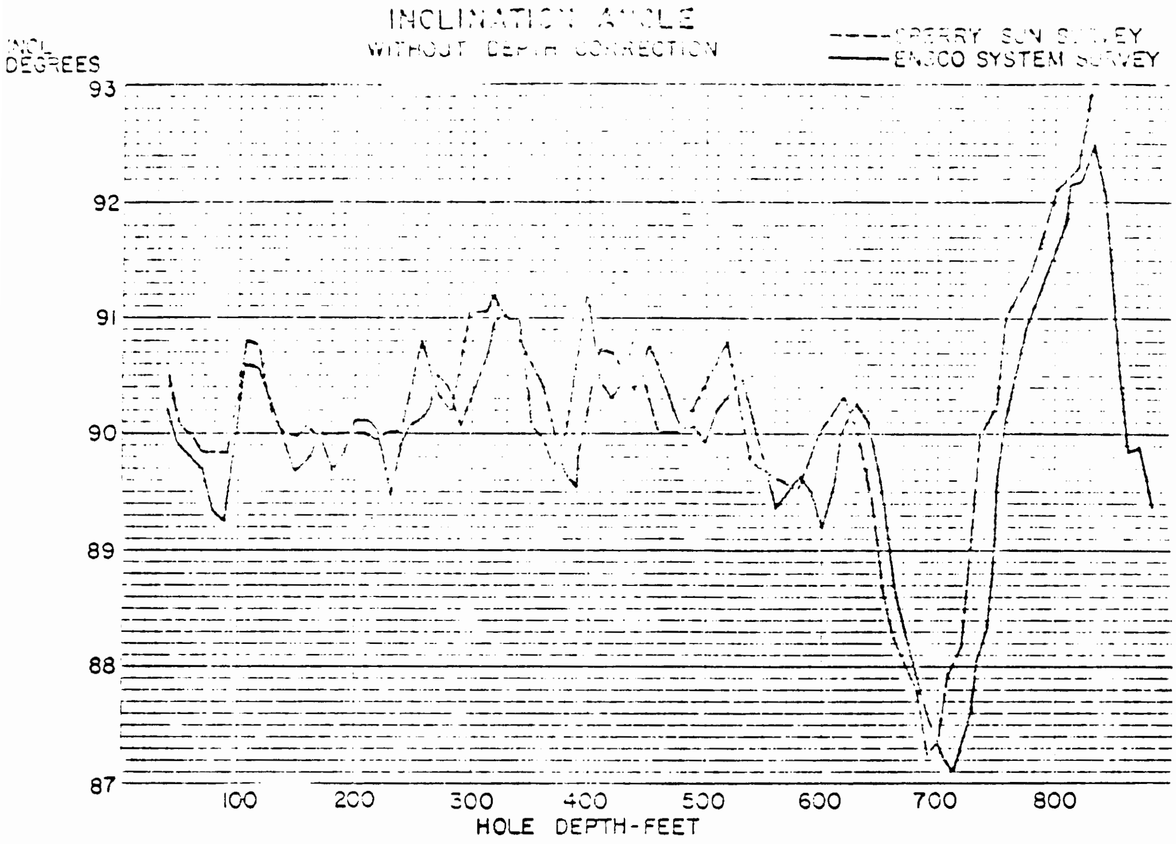


Figure 12a.

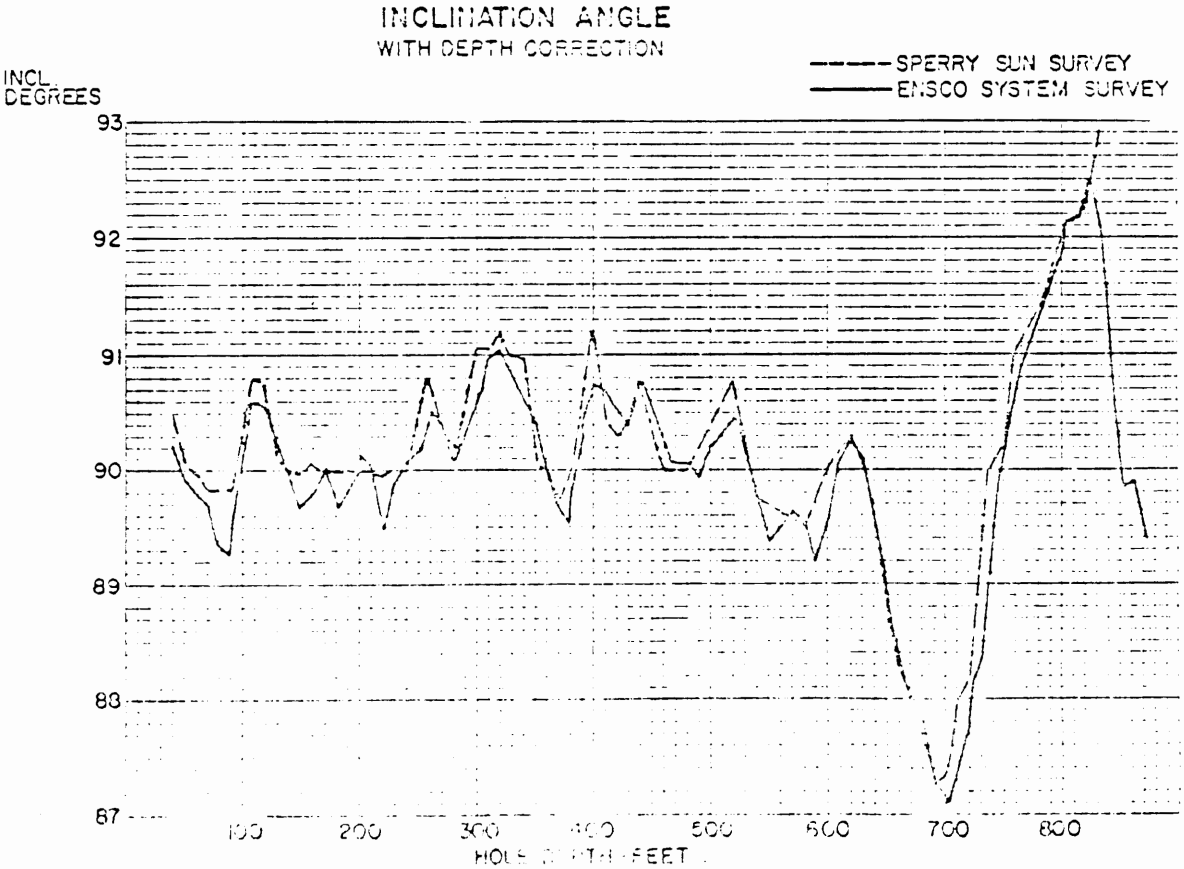


Figure 12b.

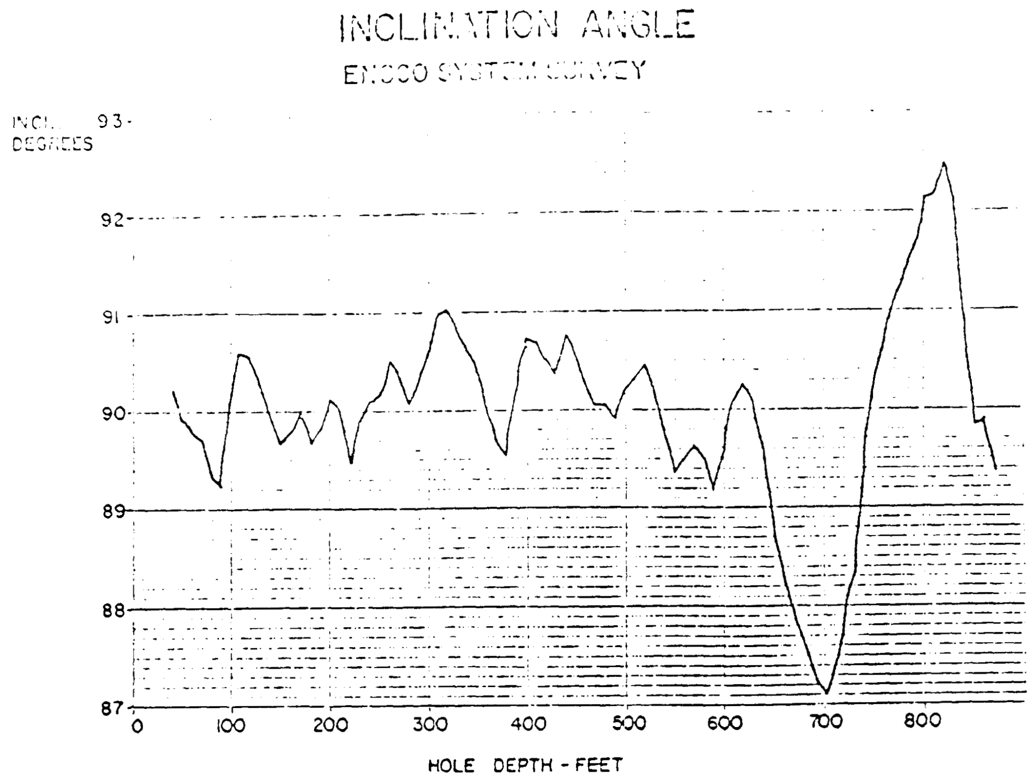


Figure 13a.

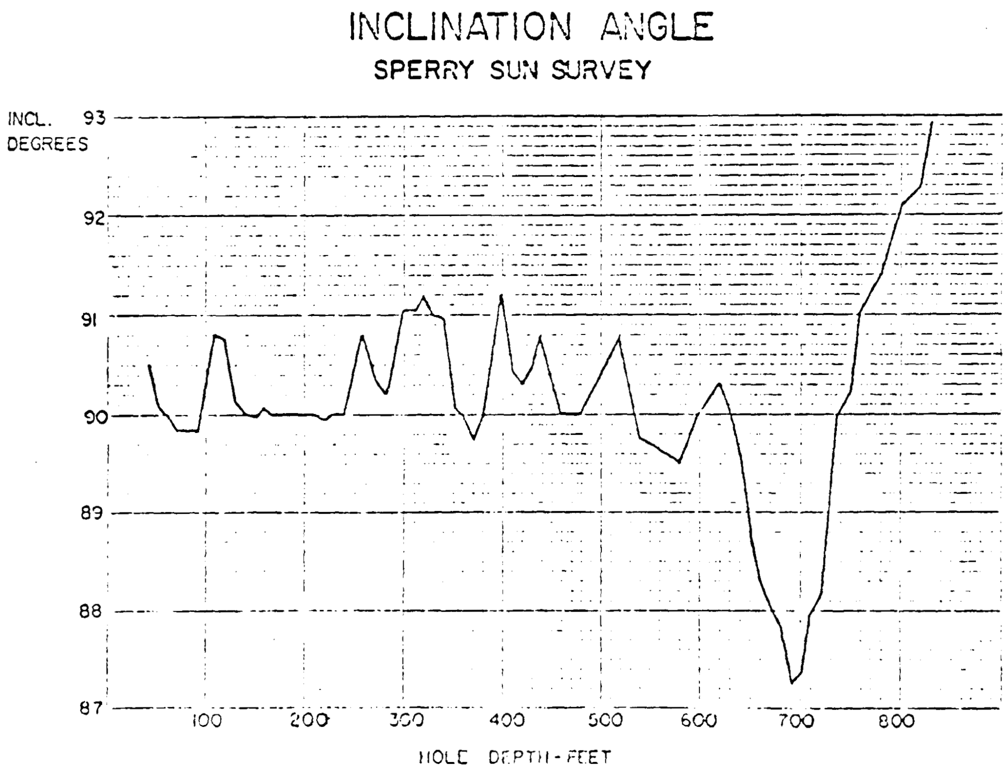
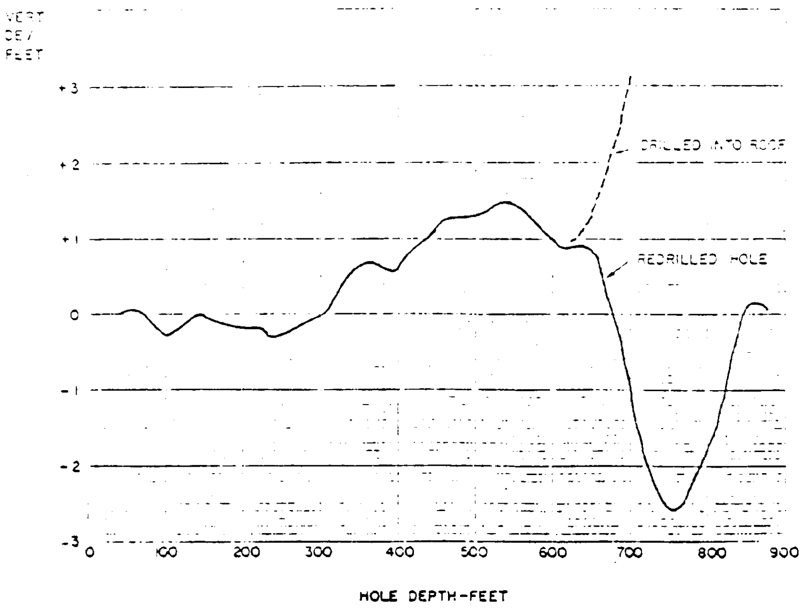
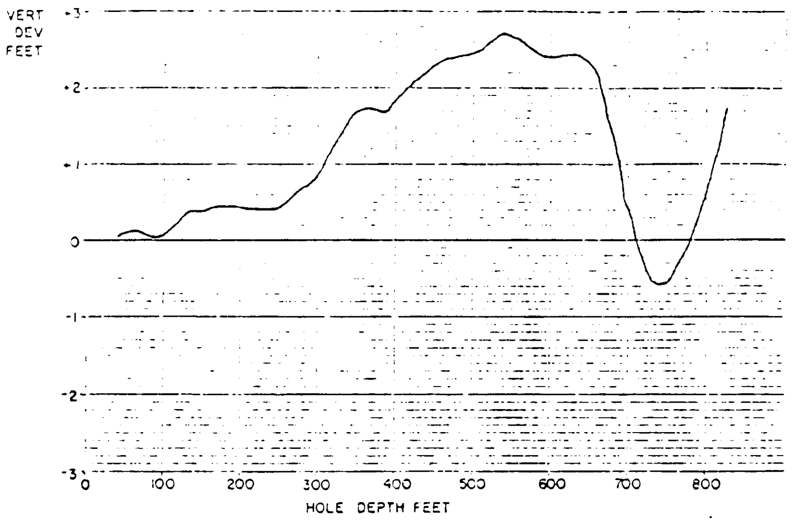


Figure 13b.

VERTICAL DEVIATION OF BOREHOLE
ENSCO SYSTEM SURVEY



VERTICAL DEVIATION OF BOREHOLE
SPERRY SUN SURVEY



VERTICAL DEVIATION
DIFFERENCE BETWEEN ENSCO SYSTEM AND SPERRY SUN SURVEYS

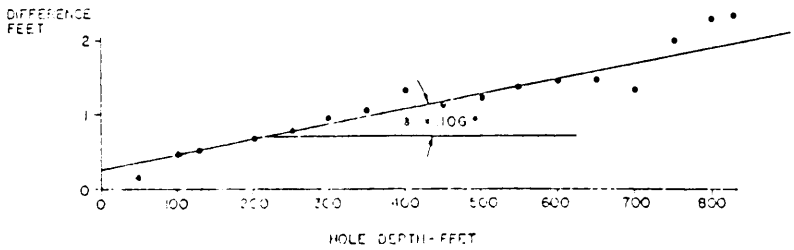
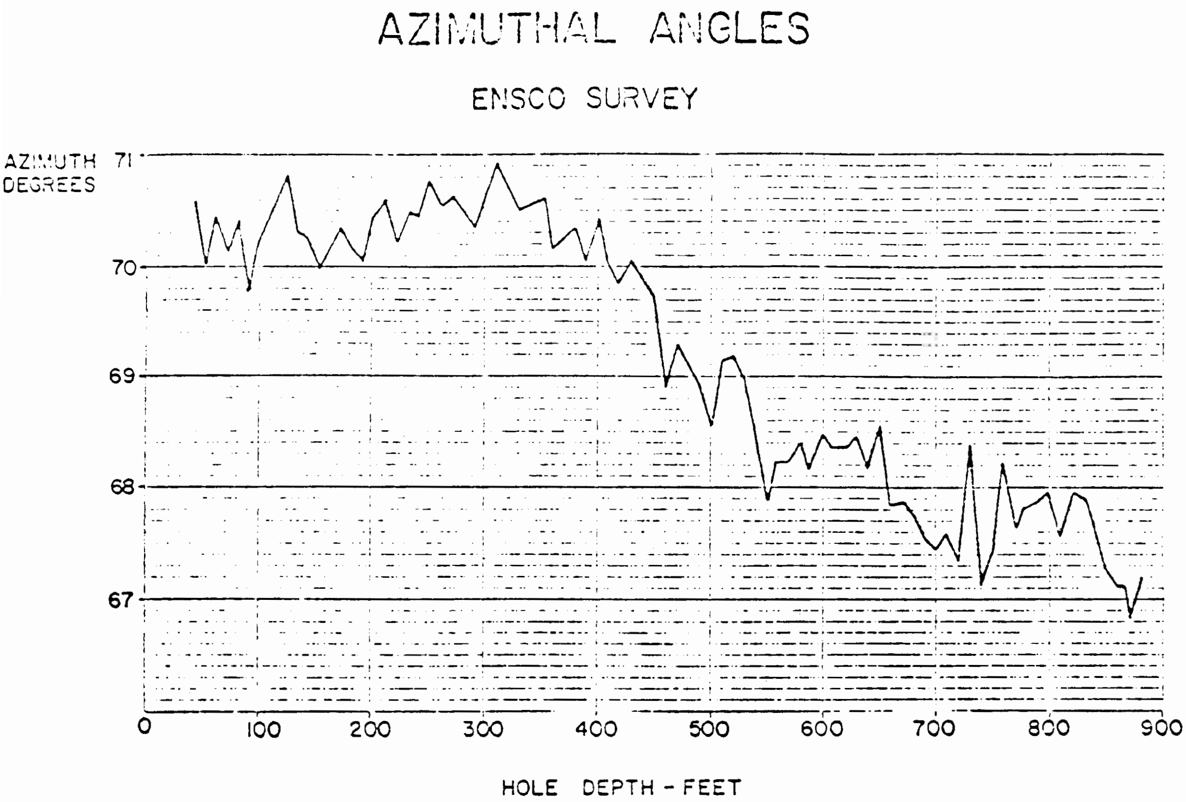


Figure 14

and the sensor system. Even with the bias, the surveys still compare very well with discrepancy of only 2.38 ft. in a 830 ft. hole. The ENSCO plot of vertical deviation includes the plot of the survey when the drill went into the roof and the hole was redrilled.

Azimuth plots for the two survey systems are shown in Figure 15 The Sperry-Sun graph includes a plot of the first survey taken March 17th and a plot of the average of two readers for the final survey. The surveys have some points of discrepancy, but once again excellent overall correlation exists. The lateral deviation plots (Figure 16 are very close with a maximum difference of only 1.17 feet and a difference of only .76 feet at the 830 ft. depth. Only the two reader averages of the final Sperry-Sun survey were used in the deviation plots. It should be noted that a standard deviation of 0.78° exists between the first and second Sperry-Sun surveys and standard deviation of 0.18° exists between the two readers of the final Sperry-Sun survey. The ENSCO survey was also the average of two different survey points as shown in Figure 17. The ENSCO survey procedure was designed to cancel errors by taking two survey points at each depth with an angular package rotation of 180° between points.

The source of the differences between the ENSCO and Sperry-Sun surveys is not clear and the correlation between the two seems more than adequate for this application. It will be noted that the two Sperry-Sun surveys have an initial bias difference between them of approximately 1°. The survey tool was initially aligned against the first Sperry-Sun survey. Since all three runs (2 Sperry-Sun and one Survey Tool run) agree very well except for this bias difference, we are inclined to believe that there is an offset error in the Sperry-Sun tool.


AZIMUTHAL ANGLES
ENSCO SURVEY
AZIMUTH DEGREES
71
70
69
68
67
0
100
200
300
400
500
600
700
800
900
HOLE DEPTH - FEET

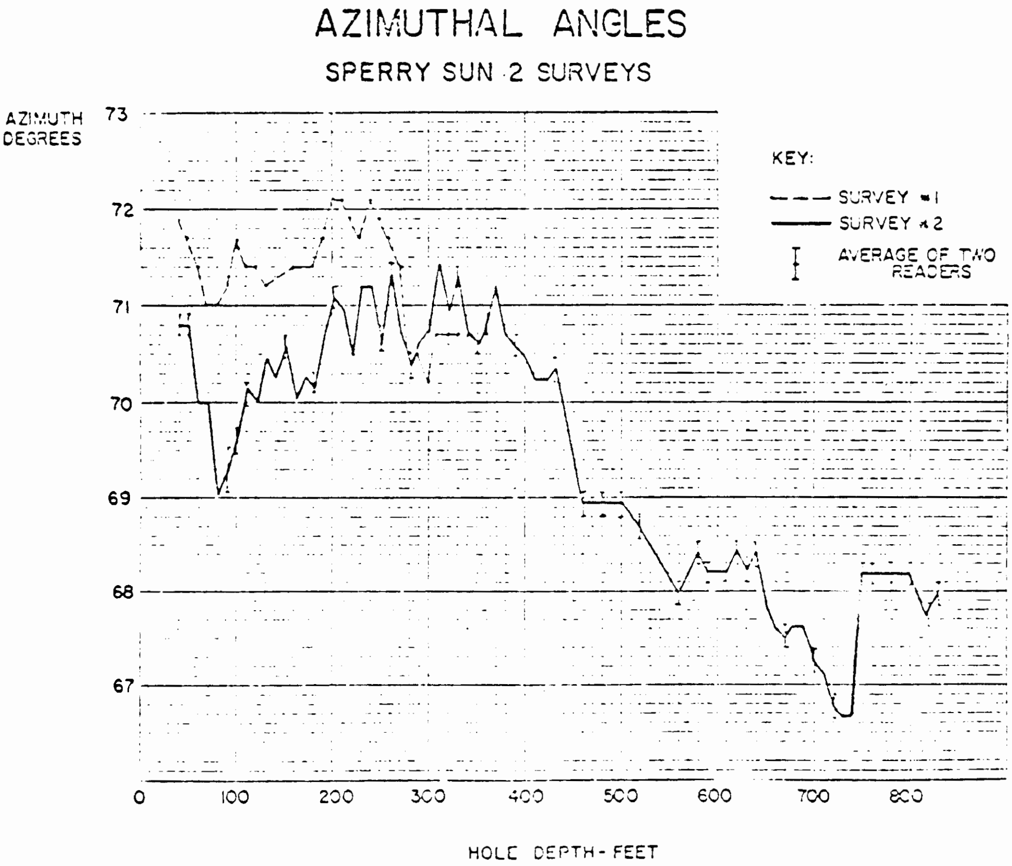
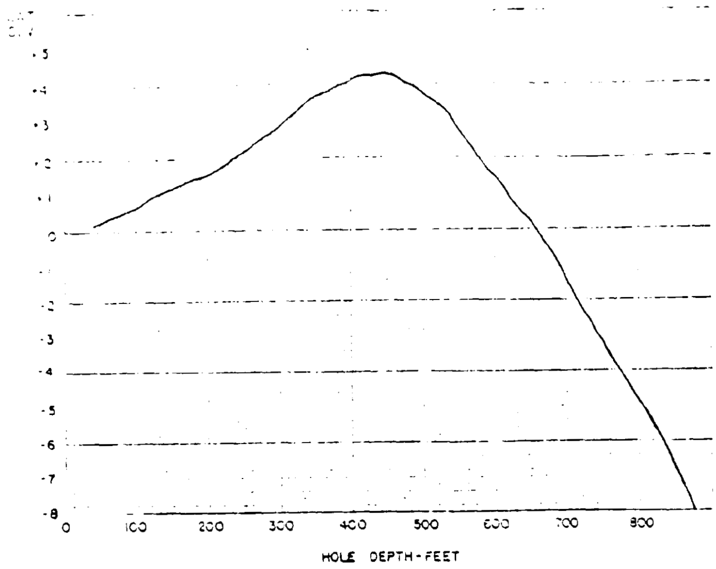

AZIMUTHAL ANGLES
SPERRY SUN 2 SURVEYS
AZIMUTH DEGREES
73
72
71
70
69
68
67
KEY:
SURVEY #1
SURVEY #2
AVERAGE OF TWO READERS
0
100
200
300
400
500
600
700
800
HOLE DEPTH - FEET

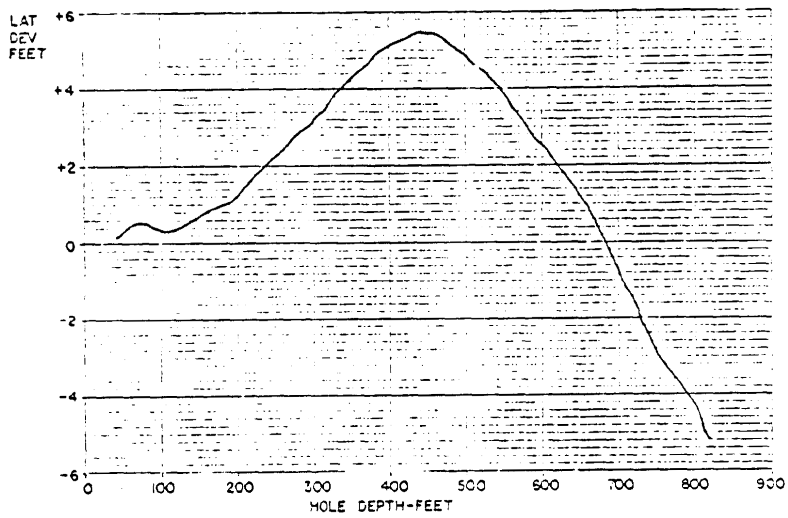
Figure 15

ENSCO SYSTEM SURVEY



LATERAL DEVIATION

SPERRY SUN SURVEY



DIFFERENCE IN LATERAL DEVIATION

BETWEEN

ENSCO SYSTEM SURVEY AND SPERRY SUN SURVEY

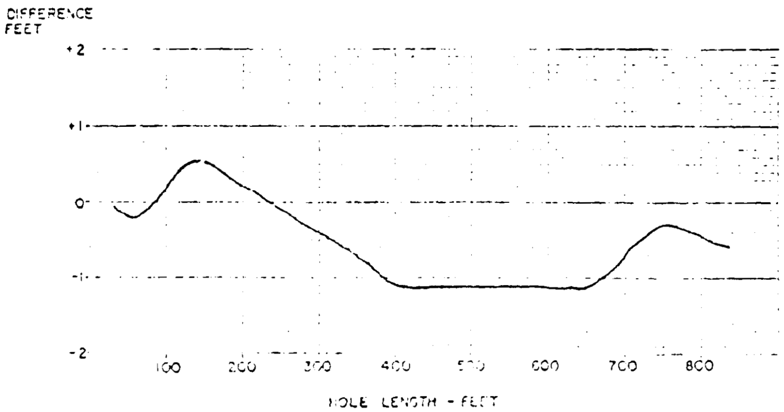


 Figure 16

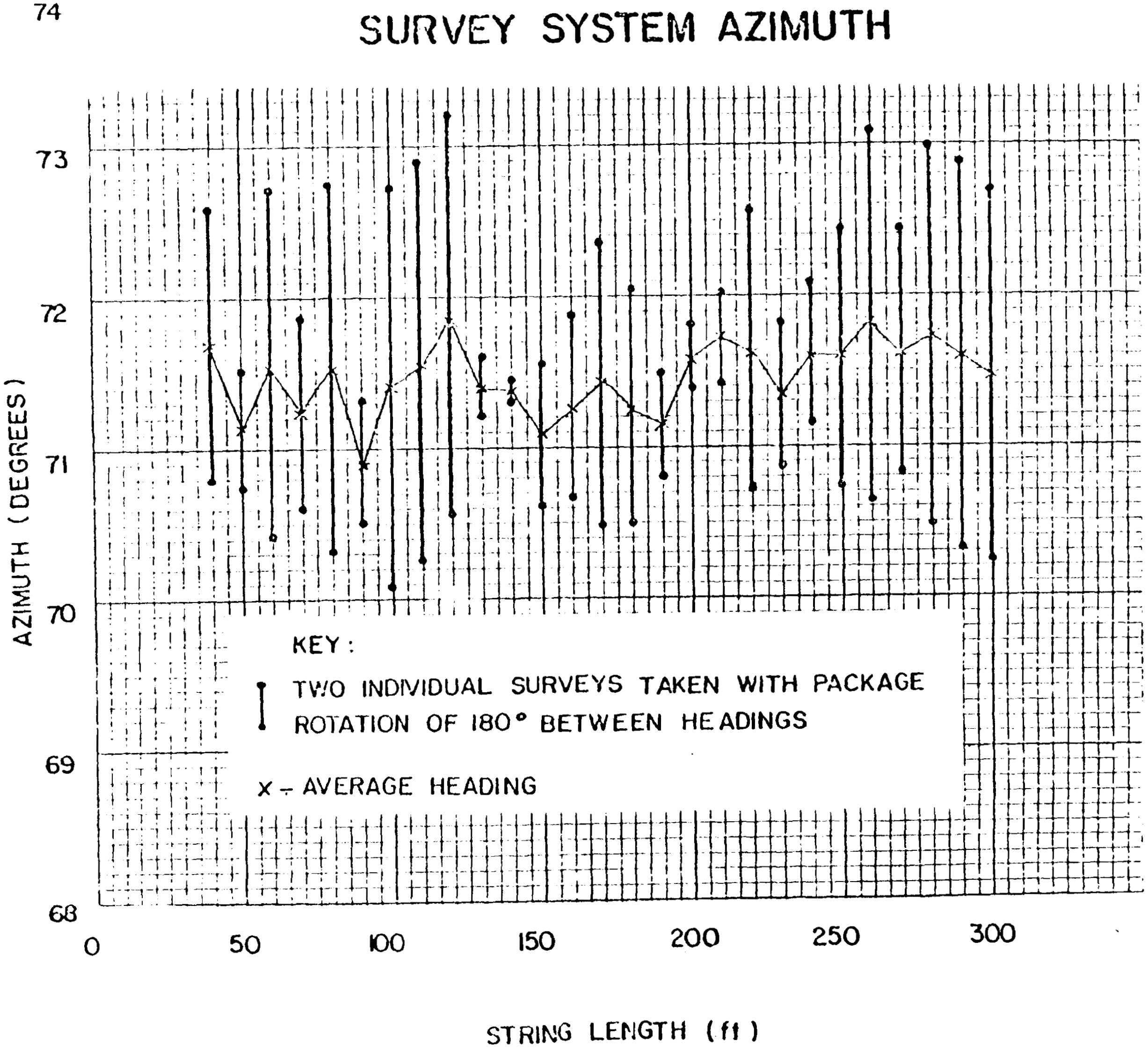

SURVEY SYSTEM AZIMUTH
74
73
72
71
70
69
68
AZIMUTH (DEGREES)
0
50
100
150
200
250
300
STRING LENGTH (ft)
KEY:
TWO INDIVIDUAL SURVEYS TAKEN WITH PACKAGE ROTATION OF 180° BETWEEN HEADINGS
X - AVERAGE HEADING

Figure 17

SPECIAL TESTING

During drill operation, significant non-linear variations in azimuth corresponding to angular package rotation were experienced as shown graphically in Figure 18a. The magnitude of these variations prompted a series of tests, relating magnetometer outputs to angular rotation, to define the source of this non-linearity.

The first test involved rotating the assembled inner package through 360° of roll in 10° intervals and triggering the package at each interval. The package outputs were picked up by the receiver, logged and processed in the computer as survey data. The resulting plot of azimuth versus package rotation (Figure 18b) reveals a variation of over ±1.5 degrees, indicating the existence of the problem without the outer canister in place. An analysis of the raw data indicated that the previously calculated magnetometer offset factors were no longer valid and a reduction in azimuth variation could be effected by offset correction.

The next step in the elimination process was to physically separate the sensor canister from the electronics canister, while retaining the electrical integrity. The resulting data had slightly less variation with rotation than data taken with the complete package, but the same character was retained, as shown in Figure 18c. The effect of the electronic canister does not appear to be a problem.

The next step was to disassemble the sensor canister, noting the resultant changes in magnetometer outputs associated with each component's removal. The component having the greatest effect was the accelerometer, followed by much smaller but significant changes associated with the magnetometer alignment rods and outer sensor canister itself. Data on the magnetometer alone shows some reduction in azimuth variation

AZIMUTH DIFFERENCE (DEGREES)

(EACH CASE NORMALIZED TO ITS MEAN AZIMUTH)

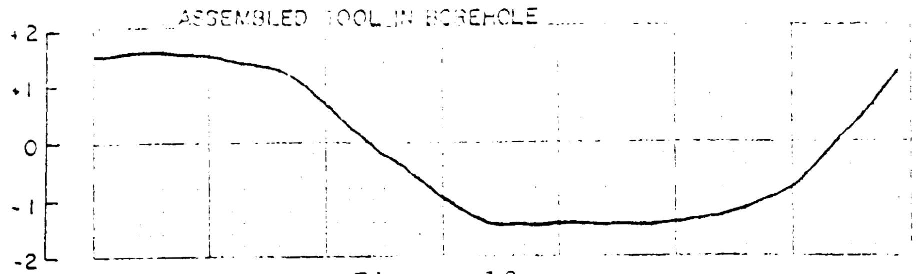


Figure 18a.

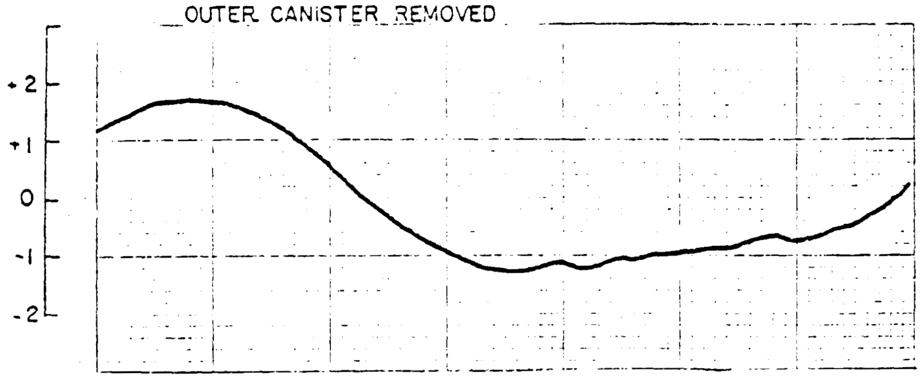


Figure 18b.

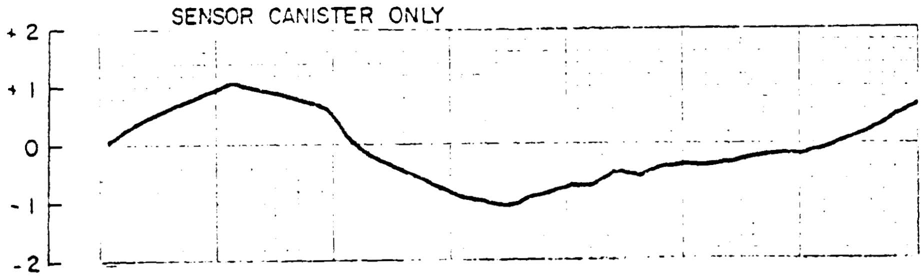


Figure 18c.

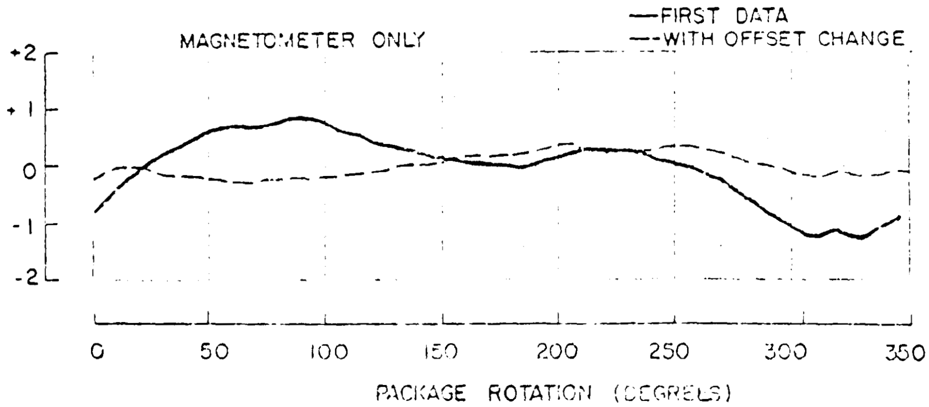


Figure 18d.

with rotation but more importantly the character of the variation was significantly different. This indicated that a change in the magnetic environment of the magnetometer had occurred.

The axis offsets were greatly changed so new offset factors, derived from current experiments, were inserted in the program. The resulting data contains only a $\pm .35°$ variation in azimuth with rotation as shown in Figure 18d. It also possesses a character conducive to further reduction.

An attempt was then made to reduce the errors in previous configurations by appropriate changes in offset factors. A small improvement resulted in each case, but in no case was the error reduced less than $\pm 1°$.

The above testing indicates that either all sources of magnetic abnormalities in the sensor canister must be removed by relocation of components and degaussing or the procedure of taking two measurements at each survey point (with an angular package rotation of 180° between measurements) must be continued.

There was no requirement to investigate the potential limits of accuracy of this type of tool. However, the question of limiting accuracy of a magnetic tool is often asked. Figure 19 is a plot of heading degrees versus the rotational angle of the drill string taken over a reasonably straight section of the hole. An envelope containing the majority of these points is shown as the solid line. The mid point of this envelope is shown as the dotted line. The mean of all points with respect to the dotted line is 7.5×10^{-3} degrees. The standard deviation, σ, is .146°. The low value of the mean indicates that the dotted line represents a systematic variation which, with sufficient design or computational effort,

HEADING
VS
ROTATIONAL ANGLE

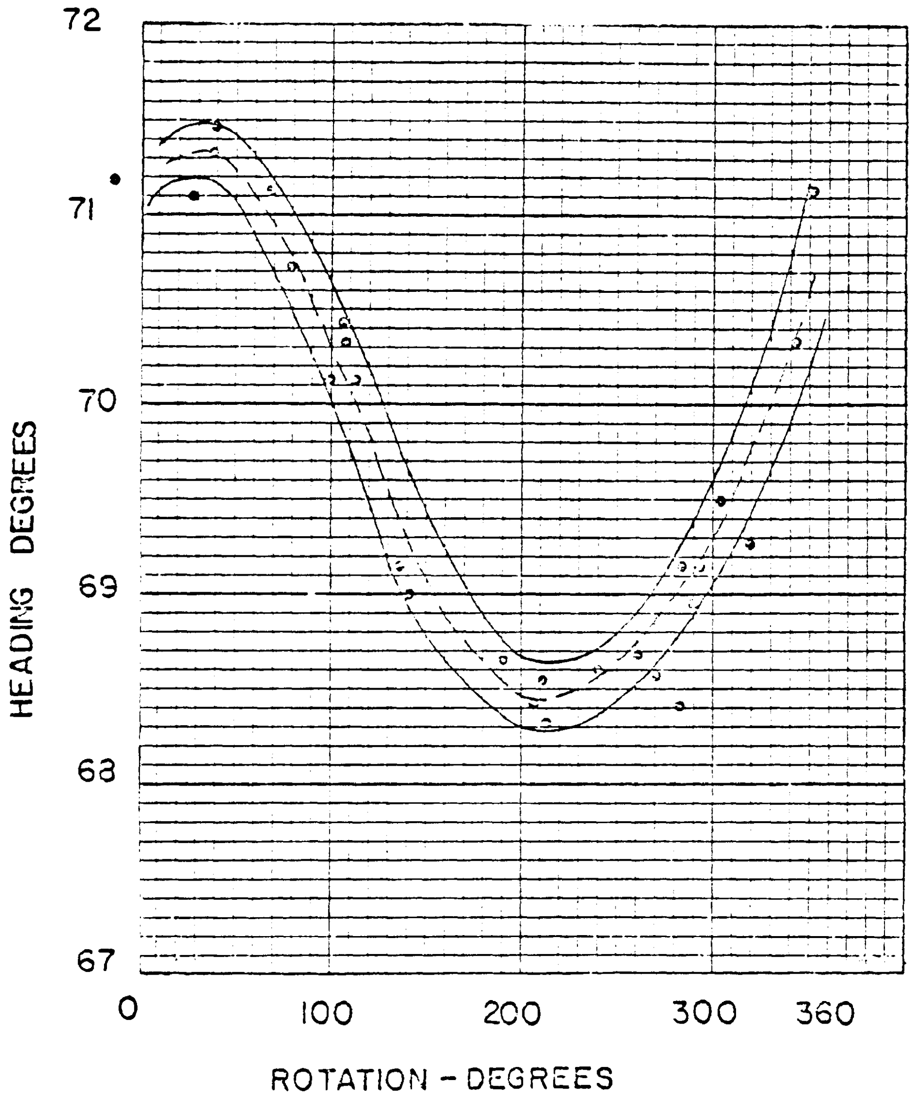


Figure 19

could be removed. The σ of .146° includes both actual changes in hole direction and statistical scatter of points. This indicates that a system such as this with an accuracy of better than $\pm$.1 degree is feasible.

ERROR ANALYSIS

CALCULATION OF LOCATION VECTOR

The RDS-500 computer was programmed to calculate the direction vectors for the down-hole package using the inputs from the package. In order to test these routines and to study the sensitivity of the calculations, simulated data was input to the programs.

Before discussing the results, the following terms must be defined:

- α = dip angle of the magnetic vector
- θ = dip of package with respect to the horizontal
- $\emptyset$ = angle of package with respect to magnetic North
- ψ = angle of rotation of a tick on the package with respect to vertical.

Using this terminology and the equations described in the proposal, we calculated θ, $\emptyset$, and ψ given α and the direction cosines from the magnetometers and the accelerometer reading.

As was discussed in the proposal, when $\emptyset$ was near 0° or 180° (i.e. north or south), the calculations become more difficult. To show this, Figure 20 shows the standard deviation of the error from 100 runs of each direction when noise is added to the magnetometer channels. The amount of noise is comparable to a Gaussian white noise with a standard deviation of 1/2 degree. The error in $\emptyset$ is small (below 1°) for directions between 20° and 160°. However, the error goes up near the north or south directions. This is because $\emptyset$ is calculated as an arc cosine function. This has more error near these values and also it is impossible to tell when the reading corresponds to negative angles.

The ambiguity of negative angles of $\emptyset$ is impossible to resolve without an additional sensor on board. No combination of

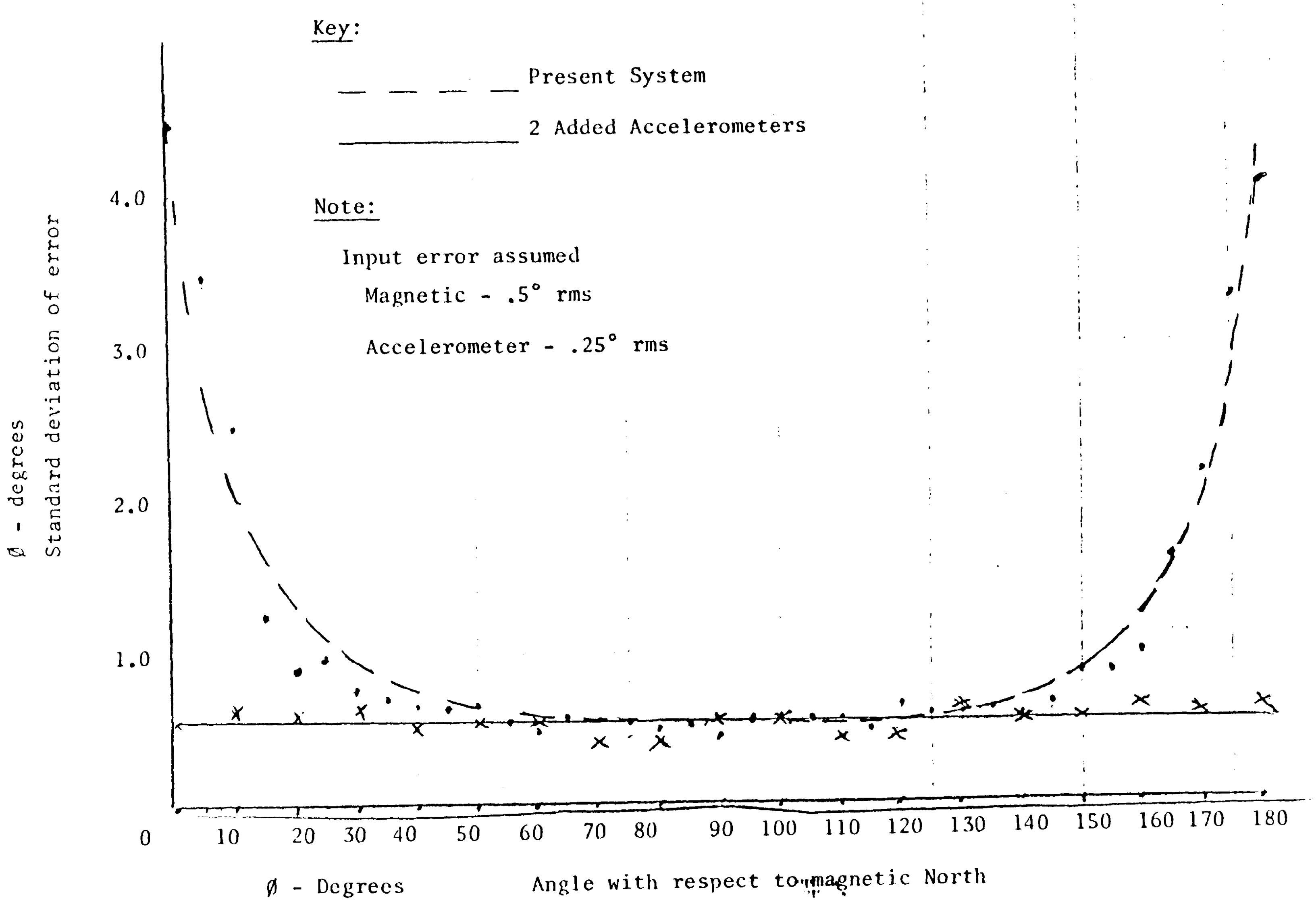


Figure 20. RMS Heading Error Vs. Heading Angle

mathematical tricks or package rotations can resolve this ambiguity.

As discussed in the proposal, two additional ambiguities exist. When the package is aligned with the magnetic vector, it is impossible to resolve the angle ψ. The final ambiguity exists when $\theta = 90°$ (i.e. drilling in a vertical direction).* Figure 21 shows this result. This figure is a plot of the error in $\emptyset$ as a function of θ for $\emptyset = 90°$.

The ambiguity of not knowing whether the package is pointing west or east of north can be relieved by telling the system the initial direction as was done previously. However, if the direction is close to the North direction small measurement errors will cause larger direction errors.

The system was next programmed for the equations using two added accelerometers. The comparative error curves are shown on Figure 1. This step would reduce all errors due to geometrical factors with the possible exception of the elevation angle. Although we have not investigated it in detail, it is believe that even these errors could be eliminated using alternate algorithms. The added accelerometers also eliminate the ambiguities which exist in the present system.

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*It should be recorded however that the system was never intended for vertical work. The original specification in fact limited the angles to horizontal, plus or minus 45°. Thus, the ambiguity associated with drilling along the magnetic vector was prohibited.

