MIL 1010 10-1-60

AC SPARK PLUG DIVISION
General Motors Corporation
Milwaukee, Wisconsin

XDE 34-S-11 Rev. B

ENGINEERING DESIGN INFORMATION EXHIBIT

PRELIMINARY APOLLO BLOCK II PERFORMANCE SPECIFICATION INERTIAL SUBSYSTEM COUPLING DATA UNITS

By M. Mastandrea

Date 25 August 1964

K. Kamm 8-2c

1. SCOPE

This specification establishes the preliminary performance requirements for the Inertial Subsystem (ISS), Optical Subsystem (OSS), and Rendezvous Radar (RR) Coupling Data Units of the Apollo G and N System for Block II.

2. APPLICABLE DOCUMENTS

The following documents form a part of this specification to the extent specified herein:

2.1 DRAWINGS

2015562	CSM IMU-Optics CDU Moding Diagram Block II (2 Line Mech)
2015566	IMU-REND RADAR CDU Block Diagram Block II (2 Line Mech)
2015567	Optics Trunnion and Shaft Block Diagram Block II (2 Line Mech)
6015562	LEM IMU-REND RADAR CDU Moding Diagram Block II (2 Line Mech)
2010073	Block II CDU Heater Connector Command Module
6010001	Block II CDU Header Connector LEM Module

2.2 INTERFACE CONTROL DOCUMENTS

MH 01-01327-216	DC Power Supply
MH 01-01349-416	G and N Thermal Requirements
MH 01-01307-216	CDU to TVC Servo Amps
MH 01-01344-216	IMU Cage Signal
MH 01-01386-216	G and N Error Signals to Saturn Guidance
MH 01-01324-416	Attitude Error Signals
LIS 390-10002	G and N Prime Power Requirements and Characteristics
LIS 510-10001	G and N Thermal Dissipation and Cooling Requirements
LIS 520-1001	LEM Design Environment

LIS 370-10006	G and N to Radar Interface
LIS 540-10003	Rendezvous Radar Interaction with G and N
LIS 540-10004	Landing Radar Interaction with G and N
LIS 300-10003	Attitude Steering Error Signal Electrical Interaction with G and N

2.3 XDE'S

XDE 34-S-12	Power Supplies

3. <u>REQUIREMENTS</u>

3.1 GENERAL. - Five coupling data units shall be located in both the Command Service Module (CSM) and the Lunar Excursion Module (LEM).

The three coupling data units of the CSM ISS shall provide coupling between the Command Guidance Computer (CGC) and the CSM Inertial Measurement Unit (IMU). The three coupling data units of the LEM ISS shall provide coupling between the LEM Guidance Computer (LGC) and the LEM IMU. Desired angles shall be transmitted by the Computer via the CDU's to the IMU in analog form while the CDU's shall be capable of repeating the IMU gimbal angles and transmitting this information to the computers in digital form. The D/A sections of the three CSM IMU CDU's shall provide DC coupling between the CGC and the Saturn Booster Vehicle (to be used in the event of a Saturn Guidance System IMU failure during Earth Ascent and Translunar Injection). Desired attitude error signals shall be provided to the Saturn Guidance System via the CDU's. In addition, the D/A sections of the three IMU CDU's in both the CSM and LEM shall provide (1) AC coupling between the computers and the Flight Director Attitude Error Indicators (FDAI), and (2) AC signals for limiting gimbal rate during the coarse align mode.

The two coupling data units of the CSM OSS shall provide coupling between the CGC and the OSS. The CDU's shall be capable of repeating the shaft and trunnion angles and transmitting this information to the CGC in digital form. During the optics computer mode, desired sextant (SXT) trunnion and shaft angles shall be obtained by providing AC inputs to the trunnion and shaft servos from the CGC via the CDU D/A's. In addition, the CDU D/A's shall provide DC coupling between the CGC and the Service Propulsion System (SPS) (to be used during Thrust Vector Control (TVC) to provide analog signals for positioning the SPS engine gimbals).

The two coupling data units of the LEM RR shall provide a coupling between the Rendezvous Radar and the LGC. The CDU shall be capable of repeating the RR shaft and trunnion angles and transmitting this information to the LGC. The LGC via the CDU D/A's shall provide AC torquing signals to the gyros located on the radar inner gimbals. In addition, the CDU D/A's shall be used to provide DC signals, proportional to inertially derived forward and lateral velocity, for meter display in the LEM.

3.2 INPUTS. - The CDU's must maintain adequate performance under the conditions specified herein.

3.2.1 POWER INPUTS

3.2.1.1 Guidance and Navigation Input Power (CSM CDU's)

DC power will be supplied to the Command Service Module G and N System from the spacecraft primary 28 VDC power system. Characteristics of the spacecraft prime DC power are as follows:

(a) The steady state voltage limits shall be between 26.8 and 29.8 volts DC.

(b) The transient voltage limits shall be between 25.8 and 31.8 volts DC.

NOTE: The values given above are sensed on the input side of the isolation diodes.

3.2.1.2 Guidance and Navigation Input Power (LEM CDU's)

DC power will be supplied to the Lunar Excursion Module G and N System from the LEM primary 28 VDC power system as specified in LIS 390-10002.

3.2.1.3 CSM Inertial Subsystem Generated Input Power

Power will be supplied to the ISS CDU's and to the OSS CDU's during TVC mode from the 28V 1% 800 cps 0 degrees supply in the ISS. (Reference XDE 34-S-12.)

28V 1% 800 cps Supply (With Synchronized Pulse Input)

(a) Voltage: 28.0 ± 0.28 VAC

(b) Frequency: 800 ± 0.0004 cps

(c) Phase: $0^\circ \pm 9^\circ$

3.2.1.4 CSM Optical Subsystem Generated Input Power

Power will be supplied to the OSS CDU's from the 28V 1% 800 cps 0 degrees supply in the OSS. The power supply requirements are as specified in Paragraph 3.2.1.3.

3.2.1.5 LEM Inertial Subsystem Generated Input Power

Power will be supplied to the LEM CDU's from the 28V 1% 800 cps 0 degrees supply in the LEM ISS. The power supply requirements are as specified in Paragraph 3.2.1.3.

3.2.2 ENVIRONMENTAL INPUTS

3.2.2.1 The environmantal inputs to the CDU's in the CSM shall be as stated in MH 01-01349-416 and ND 1002037.

3.2.2.2 The environmental inputs to the CDU's in the LEM shall be as stated in LIS 510-10001 and LIS 520-10001.

3.2.3 DRIVING INPUTS

3.2.3.1 Computer Inputs

The signals that will be supplied by the CGC or LGC shall have the following characteristics:

3.2.3.1.1 Pulses which shall be supplied as inputs to the D/A Converter:

(a) Voltage: 7V ± 3V

(b) Frequency: 3200 pps

(c) Pulse Width: 3 ± 0.5 μ sec

(d) Backswing: less than 4 volts

(e) Rise Time: 10-90% of (a) 0.5 μ sec max

(f) Droop: less than 20% at 2 μ sec point

(g) Noise: less than 0.5 volts peak-to-peak

(h) Input Impedance: 600 ohms max.

