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BELLCOMM, INC.

COVER SHEET FOR TECHNICAL MEMORANDUM

TITLE – Saturn IB ESE Interlock System

TM – 66-2032-2

FILING CASE NO(S) – 330

DATE – April 26, 1966

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FILING SUBJECT(S) – (ASSIGNED BY AUTHOR(S) – Saturn IB
Launch
Interlocks

ABSTRACT

The results of an OMSF AS-201 Interlock and RCA 110A Computer Review were published (see Reference 12). Recognizing that this was a "quick-look", it was determined that a more detailed approach should be taken with respect to launch interlocks for the remainder of the Apollo Saturn IB-V programs. Meetings have been held at MSFC, KSC and MSC to discuss the interlock philosophy and design criteria and its implementation.

The intent of this memorandum is to present a description of the Saturn IB Interlock system for the purpose of facilitating better understanding and further discussion.

In the continuation of the interlock effort, the following actions are proposed:

1. Coordination of an interlock philosophy, a draft of which is included as Appendix H.

2. Compilation of data on Saturn V/Apollo similar to that contained in this memorandum.

3. For both Saturn IB-V/Apollo, coordinate an examination of the interlock systems for agreement with the proposed design philosophy and prepare evaluation reports.

The assistance provided by MSFC, MSC and KSC personnel in the compilation of this document is acknowledged. Constructive critical comments are invited.

BA-145A (7-65)

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BELLCOMM, INC.

SUBJECT: Saturn IB ESE Interlock System - Case 330

DATE:

FROM: C. H. Eley III
S. G. Embrey
H. E. Stephens

TM-66-2032-2

TECHNICAL MEMORANDUM

1. INTRODUCTION

In the final moments preceding launch, the state of a Saturn IB vehicle is changing at a rapid rate. Propellant tanks are in the process of being pressurized. Upper stage engines are thermally conditioned for ignition during the ascent phase. Electrical power supplying the vehicle is transferred from ground supplies to vehicle batteries, and first stage engines are stepped through their ignition sequences in the proper order to minimize induced shock on the vehicle structure.

This philosophy of requiring a system to be in the proper state before the next action is taken to operate the system or to change the system to the next level of readiness is implemented in the interlock system.

Each of the significant changes in the state of the vehicle can be represented by predetermined discrete actions or indications which record the initiation and/or completion of the change. For example, the proper operation of an engine can be represented by the fact that it has attained 90% of its rated thrust. The fact that the propellant tanks are properly pressurized can be represented by the fact that the tank pressure is above a certain value and below another. The fact that these vehicle state vectors or state indicators either are discrete in nature, or can be represented by discrete threshold values, allows them to be controlled logically by a combination of binary devices such as relays or flip-flop circuits. In essence, this combination of relays is a special purpose digital computer used to control the transition of the vehicle from one state to another and to report on the vehicle's state or change of state by activating discrete indications to operational personnel and the launch control computer.

In the Saturn program these special purpose devices are known as the "Interlocks" or the "Interlock System". They consist of one sub-part per stage, an integration sub-system which ties the stage associated ESE together, and a timing device called the Automatic Launch Sequencer (ALS).

Although the interlock system is used throughout the launch countdown in a safeguarding role (i.e., before power is applied to any stage the interlock system must indicate the proper vehicle/GSE state), its role changes to one of control late in the operations. At this time it initiates or performs those functions necessary for launch.

These characteristics allow the interlocks to be separated into three general categories with respect to time:

a. Interlocks used prior to T-163 seconds (start of the ALS).

b. Interlocks used from initiation of the ALS to issuance of the engine Ignition Command. This will include some interlocks from a above.

c. Interlocks used from the issuance of the engine Ignition Command through the Launch Commit signal and vehicle liftoff, including some interlocks from a and b above.

This paper will be concerned mainly with describing the Saturn IB interlock system and its operation for categories b and c above, including the interlock requirements which must be met in order to initiate the ALS.

During the investigation of this subject, visits were made to KSC, MSC and MSFC for discussions with some of the personnel directly concerned. Further comments on this memorandum are invited.

During the meetings at the centers, it was determined that a statement of interlock philosophy was necessary. A statement of interlock design philosophy and criteria has been drafted and is in the final stages of intercenter coordination, a copy being provided as Appendix H.

In order to make the SIB interlock system and its functional relationships more easily understood, this paper is presented in two parts. The first part summarizes the general sequence of interlock functions and operations (Section 2). This includes comments concerning the constraints which must be considered. The second part, consisting of Appendices A through G, presents the interlock system in more detail.

2. SUMMARY DESCRIPTION

The overall Saturn IB interlock system is functionally shown in Figure 1 from T-163 seconds to liftoff. This is a completely automatic sequence and is controlled by an Automatic Launch Sequencer. The ALS itself is started in the Launch Control Center (LCC) by a manually initiated signal called the "Firing Command."

A "Preparation Complete" interlock chain is used as a prerequisite for issuance of the Firing Command to ensure systems readiness. Once this interlock chain is completed, the Firing Command Switch is enabled and when manually operated will start the ALS. The Firing Command signal also simultaneously performs enabling and inhibit functions, and bypasses the Preparation Complete interlock chain. The ALS timed outputs initiate actions which change the state of the space vehicle and/or GSE, most of which must be reflected in interlock functions. A second interlock chain, called "Ready for Ignition", is then built up to prepare for engine ignition. This must be completed by T-3 seconds. If completed by that time, an "Ignition Command" signal is issued. If the Ready for Ignition interlock chain is not completed by T-3 seconds, the countdown will be stopped automatically by a "Cutoff" signal which de-energizes the ALS. The Cutoff signal is itself the result of an interlock chain which is activated when specific operational parameters are unsatisfactory.

Once the Ignition Command is issued, it starts a second automatic sequencer called the Automatic Ignition Sequencer (AIS). The Ignition Command also simultaneously bypasses the Ready for Ignition interlock chain and performs enabling and inhibit functions. One of these functions enables the automatic Cutoff interlock chain. Up to this point in the countdown, stoppage of the ALS could only be accomplished by a Manual Cutoff Switch.

The next milestone is "Commit". This occurs at T-0 and requires a new interlock chain be completed for issuance of the Commit signal. During the 3 second interval from Ignition Command to Commit, the SIB engines have been ignited followed by thrust build-up. Engine Cutoff interlocks are also provided for a safe shutdown in case of a Cutoff signal prior to Commit, or for a failure to liftoff following Commit.

The relationship of the interlocks within the principal interlock chains is summarized in the following:

a. Preparation Complete

A Preparation Complete Interlock chain consisting of two primary groups - those which are common to the Firing Command and Ready for Ignition chains, and those peculiar to the Firing Command chain - is utilized to ensure system readiness to accept the Firing Command. Of these, the common interlocks cover parameters that should not change between the Firing Command and Ready for Ignition. Those peculiar to the Firing Command are ones which are subject to change in status before the Ignition Command and/or ones which it is not considered necessary to sample again. The parameters comprising these groups are summarized in Figure 2. (A more detailed discussion is provided in Appendix A supplemented by Figures A-1 and A-2). With the completion of the Preparation Complete interlocks and the Range Safety Officer Permission Switch, the Firing Command may be issued by manually closing the Firing Switch. This starts the ALS at T-163 seconds.

b. Firing Command

The Firing Command signal is held in as soon as it is issued by a locking circuit, thus eliminating the Preparation Complete interlock chain. The Firing Command also performs many direct functions as well as serving to enable or inhibit others. Of particular importance is the start command to the ALS. (The specific outputs and functions performed by the Firing Command and the ALS are shown in Table I, Appendix B.) Once the ALS is started, it will continue until T-3 seconds (or time for ignition) unless stopped by actuation of the Manual Cutoff Switch.

c. Ready for Ignition

The second interlock chain milestone is termed "Ready for Ignition." The parameters comprising this interlock chain are summarized in Figure 3 (with a more detailed discussion in Appendix C supplemented by Figures A-1 and C-1). This chain consists of two main groups, which are (1) the "no change" parameters also common to the Firing Command and (2) those peculiar to Ready for Ignition which reflect completion of action initiated by the Firing Command signal and/or ALS.

Completion of the Ready for Ignition chain must be accomplished prior to T-3 seconds.

d. Ignition Command

The Ready for Ignition signal, the Time for Ignition signal (from ALS) and absence of the Cutoff signal are combined at T-3 seconds to issue the Ignition Command (see Figure 4). Once issued, the Ignition Command is locked in. If, however, the Ready for Ignition interlock chain has not been completed by T-3 seconds, the "Sequence Failure" relay will be energized and the Cutoff signal issued.

The Ignition Command signal performs many direct, enabling and inhibiting functions. (enumerated in Appendix D) Of those functions, the following are of particular importance with respect to the interlock system:

(1) Starts Ignition Sequencer

(2) Activates the Commit Backup Timer and the Launch Failure Timers.

(3) Enables Cutoff functions from the following interlock chains:

- (a) SC Ready
- (b) EDS Ready
- (c) Fire Detection System
- (d) Networks 1 and 2 OK
- (e) SIVB Ready to Launch
- (f) IU Ready to Launch

(4) Reduces the SIVB Ready to Launch function to a monitoring of "Power Transfer Complete" and the absence of electrical networks malfunction.

(5) Reduces the IU Ready to Launch interlock chain to one consisting of voltage monitoring and the absence of LVDA Fire Commit Inhibit.

e. Cutoff Function (T-3 to T-0)

The Cutoff function and parameters applicable in the period from Ignition Command to Commit are summarized in Figure 5 (also discussed in Appendix G and Figure G-1). If the Cutoff signal is initiated during this period, some of the immediate actions which will occur are; ALS stop, engine shutdown, vehicle return to ground power, and fuel and LOX tank venting.

f. Commit

The Commit requirements are summarized in Figure 6 (and supplemented by Appendix E and Figure E-1). The Commit interlock chain requirements are:

(1) All Engines Running (majority voting of three "thrust OK" switches in each engine)

(2) Absence of the Cutoff Signal

(3) Time for Commit (T-0 from the ALS or T+0.3 seconds from the Commit Backup Timer)

When the above Commit chain is satisfied, the Commit signal is issued and locked-in. The Commit signal then performs the following major functions:

(1) Energizes swing arm retraction mechanisms

(2) Initiates SIB LOX and fuel mast retraction

(3) Energizes SIB cable mast retraction mechanisms

(4) Bypasses all engine Cutoff parameters except from the Launch Failure Timers, or the Emergency Manual Cutoff Switch

(5) De-energizes certain electrical power buses.

g. Launch Failure Cutoff

If liftoff does not occur after Commit, shutdown may be initiated at any time by the Emergency Cutoff Switch (discussed in Appendix G). Also, if liftoff does not occur, shutdown will be automatically initiated at T+5 seconds by the Launch Failure Timers which were started with the Ignition Command (See Figure 7).

3. CONTINUING WORK

This paper has been concerned solely with describing the existing Saturn IB interlock system and its operation from the circuitry point-of-view.

As a result of this review, it can be concluded that from a logic standpoint the circuitry has been well designed. It does not possess protection against single circuit component failures found in many vehicle electrical systems; however, it is accessible during the launch operation to allow for rapid repair and/or work arounds.

Due to lack of information on sensor reliability and quality and a lack of detailed vehicle system knowledge, the authors cannot justify and comment on the need for each interlock parameter or the effect of sensor imperfections at this time.

Continuing efforts in the area of interlocks should accomplish the following:

a. Examine the Apollo Saturn IB interlock system for agreement with the design philosophy and criteria now being coordinated with KSC, MSC, MSFC, MA, and MO. It is envisioned that this effort would be executed by the Development Center performing a detail interlock design review of the basic system, with MAS maintaining adequate technical liaison with the review effort to permit coordination of operational requirements and possible interlock changes with KSC and MSC.

b. Evaluate the Saturn IB interlock system from a sensor and parameter point-of-view.

c. Conduct a similar investigation and evaluation of the Saturn V interlock system.