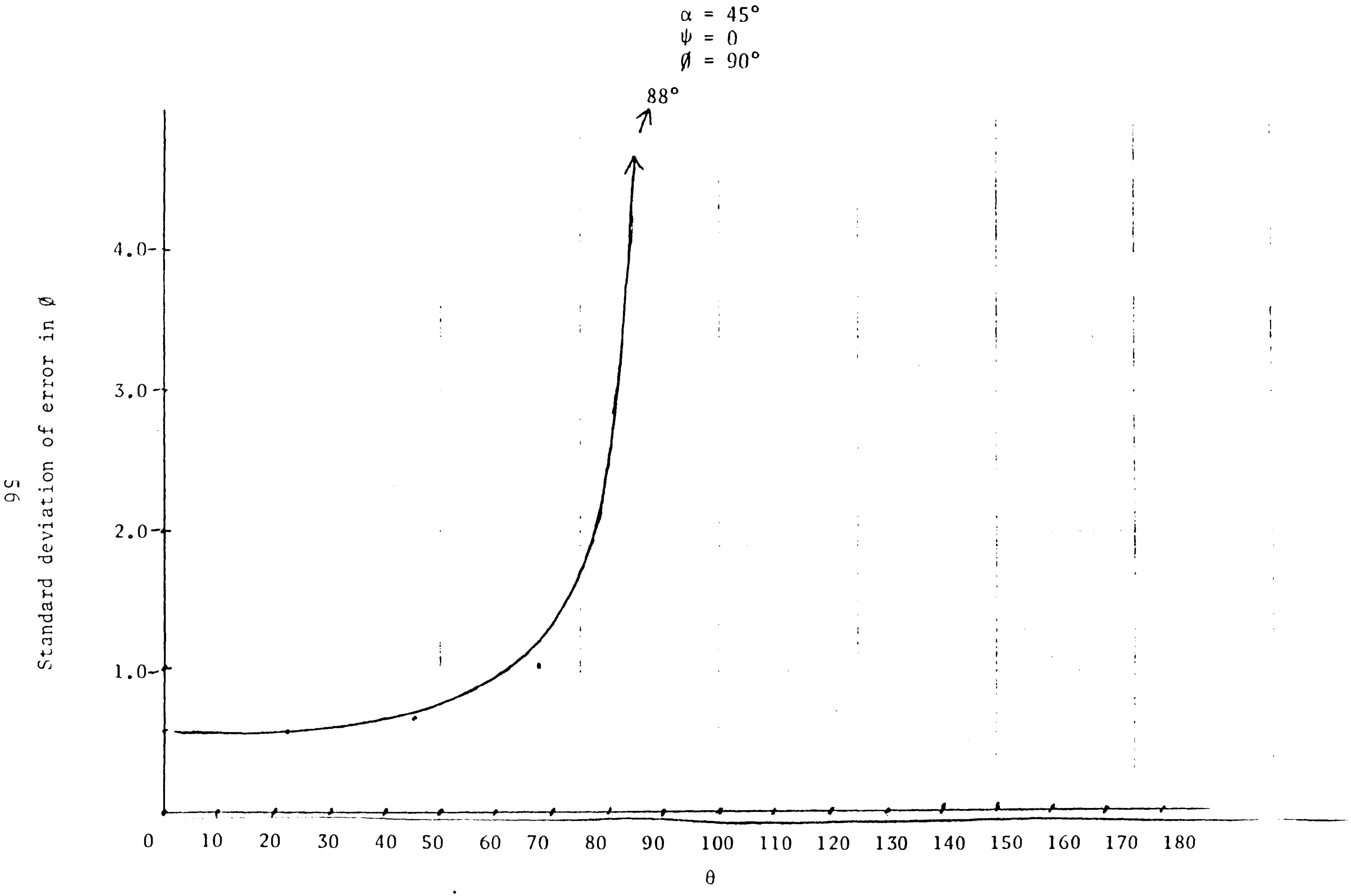


Figure 21. RMS Elevation Error Vs. Elevation Angle

APPENDIX B

Cableless Survey System Downhole Tool Specifications

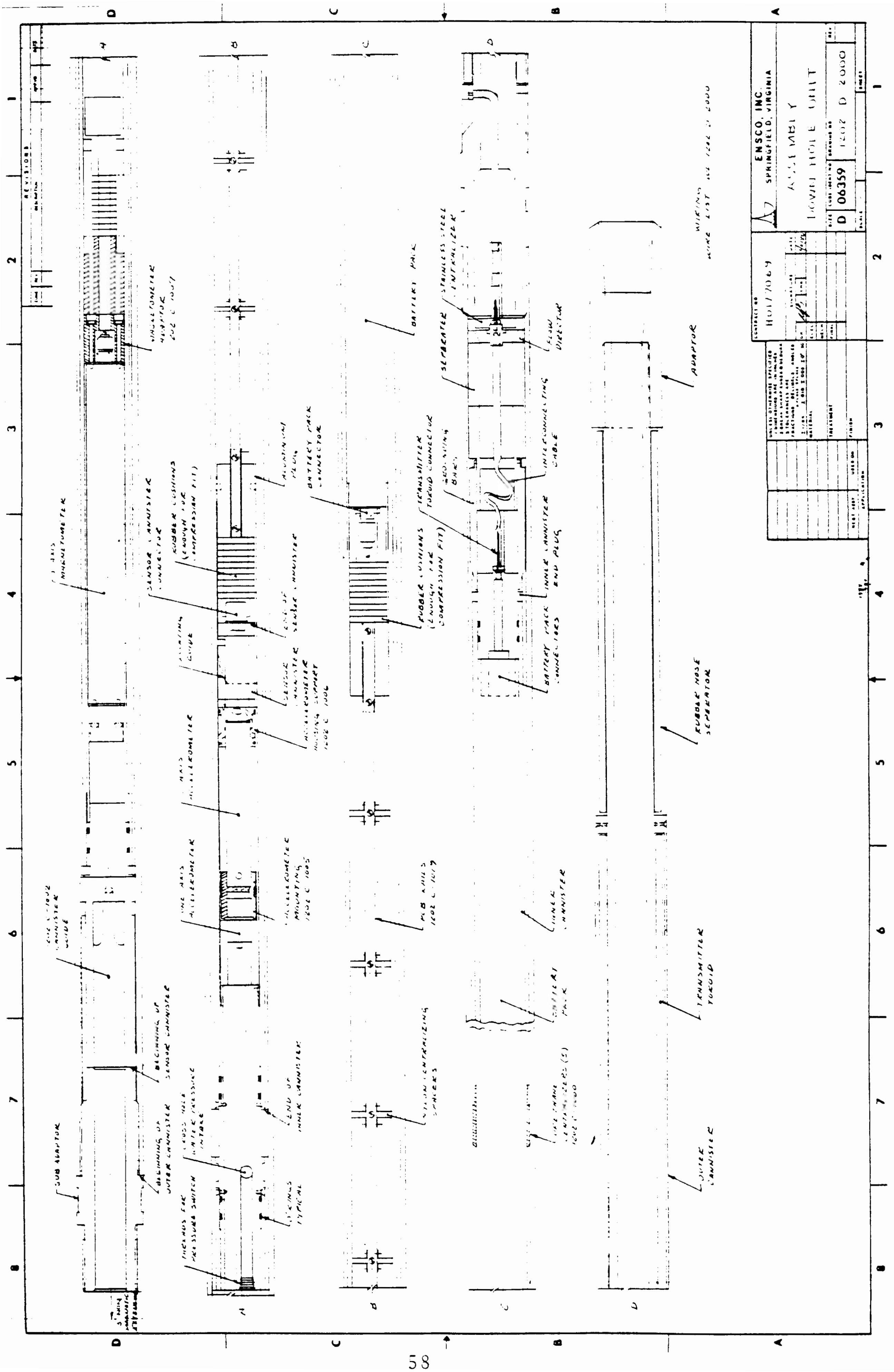

ENSCO, INC.
SPRINGFIELD, VIRGINIA
D
06359
BATTERY PACK
SEPERATOR
FLOW DIRECTOR
INTERCONNECTING CABLE
ADAPTOR
RUBBER HOSE SEPERATOR
INNER CANNISTER
TRANSMITTER TOROID
OUTER CANNISTER
SUB ADAPTOR

Figure 22.

CABLELESS SURVEY SYSTEM DOWNHOLE TOOL OUTPUT SPECIFICATION

Carrier Frequency: 4.0527KHz ± .005% Crystal Controlled

Transmitter Output Power: 1 watt nominal to input of transmit Toriod) varies with coupling conditions)

Modulation: Manchester Code ± 60° Phase Modulation

Data Rate: 31.66Hz = Carrier divided by 128

Transmitter Sequence:

16	Seconds	0° Phase Shift Carrier
4	Seconds	All 1's data
32	Bits	Preamble
30	Bits	Random Data (Not Used)
130	Bits	Ten 12 Bit Data Channel Parity

- Upon triggering the downhole tool transmits 16 seconds of 0° phase shift carrier (no modulation) which is used by the receiver to establish carrier phase lock and auto gain range.

- The downhole tools follows the carrier with 4 seconds of all 1's data which is used by the receiver to establish the data clock phase lock.

- The downhole tool follows the all 1's with a 32 bit preamble which the receiver uses to acknowledge that the upcoming data is real and prepares to alert the microprocessor.

The preamble code is:

10110000110111001011000011011100

If the exact code is not recognized, the receiver will ignore the remainder of the transmission.

- The next 30 bits of data transmitter are sent to the microprocessor but are thrown away as meaningless.

- The last 130 bits are transmitted and received by the receiver and serially passed onto the microprocessor unchanged. They represent 10 channels of 12 Bit offset binary data plus one parity bit per channel as outlined below:

	MSB										LSB		P
1 channel data + parity:	1	2	3	4	5	6	7	8	9	10	11	12	13

TIME→

	MSB											LSB	
A/D Scaling:	0	0	0	0	0	0	0	0	0	0	0	0	+ Full Scale + 5.000 Volts
	0	0	0	0	0	0	0	0	0	0	0	1	+ Full Scale - 1 Count ≅ 4.99976 Volts
	0	1	1	1	1	1	1	1	1	1	1	1	+ 1 Count ≅ 0.0024 Volts
	1	0	0	0	0	0	0	0	0	0	0	0	Zero
	1	0	0	0	0	0	0	0	0	0	0	1	- 1 Count ≅ 0.0024 Volts
	1	1	1	1	1	1	1	1	1	1	1	0	- Full Scale + 1 Count ≅ 4.9951 Volts
	1	1	1	1	1	1	1	1	1	1	1	1	- Full Scale ≅ 4.9976 Volts

Parity: Parity is a single bit for each channel that is based on the number of 1's output by the A/D and is added only to maintain even longitudinal parity.

Channel Assignment:

Ch. 1: Magnetometer X Axis ± 0.7 gauss = ± 5 volts

Ch. 2: Magnetometer Y Axis ± 0.7 gauss = ± 5 volts

Ch. 3: Magnetometer Z Axis ± 0.7 gauss = ± 5 volts

Ch. 4: Acceleromter Single Axis "Z" Axis 1g = ± 5 volts

Ch. 5: Accelerometer Biaxial "A" Axis 1g = ± 5 volts

Ch. 6: Accelerometer Biaxial "B" Axis 1g = ± 5 volts

Ch. 7: Temperature 0°C + 50°C = 0 to +5 volts

Ch. 8: Reference Voltage + 2.45 volts

Ch. 9: Negative Battery Voltage Monitor -2.85 volts nominal

Ch. 10: Positive Battery Voltage Monitor +2.85 volts nominal

Transducers:

1) "Z" Axis Accelerometer:

Manufacturer: Sunstrand Data Control
Model: QA 116-15

Range (Full Scale).	±15/g
Sensitivity (Nominal)	250 mV/g
Output Resistance (Nominal)	250 ohms
Frequency Response (Nominal, ±5%)	DC to 500Hz
Natural Response (Nominal).	100Hz
Noise (Nominal): 0 to 10Hz	100 μV rms
0 to 500 Hz	300 μV rms
500 to 10Hz	600 μV rms
Broadband	1 mV rms
Excitation Voltage.	±15 VDC ±10%
Excitation Current.	17 mA quiescent, 35 mA full scale
Sensitivity Shift with Excitation Voltage	0.005%/V
Zero Shift with Excitation Voltage	50 μg/V
Resolution (DC)	0.000001 g
Threshold (DC)	0.000001 g
Linearity (DC)	0.03% of reading
Hysteresis (Less Than).	0.001% of full scale
Repeatability	0.003% of full scale
Zero Unbalance (Less Than).	±0.02 g
Damping Ratio (Approx) (3).	0.6
Thermal Zero Shift (Max)	0.0002 f/°F
Thermal Sensitivity Shift (Max)	0.01%/°F
Transverse Sensitivity	0.002 g/g

2) X and Y Axis Accelerometer

Manufacturer: Terra Technology
Model: MP-200A

Range: ±1 g (minimum)

Scale Factor: 8.5 VDC/g ±0.5%

Null Offset: <0.020 volts

Temperature Coefficient: 0.01% of FS/°F (Max)

Lineraity: ±0.02% of Full Scale

Hysteresis and Resolution: 0.0001% of Full Scale

Turn-on to turn-on Repeatability: <2mv
(no tapping allowed)

Axis Alignment (WRT Case): ±0.50°

Biaxial Orthagonality: ±0.25°

Output Impedance: <15,000 ohms

"A" Axis to be aligned to 8-32 Hole within 0.5°

Excitation Voltage: ±10 to ±15V

Excitation Current: ±24

3) Tri Axis Magnetometer

Manufacturer: EMCO
The Electro Mechanics Company
Model: 6713

Range: ±0.7 Gauss

Scale Factor: .14 Gauss/volt (±5V)

Resolutions: ±0.5°

Excitation Voltage: ±13 to ±18 VDC

Excitation Current: 60ma max

Voltage Ripple: ±5%

Batteries:

Manufacturer: Gould Inc.
Model: 2.2SC (1/2D) NiCad
Quanity: 24

APPENDIX C

Cableless Survey System Test Plan And Test Results

This Appendix C contains the test plan submitted to the USBM in September 1978. Immediatly following the plan is the results of the system test and description of any deviations which were noted.

TEST PLAN FOR CABLELESS SURVEY SYSTEM

1. DESIGN REQUIREMENTS

A. Check to verify that the following are displayed:

YES	NO	
	✓	• Bearing in degrees and minutes
	✓	• Inclination in degrees and minutes
✓		• Rotation Angle in degrees
✓		• Horizontal deviation in feet
✓		• Vertical deviation in feet
✓		• Drill string depth

B. Verify that the following can be entered from the keyboard:

YES	NO	
✓		• Magnetic dip angle
✓		• Initial bearing
✓		• Number of drill rods

C. Verify that hard copy can be produced from data received from the downhole unit.

YES	NO
✓	

D. Verify that self-checking can be performed on the:

YES	NO	
✓		• Receiver
✓		• Computational circuitry

E. Verify that data error detection and warning capability is functioning

YES	NO
✓	

F. Verify the following physical requirements:

YES	NO	
✓		• Weight, approx. 40 lbs.
		• Size Width 13-3/4 inches Height 14-1/4 inches Depth 11/7/16 inches
✓		• Unit's own carrying case with Protective cover Handle
	✓	• Does handle serve as means to position and display at various viewing angles?
✓		• Is transit case supplied?

G. Is the unit intrinsically safe as defined in MESA Schedule 2G ?

YES	NO	
✓		• Does the system operate from an external 12-volt automobile battery?

H. Is the electronic construction of modular design to allow rapid rapair?

YES	NO
✓	

2. RECEIVER TESTS

Equipment necessary for this test will include a down-hole transmitter link emulator. This emulator will generate lock and transmit signals in strict accordance with those transmitted by the down-hole package at a carrier frequency of 4.0525 KH ±.02%. The data field will be missing, however. It will also contain a white noise generator and a means to sum the two outputs. The signal should have a range of -30µv to 3v (100 dB) in 10 dB steps an- the output noise levels should be adjustable to -3 dB below the signal. If a signal is properly received and decoded, the computer will detect the preamble and generate a "data error" signal because of the absence of the data field.

Procedure

1. With a full battery charge, turn the unit on and verify proper operation with Self-Test function.

2. Connect the emulator to the receiver input and begin the tests with a signal level of 30µv and a noise level of -3 dB, at a carrier center frequency of 4052.5 Hz. Send the preamble five times and note presence or absence of data error indication.

3. Repeat Step 2 nine more times, each time increasing signal and noise levels +10 dB.

4. Repeat Steps 2 and 3 for 4052 Hz and 4053.5 carrier center frequencies.

5. Measure receiver battery voltage and note elapsed test time.

NOTE: If at any time there is a low battery voltage indication in the computer section, stop the test and recharge those batteries.

Record

1. Any conditions under which an error is not detected. If any preambles are sent (under allowable conditions) that do not cause data error indications, the receiver problem must be corrected and the tests run again from Step 1.

2. Results of Step 5.

3. BATTERY LIFE TESTS

The purpose of this test is to determine whether the unit will operate for six hours continuously, given a reasonable set of operating conditions.

Procedure

1. Charge the batteries normally, and measure the resultant battery voltage.

2. Apply the proper preamble from the emulator to the receiver every 15 minutes and check for data error indication. Every hour, operate the self test function and then measure battery voltage.

3. After six continuous hours, continue the test, measuring battery voltage every 15 minutes until that voltage indicates a cell voltage of 1.1v, or until a malfunction occurs.

Record

1. Results of Step 3 versus time of day.

2. Results of Step 4 versus time of day, and condition of battery voltage indicators.

Preface

"The unit" will refer to the processing and display system.

4. ENVIRONMENTAL TESTS

4.1 IMMERSION

The purpose of this test is to prove compliance with Mil-Std-810C Method 512, Procedure 1.

Procedure

1. Obtain a clean vessel with a cross section large enough to accept the unit and a total height of 48", and fill with water at 18° ±5°C to within 10" of the top.

2. Remove all internal components from the unit that are not secured with external fasteners.

3. Heat the unit, cover open, in a temperature chamber, for two hours at 45° ±3°C.

4. Open and close the cover three times, then secure it with the built in latches.

5. Submerge the unit, as modified in Step 2, to the bottom of the vessel, using a method that will restrain the buoyancy of about 100 lbs. wihtout damage to any part of the unit.

6. After 120 ±5 minutes, remove the unit from the water and wipe the exterior surfaces dry.

7. Open the unit and inspect the interior and contents for evidence of leakage.

Record

1. Location and approximate amount of interior moisture observed in Step 7.

4.2 SHOCK TESTS

The purpose of this test is to prove compliance with Mil-Std-810C, Method 516.1, Procedure II, Transit Drop Test.

Procedure

1. Provide a test bed of 2" plywood, with greater cross section than the unit's transit case, on a concrete base.

2. Place the unit in its transit case and secure properly all closures.

3. From a height of 48" above the plywood surface, drop the case on each face, edge, and corner for a total of 26 drops.

4. Run the unit through all initial tests (Steps 1 and 4 of Receiver Testing).

Record

1. Results of Step 4.

2. Any observable physical changes in the transit case, foam packing, or the unit itself.

4.3 OPERATING TEMPERATURE TESTS

The purpose of this test is to verify operation of the unit over the specified range of 0°C to 50°C.

Procedure

1. The unit will be turned on and the specified warm up time allowed to elapse. Test conditions will be entered into the processor on the keyboard.

2. The unit will be placed in a chamber with a viewing port in the front, of sufficient size to view the display, and with a means to allow signal lines from the normal receiver input to be led out of the chamber.

3. Connect the emulator to the receiver input with an input level of 300μv and a noise level -6 dB and a carrier frequency of 4052.5 Hz.

4. Send preamble and record presence or absence of data error indication. NOTE: Presence of data error verifies proper decoding of preamble.

5. Repeat Steps 3 and 4 at carrier frequencies of 4053 Hz and 4053.5 Hz.

6. Temperature of the chamber will be lowered to 0°C and allowed to stabilize for one hour.

7. Repeat Steps 3-5.

8. The temperature of the chamber will be raised to +50°C and the unit allowed to stabilize for one hour.

9. Repeat Steps 3-5.

Record

1. Operating conditions and results of each Step 4 test.

4.4 TEMPERATURE SHOCK TEST

The purpose of this test is to prove compliance with Mil-Std-202E, Method 107D,A, as modified to protect certain components and conserve testing time. Specifically, the liquid crystal display and the batteries are not specified to withstand the high temperature extreme of 80°C. The display, the batteries, the DC/DC converters, the keyboard, and the printer will not withstand the low temperature extreme of -55°C. The batteries, converters, and display are not easily removed. The display has the narrowest range, namely -20°C to +70°C, so we are modifying this thermal shock test to be performed over that range.

Procedure

1. The unit, with cover closed, will be placed in a temperature chamber cooled to -20°C for four hours, with no more than five minutes elapsed if it is being cooled from the high temperature.

2. The unit is then heated to +70°C, with no more than five minutes in the transition from -20°C, where it will remain for four hours.

3. Steps 1 and 2 are each performed a total of five times in sequence.

4. At room temperature, turn the unit on, allow time to warm up, then perform the Receiver Test Section, Steps 1 and 5.

NOTE: If the unit weight is below 30 lbs., times at temperature extremes may be reduced to two hours each.

Record

1. Results of Step 5.

2. Any physical changes evident on post test inspection.

4.5 HUMIDITY TEST

The purpose of this test is to prove compliance of the unit with Mil-Std-810C, Method 507.1, Procedure I, as modified by ENSCO to conserve costs.

Procedure

1. Full charge the unit batteries, remove the protective cover, and connect a dummy connector to the receiver input. Install the connector caps for the power and computer connectors.

2. Place the unit in the temperature chamber and slowly raise the temperature and humidity over a period of two hours to 65°C and 92% r.h., respectively.

3. Maintain the condition of Step 2 for six hours.

4. Open the test chamber and allow it to stabilize at room temperature.

5. Operate the self-test and note proper response.

Record

1. Results of Step 5.

2. Any physical changes noted in the unit.

5. FIELD SURVEY TEST

This test will demonstrate the integrity of the system as a whole. Several compass points and package inclinations will be surveyed and compared with coincident transit readings. Transit accuracies will be kept to ±.01°.

Procedure

5.1 INITIAL MEASUREMENTS

1. Assemble the cableless survey tool with all batteries at full charge.

2. Run Self-Test.

3. Position and level the tool at due magnetic north (0°) and trigger the package.

4. Check the axis alignment offset constants and monitor housekeeping data from the down-hole package.

5. Initiate dip calculation on computer. NOTE: In the following steps, use the external control panel of the computer to read out sensor readings for each point desired.

6. Align the package with an elevation of -1°, and a heading of 0°, and take readings for the following package rotations: 0°, 45°, 90°, 135°, 180°, 225°, 270°, and 315°. Use a transit at each point for a reference reading.

7. Repeat Step 6 for an elevation of 0°.

8. Repeat Step 6 for an elevation of +1°.

9. Repeat Steps 6, 7, and 8 at a heading of 90°.

5.2 SIMULATED DRILLING TRAJECTORY TEST

10. Align the package to 0° heading. Perform 10 random alignments within the range of 359° to 1° (heading) and -1° to 1° (elevation) to simulate the drilling operation. Each point will be entered into the processor as though it were 10' of drill rod from the previous point. Take transit readings of each point for reference.

11. Repeat Step 10, but within the heading range of 269° to 271°.

12. Calculate the simulated course from the transit readings. Then compare with the survey tool results.

Record

1. Results of Steps 2, 4, and 5.

2. Sensor readouts and corresponding transit reading for each of the 24 points in Steps 6, 7, 8, and 9.

3. Results of Steps 10 and 11.

4. Deviations from actual course derived in Step 12.

5.3 DRILLING TESTS

This test will insure that the cableless survey tool operates to design specifications in the actual drilling environment.

Procedure

Initial Measurements

1. Complete assembly of cableless survey tool, with all batteries fully charged, at the surface site of the chosen drilling location.

2. Initiate Self-Test.

3. Trigger the package transmission and determine the mechanical offset of the assembled package.

4. Determine local dip angle, using the computer.

Installation in the Mine

5. Set up the driller console (processing and display subsystem) in the mine. Be certain that connector caps are installed on power and computer connectors.

6. Enter initializing data.

7. Install receiver transducer.

8. Initiate Self-Test.

Initial Survey

9. Perform a Sperry-Sun Multi-Shot survey of the existing portion of the hole.

10. Survey the existing hole with the cableless survey tool. At each 10-foot measurement, stop the drill and trigger a transmission. Then rotate the package 180° ±10° and trigger another transmission.

11. Compare the results of Steps 9 and 10.

Drill and Survey

12. Continue drilling and survey every 10', as in Step 10, to a depth of 1500'.

13. Remove the tool and survey the new hole drilled in Step 12 every 20 feet, using the Sperry-Sun Multi-Shot.

14. Compare the results of Steps 12 and 13.

NOTE: Recharge the batteries and service the printer at the end of each day's operation or sooner if required. Compare daily results with printer output.

Record

1. Results of Step 2.

2. Results of Steps 3 and 4.

3. Results of Step 8.

4. Enter log obtained in Step 9, including house-keeping data from the down-hole package.

5. Parameters of bearing, inclination, angle, horizontal and vertical deviation, drill string depth, and true depth for each point in Step 10.

6. Results of Step 12, as above.

7. Enter log obtained in Step 13.

DEVIATIONS FROM TEST PLAN

1. DESIGN REQUIREMENTS

1.A Bearing and inclination angles are displayed as decimal degrees - example: Bearing + 69.28° rather than degrees and minutes.

1.B No Deviations

1.C No Deviations

1.D No Deviations

1.E No Deviations

1.F All requirements are met except that handle cannot be used to position unit at various display angles.

1.G The system is designed to be intrinsically safe, although as of this date, the uphole processor has not completed certification by MSHA. The downhole tool's explosion proof housing was retained unaltered and continues to remain certified explosion proof.

1.H No Deviations

2. RECEIVER TEST

Under this contract no downhole emulator was constructed. Internal self test in the receiver/processor were included within the uphole unit. This self test does include a complete simulation of carrier lock, preamble recognition and data verification.

The receiver was tested using the downhole breadboard unit. Signal to noise ratios from 0dB to +6dB was inserted in the input of the receiver with a signal level of 3μv and 30μv. At 30μv no errors occurred above a signal to noise ratio of +2dB. At a signal level of 3μv phase shift which occurred during the auto gain ranging did not always allow adequate time for the carrier phase lock loop to stabilize thereby prohibiting the preamble from being detected. This problem was corrected by employing wider bandwidth amplifiers in the auto gain ranging section of the receiver. After this correct transmission was received without error with a signal to noise ratio of +3dB.

At 30µv signal level some data was received without error with a signal to noise ratio of 0dB. However, since less than 90% of the transmissions were correct, the false alarm or error detection rate was deemed to high. It should be noted that in more than 90% of the cases when the preamble is recognized all data is transferred without error. Conversley, since the receiver does not indicate a data transmission unless the preamble is recognized, very few bad transmissions are even detected.

3. BATTERY LIFE TEST

The battery life test was performed for six continuous hours, at which time the receiver battery was automatically disconnected due to low voltage (as designed). Four data errors were encountered during that time, but this was due to inadvertently not terminating the receiver input.

4. ENVIRONMENTAL TESTS

4.1 Immersion

No interior moisture was evident.

4.2 Shock Tests

Deleted by Contract Modification.

4.3 Operating Temperature Tests

At 0°C, there was no data errors using the self test, the LCD display was slow but functional, and the printer performed properly. At 50°C, there was no data errors using the self test and all other devices functioned normally.

4.4 Temperature Shock Test

As noted before a downhole survey tool emulator was not produced. Therefore, the self-test function was used. After the cycling and at room temperature, all systems functioned properly with no errors. No physical changes were evident.

4.5 Humidity Test

The proper response was obtained from the self test.

5. FIELD SURVEY TEST

5.1 Initial Measurements

See Figure - Magnetometer output for Y axis and Z axis for rotation about X axis.

See Figure - Accelerometer output for Y axis and Z axis for rotation about X axis.

See Figure - Magnetometer output for Y axis and X axis for rotation about Z axis.

5.2 Simulated Drilling Trajectory Test

The simulated trajectory test was done by placing a pattern of nine holes in a board as shown below:

●2	●3	●4
●9	●1	●5
●8	●7	●6

The coordinate distance between each hole was such that movement between any two adjacent holes vertically or horizontally repositioned the tool by 1° in bearing for horizontal and 1° in inclinations vertically. The simulated survey was performed by entering the initial conditions for hole #1 at an initial

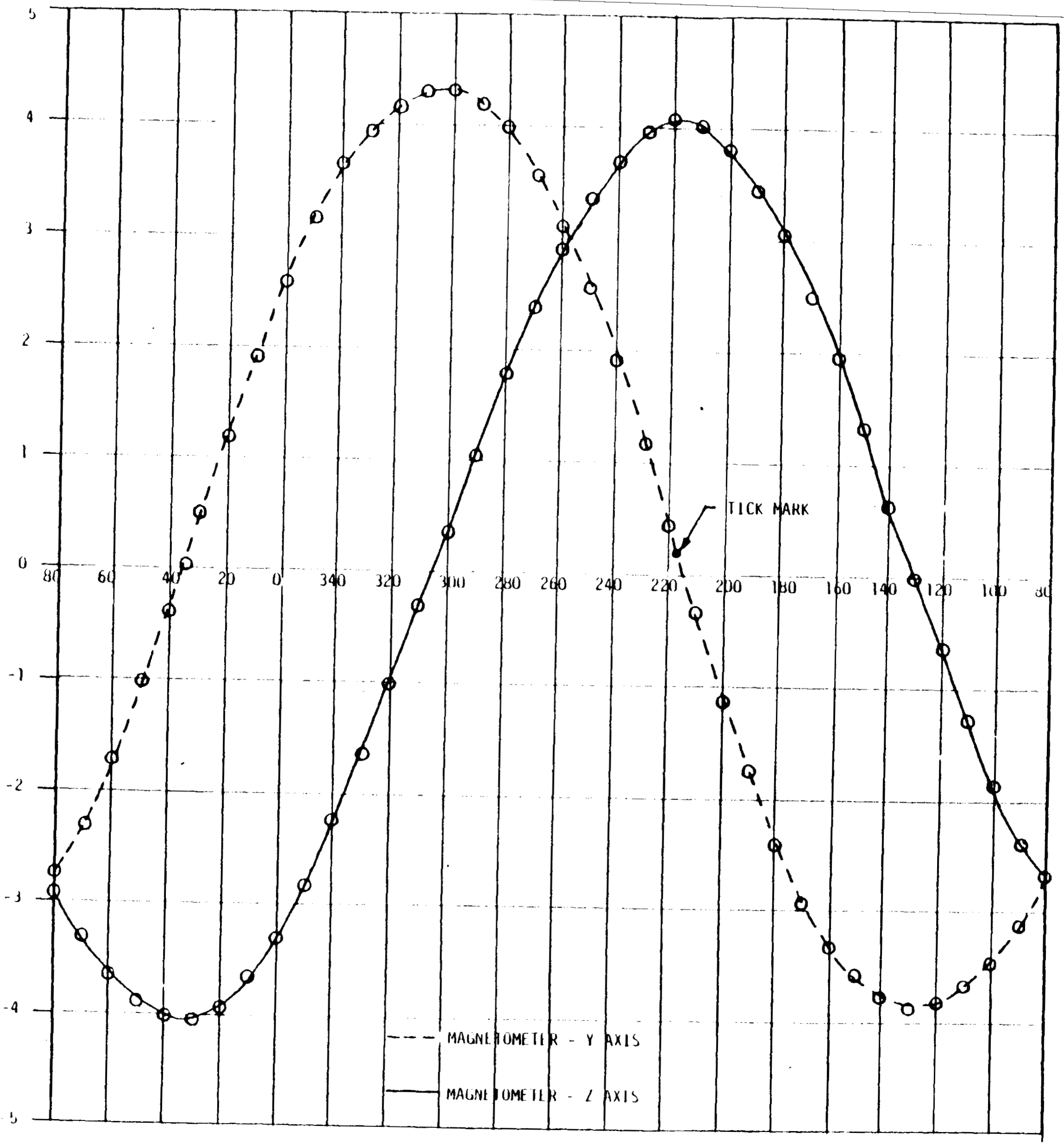


Figure 23. Magnetometer Output for Y Axis and Z Axis

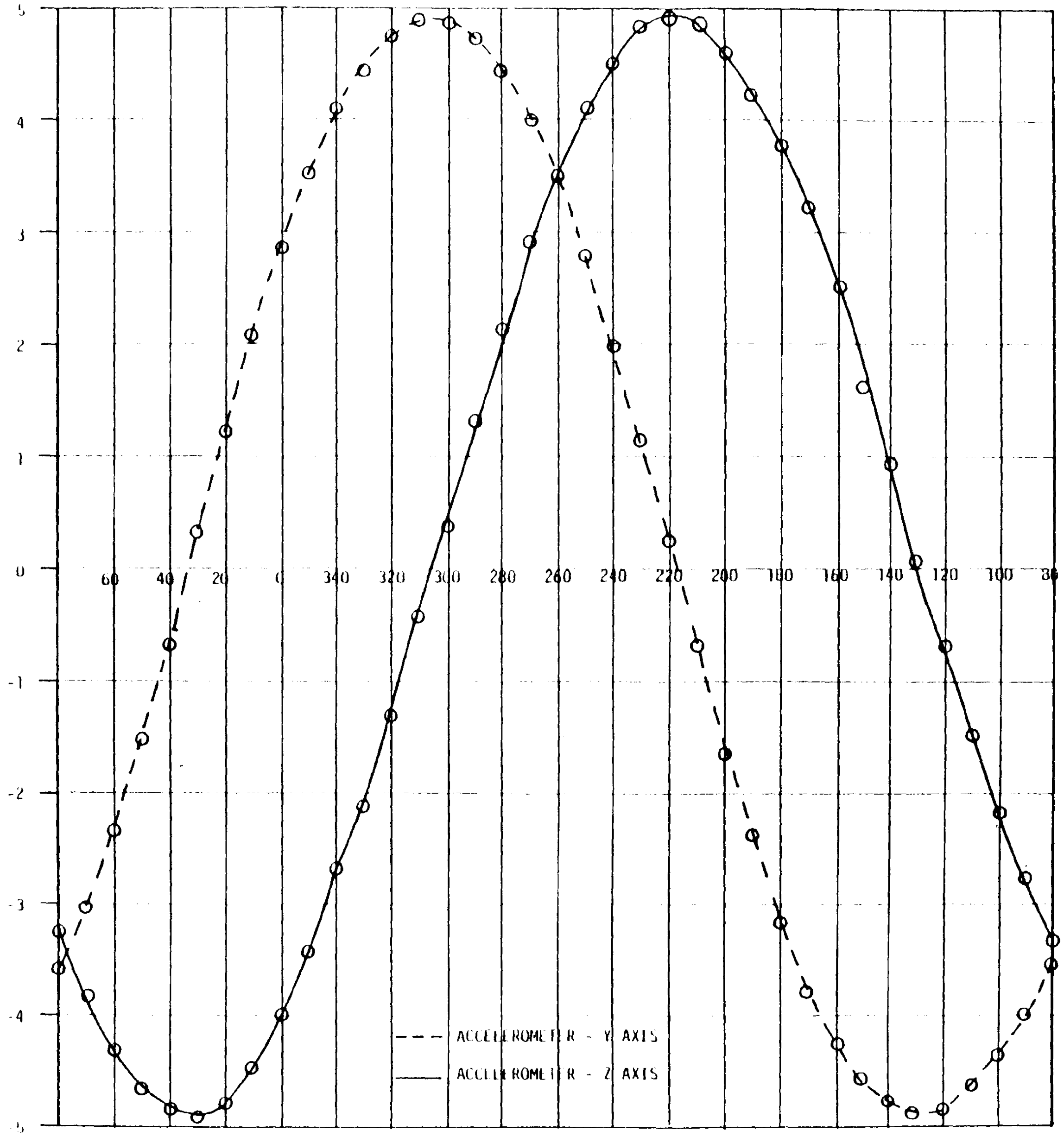


Figure 24. Accelerometer Output for Y Axis and Z Axis for Rotation about X Axis

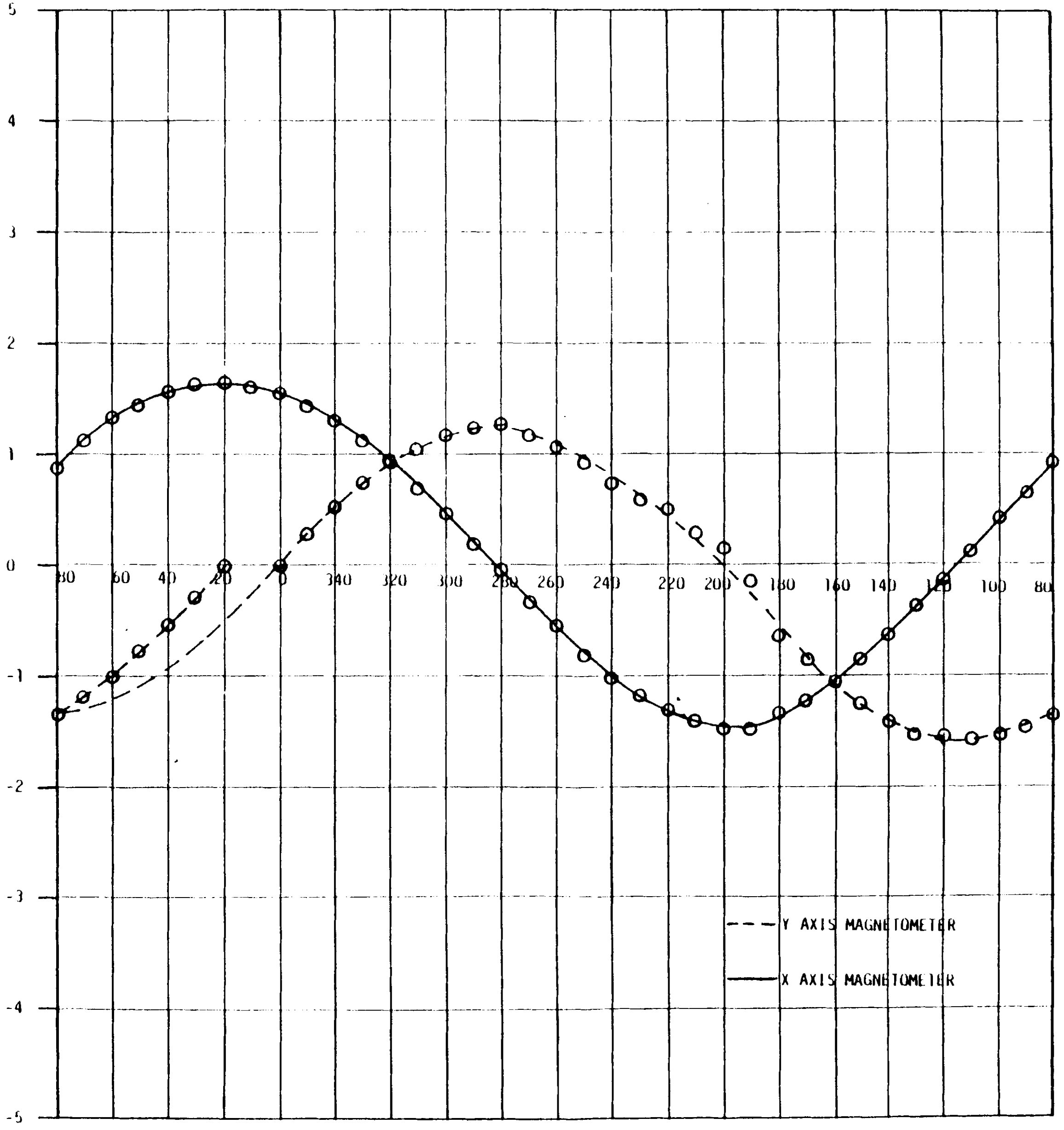


Figure 25. Magnetometer Output for Y Axis and X Axis for Rotation about X Axis

string length of 20 feet. Then a survey of the dirst hole position was done and an assumed 10 foot drill rod added. The tool was then positioned sequentially in each hole and a survey done adding 10 foot rod sections for each hole until hole #1 was repeated. This resulted in a total simulated survey of 120 feet of string length. Figure 26A shows a comparison of calculated bearings versus tool measurements. Figure 26B gives the same comparison for inclination. Figure 26c compares the theoretical survey path to the computer results provided by the cableless survey system.

5.3 Drilling Tests

Drilling tests were performed at the Federal #1 mine in Granttown West Virginia. The following deviations from this test plan are noted.

- The hole depth was terminated at 330 feet due to drilling problems with the drilling equipment and the contact of a ceized drill string located in an adjacent hole.
- No readings were taken with the Sperry Sun Multishot system between 75 and 165 feet.

Figure 27 shows the comparison of vertical deviation as measured by the two systems.

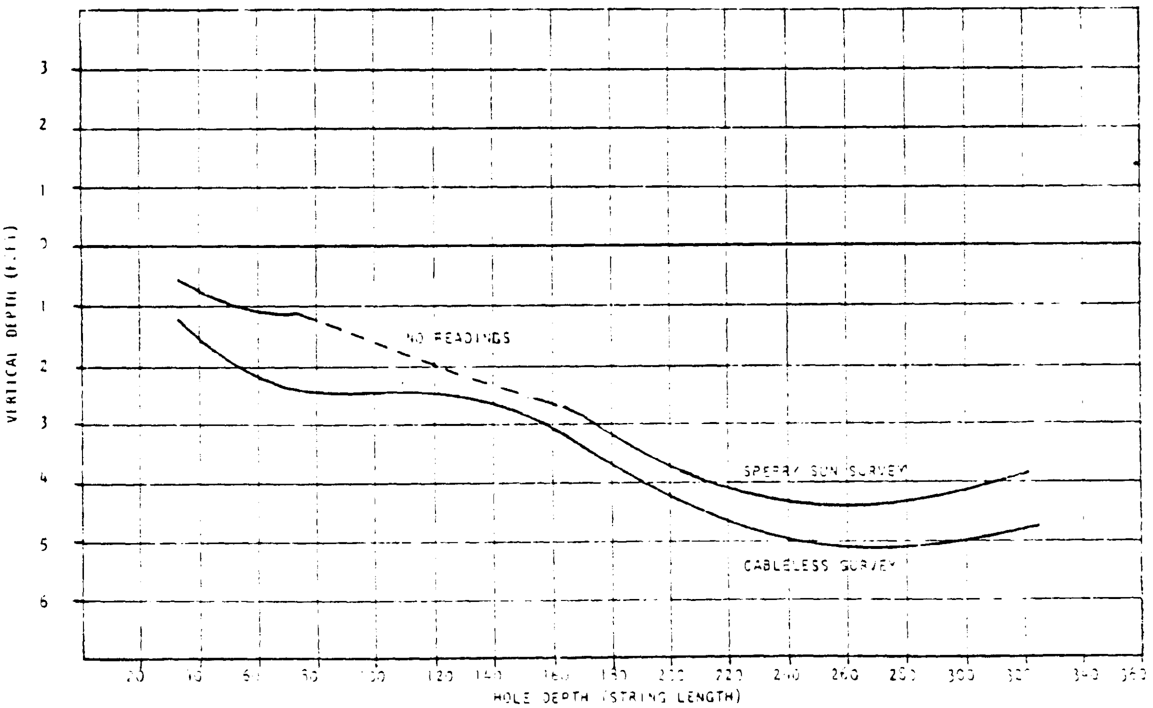


Figure 27 . Vertical Survey of "Horizontal" Drill Hole Using Sperry Sun Survey System and Cableless Electronic Survey System

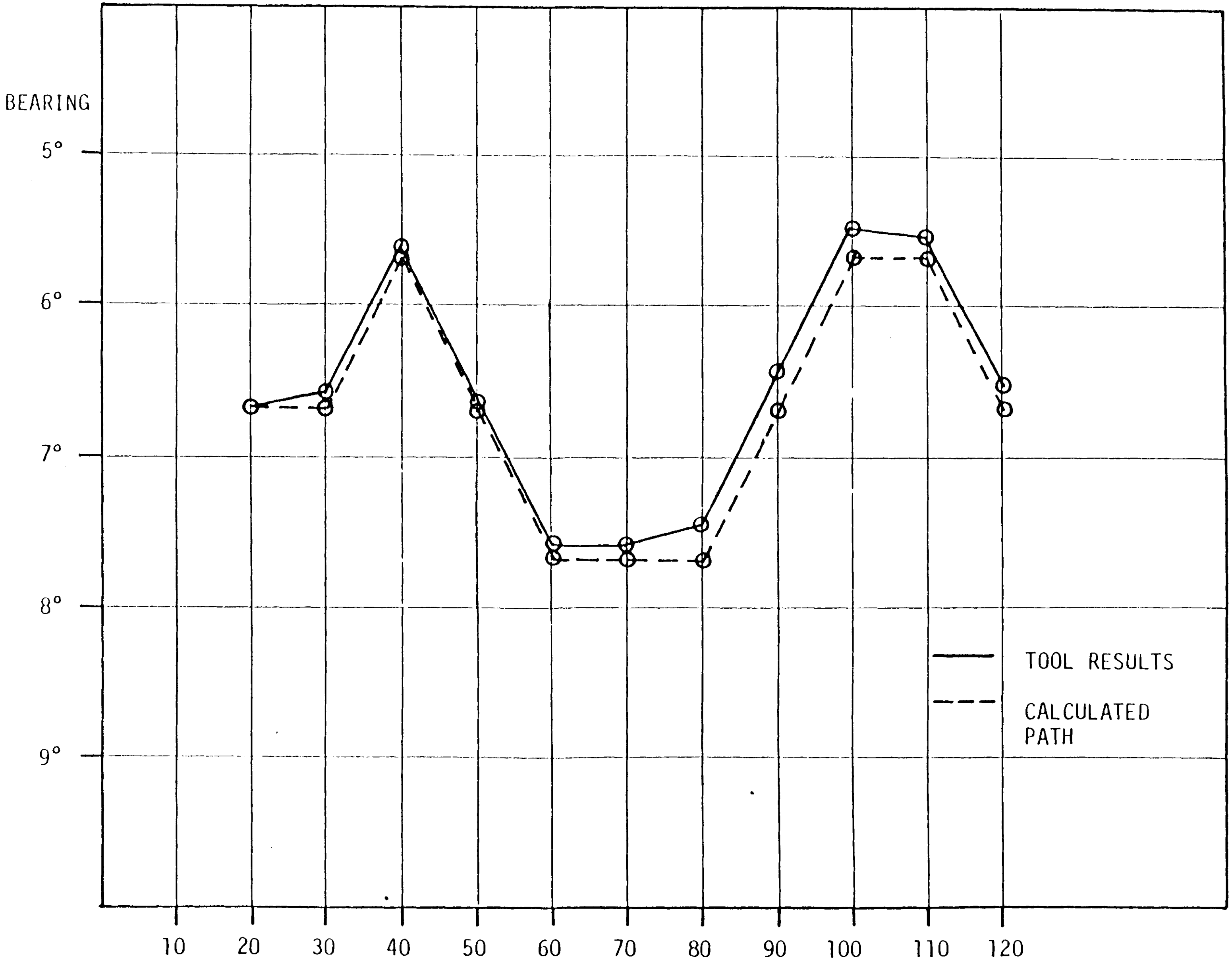


Figure 26a Comparison of Calculated Survey Path vs. Measured Bearings for Simulated Trajectory Test

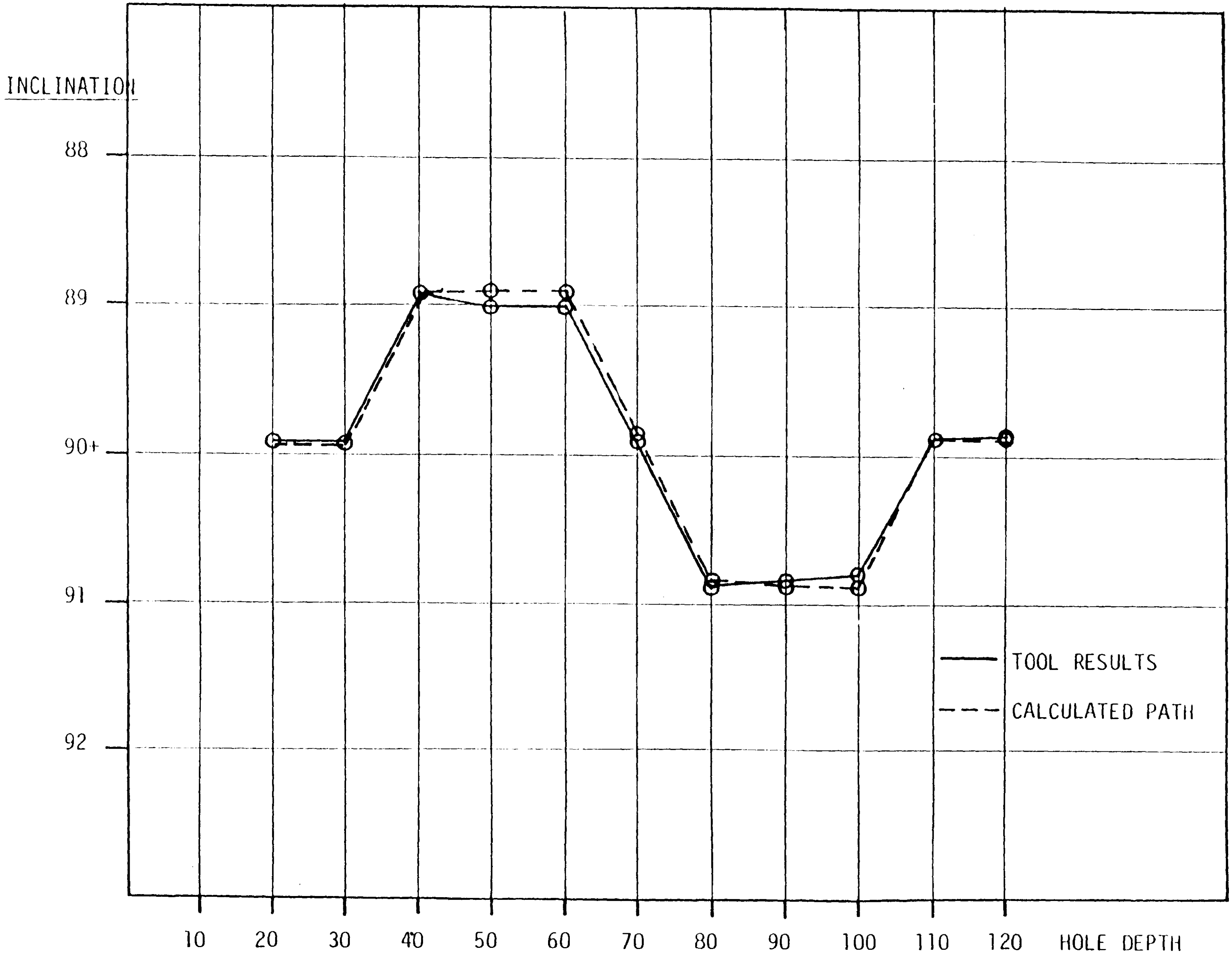


Figure 26b. Comparison of Calculated Survey Path vs. Measured Inclination for Simulated Trajectory Test

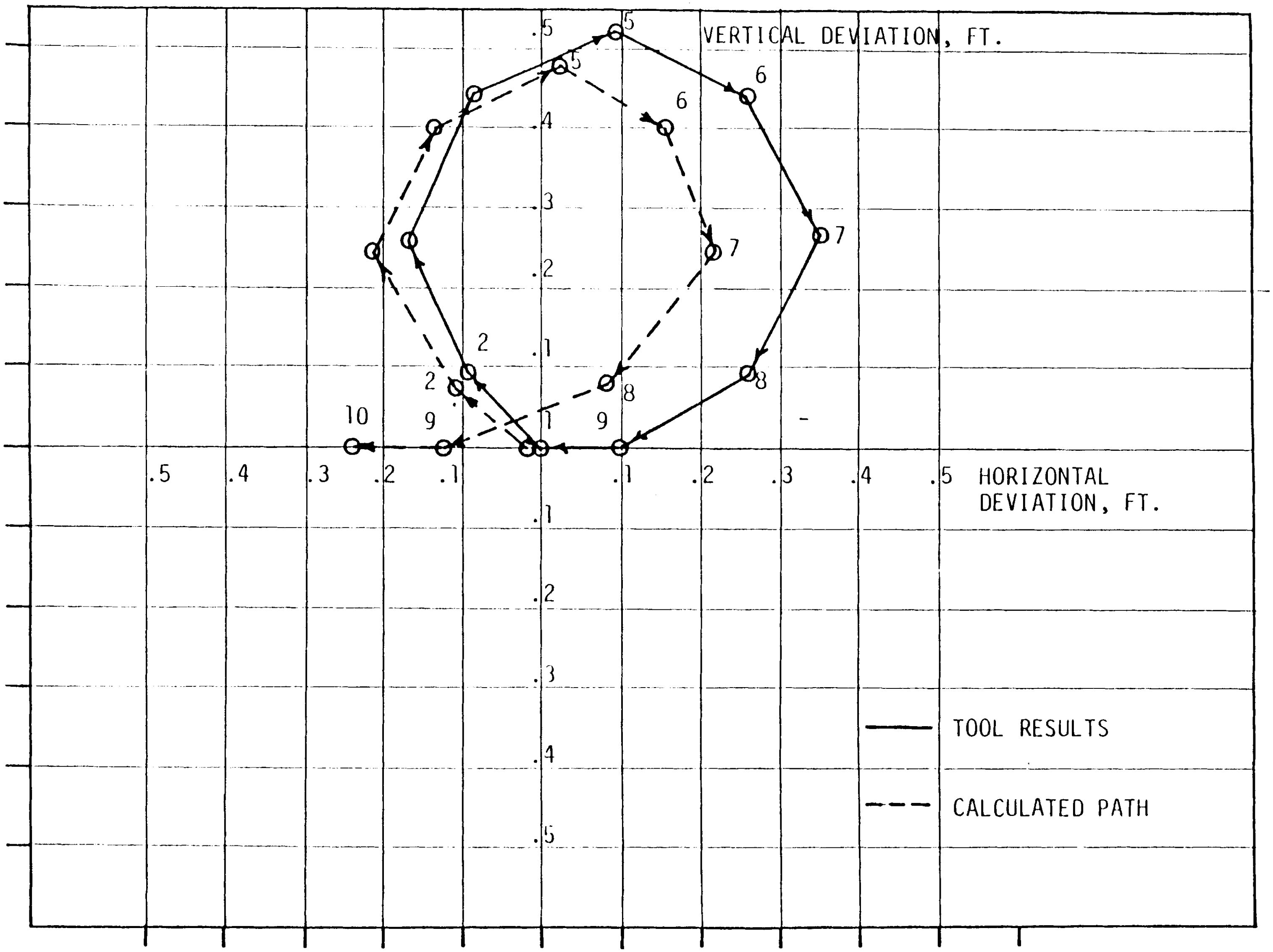


Figure 26c. Comparison of Calculated Survey Path vs. Measured Survey Path for Simulated Trajectory Test.