3.2.3.1.2 Signals which shall be supplied to the CDU's to enable the various modes shall be as follows:

(a) Voltage: 0 ± 2 VDC

(b) Source Impedance: 2K ± 5% (enable); more than 1 meg (disable)

(c) Duration: 400 ms min (CDU Z)
200 ms min (all other modes)

3.2.3.1.3 Pulses which shall be supplied to a frequency divider network in the Interrogate Module to provide the 12.8K pps signals used in the logic modules:

(a) Voltage: 7V ± 3V

(b) Frequency: 51.2K pps

(c) Pulse Width: 3 ± 0.5 μsec

(d) Backswing: less than 4 volts

(e) Rise Time: 10-90% of (a) 0.5 μsec max

(f) Droop: less than 20% at 2 μsec point

(g) Noise: less than 0.5 volts peak-to-peak

(h) Input Impedance: 600 ohms max.

3.2.3.2 <u>ISS Gimbal Shaft Position Input</u>

For the ISS CDU's located in both the CSM and the LEM, the location of the gimbal shafts shall provide inputs to the CDU's via the gimbal resolvers. The resolvers shall be located between the IMU gimbals and shall transmit gimbal angle information to the CDU's in the form of electrical signals proportional to the sine and cosine of the 1X or 16X gimbal angles.

Listed below are some of the characteristics of the multiple speed (16X and 1X) resolvers (Reference Apollo G and N Specification Number PS-2018631A) which will be used in both the CSM and LEM IMU's.

3.2.3.2.1 Sixteen Speed Resolver

(a) Output Voltage: 5V rms

(b) Transformation Ratio: 0.179 ± 4%

(c) Total Angular Error: 20 arc sec max referred to the 1X mechanical shaft

(d) Phase Shift: $11^\circ \pm 2^\circ$

(e) Total Null: 5.0 mv, max

(f) Fundamental: 3.5 mv, max

(g) Frequency: 800 cps.

3.2.3.2.2 One Speed Resolver

(a) Output Voltage: 28V rms

(b) Transformation Ratio: 1 ± 2%

(c) Total Angular Error: 4 arc min max

(d) Phase Shift: $3^\circ \pm 1.5^\circ$

(e) Total Null: 28 mv, max

(f) Fundamental: 28 mv, max

(g) Coincidence of Electrical Zero: 3 arc min max referred to the 1X mechanical shaft

(h) Frequency: 800 cps

3.2.3.3 <u>Optics Shaft and Trunnion Position Input</u>

For the OSS CDU's, the location of the optics shaft and trunnion shall provide inputs to the CDU's via the optics resolvers. The resolvers shall be located on the sextant shaft and trunnion axes and shall transmit angular information to the CDU's in the form of electrical signals proportional to the sine and cosine of 16X shaft and 64X trunnion angles. Listed below are some of the characteristics of the 16X and 64X resolvers (Reference Apollo G and S Specification No. PS-1012066 and No. PS-1012065).

3.2.3.3.1 Sixteen Speed Resolver

(a) Output Voltage: 5V rms

(b) Transformation Ratio: 0.179 ± 4%

(c) Total Angular Error: 20 arc sec max referred to the one speed mechanical shaft

(d) Phase Shift: 11° ± 4°

(e) Total Null: 5.0 mv, max

(f) Fundamental: 3.5 mv, max

(g) Frequency: 800 cps

3.2.3.3.2 Sixty-Four Speed Resolver

(a) Output Voltage: 5V rms

(b) Transformation Ratio: 0.179 ± 10% -7%

(c) Total Angular Error: 10 arc sec peak-to-peak of one speed shaft and a bias of ± 3 arc sec

(d) Phase Shift: 50° ± 7°

(e) Total Null: 20 mv, max

(f) Fundamental: 20 mv, max

(g) Frequency: 800 cps

3.2.3.4 <u>Rendezvous Radar Shaft and Trunnion Position Input</u>

For the RR CDU's, the location of the radar shaft and trunnion shall provide inputs to the CDU's via the radar 1X and 16X resolvers. The resolvers shall be located on the radar shaft and trunnion axes and shall transmit angular information to the CDU's in the form of electrical signals proportional to the sine and cosine of the 1X and 16X radar shaft and trunnion axes. The resolver requirements are as specified in Paragraph 3.2.3.2.

3.3 PERFORMANCE. - The static and dynamic performance of the coupling data units shall be in accordance with the following specifications.

3.3.1 ACCURACY

The accuracy at which the CDU's can transmit ideal resolver angle information to the computers shall be as follows:

CDU	ROTATION RATE	ACCURACY (Worst Case)
CSM-ISS	$\leq 4.4°$/sec	60.9 arc sec
	$\leq 70.3°$/sec	460.9 arc sec
	(35.15°/sec during coarse align)	
CSM-OSS Shaft	$\leq 4.4°$/sec	60.9 arc sec
	$\leq 70.3°$/sec	460.9 arc sec
CSM-OSS Trunnion	$\leq 1.1°$/sec (line of sight)	8.2 arc sec
	$\leq 17.7°$/sec (line of sight)	108.2 arc sec
LEM-ISS	$\leq 4.4°$/sec	60.9 arc sec
	$\leq 70.3°$/sec	460.9 arc sec
LEM-RR	$\leq 4.4°$/sec	60.9 arc sec
	$\leq 70.3°$/sec	460.9 arc sec
	(35.15°/sec during coarse align)	

3.3.2 RATE LIMITING

During the ISS coarse align mode, the CDU's shall have a maximum counting speed of 6.4K pps and shall provide an analog error signal feedback through the CDU D/A converters which will limit the IMU gimbal rate to 35°/second.

3.3.3 LOOP OUTPUTS

The CDU's shall have the following outputs in the indicated operating modes:

3.3.3.1 CDU Output Pulses ($\Delta \theta_G$)

The CDU output pulses ($\Delta \theta_G$) shall be sent to the CGC from the CSM CDU's and to the LGC from the LEM CDU's during all CDU modes and shall have the following characteristics:

(a) Voltage: 7V ± 3V (positive with respect to reference)

(b) Frequency: has an upper limit determined by the availability of the computer computation (6.4K pps max)

(c) Pulse Width: 3 ± 0.5 μsec

(d) Backswing: less than 4 volts

(e) Rise Time: 10-90% of (a) 0.5 μsec max

(f) Droop: less than 20% at 2 μsec point

(g) Noise: less than 0.5 volts peak-to-peak

(h) Source Impedance: 51 ohms

3.3.3.2 Digital-to-Analog Converter (D/A) Output

The CDU's shall provide three separate isolated outputs (two AC and one DC) from each D/A converter.

