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APOLLO

GUIDANCE AND NAVIGATION

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MASSACHUSETTS INSTITUTE OF TECHNOLOGY

E-1551

Functions and Mechanization
of the Apollo Guidance and
Navigation System

Volume One: Inertial Subsystem

by

N. Sene

7-119

R. Larson (ACSP) and A. Klumpp

August 1964

MIT

**INSTRUMENTATION
LABORATORY**

CAMBRIDGE 39, MASSACHUSETTS

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APOLLO

GUIDANCE AND NAVIGATION

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E-1551

FUNCTIONS AND MECHANIZATION OF THE
APOLLO GUIDANCE AND NAVIGATION SYSTEM
VOLUME ONE: INERTIAL SUBSYSTEM

FOREWORD

The purpose of this document is to provide definition of the Block I G&N System for engineering evaluation and also to provide information for the Systems Assembly and Test People. The level of detail will be that required for engineering evaluation down to the individual subsystem.

In order to gain the greatest utilization of this document, it will be issued in a series of sections which will be released as they are compiled. The first section contains a brief general description of the Apollo Guidance Equipment and a detailed description of the Inertial Subsystem. The second section will contain a description of the Optical Subsystem. The third section will contain a description of the Computer Subsystem as viewed from its interfaces.

Russell Larson
and
Allan Klumpp

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FUNCTIONS AND MECHANIZATION
OF THE APOLLO GUIDANCE AND NAVIGATION SYSTEM
VOLUME ONE: INERTIAL SUBSYSTEM

INTRODUCTION

1.0 GUIDANCE AND NAVIGATION SYSTEM FUNCTIONS

The guidance and navigation (G&N) system performs two basic functions during the APOLLO mission.

1. Guidance is control of rocket thrust during the powered phases of a mission and control of re-entry lift during re-entry.
2. Navigation is the determination of the position, velocity and trajectory of the spacecraft and the determination of the velocity changes necessary to reach target points.

1.1 GUIDANCE

Guidance is based primarily on inertial measurements from gyroscopes, accelerometers and clocks. On the basis of these measurement signals, the G&N system generates steering signals in order for the autopilot to accomplish the desired changes in trajectory.

1.2 NAVIGATION

The navigation of the APOLLO spacecraft is primarily based on optical line-of-sight measurements. In addition, communications from down-tracking can serve as a back-up and may be used during the mission as inputs to assist in navigation.

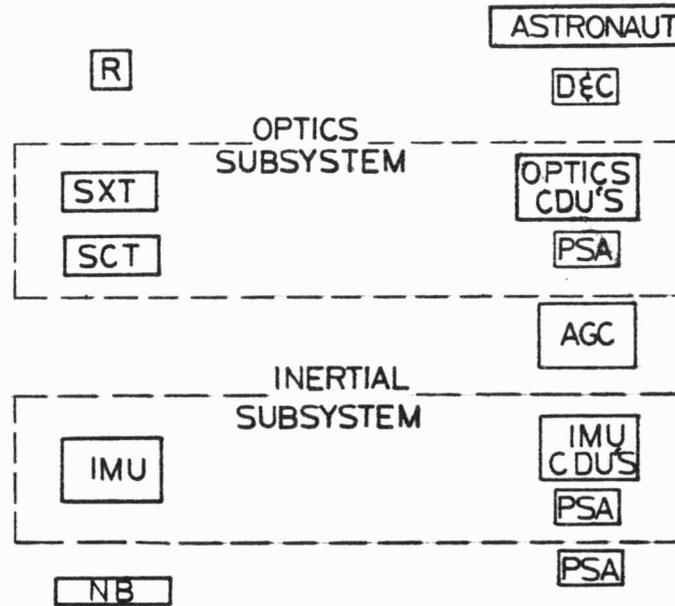
1.3 APOLLO GUIDANCE EQUIPMENT (AGE)

Figure 1.1 identifies the major functional groups or

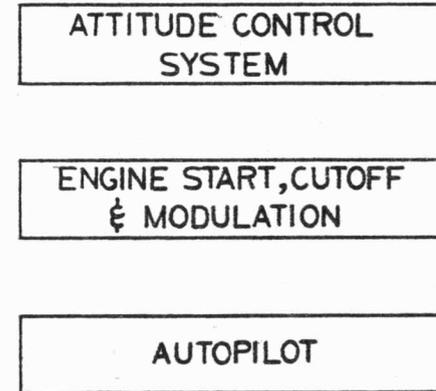
GUIDANCE AND NAVIGATION SYSTEM
(G & N)

SENSORS

CONTROL
&
DATA PROCESSING



SPACECRAFT
STABILIZATION CONTROL SYSTEM
(SCS)



R RADAR
SXT SEXTANT
SCT SCANNING TELESCOPE
IMU INERTIAL MEASUREMENT UNIT
NB NAVIGATION BASE

D & C DISPLAY & CONTROLS
CDU COUPLING DISPLAY UNIT
AGC APOLLO GUIDANCE COMPUTER
PSA POWER & SERVO ASSEMBLIES

Fig. 1.1 Apollo guidance equipment.

subsystems of the guidance and navigation system. The left-hand boxes in the figure represent the sensing devices of the system. Similarly, the center boxes represent the control and data-processing devices. The right-hand column lists the other spacecraft subsystems that are directly involved in the guidance and navigation functions.

1.3.1 G & N SENSORS

The sensors of the G&N system are the radar, scanning telescope, sextant, and inertial measurement unit. The latter three are mounted on the Navigation Base (NB) in the command module of the spacecraft so that angle measurements can be related to a common rigid structure representing the spacecraft.

1.3.1.1 RADAR

The radar equipment is located in the service module and the lunar excursion module. This equipment, which is used for close-in sensing during the rendezvous and lunar-landing phases, consists of a tracking radar and a doppler radar.

1.3.1.2 OPTICAL INSTRUMENTS

The Scanning Telescope (SCT) has a wide field of view for use by the astronaut in general finding, recognition, and short-range tracking. It is a single line-of-sight instrument having two degrees of freedom with respect to the spacecraft. The Sextant (SXT) is a precision, high-magnification, narrow field of view navigation instrument having two lines-of-sight. It is used for making navigation measurements, such as star-to-planet angles. In addition, during phases where the inertial measurement unit (IMU) has to be precisely aligned, the sextant is used for star sightings for IMU orientation reference.

1.3.1.3 INERTIAL COMPONENTS

The IMU consists of a stable member mounted to a three-degree-of-freedom gimbal system in which the outer gimbal axis

is along the re-entry roll axis of the command module. The two major IMU outputs are (1) the signals from gimbal-angle transducers that represent the attitude of the spacecraft relative to the stable member and (2) velocity increments from accelerometers mounted on the stable member. During control phases, the stable member holds a fixed inertial orientation through gyros and associated stabilization loops. During final alignment phases, the gyros can be torqued from the computer to precess the stable member.

1.3.2 CONTROL AND DATA PROCESSING

Control and data processing in the G&N system is performed by the astronaut using display and controls, the computer, the coupling display units, and the power servo assembly.

1.3.2.1 DISPLAY AND CONTROLS

The astronaut is represented explicitly since he is to be a major part of the guidance and navigation system. The interface between the astronaut and the rest of the guidance and navigation system occurs at the display and controls (D&C).

1.3.2.2 COMPUTER

The APOLLO guidance computer (AGC) is the primary data processing element in the guidance and navigation system. It is a special purpose digital computer having large wired-in memory and programs.

1.3.2.3 COUPLING DISPLAY UNITS

The coupling display units are electromechanical assemblies consisting of a motor-tach, gear trains, dials, an encoder wheel, switches, a thumbwheel, and resolvers. The IMU CDU's are used to transfer angular information between the IMU, the computer, the astronaut and the spacecraft autopilot. The optics CDU's are used to transfer angular commands from the astronaut through the D&C to the SXT and SCT and also to transfer indicated angles

from the optics into the AGC.

1.3.2.4 POWER SERVO ASSEMBLY

The power servo assembly (PSA) is a support item. It provides several types of DC and AC power to the rest of the G&N system and is the location of most of the other support electronics--in particular, the servo control amplifiers for the inertial and optical subsystems.

1.4 OTHER SPACECRAFT SYSTEMS

Three spacecraft subsystems outside the G&N system and contained in part of the spacecraft stabilization and control system (SCS) are directly involved in the guidance and navigation. (1) The attitude control system determines spacecraft orientation during nonaccelerated phases. It is used during optical sightings for navigation and IMU alignment. (2) Operation of the equipment for control of thrust magnitude--starting and stopping the rocket engines and modulating the thrust level--is initiated by signals from the G&N system. (3) The autopilot of the SCS receives the guidance steering error signals during accelerated phases to direct and control the thrust direction (or lift forces during re-entry) to achieve the desired trajectory.

2.0 INERTIAL SUBSYSTEM (ISS)

The inertial subsystem is a functional group of components of the G&N system. Included in this group are (1) the inertial measurement unit (2) three coupling display units (3) part of the power servo assembly and (4) displays and controls consisting of the IMU control panel assembly, part of the G&N control panel assembly and part of the D&C electronics assembly.

During thrusting phases the inertial subsystem provides attitude references, processes steering commands from the computer to the autopilot, and provides the velocity increment signals which are counted by the computer and used for thrust termination. During non-thrusting phases the inertial subsystem is used to hold or control changes in spacecraft attitude at the direction of the navigator or the computer. Use of the inertial subsystem during non-thrusting phases is optional within the limitations of available electrical energy.

A functional block diagram of one axis of the ISS is shown in Fig. 2.1. The three loops shown are the basic loops of the ISS. The accelerometer loop generates velocity increments with respect to an orthogonal triad. The accelerometers are mounted on the stable member. The stabilization loops maintain the stable member rigid with respect to an inertial frame through the torque motors on the gimbals. The CDU loop transfers the gimbal angle to the AGC and the astronaut. This is done in a "CDU-follow-IMU" configuration. For initial IMU alignment, the CDU loop commands the IMU gimbal to follow the CDU. This is done in an "IMU-follow-CDU configuration." For attitude control the CDU signals are transmitted to the stabilization and control system (SCS). This is done as a "spacecraft-follow-CDU" configuration.

Conceptually, the inertial subsystem consists of two parallel paths as shown in Fig. 2.2. The first path is from computer or manual inputs to reference angles which are produced

on the coupling display unit resolvers. The second path is from computer inputs to IMU gimbal angles, which are also applied to resolvers. The error signals generated by the differences between the reference angles of the CDU resolvers and the gimbal angles of the IMU resolvers may be switched either to the stabilization and control system, or to the stable member torquing system (IMU-follow-CDU configuration), and/or to the CDU motor drive amplifier (CDU-follow-IMU configuration).

2.1 INERTIAL SUBSYSTEM COMPONENTS

1. Inertial Measurement Unit

The inertial measurement unit is the primary inertial sensing device. It consists of a three-degree-of-freedom gimbal system containing three accelerometers and three gyroscopes. The inertial components are mounted on the stabilized member, which may be held non-rotating with respect to inertial space by use of error signals from the three gyroscopes.

The inertial measurement unit produces angular outputs and translational acceleration outputs. The angular outputs are produced by three sets of resolvers mounted across the three gimbal angles respectively. The resolvers of the inertial measurement and the coupling display units will be described jointly later. The translational acceleration outputs are produced by three orthogonal pulsed integrating pendulums mounted on the stable member.

2. Coupling Display Units and Motor Drive Amplifiers

There are three coupling display units. Each unit contains reference resolvers, angular display dials, a digital encoder, motor-generator and thumbwheel drive systems, and a slew switch. There is one motor drive amplifier for each of the three coupling display units.

The motor drive amplifiers drive the resolvers from

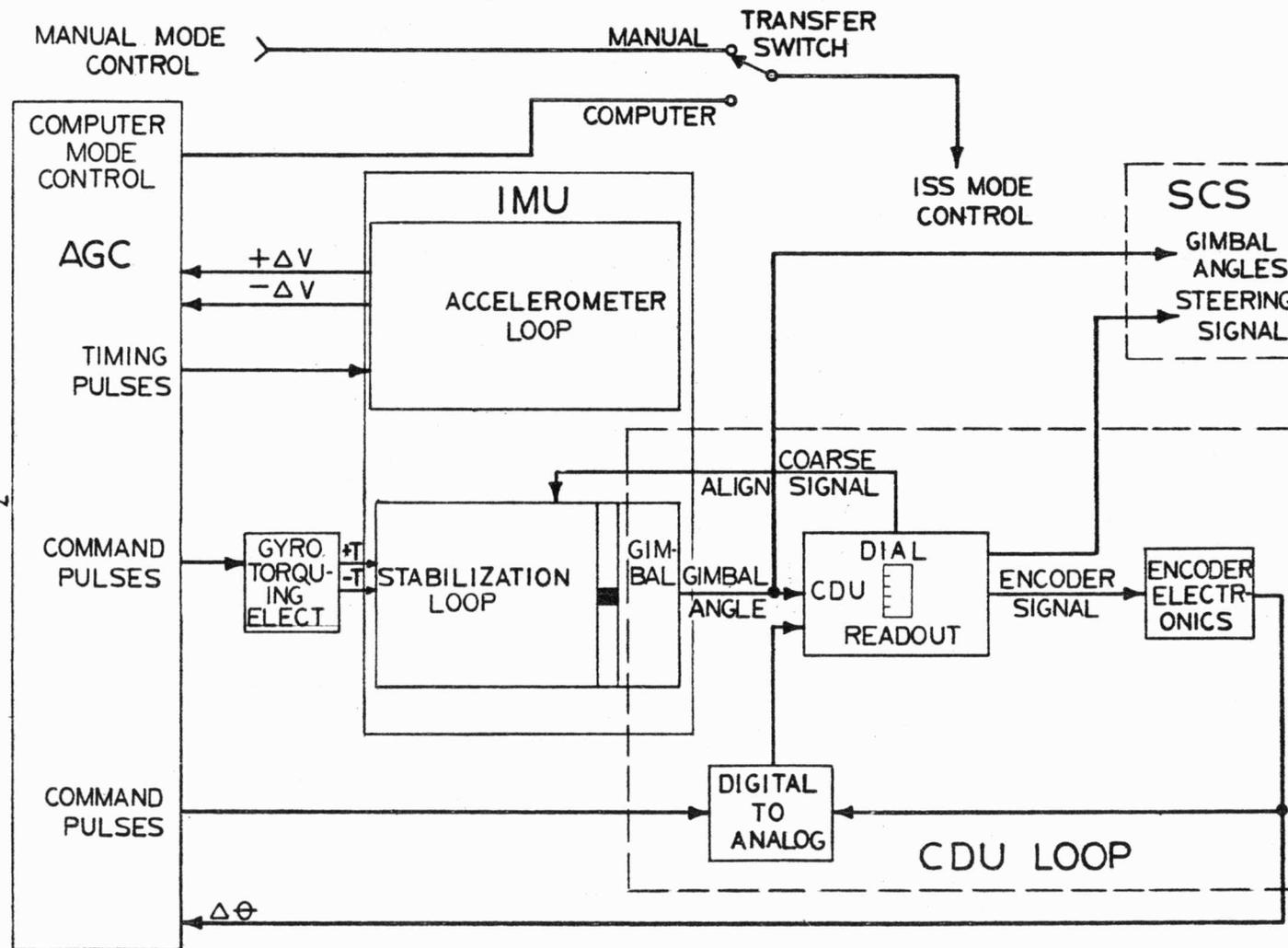


Fig. 2.1 ISS function block diagram.

