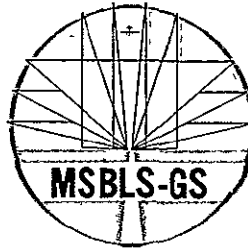


CR 151428



# MICROWAVE SCANNING BEAM LANDING SYSTEM-GROUND STATION

AIL Project A980

## MSBLS SYSTEM COMPATIBILITY AND PERFORMANCE

## ENGINEERING ANALYSES 75-1 AND 75-2

FINAL APRIL 1977

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MICROWAVE SCANNING BEAM  
LANDING SYSTEM  
COMPATIBILITY AND PERFORMANCE

ENGINEERING ANALYSES  
75-1 AND 75-2

FINAL REPORTS

## INTRODUCTION

The Microwave Scanning Beam Landing System (MSBLS) will be the primary position sensor of the Orbiter's navigation subsystem during the autoland phase of the flight. The compilation of reports presented under this cover represent summaries of analytical work performed on the MSBLS system by individuals at AIL, with inputs from NASA and LEC personnel. Portions of the MSBLS system come under investigation with special emphasis placed on potential problem areas as referenced to the Orbiter's mission.

Each of the reports is in itself complete, and capable of standing on its own. The reports are grouped into several broad categories: Section I, System Compatibility, deals with MSBLS performance after integration of ground stations, airborne receivers, airborne antennas, and the intended Orbiter flightpath. Section II is a block and flow diagram of MSBLS system operation. Section III deals with expected RF signal levels. Section IV deals with system accuracy. Section V is a compilation of special tests required for some of these investigations.

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SECTION I

SYSTEM COMPATIBILITY

(TASK 01)

PART A

EFFECTS OF MSBLS-GS SWITCHOVER  
ON THE AIRBORNE RECEIVER

A. CHARYCH AND J. SANTINI

TECHNICAL REPORT Y220-03

INTERIM - SEPTEMBER 1975  
OCTOBER 1975  
JANUARY 1976

FINAL

FEBRUARY 1976

## 1-A1. INTRODUCTION

The MSBLS-GS is a dual redundant system. If for any reason the MSBLS primary ground station fails, the backup system is automatically switched in. The switchover process represents an interruption of service for some period of time, with other transient effects.

The two systems (primary and backup) operate independently of each other. Both systems are radiating simultaneously; the primary system through its antennas, the backup system into a dummy load. Switchover can be caused by any of the internal alarm circuits which monitor key system parameters, or by the external field monitors. At switchover, the primary system RF power is directed to its dummy load while the backup system is switched to radiate out of the antennas.

The purpose of this report is to consider all possible effects on the airborne receiver in the event of ground station switchover to backup at any point in the mission.

## 1-A2. POSSIBLE EFFECTS OF SWITCHOVER

1-A3. THE BEAM WOULD ORIGINATE FROM A DIFFERENT POINT. The ground station antennas (primary and backup) are spaced approximately 8 feet apart, so that at switchover, the orbiter would appear to shift position laterally by about 8 feet.

This apparent shift in azimuth position is not a problem for the airborne processor since angle tracking is not employed, but it may have to be taken into consideration in the design of the navigation system software. At long range (greater than 50,000 feet from the stop end of the runway) this shift would not be noticeable because it is small (less than 0.01 degree) and represents, a small fraction of the system's 1 sigma error specification. At touchdown, the apparent shift in azimuth angle is 0.035 degree which may be large enough to be noticed.

1-A4. A GROUND STATION FAILURE DURING THE RECEPTION OF A BEAM. Ground station failure during the reception of a beam would cause an error in decoded beam angle. Since this error would remain with the system during the switchover process, it deserves further consideration.

A worst-case situation would be the case where an elevation beam was being tracked approximately 1.8 degrees wide. (This corresponds to a tracking level of -6 dB from the beam peak.) This beam, at 20 degrees elevation, would contain approximately 55 pulse pairs. If the primary ground station failed after receiving only nine pulse pairs, the beam would be different from the actual beam center. This is due to the nature of the transmitted data. Each interpair pulse space represents the angle of the ground station antenna at the moment the pulse pairs were transmitted. Since the beam could be relatively wide, the pulse spacings are normally averaged to find the beam center. If the beam were lost after only nine pulse pairs (minimum number of pulse pairs which could be declared a valid beam), the average pulse pair spacing would not correspond to the center of the beam. Figure 1-A1 illustrates the situation. The maximum error introduced in azimuth or elevation would be approximately 0.75 degrees. There would be no error introduced if the system switchover were to occur during a DME period or when a beam was not being received.

This error would probably have little if any effect on the overall system because it would only be in azimuth or elevation (not both) and because the computer data processing algorithm would probably recognize an obviously large error.

1-A5. LOSS OF GUIDANCE DATA. Guidance data could be lost for some period of time after switchover due to the following:

- a. The switchover process could take 1 second to complete.

b. Synchronization would be lost, requiring one data cycle for a complete update.

c. A difference in primary and backup system gain could cause a step change in receiving signal power at switchover.

1-A6. Switchover Time. The maximum time specified for switchover to be completed is 1 second (AIL Spec No. 502498). This represents the time taken to detect the fault in transmitted data, the time needed to switch the primary station off and the time needed to switch the backup system to its antenna, enabling it to radiate. This 1 second time period represents a worst-case downtime for the ground station.

1-A7. Loss of Synchronization. During normal system operation, data on azimuth, elevation, and distance is updated every 200 ms. This sequential operation is interrupted at switchover, and under worst-case conditions, could delay an update of one of the modes by one data cycle (Figure 1-A2).

This one-cycle delay in a complete update could occur if the backup system were only slightly out of sync with the primary station, and switchover occurred just before a beam was received. A one-cycle delay would be approximately 200 ms.

1-A8. Difference Between Primary and Backup System Gain. The primary and backup ground stations are expected to vary in system gain due to differences in transmitter power, antenna gain, and transmitter frequency.

The transmitter power cannot fall below 1.6 kW at the antenna without generating an alarm, and it could be as high as 3.5 kW.

Magnetron output power in excess of 3500 watts is not permitted during MSBLS-GS assembly. If a magnetron output exceeds this level, it is de-gaussed to the point where its output is below 3500 watts. The 3500 watt power limit refers to power out of the transmitter, not power at the antenna.

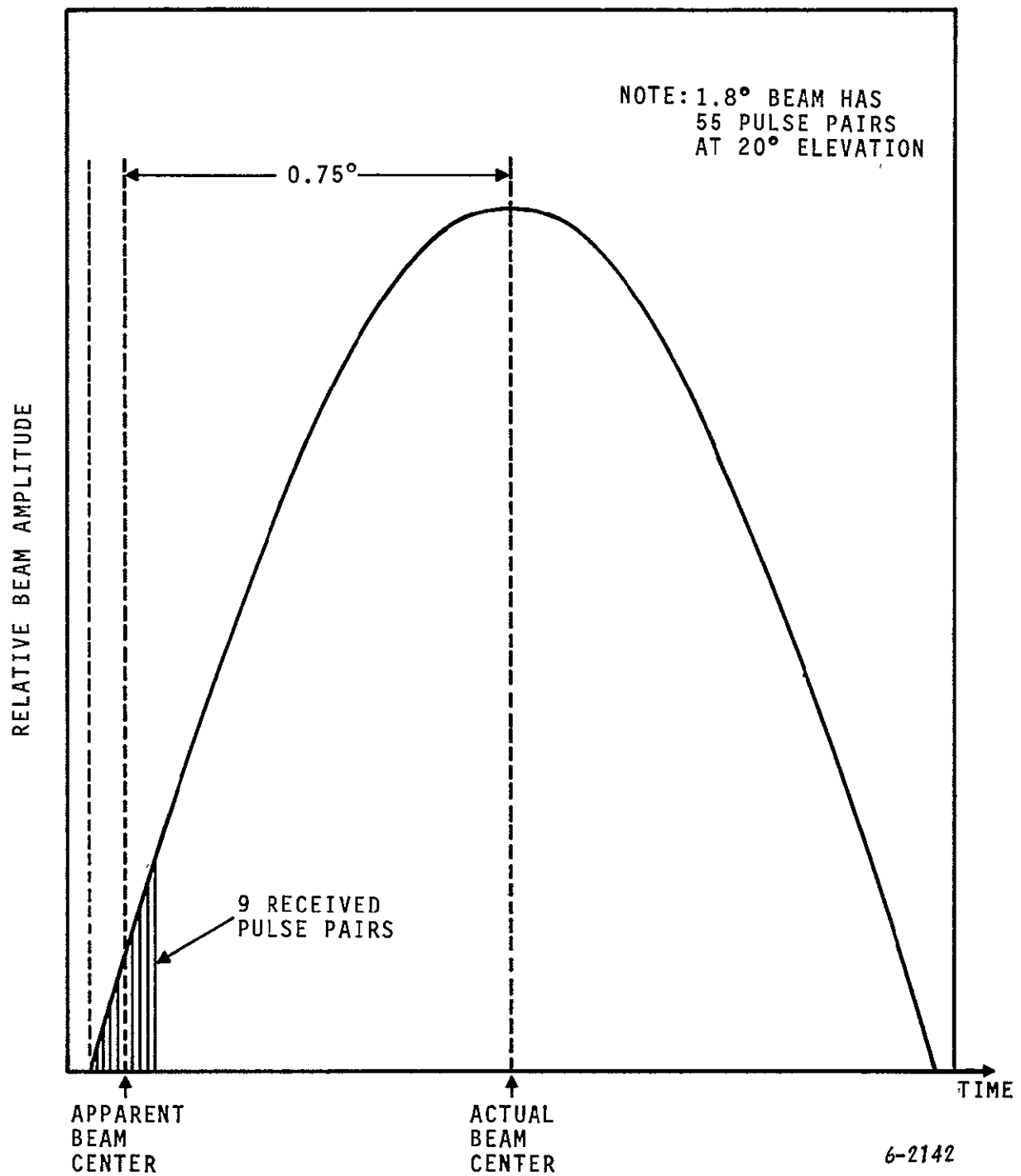
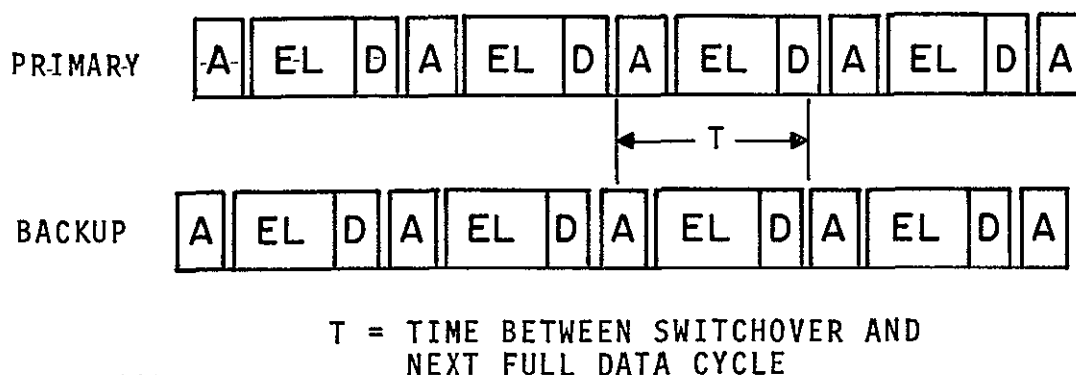


Figure 1-A1. Simulated Failure During Beam



6-2143

Figure 1-A2. Switchover

Power losses in the waveguide system must be subtracted from this apparently-possible power to obtain the true power differential at the antenna. Waveguide losses will be at least 0.35 dB. We, therefore, expect the maximum transmitter power differential to be 3.05 dB.

Antenna gain is usually within 0.5 dB across the service sector, but a comparison of eight typical C-SCAN azimuth antennas (similar to MSBLS antenna) revealed a 2.8 dB gain differential between two particular antennas at high elevation angles (Figure 1-A3). Antenna patterns of seven elevation antennas built for the C-SCAN program were also checked, but the maximum differential found was much less than 2.8 dB.

On the basis of the reviewed antenna patterns, we tend to conclude that it is possible for two antennas to vary widely in gain, but very few pairs of antennas (picked at random) would exhibit a gain differential as high as 2.8 dB.

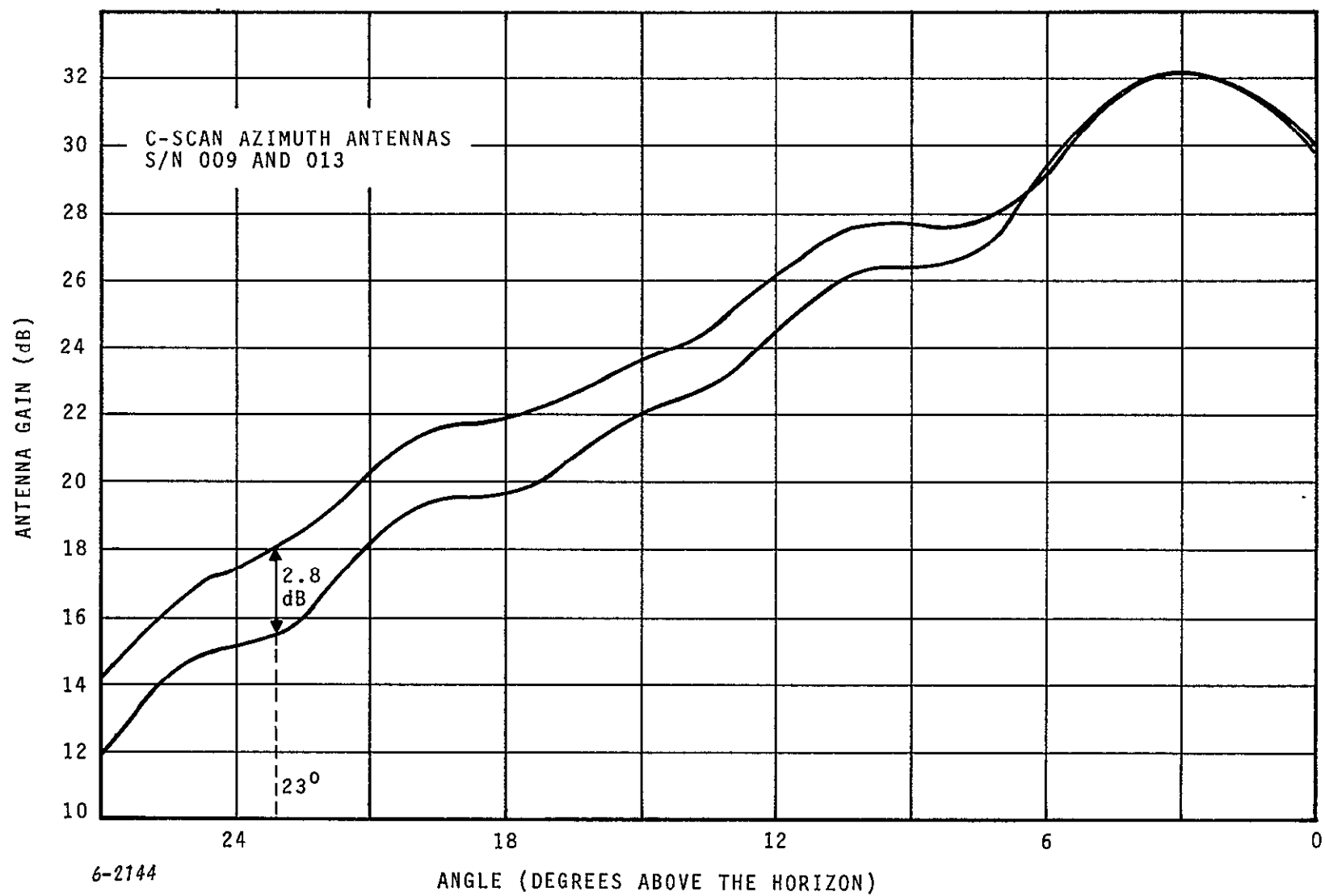


Figure 1-A3. Antenna Gain Variation

A frequency differential between the primary and backup transmitters could cause the received signal from the backup transmitter to appear either stronger or weaker, due to the frequency response of the IF amplifier. The worst case for this situation would be if one station were 1 MHz off frequency and the Nav Set receiving data were also 1 MHz off. (1 MHz is the spec limit frequency error of the local oscillator.) This would place the transmitting station exactly in the center of the Nav Set's IF passband. If the other station were 2.5 MHz off in the opposite direction (specified maximum), a shift in frequency of 3.5 MHz at switchover, with respect to the IF passband, would result.

Inspection of three Nav Set IF passband characteristics revealed an approximate 1 dB difference in gain, 3.5 MHz from passband center. The IF passband characteristics are not easily predictable, but a 1.5 dB worst-case estimate is probably conservative enough to encompass most Nav Sets.

Worst-case difference between primary and backup signal strength at switchover, due to all considered sources, could be as high as 7.35 dB (3.05 dB due to transmitter power, 2.8 dB due to antenna gain, and 1.5 dB due to a frequency difference). If the backup station happens to be 7.35 dB above the primary in signal strength, then not much is lost. The Nav Set begins to track the backup station instantaneously with the AGC tracking approximately 11 dB below the peak of the beam. No data loss will result for this condition.

If the backup station is 7.35 dB lower in signal strength, a loss of data will result. The time during which the Nav Set is without data depends on:

- a. Nav Set AGC slew rate
- b. Instantaneous tracking level at switchover
- c. Shuttle trajectory

A computer simulation of the airborne receiver's azimuth AGC system was used to determine what the receiver's tracking level would be as a function of time. The program was run with the simulated orbiter approach course (glide path) and the OV102 airborne antenna pattern (Document EE33-75-103) in order to find the received azimuth signal strength as a function of time. A step change of 7.35 dB was then programmed to occur at random times, in order to simulate a worst case ground station switchover. The AGC system response was then checked to determine whether the receiver would drop lock, and if so, for how long.

Figures 1-A4, 1-A5, and 1-A6 show the AGC tracking threshold in dB below the beam peak. The program shows that the video would drop below tracking level (-0.2 dB) for approximately 2.6 to 4 seconds if the signal strength suddenly decreased by 7.35 dB.

The three plots represent three particular simulation results. They do not necessarily show worst-case response to a 7.35 dB signal difference. A worst-case response could at best be estimated using the simulations as a guide.

Considering the results of the simulations and the fact that data dropout time at longer distances, or for operation in rain, will in general be longer, a worst-case estimate of data dropout time is taken as 5 seconds.

It should be noted that this loss of guidance, due to a step change in signal strength, affects the azimuth and elevation functions only. Tracking level of the distance function is low (approximately 11 dB below the beam peak) so that it is not affected by this type of interference.

1-A9. Nav Set Flag Criteria. The MSBLS Nav Set has a flag output which indicates whether or not the Nav Set has received eight consecutive valid beams. This flag is useful at acquisition to indicate that the Nav Set has received eight consecutive valid beams, and that therefore, the airborne receiver is firmly locked to the ground station. This flag does not alter system

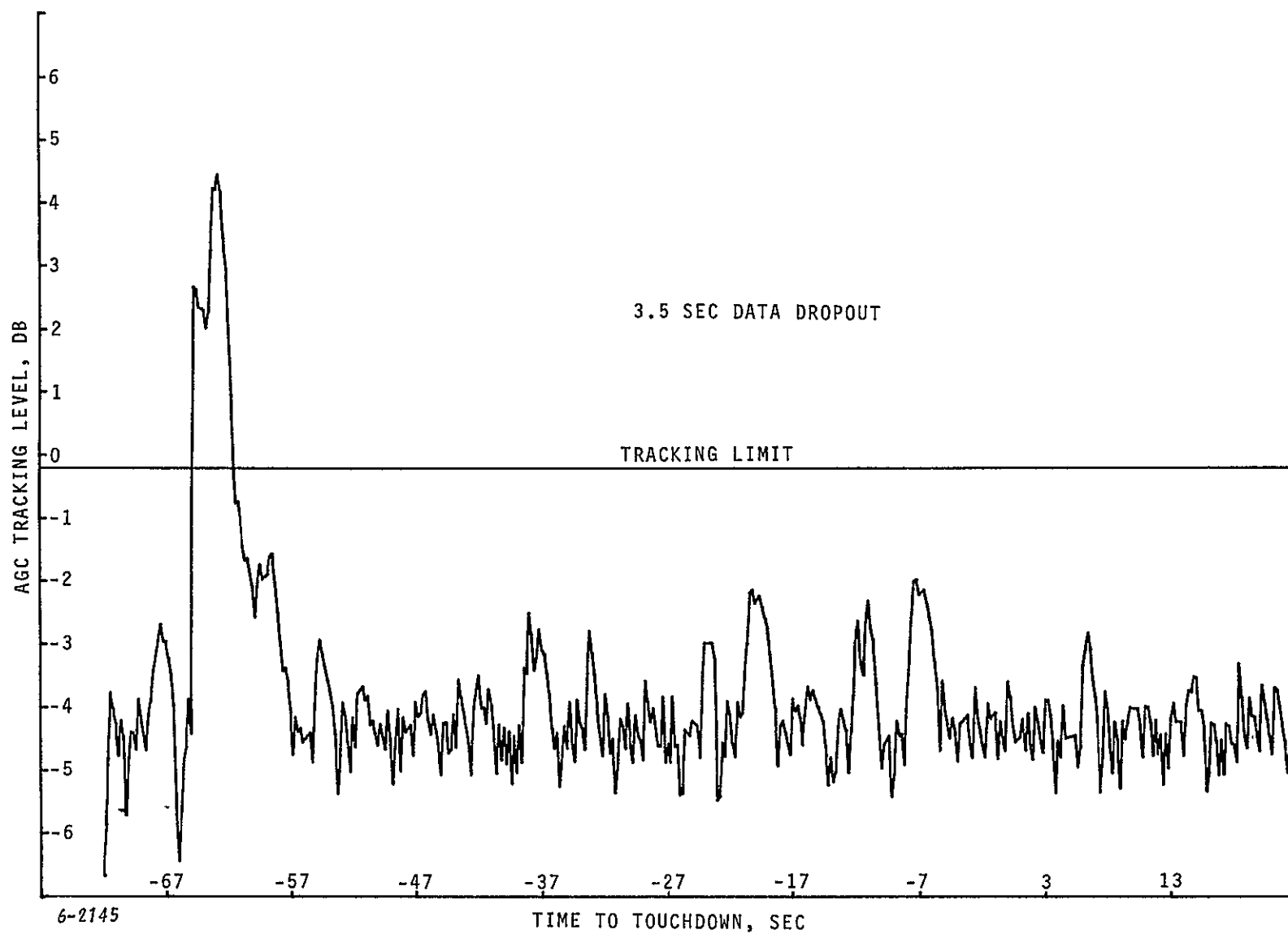


Figure 1-A4. Switchover at -65 Seconds (7.35 dB Signal Difference, 0 mm/hr Rain)

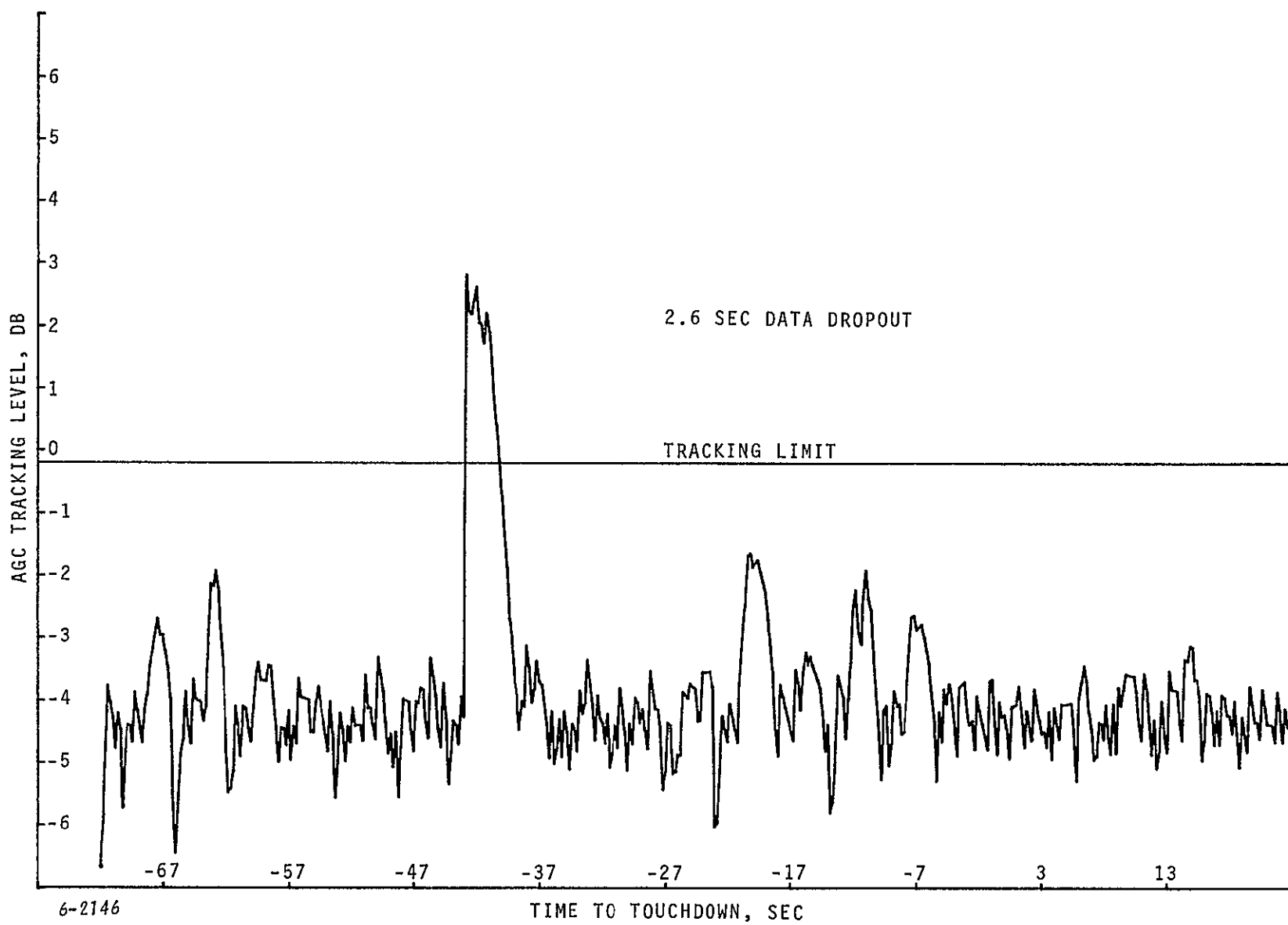


Figure 1-A5. Switchover at -43 Seconds (7.35 dB Signal Difference, 0 mm/hr Rain)

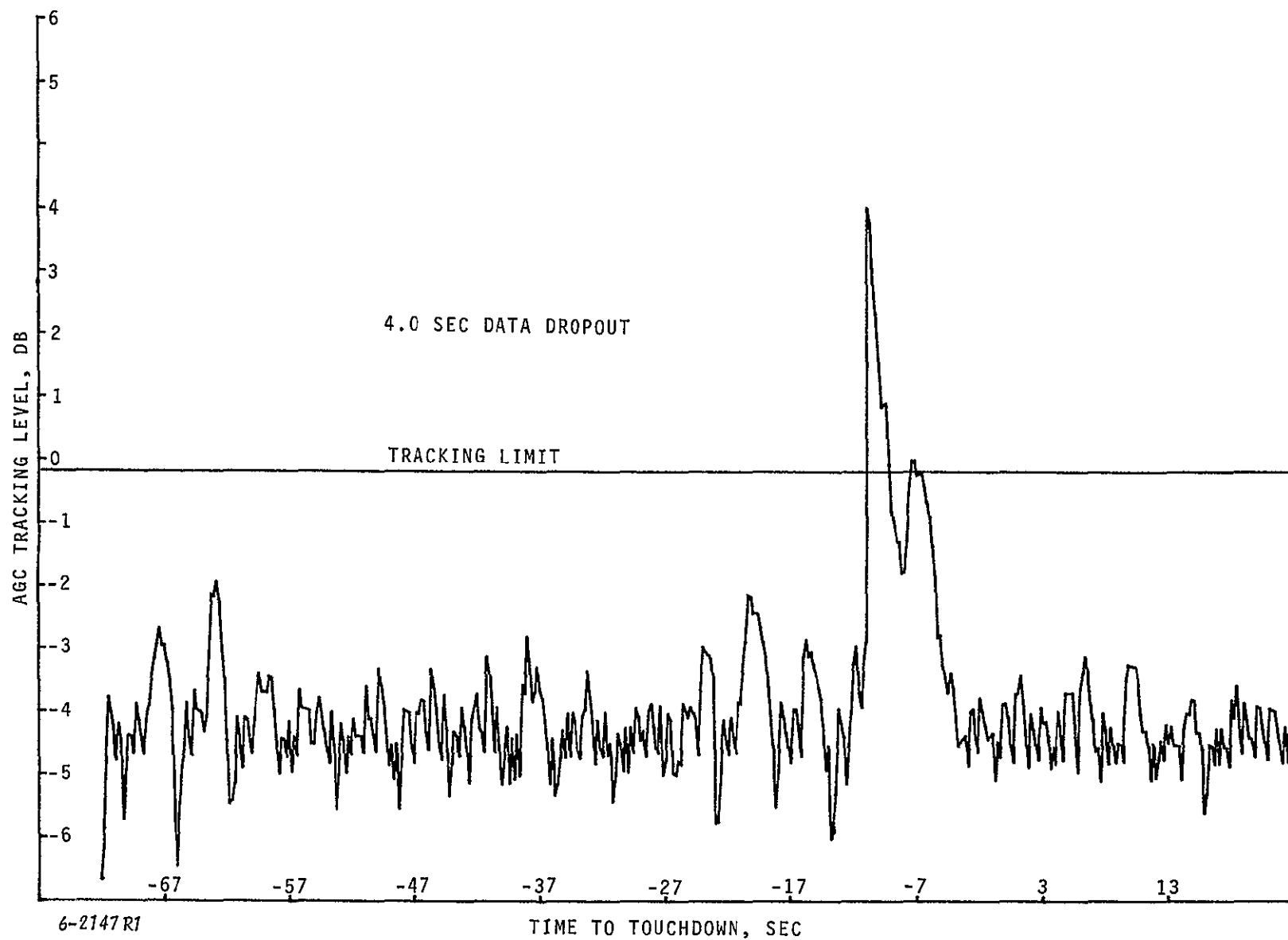


Figure 1-A6. Switchover at -11 Seconds (7.35 dB Signal Difference, 0 mm/hr Rain)

operation in any other way. As soon as valid data is received, it is processed and available at the Nav Set output. The flag is simply an indicator of the data history over the past eight beams (1.6 seconds).

In the case of a ground station switchover, if the receiver were to miss one beam passage, the data from the backup station would remain flagged for eight consecutive scans. Since the Nav Set may be outputting valid data during this time period, the data could be utilized if the data processing algorithm were to consider its history. But, because the flag criteria does not consider the data valid, it must be assumed that the data will not be used. This adds a possible 1.6-second additional delay at switchover before valid data is again received.

The Nav Set could also flag if switchover occurred too quickly. Circuits within the Nav Set guard against two beams of the same function identity appearing sequentially (one after the other) within 64 milliseconds of each other (multibeam). Such could be the case if, for example, a primary to backup switchover occurred precisely after, say, an azimuth update. If the backup system comes on the air quickly enough and the backup azimuth antenna happens to sweep past the orbiter within 64 milliseconds of the last azimuth update, a multibeam condition is declared and azimuth data is flagged for 1.6 seconds.

Specifications of waveguide switches used for primary to backup switchover (AIL Specification No. 502264) set the switchover time at less than 100 milliseconds. Minimum times are not given. From our own lab measurements, the waveguide switches performed at speeds between 40 and 50 milliseconds; fast enough to cause output data to be flagged.

#### 1-A10. EFFECTS OF SWITCHOVER--SUMMARY

The major effect on the airborne receiver in the event of a primary to backup switchover is seen to be a temporary loss of guidance data. The causes could be subdivided into:

- a. A time period during which data is not received.
- b. A time period during which data is received but is not properly processed by the Nav Set.

The first effect is due to the actual time taken for the ground station to switch from primary to backup (1 second), and the worst case time needed for a complete data update to be received (200 ms). The total maximum time that the receiver would be without data could, therefore, be 1.2 seconds. These effects are inherent in the MSBLS-GS design and specification and probably cannot be further reduced.

The second effect may or may not cause a further delay in receiving a data update after ground station switchover. The total signal strength variation could be as high as 7.35 dB. If the change in signal strength is relatively small (a few dB or less), the receiver will be able to track the backup ground station as soon as it begins to transmit.

If the backup system gain is much lower than the primary system, the receiver will not be able to track the new beam. The valid data flag would indicate invalid data, and the receiver's AGC system would begin to adjust the receiver's gain until the received signal is within tracking level. The receiver begins normal processing of the angle data 1.6 seconds after tracking level is reached.

These two effects would delay outputting valid data by as much as 6.6 seconds (5 seconds due to the difference in gain, and 1.6 seconds due to Nav Set flag criteria). These effects could be reduced by MSBLS-GS design changes and by choosing a correct interpretation of the Nav Set's data valid flags.

#### 1-A11. THE OBJECTIVE

Ideally, the Nav Set would supply valid data immediately after a ground station switchover. If the signal amplitudes are relatively close, the Nav Set would immediately begin processing the new data. The valid data flag, however, may indicate the data to be invalid for 1.6 seconds, depending on whether the first update after switchover is less than 0.2 second and greater than 0.064 second of the last valid update prior to switchover. Since the valid data flag does not inhibit data output, but merely states its history over the last eight consecutive updates, the 1.6-second time lag could be most easily reduced by a software processing routine outside the Nav Set.

The eight consecutive valid beams criteria could be used at acquisition, and a less severe test could be employed some period of time after acquisition. For instance, the eight valid beam test could be required at acquisition and only two consecutive valid beams (using reasonableness tests) would be required after acquisition. This would reduce the time needed to accumulate enough valid data from 1.6 seconds to 0.4 second during the final approach.

If the drop in signal strength at switchover is held to no more than 3 dB, then the Nav Set will usually continue to track the ground station. Since the tracking level at the airborne receiver is constantly hunting, due to AGC action, there are times when the Nav Set would lose lock at switchover. The 3 dB limit in signal difference would prevent the receiver from losing lock at switchover approximately 90 percent of the time. If the signal change could be held to 2 dB, the switchover would not cause the receiver to lose lock approximately 98 percent of the time.

So far we have only considered the case of the primary system having a gain higher than the backup system. Since automatic switchover is always from primary to backup, it would seem sufficient to ensure that backup system gain is at least as high or higher than primary system gain. However,

situations may arise which require a manual switchover from backup to primary. One such example would be the case of a false primary to backup switchover. There is a finite possibility of the occurrence of false switchover since, as with practically any type of monitoring system, a tradeoff of sensitivity versus false alarm rate has to be made. A hard failure of the backup system after a false switchover would require a manual override to the primary system. Consideration of this type of case requires the primary and backup system gain to be matched.

A worst-case signal strength difference between the primary and backup systems of 3 dB (within the coverage volume) is a reasonable goal. This power differential could be apportioned to the individual parameters as follows:

- a. Transmitter power: 1 dB
- b. Antenna gain: 1 dB
- c. Frequency difference: 1 dB

This budget will be used in investigating ways to reduce the difference in signal strength at switchover.

#### 1-A12. METHODS FOR REDUCING CHANGE IN SIGNAL STRENGTH AT SWITCHOVER

1-A13. ANTENNA MATCHING. If the primary and backup antennas are picked at random, there could be a 2.8 dB gain difference at some points in the coverage sector.

Presently, the antennas are checked for minimum gain but there is no check for maximum gain. When the antenna pattern is measured, the antennas should be checked for similar gain plots. The antennas could then be matched in pairs within 1 dB for use in a primary and backup station. In order to match the antennas to within 1 dB, several extra antennas may have

to be built, so that matched pairs could be selected. Judging from the patterns that were reviewed, matching to within 1 dB does not appear to be overly difficult. The number of required extra antennas will probably be small. Antenna pairing would impact spares and system maintenance procedures. Antenna replacement would have to be done in matched pairs.

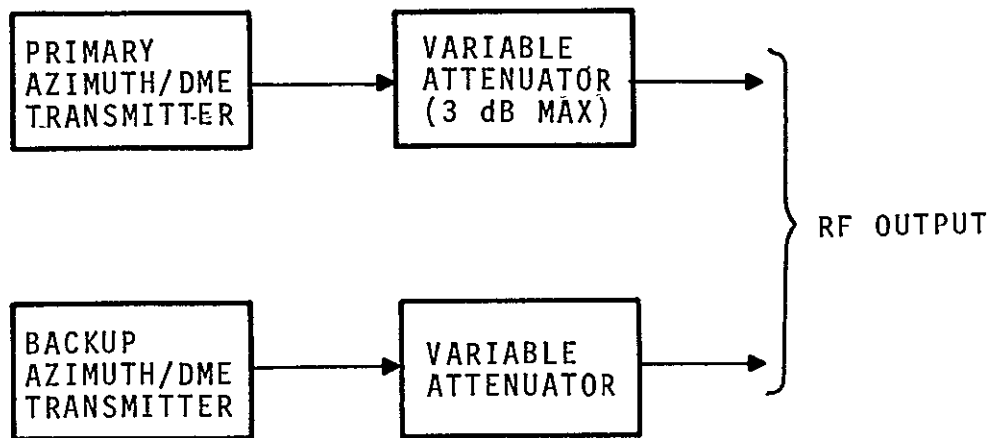
As explained previously, we are referring to the azimuth and elevation antennas only. Pairing of DME antennas will not be required.

1-A14. MATCHING TRANSMITTER POWER. Once in service, the transmitter output powers could be as much as 3.05 dB apart. The high voltage power supply could be adjusted so as to vary the power output by about 1 dB. This, however, is not considered a good way to adjust power because of the many other variables which are involved. Bounds on modulator current, efficiency of the system, and differences in magnetrons from different vendors make this type of adjustment rather unattractive.

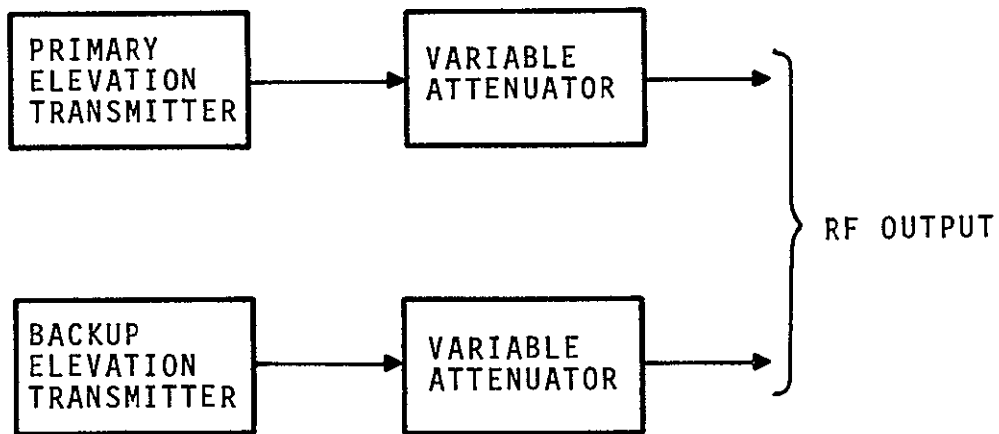
The addition of a variable attenuator would enable the transmitter powers to be precisely matched (Figure 1-A7). As the magnetrons age, the output powers might have to be readjusted, although experience indicates that they age in a similar manner.

In order to maintain a power differential limit of 1 dB, a measurement accuracy of 1/4 dB is required. It is not readily apparent whether this sort of accuracy can be achieved at the ground station power measurement port. The waveguide run and the 40 dB coupler will be calibrated, but uncertainties in other RF components (RF switches, rotary joints, etc.) will add too much ambiguity in trying to determine the true power differential at the primary and backup antenna.

One way to precisely align the primary and backup power outputs is to monitor the signal power at the field monitor. The difference in power between the primary and backup system at the field monitor can be measured by



#### AZIMUTH/DME SHELTER



#### ELEVATION SHELTER

6-2148

Figure 1-A7. Location of Variable Attenuators

counting the number of pulses received above the field monitor threshold. This detected RF is fed back to the MSBLS-GS shelter so that the measurement can be performed inside the shelter, if the appropriate test points are provided. The adjustment procedure would be as follows: The primary system is placed on the air. Detected RF from one of the field monitors is fed to a frequency counter. This counter must be capable of being externally triggered by a pulse signifying the start of a transmission sector. The time base is set to take a frequency reading averaged over a 10 second interval. For the elevation function, for example, assuming a field monitor tracking threshold of 4 dB, the frequency reading would be approximately 700 pulses per second. A 10-second averaging time synchronized to the start of transmission sector should yield a good mean value. Now the backup channel is placed on the air and the reading is again taken. A difference between primary and backup gain of 1 dB would yield a difference in frequency of approximately 100 pulses per second. This measurement should, therefore, be accurate enough to allow transmitter power adjustment to within 1/4 dB.

If this adjustment procedure is used, a slightly different approach to antenna selection would be required. Since the power output of the primary and backup system is matched at the field monitor (peak of antenna beam), differences in antenna peak gain are compensated for. The antenna matching procedure would then be to: superimpose the two gain plots; align the patterns such that peak gains fall one on top of the other; and make sure that gains at any other point are within 1 dB of each other.

1-A15. FREQUENCY DIFFERENCE. Based on conservative judgment, difference in gain due to a primary/backup frequency difference was taken as 1.5 dB worst-case. In order to lower this number to the apportioned 1 dB, it is necessary that the primary and backup transmitters not deviate in frequency too far from each other.

Based on the IF passband characteristics of the three reviewed Nav Set IF strips, it is estimated that a difference in frequency between the primary and backup system of less than 2 MHz would achieve the desired results. This would be required in addition to having each system within 2.5 MHz of the desired RF channel.

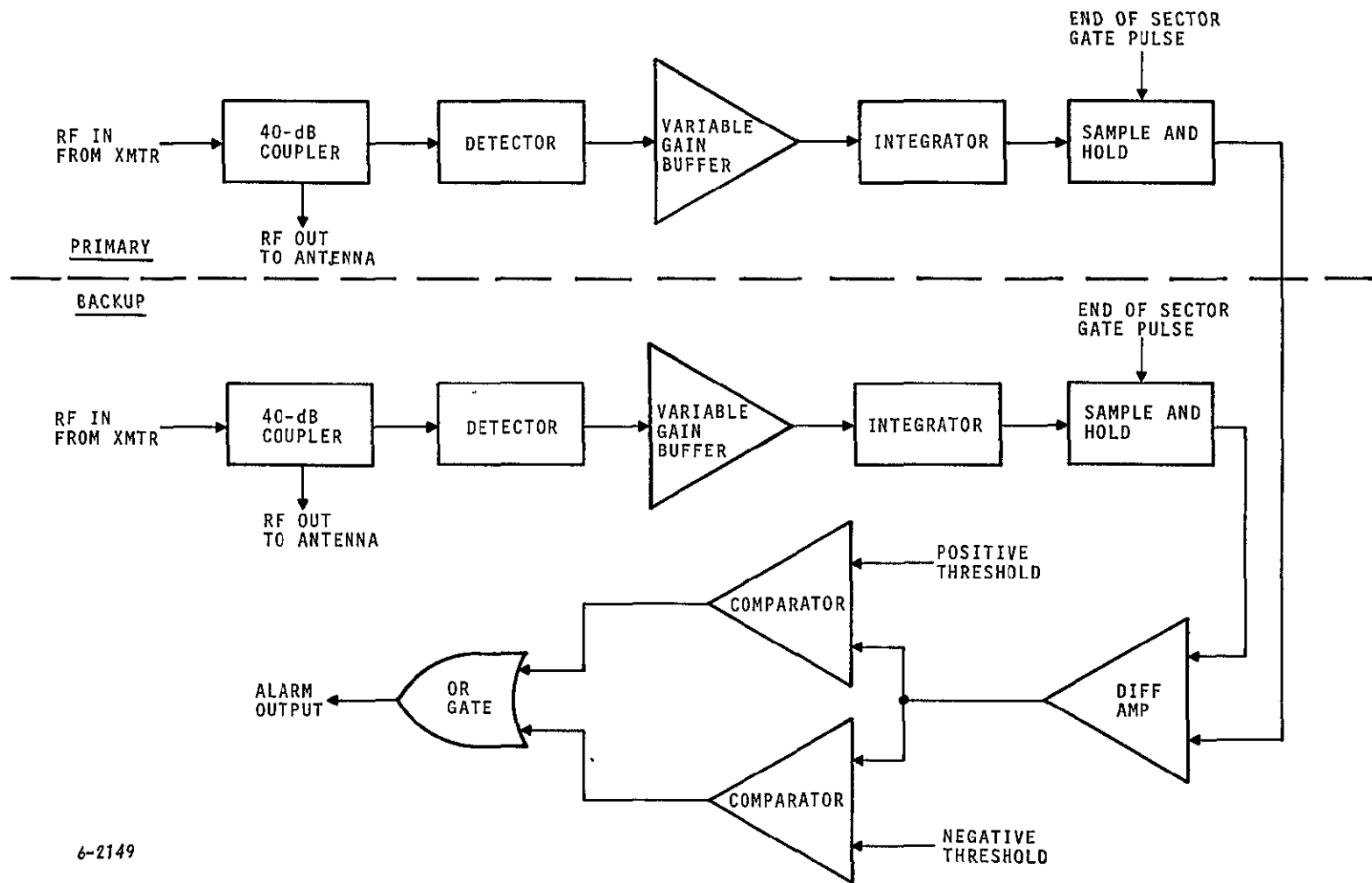
There should be no problem achieving the required setting accuracy since a single measuring device will be used to set up the primary and backup channels.

1-A16. DIFFERENTIAL POWER ALARM. Once the transmitter power have been correctly adjusted, they can be periodically checked using the same procedure, or, an alarm which is capable of detecting a power difference of 1 dB can be constructed.

In order to maintain a power differential limit of 1 dB, an alarm accuracy of approximately 1/4 dB is required. To realize this degree of accuracy, it is necessary to consider the smallest differences in all the IF components of the primary and backup systems. Also, from a reliability standpoint, it is desirable to add as few new components as possible. The proposed differential power monitor shown in Figure 1-A8 uses the coupler and detector already in the system.

The variable gain buffer amplifiers would adjust the detector outputs such that the signals are equal when the signal powers from the primary and backup stations are equal at the field monitor.

Since the two stations are not necessarily transmitting at the same time, the output of the variable gain buffer is integrated over a transmission period, and the integrated video is then sampled. This level is stored, and compared with the other transmitter's sampled video. The sample pulse is a short pulse which arrives at the end of a sector gate.



6-2149

Figure 1-A8. Differential Power Alarm

Outputs of the primary and backup sample and hold circuits are fed to a differential amplifier. Output of this amplifier is directly proportional to the power difference (in dB) between the primary and backup system. This output, compared to an upper and lower threshold provides the necessary logic for an alarm condition. The upper and lower thresholds are set to the same value; one is a positive voltage, the other a negative voltage. The output of the differential amplifier would be positive or negative depending on whether the primary station is stronger than the backup or the backup station is stronger than the primary.

This method is not sensitive to differences in the couplers, detectors, or waveguide components. Any differences in these components would be compensated for, since the reference is a single RF monitor which is measuring the signal power in space.

#### 1-A17. SUMMARY AND RECOMMENDATIONS

Possible effects of switchover between primary and backup system were considered. The most significant effect is a loss of guidance for some time interval. Worst-case interval without guidance is composed of 1.2 seconds required for the MSBLS-GS to complete a switchover, 5 seconds due to airborne AGC response and 1.6 seconds due to airborne data valid criteria.

The 1.6 seconds due to data valid criteria can be reduced by correctly interpreting MSBLS data outside the Nav Set. It is not recommended that Nav Set flag circuits be changed.

The 5 seconds due to airborne AGC response can be reduced by matching ground station primary and backup system gain. The goal is to hold the difference between primary and backup gain to less than 3 dB at any point in the coverage. This will result in no data dropout for approximately 90 percent of all switchovers from primary to backup and from backup to primary

(manual switchover). The 3 dB is apportioned to allow 1 dB due to a frequency difference, 1 dB due to difference in antenna gain, and 1 dB due to a difference in transmitter power.

It is recommended that transmitter power be adjustable by adding variable attenuators into the RF path. It is further recommended that RF power adjustment be made by utilizing the pulse count measurement procedure of the field monitor's detected RF. This differential power adjustment procedure should be made part of the MSBLS checkout and alignment. (It can also be used to check field monitor tracking thresholds from the MSBLS-GS shelter.) Accessible test points should be provided for sampling field monitor detected RF and timing of the transmission sector.

The differential power alarm may be incorporated, but it is felt that change in transmitter power due to magnetron aging is so slow that it would be hard to justify MSBLS-GS modification as long as the differential power adjustment procedure is part of MSBLS-GS alignment and checkout.

Primary and backup azimuth and elevation antennas should be matched in relative gain to within 1 dB across the coverage sector. The matching procedure should disregard gain offset at the peak of the antenna beam (since this will be compensated for in the power adjustment procedure) and verify that difference in gain (minus the offset) is below 1 dB across the coverage sector.

The RF frequency adjustment procedure should be modified such that the primary and backup channels be set within 2.0 MHz of each other. This should also become part of the MSBLS-GS alignment and checkout procedure.

PART B

EVALUATION OF MSBLS NAV SET  
AGC TRACKING CAPABILITY AS A FUNCTION OF RECEIVED SIGNAL

A. CHARYCH

TECHNICAL REPORT Y220-02

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FINAL

JUNE 1976

## 1-B1. INTRODUCTION

The MSBLS Nav Set receives azimuth, elevation and distance data from ground based equipment, sequentially, in a time multiplexed manner. Each of the guidance functions (azimuth, elevation, and DME) is transmitted from a different ground station antenna so that received signal strength for each of these functions is different. Three automatic gain control (AGC) circuits are, therefore, provided within the Nav Set in order to keep track of each guidance function separately. Since the data update rate for each function is five times per second, the AGC loops are also updated five times per second. Because of this relatively slow update rate, there is a limit as to how fast the received signal strength is allowed to change before guidance accuracy begins to suffer and eventual data dropout results.

The purpose of this investigation is to evaluate the performance of the Nav Set's AGC loop as a function of several Space Shuttle trajectories, ground station antenna patterns, and airborne antenna patterns.

## 1-B2. GENERAL DESCRIPTION OF EVALUATION PROCEDURE

The Nav Set AGC loop was modeled assuming ideal circuit parameters. A description of how this mode was arrived at is given in Report No. Y220-01 (Examination of MSBLS Nav Set Operation During the Acquisition Mode). This model was subsequently verified experimentally (Report No. Y220-06, Nav Set AGC Tracking Tests), and was simulated on a digital computer. Input to the computer simulation was one of several NASA supplied Space Shuttle trajectories. These trajectories yield MSBLS signal strength as a function of time, which is then used to update the AGC model. Output of the simulation is the tracking level on the received MSBLS beam envelope. AGC action is evaluated by verifying that the output tracking level stays within acceptable bounds.

Simulations were performed for the ALT-3, ALT-2, and OFT-1 trajectories. The OFT-1 trajectory assumed 99 percent headwind.

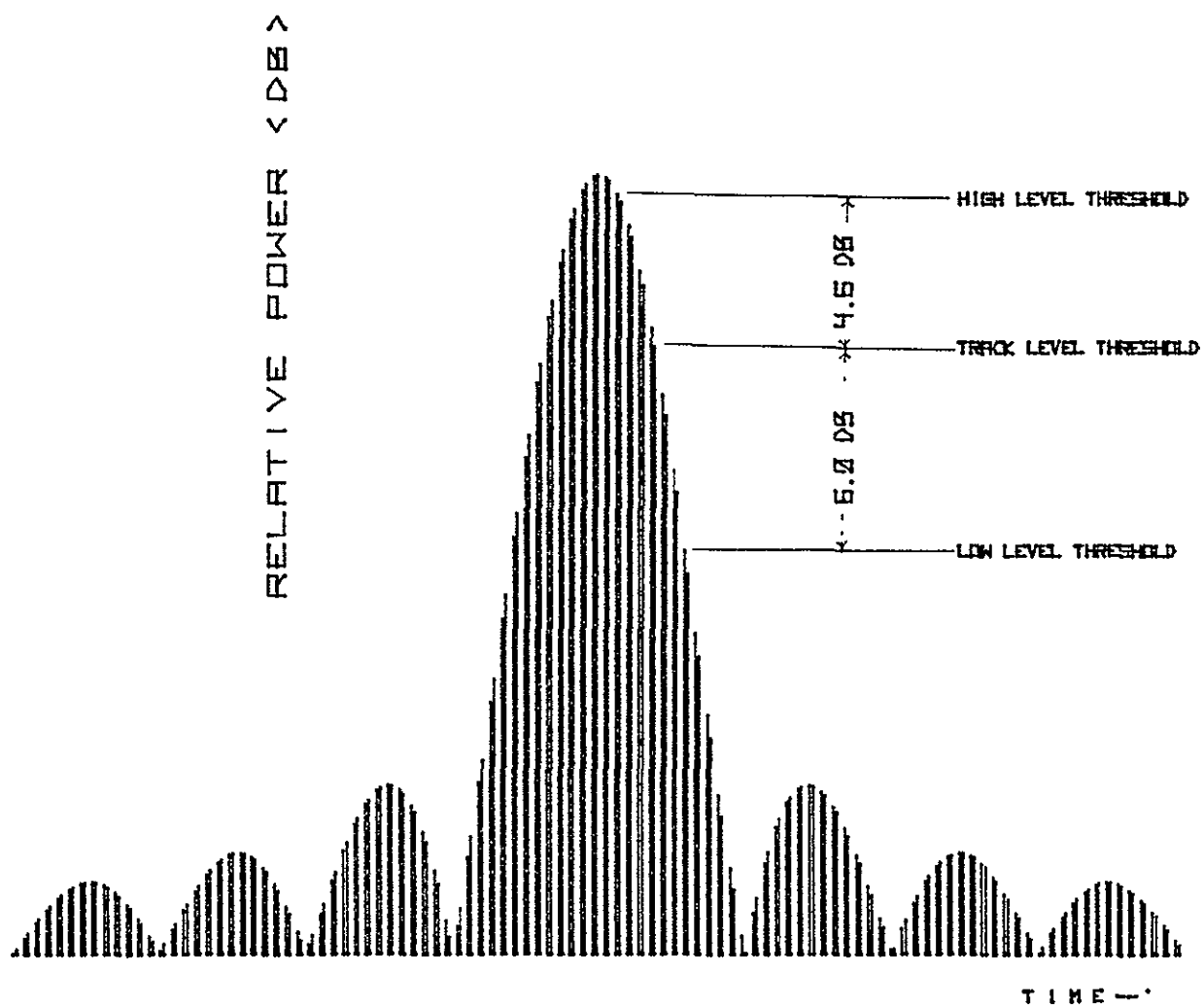
The ground station antenna gains for these trajectories were taken from interpolated measurements of a typical set of MSBLS ground station antennas. The airborne antenna gains were taken from NASA Document EE33-75-103. This document contains preliminary gain measurements of the airborne antenna for Orbiter Vehicle 102 (OV102), with thermal protection in place.

It should be noted that the ALT trajectories will be used with Orbiter Vehicle 101 (OV101). The Orbiter Vehicle 101 will be fitted with a boom which extends forward of the Orbiter's nose. The boom is expected to disturb the airborne antenna pattern somewhat. Trajectories with OV101 antenna patterns were not available at this time.

AGC simulations and performance evaluations were performed for the azimuth function only. This was done because the elevation and DME AGC loops are expected to perform better than azimuth. The reasons for this are discussed later in detail.

### 1-B3. ACCEPTABLE TRACK LEVEL BOUNDS

Figure 1-B1 shows an azimuth beam as would be seen at the output of the Nav Set's IF Amplifier. Three fixed amplitude thresholds are utilized after the IF amplifier. Pulse pairs above the low level threshold (nominally 10.6 dB below the beam peak) are used for identity decoding and processing DME replies. Pulse pairs above the track level threshold (nominally 4.6 dB below the beam peak) are used for angle decoding. System accuracy is dependent upon the correct setting of this threshold. The high level threshold (nominally 0.2 dB below beam peak) is used within the AGC loop. If this threshold occurs lower than approximately 0.2 dB below the beam peak, more than eight pulse pairs will be intercepted above this threshold. Under this condition, the AGC voltage to the IF amplifier is increased (receiver desensitized) by a fixed amount. This process continues for each received beam until less than eight pulses are intercepted above the high level threshold.



# AZIMUTH BEAM RECEIVED BY NAV SET

6-2150

Figure 1-B1. Azimuth Beam Received by Nav Set

The AGC voltage is then decreased by a fixed amount (receiver sensitized). The process now repeats itself. A more detailed explanation of AGC action is given in Report No. Y220-01 (paragraph 1-B7a.).

Since the receiver is sensitized (or desensitized) by a fixed amount for a fixed time interval, there is a limit as to how fast the received signal can change amplitude before the AGC loop could not keep up with the change. If the received signal increases in amplitude too rapidly, the tracking threshold will drop below -4.6 dB. If the tracking threshold gets to approximately -20 dB below the beam peak for azimuth (-18 dB for elevation) data dropout will occur because more than 127 pulse pairs are received above the track level. Even before this happens, however, system accuracy would be diminished because antenna beam symmetry could not be guaranteed so low on the beam envelope. Ideally, the tracking threshold should always be above approximately -10 dB.

If the tracking level ever increases to above approximately -0.2 dB, data dropout will occur because less than eight pulse pairs are intercepted above the tracking threshold. Even before data dropout occurs, angle accuracy for a high tracking threshold will suffer because:

- a. A small number of pulse pairs are used in decoding the beam's central angle.

- b. The beam envelope has a gentler slope in this region so it is more susceptible to amplitude perturbations. The tracking threshold, therefore, should always be below approximately -1 dB.

In summary, in order for data dropout not to occur, an angle tracking level between -0.2 and -18 dB is required. In order for system accuracy to be acceptable, it is desired to have the tracking level between -1 dB and -10 dB below the beam peak.

#### 1-B4. ACG SIMULATION

As previously noted, AGC simulations were performed for the azimuth function only. This was done because azimuth AGC is expected to yield the worst-case results. The reasons for this are the following:

a. Figure 1-B2 shows the theoretical maximum Nav Set AGC tracking rates as a function of received signal strength. It is seen here that the maximum negative tracking rate (the ability to chase a signal which is decreasing in power) is lower than the positive rate. Also, data dropout will occur if a signal drops by 4.4 dB relative to track level (-4.6 to -0.2 dB), but in the opposite direction the signal must increase by 15.4 dB (13.4 for elevation) relative to track level before data dropout occurs. Data dropout therefore is far more likely to occur because a signal dropped in power rather than increased in power.

Now if the angle functions are compared to DME, DME replies are nominally tracked 10.6 dB below the beam peak. In order for DME dropout to occur, the DME reply must drop 10.4 dB relative to track level. Since data dropout for the angle functions would occur at a nominal 4.4 dB relative signal drop, angle data is more susceptible to dropout than DME data.

b. Data dropout is most likely to occur in low signal strength areas (at signal acquisition) because of the decreased negative AGC tracking rate in that region (Figure 1-B2). The elevation angle from the azimuth scanner at acquisition is quite high, ranging from 12 to 16 degrees for the trajectories analyzed. The azimuth antenna gain at acquisition is therefore lower than elevation antenna gain. Coupled with the fact that the Orbiter is closer to the elevation station, elevation signal strength at acquisition will be higher than azimuth. This in turn implies that the elevation negative AGC tracking rate is higher than azimuth. Azimuth data dropout at acquisition is therefore more likely than elevation data dropout.

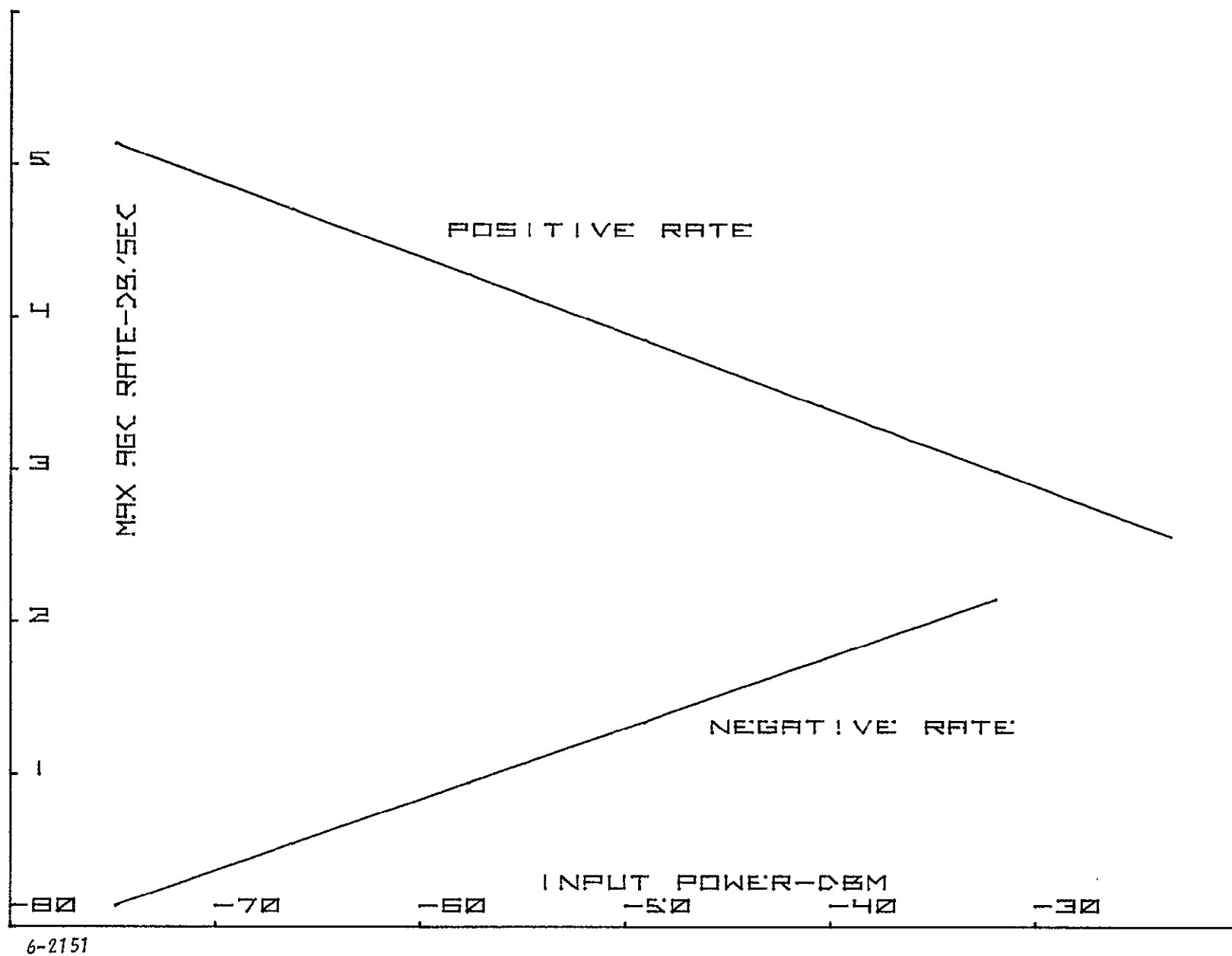


Figure 1-B2. Maximum AGC Tracking Rate

In summary, if data dropout occurs, it is most likely that it occurs on the azimuth channel. Simulation of the azimuth AGC should therefore yield the worst-case AGC performance.

A flow diagram of the azimuth AGC simulation is shown in Figure 1-B3. The simulation starts by initializing the starting time,  $T$ , to zero, AGC voltage,  $V_{agc}$ , to 0.18 V (maximum receiver sensitivity), and the increment between AGC updates,  $\Delta T$ , to 0.2 second. The nearest link margin and azimuth angle is next taken from the trajectory data for time  $T$ . The data is interpolated to find the actual signal strength at time  $T$ .

The track level in dB below the beam peak is next computed based on the current AGC voltage and input signal strength. The track level becomes the simulation output. If the track level is less than -4.6 dB, the AGC voltage is increased (received desensitized) according to the ideal circuit model. A track level greater than -4.6 dB results in a decreased AGC voltage (receiver sensitized). A new time increment,  $\Delta T$ , is next computed as a function of azimuth angle. Trajectory time,  $T$ , is then updated and the loop repeats itself by getting new values from the trajectory data.

#### 1-B5. SIMULATION RESULTS

Simulation of the AGC characteristics for the ALT-3 trajectory is shown in Figures 1-B4 through 1-B7. Figure 1-B4 shows the azimuth signal strength as a function of time; 0 mm/hr rain condition. Figure 1-B5 is the corresponding AGC tracking level in dB below the beam peak. The tracking level is seen to stay consistently between 4 and 5 dB below beam peak. The AGC loop has no problem tracking this signal.

Figures 1-B6 and 1-B7 are a repeat simulation but with an added signal attenuation due to 10 mm/hr rain. The AGC tracking level is seen to fluctuate a bit more for this condition, but overall, the tracking level is well below the data dropout point of -0.2 dB below the beam peak.

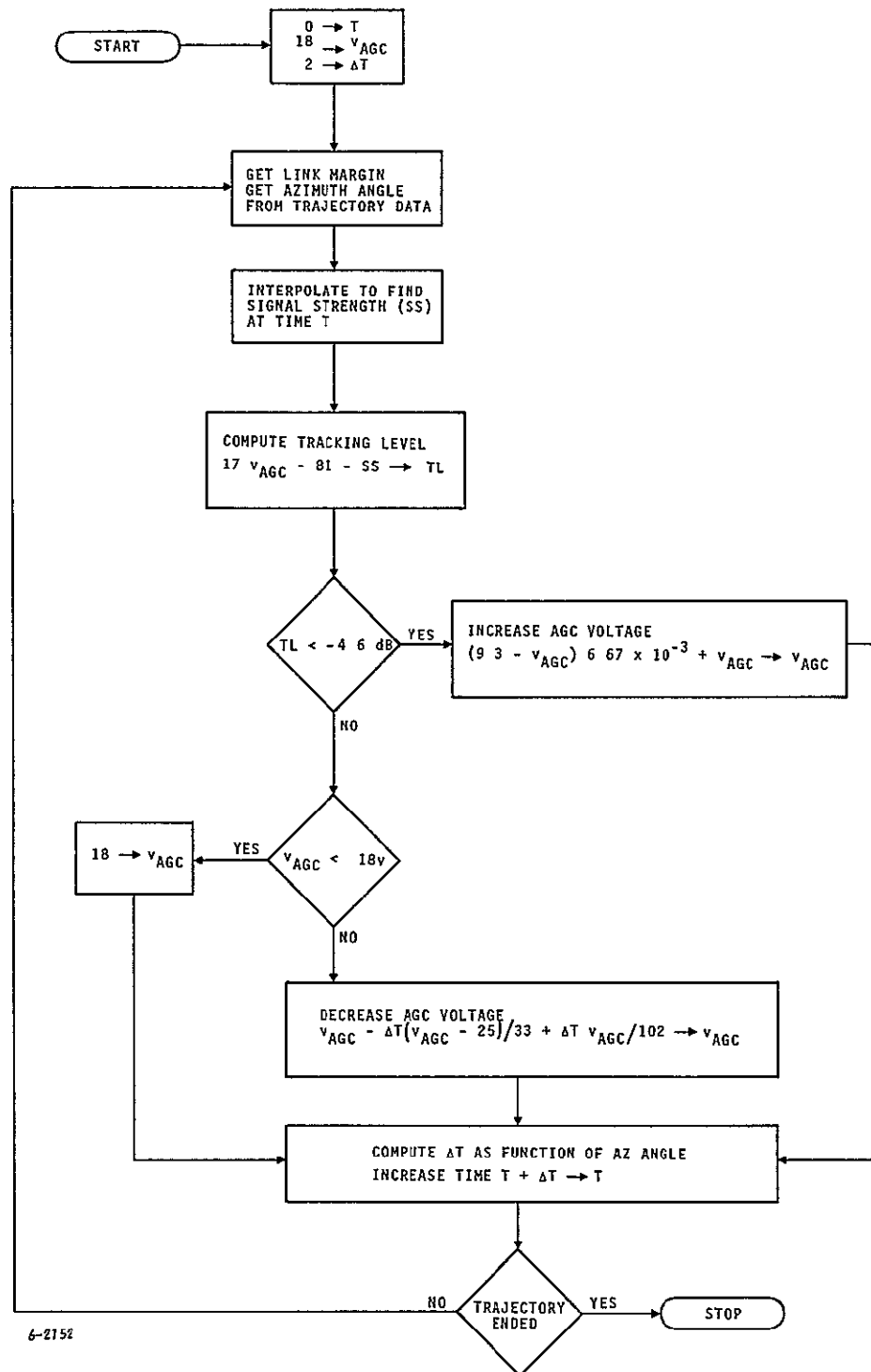


Figure 1-B3. AGC Simulation Flow Diagram

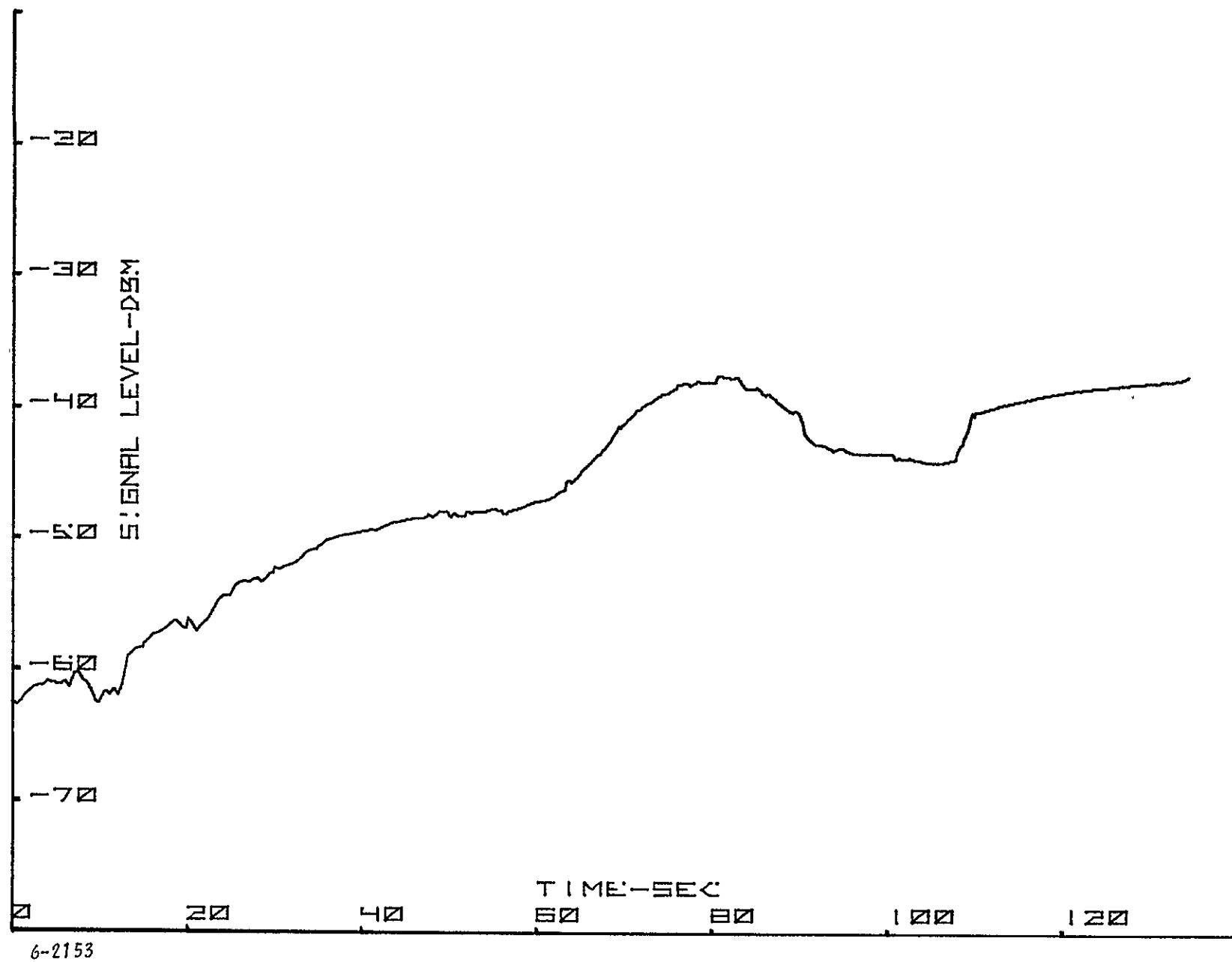


Figure 1-B4. Azimuth Signal Strength, ALT-3 Trajectory (0 mm/hr Rain)

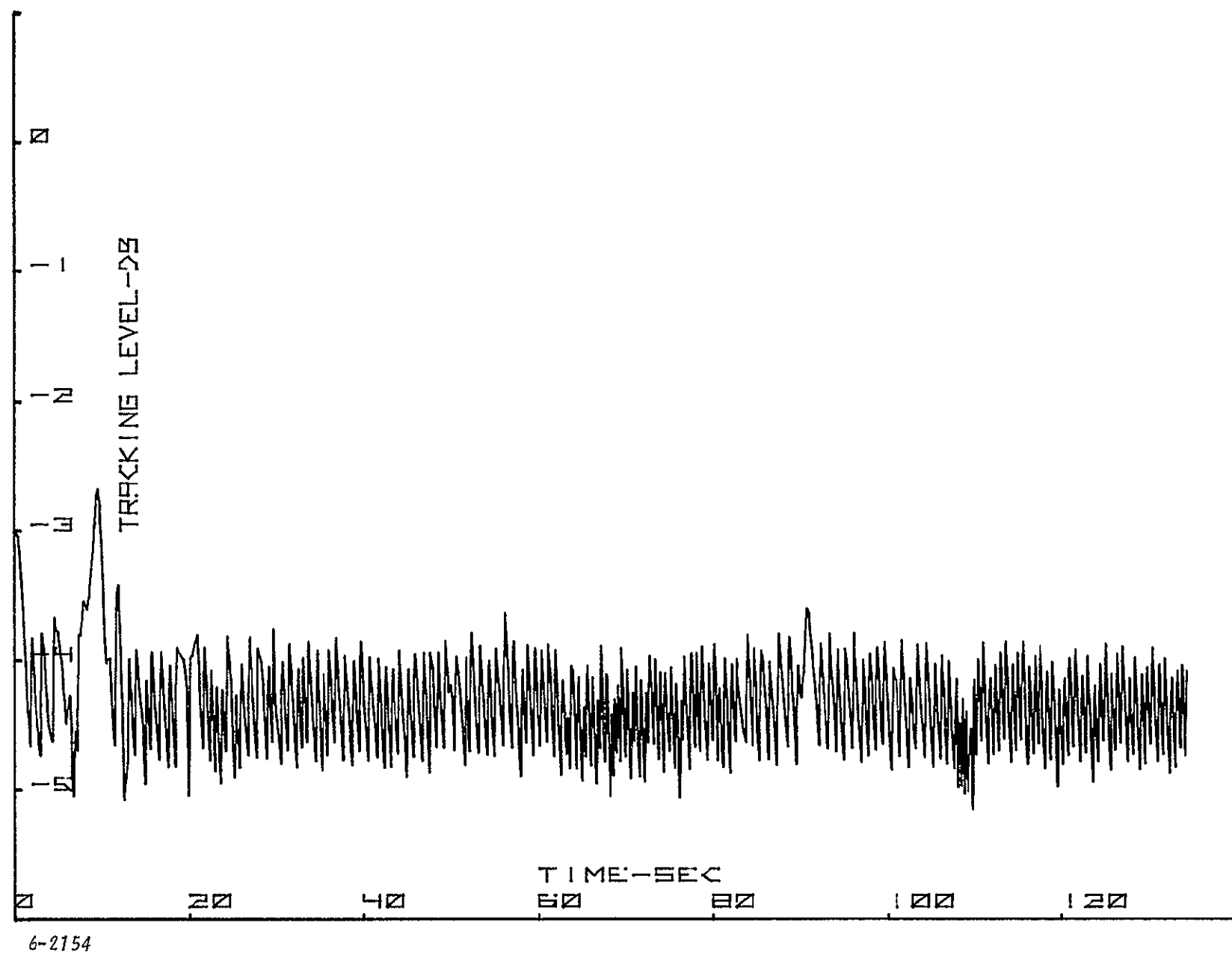


Figure 1-B5. Azimuth AGC Tracking Level, ALT-3 Trajectory (0mm/hr Rain)

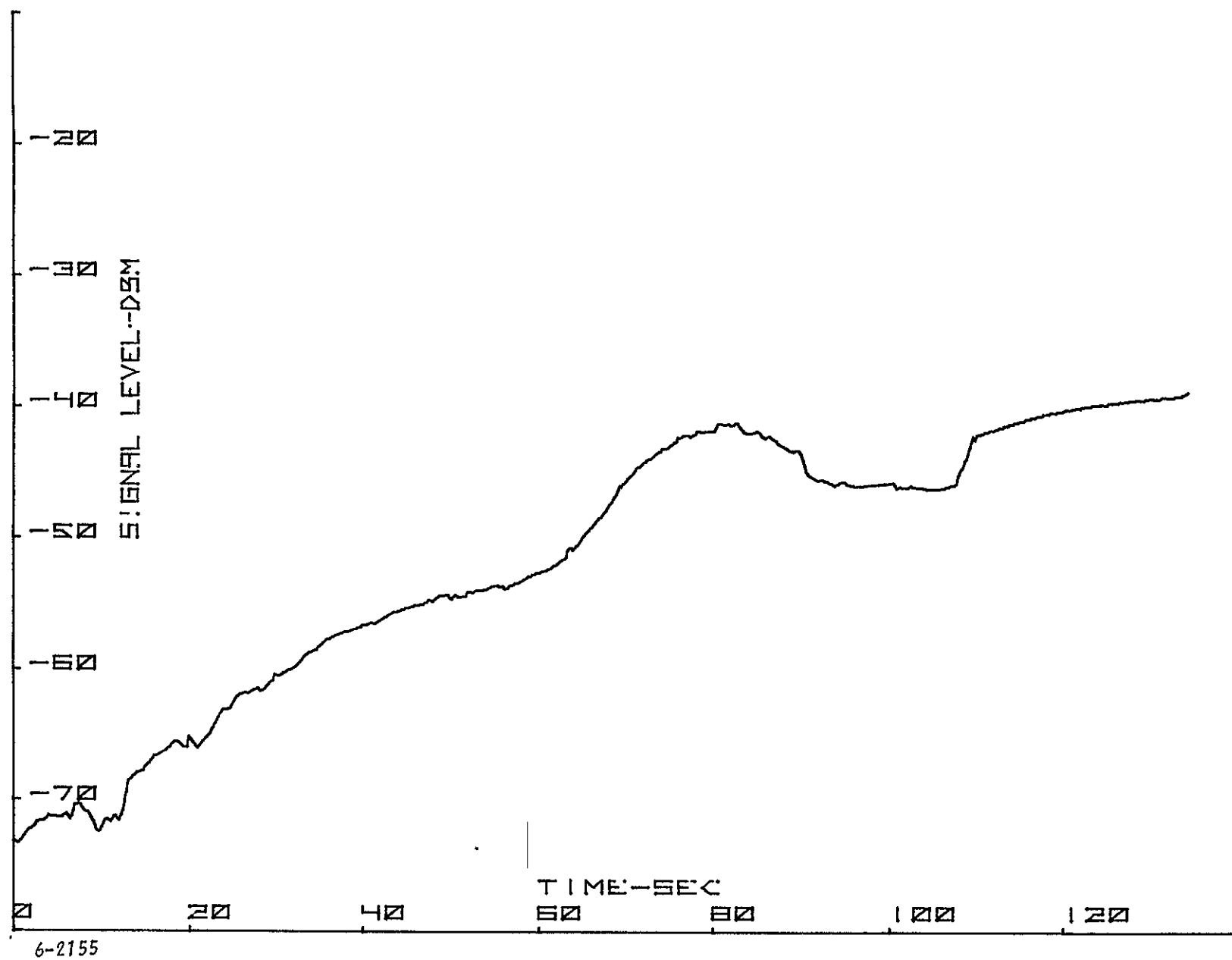


Figure 1-B6. Azimuth Signal Strength, ALT-3 Trajectory (10 mm/hr Rain)

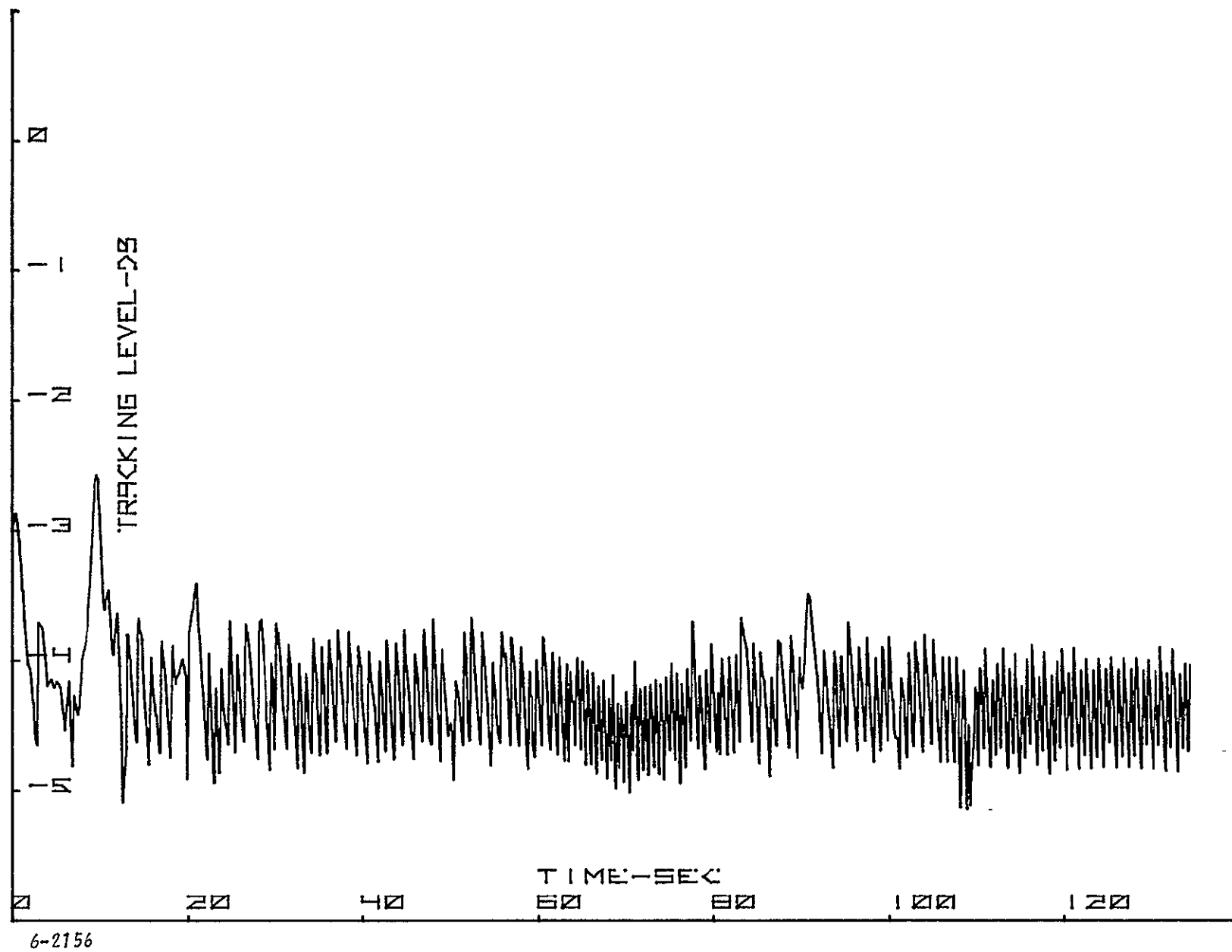


Figure 1-B7. Azimuth AGC Tracking Level, ALT-3 Trajectory (10 mm/hr Rain)

Simulation results utilizing the ALT-2 and OFT-1 trajectories are given in Figures 1-B8 through 1-B15.