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H. E. Stephens

2032-CHE
HES-lmp
2031-SGE

Attachments
Figures 1-7, References,
Appendix A-H and Figures A1-G1

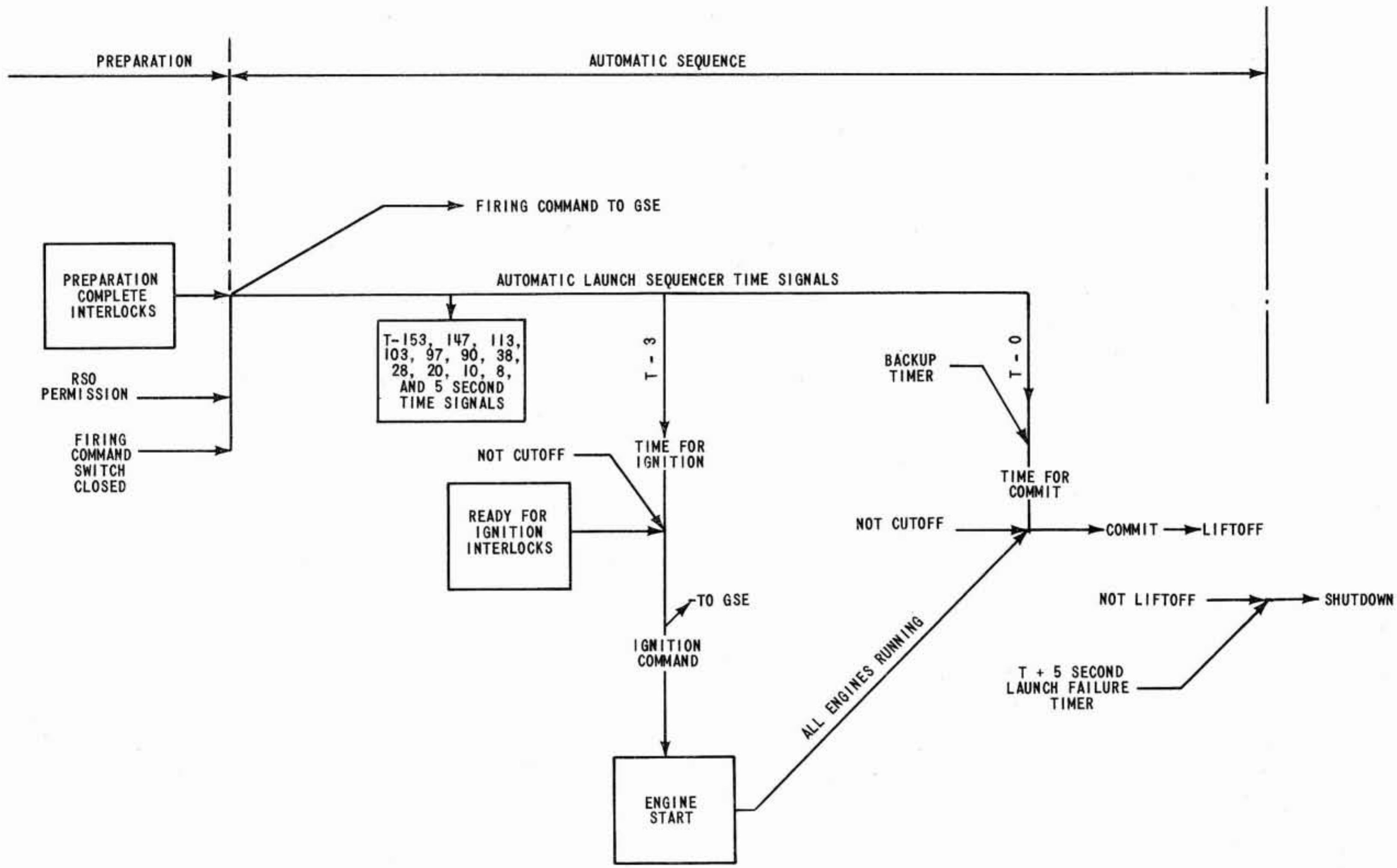


FIGURE 1 - SATURN IB INTERLOCK SYSTEM