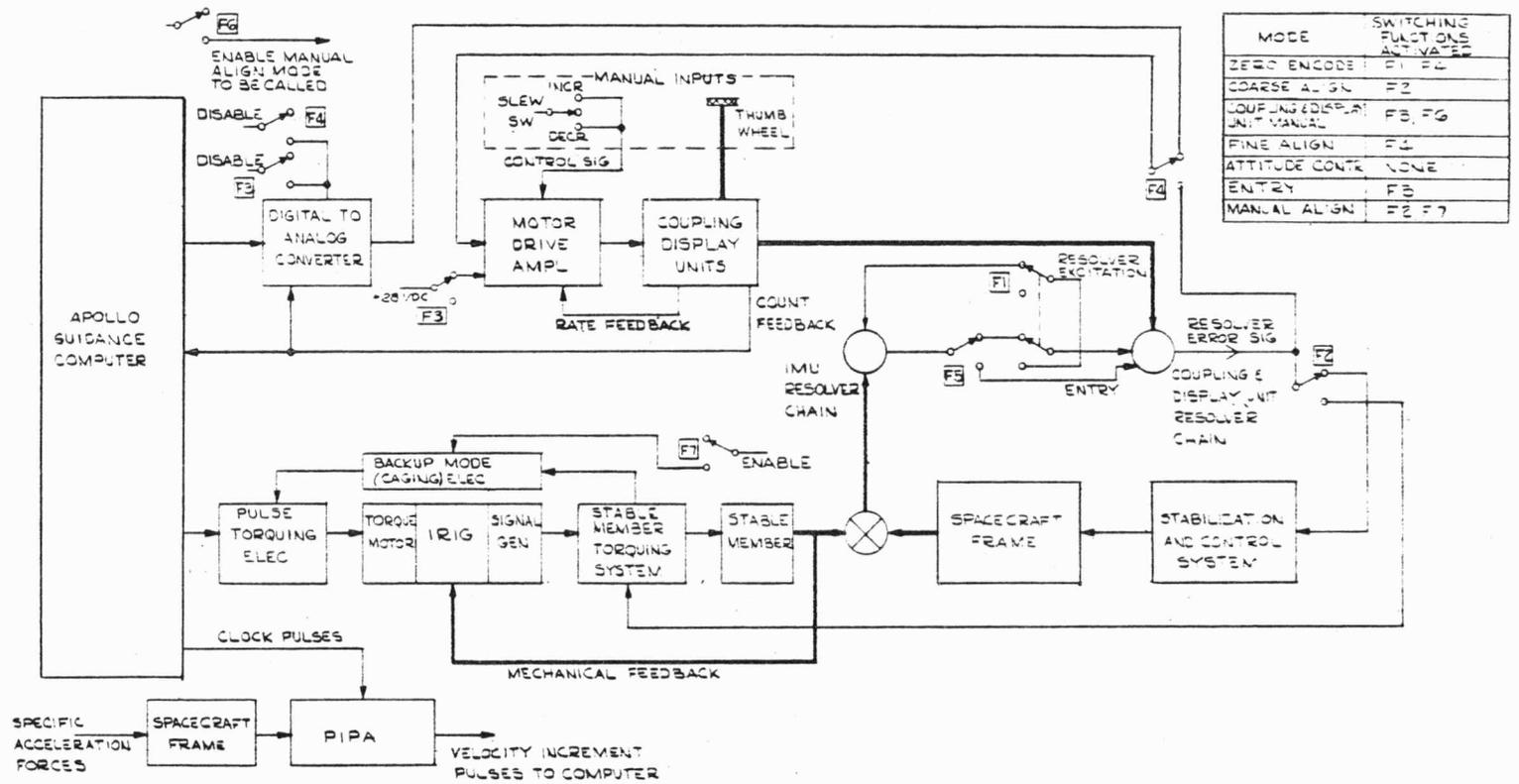


Fig. 2.2 Inertial subsystem configuration.

computer commands, resolver error signals, or slew switch commands. The slew switch and the thumbwheel allow the navigator to set the reference angles manually.

The angular display dials provide the navigator with a visual indication of (1) the reference angles being generated by the coupling display units and (2) the gimbal angles of the spacecraft with respect to the inertially stable member when the resolver error signals are nulled.

CDU resolver and IMU resolver functions will now be described.

3. Inertial Measurement and Coupling Display Units Resolvers

The resolver system is depicted in Fig. 2.3. For each axis of the inertial measurement unit there is a one speed (1X) and a 16 speed (16X) resolver transmitter used for generating angular error signals. In addition there is a "Gyro Error" resolver on the inner gimbal axis, and a "Pitch Yaw" resolver on the outer gimbal axis of the inertial measurement unit, and a fixed resolver in the PSA.

The two IMU resolver transmitters per axis operate in conjunction with two CDU resolver receivers. The one speed resolver and the sixteen speed resolver for a given axis of the inertial measurement unit are both connected directly across the gimbal angle, so that the physical angle imparted to the two resolvers is identical to the gimbal angle. But the sixteen speed resolver is wound to act as if it were geared to turn faster by a factor of sixteen. The angle imparted to the one speed resolver in the coupling display unit for a given axis is by definition the reference angle for that axis, and the sixteen speed resolver is physically geared to turn faster by a factor of sixteen. Thus if for a given axis the one speed resolver transmitter in the inertial measurement unit is connected to the one speed resolver receiver

in the coupling display unit, the error signal generated by the combination will be proportional to the sine of the difference between the reference angle and the gimbal angle. Likewise, if the two sixteen speed resolvers are connected, the error signal will be proportional to the sine of sixteen times the difference between the reference angle and the gimbal angle.

In one mode (ENTRY) the one speed resolver in the inertial measurement unit (outer gimbal axis only) is connected to the sixteen speed resolver in the coupling display unit, and the other two resolvers for that axis are not used. This reduces by a factor of sixteen the speed at which the coupling display unit must be driven to produce a given spacecraft attitude response rate. For the entry mode the precision available from the sixteen speed resolver transmitter - receiver pair is not required.

The one-half speed and the sixteen-speed resolvers in the coupling display units (See Fig. 2, 3) are used together in the ZERO ENCODE mode. They produce error signals which cause the reference angles to servo to zero.

The gyro error resolver (See Fig. 2, 3) transforms the three error signals generated by the three gyros according to the inner gimbal angle before these signals are applied to the three channels of the stable member torquing system. This prevents the coupling between the middle and outer gimbal channels which would otherwise occur due to rotation of the spacecraft about the inner gimbal axis. There is also interchannel coupling and gain reduction in the stable member torquing loops due to rotation of the spacecraft about the middle gimbal axis. This coupling need not be compensated for. In spite of these uncompensated effects, the stable member torquing loops are designed to operate satisfactorily over the entire range of middle gimbal angles allowed in the APOLLO mission. Therefore no compensation for middle gimbal angle is planned either for Block I or for Block II for signals used in the stable member torquing loops.

The pitch yaw resolver shown in Fig. 2.3 transforms the error signals generated by the resolver chains of the three gimbal channels according to the outer gimbal angle before these signals are transmitted to the stabilization and control system. This prevents the intercoupling of attitude control channels which would otherwise result from rotation of the spacecraft about the outer gimbal axis. There is also interchannel coupling due to rotation of the spacecraft about the middle gimbal axis. Although no compensation for middle gimbal angle is planned for Block I, the mission requirements for Block II are sufficiently more demanding that compensation for middle gimbal angle is planned for signals transmitted to the stabilization and control system.

The fixed resolver shown in Fig. 2.3 compensates for the 33° offset angle of the navigation base with respect to spacecraft body coordinates. All guidance and navigation signals are originally generated in navigation base coordinates. The fixed resolver transforms from navigation base to spacecraft body coordinates.

4. Digital to Analog Converter

The digital to analog converter produces an analog command for the motor drive amplifier in response to command pulses from the computer and feedback pulses from the coupling display unit.

5. Pulse Torquing Electronics

Each of the three pulse torquing electronics units (Fig. 2.2) produces current pulses for the corresponding gyro torquer in response to command pulses from the computer. The magnitude of the current pulses is precise and is calibrated in conjunction with the particular gyro with which the torquing electronics unit operates. This is such that when the gyro gimbal is rebalanced through the stable member torquing loop, each computer command pulse will always produce a precisely determined angular increment of the stable member about the gyro input axis.

2.2 FUNCTIONAL DESCRIPTION OF THE INERTIAL SUBSYSTEM MODES

The inertial subsystem operates in six primary modes and one submode. A primary mode may be called into operation either by the navigator or by the computer depending upon which position the navigator has placed the "transfer switch" (described in a later section). Only one primary mode may be selected at any one time, and, for considerable periods during the non-thrusting phases of the mission, the inertial subsystem is turned to standby (no mode operative). The inertial subsystem modes are:

1. ZERO ENCODE
2. COARSE ALIGN
3. FINE ALIGN
4. ATTITUDE CONTROL
5. ENTRY
6. CDU MANUAL
- 6A. MANUAL ALIGN (submode of CDU MANUAL)

The inertial subsystem is arranged to operate in any one given mode by utilizing certain basic switching functions as building blocks (illustrated in Figs. 2.2, 2.3 and 2.4). The basic switching functions are:

F1: Remove excitation from the resolvers in the inertial measurement unit and apply it to the 1/2 and 16 speed resolvers in the coupling display units.

F2: Switch the resolver error signals from the stabilization and control system to the stable member torquing system.

F3: Remove the DC excitation from the coupling display unit amplifiers and disable the digital to analog converters.

F4: Switch the motor drive amplifier inputs from the digital to analog converters to the resolver error signals, and

disable the digital to analog converters.

F5: In the outer gimbal axis channel only, connect the one speed resolver in the inertial measurement unit with the 16 speed resolver in the coupling display unit.

F6: Enable the MANUAL ALIGN submode to be called into operation.

F7: Energize the gyro caging electronics.

F8: Have computer turn on the attitude control light.

Associated with each switching function are several relays in various locations throughout the inertial subsystem. When a given switching function is activated, the associated relays are energized through a function bus which is switched to ground in the IMU control panel.

Figure 2.4 shows the switching functions activated by each of the operational modes and, in turn, the relays energized by each of the switching functions. For example, in the ZERO ENCODE mode, functions F1 and F4 are activated. F1 in turn energizes relays K1 in the displays and controls electronics assembly; K1, K2, and K3 in the CDU zeroing transformer and relays module in tray 6; and K1 in the CDU zero and lock relay module in tray 5 of the PSA. F4 in turn energizes K4 in the D&C electronics assembly and K1 in the three motor drive amplifier modules in tray 6 of the PSA. F4 also inhibits the digital to analog converter.

2.2.1 ZERO ENCODE MODE

The purpose of this mode is to equate the values stored in the CDU registers in the computer with the physical CDU reference angles. This is accomplished by driving the CDU reference angles to zero and then setting the computer registers to zero. The computer keeps track of the reference angles thereafter by counting pulses from the digital encoders. With the ZERO ENCODE mode it is not necessary for the computer to count the

digital encoder pulses without interruption throughout the mission. The ZERO ENCODE mode allows that the computer may be shut off during operation of the coupling display units and the computer registers corrected later when necessary. In the ZERO ENCODE mode, functions F1 and F4 are activated.

Activating switching function F1 switches the inputs of the resolvers in the coupling display units from the platform resolver outputs to fixed signals. These fixed signals are applied only to the half-speed and the sixteen speed coupling display unit resolvers. The angle of the half-speed resolver is by definition half the reference angle, and a similar definition applies to the sixteen speed resolver. Thus the half-speed resolver produces a signal which is proportional to the sine of one half of the reference angle, and the sixteen speed resolver produces a signal proportional to the sine of sixteen times the reference angle. Both signals become zero when the reference angle is zero.

Activating F4 switches the input to the motor drive amplifiers from the outputs of the digital to analog converters to modified signals from the resolvers. These signals are thus used to drive the reference angle to zero. The signal from the sixteen speed resolver is modified by a limiter, and the signal from the one-half speed resolver is modified by a dead band at zero. These modified signals are summed by the motor drive amplifier mixing network. Thus the modified signal from the half-speed resolver is controlling for large reference angles and is able to swamp out sign reversals in the clipped signal from the sixteen speed resolver. For reference angles near zero, however, the signal from the sixteen speed resolver is controlling, and provides a very precise zeroing of the reference angle.

2.2.2 COARSE ALIGN MODE

Alignment of the stable member is done in two steps; coarse alignment and fine alignment. The stable member is

coarse aligned by setting the gimbals angles to computed values based on a known spacecraft orientation. It is imperative that spacecraft attitude variations be minimized during coarse alignment because they cannot be detected or compensated for. In the COARSE ALIGN mode, switching function F2 is activated.

