BELLCOMM, INC. 64-216-4-1

COMMAND MODULE
PROGRAMMERS FOR
UNMANNED APOLLO MISSIONS

June 15, 1964

By: C. M. Klingman
J. L. Marshall

Work Performed for Manned Space Flight, National Aeronautics and Space Administration, as part of Task 16-4 under Contract NASw-417.

ABSTRACT

Bellcomm has been working in cooperation with NASA's Manned Spacecraft Center and some of its contractors to define the general concepts and system configuration for a Command Module programmer for the unmanned Saturn IB and Saturn V missions. This final report of Bellcomm's activities on the programmer (three earlier reports have been issued) discusses the principal problem areas encountered and recommends a system configuration.

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1.0 INTRODUCTION

Bellcomm has been working in cooperation with NASA's Manned Spacecraft Center (MSC), North American Aviation (NAA), and the Massachusetts Institute of Technology Instrumentation Laboratories (MIT/IL) to define the general concepts and system configuration for a Command Module (CM) programmer for the unmanned Saturn IB and Saturn V missions. The purpose of this programmer is to automate those spacecraft functions (normally manually controlled) necessary to accomplish the unmanned missions.

Bellcomm began this task on February 14, 1964 at NASA's request (initiated by the Apollo Spacecraft Project Office). This final report discusses the principal problem areas encountered and recommends a system configuration. The recommended configuration is essentially the same as that presented by NAA to MSC on April 27th.

The Appendix lists three earlier Bellcomm reports and summarizes the meetings and conferences in which Bellcomm participated since beginning the task.

2.0 BACKGROUND

The first Saturn IB mission (Launch Vehicle 201, Airframe 009) is planned as a lob shot with Command Module entry at 29,000 fps. Airframe (AFRM) 009 will not contain a guidance system, and its maneuvers will be controlled by a programmer. This programmer had progressed into the design stage when this task was initiated, and Bellcomm did not examine its performance in detail.

The programmer concepts discussed in this report are based upon use of the Command Module guidance computer as the prime spacecraft sequencer. In the present plan, the spacecraft guidance system is first flown on the second Saturn IB flight (Launch Vehicle 202, AFRM 011).

Two types of unmanned Saturn IB missions were considered. The first, currently planned for Launch Vehicle 202, consists of an earth orbital phase (105 nautical miles circular orbit) followed by a propulsive maneuver to achieve a 29,000 fps entry. The entry conditions may be achieved either directly from circular orbit or by first transferring to an elliptical orbit. The other mission type considered is a long duration earth orbital flight (approximately 24 hours) using the service propulsion system to deorbit.

During the course of the task, it became apparent that the spacecraft hardware and trajectories for the unmanned Saturn V flights, 501 and 502, contained too many uncertain factors to make firm recommendations as to the programmer requirements for these flights. Therefore, the programmer configuration described in this report applies specifically to the unmanned Saturn IB missions, but it is expected that much of the design will be applicable to the 501 and 502 flights.

3.0 SCOPE

This report discusses the general concepts and system configuration recommended for the Command Module programmer for the unmanned Saturn IB missions described above. The principal problem areas investigated were as follows:

a. the equipment to be used for the prime mission sequencing function,

b. the method for aligning the backup attitude reference system, and

c. the equipment to be used for backup sequencing.

The configuration presented in this report satisfies the guidelines and assumptions established at the beginning of this task,* with the exception that alignment of the backup attitude reference system is not independent of the primary initial measurement unit (IMU). Updating the backup attitude reference from the IMU is now considered satisfactory, primarily because of the simplicity of implementing the updating scheme.

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*See report number 1 in Appendix.

4.0 EQUIPMENT CONFIGURATION

A simplified block diagram of the CM programmer for the unmanned Saturn IB missions is shown in Figure 1. The main components are the Apollo Guidance Computer (AGC), the Body Mounted Attitude Gyros (BMAG's), and an electromechanical sequencer of the type to be used in the programmer for AFRM 009. The AGC is used to control both the mission sequencing functions and the normal guidance functions, including alignment of the IMU. The BMAG's, their alignment periodically updated from the IMU, serve as a backup attitude reference which would be used in conjunction with the electromechanical sequencer to return the spacecraft in the event of a Guidance and Navigation (G&N) failure. Other components shown in the figure are the following: (1) the Master Caution and Warning System (MCWS), used to monitor spacecraft systems and to send failure signals to the AGC, the drivers, and the ground (via the DDL); (2) a modified display and keyboard (DSKY), used to extend the input/output capabilities of the AGC; (3) drivers, used to provide an interface between the programmer equipment and spacecraft systems; and (4) the Up Data Link (UDL) and Down Data Link (DDL), used to transfer information between the spacecraft and ground.