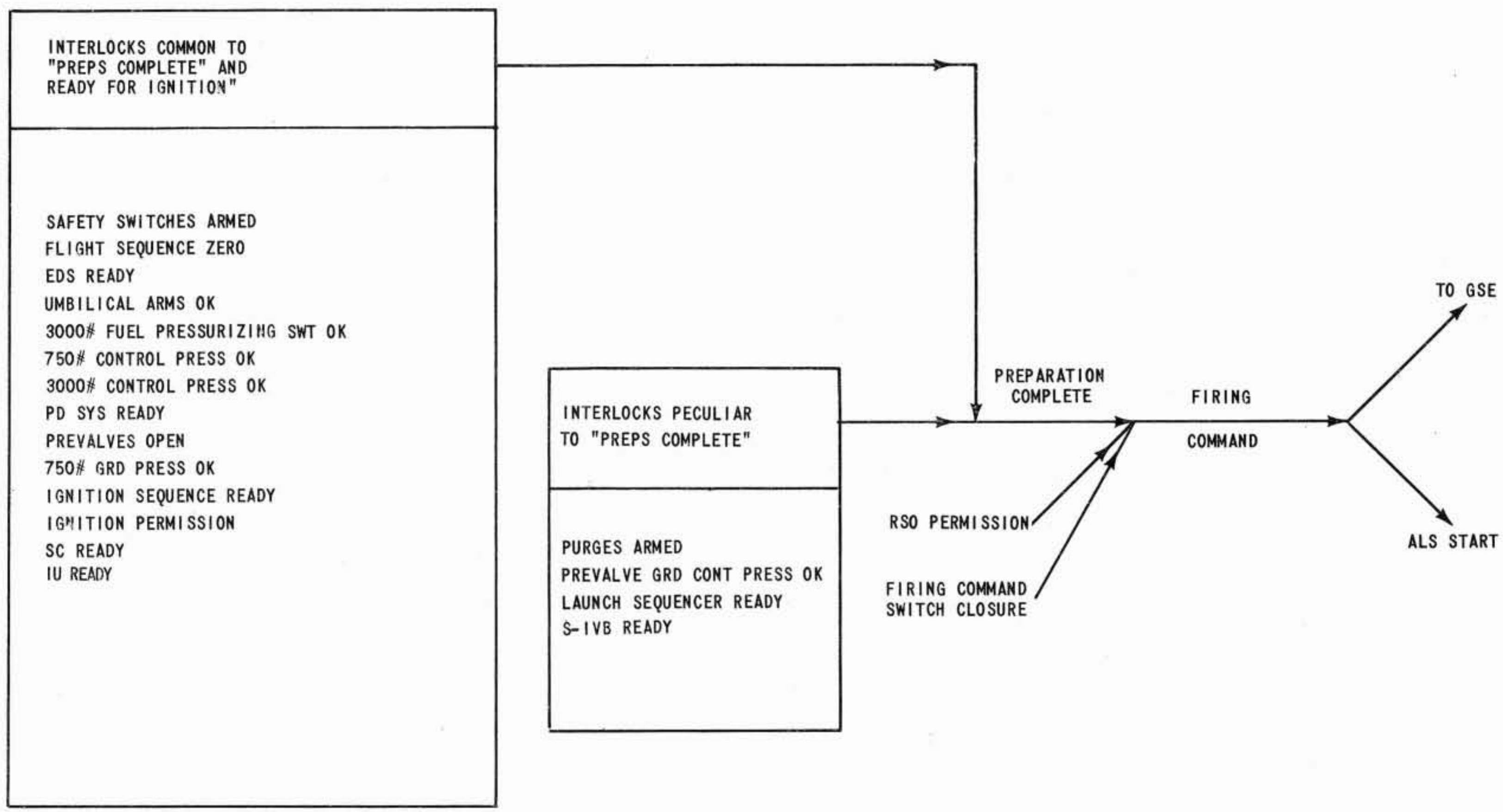


FIGURE 2 - PREPARATION COMPLETE INTERLOCKS SATURN IB

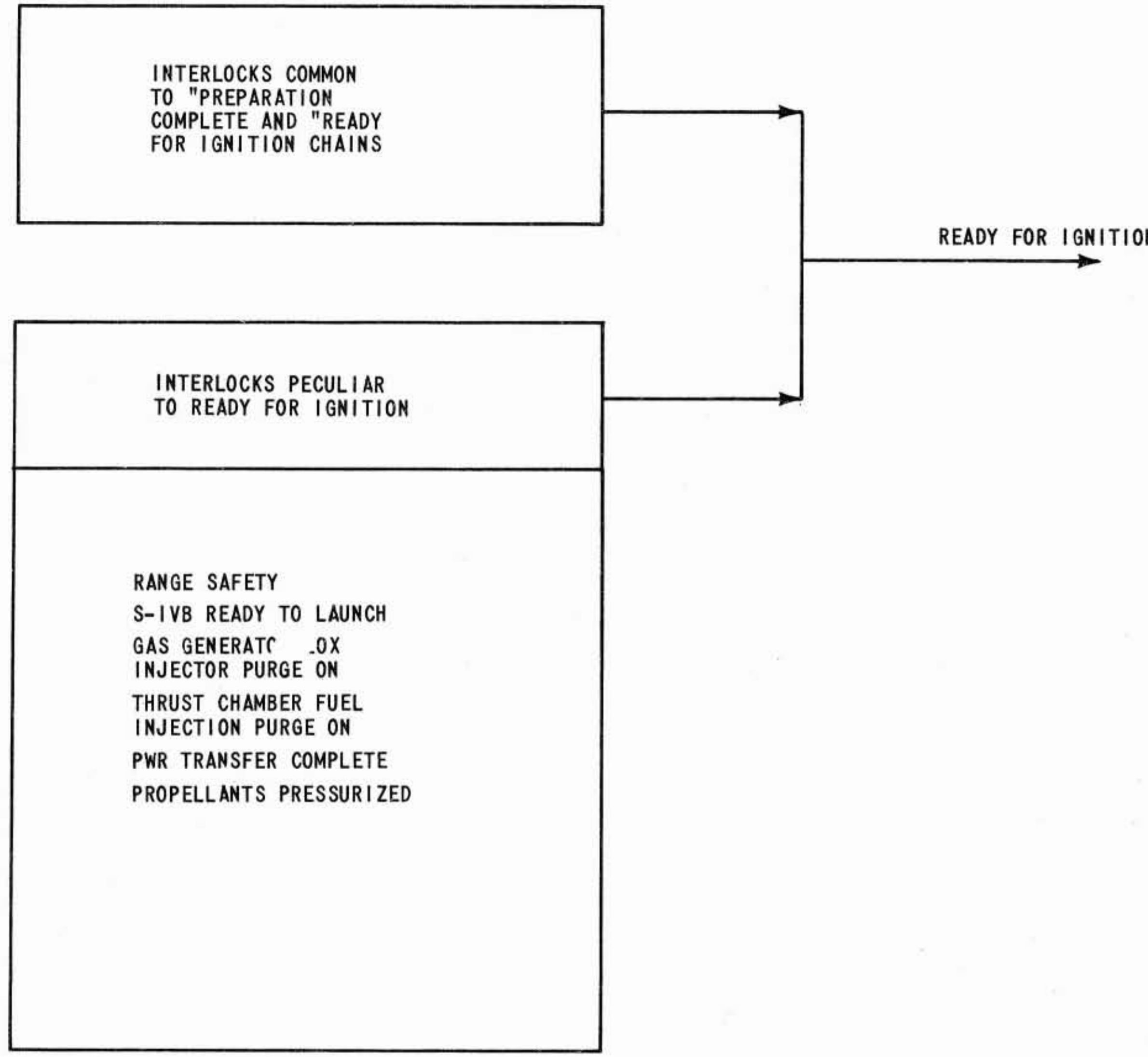


FIGURE 3 - READY FOR IGNITION INTERLOCKS SATURN IB

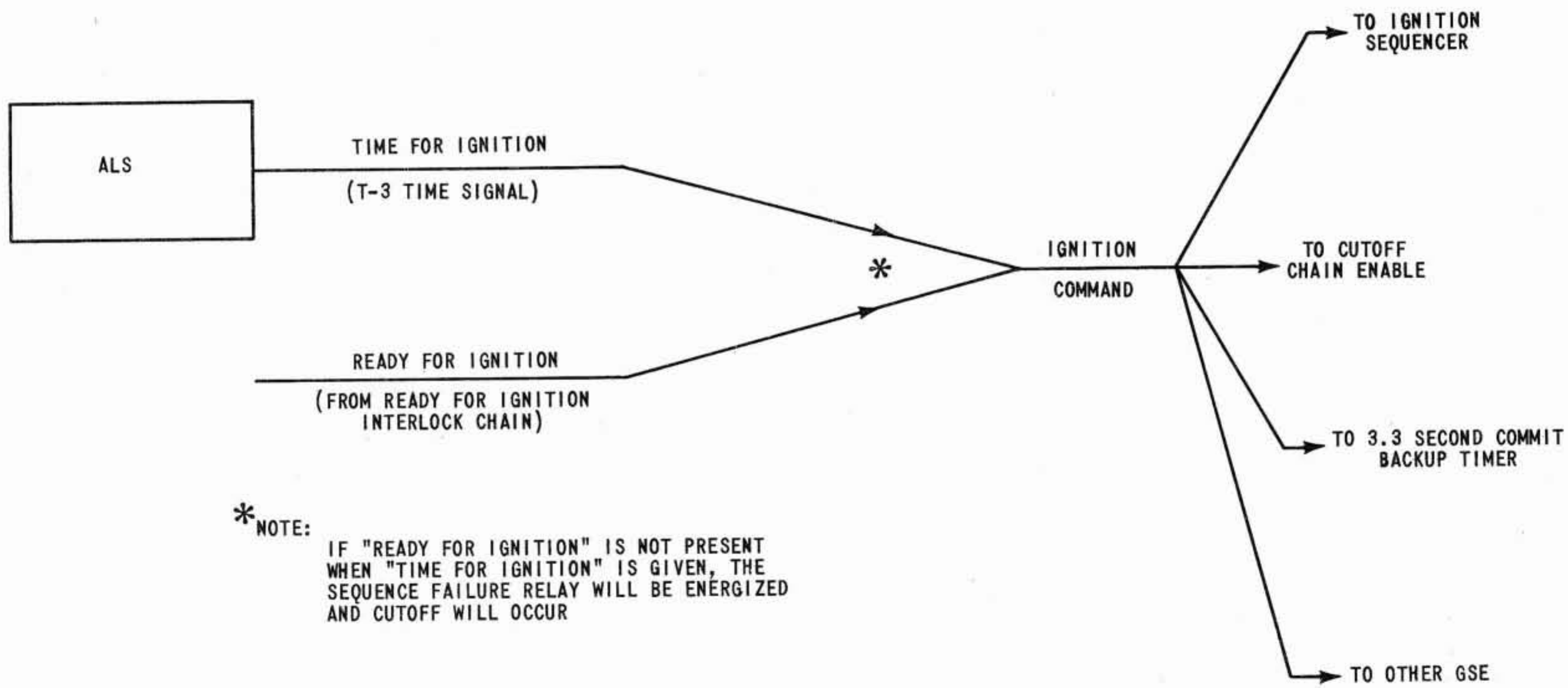
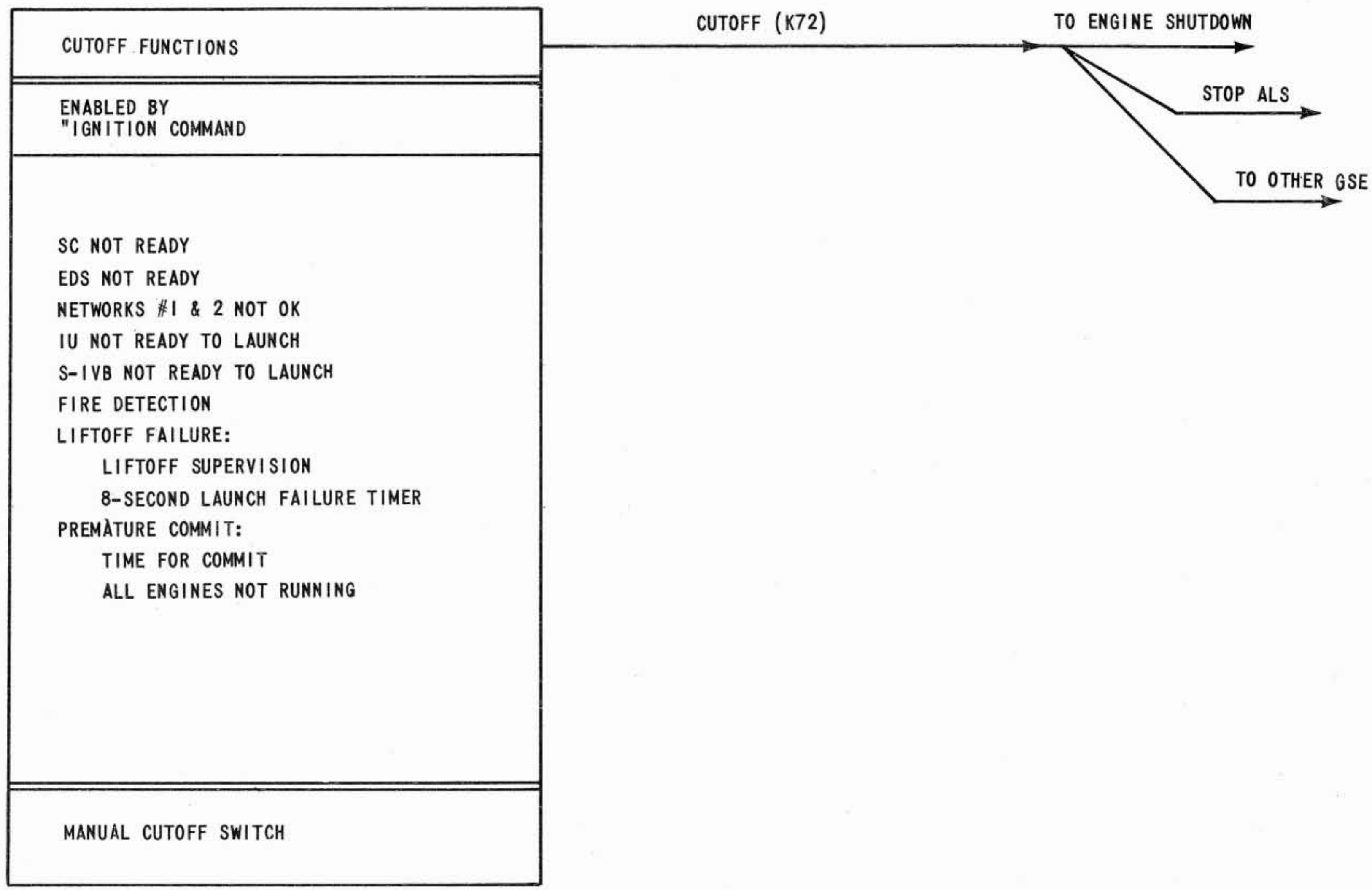