Response of the AGC tracking loop for these flightpaths were also evaluated assuming conditions of fair weather, and 10 mm/hr rain.

There was no evidence of data dropout due to AGC action for these simulations. Worst-case occurred for the ALT-2 trajectory, 10 mm/hr rain, 36 seconds after separation (Figure 1-B11). Here the tracking level increased to 0.3 dB below the peak of the beam. Data dropout occurs at -0.2 dB below the beam peak.

#### 1-B6. CONCLUSIONS AND RECOMMENDATIONS

AGC response for the three trajectories evaluated was adequate for the assumed conditions.

Since the ALT trajectories assumed no wind and were performed with an airborne antenna pattern which is not completely representative of the OV101 vehicle, it is recommended that additional ALT simulations be performed with worst-case headwinds, crosswinds and gusts, and with an airborne antenna pattern measured with boom in place.

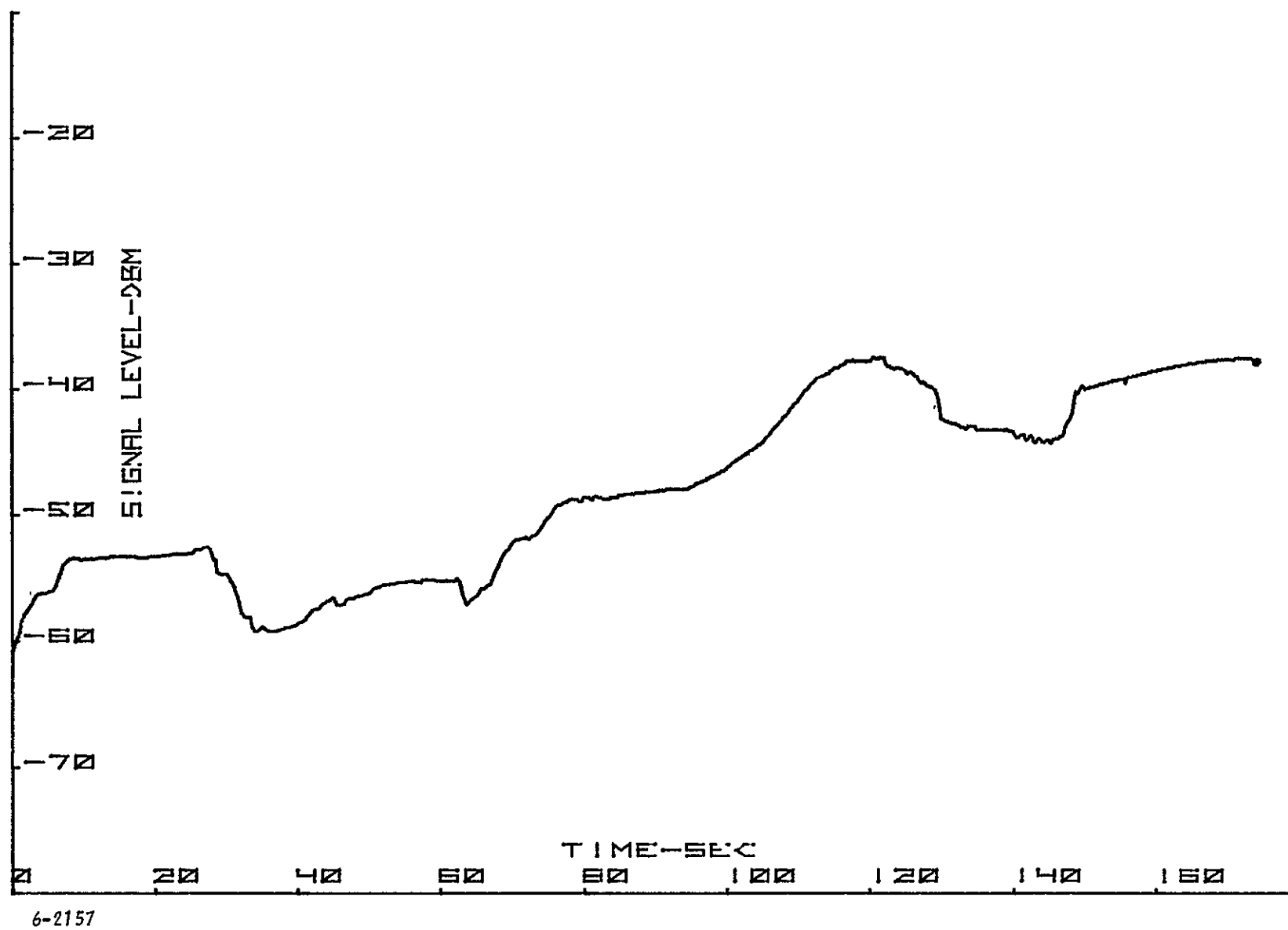


Figure 1-B8. Azimuth Signal Strength, ALT-2 Trajectory (0 mm/hr Rain)

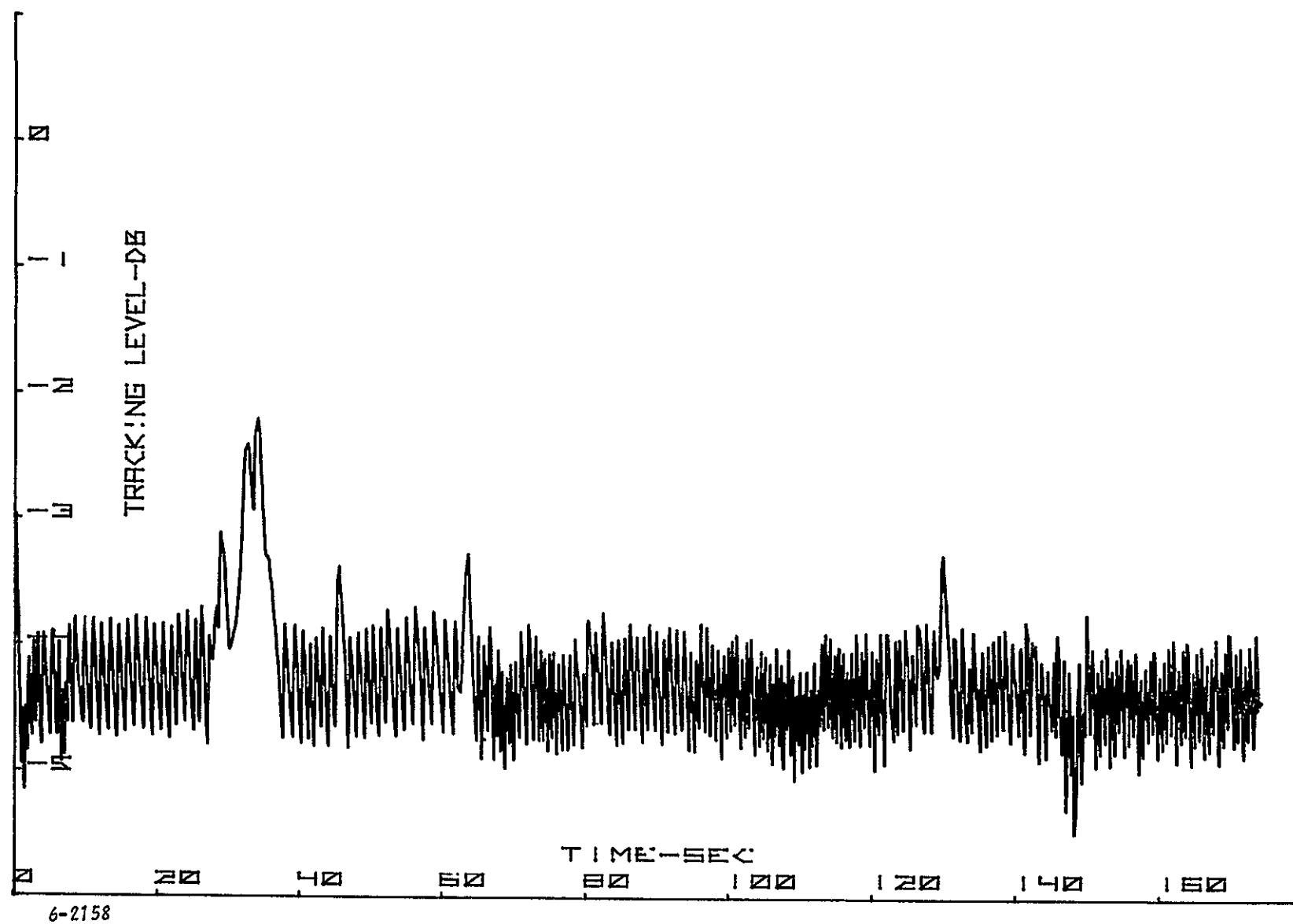


Figure 1-B9. Azimuth AGC Tracking Level, ALT-2 Trajectory (0 mm/hr Rain)

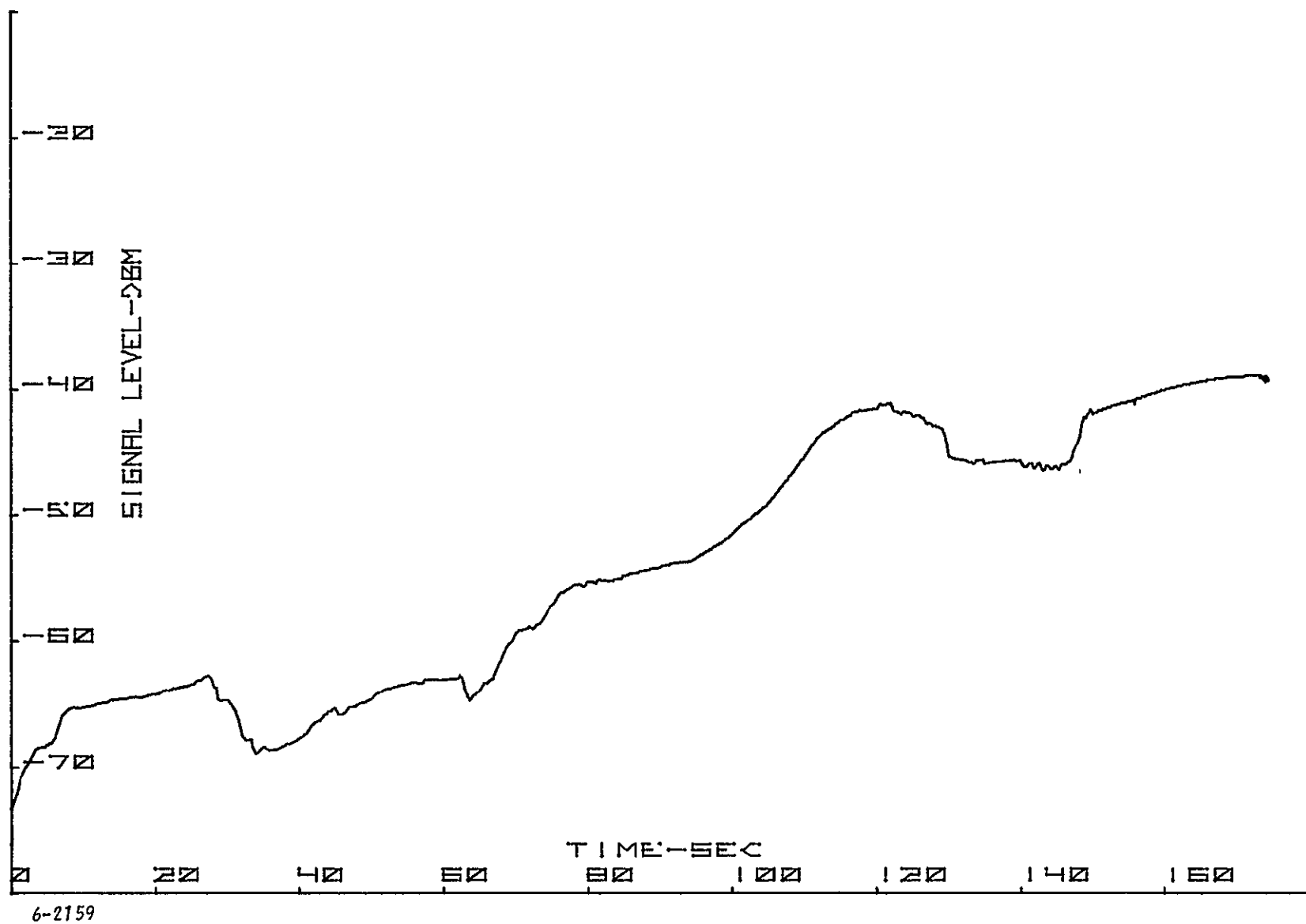


Figure 1-B10. Azimuth Signal Strength, ALT-2 Trajectory (10 mm/hr Rain)

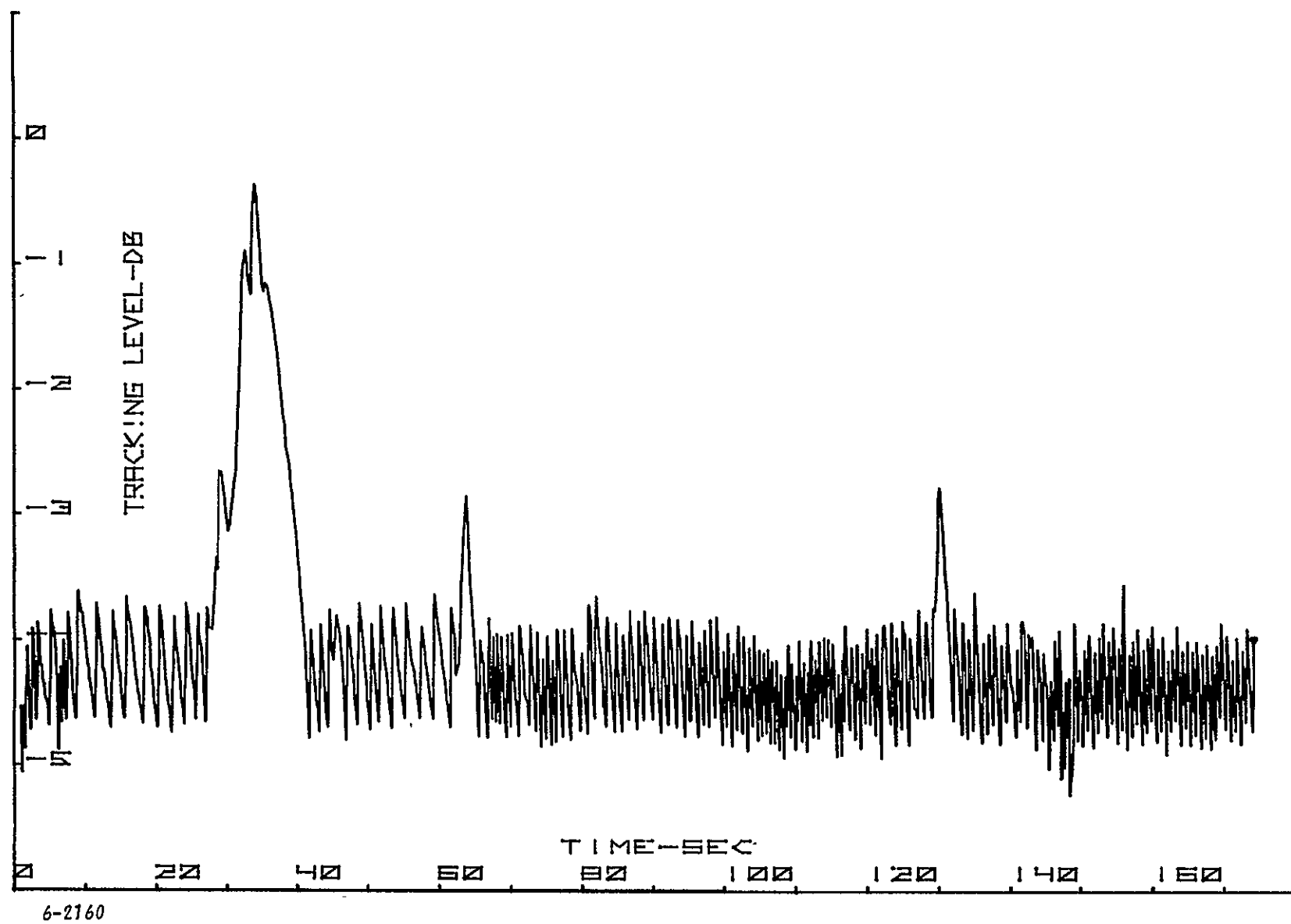


Figure 1-B11. Azimuth AGC Tracking Level, ALT-2 Trajectory (10 mm/hr Rain)

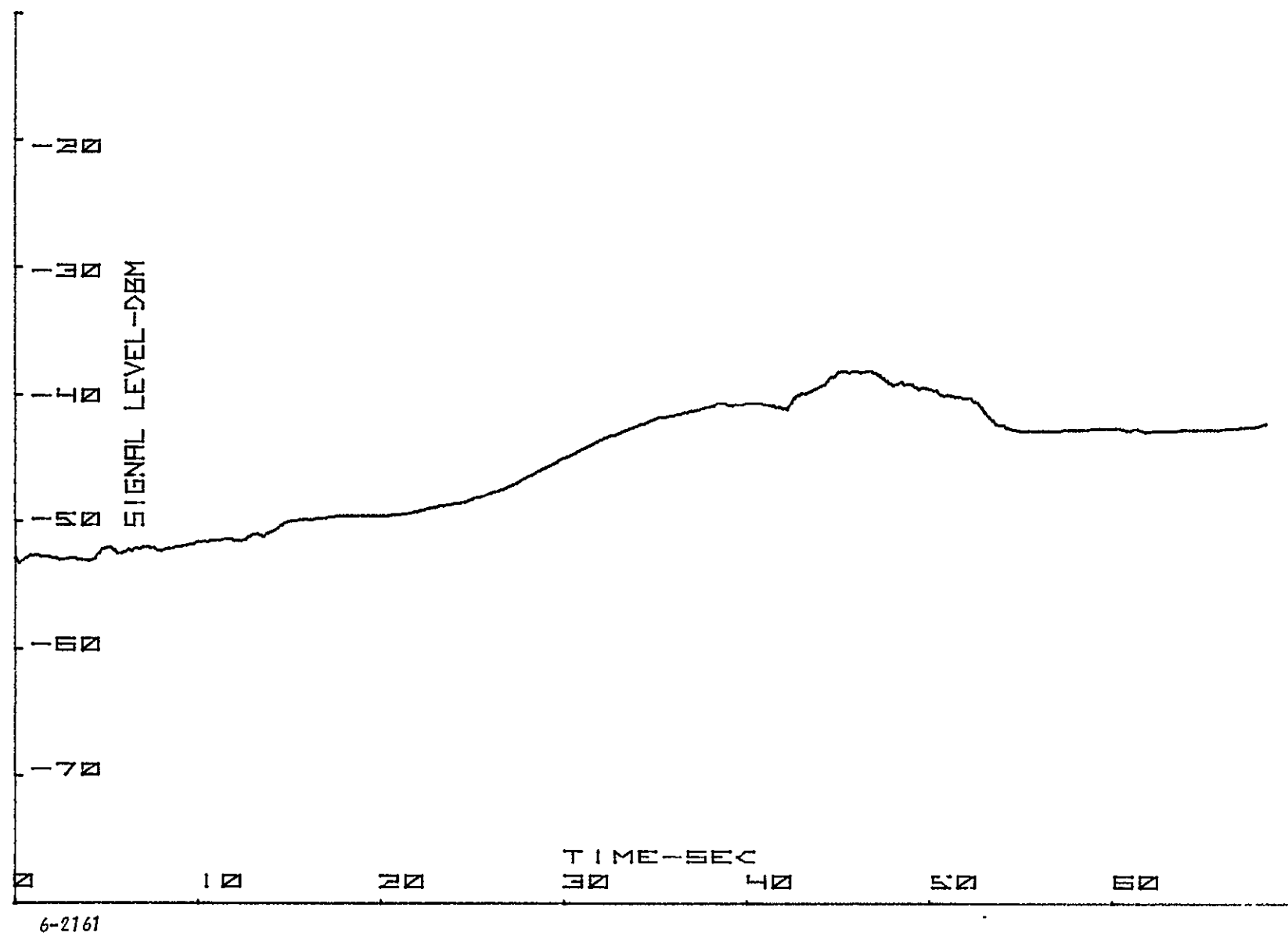


Figure 1-B12. Azimuth Signal Strength, OFT-1 Trajectory (0 mm/hr Rain)

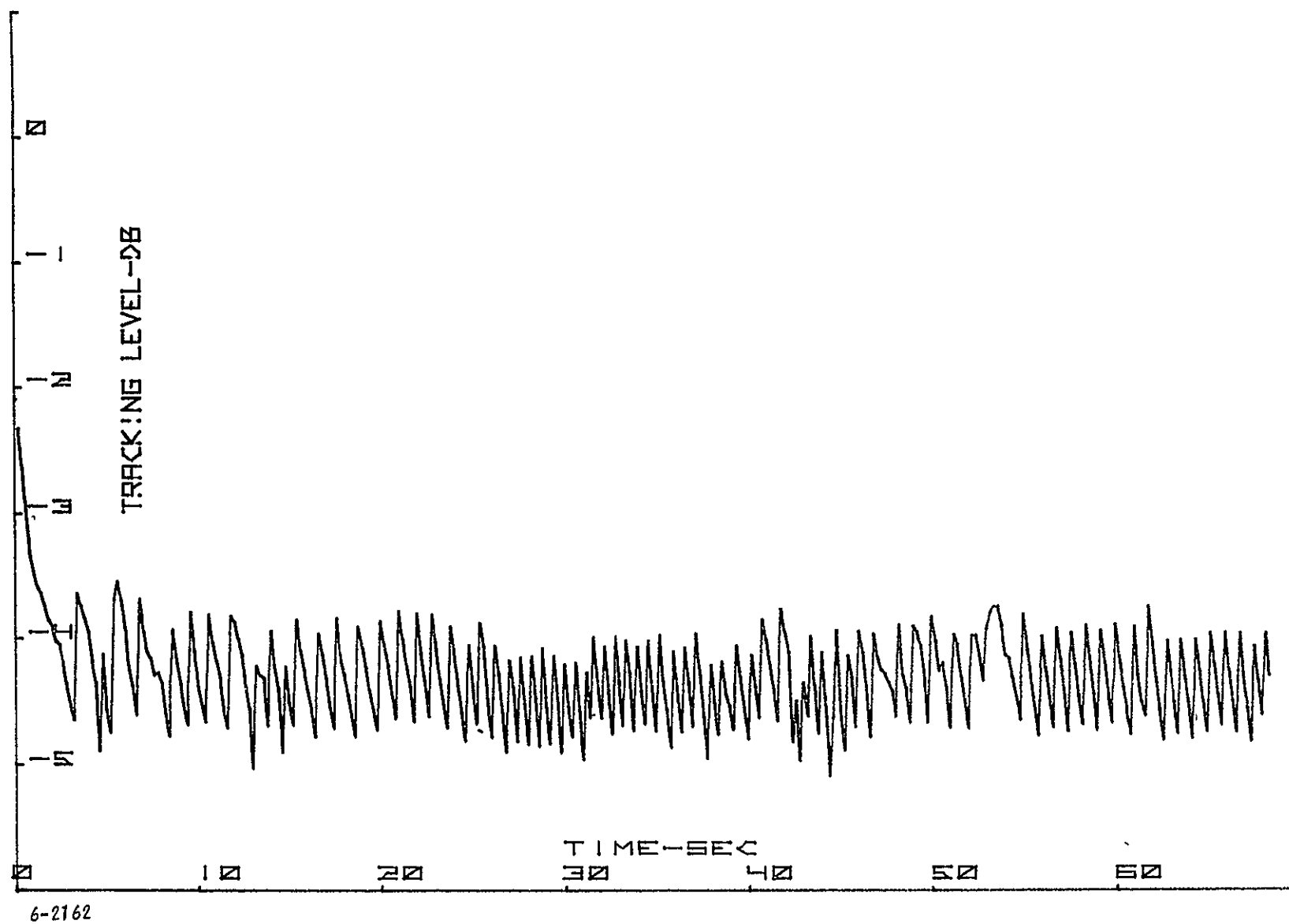


Figure 1-B13. Azimuth AGC Tracking Level, OFT-1 Trajectory (0 mm/hr Rain)

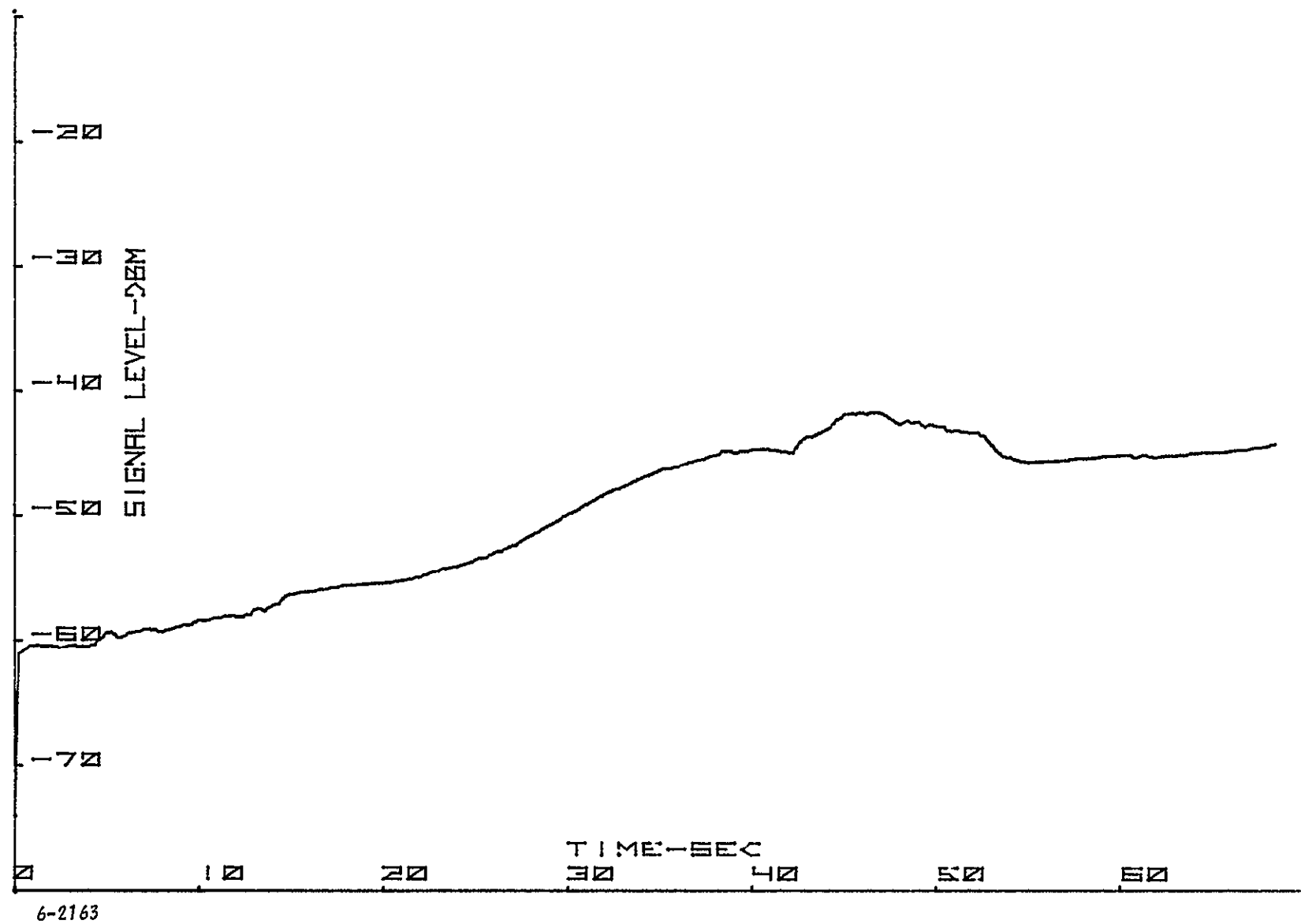


Figure 1-B14. Azimuth Signal Strength, OFT-1 Trajectory (10 mm/hr Rain)

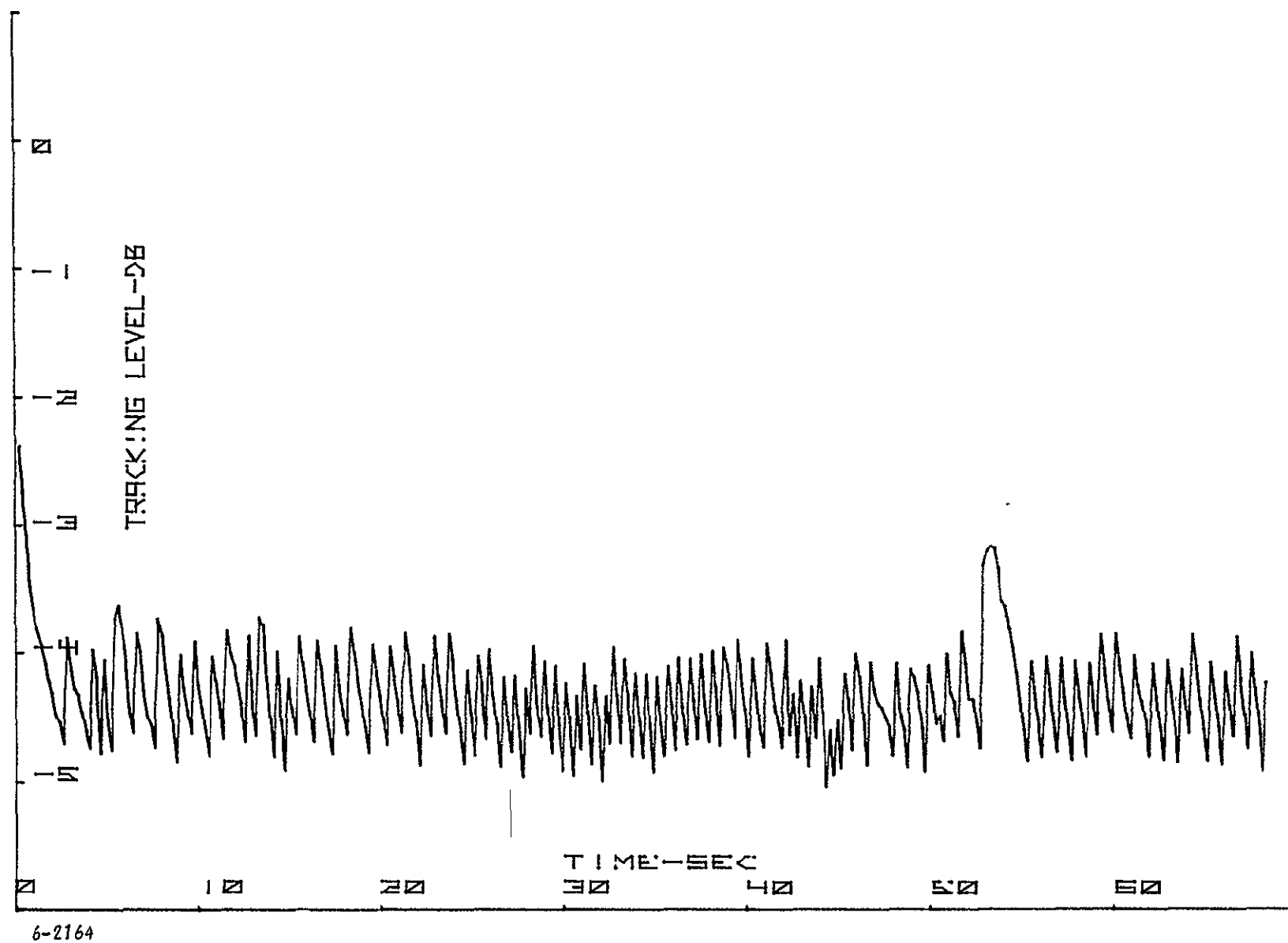


Figure 1-B15. Azimuth AGC Tracking Level, OFT-1 Trajectory (10 mm/hr Rain)

1-B7. REFERENCES

- a. W. Wong, Report No. Y220-01. Examination of MSBLS Nav Set Operation During the Acquisition Mode.
- b. W. Wong, Report No. Y220-06B. AGC Tracking Tests.
- c. Manual for MSBLS Navigation Set. PDRD No. TG01A AIL WBS No. 19-48-00 Rev A., March 1975.
- d. Orbiter Nav Set Specification. Rockwell MC409-0017 (Rev C)
- e. MSBLS Flight Performance Data Run No. 30, Azimuth OFT-1 Trajectory With 99 Percent Headwind, March 2, 1976 Run Date.
- f. MSBLS Flight Performance Data Run No. 10, Azimuth ALT-3 Trajectory No Wind, December 19, 1975 Run Date.
- g. MSBLS Flight Performance Data Run No. 27 Azimuth ALT-2 Trajectory, No Wind, February 1976 Run Date.

PART C

INTERACTION OF MSBLS DME INTERROGATORS

W. WONG

TECHNICAL REPORT

Y220-15

INTERIM - OCTOBER 1976

FINAL

JANUARY 1977

## 1-C1. INTRODUCTION

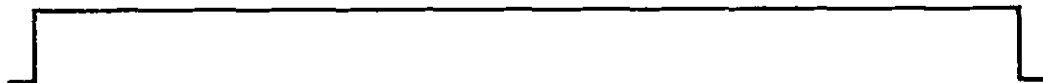
A laboratory test is to be performed to investigate MSBLS DME mutual interference among the three Nav Set interrogators. Following the ground station solicit signal, each Nav Set interrogates the ground station 16 times, with a period of 1666 microseconds, jittered by plus or minus 500 microseconds. Each interrogation reaching the ground transponder attempts to elicit a reply. Interference occurs whenever an interrogation reaches the transponder within 60 microseconds of a previous interrogation. In this case, no reply is generated for the second interrogation. The 60 microsecond inhibit, or dead time, is required in order to allow for transmitter charge up and recovery times (Figures 1-C1 and 1-C2).

The purpose of having a jittered interrogation period rather than a fixed one is to avoid having one interrogator follow a second interrogator inside the 60 microsecond inhibit time, and thereby have all of its interrogations unanswered by the transponder. For maximum reply efficiency, the amount of jitter should be uniformly distributed from -500 microseconds to +500 microseconds, and also should be independent from one interrogation to the next. In practice, using real electronic components, the jitter probability function would be other than uniform and successive jitter times could be correlated.

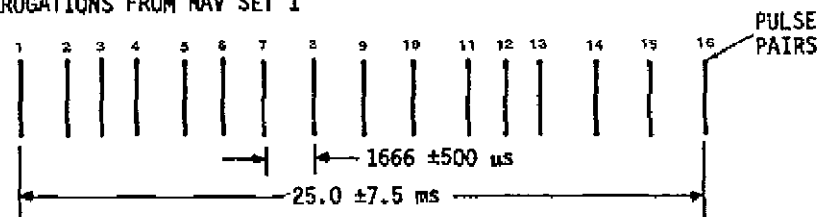
The test determines the following:

- a. The probability of any single interrogation being answered.
- b. The probability of having exactly  $r$  missed replies out of 16 interrogations for any DME period.
- c. The probability of having 8 or more missed replies. This is of particular significance, because, for this condition the Nav Set sets the DME flag and does not update the range word.

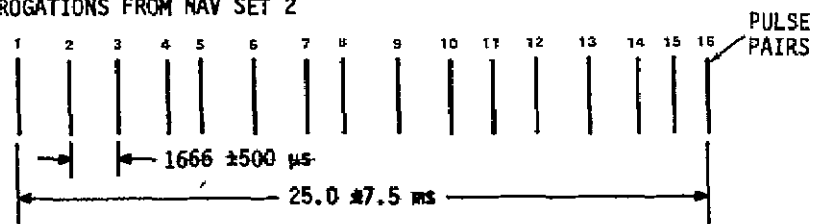
(A) DME PERIOD



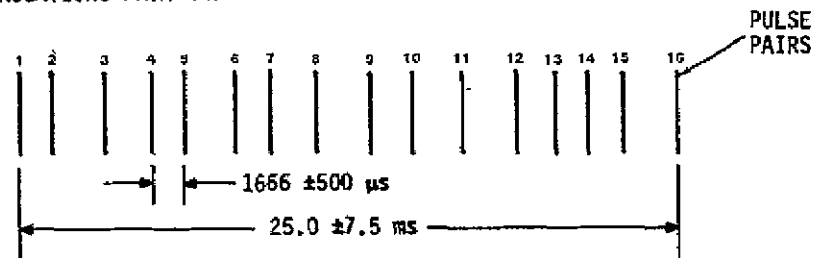
(B) INTERROGATIONS FROM NAV SET 1



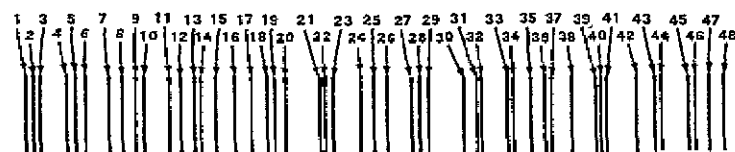
(C) INTERROGATIONS FROM NAV SET 2



(D) INTERROGATIONS FROM NAV SET 3



(E) INTERROGATIONS RECEIVED BY TRANSPONDER



(F) TRANSPONDER SOLICIT AND REPLY TRANSMISSION

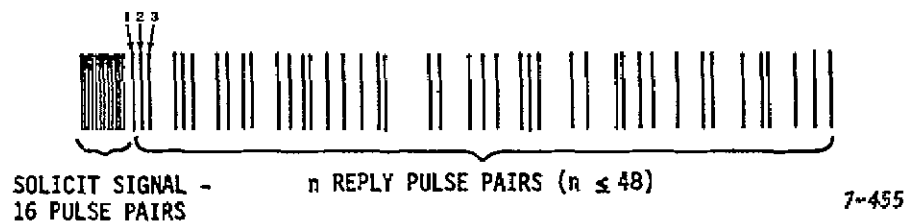
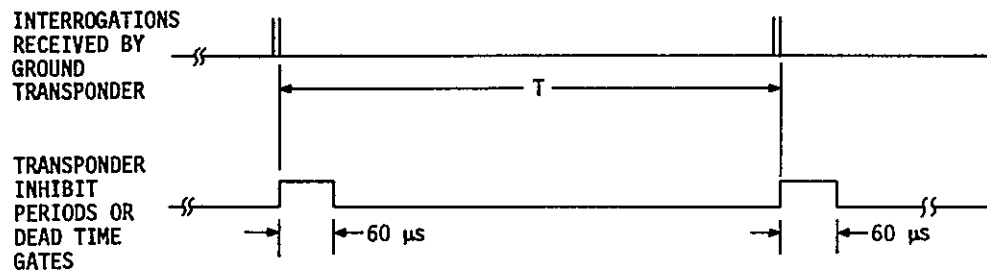


Figure 1-C1. MSBLS DME Signals



FOR THREE INTERROGATIONS EACH INTERROGATING AT AN AVERAGE 600 Hz (OR 1666 μs PERIOD) RATE, THE AVERAGE RATE THE TRANSPONDER IS BEING INTERROGATED IS 1800 Hz (OR 555 μs PERIOD). THEREFORE  $T_{AVG} = 555 \mu s$ , WHERE T CAN FALL BETWEEN 1166 AND 2166 μs (MAXIMUM THEORETICAL TIME BETWEEN INTERROGATIONS FROM A SINGLE INTERROGATOR IF UNIFORM JITTERING IS ASSUMED).

7-456

Figure 1-C2. Transponder Inhibit Periods

The test described here only determines DME interference due to unanswered replies. Therefore, it is necessary to only perform the test at video.

A second test which will evaluate the performance of a Nav Set in the presence of RF replies intended for other Nav Sets will also be performed. According to the Nav Set specification, a Nav Set should be able to operate simultaneously with as many as 9 additional interrogators.

#### 1-C2. INTERFERENCE DUE TO TRANSPONDER INHIBIT PERIODS

1-C3. TEST EQUIPMENT. The basic configuration of the test setup is shown in Figure 1-C3. The required equipment includes:

- a. Three Nav Set decoders.
- b. One Nav Set test equipment.
- c. One test board to monitor interference due to the 60  $\mu$ s transponder inhibit period and to provide results to a printer or display.
- d. Printer.
- e. Displays.
- f. Power divider.

Due to the unavailability of three Nav Set decoders, it became necessary to substitute a simulator board for the third Nav Set as shown in Figure 1-C4. The simulator board contains the exact circuitry for generating interrogation data triggers as is found in the Nav Set decoder units.

1-C4. TEST PROCEDURE. At the beginning of the DME information period shown in Figure 1-C5, the NSTE generates 14 RF solicit signal pulse pairs. The solicit signal passes into the RF receiving section of Nav Sets 1 and 2 and comes out as video. The resulting video pulses are then threshold detected and digitally processed to identify and track ten solicit pulse pairs.

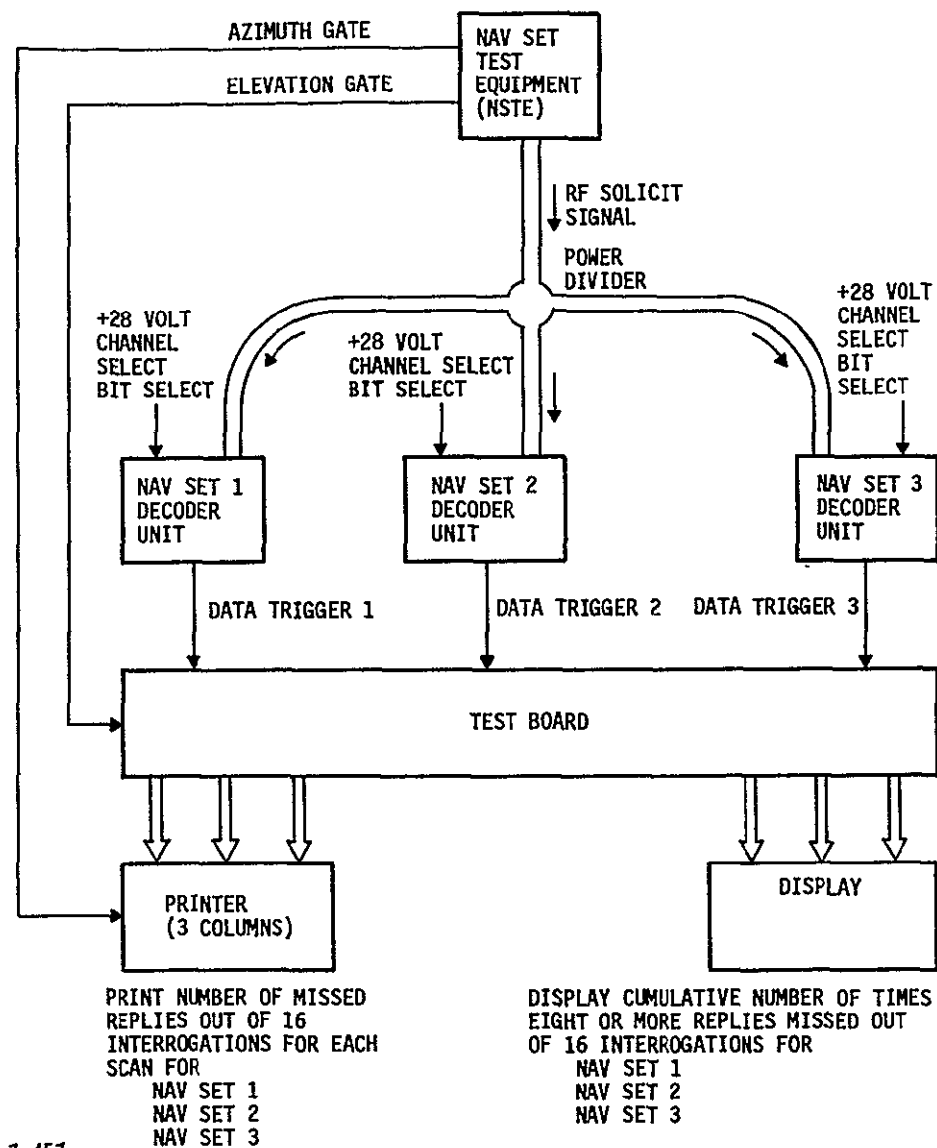
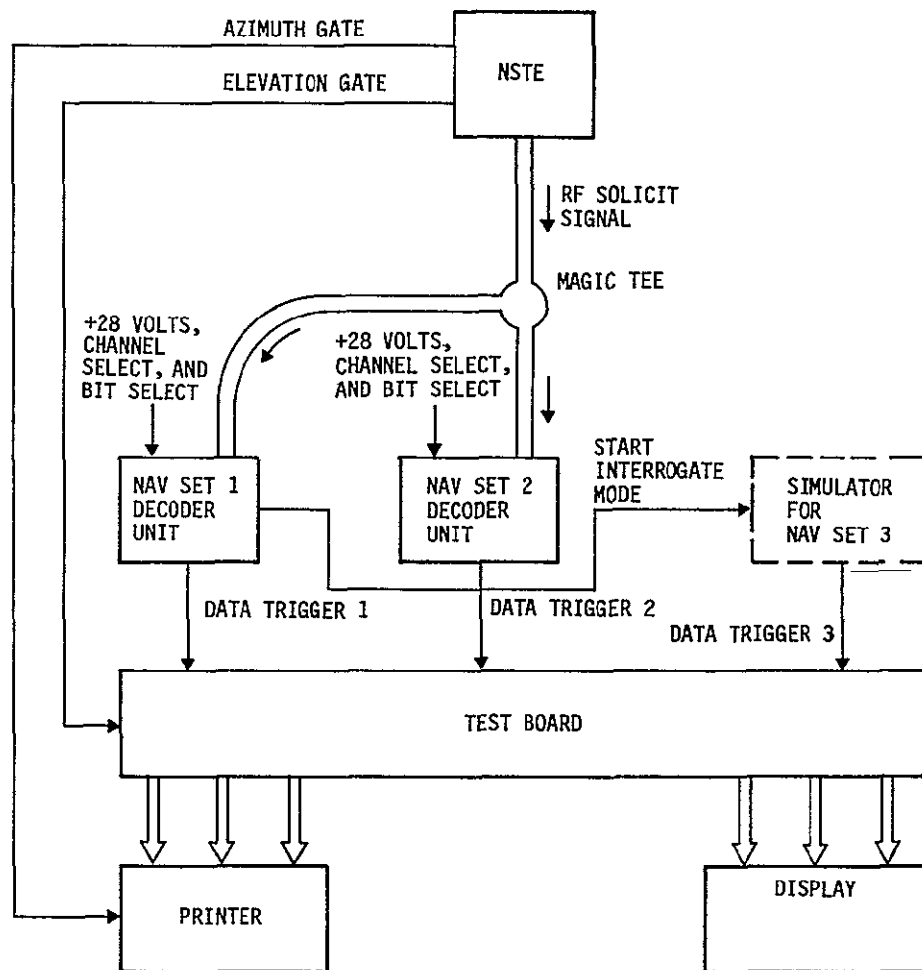
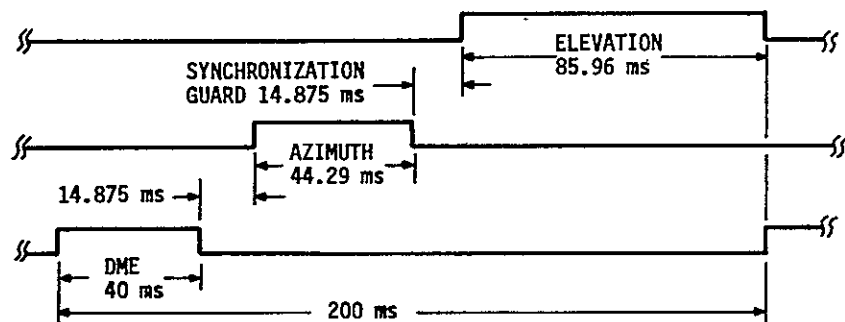


Figure 1-C3. Test Configuration



7-458

Figure 1-C4. Modified Test Configuration



NOTE:

FROM TECHNICAL SPECIFICATION FOR  
MSBLS-GS 8/13/75, FIGURE 2

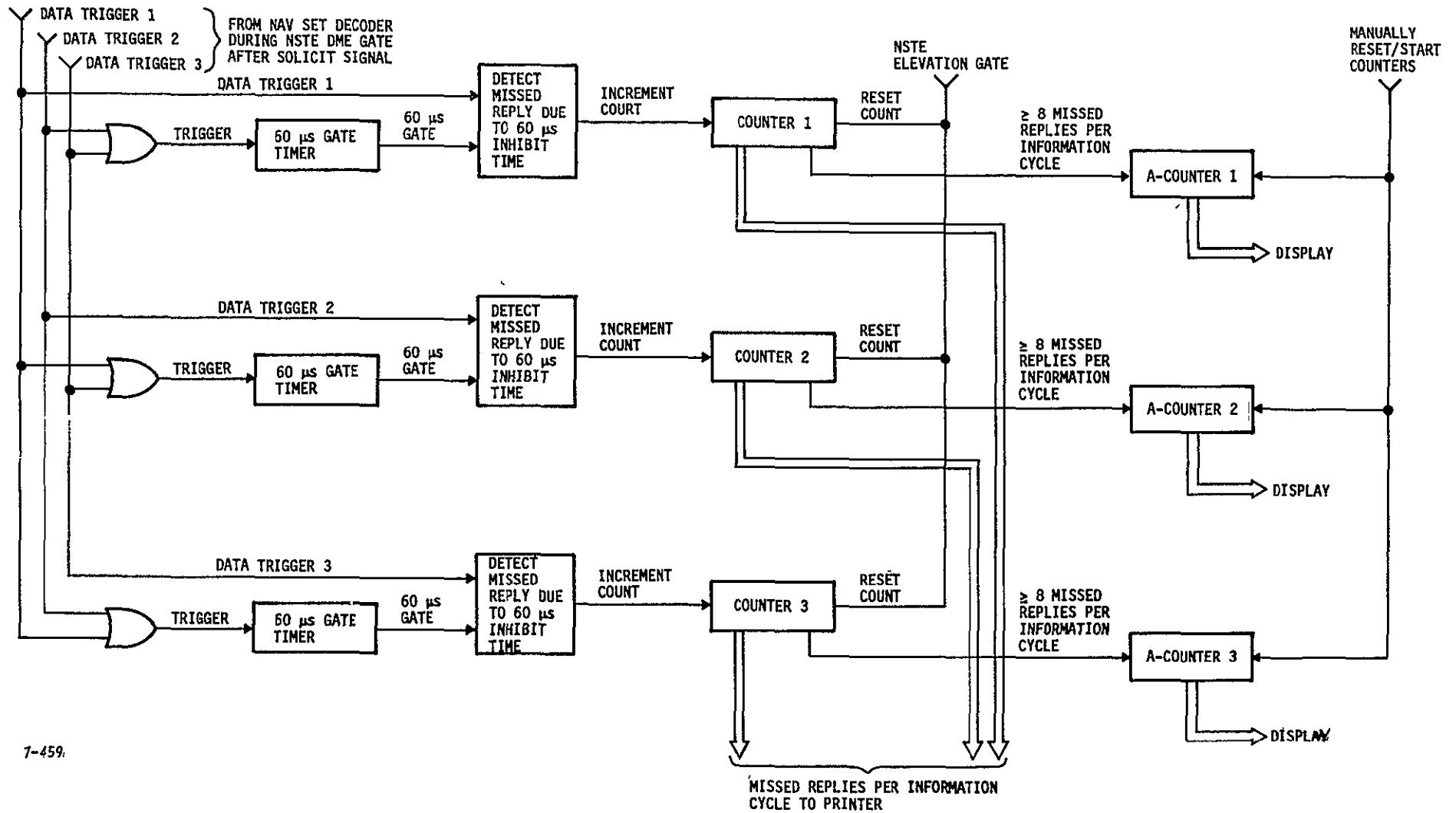
6-2995

Figure 1-C5. NSTE and MSBLS-GS Timing and Sequence Format

After processing the solicit signal, the Nav Set digital signal processor generates the start interrogation mode pulse (SITM) which starts the generation of 16 TTL identity and data triggers with the appropriate channel spacing. These triggers are normally directed by wire to a Nav Set RF unit to trigger an RF interrogation pair from the transmitter. Generally, for any given Nav Set transmitter, the input to output delay is fixed, and is less than 1 microsecond. Also, in the MSBLS system, the transmission delay time from the three collocated Nav Set interrogators to the ground station transponder would be the same. Therefore, in order to investigate DME interference due to interrogations reaching the transponder during its inhibit periods, it is necessary only to monitor the Nav Set's TTL triggers since we are only interested in the relative occurrences of the interrogations. The bench test using this approach is shown in Figure 1-C4.

Since the transponder inhibit period applies to the time between interrogation data pulses, only the Nav Set data triggers need to be monitored by the test board. The SITM pulse is directed to the simulated Nav Set board in order to allow it to start generating data triggers.

During each DME period, the test board receives a total of 48 data triggers; 16 from each Nav Set. A block diagram of the test board is given in Figure 1-C6. In order to determine the number of times replies to Nav Set 1 would be inhibited due to interrogations from Nav Sets 2 or 3, data trigger 2 and data trigger 3 are used to trigger 60  $\mu$ s inhibit gates. Whenever data trigger 1 occurs inside the 60  $\mu$ s gate, a binary counter, A, is incremented. Counter A is cleared before the DME period. After all 16 data triggers have been generated, this counter indicates the total number of missed replies for that DME period for Nav Set 1. Counters B and C perform the same function for Nav Sets 2 and 3. After the DME period, the NSTE azimuth gate is used to trigger a print command to the printer for a printout of counters A, B, and C, in hexadecimal form. The three columns of data indicate the number of missed replies during each DME period for



7-459.

Figure 1-C6. Test Board Block Diagram

each Nav Set. The NSTE elevation gate, which follows the NSTE azimuth gate and precedes the NSTE DME gate, clears counters A, B, and C.

The displays to the right of counters D, E, and F are used to display the accumulated number of DME periods during which eight or more replies were missed for each Nav Set. Whenever a Nav Set does not receive at least eight tracked replies, there is no updating of the MDM range word, and the validity bit of the MDM range word will be flagged.

Data from the printout and displays can be used for a statistical evaluation of DME interference.

#### 1-C5. PREDICTED RESULTS

1-C6. Overall Reply Efficiency. The probability of an interrogation being successfully answered can be predicted from the following equations:

$$P = \frac{1}{1 + \frac{T_d}{T_i} (N - 1)} \quad (6a)$$

$$Q = 1 - P \quad (6b)$$

where:

P = probability of an interrogator eliciting a reply

Q = probability of an interrogation falling inside a transponder inhibit period

$T_d$  = transponder inhibit time = 60  $\mu$ s

$T_i$  = average interrogation period = 1666  $\mu$ s

N = number of interrogators = 3

Therefore:

$$P = \frac{1}{1 + \frac{60}{1666} \times 2} = 0.933$$

$$Q = 0.067$$

1-C7. Information Cycle Reply Efficiency. The probability of exactly  $r$  missed replies out of 16 interrogations for any DME period is equal to:

$$q_r = \binom{16}{r} (0.067)^r (0.933)^{16-r} \quad (7a)$$

where:

$q_r$  = probability of exactly  $r$  misses out of 16 interrogations  
 $r$  = number of missed replies

A graph of  $q_r$  versus  $r$  is given in Figure 1-C7.

The probability of having exactly  $h$  replies out of 16 interrogations is equal to:

$$P_h = 1 - q_r \quad (7b)$$

where:

$h + r = 16$   
 $h$  = number of successful replies

1-C8. System Reply Efficiency. The probability of having eight or more missed replies out of 16 interrogations is equal to:

$$q (\text{misses} \geq 8) = \sum_{i=8}^{16} \binom{16}{i} (0.067)^i (0.933)^{16-i} \quad (8a)$$

$$q (\text{misses} \geq 8) = 0.000\ 0032$$

This number corresponds to a single occurrence once every:

$$\frac{1}{0.000\ 0032} = 312000 \text{ scans (0.2 second per scan)}$$

or equivalent in hours:

$$312000 \text{ scans} \times \frac{1 \text{ sec}}{5 \text{ scans}} \times \frac{1 \text{ hr}}{3600 \text{ sec}} = 17 \text{ hrs}$$

The expected rate of finding eight or greater missed replies is, therefore, once every 17 hours.

The general form of the cumulative distribution used above is given by:

$$q(\text{misses} \geq r) = \sum_{i=r}^{16} \binom{16}{i} (0.067)^i (0.933)^{16-i} \quad (8b)$$

$$r = 0, 1, 2 \dots 16$$

A graph of the equation is given in Figure 1-C8.

1-C9. RESULTS. Each of the three Nav Sets used in the test are identified as Nav Set 1, 2, and 3 as follows:

- a. Nav Set 1 - A predeliverable Nav Set unit.
- b. Nav Set 2 - The engineering model Nav Set
- c. Nav Set 3 - Test board to simulate interrogation data triggers for a Nav Set.

The first part of the test consists of a printout of the number of interrogations falling in an inhibit gate for each Nav Set for each DME period. A compilation of the data is given in Table 1-C1.

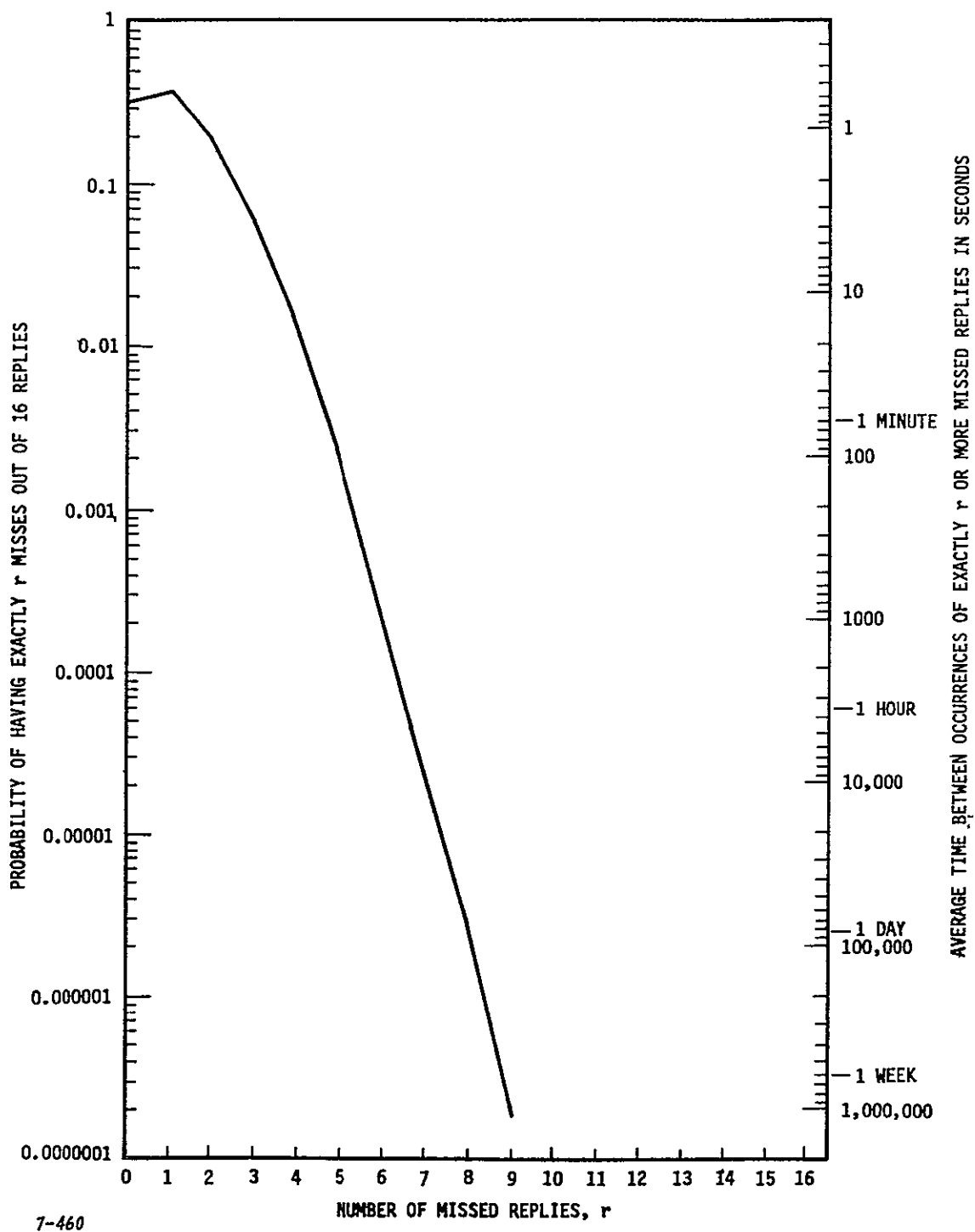


Figure 1-C7. Probability of Having Exactly  $r$  Misses Out of 16 Interrogations and Average Time Between Such Occurrences

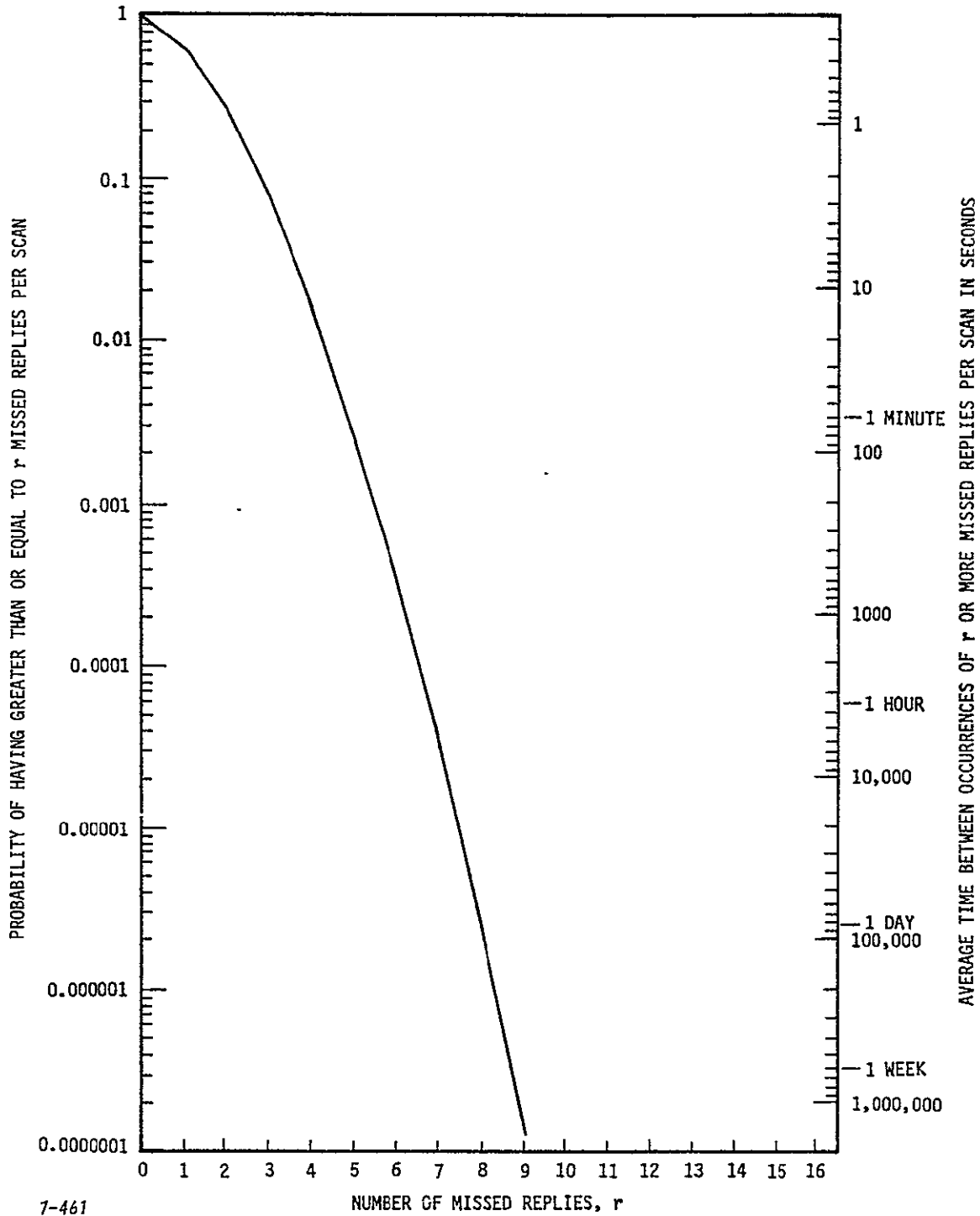


Figure 1-C8. Probability of Having  $r$  Or More Missed Replies Per Scan and Average Time Between Such Occurrences

Table 1-C1. Interrogation Falling in an Inhibit Gate  
for Each Nav Set for Each DME Period

Total Number of Scans = 566

| Number of<br>Interrogations (K)<br>Falling Into<br>The Inhibit Gate<br>Out of 16<br>Interrogations | Number ( $X_K$ ) of Scans K Interrogations Are<br>Inhibited |           |           |
|----------------------------------------------------------------------------------------------------|-------------------------------------------------------------|-----------|-----------|
|                                                                                                    | Nav Set 1                                                   | Nav Set 2 | Nav Set 3 |
| 0                                                                                                  | 145                                                         | 174       | 177       |
| 1                                                                                                  | 221                                                         | 197       | 214       |
| 2                                                                                                  | 150                                                         | 140       | 133       |
| 3                                                                                                  | 37                                                          | 40        | 31        |
| 4                                                                                                  | 13                                                          | 13        | 9         |
| 5                                                                                                  | 0                                                           | 2         | 1         |
| 6                                                                                                  | 0                                                           | 0         | 1         |
| 7                                                                                                  | 0                                                           | 0         | 0         |
| 8                                                                                                  | 0                                                           | 0         | 0         |
| 9                                                                                                  | 0                                                           | 0         | 0         |
| 10                                                                                                 | 0                                                           | 0         | 0         |
| 11                                                                                                 | 0                                                           | 0         | 0         |
| 12                                                                                                 | 0                                                           | 0         | 0         |
| 13                                                                                                 | 0                                                           | 0         | 0         |
| 14                                                                                                 | 0                                                           | 0         | 0         |
| 15                                                                                                 | 0                                                           | 0         | 0         |
| 16                                                                                                 | 0                                                           | 0         | 0         |

For Table 1-C1, the overall reply efficiency can be computed from the equation:

$$1 - \frac{1}{16} \sum_{K=0}^{16} K X_K \quad (9a)$$

for each NAVSET. The results are given in Table 1-C2.

Table 1-C2. Overall Reply Efficiency

| <u>Nav Set</u> | <u>Efficiency</u> |
|----------------|-------------------|
| Theoretical    | 0.933             |
| Nav Set 1      | 0.924             |
| Nav Set 2      | 0.927             |
| Nav Set 3      | 0.931             |

In the second part of the test, a display was used to show the number of times eight or more replies were missed during a DME period for each Nav Set. The test was run for 65 hours and there were no occurrences of eight or more missed replies for any of the Nav Sets. As derived previously, the expected rate is 17 hours between occurrences for each Nav Set.

The display was also used to show r or more misses per DME period, for r equaling 0, 1, 2, 3, 4, 5, 6, and 7. A tabulation of the results is given in Table 1-C3.

The data from Table 1-C3 are plotted in Figures 1-C9, 1-C10, and 1-C11 for comparison with the theoretical curve. The points for the plots are obtained from the raw data, by dividing the number of occurrences by the total time, and then dividing the result by 5.