4.1 Prime Sequencer

The prime sequencer for the unmanned missions is the AGC. Discussions with MIT/IL* have confirmed that although some further design effort will be required, it is entirely feasible to use the AGC to perform both the mission sequencing functions and the normal guidance functions. Both the portion of memory available for mission sequencing and the portion of time during which the AGC would be available for performing mission sequencing functions appear to be adequate. The problem of writing, debugging and fabricating the programs for the mission sequencing functions would require a close interface between NAA and MIT/IL. The only equipment change required would be the modification of a DSKY to extend the present input/output capability of the AGC and thus provide the means for the AGC to perform the additional tasks. On the unmanned missions this modified DSKY would be substituted for the DSKY on the main panel, but the DSKY on the navigation panel would be unchanged.

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*See report number 2 in Appendix

The modified DSKY would be fabricated with the same type of decoder and relay matrix as is presently used in the DSKY's being fabricated for use on the manned missions. A basic guideline to be followed in the design of the modified DSKY is that it shall be designed such that the present DSKY programs will not operate any relays in the modified DSKY, and the mission sequencing programs will not operate any relays in the DSKY on the navigation panel. With this type of design the DSKY on the navigation panel may be used in conjunction with pre-launch checkout activities without any modification of the present DSKY programs.

The design of the modified DSKY should be such that the AGC can determine the state of output relays controlling critical functions. It is suggested that this be accomplished by reserving one set of the two sets of contacts on each output relay for the purpose of providing an input to the AGC.

It is suggested that the following guidelines be followed in determining the functions to be controlled by the AGC:

a. The AGC should be used as a time sequencer and/or logic device, not merely as a "piece of wire".

For example, if, when fail signal A occurs, relay B is to be operated, and it is to be operated independent of any other timing or logic considerations, then signal A should be connected directly to relay B and not via the AGC.

b. The AGC should not be part of an active servo loop in the non-G&N subsystems.

The purpose of this guideline is to prevent an AGC failure from causing the failure of other subsystems.

c. The AGC should not be the sole source for switching those systems which could induce AGC failures.

For example, the AGC should not be the only means for switching its own electrical power. Observance of this guideline will reduce the probability of a single failure causing an abort.

d. The capability should exist for transferring command to and from the AGC via GOSS.

If this guideline is adhered to, the following two types of situations can be corrected from the ground: 1) a transient condition which resulted in an AGC failure signal, and 2) a faulty AGC which has not generated a fail signal. Although it is anticipated that the probability of the occurrence of either of these situations will be extremely low, the small amount of switching circuitry required to provide the ground with the capability of correcting for either case is considered to be completely justified.

4.2 Backup Attitude Reference

The backup attitude reference system consists of the body mounted attitude gyros and Attitude Gyro Coupler Unit (BMAG/AGCU) which are presently a part of the Command Module Stabilization and Control System (SCS). The reference for aligning the BMAG/AGCU will be the primary IMU. The IMU alignment will be automatically updated under command of the AGC. A star tracker device, which is already built into the sextant, will be periodically locked onto preselected stars. The frequency of this updating procedure (approximately once per hour) will be such that, with the maximum acceptable drift rate of the IMU, the proper star will still be within the 0.5 degree square field of view of the star tracker.

The BMAG/AGCU alignment will be periodically updated with the IMU as a reference. Then, in the event of a G&N failure, the BMAG/AGCU can be used as a backup reference for attaining the required attitudes for retro, separation, and entry. The mechanization of this backup capability involves two functions: (1) aligning the backup attitude reference, and (2) using the reference to attain the required attitudes. Independent alignment of the BMAG/AGCU is a desirable feature which could be achieved by using horizon sensors and gyrocompassing or sun sensors, but such an approach would require a significant development effort. Updating the BMAG/AGCU alignment with the primary IMU as a reference is much simpler in terms of both development effort and hardware changes and additions, since most of the signals required are already present in the SCS. Several methods for accomplishing this updating are possible, but they are quite similar in principle and vary only in the details of mechanization or operation. This section describes one updating procedure and suggests a further modification that would remove some operational constraints.