APPENDIX D

SYSTEM SCHEMATIC DIAGRAMS AND SOFTWARE LISTINGS

CONNECTOR DESIGNATION AND PIN ASSIGNMENTS FOR DOWNHOLE PACKAGE

Sensor Canister/Electronics: J1/P1

Connector: Bendix PT02A-14-18S/P

Pin	Signal
A	Wiper Pressure Switch
B	X Axis Accelerometer
C	Y Axis Accelerometer
D	+12 volts, Z Axis Accelerometer
E	Power Return, Z Axis Accelerometer
F	NC
H	Signal Return, Z Axis Accelerometer
J	+12 volts, X,Y Axis Accelerometer and X,Y,Z, Axis Magnetometer
K	-12 volts, X,Y Axis Accelerometer and X,Y,Z, Axis Magnetometer
L	Power and Signal Retrun, X,Y Axis Accelerometer and X,Y,Z, Axis Magnetometer
M	+12 volts, Pressure Switch
N	Signal Return, Pressure Switch
P	-12 volts, Z Axis Accelerometer
R	Signal Output Y Axis Magnetometer
S	Signal Output X Asis Accelerometer
T	Signal Output X Axis Magnetometer
U	Signal Output Z Axis Magnetometer

Electronics/Battery Pack: P2/J2

Connector: Bendix PT06-10-6- S/P

Pin	Signal
A	Transmit Toriod
B	Return, Transmit Torriod and Case Ground
C	- Battery Voltage
D	± Battery Return
E	+ Battery Voltage
F	NC

Z-Axis Accelerometer: J3

Connector: Sunstrand Date Control CA-116-15-30

Pin	Signal
1	+12 volts
2	Signal Return
3	Signal Output
4	-12 volts
5	Power Return
6	Self Test

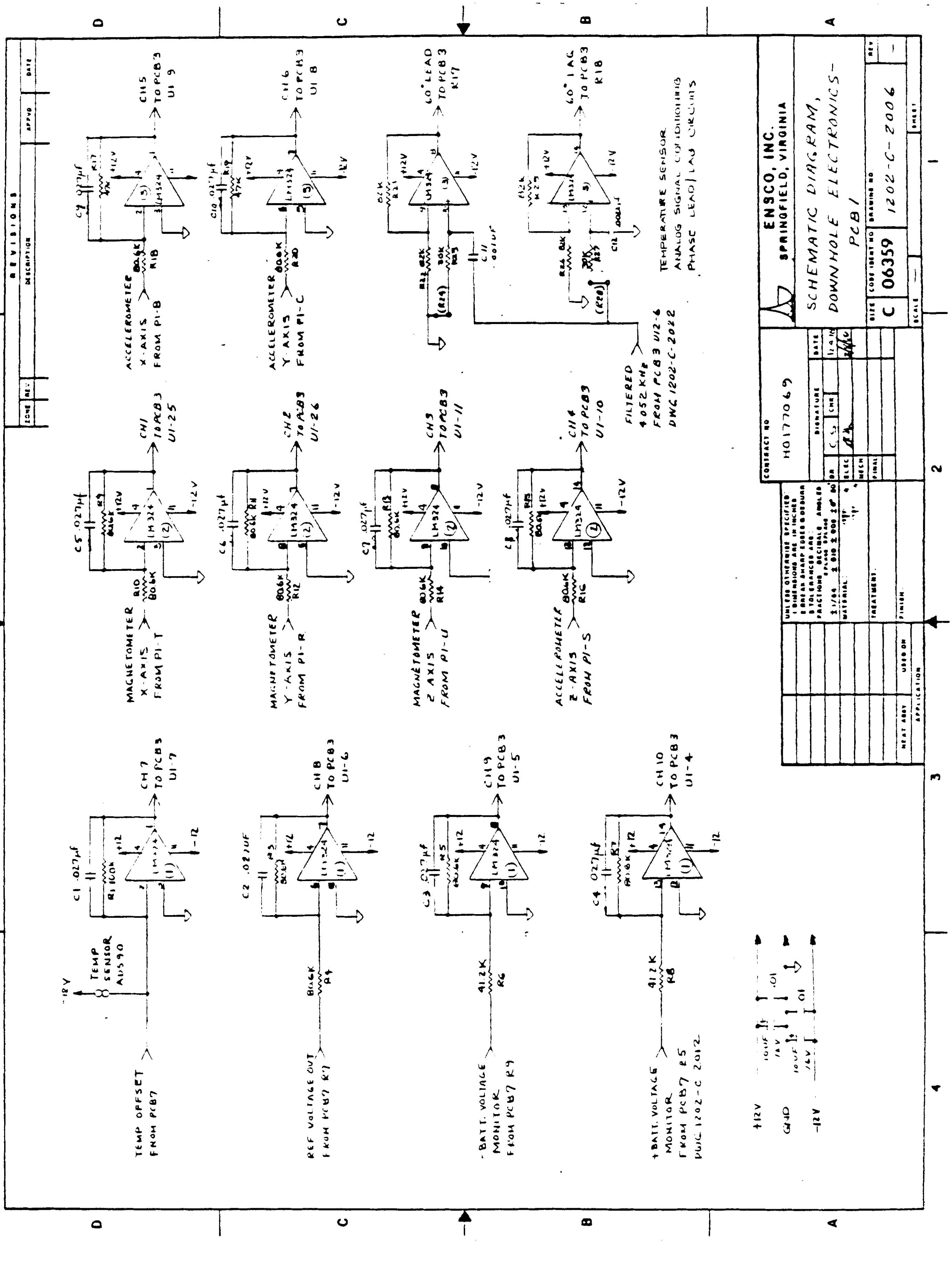
X,Y Axis Accelerometer: No Connector

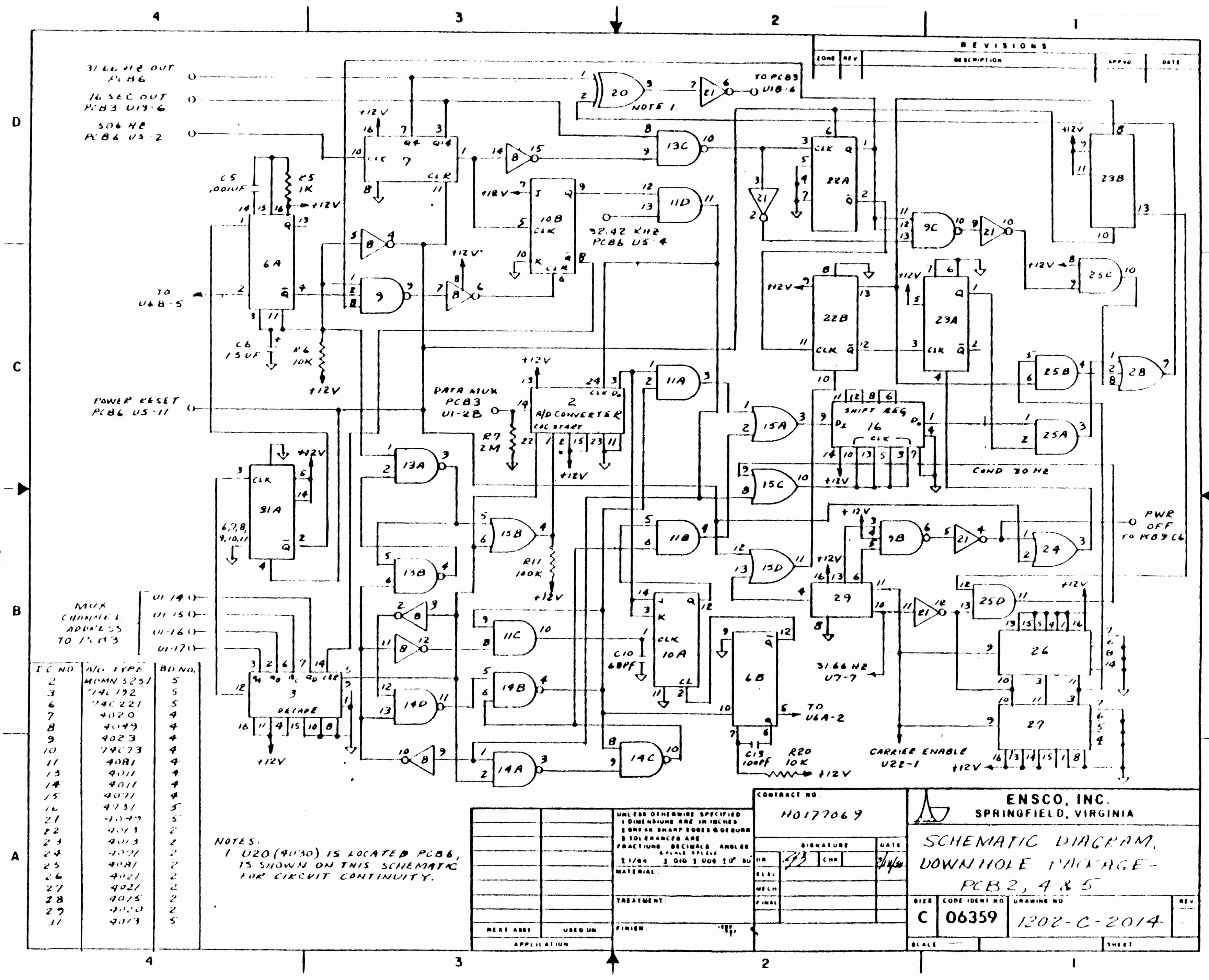
Pin	Signal
1	+12 volts
2	-12 volts
3	Power and Signal Return
4	X Axis Output
5	Y Axis Output

Magnetometer J4

Connector: PT02-C-10-6S

Pin	Signal
A	+12 volt
B	Power and Signal Return
C	-12 volt
D	X Axis Output
E	Y Axis Output
F	Z Axis Output


ENSCO, INC.
SPRINGFIELD, VIRGINIA
SCHEMATIC DIAGRAM, DOWNHOLE ELECTRONICS- PCB1
C 06359 1202-C-2006
H0177069
TEMPERATURE SENSOR ANALOG SIGNAL CONDITIONING PHASE LEAD/LAG CIRCUITS
ACCELEROMETER X-AXIS FROM P1-B
ACCELEROMETER Y-AXIS FROM P1-C
MAGNETOMETER X-AXIS FROM P1-T
MAGNETOMETER Y-AXIS FROM P1-R
MAGNETOMETER Z AXIS FROM P1-U
ACCELEROMETER Z-AXIS FROM P1-S
FILTERED 4052 KHz FROM PCB3 U12-6 DWG 1202-C-2022
TEMP OFFSET FROM PCB7
REF VOLTAGE OUT FROM PCB7 R7
-BATT. VOLTAGE MONITOR FROM PCB7 R9
+BATT. VOLTAGE MONITOR FROM PCB7 R5 DWG 1202-C 2012
CH1 TO PCB3 U1-25
CH2 TO PCB3 U1-26
CH3 TO PCB3 U1-11
CH4 TO PCB3 U1-10
CH5 TO PCB3 U1 9
CH6 TO PCB3 U1 8
60° LEAD TO PCB3 K17
60° LAG TO PCB3 K18
CH7 TO PCB3 U1-7
CH8 TO PCB3 U1-6
CH9 TO PCB3 U1-5
CH10 TO PCB3 U1-4
TEMP SENSOR AD590
+12V
GND
-12V



NOTES:
1. U20 (4030) IS LOCATED PCB6, IS SHOWN ON THIS SCHEMATIC FOR CIRCUIT CONTINUITY.

IC NO	A/O TYPE	BD NO.
2	MCMN 5251	5
3	74C192	5
6	74C221	5
7	4020	4
8	4049	4
9	4023	4
10	74C73	4
11	4081	4
13	4011	4
14	4011	4
15	4071	4
16	4731	5
21	4049	5
22	4013	2
23	4013	2
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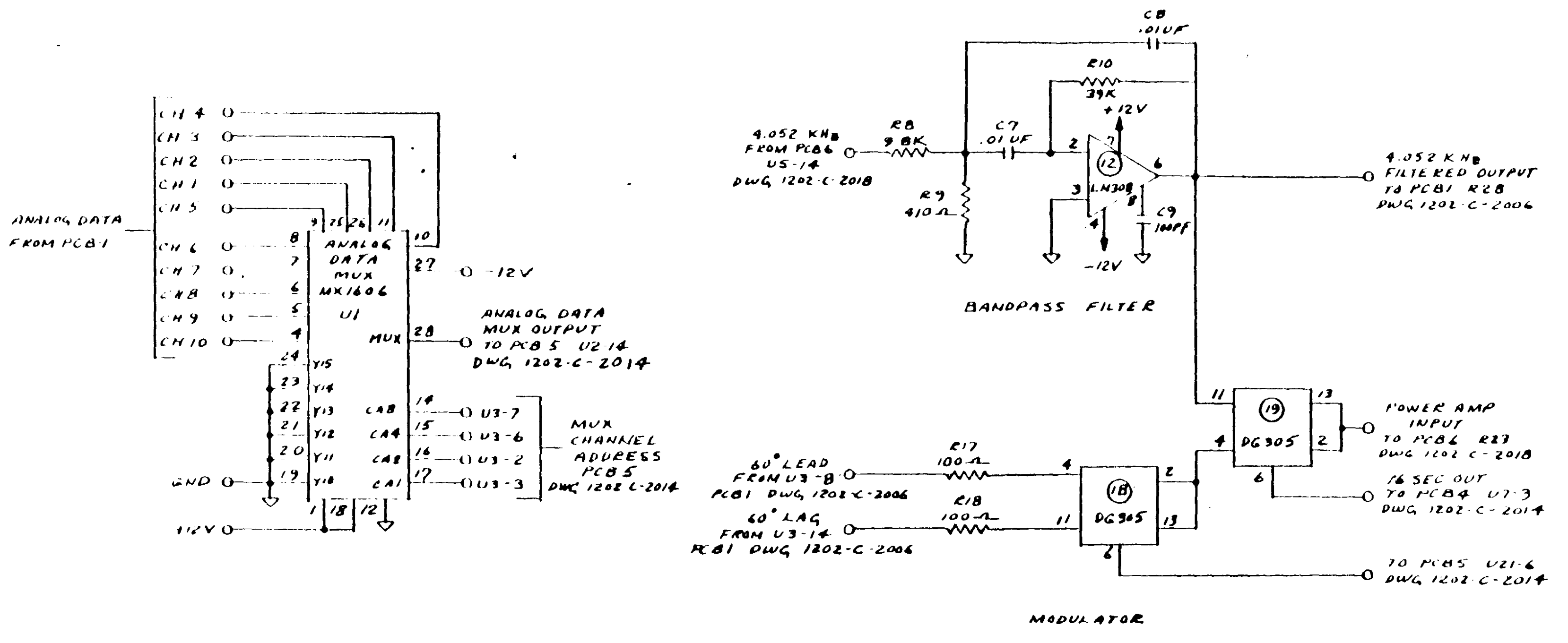
25	4081	2
26	4021	2
27	4021	2
28	4075	2
29	4020	2
31	4013	5



REVISIONS				
ZONE	REV	DESCRIPTION	APPVD	DATE

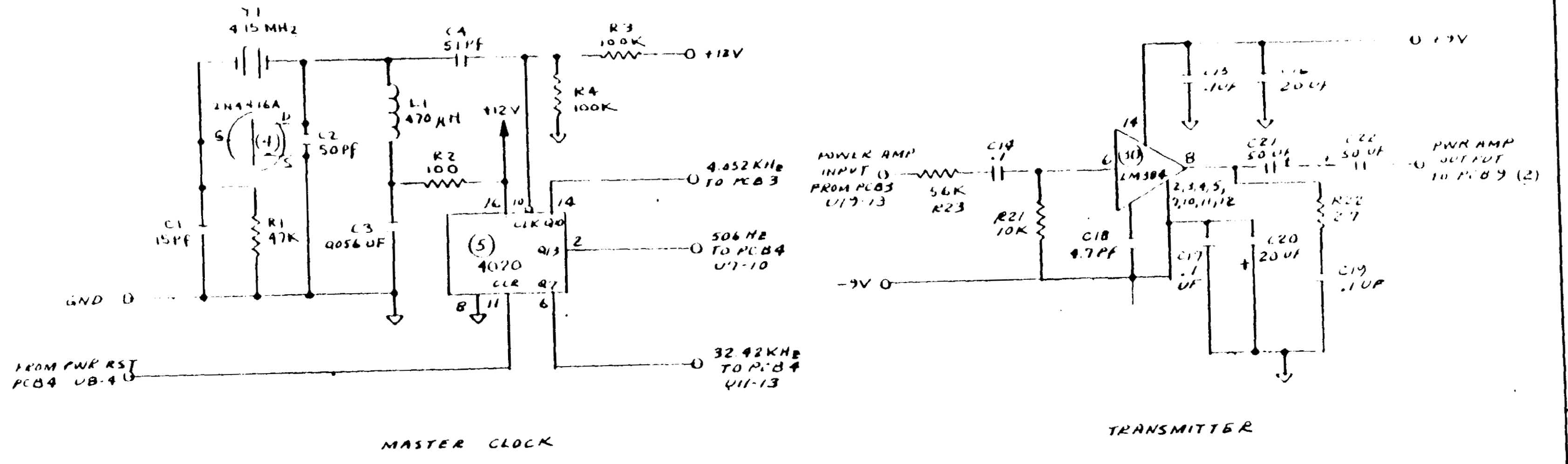
UNLESS OTHERWISE SPECIFIED
1 DIMENSIONS ARE IN INCHES
2 BREAK SHARP EDGES & DEBURR
3 TOLERANCES ARE
FRACTIONS DECIMALS ANGLES
2 PLACE 3 PLACE
±1/64 ±.010 ±.005 ±0° 30'
MATERIAL:
TREATMENT:
FINISH:
NEXT ASSY | USED ON
APPLICATION

CONTRACT NO: H0177069

ENSCO, INC.
SPRINGFIELD, VIRGINIA

SCHEMATIC DIAGRAM - DOWNHOLE ELECTRONICS, PCB 3

SIZE: C | CODE IDENT NO: 06359 | DRAWING NO: 1202 C 2022
SCALE: -

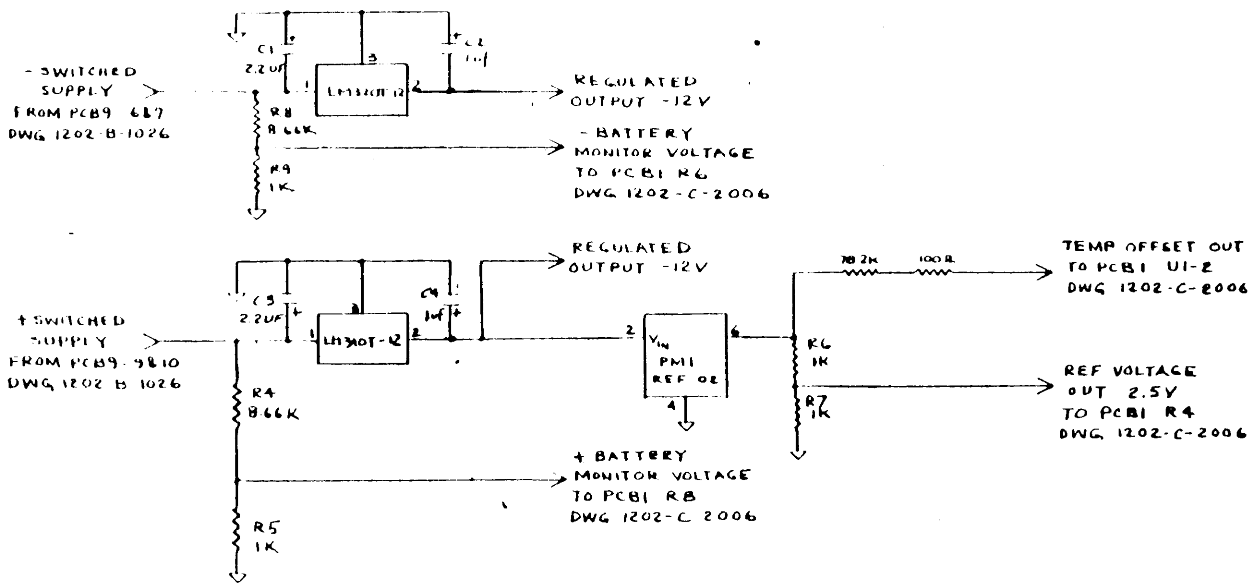


NOTE:
1 INTEGRATED CIRCUIT U20 IS LOCATED ON PCB6, IT IS SHOWN ON SCHEMATIC DIAGRAM 1202-C-2014 FOR CLARITY OF CIRCUIT.

CONTRACT NO	H0177069
ENSCO, INC. SPRINGFIELD, VIRGINIA	SCHEMATIC DIAGRAM - DOWNHOLE ELECTRONICS, PCB 6
SIZE	C
CODE IDENT NO	06359
DRAWING NO	1202-C-2018

UNLESS OTHERWISE SPECIFIED DIMENSIONS ARE IN INCHES. BREAK SHARP EDGES & DEBURR. TOLERANCES ARE: FRACTIONS ± 1/64, DECIMALS ±.010 ±.005, ANGLES ±0° 30'

MATERIAL
TREATMENT
FINISH
NEXT ASSY | USED ON
APPLICATION



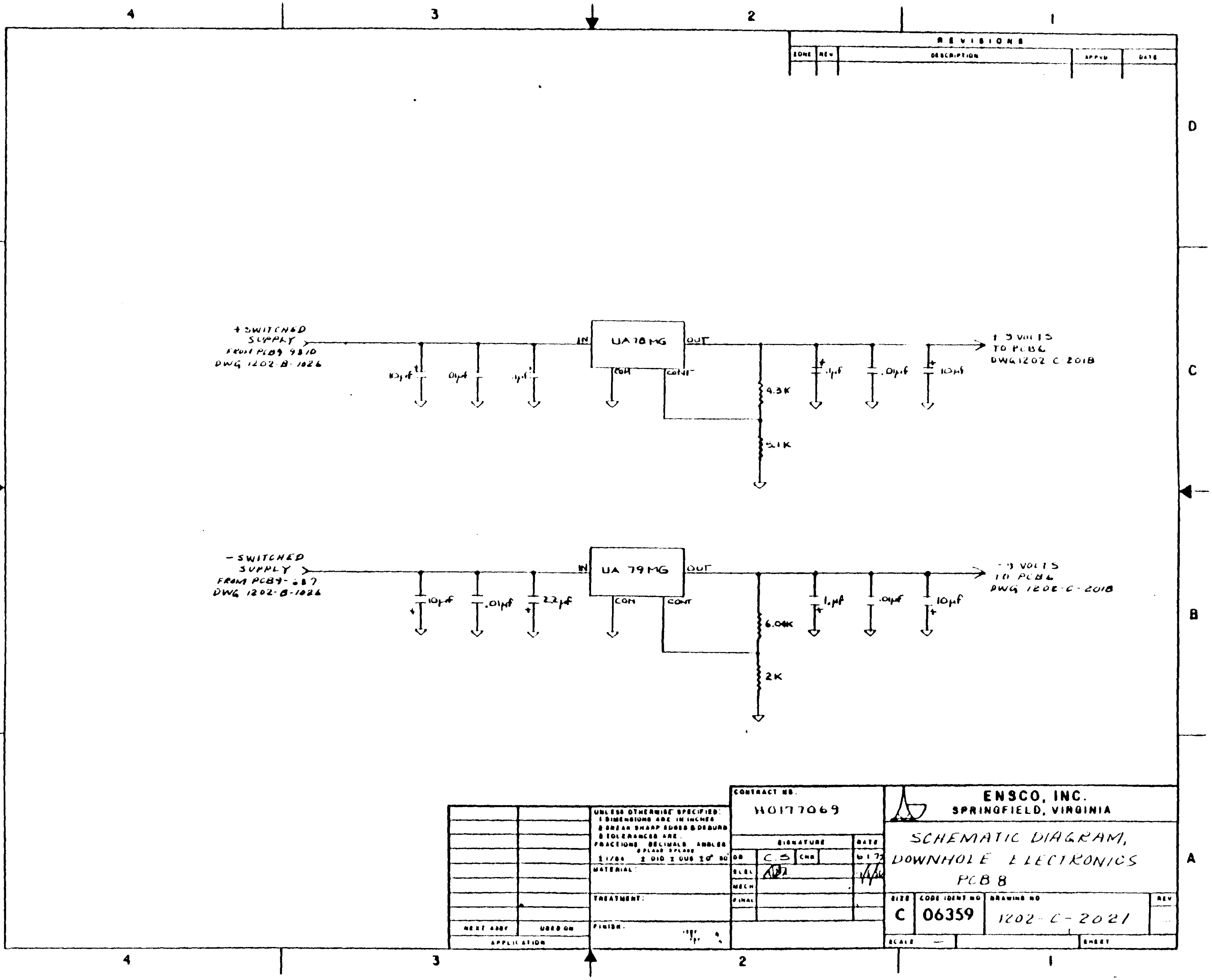
+12V REGULATOR
-12V REGULATOR
REFERENCE VOLTAGE
TEMPERATURE OFFSET

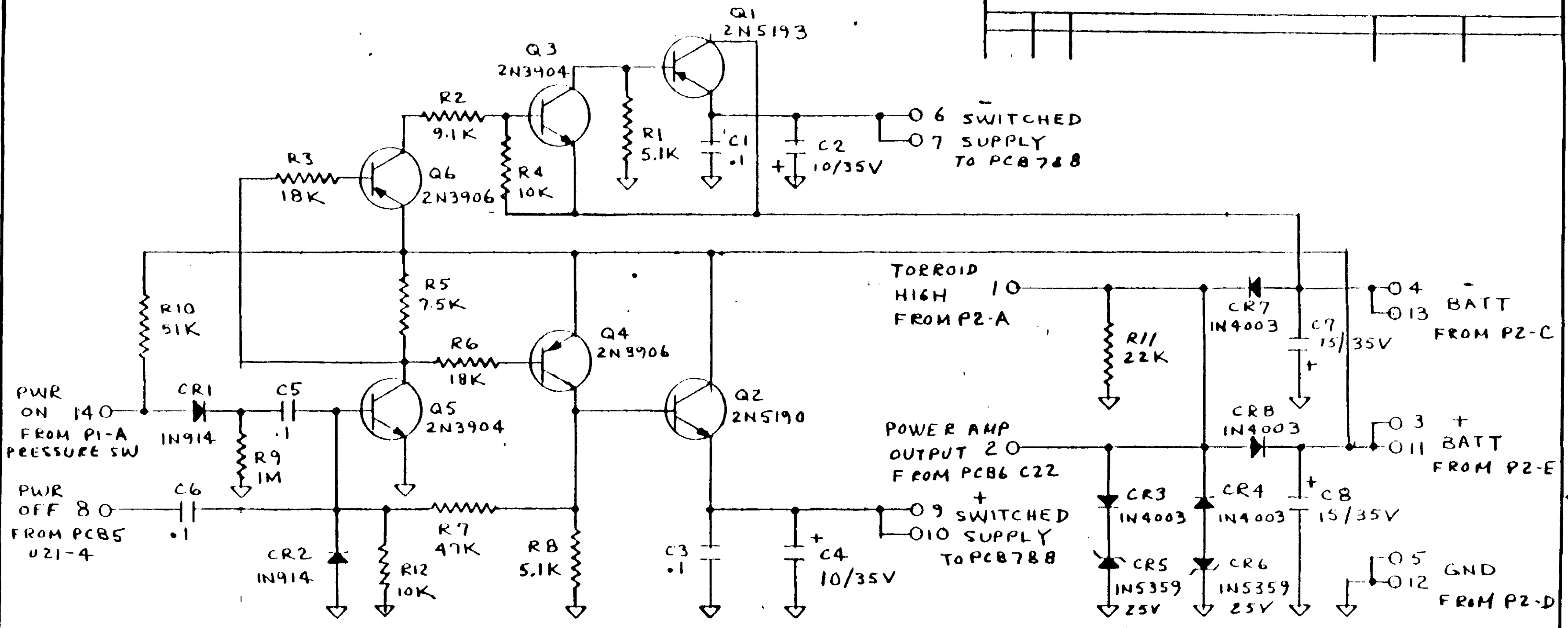
ENSCO, INC.
SPRINGFIELD, VIRGINIA

SCHEMATIC DIAGRAM, DOWNHOLE ELECTRONICS - PCB 7

CONTRACT NO. H0177069

SIZE C | CODE IDENT NO 06359 | DRAWING NO 1202-C-2012


REVISIONS
ZONE
REV
DESCRIPTION
APPVD
DATE
+SWITCHED SUPPLY FROM PCB9 9810 DWG 1202-B-1026
10µf
.01µf
.1µf
IN
UA78MG
OUT
COM
CONT
4.3K
5.1K
.1µf
.01µf
10µf
+5 VOLTS TO PCB6 DWG 1202-C-2018
-SWITCHED SUPPLY FROM PCB9-687 DWG 1202-B-1026
10µf
.01µf
2.2µf
IN
UA 79MG
OUT
COM
CONT
6.04K
2K
1µf
.01µf
10µf
-5 VOLTS TO PCB6 DWG 1202-C-2018
CONTRACT NO.
H0177069
UNLESS OTHERWISE SPECIFIED:
1 DIMENSIONS ARE IN INCHES
2 BREAK SHARP EDGES & DEBURR
3 TOLERANCES ARE:
FRACTIONS DECIMALS ANGLES
MATERIAL:
TREATMENT:
FINISH:
NEXT ASSY
USED ON
APPLICATION
SIGNATURE
DATE
DR
C.S
CHK
ELEC
MECH
FINAL
ENSCO, INC.
SPRINGFIELD, VIRGINIA
SCHEMATIC DIAGRAM, DOWNHOLE ELECTRONICS PCB 8
SIZE
C
CODE IDENT NO
06359
DRAWING NO
1202-C-2021
REV
SCALE
SHEET



UNLESS SPECIFIED:
ALL RESISTORS ARE
1/4 W ± 5% CARBON

NEXT ASSY	USED ON
APPLICATION	

UNLESS OTHERWISE SPECIFIED:
1 DIMENSIONS ARE IN INCHES
2 BREAK SHARP EDGES & DEBURR
3 TOLERANCES ARE:
FRACTIONS DECIMALS ANGLES
2 PLACE 3 PLACE
±1/64 ±.010 ±.005 ±0° 30'
MATERIAL:
TREATMENT:
FINISH:

CONTRACT NO. H0177069

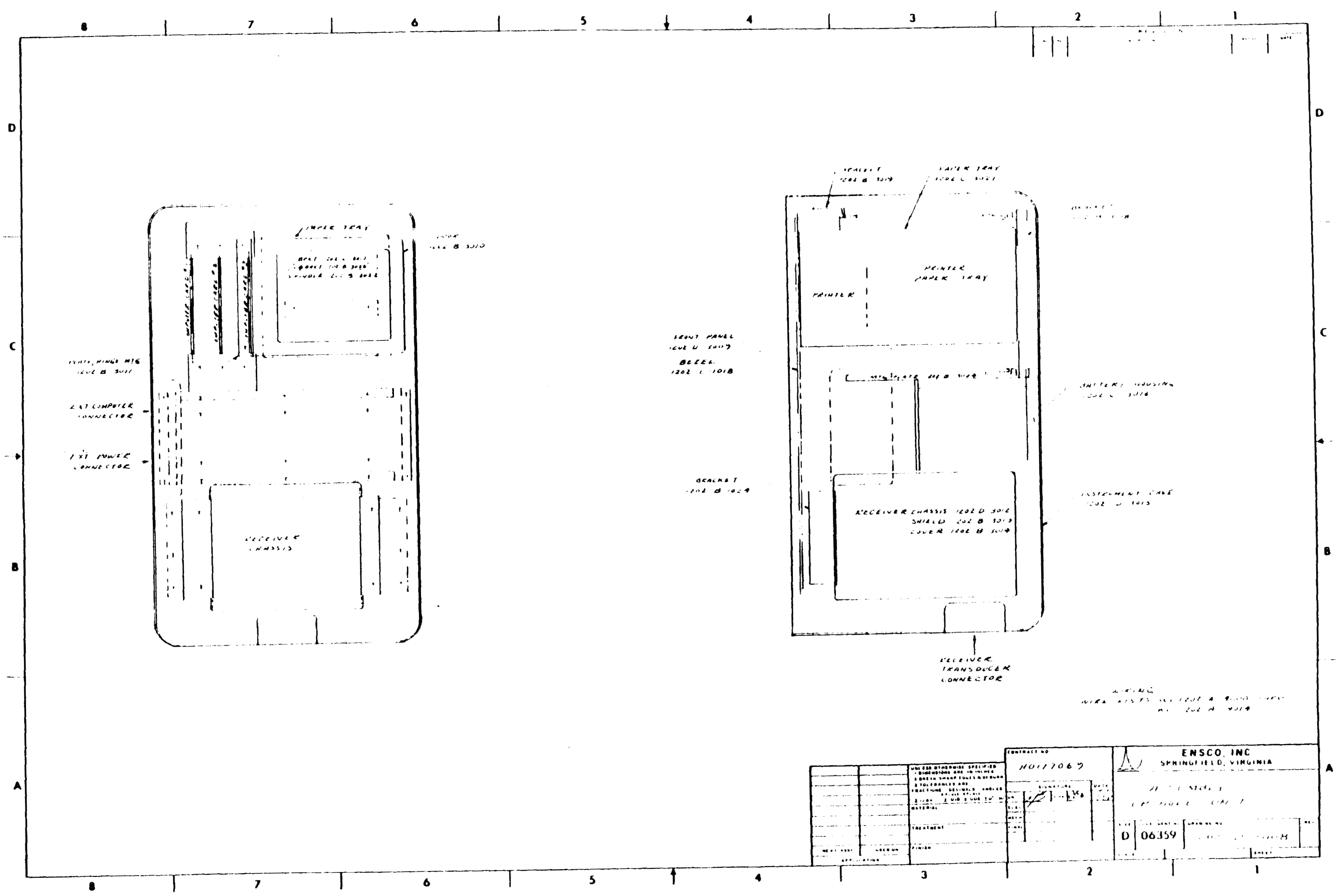
	SIGNATURE		DATE
DR	CB	CHK	7/20/[illegible]
ELEC	[illegible]		7/1/[illegible]
MECH			
FINAL			

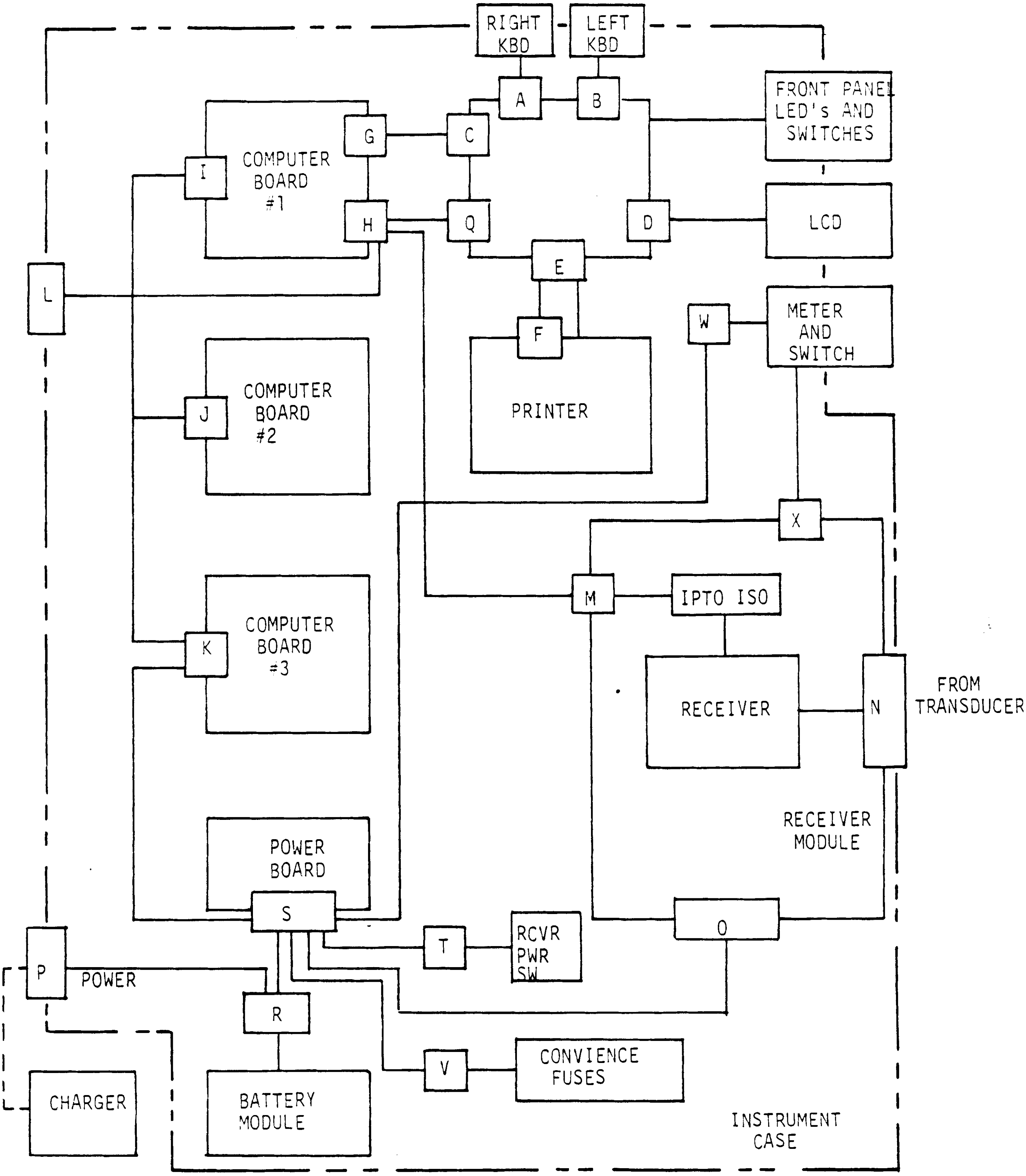
ENSCO, INC.
SPRINGFIELD, VIRGINIA

SCHEMATIC DIAGRAM,
DOWNHOLE ELECTRONICS –
POWER TRIGGER PCB9

SIZE	CODE IDENT NO	DRAWING NO.	REV
B	06359	1202-B-1026	A

SCALE: – SHEET


PRINTER
PRINTER PAPER TRAY
PAPER TRAY
RECEIVER CHASSIS 1202 D 3012
RECEIVER TRANSDUCER CONNECTOR
BEZEL
1202 C 1018
RECEIVER CHASSIS
ENSCO, INC
SPRINGFIELD, VIRGINIA
D
06359



Processing and Display Subsystem Interconnection Diagram

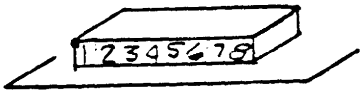
CONNECTOR DESIGNATIONS AND PIN ASSIGNMENTS
FOR UPHOLE RECEIVER/PROCESSOR PACKAGE

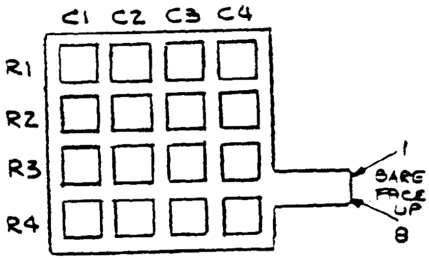
Right Keyboard to Front Panel PCB: JA

Left Keyboard to Front Panel PCB: JB

Connector: Burndy 8 Pin

Pin	Signal
1	R1
2	C2
3	C3
4	C4
5	R2
6	R3
7	R4
8	C1





Front Panel to Computer Board #1: JC/PC

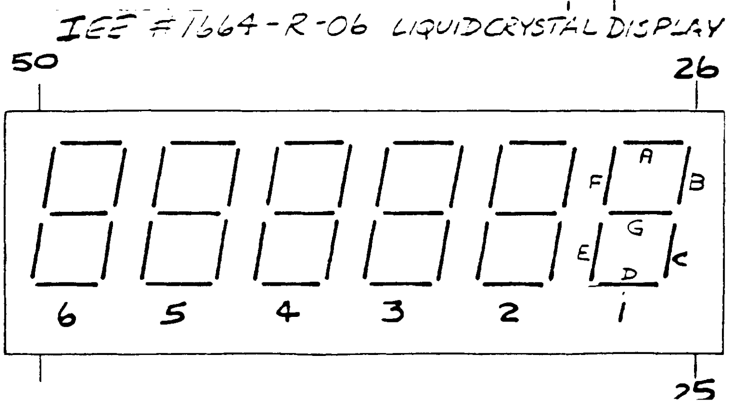
Connector: Augat 110-26001-102

Pin	Signal
1	DX0
2	DX1
3	DX2
4	DX3
5	DX4
6	DX5
7	DX6
8	DX7
9	DX8
10	DX9
11	DX10
12	DX11
13	GND
14	$+5V_m$ (Switched)
15	SYS RESET

Pin	Signal
16	KACK-
17	KREQ2+
18	KREQ1+
19	$+5V_m$ (Switched)
20	$+5V_m$ (Switched)
21	$+5V_m$ (Source)
22	AF1
23	AF2
24	AW2
25	$+5V_m$ (Source)
26	$+5V_m$ (Source)

Front Panel PCB to LCD: JD
Connector: Augat 325AG1F

Pin	Signal
1	BP
2	E6
3	D6
4	C6
5	DP5-6
6	E5
7	D5
8	C5
9	DP4-5
10	E4
11	D4
12	C4
13	DP3-4
14	E3
15	D3



Pin	Signal
16	C3
17	DP2-3
18	E2
19	D2
20	C2
21	DP1-2
22	E1
23	D1
24	C1
25	B1
26	A1
27	F1
28	G1
29	B2
30	A2
31	F2
32	G2
33	L
34	B3
35	A3
36	F3
37	G3
38	B4
39	A4
40	F4
41	G4
42	L
43	B5
44	A5
45	F5
46	G5
47	B6
48	A6
49	F6
50	G6

Front Panel Electronics to Printer: JE/PE

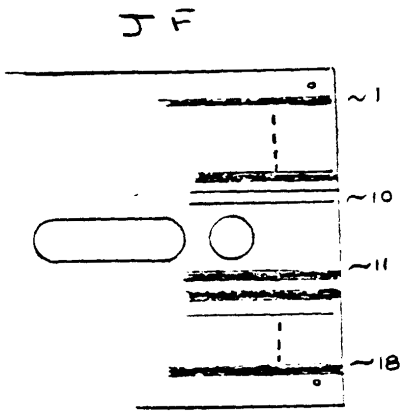
Connector: Augat 110-26001-102

Pin	Signal
1	DIG 11
2	DIG 9
3	DOT 5
4	DIG 7
5	DOT 4
6	DIG 5
7	DIG 3
8	DIG 1
9	NC
10	NC
11	NC
12	NC
13	NC
14	DIG 12
15	DIG 10
16	DIG 8
17	DOT 3
18	DIG 6
19	DOT 2
20	DIG 4
21	DIG 2
22	DOT 1
23	Motor Yellow
24	Motor Red
25	Motor Orange
26	Motor Brown

Front Panel Cable to Printer Element: JF

Connector: Part of Texas Instruments Printer EPN9112

Pin	Signal
1	NC
2	DIG 12
3	DIG 11
4	DIG 10
5	DIG 9
6	DIG 8
7	DOT 5
8	DOT 3
9	DIG 7
10	DIG 6
11	DOT 4
12	DOT 2
13	DIG 5
14	DIG 4
15	DIG 3
16	DIG 2
17	DIG 1
18	DOT 1



Computer Board #1 to Front Panel: JG/PG

Connector: Augat 110-26001-601

Pin	Signal

(Same as JC/PC)

Computer Board #1 (JH) to Front Panel (JQ), Receiver (JM), Ext. Computer (JL)