3.3.3.2.1 The AC output signal from the CDU D/A converters shall have the following characteristics:

(a) Voltage Range: ± 5V rms ± 6%

(b) Frequency: 800 cps

(c) Scale Factor: 300 mv rms/degree ± 6%

(d) Linearity: within ± 3% of Full Scale

(e) Quantization: 13.2 mv rms ± 6%

(f) AC Offset: 10 mv rms max

(g) Total Null Voltage: 50 mv rms max

(h) Phase Shift: $0^\circ \pm 10^\circ$

(i) Source Impedance: less than 1K

(j) Load Impedance: 40K ± 5%

3.3.3.2.2 The DC output signals from the CDU D/A converters shall have the following characteristics:

(a) Voltage Range: ± 5VDC ± 6%

(b) Scale Factor: 300 mv DC/degree ± 6%

(c) Linearity: within ± 3% about the nominal above 0.2° and ± 9% below 0.2°

(d) Quantization: 13.2 mv DC ± 6%

(e) DC Offset: 10 mv max

(f) Noise: 50 mv rms max

(g) Source Impedance: less than 2K

(h) Load Impedance: 40K ± 5%

3.3.3.2.3 The AC Rate limiting signals from the mixing amplifier output in the CDU D/A converters are to be defined.

3.3.3.3 <u>CDU Failure Output</u>

The CDU shall generate a +28 VDC output to the CGC or LGC if any of the following conditions exist for more than 7 ± 3 seconds.

3.3.3.3.1 When the fine error signal is greater than 1.2V rms, the failure shall always be present. When the error signal is less than 0.5V rms, the failure shall never be generated by this error signal.

3.3.3.3.2 When the coarse error signal is greater than 4.0V rms, the failure shall always be present. When the error signal is less than 2.5V rms, the fail shall never be generated by this error signal.

3.3.3.3.3 When the cos $(\Theta - \psi)$ error signal is less than 1.2V rms, the failure shall always be present. When the error signal is greater than 1.8V rms, the fail shall never be generated by this error signal.

3.3.3.3.4 When the limit cycle frequency is greater than 275 cps, the failure shall always be present. When the limit cycle frequency is less than 150 cps, the fail shall never be generated by this signal.

3.3.3.3.5 When the 14 VDC supply output is less than 6.5 VDC the failure shall always be present. When the output voltage is more than 10 VDC the fail shall never be generated by the 14 VDC supply.

4. QUALITY ASSURANCE PROVISIONS

4.1 GENERAL

In order to verify the performance requirements of Section 3, the following shall be demonstrated.

4.2 CDU LEVEL

4.2.1 COMPUTER OUTPUT PULSES ($\Delta \Theta_G$)

The CDU output $\Delta \Theta G$ pulses to the computer shall have the following characteristics at the CDU Header Connector:

(a) Voltage: 7 ± 3V into a 510 ohm load

(b) Frequency: 400 or 6400 pps rate

(c) Pulse Width: 3 ± 0.5 μsec

(d) Droop: less than 20% at 2 μsec point

(e) Noise: less than 0.5 volts peak-to-peak

4.2.2 CDU 4 VDC SUPPLY

The CDU 4 VDC Supply shall have the following characteristics when measured at the load:

(a) Voltage: 4.0 ± .2 VDC

(b) Noise: less than _____ mv peak-to-peak

(c) Ripple: leaa than _____ mv peak-to-peak

4.2.3 CDU 14 VDC SUPPLY

The CDU 14 VDC Supplies (one in Interrogate Module and one in the Mode Module) shall have the following characteristics when measured at the CDU Header Connector:

(a) Voltage: 14.5 ± 1.0 VDC

(b) Noise: less than _____ mv peak-to-peak

(c) Ripple: less than _____ mv peak-to-peak

4.2.4 CDU INSTRUMENTATION ERROR

The CDU instrumentation error shall be checked at sufficient angular positions to insure that all the coarse and fine ψ selection switches are exercised. The maximum CDU error shall not exceed _____ arc seconds.

4.2.5 BIT SIZE

The fine error voltage required to produce a one bit change in the read counter shall be _____ ± _____ mv.

4.2.6 SCHMITT FIRING LEVELS

The proper firing levels of the Schmitt trigger circuits shall be determined as a function of resolver angles. The Schmitt trigger firing levels shall be as follows:

(a) Fine Schmitt: _____ ± _____° of 16X

(b) Fine Two Speed Schmitt: _____ ± _____° of 16X

(c) Coarse Schmitt: _____ ± _____° of 1X

(d) Ambiguity Schmitt: _____ ± _____° of 1X

4.2.7 AMBIGUITY OPERATION

4.2.7.1 Turn-on

With the resolver angle set at 225° and with CDU zero commanded, the fine error, coarse error, and mixing amplifier outputs shall be at null. After CA enable, the coarse error and mixing amplifier error shall be as follows:

(a) Coarse Error: ____ ± ____ mv

(b) Mixing Amplifier Error: ____ ± ____ mv

After the resolver setting is decreased to 0°, the coarse error and mixing amplifier error shall be 0 ± ____ mv.

4.2.7.2 Override

With an initial resolver angle of 225° and after release of the CDU zero command, the CDU shall repeat the resolver angle within ± 1 bit.

4.2.8 SPEED CHECK

The purpose of this requirement is to check the CDU dynamic response by checking the coarse-fine, high-low operation.

With the resolver angle set at 110 ± ____° and after release of the CDU zero command, the time required for the CDU to repeat the resolver angle within ± 1 bit shall be ____ ± ____ seconds.

4.2.9 PULSE TRANSMISSION TEST

Proper operation of the CDU in repeating resolver angles shall be determined by checking that no pulses are lost at the header connector if the CDU counts to large resolver angles repeatedly.

4.2.10 COARSE-FINE MIX

Proper operation of the coarse-fine mix shall be determined by checking that oscillation does not occur when the 1X resolver excitation is varied over its phase and amplitude limits or when the 16X resolver excitation is varied over its amplitude limits.

4.2.11 CDU FAIL CHECKS

Proper operation of the CDU fail circuitry shall be determined by checking that the CDU failure detection circuit will indicate out-of-tolerance conditions as specified in Paragraph 3.3.3.3.

4.2.12 D/A CONVERTER LINEARITY AND GAIN

The D/A Converter outputs shall have the following characteristics:

4.2.12.1 The AC output shall be as follows:

(a) Voltage Range: ± 5V rms ± 6%

(b) Scale Factor: 300 mv rms/degree ± 6%

(c) Linearity: ± 3% about the nominal

(d) Quantization: 13.2 mv rms ± 3%

(e) AC Offset 10 mv rms max

(f) Noise: 50 mv rms max

(g) Phase Shift: 0 ± 10°

4.2.12.2 The DC output shall be as follows:

(a) Voltage Range: ± 5 VDC ± 6%

(b) Scale Factor: 300 mv dc/degree ± 6%

(c) Linearity: ± 3% about the nominal above 0.2°
± 9% about the nominal below 0.2°

(d) Quantization: 13.2 mv dc ± 3%

(e) DC Offset: 10 mv dc max

(f) Noise: 50 mv rms

4.2.12.3 The mixing amplifier output is to be defined.

4.2.13 MIXING AMPLIFIER

The purpose of this requirement is to check that the mixing amplifier is within tolerance. The following parameters will be checked:

(a) DAC Gain
(b) DAC Saturation
(c) Fine Gain
(d) Fine Saturation
(e) Coarse Gain
(f) Coarse Saturation (mixing amplifier saturation)

4.2.14 CAGE VOLTAGE

The purpose of this requirement is to insure that the cage voltage output is of proper magnitude as a function of gimbal angle.