Following is an outline of the updating procedure:

a. The SCS is placed in the "G&N Attitude Control Mode" and the 0.5 degree deadband is selected.

b. The spacecraft is maneuvered to a predetermined reference attitude under command of the AGC. The reference attitude could be stored in the AGC or commanded from the ground via the UDL and the AGC.

c. After the reference attitude has been obtained, the BMAG/AGCU is aligned to this reference by actuating the "FDAI ALIGN" switch. This causes the AGCU shafts to rotate until the differences between the AGCU shaft positions and the attitude set thumbwheel positions on the Attitude Set/Gimbal Position Display (AS/GPD) are zero.

d. It is expected that the SCS will be placed in the "G&N Attitude Control Mode" during most of the mission. When the spacecraft is maneuvered under control of the G&N system in this mode, the BMAG/AGCU system will remember the reference attitude to which it was aligned. That is, the BMAG's sense any change in attitude and generate error signals that are used to torque the BMAG's back to their null position. The time integral of the torquing signals represents the change in attitude. The AGCU combines this change with the previous known attitude to yield the present attitude of the spacecraft relative to the reference.

e. Steps a, b, and c are repeated periodically to remove the effect of accumulated errors.

f. If a G&N failure should occur, it would be necessary to maneuver the spacecraft back to the reference attitude attained in step b, using the BMAG/AGCU as a reference.

The suggested method for attaining this reference attitude requires a relatively simple SCS modification. In the present mechanization, signals representing the difference between the AGCU shaft positions and the attitude set thumbwheel positions are generated in the AS/GPD. Normally, these signals are used only for aligning the AGCU or for display. However, they could be used as error signals to drive the spacecraft to the reference attitude.

g. Once a reference attitude is obtained, other predetermined attitudes for retro, separation, and entry are achieved by torquing the appropriate gyro with a fixed current for a given amount of time. The torquing times would be preset in the backup sequencer described later.

With the procedure described, it is necessary to drive the spacecraft to the reference attitude each time the BMAG/AGCU alignment is updated. This requirement can be eliminated by providing additional resolvers and motor-tachometers of the type already used in the SCS. Signals representing the IMU gimbal angles are presently used by the SCS for display purposes. These signals could be used in conjunction with the additional resolvers and motor-tachometers to align the AGCU to the IMU Euler angles without the need for repositioning the spacecraft. The alignment process would be fast and could be performed quite often. Signals representing the difference between the IMU Euler angles and the AGCU shaft angles would also be available, so the alignment procedure could be inhibited in the event of a large discrepancy indicating a possible IMU failure. Although the additional capability described in this paragraph requires extra components, the modification is not a complex one and it should be carefully considered.

A basic limitation of this backup attitude reference system is its high drift rate. When the SCS is in a G&N mode with the BMAG/AGCU in the attitude follow configuration, the BMAG torquing amplifiers are continuously connected to the gyros. The specification on the torquing amplifiers is such that a bias equivalent to a gyro drift rate of about 10 degrees per hour is possible. This makes it necessary to update the BMAG/AGCU alignment often. Since it should not be difficult to provide a torquing amplifier with a much lower bias, it is suggested that the specification on this parameter be changed and the torquing amplifier redesigned if necessary.

It is expected that the BMAG/AGCU could be aligned to within one degree of the IMU alignment. The actual retro and entry attitude errors would depend upon several additional factors, including drift rate, AGCU integration errors, SCS deadband, torquing errors during timed attitude maneuvers, and BMAG non-orthogonality. The AGCU integration errors are a function of the magnitude of the angles through which the spacecraft is rotated while the BMAG/AGCU is in an attitude follow configuration. They would accumulate only during attitude changes commanded by the G&N system. The torquing errors are those generated while the gyros are being torqued to provide an attitude change for retro, separation, or entry. They are due to factors such as scale factor, power supply and torquing time errors. It is expected that the total attitude error at entry would be less than 10 degrees.