Connector: Augat 110-26001-601

Pin	Signal	Destination
1	AF4	JQ
2	AF3	JQ
3	BS4	JQ
4	BW2	JQ
5	RCVR CLK	JM
6	RCVR DATA	JM
7	UART CLK	JL
8	720 DATA	JL
9	GND	JL
10	300 BAUD	JL
11	+5V from TTY	JL
12	5V UART	JL
13	NC	-
14	NC	-
15	Printer $+5V_B$	JQ
16	Printer Pwr Control	JQ
17	Printer $+12V_B$	JQ
18	$+5V_m$ to RCVR OPTO ISO	JM
19	GND to RCVR OPTO ISO	JM
20	SELF Test Output	JM
21	+12V from TTY Interface	JL
22	UART DATA	JL
23	-12V FROM TTY Interface	JL
24	CR Wait from TTY	JL
25	Printer $+12V_B$	JQ
26	NC	-

Computer Board 1,2,3, JI, JJ, JK (all connectors bussed pin for pin)
Connector: Viking 3VH 36/IJND

Pin	Signal
1	NC
2	BF3
3	$+5V_C$ Unswitched
4	$+12V_A$
5	$+5V_M$
6	XTB
7	XTA
8	V_M Lo
9	INT GNT
10	SKP INT
11	DEVSEL
12	GND
13	Sys Res & Pwr Up
14	Sys Res
15	Y
16	AS2
17	C2
18	MEMSW
19	$\overline{\text{MEMSW}}$
20	C1
21	$+12V_B$
22	GND
23	NC
24	$+5V_A$
25	APU OFF
26	2.4315MHz
27	XTC
28	24.315KHz
29	READD
30	MEMSEL
31	AS2

Pin	Signal
32	NC
33	NC
34	Wait
35	AR1
36	$+5V_B$
37	NC
38	LXMAR
39	S-T DATA
40	NC
41	NC
42	DX8
43	DX7
44	DX9
45	DX0
46	GND
47	DX10
48	DX1
49	NC
50	DX11
51	DX6
52	GND
53	AW1
54	DX2
55	4MHZ
56	DX3
57	Power A CTL
58	GND
59	DX4
60	NC
61	NC
62	DX5
63	NC
64	GND
65	PWR B Control

Pin	Signal
66	BF4
67	NC
68	NC
69	NC
70	$+5V_M$
71	NC
72	$+5V_M$

External Computer Connector: JL

Connector: ITT KPT07E16-26S

Pin	Signal
A	CR Wait
W	Spare
X	UART DATA
Y	-12V
Z	+12V
a	GND
c	+5V (from TTY)
B	UART CLK
C	300 BAND

Receiver to Computer JM

Connector: Winchester MRE-9P/PR

Pin	Signal
A	Receiver Data Out
B	Receiver Clock Out
C	Computer GND
D	$+5V_M$
E	Self Test Input

External Receiver Input Connector JN
Connector: KPT07E 16-8S

Pin	Signal
C	Input 1
D	Shield
E	Input 2

Receiver Power Input: JO
Connector: Winchester MRE 95J

Pin	Signal
A	+8 Volts
B	- 8 Volts
C	GND
D	Low Voltage Alarm
E	+5V

External Power and Charging Connector: JP
Connector: ITT KPT07E12-8S

Pin	Signal
A	Ext. Pwr
B	RCVR Batt Chg
C	RCVR GND
D	Processor Batt Chg
E	Processor GND
F	Spare
G	RCVR Batt Sense
H	Proc Batt Sense

Front Panel to Computer Board #3: JQ
Connector: Augat 110-26001-601

Pin	Signal
1	AF4
2	AF3
3	BS4
4	BW2

Pin	Signal
15	$+5V_B$ Printer
16	Printer Power Control
17	$+12V_B$ Printer
25	$+12V_B$ Printer

Battery Module Connector: JR
Connector: Winchester MRE 95

Pin	Signal
A	Ext Pwr
B	RCVR Batt Chg
C	RCVR GND
D	Processor Batt Chg
E	Processor GND
F	RCVR Source
H	RCVR Sense
J	Processor Source
K	Processor Sense

Power Supply Board: JS
Connector: Elco 6007-22-44B

Pin	Signal
1	NC
2	-8V to RCVR
3	+8V to RCVR
4	+5V to RCVR
5	RCVR GND
6	RCVR LOW Voltage Alarm
7	NC
8	RCVR Batt Sense
9	RCVR Pwr +5V (Unswitched)
10	RCVR Batt Source
11	Proc GND

Pin	Signal
12	Proc Batt Low Alarm
13	Proc Battery Sense
14	$+5V_C$ to RAM & Proc. Switch (Unswitched)
15	Proc Batt Source
16	$+12V_B$ to Printer
17	Printer Pwr Control B
18	$+5V_M$ to Proc
19	AM9511 Pwr Control A
20	$+5V_B$ to Printer
21	$+5V_A$ to AM9511
22	$+12V_A$ to AM9511

Power Supply Board to Power Switch JT
Connector: Waldom 03-06-1041

Pin	Signal
1	$+5V_R$ Unswitched
2	GND
3	$+5V_R$ Switched

Battery Modules to Concience Fuser: JV
Connector: Waldom 03-06-10Y1

Pin	Signal
1	RCVR Source
2	RCVR Source (Fused)
3	PROC Source
4	PROC Source (Fused)

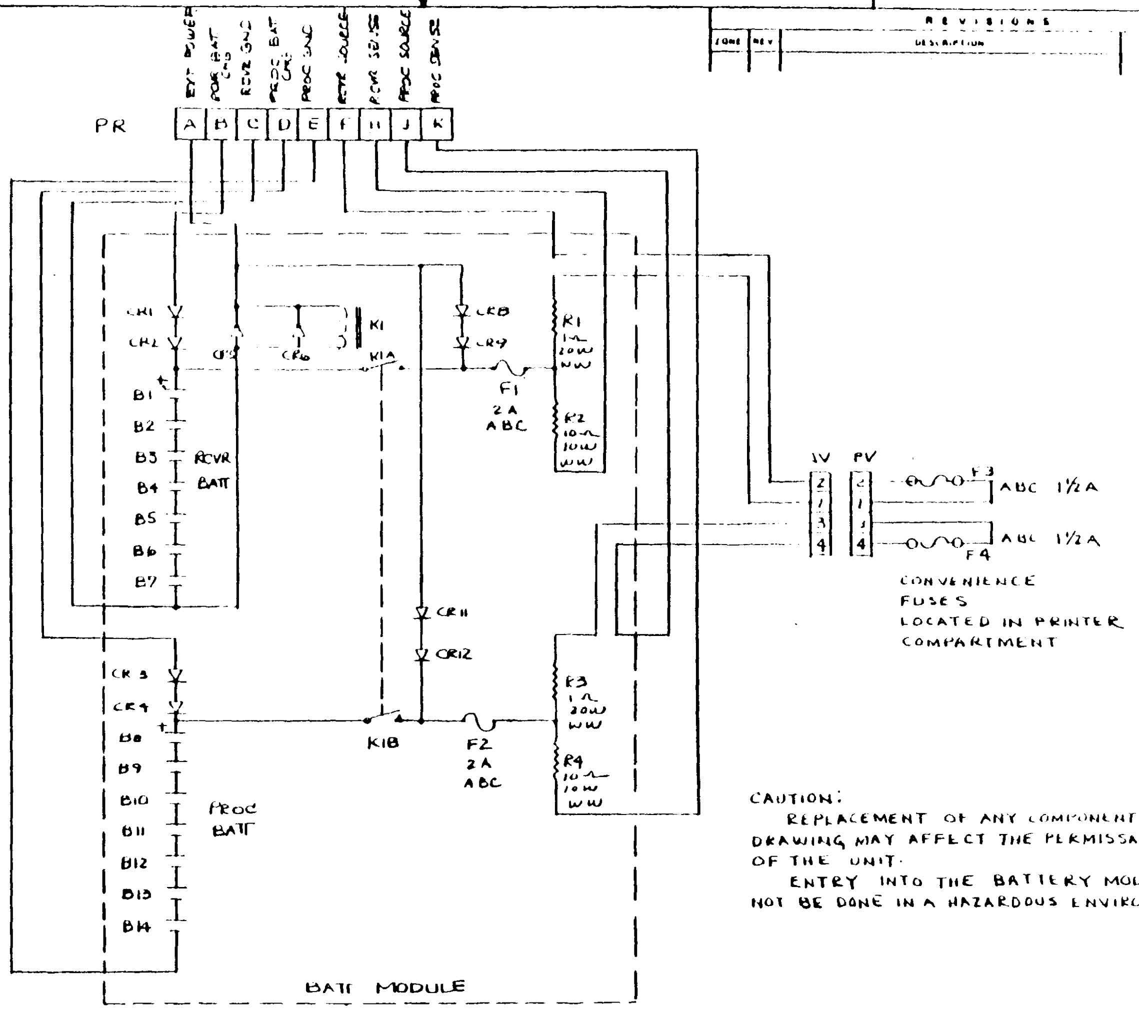
Front Panel Meter to Power Supply: JW
Connector: Waldom 03-06-1041

Pin	Signal
1	PROC GND
2	RCVR Source
3	PROC Source

Front Panel Meter to RCVR: JX

Connector: RCA Phono

Pin	Signal
Tip	RCVR VCXO Control Voltage
Ring	RCVR GND



B1 - B14:
ARE TYPE F
NiCAD BATTERIES

CR1 - CR12:
ARE MR501
MOTOROLA DIODES

K1:
12V RELAY
BABBCOCK W399-2

CAUTION:
REPLACEMENT OF ANY COMPONENT ON THIS DRAWING MAY AFFECT THE PERMISSABILITY OF THE UNIT.
ENTRY INTO THE BATTERY MODULE MUST NOT BE DONE IN A HAZARDOUS ENVIRONMENT.

REVISIONS
ZONE | REV | DESCRIPTION | APPROVED | DATE

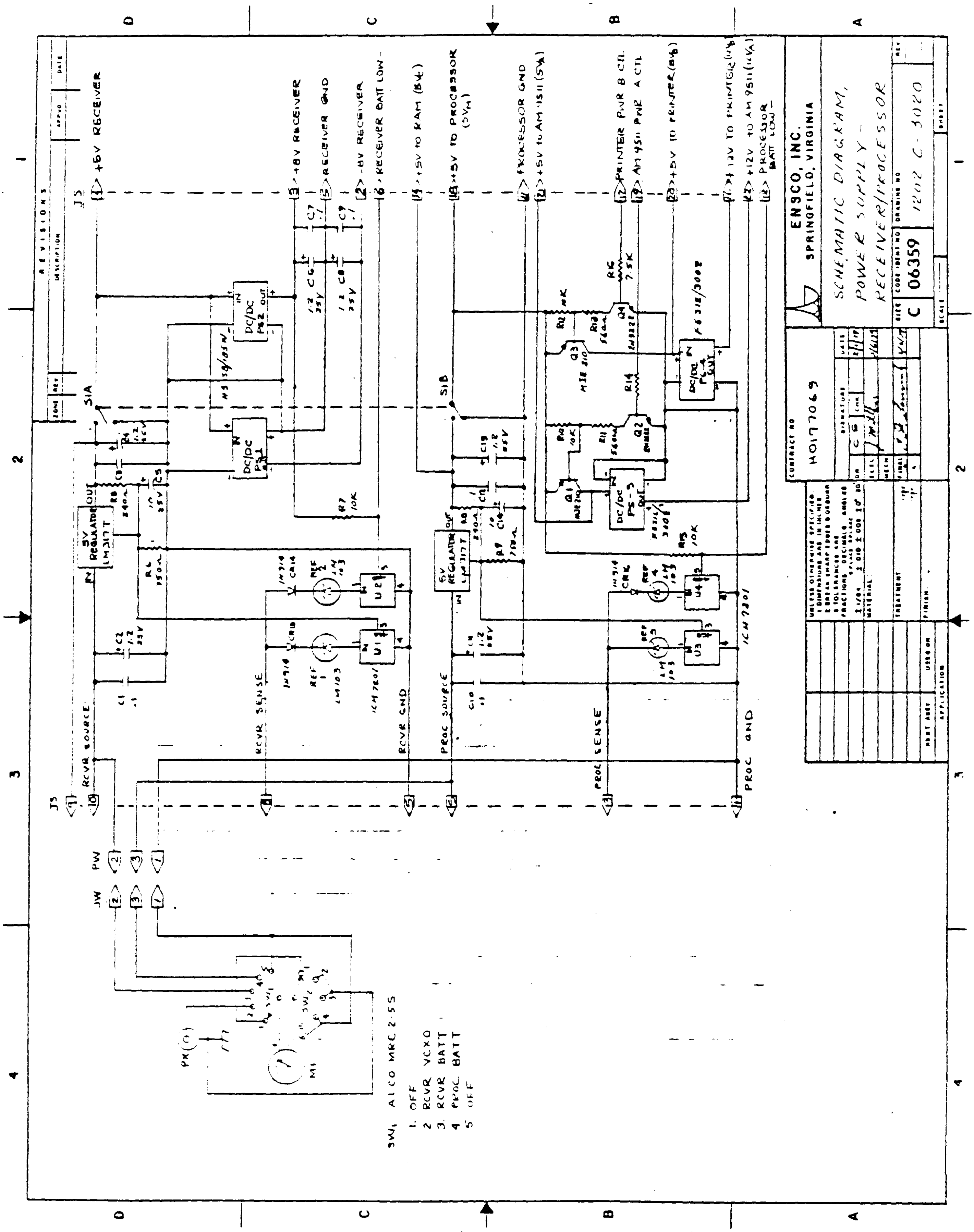
CONTRACT NO. H0177069

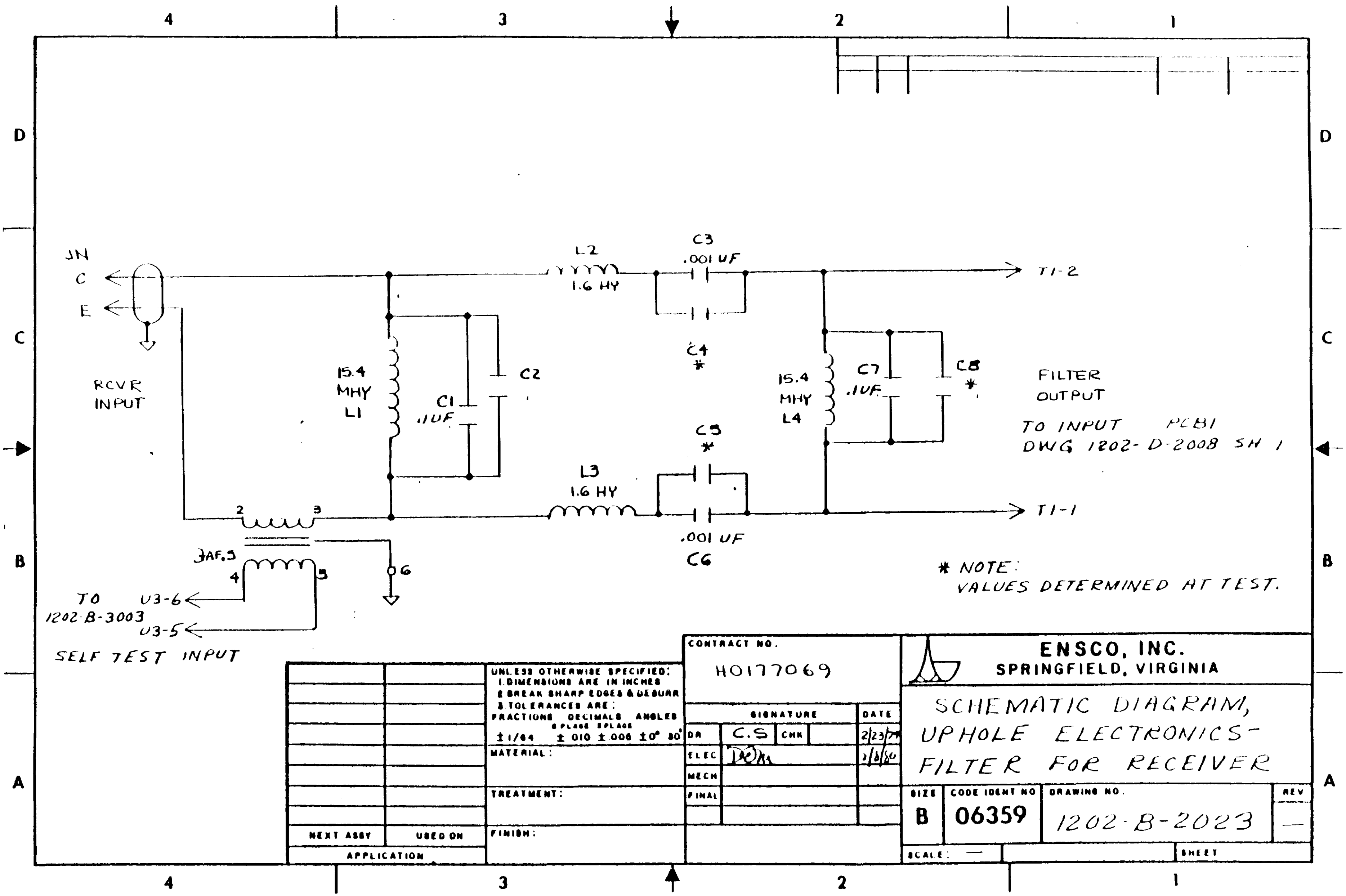
ENSCO, INC.
SPRINGFIELD, VIRGINIA

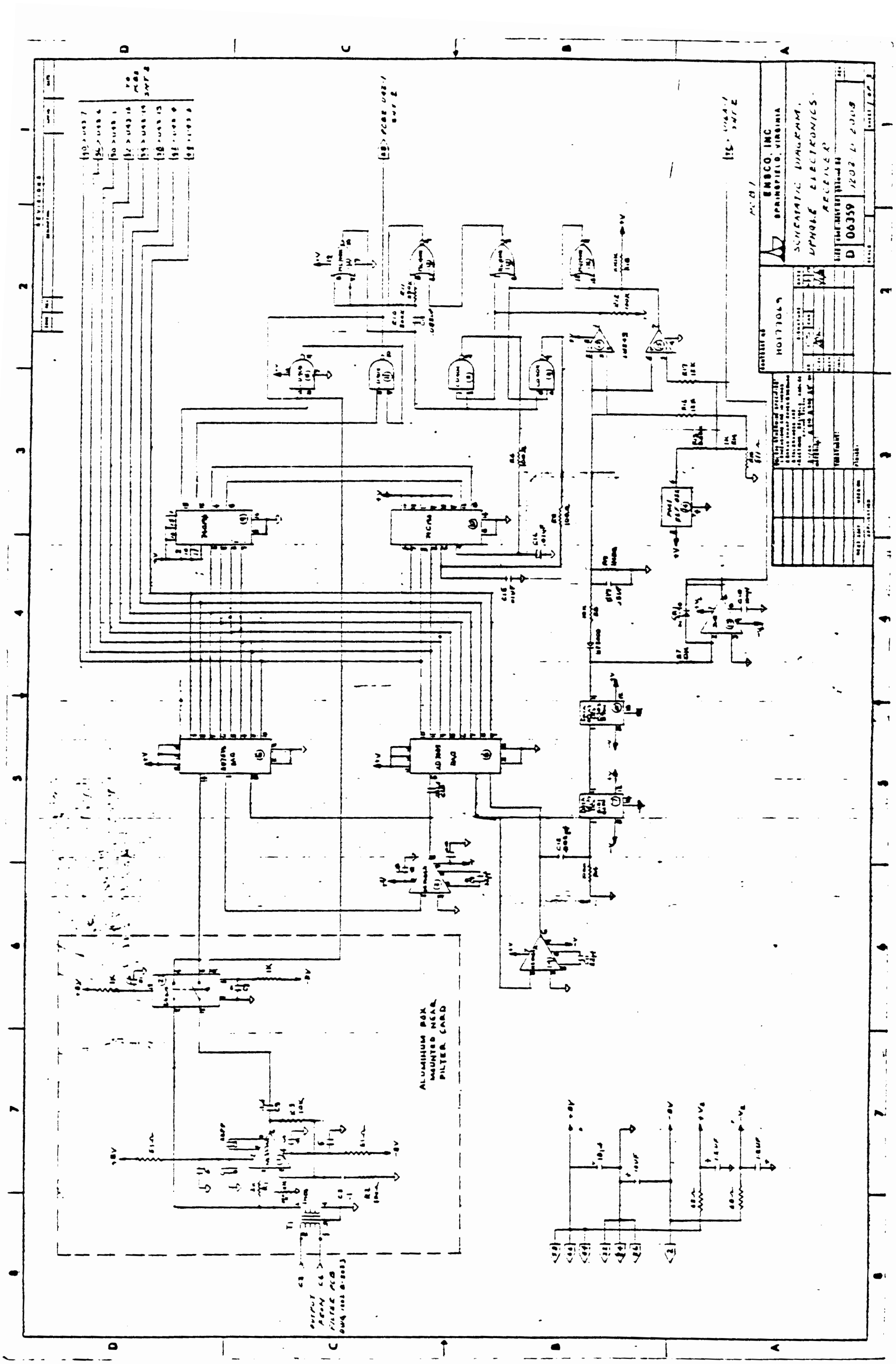
SCHEMATIC DIAGRAM,
BATTERY MODULE

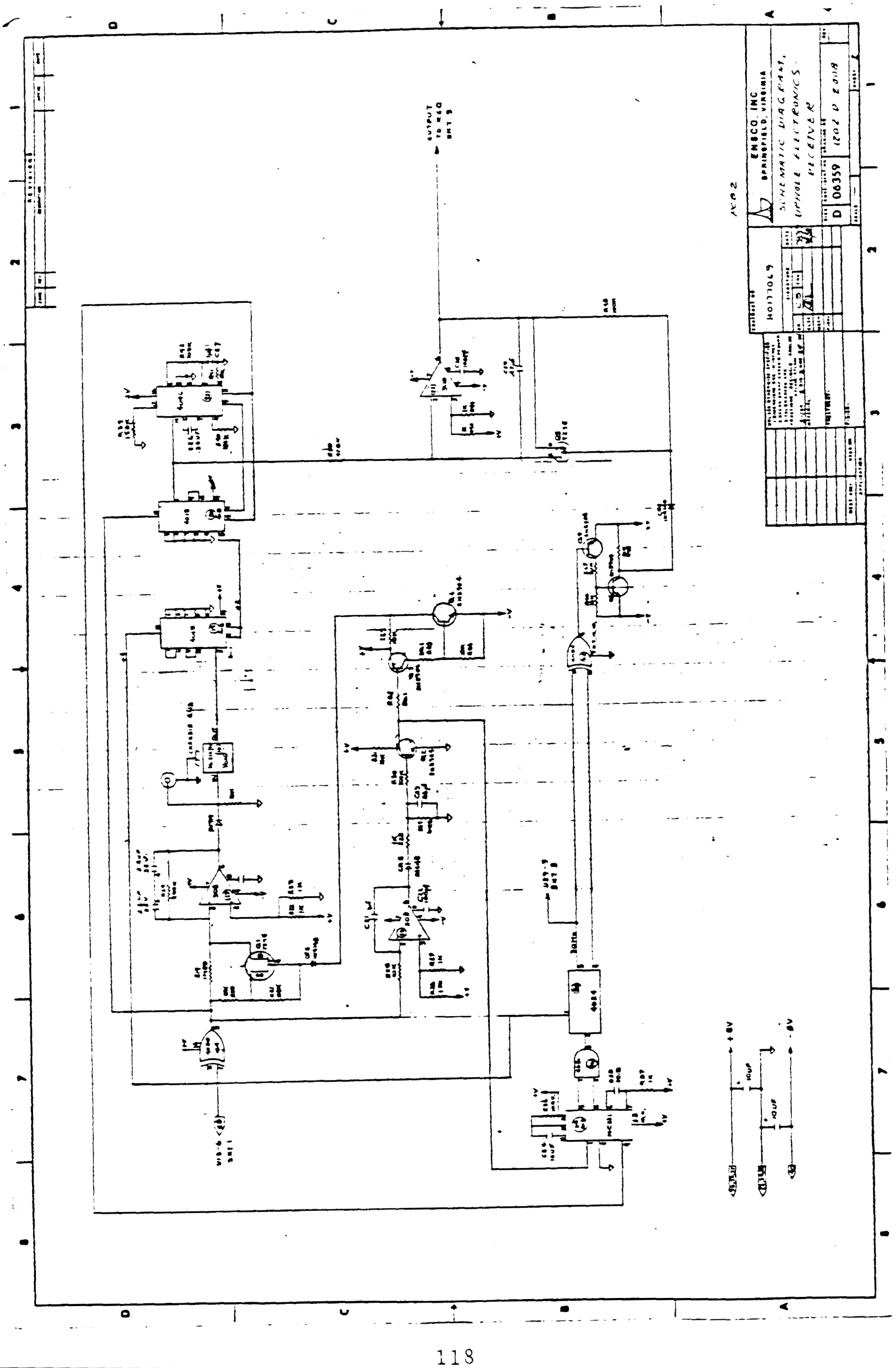
SIZE C | CODE IDENT NO 06359 | DRAWING NO 1202-C-3033 | REV

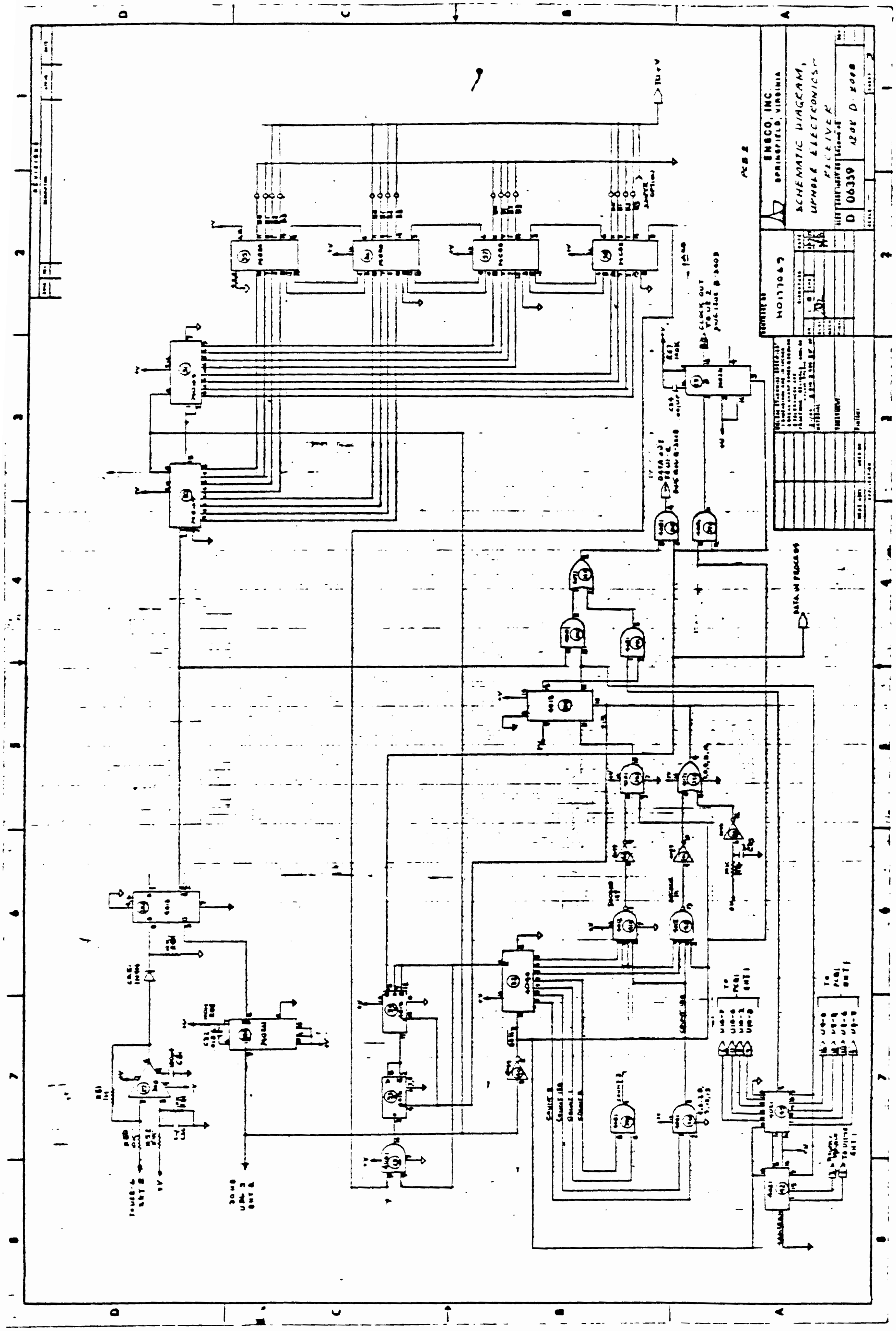
UNLESS OTHERWISE SPECIFIED
DIMENSIONS ARE IN INCHES
BREAK SHARP EDGES & DEBURR
TOLERANCES ARE:
FRACTIONS DECIMALS ANGLES
±1/64 ±.010 ±.005 ±0°30'
MATERIAL:
TREATMENT:
FINISH:
NEXT ASSY | USED ON
APPLICATION
SIGNATURE | DATE
DR
ELEC
MECH
FINAL
SCALE | SHEET

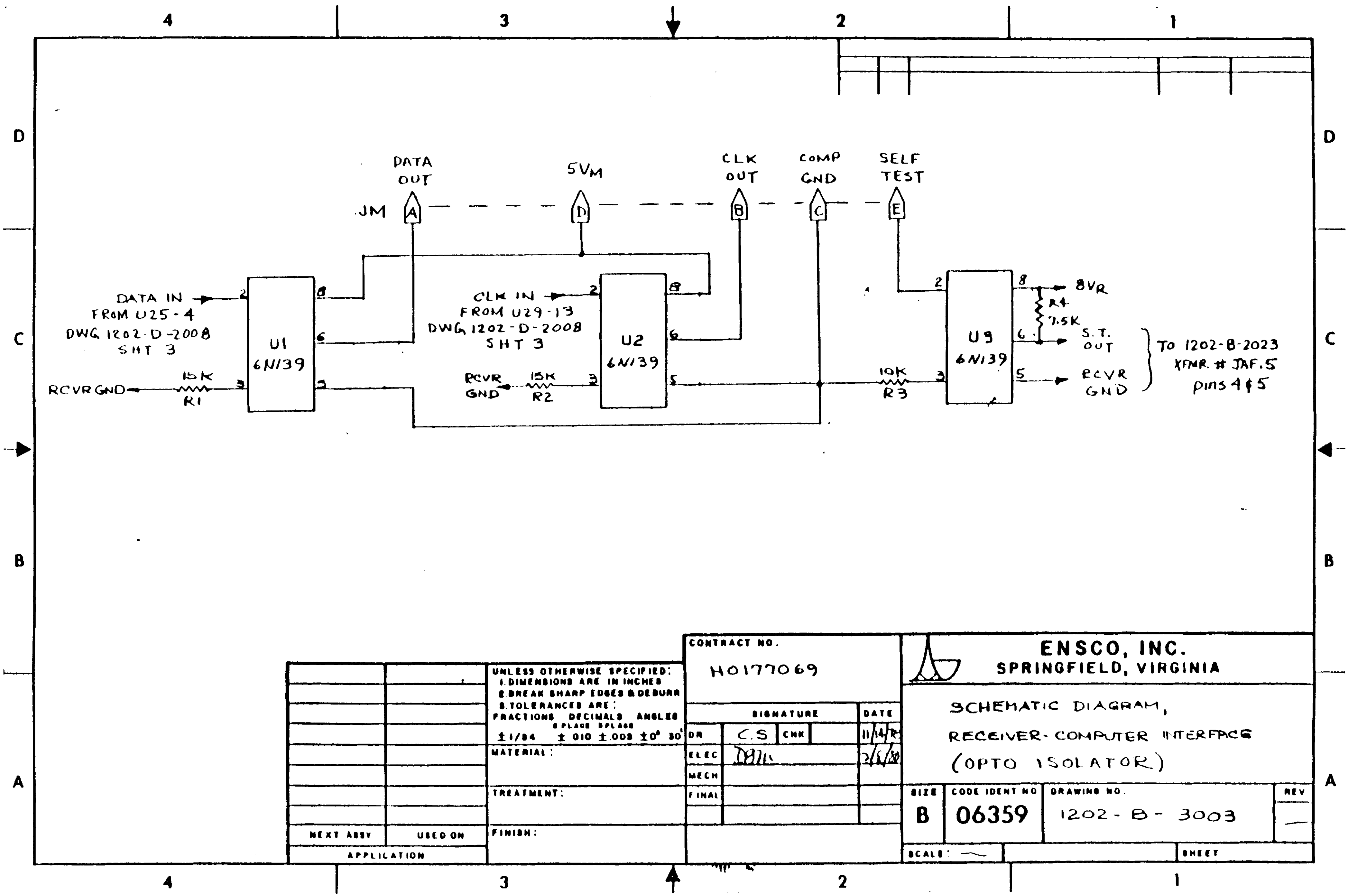

ENSCO, INC.
SPRINGFIELD, VIRGINIA
SCHEMATIC DIAGRAM,
POWER SUPPLY -
RECEIVER/PROCESSOR
C
06359
1212 C 3020

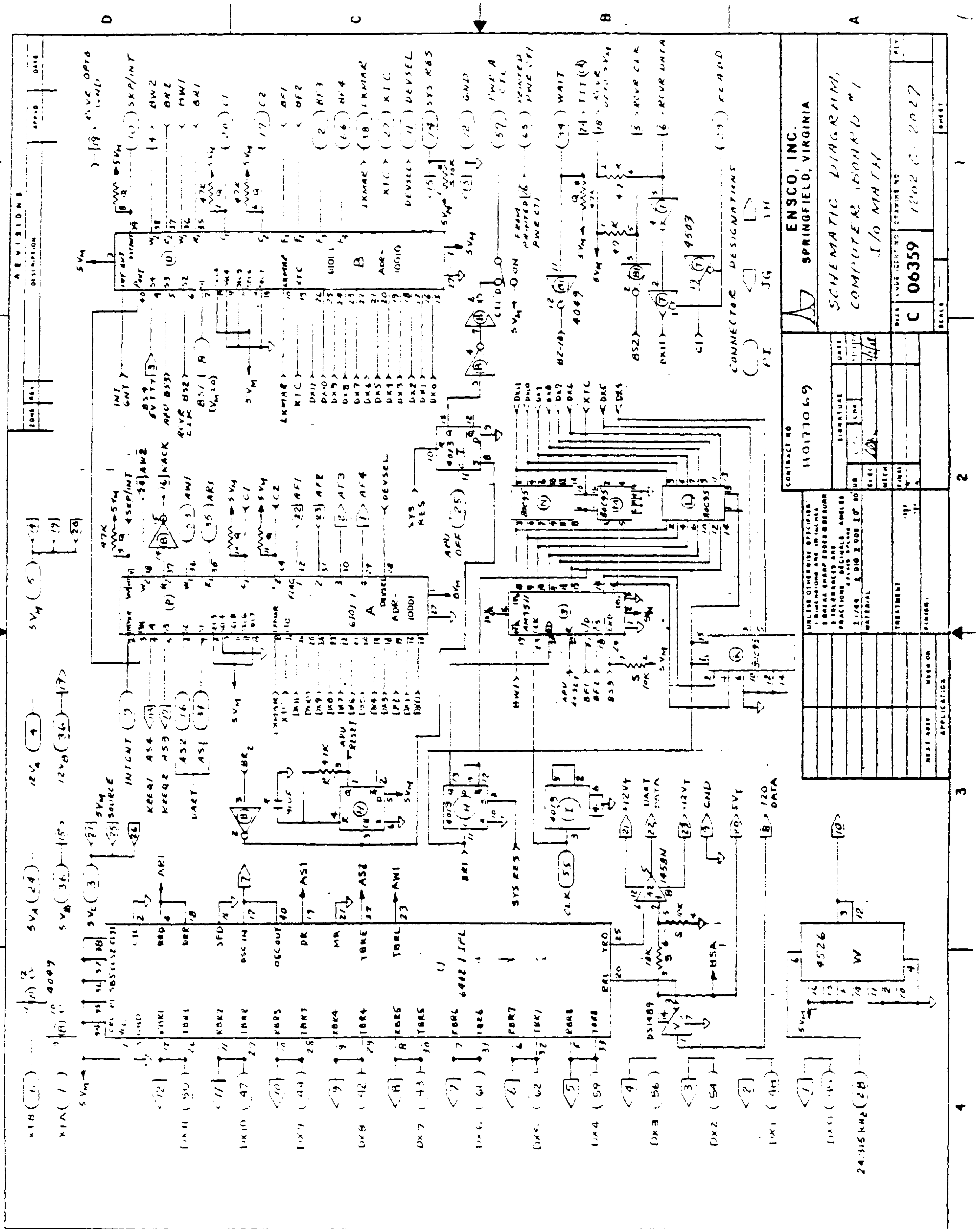

JN
C
E
RCVR
INPUT
15.4
MHY
L1
C1
.1UF
C2
L2
1.6 HY
C3
.001 UF
C4
*
C5
*
L3
1.6 HY
.001 UF
C6
15.4
MHY
L4
C7
.1UF
C8
*
T1-2
T1-1
FILTER
OUTPUT
TO INPUT PCB1
DWG 1202-D-2008 SH 1
2
3
3AF.5
4
5
6
TO U3-6
1202-B-3003
U3-5
SELF TEST INPUT
* NOTE:
VALUES DETERMINED AT TEST.
CONTRACT NO.
H0177069
SIGNATURE
DATE
DR
C.S
CHK
2/23/79
ELEC
2/8/80
MECH
FINAL
UNLESS OTHERWISE SPECIFIED:
1. DIMENSIONS ARE IN INCHES
2. BREAK SHARP EDGES & DEBURR
3. TOLERANCES ARE:
FRACTIONS DECIMALS ANGLES
±1/64 ±.010 ±.005 ±0° 30'
MATERIAL:
TREATMENT:
FINISH:
NEXT ASSY
USED ON
APPLICATION
ENSCO, INC.
SPRINGFIELD, VIRGINIA
SCHEMATIC DIAGRAM,
UPHOLE ELECTRONICS-
FILTER FOR RECEIVER
SIZE
B
CODE IDENT NO
06359
DRAWING NO.
1202-B-2023
REV
SCALE:
SHEET

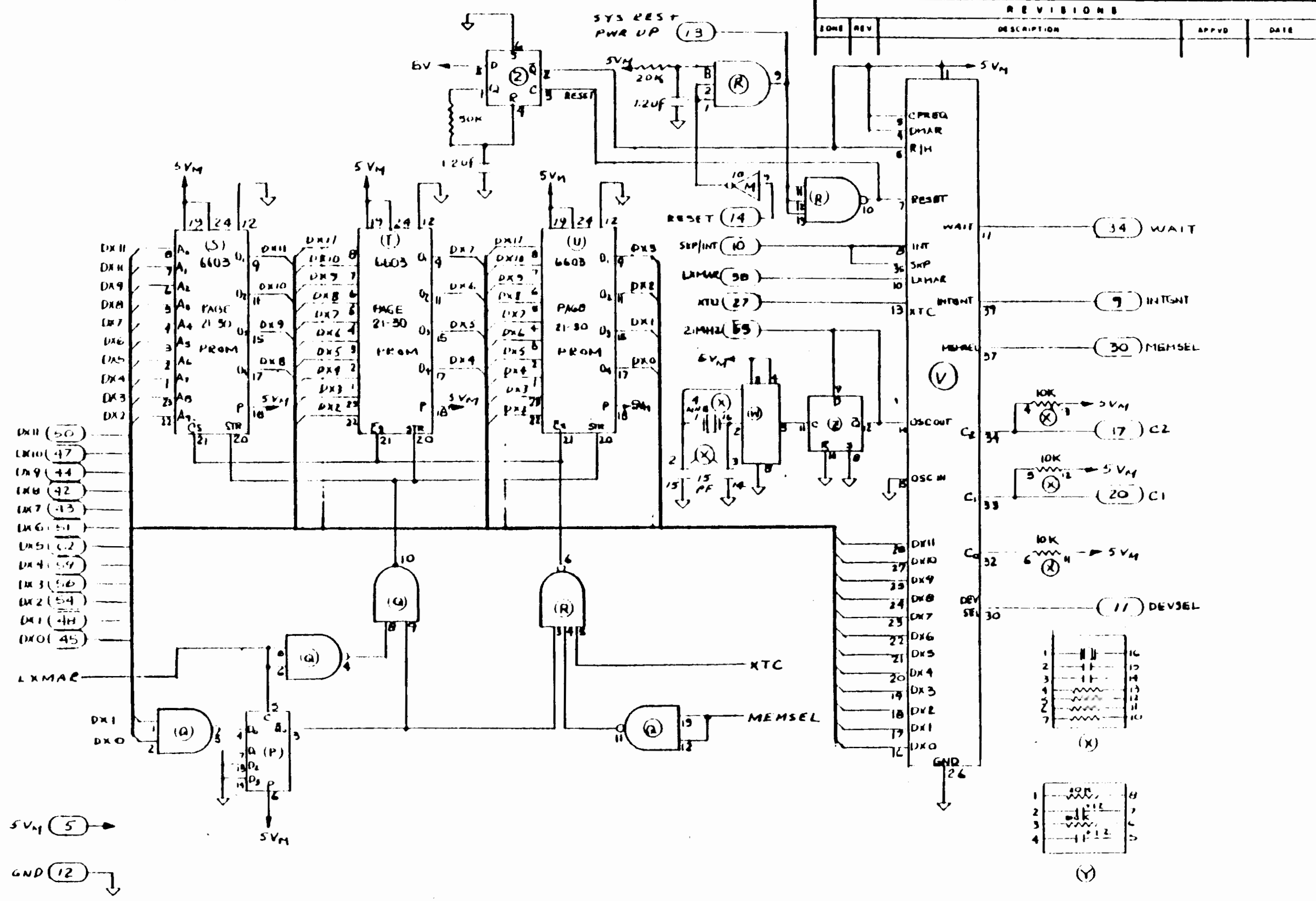

ENSCO, INC
SPRINGFIELD, VIRGINIA
SCHEMATIC DIAGRAM,
UPHOLE ELECTRONICS
RECEIVER
D 06359
ALUMINUM BOX
MOUNTED NEAR
FILTER CARD


ENSCO, INC
SPRINGFIELD, VIRGINIA
SCHEMATIC DIAGRAM,
DIPOLE ELECTRONICS -
RECEIVER
D 06359
1202 D 2008


ENSCO, INC.
SPRINGFIELD, VIRGINIA
SCHEMATIC DIAGRAM,
UPHOLE ELECTRONICS
RECEIVER


DATA OUT
5VM
CLK OUT
COMP GND
SELF TEST
JM
A
D
B
C
E
DATA IN FROM U25-4 DWG 1202-D-2008 SHT 3
RCVR GND
15K R1
U1 6N139
CLK IN FROM U29-13 DWG 1202-D-2008 SHT 3
RCVR GND
15K R2
U2 6N139
10K R3
U9 6N139
8VR
R4 7.5K
S.T. OUT
RCVR GND
To 1202-B-2023 XFMR. # JAF.5 pins 4 & 5
CONTRACT NO.
H0177069
UNLESS OTHERWISE SPECIFIED:
1. DIMENSIONS ARE IN INCHES
2. BREAK SHARP EDGES & DEBURR
3. TOLERANCES ARE:
FRACTIONS DECIMALS ANGLES
±1/64 ±.010 ±.005 ±0° 30'
MATERIAL:
TREATMENT:
FINISH:
NEXT ASSY
USED ON
APPLICATION
SIGNATURE
DATE
DR
C.S
CHK
ELEC
MECH
FINAL
ENSCO, INC.
SPRINGFIELD, VIRGINIA
SCHEMATIC DIAGRAM,
RECEIVER-COMPUTER INTERFACE
(OPTO ISOLATOR)
SIZE
B
CODE IDENT NO
06359
DRAWING NO.
1202-B-3003
REV
SCALE
SHEET


ENSCO, INC.
SPRINGFIELD, VIRGINIA
SCHEMATIC DIAGRAM, COMPUTER BOARD #1 I/O MATH
C 06359



CHIP	DESIGNATION	
LTR	TYPE	PINS
Z	4013	14
P	4042	16
Q	4011	14
R	4023	14
S,T,U	6603	24
V	IM6100 AIP6	40
W	7209	8
X	COMP CARRIER	16
Y	COMP CARRIER	8