For specified resolver angles, the output voltage shall be V sin θ (θ is the resolver angle).

4.2.15 CAGE OVERRIDE

Proper operation of the IMU cage override function shall be determined by checking that the error counter is cleared and inhibited and a low (0 volts) is provided to the PSA when IMU cage override is commanded.

4.2.16 CROSS-TALK (IMU - OPTICS/RR)

A test shall be performed to insure that operation of the IMU CDU's have no adverse effect on the operation of the Optics/RR CDU's and vice versa.

4.2.17 STABILITY AND NOISE TESTS

Requirements are to be defined.

4.2.18 MODING

Proper CDU functioning; i.e., activate relays or enable logic circuits; shall be checked during the following modes:

(a) CDU Zero
(b) Enable Error Counter
(c) D/A Enable
(d) TVC Enable

(e) SIVB Takeover Enable
(f) Coarse Align Enable
(g) Display Inertial Data

4.3 ISS LEVEL

4.3.1 CDU REPEATING ACCURACY

The purpose of this test is to determine the accuracy at which the gimbal angle can be repeated in the Inertial Mode. The GSE gimbal positioners and the table shall be used to orient the gimbal under test. The IA of the controlling IRIG is positioned in the latitude plane and the table (tilt axis for IG and MG test and rotary axis for OG test) is adjusted to reduce the total drift to less than 0.5 meru. The IRIG is then pulse torqued to null the 16X sine winding output. The table axis which is parallel to the gimbal under test is rotated and the table readout is used to determine the accuracy of the angle indicated by the CDU $\Delta\theta_G$ output. In all cases the actual gimbal angle shall not deviate from the ideal gimbal angle by more than ± _____ arc seconds.

4.3.2 CDU AMBIGUITY OPERATION (COARSE ALIGNMENT OF THE GIMBALS)

The purpose of this requirement is to check the operation of the CDU ambiguity circuitry when the ISS is first turned to operate (CDU zero and coarse align commanded). If the gimbals are between 125° and 235°, the ambiguity circuitry drives the gimbals out of this range to avoid a false null which would occur if the gimbals were at 225°. The gimbals will continue to be driven until the gimbal angles and the CDU values are approximately equal to zero.

With the IMU gimbal angle at 225° ± 2°, place the ISS in operate. The CDU steady state output shall be 0° ± 1° within ten seconds. The one speed sine winding shall be monitored for an in-phase minimum. This test shall be started with the gyro wheels off to prevent damage to the gyros.

4.3.3 COARSE ALIGN POSITIONING

4.3.3.1 <u>Slewing Performance</u>

With the ISS in the coarse align mode and 4096 + $\Delta\theta_C$ input pulses applied to the CDU (in bursts of 256 pulses), the CDU steady state output shall be 16,384 ± 135 pulses. This test shall also be with 4096 - $\Delta\theta_C$ input pulses applied.

4.3.3.2 Transient Response

With the ISS in the coarse align mode and a burst of _____ pulses applied, the gimbal shall reach its final value (first crossing) within _____ milliseconds after the last command pulse. The gimbal angle as indicated in a recording of the 1X sine signal shall have no more than one overshoot in excess of _____.

4.3.3.3 Rate Test

To be defined.

4.3.4 IMU CAGE OPERATION

With the gimbal angle set at 180 ± _____°, place the ISS in IMU cage. The IMU gimbal angle shall return to 0° ± _____°. The test shall be performed with the gyro wheels off to prevent damaging the gyros.

4.4 OSS LEVEL

4.4.1 CDU REPEATING ACCURACY

The ability of the CDU A/D converter to accurately repeat the SXT shaft and trunnion angles shall be demonstrated. This function shall be checked for at least at one angle in each quadrant.

4.4.2 COMPUTER CONTROLLED POSITIONING

The ability of the CDU to position the SXT shaft and trunnion axes at given angles in both the positive and negative directions shall be demonstrated. These tests will also include measurement of steady state error, transient response to step input (time to first crossing of final value and overshoot), and maximum drive rate.

4.5 G AND N LEVEL

4.5.1 CSM IMU CDU'S

4.5.1.1 IMU Turn-On Test

The ability of the CDU's to drive the gimbals to zero positions and hold them there during the IMU turn-on period shall be demonstrated.

With the IMU gimbals set at 225°, initiate turn-on by closing the ISS operate circuit breaker. (This allows for a 90 second gyro runup period and enables a +28V discrete from the CDU to the CGC to initiate this mode.) The IMU gimbals shall return to 0° ± _____ ° as determined by reading out the gimbal angles via the DSKY. The steady state voltage output of the one speed gimbal resolver sine windings shall be less than ± _____ mv (total).

4.5.1.2 Coarse Align Positioning Test

The ability of the CGC to perform the following functions, via the CDU, shall be demonstrated for each axis:

(a) Position the gimbals in both the positive and negative direction upon computer command.

(b) Read out a gimbal angle via the DSKY upon termination of the CDU zero command.

This test shall be performed such that IRIG drift is minimized.

The following shall be performed for each axis:

(a) Place the system in the coarse align mode and zero the gimbal under test. The other gimbals shall be positioned for minimum gimbal drift.

(b) Command gimbal angle changes of +2.81°, -5.625°, +11.25°, -16.875°.

(c) For each of the angles specified in (b), read out the gimbal angle obtained via the DSKY. The gimbal shall be positioned within ± _____ ° of the desired value. After this value has been obtained, the CDU Zero Command shall be initiated and then removed allowing at least _____ seconds in CDU Zero Mode. The gimbal angle shall again be determined by reading the DSKY and the value obtained shall not deviate from the first reading by more than ± _____ °.

4.5.1.3 D/A Linearity and Gain Test

With the system in the spacecraft control of Saturn mode, monitor the D/A DC outputs to the Saturn guidance and the AC output to the FDAI. Apply $\Delta\theta_C$ pulses from the CGC to the CDU D/A Converters and check that the interface requirements are met (Paragraphs 3.3.3.2.1 and 3.3.3.2.2).

4.5.1.4 Failure Detection Test

The capability of the failure detection circuits to indicate out-of-tolerance conditions within the CDU shall be demonstrated. These tests will require a CGC program that will allow a fail light during CDU zero.

NOTE: The cos $(\theta - \psi)$ and 14 VDC fail will be checked at the CDU level.

4.5.1.4.1 Fine Error Fail

Coarse align to an angle of 5°, then command CDU zero. After ten seconds the CDU fail indication shall be lighted.