The data required in computer memory for coarse alignment are the required stable member orientation and the spacecraft orientation. With this data the computer calculates the required gimbal angles. Normally the required stable member orientation is computed by the navigation program such that the x-axis of the stable member will be aligned with the thrust vector during a trajectory correction. The spacecraft orientation is normally computed from two star fixes which the navigator will take immediately prior to entering the COARSE ALIGN mode. Alternately, as a backup for inoperative optics, the navigator may manually enter the required gimbal angles directly into the computer through the keyboard. The gimbal angles would be computed on earth and transmitted by radio. The computation would be based on the spacecraft attitude resulting from alignment of the spacecraft with two predetermined celestial references.

Activating F2 removes the resolver error signals from the stabilization and control system and applies them to the stable member torquing system. This is the IMU-follow- CDU configuration. The computer drives the resolvers in the coupling display units to the required gimbal angles, and the stable member follows by being torqued according to the resolver error signals.

Unlike the function of the resolvers as used in the ZERO ENCODE mode, in the COARSE ALIGN mode only the error signals from the single speed resolvers are used. There is no error signal modification such as limiting or dead zone. This type of signal modification is unnecessary in the COARSE ALIGN mode because of the accuracy required.

The accuracy achieved by coarse alignment is determined primarily by the accuracy with which the orientation of the spacecraft is known. The CDU reference angles are set with more precision than that required by coarse alignment. The error allowed is roughly 200 microradians, equivalent to one count from the digital encoders. The stable member orientation error at the end of coarse align should not exceed a few degrees.

2.2.3 FINE ALIGN MODE

The purpose of the FINE ALIGN mode is to trim the orientation of the stable member by rotating it through small angles about the three stable member axes. The required angles are calculated and stored in computer memory from optical fixes. In the FINE ALIGN mode, switching function F4 is activated.

The optical fixes are two star fixes made with the sextant. The scanning telescope with its wide field of view is used to locate the correct star. The astronaut, using the optics controller in the display and controls, centers the star in the sextant field. The encoders on the optics CDU's will transfer the angles of the indicated star line relative to the navigation base into the computer. With switching function F4 activated, the CDU-follow-IMU configuration is established, and the computer is able to monitor the IMU gimbal angles by counting pulses from the CDU digital encoders.

When the astronaut presses the MARK button indicating that the star is centered in the SXT field, the computer records the current values of the IMU gimbal angles and the SXT angles. Using the indicated IMU gimbal angles, the AGC transforms the star line from navigation base coordinates into stable member coordinates. The astronaut next makes a sextant sighting on a second star. At the completion of this operation the computer contains the components of the two star lines on stable member axes.

The AGC compares the indicated star line components with the components which would exist if the stable member were correctly oriented. The differences are used to compute the angular rotation about each stable member axis which will carry the stable member into the correct orientation.

Stable member torquing is accomplished by gyro pulse torquing in response to computer commands. Each pulse produces a precisely calibrated rotation of the stable member about the input axis of the particular gyro being torqued. Therefore feedback from the digital encoders in the coupling display units is not required for precise torquing, and, unlike the coarse align mode, spacecraft attitude rates (within the limitations of the stable member torquing system) are immaterial.

With the CDU-follow-IMU configuration, the initial error signals will be zero when the attitude control mode is introduced later, and thus no attitude transient will result. Of course the resolver error signals are also fed to the stabilization and control system during the FINE ALIGN mode, but it is presumed that the stabilization and control system is in a mode which rejects these signals, and therefore the error signals would not be nulled during fine alignment by spacecraft attitude corrections.

2.2.4 ATTITUDE CONTROL MODE

This section is concerned with that attitude control mode which is directed by the Guidance and Navigation system. During non-thrusting phases of the mission, the attitude control mode may be introduced by the navigator or by the computer and used to hold or control changes in spacecraft attitude by computer command. During thrusting phases the attitude control mode is used to produce steering commands for the autopilot with respect to IMU established references. Also during thrusting the computer counts pulses from the accelerometer loops and, when the required count is reached, commands thrust termination. In the attitude

control mode, none of the seven switching functions is activated.

With no switching functions activated, the inertial subsystem is in a spacecraft-follow-CDU configuration. The stable member is held stationary by the gyro error signals. The CDU reference angles are established by computer command through the digital to analog converter with feedback to the computer from the digital encoder. Thus the reference angles may be precisely set.

During non-thrusting phases the resolver error signal is fed through switching amplifiers in the stabilization and control system. The precision of attitude control is therefore established by the dead zone in the switching amplifiers of the stabilization and control system. The computer does not use the resolver error signals or any other data to improve attitude precision.

During thrusting phases the computer receives signals from the accelerometers normal to the thrust direction and uses these signals to achieve precise steering.

2.2.5 ENTRY MODE

During the ENTRY mode the Guidance and Navigation system supplies roll attitude signals to the stabilization and control system. In order to supply the rapid roll rate commands which are required during entry, the inertial subsystem must be arranged in a different configuration than in the ATTITUDE CONTROL mode. Function F5 is activated during the ENTRY mode.

Activating F5 affects outer gimbal axis (roll) channel only. In this channel (see Fig. 2.3) the 16 speed resolver in the coupling display unit is connected to the one speed resolver in the inertial measurement unit. The SCS system uses only the error signals from the 16 speed CDU resolver. The signals from the other two resolvers in the outer gimbal axis channel are not used. This configuration allows the CDU to produce changes in the

angular reference at sixteen times the rate which would be possible in the attitude control mode.

During entry, the stabilization and control system uses the error signal $E \phi_s$ shown in Fig. 2.3. The subscript s indicates that the signal is in stability axis coordinates. The navigation base is aligned with the nominal stability axes and therefore error signals in stability coordinates do not pass through the fixed resolver.

The IMU is oriented so that the input of the X-accelerometer is also along the entry roll axis. The velocity changes indicated by the accelerometers are processed by the computer to generate a roll command to change the CDU roll reference angle. This will result in a roll attitude error being fed to the autopilot which then controls the roll attitude in order to null the error.

2.2.6 CDU MANUAL MODE AND MANUAL ALIGN SUB-MODE

The CDU MANUAL mode has three primary purposes. These are:

1. To electrically disable or lock the CDU shaft drive.
2. To provide a capability for the astronaut to manually position the CDU reference angles by a slew switch and a thumbwheel as a computer back-up.
3. To enable the navigator to call the MANUAL ALIGN submode into operation.

In addition to the primary purposes of the CDU MANUAL mode, it may also be used by the navigator to manually control the spacecraft attitude by manipulating the CDU thumbwheels. In the CDU MANUAL mode switching functions F3 and F6 are activated.

Activating F3 produces identically the same configuration of the inertial subsystem as in the ATTITUDE CONTROL mode except that the coupling display units cannot be driven by the computer, but may be driven only by the slew switch or the

thumbwheel. This is accomplished by removing the amplifier excitation to each CDU drive motor. The reference excitation is restored and an increase or decrease command is supplied the motor drive amplifier by the slew switch. The thumbwheel is used to refine the angle after slewing.

Using the CDU mode in preparation for manual alignment of the stable member, the navigator will set the CDU reference angles to the set of gimbals which will produce the required stable member orientation for a preassigned known orientation of the spacecraft.

The required gimbals are computed on earth and transmitted to the navigator by radio. The computation is based on the spacecraft attitude resulting from alignment of the spacecraft with two predetermined attitude references. During the setting of the CDU reference angles, the resolver error signals are transmitted to the stabilization and control system, but are not used. Instead the stabilization and control system is used to achieve the preassigned spacecraft orientation at which time the MANUAL ALIGN submode is introduced.

The MANUAL ALIGN submode cannot be introduced unless the inertial subsystem is in the CDU MANUAL mode, activating F6. The MANUAL ALIGN submode is introduced through a momentary contact pushbutton switch. When the switch is released, the inertial subsystem returns to the CDU MANUAL mode.

The MANUAL ALIGN submode is used to orient the stable member such that it both produces gimbals equal to the CDU reference angles and cages the gyros. In the MANUAL ALIGN submode, function F2 is activated.

Activating F2 introduces the IMU-follow-CDU configuration. The stable member is torqued to produce the required gimbals, and, with the spacecraft in the preassigned orientation, the stable member will be inertially oriented as computed on earth.

2.3 ISS MODE CONTROL

The ISS modes of operation are normally automatically controlled by the computer through its major programs. The modes are also controllable manually either through the computer keyboard together with an associated program or directly through the mode select switches on the IMU Control Panel. Selection between direct manual control and computer control is provided through the Transfer Switch on the IMU Control Panel.

An indication of the current mode of operation is provided by a lamp internal to the mode select switches on the IMU Control Panel. Whenever the mode is changed, the new mode lamp is illuminated and the light behind the previously selected mode will go out indicating that the mode has been changed. These mode lamps are functional for both computer and manual operation.

2.3.1 ISS MODE CONTROL MECHANIZATION (Fig. 2.5)

The ISS modes of operation are controlled by the operation of function relays in the D and C electronics and the Power Servo Assembly. These function relays perform three basic functions:

1. The functional switching required within the ISS to actuate the mode.
2. Control of the mode lamp illumination.
3. Control of the mode switching indication sent to the computer.

The first function is not performed in the Attitude Control Mode, since for this mode all function relays are in a normal state.

The function relays are controlled by energizing the

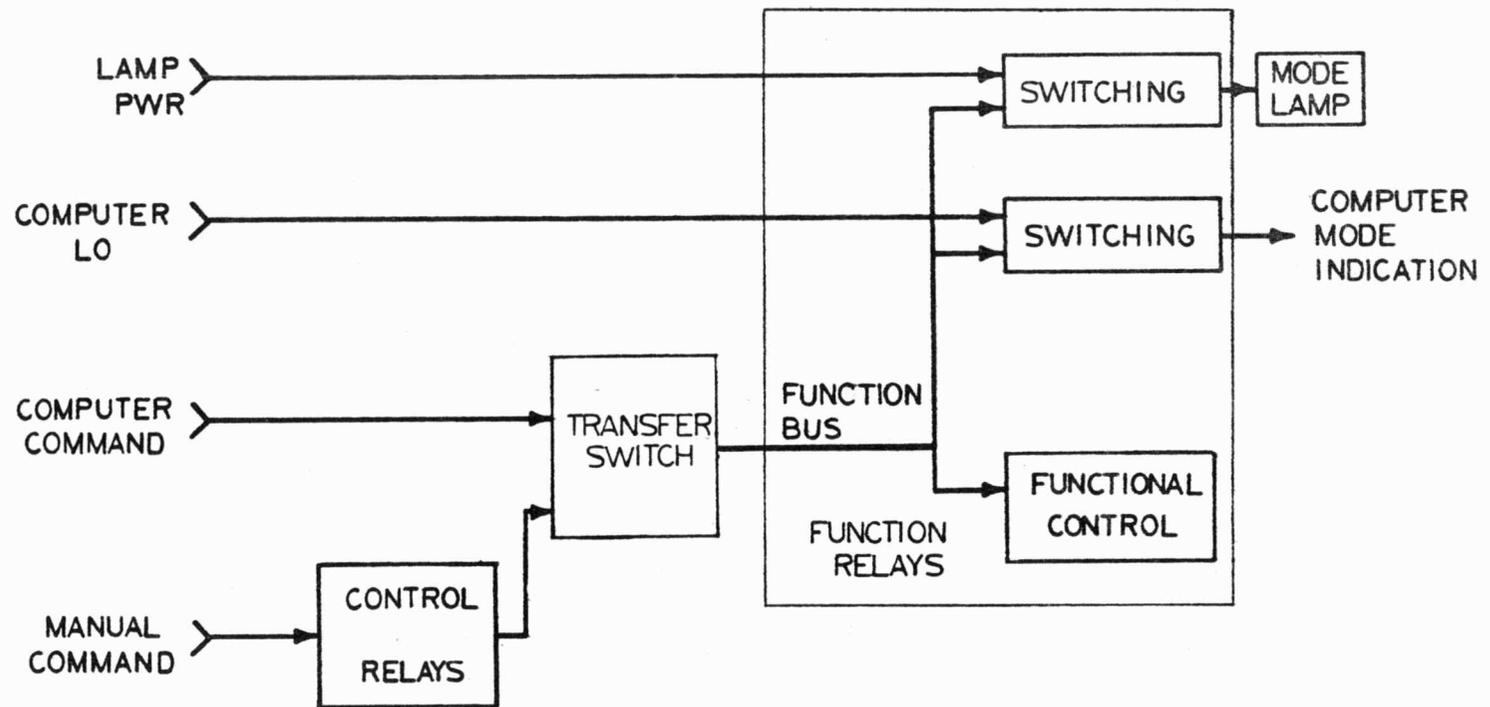


Fig. 2.5 ISS mode control mechanization.

respective function bus. The general scheme employed for relay control in the ISS is to apply +28 V DC to all coils upon system turn-on and then provide control through switching of the 0 V DC.

The mode busses are energized through the Transfer Switch. This two position toggle switch (S4) on the IMU Control Panel is used to control the source of moding control of the ISS. With the switch in the "COMPUTER" position, the moding is controlled through the AGC. In the "MANUAL" position the moding is controlled through the mode switches on the IMU Control Panel.

2.3.1.1 COMPUTER MODE CONTROL

With the Transfer Switch in the "COMPUTER" position, the computer will actuate a mode by applying 0 V DC through an energized "C" relay to the mode bus. A functional description of the "C" relay operation will be given in a future draft.

2.3.1.2 MANUAL MODE CONTROL

With the Transfer Switch in the "MANUAL" position, the mode switches on the IMU Control Panel will actuate a mode by energizing a control relay. This relay in turn will apply 0 V DC to the function bus. These mode switches are momentary contact, internally lighted push button switches. Whenever a mode switch is depressed (see Fig. 2.6), the appropriate control relay is energized. When the mode switch is released, the control relay is maintained in an energized state by a series holding circuit. By depressing a mode switch, the holding circuit for the previously selected mode is interrupted and thus the function is dropped out.

