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PROJECT NO. A-8013

ADVANCED MICROWAVE PRECIPITATION RADIOMETER (AMPR) FOR REMOTE OBSERVATION OF PRECIPITATION

By:
J. A. Galliano and R. H. Platt

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MSFC, Alabama 35812

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GEORGIA INSTITUTE OF TECHNOLOGY
A Unit of the University System of Georgia
Atlanta, Georgia 30332
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Final Technical Report
(December 1990)

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Georgia Institute of Technology
Atlanta, GA 30332

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FOREWORD

This final technical report was prepared by the Electromagnetics Laboratory of the Georgia Tech Research Institute, Georgia Institute of Technology under Contract NAS8-37142. The contract was initiated by the Atmospheric Sciences Division of NASA Marshall Space Flight Center. The contract was administered by Dr. Roy Spencer, Code ED43, of the Atmospheric Physics Branch.

Report authors are J. A. Galliano and R. H. Platt. The valuable assistance of J. M. Cotton, D. J. Swank, M. L. Elyler, R. W. Hoffner, and V. C. York in the performance of this program are acknowledged.

The views and conclusions contained in this report are those of the authors and should not be interpreted as necessarily representing the official policies, either expressed or implied, of NASA Marshall Space Flight Center or the U.S. Government.
PREFACE

This report describes the design, development, and tests of the Advanced Microwave Precipitation Radiometer (AMPR) operating in the 10 to 85 GHz range specifically for precipitation retrieval and mesoscale storm system studies from a high altitude aircraft platform (i.e., ER-2). The primary goals of AMPR is the exploitation of the scattering signal of precipitation at frequencies near 10, 19, 37, and 85 GHz together to unambiguously retrieve precipitation and storm structure and intensity information in support of proposed and planned space sensors in geostationary and low earth orbit, as well as storm-related field experiments.

The development of AMPR will have an important impact on the interpretation of microwave radiances for rain retrievals over both land and ocean for the following reasons:

1. A scanning instrument, such as AMPR, will allow the unambiguous detection and analysis of features in two dimensional space, allowing an improved interpretation of signals in terms of cloud features, and microphysical and radiative processes;

2. AMPR will offer more accurate comparisons with ground-based radar data by feature matching since the navigation of the ER-2 platform can be expected to drift 3 to 4 km per hour of flight time; and,

3. AMPR will allow underflights of the SSM/I satellite instrument with enough spatial coverage at the same frequencies to make meaningful comparisons of the data for precipitation studies.
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INTRODUCTION

Scattering-induced brightness temperature depressions from precipitation are strong enough in the millimeter wave region to provide a meaningful contrast with the radiometrically warm land background. Higher frequencies (37 GHz and above) yield greater cloud penetration because of less sensitivity to small non-precipitating ice. Lower frequencies (18 GHz and below) when used with the higher frequency channels allow an unambiguous separation of the rain signal from wet ground and water bodies, because the emissivity decreases with frequency for precipitation (volume scatterer), while the emissivity increases with frequency for water (emissive surface).

Figure 1 provides evidence of how different frequencies of radiation might respond to different heights within a rain system. As the frequency decreases, the depth in the cloud from which most of the information is obtained increases. For precipitation measurements, one would like the response to be from a level as close to the ground as possible. However, the brightness temperature contrast between rain and the warm land background is small at such a low level. At the other extreme (highest frequency), the contrast temperature between the storm and land background is very strong, but it is not likely well related to the precipitation rate near the surface. Therefore, it is advantageous to select an intermediate frequency (such as 37 GHz) that has a relative strong signal due to attenuation by precipitation, and is still responsive to processes from deep enough in the cloud to be well related to rain rate.

Figure 1 suggests a need for an instrument to cover the frequency range of 10 to 85 GHz in order to investigate and better understand the scattering effects of precipitation on the convective scale. In addition, a suitable high altitude version of this instrument would impact the design requirements for, and the data analysis from, future proposed spaceborne instruments. These issues were the primary justifications for the development of the Advanced Microwave Precipitation Radiometer (AMPR). Table 1 summarizes the key technical issues of the AMPR which were addressed during the course of this program.
Rain Rate = 64 mm/hr

Land Background

Figure 1. Response(Weighting) Function for Severe Storm (Multiple Frequencies vs Altitude)
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<th>Task</th>
<th>Issue</th>
<th>Design Approach</th>
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<td>Implement MFFH design (note 1)</td>
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<td>ER-2 platform</td>
<td>AMPR/hatch compatible (note 2)</td>
<td>Hatch/rack, power, EMI</td>
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Note 1. Multifrequency feedhorn (MFFH) is identical antenna used on SSM/I airborne radiometer.

Note 2. Design AMPR package to be compatible with ER-2 HI-camp hatch.
TECHNICAL DISCUSSION

Figure 2 provides a pictorial of the AMPR system technical parameters which were considered during the initial design phase of the program. Design experiences gained from an earlier NASA radiometer program, i.e. the Advanced Microwave Moisture Sounder (AMMS), were incorporated into the development of the AMPR instrument. Each of the subsystems illustrated in Figure 2 are fully described in this section.

RF SYSTEM

The initial design study included an investigation into using the SMMR feedhorn rather than the SSM/I design. The SMMR offered the potential for ten channels in the 6.6 to 37 GHz region, i.e. five frequencies with dual orthogonal polarization at each frequency. However a decision by the sponsor to include 85.5 GHz as the highest frequency channel complicated the antenna design because a folding mirror was required to fold the optics in the lower frequency bands and to pass the 85.5 GHz band through the mirror. Further investigations revealed that insufficient space was available in the ER-2 HI Camp hatch to locate the 45° folding mirror between the horn and the illuminating lens.

At this point the antenna design effort was redirected toward implementing the SSM/I multifrequency feedhorn with a lens designed to obtain the desirable spatial resolution. Since the SSM/I MFFH included the higher frequency band, then the antenna design was more easily achievable within the size constraints of the ER-2 hatch. A separate horn/lens design was required for the lowest band of 10.7 GHz because the SSM/I feedhorn's lowest frequency band is 19.35 GHz.

It was necessary to design a dual lens antenna capable of fitting within the hatch such that the sum of the lenses diameters did not exceed 15 inches, which was the maximum opening available in the hatch bottom. Setting $D_1$, equal to the 10.7 GHz lens diameter and $D_2$ equal to the MFFH lens diameter and assuming that the spatial resolutions at 10.7 and 19.35 GHz are designed to be identical, then
Figure 2. Advanced Microwave Precipitation Radiometer (AMPR) System Parameters
\[ D_1 + D_2 = 15.0 \text{ in.} \]

or

\[ D_1 + \left( \frac{\lambda_2}{\lambda_1} \right) D_1 = 15.0 \text{ in.} \]

for \( \lambda_1 = 28.04 \text{ mm (10.7 GHz band)} \)

and \( \lambda_2 = 15.50 \text{ mm (19.35 GHz band)} \).

Therefore \( D_1 = 9.7 \text{ in.} \) and \( D_2 = 5.3 \text{ in.} \) for the 10.7 GHz lens antenna aperture and the SSM/I MFFH lens antenna aperture, respectively. Table 2 summarizes the spatial resolution for each of the four frequency bands assuming an aircraft altitude of 20 km or 65,600 ft.

A major design issue for the RF system was a determination of the sensitivity required to achieve a minimum temperature resolution \( (\Delta T_{\text{min}}) \) of 1.0K as specified by the sponsor. It can be shown that the total power radiometer’s sensitivity \( (F_{\text{dB}}) \) is given by:

\[
F_{\text{dB}} = 10 \log \left[ \left( \frac{\Delta T_{\text{min}}}{T_0} \right) (\beta T)^{1/2} \right].
\]

This assumes that the radiometer’s antenna temperature \( (T_A) \) is equal to the ambient temperature \( (T_o) \) and that the system’s normalized gain variation is negligible. Table 3 summarizes the required sensitivity for each of the four channels assuming a maximum temperature resolution of 1.0K.

The sensitivity goals given in Table 3 are based on a maximum temperature resolution of 1.0K. By achieving lower sensitivity levels, the resolution is improved beyond the system specification. Figure 3 is a block diagram of the AMPR RF system for each of the four frequency bands. Table 4 summarizes the receiver sensitivity for each channel based on measurements performed during the test.
TABLE 2. AMPR SPATIAL RESOLUTION FOR $D_b$ EQUAL TO THE ALONG TRACK BEAMSPOT DIAMETER

<table>
<thead>
<tr>
<th>Channel (GHz)</th>
<th>$\theta_{3\text{dB}}$ (radians)</th>
<th>$D_b$ (meters)</th>
</tr>
</thead>
<tbody>
<tr>
<td>10.70</td>
<td>0.139</td>
<td>2,780</td>
</tr>
<tr>
<td>19.35</td>
<td>0.139</td>
<td>2,780</td>
</tr>
<tr>
<td>37.10</td>
<td>0.074</td>
<td>1,480</td>
</tr>
<tr>
<td>85.50</td>
<td>0.032</td>
<td>640</td>
</tr>
</tbody>
</table>

Note 1. $\theta_{3\text{dB}}$ (radians) = 1.222 $\lambda/D$, for $D =$ antenna diameter and $\lambda =$ signal wavelength.

Note 2. $D_b = \theta_{3\text{dB}} \times$ aircraft altitude, for aircraft altitude = 20 km.
TABLE 3. AMPR SENSITIVITY REQUIREMENTS FOR
\( \Delta T_{\text{min}} = 1 \text{K AND } T_A = 300 \text{K} \)

<table>
<thead>
<tr>
<th>Channel (GHz)</th>
<th>IF BW (( \beta ) in MHz)</th>
<th>Integ. Time (( t ) in ms)</th>
<th>( F_{\text{bs}} ) (max.)</th>
</tr>
</thead>
<tbody>
<tr>
<td>10.70</td>
<td>100</td>
<td>50</td>
<td>8.7</td>
</tr>
<tr>
<td>19.35</td>
<td>240</td>
<td>50</td>
<td>10.6</td>
</tr>
<tr>
<td>37.10</td>
<td>900</td>
<td>50</td>
<td>13.5</td>
</tr>
<tr>
<td>85.50</td>
<td>1400</td>
<td>50</td>
<td>14.4</td>
</tr>
</tbody>
</table>

Note 1. IF BW specified per SSM/I requirements.

Note 2. Integ. time based on ER-2 altitude of 20 km, aircraft speed of 500 mph, and scan angle of \( \pm 45^\circ \) and contiguous imaging at 85.5 GHz.
Figure 3. AMPR RF System Block Diagram.
<table>
<thead>
<tr>
<th>Channel (GHz)</th>
<th>$F_{db}$</th>
<th>$F_{ratio}$</th>
<th>IF Bw ($\beta$ in MHz)</th>
<th>$\Delta T_{min}$ (°K)</th>
</tr>
</thead>
<tbody>
<tr>
<td>10.70</td>
<td>3.4</td>
<td>2.188</td>
<td>100</td>
<td>0.30</td>
</tr>
<tr>
<td>19.35</td>
<td>5.8</td>
<td>3.802</td>
<td>240</td>
<td>0.35</td>
</tr>
<tr>
<td>37.10</td>
<td>5.6</td>
<td>3.631</td>
<td>900</td>
<td>0.20</td>
</tr>
<tr>
<td>85.50</td>
<td>6.9</td>
<td>4.898</td>
<td>1400</td>
<td>0.23</td>
</tr>
</tbody>
</table>

Note 1. $\Delta T_{min} = T_o \cdot F_{ratio} \left[ \frac{1}{\beta \tau} + \left( \frac{\Delta G^2}{G} \right) \right]^{1/2}$

$T_o =$ ambient temperature = 300K
$\tau =$ 50 ms
$\frac{\Delta G}{G} =$ nominal gain variation = 0.01%
phase of the program. It can be shown that for a maximum gain variation of 0.05%, (easily achievable with current component technology) a minimum temperature resolution of 0.44K occurs at 10.7 GHz and a maximum temperature resolution of 0.76K occurs at 85.5 GHz.

**SCANNER SYSTEM**

The geometry for the AMPR scanner is depicted in Figure 4. In this configuration the AMPR scanning cycle begins at 315°, maps through the nadir (downward looking) view, and finishes at 45°. Upon command, the scanner's metal reflector swings up to view each of the two calibration loads for a designated period of time. The scan routine is designed to accelerate the reflector between the end scan point and the point at which the beam initially intersects the hot calibration load. At that point the reflector is made to decelerate to a complete stop at the center of the hot calibration load. This routine is repeated for the cold calibration load.

Figure 5 is a pictorial view of the AMPR scanner mounted in the ER-2 HI-CAMP hatch with the extended fiberglass fairing as shown. The 15.50 inch dimension represents the rotating elliptical reflector's major axis. A maximum scan extent of ± 40.59° about nadir is available. Figure 6 is a side looking view of the AMPR showing the SSM/I feedhorn (upper) and the 10.7 GHz feedhorn (lower). Dual calibration loads situated above the scanner are provided for calibration.

Figure 7 shows the scanner system block diagram. A scanner processor is incorporated into the system to provide flexibility in the operation of the AMPR imager. The scanner processor is based on the Motorola MC68HC705C8 microcontroller. This single chip micro handles system timing, scanner control, encoder feedback, data interface, and system diagnostics. Appendix A provides the complete software source code for the AMPR scanner processor. Table 5 shows the various scanner modes that can be selected by turning a thumbwheel switch located in the AMPR power and signal distribution box. Table 6 shows the different menu options available when operating in mode 0. The interactive nature of mode 0 requires that an RS-232 device be attached to the AMPR serial (DCE) port.
Note: Above start & stop scan positions do not provide totally unobstructed view of scene below aircraft.