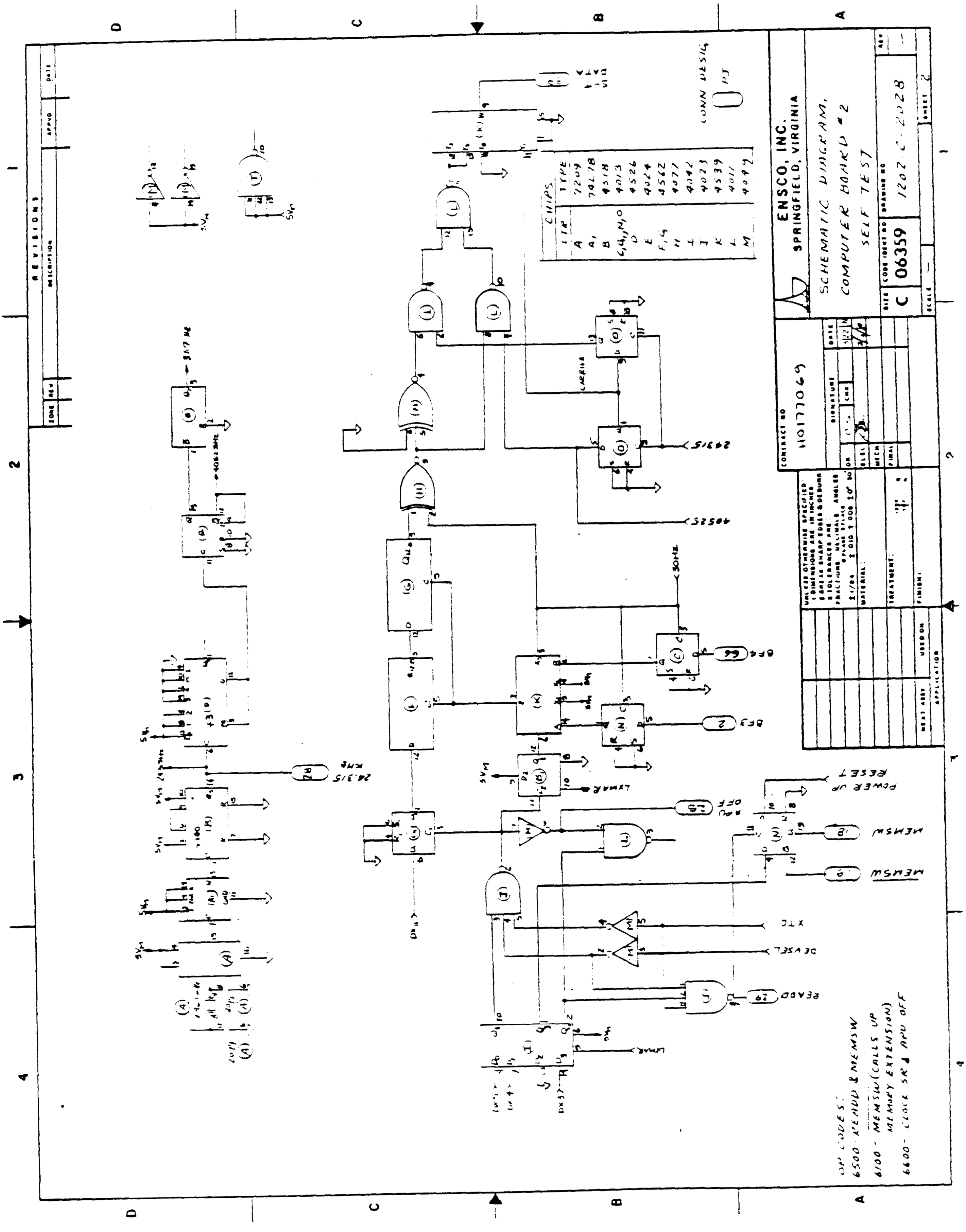
CONTRACT NO H0177069

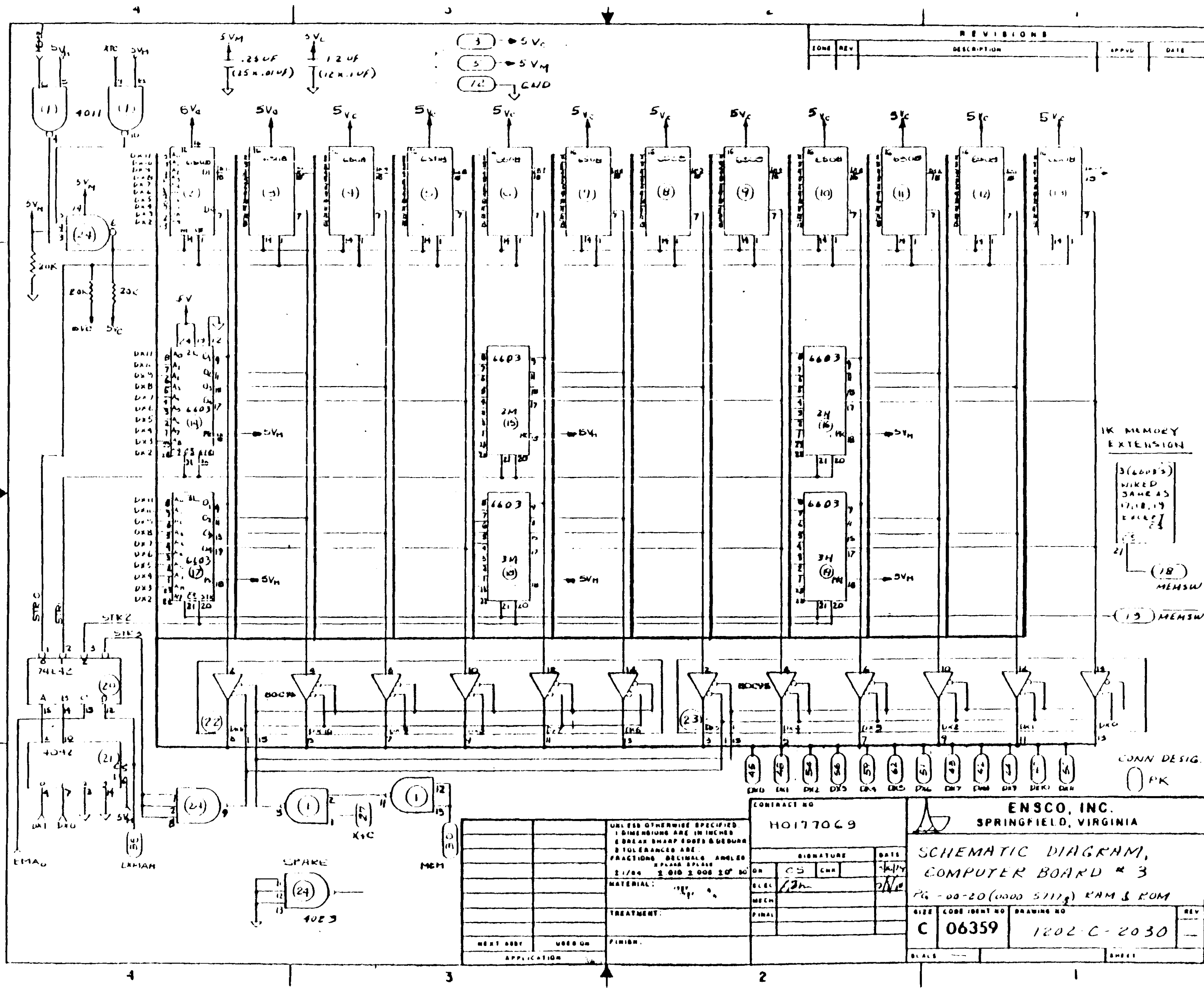
ENSCO, INC.
SPRINGFIELD, VIRGINIA

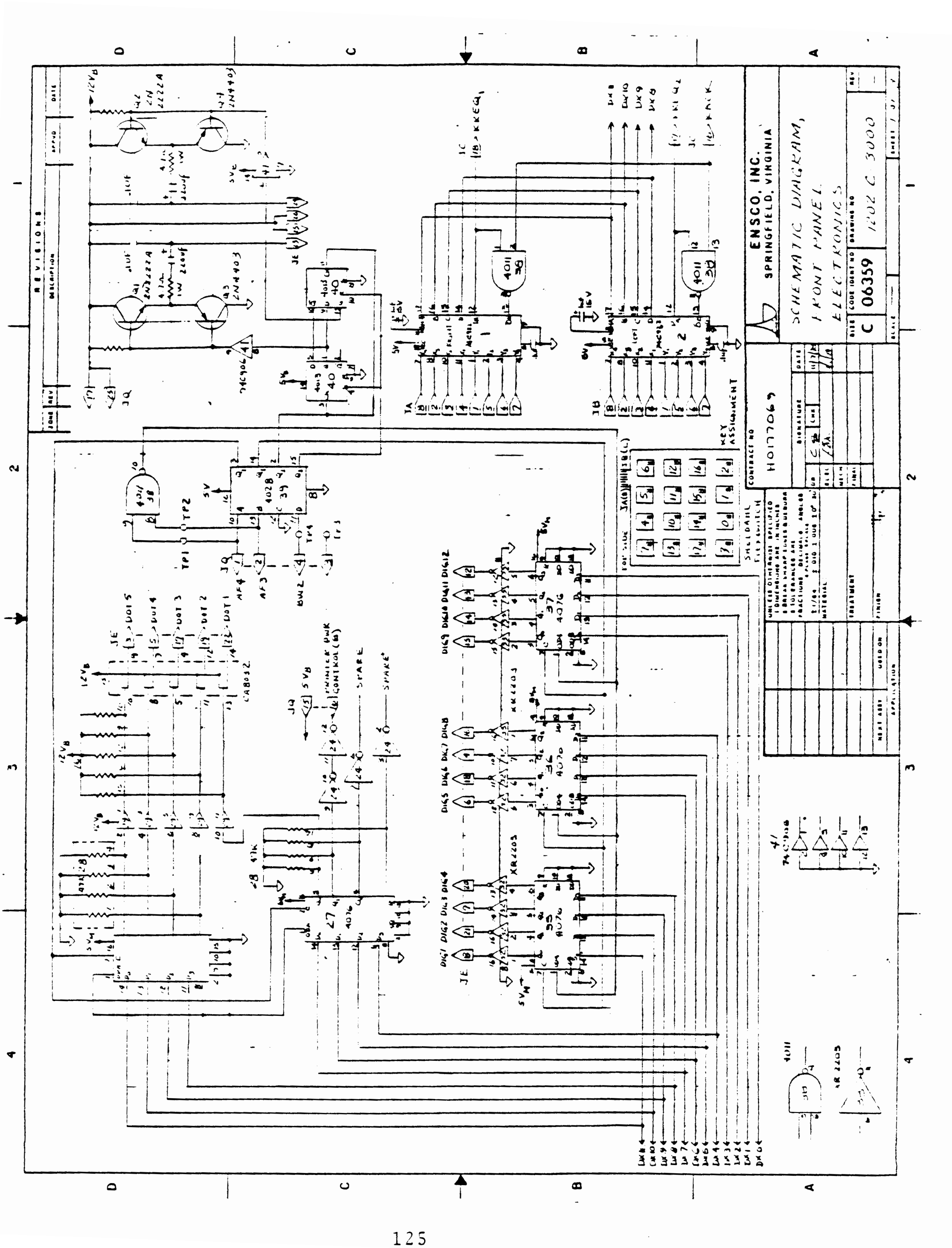
SCHEMATIC DIAGRAM, COMPUTER BOARD #2 - PAGE 21-30 (6000_8 - 7777_8) FR 6100 CPU

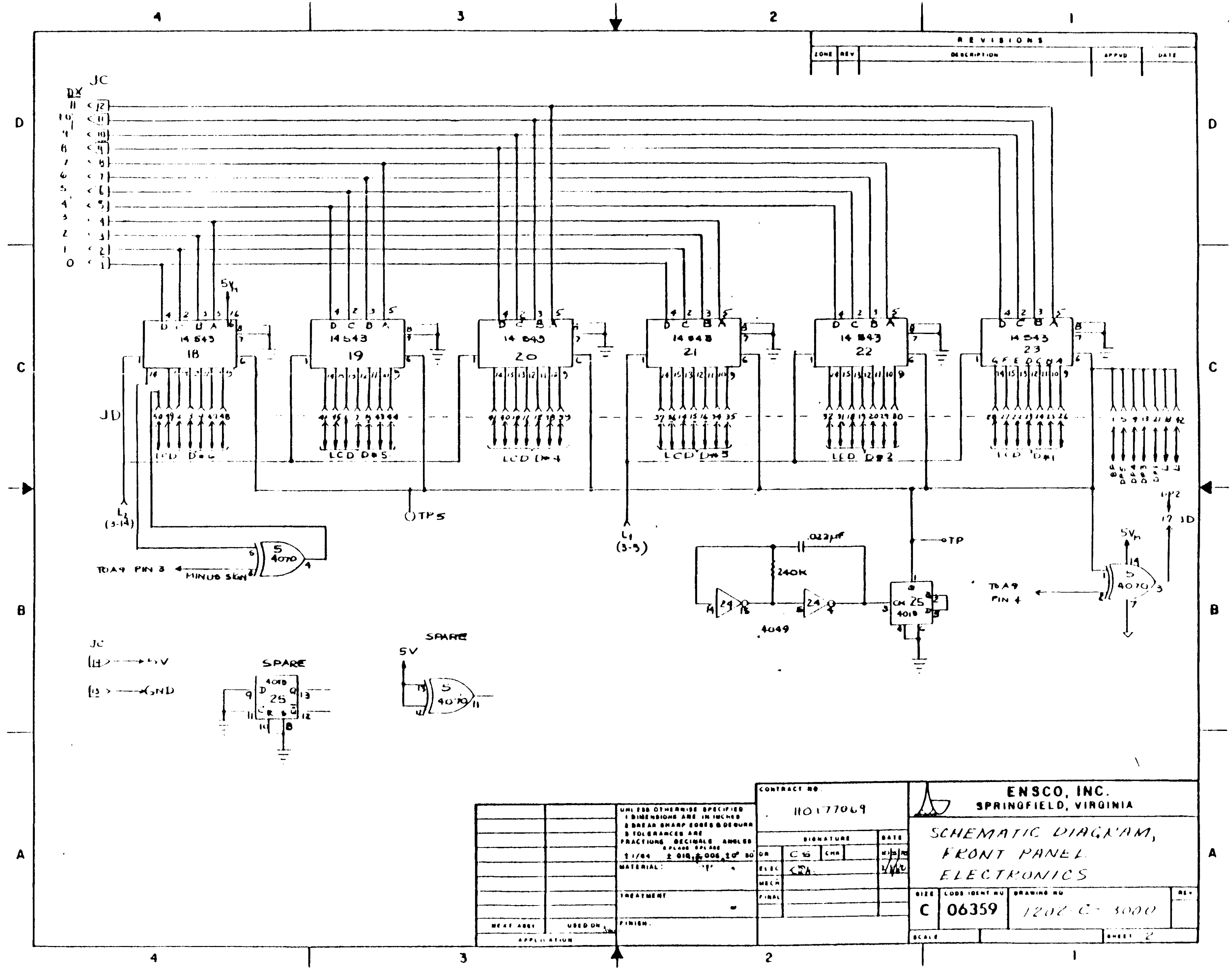
SIZE C | CODE IDENT NO 06359 | DRAWING NO 1202-C 2028

SHEET 1 OF 2

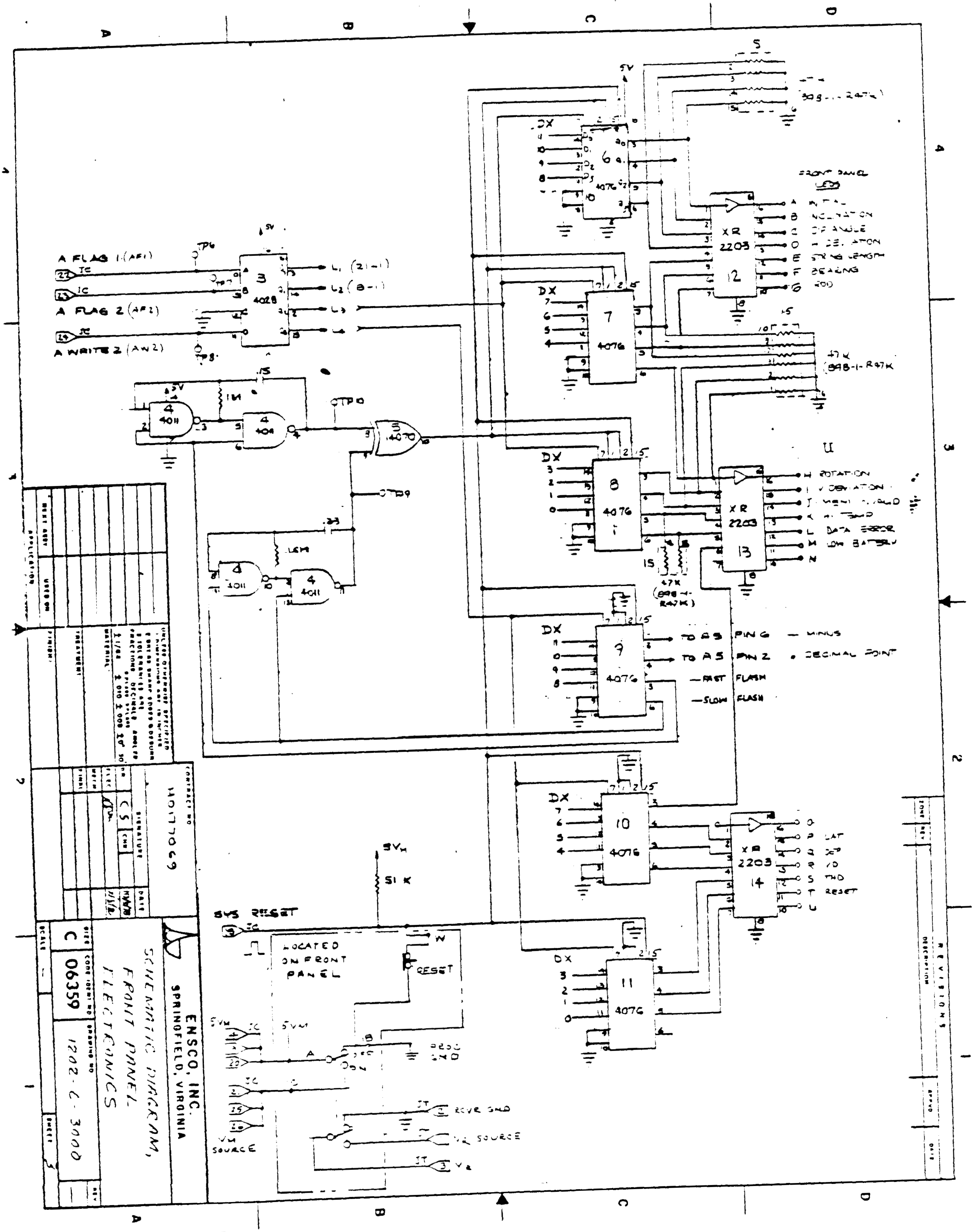

ENSCO, INC.
SPRINGFIELD, VIRGINIA
SCHEMATIC DIAGRAM,
COMPUTER BOARD #2
SELF TEST
C
06359
1202-C-2028
CONTRACT NO
10170069
CHIPS


ENSCO, INC.
SPRINGFIELD, VIRGINIA
SCHEMATIC DIAGRAM,
COMPUTER BOARD # 3
CONTRACT NO
H0177069
C
06359
1202-C-2030
1K MEMORY EXTENSION
CONN DESIG.
SPARE
REVISIONS

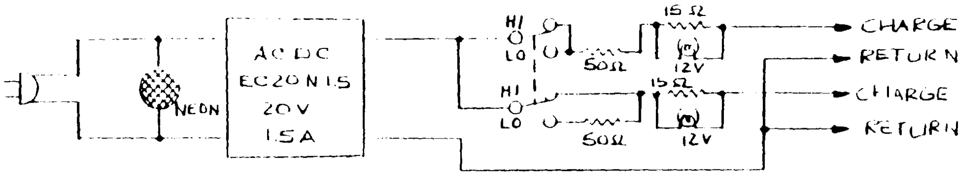

ENSCO, INC.
SPRINGFIELD, VIRGINIA
SCHEMATIC DIAGRAM,
FRONT PANEL
ELECTRONICS
C
06359
1202 C 3000
KEY ASSIGNMENT
REVISIONS



REVISIONS
ZONE
REV
DESCRIPTION
APPVD
DATE
JC
DX
JD
14543
18
19
20
21
22
23
LCD D#5
LCD D#4
LCD D#3
LCD D#2
LCD D#1
5V
TP5
TP
4070
4049
4010
240K
.022µF
TO A9 PIN 8
MINUS SIGN
TO A9 PIN 4
SPARE
GND
CONTRACT NO.
110177069
ENSCO, INC.
SPRINGFIELD, VIRGINIA
SCHEMATIC DIAGRAM,
FRONT PANEL
ELECTRONICS
SIZE C
CODE IDENT NO 06359
DRAWING NO 1202-C-3000
SHEET 2
UNLESS OTHERWISE SPECIFIED
DIMENSIONS ARE IN INCHES
BREAK SHARP EDGES & DEBURR
TOLERANCES ARE
FRACTIONS DECIMALS ANGLES
MATERIAL:
TREATMENT
FINISH
NEXT ASSY
USED ON
APPLICATION


ENSCO, INC.
SPRINGFIELD, VIRGINIA
SCHEMATIC DIAGRAM,
FRONT PANEL
ELECTRONICS
C
06359
1202-C-3000
A FLAG 1 (AF1)
A FLAG 2 (AF2)
A WRITE 2 (AW2)
4028
4011
4070
4076
XR 2203
FRONT PANEL LEDS
TO AS PIN 6
TO AS PIN 2
FAST FLASH
SLOW FLASH
SYS RESET
LOCATED ON FRONT PANEL
RESET
51 K

The following schematics represent auxillary equipment developed during this project, but are not part of either the downhole or uphole package. None of these items are required for operational use.



NOTES
1. ALL RESISTORS = 10W
2. HI WILL CHARGE IN 14 HOURS MAX
3. LO WILL TRICKLE CHARGE

ENSCO, INC.
SPRINGFIELD, VIRGINIA

Schematic Diagram
Vehicle Battery Charger

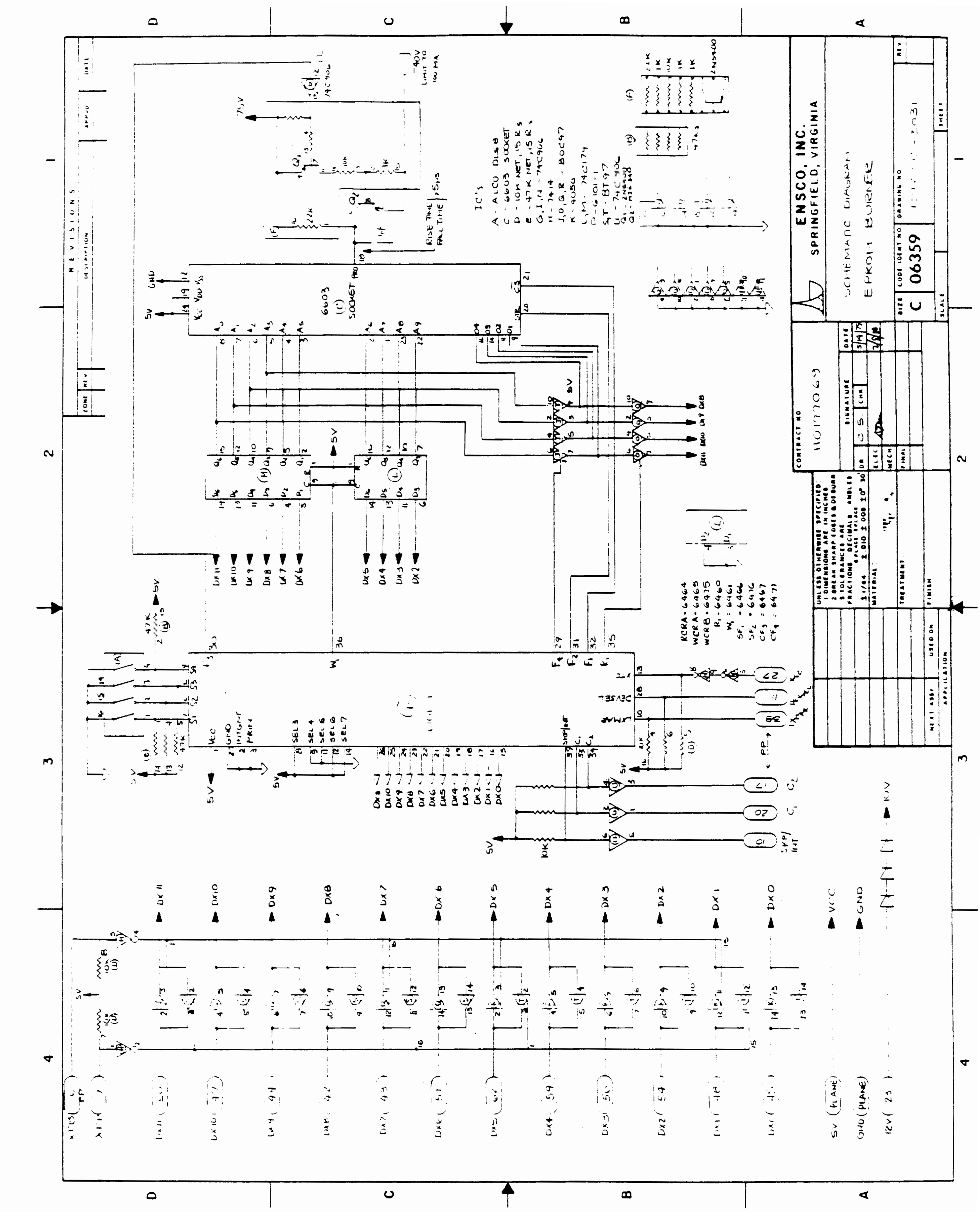
CONTRACT NO.	110177069	
	SIGNATURE	DATE
DR	C.S. CHK	12/8/78
ELEC	Ow	2/1/80
MECH		
FINAL		

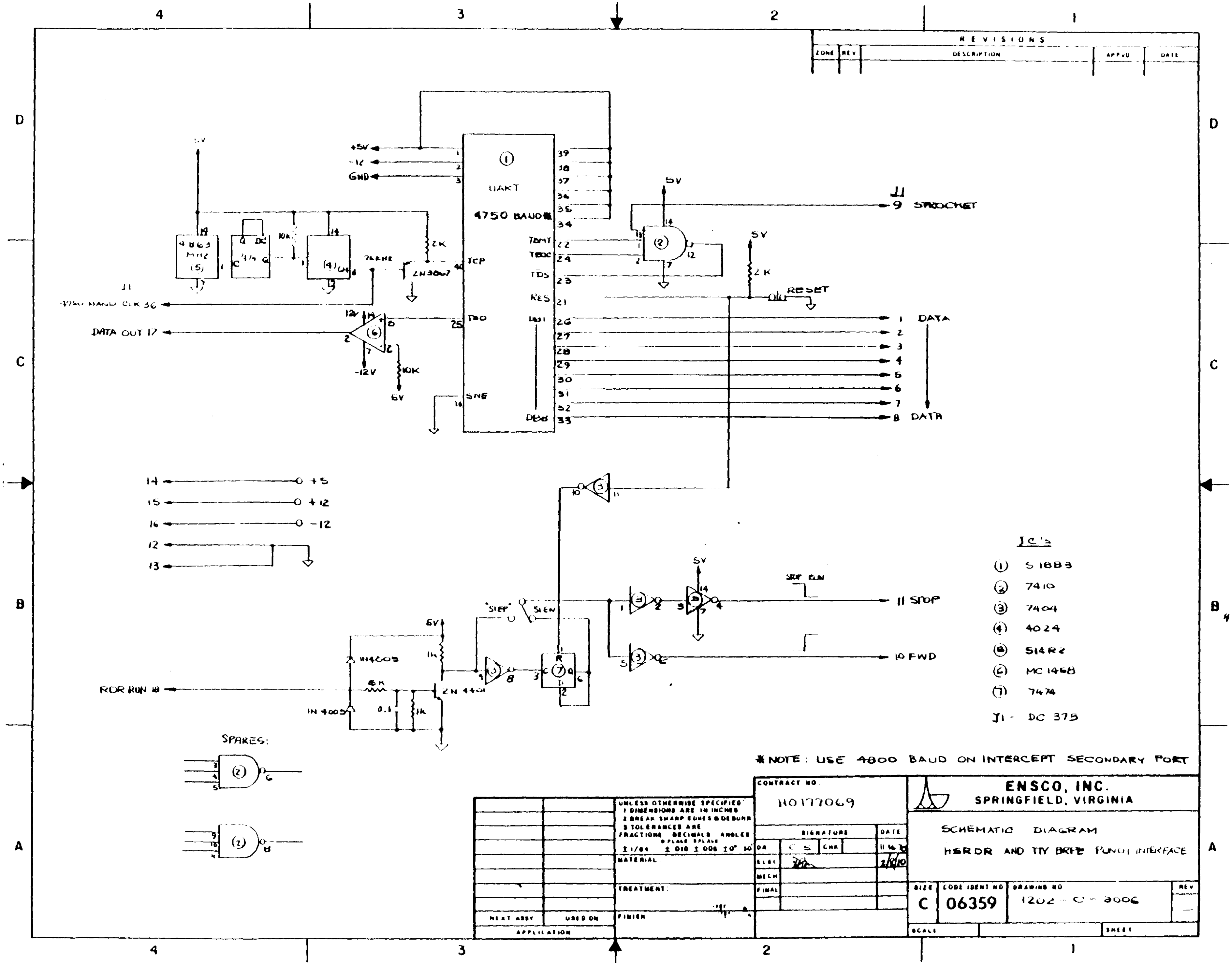
UNLESS OTHERWISE SPECIFIED:
1 DIMENSIONS ARE IN INCHES
2 BREAK SHARP EDGES & DEBURR
3 TOLERANCES ARE:
FRACTIONS ±1/64; DECIMALS 2 PLACE ±.010, 3 PLACE ±.005; ANGLES ±0° 30'
MATERIAL:
TREATMENT:
FINISH:

NEXT ASSY	USED ON
APPLICATION	

SIZE	CODE IDENT NO	DRAWING NO.	REV
B	06359	1202-B-2029	—

SCALE — SHEET


ENSCO, INC.
SPRINGFIELD, VIRGINIA
SCHEMATIC DIAGRAM
EPROM BURNER
C 06359
6603 (C) SOCKET PRO
IC's
A - ALCO DIS8
C - 6603 SOCKET
H - 7414
K - 4050
P - 6101-1
ST - 8T97


REVISIONS
ZONE
REV
DESCRIPTION
APPVD
DATE
UART
4750 BAUD
+5V
-12
GND
TBMT
TEOC
TDS
RES
TCP
TBO
SNE
DB8
2N3807
76KHZ
4750 BAUD CLK 36
DATA OUT 17
-12V
10K
6V
5V
2K
RESET
9 SPROCKET
DATA
14
15
16
12
13
+5
+12
-12
"STEP"
SLEW
STOP RUN
11 STOP
10 FWD
RDR RUN 18
1N4005
IN 4005
2N 4401
SPARES:
IC's
(1) S 1883
(2) 7410
(3) 7404
(4) 4024
(5) 514R2
(6) MC 1458
(7) 7474
J1 - DC 37S
* NOTE: USE 4800 BAUD ON INTERCEPT SECONDARY PORT
CONTRACT NO.
H0177069
ENSCO, INC.
SPRINGFIELD, VIRGINIA
SCHEMATIC DIAGRAM
HSRDR AND TTY BRPE PUNCH INTERFACE
SIZE
C
CODE IDENT NO
06359
DRAWING NO
1202 - C - 3006
REV
SCALE
SHEET
SIGNATURE
DATE
MATERIAL
TREATMENT
FINISH
NEXT ASSY
USED ON
APPLICATION

The microprocessor employed in the uphole processor is the Intersil IM6100. It is a 12 bit CMOS type LSI Integrated Circuit that evaluates the software of the Digital Equipment Corporation (DEC) PDP8/E. All of the assembly language programs listed below are assembled using PDP8/E assembler available from DEC.

COMPUTER PROGRAM INDEX

PROGRAMS	
ACC	Accumulate keyboard #'s
ANG,AVG	Displays angle average
ANGA,ANGE	Displays angle; changes keyboard # to radians
AON	Turns on APU power
APU DRIVERS	FLT; DIVF; ADDF; SUBF; PUSH; ARTAN; POP; MULF; MULD; ARSIN; SORT; FIX; DIVD; SUBD; SINE; CRAB; BW; WTAPUF; RDAPUF
APU OPERATORS	LDS; ADDS; MULS; XCH CHS
AVGV	Averages values
BATCHK	Checks batteries
BLANK & DISPR	Writes Display
BRTAB	KYSR branch table
CHEK	BATCHK extended
CHLITE	Changes lights
COM,COM1	Compares 2 values for out of limits
CONOE	Continue or enter
CONV	Displays memory
DATA	Accepts receiver data
DATCAL	Calculates data; battery condition and temperature
DAT1	DATCAL extended
DELAY	Delay
DIP/CAL	Calculates dip angle
DISCO	Displays code
DISTR	Distributes data for APU
DOOB	Loads and floats #
ENT	Enters 10,000
EXEC	Examines and modifies
EXEC OVERFLOW	EXEC extended
EXITE	EXEC extended

COMPUTER PROGRAM INDEX (CONT'D.)

FAULT	Handles the 9 code
GET	Gets a data word
GETIN	Computes initial conditions
GTIN	Sequences initial conditions
GTIN EXTENDED	Extends rouginte GTIN
INIT	Initialization bootstrap
INITCO	Initial conditions print routine
KYBLK	Key blank; KYSR patch
KYEX	KYSR extended
KYSR	Left-hand keyboard service routine
KYSRC	KYSR calling routine
LOA,B	Lights off - A,B
LSW	Least significant word
MAIN1	Main program, part 1
MAIN2	Main program, part 2
MA1EX	MAIN1 extended
MONITOR	System monitor
M2EX	MAIN2 extended
NORM	Normalizes data
ONES FILLER	Fills memory with 1's
PIAS	Pi; add or subtract
POF	Adds .005
PRINT	Operates printer
PRINT ROUTINES	INCO; RST; SUR
PROC1	Process 1
PROC2	Does survey calculations
PROM BURNER	Burns programmable read-only memory chips
PROPA	Process 1 extended
RBAT	Checks receiver batteries
RDT	Handles data monitoring
RESTR	Restart-print routine
RESTART	Restart
RSTC	Restart calling routine

```
            [P1AS] /from P1...Add or Subtract
            *2305
2305  1043  P1AS, TAD PBUF;/ if PBUF is 0
2306  7650   SNA CLA;
2307  5320   JMP P10; /return
2310  4172   CALL; /otherwise, load P1 and proceed
2311  6144   PI;
2312  1033   TAD KEYT;  /if keyt hard 0
2313  7650   SNA CLA;
2314  5317   JMP P13 /add P1
2315  4155   S;        /otherwise, subtract P1
2316  5320   JMP P10
2317  4153  P13, A
2320  5575  P10, RETURN

            [/NORM]
            *2337
2337  7774  FORM, -4;
2340  7775  THM, -3
2341  3042  NORM, DCA CTR2; /make CTR2 point to beginning of data
2342  1340   TAD THM; /make CTR count 3 things
2343  3020   DCA CTR;
2344  1042   TAD CTR2 /AC point to 1st word
2345  4137  MA, W;    /write the word
2346  4145   P;       /square it
2347  4150   M;
2350  1010   TAD TEM; /"w" makes TEM point to next word
2351  2020   ISZ CTR; /3 times?
2352  5345   JMP MA;  /no, do it again
2353  4153   A;       /yes, do (DW1)^2+(DW2)^2+(DW3)^2
2354  4153   A;
2355  4172   CALL; /√((DW1)^2+(DW2)^2+(DW3)^2)=N
2356  2703   SQRT;
2357  1340   TAD THM /set up CTR for 3 things again
2360  3020   DCA CTR;
2361  1042   TAD CTR2; /point to 1st word again
2362  3010   DCA TEM
2363  4145  NB, P; /save N
2364  1010   TAD TEM; /write DW1
2365  4137   W;
2366  4172   CALL; /do DW1÷N
2367  3144   SCH;
2370  4161   D;
2371  1010   TAD TEM; /point back to DW1
2372  1337   TAD FORM; /replace DW1 with DW1÷N
2373  4142   F;
2374  2020   ISZ CTR; /3 times?
2375  5363   JMP NB /no, do it again
2376  5575  RETURN /yes
```

```
/PROC1
P=4145;
M=4150;
F=4142;
W=4137;
S=4156;
SINE=2723;
ARSIN=2677;
ARTAN=2655
D=4161;
XCH=3144;
A=4153;
PBUF=43;
KEYT=33;
STATUS=4347;
CALL=4172;
RETURN=5575
TEM=10;
COS=6136;
PI=6144;
SQRT=2703;
CTR2=42;
CTR=20;
CHS=3761;
POP=2661;
PROPA=6260
*2000
2000   0373   PIT, 373;
2001   0257   SGX, 257;
2002   0267   SGY, 267;
2003   0263   SGZ, 263;
2004   0253   XCOS, 253;
2005   0243   YCOS, 243;
2006   0247   ZCOS, 247
2007   0513   INC2, 513;
2010   0357   COST, 357;
2011   0317   DIP, 317;
2012   0323   SIND, 323;
2013   0327   COSD, 327;
2014   0233   COSP, 233;
2015   0237   SINP, 237
2016   0333   PSI, 333;
2017   0223   P1, 223;
2020   0227   P2, 227;
2021   2020   PCO, PCO-1;
2022   0327     327;
2023   0243     243;
2024   0172     172;
2025   2024   TWO, TWO-1;
2026   0000     0;
2027   0200     200;
2030   0002     2
```

```
2031  7200   PROC1, CLA;
2032  1201    TAD GGX;
2033  4137    W;
2034  4172    CALL;
2035  2677    ARSIN;
2036  4145    P;
2037  1200    TAD FIT;
2040  5641    JMP I .+1; /patch in PROPA (W;XCH;CHS;A)
2041  6260    PROPA;
2042  1207    TAD INC2
2043  4142    R;
2044  4172    CALL;
2045  6136    COS;
2046  1210    TAD COST;
2047  4142    R;
2050  1211    TAD DIF;
2051  4137    W;
2052  4145    P;
2053  4172    CALL;
2054  2723    SINE;
2055  1212    TAD SIND;
2056  4142    R;
2057  4172    CALL;
2060  6136    COS
2061  4145    P;
2062  1213    TAD COSD;
2063  4142    R;
2064  1210    TAD COST;
2065  4137    W;
2066  4150    M;
2067  1204    TAD XCOS;
2070  4137    W;
2071  1212    TAD SIND;
2072  4137    W;
2073  1201    TAD GGX;
2074  4137    W;
2075  4150    M;
2076  4156    S
2077  4172    CALL;
2100  3144    XCH;
2101  4161    D;
2102  1214    TAD COSF;
2103  4142    R;
2104  1202    TAD GGY;
2105  4137    W;
2106  4172    CALL;
2107  3761    CHS;
2110  4172    CALL;
2111  4347    STATUS;
2112  3033    DCA KEYT
2113  1203    TAD GGZ;
2114  4137    W;
2115  4172    CALL;
2116  3761    CHS;
2117  4172    CALL;
2120  4347    STATUS;
2121  3043    DCA FBUF;
2122  4161    D;
```

```
2123  4172   CALL;
2124  2655   ARTAN;
2125  4172   CALL;
2126  2305   PIAS
2127  4145  P;
2130  1216   TAD PII;
2131  4142   R;
2132  4145   P;
2133  4172   CALL;
2134  2723   SINE;
2135  1206   TAD ZCOS;
2136  4137   W;
2137  4150   M;
2140  4172   CALL;
2141  3144   XCH;
2142  4172   CALL;
2143  6136   COS;
2144  1205   TAD YCOS
2145  4137   W;
2146  4150   M;
2147  4156   S;
2150  1213   TAD COSD;
2151  4137   W;
2152  4161   D;
2153  4172   CALL;
2154  4347   STATUS;
2155  3033   DCA KEYT;
2156  1214   TAD COSP;
2157  4137   W;
2160  4145   P
2161  4172   CALL;
2162  4347   STATUS;
2163  3043   DCA FBUF;
2164  4172   CALL;
2165  2661   POP;
2166  4161   D;
2167  4172   CALL;
2170  2655   ARTAN
2171  4172  CALL;
2172  2305   PIAS;
2173  4172   CALL;
2174  3761   CHS;
2175  5776   JMP I .+1;
2176  2200   PP
            *2200
2200  1207  PP, TAD MSVR;
2201  4137   W;
2202  4156   S;
2203  1210   TAD BER2;
2204  4142   R;
2205  5575   RETURN
2206  0337  PHI, 337;
2207  0347  MSVR, 347;
2210  0507  BER2, 507
```

```
                    DATA
                        TEM0=77
                    CALL=4172              Loads up the data bytes
                        RETURN=5575
                        DATD=74
                        READD=6500         Comes back with AC=0...timeout
                        TEM1=26            error, >25 ms between clks
                        TEM2=DATD                    1...no errors
                        CTR=20
                        CTR1=22
                        CTR2=42
                        BS2=6443
                        RBUF=43
                        LGA=3154

                        *2400

2400  7742  TM,      -36
2401  0243  DAT1,    243
2402  0001  MSK,     1
2403  7766  TE,      -12
2404  0006  SI,      6

2405  7305  DATA,    CLA CLL IAC RAL  /0002_8
2406  4172           CALL
2407  3234           DISCO /display "2"
2410  4172           CALL
2411  3154           LGA/lights off
2412  7120           STL/make sure all of L4 is off
2413  4172           CALL
2414  2516           CHLITE
2415  1200           TAD TM/set CTR up to count 30_10 data bits that will
2416  3020           DCA CTR/#1 has already been       be thrown away
2417  5224           JMP GARB1      thrown away by EXEC, so
2420  4172  GARB,    CALL        /jump right to GARB1
2421  2557           WAIT
2422  7450           SNA
2423  5575           RETURN
2424  3077  GARB1,   DCA TEM0/has a 1 if no timeout error here
2425  2020           ISZ CTR
2426  5220           JMP GARB/throw away another one
2427  1201           TAD DAT1/addr of 1st 4 byte data location
2430  3010           DCA 10/into an autoindex
2431  1203           TAD TE/CTR1 is channel counter, set up with 10_10
2432  3022           DCA CTR1
2433  3043  A,       DCA RBUF/clear PFOB
2434  4172           CALL/get a data word of 12_10 bits
2435  3727           GET
2436  7650           SNA CLA/timeout error?
2437  5575           RETURN /yes
2440  1074           TAD TEM2/get data word
2441  7004           RAL/adjust it to be 2's complement binary
2442  7040           CMA
```

lower order 8 bits — higher order 4 bits

```
2443   7010        RAR
2444   3074        DCA TEM2/and save it
2445   4172        CALL/form 16 bit # in TEM2(LO) & TEM1(HI)
2446   3203        DISTR
2447   1074        TAD TEM2/get data word LO
2450   3410        DCA I 10/put in 1st of 4 bytes (i.e., location 244 & 245)
2451   1026        TAD TEM1/get data word HI
2452   3410        DCA I 10/put in 2nd of 4 bytes. Now a single precision 16 bit
2453   3410        DCA I 10 /INCR autoindex     integer is available in the for
2454   3410        DCA I 10 /INCR autoindex     the APU likes
2455   4172        CALL/wait for next clock
2456   2557        WAIT
2457   7650        SNA CLA/timeout error?
2460   5575        RETURN/yes
2461   7300        CLA CLL/no, get parity bit
2462   6500        READD
2463   0202        AND MSK/mask off LSB, bit 11
2464   1043        TAD FBUF/add the parity counter
2465   7010        RAR/get CSB of result into link
2466   7630        SZL CLA/Parity OK?
2467   5273        JMP C /no
2470   2022        ISZ CTR1/parity OK, chalk up another channel in CTR1
2471   5233        JMP A /get another one
2472   5305        JMP D /all done
2473   7040   C,   CMA/turn on data error light
2474   7421        MQL
2475   7010        RAR/link is set, so make bit 0=1 for "data error" light
2476   4172        CALL/do it
2477   2516        CHLITE
2500   1204        TAD SI /display a "6" for parity error
2501   4172        CALL
2502   3234        DISCO
2503   3077        DCA TEM0/put a 0 in TEM0 to signal "data error"
2504   5233        JMP A /get another word without stopping
2505   4172   D,   CALL/get receiver data
2506   3727        GET
2507   7650        SNA CLA/timeout error?
2510   5575        RETURN/yes
2511   1074        TAD TEM2/TEM2 has binary receiver data
2512   3410        DCA I 10 /put it into last data location
2513   1077        TAD TEM0/recall error info
2514   5575        RETURN
```

CHLITE /CHANGE LITE

```
                                L3R=44
                                L4R=21
                                WCRAA=6425
                                AW2=6431
                                TEMC=73
```

LINK: 0=L3 latches
1=L4 latches

MQ: 0=turn off an item
0=turn on an item

AC: bit to be turned on or off
turn on-all zeros but desired bit
turn off-all ones but desired bit

```
                                *2516
2516   3026   CHLITE,   DCA TEM1/hold AC
2517   7430             SZL/L3 or L4?
2520   1352             TAD L4/AC=1400(8) signifies L4 latches
2521   1351             TAD L3/AC=1000(8) signifies L3 latches
2522   6425             WCRAA/select the appropriate latch
2523   7630             SZL CLA
2524   5330             JMP T
2525   1353             TAD CH3/if L3, load TEMC with L3R address
2526   3073             DCA TEMC
2527   5332             JMP U
2530   1354   T,        TAD CH4/if L4, load TEMC with L4R address
2531   3073             DCA TEMC
2532   7521   U,        SWP/see if it's a turn on or a turn off
2533   7640             SZA CLA
2534   5341             JMP CH2/its a turn on
2535   1473             TAD I TEMC/get contents of latch register for turn off
2536   0026             AND TEM1/turn off the selected bit (i.e., latch the register)
2537   6431             AW2 /by doing an AW2
2540   5346             JMP EXIT
2541   1473   CH2,      TAD I TEMC/get contents of latch register
2542   7421             MQL/put in MQ so can do an OR
2543   1026             TAD TEM1/get the turn on word
2544   7501             MQA/OR the latch register with the desired turn on word
2545   6431             AW2/turn on that bit
2546   3473   EXIT,     DCA I TEMC/update the latch holding register
2547   7100             CLL
2550   5575             RETURN
2551   1000   L3,       1000
2552   0400   L4,       400
2553   0044   CH3,      L3R
2554   0021   CH4,      L4R
```

/WAIT — Return with AC=1 if no timeout error, else AC=0

```
2555  0005  FI,     5
2556  4416  WATE,   -3362
2557  1356  WAIT,   TAD WATE/load CRT2 with timeout delay
2560  3042          DCA CTR2
2561  6443  W1,     BSZ/data clock?
2562  5365          JMP W2 /no, jump to count down for timeout
2563  7201          CLA IAC /set AC=1
2564  5575          RETURN
2565  2042  W2,     ISZ CTR2/incr timeout counter
2566  5361          JMP W1/check again for data clock
2567  7340          CLA CLL CMA/signal "L3" & "turn on" to CHLITE
2570  7421          MQL
2571  7130          STL RAR /set "data error" bit
2572  4172          CALL
2573  2516          CHLITE /tight up "data error"
2574  1355          TAD FI /send "5" message code to display
2575  4172          CALL
2576  3234          DISCO
2577  5575          RETURN
```

/GET — Forms a raw 12 bit data word & return with PBUF indicating parity of that word

```
                    *3725

3725  0001  MSK1,   1
3726  7764  TW,     -14
3727  1326  GET,    TAD TW/CTR will count 12_10 bits
3730  3020          DCA CTR
3731  3074          DCA TEM2/clr TEM2, the data word accumulator (DWA)
3732  7004  GET1,   RAL/get link back in bit 11
3733  1074          TAD TEM2/put into DWA
3734  7004          RAL/move to the left
3735  3074          DCA TEM2/store back
3736  4172          CALL /wait for a data clk
3737  2557          WAIT
3740  7450          SNA/timeout error?
3741  5575          RETURN/yes
3742  7300          CLA CLL
3743  6500          READD /read a data bit (appears in AC's LSB)
3744  0325          AND MSK1 /and mask it off
3745  7010          RAR /put it in link
3746  7430          SZL/is it a 1?
3747  2043          ISZ PBUF/yes, coutn it in PBUF
3750  2020          ISZ CTR/no or yes, count # of bits, skip if 12_10 counted
3751  5332          JMP GET1/get another one
3752  7004          RAL/put LSB of data into bit 11
3753  1074          TAD TEM2 /add to DWA
3754  3074          DCA TEM2 /& replace
3755  7101          CLL IAC /signal no timeout error
3756  5575          RETURN
```

/DIITR

Forms a 16 bit 2's complement binary # for APU from data word

```
                    *3200
3200  0010  MASK,   10
3201  0360  MIN,    360
3202  7774  FR,     -4
3203  7621  DIITR,  CAM
3204  1202          TAD FR /set up CTR to count 4 times
3205  3020          DCA CTR
3206  1074          TAD TEM2/get data word
3207  7100  DII1,   CLL/get 4 msb's into 4 LSB's of MQ
3210  7004          RAL
3211  7521          SWP
3212  7004          RAL
3213  7521          SWP
3214  2020          ISZ CTR
3215  5207          JMP DII1
3216  7012          RTR/put 8 LSB's of data word back in place
3217  7012          RTR
3220  3074          DCA TEM2/store in TEM2, call it DATA WORD LOW
3221  7521          SWP
3222  3026          DCA TEM1/store in TEM1, call it DATA WORD HI
3223  1026          TAD TEM1
3224  0200          AND MASK/mask off sign bit
3225  7650          SNA CLA /negative?
3226  5230          JMP .+2
3227  1201          TAD MIN/its negative...fill in one's for the 8 bit APU
3230  1026          TAD TEM1/get DATA WORD HI
3231  3026          DCA TEM1/restore
3232  7100          CLL
3233  5575          RETURN
```

/DIICO

Enter with # to be message in AC exits with that # saved in TEMD

```
                    BLANK=3606
                    TEMD=75
                    DIS3=3672
                    D1=24
                    D2=25
                    DISPR=3630

            *3234
3234  3075  DIICO, DCA TEMD;/save AC
3235  4172   CALL;/blank display
3236  3606   BLANK;
3237  1075   TAD TEMD;/get display number
3240  1250   TAD DMSK /put all one's in first two MSD's of display
3241  3025   DCA D2;/put in D2
3242  7040   CMA;/put all 1's in last 3 MSD's of display
3243  3024   DCA D1;
3244  4172   CALL;/DIS3 puts D2-D1 onto display
3245  3672   DIS3;
3246  7200   CLA;
3247  5575   RETURN;
3250  7760   DMSK, 7760
```

```
VDVT
*3252

3252  0373  FIT, 373;
3253  0327  LD, 327;
3254  0433  VD, 433;
3255  0453  VDEV, 453
3256  4137  VDVT, W;
3257  1252   TAD FIT;
3260  4137   W;
3261  4156   D;
3262  4172   CALL;
3263  2723   DINE;
3264  4150   M;
3265  1253   TAD LD;
3266  4137   W;
3267  4150   M
3270  1254  TAD VD;
3271  4137   W;
3272  4172   CALL;
3273  3144   XCH;
3274  4156   D;
3275  1255   TAD VDEV;
3276  4142   F;
3277  5575   RETURN
```