4.3 Backup Sequencing

The rest of the backup equipment is required to initiate the abort at the proper time and to sequence the various abort maneuvers needed to return the spacecraft in case of an AGC failure. A simplified block diagram of this equipment is shown in Figure 2. The time to initiate an abort is set into a match register via the UDL. When the time, as indicated by the central timing equipment (CTE), matches this pre-set time, a start signal will be sent to an electromechanical sequencer which will sequence the abort functions. The 1 out of 16 selection circuit is used to provide up to 16 different pitch attitudes. Since the BMAG/AGCU will be referenced to an inertial coordinate system rather than a local vertical system, aborts at different mission times would necessitate different pitch maneuvers to provide the same retro attitude relative to the local vertical. Thus, if it is assumed that the capability of performing an abort once per orbit is satisfactory, this selector would be adequate for a 24-hour earth orbital mission.

It has been assumed that the amount of ΔV required for the retro maneuver would not be a variable. However, if this is shown to be a significant limitation, a simple selector circuit could also be added for ΔV selection. This would probably be only a 1 out of 2 or 1 out of 4 selector, which would be simpler than the one suggested for choosing pitch attitude.

The sequencer shown in Figure 2 would be of the type used on the Agena vehicle. This is a motor driven device which provides switch closures at up to 22 discrete times selectable over a range of 0 to 6000 seconds with a resolution of 0.5 second. It reportedly is a very reliable device with a failure rate of 138×10^{-6} per 1000 hours. Sequencers of this type will be used in the programmer for AFRM 009.

The switching circuitry shown between the match register and the sequencer provides for the ground to control whether or not a fail signal from the AGC will allow the output signal from the match register to start the abort sequencer. Whether the ground must initiate an abort or whether an AGC failure will cause an abort to be initiated at the time specified by the match register is not yet resolved. For this reason, and since the desirable source for initiating an abort may be dependent upon a particular mission or portion of a mission, the capability of operating in either mode is shown.

Both the match register and the 1 out of 16 selection circuit can be mechanized with relay circuitry, using approximately 44 relays for the match register and 20 relays for the selector. The match register could be expanded to provide another timed output at the expense of approximately 24 relays. It should also be noted that if the time accumulator in the CTE had the capability of being updated via the UDL, the match register could be eliminated. At present, it is not clear whether the CTE will have this capability.

It is considered highly desirable for the ground to be able to verify the state of all of the relays in the match register and selector that have been controlled by the ground. One method of providing this capability would be to fabricate these units with magnetic-latching relays which have one spare set of contacts. This set of contacts could then be sampled by the PCM system and thereby provide the ground with the ability of checking if a command has been properly executed.

It is expected that when consideration is given to all of the details of the programmer requirements, more than one match register, selector, and/or sequencer may be required. However, since the purpose of this backup system is merely to provide recovery of the spacecraft and not completion of the mission, the amount of equipment should not exceed two or three of each of these units.

Although consideration was given to using another AGC as the backup sequencer,* it is felt that the approach described above is the best solution in terms of complexity. However, it is recognized that the use of another AGC would probably require less overall development effort.

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*See report number 3 in Appendix.

5.0 SUMMARY

An Apollo spacecraft programmer configuration suitable for the unmanned Saturn IB missions beginning with SA 202 has been presented. Key issues in the programmer concept discussed in this report are:

a. the use of the AGC as the prime mission sequencer,

b. the method of updating the BMAG/AGCU attitude reference from the IMU so that the BMAG's can be used as a backup attitude reference, and

c. the use of electromechanical sequencers to control de-orbit maneuvers should the AGC fail.

C. M. Klingman

C. M. Klingman

J. L. Marshall

J. L. Marshall

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APPENDIX

Meetings and Conferences

February 19	Visit to NAA to obtain background material on the proposed CM mission programmers.
February 24-25	Conference at NAA to assist NASA/ASPO and NAA in establishing a mutually acceptable set of guidelines under which NAA could proceed to define programmer requirements.
March 4	Conference at MIT to discuss the capabilities of the AGC as a prime sequencer for the unmanned missions.
March 16-17	Conference at MIT with NAA and MIT to discuss the G&N role in the unmanned missions.
March 24-25	Conference at NAA to discuss NAA's programmer concepts.
April 1	Visit to NAA to review a programmer presentation by NAA for MSC.
April 6	Presentation by NAA to MSC.
April 10	Visit to MIT to discuss interconnection of two Block I AGC's to serve as prime sequencer.
April 21	Conference at NASA Headquarters with J. F. Shea of MSC to discuss Bellcomm's concepts of the unmanned mission programmers.
April 22	Visit to MIT to monitor meeting between MIT and NAA to review AGC capabilities.
April 23	Visit to Bellcomm by NAA to present latest NAA concepts on programmers.
April 27	Presentation by NAA to MSC.