FIGURE 4 - IGNITION COMMAND INTERLOCKS SATURN IB



NOTE:
EMERGENCY MANUAL SHUTDOWN
SWITCH IS A DIFFERENT FUNCTION

FIGURE 5 - CUTOFF FUNCTIONS AFTER IGNITION COMMAND - SATURN IB

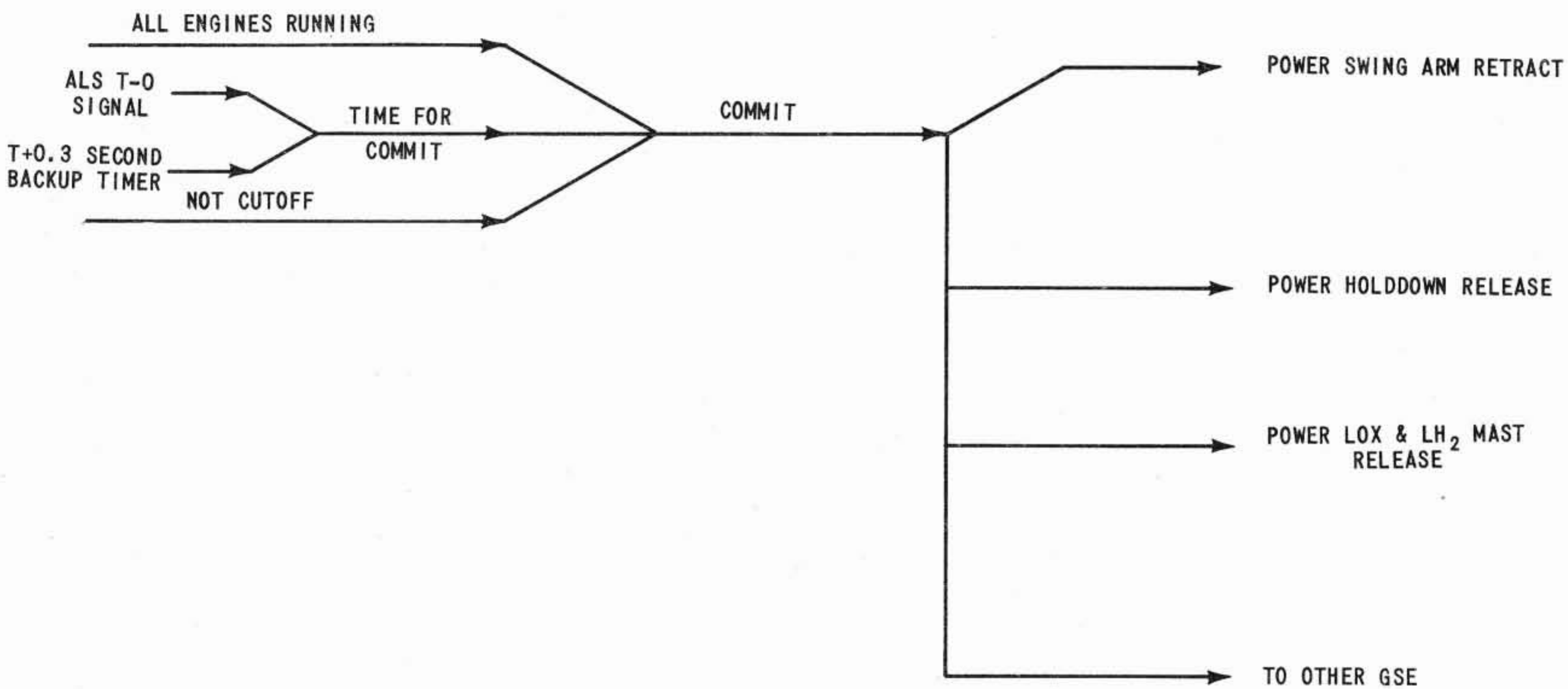


FIGURE 6 - COMMIT SATURN IB

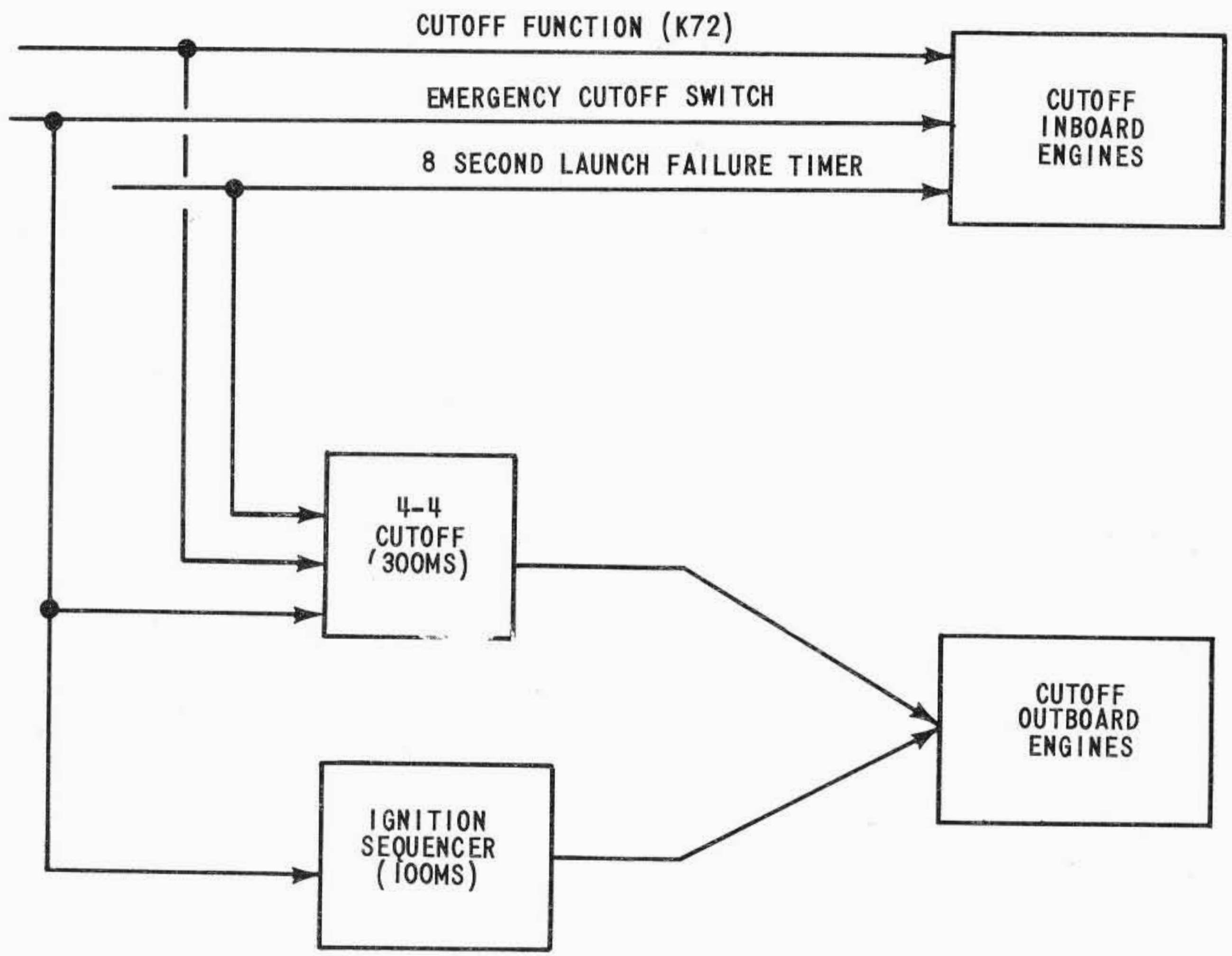


FIGURE 7 - ENGINE CUTOFF FUNCTION SATURN IB

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3. "Saturn/Apollo Interface Control Document, Emergency Detection System Checkout Schematics, SA-201/SC-009", December 8, 1966.

4. "MSFC Advanced Electrical System Schematics - IU Power ESE, Saturn IB", June 22, 1965 (updated).

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6. "KSC Apollo/Saturn IB Safety Circuits", November 30, 1965 (updated).

7. "MSFC Advanced Electrical System Schematics, SIB ESE - Saturn IB", July 16, 1965 (updated).

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10. LC-34, Saturn IB LSEED System Drawings, July 29, 1965.

11. "MSFC Advanced Electrical System Schematics, SIB ESE Saturn IB", February 7, 1966.

12. "AS-201 Interlocks and RCA 110A Computer Review", C. H. Bolender, R. V. Murad and J. P. Downs, January 18, 1966.

APPENDIX A

INTERLOCK REQUIREMENTS FOR FIRING COMMAND

1. General

A Preparation Complete interlock chain must be completed as a prerequisite to issuance of the Firing Command and start of the Automatic Launch Sequencer (ALS) at T-163 seconds. The use of such a Preparation Complete interlock chain is essential as (a) assurance must be provided that all operations on the space vehicle and GSE that must be performed prior to the automatic sequence are complete and that the systems are performing properly, (b) with the start of the Sequencer all launch operations for a nominal launch are automatic and (c) positive detection of critical system failures is needed.

The master interlock chain for Preparation Complete is shown in Figure A-1, with the next lower level of detail shown in Figure A-2. A brief description of the parameters for this interlock chain follows.

2. Interlocks Common to Preparation Complete and Ready For Ignition:

   a. Bus 1D116 Power

   The interlock chain is powered by the SIB oriented launch bus, 1D116. The interlock relays are in general powered by other buses.

   b. Safety Switches Armed (K-63)

   This interlock is based on an indication that the SIB stage safety switches are armed.

   c. Flight Sequence Zero (K-223)

   This interlock combines two functions (SIB switch selector reset to an all zero indication and the stage logic set to indicate zero) for readiness of the SIB flight sequence.

d. EDS Ready (K-291)

The EDS interlock is discussed in Appendix G. This parameter is used both as a Preparation Complete requirement and a Cutoff parameter up to Commit.

e. Umbilical Arms OK (K-87)

This is an interlock to reflect the readiness of the four swing arms to retract upon liftoff. It combines indications of the umbilical release 750 psi GN_2 pressure and retract 1500 psi hydraulic accumulator liquid level and pressure for each swing arm.

f. 3000 PSI Fuel Pressurizing Pressure OK (K-101)

The parameter for this interlock is the pressure in the SIB 3000 psi helium fuel pressurizing spheres reflecting their readiness to operate.

g. 3000 and 750 PSI Control Pressure OK (K-13 and K-14)

These two related interlocks reflect the SIB 3000 psi GN_2 control sphere pressure and the 750 psi control manifold pressure obtained from the control spheres by pressure reducers.

h. SIB Propellant Dispersion System Ready (K-84)

To determine that the SIB propellant dispersion system is ready, the following parameters are combined:

(1) RSCR #1 and #2 ON

(2) RSCR #1 and #2 not on ground power

(3) EBW #1 and #2 not ON

(4) Safety and Arm (S&A) devices armed

i. Prevalves Open (K-67)

This interlock monitors whether all SIB fuel and oxidizer prevalves are open (normally open except for engine failure and line break).

j. 750 Ground Pressure OK (K-94)

This interlock monitors the pressure of both the 750 psi H_e holddown arm release and cable, fuel, and LOX mast 750 psi GN_2 retract systems.

k. Ignition Sequencer Ready (K-78)

The two primary input parameters to this interlock are Ignition Armed and Ignition Sequencer Zero Indication.

l. Ignition Permission (K-47)

This interlock is operated by closure of the Ignition Permission Switch on the Pad Safety Panel and is also a prerequisite for Ignition Sequencer Zero Indication.

m. IU Ready (K-60)

The IU Ready interlock is used throughout the automatic sequence, but utilizes different parameters during various phases of the automatic sequence. The primary parameters on which the IU Ready signal is based for the Preparation Complete chain are:

(1) 400 cycle power ON

(2) 56 Volt OK

(3) LVDA Fire Commit Inhibit not present

(4) Switch Selector Verification IU Power ON

(5) CAT Zero

(6) ST 124 System Ready

(7) Networks OK

(8) Control Voltage OK

(9) Guidance Release not present

(10) Guidance Alert not present

n. Spacecraft Ready (K-104)

Manual Switch.

3. Interlocks Peculiar to Preparation Complete Chain

a. Purges Armed (K-143)

This interlock reflects that the LOX dome, gas generator injector, and boattail deluge purges have been prepared to accept a later signal to commence purging. This requires that the Manual Purge Command and Automatic Off Command not be present for any of the purges.

b. Prevalve Ground Control Pressure OK (K-275)

This interlock requires that the 750 psi GN_2 prevalve ground control system be pressurized.

c. Launch Sequencer Ready (K-118)

This interlock monitors the readiness of the ALS to accept the Firing Command. Requirements are:

(1) D1, D2, and D3 Zero Indication

(2) Time Pulse Switch

(3) Sequence Arm Switch

(4) Cutoff Signal not present

d. SIVB Ready (K-33)

As with the SIB, some of the parameters of this interlock are also common to the Ready for Ignition interlock chain. The parameters on which this interlock depend for Preparation Complete are:

(1) SIVB Parameters Common to both Ready for Firing Command and Ready for Ignition

(a) Recirculation OK

(b) Control Stage Pressure not high

(c) Engine Ready

(d) APS Module #1 and #2 Buses ON

(e) 4D110 Bus power

(f) Absence of APS #1 and #2 Regulator Standby

(g) RSCR #1 and #2 ground power not ON

(h) RSCR #1 and #2 ON indication

(i) S&A Unit Armed

(j) EBW #1 and #2 not ON indication

(2) <u>SIVB Parameters Peculiar to Preparation Complete</u>

(a) Propellant Utilization (PU) Power ON indication

(b) PU Active

(c) Flight Multiplexer Group ON

(d) Flight XTMR Group ON

(e) Inflight Relays ON

(f) Flight Subcarrier Oscillator Group ON

(g) Orbit XTMR Group ON

(h) Recorder Measurement Group ON

(i) Hydraulic Pump ON

(j) Auxiliary Hydraulic Pump In Flight Mode Pilot Relay Reset not present

(k) Ullage Rocket Pilot Relay reset

All of the interlocks enumerated above are in series and function as a master "AND" gate. Closure of all these interlocks issues a signal signifying Preparation Complete and that the systems are ready for issuance of the Firing Command. This Preparation Complete signal, when combined in series with Firing Command Pilot (obtained by closing the Firing Switch on the SIB Firing Panel) and the Range Safety interlock, issues the Firing Command (K-27). It is noted that once issued a holding circuit locks in the Firing Command. Thus, subsequent loss of any of the interlocks does not nullify the Firing Command signal.

APPENDIX B

INTERVAL FROM FIRING COMMAND TO READY FOR IGNITION

A tabulation of the operations which are performed after issuance of the Firing Command at T-163 seconds to launch is given in Table I. During the period from issuance of the Firing Command to the Time for Ignition, operations are initiated in two ways -- directly by the Firing Command or by the ALS. In addition to direct initiation of operations, the Firing Command performs other inhibit and enabling functions. Some, but not all, of the actions initiated by the Firing Command and ALS are reflected in the Ready for Ignition interlock chain.

TABLE I

FIRING COMMAND FUNCTIONS AND
AUTOMATIC LAUNCH SEQUENCER OUTPUTS

EVENT

T-Time (seconds)	Firing Command Functions:
	1. Issues start signal to Automatic Launch Sequencer (ALS).
	2. Stops SIB LOX tank replenishment.
	3. Closes SIB LOX vent valves by inhibiting "open command," (K28/1260A1).
T-163-Firing Command (see figure A-2 for prerequisites)	4. Stops SIB fuel bubbling and pressurizes tanks by the following sequence: Firing Command inhibits "fuel vent open command" (K37/1260A1) which closes the vents. Vent closure plus an enable by the Firing Command issues "fuel pressurizing command" (K232/1260A1). Vent closure inhibits "fuel bubbling line control valve open" command.
	5. Enables SIB auxiliary hydraulic pump thermal by-pass mode.
	6. Starts SIVB LOX tank prepressurizing.
	7. Inhibits such as: venting of pressurizing and control spheres, RSCR transfer to external, S&A device safe commands, SIVB LH_2 and LOX pressurization for drain, and APS commands.
T-153	ALS signal to K119/1260A1, plus Firing Command enable issues a start command for SIB LOX bubbling.
T-147	ALS signal to the firing accessory equipment enables termination of SIVB LOX tank replenishment upon reaching 100% flight mass.

FIRING COMMAND FUNCTIONS AND
AUTOMATIC LAUNCH SEQUENCER OUTPUTS

T-Time (seconds)	EVENT (Cont'd)
T-113	ALS signal to firing accessory equipment starts SIVB LH_2 tank prepressurization.
T-103	ALS signal to K212/1260A1, stops SIB LOX bubbling. End of LOX bubbling plus replenish valve closure (accomplished at T-163) issues SIB LOX tank pressurization command.
T-97	ALS signal to firing accessory equipment enables termination of SIVB LH_2 tank replenishment upon reaching 100% flight mass.
T-90	ALS camera control signal.
T-38	ALS signal for: Pad flush Camera control Inhibit AGCS computer
T-28	One ALS T-28 second output issues a signal for SIB, SIVB and IU power transfer to internal.
T-28	A second T-28 second ALS signal starts: LOX dome purge Gas generator LOX injector purge Thrust chamber fuel injector purge
T-20	ALS signal (through K318/1260A1) issues the LOX main fill shutoff command to the firing accessory equipment.

FIRING COMMAND FUNCTIONS AND
AUTOMATIC LAUNCH SEQUENCER OUTPUTS

T-Time (seconds)	EVENT (Cont'd)
T-10	ALS signal causes the guidance release alert signal to be issued to the IU.
T-8	ALS signal (through K264/1260A1) operates cable masts 2 and 4 retract valves 1 of the launcher arm retract and simulated liftoff valving.
T-5	ALS signal causes the guidance release signal to be issued to the IU.
T-3	ALS time for Ignition signal. (see Figure D-1 for Ignition Command requirements). The Ready for Ignition interlock chain must be completed by this time (see Figure C-1).
T-0	ALS Time for Commit signal (see Figure E-1).
T+0.3	Backup timer "Time for Commit".
T+5	Launch Failure Timer output.