2.3.2 ISS TURN-ON

The ISS turn-on is controlled by the IMU STANDBY-OPERATE switch on the Circuit Breaker and Bus Switching Panel. This panel is located on the right hand side console of the Main Panel. With the switch in the "STANDBY" position, excitation

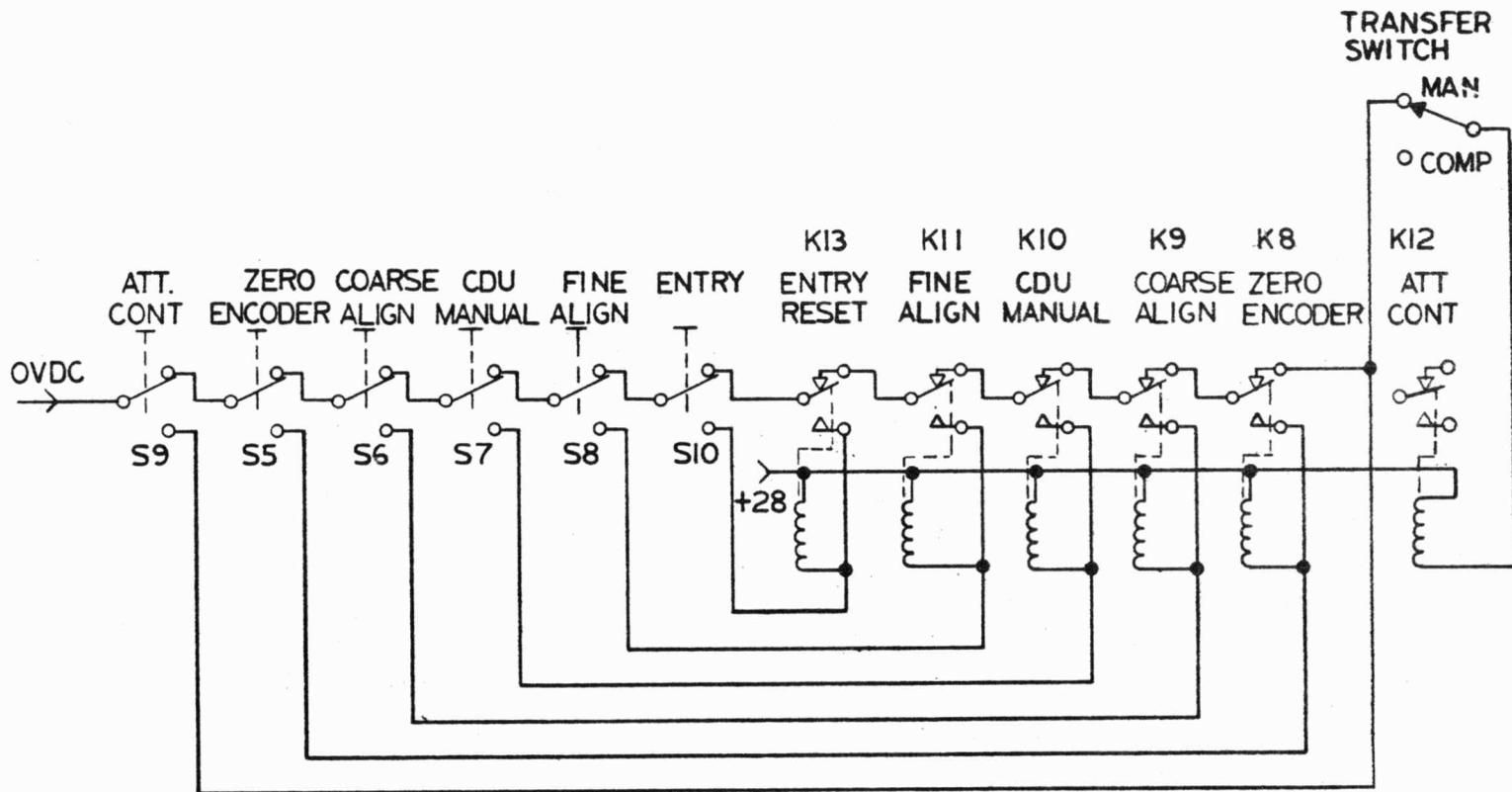


Fig. 2.6 Control relay energize and hold circuit.

is applied to the 3200 cycle temperature control and microsyn excitation power supplies. With the switch in the "OPERATE" position, excitation is applied to the rest of the ISS.

When the IMU STANDBY - OPERATE switch is placed in the "OPERATE" position, there is a time delay of 40 seconds which causes the system to remain in the COARSE ALIGN Mode. Thus the gimbals are slaved to the CDU angles while the gyros are coming up to speed. At the end of the time delay, the system will advance to the commanded mode. If no mode is commanded, the system will step into the Attitude Control mode provided the system had not been in Entry at turnoff.

During the turn-on time delay, the IMU DELAY lamp on the Map and Data Viewer and the COARSE ALIGN mode lamp on the IMU Control Panel will be illuminated. The following Conditions Lamps on the Map and Data Viewer may come on during the turn-on: 1) ERROR DETECTOR, 2) IMU FAIL, and 3) ACCEL FAIL.

2.4 DETAILED FUNCTIONAL DESCRIPTION

This section gives a detailed functional description of the moding and mode control circuits of the ISS.

2.4.1 ISS TURN-ON TIME DELAY (Fig. 2.7)

When the IMU STANDBY-OPERATE switch is placed in the "OPERATE" position, +28 V DC is applied to the operate bus of the ISS. This excitation is applied to the 40 second time delay circuit. The time delay circuit controls the operation of the STANDBY-OPERATE relay K6 by delaying the application of 0 V DC to the coil for this duration and thus keeping it de-energized. When K6 is de-energized, it applies 0 V DC to the Coarse Align bus through isolation diode CR1. This holds the system in Coarse Align for the 40 second time delay. De-energized K6 also applies 0 V DC to the coil of the Delay relay K7 energizing it. When K7 is energized, it applies excitation to the IMU Delay Lamp on the

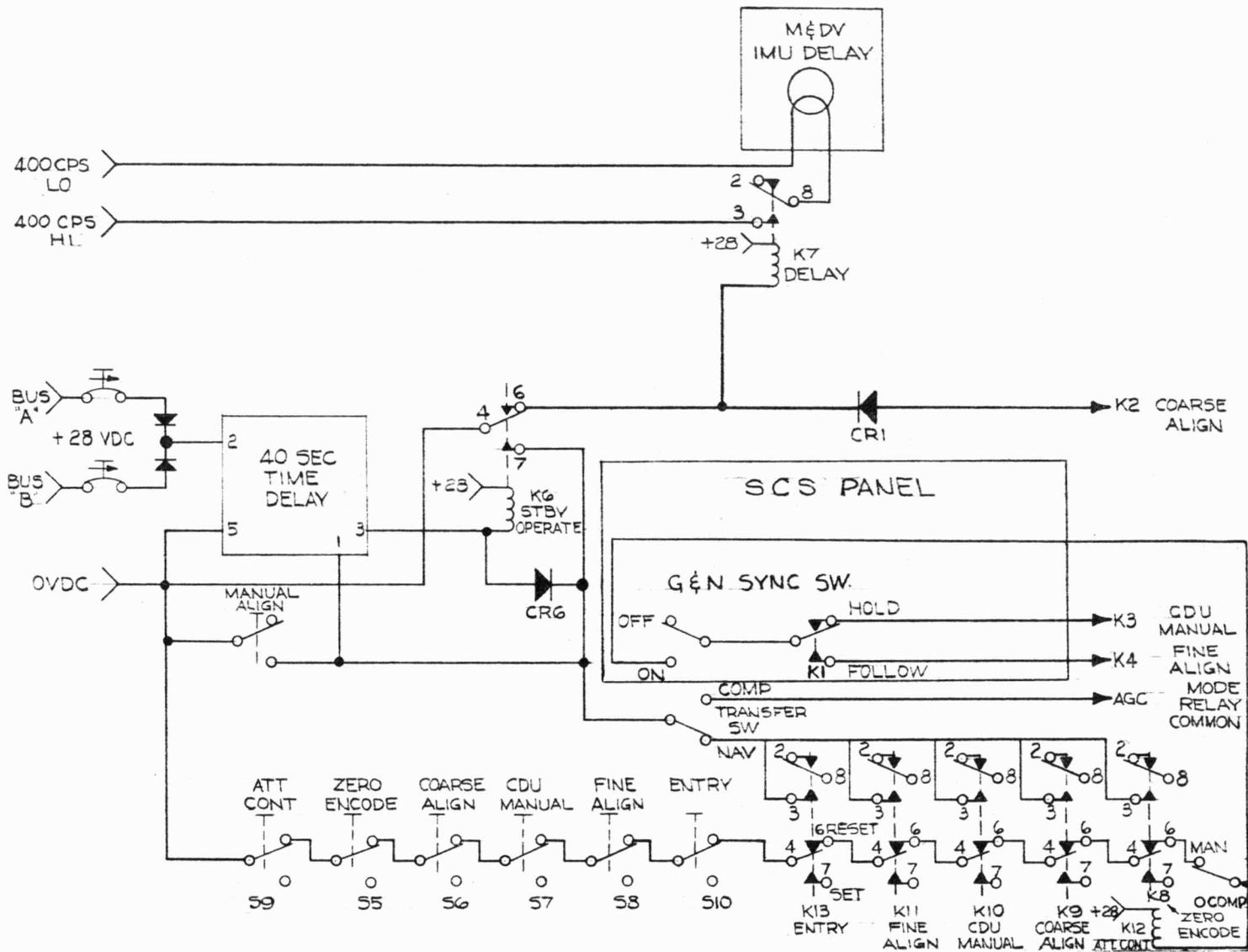


Fig. 2.7 "ISS turn on time delay".

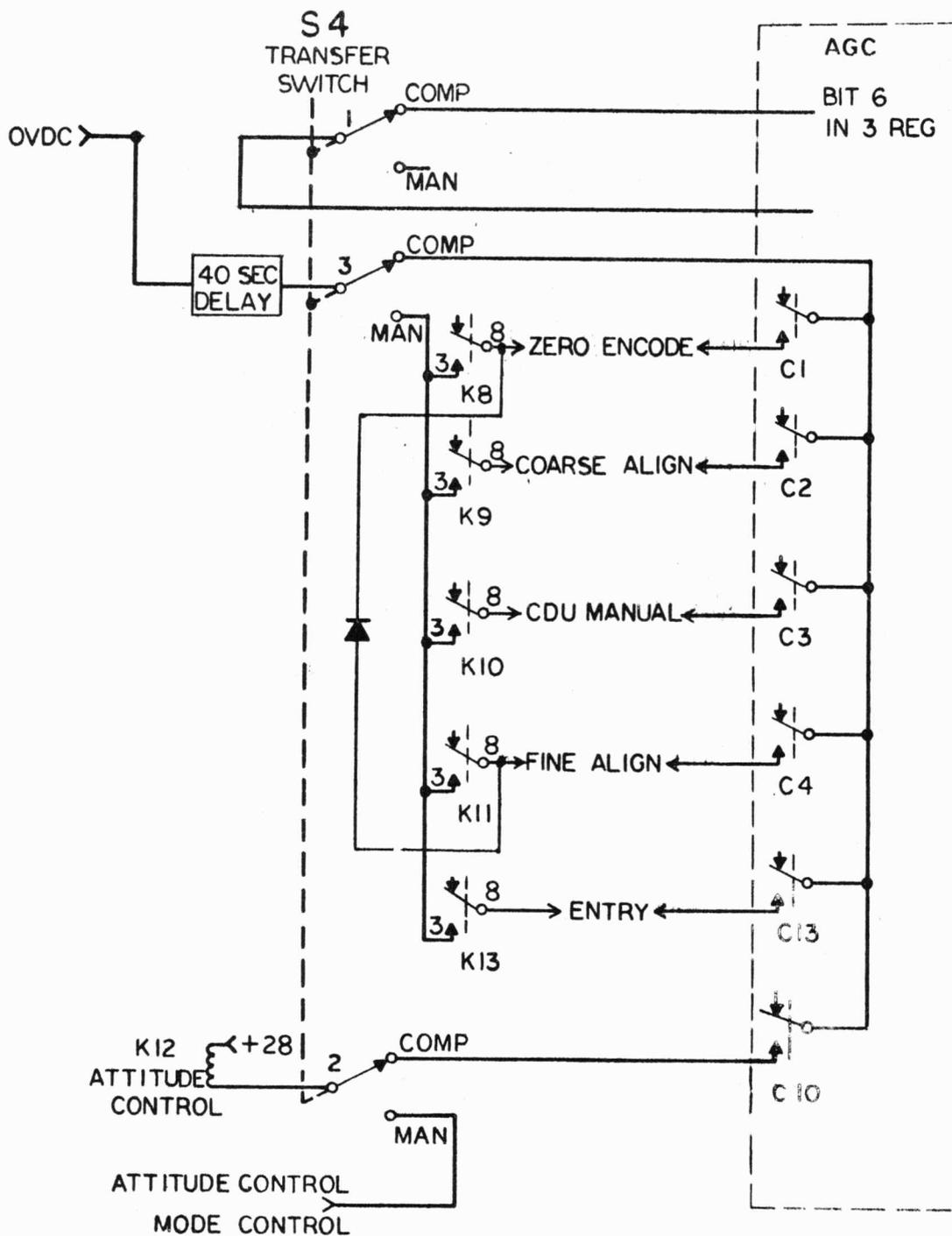


Fig. 2.8 ISS transfer switch function.

Map and Data Viewer Panel.

At the end of 40 seconds the time delay circuit will apply 0 V DC to the coil of K6; this energizes K6 and thus de-energizes the Coarse Align Mode and the Delay relay. When K6 is energized, it applies 0 V DC to the TRANSFER SWITCH in order to enable ISS mode selection. Energized K6 also applies 0 V DC to the G&N SYNC switch on the Main Panel. The ISS is now operable.

Relay K6 is maintained energized by applying 0 V DC through the holding circuit consisting of the energized contacts 4 to 7 of K6 and isolation diode CR6.