ENT /used by DATCAL to enter $10,000_{10}$ and float it

```
*3765

3765  0020  THA, 20;
3766  0047  THB, 47
3767  1365  ENT, TAD THA; /write 0020 (octal)
3770  6441   BW1;
3771  7200   CLA;
3772  1366   TAD THB;/write 0047 (octal)
3773  6441   BW1;
3774  4200   F;/float it
3775  5575   RETURN

F=JMS FLT
FLT=164
BW1=6441
XCH=3144
W=4137
D=4156
DINE=2723
M=4150
F=4142
```

```
[ SUM ]
                    CALL=4172
                    RETURN=5575
                    CHS=3761
                    KYCTR=60
                    K1=34
                    TEM=10
                    TENF=220
                    CTR=20
                    CTR1=22
                    MINUS=31
                    SKP3=6452
                    WCRBB=6455
                    WCRAB=6445
                    BW1=6441
                    TEM1=26
                    REG6=343
                    CONV=6014
                    KEYCTR=27
                    SUMT=76
                    R=4142;
               AON=5440

                    *3000
3000  0005  FIVS,   5
3001  0012  TEN,    12
3002  7775  TM,      -3
3003  0006  SIX,    6
3004  0343  R6,     REG6
3005  0034  K,      K1
3006  0217  TEN2,   TENF-1
3007  4172  BEGIN, CALL
3010  5440          AON
3011  7200          CLA
3012  3060          DCA KYCTR
3013  1605          TAD I K
3014  7040          CMA
3015  7440          SZA
3016  7040          CMA
3017  4172          CALL
3020  3124          LDS
3021  2060  SUM1,   ISZ KYCTR
3022  1060          TAD KYCTR
3023  1205          TAD K
3024  3026          DCA TEM1
3025  1426          TAD I TEM1
3026  7040          CMA
3027  7650          SNA CLA
3030  5247          JMP SUM2
3031  1201  TAD TEN
3032  4172  CALL
3033  3124  LDS
3034  4172          CALL
3035  3140          MULS
3036  1426  TAD I TEM1
3037  4172          CALL
3040  3124          LDS
3041  4172          CALL
3042  3134          ADDS
```

```
3043   1060              TAD KEYCTR
3044   1202              TAD TM
3045   7640              SZA CLA
3046   5221              JMP SUM1
3047   4164   SUM2,      JMS F
3050   1205              TAD K
3051   1203              TAD SIX
3052   3026              DCA TEM1
3053   1426              TAD I TEM1
3054   4172              CALL
3055   3124              LDS
3056   4164   JMS F
3057   1206              TAD TEM2
3060   4137   JMS WT
3061   4161   JMS D
3062   1200              TAD FIVE
3063   1205              TAD K
3064   3026              DCA TEM1
3065   1426              TAD I TEM1
3066   4172              CALL
3067   3124              LDS
3070   4164   JMS F
3071   4153   JMS A
3072   1206   TAD TEM2
3073   4137   JMS WT
3074   4161   JMS D
3075   4153   JMS A
3076   7100              CLL
3077   1031              TAD MINUS
3100   7010              RAR
3101   7620              SNL CLA
3102   5305              JMP SUM3
3103   4172              CALL
3104   3761              CHS
3105   1204   SUM3, TAD R6;
3106   4142    R;
3107   1027    TAD KEYCTR
3110   7450    INA;
3111   5575    RETURN
3112   3076    DCA SUMT;
3113   1204    TAD R6;
3114   4172    CALL;
3115   6014    CONV;
3116   1204    TAD R6;
3117   4137    JMS WT
3120   1076    TAD SUMT;
3121   3027    DCA KEYCTR;
3122   5575    RETURN
```

APU OPERATORS

```
                *3124
3124   6441   LDS,     BW1     /take a number in the AC and load it into
3125   7300            CLA      APU as a single fixed #
3126   6441            BW1
3127   5575            RETURN
3130   0071   XCHD,    71
3131   0156   SMUL,    156
3132   0154   SADD,    154
3133   2734   BWX,     BW
3134   4172   ADDS,    CALL    /add TOS and NOS as single fixed
3135   2727            CRAB
3136   1332            TAD SADD /get ADDS code
3137   5733            JMP I BWX  /go do the command and return
3140   4172   MULS,    CALL    /multiply TOS and NOS as single fixed
3141   2727            CRAB
3142   1331            TAD SMUL
3143   5733            JMP I BWX
3144   4172   XCH,     CALL   /exchange TOS and NOS as double #'s
3145   2727            CRAB
3146   1330            TAD XCHD
3147   5733            JMP I BWX
```

/LOA,B /Lights off A&B

```
                *3151        Turns off LED's & other bits in the latcher, excep
3151   0003   L1, 3;                        LOA -   .
3152   6000    L3, 6000;                    LOB - all but -,. and error lites
3153   0023   L4, 23
3154   7320   LOA, CLA STL;/tell CHLITE to turn off L4's
3155   7421    MQL;
3156   1351    TAD L1;/turn off all but minus & decimal point
3157   4172    CALL;
3160   2516    CHLITE;/comes back with CLL
3161   7421    MQL;/turn off all of L3
3162   4172    CALL;
3163   2516    CHLITE
3164   7320   LOB, CLA STL;/set up to turn off L4's
3165   7421    MQL;
3166   1353    TAD L4;/turn off all but LO BATT & - & .
3167   4172    CALL;
3170   2516    CHLITE;
3171   7421    MQL; /turn off L3's
3172   1352    TAD L3;/except for HI TEMP & DATA ERROR
3173   4172    CALL;
3174   2516    CHLITE;
3175   5575    RETURN

                       CHLITE=2516
```

```
                    ER1=6440

                    *2600

                    APU DRIVER ROUTINES

                    F=164;      /Arithmetic Processor Unit
              D=161;
              A=153;
              S=156;            FLT, DIVF, ADDF, SUBF, PUSH & MULF can be
              P=145;            executed with a single instruction like
              M=150;            JMS D; where D is the RAM location for a
              WT=137;           subroutine calling program loaded by INIT
              RD=142            All the rest require, e.g., CALL; POP

2600  0400    CRA,   400        Result always in TOS if a function
2601  0003    COS,   3
2602  0035    FLTS,  35
2603  0023    FDI,   23
2604  0020    FAD,   20
2605  0007    ATAN,  7
2606  0070    POPD,  70
2607  0056    DMUL,  56
2610  0005    ASIN,  5
2611  0021    FSU,   21
2612  0067    PTOD,  67
2613  0022    FMUL,  22
2614  0037    FIXS,  37
2615  0057    DDIV,  57
2616  0055    DSUB,  55
2617  4172    FLT,   CALL /set up APU for command
2620  2727           CRAB
2621  1202           TAD FLTS /get FLOAT code (floats a single fixed #)
2622  4172           CALL/go do the command
2623  2734           BW
2624  5564           JMP I F/exit through address stored in Page 0
2625  4172    DIVF,  CALL /divide NOS by TOS in float
2626  2727           CRAB
2627  1203           TAD FDI
2630  4172           CALL
2631  2734           BW
2632  5561           JMP I D
2633  4172    ADDF,  CALL /add TOS & NOS in float
2634  2727           CRAB
2635  1204           TAD FAD
2636  4172           CALL
2637  2734           BW
2640  5553           JMP I A
2641  4172    SUBF,  CALL/subtract TOS from NOS in float
2642  2727           CRAB
2643  1211           TAD FSU
2644  4172           CALL
2645  2734           BW
2646  5556           JMP I S
2647  4172    PUSH,  CALL/pushes TOS to NOS in float. Last variable is lost.
2650  2727           CRAB
2651  1212           TAD PTOD
2652  4172           CALL
2653  2734           BW
2654  5545           JMP I P
```

```
2655  4172  AATAN,  CALL /set up APU for commands
2656  2727          CRAB
2657  1205          TAD ATAN/get code for Arc tangent
2660  5334          JMP BW /exit thru BW
2661  4172  POP,    CALL/pop NOS to TOS in double precision
2662  2727          CRAB
2663  1206          TAD POPD
2664  5334          JMP BW
2665  4172  MULF,   CALL/multiply TOSxNOS in float
2666  2727          CRAB
2667  1213          TAD FMUL
2670  4172          CALL
2671  2734          BW
2672  5550          JMP I M
2673  4172  MULD,   CALL /multiply TOSxNOS in double prec. integer
2674  2727          CRAB
2675  1207          TAD DMUL
2676  5334          JMP BW
2677  4172  ARSIN,  CALL/do Arc sin in float
2700  2727          CRAB
2701  1210          TAD ASIN
2702  5334          JMP BW
2703  4172  SQRT,   CALL/do SQRT of TOS
2704  2727          CRAB
2705  7001          IAC/code for SQRT
2706  5334          JMP BW
2707  4172  FIX,    CALL/FIX the TOS from foalt to single precision
2710  2727          CRAB
2711  1214          TAD FIXS
2712  5334          JMP BW
2713  4172  DIVD,   CALL/divide NOS by TOS in double prec. integer
2714  2727          CRAB
2715  1215          TAD DDIV
2716  5334          JMP BW
2717  4172  SUBD,   CALL/subtract TOS from NOS in double prec. integer
2720  2727          CRAB
2721  1216          TAD DSUB
2722  5334          JMP BW
2723  4172  SINE,   CALL/do SINE of TOS
2724  2727          CRAB
2725  7305          CLA CLL IAC RAL
2726  5334          JMP BW
```

```
2727  7200  CRAB,    CLA /set up APU for command
2730  1200           TAD CRA/get code for FLAG1 on, all else off
2731  6445           WCRAB /write CRA of PIE B
2732  7200           CLA
2733  5575           RETURN
2734  6441  BW,      BW1/do the command
2735  6452           SKPS /(or BS3) wait for APU to do it
2736  5335           JMP .-1
2737  7200           CLA
2740  6445           WCRAB /reset PIE B for APU "DATA"
2741  5575           RETURN                                            1st byte of
2742  3010  WTAPUF,  DCA TEM /call WTAPUF by doing JMS 0137, AC=(floating # to be)
2743  6445           WCRAB /set up APU for "DATA"                      written into APU
2744  1376           TAD FM/count 4 things
2745  3022           DCA CTR1                                         arranged:
2746  1410  W1,      TAD I TEM /get 1st (or next) of 4 bytes (  1 LSB; 2--; 3--;)
2747  6441           BW1                                                4 MSB
2750  7200           CLA
                                                                     each byte:
2751  2022           ISZ CTR1/done 4 bytes?                          000/00xx/xxx/xxx
2752  5346           JMP W1/no                                       b0   b11
2753  5537           JMP I WT/yes; exit via zero page
2754  7001  RDAPUF,  IAC/call RDAPUF:JMS0142
2755  3026           DCA TEM1/enter with AC=(1st byte of destination for TOS)-1
2756  6445           WCRAB /set up "DATA" for APU
2757  1376           TAD FM/count 4 things
2760  3022           DCA CTR1
2761  1026           TAD TEM1
2762  1201           TAD C03/add 3 to address, since data comes off MSB 1st from 
2763  3026           DCA TEM1/store back in TEM1
2764  6440  R1,      BR1/1st BR1 gets up APU fo read,but puts garbage in AC
2765  7200           CLA
2766  6440           BR1/2nd BR1 actually reads it
2767  3426           DCA I TEM1/store in destination
2770  1026           TAD TEM1/decrement address pointer
2771  1377           TAD ONM
2772  3026           DCA TEM1/replace
2773  2022           ISZ CTR1/4 times?
2774  5364           JMP R1/no
2775  5542           JMP I RD/yes, exit thru RAM
2776  7774  FM,      -4
2777  7777  ONM,     -1
```

```
                    /BLANK AND DISPR
                                        WCRAA=6425
                                        LDN1=4622
                                        AW2=6431
                                        CALL=4172
                                        RETURN=5575
                                        *20
0020  0000  CTR,                        0
0021  0000  L4R,                        0
0022  0000  CTR1,                       0
0023  0000  AC,                         0
0024  0000  DISPR1,                     0
0025  0000  DISPR2,                     0
0026  0000  TEM1,                       0
0027  0000  KEYCTR,                     0
                                        *3600
3600  1400  L4,                         1400
3601  0400  L2,                         0400
3602  0000  L1,                         0000
3603  7774  DP,                         7774
3604  7773  DP1,                        -5
3605  7772  DP2,                        -6
3606  7200  BLANK,                      CLA
3607  3027              DCA KEYCTR
3610  7040              CMA
3611  3024              DCA DISPR1
3612  7040              CMA
3613  3025              DCA DISPR2
3614  4172              CALL
3615  3673              DIS3
3616  7000              NOP
3617  7200                              CLA
3620  1200                              TAD L4
3621  6425                              WCRAA
3622  7300                              CLA CLL
3623  1021                              TAD L4R
3624  0203                              AND DP
3625  6431                              AW2
3626  3021              DCA L4R
3627  5575                              RETURN
3630  3023  DISPR,                      DCA AC
3631  7004                              RAL
3632  3026                              DCA TEM1
3633  1027                              TAD KEYCTR
3634  1204                              TAD DP1
3635  7650                              SNA CLA
3636  5310                              JMP KEY5
3637  1027                              TAD KEYCTR
3640  1205              TAD DP2
3641  7650                              SNA CLA
3642  5317                              JMP KEY6
3643  1025  DIS1,                       TAD DISPR2
3644  7421                              MQL
3645  1203                              TAD DP
3646  3022                              DCA CTR1
3647  1024                              TAD DISPR1
```

```
3650  7104  DIS2,            CLL RAL
3651  7521                   SWP
3652  7004                   RAL
3653  7521                   SWP
3654  2022                   ISZ CTR1
3655  5250                   JMP DIS2
3656  1023                   TAD AC
3657  3024                   DCA DISPR1
3660  7521                   SWP
3661  3025                   DCA DISPR2
3662  1026                   TAD TEM1
3663  7650                   SNA CLA
3664  5272                   JMP DIS3
3665  7305                   CLA CLL IAC RAL
3666  4172           CALL
3667  4622           LDN1
3670  3026           DCA TEM1
3671  5243                   JMP DIS1
3672  1201  DIS3,            TAD L2
3673  6425                   WCRAA
3674  7200                   CLA
3675  1025                   TAD DISPR2
3676  6431                   AW2
3677  7200                   CLA
3700  1202                   TAD L1
3701  6425                   WCRAA
3702  7200                   CLA
3703  1024                   TAD DISPR1
3704  6431                   AW2
3705  7300                   CLA CLL
3706  1023                   TAD AC
3707  5575                   RETURN
3710  7100  KEY5,            CLL
3711  1023           TAD AC
3712  7006                   RTL
3713  7006                   RTL
3714  1024  DIS4,            TAD DISPR1
3715  3024                   DCA DISPR1
3716  5272                   JMP DIS3
3717  1023  KEY6,            TAD AC
3720  5314                   JMP DIS4
```

```
                 *3757
```

CHS CRAB=2727 CHange Sign

```
3757  2734  BW1,   2734     /ROM ADR OF BW
3760  0025  CHSF,  25
3761  4172  CHS,   CALL
3762  2727         CRAB
3763  1360         TAD CHSF
3764  5757         JMP I BW1
```

ANGA ANGE SYMBOL TABLE

```
A        4153
ANG      5355
ANGA     2214
ANGE     2233
ANGF     2251
AN1      2230
CALL     4172
CHS      3761
D        4161
KEYCTR   0027
P        4145
PF       2276
PI       6144
POF      2257
POOF     5474
POP      2661
RETURN   5575
S        4156
STATUS   4347
TEM8     0051
W        4137

 PC00241 MD5214 A0000 L1 D0
>S2002 7002
>C
```

```
  /ANGA, ANGE       /ANGA takes an angle in radians, converts to 0-2π
                     radians, then gets ANG to display it in degrees
 CALL=4172;
  RETURN=5575;      /ANGE-see next page
  W=4137;
  P=4145;
  STATUS=4347;
  PI=6144
  A=4153;
  ANG=5355;
  D=4161;
  S=4156;
  CHS=3761;
  TEM8=51;
  POP=2661
  POOF=5474;
  KEYCTR=27

 *2214
2214  4137  ANGA, W;/write the value
2215  4145   P;/save
2216  4172   CALL;/+ or -?
2217  4347   STATUS;
2220  7650   SNA CLA;/1 if minus; 0 if plus
2221  5230   JMP AN1;
2222  4172   CALL; /-, add 2π then display it
2223  6144   PI;
2224  4172   CALL;
2225  6144   PI;
2226  4153   A;
2227  4153   A
2230  4172  AN1, CALL; /+, its OK - display it
2231  5356   ANG+1;
2232  5575   RETURN
```

```
                     /ANGE adjusts a number input by the keyboard so it is in
                      -π< a <π form in TOS
2233   4161   ANGE, D;/ ÷ iso/π
2234   4145    P;/save it
2235   4172    CALL;/see which hemisphere it's in by subtracting PI & checking sign
2236   6144    PI;
2237   4156    S;
2240   4172    CALL;
2241   4347    STATUS;
2242   7640    SZA CLA;/0 if pos, 1 if neg
2243   5251    JMP ANGP/OK do it
2244   4172    CALL;/needs to have π subtracted so answer is -π< x <π
2245   6144    PI;
2246   4156    S;
2247   3051    DCA TEM8;/clear TEM8, which indicates 'ANGLE'
2250   5575    RETURN
2251   4172   ANGP, CALL; /get answer on TOS
2252   2661    POP;
2253   3051    DCA TEM8;/clear TEM8
2254   5575    RETURN

              [POF]       *2257  POF/point 00five used by convert to avoid round
2257   4137   POF, W; /write #                       up/down error in CONN
2260   4145    P;/save
2261   4172    CALL; /tor-?
2262   4347    STATUS;
2263   7421    MQL;/save answer in MQ
2264   1276    TAD PF;/write .005
2265   4137    W;
2266   7501    MQA;/look at MQ
2267   7650    SNA CLA;/1 if # neg, 0 if # was pos
2270   5273    JMP .+3;/pos, get add .005
2271   4172    CALL;/neg, subtr .005
2272   3761    CHS;
2273   4153    A
2274   3027    DCA KEYCTR;/zeroize KEYCTR
2275   5575    RETURN
2276   5473   PF, POOF-1/address of floating .005
```

```
ACC

CALL=4172
RETURN=5575
LCM1=4622
WCRPA=6425
AW2=6431
KRE02=6433
KYBLK=6554
AR2=6430
DIM=3007
DISPR=3630
BLANK=3606
KEYCTR=27
L4R=21
AC=23

                         *23
0030   0000   JMPR,      0
0031   0000   MINUS,     0
0032   0000   DONEF,     0
0033   0000   KEYT,      0
0034   0000   K1,        0
0035   0000   K2,        0
0036   0000   K3,        0
0037   0000   K4,        0
0040   0000   K5,        0
0041   0000   K6,        0
0042   0000   K7,        0

                         *3300

3300   0005   FIV,       5
3301   7773   FIVE,      -5
3302   0034   K,         K1
3303   3540   A1,         ACCA
3304   7774   FOUR,      -4
3305   7771   SEVEN,     -7
3306   1400   L4,        1400
3307   1032   ACC4,      TAD DONEF
3310   7640              SZA CLA
3311   5703              JMP I A1
3312   1023              TAD AC
3313   7100              CLL
3314   4172              CALL
3315   3630              DISPR
3316   7200              CLA
3317   1027              TAD KEYCTR
3320   1302              TAD K
3321   3030              DCA JMPR
3322   1023              TAD AC
3323   3430              DCA I JMPR
3324   2027              ISZ KEYCTR
3325   1027              TAD KEYCTR
3326   1304              TAD FOUR
3327   7650              SNA CLA
3330   5336              JMP ACC1
3331   1027              TAD KEYCTR
3332   1305              TAD SEVEN
3333   7640              SZA CLA
3334   5703              JMP I A1
3335   5351              JMP ACC2
```

```
3336  1306  ACC1,   TAD L4
3337  6425          WCRAA
3340  7201          CLA IAC
3341  7040          CMA
3342  0021          AND L4F
3343  6431          AW2
3344  3021          DCA L4F
3345  7330          CLA STL RAR
3346  3031          DCA MINUS
3347  7120          STL
3350  5357          JMP ACC5
3351  2032  ACC2,   ISZ DONEF
3352  5703          JMP I A1
3353  1027  ACC3,   TAD KEYCTR
3354  1301          TAD FIVE
3355  7620          SNL CLA
3356  5703          JMP I A1
3357  4172  ACC5,   CALL
3360  3630          DISPR
3361  3032          DCA DONEF
3362  1300          TAD FIV
3363  3027          DCA KEYCTR
3364  5703          JMP I A1

                    *3400
3400  7773  FIVM,   -5
3401  3501  KB,     KEYB
3402  0017  ACCMK,  17
3403  3353  A,      ACC3
3404  3307  A4,     ACC4
3405  1400  L4A,    1400
3406  5356  KY0,    JMP ACCC
3407  1211  KY1,    TAD KY1+2
3410  5356          JMP ACCC
3411  0001          1
3412  1214  KY2,    TAD KY2+2
3413  5356          JMP ACCC
3414  0002          2
3415  1217  KY3,    TAD KY3+2
3416  5356          JMP ACCC
3417  0003          3
3420  1222  KY4,    TAD KY4+2
3421  5356          JMP ACCC
3422  0004          4
3423  1225  KY5,    TAD KY5+2
3424  5356          JMP ACCC
3425  0005          5
3426  1230  KY6,    TAD KY6+2
3427  5356          JMP ACCC
3430  0006          6
3431  1233  KY7,    TAD KY7+2
3432  5356          JMP ACCC
3433  0007          7
3434  1236  KY8,    TAD KY8+2
3435  5356          JMP ACCC
3436  0010          10
3437  1241  KY9,     TAD KY9+2
3440  5356          JMP ACCC
3441  0011          11
```

```
3442  7120  KYP,   STL
3443  5356         JMP ACCC
3444  1031  KYM,   TAD MINUS
3445  7710         SPA CLA
3446  5340         JMP ACCA
3447  2031         ISZ MINUS
3450  1205         TAD L4A
3451  6425         WCRAA
3452  7200         CLA
3453  1031         TAD MINUS
3454  7012         RTR
3455  7700         SMA CLA
3456  5263         JMP KYM1
3457  7001         IAC
3460  4172         CALL
3461  4622         LDN1
3462  5340         JMP ACCA
3463  7201  KYM1,  CLA IAC
3464  7040         CMA
3465  0021         AND L4R
3466  6431         AW2
3467  3021         DCA L4R
3470  5340         JMP ACCA
3471  4172  KYC,   CALL
3472  3606         BLANK
3473  5333         JMP ACC6
3474  4172  KYE,   CALL
3475  3007         SUM
3476  5575         RETURN
3477  5340  KYD,   JMP ACCA
3500  5340  KY.,   JMP ACCA
3501  5242  KEYB,  JMP KYP
3502  5234         JMP KY8
3503  5220         JMP KY4
3504  5271         JMP KYC
3505  5244         JMP KYM
3506  5223         JMP KY5
3507  5207         JMP KY1
3510  5277         JMP KYD
3511  5237         JMP KY9
3512  5226         JMP KY6
3513  5212         JMP KY2
3514  5274         JMP KYE
3515  5206         JMP KY0
3516  5231         JMP KY7
3517  5215         JMP KY3
3520  5300         JMP KY.
```

```
3521  6433  ACC,    KRE02
3522  7300          CLA CLL
3523  3031  ACC6,   DCA MINUS
3524  3027          DCA KEYCTR
3525  3032          DCA DCMEF
3526  3041          DCA K6
3527  3042          DCA K7
3530  7040          CMA
3531  3034          DCA K1
3532  7040          CMA
3533  3035          DCA K2
3534  7040          CMA
3535  3036          DCA K3
3536  7040          CMA
3537  3037          DCA K4
3540  6433  ACCA,   KRE02
3541  5340          JMP .-1
3542  7000          NOP
3543  7000          NOP
3544  7000          NOP
3545  7000          NOP
3546  7000          NOP
3547  7000          NOP
3550  7100  OUT,    CLL
3551  6430          AR2
3552  0202          AND ACCMK
3553  1201          TAD KB
3554  3030          DCA JMPR
3555  5762          JMP I KBK /go write ou what KYBLK is
3556  3023  ACCC,   DCA AC
3557  7630          SZL CLA
3560  5603          JMP I A
3561  5604          JMP I A4
3562  6554  KBK,    KYBLK
```

```
            *LSW    /Least Significant Word
            *3365   takes LWS of a floating # & displays it

3365  0017  MSK, 17;
3366  0224  RG1, REG1;
3367  0223  RG1M, REG1-1
3370  1367  LSW, TAD RG1M;/get TOS into scratchpad
3371  4142   JMS RD;
3372  1766   TAD I RG1;/get LSW
3373  0365   AND MSK;/mask off least significant 4 bits
3374  4172   CALL;/display them as a decimal #, using DISPR.  DISPR pushes the
3375  3430   DIIFF;   displayed #'s to the left to make room for the new one.
3376  7200   CLA;
3377  5575   RETURN

            STATUS=4347;
            REG1=224;
            RD=142
```

```
               CONOE      /from CON time Or Enter
              *5700
              TEM10=54;   /holds program and flashes the lights to let operator handl
              KR2=6433;
              AR2=6430;   /any errors: pressing DISP shown the last message code
              TEMD=75;     displayed (if "2", no errors), pressing CON will not acce
              DISCO=3234;  the current parameters.  ENT does accept them.  Must
              BLANK=3606;  enter with TEMN=0, exits with TEMN=1 if CLR/CONT presse
              LOA=3154;                                    0 if ENT pressed
              CHAR1=63
              CALL=4172;
              RETURN=5575;
              TEMN=101;
              LON1=4622
5700   7775   CNT, -3;
5701   7771   DSP, -7;
5702   0017   MK, 17;
5703   7765   ENT, -13
5704   1343   CONOE, TAD FLSH;/flash all the lights
5705   4172    CALL;
5706   4622    LON1
5707   6433   CN1, KR2;/wait for a KBR
5710   5307    JMP .-1;
5711   6430    AR2; /read & mask it
5712   0302    AND MK;
5713   3063    DCA CHAR1; /and store in CHAR1
5714   1063    TAD CHAR1;
5715   1300    TAD CNT;/is it CLR/CONT?
5716   7640    SZA CLA
5717   5326    JMP CN2;/no, try again
5720   2101    ISZ TEMN;/yes, indicate such in TEMN
5721   4172   O, CALL;/blank display
5722   3606    BLANK;
5723   4172    CALL; /turn off lights
5724   3154    LOA;
5725   5575    RETURN
5726   1063   CN2, TAD CHAR1;
5727   1301    TAD DSP;/is it DISP?
5730   7640    SZA CLA;
5731   5336    JMP CN3;/no, try again
5732   1075    TAD TEMD;/fetch the last displayed message
5733   4172    CALL; /and display it
5734   3234    DISCO;
5735   5307    JMP CN1/wait for another keystroke
5736   1063   CN3, TAD CHAR1;
5737   1303    TAD ENT;/is it ENTER?
5740   7640    SZA CLA;
5741   5307    JMP CN1;/no, illegal entry.  Ignore & start over
5742   5321    JMP O /yes, exit with TEMN=0
5743   0010   FLSH, 10
```

```
                DIPCAL   /calculates DIP angle
                PIAI=2305;
                PBUF=43;
                KEYT=33;
                DATCAL=4250;
                ARTAN=2655;
                REG4=527;
                ANG=5355;
                SQRT=2703
                STATUS=4347;
                W=4137;
                R=4142;
                F=4145;
                M=4150;
                A=4153;
                D=4161;
                YCOS=243
                XCOS=253;
                ZCOS=247
                *5745
5745    0243    Y, YCOS;
5746    0253    X, XCOS;
5747    0247    ZC, ZCOS;
5750    0527    R4, REG4
5751    1345    DIPCAL, TAD Y;/write Y cos
5752    4137     W;
5753    4145     F;
5754    4150     M;/YCOS^2
5755    1347     TAD ZC
5756    4137     W;
5757    4145     F;
5760    4150     M;/ZCOS^2
5761    4153     A;/YCOS^2+ZCOS^2
5762    4172     CALL;
5763    2703     SQRT;/√(YCOS^2+ZCOS^2)
5764    1346     TAD X;
5765    4137     W;
5766    4161     D;/XCOS÷√(YCOS^2+ZCOS^2)
5767    4172     CALL;
5770    2655     ARTAN /tan^-1(YCOS÷√(YCOS^2+ZCOS^2))=dip angle
5771    1350     TAD R4;/put in REG4
5772    4142     R;
5773    1350     TAD R4;/display REG4 as a -180<x<180 angle
5774    4172     CALL;
5775    5355     ANG;
5776    5575     RETURN
```

```
            *GTIN      /sequences throu intitial conditions necessarv
             CALL=4172;
             RETURN=3575;
             M=4710;
             L=4732;
             LOA=3154;
             E=4664
             GETIN=4463;
             MAIN2=6620;
             SLEN=4703
             *5400
5400  4172   GTIN, CALL;/lights off
5401  3154    LOA;
5402  4172    CALL;/go to BRTAB to handle INITIAL BER input
5403  4732    L;
5404  4172    CALL;/lights off
5405  3154    LOA;
5406  4172    CALL;/go to BRTAB to handle INITIAL INC input
5407  4710    M
5410  4172    CALL;/lights off
5411  3154    LOA;
5412  4172    CALL;/go to BRTAB to handle INITIAL ROD input
5413  4664    E;
5414  4172   GTIN1, CALL;/lights off
5415  3154    LOA;
5416  4172    CALL;/go to BRTAB to handle INITIAL SLEW input
5417  4703    SLEN;
5420  5266    JMP EXTEN;/patch to EXTEN (5466)
5421  6620    MAIN2 /unnecessary

            *M2EX     /MAIN2 EXTENDED
             EXEC=5011;
             PROC2=4022;
             M4=6640;
             MAIN2=6620;
             TEM13=57;
             TEM11=55

5422  7040   M2EX, CMA;/disallow continue
5423  3057    DCA TEM13;
5424  4172    CALL;/wait for new data or "AR","ENTER"
5425  5011    EXEC;
5426  1055    TAD TEM11/what was it?
5427  7700    SMA CLA;
5430  5637    JMP I MN4;/new data, go back to M4
5431  4172    CALL;/AR ENTER
5432  5440    ACM;
5433  4172    CALL;/get the PROC2 values
5434  4022    PROC2
5435  5636    JMP I MN2/go back to MAIN2
5436  6620   MN2, MAIN2;
5437  6640   MN4, M4
```

```
DATCAL

DIS3=3476;
DISPR2=25;
BLANK=3606;
DISPR=3627;
SUBD=2717;
FIX=2707
MULD=2673;
MINUS=31;
DIVD=2713;
REG1=224;
CALL=4172;
RETURN=5575
TEM3=11;
TEM4=12;
TEM=10;
TEM1=26;
BW1=6441;
WT=137;
RD=142;
SUBF=156;
LCN=4620
PUSH=145;
ADDF=153;
MULF=150;
CHS=3761;
FLT=164;
CRAB=2727;
RF1=6440;
CHLITE=2516
POP=2661;
STACK=175;
DIVF=161;
SQRT=2703;
CTR=20;
CTR1=22;
XCH=3144;
LDS=3124
ADDS=3134;
MULS=3140;
CTR2=42;
REG2=230;
BW=2734;
KEYCTR=27;
NORM=2341
SCDATA=6305;
CHEK=6536;
ENT=3767;
RBAT=6520;
TEM5=6516;
FAULT=5452
```

NEEDS WORK

DATCAL DOES:

$$\frac{(\text{Data Word})\times 10000-AV}{AM} \longrightarrow \text{data}$$

```
                        *4200

4200  0277  REF,     277         
4201  0174  AV1,     174          /YCOS
4202  0010           10
4203  0360  AM1,     360
4204  0330           330
4205  0071  AV2,     71           /ZCOS
4206  0377           377
4207  0331  AM2,     331
4210  0046           046
4211  0210  AV3,     210          /XCOS
4212  0002           2
4213  0367  AM3,     367       CHANGED THE VALUES
4214  0046           46
4215  0043  AV4,     43           /GGX (CHANGE SIGN)
4216  0000           0
4217  0014  AM4,     14
4220  0333           333
4221  0043  AV5,     43           /GGZ
4222  0000           00
4223  0020  AM5,     20
4224  0047           47
4225  0042  AV6,     42           /GGY (CHANGE SIGN)
4226  0000          0
4227  0047  AM6,     47
4230  0331           331
4231  7772  SM,      -6
4232  4200  AV,      AV1-1
4233  0243  DATL,    243
4234  7774  FM,      -4
4235  0273  TEMP,    273/downhole temperature
4236  0004  TEML, 4     /temperature limit, high end
4237  0040  MASK,    40
4240  4237  TPFA,    TPFA-1  /2.47 /reference voltage check
4241  6424           6424
4242  6636           6636
4243  6402           6402
4244  4243  TPA,     TPA-1   /.05
4245  6714           6714
4246  6714           6714
4247  6574           6574

4250  4172  DATCAL,  CALL /scale the data
4251  6305           SCDATA
4252  1240           TAD TPFA/check reference voltage
4253  4137           JMS WT
4254  1200           TAD REF
4255  4137           JMS WT
4256  4156           JMS SUBF/APUTOS has 2.47-REF
4257  4172           CALL
4260  4347           STATUS
4261  7650           SNA CLA /negative?
4262  5265           JMP .+3/no, skip ahead to 4265
4263  4172           CALL/yes, falut
4264  5452           FAULT
4265  1244           TAD TPA /subtract .05 from the remainder
4266  4137           JMS WT
4267  4156           JMS SUBF
4270  4172           CALL
```

```
4271  4347           STATUS
4272  7640           SZA CLA/positive?
4273  5276           JMP .+3/no, OK
4274  4172           CALL/yes, 247-rd-.05 was >0
4275  5452           FAULT/fault displays "9" & waits for a go-ahead from KBR
4276  1235           TAD TEMP/check for interrupt, load APU with temp. word
4277  4137           JMS WT
4300  1236           TAD TEML/load temperature limit (4.0 is 40°C)
4301  4172           CALL
4302  3124           LDS
4303  4164           JMS FLT /should be a JMS SUBF here
4304  4172           CALL</check if negative: 0 is x>0, 1 is x<0
4305  4347           STATUS
4306  7650           SNA CLA<——should be SZA CLA
4307  5312           JMP DAT2
4310  4172           CALL/temperature error—TEME sets HI TEMP light & puts 7777(8)
4311  6526           TEME/into TEMD and 0001(8) into TEMD( 0100)
4312  1343  DAT2,    TAD BATN/get addr of neg batt voltage
4313  4137           JMS WT /write it
4314  4172           CALL/change sign
4315  3761           CHS
4316  1240           TAD TFFA/write 2.5
4317  4137           JMS WT
4320  4156           JMS SUBF/get BATN-2.5V
4321  4172           CALL/CHEK sets Lo Bat light & puts 1 into TEMP(0100) if error
4322  6536           CHEK
4323  1344           TAD BATP/write postive battery voltage
4324  4137           JMS WT
4325  1240           TAD TFFA/write 2.5V
4326  4137           JMS WT
4327  4156           JMS SUBF/get Bat p-2.5
4330  4172           CALL/CHEK sets Lo Bat light & puts 1 into TEMP(0100) if error
4331  6536           CHEK
4332  4172           CALL/check receiver battery; if OK, return; if not OK
4333  6520           RBAT/set LO BATT lite & put 1 into TEMP(0100)
4334  1231           TAD TM /load CTR2 to count 6
4335  3042           DCA CTR2
4336  1232           TAD AV /set TEM3 to point to data coefficients AV1-> AM6
4337  3011           DCA TEM3
4340  1233           TAD DATL/set AC to point to 1st data word
4341  5742           JMP I .+1
4342  4401           DAT1/end of DATCAL is located at 4401
4343  0303  BATN,    303
4344  0307  BATP,    307
4345  7775  TM,      -3
```

```
        /STATUS        /checks APU TOS & exits: AC=0 if positive
                                                AC=1 if negative

            *4346
4346  0100  MSK,    100
4347  4172  STATUS, CALL/get status word from APU
4350  2727          CPAB
4351  6440          BP1
4352  7200          CLA
4353  6440          BP1
4354  0346          AND MSK/mask sign info 0=positive
                                           1=negative
4355  5575          RETURN
```

/COM /COMPARE - works out data limits & determines if out of lim

```
              S=4156;
              W=4137;
              TEM9=53
4356   4137   COM, W;/write 2nd parameter
4357   4156    S;/param 1 - param 2
4360   4172    CALL; /get absolute value
4361   4347    STATUS;
4362   7650    SNA CLA;
4363   5575    RETURN;/done - its positive
4364   4172    CALL; /change sign - its negative
4365   3761    CHS;
4366   5575    RETURN /done
```

/COM1

```
4367   4137   COM1, W;/subtract limit from parameter difference
4370   4156    S;
4371   4172    CALL;
4372   4347    STATUS;
4373   7640    SZA CLA;/error? (result of line 4370 will be neg if limit was bigg
4374   5575    RETURN;/no                              than difference, i.e., OK)
4375   2053    ISZ TEM9; /yes, signal TEM9
4376   5575    RETURN
```

/DAT1 *4400 /DATCAL EXTENDED - does $\frac{\text{(data word)x10000-AV}}{\text{AM}}$

```
4400   7774   TMD,      -4
4401   3010   DAT1, DCA TEM/put start of data into TEM
4402   1010   DATX, TAD TEM
4403   4137             JMS WT/write data word
4404   4172             CALL/enter 10,000
4405   3767             ENT
4406   4150             JMS MULF/multiply
4407   4172             CALL/load & float 1st (next) coefficient (AV)
4410   4426             DGOB
4411   4156             JMS SUBF/subtract
4412   4172             CALL/load & float 2nd (next) coefficient (AM)
4413   4426             DGOB
4414   4151             JMS DIVF/divide
4415   1010             TAD TEM /point back to
4416   1200             TAD TMD /beginning of this word
4417   4142             JMS RD/replace if with adjusted value
4420   2042             ISZ CTR2 /done it 6 times?
4421   5202             JMP DATX /no, do it again
4422   1235             TAD DTL/yes, make AC point to beginning of data
4423   4172             CALL /normalize the data
4424   6570             NRMCAL
4425   5575             RETURN

4426   1411   DGOB,     TAD I TEM3 /loads & floats # pointed to by TEM3
4427   6441             BW1
4430   7200             CLA
4431   1411             TAD I TEM3
4432   6441             BW1
4433   4164   JMS FLT
4434   5575             RETURN
4435   0243   DTL,      243
                        NRMCAL=6570
```

```
                RESTART           /sequence thru what values are necessary to put
                CALL=4172;         computer at an old position in the borehole;
                RETURN=5575;       will fill in value for BER1; INC1; SLEW; LAT;
                L=4732;            DEP & Vertical Depth
                M=4710;
                H=4703;
                B=4645;
                K=4725;
                G=4676
                CTR4=72;
                TEM5=45;
                LDA=3154;
                LDM=4620;
                LDM1=4622;
                TEM8=51;
                D=4657
                *5125
5125    1000    FLT, 1000;
5126    0507    BNG, 507;/BER2 (not used)
5127    0513    INCL, 513;/INC2 (not used)
5130    0403    SLE, 403;
5131    0413    LAT1, 413;
5132    0423    DPT, 423;
5133    0433    VDD, 433
5134    4732    LK, L;/BER1
5135    4710    IK, M;/INC1
5136    4703    HK, H;/SLEW
5137    4645    BK, B;/LAT
5140    4725    KK, K;/DEP
5141    4676    GK, G;/VD
5142    5133    LKA, LK-1
5143    5161    RON, RIT1;
5144    4172     CALL;
5145    5464     JMP I 64;
5146    7771    CM, -7
5147    1346    RIT, TAD CM;/6 parameters (put LSZ CET4 in such a place that it
5150    3072     DCA CTR4;                 needs to count to 7)
5151    1342     TAD LKA;/start with BER address in BRTAB
5152    3011     DCA 11;/put in autoindex
5153    1343     TAD RON;/set up call routine in RAM
5154    3064     DCA 64;
5155    1344     TAD RON+1;
5156    3065     DCA 65
5157    1345     TAD RON+2;
5160    3067     DCA 67
5161    4172    RIT1, CALL;/lights off
5162    3154     LDA;
5163    1325     TAD FLT;/turn on "RS" light
5164    4172     CALL;
5165    4622     LDM1;
5166    7046     CMA RTL;
5167    7006     RTL;
5170    3045     DCA TEM5;/signal "INITIAL" to KYSR (TEM5>0) AC=7767 L=1 and INC1,BER1
5171    1411     TAD I 11
5172    3066     DCA 66;
5173    2072     ISZ CTR4;
5174    5065     JMP 65;
5175    4172     CALL; /all done/turn off lights
5176    3154     XXXXXX  JMP I+1 (5776)
5177    5575     XXXXXX  6440
```

```
                   /BRTAB        BRANCH TABLE
                   TEM7=50;
                   CHLITE=2516;
                   CALL=4172;
                   RETURN=5575;
                   TEM6=46;
                   TEM8=51;
                   TEM5=45;
                   KYSR=5611
                   KYSRC=5647;
                   KYSR2=5631
                   *4600
4600    5240       DIP, JMP A;/branch table
4601    5245       LAT, JMP B;
4602    5765       TEST, JMP I KR;/ignore, start over at KYSR (5611)
4603    5766       INIT, JMP I K2;/initial into service with KYSR2 (5631)
4604    5252       VDEV, JMP C;
4605    5257       THD, JMP D
4606    5765       ADRD, JMP I KR;/ignore, start over at KYSR (5611)
4607    5264       ROD, JMP E;
4610    5271       LDEV, JMP F;
4611    5276       VD, JMP G;
4612    5303       CLEN, JMP H;
4613    5310       INC, JMP M
4614    5320       SOT, JMP J;
4615    5325       DEP, JMP K;
4616    5765       RI, JMP I KR;/ignore
4617    5332       BER, JMP L
4620    7100       LON, CLL;
4621    7410        SKP;          call LON writes an L1 LED latch with contents of AC
4622    7120       LON1, STL;
4623    7421        MQL;
4624    7501        MQA;          call LON1 writes an L2 LED latch with contents of AC
4625    4172        CALL;
4626    2516        CHLITE;
4627    5575        RETURN
4630    3046       ANGL, DCA TEM6;/put value in TEM6
4631    7040        CMA;/signal it's an angle by putting somethin in TEM8
4632    3051        DCA TEM8;
4633    5764        JMP I KC /back to KYSR to finish (5647)
4634    3046       END, DCA TEM6;/put value in TEM6
4635    3051        DCA TEM8;/clear TEM8
4636    5764         JMP I KC /back to KYSR to finish (5647)
```

```
                *4640
4640   7007   R, IAC RTL;/turn on DIP light
4641   4172    CALL;
4642   4620    LON;
4643   1346    TAD DP;/get addr of DIP
4644   5230    JMP ANGL/exit (angle)
4645   1342   B, TAD LTL;/turn on LAT light
4646   4172    CALL;
4647   4622    LON1;
4650   1347    TAD LT;/get addr of LAT
4651   5234    JMP END/exit
4652   1350   C, TAD VV;/turn on V DEVIATION
4653   4172    CALL;
4654   4620    LON;
4655   1351    TAD VDE;/get addr of VDEV
4656   5234    JMP END
4657   1345   D, TAD THDL;/turn on THD
4660   4172    CALL;
4661   4622    LON1;
4662   1352    TAD TH;/get addr of THD
4663   5234    JMP END/exit
4664   1374   E, TAD RDL;/turn on ROD
4665   4172    CALL;
4666   4620    LON;
4667   1354    TAD RD;/get addr of ROD
4670   5234    JMP END/exit
4671   1355   F, TAD LD;/turn on HOR DEVIATION
4672   4172    CALL;
4673   4620    LON;
4674   1356    TAD LW;/get contents of LDEV
4675   5234    JMP END/exit
4676   1344   G, TAD VDL;/turn on VD (vertical depth)
4677   4172    CALL;
4700   4622    LON1;
4701   1357    TAD VDF;/get contents of VD
4702   5234    JMP END/exit
4703   1360   H, TAD SL;/turn on string length
4704   4172    CALL;
4705   4620    LON;
4706   1361    TAD STP;/get contents of SLEW
4707   5234    JMP END/exit
4710   7105   M, CLL IAC RAL;/turn on INCLINATION
4711   4172    CALL;
4712   4620    LON;
4713   1045    TAD TEM5;/"INITIAL"
4714   7440    SZA;/DO NOT CLA
4715   1362    TAD TM;/yes, subtract 16_10(if "INITIAL" TEM5=-1) or 24_10(if RESTART
4716   1363    TAD AVI;/no, just load  AVI→AC(addr   TEM5=9 DOES THIS) from AVI (addr of AVINC)
4717   5230    JMP ANGL/exit  of AVINC)   to make it addr AINC or INC1
4720   1367   J, TAD RT;/turn on ROTATION light
4721   4172    CALL;
4722   4620    LON;
4723   1370    TAD RTA;/get addr of ROT
4724   5230    JMP ANGL/exit (angle)
4725   1343   K, TAD DPL;/turn on DEPARTURE light
4726   4172    CALL;
4727   4622    LON1;
4730   1371    TAD DE;/get addr of DEP
4731   5234    JMP END/exit
```

```
4732  1372  L, TAD BR;/turn on BEARING light
4733  4172   CALL;
4734  4620   LDN;
4735  1045   TAD TEM5;/"INITIAL" pressed?
4736  7440   SZA;/do not CLA
4737  1362   TAD TM;/yes,subtr 16(10)(if "INITIAL" TEM5=-1) or 24(10)(if RESTART TEM5
4740  1373   TAD AVB;/no, just load addr of    does this) from addr of AVBER & pu
4741  5230   JMP ANGL/exit  AVBER into AC      in 4C (induce it A-BER) or BER1
                      (angle)
4742  0040  LTL, 40;
4743  0100  DPL, 100;
4744  0200  VDL, 200;
4745  0400  THDL, 400;
4746  0317  DP, 317;
4747  0413  LT, 413;
4750  0400  VV, 400;
4751  0453  VDE, 453;
4752  0443  TH, 443
4753  0100  PO, 100;
4754  0367  PD, 367;
4755  0010  LD, 10;
4756  0463  LV, 463;
4757  0433  VDP, 433;
4760  0020  IL, 20;
4761  0403  ITR, 403;
4762  7761  TM, -17;/-15(10)
4763  0523  AVI, 523/AVINC
4764  5647  KC, KYSRC;
4765  5611  KR, KYCR;
4766  5631  K2, KYCR2;
4767  0200  PT, 200;
4770  0333  PTA, 333;
4771  0423  IE, 423;
4772  0040  BR, 40;
4773  0517  AVB, 517/AVBER
4774  0100  PDL, 100
```

```
INIT        INITIALIZATION
            *5510
            SETUP=7706;
            CHK=125;
            LDN=4620;
            LDA=3154;
            CALL=4172;
            RETURN=5575;
            BLANK=3606
            L4R=44;
            L3R=21;
            ADN=5440;
             APUCF=6600
            W=4137;
            R=4142;
            F=4164;
            LDS=3124;
            STUP=71;
            INP=70;
            BR2=6450
5510  5253  CH, -2525;
5511  1000  MI, 1000;
5512  5522  TF, TNF-1;
5513  0347  MG, 347;
5514  5516  POT, PIOT-1;
5515  0217  TEMP, 217;
5516  0373  PIT, 373
5517  6732  PIOT, 6732;/π/2 float
5520  6417   6417;
5521  6711   6711;
5522  6401   6401;
5523  6400  TNF, 6400;/10 float
5524  6400   6400;
5525  6640   6640;
5526  6404   6404;
5527  7706  STP, SETUP
5530  5534  IN2A, IN2
5531  1330  INIT, TAD IN2A;/start. set up return addr
5532  3071   DCA STUP;/in 0071 so you can
5533  5727   JMP I STP /do 7706 routine in MONITOR
```

```
5534  3044  IN2, DCA L4R;/OK, clear LAR & L3R
5535  3021   DCA L3R;
5536  4172   CALL;/lights off
5537  3154   LOA;
5540  4172   CALL;/blank display
5541  3606   BLANK;
5542  1125   TAD CHK;/check memory valid
5543  1310   TAD CH;
5544  7650   SNA CLA/OK?
5545  5354   JMP IN1;/yes
5546  1311  TAD MI;/no, turn on memory invalid light
5547  4172   CALL;
5550  4620   LON;
5551  1310   TAD CH;/put correct value in mean check location (125)
5552  7041   CIA;
5553  3125   DCA CHK
5554  4172  IN1, CALL;/turn on APU
5555  5440   AON;
5556  4172   CALL;/load a single 0 into APU
5557  3124   LDC;
5560  4164   F; /float it
5561  1313   TAD MG;/put in MAGNETIC VECTOR
5562  4142   F;
5563  1312   TAD TF;/put 10 floated into TENF
5564  4137   W;
5565  1315   TAD TENF;
5566  4142   F
5567  1314   TAD POT;/put π/2 floated into PIT
5570  4137   W;
5571  1316   TAD PIT;
5572  4142   R;
5573  5470   JMP I INP/jump wherever calling routine wants to go
```

```
*EXEC   EXECUTIVE
BI2=6443;
BI4=6453;
RDT=7035;
CHAR1=63;
CALL=4172;
RETURN=5575;
BLANK=3606
TEM11=55;
AR2=6430;
KYSR=5511;
TEM13=57;
KR1=6432;
STEST=6412;
RST=5147
DISCO=3234;
KR2=6433;
 LDA=3154;
 APUGF=6600;
 AON=5440;
 BKPT=4167
 KYSRC=6210;
 RSTC=6222;
 STESTC=6215;
 EXEX=6200;
 EXITE=6244
*5000
5000  7771  DISP, -7;
5001  0017  MEK, 17;
5002  7035  DATR, RDT;
5003  7775  CONT, -3;
5004  7776  TEST, -2;
5005  7772  AR, -6;
5006  7761  TTY, -17;
5007  7762  RI, -16;
5010  7765  ENT, -13
5011  5612  EXEC, JMP I .+1;/patch to 6200
5012  6200   EXEX;/CAF, turn on "RESET" lite, turn off APU
5013  3055   DCA TEM11;/clear TEM11
5014  6433   KR2;/KBR request?
5015  5251   JMP E4;/no
5016  6430   AR2; /yes, mask & save
5017  0201   AND MEK;
5020  3063   DCA CHAR1
5021  1063   TAD CHAR1;/recall
5022  1200   TAD DISP;/was it DISPLAY request?
5023  7640   SZA CLA;
5024  5227   JMP E2;/no, check further
5025  4172   CALL;/yes
5026  6210   KYSRC
5027  1206  E2, TAD TTY;/was it MONITOR request?
5030  1063   TAD CHAR1;
5031  7640   SZA CLA;
5032  5236   JMP E3;/no, check further
5033  6453   BI4; /yes, see if TTY plugged in
5034  7000   NOP;
5035  5602   JMP I DATR /doesn't matter - go to RDT (7038) - calls out raw data
```