APPENDIX C

READY FOR IGNITION

1. General

As discussed in Appendix A, a Preparation Complete interlock chain must be completed as a prerequisite for issuance of the Firing Command. A second interlock chain for the Ready for Ignition signal must be completed by T-3 seconds. Some of the interlocks in this second chain are common to the Preparation Complete chain, while others are dependent on completion of action initiated by the Firing Command and/or ALS. The Ready for Ignition interlock chain, which is shown in Figures A-1 and C-1, is composed of the following:

2. Interlocks Common to Preparation Complete and Ready for Ignition.

These are enumerated in Appendix A.

3. Interlocks Peculiar to Ready for Ignition

a. IU Ready (K60)

This is the same interlock relay as for Preparation Complete, but based on slightly different parameters. The primary difference is that the ALS T-10 second and T-5 second outputs must have caused Guidance Release Alert and Guidance Release signals to be issued to the IU with a LVDA Fire Commit Enable signal out of the IU.

b. Range Safety (K32)

Based on closure of RSO Permission Switch.

c. SIVB Ready for Launch (K34)

(1) Interlocks Common to SIVB Ready for Firing Command and SIVB Ready for Launch were given in Appendix A.

(2) Interlocks Peculiar to SIVB Ready for Launch

(a) LOX fill and drain valve closed -- Reflects valve closure initiated by Firing Command.

(b) LH_2 fill and drain valve closed -- Reflects valve closure initiated by ALS T-113 second signal.

(c) LH_2 directional vent in flight position.

(d) LOX tank pressurized -- Reflects pressurization initiated by the Firing Command.

(e) LH_2 tank pressurized -- Reflects tank pressurization initiated by the ALS T-113 second signal.

(f) Power transfer complete -- Monitors (1) completion to transfer to internal power initiated by the ALS at T-28 seconds and (2) absence of network failures.

d. Gas Generator LOX Injector Purge ON and Thrust Chamber Fuel Injector Purge ON

The readiness of these systems was included in the Preparation Complete interlock chain (K143). The systems are turned on by the ALS T-28 second output and this interlock monitors their pressure.

e. Power Transfer Complete (K-8)

The signal for power transfer is issued by the ALS at T-28 seconds. This interlock monitors completion of SIB, SIVB, and IU transfer to internal power and absence of networks malfunction.

f. Propellants Pressurized (K-40)

This interlock monitors the pressurization of the SIB fuel and LOX tanks. The pressurization is initiated by the Firing Command and ALS T-103 second output.

The completion of the interlock chain described above operates the Ready for Ignition master interlock (K59, 1250A1). Closure of this interlock is a prerequisite for issuance of the Ignition Command at T-3 seconds as discussed in Appendix D.

APPENDIX D

IGNITION COMMAND UP TO COMMIT (T-3 SECONDS TO T-0 SECONDS)

As indicated in Table 1, Appendix B, the ALS issues the Time for Ignition signal at T-3 seconds. Figure D-1 shows how this is interlocked with the Ready for Ignition signal (K-59) and power from the launch bus to generate the Ignition Command signal (K-68). As also shown, the 3.3 second Commit Backup Timer (K-96) and the 7.5 and 8 second Launch Failure Timers (K286/77) are simultaneously activated with the Ignition Command. It is important to note that once the Ignition Command is issued, it is locked in by recombining the signal with power from the main GSE bus. The reasons for this were covered in the section on Cutoff functions and engine shutdowns (Appendix G). The Ignition Command starts the Ignition Sequencer which in turn fires the SIB engines in pairs at 100 m.s. intervals (figure D-1). The Ignition Command also performs the following functions:

1. Venting of the fuel pressurizing line. (Fuel spheres supply vent-valve open.)

2. Enables the deluge purge valve to activate in the event an engine out occurs.

3. Inhibits the fuel vent opening control valve from operation (except by the Cutoff signal).

4. Enables the gas generator LOX injector purge valve control to remain powered after a Cutoff signal. (This purging operation has already commenced at T-28 seconds but is powered by the launch bus. The Ignition Command allows this operation to continue in the event of Cutoff because the Cutoff signal will de-energize the launch bus.)

5. Unsafes the engine CONAX valve squibs. (The CONAX squibs are required in the engine shutdown sequence.)

6. Enables the individual engine-out commands from the Combustion Stability Monitor (if used).

7. Enables the following cutoff interlock gates to issue the Cutoff signal in the event that the parameter represented is unsatisfactory:

   a. SC Ready

   b. EDS Ready

   c. Fire Detection System

   d. Networks #1 OK

   e. Networks #2 OK

   f. SIVB Ready to Launch

   g. IU Ready to Launch.

In the nominal sequence of operations following the Ignition Command, main propellant ignition results in thrust build-up. Three "thrust OK" voting relays in each engine will satisfy the All Engines Running interlock when sufficient thrust has been achieved based on majority voting by the pressure switches.

APPENDIX E

REQUIREMENTS FOR ISSUANCE OF COMMIT

As shown in figure E-1, the Commit interlock (K-86) gate is comprised of three parameters:

1. All Engines Running (K-81) - In the nominal sequence of events following Ignition Command, main propellant ignition results in thrust build-up. Three "thrust OK" relays in each engine operate on a majority voting of the pressure switches during this period. As soon as sufficient thrust has built up in all engines, this signal is sent to the Commit gate. The signal must be sent prior to the Time for Commit signal or Cutoff will be sent (see figure G-1).

2. Time for Commit (K-71) - As shown in figure E-1, this signal is originated from either of two sources. At T-0, the ALS issues a signal and 0.3 seconds later the Commit Backup Timer (K-96) also issues a signal, either of which is combined with power from the launch bus to generate the Time for Commit signal. The output from either the ALS or the Commit Backup Timer will lock-in the Time for Commit signal.

3. Cutoff (K-72) - The Commit signal cannot be issued if the Cutoff signal is present.

APPENDIX F

COMMIT T-0 SECONDS

Issuance of the Commit signal nominally constitutes a point of no return. Only a failure to liftoff within 5 seconds will allow the SIB engines to be automatically shut down and the space vehicle remain on the pad.

As shown in Figure E-1, once the parameters for the Commit interlock gate are satisfied, the Commit signal (K-86) is issued and the following actions are initiated:

1. Holddown release #1 and #2 - the release mechanisms are energized by the Commit signal in addition to initiating LOX mast retraction and fuel mast retraction by the same D.C. power modules.

2. Swing arm retraction - the commit signal causes the retraction mechanism to be energized.

3. Causes all Cutoff gates to be bypassed (see Figure G-1) with the exception of the 7.5 and 8 second Launch Failure Timers; also the Emergency Manual Cutoff Switch.

4. De-energizes the following buses:

   a. Commit Bus ($^{+}$1D113).

   b. Launch Bus ($^{+}$1D116) - through loss of $^{+}$1D113.

   c. IU oriented power transfer bus ($^{+}$6D121).

   d. IU oriented indication bus ($^{+}$6D119).

   e. IU oriented Commit bus ($^{+}$6D131).

   f. Indication Bus ($^{+}$1D119).

   g. SIVB oriented Commit bus ($^{+}$4D113).

   h. SIVB stage indication bus ($^{+}$4D119).

5. De-energizes the Combustion Stability Monitor (if it has been used).

Release of the holddowns and ejection of the fuel and LOX masts occur simultaneously, allowing the space vehicle to commence liftoff. All electrical cables remain connected to the vehicle until after vehicle first motion (in case of liftoff failure). Therefore, the Commit signal energizes and arms the umbilical arm release and retract system. When the vehicle lifts off, the umbilical swing arm control switches close activating the eject and retract valves.

APPENDIX G

CUTOFF FUNCTIONS AND ENGINE SHUTDOWNS

Figure G-1 shows the functional relationship of the parameters which comprise the Cutoff (K72) interlock gates and shutdown of the SIB engines. The Cutoff modes are considered operationally in three categories.

1. Prior to Ignition Command

As shown in Figure G-1, the only two ways the Cutoff signal can be issued prior to the Ignition Command are:

a. Sequencer Failure Cutoff - This can only occur at T-3 seconds when the Time for Ignition signal (K76) is sent by the ALS and the Ready for Ignition interlock chain is not complete.

b. Manual Cutoff - This mode can be utilized at any time, but will not cause an engine shutdown after the Commit signal is issued.

2. Ignition Command up to Commit

These Cutoff modes (see Figures G-1) are in addition to the manual capability already mentioned.

a. SC Ready Cutoff - Enabled by the Ignition Command, this is currently a switch function for the unmanned Saturn IB launches.

b. EDS Ready Cutoff - Enabled by the Ignition Command, this Cutoff mode is essentially comprised of a large number of parameters for the SC and the IU (see Figure E-1), any one of which can cause Cutoff if not in the desired condition.

c. Networks #1 and #2 Voltage OK Cutoff - Enabled by the Ignition Command, this Cutoff mode is initiated if the Networks #1 and #2 voltages from the wide-range voltage monitors are not satisfactory.

d. IU Ready Cutoff - Enabled by the Ignition Command, this Cutoff mode essentially represents only four parameters, any one of which can initiate the Cut-off signal through a malfunction. Three of these are electrical power parameters (56 Volts OK, 400 Cycle Power and Control Voltage OK). The fourth parameter, absence of LVDA Fire Commit Inhibit (see Figure A-2), is an output from the IU.

e. SIVB Ready to Launch Cutoff - Enabled by the Ignition Command, this Cutoff mode monitors the SIVB power transfer switches in the internal position and that networks malfunctions have not occurred.

f. Fire Detection Cutoff - Also enabled by the Ignition Command, this Cutoff mode is slightly different from the other modes enabled by the Ignition Command in that an output is required from the Fire Detection System "rate of rise" thermocouples in order to complete the gate and send the Cutoff signal. As shown in Figure G-1, the Cutoff gates already mentioned are kept from interlocking by a previously established output signal. Cutoff will be sent if the signal should drop out. It should be noted that the interlocks in (a) thru (e) above are also part of the Ready for Ignition interlock chain.

g. Thrust Failure Cutoff - At T-0 seconds, this Cutoff gate will generate the Cutoff signal if sufficient thrust has not built-up in all engines to activate the All Engines Running relay.

h. Premature Commit Cutoff - If the Commit signal is inadvertently activated prior to the Time for Commit (K71) signal from the ALS, this gate will send the Cutoff signal. The Commit signal normally energizes the Vehicle Cutoff Bus (+1D14). Thus, if the Vehicle Cutoff Bus is activated before the Time for Commit signal, this interlock chain will be completed and Cutoff will be sent.

3. Commit to Liftoff

a. Liftoff Failure Cutoff - As previously mentioned, the two Launch Failure Timers are activated simultaneously with the Ignition Command. Eight seconds later, the timers activate. If liftoff has not occurred, the Cutoff signal will be sent (see Figures D-1 and G-1).

It should be noted that the nominal engine shutdown sequence of operations is accomplished by firing the engine CONAX valve squibs. This results in closure of the main LOX valves causing the turbopump speed and pressure to decay. This in turn closes the main fuel valve. The interlock system is set up such that a Cutoff signal issued prior to the Ignition Command will not fire the engine CONAX valve squibs. This is the reason for locking-in the Ignition Command signal (previously referred to in Appendix D) when it is issued, and making it an integral part of the Cutoff path to the SIB engines (see Figure G-1).

The Emergency Manual Cutoff Switch initiates engine shutdown and Cutoff in a slightly different manner than any of the interlock modes utilizing the K-72 Cutoff relay. As shown in Figure G-1, this switch is not interlocked in bypassing the K-72 cutoff gates. It directly initiates the engine shutdown sequence by first sending an engine shutdown signal to the inboard engines and the Launch Sequencer. One hundred m.s. later, the Ignition Sequencer sends a shutdown command to the outboard engines. The 4-4 Cutoff Timer (K116) sends a backup Cutoff signal to the outboard engines 300 m.s. after the inboard engine shutdown command. The important difference between the Emergency Manual Cutoff mode and the modes involving the Cutoff interlock gate is that the emergency mode can be initiated at any time--even after Commit has been sent. The only other engine shutdown capability (from the GSE) after Commit is thru the Launch Failure Timers. The Emergency Manual Cutoff Switch provides a backup in case the timers should fail. This switch is not intended to be used prior to the Ignition Command, even though it would eventually cause the interlocked Cutoff signal to be issued. Since the emergency mode directly fires the inboard engine CONAX valve squibs, as opposed to the Cutoff signal which cannot reach the vehicle until after the Ignition Command, an Emergency Cutoff prior to Ignition Command would necessitate replacing the engine CONAX valve squibs.