Figure 4. Scan/Calibration Geometry for AMPR Instrument.
Figure 5. AMPR/HI-CAMP Hatch End View With Calibration Loads Above
SERIAL PORT (DCE)  
(FOR DIAGNOSTIC USE)

AMPR SCANNER PROCESSOR  
(A8013/001)

AMPR SCANNER MICROSTEP SEQUENCER  
(A8013/005)

ENCODER  
(SUPERIOR ELECTRIC)

STEPPER MOTOR  
(SUPERIOR ELECTRIC)

REFLECTOR  
(GTRI)

P1  
J1 J2

SAMPLE/HOLD COMMAND  
INTEGRATE/DUMP COMMAND

J3  
POSITION DATA  
(8 BIT)

DATA VALID  
MODE SELECT  
(4 BIT)

J4  
+5VDC

P5 SCAN SIGNAL

J4 SCAN POWER

+28VDC

FIGURE 7. SCANNER SYSTEM BLOCK DIAGRAM
<table>
<thead>
<tr>
<th>Mode Number</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>Monitor mode</td>
</tr>
<tr>
<td>1</td>
<td>Scan mode; 4 scans/calibrate, CCW retrace</td>
</tr>
<tr>
<td>2</td>
<td>Scan mode; 6 scans/calibrate, CCW retrace</td>
</tr>
<tr>
<td>3</td>
<td>Scan mode; 8 scans/calibrate, CCW retrace</td>
</tr>
<tr>
<td>4</td>
<td>Scan mode; 10 scans/calibrate, CCW retrace</td>
</tr>
<tr>
<td>5</td>
<td>Scan mode; 12 scans/calibrate, CCW retrace</td>
</tr>
<tr>
<td>6</td>
<td>Scan mode; 14 scans/calibrate, CCW retrace</td>
</tr>
<tr>
<td>7</td>
<td>Scan mode; 16 scans/calibrate, CCW retrace</td>
</tr>
<tr>
<td>8</td>
<td>Scan mode; 4 scans/calibrate, CW retrace</td>
</tr>
<tr>
<td>9</td>
<td>Scan mode; 6 scans/calibrate, CW retrace</td>
</tr>
<tr>
<td>A</td>
<td>Scan mode; 8 scans/calibrate, CW retrace</td>
</tr>
<tr>
<td>B</td>
<td>Scan mode; 10 scans/calibrate, CW retrace</td>
</tr>
<tr>
<td>C</td>
<td>Take data in stare mode</td>
</tr>
<tr>
<td>D</td>
<td>1 kHz on port &quot;A&quot; bit 7 of microcontroller</td>
</tr>
<tr>
<td>E</td>
<td>Stepper motor test diagnostic</td>
</tr>
<tr>
<td>F</td>
<td>Port &quot;A&quot; test mode</td>
</tr>
<tr>
<td>Mode 0 Menu Option</td>
<td>Description</td>
</tr>
<tr>
<td>-------------------</td>
<td>--------------------------------------------------</td>
</tr>
<tr>
<td>A</td>
<td>Perform one &quot;n&quot; scans/calibrate cycle</td>
</tr>
<tr>
<td>C</td>
<td>Move scan reflector to cold load</td>
</tr>
<tr>
<td>D</td>
<td>Toggle motor direction bit (CW/CCW)</td>
</tr>
<tr>
<td>E</td>
<td>Read encoder data continuously</td>
</tr>
<tr>
<td>G</td>
<td>Get data for current scanner location</td>
</tr>
<tr>
<td>H</td>
<td>Move scan reflector to hot load</td>
</tr>
<tr>
<td>I</td>
<td>Toggle integrate/dump bit (dump/integrate)</td>
</tr>
<tr>
<td>L</td>
<td>List AMPR status</td>
</tr>
<tr>
<td>M</td>
<td>Set exit mode: 0-F (hex)</td>
</tr>
<tr>
<td>N</td>
<td>Set number (n) of scans per calibrate: 0-F (hex)</td>
</tr>
<tr>
<td>P</td>
<td>Take step; report position</td>
</tr>
<tr>
<td>R</td>
<td>Return to encoder index position</td>
</tr>
<tr>
<td>S</td>
<td>Toggle sample/hold bit (sample/hold)</td>
</tr>
<tr>
<td>V</td>
<td>Toggle data valid bit (low/high)</td>
</tr>
<tr>
<td>W</td>
<td>Toggle windings bit (on/off)</td>
</tr>
<tr>
<td>X</td>
<td>Exit to next mode</td>
</tr>
<tr>
<td>?</td>
<td>Monitor command menu</td>
</tr>
</tbody>
</table>
CALIBRATION SYSTEM

The AMPR calibration loads are required to operate over the frequency range of 10.7 to 85.5 GHz to insure absolute temperature data at the four distinct AMPR RF channels. The lowest frequency channel at 10.7 GHz requires a highly emissive RF load with sufficient depth to insure that the longer wavelength (28 mm or 1.1 in.) signal is fully absorbed by the near perfect black body load. At the other extreme, the highest frequency channel at 85.5 GHz requires that the load material be conductive enough to insure that the physical temperature is approximately uniform over the full depth of the load material.

The material for the calibration loads was obtained from Emerson & Cuming under the designation "Eccosorb UHP-2-NRC" with a specified return loss exceeding 40 dB (ε greater than 0.9999) up to a maximum frequency of 93 GHz. Under this condition the calibration load radiometric temperature \( T_R \) is given by:

\[
T_R = (1 - \epsilon) T_B + \epsilon T_p
\]

for \( T_B = \) background temperature which illuminates load

and \( T_p = \) calibration load physical temperature.

Assuming that the minimum observed temperature \( T_B \) is 10K and the maximum physical load temperature \( T_p \) is 350K for the hot load, then

\[
T_R = (0.0001) (10K) + (0.9999) (350K) = 349.966K.
\]

Therefore the calibration load radiometric temperature \( T_R \) very nearly equals the physical temperature \( T_p \) which implies a nearly perfect black body calibration load.

Figure 8 is a photograph of the calibration loads without the low loss insulating foam cover (view a) and with the foam cover installed (view b). The hot load temperature of 320K is implemented using dc heater strips mounted on the
Figure 8. AMPR Calibration Load

(a) Foam Cover Removed

(b) Foam Cover Installed
metal back plate used to support the RF absorber material. The cold load is implemented using an inlet hose connected to outside air (about 233K at 20 km altitude). A ram air scoop is provided on the ER-2 fairing for connection to the cold load. The RF loss of the insulating cover used on each load is specified to be less than 0.1 dB over the full frequency range.

Figure 9 shows the calibration system block diagram. Monitor circuitry measures thermistors mounted in both the hot and cold calibration loads. The seven thermistors mounted in the hot load (Model # 44201) are accurate to within ± .15°C over the range from 0° to 100°C while the seven thermistors mounted in the cold load (Model # 44212) are accurate to within ± .1°C over the range from -50°C to 50°C. Thermistor placement within each load is shown in Figures 10 and 11. Figure 10 also shows the placement of the two dc heater strips. The hot load temperature is controlled by using one of the hot load thermistors to feed back and compare to a reference set point. A pulse width modulation technique is then employed based on this temperature comparison to drive current through the dc heaters. As shown in Figure 9, cold and hot load temperature multiplexers take the conditioned thermistor temperatures and make them available based on the channel select lines input from the MSFC data acquisition system. The channel designations are given in Table 7.

Figure 12 illustrates the absolute temperature accuracy of the AMPR using the hot and cold calibration loads described above. A hot load temperature of +37°C (310K) and a cold load temperature of -43°C (230K) are used in the curves of Figure 12. The curve with a ΔT_mn value of 0.4K represents the 19.35 GHz AMPR data channel and the curve with a ΔT_mn value of 0.2K represents the 37.10 GHz AMPR data channel. For example, if the radiometer unknown temperature is 100K, then the AMPR measurement will be accurate within ± 2.1K at 19.35 GHz and within ± 1.3K at 37.1 GHz. The 10.7 GHz and 85.5 GHz AMPR data channels fall in between these two curves. Table 8 summarizes the AMPR absolute temperature accuracy range for an unknown scene temperature.
FIGURE 9. CALIBRATION SYSTEM BLOCK DIAGRAM
FIGURE 10. HOT CALIBRATION LOAD (BOTTOM VIEW)
Thermistor locations 1-8 as shown
Heater strips as shown
S- shallow
M- medium
D- deep
<table>
<thead>
<tr>
<th>Channel No.</th>
<th>Hot Load</th>
<th>Cold Load</th>
</tr>
</thead>
<tbody>
<tr>
<td>0(0000)</td>
<td>Thermistor #1</td>
<td>Thermistor #1</td>
</tr>
<tr>
<td>1(0001)</td>
<td>Thermistor #2</td>
<td>Thermistor #2</td>
</tr>
<tr>
<td>2(0010)</td>
<td>Thermistor #4</td>
<td>Thermistor #3</td>
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<td>3(0011)</td>
<td>Thermistor #5</td>
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<td>4(0100)</td>
<td>Thermistor #6</td>
<td>Thermistor #5</td>
</tr>
<tr>
<td>5(0101)</td>
<td>Thermistor #7</td>
<td>Thermistor #6</td>
</tr>
<tr>
<td>6(0110)</td>
<td>Thermistor #8</td>
<td>Thermistor #7</td>
</tr>
<tr>
<td>7(0111)</td>
<td>Not used</td>
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<tr>
<td>8(1000)</td>
<td>Not used</td>
<td>Not used</td>
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<tr>
<td>9(1001)</td>
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<tr>
<td>10(1010)</td>
<td>Not used</td>
<td>Not used</td>
</tr>
<tr>
<td>11(1011)</td>
<td>Not used</td>
<td>Not used</td>
</tr>
</tbody>
</table>
Figure 12. AMPR Absolute Temperature Inaccuracy ($\Delta T_U$) Goals For Hot Calibration Load ($T_h$) of 310K And Cold Calibration Load ($T_c$) of 230K
TABLE 8. AMPR ABSOLUTE TEMPERATURE INACCURACY ($\Delta T_u$) PERFORMANCE SUMMARY FOR UNKNOWN SCENE TEMPERATURE ($T_u$)

<table>
<thead>
<tr>
<th>$T_u$ (K)</th>
<th>$\pm \Delta T_u$ (K) For AMPR Channel</th>
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</thead>
<tbody>
<tr>
<td></td>
<td>19.35 GHz</td>
</tr>
<tr>
<td>10</td>
<td>3.3</td>
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<tr>
<td>20</td>
<td>3.1</td>
</tr>
<tr>
<td>40</td>
<td>2.9</td>
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<tr>
<td>80</td>
<td>2.4</td>
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<tr>
<td>100</td>
<td>2.1</td>
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<tr>
<td>140</td>
<td>1.6</td>
</tr>
<tr>
<td>200</td>
<td>0.9</td>
</tr>
<tr>
<td>230 ($T_{COLD}$)</td>
<td>0.5</td>
</tr>
<tr>
<td>300</td>
<td>0.5</td>
</tr>
<tr>
<td>310 ($T_{HOT}$)</td>
<td>0.5</td>
</tr>
<tr>
<td>340</td>
<td>0.9</td>
</tr>
<tr>
<td>400</td>
<td>1.6</td>
</tr>
</tbody>
</table>

Note 1. 10.7 and 85.5 GHz channels fall in between above range for each $T_u$ value.

Note 2. Example: At $T_u = 100$K,
\[ \Delta T_u = \pm 1.7 \text{K for 10.7 GHz channel} \]
and \[ \Delta T_u = \pm 1.4 \text{K for 85.5 GHz channel}. \]
VIDEO PROCESSOR SYSTEM

The AMPR video processor system consists of the post detection circuitry and the interface circuitry to the data acquisition system (provided by MSFC). The primary design criteria as regards the interface circuitry was to insure that the AMPR operated as a stand-alone system. This design approach insured that AMPR does not depend on the data acquisition system for control or handshaking information that might affect a critical operation, such as the scanner timing. A secondary design goal for the interface system was insuring that the data transfer between AMPR and the data acquisition system would be simple and repeatable.

The post detection circuitry for the AMPR consists of the video amplifier which amplifies the radiometer's square law detector output, the integrate and dump circuit which integrates the video amplifier output, and the sample and hold circuit which maintains the data output until the data acquisition system samples the AMPR data. The AMPR interface provides a data valid signal which alerts the data acquisition system that the analog data is valid and ready for sampling. Figure 13 is the AMPR video processor block diagram (a) and the timing diagram (b) for the integrate/dump, sample/hold, and the data valid signals.

MECHANICAL PACKAGING

The AMPR system consists of two packages, i.e. the radiometer unit and the power supply unit. The radiometer package includes the scanner, calibration loads, RF front-end, and video processing subsystems. The power supply unit contains all the power supplies required to operate the radiometer, the power conditioning interface to the aircraft power distribution unit, and the interface circuitry to the data acquisition system. Figure 14 is a photograph of the power supply unit package designed to adapt to the existing aircraft rack located in the ER-2 upper Q-Bay compartment. Table 9 indicates the system power supply designations for each unit supply used in the AMPR. The seven multi-pin connectors are the connections between the power supply unit and the radiometer package (four cables), the data acquisition system (two cables), and the aircraft power distribution unit (one cable). A removable cover is shown in the photograph and is used to
FIGURE 13. AMPR VIDEO PROCESSOR SYSTEM
<table>
<thead>
<tr>
<th>Channel No.</th>
<th>Mux A Output</th>
<th>Mux B Output</th>
</tr>
</thead>
<tbody>
<tr>
<td>0(0000)</td>
<td>37.1 GHz bias (+4.0 V)</td>
<td></td>
</tr>
<tr>
<td>1(0001)</td>
<td>85.5 GHz bias (+5.4 V)</td>
<td></td>
</tr>
<tr>
<td>2(0010)</td>
<td>19.35 GHz bias (+7.0 V)</td>
<td></td>
</tr>
<tr>
<td>3(0011)</td>
<td>Analog supply + (+10 V)</td>
<td></td>
</tr>
<tr>
<td>4(0100)</td>
<td>Analog supply - (-10 V)</td>
<td></td>
</tr>
<tr>
<td>5(0101)</td>
<td>Not used</td>
<td></td>
</tr>
<tr>
<td>6(0110)</td>
<td>Not used</td>
<td></td>
</tr>
<tr>
<td>7(0111)</td>
<td>Not used</td>
<td></td>
</tr>
<tr>
<td>8(1000)</td>
<td>Digital supply + (+5V)</td>
<td></td>
</tr>
<tr>
<td>9(1001)</td>
<td>Scanner supply + (+9.3 V)</td>
<td></td>
</tr>
<tr>
<td>10(1010)</td>
<td>Temperature supply + (+10 V)</td>
<td></td>
</tr>
<tr>
<td>11(1011)</td>
<td>Temperature supply - (-10 V)</td>
<td></td>
</tr>
<tr>
<td>12(1100)</td>
<td>Not used</td>
<td></td>
</tr>
<tr>
<td>13(1101)</td>
<td>Not used</td>
<td></td>
</tr>
<tr>
<td>14(1110)</td>
<td>Not used</td>
<td></td>
</tr>
<tr>
<td>15(1111)</td>
<td>Not used</td>
<td></td>
</tr>
</tbody>
</table>
protect the internal power supplies during shipment and aircraft installation. The cover is removed during aircraft flights to reduce the internal temperature caused by heat generated by the power supplies.