4.5.1.4.2 Coarse Error Fail

Coarse align to an angle of 90°, then command CDU zero. After ten seconds the CDU fail indication shall be lighted.

4.5.2 OPTICS CDU'S

4.5.2.1 Optics CDU - Zero

The proper operation of the CDU during the Optics Zero Mode shall be checked. Command the Optics Zero Mode and after thirty seconds, remove the CDU Zero discrete and read out the SXT shaft and trunnion angles via the DSKY. These values shall be 0 ± _____° for shaft and 0 ± _____° for trunnion.

4.5.2.2 Positioning Test

The ability of the CDU, upon command from the CGC, to position the optics in both a positive and negative direction and to repeat the shaft and trunnion angles obtained shall be demonstrated.

(a) Following Optics - Zero Mode, send the optics D/A enable discrete.

(b) For the shaft axis, command changes of +2.81°, -5.625°, +11.25°, and -16.875°. For the trunnion axis, command changes of +0.705°, -1.41°, +2.81° and -4.21°.

(c) For each of the commands specified in (b), determine the steady state shaft or trunnion angles by reading the DSKY. The angle thus obtained shall equal the commanded angle within ± _____° for shaft and ± _____° for trunnion. Following the first determination of the angle via the DSKY, the CDU zero discrete shall be generated for at least thirty seconds and then removed. The DSKY shall again be read to determine the shaft or trunnion angle and this value shall not deviate from the first value obtained by more than ± _____°.

4.5.2.3 D/A Linearity and Gain Test

With the system in the Thrust Vector Control Mode, monitor the optics CDU D/A DC outputs to the SPS engine gimbal amplifiers. Apply $\Delta\theta_C$ pulses from the CGC to the CDU D/A converter and check that the interface requirements are met (Paragraph 3.3.3.2.2).

4.5.2.4 Failure Detection Test

The capability of the failure detection circuits to indicate out-of-tolerance conditions within the CDU shall be demonstrated for the optics CDU's.

4.5.2.4.1 Fine Error Fail

(a) Place the system in the optics CDU Zero Mode.

(b) Command the TVC enable discrete and the optics CDU zero discrete. This will inhibit the transmission of incrementing pulses to the optics read counters.

(c) Drive the optics shaft to 5° by use of the hand controller. After ten seconds the CDU fail indication shall be lighted.

(d) Repeat Steps (a) and (b). Then drive the optics trunnion to 1.25° by use of the hand controller. After ten seconds the CDU fail indication shall be lighted.

4.5.3 LEM IMU CDU'S

The same testing as required for the CSM IMU CDU's shall be accomplished with the exception that the DC analog error signal output of the D/A converter need not be checked.

4.5.4 LEM RR CDU'S

Quality assurance tests are to be defined.

5. PREPARATION FOR DELIVERY. - Not Applicable.

6. ANALYSIS

6.1 INTRODUCTION

The purpose of this section is to give a brief summary of the CDU operation. The electronic CDU is a combination of an analog system and a digital system, and consists of the following modules:

(a) Quadrant Selector Module
(b) Main Summing Amplifier and Quadrature Rejection Module
(c) D/A Converter Module
(d) Read Counter Module
(e) Error Counter and Logic Module
(f) Digital Mode Module
(g) Mode Module
(i) Interrogate Module
(j) 4 VDC Supply Module
(k) Coarse Module (not used in optics CDU's).

The CDU's provide analog-to-digital (A/D) and digital-to-analog (D/A) conversion capability. The A/D converter converts the resolver outputs into digital information which is stored in a binary counter (read counter) and is transmitted to the computers in the form of pulses. The D/A converter accepts pulses from the computer, stores them in a binary counter (error counter), and provides an AC and a DC output proportional to the stored pulses. A digital feedback path between the read counter and error counter is provided to count the error counter up as the read counter is counted down and vice versa.

The ISS and RR CDU's convert the angular information of the 1X and 16X resolver outputs (sin θ, cos θ, sin 16θ and cos 16θ) into digital information. The resolver angle is digitized to 20 sec bits and stored in a 16 stage binary (read) counter. An error signal proportional to the difference between the resolver angle and the CDU angle ψ (read counter content) causes the read counter to count until the error signal is nulled. If the difference between the resolver angle and the CDU angle ψ is greater than 0.1°, the read counter will be incremented at a 12.8K pps rate. The count rate is 800 pps if the difference is less than 0.1°. A coarse system and fine system are used for accomplishing the null. In the coarse system the signals from the one-speed resolver (sin θ and cos θ) go to the gain change resistors in the Coarse Module. The gimbal angle θ is compared with the angle in the read counter ψ by use of the mathematical relationship $\sin\theta\cos\psi - \cos\psi\sin\theta = \sin(\theta - \psi)$. If $\theta \neq \psi$, the error detector in the Coarse Module will not be at null. As a result a signal will be sent to the Read Counter Module. This module will provide the signals to increment the read counter angle ψ and to change the switching arrangement for different values of gain resistors in the Coarse Module in order to produce a null output of the error detector. For each read counter angle ψ there is a corresponding switch arrangement which will produce a null output. When ψ is within 22.5° of θ, a nulling ladder is used to null the remaining signal $\sin(\theta - \psi)$. The output of the nulling ladder goes from 0° to 22.5° in steps of 2.81°. The accuracy of the coarse system is approximately equal to the smallest bit in the ladder network (2.81°). The fine system is then utilized to repeat the gimbal angle within approximately 1 bit (20 $\widehat{sec}$). The fine system is similar to the coarse system but is more complex since greater accuracy is required.

Each pulse stored in the CDU D/A converter is equivalent to ≈160 $\widehat{sec}$. A maximum of 384 pulses can be stored without saturating. Each pulse provides an AC output of 13.2 mv rms, 800 cps and a DC output of 13.2 mv DC. In addition, a third output is available which is derived from the sum of a signal proportional to the pulses stored in the error counter and the CDU coarse and fine error signals. This output can be used where rate limiting is desired.

The CDU D/A converter also provides the output to the computer. Pulses equal to 40 $\widehat{sec}$ of increasing or decreasing resolver angle are sent to the computer at a 400 pps or 6400 pps rate. A functional diagram of the ISS CDU is shown in Figure 1.

The OSS CDU's perform the same general functions as the ISS and RR CDU's but do not require a coarse system. To assure CDU optics synchronization, the optics are zeroed by closing the loop about the sine windings of the optics resolvers and thus physically driving the shaft and trunnion to electrical zero. The zero optics CDU discrete is then applied. The trunnion CDU uses 64X resolver inputs and has an additional switch in the fine system ladder network. As a result, the trunnion CDU is digitized to 2.5 $\widehat{sec}$ (referred to the 1X shaft) in the 16 stage binary read counter. Hence, the CDU output pulses to the CGC are equivalent to 5 $\widehat{sec}$ while each pulse in the trunnion CDU D/A converter is equivalent to 20 $\widehat{sec}$.