In reference to Figure G-1, once the Ignition Command signal is issued, a Cutoff signal from any source (including the Emergency Manual Cutoff) results in the same events. Those events of major interest (within 300 m.s. after the Cutoff signal) are:

1. Inboard engine shutdown command (inboard engine CONAX valve squibs immediately fired). Signal to Ignition Sequencer and 4-4 Cutoff Timer.

2. 100 m.s. after the inboard engine shutdown command, the Ignition Sequencer sends a shutdown command to the outboard engines.

3. 300 m.s. after inboard engine shutdown command, the 4-4 Cutoff Timer actuates and sends a backup shutdown command to the outboard engines.

4. Power to the ALS is interrupted causing sequencer shutdown.

5. De-energize the thrust chamber fuel injector purge valve control (prior to the All Engines Running signal which also does this).

6. Locks the Cutoff signal in.

7. Energizes engine purge to on.

8. Energizes the gas generator LOX injector purge valve control.

9. Energizes LOX dome purge valve control.

10. Energizes fuel vent opening control.

11. Launch bus is de-energized which returns the vehicle to ground power.

12. Loss of the launch bus de-energizes:

    a. EDS Ready (K-24).

    b. Commit Back-up Timer (K-96).

    c. Time for Commit (K-71).

    d. Firing Command (K-26).

13. Closes LOX and fuel prevalves.

14. Opens fuel vent valves.

15. Starts deluge purge.

APPENDIX H

1. SUBJECT: Apollo/Saturn Launch Interlocks

2. PURPOSE: This document sets forth the objective, design philosophy and criteria for design of launch interlocks in the Apollo/Saturn program.

3. OBJECTIVES:

As limited and rigid launch opportunities will be available for the Saturn/Apollo missions, it is important that the checkout and launch system be designed to give maximum assurance that:

(1) A launch will be achieved if the space vehicle and essential GSE are in proper operating condition, and conversely,

(2) A safe and orderly hold or shutdown action will be taken if essential readiness criteria are not met at any point in the countdown.

Accordingly, means shall be provided to ascertain the readiness of all essential space vehicle and GSE systems, and to provide for appropriate manual or automated reaction in event of discrepancies.

4. SCOPE:

Interlocks are system elements utilized to provide assurance that each step in the countdown sequence will proceed if, and only if, all essential readiness criteria are met. Interlocks fall into three general categories with respect to time:

(1) Interlocks employed prior to start of the Automatic Launch Sequencer which provide the bases for hold or workaround decisions, or protect hardware and personnel.

(2) Interlocks employed from start of the Automatic Launch Sequencer to issuance of Ignition Command, which will stop the countdown process if readiness criteria are not met.

(3) Interlocks employed between issuance of Ignition Command and Launch Commit, which initiate shutdown if criteria essential for liftoff are not met.

5. CRITERIA FOR INTERLOCK SELECTION

At each step in the countdown the interlock system shall include, and be limited to, those functions and conditions which are prerequisite to proceeding to a safe launch which will accomplish primary mission objectives. Selection of each interlock will be based on demonstration that:

(1) The function or condition is a prerequisite for proceeding to launch.

(2) It is interlocked while and only while it is a prerequisite for progression.

(3) The measured parameter is the best available indicator of the required condition.

(4) All parameter limit values are substantiated by adequate engineering and test data. The limits shall be as wide as possible, consistent with crew safety and mission success.

6. CRITERIA FOR DESIGN AND IMPLEMENTATION

The design and implementation of each interlock function shall provide high assurance that the countdown will proceed if, and only if, the function is satisfactory.

(1) Interlocks shall be accomplished directly and automatically by hardware when reliability and response time considerations demonstrate this to be the preferred method of meeting basic objectives of crew safety and mission readiness.

(2) For equipment design, the Ignition Command shall be regarded as the beginning of the mission, and all GSE and interlock circuitry that could initiate cutoff after Ignition Command shall be designed and qualified as Mission Critical hardware.

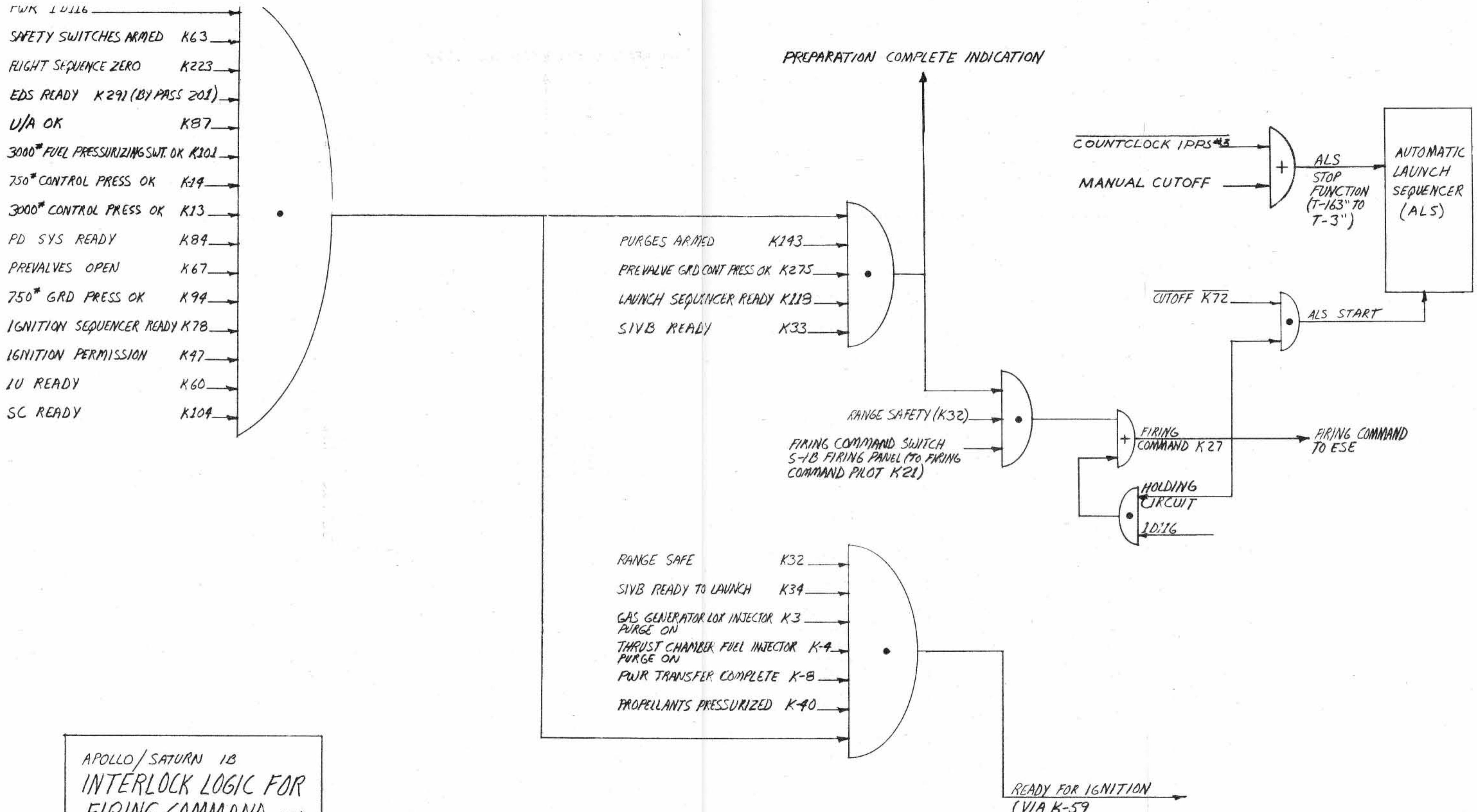
(3) The sensing system and interlock circuitry shall be designed to have reliability better than the system being sensed.

(4) Wherever possible, sensors that are used for interlocking shall be discrete sensors, and should directly sense the media or component that is being measured.

(5) After initiation of Firing Command, the computer discrete output shall be inhibited and any discretes required to be issued during this period come from the Automatic Launch Sequencer/Ignition Sequencer.

(6) The capability to bypass interlock chains in the event of an interlock malfunction shall be provided in the LCC. The bypass implementation which will be used only in the event of substantiated interlock malfunction, shall provide access to the lowest reasonable level of interlock functions.

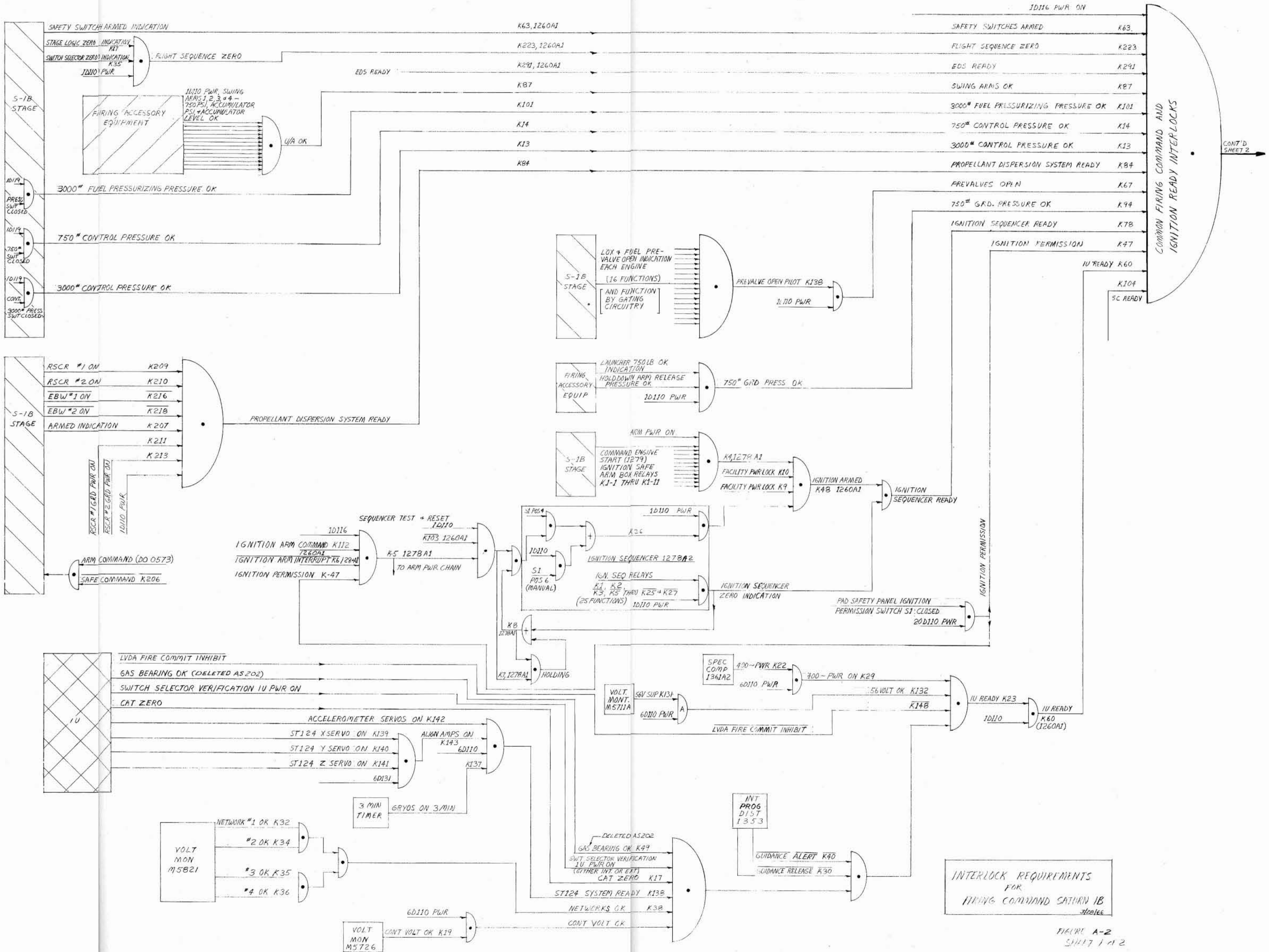
(7) All parameters incorporated in the interlock system shall be available for independent verification in the LCC. Failures which will lead to a hold or a cutoff shall be positively indicated and displayed in a manner which will assure earliest possible recognition for analysis and action.