Figure 15 is a photograph of the AMPR radiometer package as viewed from the RF front-end. View (a) depicts the radiometer with RF cover installed and view (b) shows the RF cover removed. The cover is lined with RF absorber material to improve system immunity to outside RF signal interference. Figure 16 is another view of the AMPR package as seen from the scanner end of the radiometer. This view depicts the elliptical reflector used to scan across the dual lens antenna. The hot and cold calibration loads are shown in the lower part of the photograph with low loss foam covers. View (a) shows the scanner cover installed while view (b) shows the cover removed.

**AMPR TEST RESULTS**

AMPR testing included subsystem, as well as, system tests following final assembly. Subsystem tests performed included: antenna pattern measurements on the 10.7 GHz antenna feedhorn/lens unit and the SSM/I multifrequency feedhorn/lens unit at the Georgia Tech Cobb County Facility antenna range; system noise figure measurements on each of the four receiver channels using the Y-factor test method; scanner routine tests using microstepping design techniques; and, temperature monitoring of the hot and cold calibration loads as well as temperature control of the hot load.

Figure 17 is an antenna range profile of the Georgia Tech Cobb County Facility which was used to perform AMPR antenna pattern measurements. This range facility offered minimum interference from ground reflections because of the natural terrain between the transmit and receive towers. Because of the rigidity of the towers and low ground reflection, accurate measurements of sidelobe levels, cross-polarization data, and mainbeam efficiency were obtained.

Antenna pattern measurements were performed at all frequencies for E-plane, H-plane, and diagonal plane cuts. These cuts represent the H polarization, V polarization, and 45° polarization plots for the antenna. When situated on the
Figure 17. Georgia Tech Antenna Range Facility with Transmit (XMT) and Receive (RCV) Towers

Dimensions in Feet

Lake Level

Range Profile (NOT TO SCALE)
ER-2 hatch, the H polarization is equivalent to looking out the right side of the aircraft, the V polarization is equivalent to looking out the left side of the aircraft, and the 45° or diagonal plane is equivalent to looking straight down (nadir view).

Figure 18 provides a view of the AMPR antenna located on the range receive tower (shown in foreground) with the transmitter tower shown in background. View (a) represents the H polarization position while view (b) represents the V polarization positions. The 45° polarization position (not shown in Figure 18) would be between the H & V position, i.e. straight up and down on the receive tower.

Table 10 summarizes the AMPR antenna subsystem performance based on the pattern measurements performed at the Cobb County Facility. The mainbeam efficiency represents the amount of power (in %) contained within the first null points. The sidelobe efficiency can be converted to sidelobe level, i.e. 0.20% efficiency means that the sidelobe level is -27 dB down from the peak power output. The cross polarization efficiency level of 0.40% means that the input cross-pol data is -24 dB down at the co-pol output port.

The 19.35, 37.10, and 85.5 GHz channels are generated using the multi-frequency feedhorn (MFFH) designed and built by Microwave Engineering Corporation. The AMPR MFFH is a replica of the antenna presently onboard the SSM/I spaceborne sensor.

The AMPR receiver sensitivity was measured for each of the four data channels using the Y-factor method. Figure 19 is a block diagram for the test setup used to measure the noise figure ($F_{db}$) for each channel. The test method consists of measuring the video output of each channel under two conditions, i.e. viewing an ambient load (290K) and viewing a liquid nitrogen load (100K). The $F_{db}$ value is given by:
<table>
<thead>
<tr>
<th>CH (GHz)</th>
<th>Antenna Sidelobe (%)</th>
<th>Cross Polarization (%)</th>
<th>Mainbeam Efficiency (%) (Note 1)</th>
</tr>
</thead>
<tbody>
<tr>
<td>10.7</td>
<td>0.20</td>
<td>0.20</td>
<td>97.8</td>
</tr>
<tr>
<td>19.35</td>
<td>0.30</td>
<td>1.60</td>
<td>98.7</td>
</tr>
<tr>
<td>37.0</td>
<td>0.20</td>
<td>0.40</td>
<td>98.8</td>
</tr>
<tr>
<td>92.5 (Note 2)</td>
<td>5.70</td>
<td>1.40</td>
<td>93.2</td>
</tr>
</tbody>
</table>

Note 1. Mainbeam efficiency data represents average of E, H, and 45° planes at each frequency and each attenuation level.

Note 2. Test equipment malfunctioning at 85.5 GHz caused increase in operating frequency to 92.5 GHz.
NOTE: \[ Y = \frac{P_{N}(\text{HOT})}{P_{N}(\text{COLD})} = \frac{k(T_{\text{SYS}} + T_{\text{HOT}})BG}{k(T_{\text{SYS}} + T_{\text{COLD}})BG} = \frac{T_{\text{SYS}} + T_{\text{HOT}}}{T_{\text{SYS}} + T_{\text{COLD}}} \]

FIGURE 19. Y-Factor Method for Measuring System Noise Figure.
\[ F_{\text{dB}} = 10 \log \left( \frac{V_{\text{HOT}}}{V_{\text{HOT}} - V_{\text{COLD}}} \right) - 1.8 \text{ dB} \]

for \( T_{\text{HOT}} = 290K \) and \( T_{\text{COLD}} = 100K \).

The measurements were performed in order to determine the temperature sensitivity of each AMPR channel. Table 11 summarizes the \( \Delta T_{\text{min}} \) values for each channel based on the noise figure data. The sensitivity values are based on a system gain variation (\( \Delta G/G \)) of 0.01\% minimum to 0.05\% maximum. In either case, the AMPR temperature sensitivities are less than 1.0K for all four data channels as required per NASA's specifications. Appendix B is a set of schematics for the electronic modules used in the AMPR system. Appendix C is a set of data sheets for vendor supplied items used in the AMPR. This appendix also includes a list of critical items recommended as spare parts for the AMPR.

The AMPR/Data Acquisition System is designed to be flown onboard the ER-2 research aircraft in the Q-bay compartment. The radiometer instrument is mounted in the HI-CAMP hatch which is located in the lower Q-bay section. The AMPR power supply package and the data acquisition system are each mounted in standard equipment racks located in the upper Q-bay section of the ER-2. Figure 20 is a cable diagram which shows the interconnection between the two AMPR packages, the aircraft input power cable (J1), and the two output cables (J6 and P7) to the MSFC data acquisition system. Cabling between the upper and lower Q-bay compartments is fed through the ER-2 bulkhead. Appendix D describes the AMPR cable interconnections including pin designations.

Figure 21 is a power schematic which shows the distribution of aircraft power to the AMPR radiometer. Power to the data acquisition system is routed through the AMPR power supplies package as shown. The ER-2 cockpit panel has two switches available for power/control of the AMPR system. The "AMPR ON" switch energizes the power relay internal to the AMPR power supply package.

This results in aircraft power applied to the radiometer as indicated by the "AMPR
<table>
<thead>
<tr>
<th>Channel (GHz)</th>
<th>$F_{sys}$ (F dB)</th>
<th>$\beta$ (MHz)</th>
<th>$\Delta T_{min}$ (K)</th>
<th>$\frac{\Delta G}{G} = 0.05%$</th>
<th>$\frac{\Delta G}{G} = 0.01%$</th>
</tr>
</thead>
<tbody>
<tr>
<td>10.7</td>
<td>2.042 (3.1)</td>
<td>100</td>
<td>0.40</td>
<td>0.27</td>
<td></td>
</tr>
<tr>
<td>19.35</td>
<td>3.548 (5.5)</td>
<td>240</td>
<td>0.59</td>
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<tr>
<td>37.1</td>
<td>3.388 (5.3)</td>
<td>900</td>
<td>0.51</td>
<td>0.18</td>
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<tr>
<td>85.5</td>
<td>3.631 (5.6)</td>
<td>1400</td>
<td>0.54</td>
<td>0.16</td>
<td></td>
</tr>
</tbody>
</table>

Note 1. $\Delta T_{min} = F_{sys} \left( \frac{1}{T_0 \beta^2} + \left( \frac{\Delta G}{G} \right)^2 \right)^{1/2}$, for $T_0 = 290K$ (ambient) and $\tau = 50\ ms$ (integ. time)

Note 2. $0.01\% \leq \frac{\Delta G}{G} \leq 0.05\%$, for $\frac{\Delta G}{G} = \text{nominal system gain variation}$
Figure 21. AMPR / ER-2 Power Interconnect Diagram
ON light in the cockpit. In addition, the MSFC Reset lines (J7/F and J7/G) are disconnected as shown in the power schematic. The second cockpit switch, "RCDR ON," is used to energize the recorder relay internal to the AMPR power supply package. This results in aircraft power applied to the data acquisition system through pins J7/B and J7/D. A control signal (J7/A) from the data acquisition system is used to turn on the "RCDR ON" lamp inside the cockpit. Two additional control lines (J7/H and J7/J) are used to turn on the "AMPR FAIL" or "RCDR FAIL" lamps if either the radiometer or the data acquisition system have problems. The data acquisition system can be reset by turning off the "AMPR ON" power switch. This causes the MSFC Reset lines to stay common until the AMPR power is turned on again. Notice that the pilot can remove all power to the system by using the "STANDBY POWER" switch located in the cockpit.
APPENDIX A

AMPR SCANNER PROCESSOR ASSEMBLY CODE
THE SCANNER PROCESSOR CONTROLS THE RADIOMETER REFLECTOR STEPPER MOTOR (THROUGH A MICROSTEP SEQUENCER) TO IMPLEMENT SEVERAL SCAN MODES. OUTPUT TIMING SIGNALS ARE PROVIDED FOR RADIOMETER DATA ACQUISITION AND REFLECTOR POSITION ACQUISITION. IN ADDITION, AN INTERACTIVE DIAGNOSTIC MODE IS PROVIDED THROUGH THE SERIAL COMMUNICATIONS INTERFACE OF THE MOTOROLA MC68HC705CB SINGLE CHIP MICROCONTROLLER.

I/O REGISTERS

POSITION DATA OUT
ANALOG DATA HANDSHAKING
ENCODER POSITION IN
DTR IN; SERIAL PORT
DIRECTION REGISTER

EQUATES

PORTA EQU $0000
PORTB EQU $0001
PORTC EQU $0002
PORTD EQU $0003
DDRA EQU $0004
DDRB EQU $0005
DDRC EQU $0006
SPCR EQU $000A
BAUD EQU $000D
SCCRI EQU $000E
SECR2 EQU $000F
SCSR EQU $0010
SCI EQU $0011
TCR EQU $0012
TSR EQU $0013
ICRH EQU $0014
ICRL EQU $0015
OCRH EQU $0016
OCRL EQU $0017
HCOUNT EQU $0018
LCOUNT EQU $0019
ALTH EQU $001A
ALTl EQU $001B
EPROG EQU $001C
COPPR EQU $001D
COPCR EQU $001E

REGISTER BIT DEFINITIONS

PORT A AT $0000 IS AN OUTPUT PORT, USED TO OUTPUT AN 8 BIT REFLECTOR POSITION VALUE

PORT B AT $0001

PORT C AT $0002 IS AN INPUT PORT, USED TO READ THE "ABSOLUTE" POSITION OF THE STEPPER MOTOR FROM THE SHAFT ENCODER AND THE HP ENCODER INTERFACE CHIP. THE HP CHIP INCREASES RESOLUTION BY A FACTOR OF 4, WHICH MUST BE DEALT WITH, AS WELL AS A CONVERSION FROM TWOS COMPLEMENT TO UNSIGNED BINARY. THE DATA FROM THE HP CHIP IS BASE 0, MEANING THAT WHEN THE MOTOR IS POSITIONED AT THE ENCODER INDEX, THE DATA FROM THE HP CHIP IS 0. VARIABLE POS IS BASE 1 (RANGE IS 1-200), AS IS THE DATA OUTPUT TO PORT A. THE VALUE ZERO HAS BEEN RESERVED TO INDICATE A START OR RESTART.

PORT D AT $0003

"ABSOLUTE" POSITION OF THE STEPPER MOTOR FROM THE SHAFT ENCODER AND THE HP ENCODER INTERFACE CHIP. THE HP CHIP INCREASES RESOLUTION BY A FACTOR OF 4, WHICH MUST BE DEALT WITH, AS WELL AS A CONVERSION FROM TWOS COMPLEMENT TO UNSIGNED BINARY. THE DATA FROM THE HP CHIP IS BASE 0, MEANING THAT WHEN THE MOTOR IS POSITIONED AT THE ENCODER INDEX, THE DATA FROM THE HP CHIP IS 0. VARIABLE POS IS BASE 1 (RANGE IS 1-200), AS IS THE DATA OUTPUT TO PORT A. THE VALUE ZERO HAS BEEN RESERED TO INDICATE A START OR RESTART.