Table 1-C3. Test Tabulation for Eight or More Misses During a DME Period

| Misses Per<br>DME Period | Theoretical<br>Rate | Total<br>Time<br>of Test | Nav Set 1        |              | Nav Set 2        |              | Nav Set 3        |          |
|--------------------------|---------------------|--------------------------|------------------|--------------|------------------|--------------|------------------|----------|
|                          |                     |                          | Occur-<br>rences | Rate         | Occur-<br>rences | Rate         | Occur-<br>rences | Rate     |
| $\geq 1$                 | 3.4/sec             | 275 sec                  | 839              | 3.1/sec      | 952              | 3.5/sec      | 921              | 3.3/sec  |
| $\geq 2$                 | 1.45/sec            | 535 sec                  | 946              | 1.77/<br>sec | 923              | 1.73/<br>sec | 850              | 1.59/sec |
| $\geq 3$                 | 26/min              | 20 min                   | 588              | 29/min       | 585              | 29/min       | 539              | 27/min   |
| $\geq 4$                 | 5.7/min             | 62 min                   | 600              | 9.7/<br>min  | 512              | 8.3/<br>min  | 462              | 7.5/min  |
| $\geq 5$                 | 0.96/min            | 60 min                   | 94               | 1.57/<br>min | 78               | 1.30/<br>min | 79               | 1.32/min |
| $\geq 6$                 | 7.2/hr              | 14.75 hrs                | 7                | 0.5/hr       | 4                | 0.3/min      | 6                | 0.4/min  |
| $\geq 7$                 | 0.72/hr             | 17.5 hrs                 | 0                | --           | 4                | 0.2/hr       | 0                | --       |
| $\geq 8$                 | 1.4/day             | 65 hrs                   | 0                | --           | 0                | --           | 0                | --       |

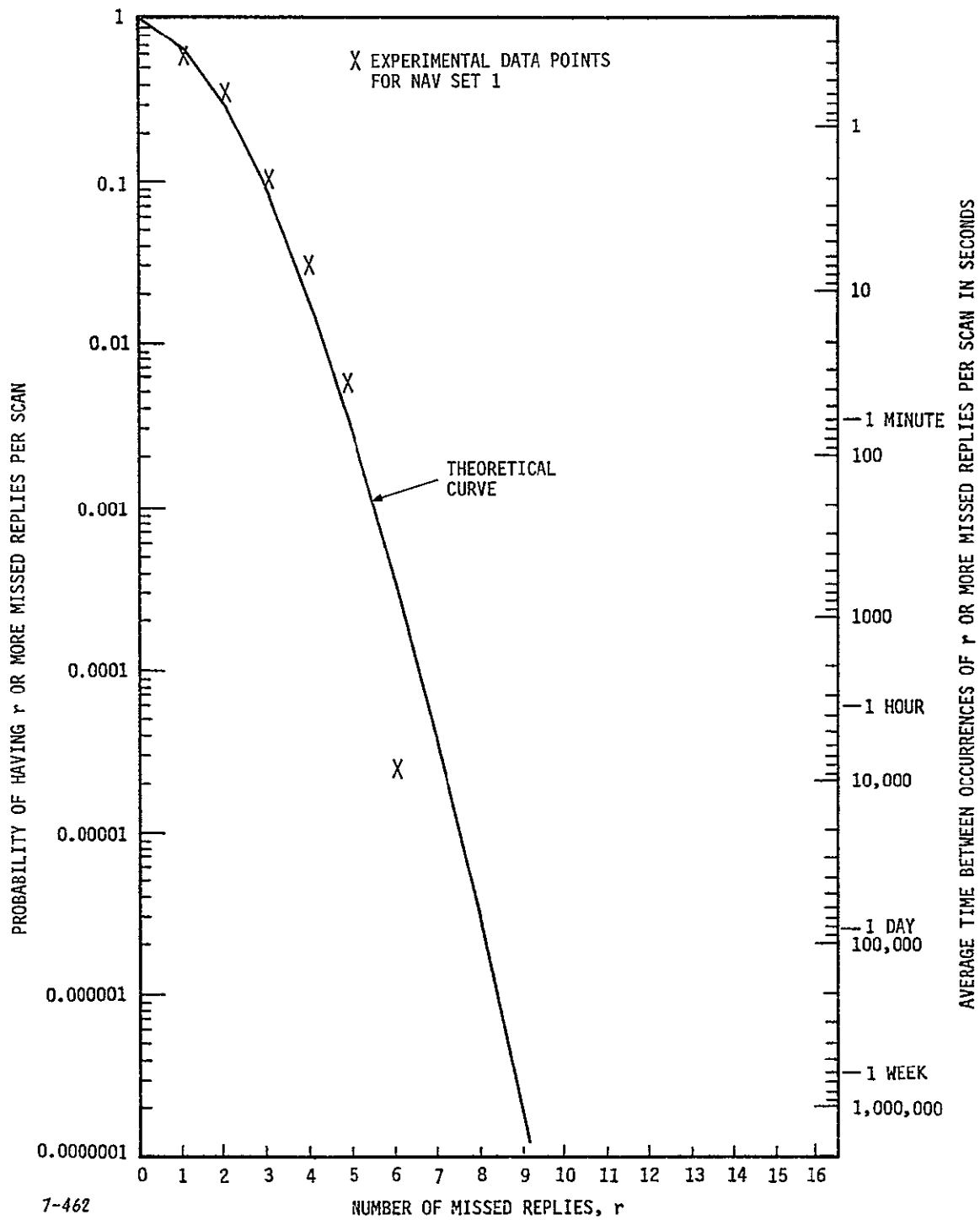


Figure 1-C9. Probability of Having  $r$  Or More Missed Replies Per Scan and Average Time Between Such Occurrences (Nav Set 1)

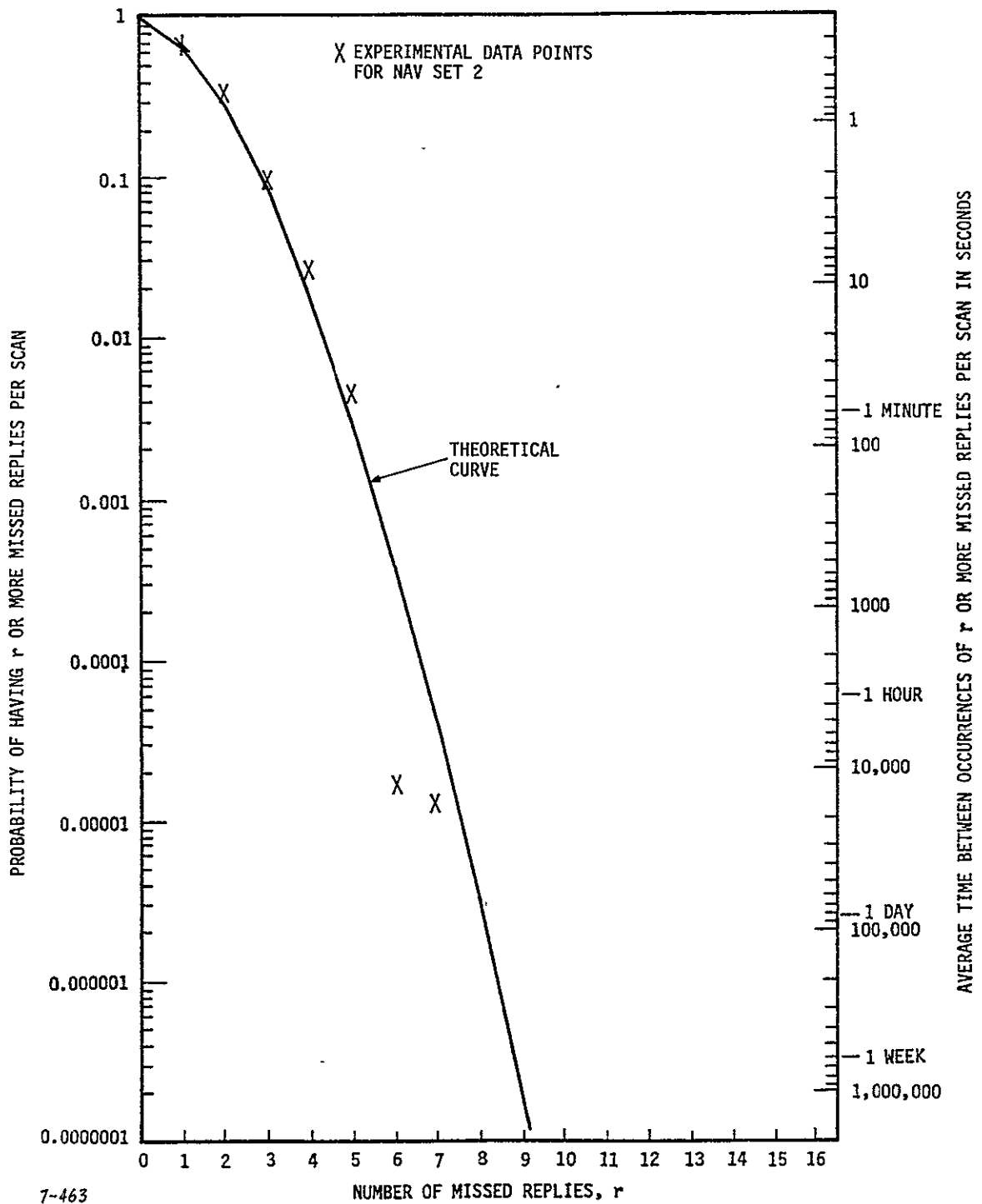


Figure 1-C10. Probability of Having  $r$  Or More Missed Replies Per Scan and Average Time Between Such Occurrences (Nav Set 2)

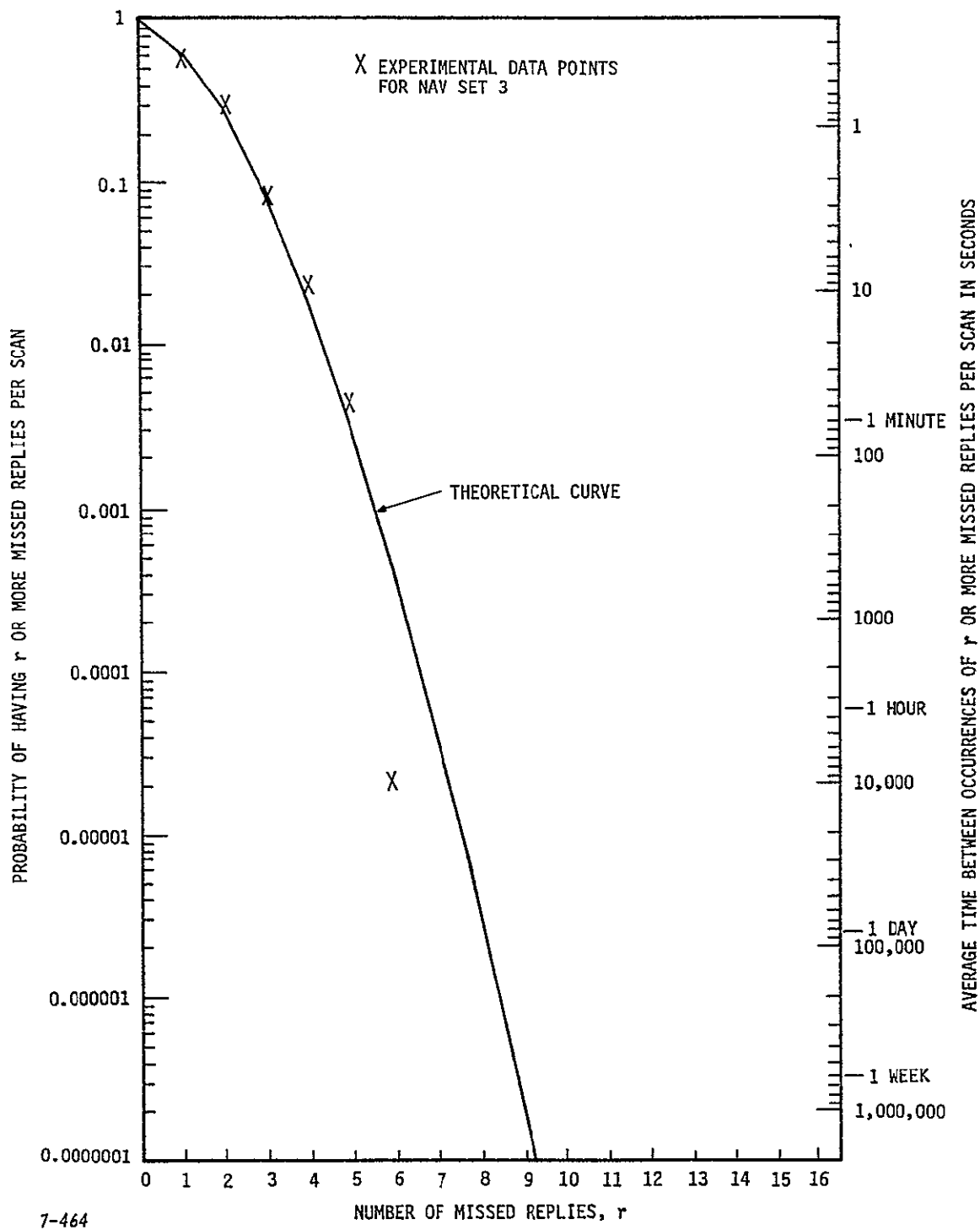


Figure 1-C11. Probability of Having  $r$  Or More Missed Replies Per Scan and Average Time Between Such Occurrences (Nav Set 3)

1-C10. DIFFERENCES IN AVERAGE INTERROGATION PERIOD. In the analysis for theoretical rates of interference, the assumption was made that the interrogations were generated by the three Nav Sets with the same average interrogation period of 1666 microseconds. However, it can be shown that for any Nav Set, the average interrogation can differ from 1666 microseconds by as much as plus or minus 15 percent due to the component tolerances of two resistors and one capacitor. The interrogation period is determined from the equation:

$$T = K (R_A + 2 R_B) C \quad (10a)$$

where:

$$R_A = 3300 \text{ ohms } \pm 5 \text{ pct}$$

$$R_B = 5100 \text{ ohms } \pm 5 \text{ pct}$$

$$C = 0.18 \text{ } \mu\text{f } \pm 10 \text{ pct}$$

$$K = 0.686$$

The maximum percent deviation of T can be found from a sensitivity analysis of the equation for T, or by inspection as follows. The maximum increase in T is obtained by multiplying the factor  $(R_A + 2R_B)$  by 1.05, and C by 1.10. The net percent increase in T is then equal to:

$$[1 - (1.05)(1.10)] \times 100\% = -14.5\%$$

The corresponding limits for the average interrogation period are 1924 microseconds and 1424 microseconds.

Differences in the interrogation periods among three Nav Sets will produce corresponding differences in interference rates. The minimum reply efficiency of 0.922 occurs when all three Nav Sets have the minimum average interrogation period, and the maximum reply efficiency of 0.941 is obtained with the maximum interrogation period. The corresponding time for eight or

more missed replies is 5.8 hours and 47 hours. In general, the average interrogation periods will differ and, therefore, the reply efficiencies for each of the three Nav Sets will differ.

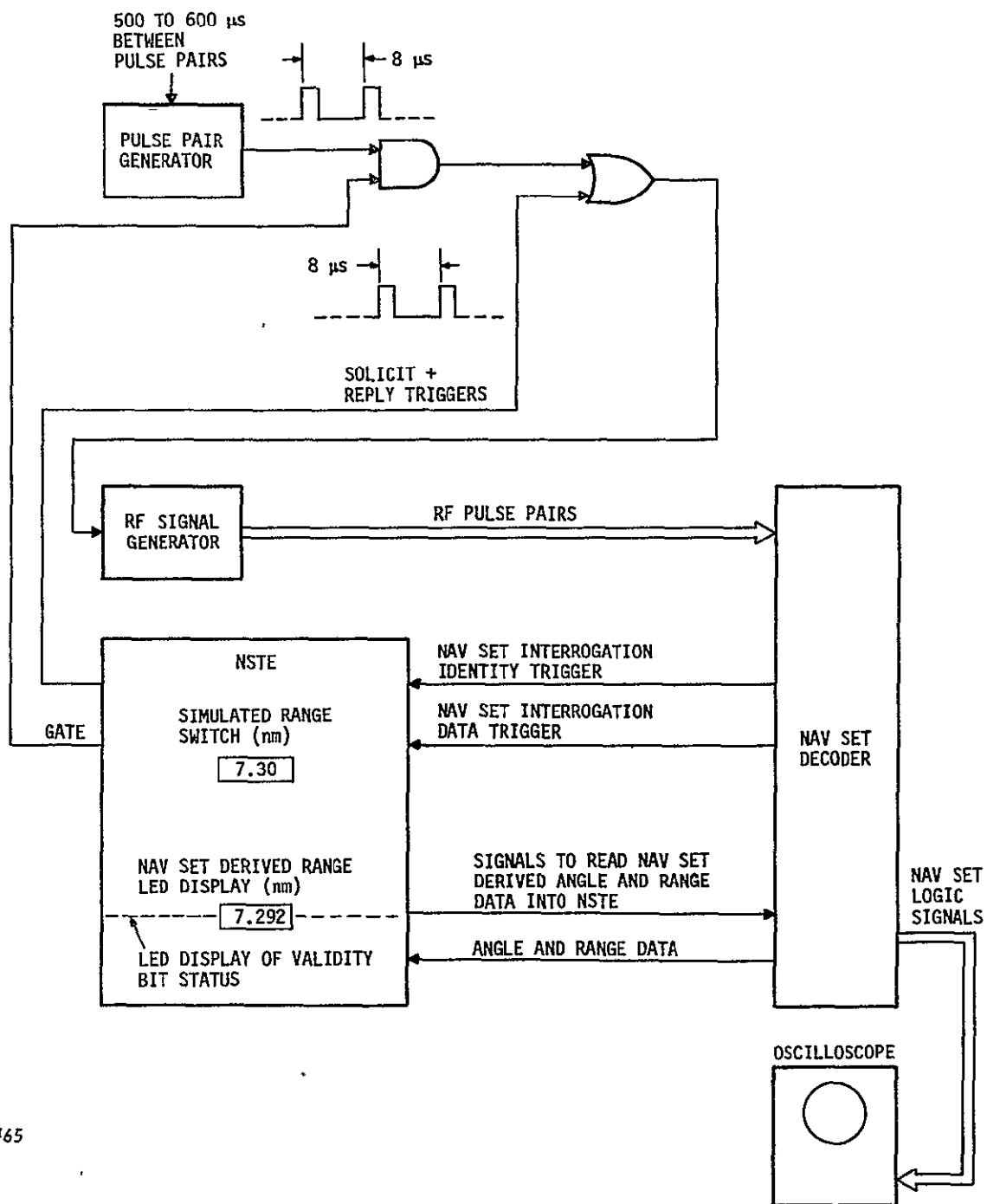
1-C11. CONCLUSION. The test of the effect of transponder inhibit times on DME performance for three interrogators conforms closely with predictions. Each interrogator occasionally has one or two missed replies due to the fact that the transponder is busy answering other interrogators. For more than two missed replies, the frequency of occurrence decreases by a factor of almost ten for each extra missed reply. There is no evidence of two interrogators' interrogations locking on to each other to produce repeated occurrences of many missed replies. The interrogation squitter scheme employed in the Nav Set appears to be adequate enough to prevent this from happening.

#### 1-C12. NAV SET PERFORMANCE IN THE PRESENCE OF SPURIOUS REPLIES

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1-C13. SUMMARY OF TEST RESULTS. The MSBLS DME system operates with a single ground station transponder and three Nav Sets. During the period reserved for DME operation, the three Nav Sets simultaneously interrogate the ground station. Each Nav Set tracks its own replies and should ignore replies intended for other Nav Sets.

A test was made to investigate Nav Set DME performance in the presence of spurious replies. Spurious replies are either replies intended for other Nav Sets, which in general do not fall into the track gate of the Nav Set in question, or replies generated by the ground station triggering on noise. Due to the unavailability of three Nav Sets, the test was performed with a single Nav Set decoder and a pulse pair generator triggering the spurious replies as shown in Figure 1-C12. During the DME period, the NSTE receives the Nav Set interrogation triggers and, after an appropriate time delay (which simulates the selected range), triggers the RF signal generator to transmit



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Figure 1-C12. Test Setup for Detecting Nav Set Decoder DME Interference Due to Spurious RF Replies

replies to the Nav Set. At the same time, the pulse pair generator generates a train of 8- $\mu$ s pulse pairs to trigger the RF signal generator to transmit spurious replies to the Nav Set. Nav Set derived range was monitored from the NSTE front panel display and Nav Set internal logic signals were monitored with an oscilloscope.

During the test, Nav Set range derived data was observed to jump to incorrect ranges without flagging the validity bit. As shown in Table 1-C4, with a simulated range of 7.3 nautical miles, the Nav Set range fell down to ranges such as 1.454, 1.513, and 2.818 nautical miles. Such data jumps were also observed at other selected ranges.

The average time between range jump occurrences varied from 10 to 60 seconds, depending on both the signal power level to the Nav Set and the period of the spurious replies to the Nav Set. A higher signal level would decrease the time between range jumps while a higher spurious reply period would decrease the time between range jumps.

1-C14. NAV SET RANGE DOUBLE COMPUTE PROBLEM. The range jumps were traced to a logic problem in which the average range is computed twice per DME cycle, producing the incorrect range at the second computation. A range jump can appear whenever the Nav Set receives a spurious reply inside a 64 microsecond window and the right combination of logic conditions exist.

#### 1-C15. EXPECTED RATE OF DOUBLE COMPUTE OCCURRENCE

The nature of Nav Set decoder logic makes the average time between double computes a function of both signal power and the period of the spurious replies. From an understanding of the sequential timing necessary for range jumps to occur, predictions can be made of the degree of the problem for three Nav Sets operating simultaneously.

Table 1-C4. Examples of Range Jumps Without  
Validity Bit Flags

| (1)<br>NSTE<br>Selected Range<br>(nm) | (2)<br>Nav Set Derived Range<br>(nm) |                                          |
|---------------------------------------|--------------------------------------|------------------------------------------|
|                                       | Typical<br>Good Data                 | Range Jumps<br>Without<br>Validity Flags |
| 0.30                                  | 0.293                                | 1.336<br>2.643<br>3.947                  |
| 1.30                                  | 1.293                                | 0.101<br>0.142<br>4.067                  |
| 2.30                                  | 2.295                                | 1.558<br>2.876<br>4.093                  |
| 3.30                                  | 3.293                                | 2.671<br>3.951<br>3.976                  |
| 4.30                                  | 4.295                                | 0.111<br>0.180<br>1.452                  |
| 7.30                                  | 7.292                                | 1.454<br>1.513<br>2.818                  |
| 9.30                                  | 9.292                                | 1.349<br>1.424<br>2.728                  |

(1) Simulated range selected from NSTE front panel switch

(2) Read from NSTE printout and display of Nav Set derived range data

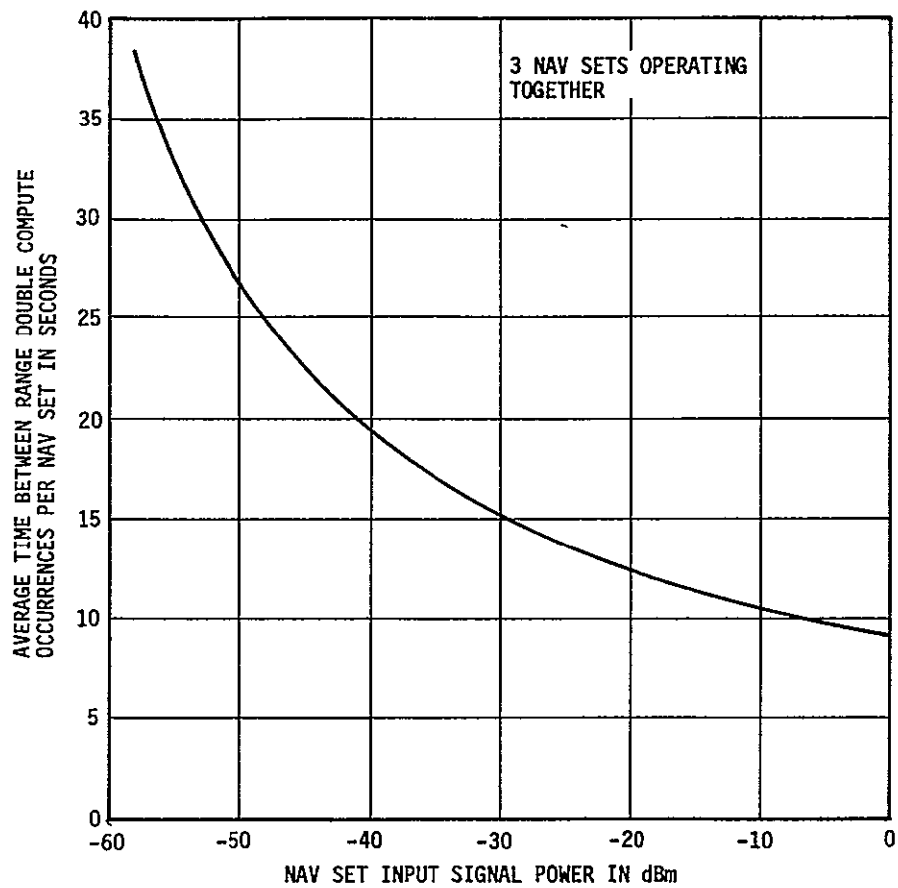
For three Nav Sets, the expected time between range jump occurrences per Nav Set as a function of signal power is given in Figure 1-C13. From -50 to -30 dBm, the average time between occurrences varies from 27 to 15 seconds.

Depending on how the computer receiving MSBLS data examines and verifies range data, it may be important to know how often two of three Nav Sets jump range data at the same time. The expected average time two of three Nav Sets jump range at the same time as a function of signal power is given in Figure 1-C14. Signal power level over the runway threshold is expected to fall between -40 and -30 dBm. In this case, the time between occurrences can vary from 12 to 20 minutes.

A detailed explanation of the timing problem and the results of the test are provided in the body of the report.

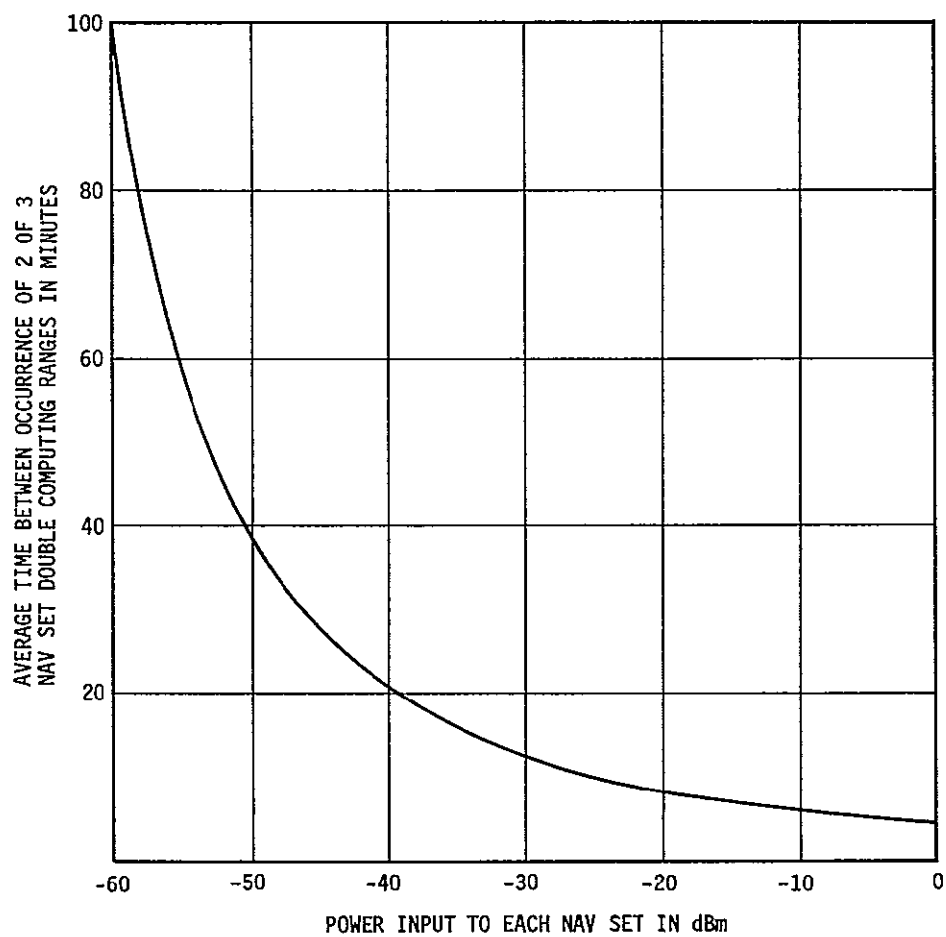
1-C16. ORIGIN OF DOUBLE COMPUTE. The double compute problem came into being during the redesign of the AN/ARQ-31 TLS receiver for the MSBLS system. A logic modification was incorporated to allow the receiver to accept more data intervals per beam passage (from 63 to 127 maximum data intervals). This change was required to maintain compatibility with the slower scanning MSBLS ground antennas. The change inadvertently made the MSBLS Nav Set susceptible to spurious replies producing range jumps.

1-C17. RANGE JUMPS IN OPERATIONAL DATA. After the double compute problem was identified, multiple Nav Set data taken in the past was re-examined and examples of range jumps without validity flag have been observed. The first instance occurred on March 7, 1976 in Peconic, New York, during software checkout (with two receivers) for the original three receiver tests. In 16 seconds of range data, a range jump from 205 feet to 15,875 feet was recorded from data received from one of the Nav Sets. Due to the inability to obtain the use of three MSBLS Nav Sets, this test was eventually scrapped. This report is a modified version of what the three receiver tests were to accomplish.



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Figure 1-C13. Expected Average Time Between Double Compute Occurrences Per Nav Set as a Function of Signal Power for Three Nav Sets Operating Simultaneously



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Figure 1-C14. Average Time Between Occurrences of Two of Three Nav Sets Double Computing Range Versus Power Input to Each Nav Set

On August 2, 3, and 4, 1976 the commissioning aircraft (Jetstar) with two Nav Sets on board was flying against the DVTU system. The purpose of the flight was to check out the instrumentation pallet and its recording capability. A review of 3 minutes worth of flight data revealed four range jumps without validity flags.

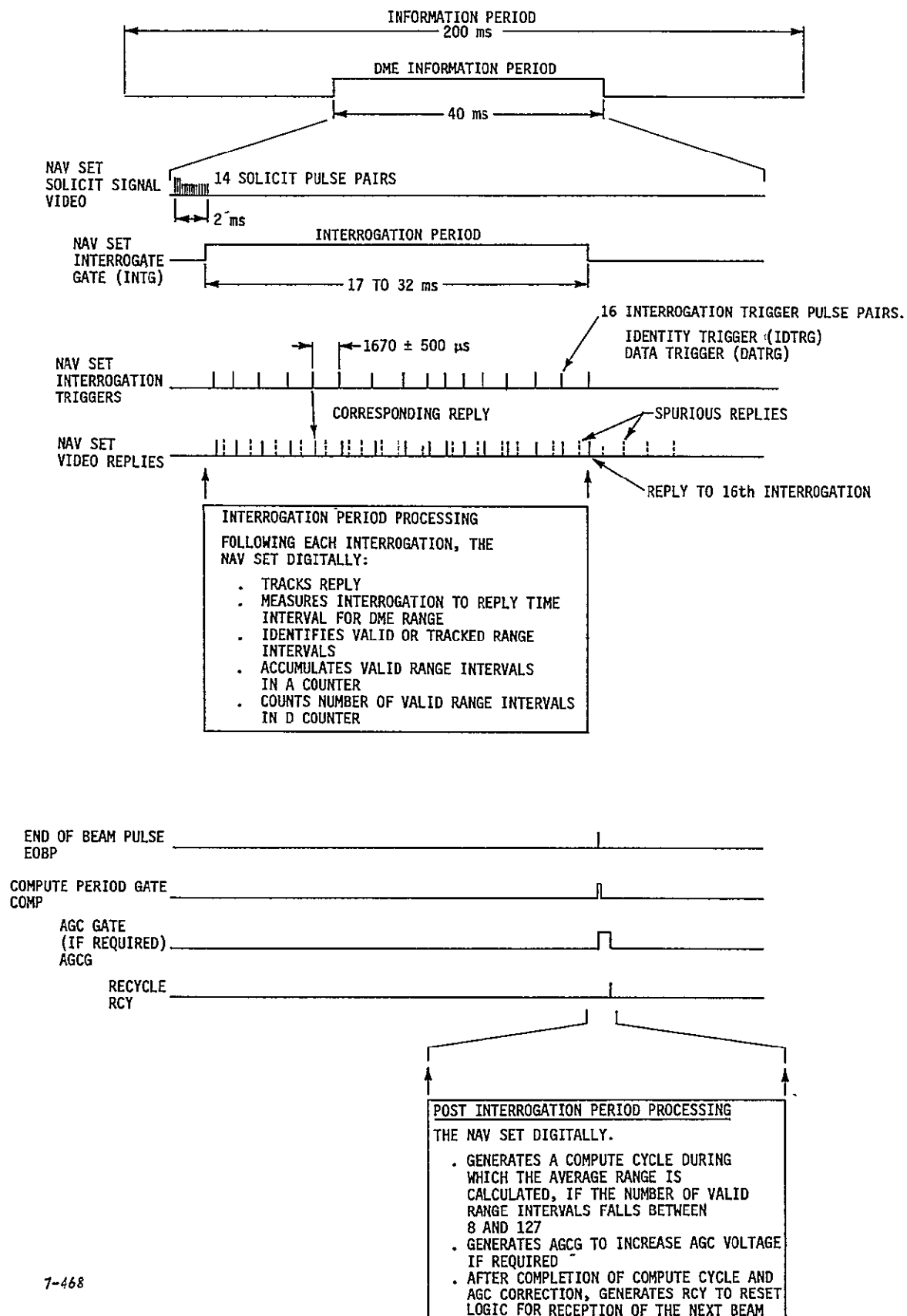
Finally, during DFRC engineering tests with a single receiver, range jumps appeared in range data with the aircraft flying against the ground station backup system. The range jumps can be seen interspersed in the data in flight days 226 through 275. The range jumps were thought to be related to a hardware problem in the pallet. Eventually, a noisy IF amplifier was found in the B/U unit which was causing the ground station to trigger on noise and transmit spurious replies to the Nav Set.

#### 1-C18. LOGIC TIMING FOR DME DOUBLE COMPUTE PROBLEM

Range jumps can occur whenever the Nav Set receives the spurious reply during the 64 microsecond window, and the reply is digitally processed in a way to cause the Nav Set to generate incorrect DME range data. This section explains the manner in which the Nav Set processes DME data, and discusses the particular set of circumstances which can cause range jumps to occur. A logic change to the Nav Set which can correct the problem is also presented.

During each 200 millisecond information period, a 40 millisecond period is reserved for DME operation as shown in Figure 1-C15. At the beginning of the DME period the Nav Set receives and identifies the solicit signal which is transmitted from the ground station. Following the solicit signal, the Nav Set interrogates the ground station 16 times with an average spacing of 1666 microseconds between interrogations.

Following each transmitted interrogation, the Nav Set tracks the expected reply and digitally measures the elapsed time from emitted interrogation to received reply, minus the 80 microsecond dead time. The



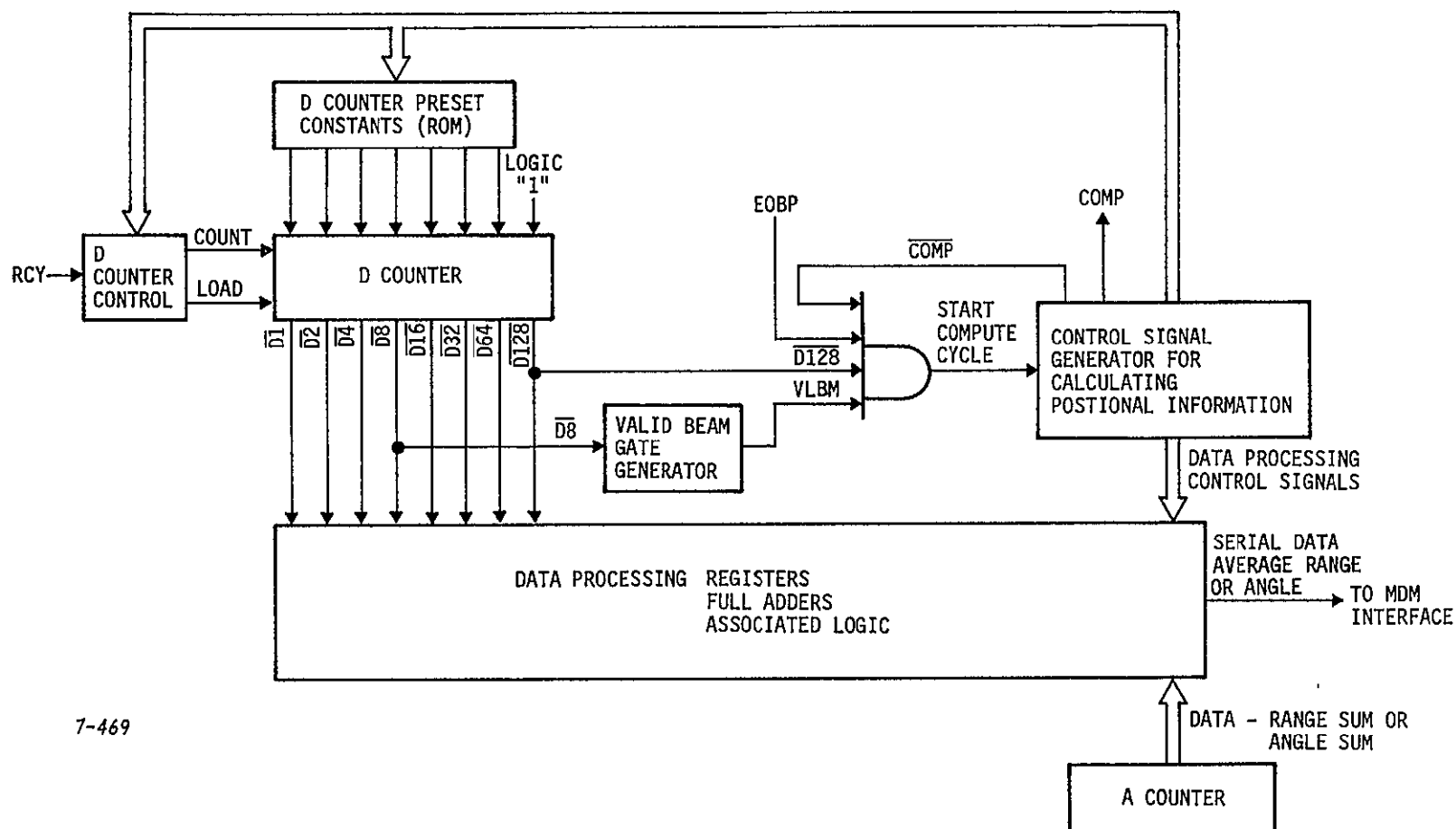
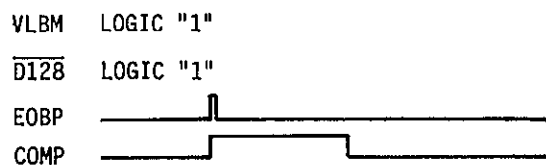
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Figure 1-C15. Nav Set DME Logic Processing

measured time represents the DME range. The number of successfully tracked replies are counted by an eight-bit binary counter (D Counter), while the corresponding measured ranges are accumulated by a second counter (A Counter). Prior to the interrogation time, both the D and A Counters are initialized to zero. When the D Counter reaches a count of eight, a valid beam is declared and the logic signal VLBM is set to logic one (Figures 1-C16 and 1-C17).

Following the last, or 16th interrogation, an end-of-beam pulse (EOBP) is generated which triggers the compute gate (COMP) if VLBM is high and the D Counter,  $\overline{D128}$  bit, is high (Figures 1-C16 and 1-C17). The D Counter counts in one's complement, so that a high on the  $\overline{D128}$  bit signifies less than 128 tracked replies, while a low signifies at least 128 tracked replies. During the beginning of the compute gate time, the Nav Set finds the average range by dividing the range sum stored in the A Counter by the number in the D Counter. While the range is being calculated it is sent to the MDM interface where it can be encoded into the range serial word sent from the Nav Set. During the remaining portion of the compute time, the Nav Set makes additional calculations which are not used by the MSBLS system. During the time the additional calculations are being performed, the D Counter is preset from a read-only memory (ROM) with the appropriate constants.

The range jumping problem occurs when a spurious reply causes the Nav Set to generate a second compute gate, approximately 500 microseconds after the first compute gate. At the beginning of the second compute gate, the Nav Set repeats the division algorithm for calculating the average range. However, an incorrect range is produced this time, since the D Counter no longer contains the number of tracked replies. The incorrect range is then sent to the MDM interface to be encoded in the MDM range word. When range data is pulled from the Nav Set at a rate greater than 5 Hz, the incorrect range resulting from the double compute cycle would appear in MSBLS data as a range jump.



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Figure 1-C16. Simplified Block Diagram of MSBLS Nav Set Compute Cycle

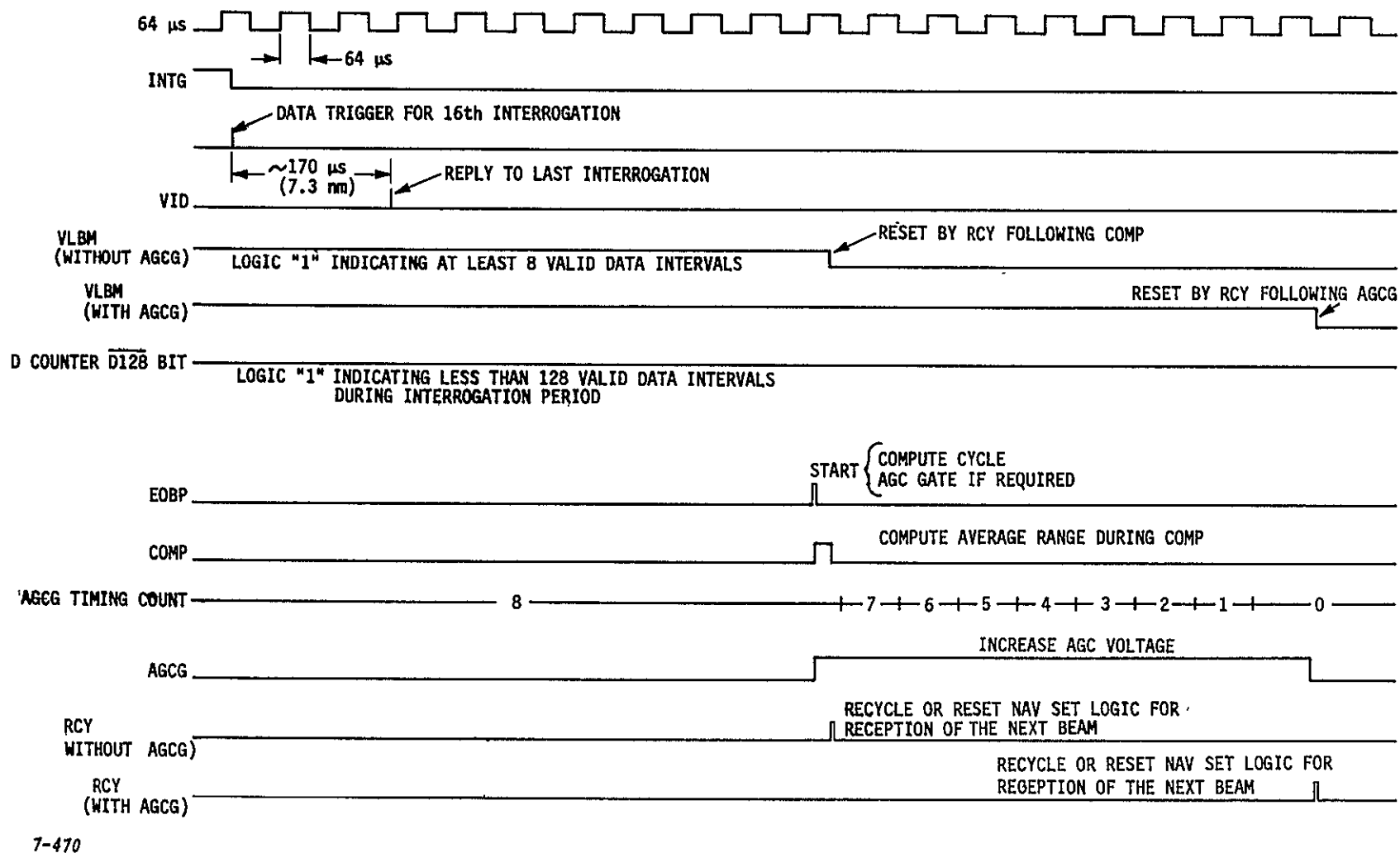
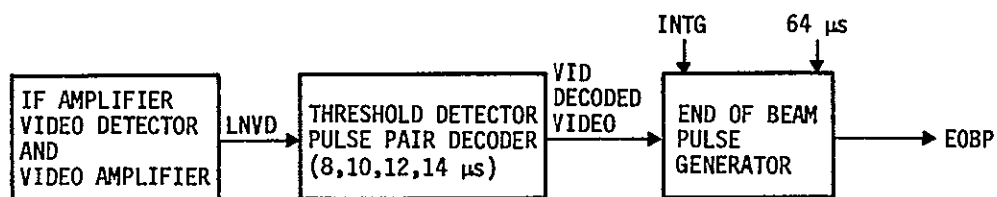
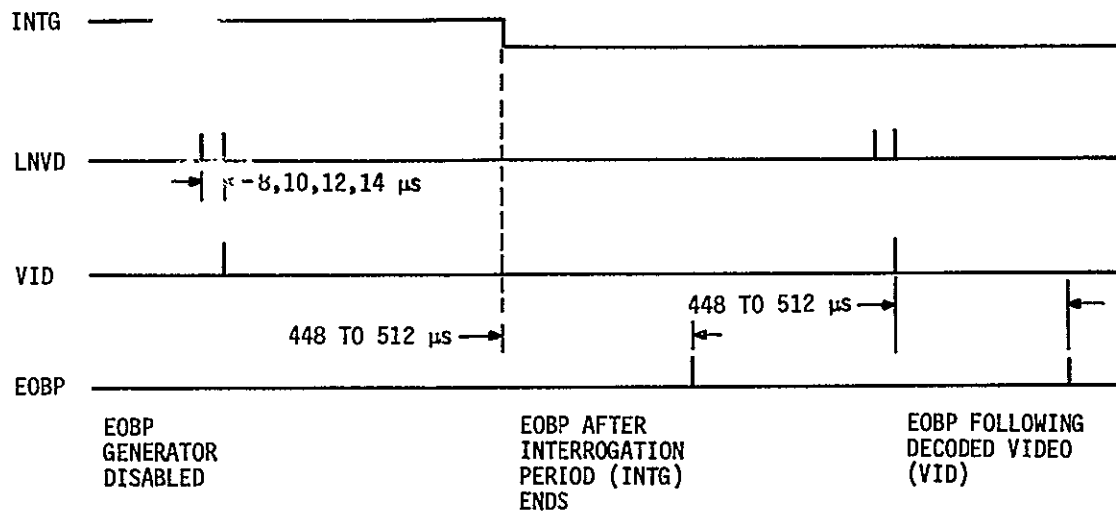


Figure 1-C17. Logic Timing Showing Processing Following Interrogation Period

As shown in Figure 1-C16, each compute cycle is triggered by the EOBP when the VLBM and the D Counter,  $\overline{D128}$  bit, are high. The basic problem is that sometimes both VLBM and  $\overline{D128}$  will stay high after the first compute cycle. If a spurious reply comes in at the right time, it can trigger an EOBP to start a second compute cycle.

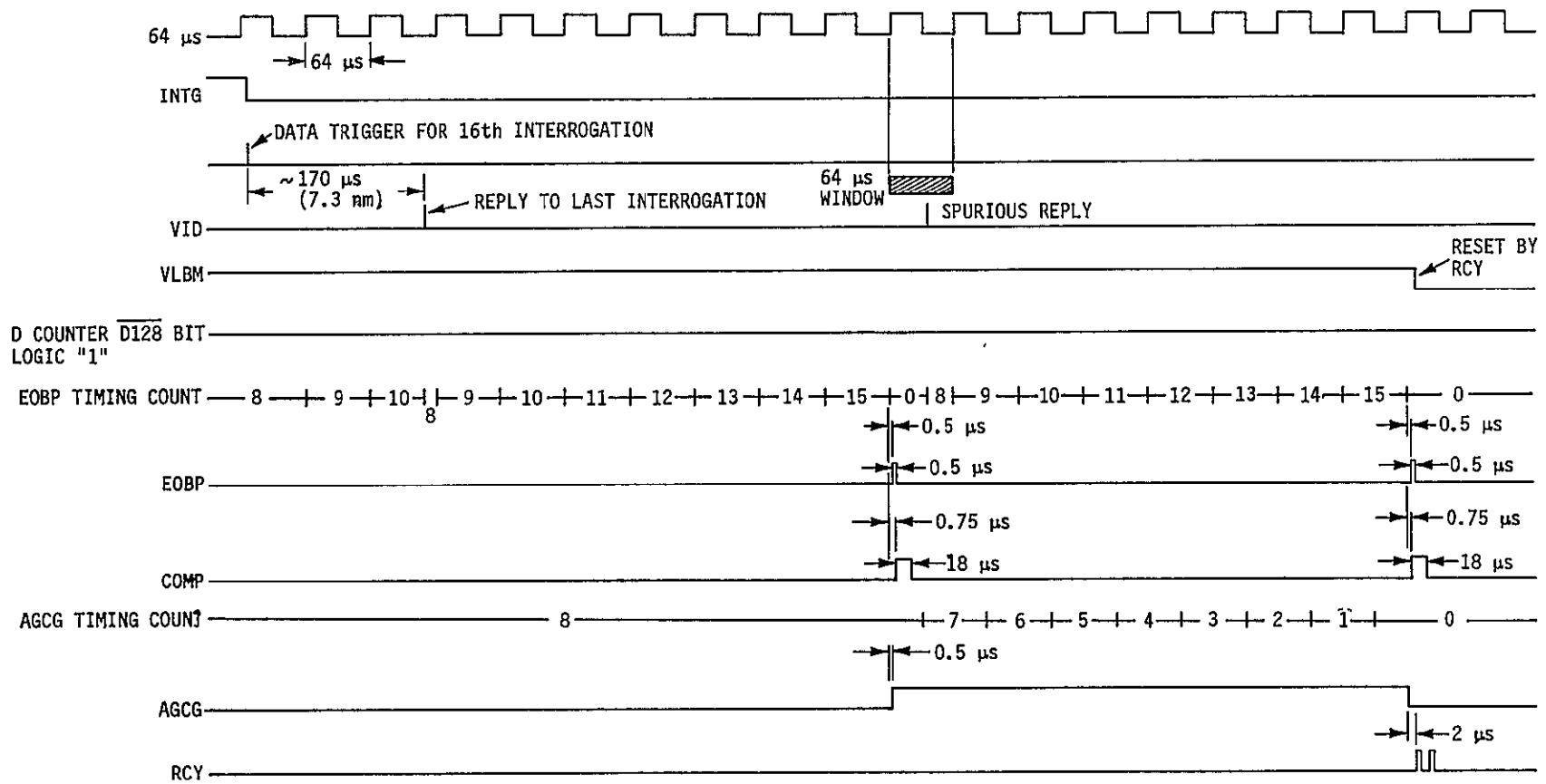
EOBP is generated by the EOBP generator shown in Figure 1-C18. The signal occurs at the end of an angle data beam or an interrogation period, and starts the angle or range computation. The EOBP generator generates an EOBP, 448 to 512 microseconds after one of the following occurrences: the end of the interrogation period when INTG goes low; following any identified pulse pair with 8, 10, 12, or 14 microsecond identity spacings.

The logic timing for triggering a compute cycle is shown in Figures 1-C19 and 1-C20. As shown, EOBP triggers the compute gate. If no reply is received for the last interrogation, the EOBP generator times out 448 to 512 microseconds from the last interrogation before generating the EOBP. If a pulse pair reply is received, a VID pulse is generated and the EOBP is generated 448 to 512 microseconds from VID as shown. Aside from triggering the compute gate, the EOBP also starts the agc gate (AGCG). The AGCG is a 512 microsecond logic gate which is used to increase the agc voltage if the video signal level is excessive. Both the EOBP timing and the AGCG timing are synchronized to the 64- $\mu$ s clock shown at the top of Figures 1-C19 and 1-C20. The recycle (RCY) signal following the AGCG resets the VLBM signal to logic "0". Since EOBP is ANDed with both VLBM and  $\overline{D128}$ , no more compute gates can be generated until the next valid beam is declared. However, a double compute can occur if the Nav Set receives a spurious reply, inside a 64 microsecond window, during a DME cycle which requires an AGCG to increase the agc voltage. The appearance of the AGCG delays the generation of RCY pulse by approximately 500 microseconds. This keeps VLBM high and  $\overline{D128}$  also stays high. Should a spurious reply fall inside



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Figure 1-C18. Simplified Block Diagram and Timing for End-of-Beam Pulse (EOBP) Generation



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Figure 1-C19. Logic Timing Showing Effect on Logic Signals, When a Spurious Reply Falls Inside a 64  $\mu\text{s}$  Window and an AGCG is Generated (Double Compute Cycle Occurs)

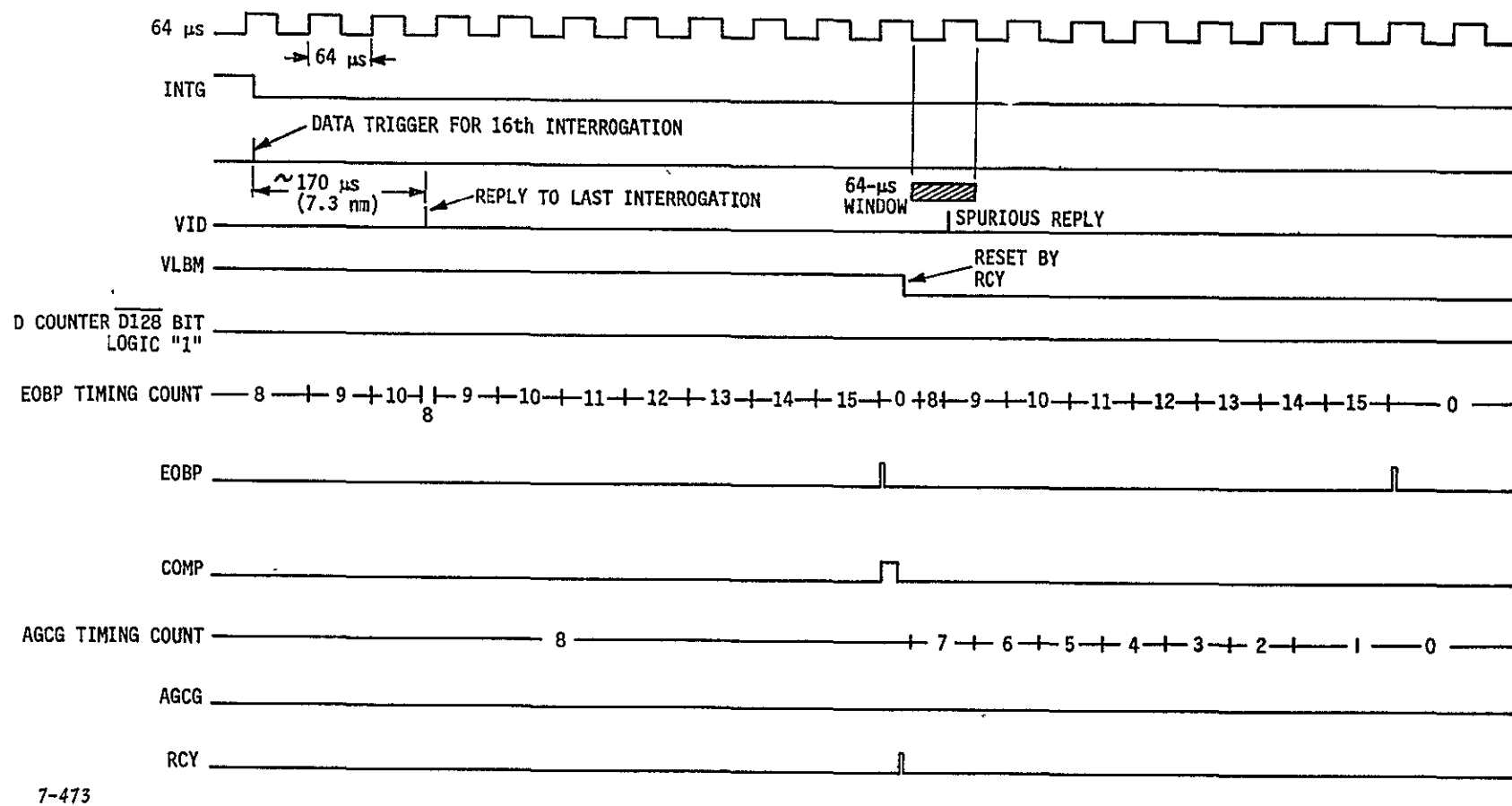


Figure 1-C20. Logic Timing Showing Effect on Logic Signals When a Spurious Reply Falls Inside a 64  $\mu$ s Window and no AGCG is Generated (No Double Compute Cycle Occurs)

the 64 microsecond window shown in Figure 1-C19, an EOBP is generated which triggers the second compute cycle. When no AGCG appears, the double compute problem does not occur, as shown in Figure 1-C20.

The double compute problem originated from a logic change made to the AN/ARQ-31 TLS receiver which was being redesigned to the Nav Set specifications. The change allowed the receiver to accept up to 127 data intervals per beam. As shown in Figure 1-C21 the  $\overline{D64}$  bit rather than the  $\overline{D128}$  bit was ANDed with EOBP for the TLS receiver. This permitted a maximum of 63 data intervals per beam. With this configuration, the double compute problem does not occur. After the correct range is calculated, during the compute period, the  $\overline{D64}$  is set to logic "0" when constants from the ROM are loaded into the D Counter during the compute cycle. If the spurious reply does fall in the 64 microsecond window during an AGCG update, an EOBP is still generated, but, it does not trigger the second compute cycle since  $\overline{D64}$  is now low. The timing is shown in Figure 1-C22.

A logic change to the Nav Set which can correct the problem is shown in Figures 1-C23, 1-C24, and 1-C25. The  $\overline{COMP}$  signal would be connected to the preset line for the  $\overline{D128}$  bit of the D Counter. When the D Counter is loaded during the compute time, the  $\overline{D128}$  bit is loaded with a logic "0" which would inhibit EOBP from triggering the false compute cycle. Although the Nav Set logic can be changed in a number of ways to correct the problem, the change just described is the simplest, since it would require a simple change to the printed circuit of a single PC board.

#### 1-C19. RESULTS OF INTRODUCING SPURIOUS REPLIES TO A SINGLE NAV SET

The frequency of occurrence of the range double compute periods for the setup shown in Figure 1-C12 depends on the following factors:

- a. The period P of the Pulse-Pair Generator. Increasing P should proportionally increase the time between double compute occurrences. The

pulse-pair generator triggers the spurious replies (and consequently the spurious VID pulses). The probability that the spurious VID occurs during the 64 microsecond problem interval causing time interval is:

$$\frac{64}{P}$$

with P given in microseconds.

b. The Rate of Occurrence of AGCG. For a given RF signal power to a Nav Set, the value of the agc voltage and the rate of AGCG stabilizes at some value. The dependence is shown in the graph in Figure 1-C26. For an agc voltage of 3.0 volts, the AGCG update rate is approximately 2.0 times per second.

The dependence of P on the rate of occurrence of double computes was confirmed using the test arrangement in Figure 1-C12. The output power of the RF generator was set at a fixed value such that the AGC voltage stabilized at 3 volts. Then, the period P was varied, and the number of occurrences of range jumps without flags was counted from observing the Nav Set derived range on the NSTE displays.

The results of the test are shown in Figure 1-C27.

The test results seem to follow the predicted curve shown in the same figure.

The equation for the predicted curve can be derived as follows:

$$P(x) = \text{probability of event } x$$

where

a = event that the spurious reply falls inside the 64 micro-second time interval and an AGC gate occurs

b = event that an AGCG gate occurs

$$P(b) = 13.3 \frac{1}{\frac{103}{V} - 1}$$

where V is the AGC voltage. The probability, P(b), can be derived from the AGC model. The AGCG occurs when an increase in AGC voltage is required for a given scan.

$$P(a) = P(b) \frac{64}{P}$$

where:

P = period of pulse-pair generator output in microseconds

$f_a$  = frequency of event a,  $\text{second}^{-1} = 5 P(a)$

$T_a = \frac{1}{f_a}$  seconds = average time interval between double compute occurrences

As an example, for V = 3 volts, P = 1000 microseconds:

$$T_a = 7.83 \text{ seconds}$$

The time  $T_a = 7.83$  seconds can also be found from the predicted curve in Figure 1-C27. The test results show an average of 7.0 microseconds between occurrences.

#### 1-C20. TIME BETWEEN DOUBLE COMPUTES WHEN OPERATING WITH THREE NAV SETS

Because of the unavailability of three Nav Sets, measurement of the time between double computes, when operating with three Nav Sets, was performed with the setup of Figure 1-C12 (single Nav Set) and the following reasoning.

The average spurious reply rate seen by a particular Nav Set depends on whether this Nav Set finished its interrogation cycle first, second, or last

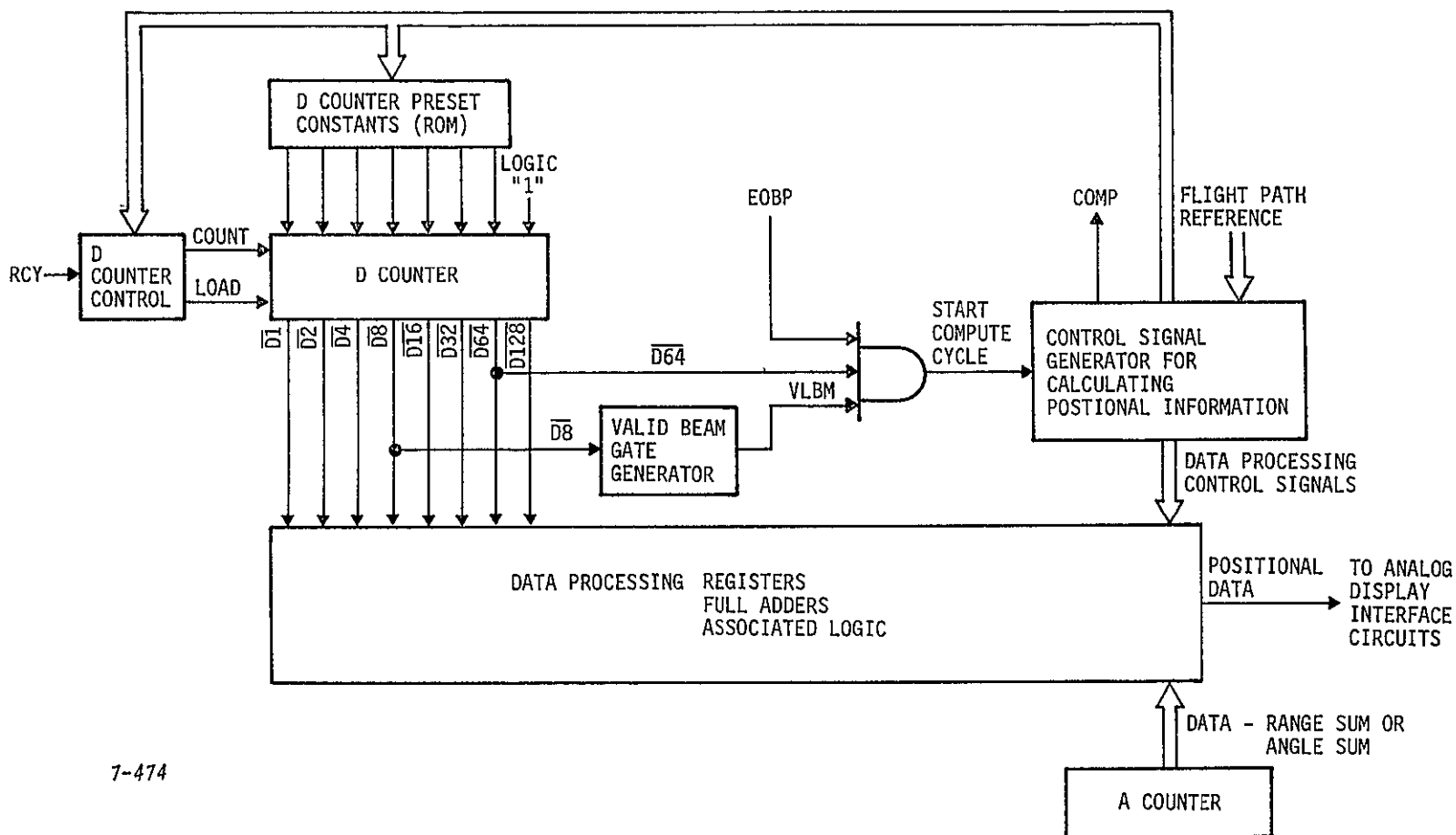


Figure 1-C21. Simplified Block Diagram of TLS Receiver (ARQ-31) Compute Cycle

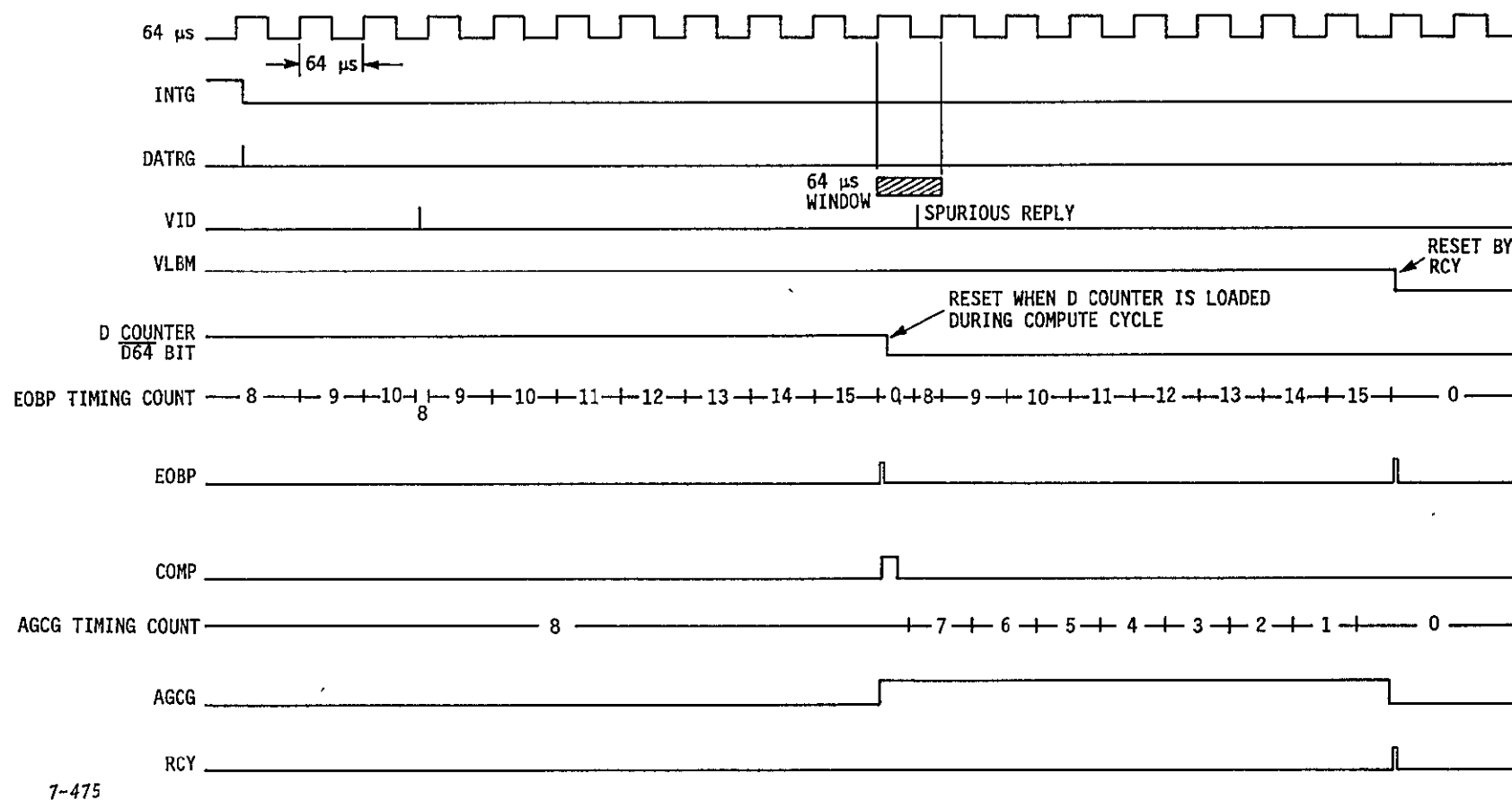
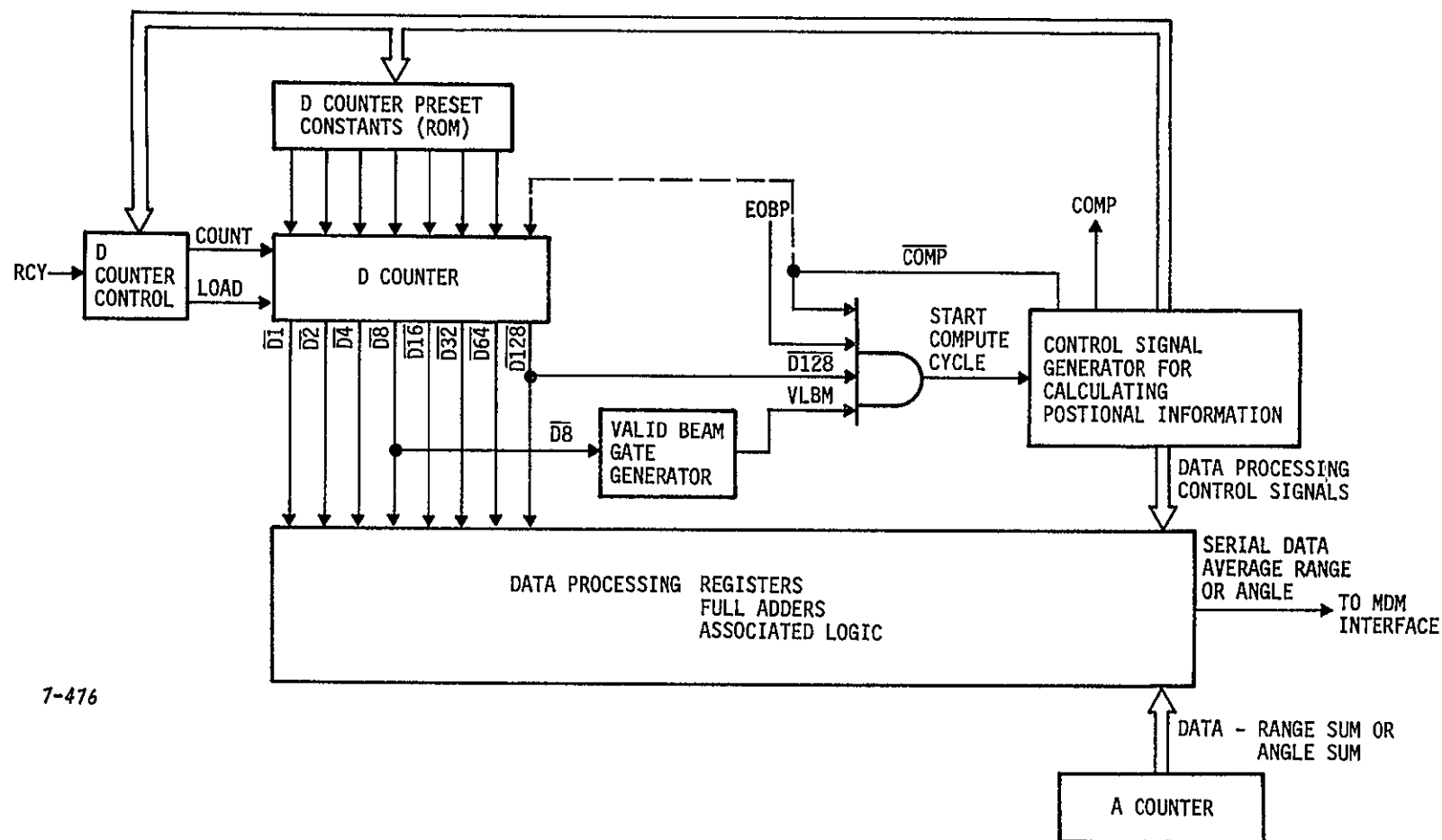


Figure 1-C22. Logic Timing for TLS Receiver (ARQ-31) When Spurious Reply Falls Inside the 64 μs Window and an AGCG is Generated (No Double Compute)

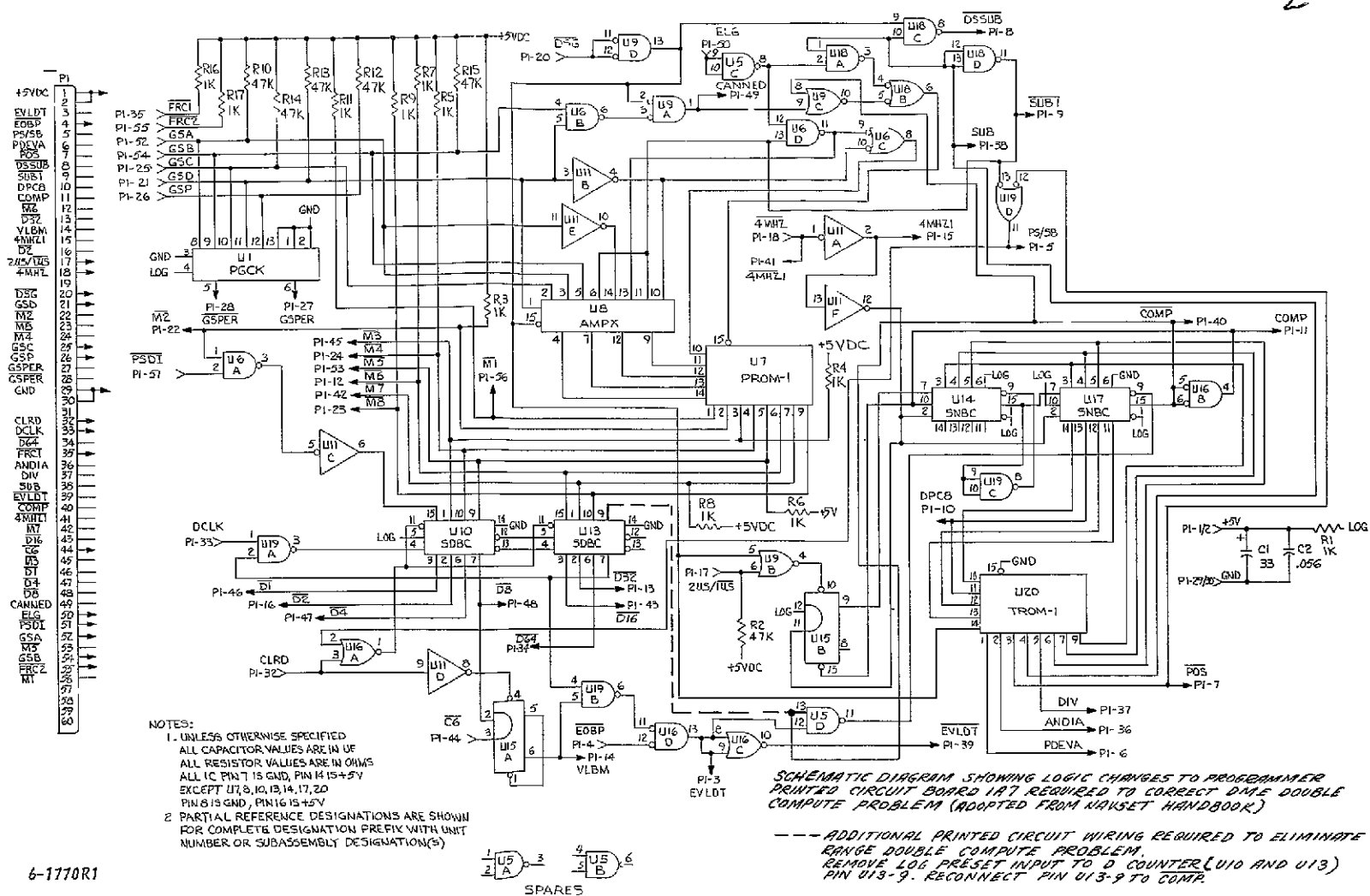


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Figure 1-C23. Simplified Block Diagram of MSBLS Nav Set Compute Cycle With Change to Eliminate Double Range Compute Cycles

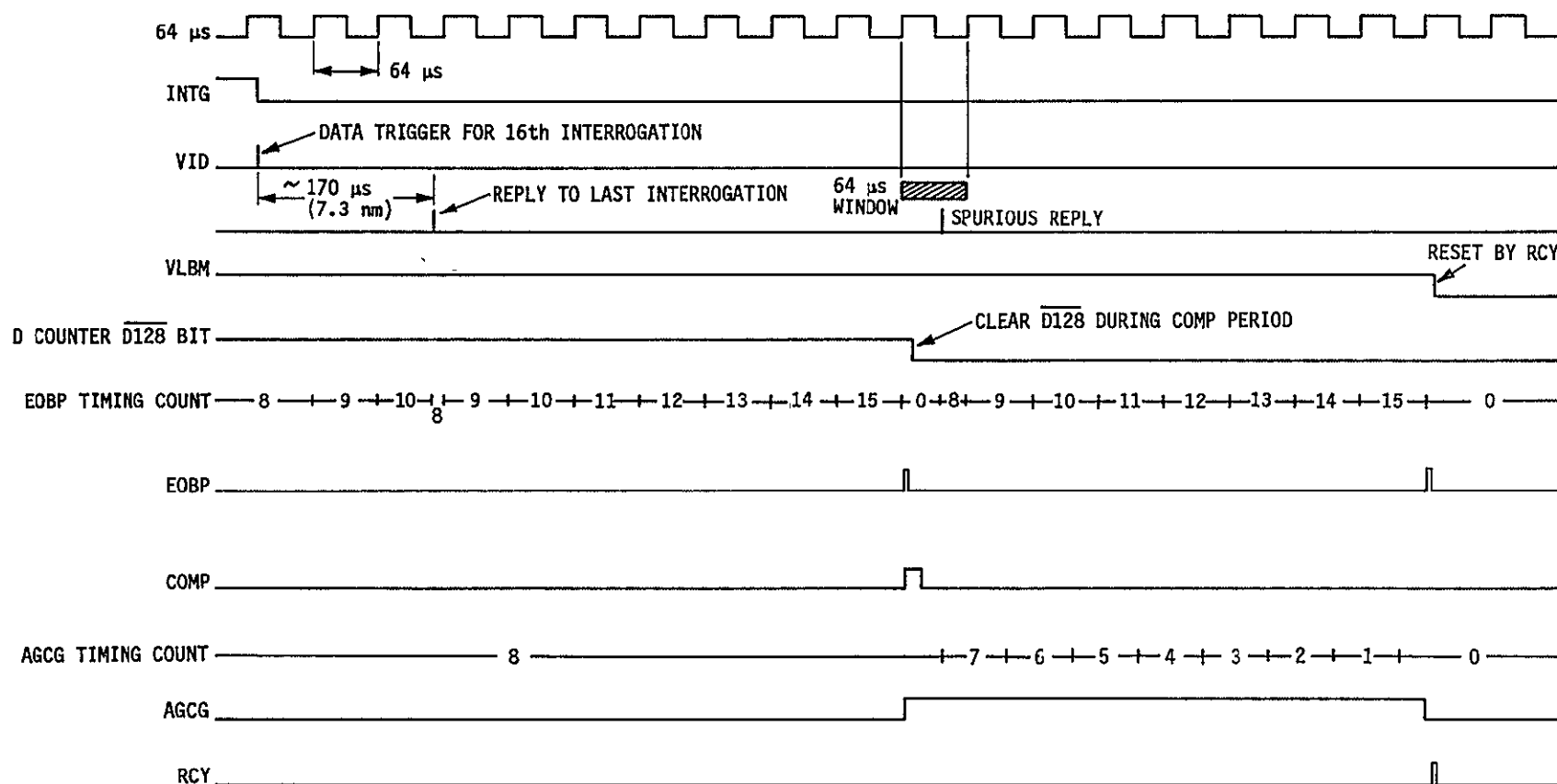
WIRING FRAME

2



6-1770R1

Figure 1-C24. Schematic Diagram Showing Logic Change to Programmer Printed Circuit Board 1A7 Required to Correct DME Double Compute Problem



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Figure 1-C25. Logic Timing Showing How Logic Change Corrects Double Compute Problem

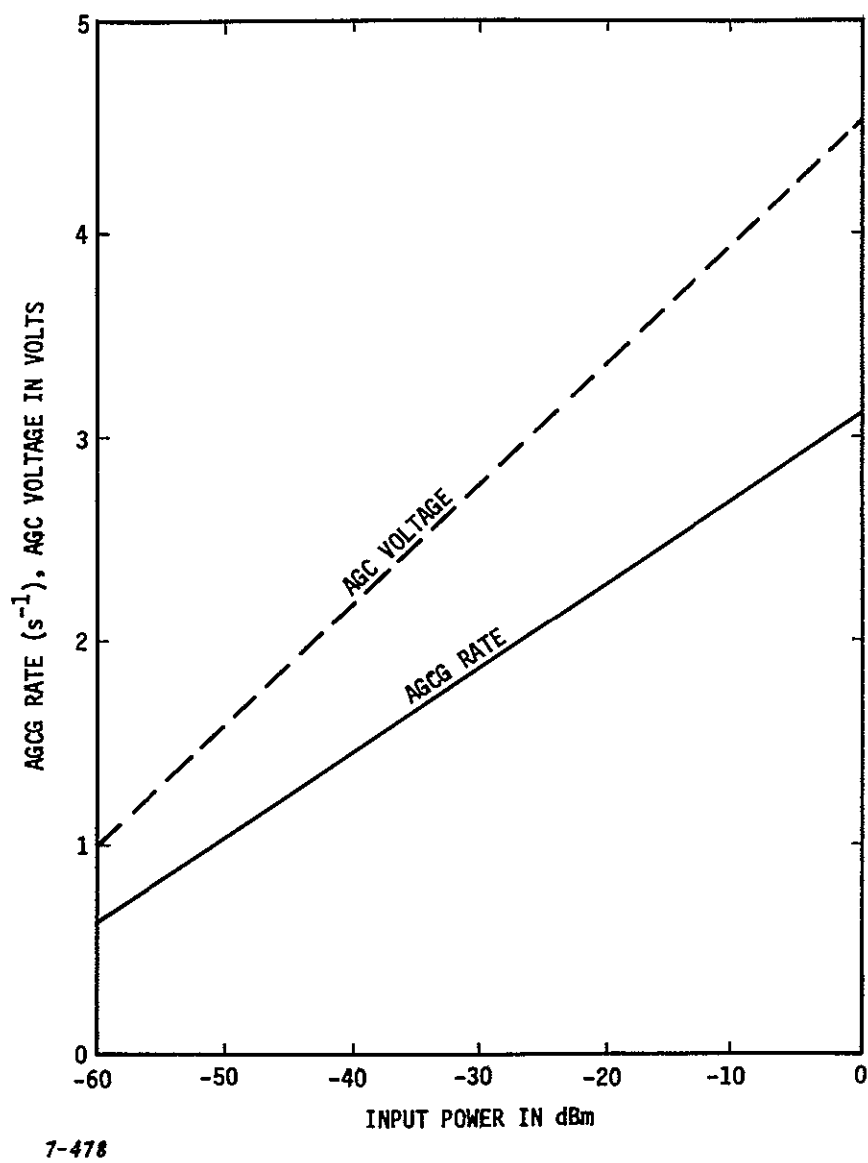
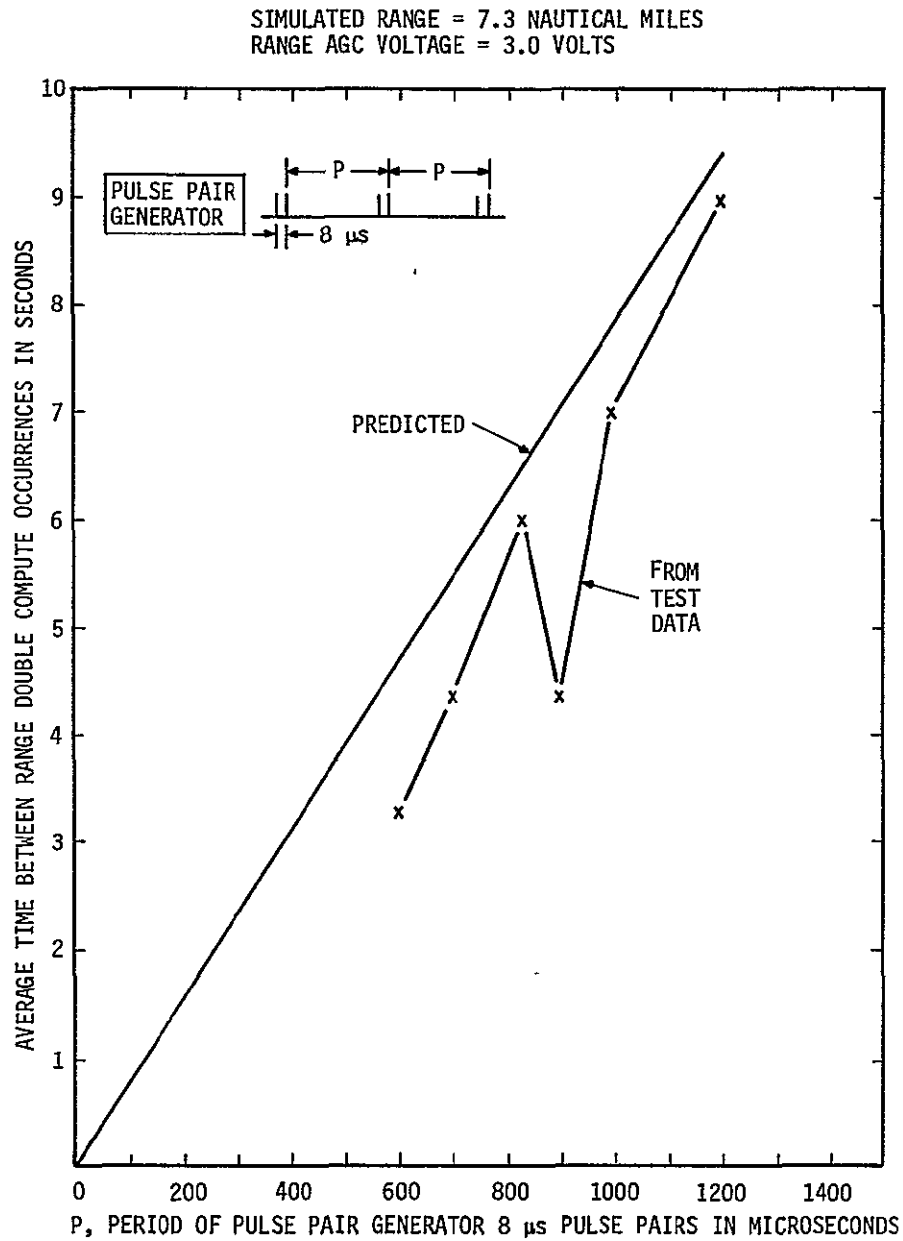


Figure 1-C26. AGCG Rate and Agc Voltage Versus Nav Set Input Power



7-479

Figure 1-C27. Average Time Between Range Double Compute as a Function of Period of Pulse Pairs

with respect to the other two Nav Sets. If it finishes first, then it sees replies to the other two Nav Sets, each transmitting with a 1666  $\mu$ s average period. The spurious reply rate is, therefore, 1/833  $\mu$ s. If the Nav Set finishes second, it sees spurious replies to only one Nav Set, so the spurious reply rate is 1/1666  $\mu$ s. Finally, if the Nav Set finishes third, there are no spurious replies, and the rate is therefore 1/ $\infty$   $\mu$ s, or 0.