APOLLO/SATURN IB
INTERLOCK LOGIC FOR FIRING COMMAND AND READY FOR IGNITION
3/28/66

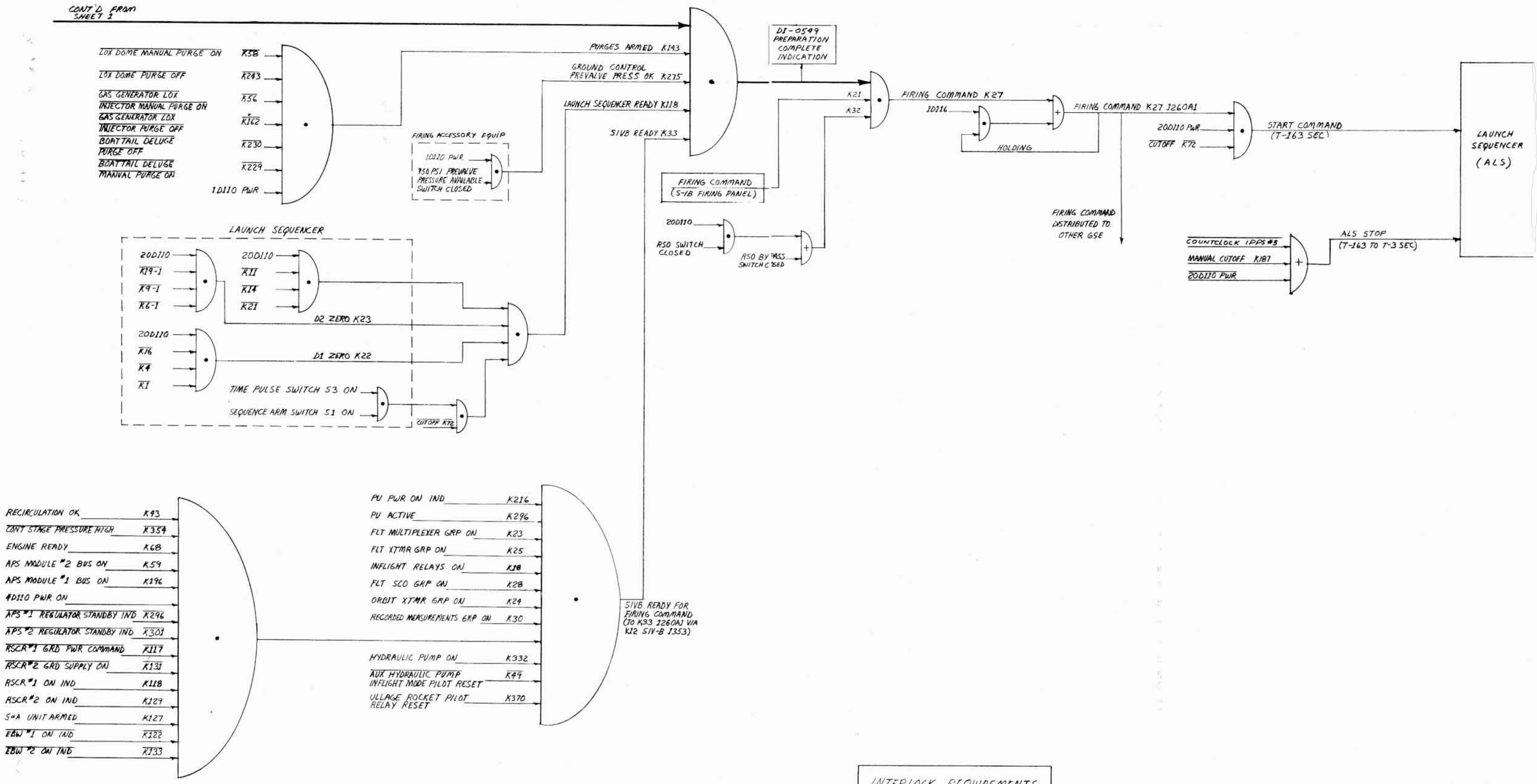
FIGURE A-1

FIGURE A-1



INTERLOCK REQUIREMENTS FOR FIRING COMMAND SATURN IB 3/20/66

FIGURE A-2
SHEET 1 of 2



INTERLOCK REQUIREMENTS FOR FIRING COMMAND — SATURN IB 3/28/66

FIGURE A-2 SHEET 2 of 2

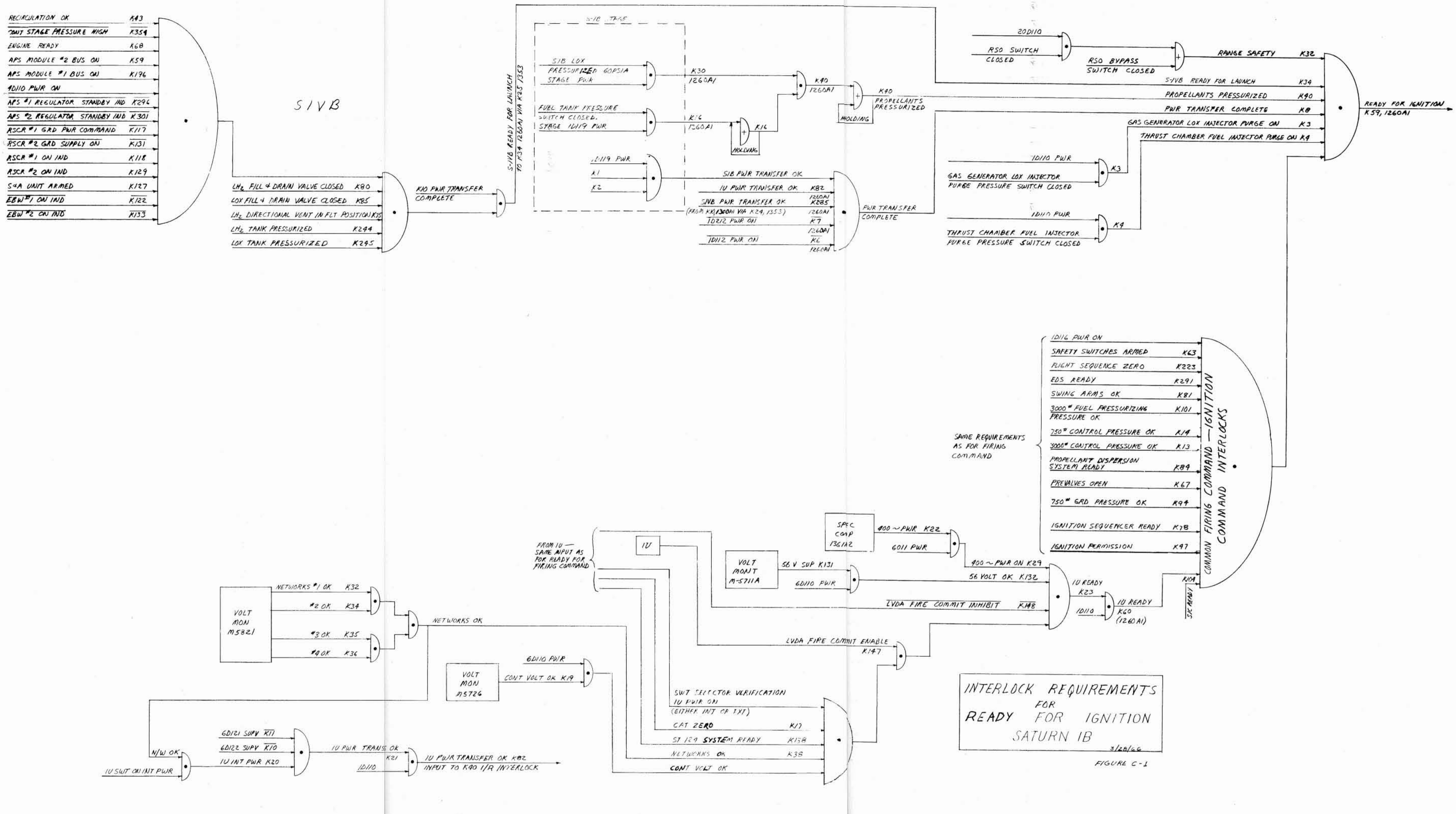
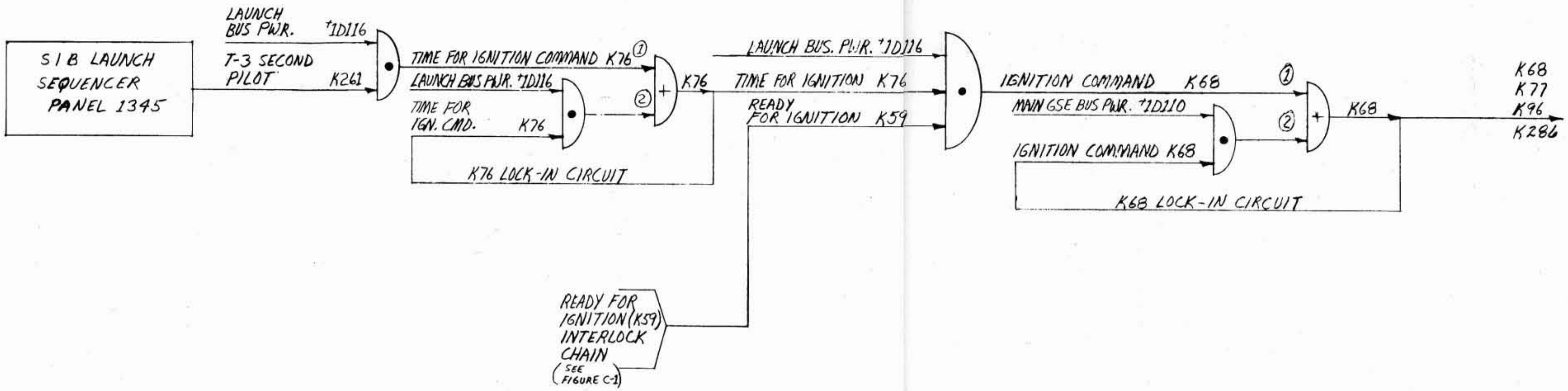