SCSI SCSR AT $0010

TIMER CONTROL REGISTER
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<th>Value</th>
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**Memory Map**

- Page Zero: 48 bytes
- Page Zero: 176 bytes
- Page One: 48 bytes
- Beginning of vectors

**Option Register (RAM)**

- RAM/EPROM at $20-$4F
- RAM/EPROM at $100-$15F

**Miscellaneous**

- INDEX transition: 1=YES
- Fast table: 0=$0100; 1=$0300
- Odd steps: 1=YES
- Direction of retrace: 1=CW

**Other Symbols**

- Carriage return
- Line feed
- End of text
- Bell
ABSOLUTE

*****************************
* MODE 0 SUBROUTINE JUMP TABLE OFFSETS *
*****************************

ORG ZROM
PAGE ZERO ROM

0020 OFFSET FCB 1,0,4,7,10
0025 FCB 0,13,16,19,0
002A FCB 0,22,25,28,0
002F FCB 31,0,34,37,0
0034 FCB 0,40,43,0,0,0
0039 00

*****************************
* RAM *
*****************************

ORG RAM
112 USER BYTES AVAILABLE

0050 POS RMB 1
0051 SCANS RMB 1
0052 SCANUM RMB 1
0053 EOS RMB 1
0054 XMODE RMB 1
0055 ALOOP RMB 1
0056 WTEMP RMB 1
0057 RTEMP RMB 1
0058 MSTEP RMB 1
0059 GSTEP RMB 1
005A MSC RMB 1
005B MPREV RMB 1
005C FLAG RMB 1
005D DEST RMB 1
005E FUDGE RMB 1
005F RLEN RMB 1
0060 A1 RMB 1
0061 A2 RMB 1
0062 A3 RMB 1
0063 A4 RMB 1
0064 X1 RMB 1
0065 X2 RMB 1
0066 X3 RMB 1
0067 X4 RMB 1
0068 LFETCH RMB 4
0069 HFETCH RMB 4
006C PAG
MICROSTEP DELAY TABLES: $S = K t^X$

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AMPR

220 0200 ORG ROM+$0100

221

222

223

224 0200 01F4 BFB6 14D3 CTABLE FDB
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225 020C 0AF2 09F2 0926 FDB
0212 087E 07F2 077A

226 0218 0712 06B8 0667 FDB
021E 0620 05E0 05A6

227 0224 0572 0522 0515 FDB
022A 04E0 04C7 04A4

228 0230 04B4 0465 0449 FDB
0236 042E 0415 03FD

229 023C 03E6 03D1 03BD FDB
0242 03AA 0398 0386

230 0248 0376 0366 0357 FDB
024E 0348 033A 032D

231 0254 0320 0314 0308 FDB
025A 02FD 02F2 02E7

232 0260 02DD 02D3 02C9 FDB
0266 02C0 02B7 02AE

233 026C 02A6 02E9 0296 FDB
0272 02E0 02D7 02B0

234 0278 0278 026B FDB
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235 0284 0252 024C 0246 FDB
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236 0290 0231 022B 0227 FDB
0296 0222 021D 0218

237 029C 0214 020F 0208 FDB
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238 02A8 01FA 01F6 01F2 FDB
02AE 01EF 01EB 01E7

239 02B4 01E4 01ED 01DD FDB
02BA 01DB 01D6 01D3

240 02C0 01CF 01CC 01C9 FDB
02C6 01CB 01C3 01C0

241 02CC 01BD 01BA 01B7 FDB
0202 01B5 01B2 01AF

242 0208 01AC 01AA 01A7 FDB
020E 01A5 01A2 01A0

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ORG ROM+$0300

 ***************************************************************
 MONITOR MODE (MODE 0) SUBROUTINE JUMP TABLE
 ***************************************************************

 JTABLE RTS
 JMP ASUB ONE SCAN/CAL CYCLE
 JMP CSUB GOTO COLD LOAD
 JMP DSUB TOGGLE MOTOR DIRECTION LINE
 JMP ESUB READ ENCODER CONTINUOUSLY
 JMP GSUB GET DATA FOR CURRENT POSITION
 JMP HSUB GOTO HOT LOAD
 JMP ISUB TOGGLE INTEGRATE/DUMP LINE
 JMP LSUB LIST AMPR STATUS
 JMP MSUB SET EXIT MODE
 JMP NSUB SET NUMBER OF SCANS/CAL
 JMP PSUB TAKE STEP; REPORT POSITION
 JMP RETURN RETURN TO INDEX
 JMP SSUB TOGGLE SAMPLE/HOLD LINE
 JMP VSUB TOGGLE DATA VALID LINE
 JMP WSUB TOGGLE WINDINGS ON/OFF

 ***************************************************************
 MODE SELECTION JUMP TABLE
 ***************************************************************

 MTABLE JMP MODE0 MONITOR MODE
 JMP MODE1 SCAN MODE: 4/CAL, CCW RT
 JMP MODE2 SCAN MODE: 6/CAL, CCW RT
 JMP MODE3 SCAN MODE: 8/CAL, CCW RT
 JMP MODE4 SCAN MODE: 10/CAL, CCW RT
 JMP MODE5 SCAN MODE: 12/CAL, CCW RT
 JMP MODE6 SCAN MODE: 14/CAL, CCW RT
 JMP MODE7 SCAN MODE: 16/CAL, CCW RT
 JMP MODE8 SCAN MODE: 4/CAL, CW RT
 JMP MODE9 SCAN MODE: 6/CAL, CW RT
 JMP MODE10 SCAN MODE: 8/CAL, CW RT
 JMP MODE11 SCAN MODE: 10/CAL, CW RT
 JMP MODE12 TAKE DATA POINTING DOWN
 JMP MODE13 1KHz ON PORT A BIT 7
 JMP MODE14 MOTOR STEP TEST
 JMP MODE15 PORT "A" TEST MODE
PAG
EXECUTION BEGINS HERE

*  INSURE NO INTERRUPTS YET
  INSURE STACK IS RESET

RESET SEI
LDA #$00
STA OPTION
LDA #$FF
STA DDRA
STA DDRB
CLR DDRC
CLR MSC
BCLR INDEX,FLAG
BCLR ODD,FLAG
BCLR RT,FLAG
BSET HS,FLAG
BSET CW.PORTB
BSET AWO°PORTB
JSR PULSE
BCLR DUMP,PORTB
BCLR NVAL,PORTB
BCLR HOLD,PORTB
BCLR TEST,PORTB
BCLR HBYTE,PORTB
BSET OE,PORTB
CLR SPCR
LDA #$08
STA SCCRI
LDA #$0C
STA SCCR2
LDA #$30
STA BAUD
CLRA
STA PORTA
STA POS
INCA
STA XMODE
LDA #$D6
STA LFETCH
STA HFETCH
CLRA
STA HFETCH+2
INCA
STA LFETCH+2
INCA
STA HFETCH+I
STA LFETCH+I
LDA #$81
STA LFETCH+3
STA HFETCH+3

NOW CAN CHANGE TABLES

** gerneuen **
LDA #$A0
STA TCR
ICIE, TOIE, NEG EDGE

JSR WAIT
MAKE STEP PULSE LINE LOW

LDA PORTD
READ THUMBWHEEL SWITCH

LSRA
MOVE BITS 5-2 TO 3-0

AND #$0F
MASK OFF UPPER NIBBLE

MUL #3
COMPUTE OFFSET INTO TABLE

TST COPCR
CLEAR POSSIBLE FLAG

LDA #$0F
ENABLE WATCHDOG

STA COPCR
INTERRUPTS OK NOW

CLI

JMP MTABLE,X
JUMP INTO MODE ON SWITCH
* SCANNER MODES (0-15)

* MODE 0 (MONITOR MODE)

* MODE 0 IS THE INTERACTIVE DIAGNOSTIC, OR "MONITOR" MODE. IT IS SELECTED BY SETTING THE THUMBWHEEL SWITCH TO 0 BEFORE POWER UP OF THE SYSTEM. UPON ENTRY, THE RS-232C DTR HARDWARE HANDSHAKE LINE IS CHECKED. IF IT IS ACTIVE, A COMMUNICATIONS DEVICE IS ASSUMED TO BE ATTACHED. IF NOT, THEN A MESSAGE IS SENT BY RS-232C INFORMING A DEVICE WHICH MAY YET BE ATTACHED TO ACKNOWLEDGE ITS PRESENCE BY SENDING A CARRIAGE RETURN CHARACTER. IF THE CHARACTER IS RECEIVED, A COMMUNICATIONS DEVICE IS ASSUMED TO BE ATTACHED. IF THE CHARACTER IS NOT RECEIVED, THE ENTIRE PROCESS JUST DESCRIBED IS REPEATED.

ONCE COMMUNICATION HAS BEEN ESTABLISHED, A MENU OF FEATURES IS SENT. THESE FEATURES INCLUDE THE ABILITY TO MANIPULATE THE STEPPER MOTOR AND THE DATA ACQUISITION HARDWARE, AND TO EXIT TO ANOTHER MODE OF OPERATION.

* MONITOR MODE (MODE 0) MAIN LOOP

```
04E0 17 01 MODE0
04E2 0F 03 1B MODE0: BCLR AWO,PORTB TURN WINDINGS OFF
04E5 5F BCLR DTR,PORTD,MON IF /DTR; ASSUME TERMINAL
04E6 00 10 FD CLRX
04E9 06 0F 55 L0 BRCRL TDOE,SCSR,L0 WAIT FOR TDOE
04EC A1 03 CMP #ETX END OF MESSAGE?
04EE 27 05 BEQ L00 IF SO, WAIT FOR INPUT
04F0 B7 11 STA SCI NO; SEND CHARACTER
04F2 5C INCX POINT TO NEXT CHARACTER
04F3 20 F1 BRA L0 REPEAT UNTIL DONE
04F5 08 10 FD L00 BRCRL RDOF,SCSR,L00 WAIT FOR INPUT
04F8 B6 11 LDA SCI GET CHARACTER
04FA A4 7F AND #$7F CLEAR UPPER BIT
04FC AE 0D CMP #CR CARRIAGE RETURN?
04FE 26 E0 BNE MODE0 MUST ANSWER OR ASSERT /DTR
0500 5F MON CLRX
0501 DB 0C 64 L1 LDA MENU,X GET CHARACTER
0504 0F 10 FD L11 BACLR TDOE,SCSR,L11 WAIT FOR TDOE
0507 B7 11 STA SCI SEND CHARACTER
0509 5C INCX NEXT CHARACTER
050A 26 F5 BNE L1 REPEAT FOR FIRST 256 BYTES
050C DB 0D 64 L12 LDA (MENU-256),X END OF MENU?
050F A1 03 CMP #ETX NON USING LAST PART OF MENU
0511 27 08 BEQ L2 IF SO, GO WAIT FOR INPUT
0513 0F 10 FD L13 BACLR TDOE,SCSR,L13 WAIT FOR TDOE
0516 B7 11 STA SCI NO; PUT CHARACTER OUT
0518 5C INCX POINT TO NEXT CHARACTER
051A 26 F5 BRA L12 REPEAT UNTIL DONE
051B 0B 10 FD L2 BRCRL RDOF,SCSR,L2 WAIT FOR INPUT
051E B6 11 LDA SCI GET INPUT
0520 A4 7F AND #$7F CLEAR UPPER BIT
```
**AMPR**

450  0522  A1 3F  CMP  "#"?
451  0524  27 DA  BEQ  MON
452  0526  A4 5F  AND  "$5F"
453  0528  A1 58  CMP  "#X"
454  052A  26 14  BNE  L25
455  052C  B6 54  LDA  XMODE
456  052E  AE 03  LDX  #3
457  0530  42  MUL
458  0531  97  TAX
459  0532  4F  CLRA
460  0533  B7 50  STA  POS
461  0535  B7 00  STA  PORTA
462  0537  1B 01  BCLR  HOLD,PORTB
463  0539  19 01  BCLR  DUMP,PORTB
464  053B  1D 01  BCLR  NVAL,PORTB
465  053D  DC 04 2E  JMP  MTABLE,X
466  0540  AE 41  SUB  "#A"
467  0542  2B BC  BMI  MON
468  0544  A1 19  CMP  #25
469  0546  22 88  BHI  MON
470  0548  97  TAX
471  0549  EE 20  LDX  OFFSET,X
472  054B  D0 04 00  JSR  JTABLE,X
473  054D  5F  CLRX
474  054F  0F 10 FD  L3  BRCLR  TDRE,SCSR,L3
475  0552  D6 0E 2D  LDA  PROMPT,X
476  0555  A1 03  CMP  #ETX
477  0557  27 C2  BEQ  L2
478  0559  B7 11  STA  SCI
479  055B  5C  INCX
480  055C  20 F1  BRA  L3
481  

- HELP REQUEST?
- REPEAT MENU
- HANDLE LOWER CASE, TOO
- EXIT REQUEST?
- CONTINUE IF NOT
- GET NEXT MODE
- COMPUTE OFFSET
- FORCE RESYNC
- REPORT RESTART
- RESET INITIAL CONDITIONS
- ENTER NEXT MODE
- ALPHA CHARACTERS ONLY
- REPEAT MENU IF ILLEGAL INPUT
- UPPER LIMIT
- IF LEGAL, RANGE IS NOW 0-25
- GET OFFSET INTO JUMP TABLE
- GO TO APPROPRIATE SUBROUTINE
- WAIT FOR EMPTY TRANSMITTER
- DONE?
- YES; GO WAIT FOR INPUT
- OUTPUT PROMPT
- REPEAT UNTIL DONE
ASUB: DO ONE SCAN/CALIBRATE CYCLE

* THIS SUBROUTINE WILL EXECUTE ONE CYCLE OF
* "n" SCANS (n-1 RETRACES) PLUS A CALIBRATION

ASUB JSR RETURN RETURN TO INDEX POSITION
CLRA OUTPUT POSITION = 0
LDX #10 10 SETS
JSR ACQ 10 SETS INDICATES RESTART

ENTRY POINT FOR SUBROUTINE MSLOOP

ASUB1 BSET 0,HFETCH+1 $0100 OR $0300
BSET 0,LFETCH+1
BRSET HS,FLAG,ASUB2 SKIP IF $0300 DESIRED
BCLR I,HFETCH+I $0100
BCLR I,LFETCH+I
JSR SCAN DO "N" SCANS
LDA #$02 CALIBRATION SPEED
STA HFETCH+I
JSR CAL DO CALIBRATE
RTS

CSUB: MOVE TO COLD LOAD

* THE REFLECTOR WILL MOVE TO THE COLD LOAD FROM
* THE CURRENT POSITION. UPON EXIT ACCUMULATOR CONTAINS 135.

CSUB TST POS IN SYNC?
BNE CS1
JSR RETURN SYNC ENCODER
CS1 LDA #135 POSITION OF COLD LOAD
CMP POS BEQ COLD THERE ALREADY?
SEC CLOCKWISE
JSR MOVE GO STEPPING
COLD RTS

DSUB: DIRECTION CONTROL SUBROUTINE

* THIS SUBROUTINE TOGGLS THE DIRECTION CONTROL
* BIT, BIT 1 OF PORT B, AND REPORTS THE NEW STATE.