Since it is equally likely that the Nav Set finishes first, second, or last, the average spurious reply rate seen by a Nav Set is:

$$\begin{aligned}\text{Average rate} &= 1/3 (1/833) + 1/3 (1/1666) + 1/3 (0) \\ &= 1/1666 \mu s\end{aligned}$$

The setup of Figure 1-C12 adjusted for a 1666  $\mu$ s spurious reply interval, should therefore approximate the conditions of operation with three Nav Sets.

Test results of operating with a 1666  $\mu$ s spurious interval as a function of signal power input are shown in Figure 1-C28 together with theoretical prediction of time between double compute occurrences. The test results seem to correlate well with the predicted curve. The time interval between double compute occurrences is seen to vary between 10 and 60 seconds as a function of Nav Set power input.

The equations which predict the expected time between double computes, when operating with three Nav Sets, are derived in this section. The expected time one Nav Set double computes or jumps range data is given by the following equation, and is shown in Figures 1-C13 and 1-C28:

$$T_{dc} = 0.42 \left( \frac{1751}{S + 77} - 1 \right) \text{ seconds} \quad (20a)$$

where S = power to the Nav Set, dBm. The expected time between occurrences of two Nav Sets jumping range data during the same DME cycle is

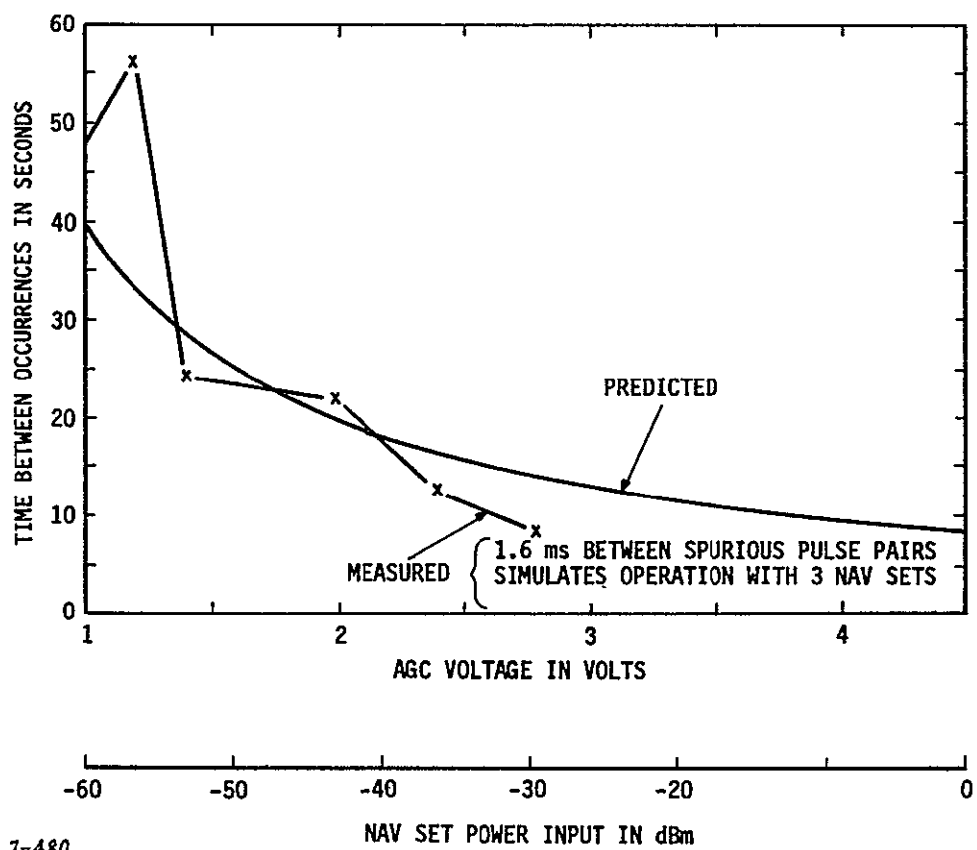


Figure 1-C28. Time Between Range Jump Occurrences Versus Agc Voltage (Simulated Three Nav Set Operation)

given by the following equation, and is shown in Figure 1-C14:

$$T_{2dc} = 0.011 \left( \frac{1751}{S + 77} - 1 \right)^2 \text{ minutes} \quad (20b)$$

After a Nav Set completes its interrogation, it can generate a double compute if:

- a. It is receiving spurious replies intended for other Nav Sets.
- b. The spurious reply falls inside the 64 microsecond window.
- c. An agc gate (AGCG) is generated during the DME period in order to increase the AGC voltage.

Consider the three possible situations:

a = a Nav Set ends its interrogations first

b = a Nav Set ends its interrogations second

c = a Nav Set ends its interrogations last

The probability for each is 1/3. Therefore:

$$P(a) = P(b) = P(c) = 1/3$$

The conditional probabilities for the spurious reply falling inside the 64 microsecond window is:

$$P(d/a) \cong 2 \times \frac{64}{1666} = \frac{64}{833}$$

$$P(d/b) \cong 1 \times \frac{64}{1666} = \frac{64}{1666}$$

$$P(d/c) \cong 0 \times \frac{64}{1666} = 0$$

The probability for an AGC gate occurring can be derived from the equations for the AGC model. With increasing signal power the incremental increase in agc voltage is:

$$\Delta V_{\text{inc}} = -0.0086V + 0.062 \text{ volts/scan} \quad (20c)$$

where  $V$  = agc voltage. The decreasing agc voltage rate is:

$$\Delta V_{\text{dec}} = 0.008V \text{ volts/scan} \quad (20d)$$

An AGC gate is generated when the agc voltage is increased. The AGC gate probability is therefore:

$$P(f) = \frac{\Delta V_{\text{DEC}}}{\Delta V_{\text{inc}} + \Delta V_{\text{dec}}} = 13.3 \frac{1}{\frac{103}{V} - 1} \quad (20e)$$

The relationship for Nav Set power input as a function of agc voltage is:

$$S = 17 V - 77 \quad (20f)$$

where  $S$  = power input to the Nav Set in dBm. By substituting for  $V$  in the probability function:

$$P(f) = 13.3 \frac{1}{\frac{1751}{S + 77} - 1} \quad (20g)$$

The probability for a single Nav Set double computing is:

$$P = P(a) P(d/a) P(f) + P(b) P(d/b) P(f) + P(c) P(d/c) P(f) \quad (20h)$$

$$= 1/3 P(f) P(d/a) + P(d/b) + P(d/c)$$

$$= 1/3 \left( 13.3 \frac{1}{\frac{1751}{S + 77} - 1} \right) \left( \frac{64}{833} + \frac{64}{1666} + 0 \right)$$

$$P = \frac{0.510}{\frac{1751}{S + 77} - 1}$$

The reply efficiency factor of 0.933 decreases the probability to:

$$P = \frac{0.475}{\frac{1751}{S + 77} - 1} \quad (20i)$$

The time in seconds between double computes for one Nav Set is found from:

$$T = \frac{1}{5P} \quad (20j)$$

$$T = 0.42 \left( \frac{1751}{S + 77} - 1 \right) \text{ seconds}$$

When the power to the Nav Set is -30 dBm, T is 15.23 seconds, which appears in the graph in Figure 1-C13.

Two Nav Sets can double compute during the same DME period if a spurious reply falls in a 64 microsecond window, and an AGC gate update appears for both the first and second Nav Set, ending their interrogations. The probability of this happening is given by:

$$P = 3! \begin{matrix} \text{ending first factor} \\ \downarrow \\ [P(a) \ P(d/a) \ P(f)] \end{matrix} \begin{matrix} \text{ending second factor} \\ \downarrow \\ [P(b) \ P(d/b) \ P(f)] \end{matrix} (0.933)^2 \quad (20k)$$

$\uparrow$  factor to include all permutations       $\uparrow$  reply efficiency factor

$$P = 6 \left[ \frac{1}{3} \frac{64}{833} \frac{13.3}{\left( \frac{1751}{S + 77} - 1 \right)} \right] \left[ \frac{1}{3} \frac{64}{1666} \frac{13.3}{\left( \frac{1751}{S + 77} - 1 \right)} \right] (0.933)^2$$

$$= \frac{0.302}{\left( \frac{1751}{S + 77} - 1 \right)^2}$$

The time in minutes is obtained from:

$$T = \frac{1}{5 \times 60 \times P} \quad (201)$$

$$T = 0.011 \left( \frac{1751}{S + 77} - 1 \right)^2 \text{ minutes}$$

PART D  
EFFECTS OF GROUND STATION MISTRACK  
ON NAV SET DATA

A. CHARYCH

TECHNICAL REPORT Y220-11

INTERIM - SEPTEMBER 1976

FINAL  
NOVEMBER 1976

## 1-D1. INTRODUCTION

The MSBLS ground station consists of two redundant channels primary and backup. The primary channel is normally radiating through the primary antennas while the backup channel radiates into dummy loads. In the event of primary channel failure, system operation automatically transfers over to the backup channel. A number of failures which may occur in the switch-over circuitry do not generate an automatic transfer. Instead, a remote operator is alerted to the failure by appropriate light and audio indicators. The operator then takes manual action (manual switchover to the backup channel is one such action) to correct the fault.

Ground station mistrack is a system failure which requires manual operator intervention. Mistrack is defined here as a condition for which the three guidance functions (azimuth, elevation and DME) are not transmitted from the same channel. For example, a primary AZ/DME station operating with a backup elevation station (or vice versa) constitutes a mistrack.

Each of the guidance functions during a mistrack condition is operating correctly by itself. The problem occurs because the scanning antennas (primary AZ and backup EL for example) are not synchronized. Since the MSBLS system relies on time multiplexing of the guidance functions (i.e., only one function at a time is allowed to radiate) interference between the functions due to mistrack may occur.

All failures uncovered to date, which result in a mistrack condition, yield a proper indication to the remote operator. These failures are manually correctible so that the mistrack condition lasts only as long as the response time of the operator involved. Since the time involved may be appreciable, depending on where the operator is at the time of failure, an investigation of the effects of ground station mistrack on Nav Set data is appropriate.

The purpose of this report, therefore, is the following:

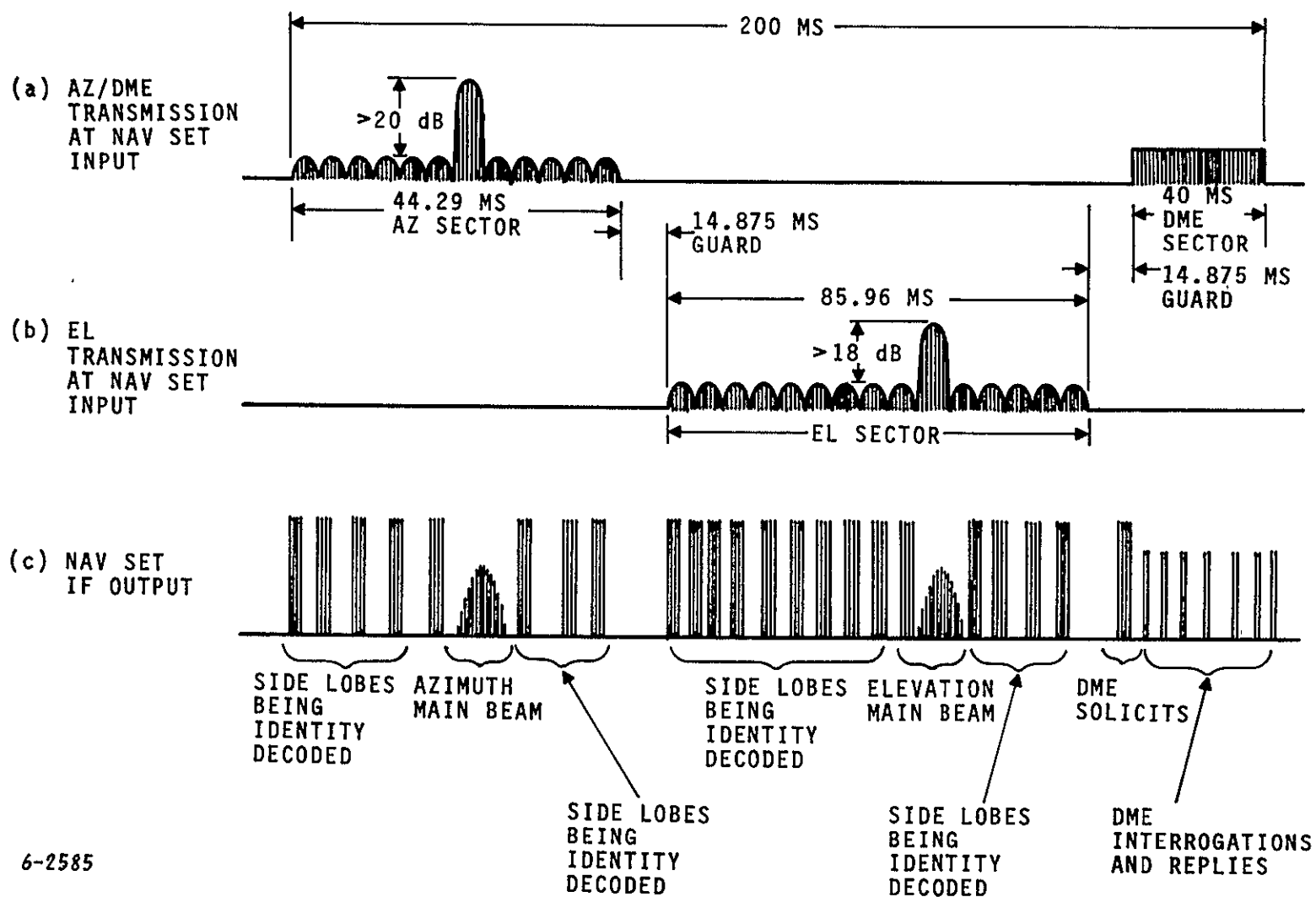
- a. Evaluate the effect of mistrack on the Nav Set's data.
- b. Evaluate the probability that a mistrack condition will have a particular effect on Nav Set data.
- c. Investigate ways of minimizing the probability of mistrack and/or minimizing its effect.

#### 1-D2. POSSIBLE EFFECTS OF MISTRACK ON AIRBORNE DATA

1-D3. BACKGROUND. Figure 1-D1, part (a) shows what the relative signal level of the azimuth and DME transmissions looks like at the input to the Nav Set. The azimuth channel is seen to transmit for 44.29 ms out of the 200 ms system timing cycle. The position of the main azimuth beam within the transmission sector is dependent on the orbiter's azimuth angle with respect to the transmitting station, and on the instantaneous direction of the scanning antenna (clockwise or counterclockwise). The rest of the azimuth sector is filled with antenna side lobes which are specified to be more than 20 dB below the peak of the main lobe. In practice, azimuth antenna side lobes are more than 25 dB down.

The 40 ms DME transmission sector is mechanically slaved to the azimuth scan cycle. At the start of the sector, the ground station transmits 14 solicit pulse pairs which place all Nav Sets within the coverage region into their interrogate modes. For the next 40 ms, the ground station replies to correctly coded interrogations from any operational Nav Set.

Figure 1-D1, part (b) shows elevation transmissions as seen at the Nav Set input. The elevation sector is similar to the azimuth sector, except that it is longer (85.96 ms) and fits into the slot between azimuth and DME transmissions. Elevation side lobes which fill most of the transmission sector are specified at more than 18 dB below the peak of the main lobe. Actual antenna side lobes often get close to this specification limit.



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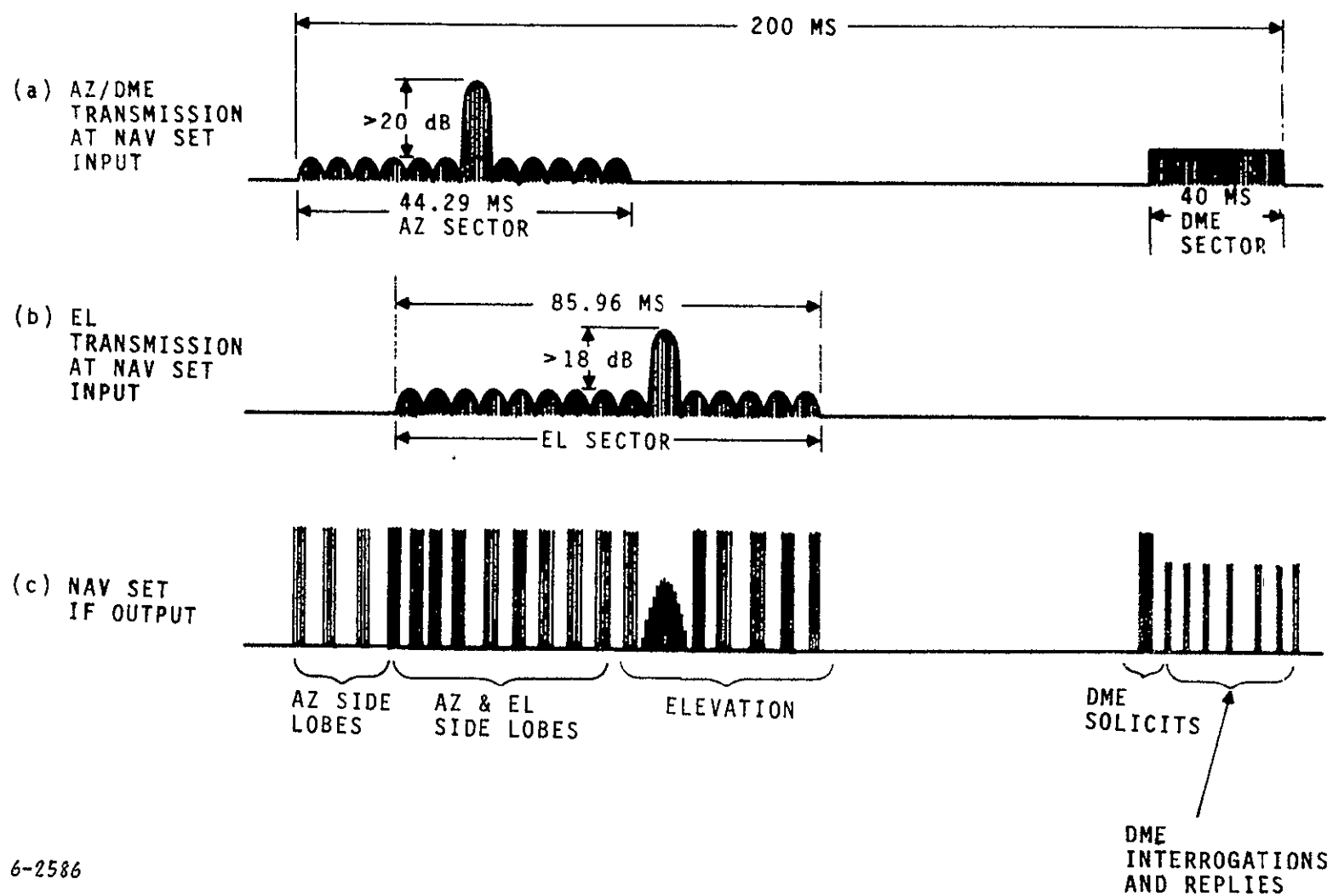
Figure 1-D1. Normal Operation

Since the azimuth and elevation antennas are electrically synchronized via land lines, the elevation transmission sector quite naturally "breathes" between the azimuth and DME sectors. A 14.875 ms guard band, during which all transmissions are inhibited, is provided on either side of the elevation sector in order to keep the sectors from overlapping.

The IF amplifier output of the Nav Sets is illustrated in Figure 1-D1, part (c). During a good portion of the orbiter's flight, many of the azimuth and elevation side lobes are above the Nav Set's angle tracking sensitivity of -74 dBm. Since the receiver is at maximum sensitivity in between valid beams (see page 2-A5 of reference a, paragraph 1-D11), it decodes the identity of the validated pulse pairs and switches on the appropriate AGC awaiting the start of the main beam. If the main beam fails to start within 512  $\mu$ s, the AGC is switched off and the identity process repeats. When the main beam finally arrives, the correct AGC is already switched in and the angle decoding process can begin.

1-D4. MOST LIKELY PROBLEM WITH MISTRACK. During a mistracked condition, synchronization between the scanning antennas does not exist. The elevation transmission sector of Figure 1-D1 does not stay in its allotted time slot but "walks" freely through the azimuth and DME sectors. A typical example is shown in Figure 1-D2. Here, a portion of the elevation side lobes cover the envelope of the main azimuth beam. At first it may seem that the elevation side lobes are far enough down so as to cause minimal interference with the main azimuth beam. The problem, however, occurs at acquisition before the Nav Set's AGC is switched on. As noted earlier, prior to decoding three valid identity pairs, the Nav Set is at maximum sensitivity. A good portion of the elevation side lobes saturate the Nav Set's IF amplifier, especially when operating near runway threshold.

Figure 2-A1 of reference a, paragraph 1-D11, shows a flow diagram for a successful completion of the Nav Set's acquisition mode. It is seen



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Figure 1-D2. Mistracked Condition

here, that in order for the correct AGC to be turned on, three consecutive pulse pairs with the same identity spacing must be received by the Nav Set. Now if pulse pairs from the elevation side lobes interlace azimuth pulse pairs near the start of the azimuth main beam, acquisition of the azimuth beam will not be completed and consequently azimuth guidance will be lost.

The probability that an azimuth beam is not decoded, given a mis-track condition, is related to the total time interval within the elevation sector during which elevation side-lobe signal level is above the Nav Set's angle tracking sensitivity. Assuming worst-case, as an example (the whole elevation sector is above tracking sensitivity), the probability of losing an azimuth beam would be  $85.96/200$  or 43 percent. Forty three percent of all azimuth data is therefore expected to be lost.

The percentage of valid azimuth data delivered to the MDM interface is somewhat lower than the 57 percent calculated above, and depends on the relative scanning period between the primary and backup system. If the primary system is scanning with an exact 200 ms period while the backup system is tuned to say 190 ms, the elevation transmission will take 4 seconds to completely "walk" through the azimuth and DME scanning period. Of the 4 seconds, azimuth data would be lost for 1.72 seconds. Of the remaining 2.28 seconds, only 0.68 second can be considered valid azimuth data since it takes 8 consecutive valid azimuth beams (1.6 seconds) before valid data is declared. Given the above constraints, valid azimuth data is received only 17 percent of the time.

There is also the danger of the relative scanning period between the primary and backup system being too close to one another. If, for example, the scanning periods are within 0.1 ms, it would take 400 seconds for the elevation transmissions to completely "walk" through the azimuth and DME sectors. Azimuth data would be expected to drop out for 87.6 consecutive seconds. For such circumstances azimuth data may be denied for most of the flight in the terminal area.

1-D5. PROBABILITY THAT ELEVATION WILL INTERFERE WITH AZIMUTH AND/OR DME DURING A MISTRACKED CONDITION. As noted earlier, the probability that elevation will interfere with the other guidance functions depends on the structure of the elevation side lobes and on the absolute elevation signal level reaching the Nav Set (on the number of side lobes above receiver tracking sensitivity). Figure 1-D3 shows vertical plane measurements of the MSBLS DVTU elevation antenna at a test frequency of 15.55 GHz. The side-lobe structure of this pattern is typical of most MSBLS elevation antennas. All side lobes above the horizontal line in Figure 1-D3 will be above the Nav Set's angle tracking sensitivity if the system link margin is greater than 20 dB. In terms of trajectory, the elevation link margin goes above 20 dB, 14 seconds after separation on the ALT-3 trajectory. For this condition, the probability of denying azimuth or DME guidance is computed to be 6.4 percent.

For a link margin of 30 dB (40 seconds after separation on the ALT-3 trajectory) the probability of denying azimuth or DME guidance increases to 41 percent. The probability increases toward the theoretical maximum of 43 percent as touchdown is reached, 107 seconds after separation (link margin >50 dB).

Both azimuth and DME guidance may be denied if the elevation sector is positioned to block at least every other azimuth beam and also DME solicits. The probability of occurrence is related to the orbiter's instantaneous azimuth position as well as on the elevation side-lobe structure. Assuming worst-case side-lobe levels (link margin >36 dB), this probability varies from 11.9 to 23 percent as the azimuth angle varies from 0 to  $\pm 15$  degrees.

Table 1-D1 summarizes the above discussion. Probabilities of losing azimuth, DME or both is given for various conditions.

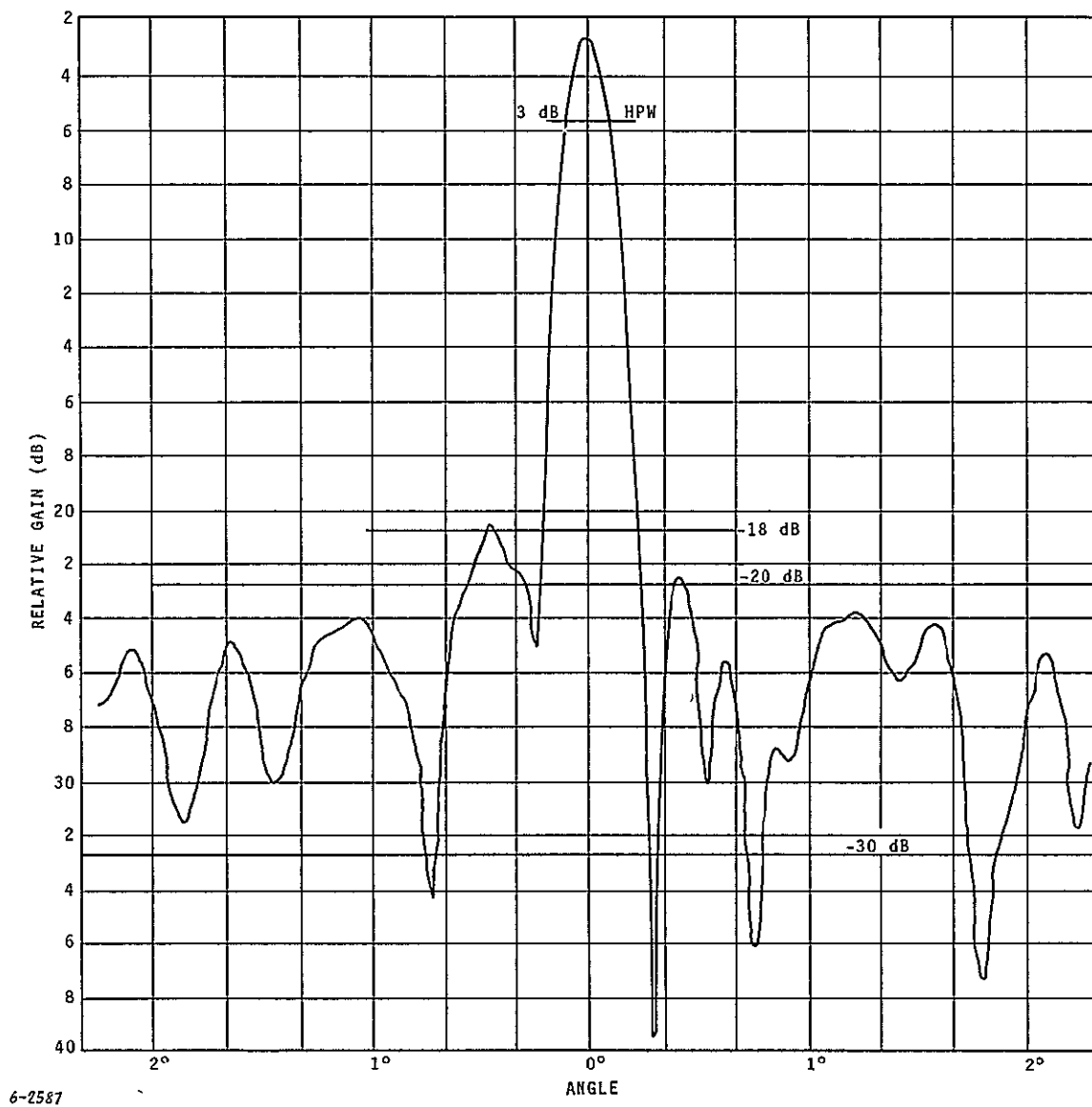


Figure 1-D3. DVTU Elevation Antenna Pattern

Table 1-D1. Probability of Losing Azimuth and/or DME

| Function Denied    | Condition               |                         | Theoretical<br>Maximum<br>(EL Link Margin<br>>35 dB) |
|--------------------|-------------------------|-------------------------|------------------------------------------------------|
|                    | 20 dB EL<br>Link Margin | 30 dB EL<br>Link Margin |                                                      |
| AZ                 | 6.4 percent             | 41 percent              | 43 percent                                           |
| DME                | 6.4 percent             | 41 percent              | 43 percent                                           |
| Both AZ      0° AZ | -                       | -                       | 11.9 percent                                         |
| and DME      5° AZ | -                       | -                       | 15.5 percent                                         |
| 10° AZ             | -                       | -                       | 19.2 percent                                         |
| 15° AZ             | -                       | -                       | 23 percent                                           |

1-D6. PROBABILITY THAT AZIMUTH OR DME WILL INTERFERE WITH ELEVATION. The probability that azimuth transmissions will interfere with elevation guidance during a mistracked condition is analogous to the situation discussed above. Interference from the azimuth function, however, is less likely because of several factors:

- a. Azimuth guidance is transmitted over a shorter time interval during the scan cycle (44.29 ms versus 85.96 ms).
- b. Azimuth side lobes are further removed from the beam peak. Most side lobes are more than 26 dB down.
- c. Azimuth link margin is lower than elevation for most of the trajectory. Maximum azimuth link margin for the ALT-3 trajectory is approximately 36 dB versus 51 dB for the elevation function.

For a link margin of 20 dB (26 seconds after separation on the ALT-3 trajectory), the probability of azimuth interfering with elevation is computed to be 2.5 percent. For a link margin of 30 dB (66 seconds after separation), the likelihood of interference increases to 4 percent. Worst-case occurs for a link margin greater than 40 dB. At that point, the whole azimuth sector is above the Nav Set's tracking sensitivity. The likelihood of azimuth interference for this condition increases to 22.15 percent. It should be noted that the maximum link margin for the ALT-3 trajectory, from reference 3, only gets up to 36 dB. However, enough uncertainty in the link margin computation exists so that the azimuth link margin may well be above 40 dB at some points in the trajectory during actual system operation.

Interference of elevation guidance due to DME transmissions differs somewhat from angle function interference. For one thing, the DME function transmits over the entire coverage volume. DME solicits would interfere with elevation only if the elevation main beam coincided with solicit transmissions. Since solicits are transmitted for approximately 2.5 ms out the 200 ms scan cycle, the likelihood of occurrence is 1.25 percent. Since

elevation would likewise interfere with the solicit signal, the Nav Set would acquire neither elevation nor DME.

The DME function can interfere with elevation in another manner. If the solicit signal is received in the clear (not interfered with from elevation) all Nav Sets are placed into their respective interrogate modes. For the next 27 ms (approximately) the Nav Sets are interrogating and, therefore, ignoring any elevation signals which may come along.

The above situation is depicted in Figure 1-D4, part A. Note that only a portion of the elevation sector is affected. Depending on whether the elevation antenna is scanning up or down, either the 0- to 6-degree elevation sector or the 24- to 30-degree sector is masked. Valid elevation guidance would be received by the Nav Set once every 400 ms. Output data to the MDM interface, however, would be considered invalid because of the flag criteria established by the Nav Set (that is, data is considered invalid if there are no valid updates within 256 ms of each other). Thereafter, it takes 8 consecutive valid scans in order to validate output data.

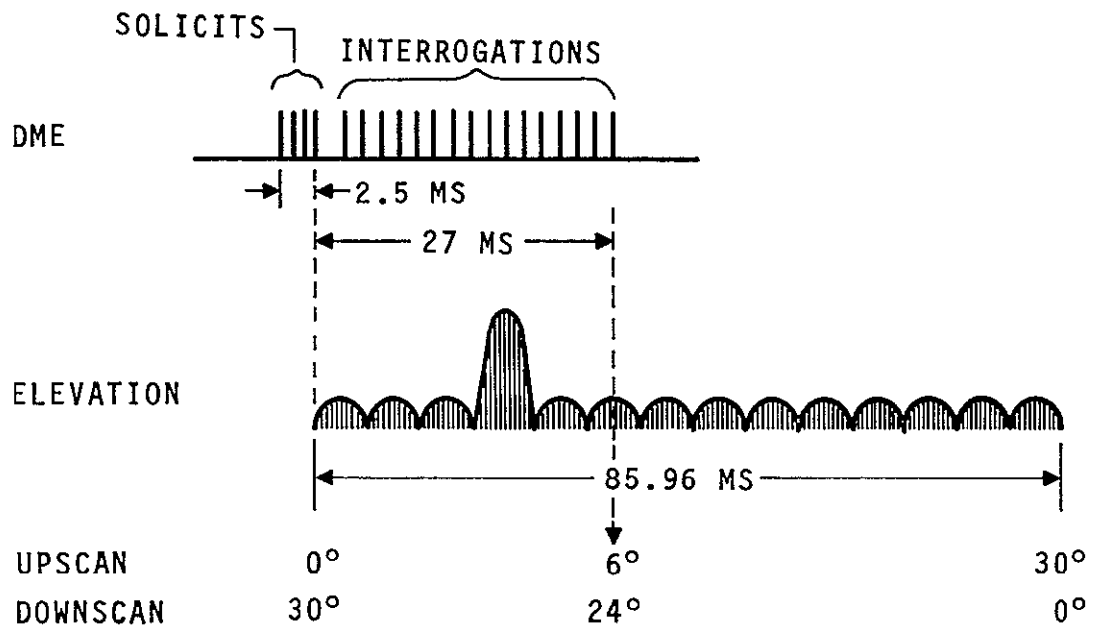
Figure 1-D4, part B shows the probability that DME will interfere with elevation guidance as a function elevation angle. The probability is seen to vary from 1.25 to 14.75 percent.

Since the azimuth and DME transmissions are mutually exclusive, the probability that one or the other will effect elevation guidance is merely the summation of the individual probabilities.

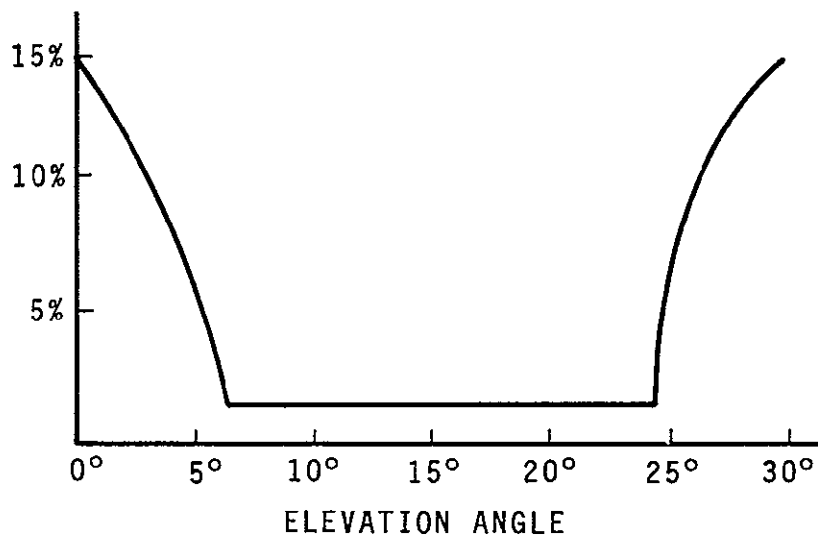
Figure 1-D5 gives the probability of loss of elevation guidance as a function of elevation angle for several azimuth link margins.

#### 1-D7. POSSIBLE HARDWARE IMPROVEMENTS TO ELIMINATE OR MINIMIZE THE MISTRACK CONDITION

1-D8. AUTOMATIC SWITCHOVER DURING MISTRACK. The mistrack condition can be eliminated by proper sensing circuitry and automatic switchover to the backup system. Mistrack sensing circuitry is already available



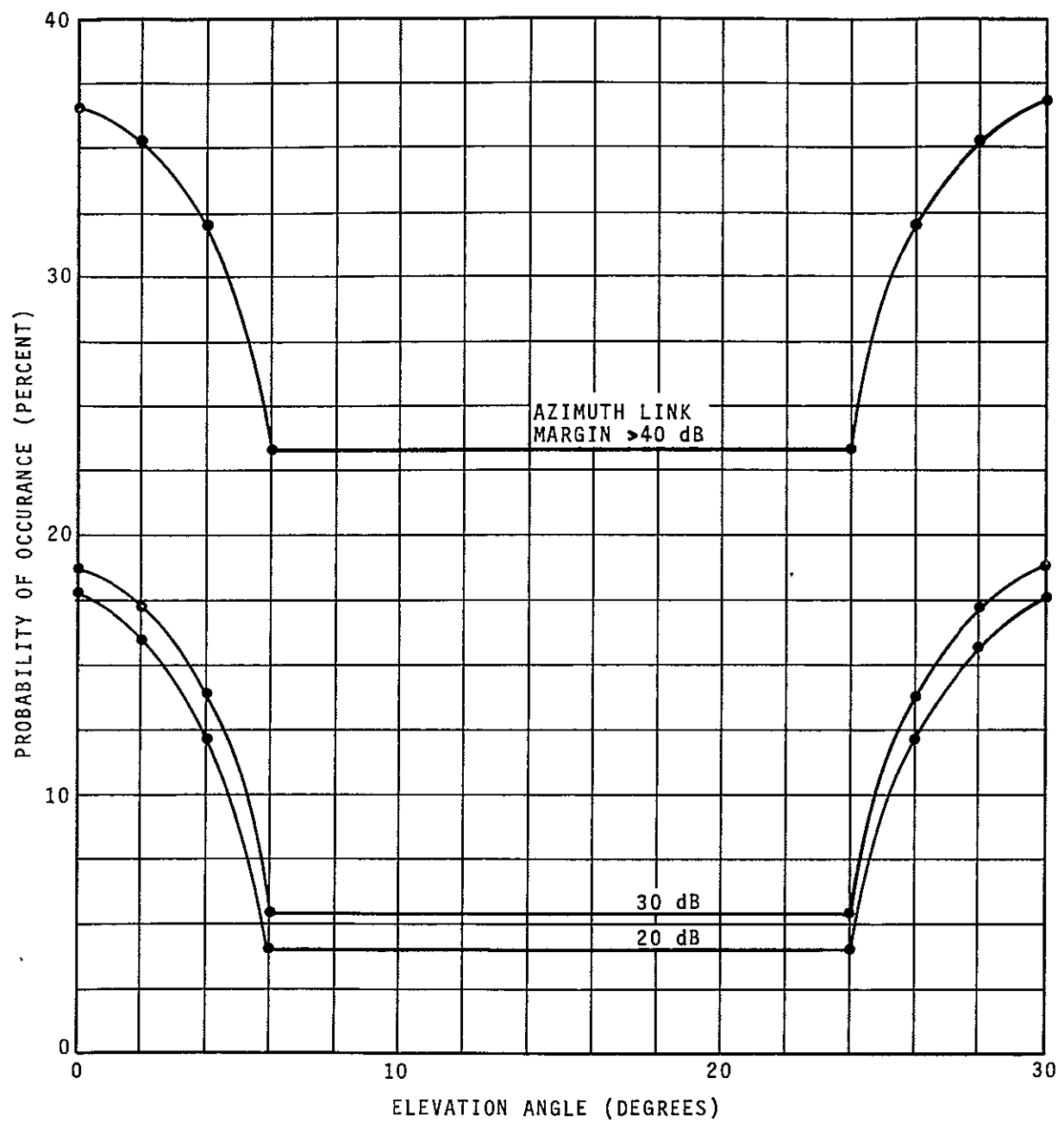
A. DME TRANSMISSIONS INTERFERING WITH ELEVATION GUIDANCE



B. PROBABILITY OF DME INTERFERING WITH ELEVATION

6-2588

Figure 1-D4. DME Transmissions Interfering With Elevation Guidance and Probability Curve



6-2589

Figure 1-D5. Probability of DME or Azimuth Interfering With Elevation

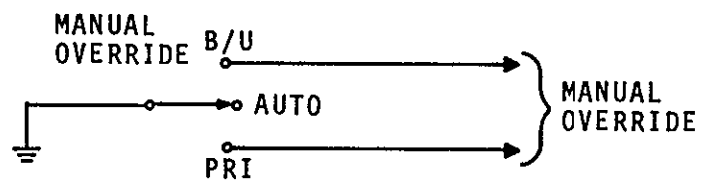
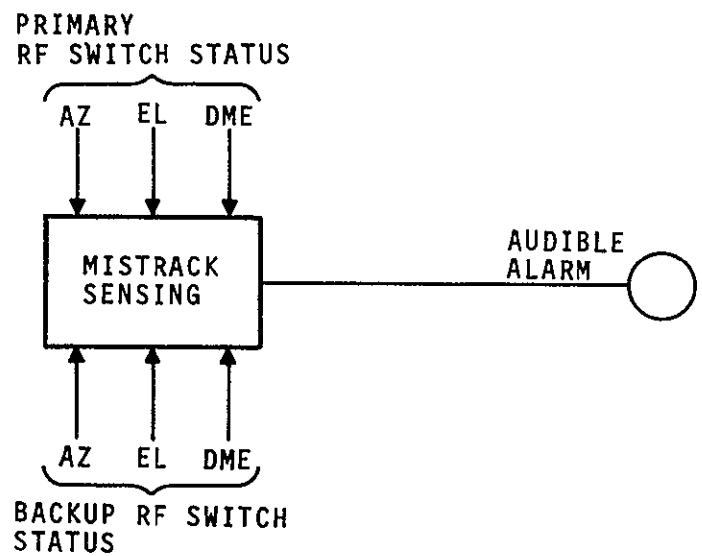
at the remote site, so it would be easiest if the switchover command originated from there. Figure 1-D6 shows a from/to diagram for this implementation. In the present design, the mistrack condition is sensed by monitoring RF switch status of the primary and backup systems. If all three functions (AZ, EL, and DME) are not from the same system (primary or backup), the audible alarm is sounded. The operator is then required to place the manual override switch into the backup position in order to overcome the problem.

The above procedure can be automated by allowing the mistrack sensing circuitry to turn on a relay which forces the system into backup. Note that the relay output is routed through the manual override switch so that autoswitch due to mistrack can only occur with the switch in AUTO position. Manual override to primary or backup is not affected by this implementation.

One problem with this particular implementation is the fact that prime equipment is not totally divorced from the remote site. Should there be a power outage at remote, for example, mistrack monitoring and switchover would not occur.

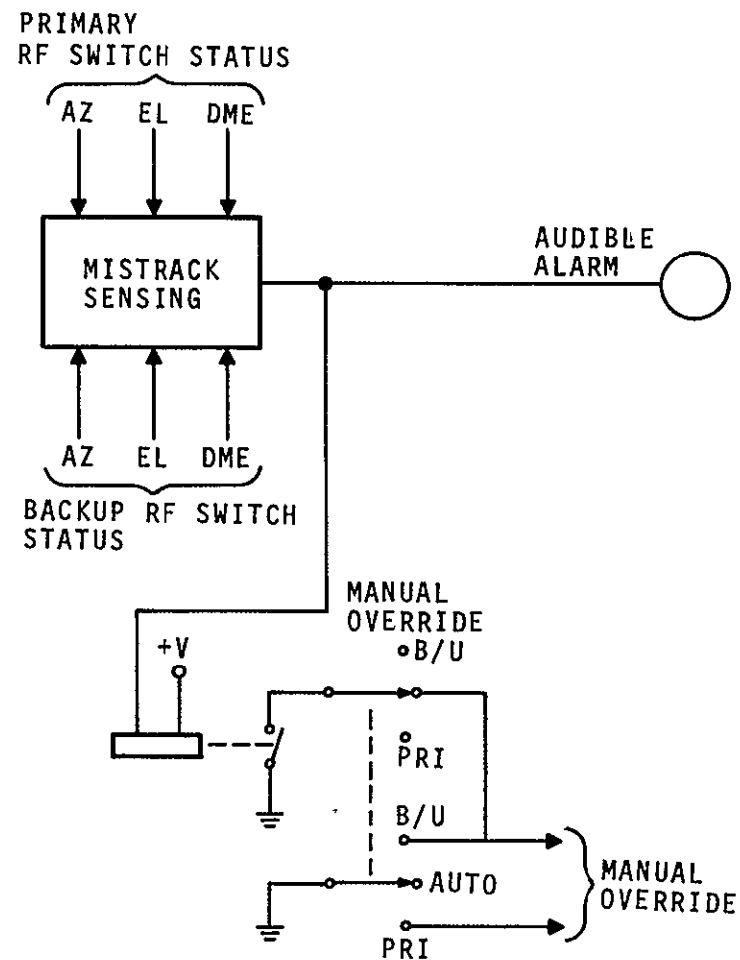
Mistrack sensing circuits can be placed at the local sites, but not very easily. Each site, AZ/DME and elevation, would require its own set of monitoring circuits. RF switch status would then have to be shipped between sites. Primary and backup azimuth and DME status would have to go to the elevation site while primary and backup elevation status would be required at the AZ/DME site. In addition, built-in-test of the monitoring circuits would be required.

1-D9. MINIMIZING THE PROBABILITY OF MISTRACK OCCURRENCE. As noted previously, all failures uncovered to date, which result in a mistrack condition, yield a proper indication to the remote operator and are manually correctable. From that standpoint, mistrack is no different than any of the



A. FROM

6-2590



B. TO

Figure 1-D6. Mistrack Autoswitch Implementation

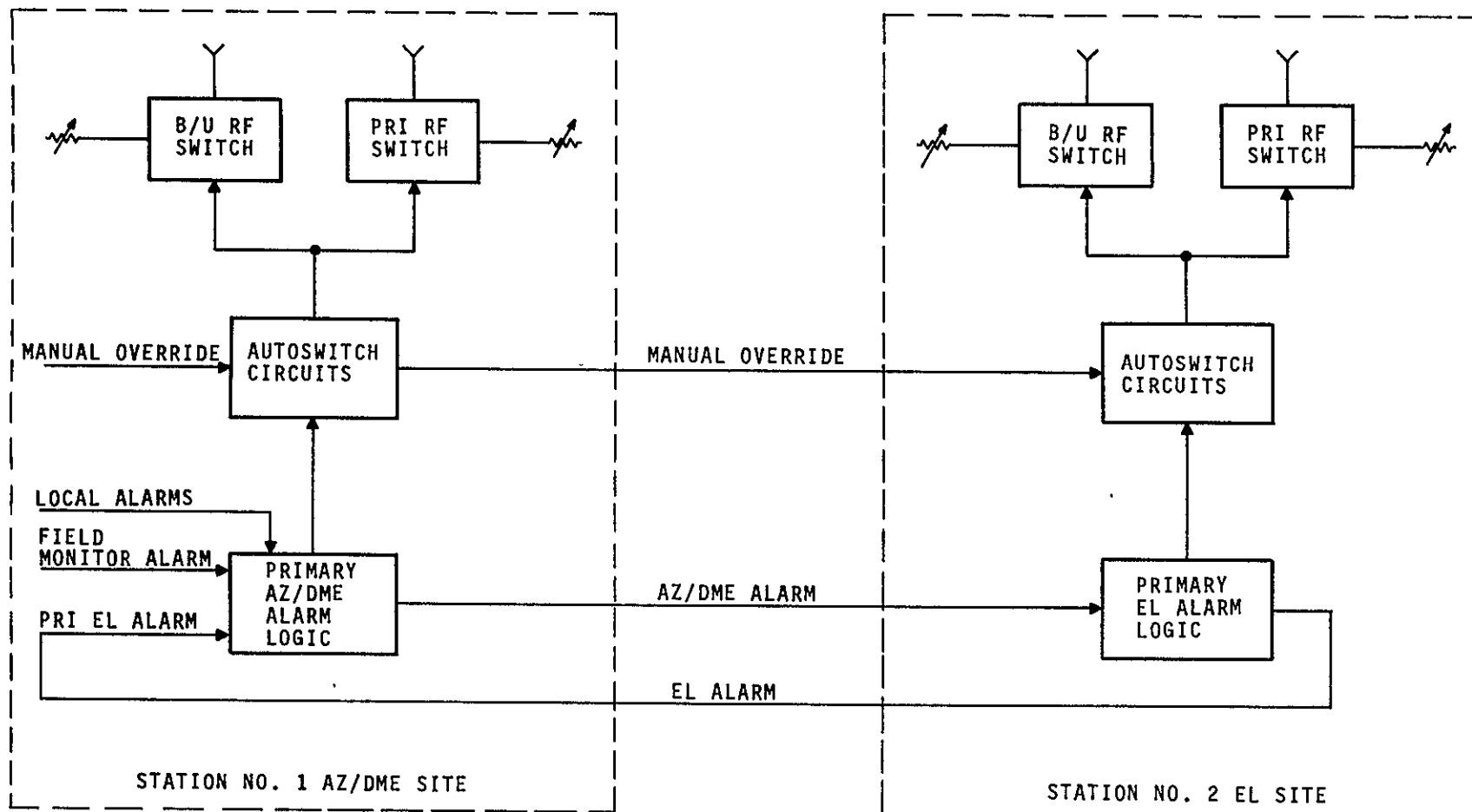
other identified single point failures. The mistrack condition adheres to the philosophy of allowing single point failures as long as they yield an unambiguous display to the operator and the manual corrective action is within allowable guidelines. (Operator response should be limited to a few well-defined actions.)

Since the mistrack condition, as some of the other single point failures, denies the orbiter guidance information for a period which depends on the operator's response time, it may be argued that if nothing is done about other single point failures, then nothing should be done about mistrack either. Conversely, if circuits are added to perform automatic switchover in case of mistrack, why not take care of the other single point failures in the same manner.

The reason why the mistrack condition may be of more concern than some of the other single point failures can be seen from reference d, paragraph 1-D11. Most single point failures are caused by a single part failing in some assumed mode. The probability of failure is usually low. The mistrack failure, however, can occur due to a large number of components. In some cases, a component failure is not even required. A voltage transient induced in one of the intersite cables may initiate a switchover in one site without any alarm or indication of switchover at the other site.

If the number of components which can generate a mistrack condition can be reduced to a small number, then mistrack will become no different than any of the other failures. Manual corrective action due to a mistrack condition will then become justifiable.

Figure 1-D7 represents a block diagram of the waveguide switch control as presently designed. The waveguide switches in each of the sites are controlled by autoswitch circuits which direct either the primary or the backup waveguide switch into the antenna position. The other switch is directed into a dummy load. The autoswitch circuits get their information



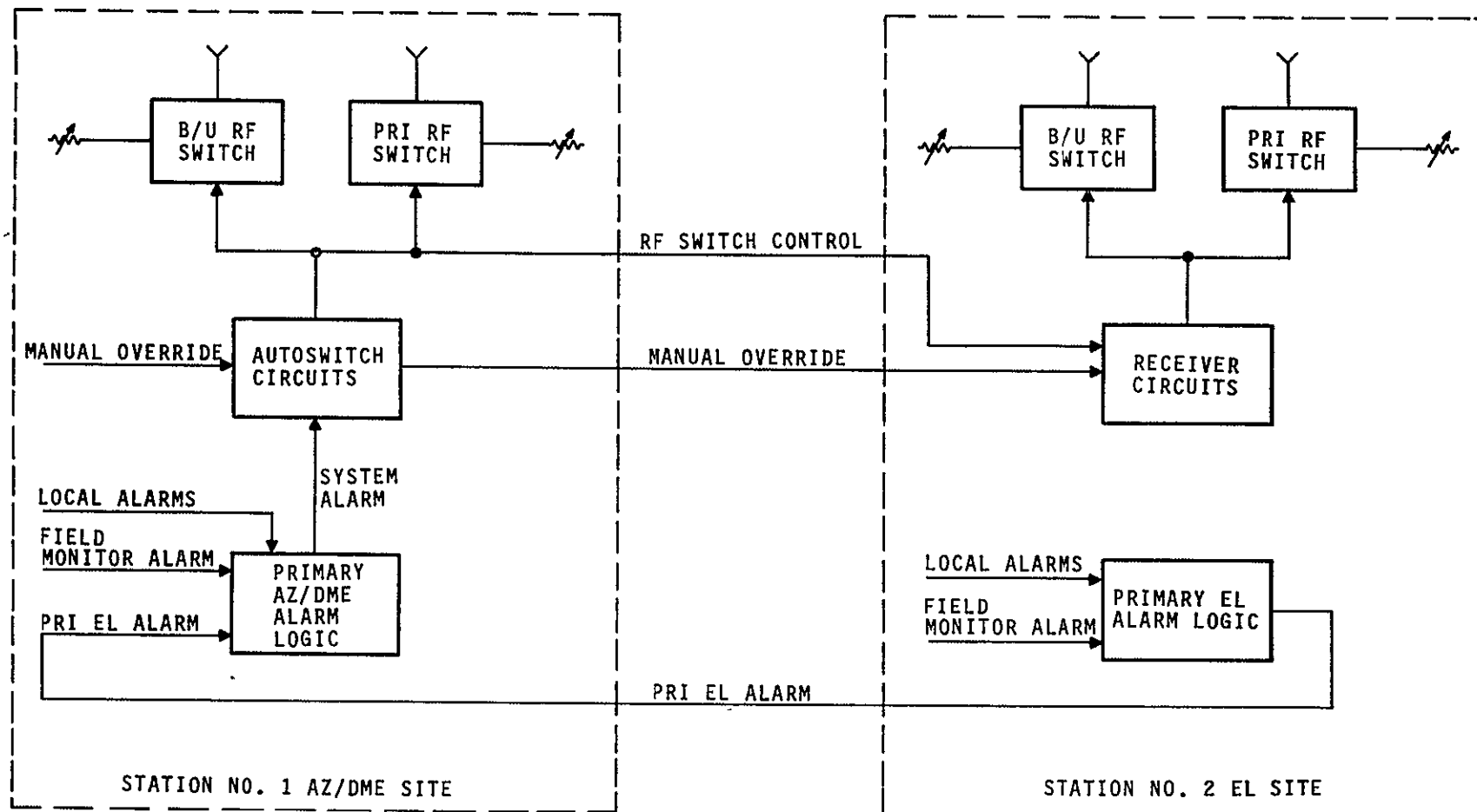
6-2591

Figure 1-D7. RF Switch Control, Present Configuration

from primary alarm logic. These logic circuits determine whether a local alarm, a field monitor alarm, or an alarm from the other site is present, and direct the autoswitch circuitry to act accordingly.

Figure 1-D7 shows why a large number of component failures can cause a mistrack condition. Each of the sites (AZ/DME and EL) is a master over its own waveguide switches. If the AZ/DME site, for example, senses an alarm condition, it directs its waveguide switches to switch over to backup and merely "informs" the elevation site, via the AZ/DME alarm, that a switchover took place. The elevation site must then sense this condition and direct its waveguide switches to switchover. Failures in the AZ/DME autoswitch circuits which cause an AZ/DME switchover to backup without causing an AZ/DME alarm, would cause a mistrack condition. Failures in primary alarm logic which generate an autoswitch without generating an alarm, or vice versa, could cause a mistrack condition. Alarm logic failure which does not allow recognition of an alarm from the other site would cause a mistrack condition. A voltage transient induced in the intersite EL alarm line would falsely switch the AZ/DME site to backup while the elevation site stays in primary. And finally, a failure of one of the waveguide switches would cause a mistrack condition.

The basic problem with the present configuration is the master/master relationship which places many components inbetween the status of AZ/DME and elevation waveguide switches. The situation would be improved if a master/slave relationship in the control of waveguide switches were to be maintained. Figure 1-D8 shows a block diagram of such an arrangement. The AZ/DME site is assumed to be the master in this case. Assuming the elevation site is in remote, control of elevation waveguide switches is carried out directly by the AZ/DME waveguide switch control signal. Now, the elevation alarm does not initiate an autoswitch in the elevation site, but only informs the master that a switchover to backup is necessary. Failures which generate a mistrack condition are now reduced to



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Figure 1-D8. RF Switch Control, Master/Slave Implementation

the waveguide switches and control signal transmitter/receiver circuits. Manual override is still available if a mistrack failure does occur. Note that a mistrack condition due to an induced transient is no longer possible.

The AZ/DME site need not always be the master. Any site which becomes station No. 1 (one closest to remote control) would become master.

Implementation of this approach would require a redesign of the auto-switch circuits to allow a master or slave configuration to be jumper selectable. Additional hardware outside of a pair of intersite wires (RF switch control) is not expected to be required.

#### 1-D10. SUMMARY AND RECOMMENDATIONS

The effect of mistrack on the Nav Set's data has been evaluated. Given a mistrack condition, a high probability exists that at least one of the guidance functions (AZ, EL or DME) will be denied to the orbiter. This probability increases as runway threshold is neared.

A way of automating the response to a mistrack condition has been discussed. This implementation does not decrease the possibility of mistrack occurrence but decreases the response time normally associated with the operator. This approach shifts some of the monitoring and autoswitch functions to the remote control so that the prime equipment could not be said to run totally independent of remote.

An approach which decreases the possibility of mistrack occurrence has also been discussed. This approach minimizes the number of components between the status of waveguide switches on station No. 1 and station No. 2 by allowing station No. 1 to be the master in autoswitch situations and station No. 2 to follow as a slave.

Whether anything is to be done about the mistrack condition depends totally on whether the operator response time is adequate, given the probabilities of mistrack occurrence. This question cannot be answered here.

Given that something is to be done about mistrack, it would seem more sensible to minimize its probability of occurrence. The problem with mistrack is not the fact that it can occur, other single point failures which deny guidance can also occur, but with the fact that it can occur so often. The whole area of automating the operators response (of eliminating identified single point failures), if it is to be considered at all, should be done in a generalized manner by addressing every identified single point failure.

1-D11. REFERENCES

2. W. Wong, Report No. Y220-01, Examination of MSBLS Nav Set Operation During the Acquisition Mode.

b. Microwave Scanning Beam Landing System Technical Specification, AIL No. 00752-502498.

c. MSBLS Signal Level Computations, J.O. 16-619, Lockheed Electronics Co., Inc., Aerospace Systems Div., Houston, Texas, Contract No. NAS 9-12200.

d. MSBLS-GS Single Point Failure Modes, Effects and Criticality Analysis (SPFMECA), DRD RA 338TA, DRL T1170, line item 17 (as amended by CCA No. 2), April, 1976.

PART E

EFFECTS OF GROUND REFLECTIONS AT  
THE DFRC SITE ON  
MSBLS DATA

A. CHARYCH  
F. BATTLE

TECHNICAL REPORT Y220-14  
INTERIM - FEBRUARY, 1977

FINAL  
APRIL, 1977

## 1-E1. INTRODUCTION

Coverage requirements of the MSBLS azimuth and DME functions necessitate directing a considerable amount of RF energy into the ground. Some of this energy is reflected by the ground surface; the amount of reflection depending on the terrain directly in front of the azimuth/DME site. The reflected multipath signal combined with the direct wave generates a space-fixed vertical peak and null pattern; the difference between peaks and nulls being primarily determined by the reflection coefficient of the terrain. The elevation signal, being quite directive vertically, is relatively immune from the effects of concern here.

If the gain difference between peaks and nulls is large, and if the trajectory through the vertical lobes is such that fast signal level fluctuations result, the Nav Set's AGC loops may have trouble maintaining correct tracking sensitivities. The result could be data loss in some parts of the trajectory. System accuracy is also affected by a high-multipath environment.

Whenever a terrain reflection is received simultaneously with the direct rays of a guidance signal, the resultant received signal strength is either increased or decreased, depending the relative RF phase. The phasing is dependent on the difference in the two signal path lengths, which change most rapidly if the receiving point moves almost vertically. Thus, the resultant signal strength variations describe a vertical lobing pattern that is repetitive at various elevation angles. As the elevation angle to a receiving vehicle changes during flight, alternate peaks and nulls in signal strength are encountered.

A consequence of terrain reflections can be errors in the guidance data. DME errors tend to result from distortion of the pulse leading edges of the reflected signals. In addition, a decrease in the direct-signal level due to a lobing null tends to increase the error from thermal noise and from some

other sources. The latter effect applies, as well, to azimuth guidance, which may also be further perturbed by any component of the resultant beam signal that is reflected from laterally sloping terrain.

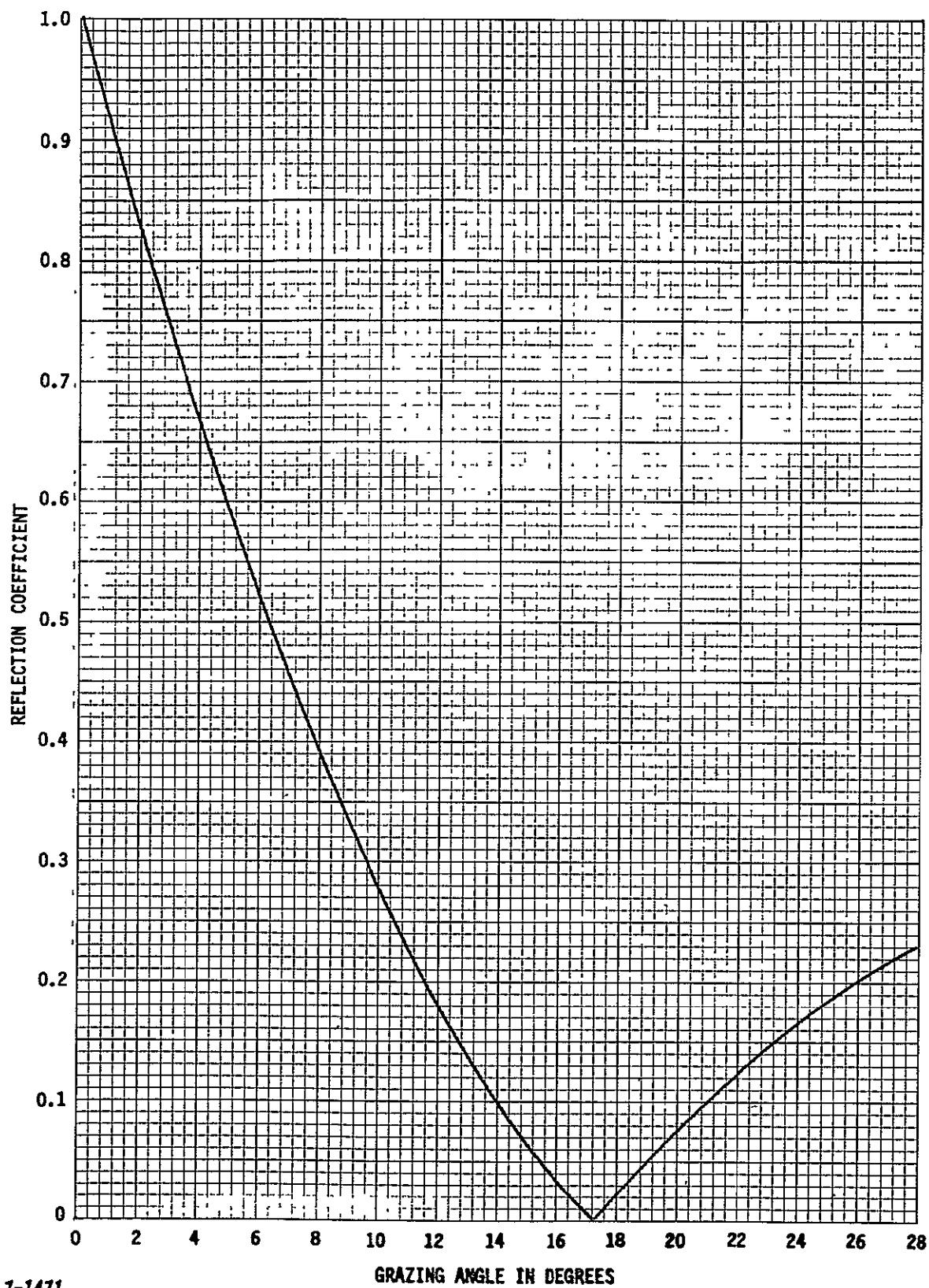
The most serious effect of the terrain reflection lobing pattern would be temporary lapses in tracking of the guidance signals by an airborne receiver/decoder. This would result from unusually rapid and extreme changes in resultant signal strength, caused by traversing the lobing pattern, such that the receiver AGC cannot maintain video levels suitable for decoding.

Ground reflections at the DFRC site are expected to be high due to the very smooth terrain in front of the MSBLS scanners. Evaluation of vertical ground lobing at DFRC should therefore establish worst-case performance at other MSBLS sites as well.

In order to evaluate how ground lobing at DFRC will affect MSBLS data at the Orbiter, simulations of Orbiter approaches with an appropriately chosen ground reflection model were performed. Prior to Orbiter approach simulations, simulations of several flight tests were performed and compared to actual flight test data. Since the simulation reasonably resembled flight test data, the reflection model was considered verified. Simulation and evaluation of Orbiter approaches were then performed.

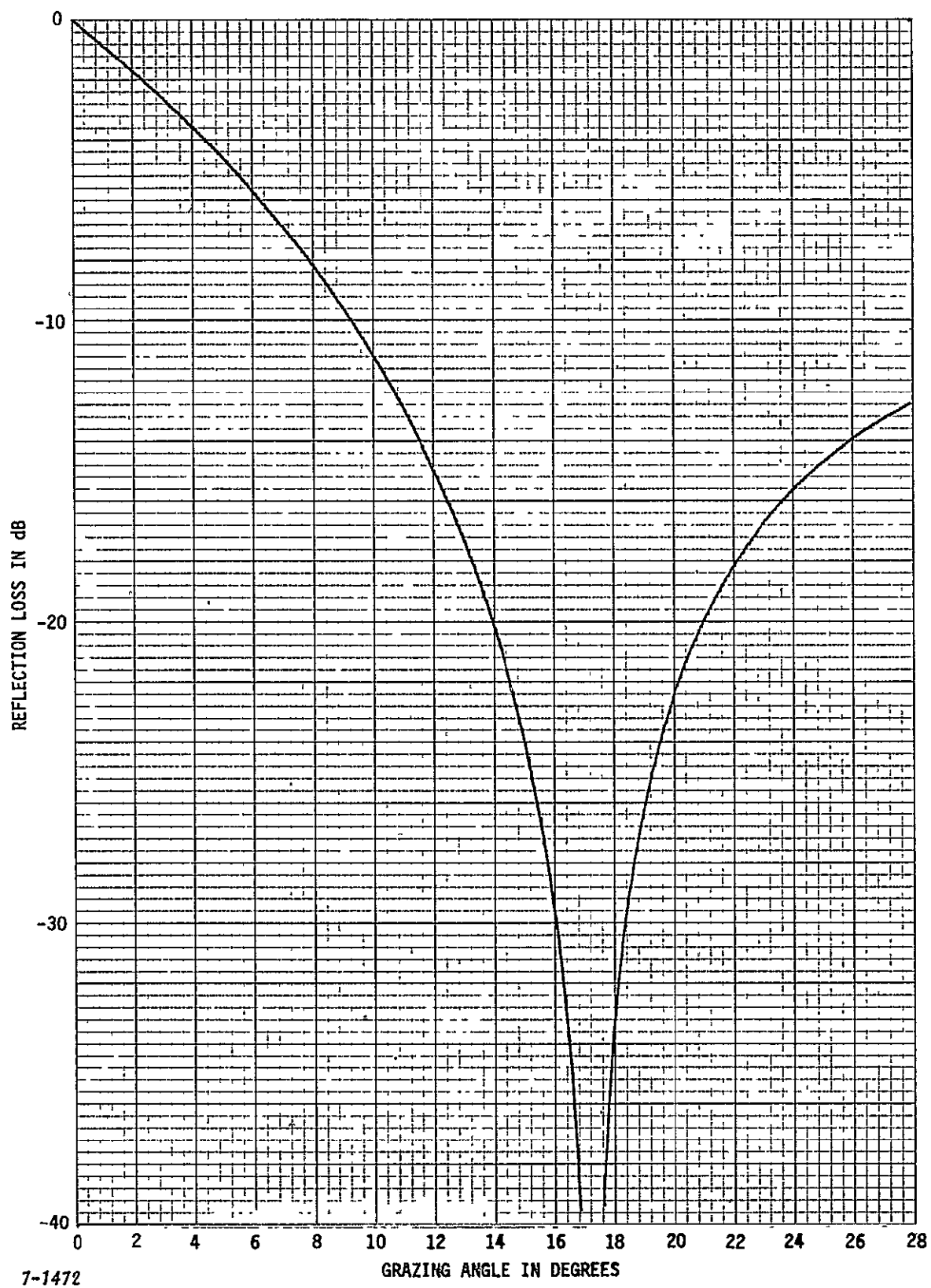
#### 1-E2. REFLECTION MODEL

A reflection model for a vertically polarized signal striking a smooth solid ground is taken from reference a. The reflection coefficient as a function of grazing angle is shown in Figure 1-E1. The reflection coefficient is almost 1 (perfect reflector) at a grazing angle of 0 degree, and drops to 0 at approximately 17.3 degrees. Phase shift on reflection is 180 degrees for a grazing angle up to 17.3 degrees, and goes to 0 at a grazing angle greater than 17.3 degrees. Figure 1-E2 shows this model in terms of dB signal loss at reflection.



7-1471

Figure 1-E1. Reflection Coefficient for Smooth Ground Vertical Polarization



7-1472

Figure 1-E2. Reflection Loss (dB) Vertical Polarization

Some limited relative signal level measurements performed at DFRC in front of the primary DME site verify the high reflectivity of the terrain at low grazing angles. Figure 1-EC1, of Appendix C shows the measurement of relative level taken at 5,000 feet in front of the primary DME site as a function of height. Taking the ground station antenna vertical gain pattern into account, in order to get a best fit through the measured data, a ground reflection coefficient of 1 was computed. Phase shift due to reflection was computed to be 209 degrees.

Since only a limited amount of this type of data has been collected, these measurements should not be interpreted as quantitative verification of the reflection model. The data does, however, suggest very high ground reflection coefficients at low grazing angles as predicted by the model.

#### 1-E3. SIMULATION OF PERFORMANCE FLIGHT TESTS

In order to develop a higher degree of confidence in the reflection model, simulations of fixed altitude radial flight test approaches have been performed. These simulations are then compared to actual flight test data.