The 40 second time delay may be overridden or by-passed by momentarily depressing the Manual Align button on the IMU Control Panel. This applies 0 V DC to the coil of K6 through CR6.

2.4.2 TRANSFER SWITCH (Fig. 2.8)

This two-position switch has three sections. With the switch in the "COMPUTER" position, the three sections perform the following functions. Section "one" applies 0 V DC to the AGC (bit 6 of the IN3 Register) in order to provide the computer indication of switch position. After the 40 second time delay, 0 V DC is applied through section "three" to the wipers of the control ("C") relays in the AGC. Section "two" applies the computer Attitude Control command to the Attitude Control relay K12 when C10 of the AGC is energized.

With the switch in the "MANUAL" position, section "two" feeds 0 V DC after the time delay to the "K" relays permit Manual mode control. Section "three" applies the manual Attitude Control Command to K12.

2.4.3 ZERO ENCODER MODE MECHANIZATION (Fig. 2.9)

When the ZERO ENCODER relays are energized, fixed excitation is applied to the 1/2 X and 16 X CDU resolvers. This

excitation is the command signal for the CDU loop. The error signal generated by the rotors is applied through the energized Fine Align relay and select circuit to the Motor Drive Amplifier. The amplifier output is applied as the control signal for the CDU servo motor, MG1. The amplifier excitation is applied through the de-energized CDU Manual relay and the NC contacts of the Slew Switches. The output shaft of MG1 will drive a gear train which will position the Dials and the encoder wheel. It will also position the rotors of the resolvers to null and drive the armature of the rate generator.

The 1/2 X resolver is used for the coarse signal generation in order to preclude the false null which would be generated if the 1 X resolver were used. When the ZERO ENCODE relays are energized, the resolver excitation to the IMU resolvers is removed and thus the 1 X resolver output is zero.

An inhibit is applied to the DAC in order to disable its operation. As the loop drives to zero, the encoder is functioning and thus applying pulses to the DAC and AGC. The DAC output is disrupted by the energized Fine Align relay. If the DAC were not disabled, it would drive the CDU whenever the Fine Align relay is de-energized. The AGC registers are kept at zero for 30 sec.

2.4.4 ZERO ENCODE MODE CONTROL (Fig. 2.10)

When the ZERO ENCODE mode is activated, the F1 and F4 buses are energized. These buses are energized by either of the following two methods:

1. With the system in "COMPUTER" operation and provided the 40 second time delay has elapsed, a Zero Encode computer command will activate the F1 function by applying 0 V DC to the F1 bus through isolation diode CR28. A Fine Align computer command will activate the F4 bus by applying 0 V DC through isolation diode CR31.

2. By depressing the ZERO ENCODE mode button on the IMU Control Panel, the Zero Encode control relay K8 is energized. When 1) the system is in "MANUAL" operation, 2) the 40 second time delay has elapsed, and 3) K8 is energized, the F1 function is activated by applying 0 V DC to the F1 bus through the energized contacts 3 to 8 and the isolation diode CR26. When K8 is energized, the F4 function is also activated by applying 0 V DC to the F4 bus through the energized contacts 3 to 8 and isolation diode CR9.

When the ZERO ENCODE mode button on the IMU Control Panel is depressed, the Zero Encode control relay K8 is energized by applying 0 V DC to the coil through the series circuit consisting of the normally closed contacts of the Attitude Control switch and the A set of activated contacts of the Zero Encode mode switch. The reset coil of the Entry relay K13 is energized by applying 0 V DC through the B set of activated contacts of the Zero Encode mode switch. When the ZERO ENCODE mode button is released, K8 is maintained in an energized state by applying 0 V DC to the coil through the series holding circuit consisting of the normally closed contacts of the Attitude Control, Zero Encode, Coarse Align, CDU Manual, Fine Align, and Entry mode switches; the reset position contacts 4 to 6 of the Entry relay K13; the de-energized contacts of the Fine Align relay K11; CDU Manual relay K10 and Coarse Align relay K9; and the energized contacts 4 to 7 of the Zero Encode relay K8.

The following paragraphs describe the result of energizing the F1 bus.

Zero Encode relay K1 on the IMU Control Panel is energized. When K1 is energized, it applies excitation to the Zero Encode mode lamp and also interrupts the excitation for the Fine Align mode lamp.

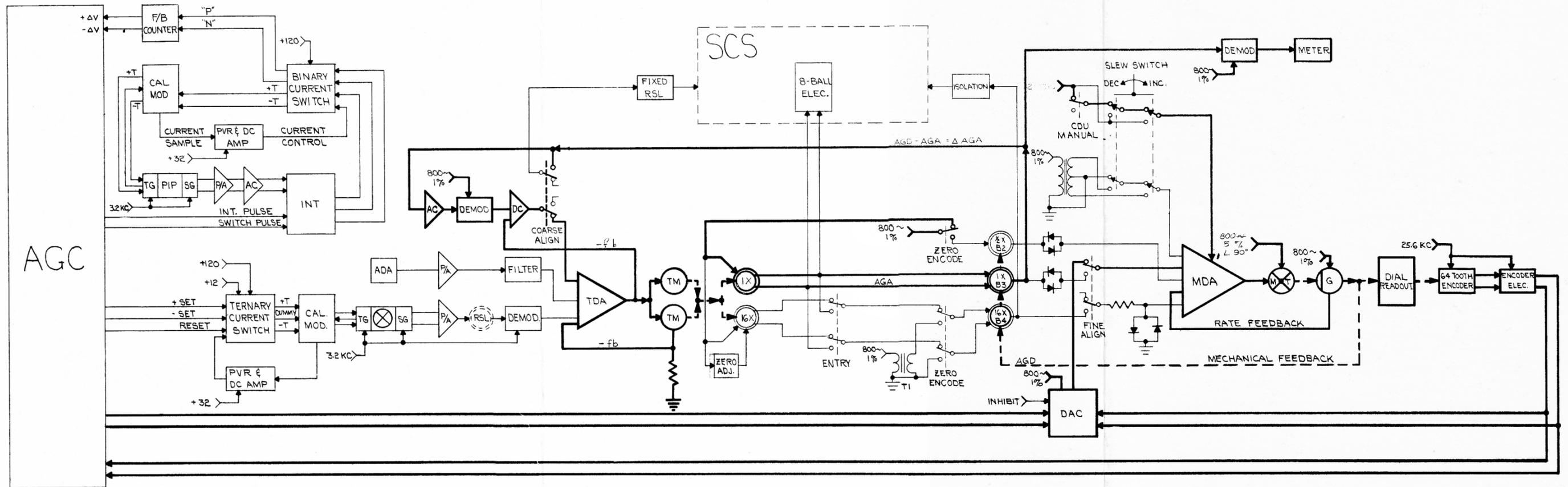


Fig. 2.11 Coarse align

Zero Encode relays K1, K2, and K3 in the CDU Zeroing Transformer and relay module in Tray 6 of the PSA are energized. When K1 is energized, it applies fixed excitation from the CDU Zeroing Transformer T1 to one stator winding of the 16 × OG CDU Resolver B4 and shorts the other stator winding. When K2 is energized, it applies fixed excitation from T1 to one stator winding of the 16 × MG CDU Resolver B4 and also one stator winding of the 16 × IG CDU Resolver B4. When K3 is energized, it removes the 28 v 800 ≈ Lo from the IMU resolver excitation and applies it to both the primary of T1 and to the stator windings of the 1/2 X resolvers B2 of the OG, MG, and IG CDU's. Energized K3 also applies the ZERO ENCODE mode switching indication to the AGC.

Zero Encode relay K1 in the CDU Zeroing and Lock Relay module in Tray 5 of the PSA is energized. When this K1 is energized, it shorts the other stator windings of the IG and MG CDU 16 × resolvers B4.

The result of energizing the F4 bus is described in section 2.4.8, Fine Align Mode Control. However, it should be noted that Fine Align relay K4 on the IMU Control Panel is energized. When K4 is energized it applies the Fine Align mode switching indication to the AGC and applies excitation to the "FINE ALIGN" mode lamp. The "FINE ALIGN" mode lamp is not illuminated because the excitation is interrupted by the energized Zero Encode control relay K1.

2.4.5 COARSE ALIGN MODE MECHANIZATION (Fig. 2.11)

The command signal for this servo loop originates in the rotors of the 1X resolvers on the axis of the IMU. Reference excitation is applied to the stator through a de-energized Zero Encode relay. The voltage induced in the rotor leads represents the actual gimbal angle AGA. These voltages are coupled to the stator leads of the CDU 1X resolver B3. The angular position of the rotors of B3 is determined by the desired gimbal angle AGC.

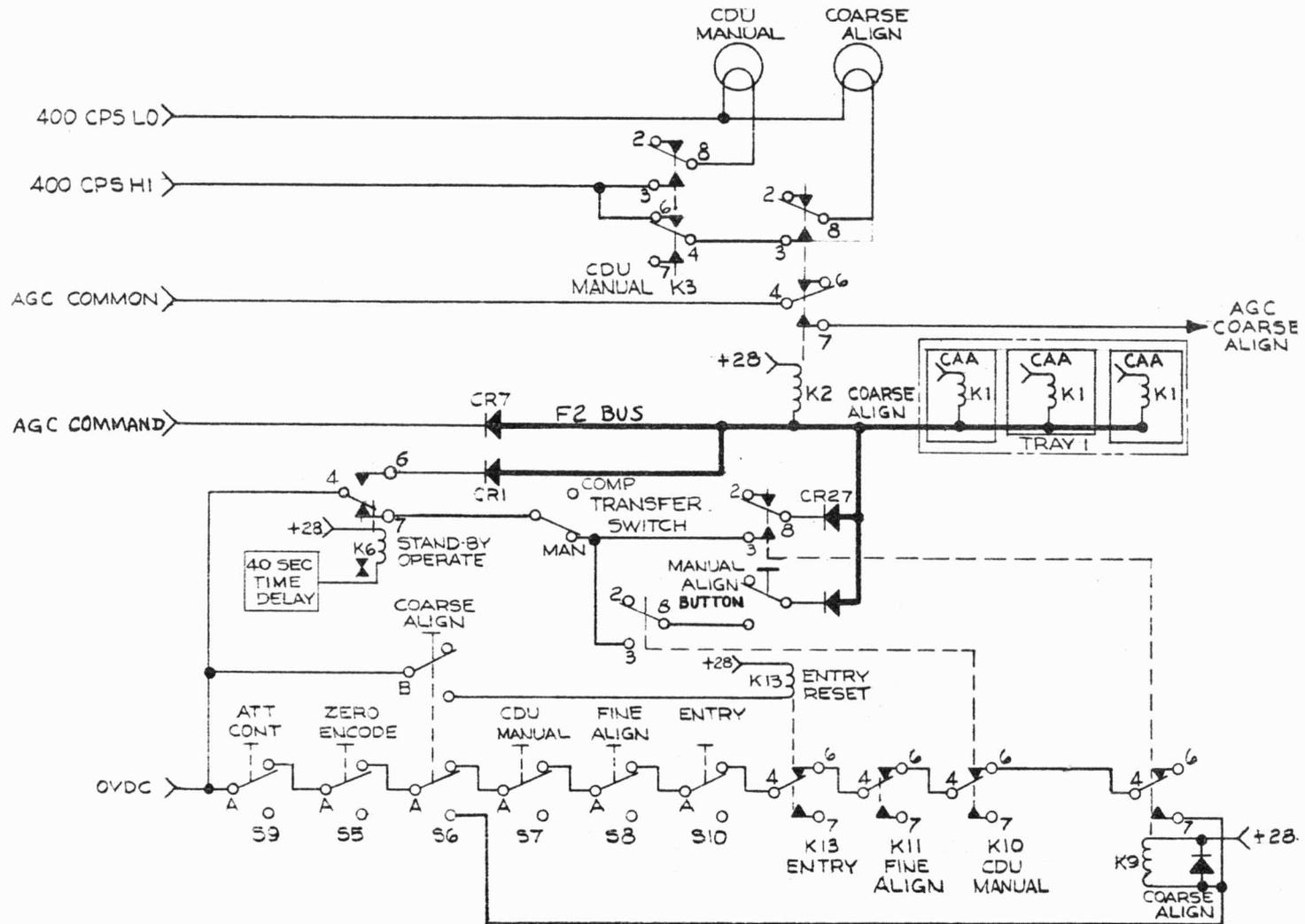


Fig. 2.12 "Coarse align mode control CKTS".

The voltages developed in the rotors of B3 represent the actual gimbal angle error signal Δ AGD. This error signal is applied to the Coarse Align Amp where it is amplified and demodulated. The output of the CAA is applied through the energized Coarse Align relay to the gimbal Torque Drive Amp. The output of the TDA is the control signal for the torque drive motors. The torque motor driving will position the gimbal and also the resolver until the value of Δ AGD is nulled and thus AGA will equal AGD.

The actual gimbal angle error Δ AGD is applied to the attitude error demodulator where it is demodulated to a DC signal. This signal is then applied to the IMU-CDU Difference Meter.

The CDU position is controlled by the computer through the DAC. The DAC output is applied through the de-energized Fine Align relay to the motor drive amplifier. The amplifier output is the control signal for the CDU motor MG1. Reference excitation is applied to MG1 through the de-energized CDU Manual relay and the NC contacts of the Slew Switches. MG1 driving will rotate the encoder wheel which will cause the encoder electronics to generate pulses of $\Delta \theta$ each. These pulses are applied to the DAC as the loop feedback signal to close the DAC loop. These pulses are also sent to the computer. MG1 driving will also position the 1 X resolver to the desired gimbal angle AGD.

2.4.6 COARSE ALIGN MODE CONTROL (Fig. 2.12)

The Coarse Align mode is activated whenever the Coarse Align mode bus is energized. This bus is energized by any one of the following four methods:

1. With the system in "COMPUTER" operation and provided the 40 second time delay has elapsed, a Coarse Align computer command will activate the mode by applying 0 V DC through isolation diode CR7

to the Coarse Align bus.