DSUB BRCLR CCW,PORTB,DCW BRANCH TO CW IF CCW
BCLR CCW,PORTB WAS CW; NOW CCW
LDX #((CCWMSG-CV) SAY SO
JMP CURSUB SNEAKY RTS
DCW BSET CW,PORTB WAS CCW; NOW CW
LDX #((CWMSG-CV) SAY SO
JMP CURSUB SNEAKY RTS
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541
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548 05A2 CD 0A B0 ESUB JSR GETPOS COMPUTE POSITION
549 05A5 B0 50 LDA POS
550 05A7 CD 07 3B JSR OUT3 OUTPUT VALUE
551 05AA AE 15 LDX #NLMSG-CV CR/LF
552 05AC CD 07 9C JSR CURSUB
553 05AF OB 10 F0 BRCLR RDRF,SCSR,ESUB KEY PRESSED?
554 05B2 B0 11 LDA SCI CLEAR FLAG
555 05B4 81 RTS

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565 05B5 18 01 GSUB BSET INT,PORTB INTEGRATE
566 05B7 A6 CB LDA #200
567 05B9 98 CLC
568 05BA CD 0B 17 JSR WAIT WAIT 10 MS
569 05BD A6 CB LDA #200
570 05BF 98 CLC
571 05C0 CD 0B 17 JSR WAIT WAIT 10 MS
572 05C3 A6 CB LDA #200
573 05C5 98 CLC
574 05C6 CD 0B 17 JSR WAIT WAIT 10 MS
575 05C9 A6 CB LDA #200
576 05CB 98 CLC
577 05CC CD 0B 17 JSR WAIT WAIT 10 MS
578 05CF 1D 01 BCLR NVAL,PORTB DATA NOT VALID
579 05D1 1A 01 BSET SMPL,PORTB SAMPLE
580 05D3 A6 CB LDA #200
581 05D5 98 CLC
582 05D6 CD 0B 17 JSR WAIT WAIT 10 MS
583 05D9 1B 01 BCLR HOLD,PORTB HOLD
584 05DB 1C 01 BSET VAL,PORTB DATA VALID
585 05DD 19 01 BCLR DUMP,PORTB DUMP
586 05DF 81 RTS
587 PAG
588
589 589 589
590
591
592
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594
595 05E0 3D 50 HSUB TST  POS  IN  SYNC?
596 05E2 26 03  BNE   HSI
597 05E4 CD 06 DB  JSR  RETURN  SYNC  ENCODER
598 05E7 A6 75  HSI  LDA  #117  POSITION  OF  HOT  LOAD
599 05E9 B1 50  CMP  POS
600 05EB 27 04  BEQ  HOT  THERE  ALREADY?
601 05ED 99  SEC  CLOCKWISE
602 05EE CD 09 30  JSR  MOVE  GO  STEPPING
603 05F1 81  HOT  RTS
604
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613 05F2 08 01 07  ISUB  BRSET  INT,PORTB,DMP  BRANCH  TO  D  IF  I
614 05F5 1B 01  BSET  INT,PORTB  WAS  D;  NOW  I
615 05F7 AE 28  LDX  #(IMSG-CV)  SAY  SO
616 05F9 CC 07 9C  JMP  CURSUB  SNEAKY  RTS
617 05FC 19 01  DMP  BCLR  DUMP,PORTB  WAS  I;  NOW  D
618 05FE AE 34  LDX  #(DMSG-CV)  SAY  SO
619 0600 CC 07 9C  JMP  CURSUB  SNEAKY  RTS
620
---
THE CURRENT STATE OF SEVERAL IMPORTANT SIGNALS AND VARIABLES IS REPORTED.

**Lsub: List AMPR Status**

The current state of several important signals and variables is reported.

**Lsub: Header**

Lsub CLRX HEADER

**Lsub: WINDINGS**

LDX #(WBMSG-CV) WINDINGS

**Lsub: LWF**

LDX #(WFMSG-CV) OFF

**Lsub: CCW**

LDX #(CCWMSG-CV) COUNTERCLOCKWISE

**Lsub: DUMP**

LDX #(DMSG-CV) DUMP

**Lsub: INTEGRATE**

LDX #(IMSG-CV) INTEGRATE

**Lsub: HOLD**

LDX #(HMSG-CV) HOLD

**Lsub: SAMPLE**

LDX #(SMSG-CV) SAMPLE

**Lsub: VALID**

LDX #(VBMSG-CV) VALID=

**Lsub: LOW**

LDX #(NVMSG-CV) LOW

**Lsub: HIGH**

LDX #(VMSG-CV) HIGH

**Lsub: SCANS**

LDX #(SCANS/CALIBRATE

**Lsub: DISPLAY IT**

LDX #(SCANS/CALIBRATE

**Lsub: FINISH TEXT**

LDX #(SCANS/CALIBRATE

**Lsub: GET EXIT MODE**

LDX #(SCANS/CALIBRATE

**Lsub: DISPLAY IT**

LDX #(SCANS/CALIBRATE

**Lsub: FINISH TEXT**

LDX #(SCANS/CALIBRATE

**Lsub: PAG**

LDX #(SCANS/CALIBRATE
A subroutine call may be made to "LPOS" (which is a part of "LSUB") for the sole purpose of displaying the current motor position.

```
LPOS  LDA  POS  GET MOTOR POSITION
     BNE  LPOS0  ENCODER NOT IN SYNC?
     LDX  #(NPMSG-CV)  ABSOLUTE POSITION UNKNOWN
     JMP  CURSUB  SNEAKY RETURN
LPOS0 CMP  #1  AT INDEX?
     BNE  LPOS1
     LDX  #(NXMSG-CV)  YES
     BRA  LPOS3  GIVE POSITION
LPOS1 CMP  #135  AT COLD LOAD?
     BNE  LPOS2
     LDX  #(CLMSG-CV)  YES
     JSR  CURSUB
     BRA  LPOS3  GIVE POSITION
LPOS2 CMP  #117  AT HOT LOAD?
     BNE  LPOS3
     LDX  #(HLMSG-CV)  YES
     JSR  CURSUB
LPOS3 LDA  POS  GET POSITION
     JSR  OUT3  DISPLAY IT
     LDX  #(POMSG-CV)  FINISH TEXT
     JMP  CURSUB  SNEAKY RETURN
```

PAG
* MSUB: SELECT EXIT MODE

* THIS SUBROUTINE ALLOWS FOR THE SELECTION OF
* THE MODE WHICH WILL BE EXECUTED UPON EXIT FROM MODE 0
* (MONITOR MODE). THE DEFAULT IS MODE 1.

MSUB CLRX

LDA MODES,X
BNE MS1

DISPLAY MODES MENU
END OF MENU?

MS1

CMP #$10

MS2

BEQ MS3

IF SO, GO GET NEW MODE

BRCLR TDRE, SCSR, MS2

WAIT FOR TDRE

STA SCI

MS2

NO; PUT CHARACTER OUT

INX

POINT TO NEXT CHARACTER

BRA MS1

REPEAT UNTIL DONE

MS3

LDX #($HMSG-CV)

GET ONE HEX DIGIT

JSR CURSUB

JSR HEXIN

MS3

SAVE IT

BRA MS1

THAT'S ALL FOLKS!

NSUB: NUMBER OF SCANS PER CALIBRATE

* THIS SUBROUTINE ALLOWS FOR THE SELECTION OF
* THE NUMBER OF SCANS BETWEEN CALIBRATIONS. THE DEFAULT
* IS 4, EQUIVALENT TO MODE 1 OPERATION. THIS COMMAND
* ONLY HAS EFFECT IN MONITOR MODE (IT DOES NOT ALTER
* ANY OF THE OTHER MODES). A VALUE OF ZERO TAKEN TO BE
* 16 SCANS PER CALIBRATION.

NSUB LDX #($HMSG-CV)

GET ONE HEX DIGIT

JSR CURSUB

JSR HEXIN

TSTA

NSUB1

BNE NSUB1

OK IF NONZERO

ADD #16

NSUB1

MAKE IT 16 SCANS

STA SCANS

NSUB1

SAVE IT

RTS

THAT'S ALL FOLKS!

PSUB: TAKE A STEP; REPORT POSITION

* PSUB LDA #$200

RESTORE INITIAL VALUES

STA MSTEP

JSR STEP

LDA #$80

STA MSTEP

JMP LPOS

DISPLAY & SNEAKY RETURN
RETURN: RETURN TO INDEX POSITION

RETURN BY THE SHORTEST PATH FROM THE CURRENT POSITION
TO THE START OF SCAN POSITION (DEFINED AS POSITION=1)
THE ACTUAL POSITION IS CHECKED BY READING THE SHAFT
ENCODER.

RETURN LDA POS GET SUPPOSED POSITION
BNE R1 IF ZERO, ENCODER NOT IN SYNC
JSR SYNC STRAIGHTEN IT OUT
BRA R4

R1 CMP #1 THERE ALREADY?
BEQ R3

R2 LDA #100 COMPUTE DIRECTION
JSR GETPOS
CMP POS

R3 STA PORTA REPORT POSITION
LDA #1 DESTINATION
JSR MOVE GO STEPPING

R4 CLR SCANUM REPORT POSITION
BSET CW,PORTB NEW DIRECTION=CW

SSUB: SAMPLE/HOLD SUBROUTINE

SSUB TOGGLES THE SAMPLE/HOLD BIT,
BIT 5 OF PORT B, AND REPORTS THE NEW STATE.
A AND X ARE DESTROYED.

BRSET SMPL,PORTB,HLD BRANCH TO H IF S
BSET SMPL,PORTB WAS H; NOW S
LDX #(SMSG-CV) SAY SO
JMP CURSUB SNEAKY RTS

HLD BCLR HOLD,PORTB WAS S; NOW H
LDX #(HMSG-CV) SAY SO
JMP CURSUB SNEAKY RTS

PAG
VSUB: DATA VALID CONTROL SUBROUTINE

THIS SUBROUTINE TOGGLES THE DATA VALID CONTROL BIT, BIT 6 OF PORT B, AND REPORTS THE NEW STATE.
A AND X ARE DESTROYED.

VSUB
LDX #(VBMSG-CV)
JSR CURSUB
BRSET VAL,PORTB NV
BRANCH TO LOW IF HIGH
BSET VAL,PORTB WAS LOW; NOW HIGH
LDX #(VMSG-CV)
JMP CURSUB
SNEAKY RTS
NV
BCLR NVAL,PORTB WAS HIGH; NOW LOW
LDX #(NVMSG-CV)
JMP CURSUB
SNEAKY RTS

VSUB: WINDINGS CONTROL SUBROUTINE

THIS SUBROUTINE TOGGLES THE WINDINGS CONTROL BIT, BIT 3 OF PORT B, AND REPORTS THE NEW STATE.
A AND X ARE DESTROYED.

WSUB
LDX #(WBMSG-CV)
JSR CURSUB
BRCLR AWO,PORTB,
BRANCH TO ON IF OFF
BCLR AWO,PORTB WAS ON; NOW OFF
LDX #(WFMSG-CV)
JMP CURSUB
SNEAKY RTS
WO
BSET AWO,PORTB WAS OFF; NOW ON
JSR PULSE
REPRIME THE SEQUENCER
LDX #(WNMSG-CV)
JMP CURSUB
SNEAKY RTS
PAG
OUT3: Output 3 Digit Decimal Number

This routine outputs to the serial port
A decimal value (0-255) equivalent to the unsigned contents of the accumulator. X and A are preserved.

OUT3 STA A1 SAVE A
STX X1 SAVE X
LDX #$30 ASCII ZERO
OUT31 CMP #$99 HUNDREDS DIGIT?
BLS OUT32 SKIP IF NONE LEFT
INX
SUB #$100 KNOCK ONE OFF
BRA OUT31 CHECK AGAIN
OUT32 CPX #$30 WERE THERE ANY?
BEQ OUT34 SKIP IF NOT
STX SCI SEND HUNDREDS DIGIT
LDX #$BO BIT 7 IS FLAG
OUT34 CMP #$9 TENS DIGIT?
BLS OUT35 SKIP IF NONE LEFT
INX
SUB #$10 KNOCK ONE OFF
BRA OUT34 CHECK AGAIN
OUT35 CPX #$30 WERE THERE ANY?
BEQ OUT37 SKIP IF NOT
ASLX CLEAR UPPER BIT
OUT36 BRCLR TDRE,SCSR,OUT36
STX SCI SEND TENS DIGIT
LDX #$80 BIT 7 IS FLAG
OUT37 BRCLR TDRE,SCSR,OUT37
ADD #$30 MAKE IT ASCII
STA SCI SEND ONES DIGIT
LDX X1 RESTORE X
LDA A1 RESTORE A
RTS
PAG
HEXIN: GET ONE HEX DIGIT

*   *   *  THIS SUBROUTINE WILL WAIT FOR THE RECEIPT  *  *  *  *  *  BY THE SERIAL PORT (SCI) OF A HEX DIGIT (0-9,A-F),  *  *  *  *  *  THEN ECHO IT BACK TO THE SERIAL PORT, AND RETURN  *  *  *  *  *  WITH THE NUMERIC VALUE OF THE CHARACTER IN THE  *  *  *  *  *  ACCUMULATOR. IF A DISALLOWED VALUE IS RECEIVED,  *  *  *  *  *  IT IS IGNORED. A VALID HEX DIGIT MUST BE  *  *  *  *  *  RECEIVED IN ORDER TO EXIT THIS SUBROUTINE.

HEXIN  BRCLR RDRF,SCSR,HEXIN
       LDA SCI  GET CHARACTER
       AND #$7F  MASK UPPER BIT
       TAX
       CMP #"0"  OUT OF BOUNDS
       BLO HEXIN
       CMP #"9"  CHECK FOR (A-F)
       BHI HEX2  MAKE IT A NUMBER
       SUB #$30  ECHO IT
       BRA HECHO

HEX2  AND #$5F  LOWER CASE OK
       CMP #"A"  OUT OF BOUNDS
       BLO HEXIN
       CMP #"F"  OUT OF BOUNDS
       BHI HEXIN
       TAX
       SUB #$37  MAKE IT A NUMBER
       BRA HECHO

HECHO  BRCLR TDRE,SCSR,HECHO
       STX SCI
       RTS

---------------------------------------------------------------------
CURSUB: OUTPUT FROM CURRENT VALUES LIST

*   *   *  THIS ROUTINE WILL OUTPUT A TEXT MESSAGE FROM  *  *  *  *  *  THE SEQUENCE OF TEXT MESSAGES BEGINNING AT LABEL  *  "CV". THE INDEX REGISTER CONTAINS UPON ENTRY  *  *  *  *  *  THE OFFSET INTO THIS LIST. NOTE THAT THIS MEANS  *  *  *  *  *  THAT THE ENTIRE LIST CAN BE NO MORE THAN 256 BYTES.  *  *  *  *  *  A AND X ARE DESTROYED.