Analog recording of flight test data taken on day 226, run 14, was used for comparison with simulation results. Very pronounced scalloping of the DME AGC voltage, due to vertical lobing, can be seen in this recording. Some scalloping, but not as pronounced, can also be seen on the azimuth AGC channel.

Precise parameters used in the simulation were taken from digital in-flight recordings. The parameters used in flight 226, run 14 simulations are listed below:

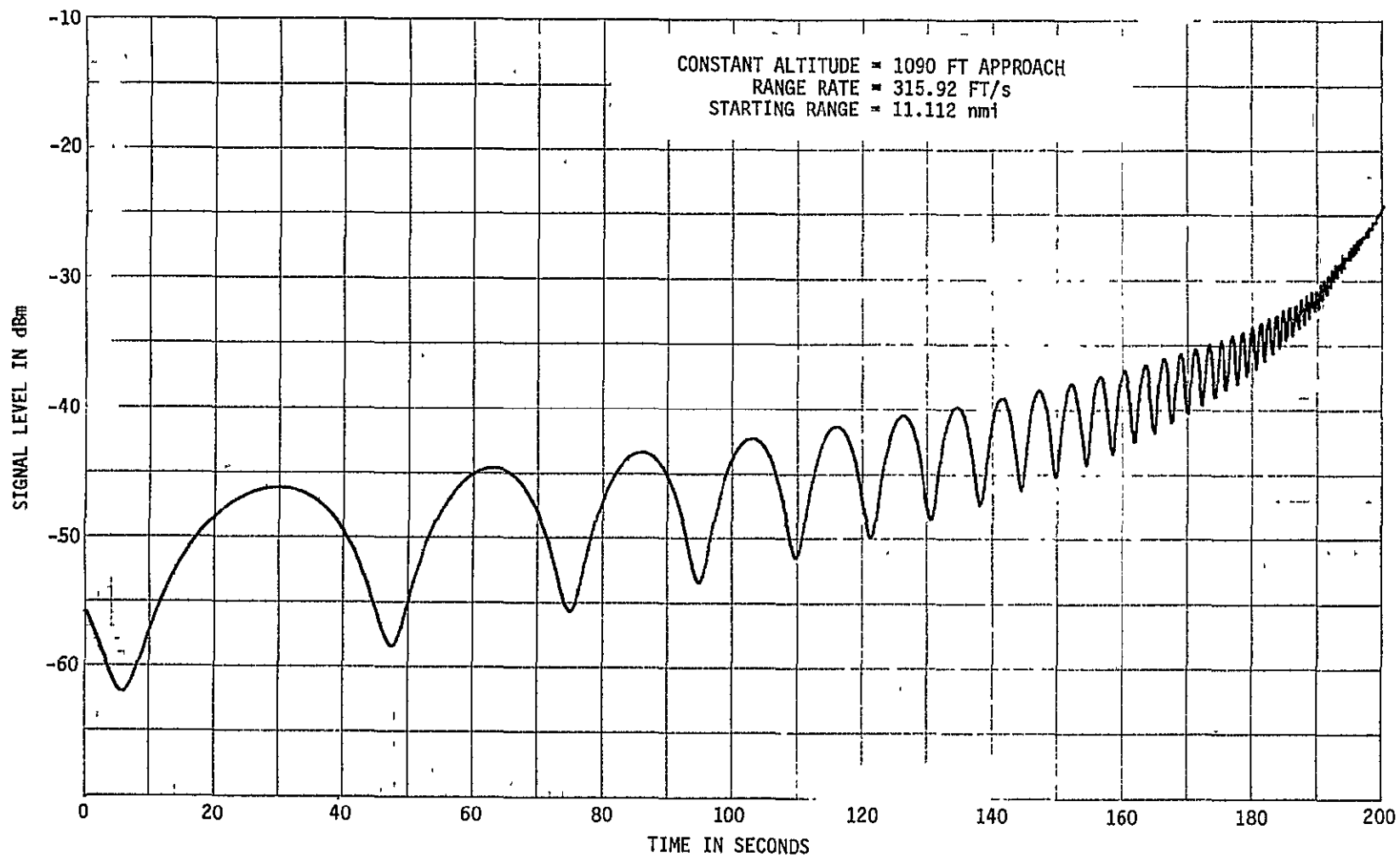
|                              |             |
|------------------------------|-------------|
| Starting Range (at $t = 0$ ) | 11.112 nmi  |
| Stop Range (at $t = 200$ s)  | 0.713 nmi   |
| Average Height               | 1090 ft     |
| Average Range Rate           | 315.92 ft/s |

Output of the simulation is given in Figures 1-E3, 1-E4, and 1-E5. Figure 1-E3 shows the simulated DME signal level and Figure 1-E4 shows the corresponding DME AGC voltage. Signal level at the start of the trajectory is seen to fluctuate by more than 12 dB. Later in the approach, the fluctuations get smaller and closer together.

In order to check how well the simulation resembles the flight data, the simulated and measured AGC voltages are compared for time at which a null occurred, AGC voltage at the null, and AGC voltage at a signal maximum. Table 1-E1 summarizes the results for the first 10 signal nulls.

The simulated results are in general agreement with the flight test data. The simulated time at which nulls occurred lagged the measured time by approximately 5 seconds. Some of the lag is explainable by a phase shift on reflection somewhat greater than the 180 degrees assumed in the simulation. Phase shift on reflection was measured to be 209 degrees (Figure 1-EC1 of Appendix C).

The simulated min/max. voltage was, on the average, approximately 0.2 volts higher than its flight test counterpart. The difference may be due to a difference in the absolute system gain used in the simulation, or the DFRC terrain may have been somewhat less reflective during this flight than predicted by the model. At any rate, the difference between the measured and simulated data is small enough to establish additional confidence in the reflective model.



7-1473

Figure 1-E3. DME Signal Level Simulation

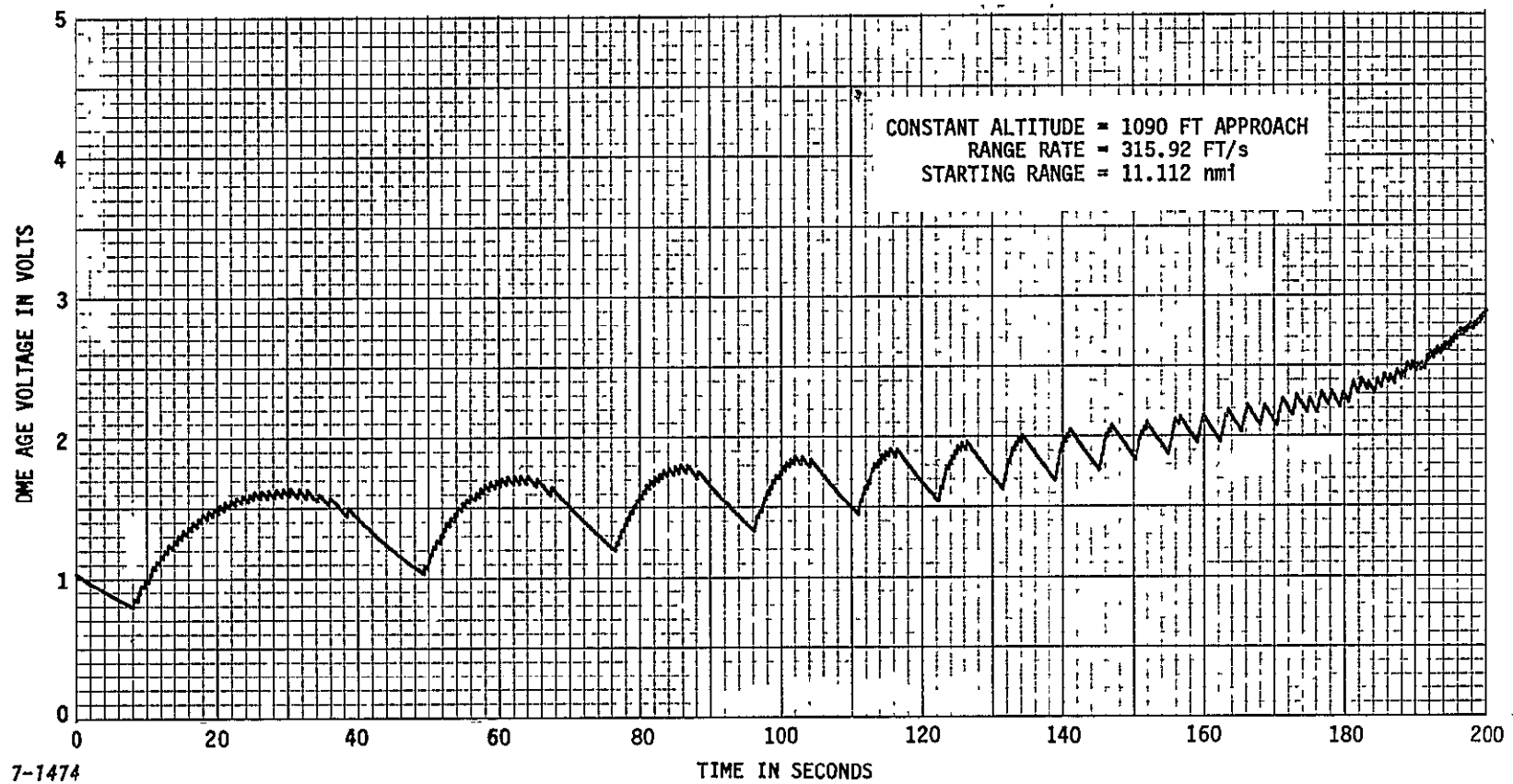


Figure 1-E4. Simulated DME AGC Voltage

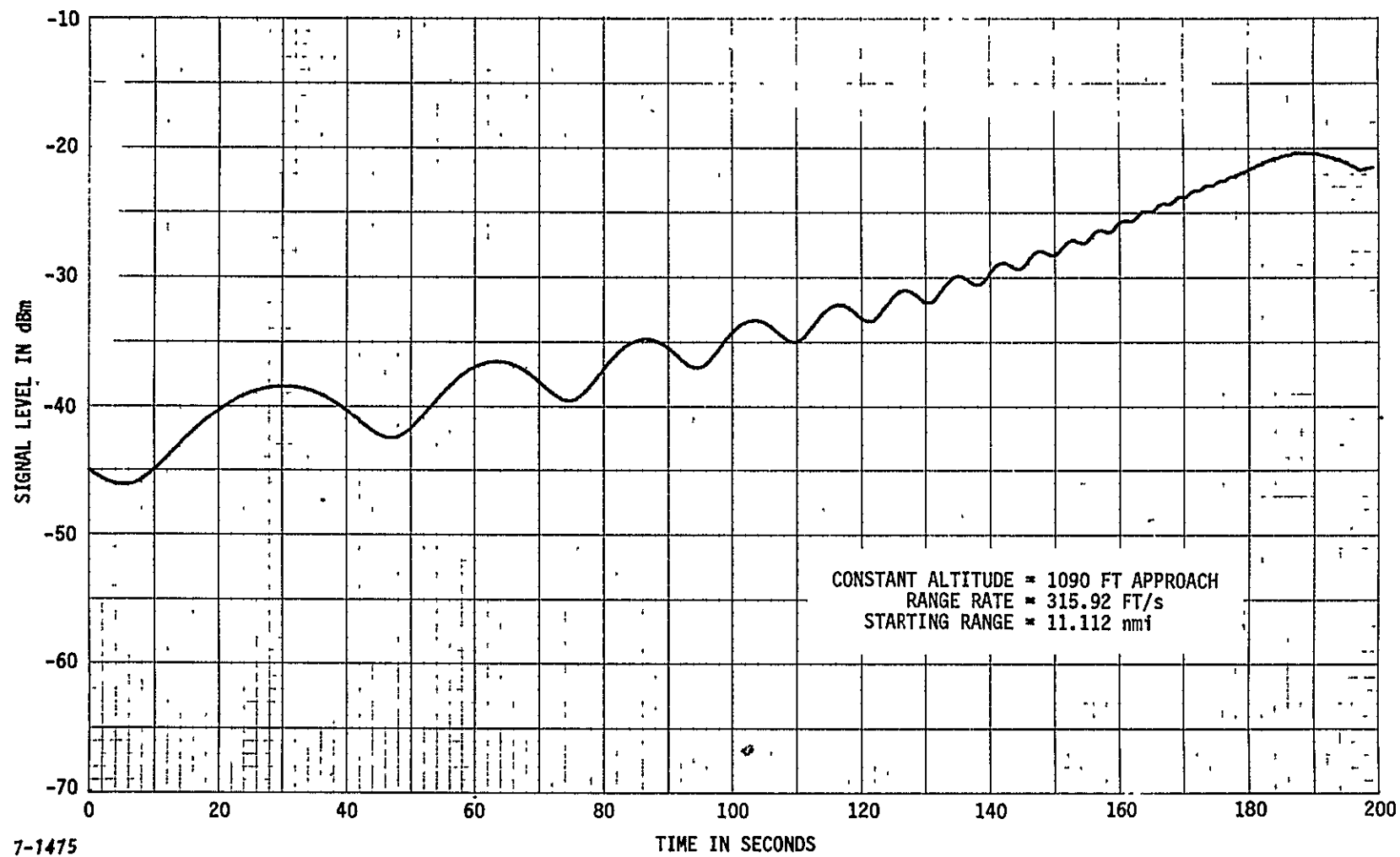


Figure 1-E5. Azimuth Signal Level Simulation

Table 1-E1. Flight Test Data Versus Simulated Results

| Null No. | Measured Time | Simulated Time | Measured<br>Min Voltage | Simulated<br>Min Voltage | Measured<br>Max. Voltage | Simulated<br>Max. Voltage |
|----------|---------------|----------------|-------------------------|--------------------------|--------------------------|---------------------------|
| 1        | 6.5 s         | 8 s            | 0.7                     | 0.8                      | 1.35                     | 1.6                       |
| 2        | 44            | 49             | 0.85                    | 1.05                     | 1.45                     | 1.7                       |
| 3        | 71            | 77             | 1.0                     | 1.2                      | 1.5                      | 1.75                      |
| 4        | 92.5          | 96             | 1.2                     | 1.35                     | 1.6                      | 1.82                      |
| 5        | 108           | 111            | 1.25                    | 1.45                     | 1.65                     | 1.9                       |
| 6        | 119.5         | 122            | 1.35                    | 1.55                     | 1.7                      | 2.0                       |
| 7        | 129           | 131.5          | 1.5                     | 1.65                     | 1.85                     | 2.03                      |
| 8        | 134           | 139            | 1.6                     | 1.7                      | 1.85                     | 2.08                      |
| 9        | 140           | 145            | 1.65                    | 1.75                     | 1.85                     | 2.1                       |
| 10       | 145           | 150            | 1.65                    | 1.82                     | 1.85                     | 2.1                       |

Simulation of the signal level fluctuations in the azimuth channel are shown in Figure 1-E5. The fluctuations are not as large as DME because the azimuth ground station antenna gain decreases much more rapidly than the DME antenna at low elevation angles. Exact comparisons were not performed for the azimuth channel. Qualitatively, the simulation does resemble flight test data.

#### 1-E4. SIMULATION OF ORBITER APPROACHES

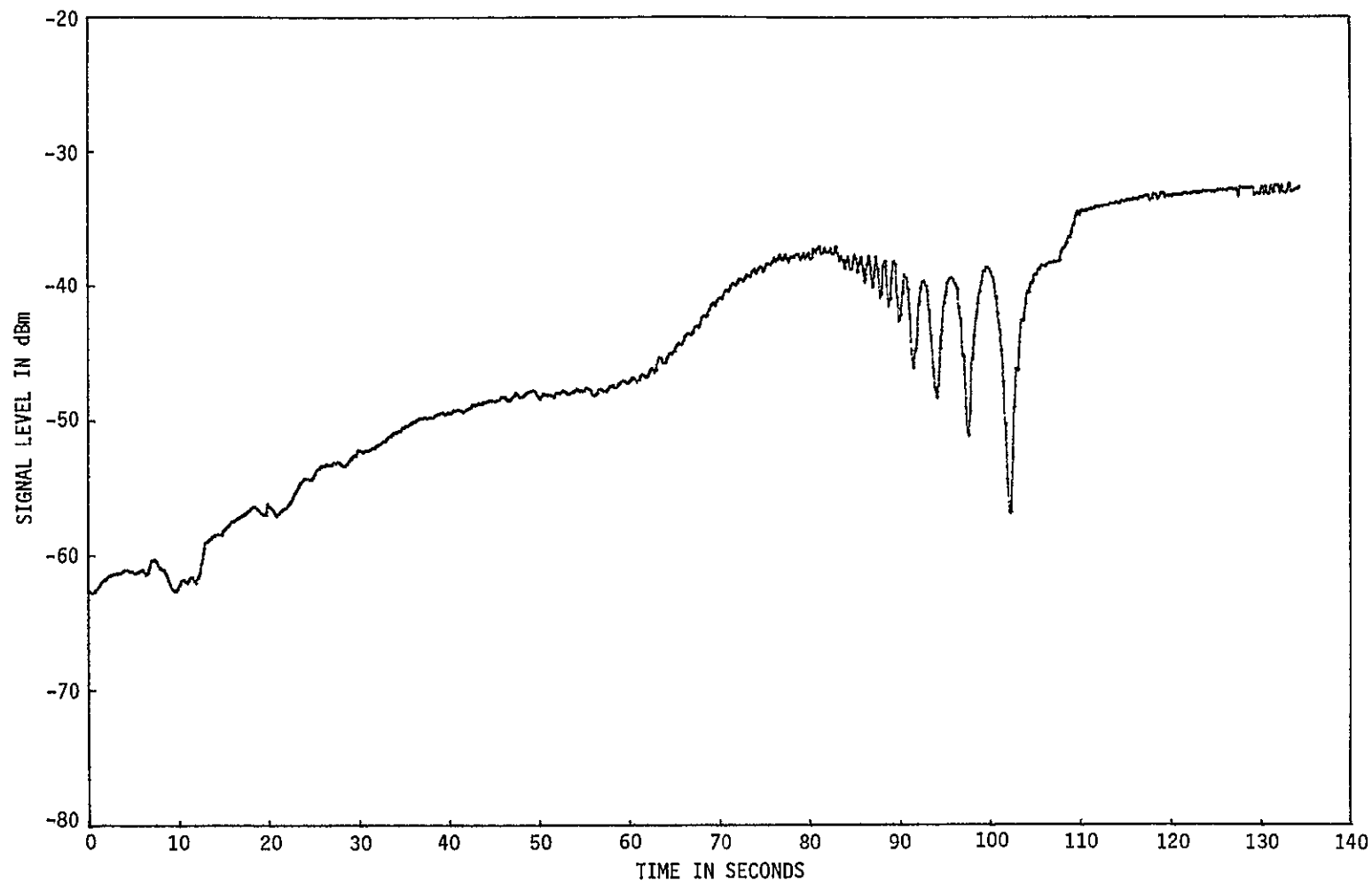
Simulation of azimuth and DME signal levels and AGC tracking levels were performed for the ALT-3 and ALT-2 trajectories taken from references c, d, e, and f. Previously described ground reflection model was used to compute the composite signal strength at the Orbiter.

The AGC tracking level simulation is identical to the flow diagram appearing in Report Y220-02 (Evaluation of MSBLS Nav Set AGC Tracking Capability As Function Of Received Signal), Figure 1-B3; the only difference being the addition of the reflective model.

#### 1-E5. RESULTS

Figure 1-E6 shows the simulated azimuth signal level for the ALT-3 trajectory. The corresponding AGC tracking level is given in Figure 1-E7. Large azimuth signal strength fluctuations are seen to occur starting approximately 90 seconds after separation. Data starts dropping out at that point as depicted by the AGC tracking level going above the -0.2 dB point on the beam envelope (Figure 1-E7).

A plot of the azimuth flag is shown in Figure 1-E7 (below the AGC tracking plot). This flag goes high whenever an azimuth data point is lost (if the tracking level gets above -0.2 dB) and retracts after eight consecutive valid beams are received (1.6 seconds later). The trace of the azimuth flag shows that a good percentage of the azimuth data, from 90 to 105 seconds after separation, is considered invalid. In terms of trajectory,  $t = 90$  seconds



7-1476

Figure 1-E6. Simulation of Azimuth Signal Strength, ALT-3 Trajectory With Ground Reflections

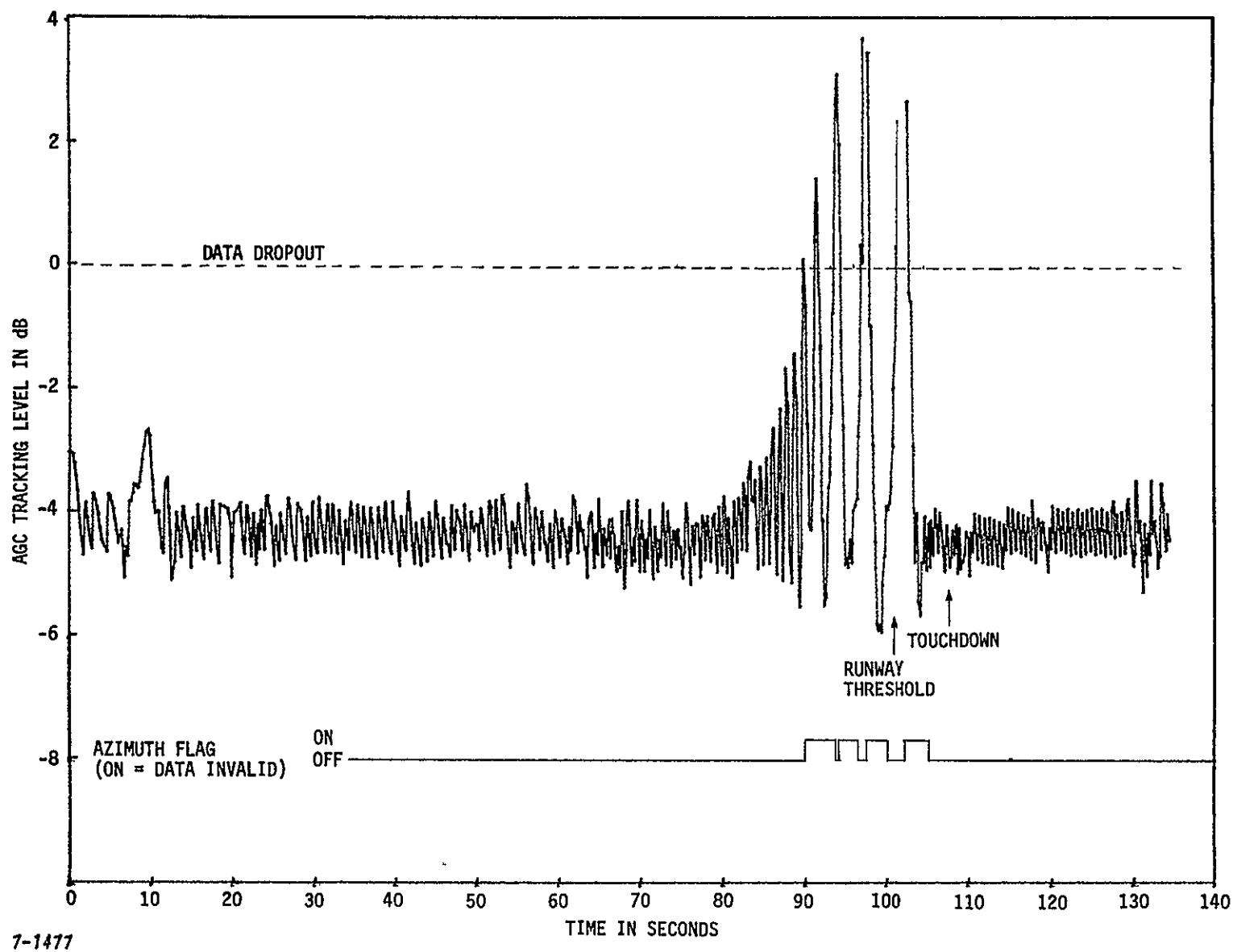


Figure 1-E7. Simulation of Azimuth AGC Tracking Level, ALT-3 Trajectory With Ground Reflections

occurs approximately 4500 feet in front of threshold at an altitude of 290 feet. Data continues to drop out through threshold up to a few seconds prior to touchdown.

DME signal level and tracking threshold for the ALT-3 trajectory is given in Figures 1-E8 and 1-E9. Peak-to-peak excursions of the DME signal level near runway threshold are larger because the ground antenna gain drops off less rapidly than azimuth with decreasing elevation angle. Data dropout for the DME channel, percentagewise, however, appears to be less of a problem. This is because the DME data does not have to wait through eight consecutive valid beams before being considered valid.

Data dropout during the ALT-2 trajectory (azimuth Figures 1-E10 and 1-E11, DME Figures 1-E12 and 1-E13) occurs between 130 and 145 seconds after separation. One hundred and thirty seconds is approximately 6600 feet in front of threshold at an altitude of 300 feet. Data dropout continues up to runway threshold.

#### 1-E6. MINIMIZING DATA DROPOUT DUE TO GROUND REFLECTIONS

Ways of reducing ground reflections have been discussed in AIL Technical Note A980-28 (October 1975). Planting and maintaining vegetation, installation of radiation fences, and grading of the ground in front of the azimuth/DME site have been proposed. For the DFRC site, installation of a radiation fence offers the only feasible solution.

Design of a radiation fence which would effectively block the first five signal nulls is described in AIL Technical Note A980-43 (March, 1977). The note is reprinted in Appendix A. The fence design is a compromise between having a large amount of fence area and avoiding disturbance of the guidance signals.

The simulations of Figures 1-E6 through 1-E13 suggest that minimizing the first five signal nulls should prevent azimuth data dropout. DME dropout due to the 6th and 7th null may still occur, but the amount of invalid data

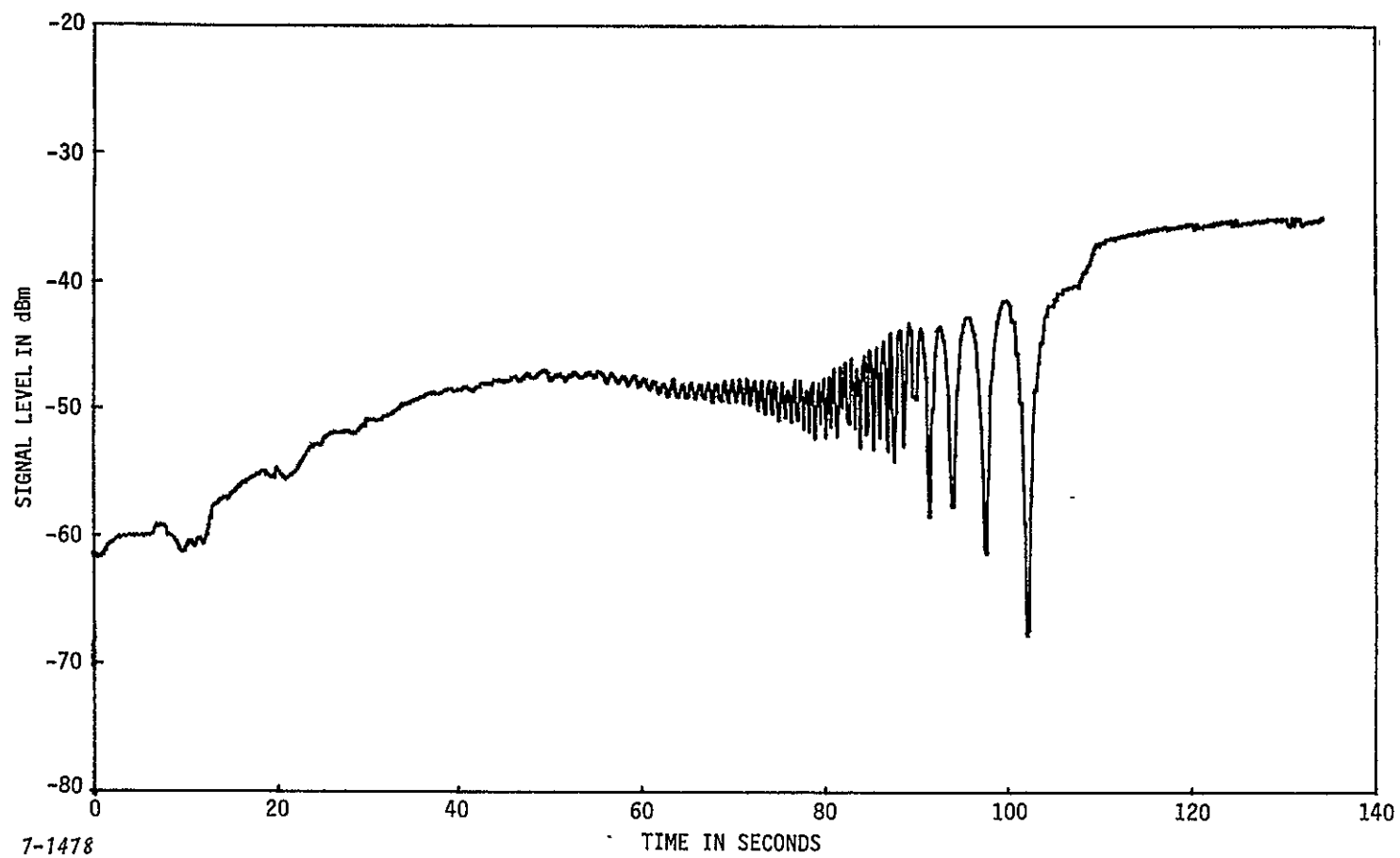


Figure 1-E8. Simulation of DME Signal Strength, ALT-3 Trajectory With Ground Reflections

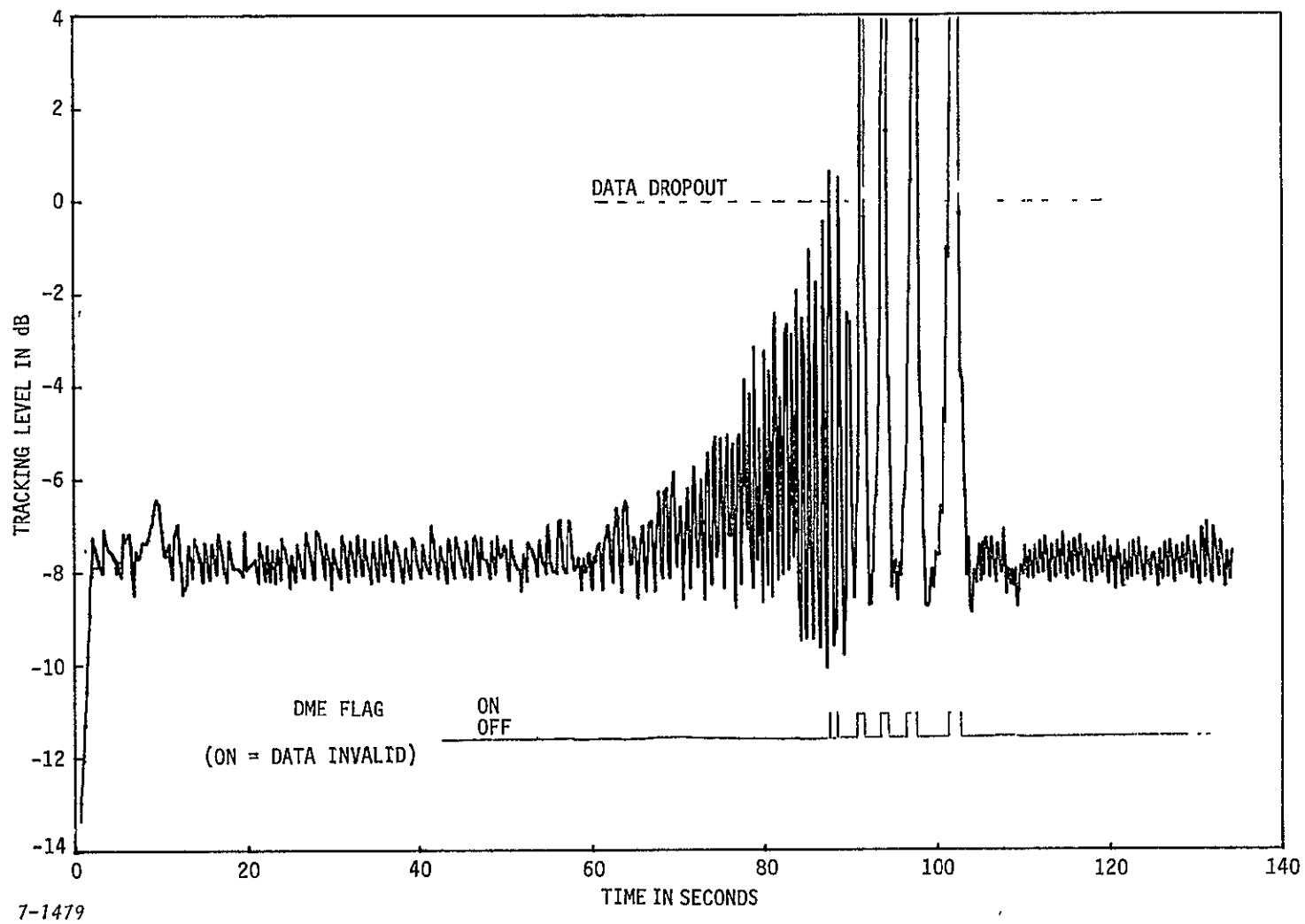


Figure 1-E9. Simulation of DME Tracking Level, ALT-3 Trajectory With Ground Reflections

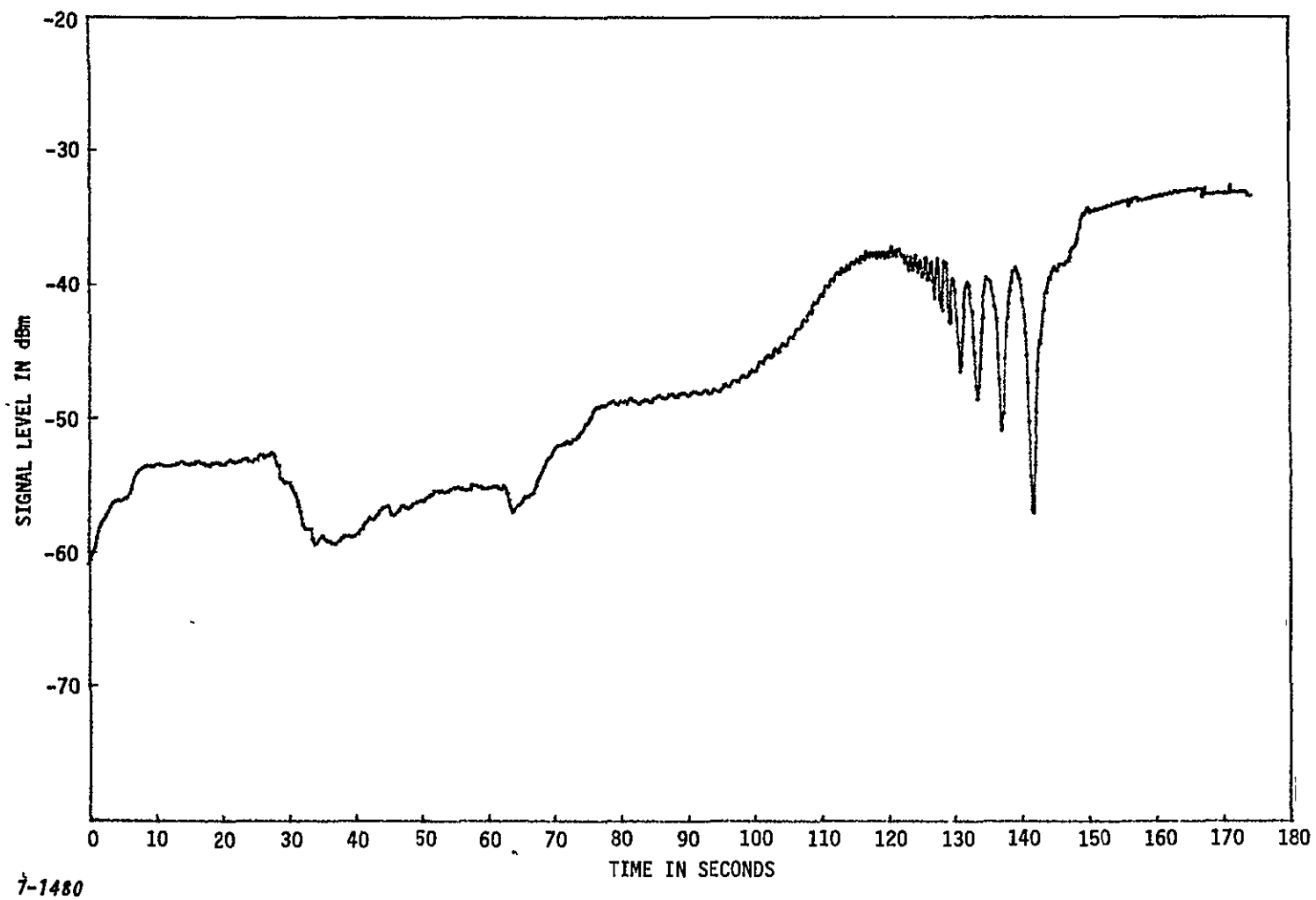


Figure 1-E10. Simulation of Azimuth Signal Strength, ALT-2 Trajectory With Ground Reflections.

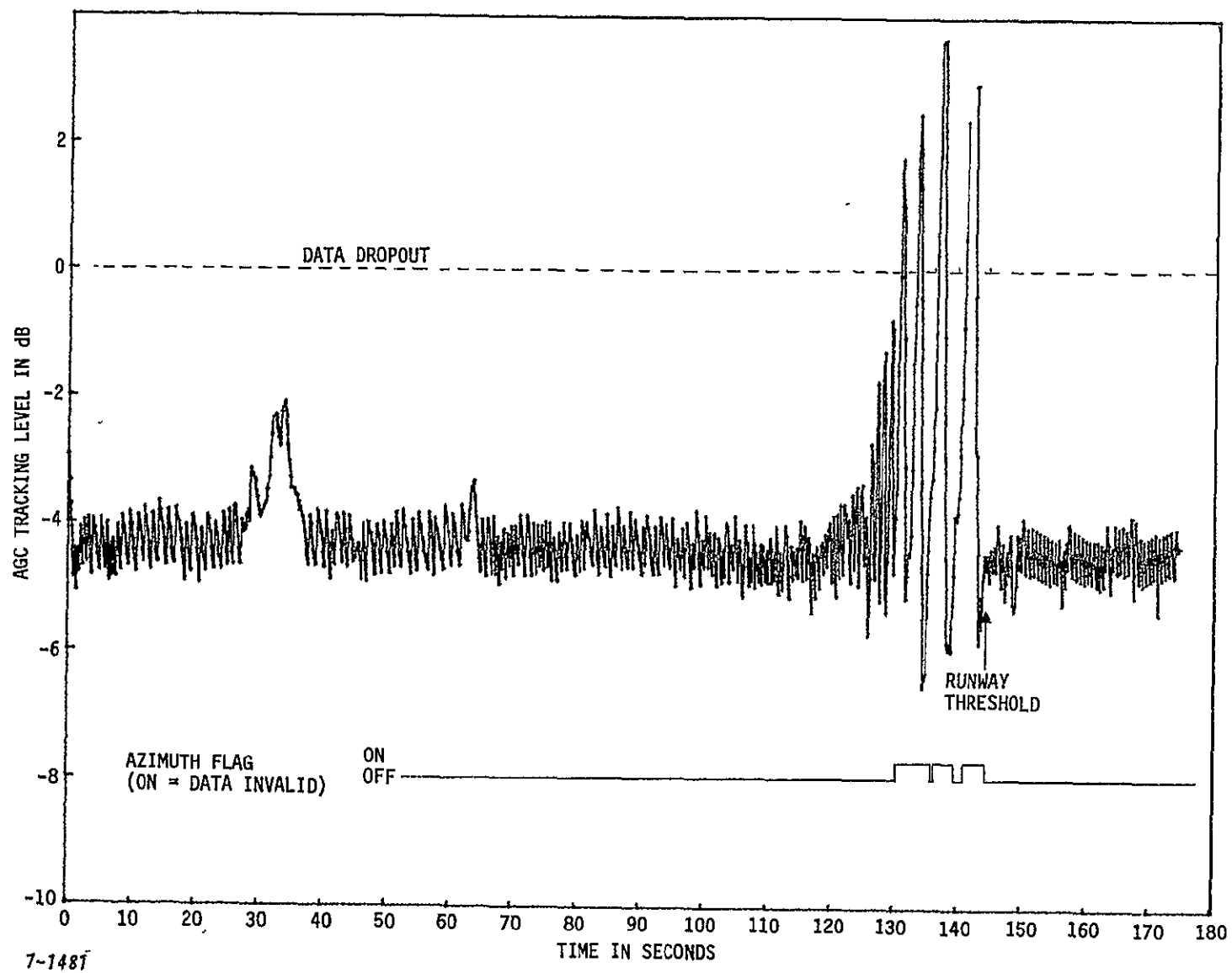


Figure 1-E11. Simulation of Azimuth AGC Tracking Level, ALT-2 Trajectory With Ground Reflections

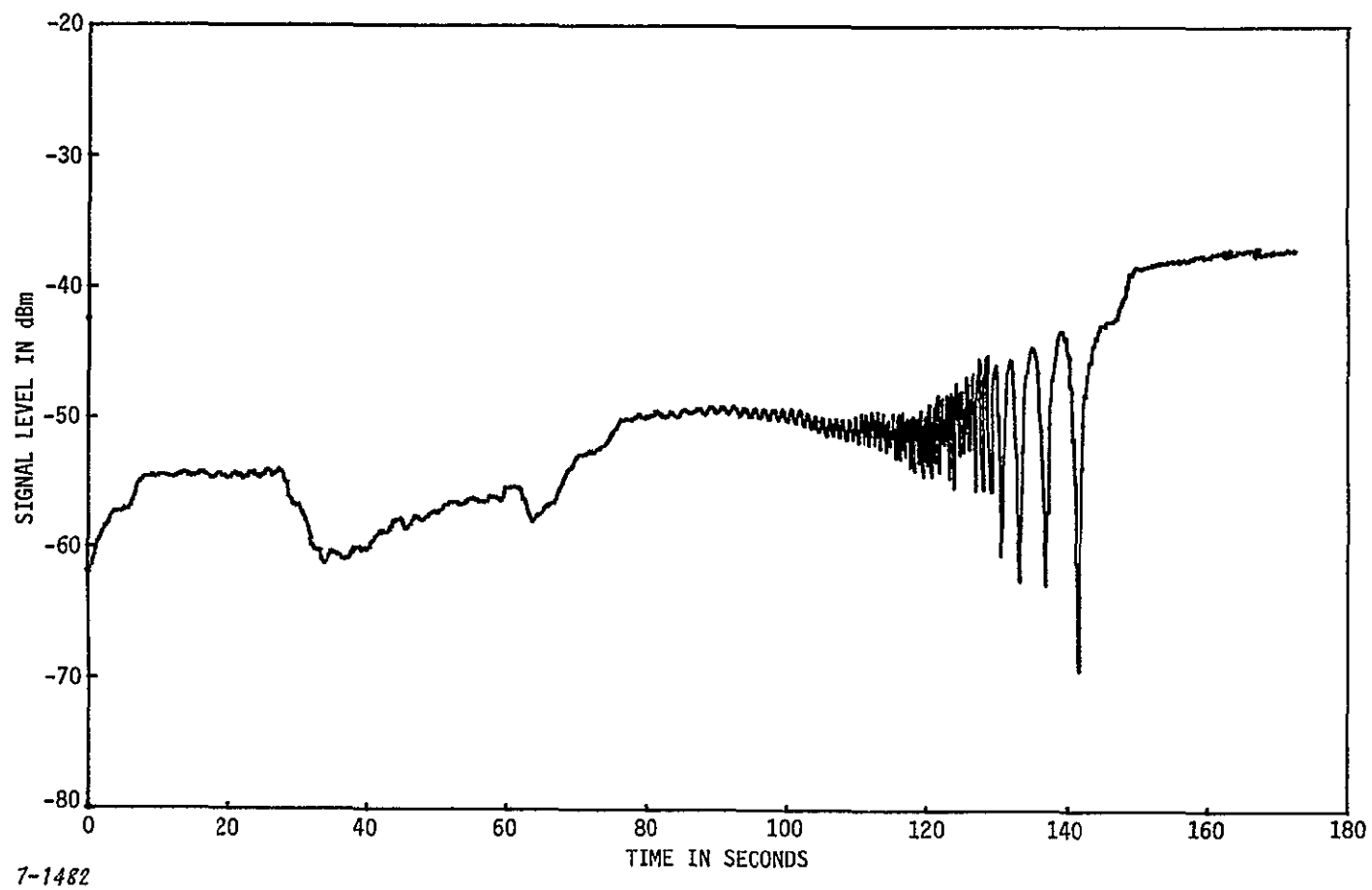


Figure 1-E12. Simulation of DME Signal Strength, ALT-2 Trajectory With Ground Reflections

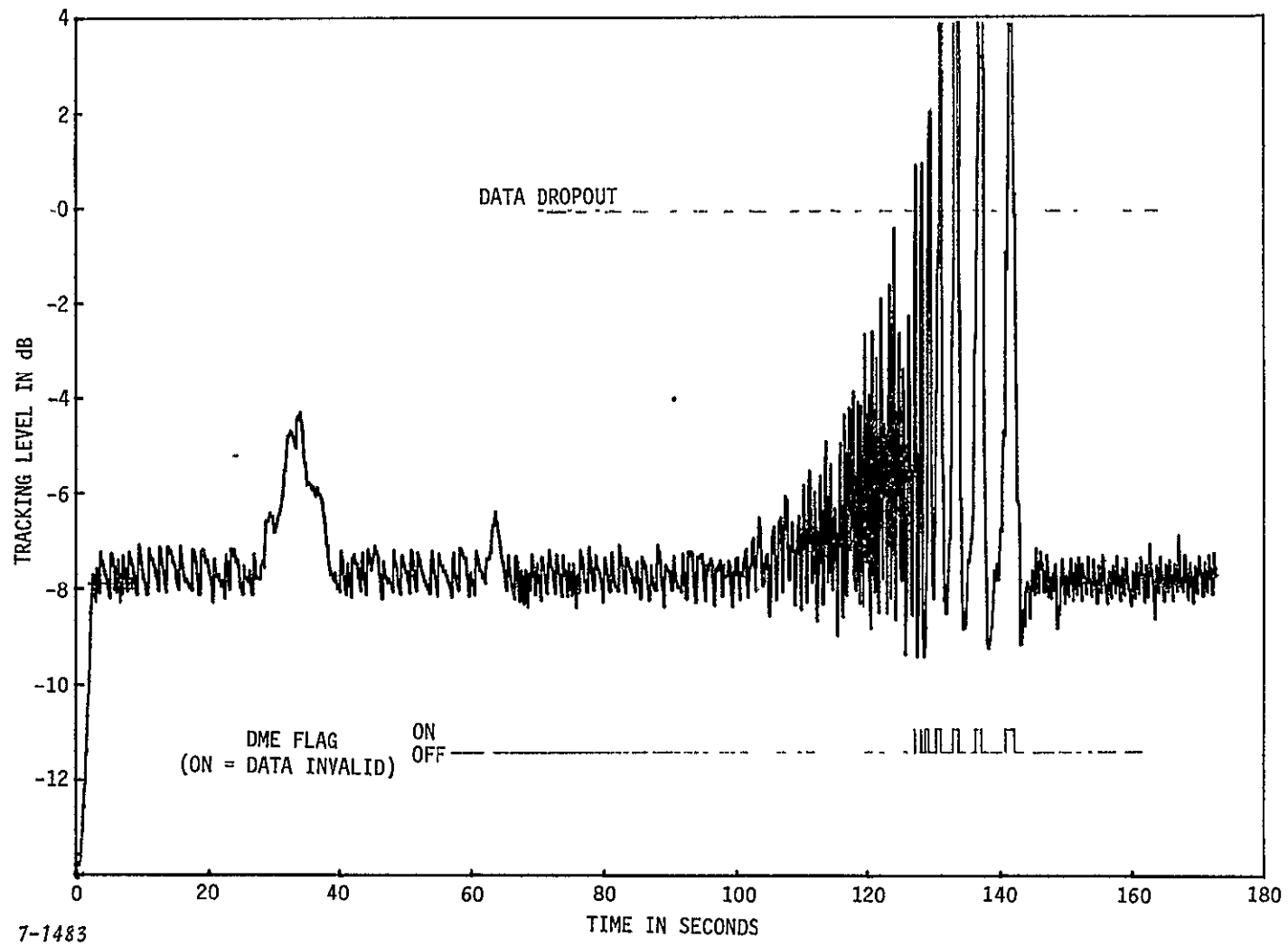


Figure 1-E13. Simulation of DME Tracking Level, ALT-2 Trajectory With Ground Reflections

appears to be small enough not to warrant increasing the height of the fence and thus risking problems with azimuth guidance accuracy.

Relative DME signal power measurements with and without the fence are given in Figures 1-EA1 and 1-EA2 of Appendix A. The measured depth of the first null decreased from 39 dB to 9 dB with the fence in place. The effective reflection coefficient decreased from 1 to 0.48. The effective phase change of the reflected signal changed from 209 to 260 degrees.

The fence represents a complex reflective object which cannot be easily modeled to a high degree of accuracy. The effective reflection coefficient, as well as the effective phase change in the reflected signal, varies with some not very predictable manner. The effect on the lower nulls (first and second) is defined well enough, but the effect at higher elevation angles is open to question.

Figures 1-E14 through 1-E17 repeat the azimuth and DME simulations using a simplified fence model, i.e., reflection coefficient of 0.48 and phase shift of 260 degrees. AGC response to the first two signal nulls is seen to be very much improved. Quantitative conclusions about performance at elevations above the first two nulls should not be drawn from these simulations since the simple fence model does not adequately describe real world conditions. The fence, however, is designed to minimize the first five signal nulls and will have some effect on the higher nulls as well. Qualitatively, at least, installation of the fence will help the situation, although the exact nature of its performance may be somewhat vague.

Static accuracy tests with and without a section of the proposed fence in place are given in MSBLS Engineering Test Summary Report No. AIL 18 (Appendix B). Effect of the fence on azimuth accuracy was judged minimal, although evidence of a disturbance does exist. This again reinforces the requirement for compromise between acceptable data dropout and azimuth system accuracy.

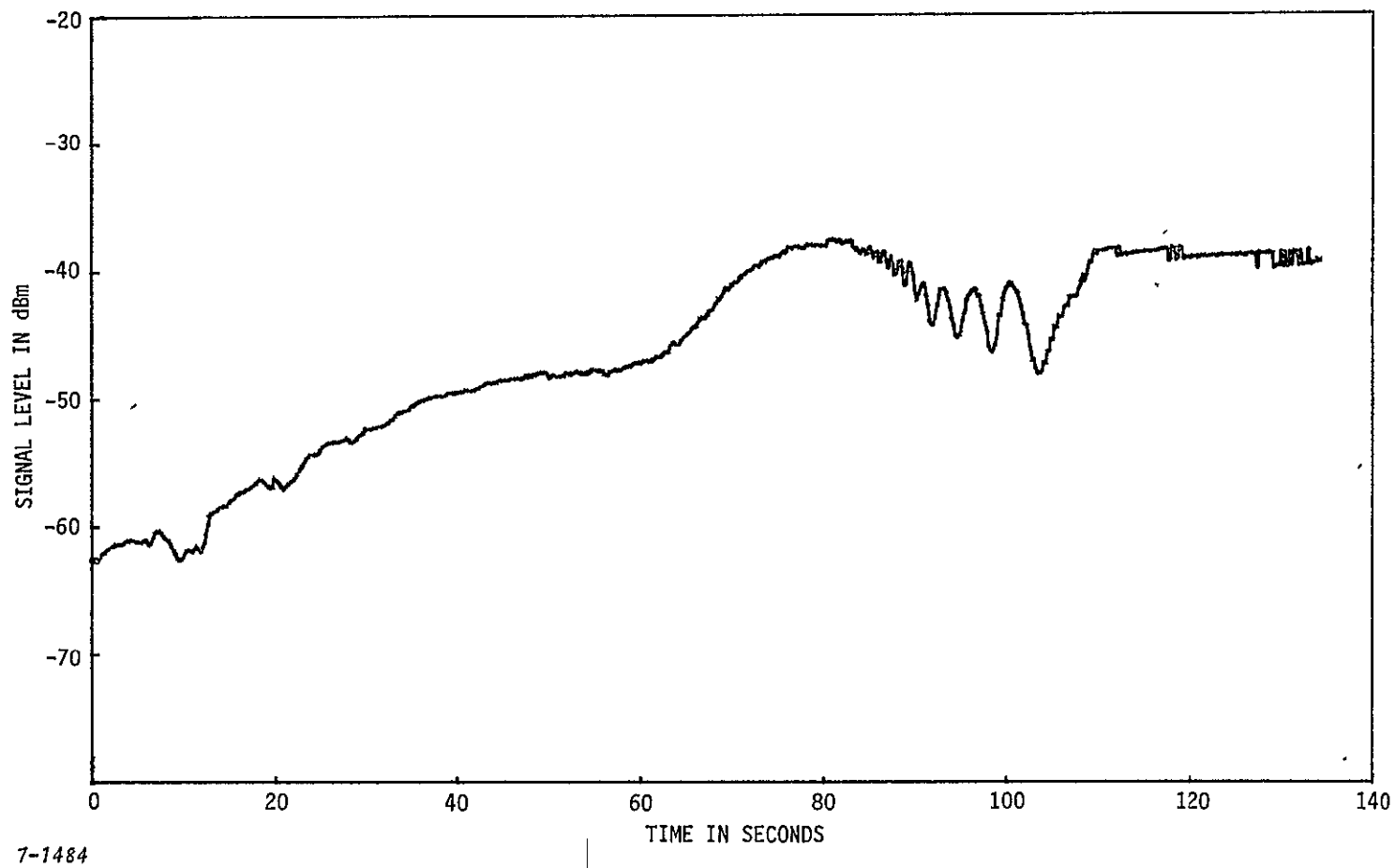
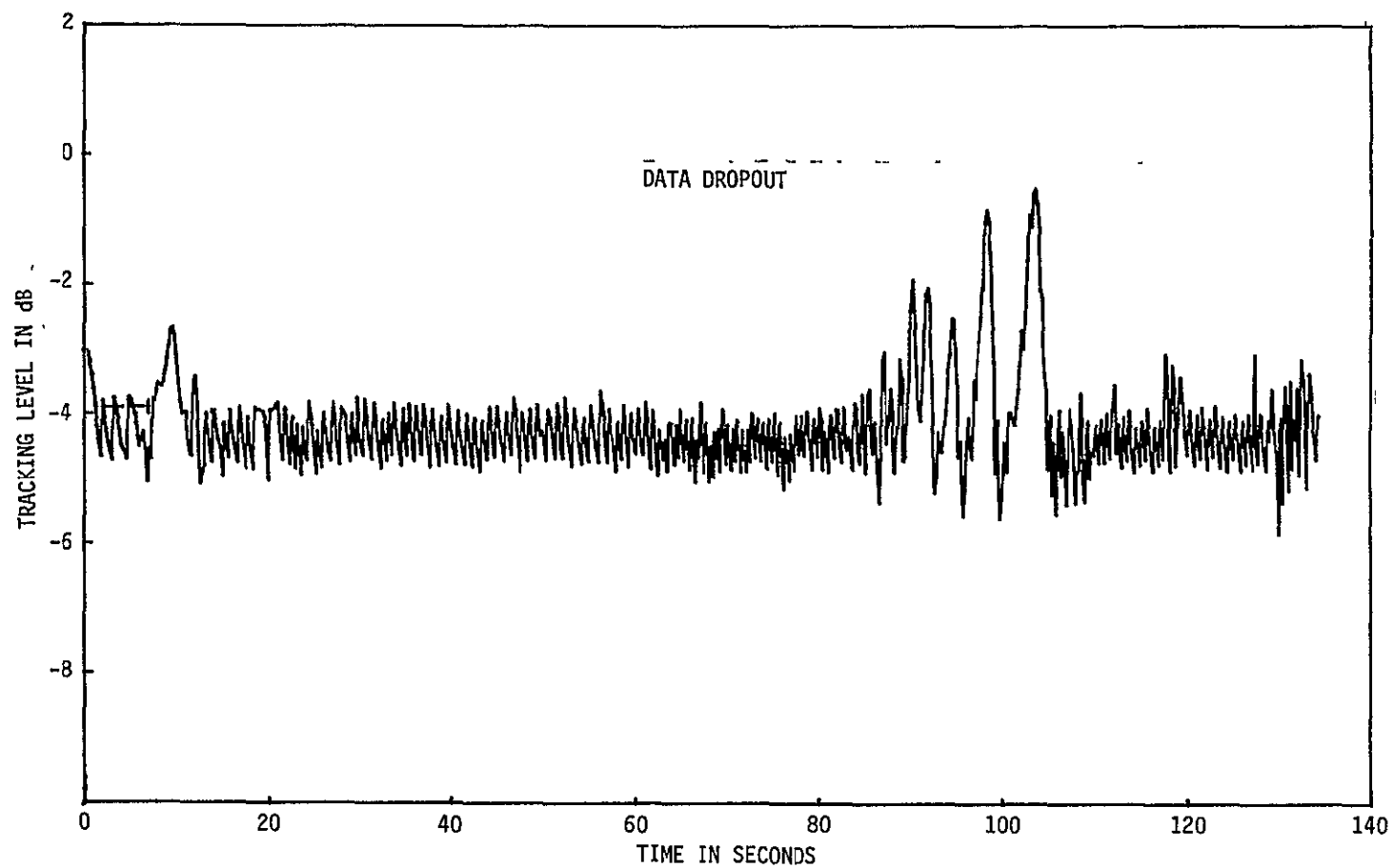


Figure 1-E14. Simulation of Azimuth Signal Strength, ALT-3 Trajectory With Ground Reflections, Simplified Fence Model



7-1485

Figure 1-E15. Simulation of Azimuth AGC Tracking Level ALT-3 Trajectory With Ground Reflections, Simplified Fence Model

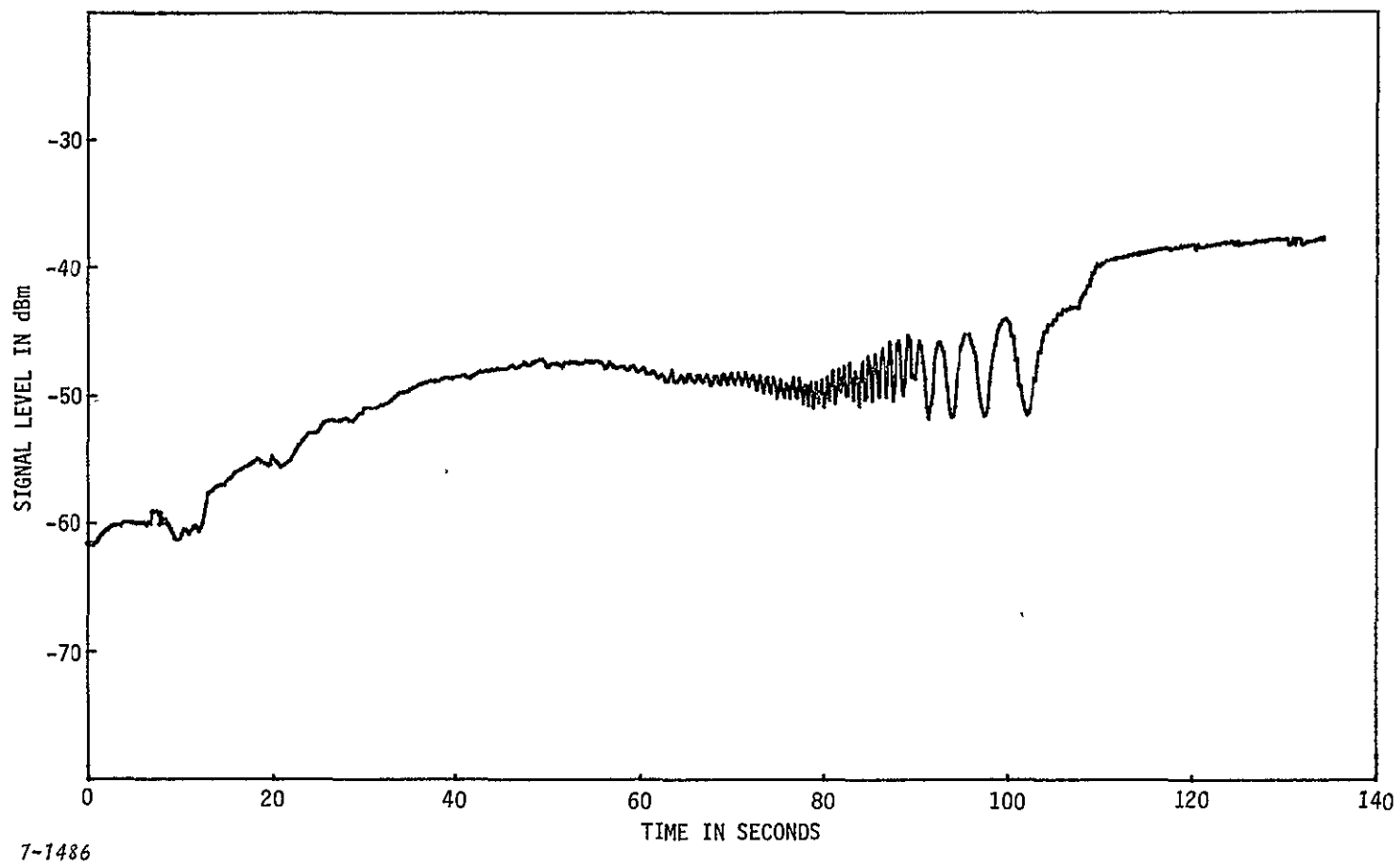


Figure 1-E16. Simulation of DME Signal Strength, ALT-3 Trajectory With Ground Reflections, Simplified Fence Model

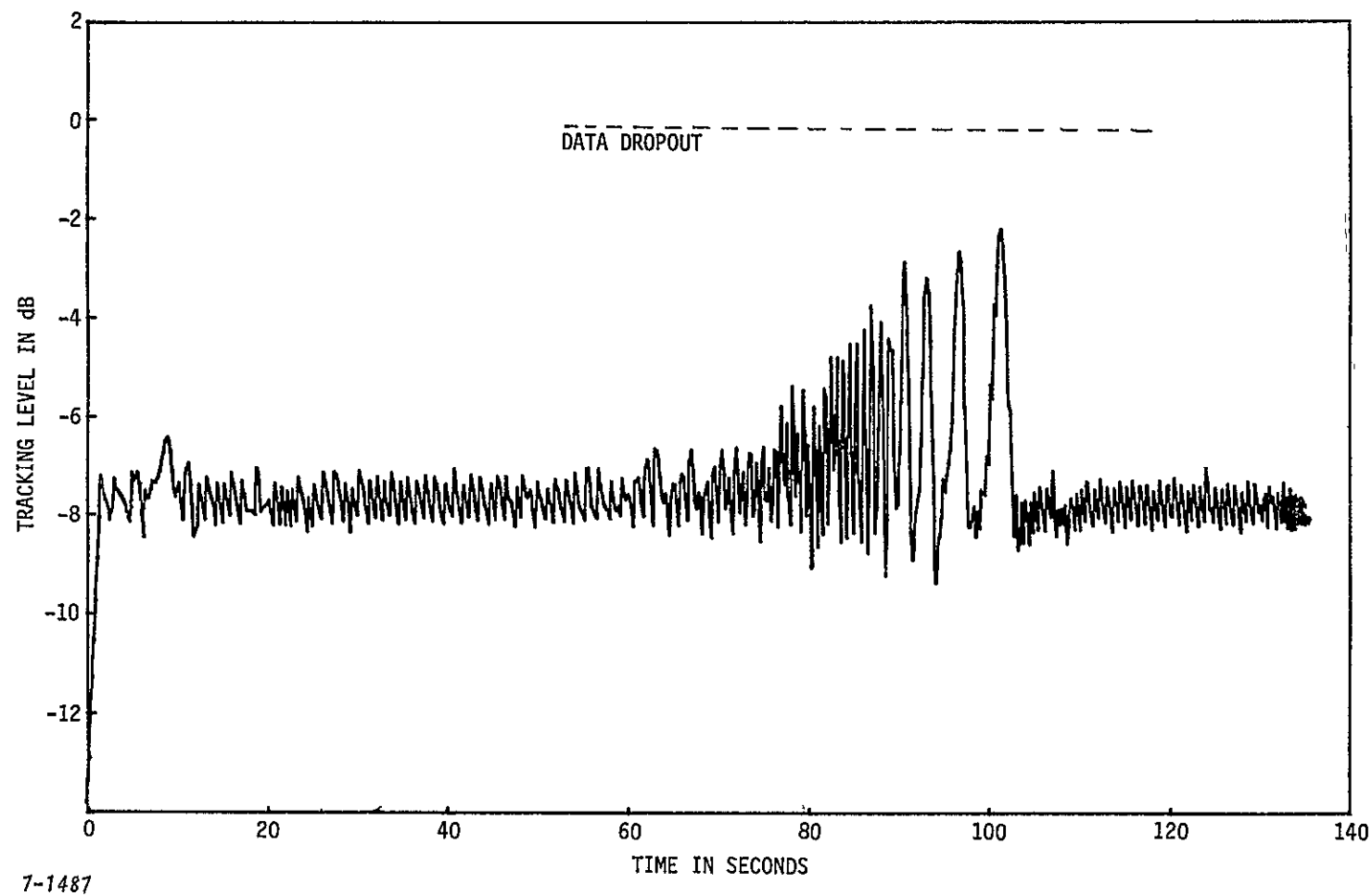


Figure 1-E17. Simulation of DME AGC Tracking Level, ALT-3 Trajectory  
With Ground Reflections, Simplified Fence Model

DME accuracy under dynamic conditions will probably improve with a fence in place, because the large fluctuations of the tracking threshold, which translate into range noise, will quiet down to some extent.

1-E7. REFERENCES

a. D.J. Povejsil et al, Airborne Radar, Principles of Guided Missile Design, Grayson Merrill, ed., D. Van Nostrand and Co., Princeton, N. J. 1961; pp.

b. Evaluation of MSBLS NAVSET AGC Tracking Capability as Function of Received Signal, Technical Report Y220-14, June 1976, A Charych.

c. MSBLS Flight Performance Data Run No. 10, Azimuth ALT-3 Trajectory, December 19, 1975 Run Data.

d. MSBLS Flight Performance Data Run No. 27, Azimuth ALT-2 Trajectory, February, 1976 Run Date.

e. MSBLS Flight Performance Data Run No. 8, DME ALT-3 Trajectory, December, 1975 Run Date.

f. MSBLS Flight Performance Data Run No. 4, DME ALT-2 Trajectory, December, 1975 Run Date.

APPENDIX A

EFFECTS OF GROUND REFLECTIONS ON MSBLS SIGNALS  
AND FENCE REQUIREMENTS FOR THEIR CONTROL

F. BATTLE

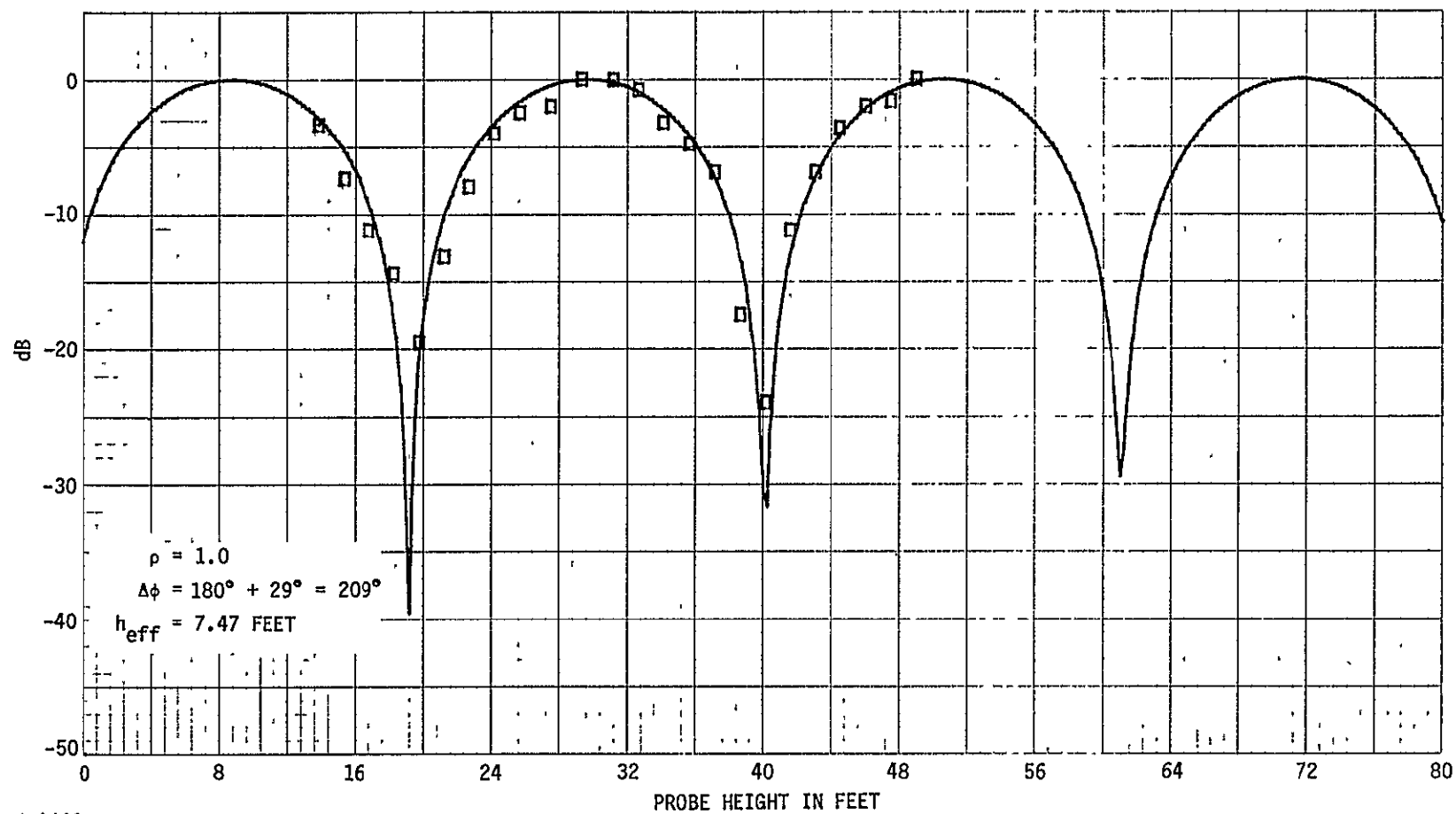
TECHNICAL NOTE A980-43

MARCH 1977

Whenever MSBLS Ground Stations radiate their signals over considerable expanses of smooth and highly reflective ground, significant interference with the desired radiation patterns tend to occur. In particular, the lakebed at Edwards Air Force Base (DFRC) is an extreme example of reflective ground. Also, the ground alongside runway 4-22 at DFRC appears nearly as reflective, since vegetation is sparse and the surface is evenly graded. (The prospect of uncropped grass beside the runway at KSC promises substantial relief at that site.)

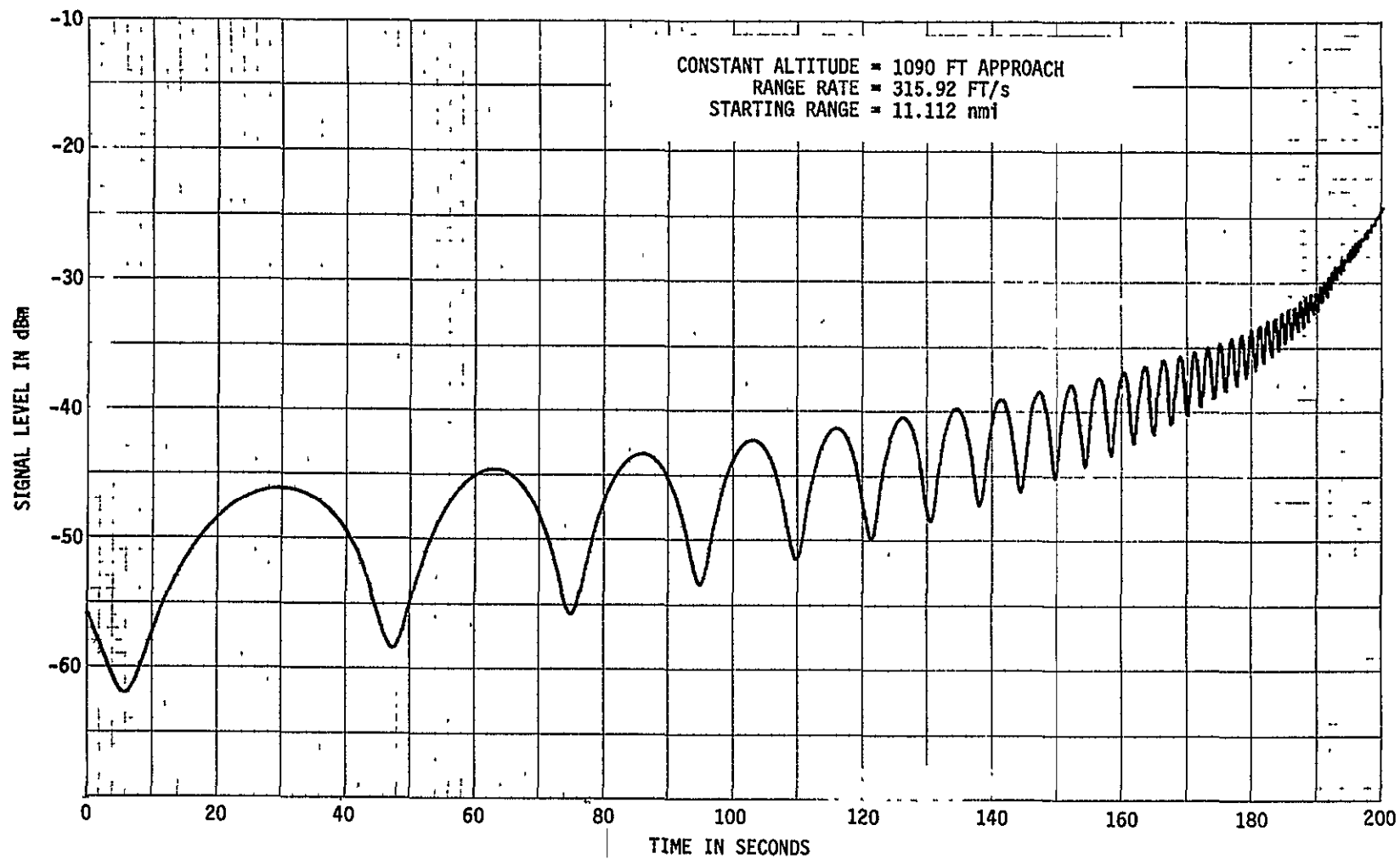
Both theory and test results indicate that corrective measures are required at DFRC. Strong ground reflections of the azimuth and DME signals have been shown to cause a vertically disposed series of alternate reinforcements and partial cancellations of received signal strength (Figure 1-EA1). During approach flights, rather severe fluctuations in signal strength are to be expected, as has been shown by simulations (Figures 1-EA2 and 1-EA3). Unless this effect is reduced, the dynamic response capabilities of the airborne Nav Set will sometimes be exceeded, and an occasional dropout of azimuth and DME guidance data will result. This has been confirmed by flight tests, as reported in Engineering Test Summary Report JSC-39. One example, given in Table 1-EA1 is taken from that report. Although signal dropout is seen to occur for only a small percentage of total approach time, each occurrence may persist for from one to several seconds, with disruptive effects on guidance.