6.2 CDU AMBIGUITY OPERATION

In the operation of the ISS and RR CDU's there is a possibility of the gimbals being positioned at 225° and the CDU indicating 0° if sufficient circuitry were not implemented to prevent an ambiguous indication from occurring.

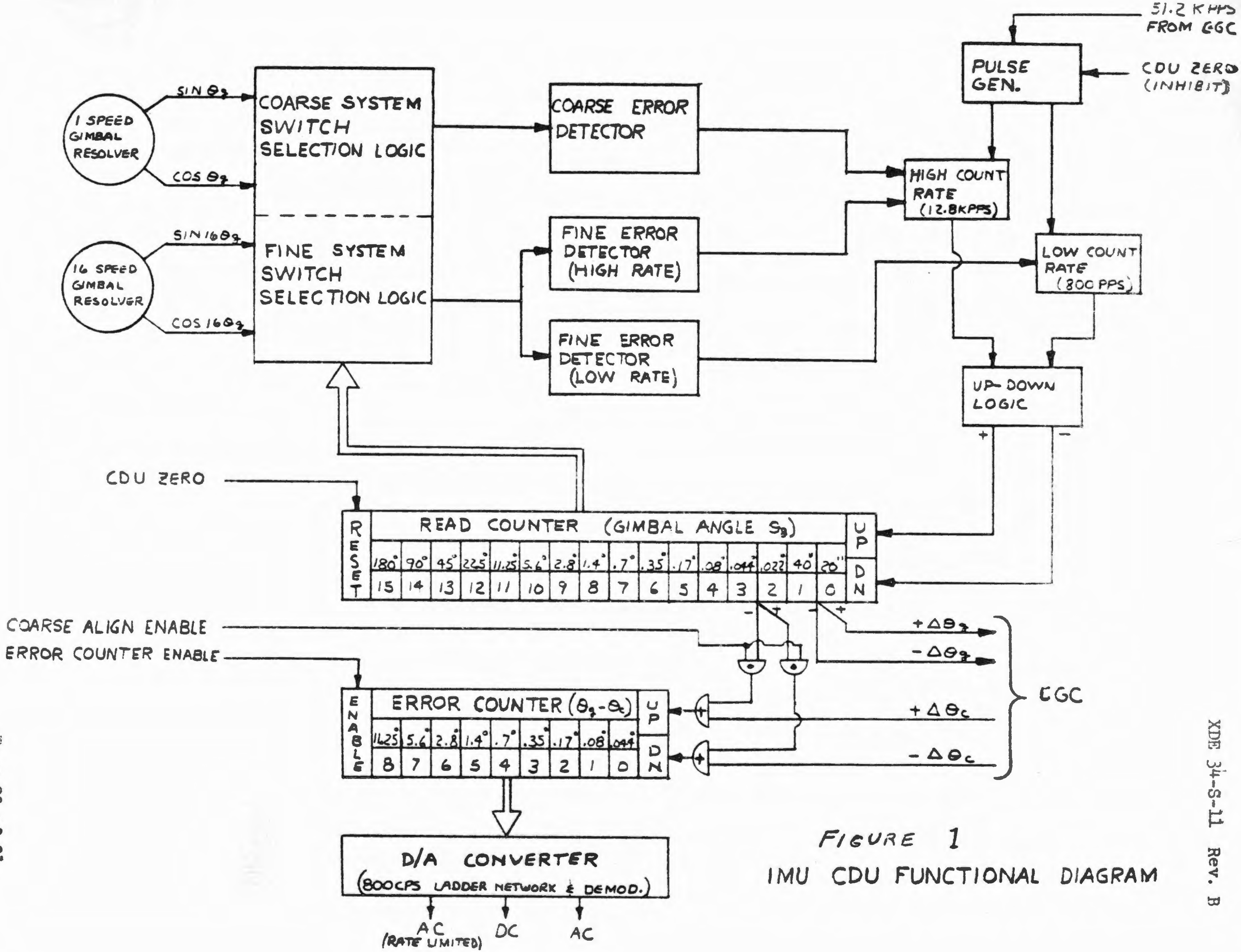

FIGURE 1
IMU CDU FUNCTIONAL DIAGRAM

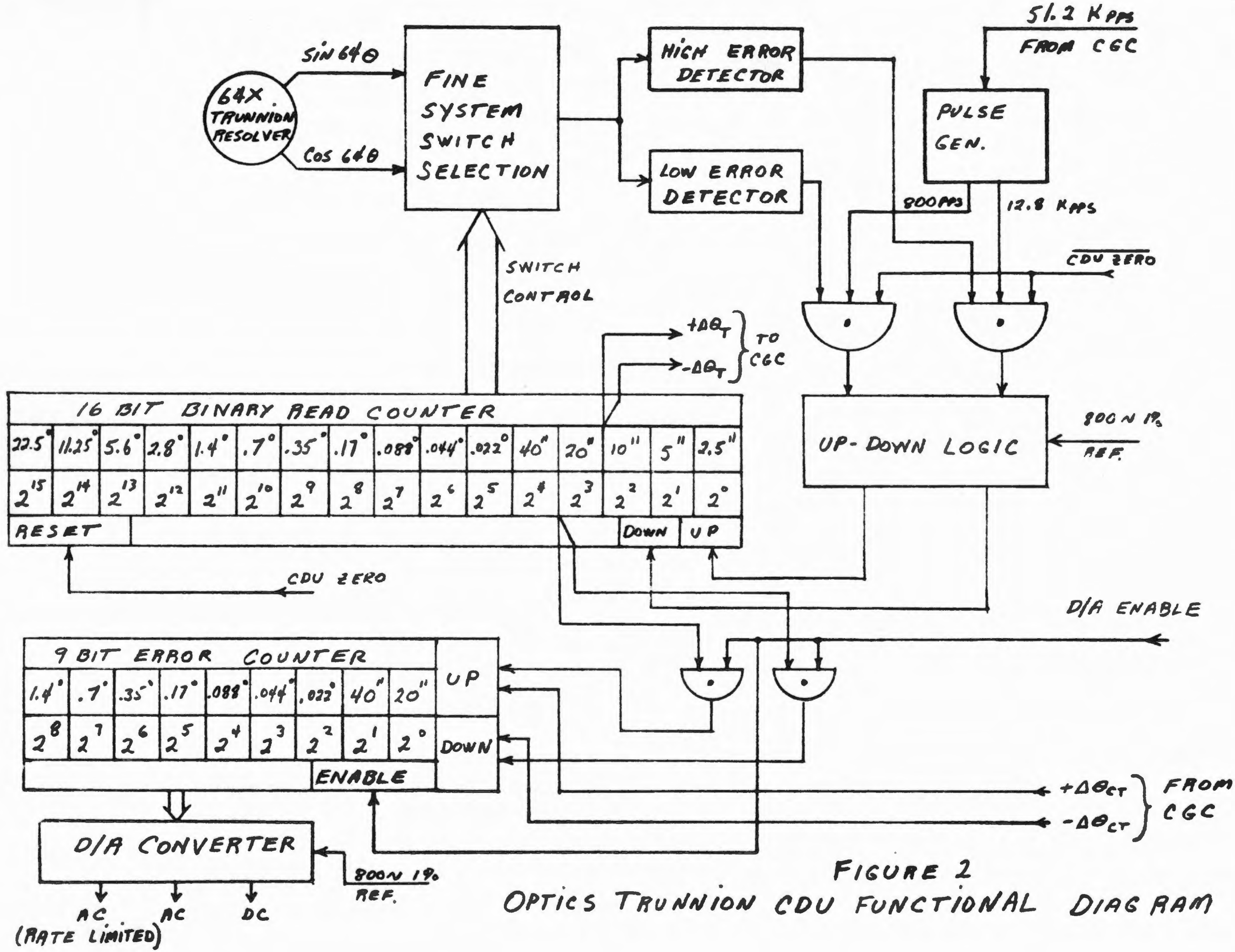

FIGURE 2
OPTICS TRUNNION CDU FUNCTIONAL DIAGRAM

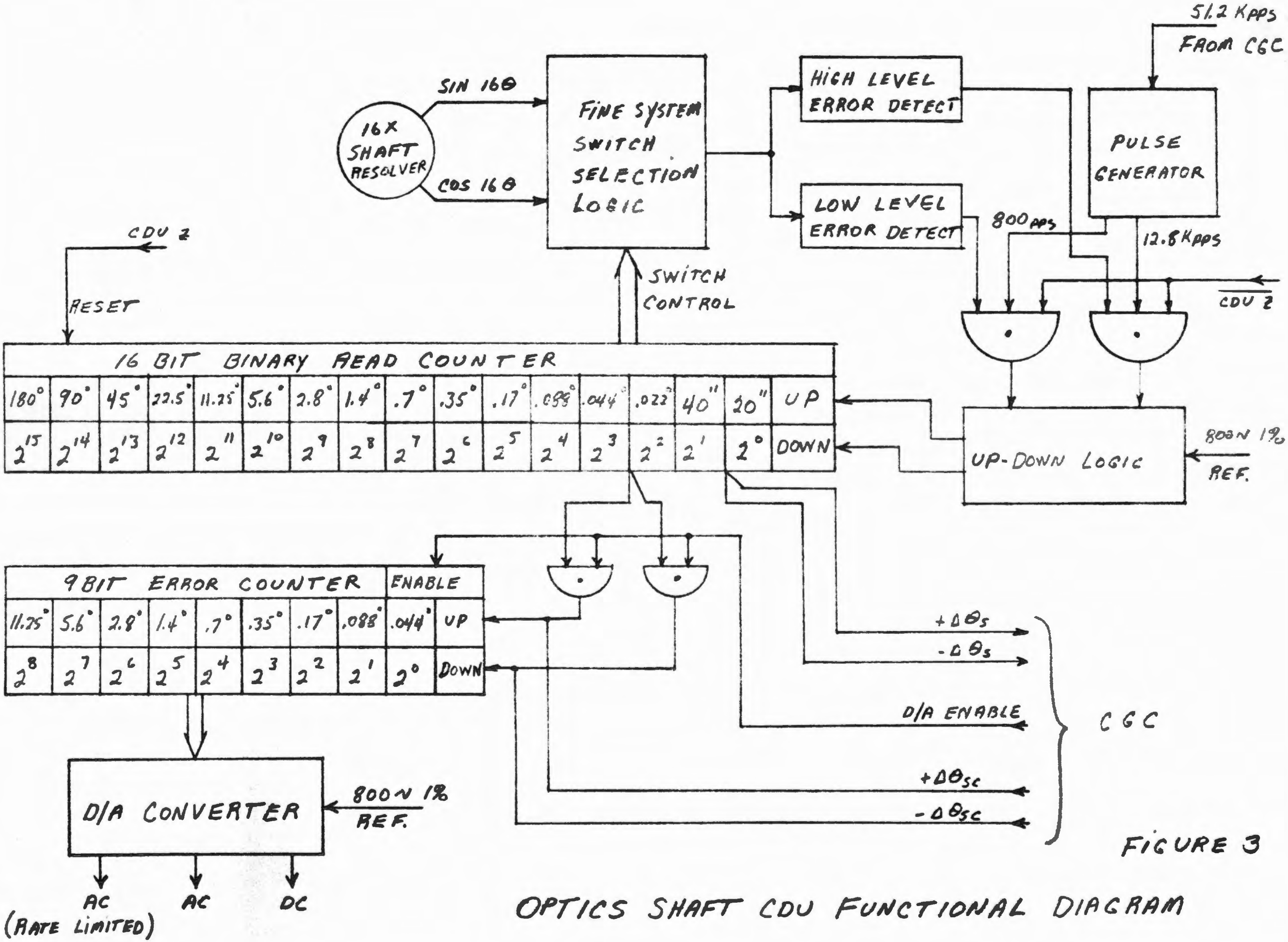

FIGURE 3

OPTICS SHAFT CDU FUNCTIONAL DIAGRAM

In the CDU zero mode the read counter is set to zero and allowed to count up to the gimbal angle. Before the read counter is enabled, 1X cos θ resolver winding is level detected and interrogated with an out-of-phase signal to determine if the gimbal is in the vicinity of 225° (123 to 235°). If it is, an ambiguity override signal, A_O, is generated and sent to the Error Counter and Logic Module at the completion of CDU Zero. This forces the CDU to count down at 12.8K pps until the CDU reaches 225° at which time the ambiguity override signal is removed. The normal CDU operation will follow since the CDU is out of the ambiguity region.