Exits with TEM11=0 got a data clock
1 "continue" pressed
7777_8 "ADD ROD","ENT" pressed

```
5036   1203   E3, TAD CONT;/"CONTINUE" pressed?
5037   1063    TAD CHAR1;
5040   7100    CLL;
5041   7640    SZA CLA;
5042   5251    JMP E4; /no, go on
5043   1057    TAD TEM13/yes, is "CONTINUE" allowed? (TEMB=0 allowed
5044   7640    SZA CLA;                                     ≠1 disallowed
5045   5251    JMP E4;/no, go on
5046   7101    CLL IAC; /yes, put a 1 in TEM11 to signal "CONTINUE"
5047   3055    DCA TEM11;
5050   5724    JMP I EXIT/exit to 6246
5051   6432   E4, KF1;/KBL request? (if it was any other KBR, program flow just
5052   5322    JMP E5;/no, go on                           clears it out)
5053   6430    AR2;/yes
5054   0201    AND MEK;/mask & save
5055   3063    DCA CHAR1;
5056   1063    TAD CHAR1;/recall
5057   1204    TAD TEST;/"TEST" pressed?
5060   7640    SZA CLA
5061   5264    JMP E6; /no, go on
5062   4172    CALL;/yes, run "self test"
5063   6215    STESTC
5064   1063   E6, TAD CHAR1;
5065   1207    TAD RG; /was "RG" pressed?
5066   7640    SZA CLA;
5067   5272    JMP E7;/no, go on
5070   4172    CALL;/do "RESTART"
5071   6222    RSTC
5072   1063   E7, TAD CHAR1;
5073   1205    TAD AR; /was "ADD ROD" pressed?
5074   7640    SZA CLA;
5075   5322    JMP E5; /no, go on
5076   4172    CALL;/yes, lights off
5077   3154    LOF;
5100   7001    IAC;/message "1"
5101   4172    CALL;
5102   3234    DISCO;
5103   7200    CLA;
5104   6433    KR2/wait for a KBR
5105   5304    JMP .-1
5106   6430    AR2;/yes, mask & test
5107   0201    AND MEK;
5110   1210    TAD ENT;/enter pressed?
5111   7640    SZA CLA;
5112   5320    JMP E8; /no, go on
5113   7040    CMA; /yes
5114   3055    DCA TEM11; /signal "AR","ENTER" pressed by loading TEM11 with 7777
5115   4172    CALL;/blank & return
5116   3606    BLANK;
5117   5575    RETURN
5120   4172   E8, CALL;/blank on general principles
5121   3606    BLANK
5122   5723   E5, JMP I BATCHK;/go to the battery check stuff, which will
5123   6502    BATCHK, 6502/recycle back to EXEC
5124   6246   EXIT, EXITE+2
```

```
MAIN1
INF=70;
ANG=5355;
FIT=374;
BLANK=3606;
TEM5=45;
TEM13=57;
TEM11=55;
DATA=2405;
TEMP=100
DIFCAL=5751;
LOA=3154;
EXEC=5011;
LDS=3124;
R=4142;
CTR3=47;
TEM10=54;
F=4164
A=4153;
M=4150;
D=4167;
P=4145;
S=4156;
W=4137;
L=4732;
M=4710;
E=4664;
TEMH=101
POTCTR=52;
TEM7=50;
AVGV=4555;
CONDE=5704;
COM=4356;
COM1=4367;
PAKL=4441
SLEG=403;
M2EX=5420;
GTIM=5400
PROC1=2031;
DICCO=3234;
PROC2=4022;
INIT=5531;
IDLE=5765;
STEST=6407;
LON=4620
PRINIT.=7773;
PRPO=7773;
CALL=4173;
RETURN=5575
DATCAL=4250;
GETIN=4463;
TEM9=53;
APUCF=6600;
AON=5440;
WCFAA=6425;
BW2=6451
MA15Y=6237
```

```
                *5200                                                   NEEDS WORK
5200  5212   MNA, MN1;                                                  CTR3=>counts # of shots for
5201  0005   ID, 5;                                                     DIP averaging
5202  0317   DIFF, 317;
5203  5531   INTA, INIT;
5204  0527   RG4, 527;
5205  0004   DP, 4;
5206  4441   FKL, FAKL;
5207  0403   ILEN, ILEG
5210  1200   MAIN1, TAD MNA;/start.  put return addr from "INIT" in loc 0070
5211  3070    DCA INP;
5212  5603    JMP I INTA /go do INIT
5213  6425   MN1, WCRAA; /set up PIE
5214  6451    BW2;
5215  5616    JMP I .+1;/patch to 6227
5216  6227    MA1EX /if KBL, continue @ MN; if KBR, go to MAIN2 @ MAZ; also clears
5217  3047   MN, DCA CTR3;/clear CTR3
5220  7100    CLL;
5221  1201    TAD ID;/turn on "DIP" LED + "INITIAL" LED
5222  4172    CALL;
5223  4620    LON;
5224  3057    DCA TEM13;/a-low "continue"
5225  1202    TAD DIFF;/display current dip value
5226  4172    CALL;
5227  5355    ANG;/displays # stored as binary radians is 0-368 angle
5230  7040    CMA
5231  3045    DCA TEM5;
5232  4172    CALL;/go to EXEC for further instructions
5233  5011    EXEC
5234  1055    TAD TEM11;/data received? (i.e., TEM11=0?)
5235  7640    SZA CLA;
5236  5336    JMP M2; /no, go on
5237  3742    DCA I DIF1;/clear "DIP" @ LOC 0320
5240  3743    DCA I DIF2;
5241  3744    DCA I DIF3;
5242  3745    DCA I DIF4
5243  4172   M1, CALL;/go get new data set
5244  2405    DATA;/AC=0, timeout error. AC=1
5245  3054    DCA TEM10;/TEM10 now has error information from DATA
5246  3100    DCA TEMP;/clear TEMP
5247  4172    CALL; /turn on APU
5250  5440    AON;
5251  4172    CALL;/do data calibration
5252  4250    DATCAL;
5253  4172    CALL;/calculate dip & put it in ROG4 & display it
5254  5751    DIPCAL
5255  1100    TAD TEMP;/is there a battery or other CHEK error?
5256  7640    SZA CLA;
5257  5261    JMP .+2; /yes
5260  5264    JMP .+4; /no
5261  1054    TAD TEM10;/yes, get TEM10
5262  7040    CMA;/complementing TEM10 make sure it indicates an error, no matter
5263  3054    DCA TEM10;/how DATA came out
5264  1205    TAD DP;/light up DIP light only
5265  4172    CALL
5266  4620    LON;
5267  1204    TAD RG4;/get AC to point to REG4 for ANG
5270  4172    CALL;/display REG4 as an angle
5271  5355    ANG;
5272  6600    APUOF;/turn off APU
```

```
5273  3101  DCA TEMN;/clear TEMN
5274  4172  CALL;/go to CONOE to handle any data error
5275  5704  CONOE;
5276  1101  TAD TEMN/CLR/CONT or ENT pressed?
5277  7650  SNA CLA;
5300  5306  JMP M8;/ENT pressed, go on
5301  7040  CMA/CLR/CONT pressed, put 7777₈ into TEM13 to disallow CONT
5302  3057  DCA TEM13;/in EXEC
5303  4172  CALL;/wait for operator requests or DATA. Assumes you didn't
5304  5011  EXEC;/like that Dip reading. It gets thrown away
5305  5243  JMP M1;/got a data clock, back to M1
5306  1047  M8, TAD CTR3;/we are continuing with a valid DIP reading
5307  3053  DCA TEM9;/put current CTR3 into TEM9 for AVGV
5310  1204  TAD RG4;/point to current value of dip
5311  3055  DCA TEM11/put in TEM11 for AVGV
5312  1202  TAD DIFF;/make TEM7 point to accumulated average for AVGV
5313  3050  DCA TEM7;
5314  4172  CALL;/turn on APU
5315  5440  AON
5316  4172  CALL; /do the current average for DIP
5317  4555  AVGV;
5320  1205  TAD DF;/turn on DIP light
5321  4172  CALL;
5322  4620  LON;
5323  1202  TAD DIFF; /get current DIP average
5324  4172  CALL; /display as an angle
5325  5355  ANG;
5326  3057  DCA TEM13/allow continue
5327  4172  CALL; /wait for operator command or data
5330  5011  EXEC;
5331  1055  TAD TEM11/what happened?
5332  7640  SZA CLA;
5333  5336  JMP M2;/continue pressed (actually "AR","ENT" will get here too)
5334  2047  ISZ CTR3/increment average counter
5335  5243  JMP M1/do it again
5336  7040  M2, CMA;
5337  3045  DCA TEM5/signal "INITIAL" by making TEM5≠0
5340  5741  JMP I .+1;
5341  5400  STIN/go on
5342  0320  DIF1, 320;
5343  0321  DIF2, 321;
5344  0322  DIF3, 322;
5345  0323  DIF4, 323
```

```
                  /ANG, AVG
                  CONV=6014;
                  REG5=533;
                  CON=5604
                  W=4137;
                  A=4153;
                  D=4161;
                  F=4145;
                  RETURN=5575;
                  CALL=4172;
                  M=4150;
                  KEYT=33
                  STATUS=4347;
                  RBUF=43;
                  P=4142
                  /ANG
                  *5353
5353    5603      CN, CON-1;
5354    0533      RG5, REG5
5355    4137      ANG, W;/write REG4
5356    1353       TAD CN;/write ISO/π
5357    4137       W;
5360    4150       M;/do REG4x180/π
5361    1354       TAD RG5;/stroe in REG5
5362    4142       P;
5363    1354       TAD RG5;/point to REG5
5364    4172       CALL;/display # in REG5
5365    6014       CONV;
5366    5575       RETURN
                  /AVG
                  TWO=2025
5367    2024      TWOT, TWO-1
5370    4137      AVG, W;
5371    4153       A;
5372    1367       TAD TWOT;
5373    4137       W;
5374    4161       D;
5375    4145       F;
5376    5575       RETURN
```

KEY SERVICE

```
        /KYSR
        KR2=6433;
        KR1=6432;
        AR2=6430;
        CHAR=61;
        TEM8=51;
        TEM7=50;
        TEM5=45;
        TEM14=62
        DISCG=3234;
        ACC1=3523;
        KEYCTR=27;
        CALL=4172;
        RETURN=5575;
        LDA=3154;
        CONV=6014
        TEM6=46;
        LON=4620;
        ANG=5355;
        M=4150;
        R=4142;
        W=4137;
        KYEX=6341;
        BLANK=3606;
        D=4161
        ANGE=2233
        *5600
5600 0017 MIKK, 17;
5601 7775 IN1, -3;
5602 4600 DI, 4600;
5603 5603 CN, CON-1;
5604 6740 CON, 6740;
5605 6456  6456;
5606 6745  6745;
5607 6406  6406
5610 0007 ZE, 7
5611 4172 KYIR, CALL;/lights off
5612 3154  LDA;
5613 4172  CALL; /blank display
5614 3606  BLANK;                               0-not "INITIAL"
5615 3045  DCA TEM5;/clear TEM5-used for else-"INITIAL"
5616 3051  DCA TEM8;/clear TEM8-used for 0=not an angle
5617 6007  CAF/clear any requests          else-an angle
5620 6432  KR1;/wait for KBL request
5621 5220  JMP .-1;
5622 6430  AR2;/read keyboard
5623 0200  AND MIKK;/mask least significant 4 bits
5624 3061  DCA CHAR;/save
5625 1061  TAD CHAR/recall
5626 1201  TAD IN1;/was "INITIAL" pressed?
5627 7640  SZA CLA;
5630 5243  JMP KYIR1/no, go on
5631 7001 KYIR2, IAC; /yes, light "INITIAL" light
5632 4172  CALL;
5633 4620  LON;
5634 7040  CMA;
5635 3045  DCA TEM5/load TEM5 with 7777
```

```
5636  6432  KYIP3, KP1;/next press?
5637  5236   JMP .-1;
5640  6430   AP2;/get it
5641  0200   AND MSKK;
5642  3061   DCA CHAR/save it
5643  1061  KYIP1, TAD CHAR
5644  1202  KYIPA, TAD DI; /add branch table starting addr to it
5645  3062   DCA TEM14;/put in RAM
5646  5462   JMP I TEM14/jump to branch table, 4600+ CHAR
5647  4172  KYIPC, CALL;/patch: KYEX displays value & gets another one in
5650  6341   KYEX /TOS of "INITIAL"
5651  7200  CLA;
5652  1027   TAD KEYCTR;/get KYCTR≠if new value has been keyed in
5653  7650   SNA CLA;
5654  5575   RETURN/return if no change to selected variable
5655  1045   TAD TEM5;/"INITIAL" selected?
5656  7650   SNA CLA;
5657  5272   JMP KF/no; ∴ error...can't change parameter w/o "INITIAL"
5660  1051   TAD TEM3;/is it an angle?
5661  7650   SNA CLA;
5662  5267   JMP KH;/no
5663  1203   TAD CN;/yes, load 180/π
5664  4137   M;
5665  4172   CALL;/do the conversion fromdegrees to radians (o°-360°)
5666  2233   ANGE
5667  1046  KH, TAD TEM6;/puts result in parameter pointed to by TEM6
5670  4142   R;
5671  5575   RETURN
5672  1210  KF, TAD IE;/signal "7" error message (never does this)
5673  4172   CALL;
5674  3234   DISCO;
5675  7200   CLA;
5676  5575   RETURN
```

can do without, just make KR, RETURN

```
             /GETIN      /GET initial conditions does initial calculations
             W=4137;      GTIN actually gets parameters
             P=4145;
             R=4142;
             S=4156;
             SINE=2723;
             COS=6136;
             M=4150;
             CALL=4172;
             RETURN=5575
             *4442
4442  6400   PAKL, 6400;
4443  6400    6400;
4444  6640    6640;
4445  6405    6405;
4446  0403   SLEN, 403;
4447  0413   LT1, 413;
4450  0423   DEFPT, 423;
4451  0373   PITT, 373
4452  0477   ABER, 477;
4453  0503   AINC, 503;
4454  0467   BER1, 467;
4455  0507   BER2, 507;
4456  0473   INC1, 473;
4457  0513   INC2, 513;
4460  0517   AVBER, 517
4461  0523   AVINC, 523;
4462  0433   VDA, 433/vd
4463  1252   GETIN, TAD ABER;/write ABER
4464  4137    W;
4465  4145    P;
4466  1254    TAD BER1;/put ABER into BER1
4467  4142    R;
4470  4145    P;
4471  1260    TAD AVBER;/and AVBER
4472  4142    R;
4473  1255    TAD BER2;/and BER2
4474  4142    R;
4475  1253    TAD AINC;/put AINC into INC1
4476  4137    W
4477  4145    P;
4500  1256    TAD INC1;
4501  4142    R;
4502  4145    P;
4503  1261    TAD AVINC;/and AVINC
4504  4142    R;
4505  1257    TAD INC2;/and INC2
4506  4142    R;
4507  1253    TAD AINC;
4510  4137    W;
```

```
4511  1251  TAD PITT;/get AINC-π/2
4512  4137  W;
4513  4156  S;
4514  4145  P
4515  4172  CALL;
4516  2723  SINE;/sin (AINC-π/2)
4517  1246  TAD SLEN;
4520  4137  W;
4521  4150  M;/slewxsin(AINC-π/2)=VD
4522  1262  TAD VDH;/VD—>0434-0437
4523  4142  R;
4524  4172  CALL;/cos(AINC-π/2)
4525  6136  COS;
4526  1246  TAD SLEN;
4527  4137  W;
4530  4150  M;/slewxcos(AINC-π/2)
4531  4145  P;
4532  1250  TAD DEPPT/store in DEPPT
4533  4142  R
4534  1252  TAD ABER;
4535  4137  W;
4536  4172  CALL;
4537  6136  COS;
4540  4150  M;/cos(ABER)xslewxcos(AINC-π/2)
4541  1247  TAD LT1;
4542  4142  R;/put in LAT
4543  1250  TAD DEPPT;
4544  4137  W;
4545  1252  TAD ABER;
4546  4137  W;
4547  4172  CALL;
4550  2723  SINE
4551  4150  M;/sin ABERxslewxcos(AINC-π/2)—>DEP
4552  1250  TAD DEPPT;
4553  4142  R;
4554  5575  RETURN
```

```
/PROC3
ADDF=153;
ARSIN=2677;
ARTAN=2655;
CALL=4173;
CHS=3761;
DIVF=161;
KEYT=33;
MULF=150
VDVT=3256;
DETT=6156;
AVG=5370
PBUF=43;
PIAS=2305;
POP=2661;
PUSH=145;
RD=142;
RETURN=5575;
SQRT=2703;
STATUS=4347
SUBF=156;
XCH=3144;
WT=137;
A=JMS ADDF;
D=JMS DIVF;
P=JMS PUSH
R=JMS RD;
S=JMS SUBF;
M=JMS MULF;
W=JMS WT;
SINE=2723;
COS=6136;
PBUF=43

/PROC2
*4000
4000   0467   BER1, 467;
4001   0503   AINC, 503;
4002   0517   AVBER, 517;
4003   0403   SLEG, 403;
4004   0367   RODL, 367;
4005   0413   LAT1, 413
4006   0473   INC1, 473;
4007   0523   AVINC, 523;
4010   0423   DEPT, 423;
4011   0433   VD, 433;
4012   0443   THDH, 443
4013   0477   ABER, 477;
4014   0327   LAD, 327;
4015   0463   LDEV, 463;
4016   0223   COB, 223;
4017   0227   COA, 227;
4020   0233   SIB, 233;
4021   0323   SIA, 323
```

```
4022  1206  PROC2, TAD INC1;
4023  4137   W;
4024  1207   TAD AVINC;
4025  4172   CALL;
4026  5370   AVG;
4027  4172   CALL;
4030  6136   COS;
4031  1221   TAD SIA;
4032  4142   R
4033  4172   CALL;
4034  2723   SINE;
4035  1217   TAD COA;
4036  4142   R /SIN&COS REVERSED TO CONV AVINC TO THETA
4037  1204  TAD RODL;
4040  4137   W;
4041  1203   TAD SLEG;
4042  4137   W;
4043  4153   A;
4044  1203   TAD SLEG;
4045  4142   R
4046  1200  TAD BER1;
4047  4137   W;
4050  1202   TAD AVBER;
4051  4172   CALL;
4052  5370   AVG;
4053  4172   CALL;
4054  2723   SINE;
4055  1220   TAD SIB;
4056  4142   R
4057  4172   CALL;
4060  6136   COS;
4061  4145   F;
4062  1216   TAD COB;
4063  4142   R
4064  1217  TAD COA;
4065  4137   W;
4066  4150   M;
4067  1204   TAD RODL;
4070  4137   W;
4071  4150   M;
4072  1205   TAD LAT1;
4073  4137   W;
4074  4153   A;
4075  4172   CALL;
4076  4347   STATUS;
4077  3043   DCA PBUF
4100  1205   TAD LAT1
4101  4172  CALL;
4102  6156   DETT
4103  1211  TAD VD;
4104  4137   W;
4105  1204   TAD RODL;
4106  4137   W;
4107  1221   TAD SIA;
4110  4137   W;
4111  4150   M;
4112  4156   S;
4113  1211   TAD VD;
4114  4142   R
```

```
4115  1205  TAD LAT1;
4116  4137   W;
4117  4145   P;
4120  4150   M;
4121  1210   TAD DEPT;
4122  4137   W;
4123  4145   P;
4124  4150   M;
4125  4153   A;
4126  4145   P;
4127  4172   CALL;
4130  2703   SQRT;
4131  1214   TAD LAD;
4132  4142   R;
4133  1211   TAD VD
4134  4137   W;
4135  4145   P;
4136  4150   M;
4137  4153   A;
4140  4172   CALL;
4141  2703   SQRT;
4142  1212   TAD THDH;
4143  4142   P
4144  1210  TAD DEPT;
4145  4137   W;
4146  1205   TAD LAT1;
4147  4137   W;
4150  4161   D;
4151  4172   CALL;
4152  2655   ARTAN;
4153  4172   CALL;
4154  2305   PIAD
4155  1213   TAD ABEF;
4156  4137   W;
4157  4156   I;
4160  4145   P;
4161  4172   CALL;
4162  6136   COS;
4163  4172   CALL;
4164  3144   SCH;
4165  4172   CALL;
4166  2723   SINE
4167  1214  TAD LAD;
4170  4137   W;
4171  4150   M;
4172  1215   TAD LDEV;
4173  4142   P
4174  1201   TAD AINC;
4175  4172  [illegible]    JMPI+1 (5776)
4176  3256  [illegible]    6451
4177  5575  [illegible]
```

AVGV, SYMBOL TABLE

```
A        4153
AVGV     4555
CALL     4172
D        4161
F        4164
LDI      3124
M        4150
R        4142
RETURN   5575
TEM11    0055
TEM7     0050
TEM9     0053
W        4137

 PC00241 MD5214 A0000 U3155 L1 D0
>32002 7002
>C
```

```
                    AVGV          /from AVeraGe Value
                    TEM9=53;                   Enter with TEM7--> (current value)
                    TEM11=55;                             TEM9--> # of iterations (0=1st time)
                    TEM7=50;                             TEM11--> (average value)
                    LDI=3124;                  Exit with  TEM7--> (unchanged)
                    W=4137;                               TEM9--> unchanged
                    M=4150;                              TEM11--> (new average value)
                    F=4164;
                    A=4153;
                    D=4161
                    CALL=4172;
                    RETURN=5575;
                    R=4142
                    *4555
4555   1053         AVGV, TAD TEM9;/fetch current # of iterations (N)
4556   4172          CALL;/load & float
4557   3124          LDI;
4560   4164          F;
4561   1050          TAD TEM7;/point to accumulated average (AV)
4562   4137          W;
4563   4150          M;/(NxAV)
4564   1055          TAD TEM11;/write current value (CV)
4565   4137          W;
4566   4153          A/(NxAV)+CV
4567   1053          TAD TEM9;/load N+1
4570   7001          IAC;
4571   4172          CALL;
4572   3124          LDI;
4573   4164          F; (NxAV)+CV
4574   4161          D;/ --------- = new AV
                           N+1
4575   1050          TAD TEM7;/put the result in loc pointed to by TEM7
4576   4142          R;
4577   5575          RETURN
```

```
                /BATCHK          /check batteries
                DISCO=3234;
                LON1=4622;
                CALL=4172;
                RETURN=5575;
                BS1=6442;
                BS2=6443;
                TEMP=100
                STATUS=4347;
                EXITE=6244
                *6500
6500    0020    LB, 20;
6501    5012    EXEC1, 5012;
6502    6442    BATCHK, BS1;/processor battery low?
6503    5313     JMP .+8;/no, go on
6504    1300     TAD LB; /yes, turn on "LO BATTERY"
6505    4172     CALL;
6506    4622     LON1;
6507    4172     CALL;/display a "0" code
6510    3234     DISCO
6511    7000     NOP;
6512    7000     NOP;
6513    5714     JMP I  .+1; /continue with EXITE
6514    6244     EXITE;
6515    7000     NOP
```

```
                 /RBAT    /Receiver Battery Check
6516   0004   STTM, 4;
6517   0314   RSTAT, 314;
6520   1717   RBAT, TAD I RSTAT; /get receiver status word
6521   0316    AND STTM;/mask off bit 9
6522   7650    SNA CLA;/battery OK?
6523   5325    JMP .+2 /no
6524   5575    RETURN;/yes, return
6525   5343    JMP CHEK2 /exit thru CHEK2 to turn on LO BATTERY
                         /lite and set TE[illegible]=1
                 /TEME    /TEMPERATURE ERROR HANDLER
              TEMD=75
6526   7132   TEME, STL RTR; /turn on HI TEMP
6527   4172    CALL;
6530   4620    LON;
6531   7040    CMA; /put 7777_8 into TEMD
6532   3075    DCA TEMD;
6533   5350    JMP CHEK3 /exit thru CHEK3 to set TEMP=1

                 /CHEK    /used to handle battery check
              TEM10=54;
              LON=4620
6534   0020   LITE, 20;
6535   0010   DIS, 10
6536   4172   CHEK, CALL; /number in TOS negative?
6537   4347    STATUS;
6540   7650    SNA CLA;
6541   5575    RETURN/yes
6542   1335   CHEKA, TAD DIS /no, display "8" code
6543   4172   CHEK2, CALL;
6544   3234    DISCO;
6545   1334    TAD LITE; /turn on "LO BATT" lite
6546   4172    CALL;
6547   4622    LON1 /LON1 turns on L4 lites
6550   7001   CHEK3, IAC; /put a "1" in TEMP
6551   3100    DCA TEMP;
6552   5575    RETURN

                 /KYBLK
              BLANK=3606;
              JMPR=30;
              KEYCTR=27;
              MINUS=31
              *6553
6553   4264   ENTER, -3514
6554   1031   KYBLK, TAD MINUS;
6555   1027    TAD KEYCTR;
6556   7640    SZA CLA;
6557   5430    JMP I JMPR;
6560   1353    TAD ENTER;
6561   1030    TAD JMPR
6562   7650    SNA CLA;
6563   5430    JMP I JMPR;
6564   4172    CALL;
6565   3606    BLANK;
6566   5430    JMP I JMPR
```

```
/KYEX
                TEM5=45;
                LON=4620;
                TEM8=51;
                TEM6=46;
                CONV=6014;
                CALL=4172;
                RETURN=5575;
                ACC=3521
                ANG=5355;
                CONV=6014;
                KEYCTR=27;
                AON=5440;
                APUOF=6600;
                ANGA=2214
                *6341
6341   4172     KYEX, CALL;/turn on APU
6342   5440      AON;
6343   1051      TAD TEM8;/is it an angle?
6344   7650      SNA CLA;
6345   5352      JMP KYSRD; /no
6346   1046      TAD TEM6;/yes, display as 0°-360°
6347   4172      CALL;
6350   2214      ANGA;
6351   5355      JMP KE
6352   1046     KYSRD, TAD TEM6;/display as a length in feet
6353   4172      CALL;
6354   6014      CONV
6355   6600     KE, APUOF;/turn off APU
6356   1045      TAD TEM5;/"INITIAL"?
6357   7650      SNA CLA;
6360   5373      JMP KM; /no
6361   7001      IAC;/yes, turn on "INITIAL" lite
6362   4172      CALL;
6363   4620      LON;
6364   4172      CALL;/get a # from operator
6365   3521      ACC;
6366   7000      NOP
6367   1027      TAD KEYCTR;/was a new # entered?
6370   7650      SNA CLA;
6371   5373      JMP KM;/no
6372   5575      RETURN
6373   3027     KM, DCA KEYCTR;/zeroize keycounter
6374   5575      RETURN

6375   7000     PRINIT, NOP;
6376   5575      RETURN
6377   7000     PRPO, NOP;
6400   5575      RETURN
```

```
                AFUOF=6600;
                 EXEC=5013;
                 STEST=6412;
                 KYSR=5611;
                 RST=5147;
                 CALL=4172;
                 RETURN=5575
                 LON1=4622;
                 TEMS=57
                /EXEX
                *6200
6200   6007     EXEX, CAF;/clear all requests
6201   6600      AFUOF;/turn off APU
6202   1207      TAD RDY; /turn on RESET lite
6203   4172      CALL;
6204   4622      LON1;
6205   5606      JMP I EXE /return to EXEC
6206   5013     EXE, EXEC;
6207   2000      RDY,2000
                /KYSRC
6210   4172     KYSRC, CALL;/calling routine for KYSR
6211   6246      EXITE+2;
6212   4172      CALL;
6213   5611      KYSR;
6214   5575      RETURN
                /STESTC
6215   4172     STESTC, CALL; /calling routine for STEST
6216   6246      EXITE+2;
6217   4172      XXXXX      JMPI.+1 5620
6220   6412      STEST;
6221   5575      RETURN
                /RSTC
6222   4172     RSTC, CALL; /calling routine for RST
6223   6246      EXITE+2;
6224   4172      CALL;
6225   5147      RST;
6226   5575      RETURN
```

```
                /MA1EX      /MAIN1 EXTENSION
                KR1=6432;
                 KR2=6433;
                 MA2=6632;
                 MN=5217;
                 DISCO=3234
6227   6007     MA1EX, CAF; /clear all requests
6230   1200      TAD EXEX; /display "T"
6231   4172      CALL;
6232   3234      DISCO;
6233   6432      KR1;/KBL?
6234   5236      JMP MA1EX1;/no, try KBR
6235   5643      JMP I MNA /yes, back to MAIN1 @ MN
6236   6433     MA1EX1, KR2;/KYBR?
6237   5227      JMP MA1EX;/no, start over
6240   3057      DCA TEM5; /yes, clear TEM5
6241   5642      JMP I MA2N;/back to MAIN2 @ MA2
6242   6632     MA2N, MA2;
6243   5217     MNA, MN
                /EXITE
                BS2=6443;
                 CHLITE=2516
6244   6443     EXITE, BS2; /this is not done
6245   5201      JMP EXEX+1;
6246   7320      CLA STL;/turn off RESET lite
6247   7421      MQL;
6250   1254      TAD RDYO;
6251   4172      CALL
6252   2516      CHLITE;
6253   5575      RETURN; /return
6254   5777     RDYO, 5777
                /PROPA      /change to PROC1 to call 0° down
                W=4137;          see PROC1 for explanation
                 XCH=3144;
                 S=4156;
                 CHS=3761;
                 A=4153
                *6260
6260   4137     PROPA, W;
6261   4172      CALL;
6262   3144      XCH;
6263   4172      CALL;
6264   3761      CHS;
6265   4153      A    /S IF 0 DEGREES IS UP
6266   5667      JMP I .+1;/back to PROC1 @ 2042
6267   2042      2042
```

```
CTR2=42;
TEM=10;
LDS=3124;
WT=137;
ADDS=3134;
MULS=3140;
FLT=164
BW1=6441;
DIVF=161;
CHS=3761;
RD=142;
CALL=4172;
RETURN=5575
```

SCDATA *6300 /Scale Data

```
6300  0243  R,        243
6301  0005  FI,       5
6302  7774  TMD,      -4
6303  0007  TFS,      7
6304  7766  TE,       -12
6305  1304  SCDATA,   TAD TE/make CTR2 count 10_10 times
6306  3042            DCA CTR2
6307  1300            TAD R /put addr of 1st data loc (244-247) into T
6310  3010            DCA TEM
6311  1301  SCA,      TAD FI/load 5 into TOS
6312  4172            CALL
6313  3124            LDS
6314  1010  TAD TEM   /load 1st (next) data word [D.W.] as 32 bit
6315  4137  JMS WT
6316  4172            CALL/create 16 bit # (single) for DW
6317  3134            ADDS
6320  4172            CALL /DW (single) x5 (single)
6321  3140            MULS
6322  4164  JMS FLT /float the result
6323  7040            CMA /load 2047_10 (float)
6324  6441            BW1
6325  0303            AND TFS
6326  6441            BW1
6327  4164  JMS FLT       D.W.x5
6330  4161  JMS DIVF/get ------- (float)
                          2047_10
6331  4172            CALL/change sign to compensate for downhole inver
6332  3761            CHS
6333  1010  TAD TEM /WT advances the addr in TEM, so get it
6334  1302  TAD TMD /back and load with the scaled data
6335  4142  JMS RD
6336  2042  ISZ CTR2 /10 times?
6337  5311  JMP SCA/no, do it again
6340  5575            RETURN /yes, return
```

/SELF TEST CALLS AND PATCHES

```
                STEST=5600;
                 LDN=4620;
                 LDN1=4622;
                 MEMSW=6100;
                 MEMNOR=6500;
                 CALL=4172
                 RETURN=5575;
                 DATA=2405;
                 ADN=5440;
                 APUSR=6600;
                 CONV=6014;
                 RET=5663;
                 TEMN=101

                *6400
6400   7240    STST, CLA CMA;
6401   4172     CALL;
6402   4620     LDN;
6403   7040     CMA;
6404   4172     CALL;
6405   4622     LDN1;
6406   6100     MEMSW;
6407   5610     JMP I.+1;
6410   5600     STEST
6411   6500    STSTD, MEMNOR;
6412   4172     CALL;
6413   2405     DATA;
6414   6100     MEMSW;
6415   5616     JMP I .+1;
6416   5663     RET
6417   6500    STSTC, MEMNOR;
6420   4172     CALL;
6421   5440     ACN;
6422   1101     TAD TEMN;
6423   4172     CALL;
6424   6014     CONV;
6425   5270     JMP END;
6426   7000     NOP;
6427   7000     NOP
```

/INITIAL CONDITIONS PRINT ROUTINE

```
               INCO=4400;
                MAIN2=6620
6430   6100    INITCO, MEMSW;
6431   5632     JMP I .+1;
6432   4400     INCO
6433   6500    INIT1, MEMNOR;
6434   4172     CALL;
6435   3606     BLANK;
6436   5637     JMP I .+1;
6437   6620     MAIN2
```

```
                /RESTART PRINT ROUTINE

                LDA=3154;
                 RST=4412
6440   4172    RESTR, CALL;
6441   3154     LDA;
6442   6100     MEMSW;
6443   5644     JMP I  .+1;
6444   4412     RST
6445   6500    RESTR1, MEMNOR;
6446   4172     CALL;
6447   3606     BLANK;
6450   5575     RETURN

                /SURVEY PRINT ROUTINE

                VDVT=3256;
                 SUR=4424;
                 BLANK=3606
6451   4172    SURVEY, CALL;
6452   3256     VDVT;
6453   6100     MEMSW;
6454   5655     JMP I  .+1;
6455   4424     SUR
6456   6500    SURV1, MEMNOR;
6457   4172     CALL;
6460   3606     BLANK;
6461   5575     RETURN


                /USED BY PRINT CALLER


                ANGA=2214
6462   6500    STSTA, MEMNOR;
6463   4172     CALL;
6464   5440     ADN;
6465   1101     TAD TEMN;
6466   4172     CALL;
6467   2214     ANGA;
6470   6600    END, APUOF;
6471   6100     MEMSW;
6472   7200     CLA;
6473   5575     RETURN
```

```
/CONV   /displays a # as a decimal #

                  *6000/enter with # to be diaplayed in TOS

6000  0004  FOUR,   4
6001  7000  BLK,    7000
6002  0217  TENF,   217 /addr of 10 floated
6003  7773  FI,     -5
6004  0240  HTH,    240
6005  0206          206
6006  0001          1
6007  0000          0
6010  6003  HTHL,   HTH-1 /addr of HTH for WT routine
6011  0230  RG2,    REG2
6012  0227  RG2M,   REG2-1/addr of REG2 for WT routine
6013  0001  TW,     1
6014  4172  CONV,   CALL/if is >xxxx.xx5, rounds up. <xxxx.xx5, rounds down
6015  2257          POP
6016  1203          TAD FI/make CTR2 count to 5
6017  3042          DCA CTR2
6020  4172          CALL/blank display
6021  3606          BLANK
6022  1202          TAD TENF/load 10
6023  4137  JMS WT
6024  4145  JMS PUSH
6025  4150  JMS MULF
6026  4150  JMS MULF/create #x100
6027  4172          CALL /plus or minus?
6030  4347          STATUS
6031  7650          SNA CLA
6032  5236          JMP .+4/plus
6033  4172          CALL/minus, change sign, &
6034  3761          CHS
6035  7013          IAC RTR/put 1 in MSB of AC
6036  3031          DCA MINUS/store in MINUS
6037  4172          CALL /FIX (double precision -16 bits) the #
6040  6130          FIXD
6041  1210          TAD HTHL/write 100,000
6042  4137  JMS WT
6043  7100  C2,     CLL
6044  2027          ISZ KEYCTR/increment keystroke counter
6045  1212          TAD RG2M/put TOS into REG2 (will have the next power of 10
6046  4142  JMS RD
6047  4145  JMS PUSH/push the working number
6050  1212          TAD RG2M/get the power of 10 back
6051  4137  JMS WT
6052  4172          CALL/÷ by the power of 10, truncate fractional part
6053  2713          DIVD
6054  4145  JMS PUSH/save it in the stack
6055  4172          CALL/picks off the 4 LSB's of TOS & uses DISPR to display
6056  3370          LSW                         it as a decimal #. Throws
6057  1212          TAD RG2M/get power of 10    out TOS
6060  4137  JMS WT
6061  4172          CALL /multiply by truncated integer
6062  2673          MULD
6063  4172          CALL /remove MSD from working #
6064  2717          SUBD
6065  2042          ISZ CTR2/done 5 times?
6066  5273          JMP C3/no
6067  2027          ISZ KEYCTR/causes DISPR to put in decimal pt. after 4 #s
6070  4172          CALL/goes to DISPR with 6th digit
6071  3370          LSW
6072  5312          JMP EXIT
```

```
6073  1212  C3,       TAD RG2M /create next lower power of 10
6074  4137  JMS WT
6075  1202            TAD TENF
6076  4137  JMS WT
6077  4172            CALL
6100  6130            FIXD
6101  4172            CALL
6102  2713            DIVD
6103  1213            TAD TW/is this the 4th time?
6104  1042            TAD CTR2
6105  7640            SZA CLA
6106  5243            JMP C2/no, do it again
6107  4172            CALL/yes, DISPR will push digits over 2 places &
6110  3630            DISPR /put in a decimal point, then return
6111  5243            JMP C2/do it again
6112  1031  EXIT,     TAD MINUS /negative #?
6113  7650            SNA CLA
6114  5575            RETURN/no, return
6115  1025            TAD DISPR2 /yes, make sure MSD of display is bl
6116  1201            TAD BLK/so minus sign may appear
6117  3025            DCA DISPR2
6120  4172            CALL
6121  3672            DIS3
6122  7240  CLA CMA/turn on minus sign
6123  7421            MQL
6124  7121            IAC STL
6125  4172            CALL
6126  2516            CHLITE
6127  5575            RETURN/done
6130  4172  FIXD,     CALL/the "fix double" APU routine
6131  2727            CRAB
6132  1335            TAD .+3
6133  5734            JMP I .+1
6134  2734            BW
6135  0036            36

                      /COS

6136  4172  COS,      CALL/the cosine routine
6137  2727            CRAB
6140  1343            TAD .+3
6141  5742            JMP I .+1
6142  2734            BW
6143  0003            3

                      /PI

6144  4172  PI,       CALL/puts PI in TOS
6145  2727            CRAB
6146  1351            TAD .+3
6147  5750            JMP I .+1
6150  2734            BW
6151  0032            32
```

```
                    RDT
                  KR2=6433;
                   AR2=6430;
                   R=4164;
                   CALL=4172;
                   RETURN=5575;
                   W=4137;
                   R=4142;
                   ADH=5440
                   CHAR1=63;
                   CT=102;
                   CONV=6014;
                   BI4=6453;
                   M=4150;
                   AFUCF=6600;
                   DISPR2=25;
                   DISS=3672
                   D=4161;
                   BW=2734;
                   CRAB=2727;
                   A=4153;
                   CTR=27;
                   P=4145;
                   MEMNOR=6500;
                   EXITE=6246
                  *7010
7010  0243        LIST, 243;
7011  0247         247;
7012  0253         253;
7013  0257         257;
7014  0263         263;
7015  0267         267;
7016  0273         273;
7017  0277         277;
7020  0303         303;
7021  0307         307
7022  7007        START, LIST-1;
7023  0314         RCVR, 314;
7024  0217         TEN, 217;
7025  0567         DEBUG, 567;
7026  7766         CONT, -12;
7027  0017         MSK, 17
7030  7771         DISP, -7;
7031  0377         MK, 377;
7032  0003         MK1, 3;
7033  5011         EXEC, 5011;
7034  7770         EM, -10
7035  5371        RDT, JMP AHD;
7036  6433         BK, KR2;
7037  5236         JMP .-1;
7040  6430         AR2;
7041  0227         AND MSK;
7042  3063         DCA CHAR1;
7043  1063         TAD CHAR1
7044  1230         TAD DISP;
7045  7640         SZA CLA;
7046  5350         JMP NEXT;
7047  7100         CLL;
7050  1226         TAD CONT;
7051  3102         DCA CT;
7052  1222         TAD START;
7053  3011         DCA 11
```

```
[illegible]          CALL;
7055  5440   AON;
7056  1411   TAD I 11;
7057  4137   W;
7060  1224   TAD TEN;
7061  4137   W;
7062  4150   M;
7063  1224   TAD TEN;
7064  4137   W;
7065  4150   M;
7066  1225   TAD DEBUG;
7067  4142   R
7070  1225   TAD DEBUG;
7071  4172   CALL;
7072  6014   CONV;
7073  6600   AFUCF;
7074  6433   KP2;
7075  5274   JMP .-1;
7076  2102   ISZ CT;
7077  5254   JMP BACK
7100  6500  REC, MEMNOR;
7101  4172   CALL;
7102  5440   AON;
7103  1353   TAD TTF;
7104  4137   W;
7105  1623   TAD I ROVR;
7106  7012   RTR;
7107  7421   MQL;
7110  1232   TAD MK1;
7111  7501   MQA
7112  6441  6441;
7113  7002   BSW;
7114  7012   RTR;
7115  0227   AND MSK;
7116  6441   6441;
7117  4164   F;
7120  4161   D;
7121  4172   CALL;
7122  7164   LOG;
7123  1224   TAD TEN;
7124  4137   W;
7125  4145   P;
7126  4153   A;
7127  4150   M;
7130  4145   P;
7131  4153   A
```

```
7132  1623   .TAD I RCVR;
7133  7012    RTR;
7134  7012    RTR;
7135  7630    SZL CLA;
7136  5342    JMP .+4;
7137  1360    TAD THY;
7140  4137    W;
7141  4153    A
7142  1225    TAD DEBUG;
7143  4142    R;
7144  1225    TAD DEBUG;
7145  4172    CALL;
7146  6014    CONV;
7147  5633    JMP I EXEC
7150  6453   NEXT, BS4;
7151  5633    JMP I EXEC;
7152  4167    4167
7153  7152   TTF, TTF-1;
7154  6400    6400;
7155  6600    6600;
7156  6413    6413;
7157  0010    LG, 10
7160  7157   THY, THY-1;
7161  6400    6400;
7162  6760    6760;
7163  6405    6405
7164  4172   LOG, CALL;
7165  2727    CRAB;
7166  1357    TAD LG;
7167  5770    JMP I .+1;
7170  2734    BW
7171  6007   AHD, CAF;
7172  4172    CALL;
7173  6246    EXITE;
7174  5236    JMP BK
```

```
/MAIN2
IR=70;
ANG=5355;
PIT=374;
BLANK=3606;
TEM5=45;
TEM13=57;
TEM11=55;
DATA=2405;
TEMP=100
DIPCAL=5751;
LOA=3154;
EXEC=5011;
LDS=3124;
R=4142;
CTR3=47;
TEM10=54;
F=4164
A=4153;
M=4150;
D=4167;
P=4145;
S=4156;
W=4137;
TEMN=101
ROTCTR=52;
TEM7=50;
AVGV=4555;
CONDE=5704;
COM=4356;
COM1=4367;
PAKL=4441
SLEG=403;
M2EX=5422;
GTIN=5400;
AON=5440;
APUOF=6600
PROC1=2031;
DISCO=3234;
PROC2=4022;
INIT=5531;
IDLE=5765;
STEST=6407;
LON=4620
PRINIT,=7772;
PRPO=7772;
CALL=4172;
RETURN=5575
DATCAL=4250;
GETIN=4463;
TEM9=53
```

```
6600  0467  B1, 467;
6601  0507  B2, 507;
6602  0473  I1, 473;
6603  0513  I2, 513;
6604  6603  BR, BR-1; /Bearing limit - should be approx. 1.5°
6605  6400   6400; 6567
6606  6600   6600; 6726   1.5° in radians* IS ON ROM 2/22/80
6607  6477   6477; 6573
6610  6607  IN, IN-1;/inclination limit - should be approx. 1.5°
6611  6400   6400; 6772 )
6612  6600   6600; 6616 } 2° in radians* IS ON ROM 2/22/80
6613  6477   6477; 6574 )
6614  0003  THR, 3;
6615  0517  AVBR, 517;
6616  0523  AVIN, 523;
6617  0002  INL, 2
6620  4172  MAIN2, CALL;/turn on APU
6621  5440   AON;
6622  1215   TAD AVBR;  )
6623  4137   W;         }   /replace BER1 with AVBER
6624  1200   TAD B1;    )
6625  4142   R;
6626  1216   TAD AVIN;  )
6627  4137   W;         }   /replace INC1 with AVINC
6630  1202   TAD I1;    )
6631  4142   R
6632  4172  MA2, CALL; /wait for new data
6633  5011   EXEC;
6634  1055  MA2N, TAD TEM11;/make sure pressing "AP","ENT" does not
6635  7640   SZA CLA;/move the program on; only new data
6636  5232   JMP MA2;
6637  3052   DCA ROTCTR/clear rotation counter
```

*- to get change these values: (1) on front panel, set initial dip to value you want (e.g., 2°)