The volumetric region in which these ground lobing effects are likely to cause signal dropout has been estimated by simulation of the AGC response of the Nav Set under typical approach conditions (representative of Orbiter approach trajectories). As illustrated in Figure 1-EA1, the depth of successive nulls in signal strength increases gradually as the height (i.e., vertical angle) of the receiver decreases. This is primarily due to the vertical patterns of the ground-based antennas, which are shaped to minimize



7-1488

Figure 1-EA1. DME Relative Power at 5000 Feet Distance (No Fence, 8-23-76)



7-1473

Figure 1-EA2. DME Signal Level Simulation

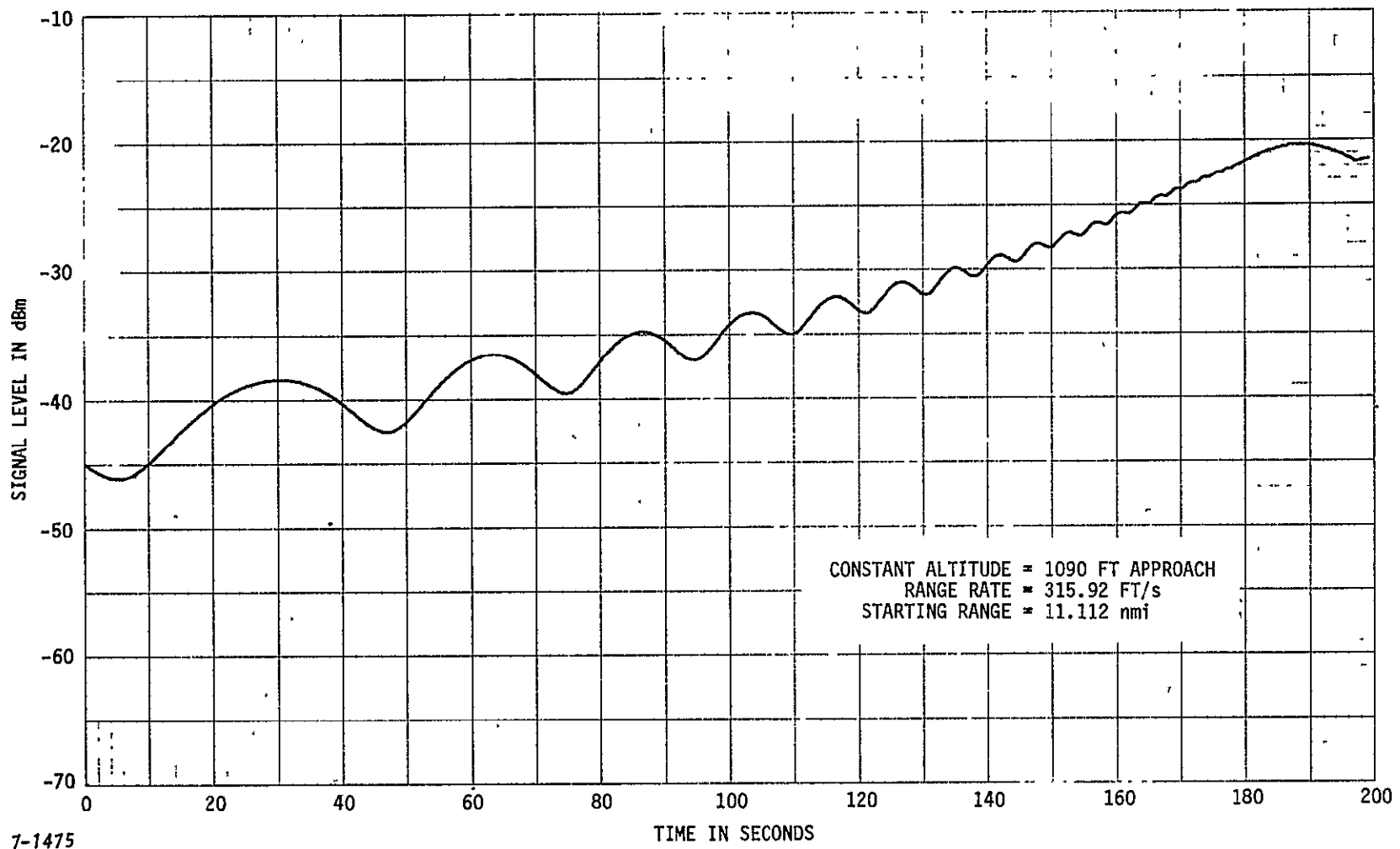


Figure 1-EA3. Azimuth Signal Level Simulation

Table 1-EA1. Periods of Invalid Data Along a 3 Degree Glide Slope  
Approach to Runway 17L at EAFB for Day 229, 1976 (Run 4)

| <u>Time<br/>(min, s)</u> | <u>Azimuth<br/>Valid</u> | <u>Elevation<br/>Valid</u> | <u>Distance<br/>Valid</u> | <u>Azimuth<br/>(Degrees)</u> | <u>Elevation<br/>(Degrees)</u> | <u>Distance<br/>(nm)</u> |
|--------------------------|--------------------------|----------------------------|---------------------------|------------------------------|--------------------------------|--------------------------|
| 21, 23.1                 | yes                      | yes                        | yes                       | 0.578                        | 1.070                          | 7.595                    |
| 22, 14.6                 |                          |                            | no                        | 0.398                        | 1.805                          | 5.585                    |
| 22, 16.0                 |                          |                            | yes                       | 0.430                        | 1.820                          | 5.524                    |
| 23, 19.4                 |                          |                            | no                        | 1.250                        | 3.086                          | 3.063                    |
| 23, 21.2                 |                          |                            | yes                       | 1.187                        | 3.125                          | 2.987                    |
| 23, 27.8                 |                          |                            | no                        | 1.250                        | 3.184                          | 2.742                    |
| 23, 28.2                 | no                       |                            |                           | 1.250                        | 3.176                          | 2.742*                   |
| 23, 28.8                 |                          |                            | yes                       | 1.266                        | 3.141                          | 2.691                    |
| 23, 30.0                 | yes                      |                            |                           | 1.148                        | 3.086                          | 2.641                    |
| 23, 32.8                 | no                       |                            |                           | 1.242                        | 3.008                          | 2.542                    |
| 23, 33.0                 |                          |                            | no                        | 1.242                        | 3.023                          | 2.542                    |
| 23, 34.4                 |                          |                            | yes                       | 1.234                        | 3.113                          | 2.479                    |
| 23, 36.0                 | yes                      |                            |                           | 1.238                        | 3.258                          | 2.405                    |
| 23, 39.0                 | no                       |                            | no                        | 1.340                        | 3.641                          | 2.302                    |
| 23, 39.5                 |                          | no                         |                           | 1.340*                       | 3.820                          | 2.302*                   |
| 23, 40.2                 |                          |                            | yes                       | 1.371                        | 4.125                          | 2.254                    |
| 23, 41.6                 | yes                      |                            |                           | 1.324                        | 4.125*                         | 2.188                    |
| 24, 8.6                  |                          |                            | no                        | 2.512                        | 4.125*                         | 1.227                    |
| 24, 8.8                  | no                       |                            |                           | 2.512                        | 4.125*                         | 1.227*                   |
| 24, 9.2                  |                          |                            | yes                       | 2.605                        | 4.125*                         | 1.186                    |
| 24, 10.6                 | yes                      |                            |                           | 2.750                        | 4.125*                         | 1.126                    |
| 24, 10.9                 | yes                      | no                         | yes                       | 2.750                        | 4.125*                         | 1.123                    |

\*Invalid and unchanging data

the effect down to the lowest practicable angles. The simulations show that the instantaneous signal level and the AGC response should be adequate to avoid either azimuth or DME dropout down to a vertical angle of about 1.5 degrees relative to the azimuth/DME site.

#### NOTE

Some uncertainty exists in this 1.5-degree vertical limit, because of dependence on the airborne antenna pattern and on Orbiter attitude changes, etc. However it is considered a safe estimate, pending further flight test experience.

Since almost identical reflection geometry applies at all azimuth angles (especially on the lakebed), the region of potential signal dropout due to ground lobing extends  $\pm 14$  degrees in azimuth and 0 to 1.5 degrees in vertical angle.

Several possible means of reducing the interference from ground reflections are discussed in Technical Note A980-28, but it appears that a radiation fence is the most feasible choice for DFRC. Criteria for the design of such a fence are discussed in Technical Note A980-40, and are also summarized and extended here. Figure 1-EA4 shows the effectiveness of a single 4 by 12 foot fence section, placed so as to reduce the lobing of Figure 1-EA1.

Figure 1-EA5, taken from Technical Note A980-40, illustrates the vertical situation for the ground reflections of primary operational concern. These reflections are out of phase with directly received signals, thus producing nulls that can cause signal dropout. The particular angles shown are theoretical values based on exactly 180 degrees phase shift due to reflection. Though slightly different angles may apply in practice, these values suffice for a nearly optimum fence design. Also, the precise intersections of such angles with a typical approach trajectory are not critically

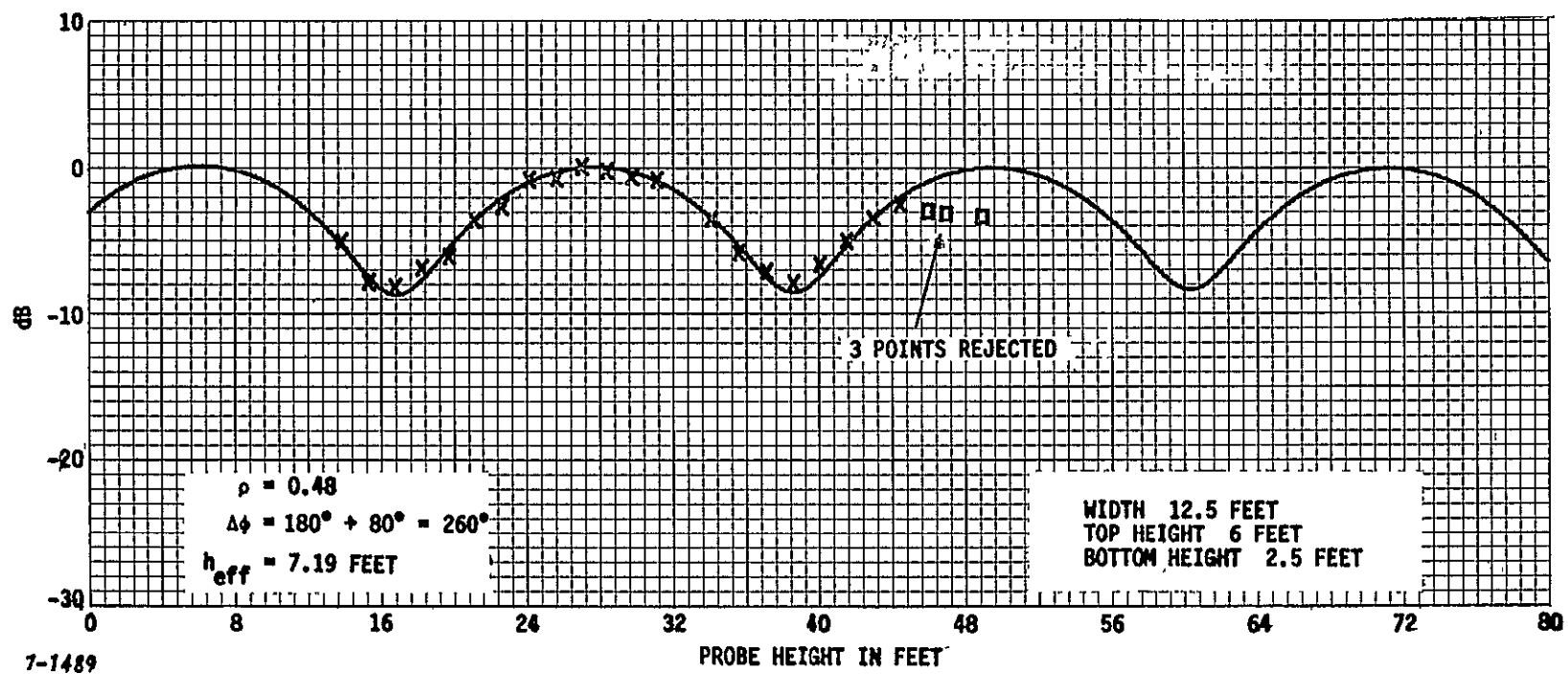
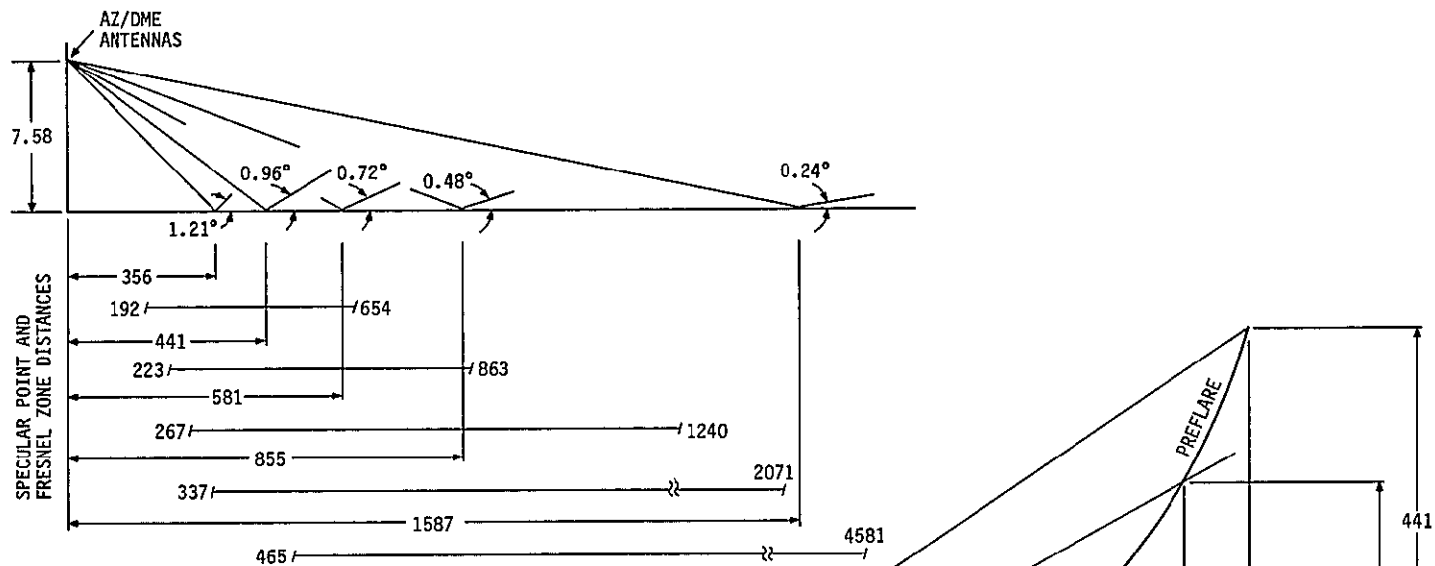
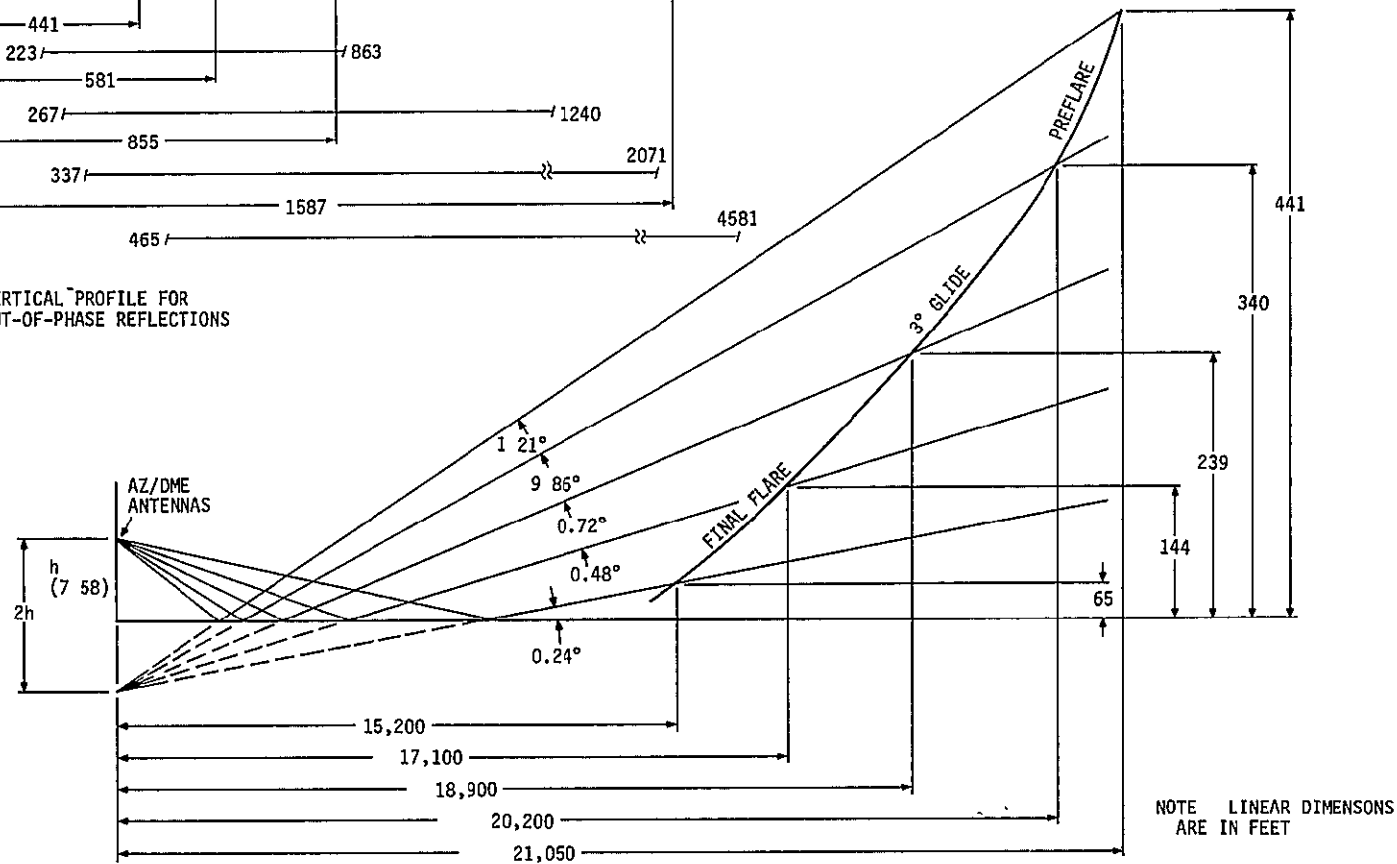


Figure 1-EA4. DME Relative Power at 5000 Feet Distance (Fence at 410 Feet, 8-23-76)



A. VERTICAL PROFILE FOR OUT-OF-PHASE REFLECTIONS



B. PREDICTED SIGNAL NULL LOCATIONS

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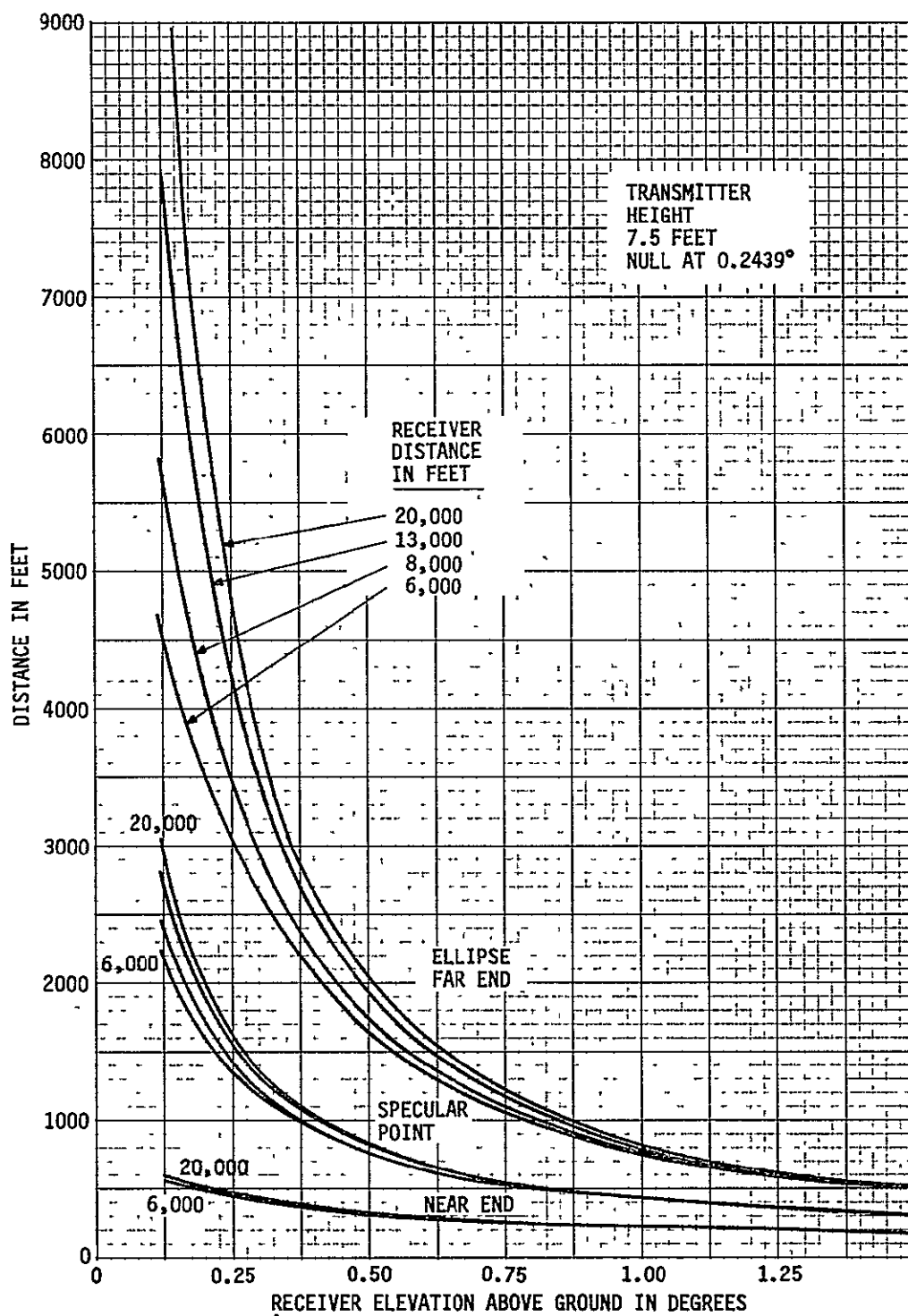
Figure 1-EA5. DFRC Lakebed MSBLS

important. A fence design tailored to these particular assumptions will remain nearly optimum despite slight changes, since it need mask only a major fraction of the first (inner) Fresnel zones in either case.

Any reflection signal that arrives at the receiver is a composite of reflections from a region, rather than a single point, on the reflecting surface, and most of its power is due to reflections from within the zone defined by the first Fresnel ellipse. The extent of this elliptical zone on the ground depends on the transmitter and receiver heights and distances (Figure 1-EA6), and can be calculated separately for each receiver position of interest. Results of such calculations are given in Figure 1-EA5 for the expected out-of-phase reflections below 1.5 degrees. (The widths of all the ellipses are less than 25 feet.) It is concluded that all such out-of-phase reflections would be greatly attenuated by masking a ground region extending from 192 to 4581 feet in front of the ground antennas. However, masking out to only 3200 feet would serve fully for all but the lowest reflection, which itself should also be considerably attenuated. For reasons to be explained, this compromise has been proposed.

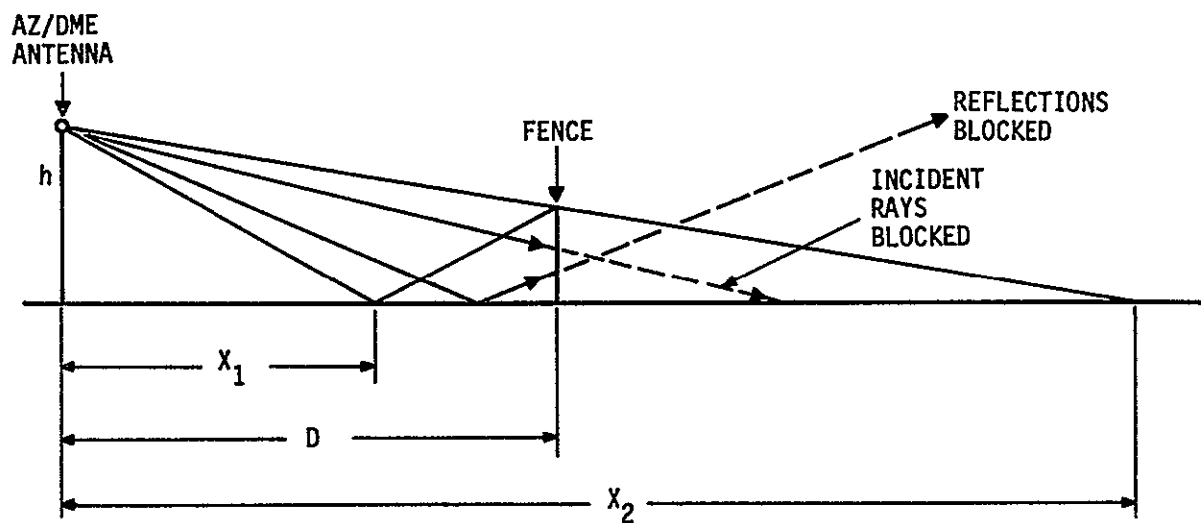
Figure 1-EA7 (from Technical Note A980-40) gives formulas for a fence distance and height that should block ground reflections between two specified distances. (Refraction over the fence is neglected, since complete blockage is not required.) For the compromise case just described, the fence should be about 360 feet in front of the azimuth/DME antennas, and 6.72 feet in height above ground. In order to protect the  $\pm 14$ -degree sector, its minimum length should be 176 feet. However, for avoidance of edge effects, it should extend about 1.5 azimuth beam widths further on each side, and the two end sections should taper downward. Hence, a total length of 230 feet has been proposed.

It is evident that a closer and slightly taller fence than illustrated in Figure 1-EA7 would also block the same reflections, and would have the



7-1491

Figure 1-EA6. Fresnel Ellipse, Inner Zone on Ground Plane



$$\text{FENCE DISTANCE } D = \frac{2X_1 X_2}{X_1 + X_2}$$

$$\text{FENCE HEIGHT } Z = h(1 - D/X_2)$$

FOR  $h = 7.58$ ,  $X_1 = 192$ ,  $X_2 = 3200$ ;  $D = 362$ ;  $Z = 6.72$

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Figure 1-EA7. Fence Blocking Reflection Zone  $X_1$  to  $X_2$

apparent advantage of requiring less length to protect the azimuth sector. However, this is not recommended because of the increased risk that diffraction effects would significantly disturb the direct-path guidance signals (especially azimuth beam signals).

A criterion to determine whether the upper edge of the fence is far enough from a radio line of sight to avoid any significant disturbance is to have at least one-half wavelength greater path length (1) to the fence, than (2) along the line of sight to the point over the fence. This turns out to require a displacement of the fence by at least  $\sqrt{\lambda R}$ , approximately, where  $\lambda$  is the wavelength (1/16 foot) and  $R$  is the distance to the fence. In terms of vertical angle, the fence should be at least  $\arctan \sqrt{\frac{\lambda}{R}}$  below the line of sight.

The MSBLS azimuth and DME signals are needed for rollout guidance on the runway, so that the radio line of sight will be as low as about 0.06 degree relative to the ground antennas. Therefore, ideally, the fence edge should be at least  $\arctan \sqrt{\frac{\lambda}{R}} - 0.06$  degree below the antennas. At the recommended fence distance of 360 feet, then, the fence height should not exceed 2.21 feet. Evidently, the calculated fence height requirement conflicts with this criterion, and provides no guarantee against disturbances that might cause guidance errors.

In recognition of the fact just stated, a test was made at DFRC see ETSR AIL-18) to determine whether a section of fence 6 feet high and 360 feet distant would cause significant azimuth or DME errors at low angles of measurement. Although the effects of the fence were judged tolerable, they were definitely in evidence. Since the placement of a sufficiently high fence even closer than 360 feet would be expected to increase these disturbance effects, that does not appear advisable.

## APPENDIX B

### MSBLS ENGINEERING TEST SUMMARY REPORT

REPORT NUMBER: AIL 18

MSBLS-GS SERIAL NUMBER: 002

FLIGHT/GROUND TEST: GROUND

LOCATION: DFRC

CHANNEL: 1

PRIMARY/BACKUP CONFIGURATION: PRIMARY

DATE OF TEST: FEBRUARY 10 TO 14, 1977

TEST TITLE: EFFECTS OF RADIATION FENCE ON AZIMUTH  
AND DME ACCURACY

#### 1-EB1. PURPOSE OF TEST

The purpose of this test is to evaluate possible azimuth and DME errors in distant, low-altitude regions, due to diffractive interference or multipath arising from a fence structure.

#### 1-EB2. TEST CONFIGURATION (FIGURE 1-EB1)

The two ground stations (with elevation inactive) were side by side, on the edge of, and facing, the dry lakebed, which was flat and empty except for the fence section and the test instrumentation van. (The field monitor poles were not raised.) All dimensions were as shown, except that the angle between fence and ground was about 47 degrees and the fence height was 6 feet. The fence material was hardware cloth with 3/16-inch mesh size.

#### 1-EB3. DESCRIPTION OF PROCEDURE

At each of two distances (5000 and 12,000 feet), and at four lateral locations each, the Nav set receiver was raised to seven successive heights about 6 feet apart. At each height, samples of 100 azimuth and 100 DME readings were recorded without moving the receiver. This was repeated with the fence both raised and laid flat on the ground (Table 1-EB1).

#### 1-EB4. RESULTS

Figures 1-EB2 and 1-EB3 show the variations, as functions of receiver azimuth and elevation angles, of mean azimuth error, defined as deviation of a 100-reading mean azimuth value from the overall mean of all azimuth readings taken (at one van location) with the fence down. These nominal azimuth references are arbitrary, so that the absolute value of each plotted error is unconfirmed. However, the variations with elevation and the differences between the two fence conditions are clearly shown.

Note that 20 dB attenuation was inserted at the receiver, so that all measurements were under weak-signal conditions and did not typify performance at 5000 and 12,000 feet.

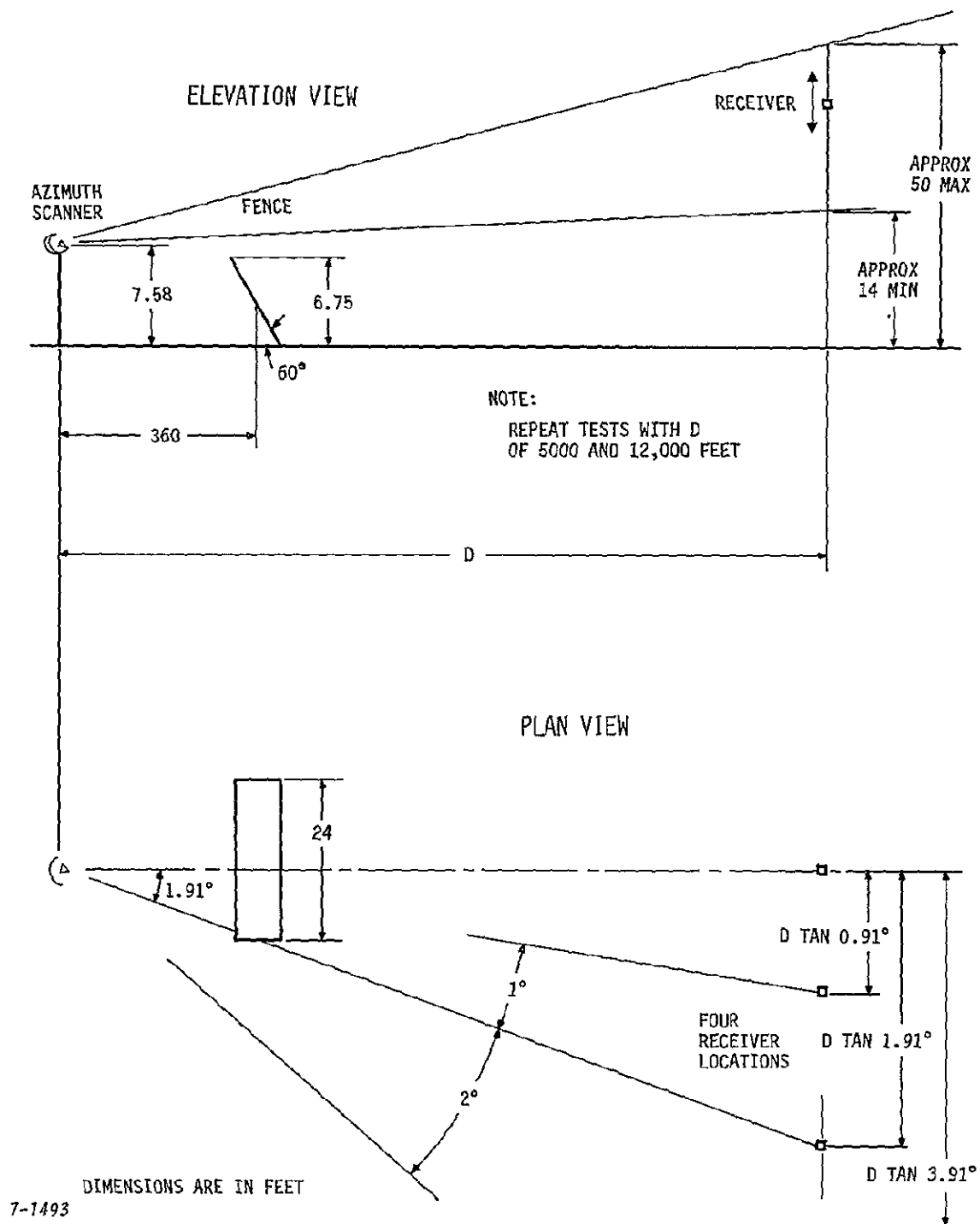
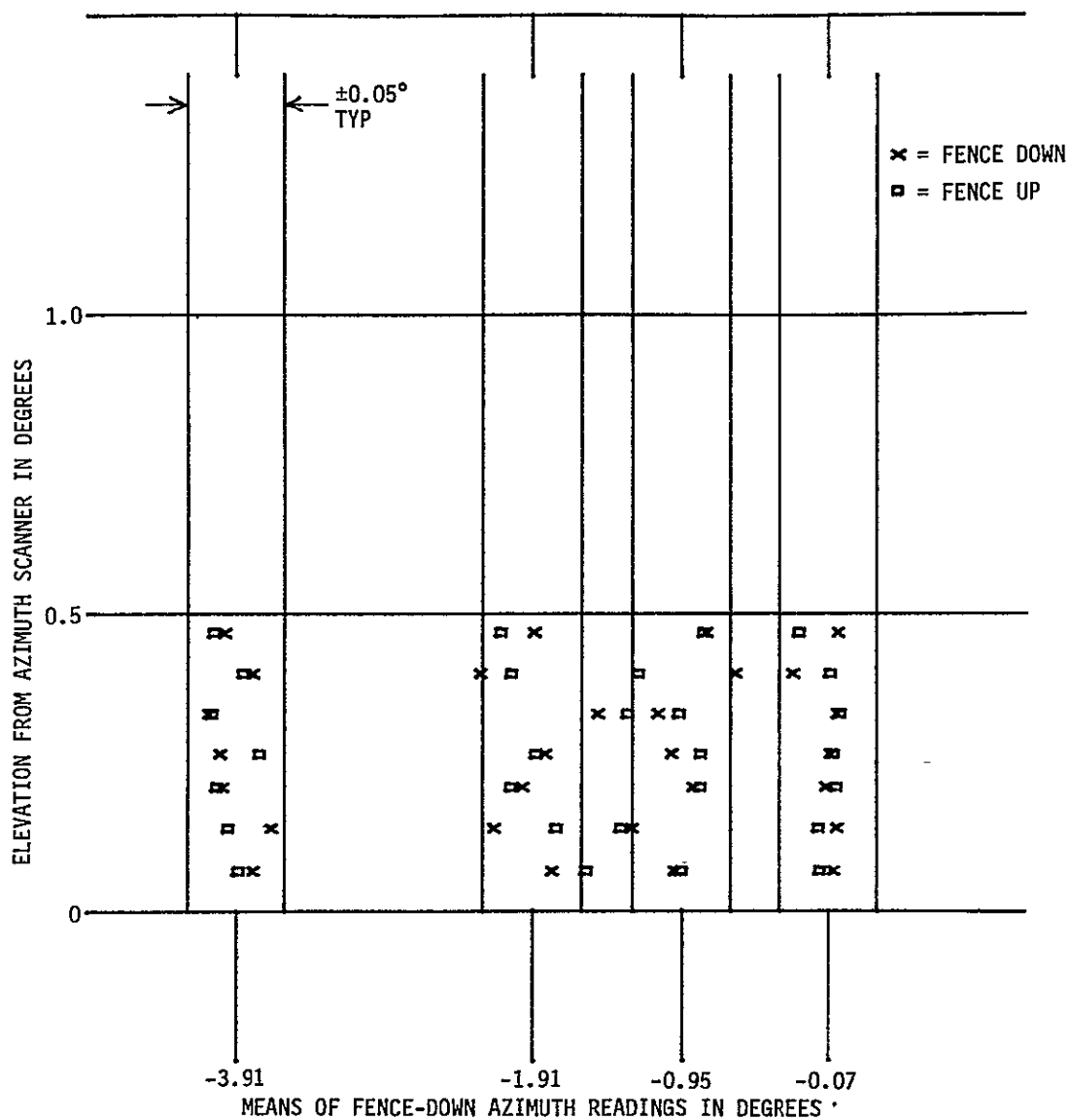
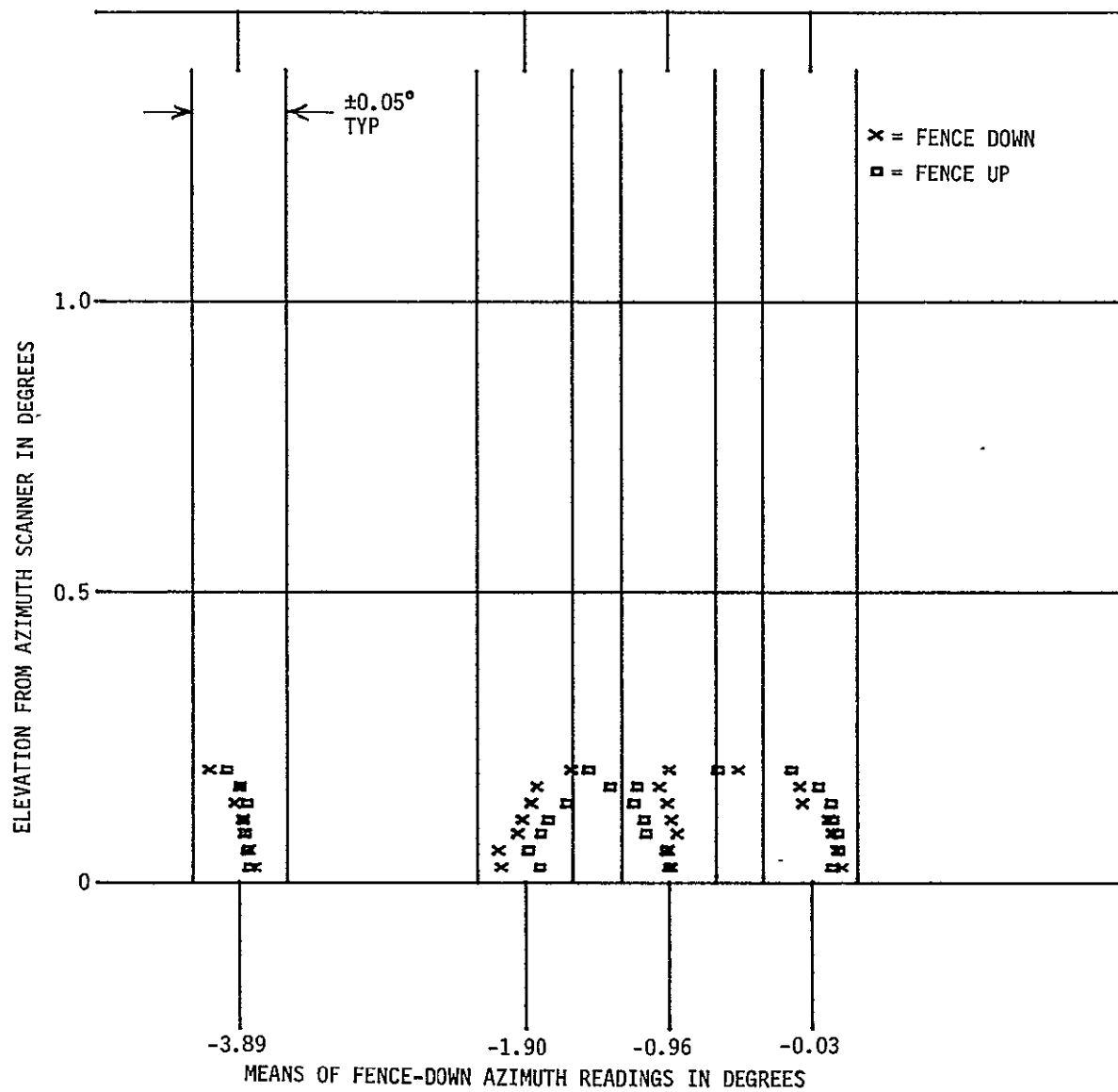


Figure 1-EB1. Fence Test Layout



7-1494

Figure 1-EB2. Deviations of Azimuth Readings at 5000 Feet



7-1495

Figure 1-EB3. Deviation of Azimuth Readings at 1200 Feet

Table 1-EB1. Fence Tests (S/N 002, 20 dB Coupler in Nav Set)

| Day        | Run | Data<br>Tape | Data<br>Cassette<br>File | Azimuth<br>Angle | Azimuth<br>Sigma | DME<br>Sigma | DME<br>(Feet) | Tower<br>Reference<br>Height | Comments          |
|------------|-----|--------------|--------------------------|------------------|------------------|--------------|---------------|------------------------------|-------------------|
| 10 Feb '77 | 1   | 1            | 1-2-3                    | -0.0602          | 0.0203           | 11.3         | 5004.9        | 0                            | Fence Down 3 P.M. |
| 10 Feb '77 | 2   | 1            | 4-5-6                    | -0.0743          | 0.0221           | 10.4         | 5004.1        | 0                            | Up                |
| 10 Feb '77 | 3   | 1            | 7-8-9                    | -0.0759          | 0.0247           | 12.1         | 5008.1        | 1                            | Up                |
| 10 Feb '77 | 4   | 1            | 10-11-12                 | -0.0568          | 0.0228           | 12.7         | 5036.5        | 1                            | Down              |
| 10 Feb '77 | 5   | 1            | 13-14-15                 | -0.0679          | 0.0223           | 11.2         | 5001.9        | 2                            | Down              |
| 10 Feb '77 | 6   | 1            | 16-17-18                 | -0.0579          | 0.0232           | 13.2         | 5003.9        | 2                            | Up                |
| 10 Feb '77 | 7   | 1            | 19-20-21                 | -0.0607          | 0.0222           | 10.3         | 5002.7        | 3                            | Up                |
| 10 Feb '77 | 8   | 1            | 22-23-24                 | -0.0633          | 0.0227           | 10.7         | 5000.6        | 3                            | Down              |
| 10 Feb '77 | 9   | 1            | 25-26-27                 | -0.0563          | 0.0216           | 11.5         | 5006.9        | 4                            | Down              |
| 10 Feb '77 | 10  | 1            | 28-29-30                 | -0.0538          | 0.0202           | 12.6         | 5006.5        | 4                            | Up                |
| 10 Feb '77 | 11  | 1            | 31-32-33                 | -0.0637          | 0.0228           | 11.8         | 5005.4        | 5                            | Up                |
| 10 Feb '77 | 12  | 1            | 34-35-36                 | -0.1007          | 0.0238           | 13.3         | 5008.9        | 5                            | Down              |
| 10 Feb '77 | 13  | 1            | 37-38-39                 | -0.0555          | 0.0259           | 12.0         | 5000.6        | 6                            | Down              |
| 10 Feb '77 | 14  | 1            | 40-41-42                 | -0.0951          | 0.0213           | 13.2         | 5002.9        | 6                            | Up                |
| 11 Feb '77 | 1   | 1            | 43-44-45                 | -0.9549          | 0.0255           | 11.6         | 5009.5        | 0                            | Up 9:10 A.M.      |
| 11 Feb '77 | 2   | 1            | 46-47-48                 | -0.9611          | 0.0211           | 11.1         | 5009.3        | 0                            | Down              |
| 11 Feb '77 | 3   | 1            | 49-50-51                 | -1.0042          | 0.0240           | 12.2         | 5047.4        | 1                            | Down              |
| 11 Feb '77 | 4   | 1            | 52-53-54                 | -1.0972          | 0.0224           | 13.0         | 5017.6        | 1                            | Up                |
| 11 Feb '77 | 5   | 1            | 55-56-57                 | -0.9352          | 0.0241           | 11.8         | 5009.5        | 2                            | Up                |
| 11 Feb '77 | 6   | 1            | 58-59-60                 | -1.0153          | 0.0228           | 13.0         | 5019.6        | 1                            | Up Repeat of 4    |
| 11 Feb '77 | 7   | 1            | 61-62-63                 | -0.9418          | 0.0238           | 11.1         | 5010.1        | 2                            | Down              |
| 11 Feb '77 | 8   | 1            | 64-65-66                 | -0.9639          | 0.0208           | 11.8         | 5007.2        | 3                            | Down              |
| 11 Feb '77 | 9   | 1            | 67-68-69                 | -0.9346          | 0.0228           | 11.8         | 5008.5        | 3                            | Up                |

Table 1-EB1. Fence Tests (S/N 002, 20 dB Coupler in Nav Set) (cont)

| Day        | Run | Data<br>Tape | Data<br>Cassette<br>File | Azimuth<br>Angle | Azimuth<br>Sigma | DME<br>Sigma | DME<br>(Feet) | Tower<br>Reference<br>Height | Comments        |
|------------|-----|--------------|--------------------------|------------------|------------------|--------------|---------------|------------------------------|-----------------|
| 11 Feb '77 | 10  | 1            | 70-71-72                 | -0.9568          | 0.0225           | 12.0         | 5010.9        | 4                            | Up              |
| 11 Feb '77 | 11  | 1            | 73-74-75                 | -0.9780          | 0.0215           | 11.8         | 5013.0        | 4                            | Down            |
| 11 Feb '77 | 12  | 2            | 1-2-3                    | -0.8988          | 0.0260           | 12.0         | 5015.0        | 5                            | Down            |
| 11 Feb '77 | 13  | 2            | 4-5-6                    | -0.9977          | 0.0245           | 11.4         | 5012.5        | 5                            | Up              |
| 11 Feb '77 | 14  | 2            | 7-8-9                    | -0.9979          | 0.0222           | 11.4         | 5014.2        | 5                            | Up Repeat 13    |
| 11 Feb '77 | 15  | 2            | 10-11-12                 | -0.9314          | 0.0237           | 13.4         | 5012.2        | 6                            | Up              |
| 11 Feb '77 | 16  | 2            | 13-14-15                 | -0.9280          | 0.0229           | 11.9         | 5005.2        | 6                            | Down 10:45 A.M. |
| 11 Feb '77 | 17  | 2            | 16-17-18                 | -1.8941          | 0.0161           | 11.1         | 5013.2        | 0                            | Down 12:36 P.M. |
| 11 Feb '77 | 18  | 2            | 19-20-21                 | -1.8601          | 0.0161           | 12.2         | 5010.7        | 0                            | Up              |
| 11 Feb '77 | 19  | 2            | 22-23-24                 | -1.8902          | 0.0215           | 12.0         | 5027.3        | 1                            | Up              |
| 11 Feb '77 | 20  | 2            | 25-26-27                 | -1.9522          | 0.0238           | 13.8         | 5039.4        | 1                            | Down            |
| 11 Feb '77 | 21  | 2            | 28-29-30                 | -1.9239          | 0.0165           | 12.1         | 5009.9        | 2                            | Down            |
| 11 Feb '77 | 22  | 2            | 31-32-33                 | -1.9355          | 0.0190           | 10.6         | 5009.6        | 2                            | Up              |
| 11 Feb '77 | 23  | 2            | 24-35-36                 | -1.9106          | 0.0196           | 13.1         | 5010.7        | 3                            | Up              |
| 11 Feb '77 | 24  | 2            | 37-38-39                 | -1.9009          | 0.0179           | 11.6         | 5008.7        | 3                            | Down            |
| 11 Feb '77 | 25  | 2            | 40-41-42                 | -1.8467          | 0.0199           | 11.8         | 5016.5        | 4                            | Down            |
| 11 Feb '77 | 26  | 2            | 43-44-45                 | -1.8477          | 0.0196           | 11.0         | 5015.3        | 4                            | Down Repeat 25  |
| 11 Feb '77 | 27  | 2            | 46-47-48                 | -1.8188          | 0.0185           | 12.1         | 5014.5        | 4                            | Up              |
| 11 Feb '77 | 28  | 2            | 49-50-51                 | -1.9351          | 0.0189           | 13.6         | 5019.0        | 5                            | Up              |
| 11 Feb '77 | 29  | 2            | 52-53-54                 | -1.9657          | 0.0217           | 11.2         | 5018.2        | 5                            | Down            |
| 11 Feb '77 | 30  | 2            | 55-56-57                 | -1.9117          | 0.0174           | 10.0         | 5008.9        | 6                            | Down            |
| 11 Feb '77 | 31  | 2            | 58-59-60                 | -1.9453          | 0.0180           | 11.9         | 5011.3        | 6                            | Up              |
| 11 Feb '77 | 32  | 2            | 61-62-63                 | -3.9314          | 0.0191           | 11.7         | 5014.5        | 0                            | Up (No Good)    |

Table 1-EB1. Fence Tests (S/N 002, 20 dB Coupler in Nav Set) (cont)

| Day        | Run | Data<br>Tape | Data<br>Cassette<br>File | Azimuth<br>Angle | Azimuth<br>Sigma | DME<br>Sigma | DME<br>(Feet) | Tower<br>Reference<br>Height | Comments              |
|------------|-----|--------------|--------------------------|------------------|------------------|--------------|---------------|------------------------------|-----------------------|
| 11 Feb '77 | 33  | 2            | 64-65-66                 | -3.9264          | 0.0177           | 10.0         | 5014.1        | 0                            | Down (No Good)        |
| 11 Feb '77 | 34  | 2            | 67-68-69                 | -3.9436          | 0.0262           | 10.5         | 5046.4        | 1                            | Down (No Good)        |
| 11 Feb '77 | 35  | 2            | 70-71-72                 | -3.9664          | 0.0242           | 12.3         | 5048.0        | 1                            | Up (No Good)          |
| 11 Feb '77 | 36  | 2            | 73-74-75                 | -3.9689          | 0.0246           | 12.6         | 5048.7        | 1                            | Up Repeat 35          |
| 11 Feb '77 | 37  | 3            | 1-2-3                    | -3.9086          | 0.0166           | 10.8         | 5014.2        | 2                            | Up (No Good)          |
| 11 Feb '77 | 38  | 3            | 4-5-6                    | -3.9313          | 0.0189           | 12.1         | 5015.6        | 2                            | Down (No Good)        |
| 12 Feb '77 | 1   | 3            | 7-8-9                    | -3.8949          | 0.0175           | 13.5         | 5016.1        | 0                            | Down 9:45 A.M.        |
| 12 Feb '77 | 2   | 3            | 10-11-12                 | -3.9106          | 0.0176           | 12.0         | 5014.6        | 0                            | Up                    |
| 12 Feb '77 | 3   | 3            | 13-14-15                 | -3.9207          | 0.0275           | 12.3         | 5057.6        | 1                            | Up                    |
| 12 Feb '77 | 4   | 3            | 16-17-18                 | -3.8884          | 0.0307           | 10.9         | 5055.0        | 1                            | Down,                 |
| 12 Feb '77 | 5   | 3            | 19-20-21                 | -3.8758          | 0.0255           | 10.2         | 5055.3        | 1                            | Down Repeat 4         |
| 12 Feb '77 | 6   | 3            | 22-23-24                 | -3.9263          | 0.0187           | 12.9         | 5019.3        | 2                            | Down                  |
| 12 Feb '77 | 7   | 3            | 25-26-27                 | -3.9324          | 0.0184           | 12.5         | 5019.0        | 2                            | Up                    |
| 12 Feb '77 | 8   | 3            | 28-29-30                 | -3.9354          | 0.0197           | 11.5         | 5017.6        | 3                            | Up                    |
| 12 Feb '77 | 9   | 3            | 31-32-33                 | -3.9286          | 0.0186           | 13.0         | 5017.2        | 3                            | Down                  |
| 12 Feb '77 | 10  | 3            | 34-35-36                 | -3.9405          | 0.0205           | 12.4         | 5023.4        | 4                            | Down                  |
| 12 Feb '77 | 11  | 3            | 37-38-39                 | -3.9376          | 0.0197           | 13.5         | 5019.9        | 4                            | Up                    |
| 12 Feb '77 | 12  | 3            | 40-41-42                 | -3.9054          | 0.0203           | 12.5         | 5023.6        | 5                            | Up                    |
| 12 Feb '77 | 13  | 3            | 43-44-45                 | -3.8941          | 0.0181           | 13.0         | 5022.2        | 5                            | Down                  |
| 12 Feb '77 | 14  | 3            | 46-47-48                 | -3.9239          | 0.0193           | 12.3         | 5017.2        | 6                            | Down                  |
| 12 Feb '77 | 15  | 3            | 49-50-51                 | -3.9351          | 0.0204           | 11.5         | 5017.2        | 6                            | Up                    |
| 12 Feb '77 | 16  | 3            | 52-53-54                 | -3.9386          | 0.0178           | 14.0         | 5016.4        | 6                            | Up                    |
| 12 Feb '77 | 17  | 3            | 55-56-57                 | -0.0037          | 0.0244           | 11.1         | 12001.6,      | 0                            | Up (Generator Failed) |

Table 1-EB1. Fence Tests (S/N 002, 20 dB Coupler in Nav Set) (cont)

| Day        | Run | Data<br>Tape | Data<br>Cassette<br>File | Azimuth<br>Angle | Azimuth<br>Sigma | DME<br>Sigma | DME<br>(Feet) | Tower<br>Reference<br>Height | Comments              |
|------------|-----|--------------|--------------------------|------------------|------------------|--------------|---------------|------------------------------|-----------------------|
| 12 Feb '77 | 18  | 3            | 58-59-60                 | 0.0070           | 0.0240           | 10.4         | 12001.8       | 0                            | Down                  |
| 12 Feb '77 | 19  | 3            | 61-62-63                 | 0.0010           | 0.0233           | 11.7         | 11997.0       | 1                            | Down                  |
| 12 Feb '77 | 20  | 3            | 64-65-66                 | 0.0034           | 0.0228           | 11.7         | 11999.9       | 1                            | Up                    |
| 12 Feb '77 | 21  | 3            | 67-68-69                 | 0.0021           | 0.0221           | 11.4         | 12000.9       | 2                            | Up                    |
| 12 Feb '77 | 22  | 3            | 70-71-72                 | 0.0039           | 0.0229           | 12.2         | 11998.1       | 2                            | Down                  |
| 12 Feb '77 | 23  | 3            | 73-74-75                 | -0.0077          | 0.0220           | 8.9          | 11999.9       | 3                            | Down                  |
| 12 Feb '77 | 24  | 4            | 1-2                      | -0.0032          | 0.0213           | 10.9         | 12001.3       | 3                            | Up                    |
| 12 Feb '77 | 25  | 4            | 3-4                      | -0.0046          | 0.0203           | 10.8         | 12003.5       | 4                            | Up (Generator Failed) |
| 12 Feb '77 | 26  | 4            | 5-6                      | -0.0370          | 0.0229           | 12.1         | 12002.1       | 4                            | Down                  |
| 12 Feb '77 | 27  | 4            | 7-8                      | -0.0346          | 0.0214           | 12.4         | 12000.9       | 4                            | Down Repeat 26        |
| 12 Feb '77 | 28  | 4            | 9-10                     | -0.0374          | 0.0231           | 10.4         | 12006.9       | 5                            | Down                  |
| 12 Feb '77 | 29  | 4            | 11-12                    | -0.0178          | 0.0260           | 12.0         | 12007.3       | 5                            | Up                    |
| 12 Feb '77 | 30  | 4            | 13-14                    | -0.0461          | 0.0264           | 11.2         | 12011.9       | 6                            | Up                    |
| 12 Feb '77 | 31  | 4            | 15-16                    | -0.1090          | 0.0365           | 18.8         | 12051.2       | 6                            | Down                  |
| 12 Feb '77 | 32  | 4            | 17-18                    | -0.1026          | 0.0298           | 11.1         | 12044.1       | 6                            | Down Repeat 31        |
| 12 Feb '77 | 33  | 4            | 19-20                    | -0.9611          | 0.0230           | 11.1         | 12006.1       | 0                            | Down                  |
| 12 Feb '77 | 34  | 4            | 21-22                    | -0.9629          | 0.0242           | 11.8         | 12006.3       | 0                            | Up                    |
| 12 Feb '77 | 35  | 4            | 23-24                    | -0.9660          | 0.0232           | 12.0         | 12004.1       | 1                            | Up                    |
| 12 Feb '77 | 36  | 4            | 25-26                    | -0.9644          | 0.0222           | 10.1         | 12002.4       | 1                            | Down                  |
| 12 Feb '77 | 37  | 4            | 27-28                    | -0.9546          | 0.0208           | 11.6         | 12001.9       | 2                            | Down                  |
| 12 Feb '77 | 38  | 4            | 29-30                    | -0.9874          | 0.0212           | 12.3         | 12002.1       | 2                            | Up                    |
| 12 Feb '77 | 39  | 4            | 31-32                    | -0.9893          | 0.0231           | 11.5         | 12003.9       | 3                            | Up                    |
| 12 Feb '77 | 40  | 4            | 33-34                    | -0.9609          | 0.0241           | 11.8         | 12003.3       | 3                            | Down                  |

Table 1-EB1. Fence Tests (S/N 002, 20 dB Coupler in Nav Set) (cont)

| Day        | Run | Dat<br>Tape | Data<br>Cassette<br>File | Azimuth<br>Angle | Azimuth<br>Sigma | DME<br>Sigma | DME<br>(Feet) | Tower<br>Reference<br>Height | Comments       |
|------------|-----|-------------|--------------------------|------------------|------------------|--------------|---------------|------------------------------|----------------|
| 12 Feb '77 | 41  | 4           | 35-36                    | -0.9652          | 0.0203           | 11.3         | 12001.9       | 4                            | Down           |
| 12 Feb '77 | 42  | 4           | 37-38                    | -1.0007          | 0.0213           | 11.5         | 12003.5       | 4                            | Up             |
| 12 Feb '77 | 43  | 4           | 39-40                    | -0.9966          | 0.0240           | 12.8         | 12009.6       | 5                            | Up             |
| 12 Feb '77 | 44  | 4           | 41-42                    | -0.9732          | 0.0243           | 13.3         | 12011.0       | 5                            | Down           |
| 12 Feb '77 | 45  | 4           | 43-44                    | -0.9629          | 0.0289           | 13.5         | 12036.4       | 6                            | Down           |
| 12 Feb '77 | 46  | 4           | 45-46                    | -0.9116          | 0.0250           | 10.8         | 12014.5       | 6                            | Up             |
| 14 Feb '77 | 1   | 4           | 47-48                    | -1.8844          | 0.0274           | 12.2         | 12014.7       | 0                            | Up 8:35 A.M.   |
| 14 Feb '77 | 2   | 4           | 49-50                    | -1.9250          | 0.0234           | 10.7         | 12013.2       | 0                            | Down           |
| 14 Feb '77 | 3   | 4           | 51-52                    | -1.9278          | 0.0268           | 10.3         | 12010.9       | 1                            | Down           |
| 14 Feb '77 | 4   | 4           | 53-54                    | -1.8970          | 0.0263           | 11.7         | 12013.9       | 1                            | Up             |
| 14 Feb '77 | 5   | 4           | 55-56                    | -1.8837          | 0.0224           | 10.3         | 12010.5       | 2                            | Up             |
| 14 Feb '77 | 6   | 4           | 57-58                    | -1.9080          | 0.0254           | 12.3         | 12011.5       | 2                            | Down           |
| 14 Feb '77 | 7   | 4           | 59-60                    | -1.9033          | 0.0242           | 9.9          | 12009.8       | 3                            | Down           |
| 14 Feb '77 | 8   | 4           | 61-62                    | -1.8756          | 0.0248           | 11.4         | 12008.9       | 3                            | Up             |
| 14 Feb '77 | 9   | 4           | 63-64                    | -1.8563          | 0.0261           | 11.6         | 12014.5       | 4                            | Up             |
| 14 Feb '77 | 10  | 4           | 65-66                    | -1.8973          | 0.0219           | 10.3         | 12010.4       | 4                            | Down           |
| 14 Feb '77 | 11  | 4           | 67-68                    | -1.8943          | 0.0215           | 11.6         | 12010.7       | 4                            | Down Repeat 10 |
| 14 Feb '77 | 12  | 4           | 69-70                    | -1.8879          | 0.0236           | 13.3         | 12017.0       | 5                            | Down           |
| 14 Feb '77 | 13  | 4           | 71-72                    | -1.8114          | 0.0227           | 12.1         | 12017.9       | 5                            | Up             |
| 14 Feb '77 | 14  | 4           | 73-74                    | -1.8338          | 0.0246           | 12.9         | 12032.1       | 6                            | Up             |
| 14 Feb '77 | 15  | 5           | 1-2                      | -1.8519          | 0.0261           | 10.6         | 12046.8       | 6                            | Down           |
| 14 Feb '77 | 16  | 5           | 3-4                      | -3.8734          | 0.0220           | 12.9         | 12029.9       | 0                            | Down           |
| 14 Feb '77 | 17  | 5           | 5-6                      | -3.8784          | 0.0197           | 12.7         | 12032.4       | 0                            | Up             |

Table 1-EB1. Fence Tests (S/N 002, 20 dB Coupler in Nav Set) (cont)

| Day        | Run | Data<br>Tape | Data<br>Cassette<br>File | Azimuth<br>Angle | Azimuth<br>Sigma | DME<br>Sigma | DME<br>(Feet) | Tower<br>Reference<br>Height | Comments     |
|------------|-----|--------------|--------------------------|------------------|------------------|--------------|---------------|------------------------------|--------------|
| 14 Feb '77 | 18  | 5            | 7-8                      | -3.8806          | 0.0207           | 11.6         | 12029.6       | 1                            | Up           |
| 14 Feb '77 | 19  | 5            | 9-10                     | -3.8791          | 0.0230           | 12.7         | 12027.0       | 1                            | Down         |
| 14 Feb '77 | 20  | 5            | 11-12                    | -3.8847          | 0.0200           | 13.5         | 12028.2       | 2                            | Down         |
| 14 Feb '77 | 21  | 5            | 13-14                    | -3.8830          | 0.0209           | 11.6         | 12026.4       | 2                            | Up           |
| 14 Feb '77 | 22  | 5            | 15-16                    | -3.8856          | 0.0213           | 13.0         | 12027.5       | 3                            | Up           |
| 14 Feb '77 | 23  | 5            | 17-18                    | -3.8860          | 0.0207           | 13.9         | 12026.8       | 3                            | Down         |
| 14 Feb '77 | 24  | 5            | 19-20                    | -3.8950          | 0.0208           | 12.8         | 12029.3       | 4                            | Down         |
| 14 Feb '77 | 25  | 5            | 21-22                    | -3.8813          | 0.0225           | 14.0         | 12030.5       | 4                            | Up           |
| 14 Feb '77 | 26  | 5            | 23-24                    | -3.8786          | 0.0236           | 11.1         | 12038.5       | 5                            | Up           |
| 14 Feb '77 | 27  | 5            | 23-24                    | -3.8895          | 0.0242           | 12.7         | 12035.6       | 5                            | Down         |
| 14 Feb '77 | 28  | 5            | 25-26                    | -3.9217          | 0.0303           | 12.6         | 12076.2       | 6                            | Down         |
| 14 Feb '77 | 29  | 5            | 27-28                    | -3.9031          | 0.0303           | 11.2         | 12069.9       | 6                            | Up           |
| 14 Feb '77 | 30  | 5            | 29-30                    | -3.8887          | 0.0244           | 12.0         | 12036.5       | 5                            | Up Repeat 26 |

The azimuth reading differences apparently due to the fence are summarized as follows:

| <u>Receiver<br/>Distance<br/>(Feet)</u> | <u>Nominal<br/>Azimuth<br/>(Degrees)</u> | <u>Maximum<br/>Difference<br/>(Degrees)</u> | <u>Average Magnitude<br/>of Difference<br/>(Degrees)</u> |
|-----------------------------------------|------------------------------------------|---------------------------------------------|----------------------------------------------------------|
| 5, 000                                  | -3.91                                    | -0.045*                                     | 0.0165                                                   |
| 5, 000                                  | -1.91                                    | -0.062                                      | 0.0315                                                   |
| 5, 000                                  | -0.95                                    | -0.099                                      | 0.0253                                                   |
| 5, 000                                  | 0                                        | -0.040*                                     | 0.0178                                                   |
| 12, 000                                 | -3.89                                    | 0.019                                       | 0.0060                                                   |
| 12, 000                                 | -1.90                                    | 0.077                                       | 0.0366                                                   |
| 12, 000                                 | -0.96                                    | 0.051                                       | 0.0250                                                   |
| 12, 000                                 | 0                                        | 0.057*                                      | 0.0185                                                   |

The values marked with asterisks are larger than might have been expected, since the 2-degree beam was entirely within, and centered on, the symmetrical fence section in two of these cases, and was a full beam width outside the fence in the other case. The major effects were expected at azimuths within a beam width of an edge of the fence, and all except three of the tabulated difference values confirm that expectation.

DME readings, as expected, were seldom affected by the fence. This is clear from a cursory inspection of the data. In the 56 comparisons, nearly all of the differences were less than 5 feet. In one case each, differences of about 40, 30, and 24 feet were observed, with the fence-down reading being the one out of line with the general trend of data. When the fence was up, in those three cases, it apparently corrected errors due to ground lobing, as intended.

## 1-EB5. CONCLUSIONS

The limited scope of these tests allows tentative conclusions to be drawn. Theoretically, diffraction effects from the fence under test might extend up to a vertical angle of 0.64 degree, whereas the measurements were confined below 0.5 degree. Also, the azimuthal sampling was rather sparse for an exploration of edge effects from the fence, which were expected to predominate. However, the average effects of the fence on azimuth readings tend to confirm that maximum error is introduced within a beam width of the fence edge, and that generally smaller errors result near the midsection of the fence. The usual magnitude of errors apparently caused by the fence midsection is somewhat less than other errors that are evident in the full set of azimuth data taken with the fence down. Hence, a fence sufficiently wide to avoid edge effects, but otherwise similar to the one tested, should not cause an excessive increase in azimuth error due to diffractive interference at low angles. Although azimuth error contributions by the fence at these low angles exist, they do not appear to require reduction by increasing fence complexity, nor do they offset the advantage of a fence in reducing ground lobing to avoid signal dropout.

No deleterious effects of the fence on DME performance are evident.

## 1-EB6. RECOMMENDATIONS

A radiation fence should be installed forward of any MSBLS azimuth/DME station that is sited on such terrain as to cause serious ground lobing problems. The fence configuration should be generally similar to that illustrated in Figure 1-EB1, except that the fence should subtend an azimuth angle at least 1.5 beam widths (3 degrees) greater on each side than the azimuth sector to be protected. Field adjustment of the fence height to compensate for sloping terrain might be necessary.

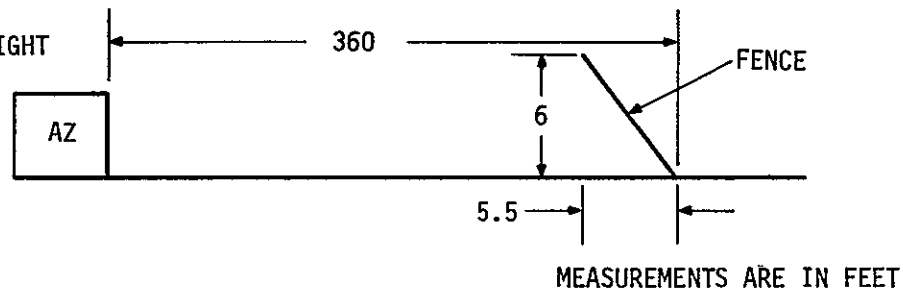
15 FEBRUARY 1977

DFRC S/N 002 FENCE TEST

1. TOWER REFERENCE HEIGHTS IN FEET (ABOVE GROUND LEVEL)

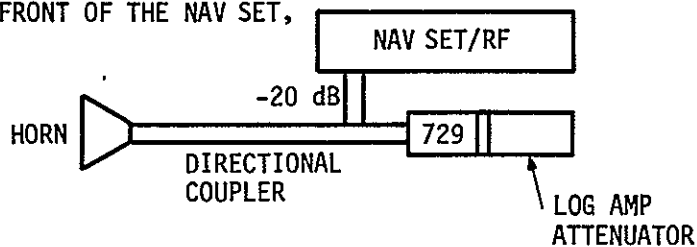
|   |       |
|---|-------|
| 0 | 13.5  |
| 1 | 19.75 |
| 2 | 25.75 |
| 3 | 30.58 |
| 4 | 36.5  |
| 5 | 42.41 |
| 6 | 48.5  |

2. FENCE HEIGHT



3. NAV SET CONFIGURATION

DECODER S/N 012  
RF BOX S/N 004  
HORN-NARDA 22469-3 16.5 dB AT 15 GHz  
NARDA 20-dB DIR COUPLER MODEL 1069-20  
NARDA VARIABLE ATTENUATOR MODEL 729  
ECCOSORB COVERED THE FRONT OF THE NAV SET,  
JUST BEHIND THE HORN

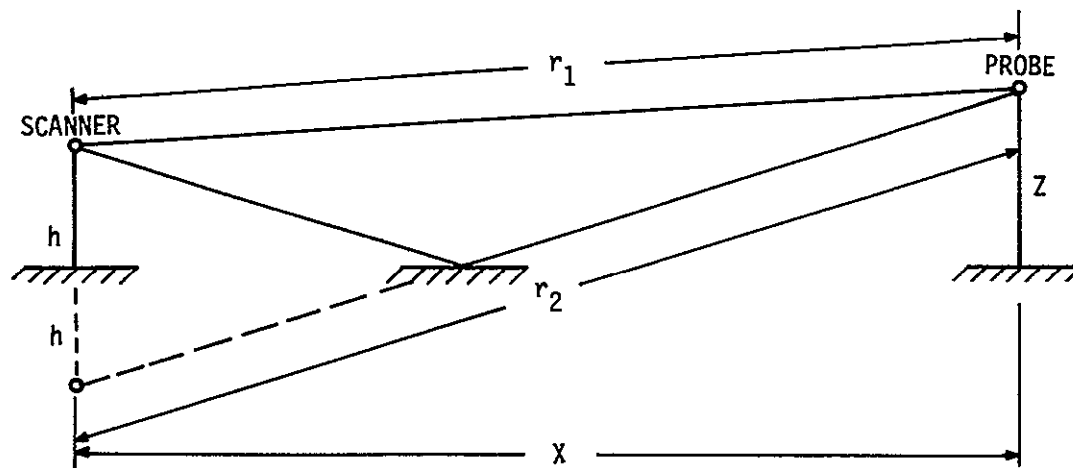


7-1496

APPENDIX C  
VERTICAL LOBING COMPUTATION AND MEASUREMENTS

F. BATTLE

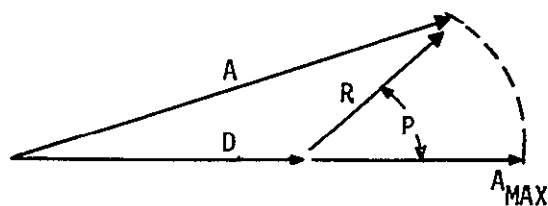
Computation of vertical lobing is based on the following analysis:



$$r_2 - r_1 = \sqrt{(z + h)^2 + x^2} - \sqrt{(z - h)^2 + x^2}$$

$$\approx \frac{(z + h)^2}{2x} - \frac{(z - h)^2}{2x} \quad (z \ll x, h \ll x)$$

$$\approx \frac{2zh}{x}$$



7-1497

Let:

D = direct signal amplitude

R = reflection amplitude

P = relative phase angle

$Q = (A/A_{\max})^2$  = power ratio to maximum observed as z varies

S = R/D = signal amplitude ratio

$\phi_0$  = reflection phase shift

$\lambda$  = wavelength

$$P = \phi_0 + \frac{r_2 - r_1}{\lambda} 360^\circ \approx \phi_0 + \frac{720^\circ}{\lambda x} h z$$

$$A^2 = D^2 + 2 DR \cos P + R^2$$

$$Q = \frac{1 + 2 S \cos P + S^2}{1 + 2 S + S^2}$$

The foregoing equations are to be further expanded for several reasons. Ideally, the scanner height h is known, and since  $\arctan(h + z) x$  is small, the reflection phase shift is 180 degrees. However, when the reflection geometry is complicated, as by the presence of a radiation fence, an effective height other than the measured value h might apply relative to the mean height of reflecting surfaces. Also, the phase shift might not be 180 degrees. Finally, the signal ratio S is the ground reflection coefficient modified by the vertical radiation pattern of the scanner. Hence, it is a function of the probe height z. At the low angles of interest, the azimuth antenna pattern gives the direct signal an amplitude advantage of about 3.2 dB per degree of elevation subtended between the probe and the reflection point. For the DME antenna, the advantage is about 0.8 dB per degree.

To account for these various considerations:

Let:

$\rho$  = reflection coefficient magnitude

$$S_{az} = (10^{-9z/x}) \rho \approx \rho \cdot 10^{-(3.2 \text{ dB/deg}) (\text{elev diff, deg})/20}$$

$$S_{dme} = (10^{-2.3 z/x}) \rho \approx \rho \cdot 10^{-(0.8 \text{ dB/deg}) (\text{elev diff, deg})/20}$$

$c$  = measured scanner height

$e = h - c$  = modification in effective scanner height

$\alpha = \theta_0 - 180^\circ$  = modification in phase shift

Rewriting:

$$P = 180^\circ + \alpha + \frac{720^\circ (c + e)}{\lambda x} z$$

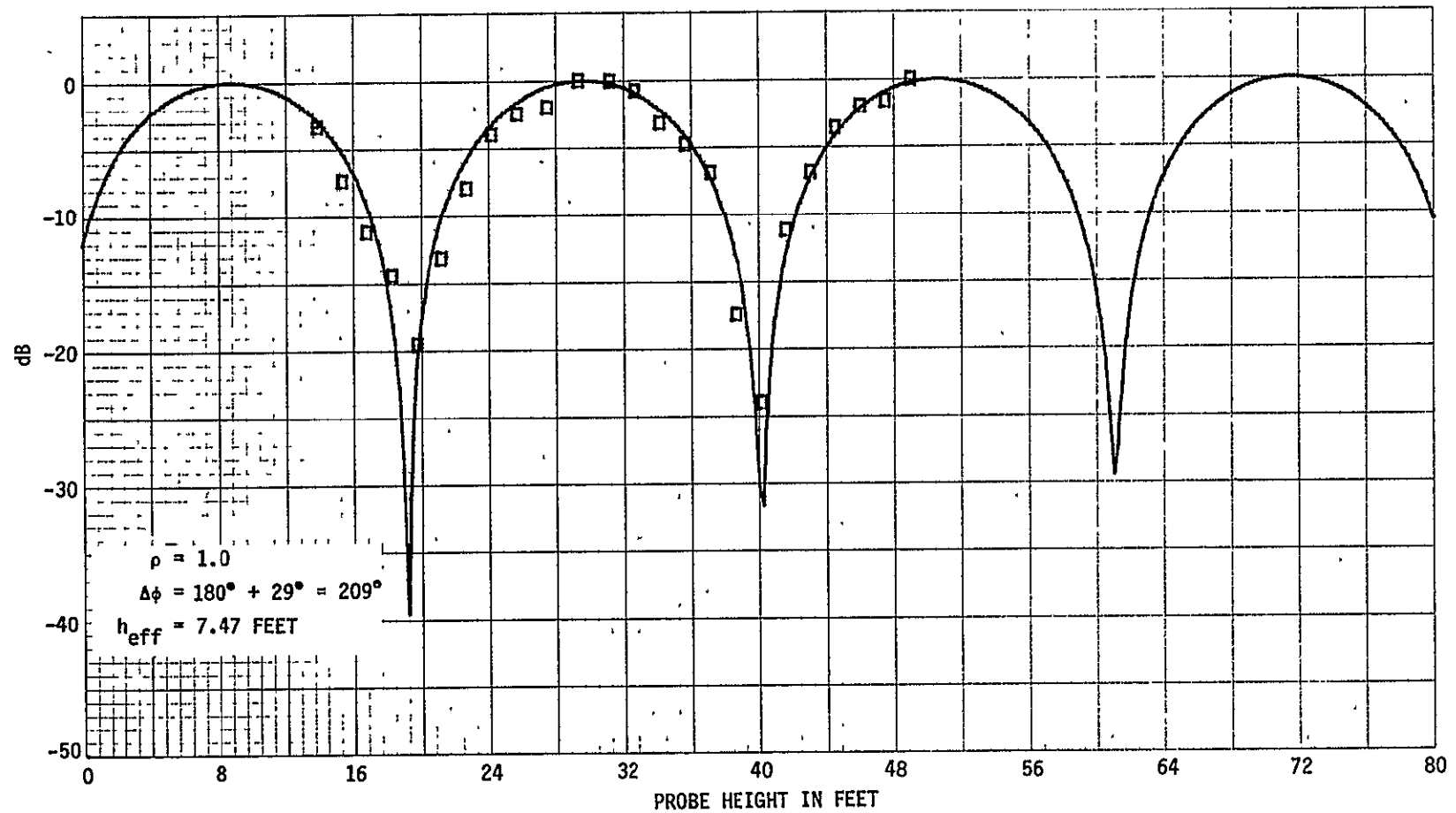
$$S = (10^{-2.3 z/x}) \rho \quad (\text{for DME antenna})$$

$$Q = \frac{1 + 2 S \cos P + S^2}{1 + 2 S + S^2}$$

where  $\lambda$ ,  $c$ , and  $x$  are known constants; and  $\alpha$ ,  $e$ , and  $\rho$  are unknown parameters that can be assumed constant.

Given a set of measured values of  $Q$  versus  $Z$  (the resultant vertical lobing pattern perturbed by measurement errors), it is desirable to determine  $\alpha$ ,  $e$ , and  $\rho$  so that a credible smooth curve can be drawn to represent the data. A computer program from the International Mathematical and Statistical Library (IMSL), designated ZXSSQ, has been used to obtain a least-squares fit of the above equation for power ratio,  $Q$ , to a set of observed data, by solving for the appropriate values of  $\alpha$ ,  $e$ , and  $\rho$ .

The measurement data of Table 1-EC1 was taken at DFRC with and without fences. Figures 1-EC1 and 1-EC2 show the plot of this data together with the least squares fit of the above equations.