2. By depressing the Coarse Align mode button on the IMU Control Panel, the Coarse Align control relay K9 is energized. When 1) the system is "MANUAL" operation, 2) the 40 second time delay has elapsed, and 3) K9 is energized, the Coarse Align mode is activated by applying 0 V DC through the energized contacts 2 to 8 and the isolation diode CR27 to the Coarse Align bus.

When the Coarse Align mode button of the IMU Control Panel is depressed, the Coarse Align control relay K9 is energized by applying 0 V DC to the coil through the series circuit consisting of the normally closed contacts of the Attitude Control and Zero Encode mode switches, and the A set of activated contacts of the Coarse Align mode switch. The reset coil of the Entry relay K13 is energized by applying 0 V DC through the B set of activated contacts of the Coarse Align mode switch. When the Coarse Align mode button is released, K9 is maintained energized by applying 0 V DC to the coil through the series holding circuit consisting of the normally closed contacts of the Attitude Control, Zero Encode, Coarse Align, CDU Manual, Fine Align and Entry mode switches, the reset position contacts 4 to 6 of the Entry relay K13, the de-energizing contacts 4 to 6 of the Fine Align and CDU Manual relay, and the energized contacts 4 to 7 of the Coarse Align relay K9.

3. During the 40 second time delay, the Coarse Align bus is energized by applying 0 V DC through the de-energized contacts 4 to 6 of the Standby-Operate relay K6 and the isolation diode CR1 to the Coarse Align bus.

4. During Manual Align, the Coarse Align bus is energized by applying 0 V DC through the energized contacts 4 to 7 of the Standby-Operate relay K6, the Manual contacts of the Transfer Switch, the energized contacts 3 to 8 of the CDU Manual relay K10, the actuated contacts of the "MANUAL ALIGN" button and isolation diode CR1.

The following paragraphs discuss the result of energizing the Coarse Align bus.

Coarse Align relay K2 on the IMU Control Panel is energized. When K2 is energized, it applies excitation to the Coarse Align mode lamp. This lamp excitation comes through the de-energized contacts 4 to 6 of the CDU Manual relay K3. Energized K2 also applies the Coarse Align mode switching to the AGC.

Coarse Align relay K1 in the three Gimbal Coarse Align Amplifier modules in Tray 1 of the PSA is also energized. When K1 is energized, it applies the output of the CAA to the TDA and interrupts the SCS signals.

2.4.7 FINE ALIGN MODE MECHANIZATION (Fig. 2.13)

The command signal for the CDU loop originates in the rotors of the one speed and sixteen speed resolver transmitters on the axis of the IMU. Reference excitation is applied to the stator winding through a de-energized Zero Encode relay. The reference excitation is also applied to a zero adjustment potentiometer. The output of this potentiometer is applied to the other stator winding of the sixteen speed resolver for precision zeroing. The voltages induced in the rotor leads represent the actual gimbal angles A_{GA} . The one speed voltages are coupled to the stator leads of the CDU one speed resolver receiver B3. The sixteen speed voltages are coupled through the de-energized Entry and Zero Encode relays to the stator leads of the CDU sixteen

speed resolver receiver B4. (The Entry relay is only used in the Outer Gimbal CDU loop). Error signals ΔA_{GA} which represent the difference between the actual gimbal angle A_{GA} and the present CDU angle A_{CDU} are generated in the rotors of the CDU resolvers B3 and B4 and are applied to the two speed switching network through the energized Fine Align relay. The output of the switching network is amplified in the Motor Drive Amplifier MDA and applied as the control signal for the CDU servo motor, MGI. The reference voltage is applied through the de-energized CDU manual relay and the normally closed contacts of the slew switches. The output shaft of MGI will drive a gear train which will position the CDU Dials and encoder wheel. It will also position the rotors of the RR's to the null point and drive the armature of the rate generator to provide a negative feedback signal proportional to the motor shaft speed. When the error signal ΔA_{GA} is nulled, the CDU angular position A_{CDU} is equal to the gimbal angle ($A_{CDU} = A_{GA}$). As the encoder wheel is positioned, it, together with its associated electronics, will generate pulses representing direction and increments of angular change. These pulses are applied to the CDU registers in the AGC.

The command signals for IMU platform positioning originate in the AGC as gyro torquing + Set and - Set pulses. These pulses are applied to the Ternary Current Switch where they trigger on-current switches which apply a regulated current through the Calibration Module to the proper torquing coil of the Torque Generator TG of the IRIG. The current switch is turned off by a Reset pulse also generated by the computer.

The Precision Voltage Reference PVR and DC Amplifier together with the Calibration Module maintain the current through the torquing coils of the torque generator constant. The torquing of the gyro appears as a gimbal disturbance torque to the stabilization loop. This develops a gyro float angle θ_g , which

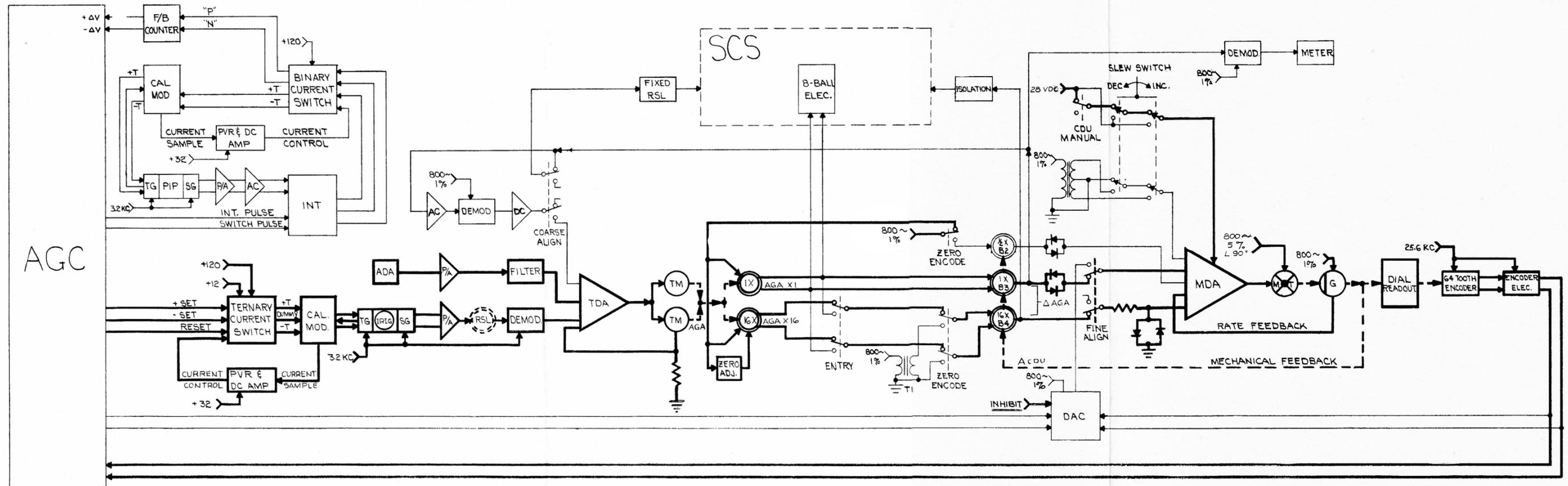


Fig. 2.13 Fine align

in turn develops a voltage output e_g of the ducosyn pickoff in proportion to the gyro float angle. The ducosyn output is amplified by the preamplifier and then demodulated to a DC signal. This signal is applied to the Torque Drive Amplifier TDA and transformed to the control signal for the gimbal Torque Motors TM. The TM output positions the gimbal. This angular rotation is sensed by the gyro through gyroscopic action which reduces the gyro float angle θ_g to zero and thus reduces the ducosyn output to zero to null the loop. The positioning of the gimbals also positions the rotors of the gimbal resolver transmitters which then transmit a new gimbal angle A_{GA} to the CDU. As the CDU drives to follow the gimbal angle change, the incremental encoder and its associated electronics will generate and transmit incremental angle pulses to the computer and DAC in response to the angular change. The DAC is disabled during the Fine Align mode in order to inhibit it from integrating the pulses and thus having an output that will be applied to the MDA when the system mode is changed such that the Fine Align relay is de-energized.

2.4.8 FINE ALIGN MODE CONTROL (Fig. 2.14)

Whenever the system is in the Fine Align mode, the F4 Function bus is energized. This bus is energized by any one of the following four methods:

1. With the system in "COMPUTER" operation and provided the 40 second time delay has elapsed, a Fine Align computer command will activate the F4 Function by applying 0 V DC to the F4 bus through isolation diode CR31.
2. By depressing the FINE ALIGN mode button on the IMU Control Panel, the Fine Align control relay K11 is energized. When 1) the system is in "MANUAL" operation, 2) the 40 second time delay has elapsed,

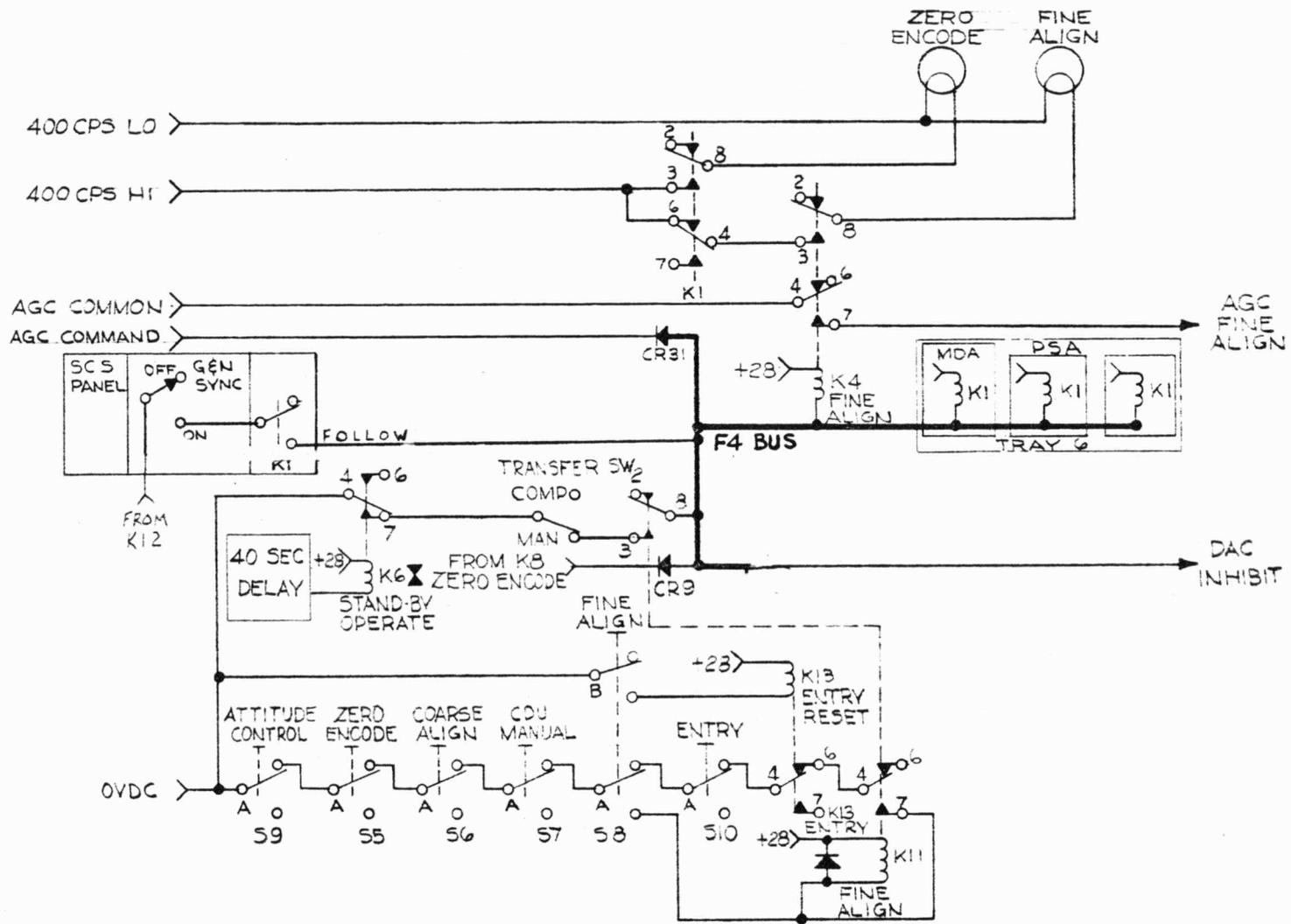


Fig. 2.14 "Fine align mode control CKTS".

and 3) K11 is energized, the F4 Function bus is activated by applying 0 V DC to the F4 bus through the energized contacts 3 to 8 to the Fine Align bus.

When the FINE ALIGN mode button of the IMU Control Panel is depressed, the Fine Align control relay K11 is energized by applying 0 V DC to the coil through the series circuit consisting of the normally closed contacts of the Attitude Control, Zero Encode, Coarse Align, and CDU Manual mode switches and the A set of activated contacts of the Fine Align mode switch. The reset coil of the Entry relay K13 is energized by applying 0 V DC through the B set of activated contacts of the Fine Align mode switch. When the FINE ALIGN mode button is released, K11 is maintained in an energized state by applying 0 V DC to the coil through the series holding circuit consisting of the normally closed contacts of the Attitude Control, Zero Encode, Coarse Align, CDU Manual, Fine Align and Entry mode switches, the reset position contacts 4 to 6 of the Entry relay K13, and the energized contacts 4 to 7 of the Fine Align relay K11.

3. When the G&N Sync Switch on the SCS Power and Functional Panel is in the G&N SYNC position and also the 40 second time delay has elapsed, the F4 Function will be energized through energized K1 in the SCS. This K1 is energized when the G&N Attitude Control Mode has been selected and one of the detent switches in the rotational controllers is closed. A detent switch is closed whenever the rotational controller is displaced from the zero position in any of the three possible directions.

4. Whenever the system is in "MANUAL" operation and the Zero Encode mode is selected, the Fine Align bus is activated by applying 0 V DC through energized K8 and isolation diode CR9. With the system in "COMPUTER" operation, the Fine Align bus is not activated by the computer Zero Encode command.