CURSUB  LDA CV,X  GET CHARACTER
       CMP #EIX  END OF MESSAGE?
       BEQ CUR10  CURTAINS! GET IT?
       STA SCI  SEND IT
       INCX  POINT TO NEXT CHARACTER
       BRA CURSUB  REPEAT UNTIL DONE
       RTS  YOU'RE DONE FOR
AUTONOMOUS SCAN MODES

MSLOOP: MAIN SCAN LOOP

MSLOOP IS THE MAIN LOOP FOR THE NORMAL "n
SCANS PLUS CALIBRATE, THEN REPEAT" MODE OF OPERATION.
IT IS ENTERED FROM MODES 1-10.

MSLOOP BCLR TOIE, TCR  DISABLE TOF INTERRUPTS
JSR ASUB
MSLI JSR ASUB1  ASUB SECONDARY ENTRY POINT
BRA MSLI

MODE 1: 4 SCANS PER CALIBRATE
MODE 1 HAS CCW RETRACE.

MODE1 LDA #4  FOUR SCANS PER CALIBRATE
STA SCANS
BCLR RT, FLAG  CCW RETRACE
JMP MSLOOP  BEGIN SCAN MODE

MODE 2: 6 SCANS PER CALIBRATE
MODE 2 HAS CCW RETRACE.

MODE2 LDA #6  SIX SCANS PER CALIBRATE
STA SCANS
BCLR RT, FLAG  CCW RETRACE
JMP MSLOOP  BEGIN SCAN MODE

MODE 3: 8 SCANS PER CALIBRATE
MODE 3 HAS CCW RETRACE.

MODE3 LDA #8  EIGHT SCANS PER CALIBRATE
STA SCANS
BCLR RT, FLAG  CCW RETRACE
JMP MSLOOP  BEGIN SCAN MODE

PAG
MODE 4: 10 SCANS PER CALIBRATE

MODE 4 HAS CCW RETRACE.

MODE 5: 12 SCANS PER CALIBRATE

MODE 5 HAS CCW RETRACE.

MODE 6: 14 SCANS PER CALIBRATE

MODE 6 HAS CCW RETRACE.

MODE 7: 16 SCANS PER CALIBRATE

MODE 7 HAS CCW RETRACE.
* MODE 8: 4 SCANS PER CALIBRATE

* MODE 8 IS IDENTICAL TO MODE 1 EXCEPT THAT THE
  * REFLECTOR RETRACE IS CLOCKWISE, AT HIGHER SPEED.

MODE8 LDA #4
STA SCANS
BSET RT,FLAG CW RETRACE
BCLR HS,FLAG USE FASTER MOVE
JMP MSLOOP

* MODE 9: 6 SCANS PER CALIBRATE

* MODE 9 IS IDENTICAL TO MODE 2 EXCEPT THAT THE
  * REFLECTOR RETRACE IS CLOCKWISE, AT HIGHER SPEED.

MODE9 LDA #6
STA SCANS
BSET RT,FLAG CW RETRACE
BCLR HS,FLAG USE FASTER MOVE
JMP MSLOOP

* MODE 10: 8 SCANS PER CALIBRATE

* MODE 10 IS IDENTICAL TO MODE 3 EXCEPT THAT THE
  * REFLECTOR RETRACE IS CLOCKWISE, AT HIGHER SPEED.

MODE10 LDA #8
STA SCANS
BSET RT,FLAG CW RETRACE
BCLR HS,FLAG USE FASTER MOVE
JMP MSLOOP

* MODE 11: 10 SCANS PER CALIBRATE

* MODE 11 IS IDENTICAL TO MODE 4 EXCEPT THAT THE
  * REFLECTOR RETRACE IS CLOCKWISE, AT HIGHER SPEED.

MODE11 LDA #10
STA SCANS
BSET RT,FLAG CW RETRACE
BCLR HS,FLAG USE FASTER MOVE
JMP MSLOOP
MODE 12

MODE 12 IMPLEMENTS A "SCAN-IN-PLACE" FUNCTION.
THE REFLECTOR WILL MOVE TO POSITION=26, SO AS TO STARE
STRAIGHT DOWN, THEN BEGIN TAKING A QUANTITY OF DATA
EQUIVALENT TO THAT OF "n" SCANS OF 50 SAMPLES EACH.
THEN A NORMAL CALIBRATION CYCLE WILL TAKE PLACE, AND
THE PROCESS REPEATS UNTIL THE ESCAPE KEY IS Pressed.

MODE 13

MODE 13 SIMPLY PRODUCES A 1 KHz SQUARE
WAVE ON BIT 7 OF PORT A, FOREVER.

MODE 13 LDA #10
MODE 14

MODE 14 IS A DIAGNOSTIC MODE. THE PURPOSE IS TO GO TO THE INDEX, THEN STEP THE STEPPER MOTOR, USING A FAST STEP ALGORITHM, A REVOLUTION CLOCKWISE, A REVOLUTION COUNTERCLOCKWISE, THEN WAIT FOR A SERIAL PORT CHARACTER BEFORE REPEATING. IT PROMPTS FOR A KEYPRESS UPON ENTRY SO AS TO AVOID ACCIDENTAL INJURY TO MAN OR MACHINE.

MODE 14

JSR RETURN

MOVal 

LDX #(KPMSG-CV)  

JSR CURSUB PROMPT FOR KEYPRESS

BRCLR RDRF, SCSR, MI4A

LDA SCI GET KEY

JSR GETPOS GET CURRENT POSITION

LDA POS

SEC CLOCKWISE

JSR MOVE

LDA POS

CLC COUNTERCLOCKWISE

JSR MOVE

BRA M14

MODE 15

MODE 15 IS A DIAGNOSTIC MODE. THERE IS NO EXIT FROM THIS MODE. ALL IT DOES IS MAKE PORT "A" ALL OUTPUT, THEN PROCEED TO OUTPUT CONSECUTIVE 8 BIT VALUES TO PORT "A", WHILE OPERATING THE SAMPLE/HOLD, INTEGRATE/DUMP, AND DATA VALID LINES.

MODE 15

CLR PORTA

M15 JSR GSUB GET DATA

INC PORTA OUTPUT NEW "FAKE" POSITION

BRA M15 REPEAT

PAG
**MOTION RELATED SUBROUTINES**

**SCAN**

- ASSUMES INDEX POSITION (POSITION=1) AND DIRECTION=CW;
- SCANS THROUGH POSITION=50; RETRACES; REPEATS FOR A
- TOTAL OF "N" SCANS AND "N-1" RETRACES (ENDS UP AT
- POSITION=50 OF SCAN "N"). "N" IS CONTAINED IN THE
- VARIABLE "SCANS".

```
SCAN BSET INT,PORTB INTEGRATE
BSET TEST,PORTB TIME SCAN CYCLE
LDA #0 STEP i IMMEDIATELY
SEC
JSR WAIT
LDA #0 CLC
JSR WAIT
LDA #166 8.3 MS
SEC
JSR WAIT
LDA #0 35 uS
CLC
JSR WAIT
LDA #166 8.3 MS
SEC
JSR WAIT
LDA #0 35 uS
CLC
JSR WAIT
LDA #133 6.65 MS
CLC STAY LOW
JSR WAIT
BCLR NVAL,PORTB DATA NOT VALID
BSET SMPL,PORTB SAMPLE
LDA #33 1.65 MS
SEC
JSR WAIT
LDA #0 35 uS
CLC
JSR WAIT
LDA #133 6.65 MS
CLC STAY LOW
JSR WAIT
BCLR NVAL,PORTB DATA NOT VALID
BSET SMPL,PORTB SAMPLE
LDA #33 1.65 MS
SEC
```
LDA \#166
B.3 MS

CLC
NO PULSE

JSR WAIT

BCLR HOLD, PORTB
HOLD

BSET VAL, PORTB
DATA VALID

LDA \#55
KICK THE DOG

STA COPRR

COMA

STA COPRR

BCLR DUMP, PORTB
DUMP

JSR GETPOS

LDA POS

CMP EOS
END OF SCAN?

BEQ SCAN2

STA PORTA
OUTPUT POSITION

BRA SCAN
NEXT POSITION IN SCAN

LDA SCANUM
GET CURRENT SCAN NUMBER

INCA

CMP SCANS
LAST SCAN IN SET?

BEQ SCAN3
OK; DONE

STA SCANUM
SAVE NEW SCAN NUMBER

LDA FLAG

LSRA RT, FLAG--> CARRY

RT, FLAG--> CARRY

LDA \#1

BCLR TEST, PORTB
TIME SCAN CYCLE

JSR MOVE
RETRACE

BSET CW, PORTB
SCAN DIR-CW

BRA SCAN1
ESTABLISH INITIAL POSITION

RTS

CALIBRATION CYCLE

THIS SUBROUTINE Executes A CALIBRATION CYCLE.

CAL: CALIBRATION CYCLE

GO TO HOT LOAD

20 INTEGRATION TIMES

GO TO COLD LOAD

20 INTEGRATION TIMES

GOTO INDEX
ASSUME CW
SET CARRY=CW
NO, IT WAS CCW
INFORM RECORDER
MOTION TO BEGIN
SAVE DESTINATION
CALCULATE # STEPS
FULL REVOLUTION?
JUST 1?
YES
>40 STEPS?
>40 STEPS?
HALF UP, HALF DOWN
ODD #STEPS?
YES; FLAG IT
RAMP UP
COUNT
TO 6
ODD STEP AT HIGHEST SPEED
RAMP DOWN
MAKE SURE IT'S THERE
FULL RAMP LENGTH
RAMP UP
YES WE WANT A PULSE
FULL STEP YET?
1331 09BC CD 0A 77  JSR NSTEP  HOW FAR TO GO?
1332 09BF 27 2B  BEQ MV15  DONE?
1333 0991 B1 5B  CMP MPREV  GETTING CLOSER?
1334 0993 22 19  BHI MV12  OVERSHOT DESTINATION?
1335 0995 B7 5B  STA MPREV  NO; SAVE NEW DIST.
1336 0997 A0 14  SUB #20  RUN INTO RAMPDOWN AREA?
1337 0999 27 05  BEQ MV9  FULL LENGTH RAMPDOWN
1338 099B 22 E3  BHI MV7  NO RAMPDOWN YET
1339 099D 40  NEGA  OVERSHOT RAMPDOWN
1340 099E 20 02  BRA MV10  RECALCULATE RAMPDOWN LENGTH
1341 09A0 A6 14  MV9 LDA #20  FULL RAMP DOWN
1342 09A2 CD 09 E2  JSR RAMPDN  RAMP DOWN
1343 09A5 B6 5D  MV10 LDA DEST
1344 09A7 CD 0A 77  JSR NSTEP  HOW FAR TO GO?
1345 09AA 27 10  BEQ MV15  DONE?
1346 09AC 2A 09  BPL MV14  JUST SHY OF TARGET
1347 09AE 04 01 04  MV12 BRSET CH,PORTB,MV13  OVERSHOT; REVERSE DIRECTION
1348 09B1 14 01  BSET CH,PORTB
1349 09B3 20 02  BRA MV14
1350 09B5 15 01  MV13 BCLR CCW,PORTB
1351 09B7 CD 0A 46  MV14 JSR STEP
1352 09BA 20 E9  BRA MV11  CHECK AGAIN
1353 09BC CD 0A 80  MV15 JSR GETPOS
1354 09BF B6 50  LDA POS  EXIT W/POS IN A
1355 09C1 B7 00  STA PORTA  SEND TO RECORDER
1356 09C3 81  RTS
1357   PAG

HOW FAR TO GO?
DONE?
GETTING CLOSER?
OVERSHOT DESTINATION?
NO; SAVE NEW DIST.
RUN INTO RAMPDOWN AREA?
FULL LENGTH RAMPDOWN
NO RAMPDOWN YET
OVERSHOT RAMPDOWN
RECALCULATE RAMPDOWN LENGTH
FULL RAMP DOWN
RAMP DOWN
OVERSHOT RAMPDOWN LENGTH
OVERSHOT; REVERSE DIRECTION
JUST SHY OF TARGET
RAMPUP

* THIS SUBROUTINE USES A TABLE OF MOTOR ACCELERATION CURVE MICROSTEP DELAY VALUES TO ACCELERATE THE MOTOR TO HIGH SPEED. UPON ENTRY, THE ACCUMULATOR CONTAINS THE NUMBER OF FULL STEPS TO RAMP UP (1-20).

    RAMPUP LDX #12          2 BYTES x 6 uSTEPS
           MUL X=0 AFTER
           STA RLEN          #BYTES OF RAMP
           BSET 5,MSC        COUNT TO 6
           RUO SEC           YES WE WANT A PULSE
           BSR RLOOP         ONE MICROSTEP
           LSR MSC
           BCC RU2           FULL STEP YET?

    RU1 LDA DEST
    RU2 INCX
    INCX
    CPX RLEN
    DONE RAMPING?

    RD1 LDA DEST
    RD2 DECX
    DECX
    CMP MPREV
    GETTING CLOSER?
    BHI RD3 OVERSHOT? THEN QUIT
    STA MPREV
    SAVE DISTANCE
    BSET 5,MSC
    RESET COUNTER

    RU3 RTS

RAMPDN

* THIS SUBROUTINE USES A TABLE OF MOTOR DECELERATION CURVE MICROSTEP DELAY VALUES TO DECELERATE THE MOTOR TO LOW SPEED OR STOP. UPON ENTRY, THE ACCUMULATOR CONTAINS THE NUMBER OF FULL STEPS TO RAMP DOWN (1-20).

    RAMPDN LDX #12          2 BYTES x 6 uSTEPS
           MUL X=0 AFTER
           TAX NOW START AT TOP
           BSET 5,MSC        COUNT TO 6
           RD0 SEC           YES WE WANT A PULSE
           BSR RLOOP         ONE MICROSTEP
           LSR MSC
           BCC RD2           FULL STEP YET?

    RD1 LDA DEST
    RD2 DECX
    DECX
    CMP MPREV
    GETTING CLOSER?
    BHI RD3 OVERSHOT? THEN QUIT
    STA MPREV
    SAVE DISTANCE
    BSET 5,MSC
    RESET COUNTER

    RD3 RTS LET'S "GIT"
RLOOP

* THIS SUBROUTINE CAUSES A DELAY, FOLLOWED BY
* AN OLVL TRANSFER. THE TWO BYTE DELAY VALUE IS POINTED TO
* BY THE INDEX REGISTER, MS BYTE FIRST. A PULSE WILL OCCUR
* IF THE CARRY BIT IS FOUND TO BE SET UPON ENTRY.