(2) read locations 0321, 0322 & 0323 for the 3 octal #'s for that angle

```
6640  4172  M4, CALL; / get DATA
6641  2405   DATA;
6642  3054   DCA TEM10; /store DATA's error-message
6643  3100   DCA TEMP; /zeroize TEMP
6644  4172   CALL; /APU ON
6645  5440   AON
6646  4172   CALL;/calibrate data
6647  4250   DATCAL;
6650  1100   TAD TEMP;/any DATCAL errors? (TEMP = 1?)
6651  7640   SZA CLA;
6652  5254   JMP .+2 /yes
6653  5257   JMP .+4;/no
6654  1054   TAD TEM10;/complement TEM10 so it will indicate error
6655  7040   CMA; /however DATA left it
6656  3054   DCA TEM10
6657  4172  M5, CALL;/calculate BER2 and INC2
6660  2031   PROC1;
6661  3053   DCA TEM9;/ clear TEM9, used here as error store for COM1
6662  1201   TAD B2; /compare BER2 with BER1 to see if it in limits
6663  4137   W;
6664  1200   TAD B1;
6665  4172   CALL;
6666  4356   COM;
6667  1204   TAD BR;
6670  4172   CALL;
6671  4367   COM1
6672  1203   TAD I2; /compare INC2 with INC1
6673  4137   W;
6674  1202   TAD I1;
6675  4172   CALL;
6676  4356   COM;
6677  1210   TAD IN;
6700  4172   CALL;
6701  4367   COM1
6702  1053   TAD TEM9
6703  7650   SNA CLA; /out of limits?
6704  5317   JMP M6; /no, go on
6705  3053   DCA TEM9; /yes
6706  1214   TAD THR; /display "3" code
6707  4172   CALL;
6710  3234   DISCO;
6711  6433   KR2; /wait for KBR to show operator acknowledge
6712  5311   JMP .-1
6713  4172   CALL;/lights off
6714  3154   LOA;
6715  4172   CALL;/APU on (unnecessary)
6716  5440   AON
```

```
6717  1217  M6, TAD INL;/turn on INC lite
6720  4172   CALL;
6721  4620   LON
6722  1203   TAD I2;/display INC2
6723  4172   CALL;
6724  5355   ANG;
6725  6600   AFUOF  /AUP off
6726  3101  DCA TEMN;/clear TEMN
6727  4172   CALL; /blink the lights and wait for operator "ENT" or "CLR"
6730  5704   CONOE; /
6731  1101   TAD TEMN; /TEMN = 1 if CLR, 0 if ENT
6732  7650   SNA CLA;/1 ENT?
6733  5341   JMP M7; /yes, go on
6734  7040   CMA; /no, disallow "CONTINUE"
6735  3057   DCA TEM13 /and wait for new data
6736  4172   CALL; /Pressing "AR", "ENT" here will cause a time out error
6737  5011   EXEC;
6740  5240   JMP M4 /go back to M4 with new data
6741  1052  M7, TAD ROTCTR; /get Rotation counter
6742  3053   DCA TEM9; /set up AVGV (average value) routine
6743  1201   TAD B2;
6744  3055   DCA TEM11; /with ROTCTR, BER2 AND AVBER
6745  1215   TAD AVBER;
6746  3050   DCA TEM7
6747  4172   CALL;
6750  5440   AON;/APU on
6751  4172   CALL
6752  4555   AVGV; /get new average (AVBER)
6753  1203   TAD I2;/now do it for INC
6754  3055   DCA TEM11;
6755  1216   TAD AVIN;
6756  3050   DCA TEM7;
6757  4172   CALL;
6760  4555   AVGV; /get new avinc
6761  2052   ISZ ROTCTR /advance ROTCTR
6762  1217   TAD INL;/turn on "INC"lite
6763  4172   CALL;
6764  4620   LON
6765  1216   TAD AVIN; /display average inclination
6766  4172   CALL;
6767  5355   ANG;
6770  5771   JMP I  .+1; /jump to the MAIN2 patch, M2EX
6771  5423   M2EX
```

```
DD PC01163 MD6111 A0304 L1 D0
>

2*A000000 MD7777 A0000 L0 D0
>2
>I0000 2002
>2006

IC   0200   AT   0200

AON       5440
CALL      4172
MEMNOR    6500
MEMIW     6100
RETURN    5575
ICDATA    6305
STZ       6270

 PC00241 MD5214 A0000 L1 D0
>I2002 7002
>C
 PC01505 MD5227 A0000 L0 D0
>I7002 7002
>C


            /ICDATA CALL

            MEMNOR=6500;
             MEMIW=6100;
             CALL=4172;
             RETURN=5575;
             AON=5440;
             ICDATA=6305

            *6270

6270   6500   STZ, MEMNOR;
6271   4172    CALL;
6272   5440    AON;
6273   4172    CALL;
6274   6305    ICDATA;
6275   6100    MEMIW;
6276   5575    RETURN
```

```
                              MONITOR

                              /SYMBOL DEFINITION

                              CALL=JMS CALLX
                              RETURN=JMP I RETX
                              WCRAA=6425
                              WCRBA=6435
                              WCRAB=6445
                              WCRBB=6455
                              PWT=6421
                              PCK=6423
                              KCK=6422
                              KRB=6420


                              *7776
7776   5210   RESET,          5210
7777   5776                   JMP I .-1

                              *7200

7200   7567   J4A,            J4
7201   7773   NCTR,           -5
7202   7770   CHK,            -10
7203   7530   CK1,           -250
7204   7561   F,              FAULT
7205   0007   OCTMK,          7
7206   1200   PACK2,          TAD J4A
7207   3131                   DCA NCTR1
7210   1201                   TAD NCTR
7211   3005                   DCA CTR
7212   2005   BEG,            ISZ CTR
7213   5215                   JMP NUMB
7214   5575                   RETURN
7215   4172   NUMB,           CALL
7216   7747                   READ
7217   1127                   TAD CHAR
7220   0202                   AND CHK
7221   1203                   TAD CK1
7222   7640                   SZA CLA
7223   5604                   JMP I F
7224   1127                   TAD CHAR
7225   0205                   AND OCTMK
7226   7100                   CLL
7227   5531                   JMP I NCTR1
7230   6420   CRLF,           KRB
7231   7200                   CLA
7232   1241                   TAD CRA
7233   4172                   CALL
7234   7742                   PRINT
7235   1242                   TAD LFA
7236   4172                   CALL
7237   7742                   PRINT
7240   5575                   RETURN
7241   0275   CRA,            275 1 = sign to save paper
7242   0275   LFA,            275 1 = sign to save paper
```

```
                        /READER

                        TRD=6420
                        SKIP=6422
                        EXIT=7
                        CTR1=6
                        CTR=5
                        DEST=4
                        TEM=3

7243   7772   LD,       ST
7244   7266   B11,      B4
7245   7273   B2,       B3
7246   7332   B70,      B7
7247   7335   B80,      B8
7250   7756   CT1,      -22
7251   7777   MONE,     -1
7252   0077   MSK,      77
7253   6420   READER,   TRD
7254   6422             SKIP
7255   7000             NOP
7256   7300             CLA CLL
7257   1244             TAD B11
7260   3003             DCA TEM
7261   1245             TAD B2
7262   3007             DCA EXIT
7263   3005             DCA CTR
7264   1250             TAD CT1
7265   3006             DCA CTR1
7266   2005   B4,       ISZ CTR
7267   5273             JMP B3
7270   2006             ISZ CTR1
7271   5273             JMP B3
7272   5643             JMP I LD
7273   7200   B3,       CLA
7274   6422             SKIP
7275   5403             JMP I TEM
7276   6420             TRD
7277   7006             RTL
7300   7006             RTL
7301   7104             CLL RAL
7302   7430             SZL
7303   5407             JMP I EXIT
7304   7004   B1,       RAL
7305   7421             MQL
7306   7420             SNL
7307   5313             JMP B5
7310   1246             TAD B70
7311   3004             DCA DEST
7312   5315             JMP B6
7313   1247   B5,       TAD B80
7314   3004             DCA DEST
```

```
7315  7501  B6,    MQA
7316  7012         RTR
7317  7012         RTR
7320  7012         RTR
7321  0252         AND MSK
7322  7002         BSW
7323  7421         MQL
7324  6422         SKIP
7325  5324         JMP .-1
7326  6420         TFD
7327  0252         AND MSK
7330  7501         MQA
7331  5404         JMP I DEST
7332  1251  B7,    TAD MONE
7333  3010         DCA 10
7334  7410         SKP
7335  3410  B8,    DCA I 10
7336  1243         TAD .
7337  3007         DCA EXIT
7340  1245         TAD B2
7341  3003         DCA TEM
7342  5273         JMP B3
7343  0000  JMSS,  0
7344  5541         JMP I WT+2
7345  2742         2742
7346  0000         0
7347  5544         JMP I RD+2
7350  2754         2754
7351  0000         0
7352  5547         JMP I PUSH+2
7353  2647         2647
7354  0000         0
7355  5552         JMP I MULF+2
7356  2665         2665
7357  0000         0
7360  5555         JMP I ADDF+2
7361  2633         2633
7362  0000         0
7363  5560         JMP I SUBF+2
7364  2641         2641
7365  0000         0
7366  5563         JMP I DIVF+2
7367  2625         2625
7370  0000         0
7371  5566         JMP I FLT+2
7372  2617         2617
7373  0000         0
```

```
                        *7400
7400   7524   CP1,      -254
7401   0272   CO,       272
7402   7540   SP,       -240
7403   0240   SPAC,     240
7404   7477   A,        -301
7405   7642   AC1,      AC2
7406   7646   AC3,      AC4
7407   7476   B,        -302
7410   7471   G,        -307
7411   7520   CHK1,     -260
7412   4167   JMPIN,    JMS JMPI
7413   7521   SLASH,    -257
7414   0136   NUM2,     NUM1
7415   0277   QUEST,    277
7416   7300   BEGIN,    CLA CLL
7417   4172             CALL
7420   7706             SETUP
7421   4172             CALL
7422   7230             CRLF
7423   1201             TAD CO
7424   4172             CALL
7425   7742             PRINT
7426   7300             CLA CLL
7427   3130             DCA NUM
7430   4172             CALL
7431   7206             PACKS
7432   4172   NEXT,     CALL
7433   7747             READ
7434   1127             TAD CHAR
7435   1202             TAD SP
7436   7450             SNA
7437   5256             JMP DISP
7440   7200             CLA
7441   1127             TAD CHAR
7442   1207             TAD B
7443   7650             SNA CLA
7444   5333             JMP BKPT
7445   1127             TAD CHAR
7446   1210             TAD G
7447   7650             SNA CLA
7450   5606             JMP I AC3
7451   1127             TAD CHAR
7452   1204             TAD A
7453   7650             SNA CLA
7454   5605             JMP I AC1
7455   5361             JMP FAULT
7456   7100   DISP,     CLL
7457   4172             CALL
7460   7614             OUTS
7461   4172   NEXT1,    CALL
7462   7747             READ
7463   1130             TAD NUM
7464   3136             DCA NUM1
7465   1127             TAD CHAR
7466   1213             TAD SLASH
7467   7650             SNA CLA
7470   5276             JMP MOD
7471   1127             TAD CHAR
7472   1200             TAD CP1
7473   7650             SNA CLA
7474   5312             JMP MOD1
7475   5361             JMP FAULT
```

```
7476  3130  .CI,     DCA NUM
7477  4172           CALL
7500  7206           PACKS
7501  4172           CALL
7502  7747           FEAD
7503  1127           TAD CHAF
7504  1200           TAD CF1
7505  7650           SNA CLA
7506  5310           JMF MOD2
7507  5361           JMF FAULT
7510  1130  MOD2,   TAD NUM
7511  3536           DCA I NUM1
7512  1136  MOD1,    TAD NUM1
7513  7001           IAC
7514  3136           DCA NUM1
7515  1214           TAD NUM2
7516  3130           DCA NUM
7517  4172           CALL
7520  7230           CFLF
7521  4172           CALL
7522  7614           OUTS
7523  1203           TAD SPAC
7524  4172           CALL
7525  7742           FRINT
7526  1136           TAD NUM1
7527  3130           DCA NUM
7530  4172           CALL
7531  7614           OUTS
7532  5261           JMF NEXT1
7533  1135  BKPT,    TAD INSTR
7534  3526           DCA I LOC
7535  1130           TAD NUM
7536  3126           DCA LOC
7537  1530           TAD I NUM
7540  3135           DCA INSTR
7541  1212           TAD JMPIN
7542  3530           DCA I NUM
7543  5216           JMF BEGIN
7544  3132  BKPT1,   DCA AC5
7545  1377           TAD AAC
7546  3130           DCA NUM
7547  7521           SWF
7550  3133           DCA MQ
7551  7004           FAL
7552  3134           DCA LINK
7553  4172           CALL
7554  7614           OUTS
7555  4172           CALL
7556  7230           CFLF
7557  5216           JMF BEGIN
7560  0200  STK,     200
7561  1360  FAULT,   TAD STK
7562  3176           DCA 176
7563  1215           TAD QUEST
7564  4172           CALL
7565  7742           FRINT
7566  5216           JMF BEGIN

7567  7004  J4,      FAL
7570  7006           FTL
7571  7004          FAL
7572  7006           FTL
7573  7004           FAL
7574  7006           FTL
7575  5776           JMF I .+1
7576  7600           7600
```

```
                          *7577
7577   0132   AAC,        AC5
7600   1130               TAD NUM
7601   3130               DCA NUM
7602   1131               TAD NCTR1
7603   7001               IAC
7604   7001               IAC
7605   3131               DCA NCTR1
7606   5607               JMP I .+1
7607   7212               BEG
7610   7625   J5AI,       J5
7611   7773   NCTRI,      7773
7612   0007   OCTMKI,     7
7613   0260   ZERO,       260
7614   1210   OUTS,       TAD J5AI
7615   3131               DCA NCTR1
7616   1211               TAD NCTRI
7617   3005               DCA CTR
7620   2005   OUTS1,      ISZ CTR
7621   5223               JMP OUTS2
7622   5575               RETURN
7623   1530   OUTS2,       TAD I NUM
7624   5531               JMP I NCTR1
7625   7010   J5,          RAR
7626   7012               RTR
7627   7010               RAR
7630   7012               RTR
7631   7010               RAR
7632   7012               RTR
7633   0212               AND OCTMKI
7634   1213               TAD ZERO
7635   4172               CALL
7636   7742               PRINT
7637   2131               ISZ NCTR1
7640   2131               ISZ NCTR1
7641   5220               JMP OUTS1
7642   1130   AC2,        TAD NUM
7643   3132               DCA AC5
7644   5645               JMP I .+1
7645   7416               BEGIN
7646   4172   AC4,        CALL
7647   7230               CRLF
7650   1134               TAD LINK
7651   7010               RAR
7652   7200               CLA
7653   1133               TAD MQ
7654   7421               MQL
7655   1132               TAD AC5
7656   5530               JMP I NUM
7657   3177   CALLY,      DCA AC
7660   2176               ISZ STACK
7661   1172               TAD CALLX
7662   7001               IAC
7663   3576               DCA I STACK
7664   1572               TAD I CALLX
7665   3172               DCA CALLX
7666   1177               TAD AC
7667   5572               JMP I CALLX
7670   3177   RETY,       DCA AC
7671   1576               TAD I STACK
7672   3172               DCA CALLX
7673   7060               CMA CML
7674   1176               TAD STACK
7675   3176               DCA STACK
7676   1177               TAD AC
```

```
7700  1360  CREGBA, 3     -1360
7701  4600  CREGBB, 4600
7702  7342  CODE,   JMS-1
7703  0136  COD,    136
7704  7747  CT,     -31
7705  7761  CD,     JSS-1
7706  6421  SETUP,  PWT
7707  6420          KRD
7710  7200          CLA
7711  6445          WCRAB
7712  6425          WCRAA
7713  1301          TAD CREGBB
7714  6455          WCRBB
7715  7200          CLA
7716  1300          TAD CREGBA
7717  6435          WCRBA
7720  7200          CLA
7721  1304  TAD CT
7722  3005          DCA CTR
7723  1302          TAD CODE
7724  3010          DCA 10
7725  1303          TAD COD
7726  3011          DCA 11
7727  1410  XX,     TAD I 10
7730  7040          CMA
7731  7450          SNA
7732  5526          JMP I LOC
7733  7040          CMA
7734  3411          DCA I 11
7735  2005          ISZ CTR
7736  5327          JMP XX
7737  1305          TAD CD
7740  3010          DCA 10
7741  5327          JMP XX
7742  6423  PRINT,  RCK
7743  5342          JMP .-1
7744  6421          PWT
7745  7300          CLA CLL
7746  5575          RETURN
7747  7200  READ,   CLA
7750  6422          KCK
7751  5350          JMP .-1
7752  6420          KRD
7753  0361          AND .+6
7754  3127          DCA CHAR
7755  1127          TAD CHAR
7756  4172          CALL
7757  7742          PRINT
7760  5575          RETURN
7761  0377          377
7762  5571  JSS,    JMP I CALLX-1
7763  7544          BKPT1
7764  0000          0
7765  5574          JMP I CALLX+2
7766  7657          CALLY
7767  7670          RETY
7770  0200          STACK+2
7771  7777          7777
7772  1375  ST,     TAD BE
7773  3126          DCA LOC
7774  5306          JMP SETUP
7775  7416  BE,     BEGIN
```

```
                          *137
0137  0000  WT,           0
0140  5541                JMP I  .+1
0141  2742                2742
0142  0000  RD,           0
0143  5544                JMP I  .+1
0144  2754                2754
0145  0000  PUSH,         0
0146  5547                JMP I  .+1
0147  2647                2647
0150  0000  MULF,         0
0151  5552                JMP I  .+1
0152  2665                2665
0153  0000  ADDF,         0
0154  5555                JMP I  .+1
0155  2633                2633
0156  0000  SUBF,         0
0157  5560                JMP I  .+1
0160  2641                2641
0161  0000  DIVF,         0
0162  5563                JMP I  .+1
0163  2625                2625
0164  0000  FLT,          0
0165  5566                JMP I  .+1
0166  2617                2617
0167  0000  JMPI,         0
0170  5571                JMP I  .+1
0171  7544                BKPT1
0172  0000  CALLX,        0
0173  5574                JMP I .+1
0174  7657                CALLY
0175  7670  FETX,         FETY
0176  0200  STACK,        .+2
0177  0000  AC,           0
                          /RAM
                          *126
0126  0000  LOC,          0
0127  0000  CHAR,         0
0130  0000  NUM,          0
0131  0000  NCTR1,        0
0132  0000  ACS,          0
0133  0000  MQ,           0
0134  0000  LINK,         0
0135  0000  INSTR,        0
0136  0000  NUM1,         0
```

```
                /PRINT
                /EQUATES
                CALL=4172;
                 RETURN=5575;
                 BACTR=100;
                 AUTO=10;
                 ALPHA=102;
                 DISPR1=24;
                 DISPR2=25
                 BA=103;
                 S=123;
                 D=114;
                 Q=115;
                 J=116;
                 T=117;
                 ROCTR=120;
                 ELCTR=121;
                 DICTR=122
                 A=77;
                 ADR=100;
                 ADR1=101;
                 C=124;
                 CTR3=47
                 DINC=1461;
                 WCRAA=6425;
                 BW2=6451;
                 DISCO=3234
                /CONSTANTS
                *5000
5000    0037    MSK1, 37;
5001    4000     DIGIT, 4000;
5002    7775     FOURM, -3;
5003    0017     MSK2, 17;
5004    5236     DOTSM, DOTS
5005    5256     CHARM, CHAR;
5006    0102     BAA, BA-1
5007    7776      RO, -2;
5010    7772     ROS, -6;
5011    7773     EL, -5;
5012    7771     DP, -7;
5013    0040     PWR, 40;
5014    0004     FOUR, 4
5015    5212     FEE12, F12;
5016    5204     FEE14, F14;
5017    5103     FES, F5
5020    4172    PRINT, CALL;
5021    5400     RON;
5022    3120     DCA ROCTR;
5023    3121     DCA ELCTR;
5024    7300     CLA CLL
5025    1206     TAD BAA;
5026    3010     DCA AUTO;
```

```
5030  7430   SZL;
5031  7002   BSW;
5032  0200   AND MSK1;
5033  3410   DCA I AUTO;
5034  7630   SZL CLA
5035  5240   JMP P2;
5036  7120   STL;
5037  5227   JMP P1;
5040  1025  P2, TAD DISPR2;
5041  4172   CALL;
5042  5443   DISSUB;
5043  1024   TAD DISPR1;
5044  4172   CALL;
5045  5443   DISSUB
5046  1214   TAD FOUR;
5047  4172   CALL;
5050  3234   DISCO
5051  1217  STPRT, TAD PES;
5052  3101   DCA ADR1
5053  7330  P6, CLA STL RAR;
5054  3114   DCA D;
5055  3122   DCA DICTR;
5056  1206   TAD BAA;
5057  3010   DCA AUTO
5060  1410  P11, TAD I AUTO;
5061  7104   CLL RAL;
5062  1205   TAD CHARM;
5063  3117   DCA T;
5064  1120   TAD ROCTR;
5065  1202   TAD FOURM
5066  7640   SZA CLA;
5067  5272   JMP .+3;
5070  1217   TAD PES;
5071  3101   DCA ADR1;
5072  7620   SNL CLA
5073  5275   JMP .+2;
5074  2117   ISZ T;
5075  1517   TAD I T;
5076  5501   JMP I ADR1
5077  7012  P4, RTR;
5100  7012   RTR;
5101  7012   RTR;
5102  7012   RTR
5103  0203  P5, AND MSK2;
5104  1204   TAD DOTSM;
5105  3100   DCA ADR;
5106  1201   TAD DIGIT;
5107  6425   WCPAA
5110  7200   CLA;
5111  1114   TAD D;
5112  6451   BW2
5113  7201  P20, CLA IAC;
5114  3124   DCA C;
5115  3121   DCA ELCTR
5116  6425  P8, WCPAA
5117  1124  P9, TAD C;
5120  0500   AND I ADR;
5121  7450   SNA;
5122  5327   JMP P7;
5123  1213   TAD PWR;
5124  6451   BW2;
5125  4172   CALL;
5126  5412   BURN
```

```
5130  7104   CLL RAL;
5131  3124   DCA C;
5132  2121   ISZ ELCTR;
5133  1121   TAD ELCTR
5134  1211   TAD EL;
5135  7640   SZA CLA;
5136  5317   JMP P9;
5137  3121   DCA ELCTR
5140  2122  P10, ISZ DICTR;
5141  1114   TAD D;
5142  7110   CLL RAR;
5143  3114   DCA D;
5144  1122   TAD DICTR
5145  1207   TAD RO;
5146  7650   SNA CLA;
5147  5340   JMP P10;
5150  1201   TAD DIGIT;
5151  6425   WCRAA;
5152  7200   CLA
5153  1114   TAD D;
5154  6451   BW2;
5155  7200   CLA;
5156  1122   TAD DICTR;
5157  1212   TAD DR;
5160  7640   SZA CLA;
5161  5616   JMP I PEE14
5162  1120   TAD RDCTR;
5163  7640   SZA CLA;
5164  5340   JMP P10;
5165  1204   TAD DOTSM
5166  7001   IAC;
5167  7001   IAC;
5170  3100   DCA ADR;
5171  5313   JMP P20


             *5200
5200  7776  ROT, -2;
5201  7766   DI, -12;
5202  7772   RDSN, -6;
5203  5053   PEE6, P6
5204  1201  P14, TAD DI;
5205  1122   TAD DICTR;
5206  7650   SNA CLA;
5207  5212   JMP P12;
5210  5611   JMP I .+1;
5211  5060   P11
5212  1101  P12, TAD ADR1;
5213  1200   TAD ROT;
5214  3101   DCA ADR1
5215  2120   ISZ RDCTR;
5216  4172   CALL;
5217  5424   MOTOR;
5220  1202   TAD RDSN;
5221  1120   TAD RDCTR;
5222  7640   SZA CLA
5223  5603   JMP I PEE6;
5224  4172   CALL;
5225  5424   MOTOR;
5226  4172   CALL;
5227  5424   MOTOR;
5230  6451   BW2;
5231  5575   RETURN
```

DOT AND CHARACTOR TABLE

*5236

				BRANCH ADDRESS
5236	0060	DOTS, 60; /includes bit 6 for <u>power on</u>		
5237	0050	50;		
5240	0044	44;		
5241	0041	41;		
5242	0052	52;		
5243	0061	61;		
5244	0062	62;		
5245	0051	51;		
5246	0045	45;		
5247	0056	56;		
5250	0063	63;		
5251	0071	71;		
5252	0065	65;		
5253	0076	76;		
5254	0057	57;		
5255	0077	77		
5256	5131	CHAR, 5131;	"0"	0_8
5257	4674	4674;		
5260	1042	1042;	"2"	2_8
5261	1042	1042;		
5262	1157	1157;		
5263	4521	4521;		
5264	0016	0016;	"3"	3_8
5265	7015	7015;		
5266	7400	7400;	"4"	4_8
5267	2525	2525;		
5270	0016	0016;	"5"	5_8
5271	7476	7476		
5272	2531	2531;	"6"	6_8
5273	4476	4476;		
5274	0442	0442;	"7"	7_8
5275	7400	7400;		
5276	2531	2531;	"8"	10_8
5277	4531	4531;		
5300	6411	6411;	"9"	11_8
5301	4525	4525;		
5302	7525	7525;	"A"	12_8
5303	1105	1105;		
5304	3156	3156;	"B"	13_8
5305	7151	7151		
5306	3156	3156;	"D"	14_8
5307	7146	7146		
5310	1477	1477;	"E"	15_8
5311	7476	7476;		
5312	2525	2525;	"H"	16_8
5313	2537	2537;		
5314	1051	1051;	"I"	17_8
5315	4442	4442;		
5316	1477	1477;	"L"	20_8
5317	1463	1463;		
5320	5525	5525;	"N"	21_8
5321	2654	2654;		
5322	4165	4165;	"R"	22_8
5323	7136	7136		
5324	0016	0016;	"S"	23_8
5325	4471	4471;		
5326	1042	1042;	"T"	24_8
5327	7442	7442;		
5330	2102	2102;	"V"	25_8
5331	2525	2525;		
5332	7777	7777;		26_8
5333	7777	7777	ROOM FOR 18 MORE CHARACTERS	

putting 1312 into 0102 prints

xxxx.xx

DISPR2 DISPR1

```
                CTR4=72
                *5400;
5400    7300    RON, CLA CLL;
5401    6425     WCRAA;
5402    1266     TAD FWRD;
5403    6451     BW2
5404    7200     CLA;
5405    1265     TAD DEL
5406    3072     DCA CTR4;
5407    2072     ISZ CTR4;
5410    5207     JMP .-1;
5411    5575     RETURN;
5412    7200    BURN, CLA;
5413    1264     TAD BRST;
5414    6425     WCRAA;
5415    7200     CLA
5416    1263     TAD BUR;
5417    3047     DCA CTR3;
5420    2047     ISZ CTR3;
5421    5220     JMP .-1;
5422    6425     WCRAA;
5423    5575     RETURN;
5424    7200    MOTOR, CLA;
5425    1271     TAD MOT
5426    6425     WCRAA;
5427    7200     CLA;
5430    1270     TAD MOTS;
5431    3047     DCA CTR3;
5432    6451    MOT1, BW2;
5433    1267     TAD MOTIM;
5434    3072     DCA CTR4;
5435    2072     ISZ CTR4
5436    5235    JMP .-1;
5437    2047     ISZ CTR3;
5440    5232     JMP MOT1;
5441    6425     WCRAA;
5442    5575     RETURN;
5443    3077    DISSUB, DCA A;
5444    1273     TAD THR
5445    3047     DCA CTR3;
5446    1077    DISS, TAD A;
5447    0272     AND MSK;
5450    7104     CLL RAL;
5451    7006     RTL;
5452    7006     RTL;
5453    3410     DCA I AUTO;
5454    1077     TAD A
5455    7006     RTL;
5456    7006     RTL;
5457    3077     DCA A;
5460    2047     ISZ CTR3
5461    5246     JMP DISS;
5462    5575     RETURN
5463    5577    BUR, 5577;
5464    7000     BRST, 7000;
5465    0320     DEL, 320;
5466    0040     FWRD, 40;
5467    7300     MOTIM, 7300
5470    7774     MOTS, -4;
5471    2000     MOT, 2000;
5472    7400     MSK, 7400;
5473    7775     THR, -3
```

```
                /IC, RST AND SURVEY PRINT ROUTINES

                CALL=4172;
                 RETURN=5575;
                 ALPHA=102;
                 INIT1=6433;
                 RESTR1=6445
                SURV1=6456;
                 AUTO1=13;
                 AUTO2=14;
                 CTR6=15;
                 STOR=30

                *4400
4400   7200     INCO, CLA;
4401   1211      TAD INI;
4402   3102      DCA ALPHA;
4403   1334      TAD ADD2;
4404   3030      DCA STOR;
4405   4172      CALL;
4406   4436      PRINIT;
4407   5610      JMP I .+1
4410   6433      INIT1;
4411   2117      INI, 2117

4412   7200     RST, CLA;
4413   1223      TAD RS;
4414   3102      DCA ALPHA;
4415   1333      TAD ADD3;
4416   3030      DCA STOR;
4417   4172      CALL;
4420   4436      PRINIT;
4421   5622      JMP I .+1
4422   6445      RESTR1;
4423   2322      RS, 2322

4424   7200     SUR, CLA;
4425   1234      TAD SV;
4426   3102      DCA ALPHA;
4427   3030      DCA STOR;
4430   4172      CALL;
4431   4436      PRINIT;
4432   5633      JMP I .+1;
4433   6456      SURV1;
4434   2523      SV, 2523
```

STEST

```
        CALL=4172;
         RETURN=5575;
         ACN=5440;
         LCN=4620;
         LCN1=4622;
         DISS=3672
         AUTO=17;
         STCLK=6600;
         IGNOP=6047;
         WCRAB=6445;
         WCRBB=6455;
         DATA=2405
         SCDATA=6305;
         BS2=6443;
         M=4150;
         W=4137;
         CTR3=47;
         CTR4=16;
         TEMN=101
         R=4142;
         TEMP=100;
         DISPR1=24;
         DISPR2=25;
         CONV=6014;
         LOA=3154
         STPRT=5046;
         ELCTR=121;
         FOCTR=120;
         FON=5400;
         STSTD=6411;
         STSTC=6417
         APUCF=6600;
         STZ=6270
        *5600
5600  7200  STEST, CLA;
5601  1366   TAD EIGHT;
5602  3024   DCA DISPR1;
5603  1365   TAD EIGHTS
5604  3025   DCA DISPR2;
5605  4172   CALL;
5606  3672   DISS;
5607  7200   CLA;
5610  1356   TAD FIV;
5611  4172   CALL;
5612  5340   DELAY;
5613  4172   CALL;
5614  3154   LOA;
5615  1327   TAD SIXT;
5616  3047  DCA CTR3
5617  1331   TAD DATAA;
5620  3017   DCA AUTO;
5621  1330  ST1, TAD TWEL;
5622  3016   DCA CTR4
5623  1417   TAD I AUTO;
```

```
5624 [illegible]
5625 6600   STCLK;
5626 7010   RAR;
5627 2047    ISZ CTR3;
5630 5232   JMP .+2;
5631 5236   JMP .+5
5632 2016   ISZ CTR4;
5633 5224   JMP ST2;
5634 7200   CLA;
5635 5221   JMP ST1;
5636 7200   CLA
5637 1352   TAD CSYNC;
5640 6445   WCRAB;
5641 7200   CLA;
5642 1355   TAD FIF;
5643 4172   CALL;
5644 5340   DELAY
5645 1353   TAD BSYNC;
5646 6445   WCRAB;
5647 7200   CLA;
5650 1356   TAD FIV;
5651 4172   CALL;
5652 5340   DELAY
5653 1354   TAD DATS;
5654 6445   WCRAB;
5655 7200   CLA;
5656 6007   CAF;
5657 6443   BS2;
5660 5257   JMP .-1
5661 5662   JMP I .+1;
5662 6411   STSTD;
5663 7200  RET, CLA;
5664 1326   TAD NUMR;
5665 3017   DCA AUTO;
5666 1362   TAD TEN;
5667 3016   DCA CTR4
5670 1325  BACK, TAD BLK;
5671 3417   DCA I AUTO;
5672 2016   ISZ CTR4;
5673 5270   JMP BACK
5674 4172   CALL;
5675 5400   RON;
5676 3121   DCA ELCTR;
5677 3120   DCA ROCTR;
5700 4172   CALL;
5701 5046   STRRT
5702 4172   CALL;
5703 6270   ST2;
5704 6600   APUOF;
5705 7200   CLA;
5706 1362   TAD TEN;
5707 3100   DCA TEMP;
5710 1357   TAD CHAN
5711 3101   DCA TEMN;
5712 4172  DISP, CALL;
5713 6417   STSTC;
5714 1362   TAD TEN;
5715 4172   CALL;
5716 5340   DELAY
5717 1101   TAD TEMN;
5720 1363   TAD FOUR;
5721 3101   DCA TEMN;
5722 2100   ISZ TEMP;
5723 5312   JMP DISP;
5724 5764   JMP I RDTREC
```

```
5725  0026  BLK, 26;
5726  0102   NUMB, 102
5727  7400  SIXT, -400;
5730  7764   TWEL, -14;
5731  5731   DATAA, .;
5732  5415      5415;
5733  0323      0323;
5734  7473      7473;
5735  7777      7777;
5736  7777      7777
5737  7774     7774;
5740  1475     1475;
5741  1467     1467;
5742  4643     4643;
5743  3111     3111;
5744  0226     0226;
5745  3100     3100;
5746  2146     2146;
5747  1146     1146;
5750  2463     2463;
5751  5314     5314
5752  2000  CSYNC, 2000;
5753  4000   BSYNC, 4000;
5754  6000   DATS, 6000;
5755  7563   FIF, -215
5756  7721   FIV, -57;
5757  0243   CHAN, 243;
5760  2024   TWO, 2024;
5761  0567   DEBUG, 567;
5762  7766   TEN, -12;
5763  0004   FOUR, 4;
5764  7100   RDTREC, 7100
5765  0210  EIGHTS, 210;
5766  4210   EIGHT, 4210
            *5340
            /DELAY
5340  3047  DELAY, DCA CTR3;
5341  3016   DCA CTR4;
5342  2016   ISZ CTR4;
5343  5342   JMP .-1;
5344  2047   ISZ CTR3;
5345  5342   JMP .-3;
5346  5575   RETURN
```

```
/PROM BURNER
/PUT HIGH ADR  IN 1000
/PUT LOW ADR IN 1001
/PUT PROM START ADR IN 1002
/ENTER 1200 FOR WRITE
/THEN, PRESS "C" TO READ, OR  ,
/ENTER 1230 FOR READ
/BELL RINGS ON ERROR, PRINTS D IF OK
/ERROR LOC IS IN 1025, PROM DATA IS IN 1023,
/          "SHOULD BE" IS IN 1021.
/HALTS AFTER START TO GIVE TIME FOR -40V, 100MA LIMIT
/          VOLTAGE TO BE TURNED ON.

PCK=6113
PWT=6111
WCRA=6465
WCRB=6475
P1=6460
W1=6461
```

1200 G must be executed before turning on 40 vo

To step in the middle of a burn, turn off -40 v
first, then hit break.

```
                           *1000
1000   0000   HI,          0
1001   0000   LO,          0
1002   0000   PROM,        0
1003   0360   W,           360
1004   6400   F1,          6400
1005   7400   F2,          7400
1006   2400   F3,          2400
1007   0400   F4,          400
1010   6000   F5,          6000
1011   0207   BELL,        207
1012   0304   D,           304
1013   0000   JUM,         0
1014   1064   J1,          JUMP
1015   7776   HUN,         -2
1016   0000   CTR1,        0
1017   5513   C15,         5513
1020   7133   C5,          7133
1021   0000   HLD,         0
1022   0000   CTR,         0
1023   0000   HLD1,        0
1024   0000   L,           0
1025   0000   P,           0
1026   0017   MAIN,        17
```

```
[illegible]
1030  6111            FWT
1031  1203            TAD W
1032  6475            WCRB
1033  7200            CLA
1034  1202            TAD FROM
1035  3225            DCA P
1036  1201            TAD LO
1037  3224            DCA L
1040  1204            TAD F1
1041  6465            WCRA
1042  7402  FB,       HLT
1043  7200  P6,       CLA
1044  1215            TAD HUN
1045  3216            DCA CTR1
1046  7604  P5,       LAS
1047  1214            TAD J1
1050  3213            DCA JUM
1051  1225            TAD P
1052  6461            W1
1053  7200            CLA
1054  1205            TAD F2
1055  6465            WCRA
1056  7200            CLA
1057  1204            TAD F1
1060  6465            WCRA
1061  7200            CLA
1062  1624            TAD I L
1063  5613            JMP I JUM
1064  7012  JUMP,     RTR
1065  7012            RTR
1066  7012            RTR
1067  7012            RTR
1070  0226            AND MASK
1071  3221            DCA HLD
1072  1221  JUMP1,    TAD HLD
1073  6461            W1
1074  7200            CLA
1075  1206            TAD F3
1076  6465            WCRA
1077  7200            CLA
1100  1207            TAD F4
1101  6465            WCRA
1102  7200            CLA
1103  1217            TAD C15
1104  3222            DCA CTR
1105  2222  P1,       ISZ CTR
1106  5305            JMP P1
1107  1206            TAD F3
1110  6465            WCRA
1111  7200            CLA
1112  1220            TAD C5
1113  3222            DCA CTR
1114  2222  P2,       ISZ CTR
1115  5314            JMP P2
```

```
1116  1204  F21,   TAD F1
1117  6465         WCRA
1120  7200         CLA
1121  1210         TAD F5
1122  6465         WCRA
1123  6460         P1
1124  0226         AND MACK
1125  3223         DCA HLD1
1126  1204         TAD F1
1127  6465         WCRA
1130  7200         CLA
1131  1221         TAD HLD
1132  7041         CMA IAC
1133  1223         TAD HLD1
1134  7640         SZA CLA
1135  5337         JMP P3
1136  5346         JMP P4
1137  2216  P3,    ISZ CTR1
1140  5246         JMP P5
1141  1211  P31,   TAD BELL
1142  6113         PCK
1143  5342         JMP .-1
1144  6111         PWT
1145  7402         HLT
1146  2225  P4,    ISZ P
1147  2224         ISZ L
1150  7000         NOP
1151  1200         TAD HI
1152  7040         CMA
1153  1224         TAD L
1154  7640         SZA CLA
1155  5243         JMP P6
1156  1212         TAD D
1157  6113         PCK
1160  5357         JMP .-1
1161  6111         PWT
1162  7402         HLT
1163  6111         6111
1164  6113         6113
1165  7000         NOP
1166  5767         JMP I .+1
1167  1230         READ

                   T=TAD BELL
                   H=TAD HLD
                   J4=JMP P4
                   J=JMP P21

                   *1200
```

```
1200   7200  WRITE,  CLA
1201   1216          TAD S7
1202   3615          DCA I S6
1203   1214          TAD S5
1204   3613          DCA I S4
1205   1221          TAD S10
1206   3620          DCA I S9
1207   5612          JMP I S3

1210   1211  S1,     T
1211   5316  S2,     J
1212   1027  S3,     BEGIN
1213   1072  S4,     JUMP1
1214   1221  S5,     H
1215   1141  S6,     F31
1216   5346  S7,     J4
1217   7000  S8,     NOP
1220   1042  S9,     FB
1221   7402  S10,    HLT
                     *1230

1230   7200  READ,   CLA
1231   1211          TAD S2
1232   3613          DCA I S4
1233   1210          TAD S1
1234   3615          DCA I S6
1235   1217          TAD S8
1236   3620          DCA I S9
1237   5612          JMP I S3

             /ONES FILLER
             /HI ADR IN 400
             /LO ADR IN 401

                     *400

0400   0000  HIGH,   0
0401   0000  LOW,    0
0402   7200  ONES,   CLA
0403   1201          TAD LOW
0404   3010          DCA 10
0405   7040  ON,     CMA
0406   3410          DCA I 10
0407   1200          TAD HIGH
0410   7040          CMA
0411   1010          TAD 10
0412   7640          SZA CLA
0413   5205          JMP ON
0414   7402          HLT
```

GENERAL DISCUSSION

Consider a right-handed rectangular coordinate system X, Y, Z, defined by the local magnetic north direction (X-axis) with the Z direction being the local gravitationally defined vertical.

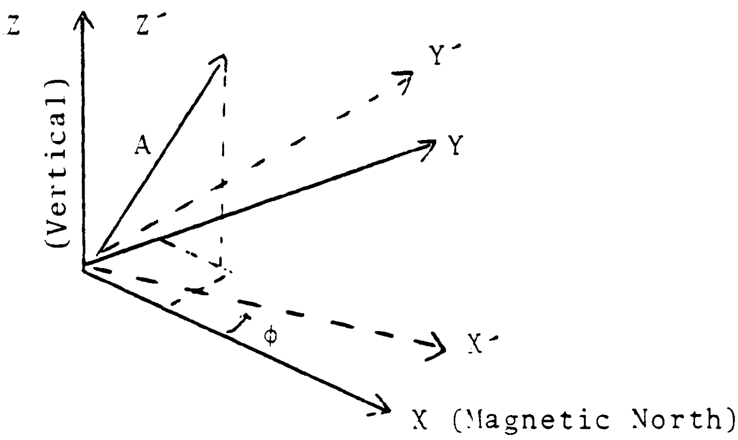


Figure 1

Let the components of an arbitrary vector $\vec{A}$ be given by A_x, A_y, and A_z in this coordinate system. Our first objective is to be able to calculate the components of this vector in another right-handed coordinate system defined by three successive and independent rotations:

a. A rotation ϕ about the Z axis $(-\pi \leq \phi \leq +\pi)$
b. A rotation θ about the new Y´ axis $(-\pi/2 \leq \theta \leq \pi/2)$
c. A rotation ψ about the new X´´ axis $(-\pi \leq \psi \leq \pi)$

Prepared by Walter Hernandez, Ph.D., Chief Scientist, ENSCO ESS/SAS Divisions.

Let $\vec{A}'$ denote the components of $\vec{A}$ in the new coordinate system defined by the first rotation about Z axis of Figure 1. Then we have:

$$A'_z = A_z$$
$$A'_x = A_x\cos\phi + A_y\sin\phi \qquad (1)$$
$$A'_y = -A_x\sin\phi + A_y\cos\phi$$

Next, let A'' denote the components of $\vec{A}$ in the coordinate system defined by the second rotation about the Y' axis (see figure below).

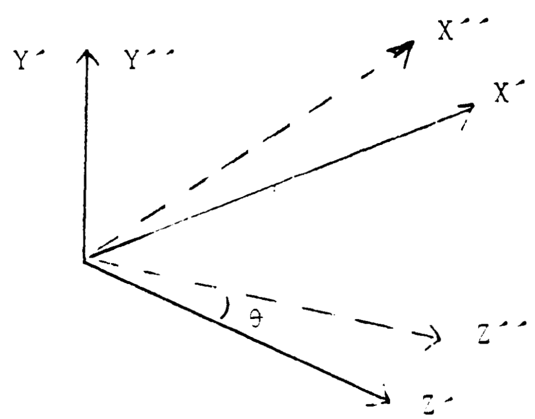


Figure 2

Thus:

$$A''_y = A'_y$$
$$A''_z = A'_z\cos\theta + A'_x\sin\theta \qquad (2)$$
$$A''_x = -A'_z\sin\theta + A'_x\cos\theta$$

Finally, let $\vec{A}'''$ denote the components of $\vec{A}$ in the coordinate system defined by the third rotation about the X'' axis (see figure below).

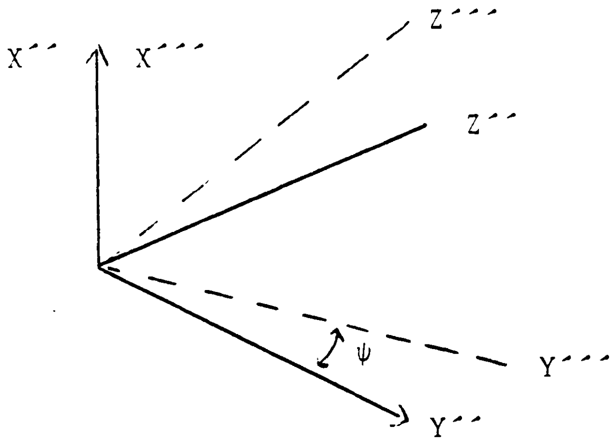


Figure 3

Again we have:

$$
\begin{aligned}
A_x''' &= A_x'' \\
A_y''' &= A_y''\cos\psi + A_z''\sin\psi \qquad (3) \\
A_z''' &= -A_y''\sin\psi + A_z''\cos\psi
\end{aligned}
$$

In matrix form, these rotations can be expressed as

$$\vec{A}' = [R_\phi]\vec{A}$$
$$\vec{A}'' = [R_\theta]\vec{A}' \qquad (4)$$
$$\vec{A}''' = [R_\psi]\vec{A}''$$

where the R's are defined by the above equations.

$$R_\phi = \begin{bmatrix} \cos\phi & \sin\phi & 0 \\ -\sin\phi & \cos\phi & 0 \\ 0 & 0 & 1 \end{bmatrix}$$

$$R_\theta = \begin{bmatrix} \cos\theta & 0 & -\sin\theta \\ 0 & 1 & 0 \\ \sin\theta & 0 & \cos\theta \end{bmatrix} \qquad (5)$$

$$R_\psi = \begin{bmatrix} 1 & 0 & 0 \\ 0 & \cos\psi & \sin\psi \\ 0 & -\sin\psi & \cos\psi \end{bmatrix} .$$

The transformation from $\vec{A}$ to the final $\vec{A}'''$ is defined by:

$$\vec{A}''' = [R_\psi][R_\theta][R_\phi]\vec{A} \qquad (6)$$

Thus the matrix product

$$[R] = [R_\psi][R_\theta][R_\phi] \tag{7}$$

defines the general matrix for transforming coordinates from the initial to final coordinate system. Performing the successive matrix multiplications yields:

$$[R] = \begin{bmatrix} \cos\theta\cos\phi & \cos\theta\sin\phi & -\sin\theta \\ -\cos\psi\sin\phi + \sin\psi\sin\theta\cos\phi & \cos\psi\cos\phi + \sin\psi\sin\theta\sin\phi & \sin\psi\cos\phi \\ \sin\psi\sin\phi + \cos\psi\sin\theta\cos\phi & -\sin\psi\cos\phi + \cos\psi\sin\theta\sin\phi & \cos\psi\cos\theta \end{bmatrix} \tag{8}$$

Our second objective is the following. Let the local magnetic field $\vec{F}$ be defined and known in the (XYZ) coordinate system as

$$\begin{aligned} F_x &= F\cos\alpha \\ F_y &= 0 \\ F_z &= -F\sin\alpha \end{aligned} \tag{9}$$

where α=dip angle $(0 \leq \alpha \leq \pi/2)$. F_y is zero since the X-axis is defined as the magnetic north. Let the local gravitational field be known and defined as

$$\begin{aligned} G_x &= 0 \\ G_y &= 0 \\ G_z &= -G \end{aligned} \tag{10}$$

Now assume that we are given measured components of $\vec{F}$ along the $(X'''Y'''Z''')$ coordinate system (or the direction cosines since magnitude F is known). Also, we are given the components of $\vec{G}$ along the $(X'''Y'''Z''')$ coordinate system.

From this information we are to estimate the values of the rotation parameter ϕ, θ, and ψ. That is, calculate the orientation of the $(X'''Y'''Z''')$ coordinate system.

Using the rotation matrix [R] given by equation (8), we get for the magnetic field components

$$\begin{aligned} Xcos &= \cos\theta\cos\phi\cos\alpha + \sin\theta\sin\alpha \\ Ycos &= -\cos\psi\sin\phi\cos\alpha + \sin\psi[\sin\theta\cos\phi\cos\alpha - \cos\theta\sin\alpha] \\ Zcos &= +\sin\psi\sin\phi\cos\alpha + \cos\psi[\sin\theta\cos\phi\cos\alpha - \cos\theta\sin\alpha] \end{aligned} \tag{11}$$

where

$$\begin{aligned} Xcos &= F_x'''/F \\ Ycos &= F_y'''/F \\ Zcos &= F_z'''/F \end{aligned} \tag{12}$$

For the gravitational field we get

$$G_x''' = (+\sin\theta)G \tag{13}$$

θ PARAMETER

Given the G_x''' and G values, equation (13) gives:

$$\theta = \sin^{-1}\left(\frac{G_x'''}{G}\right) \tag{14}$$

Given that G and G_x''' are well defined and G>0 and that θ is restricted to $-\pi/2 \leq \theta + \pi/2$, we have a valid and unique estimation for θ .

ϕ PARAMETER

The first equation of equations (11) can be solved for $\cos\phi$ as

$$\cos\phi = \frac{X\cos - \sin\theta\sin\alpha}{\cos\theta\cos\alpha} \tag{15}$$

where θ and α are known quantities.

The second and third of equations (11) are solved for $\sin\phi$:

$$Y\cos(\cos\psi) = -\cos^2\psi\sin\phi\cos\alpha + A$$

$$Z\cos(\sin\psi) = \sin^2\psi\sin\phi\cos\alpha + A$$

where: $A = \sin\psi\cos\psi[\sin\theta\cos\phi\cos X - \cos\theta\sin\alpha]$

subtracting the two, and solving for $\sin\phi$:

$$\sin\phi \quad \frac{\sin\psi Z\cos - \cos\psi Y\cos}{\cos\alpha}$$

$$\text{or } \phi = \tan^{-1}\left[\frac{\sin\phi}{\cos\phi}\right] \tag{16}$$

ψ PARAMETER

The ψ parameter is derived from the components of the $\vec{G}$ in the direction of G_Y and G_Z as follows:

$$\psi = \tan^{-1} \frac{-G_Y}{-G_Z}$$

θ is inclination $-\pi/2$, ϕ is bearing and ψ is package rotation.

NORMALIZATION

Each of the three sensor values from the magnetometers and the accelerometers must be normalized as in the following example:

$$Xcos_{norm} = \frac{Xcos}{\sqrt{Xcos^2 + Ycos^2 + Zcos^2}}$$

Therefore, all of the operational algorithms use normalized values.

THE SURVEY EQUATIONS

The following are used for survey equations. This is a straight line between points, angle averaging method, and the assumed rod length normally is 10 feet to minimize errors.

Survey

$$\cos(\overline{INC})\cos(\overline{BER})\ rodl + LAT2 = LAT1$$

$$\cos(\overline{INC})\sin(\overline{BER})\ RODL + DEP2 = DEP1$$

$$VD2 - \sin(\overline{INC})\ RODL = VD1$$

$$\sqrt{(VD1)^2 + (LAT1)^2 + (DEP1)^2} = THD$$

$$\sin\left(TAN^{-1}\left(\frac{DEP1}{LAT1}\right) - ABER\right) \cdot \sqrt{(LAT1)^2 + (DEP1)^2} = HDEV$$

$$VD1 - \sin(AINC - \pi/2)\cos\left(TAN^{-1}\left(\frac{DEP1}{LAT1}\right) - ABER\right)\sqrt{(LAT1)^2 + (DEP1)^2} = VDEV$$

Initial Hole Conditions

$$\sin(AINC-\pi/2)SLEN = VD1$$

$$\sin(ABER)\cos(AINC - \pi/2)SLEN = DEP1$$

$$\cos(ABER)\cos(AINC - \pi/2)SLEN = LAT1$$

where

ABER = initial bearing
AINC = initial indication
$\overline{BER}$ = average bearing, previous survey and current survey
$\overline{INC}$ = average inclination, previous survey and current survey
VD1 = current vertical depth
VD2 = previous vertical depth
LAT1 = current latitude
LAT2 = previous latitude
DEP1 = current departure
DEP2 = previous departure
RODL = rod length
THD = tone hole depth
HDEV = horizontal deviation
VDEV = vertical deviation
SLEN = string length