7-1488

Figure 1-EC1. DME Relative Power at 5000 Feet Distance (No Fence, 8-23-76)

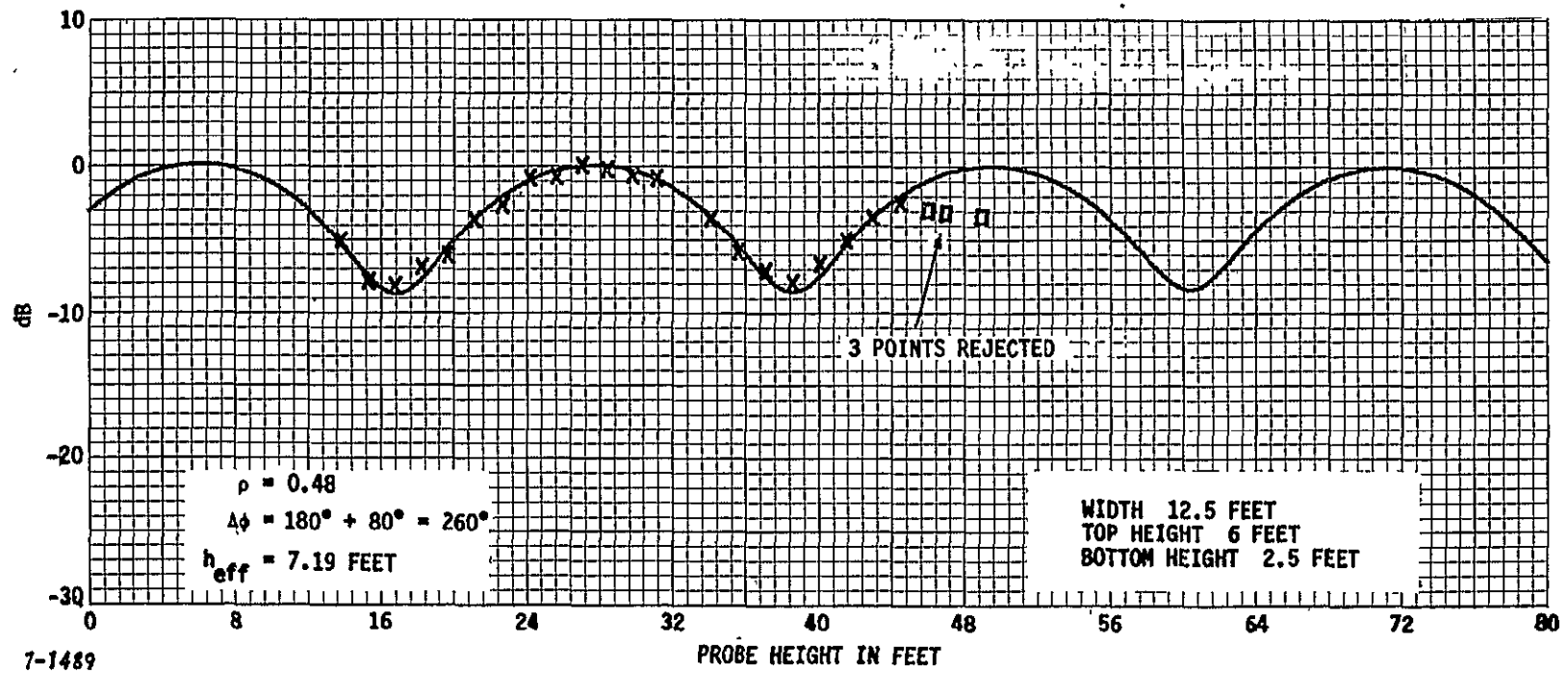


Figure 1-EC2. DME Relative Power at 5000 Feet Distance (Fence at 410 Feet, 8-23-76)

Table 1-EC1. DME Relative Signal Power Received at 5000 Feet Distance

DFRC - 8/23/76

(Transmitting Antenna Height 7.58 Feet)

| <u>Receiver Probe<br/>Height (feet)</u> | <u>No Fence</u> | <u>Fence 410 Feet Distant, 12.5 Feet Wide<br/>Top Height 6 Feet, Bottom Height 2.5 Feet</u> |
|-----------------------------------------|-----------------|---------------------------------------------------------------------------------------------|
| 13.85                                   | - 3.4 dB        | -6.5 dB                                                                                     |
| 15.34                                   | - 7.4           | -9.3                                                                                        |
| 16.82                                   | -11.2           | -9.6                                                                                        |
| 18.31                                   | -14.5           | -8.3                                                                                        |
| 19.79                                   | -19.7           | -7.5                                                                                        |
| 21.27                                   | -13.2           | -5.0                                                                                        |
| 22.76                                   | - 8.0           | -4.0                                                                                        |
| 24.24                                   | - 4.0           | -2.2                                                                                        |
| 25.73                                   | - 2.5           | -2.1                                                                                        |
| 27.10                                   |                 | -1.3                                                                                        |
| 27.55                                   | - 2.0           |                                                                                             |
| 28.47                                   |                 | -1.6                                                                                        |
| 29.37                                   | 0               |                                                                                             |
| 29.84                                   |                 | -2.0                                                                                        |
| 31.20                                   | 0               | -2.2                                                                                        |
| 32.69                                   | - 0.8           |                                                                                             |
| 34.17                                   | - 3.2           | -4.9                                                                                        |
| 35.66                                   | - 4.8           | -7.2                                                                                        |
| 37.15                                   | - 6.9           | -8.5                                                                                        |
| 38.63                                   | -17.5           | -9.3                                                                                        |
| 40.12                                   | -23.7           | -8.0                                                                                        |
| 41.60                                   | -11.2           | -6.4                                                                                        |
| 43.09                                   | - 6.9           | -4.8                                                                                        |

Table 1-EC1. DME Relative Signal Power Received at  
5000 Feet Distance (cont)

DFRC - 8/23/76

(Transmitting Antenna Height 7.58 Feet)

| <u>Receiver Probe<br/>Height (feet)</u> | <u>No Fence</u> | <u>Fence 410 Feet Distant, 12.5 Feet Wide<br/>Top Height 6 Feet, Bottom Height 2.5 Feet</u> |
|-----------------------------------------|-----------------|---------------------------------------------------------------------------------------------|
| 44.57                                   | - 3.6           | -3.8                                                                                        |
| 46.06                                   | - 2.0           | -4.3                                                                                        |
| 47.05                                   |                 | -4.5                                                                                        |
| 47.54                                   | - 1.6           |                                                                                             |
| 49.03                                   | 0               | -4.7                                                                                        |

SECTION II

DESCRIPTION OF SYSTEM OPERATION

(TASKS 03 AND 05)

PART A

EXAMINATION OF THE MSBLS NAV SET  
OPERATION DURING THE ACQUISITION MODE

W. WONG

TECHNICAL REPORT Y220-01

INTERIM - AUGUST 1975  
SEPTEMBER 1975

FINAL  
OCTOBER 1975

## 2-A1. INTRODUCTION

The following information is an examination of the MSBLS Nav Set operation during the various phases of the acquisition mode. This analysis consists of logic flow diagrams, block diagrams, and timing diagrams which can be used to follow the logical sequence of events that the Nav Set goes through as it is processing information during acquisition. The criteria for leaving the acquisition mode and going into the search mode are also made clear.

This report utilizes specifications given in the following documents:

- a. AIL Spec No. 00752-502498, dated 8/13/75

"Technical Specification for Microwave Scanning Beam  
Landing System - Ground Station"

Items:

- |           |                           |
|-----------|---------------------------|
| 3.2.1.2.1 | Scanning Beam Technique   |
| 3.2.1.4   | Scan Rate                 |
| 3.2.1.4.1 | Angular Velocity Rates    |
| 3.2.1.5   | Elevation Function        |
| 3.2.1.6   | Azimuth and DME Functions |

- b. Rockwell International Space Division

Spec Document No. MC409-0017A (Rev C)

"Navigation Set, Microwave Scan Beam Landing System"

Item: 3.2.1 Performance

## 2-A2. ACQUISITION

2-A3. GENERAL. The acquisition mode is the mode of operation the Nav Set goes through when it is attempting to acquire signals to operate on. For elevation and azimuth angle data reception, the Nav Set in acquisition must:

- a. Determine the beam type

b. Determine if it is intercepting track level signals from the main beam.

c. Set the gain of the IF amplifier to maintain a constant track level and if a and b are satisfied, prepare for information decoding.

Figure 2-A1 is a flow diagram showing the logical sequence of events the Nav Set goes through in acquisition. Initially all beam gates are off with the receiver at maximum sensitivity. When three consecutive pulse pairs from the same beam (same identity pulse pair spacing) are received, the appropriate beam gate and AGC are turned on. The beam gate and AGC are kept on as long as low level video pulse pairs (1 volt video) are received within 512 microseconds. When a track level or 2 volt video pulse pair is detected, the Nav Set leaves acquisition and goes into the search mode.

The various phases of acquisition such as beam gate decoding, beam gate generation and AGC are discussed further in the following paragraphs.

2-A4. IDENTITY DECODING. One phase of acquisition is beam identity decoding. Since the MSBLS-GS is transmitting azimuth, elevation, and DME information in three time multiplexed periods per antenna scan, this phase enables the Nav Set to determine which beam it is intercepting.

Figures 2-A2 through 2-A7 pertain to the beam identity decoding. Nominally, 0 to 5.5 volt video is received by the tracker/computer from the IF amplifier output. The tracker/computer establishes three thresholds which classify video received into 1-volt, 2-volt, and 3.4 volt level video as follows:

|     |                                              |
|-----|----------------------------------------------|
| LLV | Low Level Video<br>Video exceeding 1 volt    |
| TLV | Track Level Video<br>Video exceeding 2 volts |

3  
2

HLV

High Level Video

Video exceeding 3.4 volts

QLLV

Quantized Low Level Video

QLLV's are used to identify the beam. The intrapair identity spacing between pulses transmitted by the ground station determines the beam type. For DME soliciting the intrapair spacing is  $8\ \mu\text{s}$ ; for azimuth fly left the spacing is  $10\ \mu\text{s}$ ; for elevation the spacing is  $12\ \mu\text{s}$ ; and for azimuth fly right the spacing is  $14\ \mu\text{s}$ .

Each QLLV received is processed to determine whether it occurs  $8\ \mu\text{s} \pm 0.75\ \mu\text{s}$ ,  $10\ \mu\text{s} \pm 0.75\ \mu\text{s}$ ,  $12\ \mu\text{s} \pm 0.75\ \mu\text{s}$ , or  $14\ \mu\text{s} \pm 0.75\ \mu\text{s}$  from the time that the previous QLLV was processed. If two QLLV's occur within these time intervals, a valid pulse pair has been identified, generating either DSV, LAZV, ELV, or RAZV signals (Figures 2-A2 and 2-A3).

Each QLLV causes the generation of four  $1.5\ \mu\text{s}$  "window" pulses, each removed from the original pulses by 8, 10, 12, and  $14\ \mu\text{s}$ . If the next QLLV the tracker/computer receives coincides in time with any of these "windows" a valid pulse pair corresponding to one of the transmitted beams is identified (Figures 2-A4 through 2-A7).

An echo guard gate is also provided to guard against multipath signals after a QLLV pulse is received. Each time a QLLV is processed a  $5.25\ \mu\text{s}$  pulse is generated, preventing further generation of QLLV pulses for  $5.25\ \mu\text{s}$  (Figure 2-A3).

The DSQ signal appearing in Figure 2-A3 is used to detect the presence of noise pulses. Each QLLV causes a  $1.5\ \mu\text{s}$  pulse to be present  $3.75\ \mu\text{s}$  to  $5.25\ \mu\text{s}$  from the time a QLLV is generated. Any noise pulse crossing the one volt threshold within this time interval will generate an LLV signal and consequently a DSQ signal is generated. DSQ is used to desensitize the IF amplifier so that noise excursions above threshold will not become a problem.

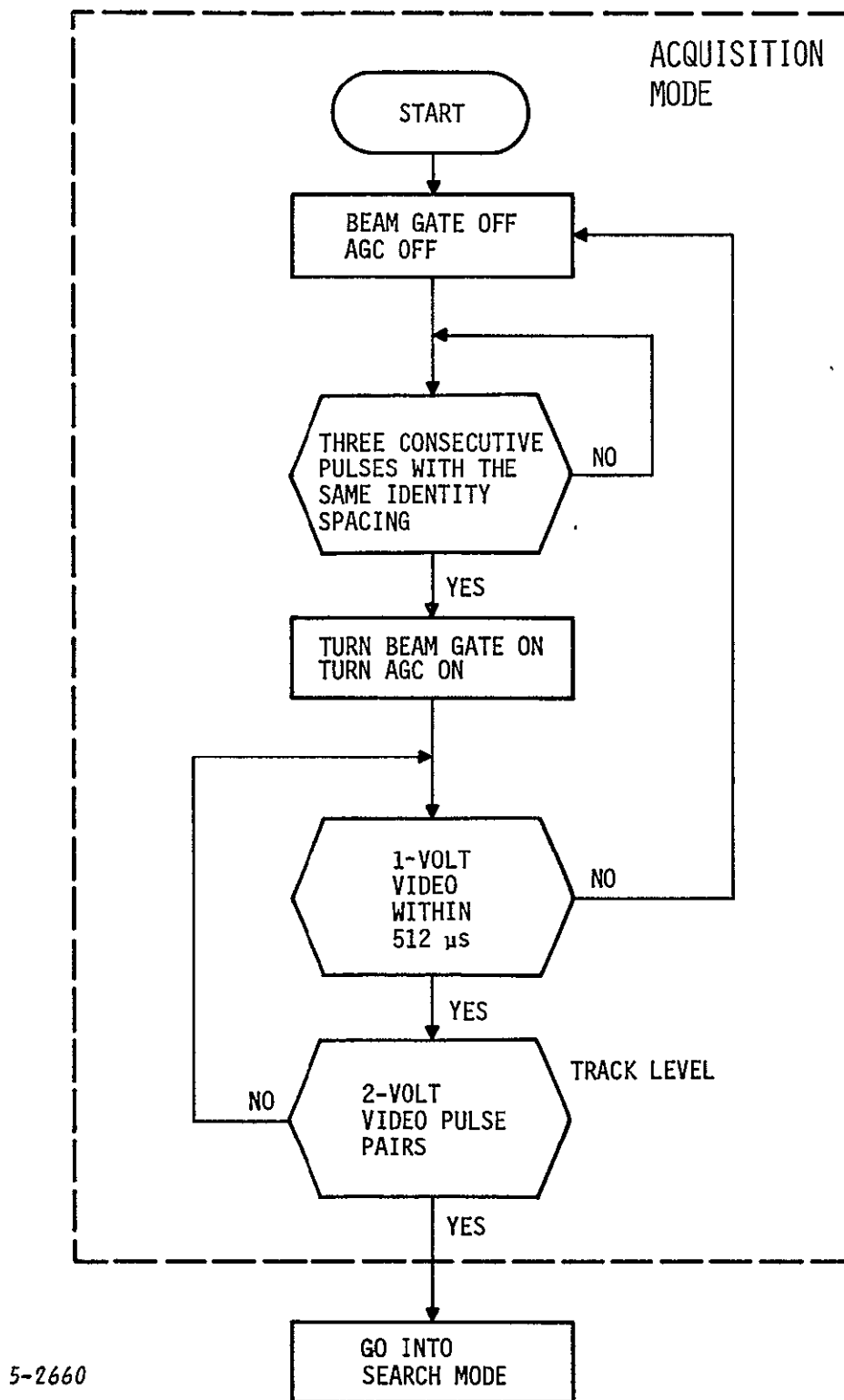


Figure 2-A1. Criteria for Going Into Search Mode

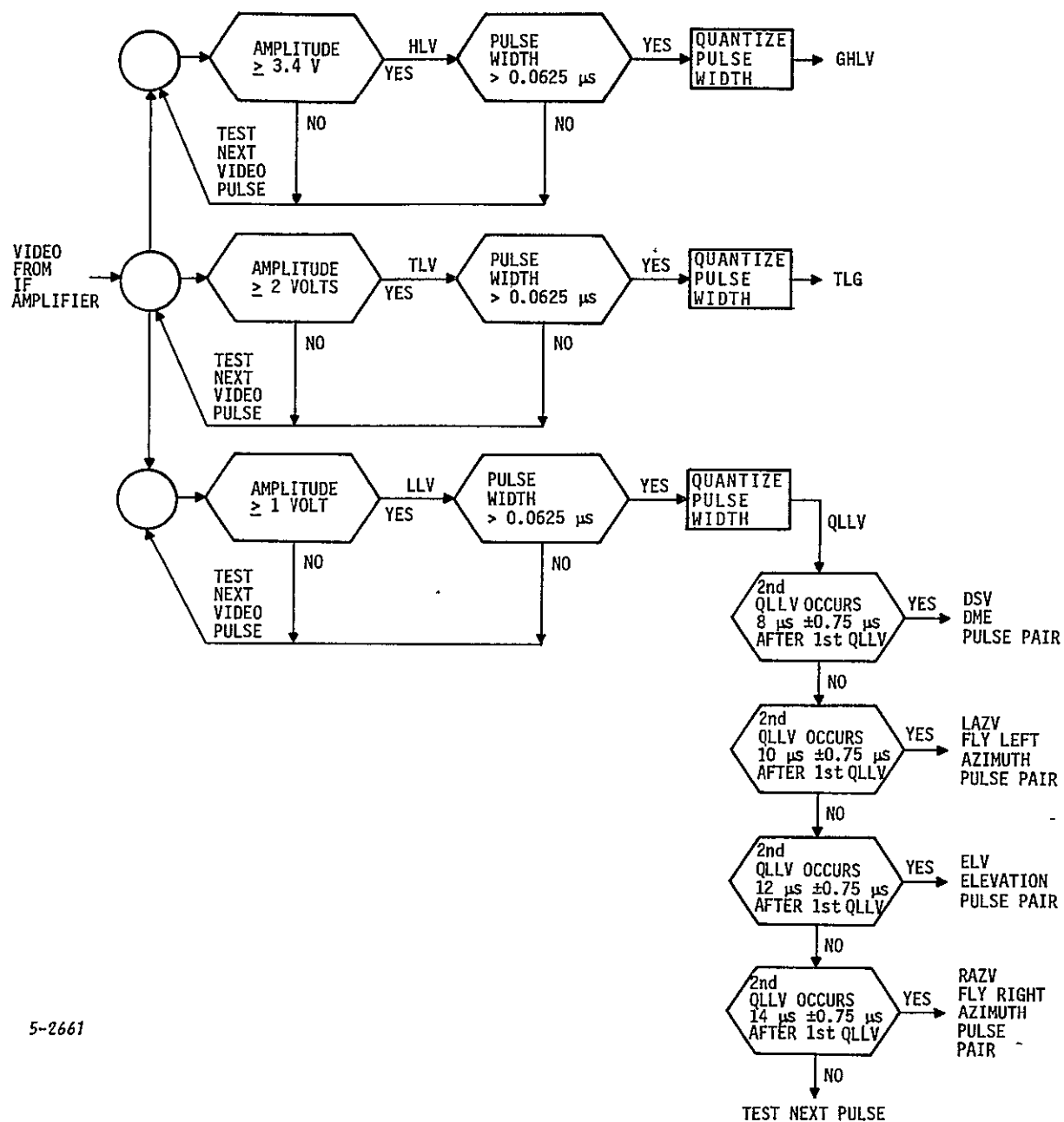
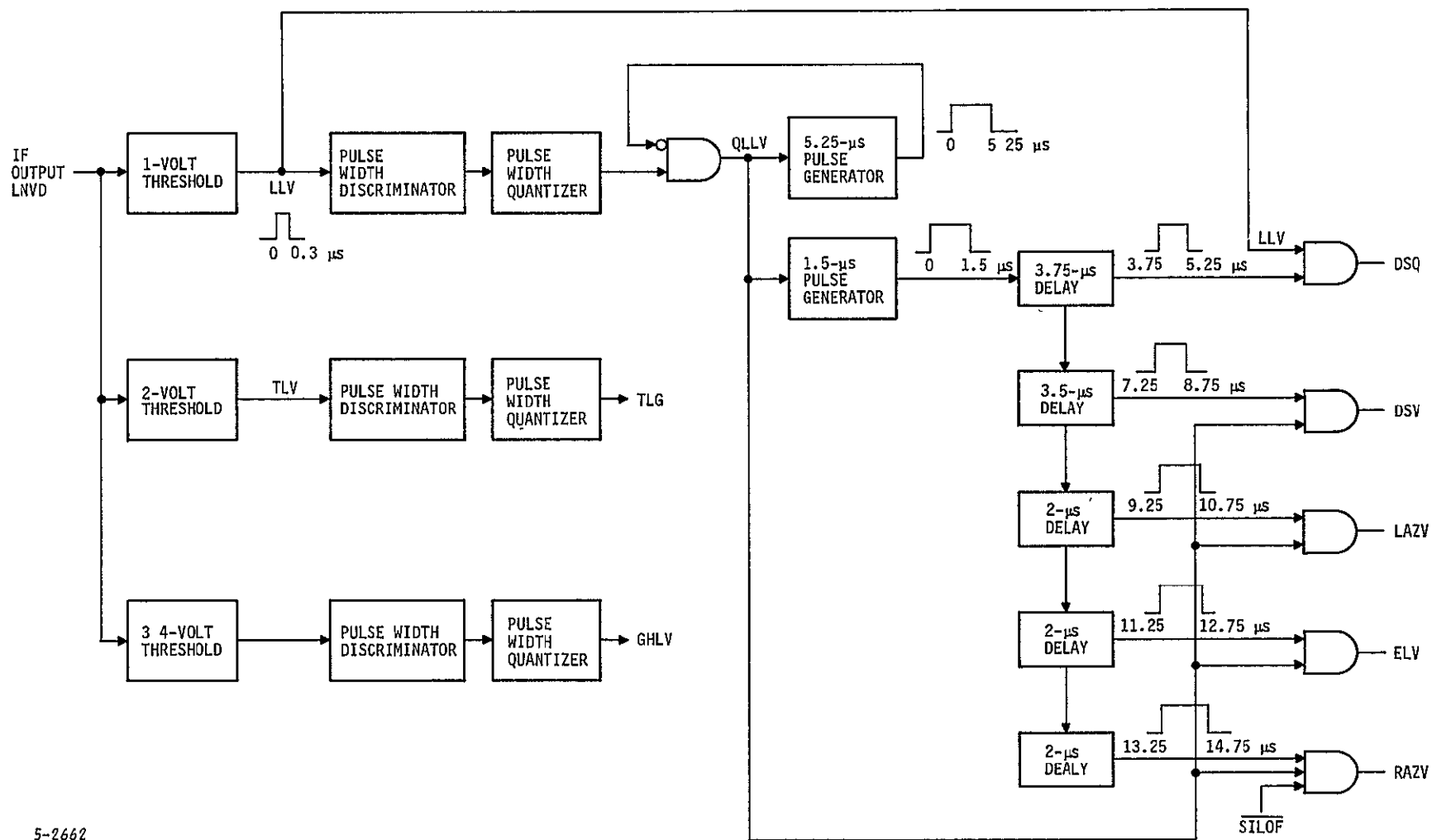


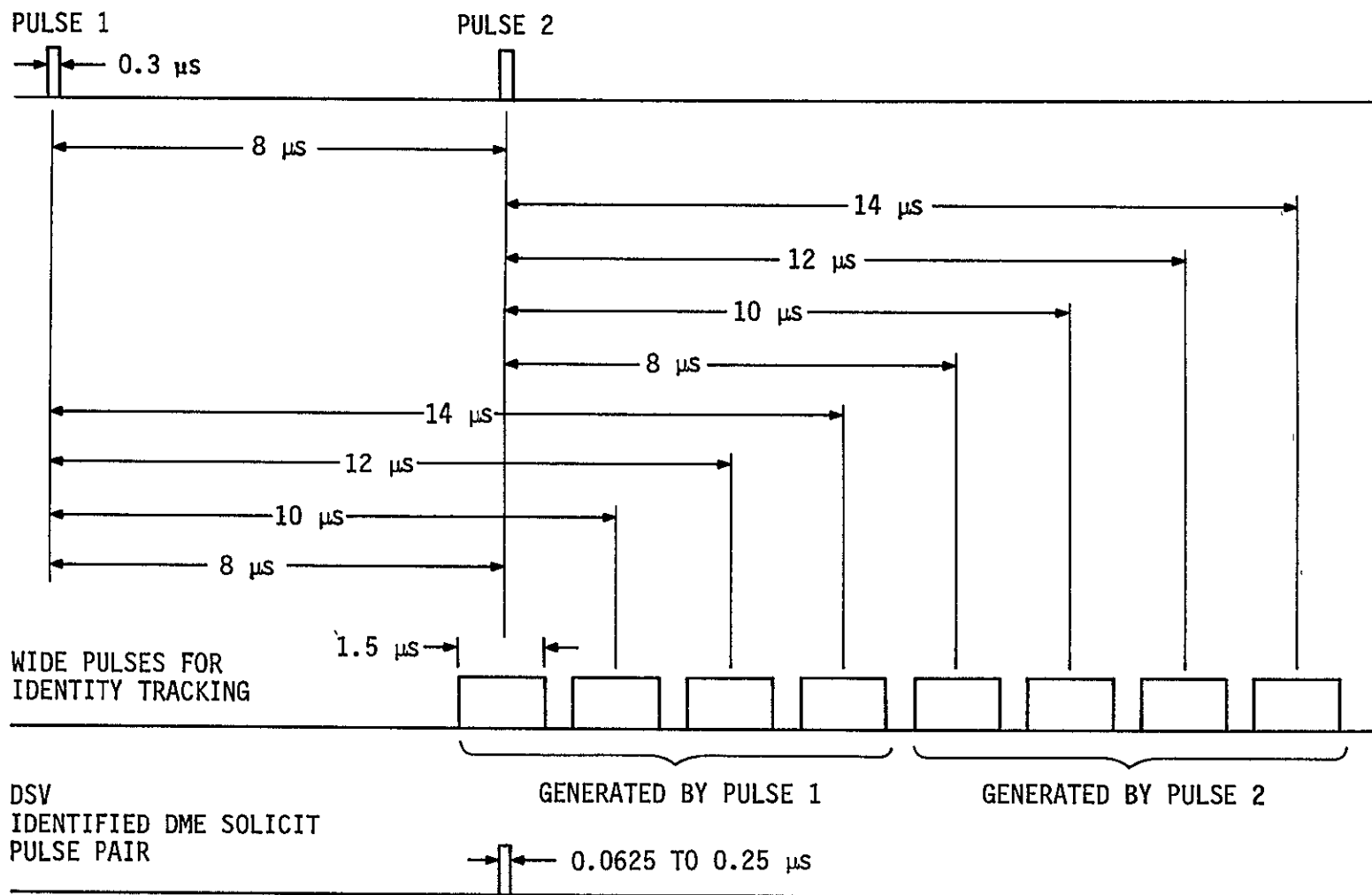
Figure 2-A2. Identity Decoding, Logic Flow Diagram



5-2662

Figure 2-A3. Beam Identity Decoding Block Diagram

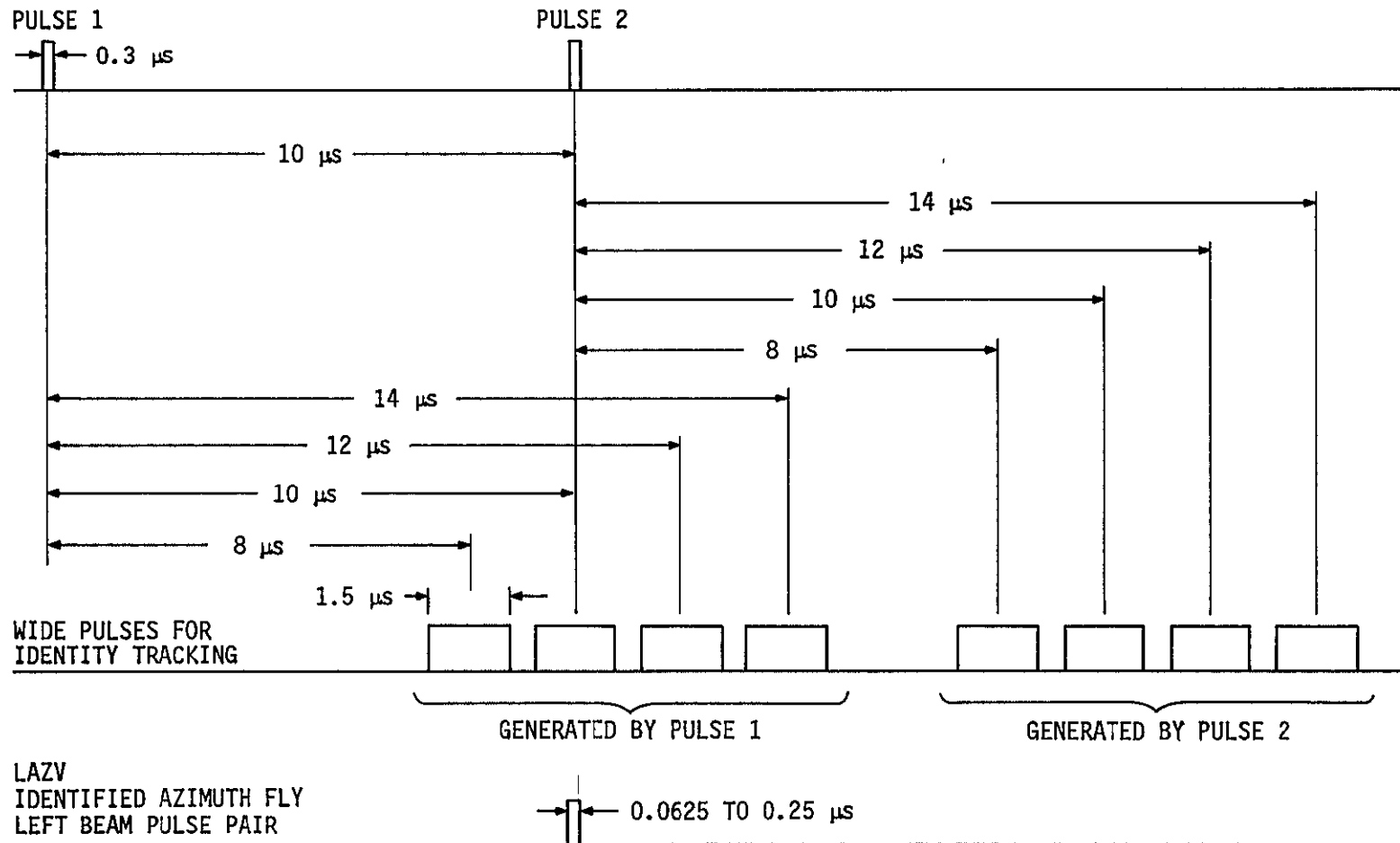
## DME SOLICIT BEAM PULSE PAIR (FROM IF OUTPUT)



5-2663

Figure 2-A4. Identity Decoding (DME)

# AZIMUTH FLY LEFT BEAM PULSE PAIR (FROM IF OUTPUT)



5-2664

Figure 2-A5. Identity Decoding (Azimuth Fly Left)

## ELEVATION BEAM PULSE PAIR (FROM IF OUTPUT)

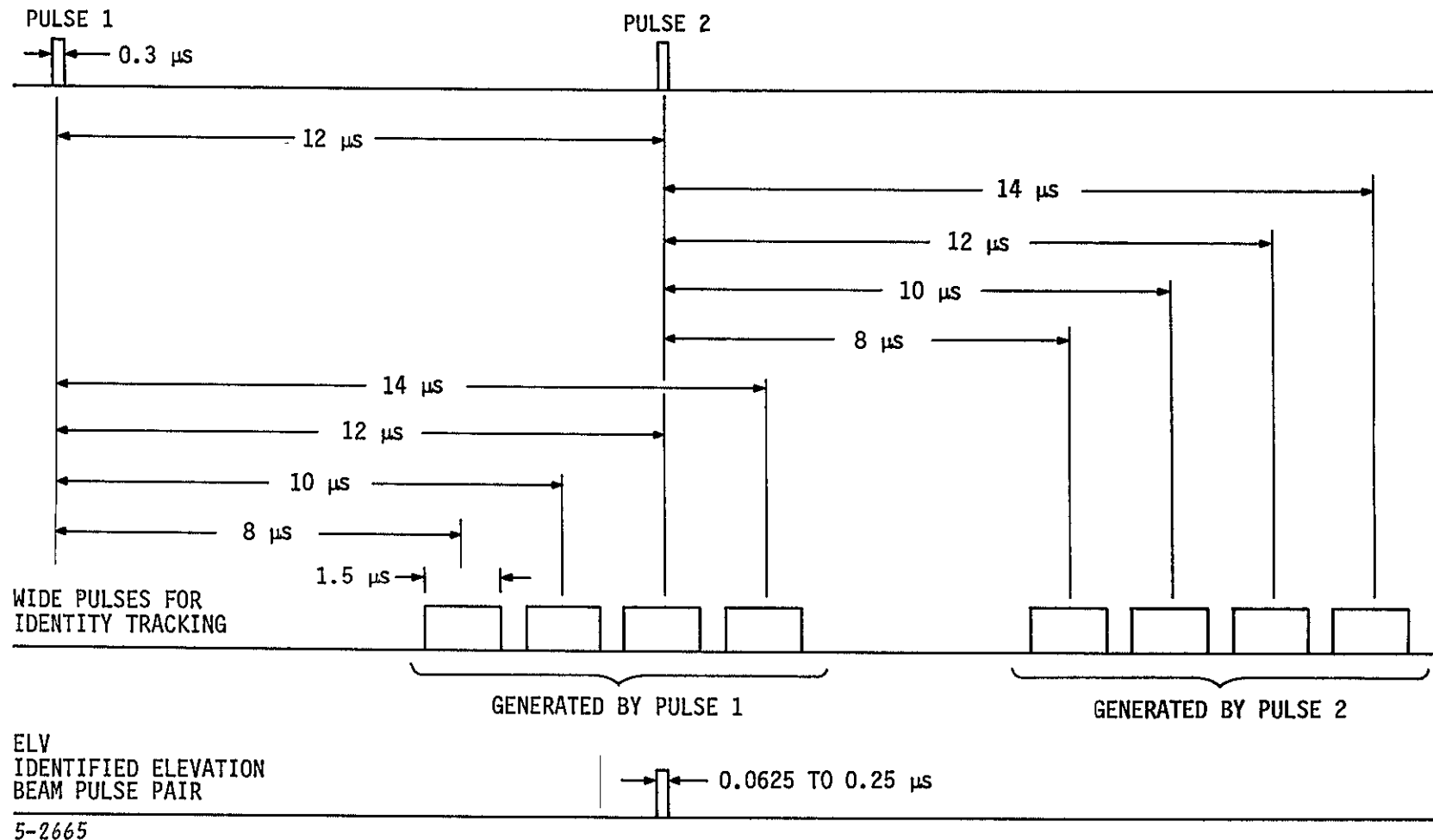


Figure 2-A6. Identity Decoding (Elevation)

AZIMUTH FLY RIGHT BEAM PULSE PAIR (FROM IF OUTPUT)

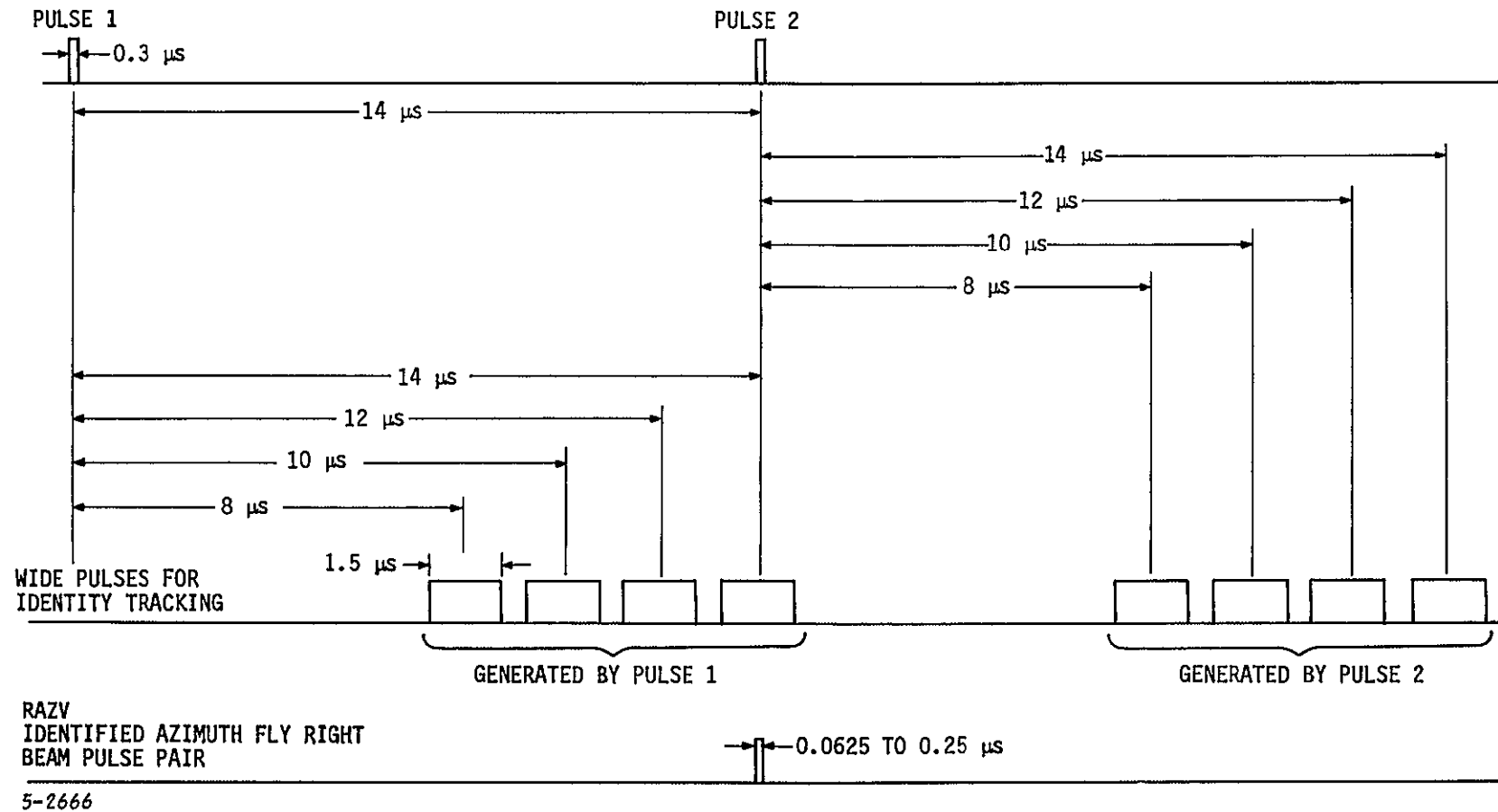


Figure 2-A7. Identity Decoding (Azimuth Fly Right)

2-A5. BEAM GATE GENERATION. The tracker/computer attempts to identify three consecutive pulse pairs with the same identity spacing (Figures 2-A8 and 2-A9). These three pulse pairs must occur within 512  $\mu$ s of each other with no intervening pulse pairs of a different identity. The inter-pair data spacings transmitted by the MSBLS ground station all fall within this 512  $\mu$ s time interval. For ground station soliciting of the Nav Set the inter-pair spacing is 160  $\mu$ s. For azimuth angle data transmission this spacing can vary from 60  $\mu$ s to 90  $\mu$ s corresponding to 0 degree to 15 degrees azimuth angle. For elevation data transmission the interpair spacing can vary from 60  $\mu$ s to 120  $\mu$ s corresponding to 0 degree elevation to 30 degrees elevation angle.

Once three consecutive pulse pairs with the same intrapair identity spacing are identified, an appropriate beam gate is generated and an appropriate AGC is turned on, desensitizing the IF amplifier. A different beam gate is generated for the azimuth, elevation, and DME beams. If no low video occurs for 512  $\mu$ s after beam gate generation, the beam gate and AGC are turned off. The tracker/computer then reverts back to attempting to identify sets of three pulse pairs.

If low level video continues to be received within 512  $\mu$ s from the time the AGC is turned on, the AGC and beam gate stay on. A beam gate lockup feature (Figure 2-A9) is provided to prevent the generation of a second beam while one is already on.

When at least one track level video pulse pair exceeding 2 volts is received by the tracker/computer, the Nav Set leaves the acquisition mode and goes into the search mode.

2-A6. AGC FUNCTIONS. The Nav Set provides a feedback AGC loop to limit the gain of the IF amplifier (Figure 2-A10). Located within the tracker/computer are four AGC control and memory circuits which are multiplexed

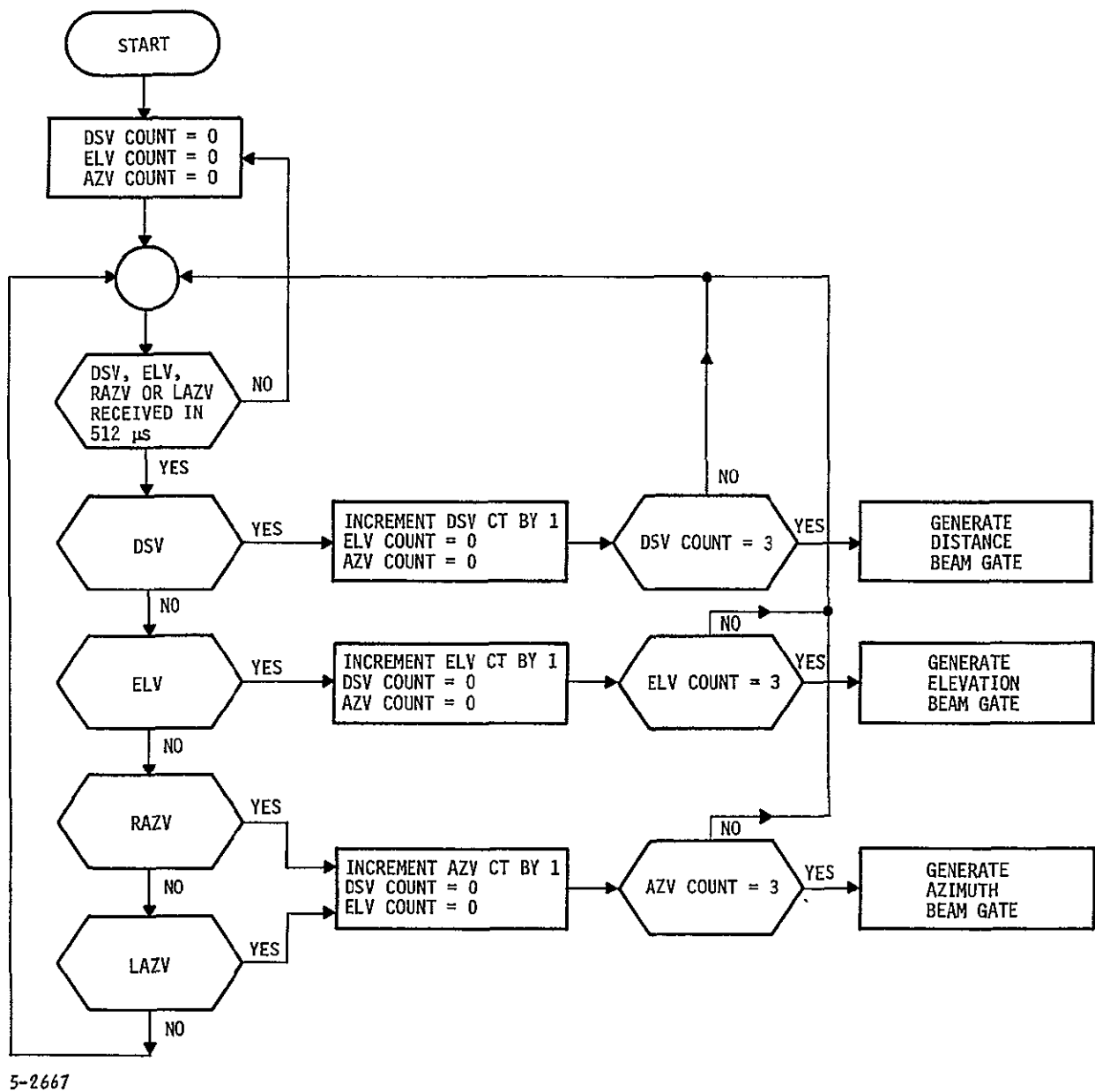
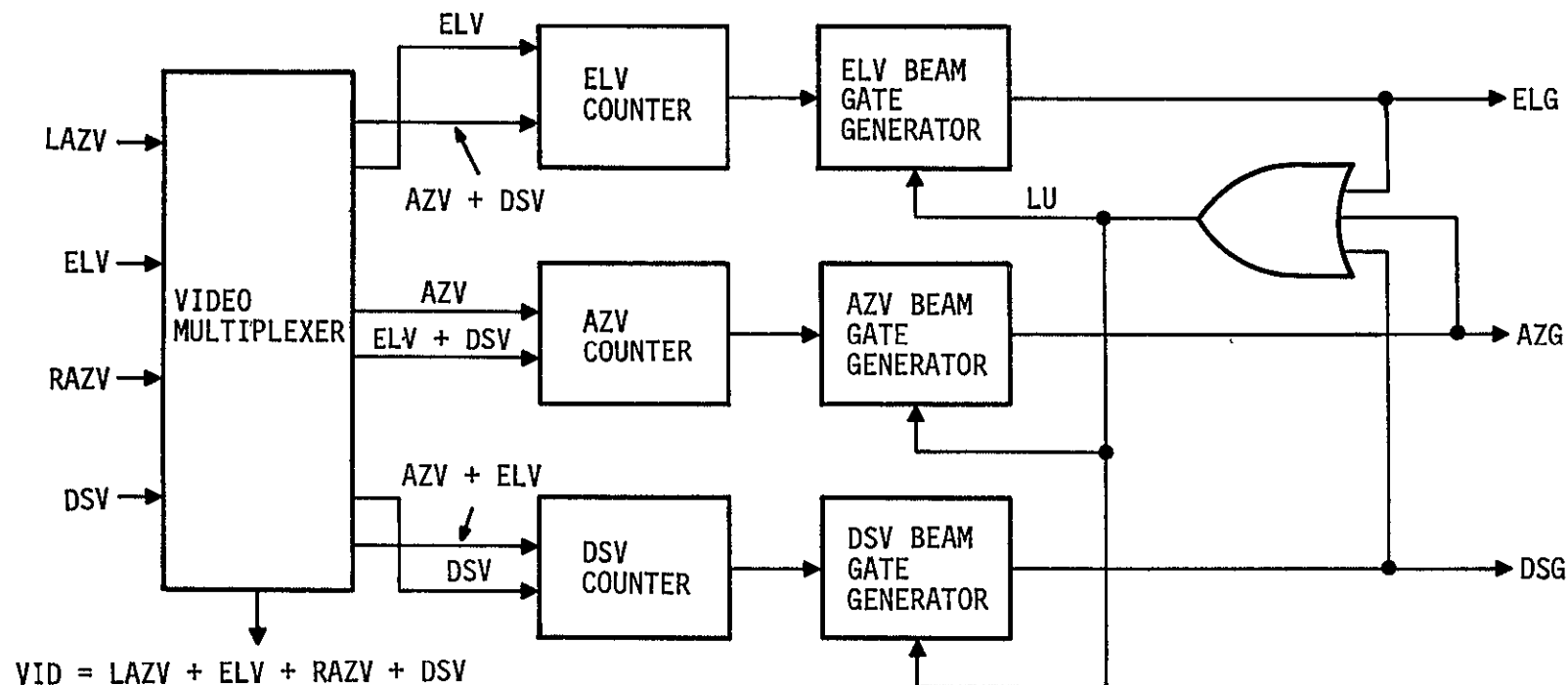


Figure 2-A8. Beam Gate Generation, Logic Flow Diagram



ELG - ELEVATION GATE

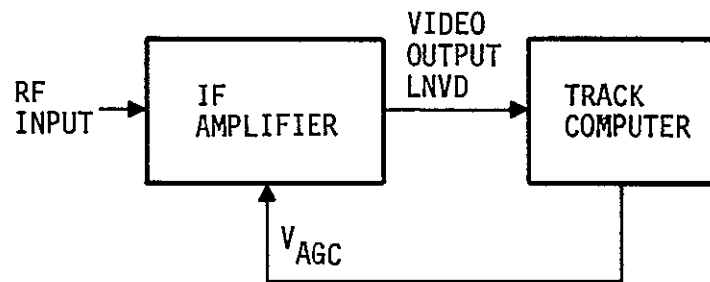
AZG - AZIMUTH GATE

DSG - DISTANCE GATE

LU - BEAM LOCK-UP (PREVENTS GENERATION OF  
MORE THAN ONE BEAM GATE)

5-2668

Figure 2-A9. Beam Demultiplexing and Beam Gate Generation, Block Diagram



GAIN IF AMPLIFIER = FUNCTION OF  $V_{AGC}$

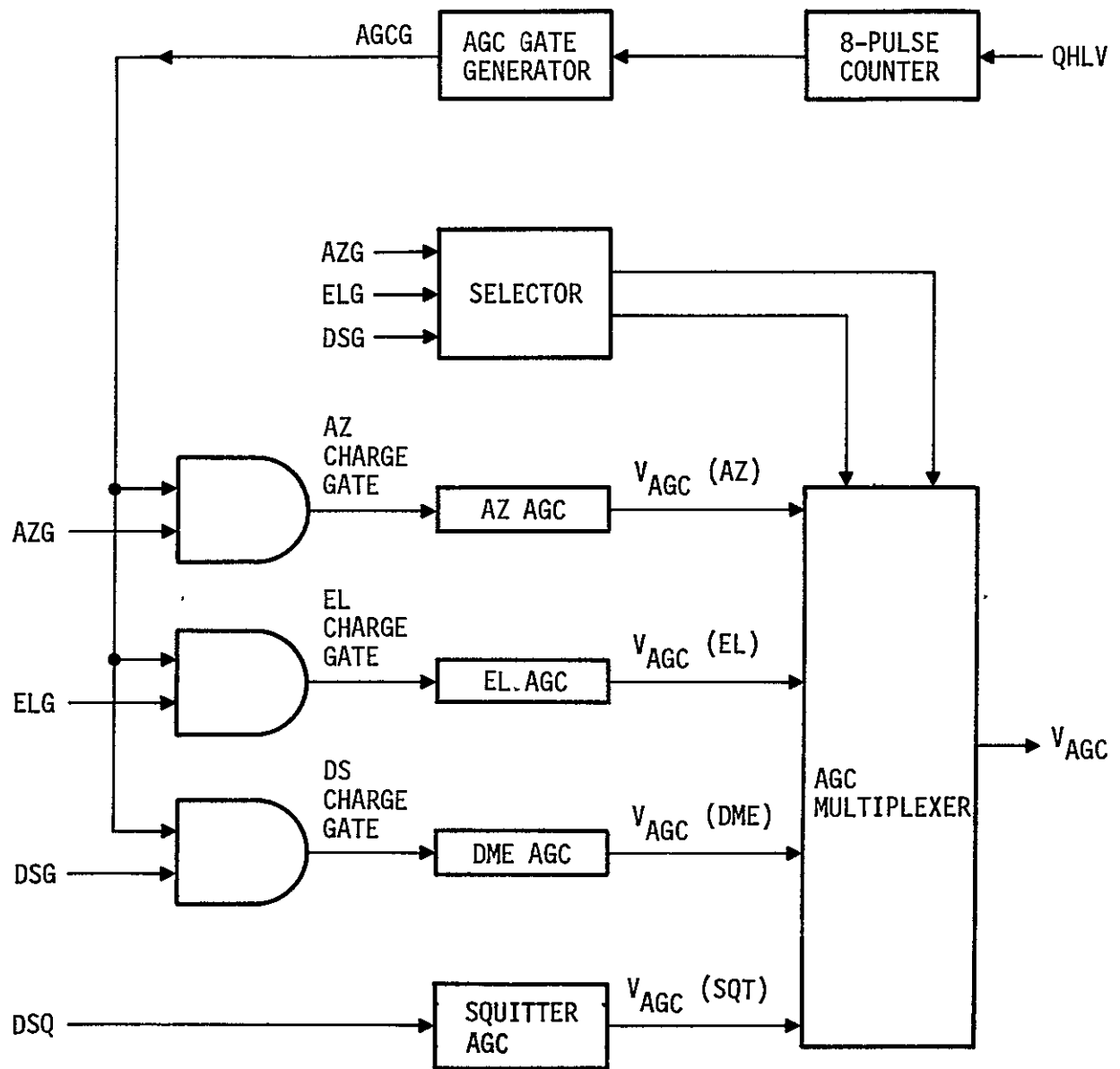
5-2669

Figure 2-A10. AGC Loop

to operate at different times. The four AGC's (Figures 2-A11 and 2-A12) are:

- a. Azimuth AGC operating during an azimuth beam gate.
- b. Elevation AGC operating during an elevation beam gate.
- c. DME AGC operating during a distance beam gate.
- d. Squitter AGC operating when no beam gate is on.

A flow diagram of azimuth AGC operation is shown in Figure 2-A13. The azimuth AGC produces a dc voltage to vary the gain of the IF amplifier such that the peak signal strength of the received beam appears as 3.4-volt video. If eight or more video pulse pairs exceed the 3.4-volt threshold (Figures 2-A11 and 2-A13) the eight pulse counter will send a signal to the azimuth AGC. The AGC voltage will increase and the gain of the IF amplifier will be reduced. If eight LHLV pulses have not been received during the



5-2670

Figure 2-A11. AGC Block Diagram

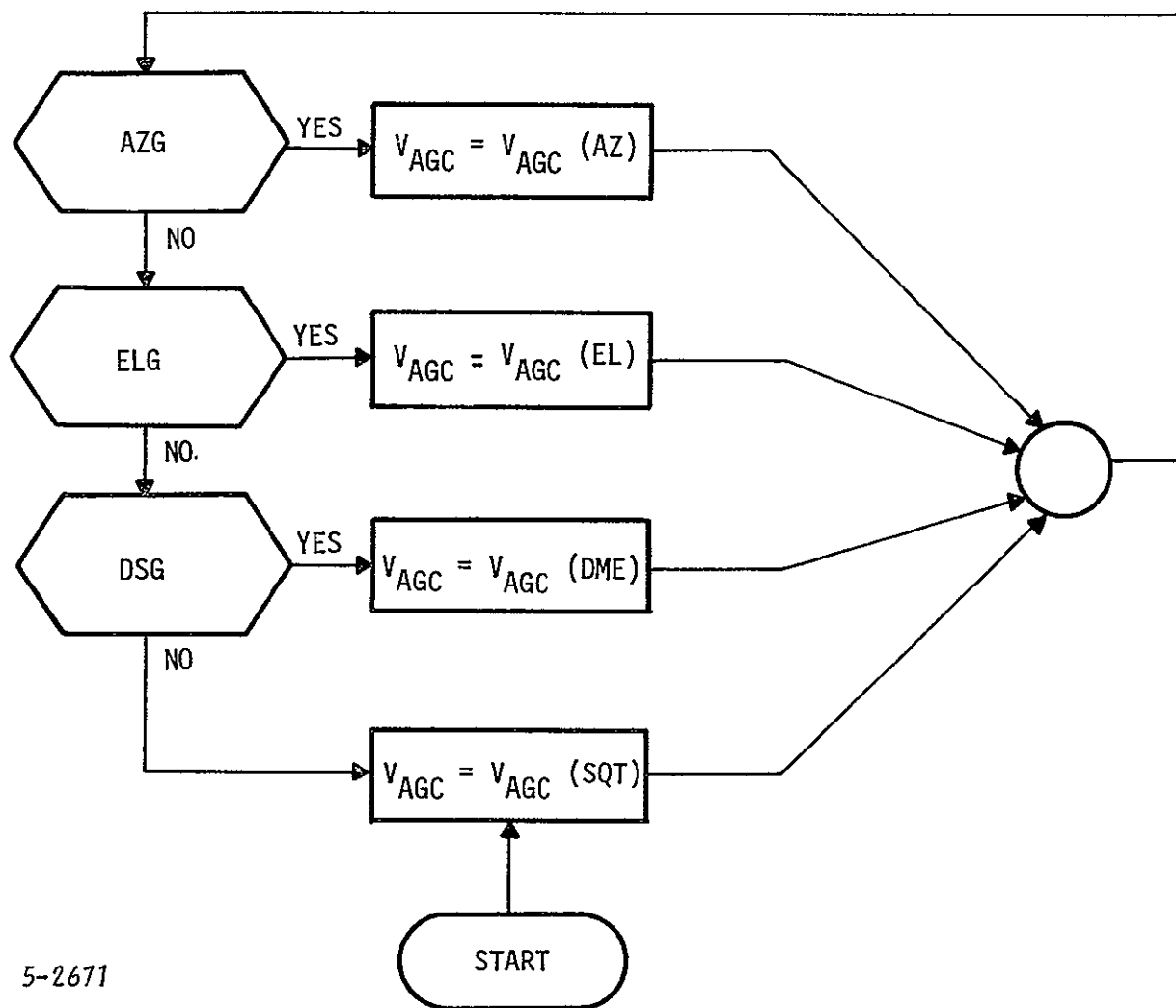
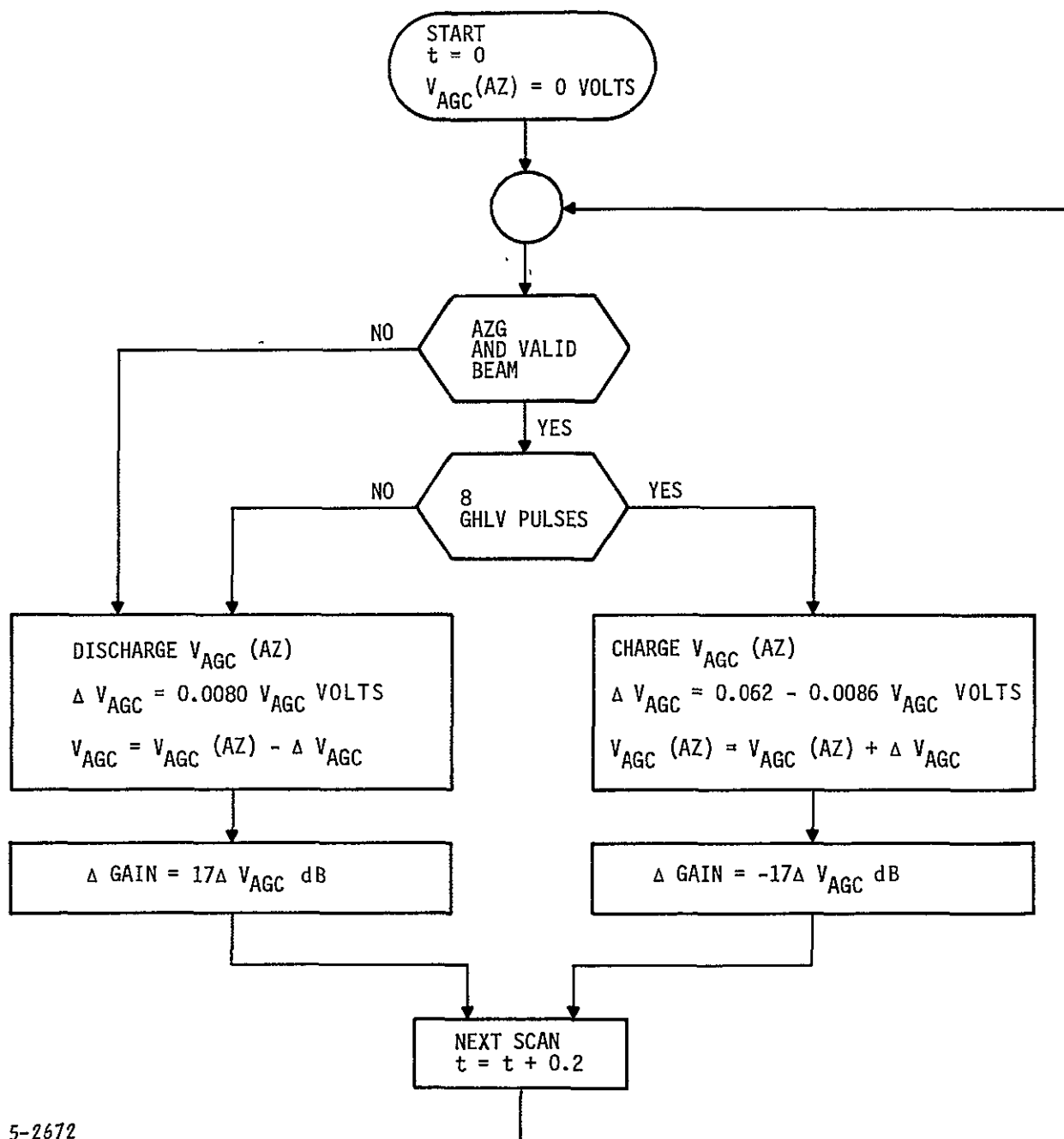


Figure 2-A12. AGC Selection



5-2672

Figure 2-A13. Flow Diagram of Azimuth AGC Operation

azimuth beam, the azimuth AGC voltage will decrease and the gain of the IF amplifier will increase. Should an azimuth flag be set, indicating no azimuth beam for one scan, the azimuth AGC voltage will also decrease. The AGC circuit consists of an RC combination which is charged up to increase AGC voltage and discharged to decrease AGC voltage (Figure 2-A14).

The function of the elevation and DME AGC is similar to that of the azimuth AGC. Separate RC circuits are provided for elevation and DME beams.

Figure 2-A15 shows the operation of squitter AGC. The squitter AGC establishes the maximum sensitivity of the receiver. It uses the DSQ signal which is generated by noise pulses to reduce the IF amplifier gain such that the LLV threshold is sufficiently above the noise rms level. This minimizes the effect of noise pulses crossing threshold. A simplified AGC squitter circuit is shown in Figure 2-A16.

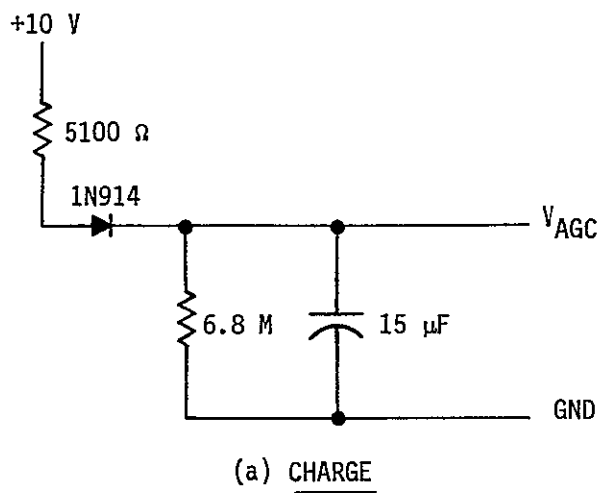
#### 2-A7. NAV SET PERFORMANCE AT ACQUISITION

Transition from the acquisition mode into the search mode depends on proper identification of the intercepted signal and correct choice of AGC voltage. In Figures 2-A17 through 2-A23, timing diagrams for elevation and azimuth acquisition mode operation are shown for various angular positions. Figures 2-A24 and 2-A25 show the main beam of the typical elevation and azimuth antenna patterns used in the timing diagrams. The AGC attempts to maintain the peak video signal level at 3.4 volts. For this nominal case, low level video corresponds to -10.6 dB and track level to -4.6 dB below the peak signal strength of the intercepted beam.

The most important requirement of acquisition from the standpoint of obtaining accurate positional information is for a beam gate to be on by the time the Nav Set starts intercepting track level video. In the MSBLS system, angular position is calculated from track level video accumulated during the

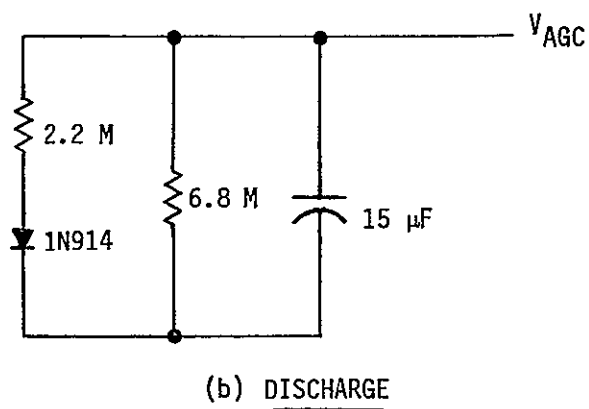
passage of the beam. If the tracker/computer has not generated the appropriate beam gate in time to accumulate the first track level video, some information will be lost. Consequently, the angular position accuracy will be affected.

In order for this not to happen, the Nav Set must intercept at least three pulses between the low video and track level thresholds for all angles and track levels. Using the typical elevation and azimuth beam patterns shown in Figures 2-A24 and 2-A25, Figures 2-A26 and 2-A27 show the number of pulses intercepted between threshold levels as a function of the track level. Graphs are drawn for various angular positions. As can be seen from these figures, enough pulses will be intercepted. At least 11 pulses will be intercepted for elevation beam acquisition and at least eight for azimuth beam acquisition.



$$\Delta V_{AGC} = 0.062 - 0.0086 V_{AGC} \text{ VOLTS/SCAN}$$

$$V_{AGC} = V_{AGC} - \Delta V_{AGC}$$



$$\Delta V_{AGC} = 0.0080 V_{AGC} \text{ VOLTS/SCAN}$$

$$V_{AGC} = V_{AGC} + \Delta V_{AGC}$$

5-2673

Figure 2-A14. Azimuth, Elevation, and DME AGC Circuits

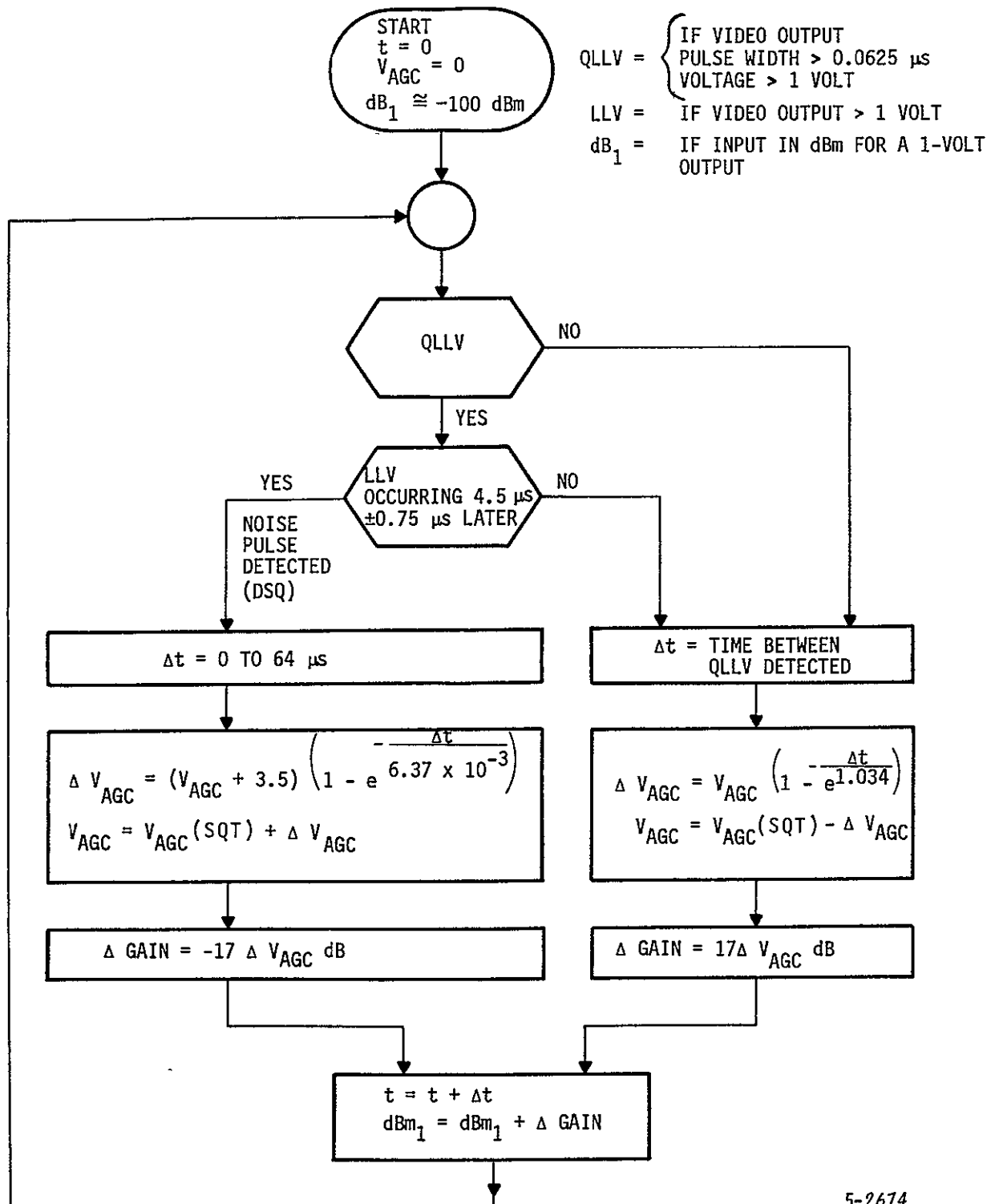


Figure 2-A15. Squitter AGC Flow Diagram

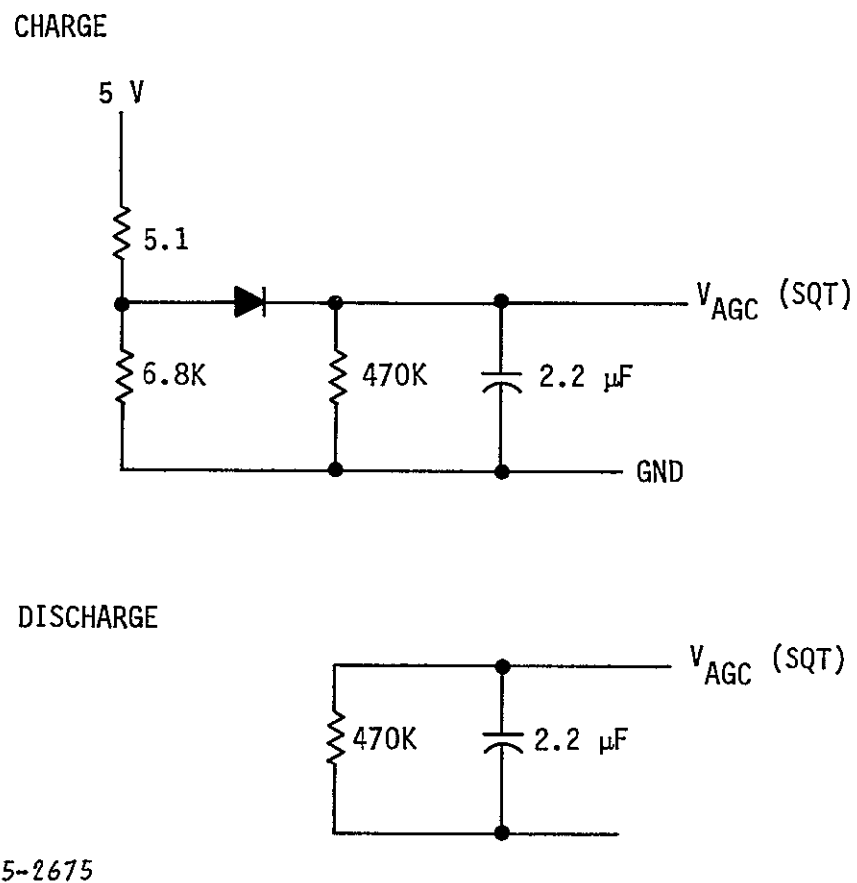


Figure 2-A16. Squitter AGC Circuit

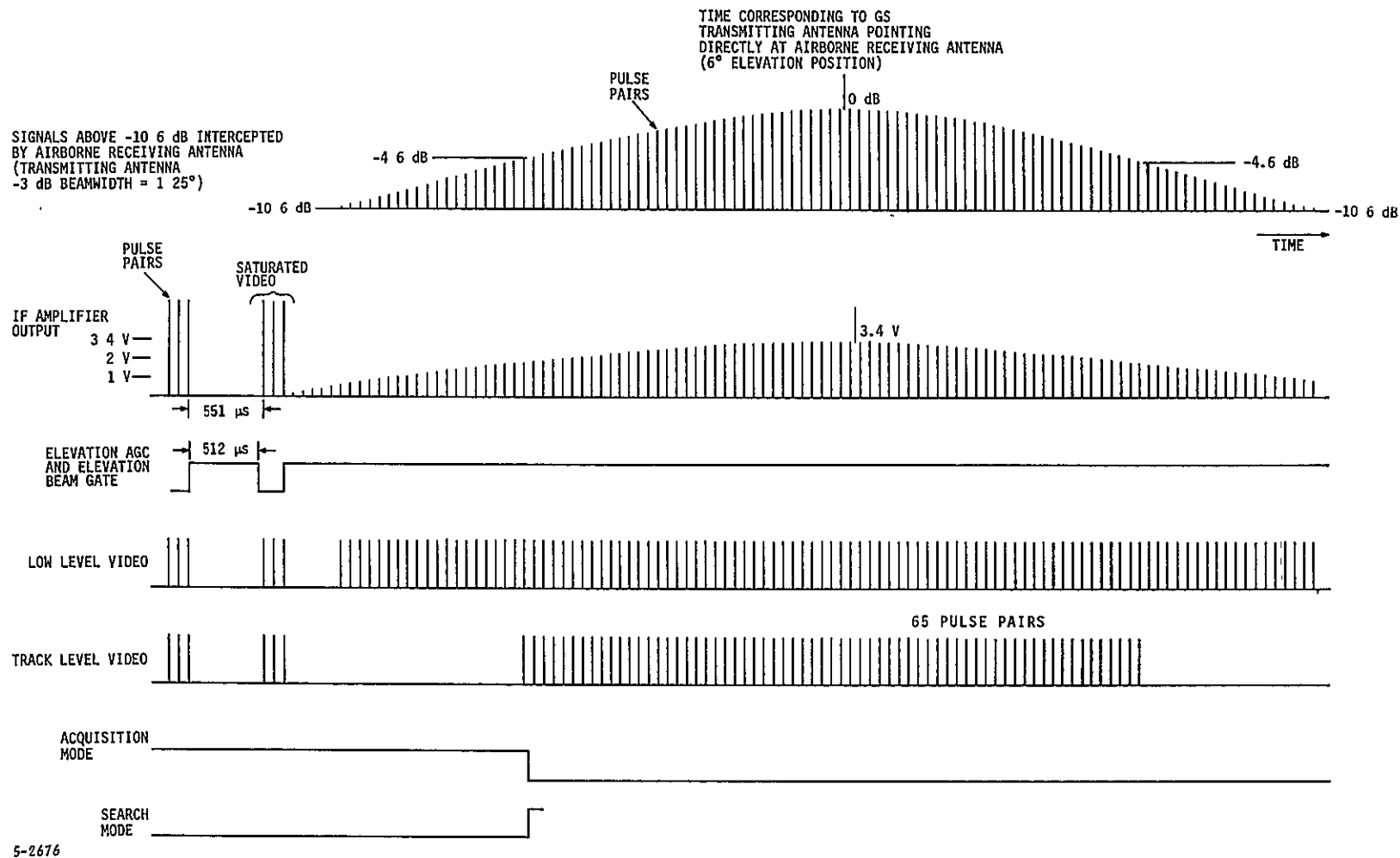


Figure 2-A17. Simulation of Acquisition for Elevation Nav Set Location (6-Degree Elevation)

SIGNALS ABOVE -10.6 dB INTERCEPTED  
BY AIRBORNE RECEIVING ANTENNA  
(TRANSMITTER ANTENNA  
-3 dB BEAMWIDTH = 1.25°)