At initial turn-on, it is desired to clear the read counter and set the gimbals to zero. CDU zero and coarse align are commanded simultaneously. With the CDU read counter cleared, the gimbal ambiguity is at 225°. Just as in CDU zero, the 1X cos resolver output is checked to determine if the gimbal is between 125 and 235°. If it is, a turn-on enable signal Q is generated and sent to the Read Counter Module to turn on the 90° bit. This causes an error signal from the summing amplifier in the Coarse Module and Main Summing Amplifier Module (coarse and fine system errors) to be applied to the mixing amplifier in the D/A converter where they are inverted and used to drive the gimbal toward 90°. As soon as the gimbal is out of the ambiguity zone, the cos θ signal is insufficient to fire the ambiguity schmitt. As a result, the turn-on enable signal (Q) is removed. The gimbal will continue to be driven until is is in correspondence with the CDU at 0°.

Note that no optics CDU ambiguity circuitry is required since the optics is physically zeroed before the CDU zero discrete is sent from the CGC. Also, the RR CDU's don't use the turn-on ambiguity logic since the radar gimbals are zeroed through the computer via the CDU D/A's.

6.3 CDU DISCRETES

6.3.1 CDU ZERO (CDU Z)

(a) ISS CDU ZERO. Clears and inhibits the three IMU CDU read counters.

(b) OPTICS/RR CDU ZERO. Clears and inhibits the two optics CDU's (CSM) or the two Rendezvous Radar CDU's (LEM).