The following paragraphs discuss the result of energizing the F4 bus.

Fine Align relay K4 on the IMU Control Panel is energized. When K4 is energized, it applies excitation to the Fine Align mode lamp. This lamp excitation comes through the de-energized contacts 6 to 4 of the Zero Encode relay K. Energized K4 also applies the Fine Align mode switching indication to the AGC.

The Fine Align relays K1 for the three Motor Drive Amplifiers in Tray 6 of the PSA are also energized. When these relays are energized, they apply the output of the one speed and sixteen speed resolver receivers to the MDA which in turn causes the CDU loop to follow the IMU.

An inhibit Lo is applied to the three DAC's in Tray 5 of the PSA.

2.4.9 ATTITUDE CONTROL MODE MECHANIZATION (Fig. 2.15)

The Stable Member of the IMU is inertially referenced during this mode through the stabilization loops. The error sensors for these loops are the gyros which are mounted on the stable member. Angular rotations of the stable member (sensed by the gyros) generate an error output of the signal ducosyn which is amplified in the gimbal mounted preamplifier and then applied to the demodulator. The demodulator demodulates the error to a DC signal. This signal is applied to the gimbal Torque Drive Amplifier and transformed to the control signal for the gimbal Torque Motors TM. The TM develops a torque which opposes the disturbance torque which caused the angular rotation.

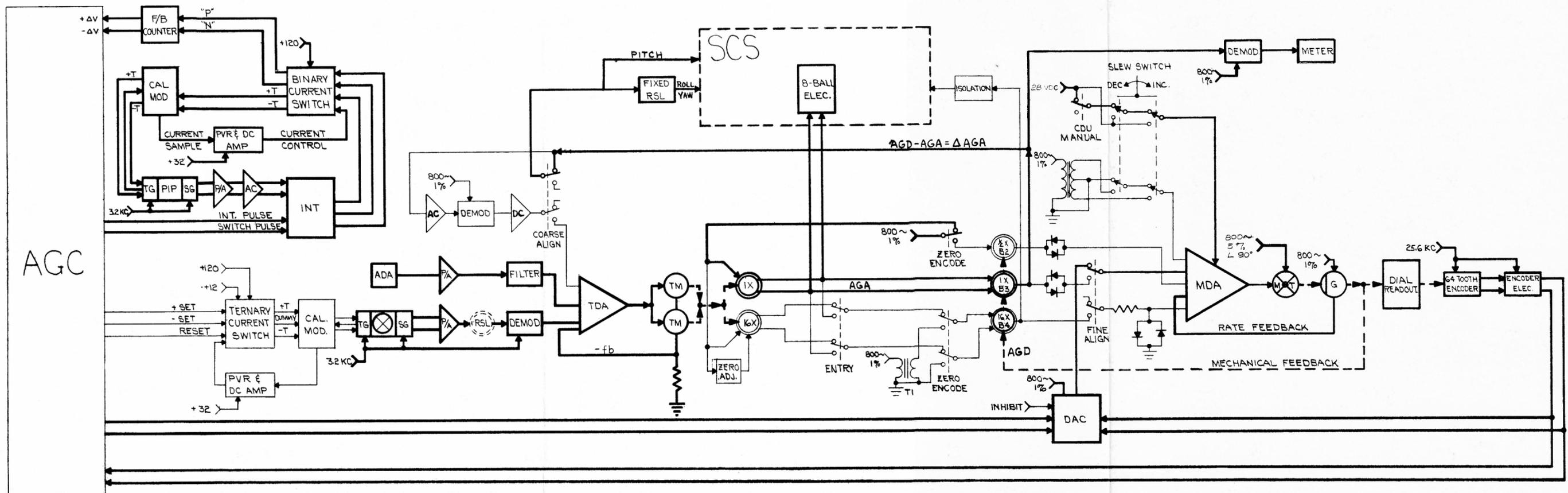


Fig. 2.15 Attitude control

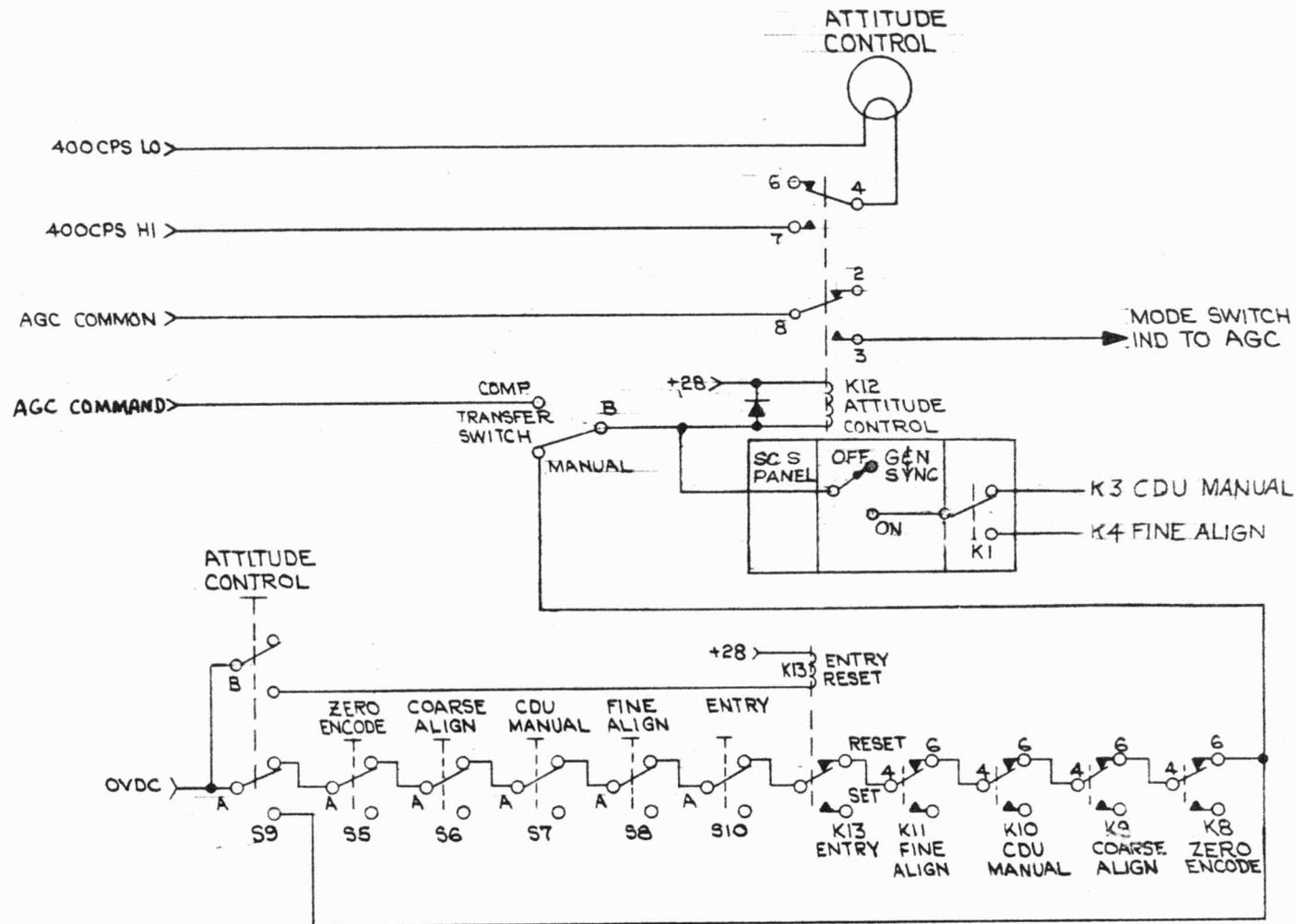
The command signal for the CDU loop originates in the computer as plus command or minus command pulses. The CDU's are positioned by the computer in the same manner utilized in the Coarse Align mode.

The steering signals generated for the SCS system originate in the rotors of the one speed resolver transmitters on the gimbal axis of the IMU. The Reference excitation is applied to the stator winding through a de-energized Zero Encode relay. If a difference exists between the Desired Gimbal Angle AGD and the Actual Gimbal Angle AGA, the voltages induced in the rotor leads represent the actual gimbal angle AGA plus the error in actual gimbal angle Δ AGA. These one speed voltages are coupled to the stator leads of the CDU one speed resolver receiver B3. The rotor position of B3 represents the desired gimbal angle AGD. Error signals Δ AGA are generated in the rotor of the CDU resolver B3 and applied to the resolution network through the de-energized Coarse Align relay. The output of the resolution network is the steering signal applied to the SCS. The SCS through the autopilot positions the spacecraft and thus changes AGA to reduce the value of Δ AGA to zero.

The velocity increments that are applied to the AGC are generated by the accelerometer loops.

2.4.10 ATTITUDE CONTROL MODE CONTROL (Fig. 2.16)

When the "ATTITUDE CONTROL" mode button on the IMU Control Panel is depressed, the Attitude Control relay K12 is energized by applying 0 V DC to the coil through the series circuit consisting of the A set of activated contacts of the Attitude Control mode switch S9 and the MANUAL position contacts of the Transfer Switch. When the "ATTITUDE CONTROL" mode button is released, K12 is maintained in an energized state by applying 0 V DC to the coil through the series holding circuit consisting of the normal closed contacts of the Attitude Control, Zero



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Fig. 2.16 "Attitude control" mode control circuits.

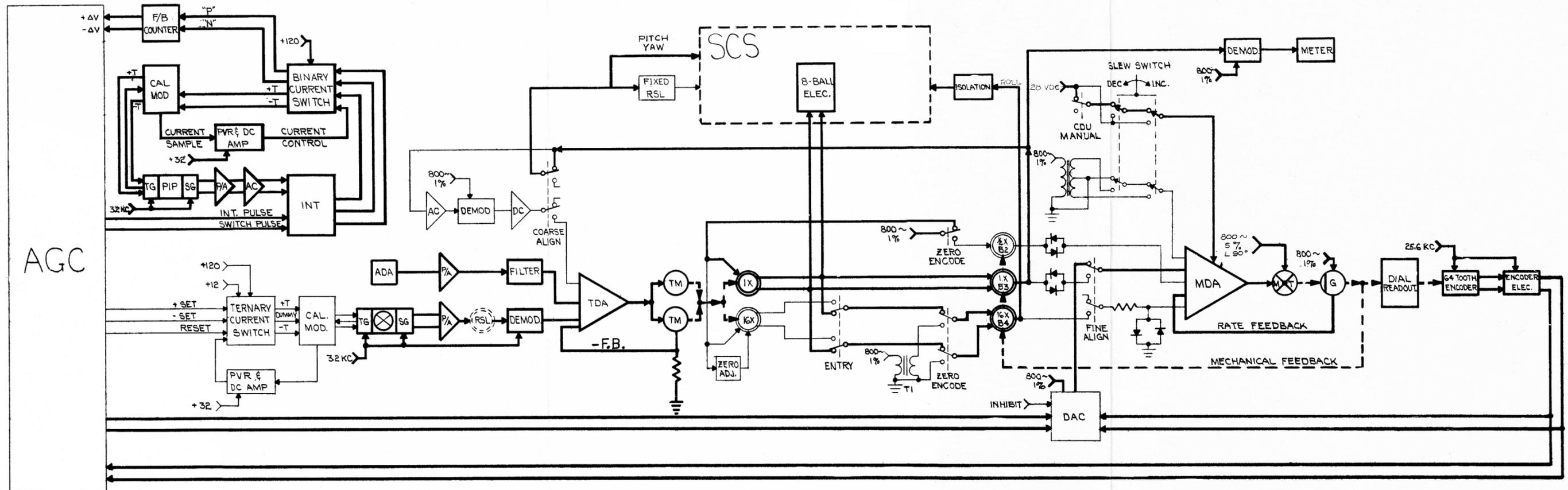


Fig. 2.17 Entry

Encode, Coarse Align, CDU Manual, Fine Align, and Entry mode switches; the reset position contacts 4 to 6 of the Entry relay K13; the de-energized contacts 4 to 6 of the Fine Align, CDU Manual, Coarse Align, and Zero Encode relay; and the MANUAL position contacts of the Transfer Switch.

When K12 is energized, it applies excitation to the Attitude Control mode lamp. Energized K12 also applies the Attitude Control mode switching indication to the AGC.

With the system in Computer operation, Attitude Control Mode is controlled by the Computer applying 28 V DC Lo through the COMPUTER position contacts of the Transfer Switch in order to energize K12.

2.4.11 ENTRY MODE MECHANIZATION (Fig. 2.17)

The generation of steering signals for the Entry mode is similar to the Attitude Control mode except that the scale factor of the roll signal is increased by a factor of sixteen. This is accomplished by applying the output of the one speed resolver in the IMU through the energized entry relays K4 and K5 in the CDU Zeroing Transformer Relays and Entry Relays module to the sixteen speed resolver in the Outergimbal CDU.

2.4.12 ENTRY MODE CONTROL (Fig. 2.18)

The Entry Mode is actuated whenever the F5 Function bus is energized. This bus is energized by either of the following two methods:

1. With the system in COMPUTER operation and provided the 40 second time delay has elapsed, an Entry computer command will activate the F5 Function by applying 0 V DC to the F5 bus through isolation diode CR29.
2. By depressing the ENTRY mode button of the IMU Control Panel, the Entry control relay K13 is set.