RLOOP LDA ALTH INHIBIT ALTL
        STA OCRH INHIBIT COMPARE
        BCC RLO C=1 FOR PULSE
        BSET OLVL,TCR

RLO JSR LFETCH DOES LDA ?TABLE+1,X
        ADD ALTL SUM LSB
        STA RTEMP
        JSR HFETCH DOES LDA ?TABLE,X
        ADC OCRH SUM MSB
        STA OCRH OUTPUT COMPARE
        LDA TSR CLEAR FLAGS
        STA RTEMP
        JSR HFETCH DOES LDA ?TABLE,X
        ADC OCRH SUM MSB
        STA OCRH OUTPUT COMPARE ENABLED
        LDA #$55 KICK THE DOG
        STA COPRR

RL1 BRCLR OCF,TSR,RL1 WAIT FOR OLVL TRANSFER
        LDA ALTH INHIBIT ALTL
        STA OCRH INHIBIT COMPARE
        BCLR OLVL,TCR FALLING EDGE
        LDA ALTL
        ADD #13 SUM LSB
        STA RTEMP
        LDA OCRH
        ADD #0 SUM MSB
        STA OCRH OUTPUT COMPARE
        LDA TSR CLEAR FLAGS
        LDA RTEMP
        STA OCF,TSR,RL2 OUTPUT COMPARE ENABLED
        LDA OCF,TSR,RL2 WAIT FOR OLVL TRANSFER
        RTS
        PAG
*STEP: STEP ONE STEP*

**THIS SUBROUTINE WILL CAUSE SIX POSITIVE**

**PULSES ON THE STEP PULSE LINE OF THE STEPPER**

**MOTOR TRANSLATOR, WHICH IS ATTACHED TO THE OUTPUT**

**COMPARE LINE OF THE MICROCONTROLLER. THE WATCHDOG**

**TIMER WILL BE REFRESHED. THE STEP PULSE WIDTH IS 35**

**MICROSECONDS. IF THIS ROUTINE IS CALLED BEFORE**

**THE ENCODER IS IN SYNC, THE VARIABLE POS WILL**

**REMAIN ZERO, SO AS TO INDICATE UNRELIABLE POSITION**

**DATA FROM THE ENCODER.**

```assembly
STEP_STX - X4
BRSET AWO, PORTB, STO WINDINGS ON?
BSET AWO, PORTB WINDINGS MUST BE ON
JSR PULSE ___ (PRIME IT)
STO JSR PULSE PULSE #1
BSET 4, MSC 5 MORE
ST1 LDA MSTP GET uSTEP DELAY
SEC RISING EDGE
JSR WAIT
ST2 LDX X4
RTS
```

---

**STEP: STEP ONE STEP**

**THIS SUBROUTINE WILL CAUSE SIX POSITIVE**

**PULSES ON THE STEP PULSE LINE OF THE STEPPER**

**MOTOR TRANSLATOR, WHICH IS ATTACHED TO THE OUTPUT**

**COMPARE LINE OF THE MICROCONTROLLER. THE WATCHDOG**

**TIMER WILL BE REFRESHED. THE STEP PULSE WIDTH IS 35**

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**DATA FROM THE ENCODER.**

```assembly
STEP_STX - X4
BRSET AWO, PORTB, STO WINDINGS ON?
BSET AWO, PORTB WINDINGS MUST BE ON
JSR PULSE ___ (PRIME IT)
STO JSR PULSE PULSE #1
BSET 4, MSC 5 MORE
ST1 LDA MSTP GET uSTEP DELAY
SEC RISING EDGE
JSR WAIT
ST2 LDX X4
RTS
```
**********************************************************************
*  NSROP: COMPUTE STEPS TO DESTINATION
*
*  THIS SUBROUTINE COMPUTES THE NUMBER OF STEPS
*  BETWEEN THE CURRENT POSITION AND A DESTINATION GIVEN IN THE
*  ACCUMULATOR. THE DIRECTION OF MOVEMENT IS ASSUMED TO BE
*  THE CURRENT MOTOR DIRECTION. THE RESULT IS RETURNED IN
*  THE ACCUMULATOR. INPUT IS ASSUMED TO BE IN THE 1-200 RANGE.
*
**********************************************************************
NSTEP STX X3
CLR FUDGE // CORRECT FOR INDEX
JSR GETPOS
SUB POS // CHECK ENCODER DATA
BEQ NS5 // ALREADY HERE! QUIT
BLO NS2
BRSET CW,PORTB,NS4 // CW?
LDX #56 // NEW CORRECTION
BRA NS3
NS2 BRCLR CCW,PORTB,NS4 // CCW?
LDX #200 // NEW CORRECTION
NS3 STX FUDGE
NS4 LDX X3
BRSET FUDGE // ADD CORRECTION
BNE NP2 // ZER0?
LDA #200 // YES; CORRECT TO 200
BRA NP3
NP2 CMP #201 // NOT ZERO; 201?
BNE NP3 // NEITHER, SO LEGAL
LDA #1 // CORRECT 201 TO 1
NP3 RTS // CONDITION CODES FOR "A"

**********************************************************************
*  NPS0: COMPUTE NEXT POSITION
*
*  THIS ROUTINE COMPUTES A NEW POSITION, ONE STEP FROM
*  THE CURRENT POSITION, BASED ON THE CURRENT MOTOR DIRECTION.
*  THE RESULT IS RETURNED IN THE ACCUMULATOR.
*
**********************************************************************
NPOS LDA #1 // ONE STEP
BSET CW,PORTB,NP1 // NEG OR POS?
NEGA
NP1 ADD POS // COMPUTE
BNE NP2 // ZERO?
LDA #200 // YES; CORRECT TO 200
BRA NP3
NP2 CMP #201 // NOT ZERO; 201?
BNE NP3 // NEITHER, SO LEGAL
LDA #1 // CORRECT 201 TO 1
NP3 RTS // CONDITION CODES FOR "A"
NEGA
**GETPOS: READ POSITION FROM ENCODER**

* THIS SUBROUTINE READS THE HP HCTL-2000 ENCODER INTERFACE CHIP, DOES A DIVIDE-BY-FOUR ON THE 10 BIT 4x RESOLUTION DATA, AND CONVERTS IT TO AN 8 BIT UNSIGNED ABSOLUTE POSITION VALUE IN THE RANGE 1-200, WHERE VALUES INCREASE WITH CLOCKWISE MOTION, AND A VALUE OF 1 REPRESENTS THE ENCODER INDEX. THE RESULT IS PLACED IN "POS".

```
GETPOS STA A2 SAVE A
STX X2 SAVE X
GPO BCLR INDEX,FLAG
BCLR OE,PORTB OUTPUT ENABLE
LDX PORTC HIGH BYTE
BSET LBYTE,PORTB LOW BYTE
LDA PORTC LOW BYTE
BSET OE,PORTB OUTPUT DISABLE
BCLR HBYTE,PORTB RESET SEL
BRSET INDEX,FLAG,GPO IF CORRUPTED, REPEAT
RORX SHIFT 2 BITS RIGHT
BEQ GPI WHICH DIR FROM INDEX?
SUB #56 SUBTRACT IF CCW
GPI INCA MAKE IT 1-200
STA POS
LDX X2
LDA A2
RTS
```

**ACQ: ACQUIRE DATA SETS WHILE STATIONARY**

* THIS SUBROUTINE WILL ACQUIRE RADIOMETER DATA "n" TIMES IN THE CURRENT POSITION, AND WILL OUTPUT (TO PORT A) AS POSITION DATA THE VALUE FOUND IN THE ACCUMULATOR UPON ENTRY.
* THIS IS SO THE ROUTINE MAY BE USED TO GENERATE THE 10 ZERO POSITIONS REQUIRED TO INDICATE STARTUP OR RESTART, AS WELL AS THE CALIBRATION INTEGRATIONS. "n" IS FOUND IN THE X REGISTER.

```
ACQ STA PORTA POSITION REPORT
STX ALOOP SAVE COUNT
JSR GSUB GET DATA
ACQL LDA #$55 KICK THE DOG
STA COPRR
COMA
STA COPRR
DEC ALOOP ONE DOWN
LDA #555 BNE ACQL ANY TO GO?
COMA
RTS ALL DONE
```

---

**ACQ: ACQUIRE DATA SETS WHILE STATIONARY**

* THIS SUBROUTINE WILL ACQUIRE RADIOMETER DATA "n" TIMES IN THE CURRENT POSITION, AND WILL OUTPUT (TO PORT A) AS POSITION DATA THE VALUE FOUND IN THE ACCUMULATOR UPON ENTRY.
* THIS IS SO THE ROUTINE MAY BE USED TO GENERATE THE 10 ZERO POSITIONS REQUIRED TO INDICATE STARTUP OR RESTART, AS WELL AS THE CALIBRATION INTEGRATIONS. "n" IS FOUND IN THE X REGISTER.

```
ACQ STA PORTA POSITION REPORT
STX ALOOP SAVE COUNT
JSR GSUB GET DATA
ACQL LDA #$55 KICK THE DOG
STA COPRR
COMA
STA COPRR
DEC ALOOP ONE DOWN
LDA #555 BNE ACQL ANY TO GO?
COMA
RTS ALL DONE
```
SYNC: SYNCHRONIZE ENCODER LOGIC

* THIS SUBROUTINE CAUSES THE REFLECTOR TO MOVE UNTIL
* THE ENCODER INDEX IS REACHED, A MAXIMUM OF ONE REVOLUTION,
* SO THAT THE INCREMENTAL TO ABSOLUTE ENCODE LOGIC WILL SYNC
* TO THE INDEX POSITION OF THE INCREMENTAL SHAFT ENCODER.

SYNC  BCLR  ICIE,TCR   DISABLE INPUT CAPTURE IRQ
SYNC  BCLR  IEDG,TCR   FALING EDGE DETECT
TST  TS R   CLEAR ANY PENDING IRQ
TST  IC R L   CLEAR ICF
BCLR  ICIE,TCR  INDEX ENCOUNTERED?
BSET  CW,PORTB   GO CLOCKWISE
JSR  STEP   TAKE A STEP
BRCLR  ICF,TSR,SYNCI
TST  ICRL   CLEAR ICF
BSET  INDEX,FLAG   INDEX TRANSITION
LDA  #1    ESTABLISH INITIAL POSITION
STA  POS
STA  PORTA
BSET  IEDG,TCR  INDEX TRANSITION
BSET  ICIE,TCR  DETECT STEP FROM INDEX
BSET  ICIE,TCR  ENABLE INPUT CAPTURE IRQ
RTS  RETURN W/POS (=1) IN A

PULSE: SINGLE MICROSTEP PULSE

* THIS SUBROUTINE SIMPLY CAUSES ONE LOW-HIGH-LOW
* (_)_.) PULSE ON THE MOTOR MICROSTEP SEQUENCER STEP
* THE ROUTINE IS USED BY THE PSUB ROUTINE IN
* MICROSTEPPING, AND TO "PRIME" THE SEQUENCER AFTER ANY
* TRANSITION. THE STEP LINE IS ASSUMED TO BE LOW UPON
* ENTRY.

PULSE  LDA  #0
SEC
JSR  WAIT   MINIMUM DELAY BEFORE LOW
MIN TIME IS 35 uS
CLC
JSR  WAIT   WAIT
RTS  PAG
**WAIT: WAIT ROUTINE**

* THIS SUBROUTINE CAUSES A DELAY OF AN INTEGER MULTIPLE OF 50 MICROSECONDS OF THE VALUE FOUND IN THE ACCUMULATOR UPON ENTRY. THIS ROUTINE USES THE TIMER FUNCTION, AND THE OLVL VALUE IS TRANSFERRED AT THE END OF THE DELAY, AS THE OUTPUT COMPARE FLAG IS SET. IF THE REQUESTED DELAY IS ZERO, THERE IS A 35 uSEC DELAY. THIS DELAY IS DUE TO THE OVERHEAD REQUIRED TO SET UP AN "IMMEDIATE" OUTPUT COMPARE AND OLVL TRANSFER. THE DESIRED OLVL LEVEL IS PASSED THROUGH THE CARRY BIT UPON ENTRY; C=1 FOR HIGH, OR C=0 FOR LOW. THE DELAY INCLUDES TIME FOR THE INVOCATION OF THIS ROUTINE AS FOLLOWS:

```
LDA # (OR CLC)
SEC
JSR WAIT
```

THE DELAY IS MEASURED TO THE OLVL TRANSFER. AN ADDITIONAL 4 uS ELAPSES BEFORE PROGRAM CONTROL IS RETURNED.

```assembly
1666 OB17 9B WAIT
1669 OB18 BE 1A SEI
1670 OB1A BF 16 LDX ALTH
1671 OB1C 10 12 STA OCRH
1672 OB1E 25 02 BSET OLVL,TCR
1673 OB20 11 12 BCS WAIT0
1674 OB22 4D TSTA
1675 OB23 26 05 BNE WAIT1
1676 OB25 5F CLRX
1677 OB26 A6 0F LDA #15
1678 OB28 20 09 BRA WAIT2
1679 OB2A AE 19 WAIT1 LDX #25
1680 OB2C 42 MUL
1681 OB2D A0 04 SUB #4
1682 OB2F 24 02 BRA WAIT2
1683 OB31 5A BCC WAIT2
1684 OB32 9B DECX
1685 OB33 BB 1B CLC
1686 OB35 B7 56 ADD ALTL
1687 OB37 9F STA WTEMP
1688 OB38 B9 16 TXA
1689 OB3A B5 16 ADC OCRH
1690 OB3C B6 13 STA OCRH
1691 OB3E B6 56 LDA TSR
1692 OB40 B7 17 LDA WTEMP
1693 OB42 0D 13 FD WAIT3 BRCRRR OCF,TSR,WAIT3
1694 OB45 9A CLI
1695 OB46 81 RTS
```
**INTERRUPT SERVICE ROUTINES**

*SPIRQ RTI* NOT USED
*SCIIRQ RTI* NOT USED
*SNI RTI* NOT USED

---

**IRQ: IRQ LINE SERVICE ROUTINE**

* THIS ROUTINE ALLOWS FOR THE TESTING OF THE WATCHDOG TIMER, AS WELL AS AN EXTERNAL HARDWARE FAILURE FUNCTION. AS ENVISIONED, ATTACHED UNITS (POWER SUPPLIES, ETC.) WOULD CAUSE A FALLING EDGE UPON FAILURE, CAUSING A WATCHDOG TIMEOUT, FOLLOWED BY A RESTART, THEREBY CREATING A RECORD IN THE DATA OF THE OCCURRENCE OF A FAILURE. THE VERSION NUMBER OF THIS AMPR SOFTWARE IS SENT VIA RS-232, FOLLOWED BY A WAIT, WHICH WILL RESULT IN THE TIMEOUT, WHICH IN TURN WILL CAUSE A SYSTEM RESET.