6.3.2 ENABLE ERROR COUNTER (EEC)

Enables the three IMU CDU error angle counters. The error counters are normally inhibited and zeroed.

6.3.3 COARSE ALIGN ENABLE (CA)

Energizes the C/A relay in the PSA which connects the coarse align error signal to the gimbal servo amplifier. Also the A/D-D/A digital feedback circuitry and the logic for inhibiting the read counter in the three IMU CDU's are enabled. Inhibit read counter = $CDUZ + CA \cdot \overline{EEC}$.

6.3.4 D/A ENABLE

Enables the error angle counters and the A/D-D/A digital feedback circuitry in the two optics CDU's (CSM).

6.3.5 TVC ENABLE

Provides a low to the TVC relay and disables the A/D-D/A digital feedback circuitry in the two optics CDU's (CSM).

6.3.6 SIVB TAKEOVER ENABLE

This mode is used in the CSM only and energizes the control relays which connect the CSM IMU D/A DC outputs to the Saturn guidance.

6.3.7 DISPLAY INERTIAL DATA

This mode energizes relays which connect the RR D/A DC outputs to the LEM display meter circuitry.

6.4 CDU - ISS MODES

The following ISS-CDU modes are available. These are controlled by discrete signals from the CGC or LGC.

NOTE: If no CDU modes are commanded, the A/D portion of the CDU will be operational. The error counter will be cleared and inhibited and the A/D-D/A digital feedback circuitry will be disabled.

6.4.1 ISS CDU ZERO

Clears and inhibits the three IMU CDU read counters.

6.4.2 ISS COARSE ALIGN

Coarse align consists of CA and EEC discretes. The CA discrete is enabled 40 milliseconds before EEC.

NOTE: For ISS testing purposes only, a CDU inhibit is available. This consists of the CA discrete which inhibits transmitting pulses to the read counters without zeroing them.

6.4.3 ISS TURN-ON

Enables CDU Z and the CA discretes and inhibits the other CDU modes for 90 seconds.

6.4.4 S/C CONTROL OF SATURN (CSM ONLY)

Enables SIVB Takeover and EEC.

6.5 CDU - OSS MODES

The following CDU-OSS modes are available. These are controlled by discrete signals from the CGC.

NOTE: If no CDU modes are commanded, the A/D portion of the CDU will be operational. The error counter will be cleared and inhibited and the A/D-D/A digital feedback circuitry will be disabled.

6.5.1 OPTICS CDU ZERO

Clears and inhibits the two optics read counters. The optics must be physically zeroed before the CGC can send this discrete.

6.5.2 D/A ENABLE

Enables the error counters and the A/D-D/A digital feedback circuitry in the two optics CDU's.

6.5.3 TVC

Enables the D/A enable and TVC enable discretes. The TVC enable discrete is enabled 40 milliseconds before D/A enable.

NOTE: For testing purposes only, a CDU inhibit is available. This consists of the TVC enable discrete followed by CDU zero. This inhibits transmission of pulses to the CDU's read counters without zeroing them.

6.6 CDU - RR MODES

The following RR CDU modes are available. These are controlled by discrete signals from the LGC.

NOTE: If no CDU modes are commanded, the A/D portion of the CDU will be operational. The error counter will be cleared and inhibited and the A/D-D/A digital feedback circuitry will be disabled.

6.6.1 RR CDU ZERO

Clears and inhibits the two CDU read counters.

6.6.2 D/A ENABLE

Enables the two RR CDU error counters.

6.6.3 DISPLAY INERTIAL DATA

Provides a low to the Display Inertial Data relays which connect the RR D/A DC outputs to the LEM display meter circuitry.

NOTE: For testing purposes only, a CDU inhibit is available. This consists of the Display Inertial Data discrete followed by CDU zero (CDUZ). This inhibits transmission of pulses to the CDU's read counter without zeroing them.

6.7 CDU ERRORS FOR 16X SYSTEM

Contributing Errors	Mean Value $\widehat{Sec}$	Max Value $\widehat{Sec}$	One Sigma $\widehat{Sec}$
(a) Digitization Error	-10	+30, -50	±23.3
(b) Dead Zone Uncertainty	0	±3	±1
(c) Scale Factor Uncertainty	0	±3	±1
(d) Linearization Error	+4.75	+14.4, -4.9	±5.6
Total Standard Deviation			±24

The digitization error is a combination of the Schmitt trigger dead-zone region (± 30 $\widehat{sec}$) and the 20 $\widehat{sec}$ quantization error. The dead-zone uncertainty is ±10% of the nominal value of the Scmitt trigger firing level. The scale factor uncertainty is due to the error amplifier gain variation of ±10%. The linearization error is the result of approximating a portion of a sine function with a straight line. This error can be obtained from the equation solved by the CDU.

$$\text{Error} = \sin(\theta - \Psi) - \phi \cos(\theta - \Psi) + K_2 \sin 11.25^\circ + K_3\ (\text{BIAS})$$

where:

ψ = 11.25°, 33.75°, 56.25°, 78.75°

ϕ is in steps of 19.8 $\widehat{\text{sec}}$ of one speed shaft.

K_2 and K_3 are either 1 or 0, depending on the value of θ. For example,

$0^\circ < \theta < 11.25^\circ \qquad K_2 = 1$ and $K_3 = 0$

$11.25^\circ < \theta < 22.5^\circ \qquad K_2 = 0$ and $K_3 = 1$

6.8 CDU ERRORS FOR 64X SYSTEM

Contributing Errors	Mean Value $\widehat{\text{Sec}}$	Max Value $\widehat{\text{Sec}}$	One Sigma $\widehat{\text{Sec}}$
(a) Digitization Error	-1.25	+3.75, -6.25	±2.91
(b) Dead Zone Uncertainty	0	±.375	±.125
(c) Scale Factor Uncertainty	0	±.375	±.125
(d) Linearization Error	+1.19	+3.6, -1.22	±1.4
Total Standard Deviation			±3.24

The error sources are the same for the 64X system as for the 16X system. Error sources (a) through (c) are reduced by a factor of eight due to the use of the 64X resolver and an additional switch in the fine system ladder network. This switch causes the quantization level to be reduced by one-half while the 64X resolver causes a reduction of one-fourth. The linearization error is not effected by the additional switch in the ladder network. As a result, this error is only reduced by a factor of 4.

6.9 DYNAMIC PERFORMANCE

The speed of the CDU in repeating a resolver angle is independent of system operation. The Read Counter will be incremented at a 12.8K pps rate provided the error between the resolver angle and the read counter angle Ψ is more than 20 bits. For an error less than 20 bits, the read counter will be incremented at a 800 pps rate. During the ISS coarse align mode, the ISS CDU's will be limited to count at 6.4K pps to prevent damage to the gyros.

M. Mastandrea
CDU Subsystem Group
APOLLO Engineering

J. Wachholz

J. J. Wachholz - Head
System's Instrumentation Group
APOLLO Engineering