RECIRCULATION OK K43
CONT STAGE PRESSURE HIGH K354
ENGINE READY K68
APS MODULE #2 BUS ON K59
APS MODULE #1 BUS ON K196
4D110 PWR ON
APS #1 REGULATOR STANDBY IND K296
APS #2 REGULATOR STANDBY IND K301
RSCR #1 GRD PWR COMMAND K117
RSCR #2 GRD SUPPLY ON K131
RSCR #1 ON IND K118
RSCR #2 ON IND K129
S&A UNIT ARMED K127
EBW #1 ON IND K122
EBW #2 ON IND K133
S IV B
LH2 FILL & DRAIN VALVE CLOSED K80
LOX FILL & DRAIN VALVE CLOSED K85
LH2 DIRECTIONAL VENT IN FLT POSITION K95
LH2 TANK PRESSURIZED K244
LOX TANK PRESSURIZED K245
K10 PWR TRANSFER COMPLETE
S-IVB READY FOR LAUNCH TO K34 1260A1 VIA K25 1353
S-IB STAGE
SIB LOX PRESSURIZED 60PSIA
STAGE PWR
K30 1260A1
FUEL TANK PRESSURE SWITCH CLOSED
STAGE 1D119 PWR
K16 1260A1
K16
HOLDING
K90 1260A1
K90 PROPELLANTS PRESSURIZED
HOLDING
1D119 PWR
K1
K2
SIB PWR TRANSFER OK
IU PWR TRANSFER OK K82
SIVB PWR TRANSFER OK K285
(FROM K10)1300H VIA K24, 1353
1D212 PWR ON K7
1D112 PWR ON K6
PWR TRANSFER COMPLETE
20D110
RSO SWITCH CLOSED
RSO BYPASS SWITCH CLOSED
RANGE SAFETY K32
S-IVB READY FOR LAUNCH K34
PROPELLANTS PRESSURIZED K90
PWR TRANSFER COMPLETE K8
GAS GENERATOR LOX INJECTOR PURGE ON K3
THRUST CHAMBER FUEL INJECTOR PURGE ON K4
READY FOR IGNITION K59, 1260A1
1D110 PWR
GAS GENERATOR LOX INJECTOR PURGE PRESSURE SWITCH CLOSED
K3
1D110 PWR
THRUST CHAMBER FUEL INJECTOR PURGE PRESSURE SWITCH CLOSED
K4
1D116 PWR ON
SAFETY SWITCHES ARMED K63
FLIGHT SEQUENCE ZERO K223
EDS READY K291
SWING ARMS OK K81
3000# FUEL PRESSURIZING PRESSURE OK K101
750# CONTROL PRESSURE OK K14
3000# CONTROL PRESSURE OK K13
PROPELLANT DISPERSION SYSTEM READY K89
PREVALVES OPEN K67
750# GRD PRESSURE OK K94
IGNITION SEQUENCER READY K78
IGNITION PERMISSION K97
SAME REQUIREMENTS AS FOR FIRING COMMAND
COMMON FIRING COMMAND — IGNITION COMMAND INTERLOCKS
SPEC COMP 1361A2
400~PWR K22
6D11 PWR
400~PWR ON K29
IU
VOLT MONT M-5711A
56 V SUP K131
6D110 PWR
56 VOLT OK K132
LVDA FIRE COMMIT INHIBIT K148
IU READY K23
1D110
IU READY K60 (1260A1)
K10A
56 READY
FROM IU — SAME INPUT AS FOR READY FOR FIRING COMMAND
VOLT MON M5821
NETWORKS #1 OK K32
#2 OK K34
#3 OK K35
#4 OK K36
NETWORKS OK
LVDA FIRE COMMIT ENABLE K147
VOLT MON M5726
6D110 PWR
CONT VOLT OK K19
SWT SELECTOR VERIFICATION IU PWR ON (EITHER INT OR EXT)
CAT ZERO K17
ST 124 SYSTEM READY K158
NETWORKS OK K38
CONT VOLT OK
6D121 SUPV K11
6D122 SUPV K10
IU INT PWR K20
N/W OK
IU SWT ON INT PWR
IU PWR TRANS OK K21
1D110
IU PWR TRANSFER OK K82 INPUT TO K90 I/R INTERLOCK
INTERLOCK REQUIREMENTS FOR READY FOR IGNITION SATURN IB
3/28/66
FIGURE C-1

FIGURE C-1

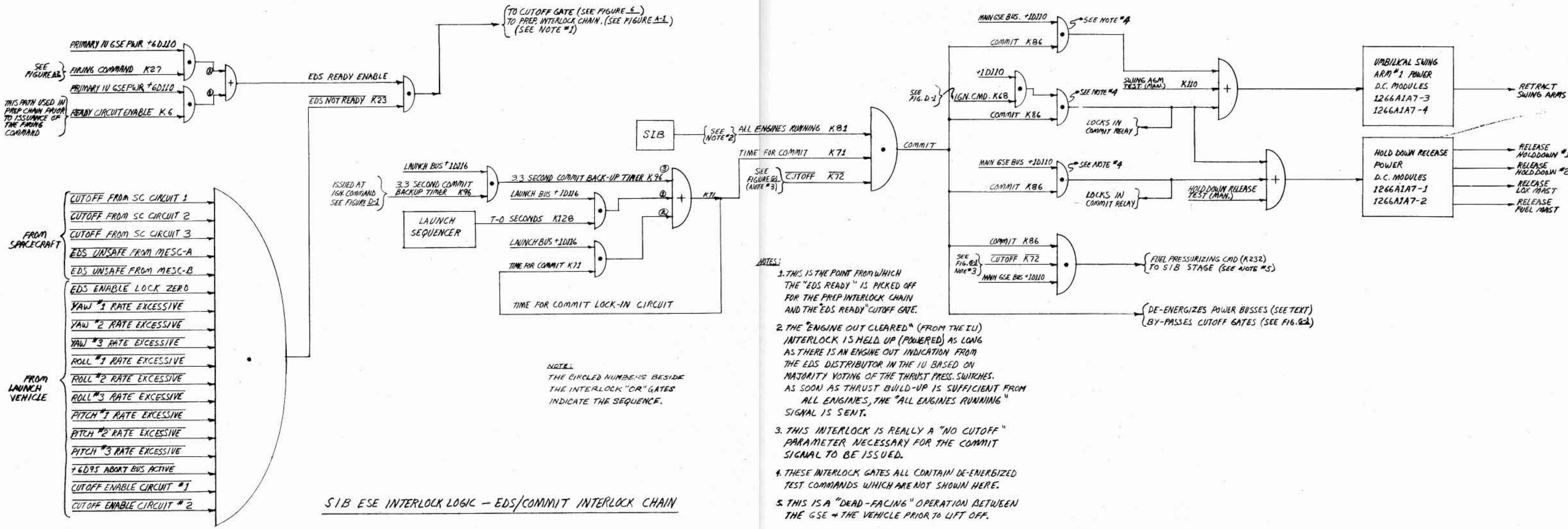


NOTE:
IN ADDITION TO IGNITION COMMAND, (K68) THIS ALSO SIMULTANEOUSLY ACTIVATES THE 3.3-SECOND COMMIT BACKUP TIMER (K96), THE 8-SECOND LAUNCH FAILURE TIMER (K77), AND THE 7.5 SECOND LAUNCH FAILURE TIMER (K286)

NOTE:
THE CIRCLED NUMBERS BESIDE THE INTERLOCK "OR" GATES INDICATE THE SEQUENCE.

SIB ESE INTERLOCK LOGIC — IGNITION COMMAND

FIGURE D-1



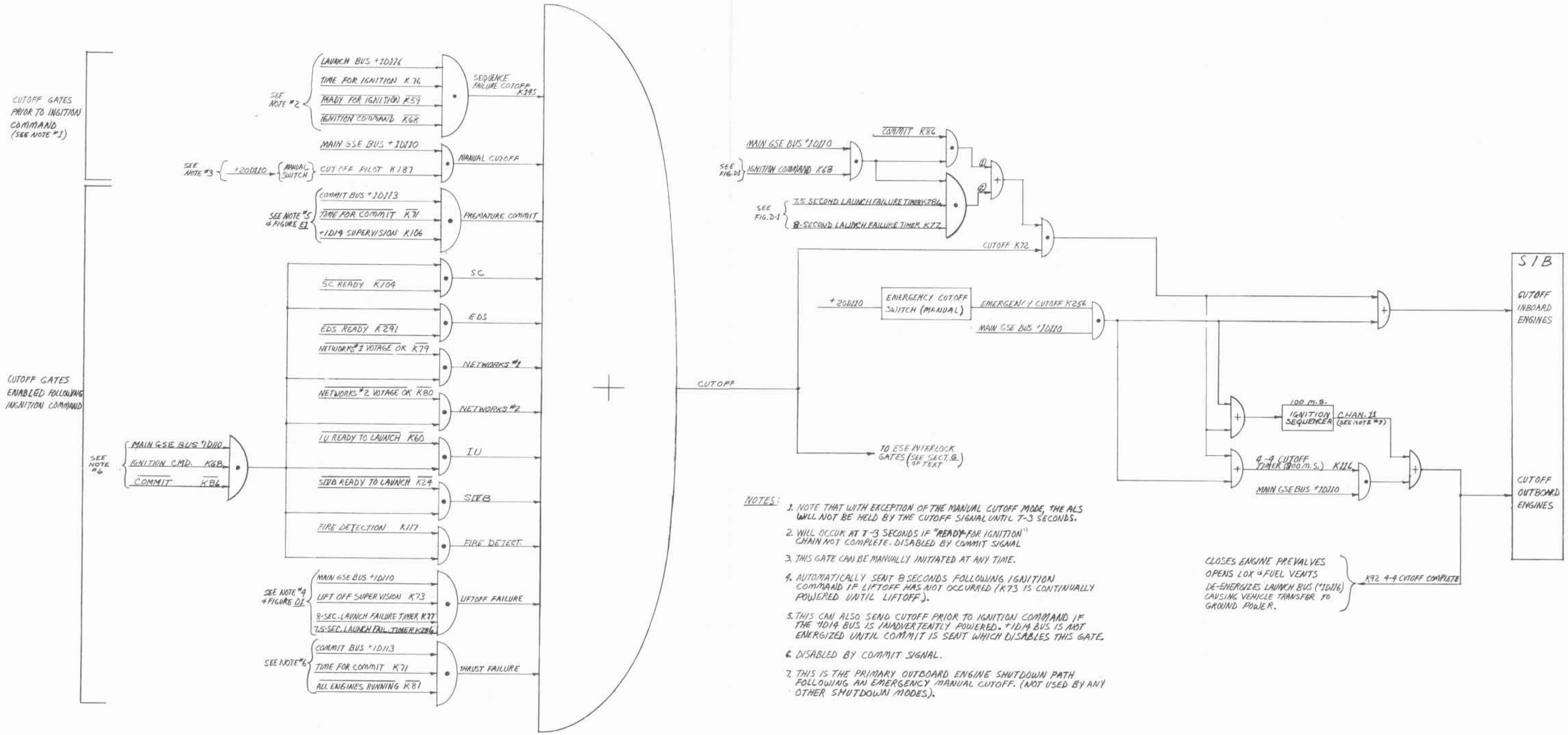
NOTE:
THE CIRCLED NUMBERS BESIDE THE INTERLOCK "OR" GATES INDICATE THE SEQUENCE.

NOTES:

1. THIS IS THE POINT FROM WHICH THE "EDS READY" IS PICKED OFF FOR THE PREP INTERLOCK CHAIN AND THE "EDS READY" CUTOFF GATE.
2. THE "ENGINE OUT CLEARED" (FROM THE IU) INTERLOCK IS HELD UP (POWERED) AS LONG AS THERE IS AN ENGINE OUT INDICATION FROM THE EDS DISTRIBUTOR IN THE IU BASED ON MAJORITY VOTING OF THE THRUST PRESS. SWITCHES. AS SOON AS THRUST BUILD-UP IS SUFFICIENT FROM ALL ENGINES, THE "ALL ENGINES RUNNING" SIGNAL IS SENT.
3. THIS INTERLOCK IS REALLY A "NO CUTOFF" PARAMETER NECESSARY FOR THE COMMIT SIGNAL TO BE ISSUED.
4. THESE INTERLOCK GATES ALL CONTAIN DE-ENERGIZED TEST COMMANDS WHICH ARE NOT SHOWN HERE.
5. THIS IS A "DEAD-FACING" OPERATION BETWEEN THE GSE + THE VEHICLE PRIOR TO LIFT OFF.

S1B ESE INTERLOCK LOGIC – EDS/COMMIT INTERLOCK CHAIN

FIGURE E-1



NOTES:

1. NOTE THAT WITH EXCEPTION OF THE MANUAL CUTOFF MODE, THE ALS WILL NOT BE HELD BY THE CUTOFF SIGNAL UNTIL T-3 SECONDS.
2. WILL OCCUR AT T-3 SECONDS IF "READY-FOR IGNITION" CHAIN NOT COMPLETE. DISABLED BY COMMIT SIGNAL
3. THIS GATE CAN BE MANUALLY INITIATED AT ANY TIME.
4. AUTOMATICALLY SENT 8 SECONDS FOLLOWING IGNITION COMMAND IF LIFTOFF HAS NOT OCCURRED (K73 IS CONTINUALLY POWERED UNTIL LIFTOFF).
5. THIS CAN ALSO SEND CUTOFF PRIOR TO IGNITION COMMAND IF THE +1D14 BUS IS INADVERTENTLY POWERED. +1D14 BUS IS NOT ENERGIZED UNTIL COMMIT IS SENT WHICH DISABLES THIS GATE.
6. DISABLED BY COMMIT SIGNAL.
7. THIS IS THE PRIMARY OUTBOARD ENGINE SHUTDOWN PATH FOLLOWING AN EMERGENCY MANUAL CUTOFF. (NOT USED BY ANY OTHER SHUTDOWN MODES).

SIB ESE INTERLOCK LOGIC — CUTOFF PARAMETERS AND ENGINE SHUTDOWN

FIGURE G-1

FIGURE G-1