**TIRQ: TIMER INTERRUPT SERVICE ROUTINE**

* THIS ROUTINE CHECKS FIRST FOR TIMER OVERFLOW, USED AS A REMINDER TO REFRESH THE WATCHDOG TIMER. THEN A CHECK IS MADE FOR INPUT CAPTURE, SO AS TO DETERMINE WHETHER THE MOTOR HAS JUST TRANSITED THE INDEX.

---

1697  O847  80
1702  O848  80
1703  O849  80
1704
1705
1706
1707
1708
1709
1710
1711
1712
1713
1714
1715
1716
1717
1718
1719  O84A  AE 0C
1720  O84C  CD 07 9C
1721  O84F  20 FE
1722
1723
1724
1725
1726
1727
1728
1729
1730
1731
1732
1733  O851  OB 12 0C
1734  O854  OB 13 09
1735  O857  B6 19
1736  O859  A6 55
1737  O85B  B7 1D
1738  O85D  43
1739  O85E  B7 1D
1740  O860  0F 13 0C
1741  O863  B6 15
1742  O865  1E 5C
1743  O867  02 12 03
1744  O86A  12 12
1745  O86C  80
1746  O86D  13 12
1747  O86F  80
1748

---

**SPIRQ**

**RTI**

**NOT USED**

**SCIIRQ**

**RTI**

**NOT USED**

**SNI**

**RTI**

**NOT USED**

**IRQ**

**LDX**

#(VER-CV) VERSION #

**JSR**

CURSUB

**BRA**

IRQ1 WAIT FOR DEATH

---

**TIRQ**

**BRCLR** TOIE,TCR,TIO SKIP IF NOT ENABLED

**BRCLR** TOF,TSR,TIO SKIP IF NO OVERFLOW

**LDA** LCOUNT CLEAR TOF

**LDA** #$55 KICK THE DOG

**STA** COPRR

**COMA**

**STA** COPRR

**LDA** 0F 13 0C

**TIO**

**BRCLR** ICF,TSR,T12 SKIP IF NO TRANSITION

**LDA** ICRL CLEAR FLAG

**BSET** INDEX,FLAG FLAG INDEX TRANSITION

**BRSET** IEDG,TCR,T11 SKIP IF LEAVING INDEX

**BSET** IEDG,TCR NEXT LOOK FOR STEP AWAY

**RTI** DONE!

**T11**

**BCLR** IEDG,TCR NEXT LOOK FOR INDEX

**RTI** GET OUT!

**PAG**
* MODES MENU (MAXIMUM 255 CHARACTERS!!)

MODES

FCB CR,LF,CR,LF

"MODE"

FCB CR,LF,CR,LF

"0 = MONITOR MODE"

FCB CR,LF,CR,LF

"1 = 4/CCW"

FCB CR,LF

"2 = 6/CCW"

FCB CR,LF

"3 = 8/CCW"

FCB CR,LF

"4 = 10/CCW"

FCB CR,LF

"5 = 12/CCW"

FCB CR,LF

"6 = 14/CCW"

FCB CR,LF

"7 = 16/CCW"

FCB CR,LF

"8 = 18/CCW"

FCB CR,LF

"9 = 20/CCW"

FCB CR,LF

"A = 22/CCW"

FCB CR,LF

"B = 24/CCW"

FCB CR,LF

"C = 26/CCW"

FCB CR,LF

"D = 28/CCW"

FCB CR,LF

"E = 30/CCW"

FCB CR,LF

"F = 32/CCW"

FCB CR,LF

"G = 34/CCW"

FCB CR,LF

"H = 36/CCW"

FCB CR,LF

"I = 38/CCW"

FCB CR,LF

"J = 40/CCW"

FCB CR,LF

"K = 42/CCW"

FCB CR,LF

"L = 44/CCW"

FCB CR,LF

"M = 46/CCW"

FCB CR,LF

"N = 48/CCW"

FCB CR,LF

"O = 50/CCW"

FCB CR,LF

"P = 52/CCW"

FCB CR,LF

"Q = 54/CCW"

FCB CR,LF

"R = 56/CCW"

FCB CR,LF

"S = 58/CCW"

FCB CR,LF

"T = 60/CCW"

FCB CR,LF

"U = 62/CCW"

FCB CR,LF

"V = 64/CCW"

FCB CR,LF

"W = 66/CCW"

FCB CR,LF

"X = 68/CCW"

FCB CR,LF

"Y = 70/CCW"

FCB CR,LF

"Z = 72/CCW"

FCB CR,LF

POPG
AMPR

1772 080F 38 20 3D 20 34  FCC  "8 = 4/CW"
0BE4 2F 43 57
1773 0BE7 0D 0A  FCB  CR,LF
1774 0BE9 39 20 3D 20 36  FCC  "9 = 6/CW"
0BEE 2F 43 57
1775 0BF1 0D 0A  FCB  CR,LF
1776 0BF3 41 20 3D 20 38  FCC  "A = 8/CW"
0BF8 2F 43 57
1777 0BFB 0D 0A  FCB  CR,LF
1778 0BFD 42 20 3D 20 31  FCC  "B = 10/CW"
OC02 30 2F 43 57
1779 0C06 0D 0A  FCB  CR,LF
1780 0C08 43 20 3D 20 41  FCC  "C = ACQUIRE STARING NADIR"
OC0D 43 51 55 49 52
OC12 45 20 53 54 41
OC17 52 49 4E 47 20
OC1C 4E 41 44 49 52
1781 0C21 0D 0A  FCB  CR,LF
1782 0C23 44 20 3D 20 31  FCC  "D = 1KHz ON PORT A BIT 7"
OC28 48 48 7A 20 4F
1784 0C30 45 20 3D 20 4D  FCC  "E = MOTOR STEP TEST"
OC42 4F 54 4F 52 20
OC47 53 54 45 50 20
OC4C 54 45 53 54
1785 0C50 0D 0A  FCB  CR,LF
1786 0C52 46 20 3D 20 50  FCC  "F = PORT A TEST"
OC57 4F 52 54 20 41
OC5C 20 54 45 53 54
1787 0C61 0D 0A 03  FCB  CR,LF,ETX
1788
1789  PAG
**MONITOR MENU AND MESSAGES**

* MENU FCB CR,LF,CR,LF

- **M** WINDINGS (ON/OFF)

- **D** DIRECTION (CW/CCW)

- **P** STEP PULSE

- **H** GO TO HOT LOAD

- **C** GO TO COLD LOAD

- **R** RETURN TO SCAN START POSITION

- **E** ENCODER POSITION

- **I** INTEGRATE (DUMP/INTEGRATE)

- **S** SAMPLE (SAMPLE/HOLD)
AMPRI

1814 0D39 56 09 44 41 54 FCC "V DATA VALID (LOW/HIGH)"
003E 41 20 56 41 4C
1815 0D51 0D 0A 0D 0A FCB CR,LF,CR,LF
1816 0D55 47 09 47 45 54 FCC "G GET DATA AT CURRENT POSITION"
005A 20 44 41 54 41
1817 0D73 0D 0A FCB CR,LF
1818 0D75 4E 09 4E 45 57 FCC "N NEW # SCANS PER CALIBRATE: 0-F (HEX)"
007A 20 23 20 53 43
1819 0D9B 0D 0A FCB CR,LF
1820 0D9D 41 09 41 43 51 FCC "A ACQUIRE DATA FOR ONE SCAN/CALIBRATE CYCLE"
00A2 55 49 52 45 20
1821 0DCC 4C 09 4C 49 53 FCB CR,LF,CR,LF
1822 0D01 54 20 43 55 52 FCC "L LIST CURRENT AMPRI STATUS"
0006 52 45 4E 54 20
1823 0DE6 0D 0A FCB CR,LF
1824 0DE6 4D 09 45 58 49 FCC "M EXIT MODE: 0-F (HEX)"
00ED 54 20 40 4F 44
1825 0DFE 0D 0A FCB CR,LF
1826 0DFD 58 09 45 58 49 FCC "X EXIT TO NEXT MODE"
005A 54 20 54 4F 20
1827 0E13 0D 0A FCB CR,LF
1828 0E15 3F 09 4D 4F 4E HELP FCC "? MONITOR COMMAND MENU"
0E0F 4D 4F 44 4F
1829 0E2B 0D 0A FCB CR,LF
1830 PAG
AMP

1831 0E2D 00 0A  PROMPT   FCB   CR,LF
1833 0E43 4E 2C 41 2C 4C
1834 0E48 2C 4D 2C 58 2C
1835 0E40 3F 20 20 3D 3D
1836 0E52 3E 20
1837 0E54 03  FCB   ETX   END OF MENU
1838 0E55 0D 0A 0D 0A  CV  FCB   CR,LF,CR,LF
1839 0E59 53 54 41 54 55  FCC
1840 0E5E 53 3A 20
1841 0E61 28 56 34 2E 30  VER  FCC
1842 0E65 3E 20
1843 0E6A OD OA
1844 0E72 45
1845 0E73 00 0A 03  FCB   CR,LF,ETX
1846 0E76 48 4F 4C 44  HMSG  FCC
1847 0E7A 0D 0A 03  FCB   CR,LF,ETX
1848 0E7E 49 4E 54 45 47  IMSG  FCC
1849 0E82 52 41 54 45
1850 0E86 0D 0A 03  FCB   CR,LF,ETX
1851 0E89 44 55 4D 50  DMSG  FCC
1852 0E8D 00 0A 03  FCB   CR,LF,ETX
1853 0E90 57 49 4E 49 44  WBMSG  FCC
1854 0E95 4E 47 53 20 4F  FCC
1855 0E9A 03  FCB   ETX
1856 0E9B 4E  WMSG  FCC
1857 0E9C 0D 0A 03  FCB   CR,LF,ETX
1858 0E9F 46 46  WMSG  FCC
1859 0EA0 0D 0A 03  FCB   CR,LF,ETX
1860 0EAB 43 4C 4F 4E 54  CCWMSG  FCC
1861 0E9A 45 52
1862 0E9B 43 4C 4F 43 48  CWMSG  FCC
1863 0E90 57 49 53 45
1864 0EB0 57 49 53 45
1865 0EB7 44 41 54 41 20  VBMSG  FCC
1866 0EBC 56 41 4C 49 44
1867 0EC1 3D
1868 0EC2 03  FCB   ETX
1869 0EC3 4C 4F 57  NMSG  FCC
1870 0EC6 0D 0A 03  FCB   CR,LF,ETX
1871 0EC9 48 49 47 48  VMSG  FCC
1872 0ECB 00 0A 03  FCB   CR,LF,ETX
1873 0ED0 3F  NMSG  FCC
1874 0ED1 20 3D 20 4D 4F  POSMSG  FCC
1875 0ED6 54 4F 52 20 50  FCC
1876 0EDB 4F 53 49 54 49
1877 0EE0 4F 4E
1878 0EE2 0D 0A 03  FCB   CR,LF,ETX
1879 0EE5 20 3D 20 45 58  XMSG  FCC
1880 0EFA 49 54 20 4D 4F
1881 0EEF 44 45
1882 0EF1 00 0A 03  FCB   CR,LF,ETX
"IS # SCANS/CALIBRATE"

"HOT LOAD;"

"COLD LOAD;"

"NEW VALUE (HEX: 0-F) =>"

"PRESS A KEY"

"DTR NOT DETECTED. PRESS RETURN IF RS-232 IS ATTACHED."

"PRESS A KEY"

"DTR NOT DETECTED. PRESS RETURN IF RS-232 IS ATTACHED."
* ---------------------------------------------------------------*
*                       OPTION REGISTER                           *
* ---------------------------------------------------------------*
1890  1FF4  0847  FDB  SPIRQ
1890  1FF6  0848  FDB  SClRQ
1890  1FF8  0851  FDB  TlRQ
1890  1FFA  084A  FDB  lRQ
1890  1FFC  0849  FDB  SWI
1890  1FE  045E  FDB  RESET  RESET/POWER UP
1890  2000  END

* ---------------------------------------------------------------*
*                       VECTORS                                    *
* ---------------------------------------------------------------*
1890  1FF4  0847  FDB  SPIRQ
1890  1FF6  0848  FDB  SClRQ
1890  1FF8  0851  FDB  TlRQ
1890  1FFA  084A  FDB  lRQ
1890  1FFC  0849  FDB  SWI
1890  1FE  045E  FDB  RESET  RESET/POWER UP
1890  2000  END

* ---------------------------------------------------------------*
*                       VECTORS                                    *
* ---------------------------------------------------------------*
1890  1FF4  0847  FDB  SPIRQ
1890  1FF6  0848  FDB  SClRQ
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- 114 RAM
- 115 RAM1
- 1392 RAMPDN
- 1366 RAMPUP
- 1396 RDO
- 1400 RD1
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- 95 RDRF
- 322 RESET
- 768 RETURN
- 1426 RLO
- 1439 RL1
- 1452 RL2
- 176 RL2N
- 1422 RLOOP
- 115 ROM
- 130 RT
- 168 RTMP
- 1370 RU0
- 1374 RU1
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APPENDIX B

AMPR ELECTRONIC MODULE SCHEMATIC DIAGRAMS
MV-1606 POWER
+15V ON PIN 1
-15V ON PIN 27
GND ON PIN 12
P3 IS A 35 PIN MALE CYLINDRICAL CONNECTOR
PART NUMBER LJ02RE-15-3SP
APPENDIX C

VENDOR SUPPLIED SPARE PARTS LIST
# AMPR SPARE PARTS LIST FOR VENDOR SUPPLIED ITEMS

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<td>M112FD8012 (MTR), C3A (Encoder)</td>
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APPENDIX D

AMPR CABLE INTERCONNECT DIAGRAMS
Figure D1. AMPR/ER-2 Cable Interconnect Diagram
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- **Scanner power supply**: A, B, C, D
- **Power supply monitor**: E
- **Digital power supply**: G, H
- **Power supply monitor**: J, K

**NC** = No Connection
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