Bellcomm Reports

1. Bellcomm Activities on Programmers for Unmanned Apollo Missions, February 28, 1964, C. R. Moster

2. Bellcomm Activities on Programmers for Unmanned Apollo Missions, (Interim Progress Report), March 13, 1964, C. M. Klingman and J. L. Marshall.

3. Two Block I AGC's Inter-connected to Function as Prime Sequencer for Unmanned Apollo Missions, April 21, 1964, C. M. Klingman.

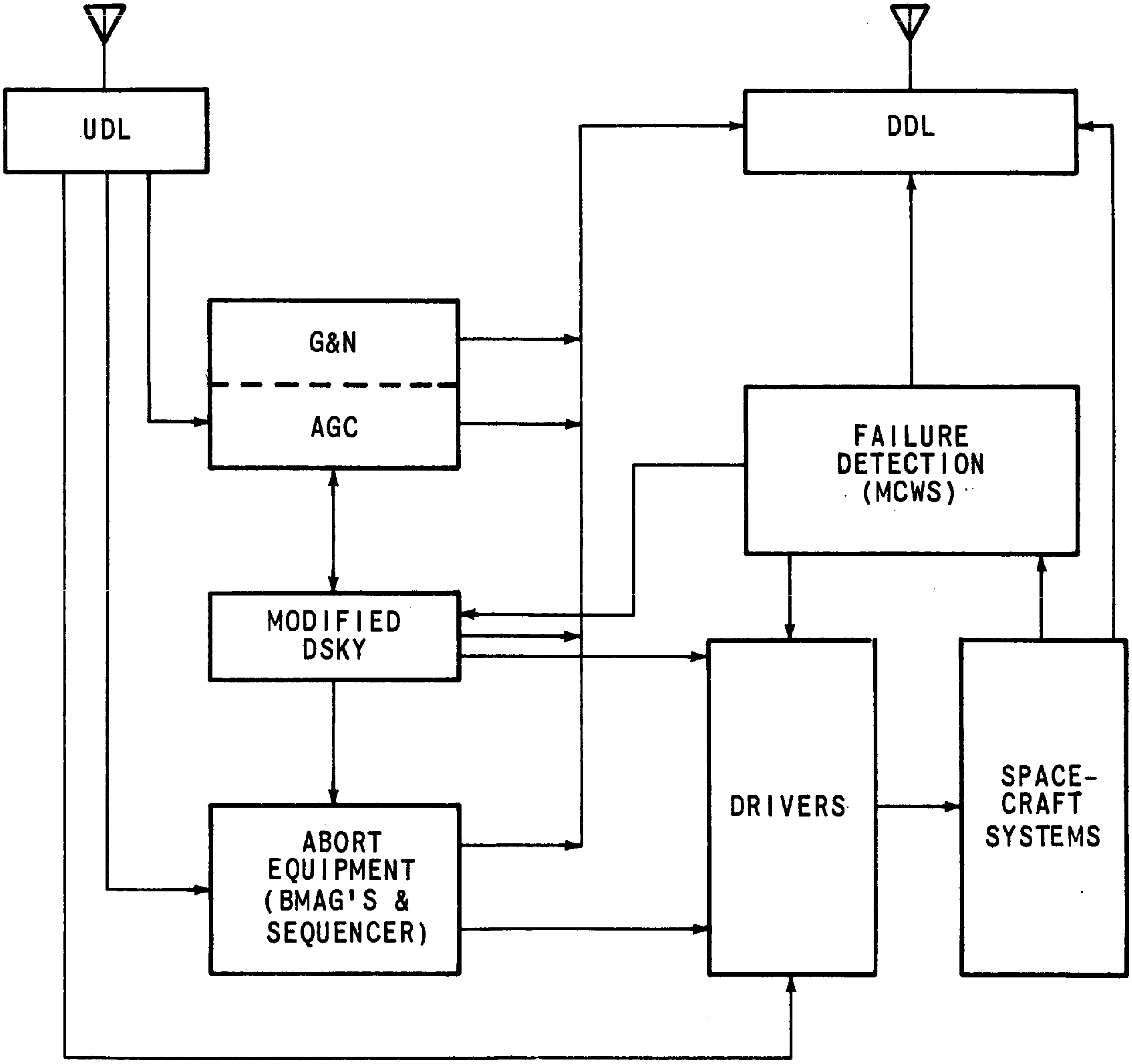

FIGURE 1 PROGRAMMER FOR UNMANNED SATURN IB MISSIONS

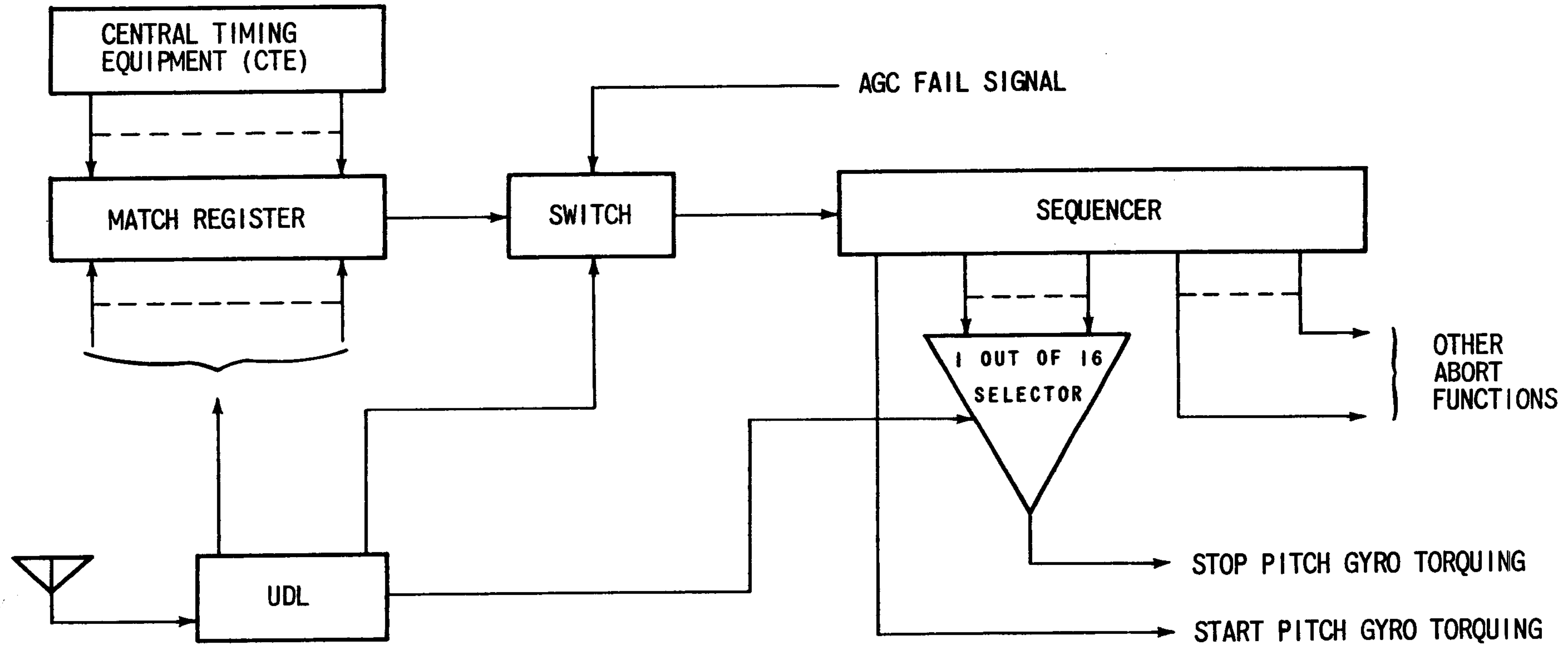

FIGURE 2 BACKUP SEQUENCING EQUIPMENT

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