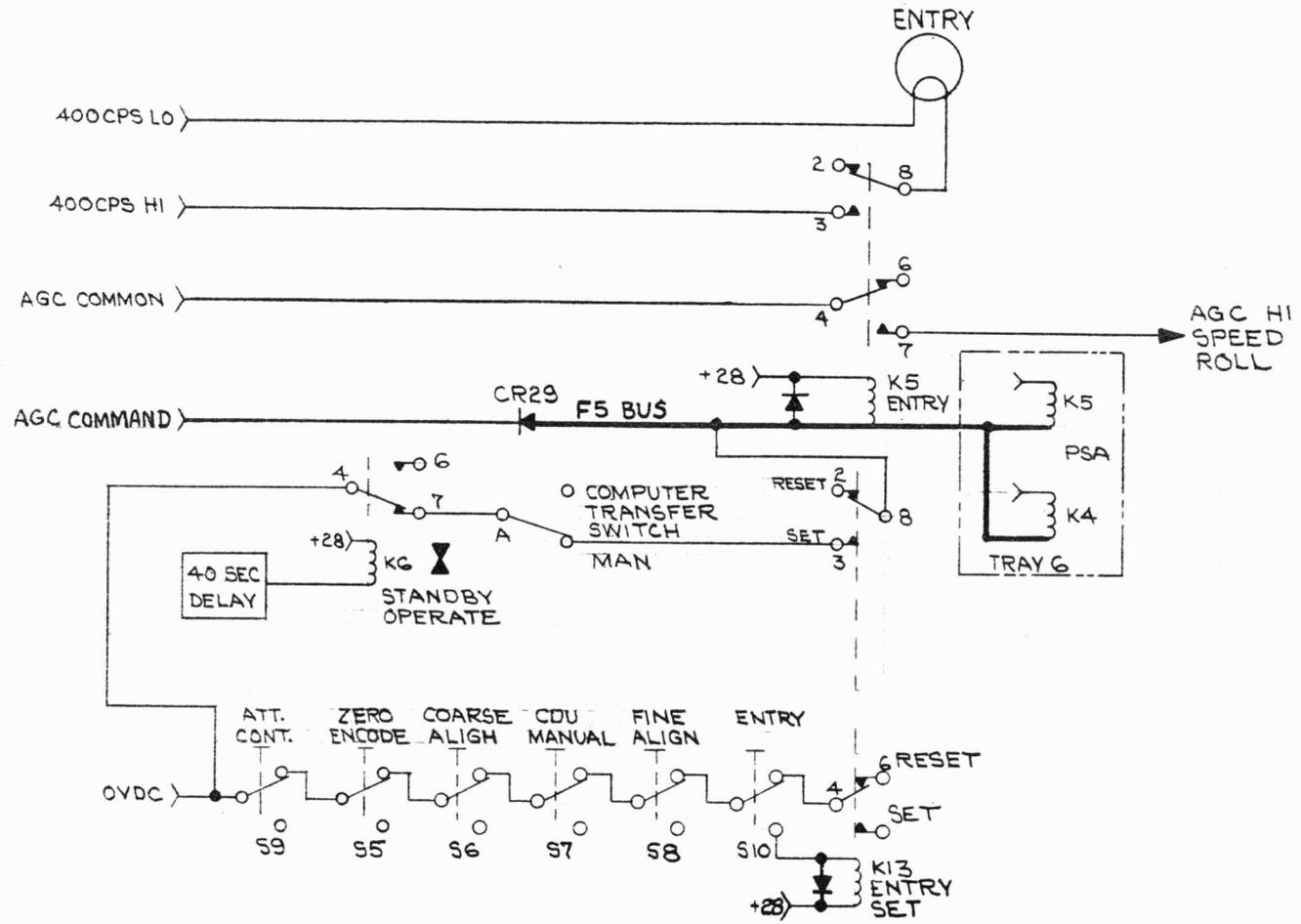


Fig. 2.18 "Entry" mode control circuits.

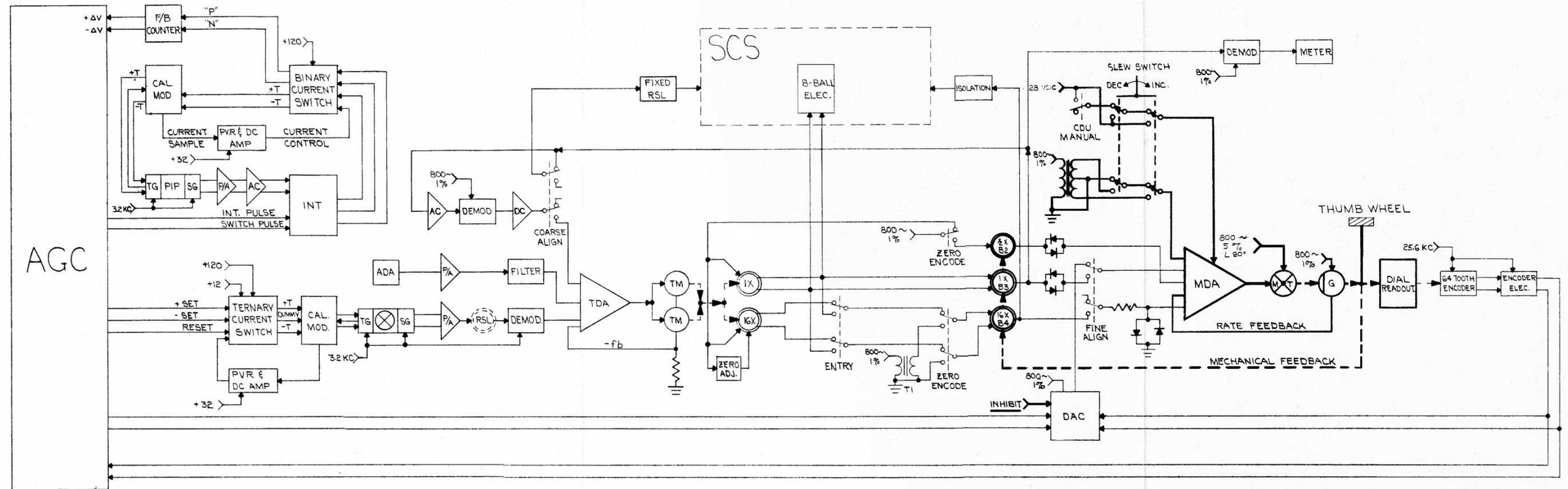


Fig. 2.19 CDU manual

When 1) the system is in MANUAL operation, 2) the 40 second time delay has elapsed, and 3) K13 is Set, the F5 Function is activated by applying 0 V DC to the F5 bus through the Set contacts 3 to 8.

When the ENTRY mode button on the IMU Control Panel is depressed, the Entry control relay K13 is Set by applying 0 V DC to the Set coil through the series circuit consisting of the normally closed contacts of the Attitude Control, Zero Encode, Coarse Align, CDU Manual, and Fine Align mode switches and the activated contacts of the Entry mode switch. When the ENTRY mode button is released, K13 is maintained Set by bi-stable action until the relay is reset by energizing the reset coil.

The following paragraphs describe the result of energizing the F5 bus.

Entry relay K5 in the D&C Electronics is energized. When K5 is energized, it applies excitation to the Entry mode lamp and applies the Entry mode switching indication to the AGC.

2.4.13 CDU MANUAL MODE MECHANIZATION (Fig. 2.19)

The command signal for the CDU loop originates in the slew transformer in the CDU. Whenever the slew switch is activated, a signal of zero or π phase is applied through one of the activated slew switch contacts to the Motor Drive Amplifier. The phase is dependent upon the direction of drive desired. This command signal is amplified in the MDA and applied as the control signal to the CDU servo motor, MGI. The MDA + 28 DC voltage is applied through the other set of activated slew switch contacts. The output shaft of MGI will drive a gear train which will in turn position the CDU dials, the rotors of the resolvers and the thumbwheel. The thumbwheel is used to refine the slewed position.

The CDU DAC's are inhibited in order to disable the inter loop feedback that otherwise would be generated. When the MANUAL ALIGN button on the IMU control panel is depressed, the F2 function is activated which then causes the IMU gimbal angles to follow the CDU angles. The caging function is also enabled by energizing the caging relay K1 in the Backup Mode electronics. The signal output of the signal ducosyn is converted in a caging interrogator to +set or - set pulses which are applied to the Ternary Current Switch in order that current pulses will be generated and applied to the IRIG Torque Generator for positioning of the IRIG towards null.

When K1 is energized, it applies +28 V DC to the caging interrogator circuits.

2.4.14 CDU MANUAL MODE CONTROL (Fig. 2.20)

The CDU Manual Mode is actuated whenever the F3 Function bus is energized. This bus is energized by any one of the following three methods:

1. With the system in COMPUTER operation and provided the 40 second time delay has elapsed, a CDU Manual computer command will activate the mode by applying 0 V DC to the F3 bus through isolation diode CR30.
2. By depressing the CDU MANUAL mode button on the IMU Control Panel, the CDU Manual control relay K10 is energized. When 1) the system is in MANUAL operation, 2) the 40 second time delay has elapsed, and 3) K10 is energized, the F3 Function bus is activated by applying 0 V DC to the F3 bus through the energized contacts 3 to 8 and the isolation diode CR11. When K10 is energized, it also applies 0 V DC to the MANUAL ALIGN button on the IMU Control Panel in order to enable the Manual Align function.

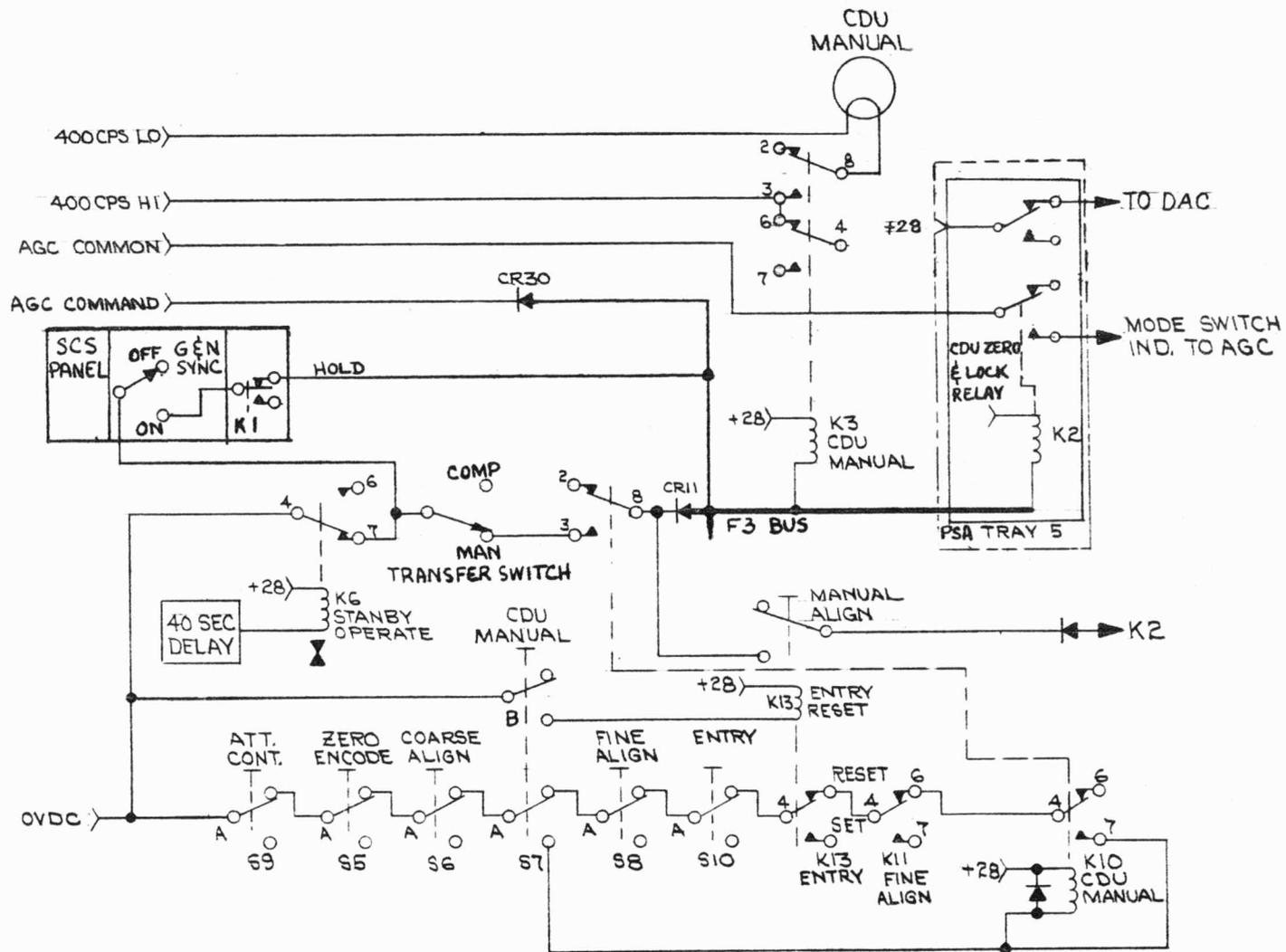


Fig. 2.20 "CDU manual" mode control circuits.

When the CDU MANUAL mode button on the IMU Control Panel is depressed, the CDU Manual control relay K10 is energized by applying 0 V DC to the coil through the series circuit consisting of the normally closed contacts of the Attitude Control, Zero Encode, and Coarse Align mode switches and the A set of activated contacts of the CDU Manual mode switch. The reset coil of the Entry relay K13 is energized by applying 0 V DC through the B set of activated contacts of the CDU Manual mode switch. When the CDU MANUAL mode button is released, K10 is maintained in an energized state by applying 0 V DC to the coil through the series holding circuit consisting of the normally closed contacts of the six mode switches; the reset position contacts 4 to 6 of the Entry relay K13; the de-energized contacts 4 to 6 of the Fine Align relay K11; and the energized contacts 4 to 7 of the CDU Manual relay K10.

3. When the G&N Sync Switch on the SCS Power and Functional Panel is in the G&N SYNC position and provided the 40 second time delay has elapsed, the F3 Function will be energized through the de-energized K1 relay in the SCS.

The following paragraphs describe the result of energizing the F3 bus.

CDU Manual relay K3 on the IMU Control Panel is energized. When K3 is energized, it applies excitation to the CDU Manual mode lamp. Energized K3 also interrupts the lamp excitation to the Coarse Align mode lamp.

F3 Function relay K2 in the CDU Zeroing and Lock Relay module in Tray 5 of the PSA is energized. When this K2 is

energized, it removes the amplifier and DAC excitation for the CDU motors MGI. Energized K2 also applies the mode switching indication to the AGC.

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