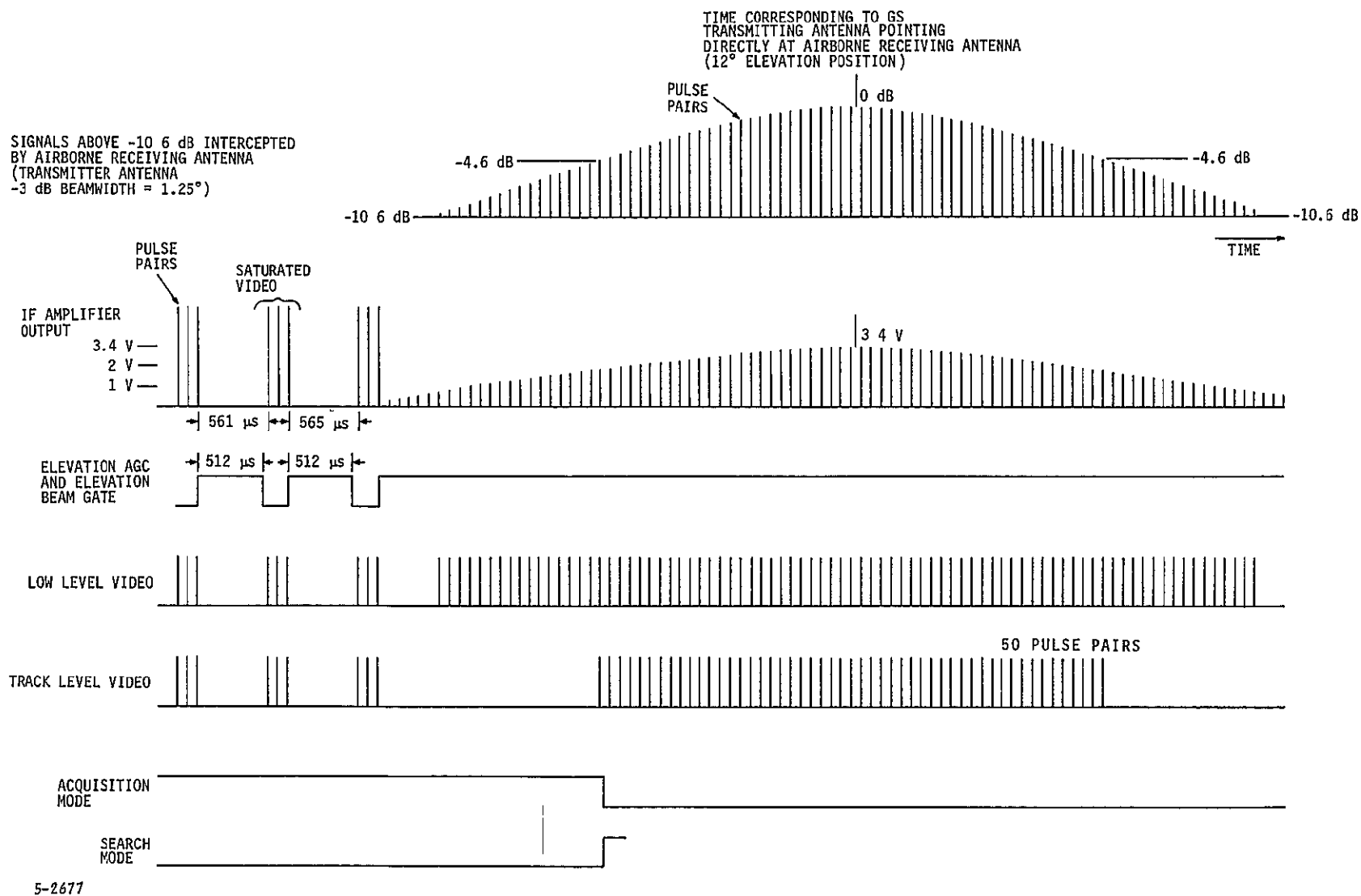


Figure 2-A18. Simulation of Acquisition for Elevation Nav Set Location (12-Degree Elevation)

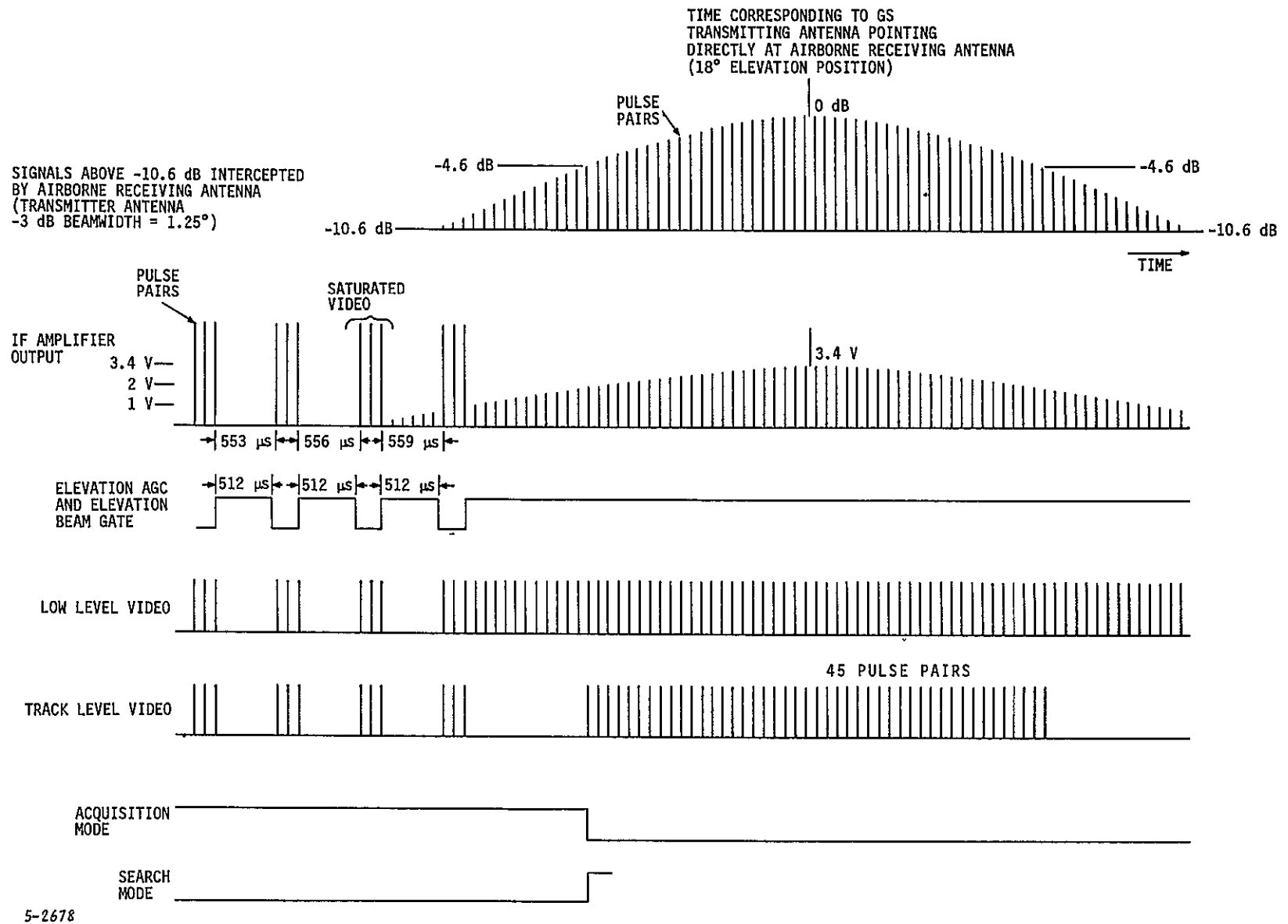
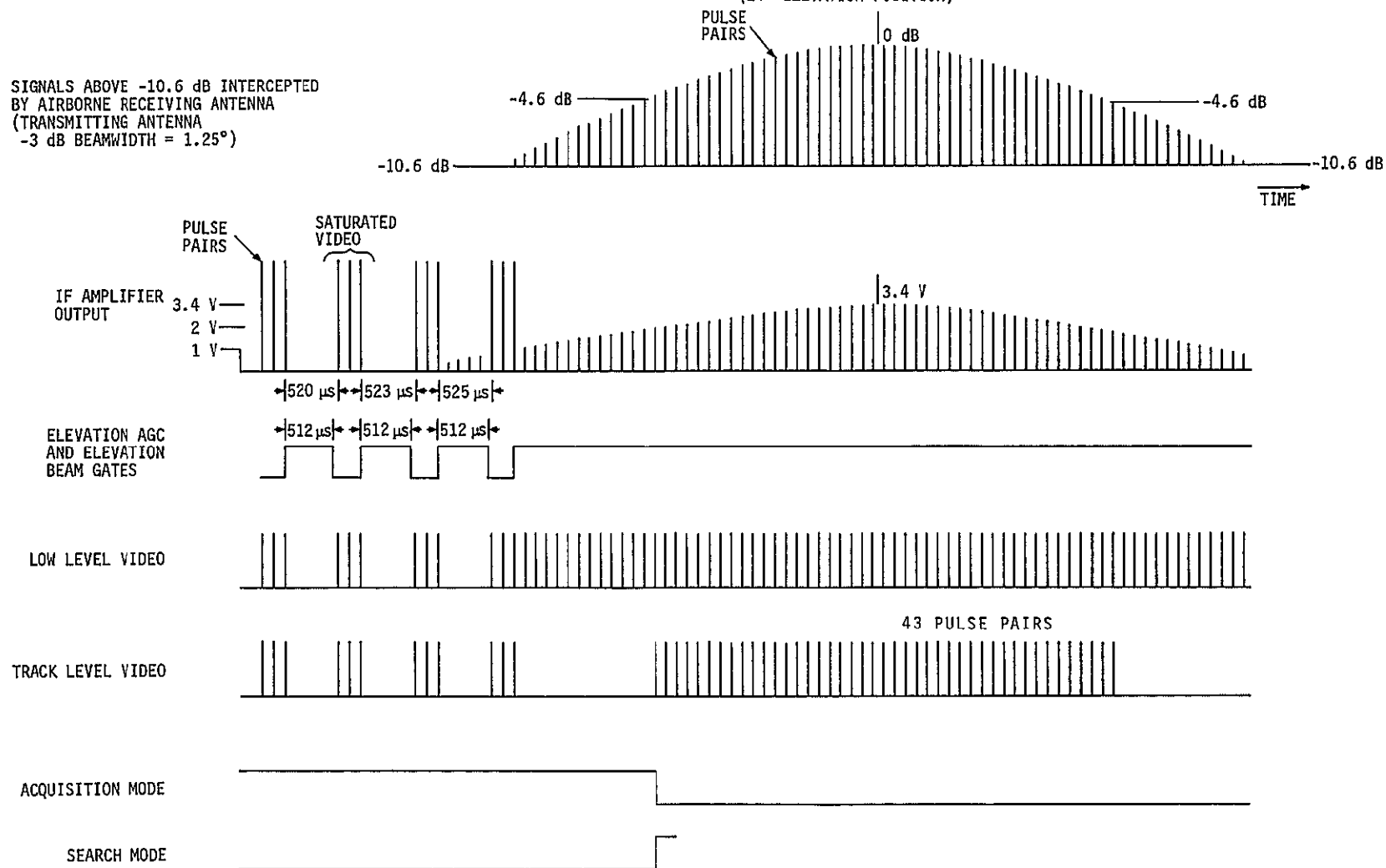


Figure 2-A19. Simulation of Acquisition for Elevation Nav Set Location (18-Degree Elevation)

SIGNALS ABOVE -10.6 dB INTERCEPTED  
BY AIRBORNE RECEIVING ANTENNA  
(TRANSMITTING ANTENNA  
-3 dB BEAMWIDTH = 1.25°)

TIME CORRESPONDING TO GS  
TRANSMITTING ANTENNA POINTING  
DIRECTLY AT AIRBORNE RECEIVING ANTENNA  
(24° ELEVATION POSITION)



5-2679

Figure 2-A20. Simulation of Acquisition for Elevation Nav Set Location (24-Degree Elevation)

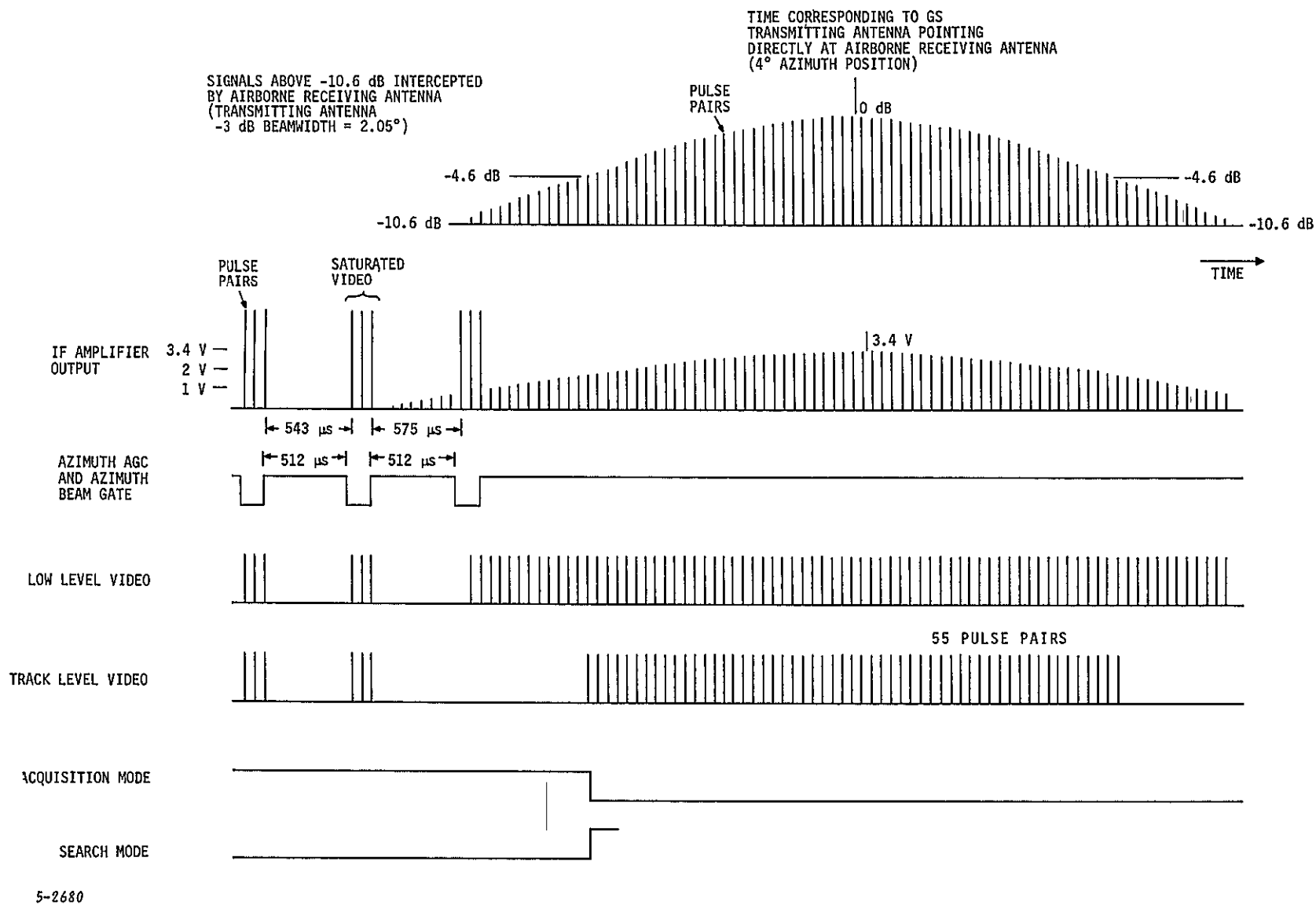


Figure 2-A21. Simulation of Acquisition for Azimuth Beam Nav Set Location (4-Degree Azimuth)

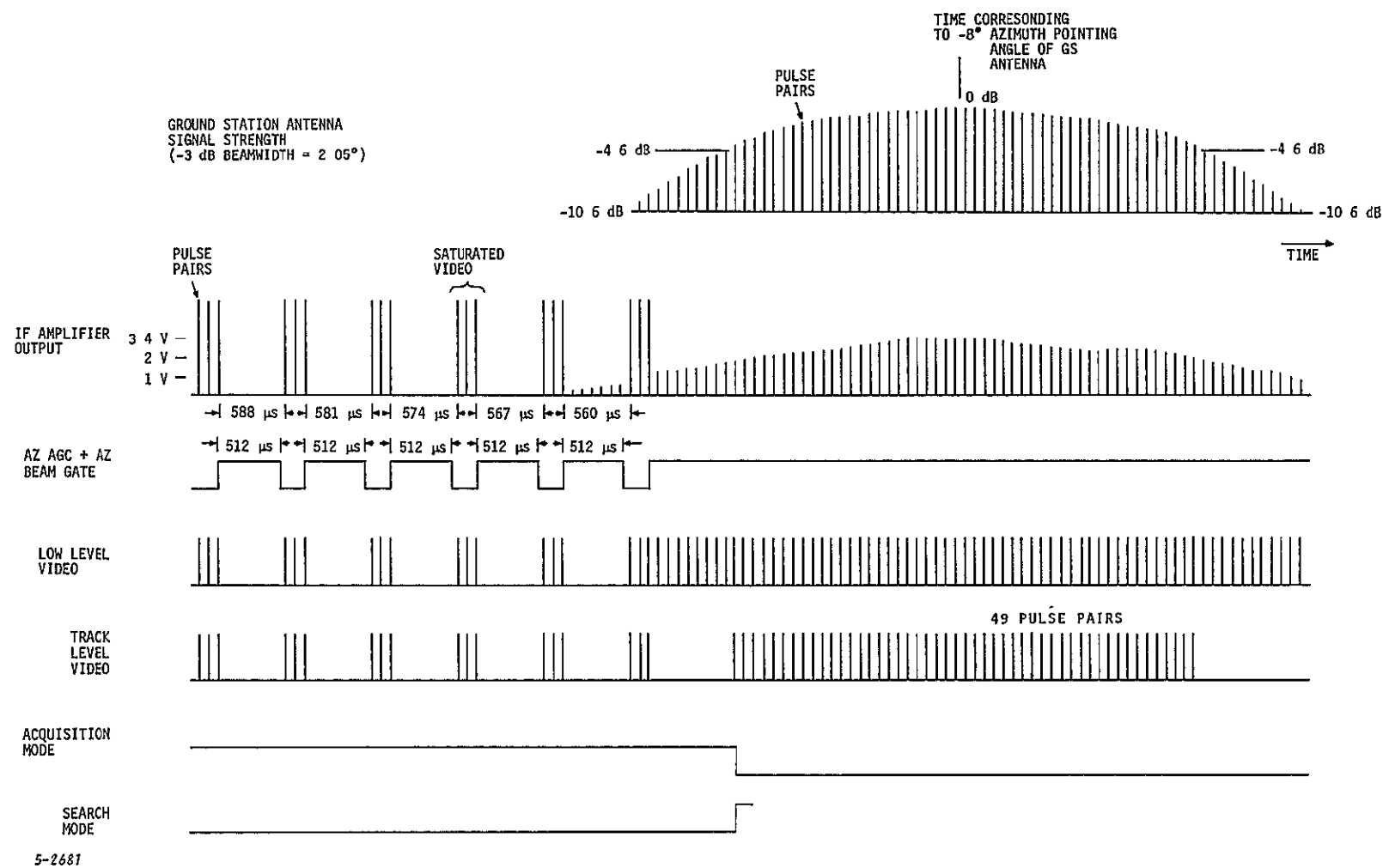
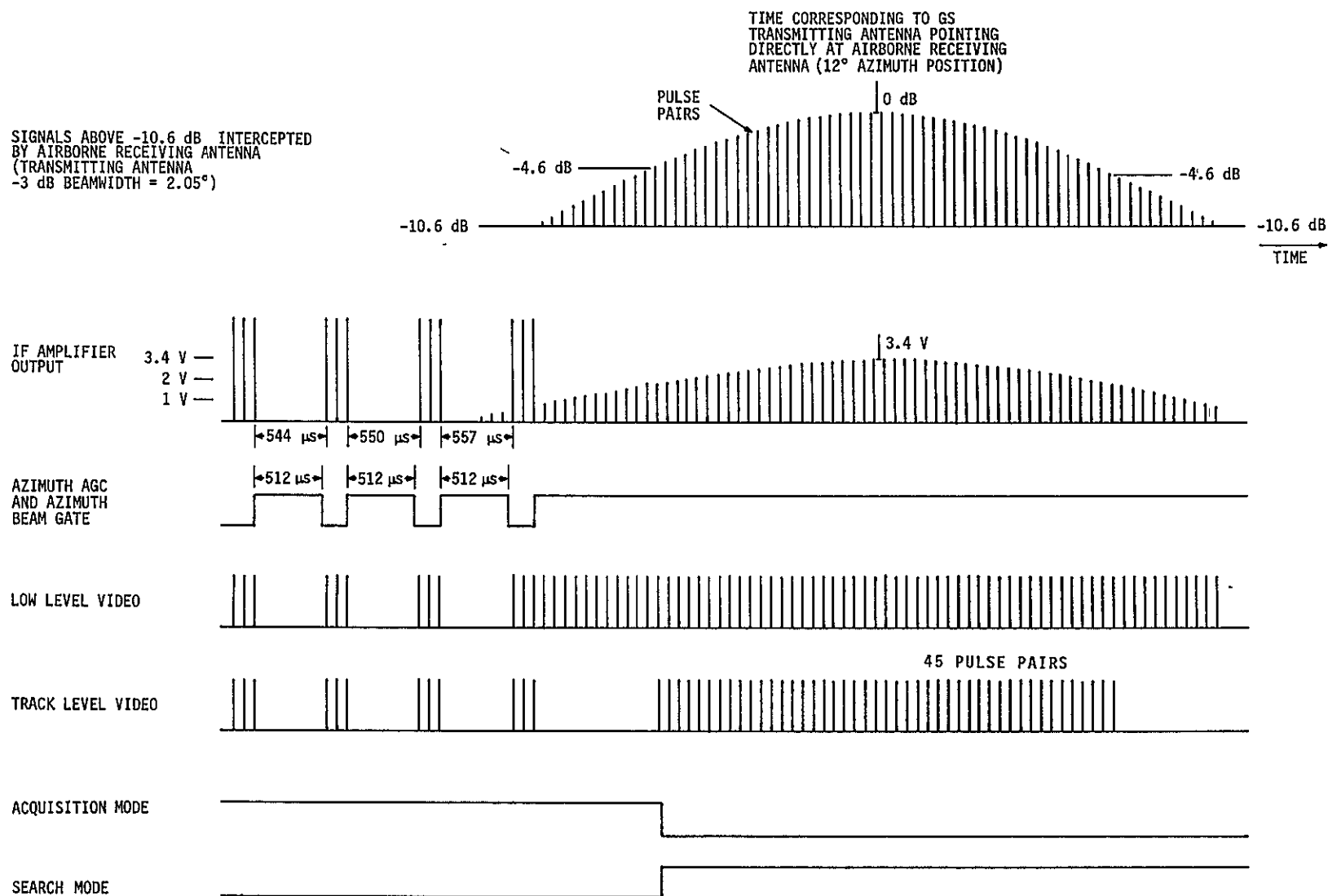


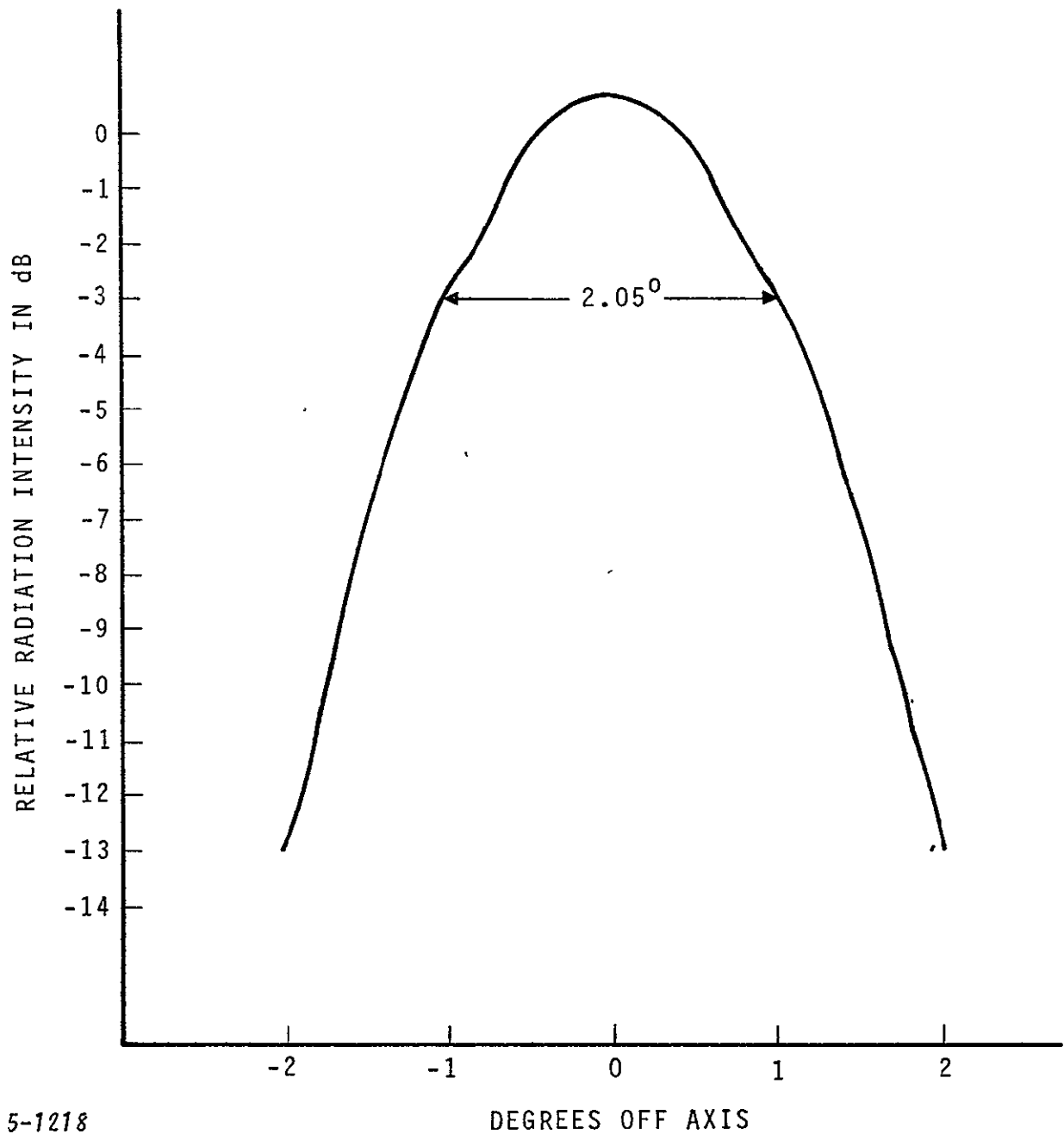
Figure 2-A22. Simulation of Acquisition for Azimuth Beam Nav Set Location (-8-Degree Azimuth)

SIGNALS ABOVE -10.6 dB INTERCEPTED  
BY AIRBORNE RECEIVING ANTENNA  
(TRANSMITTING ANTENNA  
-3 dB BEAMWIDTH = 2.05°)



5-2682

Figure 2-A23. Simulation of Acquisition for Azimuth Beam Nav Set Location (12-Degree Azimuth)



5-1218

Figure 2-A24. Main Beam of a Typical Azimuth Beam Antenna Radiation Pattern (-3 dB Beamwidth = 2.05 Degrees)

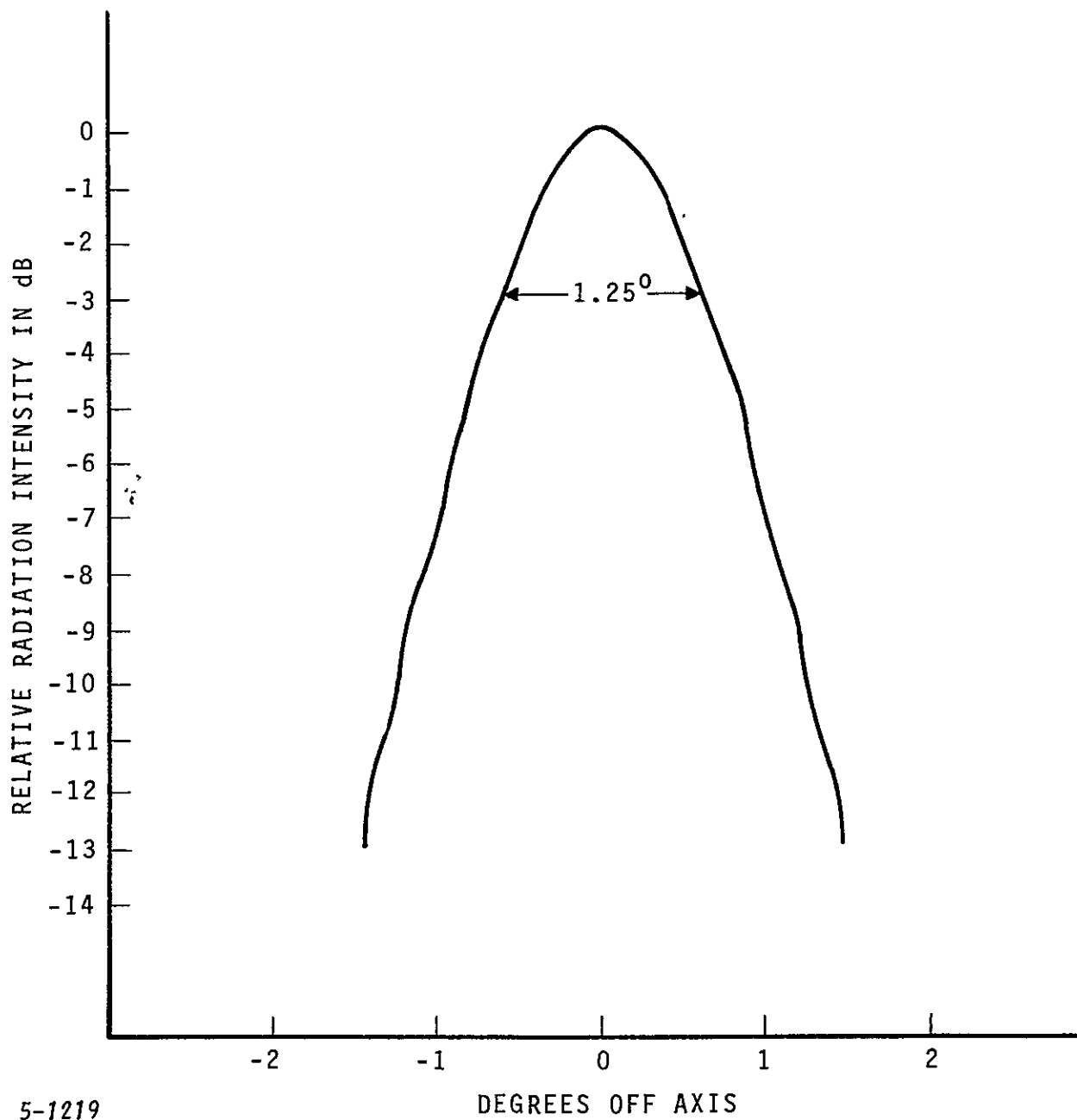


Figure 2-A25. Main Beam of a Typical Elevation Beam Antenna Radiation Pattern (-3 dB Beamwidth = 1.25 Degrees)

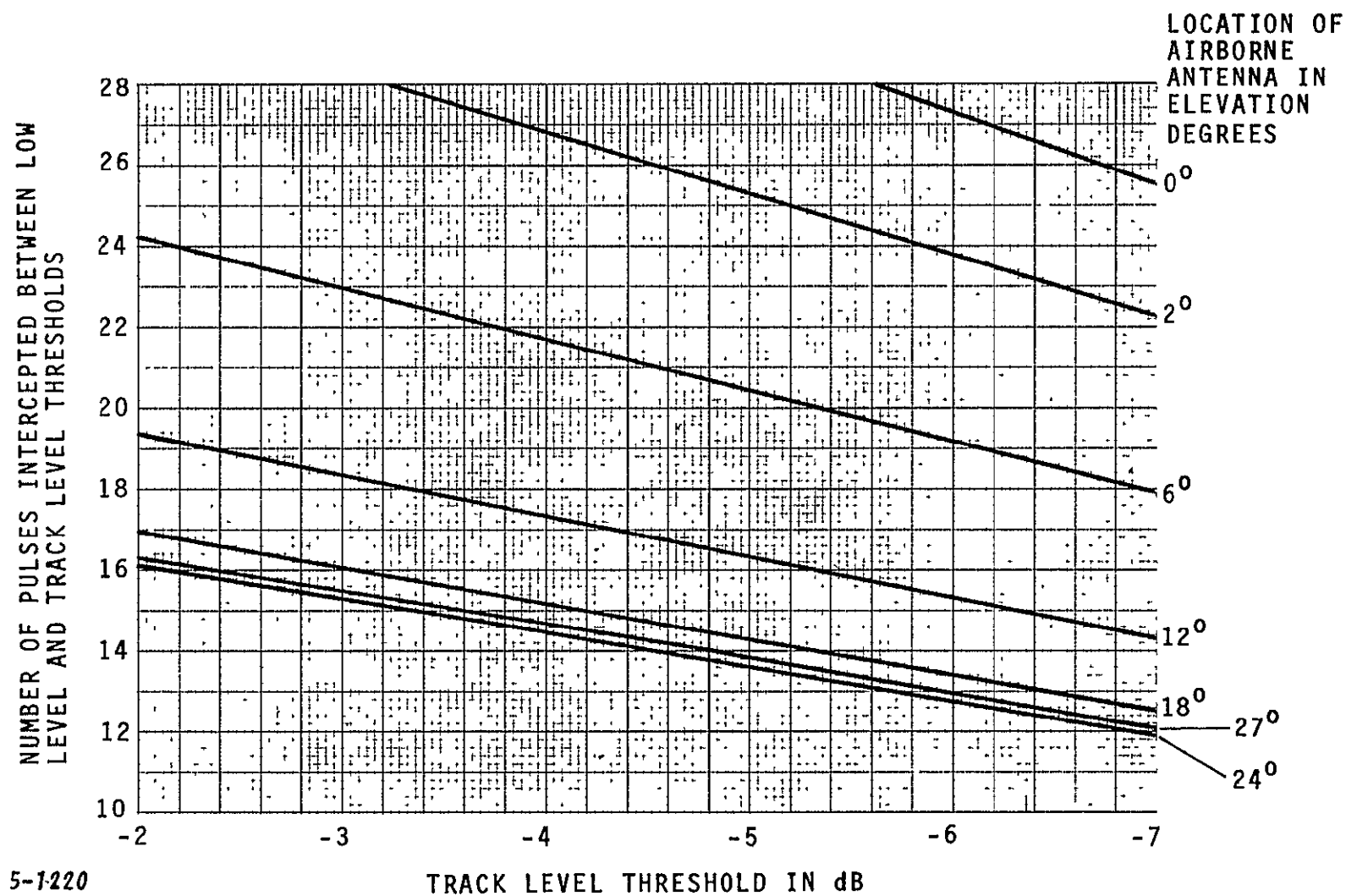


Figure 2-A26. Elevation Beam Acquisition - Number of Pulse Pairs Intercepted Between Low Level and Track Level Thresholds as a Function of Track Level Threshold

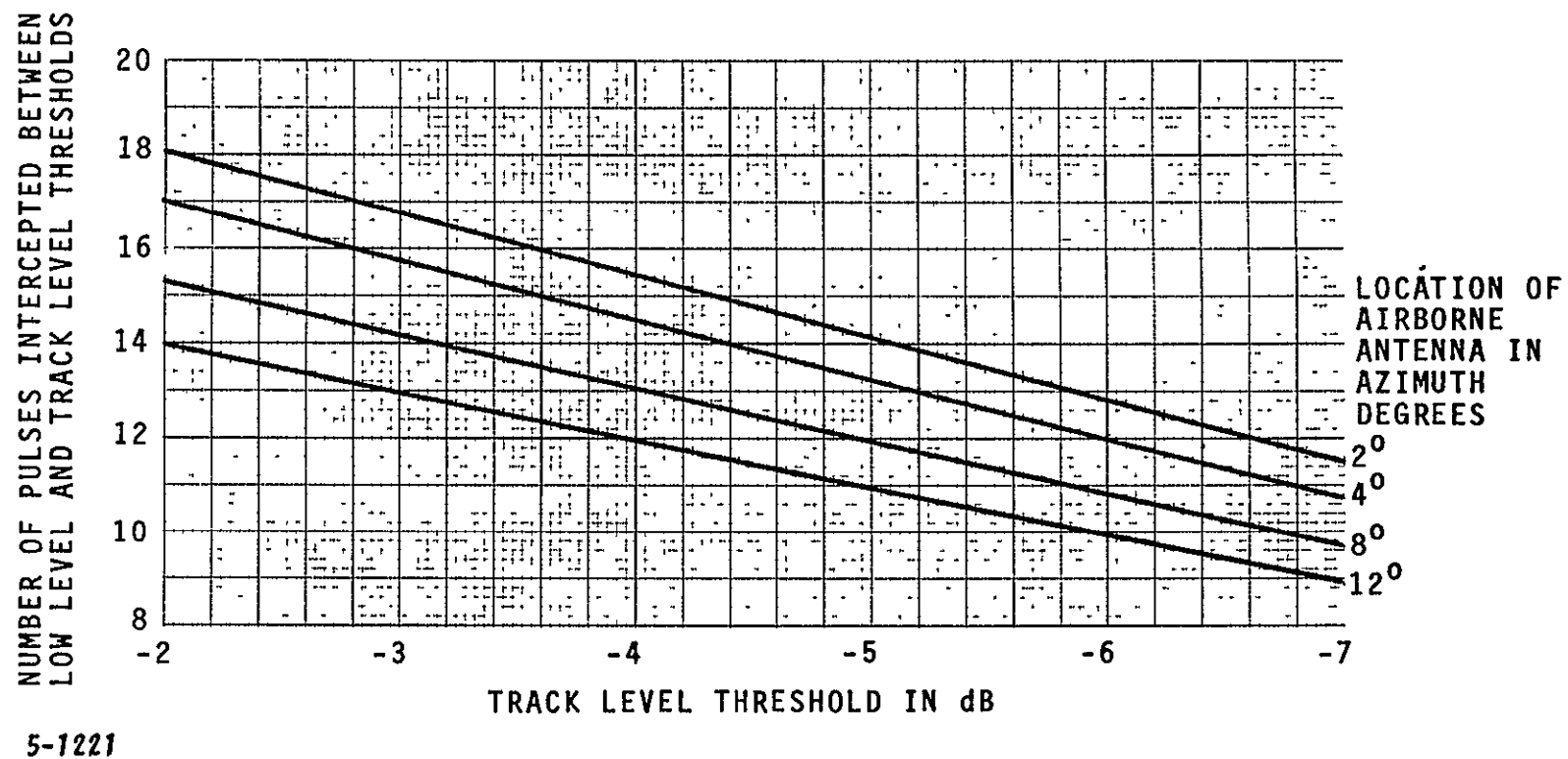


Figure 2-A27. Azimuth Beam Acquisition - Number of Pulse Pairs Intercepted Between Low Level and Track Level Thresholds as a Function of Track Level Threshold

PART B

MSBLS-GS ENCODER OPERATION

W. WONG

TECHNICAL REPORT Y220-04

INTERIM - OCTOBER 1975  
DECEMBER 1975

FINAL  
JANUARY 1976

## 2-B1. GENERAL

The MSBLS-GS provides azimuth and elevation information to the airborne navigation set through two oscillating antennas on the ground. Each of the two antennas radiate narrow, fan-shaped radio beams which are encoded with the ground antenna's angular position. Each antenna scans past the Orbiter five times per second or every 200 ms. The two antennas are synchronized with each other such that the azimuth and elevation beams alternately sweep past the Orbiter within this 200 ms period. Signals called sector gates are generated by the MSBLS-GS encoding system to allow only one beam to be transmitted at a time (Figure 2-B1, part a and Figure 2-B2, part a).

The azimuth antenna scans horizontally across the approach volume. Mechanically the azimuth antenna oscillates with an amplitude of  $\pm 44$  degrees azimuth about the runway centerline reference. The azimuth beam is transmitted only while the azimuth antenna is pointing  $\pm 15$  degrees azimuth. During the time the azimuth beam is off, elevation or DME information is being transmitted.

The elevation antenna oscillates  $\pm 24$  degrees from the 15 degrees elevation angle and transmits only from 0 to 30 degrees elevation.

The azimuth and elevation beams consist of trains of RF pulses that are  $0.3 \mu s$  in duration. Information identifying the beam and indicating the pointing angle of the transmitting antenna are encoded onto the beam by modulation of the time spacing between RF pulses.

Closely spaced pulse pairs with a unique identity spacing identifies the transmitting beam. The identity spacing of the azimuth beam is  $10 \mu s$  when the beam is on the fly-left side of the runway centerline, and it is  $14 \mu s$  when the beam is on the fly-right side (Figure 2-B1, part d). The elevation identity spacing is  $12 \mu s$  (Figure 2-B2, part d).

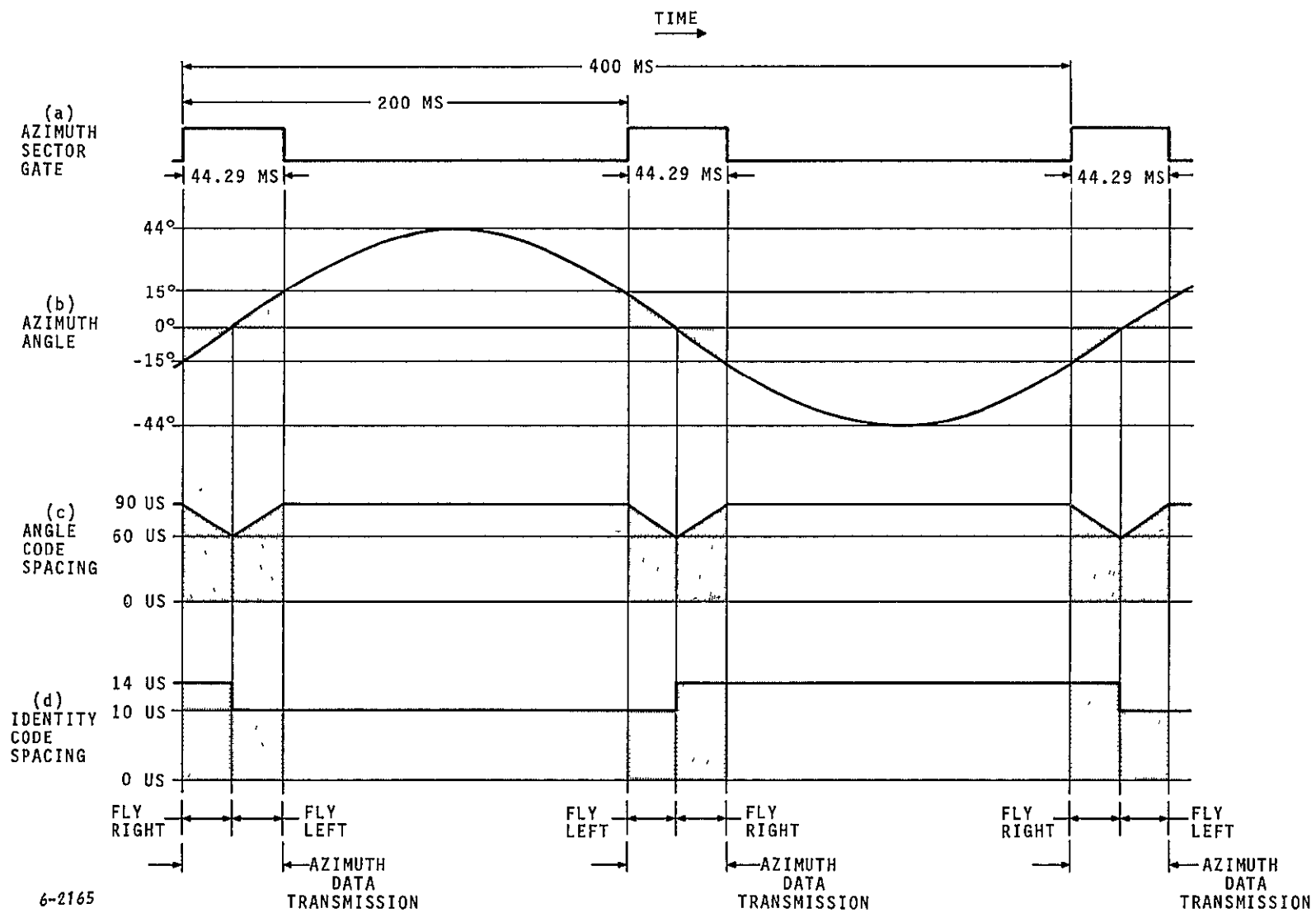


Figure 2-B1. Azimuth System Timing

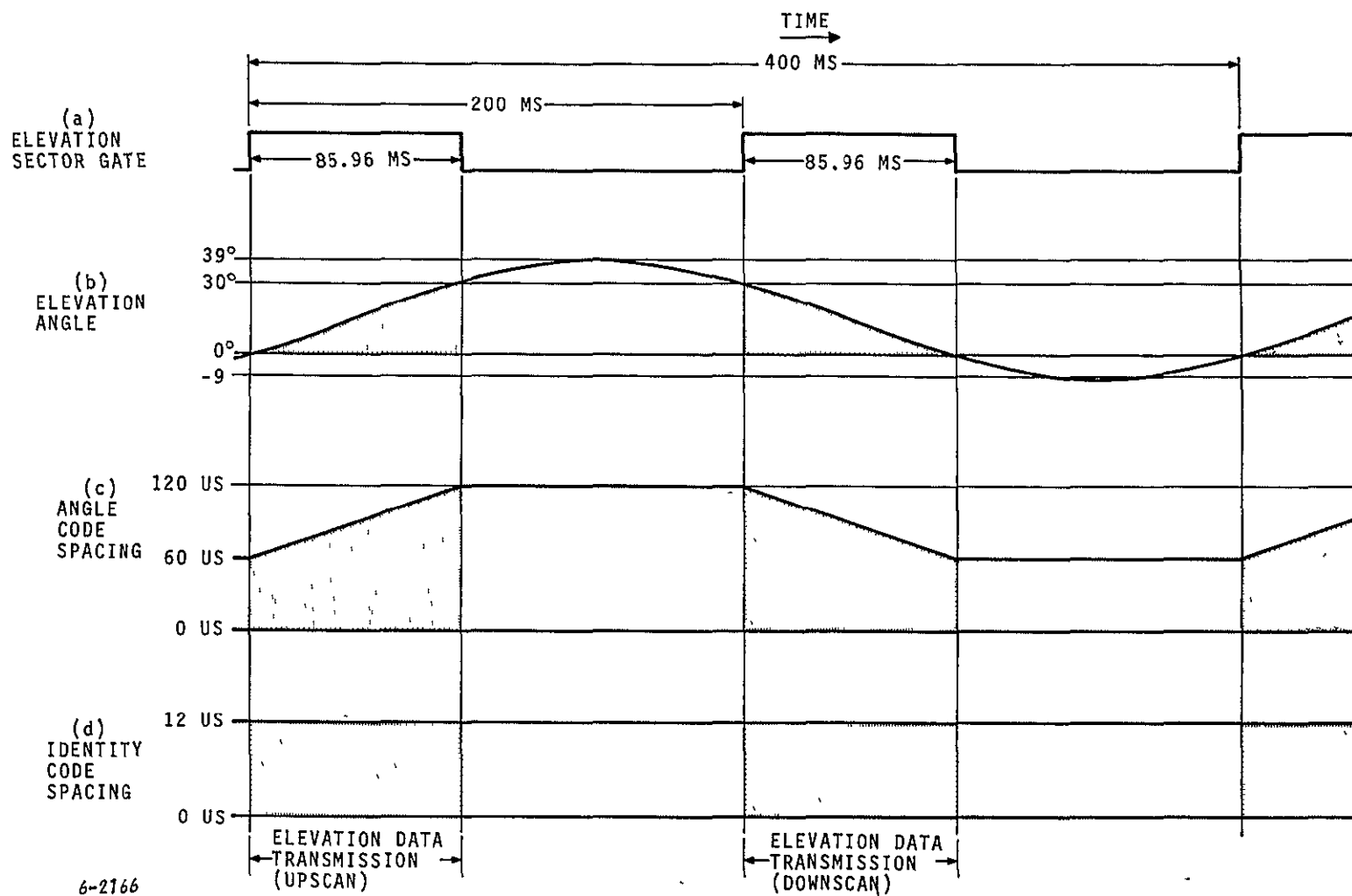


Figure 2-B2. Elevation System Timing

The data time spacing between two adjacent pairs of pulses provides angular information. The azimuth beam data spacing is initially  $90\ \mu\text{s}$  when the azimuth antenna starts to scan from 15 degrees azimuth. The data spacing decreases, at a rate of  $2\ \mu\text{s}$  per degree, to  $60\ \mu\text{s}$  when the antenna scans past the runway centerline (Figure 2-B1, parts b and c). Then the azimuth data spacing increases to  $90\ \mu\text{s}$  when the beam scans to 15 degrees on the opposite side of the runway centerline.

When the elevation antenna is scanning up, the elevation beam data spacing is  $60\ \mu\text{s}$  at the antenna pointing angle of 0 degrees elevation and increases at a rate of  $2\ \mu\text{s}$  per degree to  $120\ \mu\text{s}$  at the antenna pointing angle of 30 degrees (Figure 2-B2, parts b and c). When the elevation antenna is scanning down the data spacing changes from  $120\ \mu\text{s}$  to  $60\ \mu\text{s}$ .

## 2-B2. SYSTEM REQUIREMENTS

The MSBLS ground station has an azimuth encoder and an elevation encoder which generate the necessary signals to run the azimuth and elevation transmitters. In order to generate these signals each encoder counts pulses from an angle data pickoff (ADP) and translates the pulse counts into time intervals which corresponds to beam identity and antenna position.

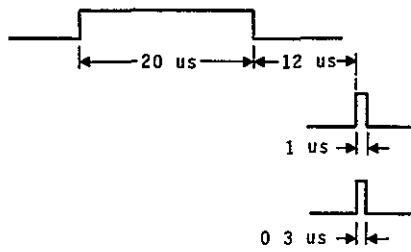
Each RF pulse the transmitter generates requires a  $20\text{-}\mu\text{s}$  charge-gate pulse followed  $12\ \mu\text{s}$  later by a  $1\text{-}\mu\text{s}$  trigger pulse (Figure 2-B3, part a). First, in order to produce the identity pulse pair, a pair of charge gate and trigger pulses are needed (Figure 2-B3, part b). The first RF pulse is generated with the identity pulse charge gate (IPC) and the identity pulse (IPLS). The second RF pulse of the pair is generated with the angle pulse charge gate (APC) and the angle pulse (APLS). The spacing between the IPLS and the APLS represents the identity spacing.

The data spacing (DS) code  $[60 + 2\theta(K)]\ \mu\text{s}$  is encoded in the time interval between successive APLS's.  $\theta(K)$  represents the antenna angular position

(a) CHARGE GATE PULSE

TRIGGER PULSE

GENERATED RF PULSE

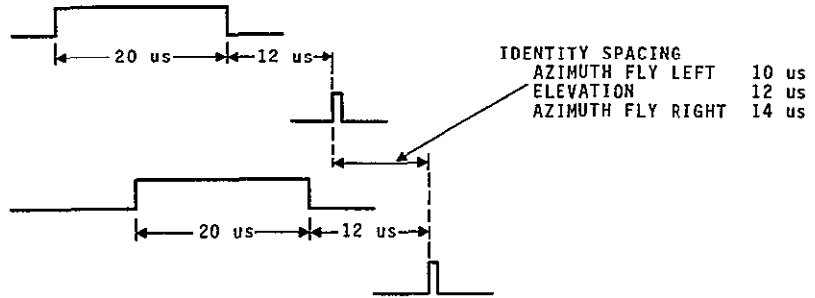


(b) IDENTITY PULSE  
CHARGE GATE (IPC)

IDENTITY PULSE (IPLS)

ANGLE PULSE  
CHARGE GATE (APC)

ANGLE PULSE (APLS)



(c) IPC

IPLS

APC

APLS

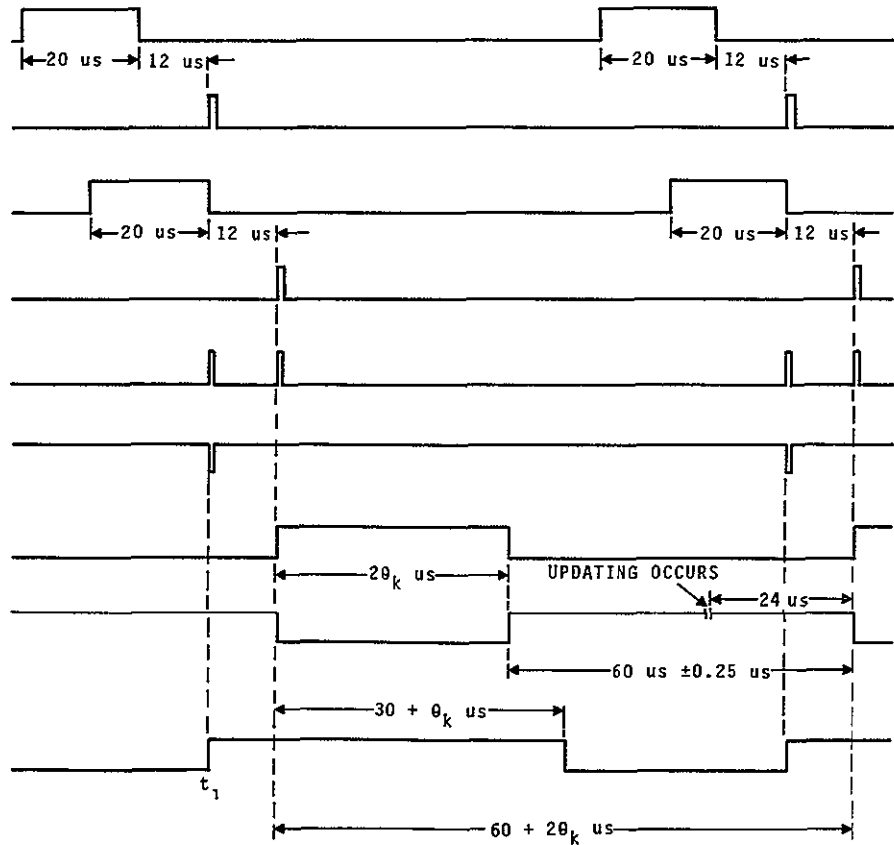
GENERATED RF

VARIABLE INTERVAL LOAD

VARIABLE INTERVAL ON

FIXED INTERVAL ON

UPDATE MONITORING  
ENABLE



6-2167

Figure 2-B3. Angle Encoding Timing

midway in time between successive APLS's and quantized to the nearest 1/8th degree (Figure 2-B3, part c). If  $t(K)$  is the time the Kth APLS occurs and  $DS(K)$  is the time to the next APLS then  $DS(K)$  represents the antenna position at time  $t(K) + [30 + \theta(K)]$ .

The data spacing code consists of a variable interval equal to  $2 \theta(K) \mu s$  and a fixed  $60 \mu s$  interval. The variable interval starts timing out at time  $t(K)$  (Figure 2-B3, part c) with angular position supplied at time  $t(i)$ . At the end of the variable interval the  $60 \mu s$  fixed interval is generated. Since the variable interval was generated using angle data at time  $t(i)$ , the total data interval must somehow be updated to indicate the angular position at time  $t(K) + [30 + \theta(K)]$ . This updating is accomplished by monitoring the change in angular position from time  $t(i)$  to time  $t(K) + [30 + \theta(K)]$  and inserting the update during the fixed interval timing. The updating will either decrease or increase the  $DS(K)$  interval, depending on whether the antenna is scanning toward an increasing or decreasing angular position. The fixed interval timing is done using a counter which also generates timing signals for generating IPC, IPLS, APC, and APLS at the proper time.

### 2-B3. DETAILED DESCRIPTION

The operations described in paragraph 2-B2 for azimuth and elevation are performed by two encoder systems each consisting of an incremental shaft encoder and a digital encoder. A block diagram of the encoder system is shown in Figure 2-B4.

The shaft angle encoder, also referred to as the angle data pickoff (ADP) is used to indicate the angular position of the azimuth or elevation antennas. The ADP, due to the mechanical scan of an antenna, produces the following signals:

- a. A square wave (ADP signal) which indicates angular change in eighths of a degree.

b. A sector gate (SG) which is 30 degrees wide for both azimuth sector gate (ASG) and elevation sector gate (ESG).

c. A level signal (DIR) which indicates the direction an antenna rotates

d. A center scan pulse.

e. A scan limit pulse

The ADP, SG, and DIR are sent to the digital encoder to be used for angle encoding.

Using angular data furnished by the ADP, the digital encoder provides the timing for, and the generation of, the IPC, IPLS, APC, and APLS signals previously described. When the SG is high, the quantizer uses the ADP signal to produce  $0.25 \mu s$  pulses which are synchronized to a 4-MHz clock and triggered or set off by transitions of the ADP square wave signal. For azimuth encoding, there are 240 such transitions during the azimuth sector gate. Therefore, 240 QADP's are produced, one for each eighth of a degree angle increment during the 30-degree sector. Similarly 240 QADP's are generated by the elevation ADP quantizer during each elevation sector gate. The time between successive QADP pulses for azimuth varies from 180 to  $200 \mu s$  and for elevation, which is scanning at a slower angular rate, varies from 330 to  $430 \mu s$  (Figures 2-B5 and 2-B6).

Each QADP produced is accumulated by the ADP counter which is a binary up/down counter. The output of the binary counter is an 8-bit binary code which represents the instantaneous antenna angular position quantized to the nearest eighth of a degree. The format of this weighted binary code is shown below:

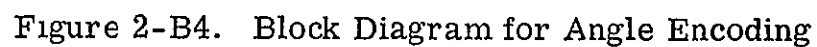
$$\text{Weighted Binary Code} = B_7 B_6 B_5 B_4 B_3 B_2 B_1 B_0 \quad (3a)$$

$$\begin{aligned} \text{Quantized Angle} = 1/8 [ & (B_7 \times 2^7) + (B_6 \times 2^6) + (B_5 \times 2^5) + \\ & (B_4 \times 2^4) + (B_3 \times 2^3) + (B_2 \times 2^2) + \\ & (B_1 \times 2^1) + (B_0 \times 2^0)] \end{aligned} \quad (3b)$$

Before the sector gate occurs, the ADP must be preset to a binary value which indicates the antenna angular position when the sector gate starts. In addition, controls are provided by the up/down control which directs the ADP counter to count up when the antenna is scanning toward an increasing angular position and to count down when it is scanning toward a decreasing angular position.

For azimuth, the ADP counter is preset to the weighted binary equivalent of 15 degrees any time a new azimuth sector begins. At this time the up/down control directs the ADP counter to count down. When the ADP counter has counted down 120 QADP's to zero, the azimuth antenna is pointing directly toward the runway centerline or zero degrees azimuth angle. At this point the up/down control senses that the ADP counter has reached zero and redirects the ADP counter to count upward. The ADP counter then counts up 120 QADP's until it has reached the binary equivalent of 15 degrees, at which time the sector gate ends thereby inhibiting further QADP pulses until the next sector gate occurs. This sequence of events is true for both the fly right to fly left scan and the fly left to fly right scan.

For elevation, the upscan preset and count direction differs from the downscan preset and count direction. During upscan, the ADP counter is preset to 0 degree and placed in a count up mode. During downscan, the ADP counter is preset to 30 degrees (240 QADP counts) and placed in a count down mode. The up/down control logic sets the count direction via the direction signal from the angle data pickoff.



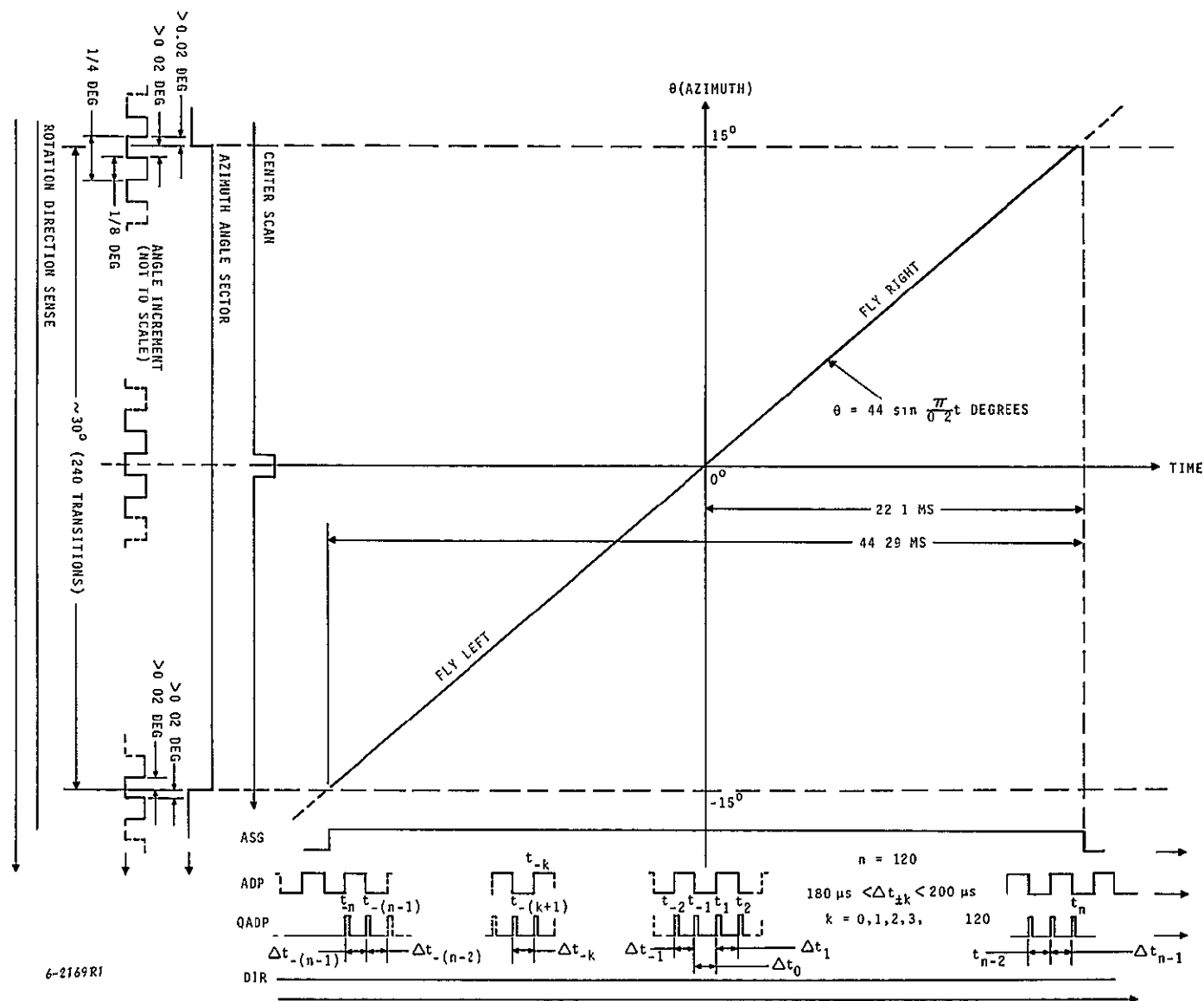


Figure 2-B5. Azimuth Angle Position Translation

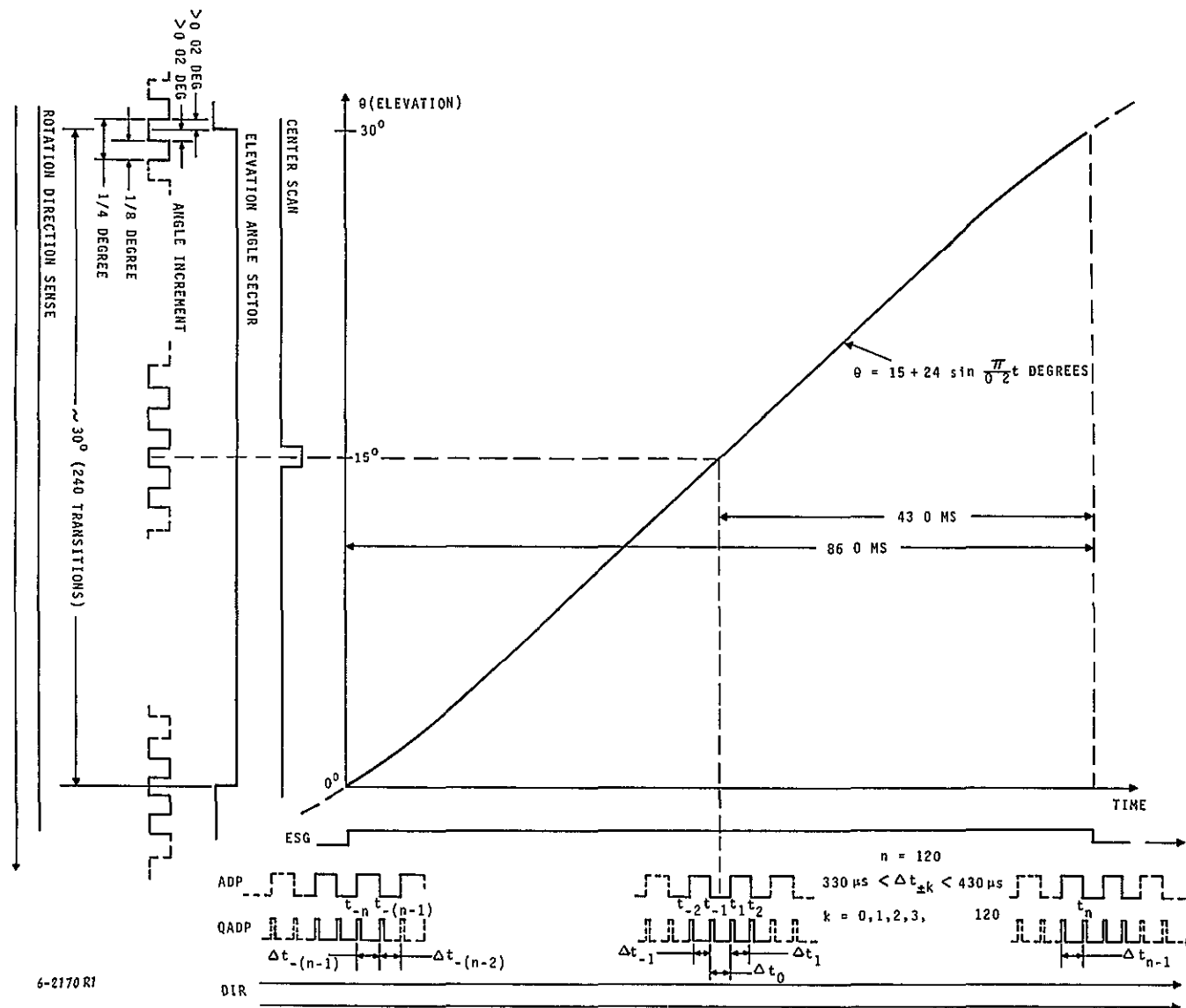


Figure 2-B6. Elevation Angle Position Translation

The angular information in the ADP counter is sampled under the control of the variable interval load control. Whenever an IPLS occurs, the VILD signal is generated which loads the contents of the ADP counter into the variable interval counter and into update enable. Let this binary code contained in the ADP counter represent angle  $\theta(i)$ .

At the occurrence of the IPLS the variable interval enable generates the signal VON to start the variable interval counter counting down 4-MHz clock pulses. When the counter counts down to zero a time interval equal to  $2\theta(i)$  will have elapsed. At this time the variable interval enable signal, VON, changes state to stop the variable interval counter and presets the fixed interval counter such that the transmitter charge gates and triggers APLS, APC, IPLS, and IPC are generated with the proper timing. APLS will occur  $60 \mu s \pm 0.25 \mu s$  from the time the variable interval ends. The fixed  $60 \mu s$  time interval is adjusted  $\pm 0.25 \mu s$  using the updating scheme previously discussed. The update enable, update control, and encoding gates perform the task of monitoring the time from an occurrence of IPLS (when the initial sample occurred) to a time halfway from one APLS to the next APLS for the occurrence of a QADP pulse thus making the update available to the fixed interval counter during the timing of the  $60 \mu s$  fixed interval.

Once IPLS, IPC, APLS, and APC are generated these signals are gated with the sector gate before going to the transmitter to ensure that RF transmission occurs during a sector gate.

75-1 TASKS 03 AND 05

PART C

MSBLS AZIMUTH/DME AND ELEVATION ANGLE FIELD MONITORS

C. CREEDON

TECHNICAL REPORT Y220-08

INTERIM - MAY 1976

FINAL

JUNE 1976

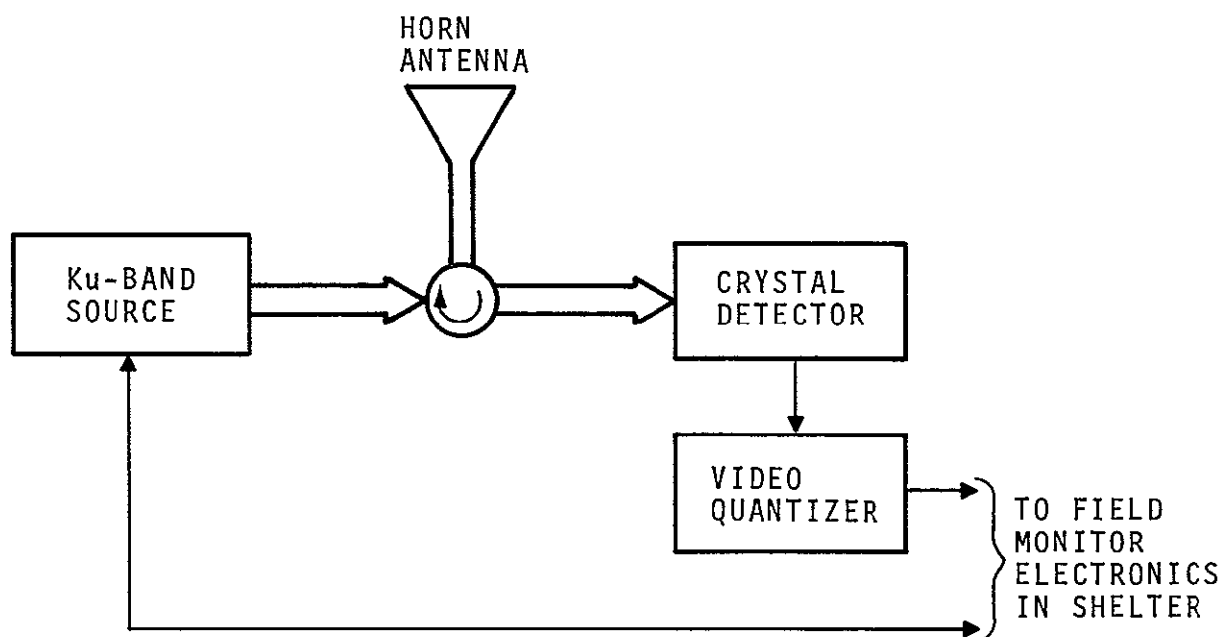
## 2-C1. GENERAL

The field monitors consist of two subassemblies. An RF unit is pole mounted about 200 feet in front of the transmitter site. This unit samples the radiated landing system signal and routes the sample to the second unit for processing. The second unit is located in the equipment rack in the shelter.

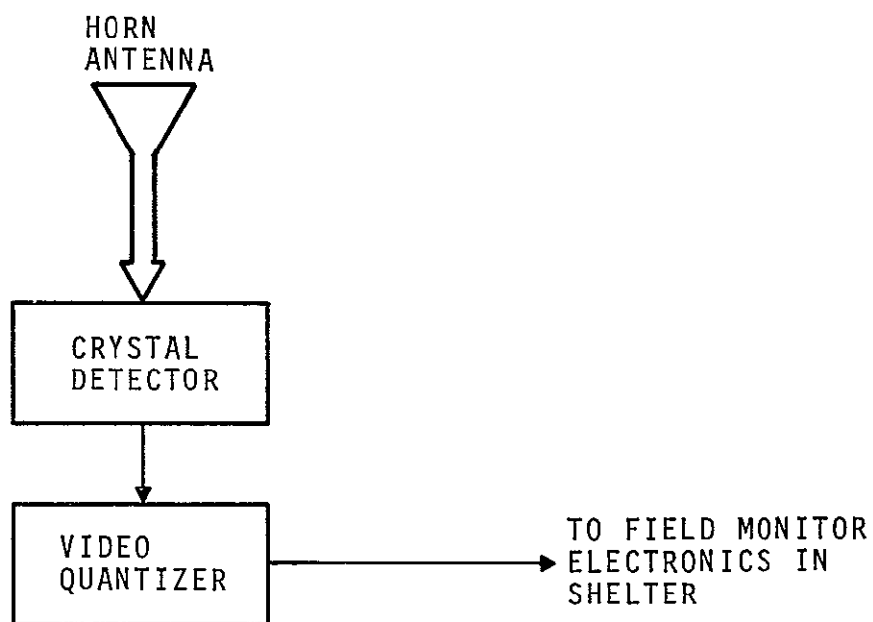
The field monitors are triple redundant. An out of tolerance condition must be declared by two of the three monitors to initiate an alarm. For simplicity, the following discussion deals with a single field monitor. The field monitor is common to both primary and backup equipments. Primary power (24 Vdc) for the unit is supplied by either the primary or backup equipment depending on which is radiating.

The elevation and azimuth/DME field monitors differ mainly by the added equipment for DME monitoring at the azimuth/DME site. Figure 2-C1 shows block diagrams of the pole mounted RF units. The angle monitoring process is similar for azimuth and elevation. Essentially, the angle field monitors are receiver/decoders looking for a specific angle signal. The monitor receives the angle coded RF signal, converts it to digital form and accumulates its deviation from the signal it expects to receive. The DME field monitor interrogates the DME ground station, detects the reply and compares it to a preset value via digital processing. The azimuth/DME field monitor contains an RF source for the interrogate signal and a circulator to isolate the detector from the interrogate. In this way, the same antenna is used for DME interrogate and azimuth and DME signal reception. The gain of the amplifier in the video quantizer is switched to provide greater gain during DME time to compensate for the lower gain of the DME transmitting antenna.

The field monitor tolerances and processing specifics are based upon ensuring that an alarm is sounded only when an out of tolerance condition



A. AZIMUTH/DME FIELD MONITOR



6-2171

B. ELEVATION FIELD MONITOR

Figure 2-C1. Block Diagram - Pole Mounted Equipment Field Monitors

exists. Basically, this is done by setting the alarm threshold quite high and integrating from scan to scan.

The specifications require the angle field monitor to alarm for two conditions: a shift in the radiated angle data of 0.125 degrees or more; and the occurrence of four or more missed pulses in a beam passage.

The angle field monitor detects changes in the radiated angle data arising from changes in beam shape (symmetry), displacement of the transmitting antenna, or errors in pulse coding.

The RF front end of the angle field monitor consists of a waveguide horn antenna, a crystal detector, and a video quantizer. Transmitted pulses are received, detected, and compared to a preset threshold level.

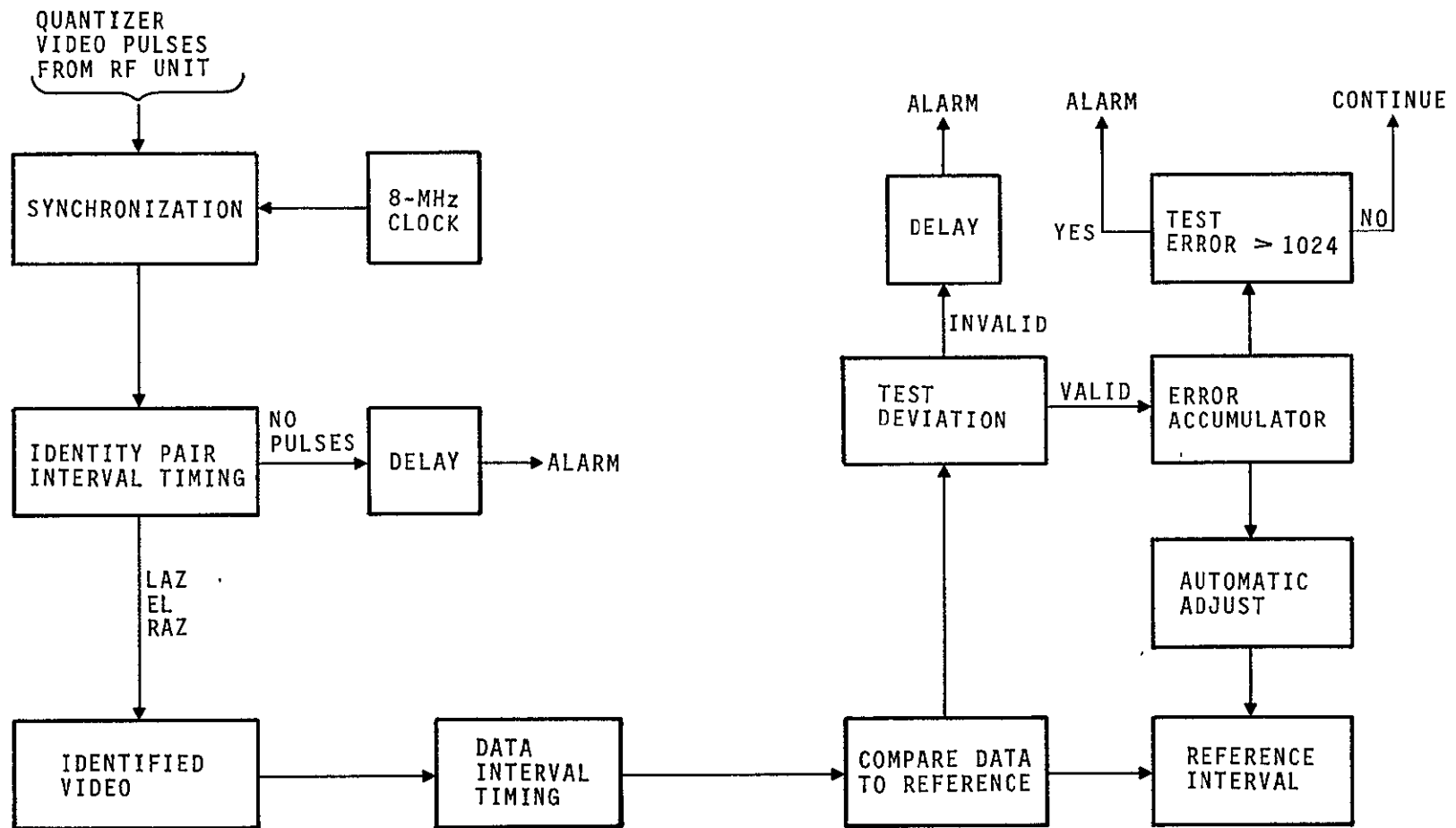
The video pulses exceeding the threshold are routed to the equipment shelter for processing by an angle decoder in the monitor assembly.

The thresholding is nominally 6 dB below (50 percent amplitude) the maximum signal received at the particular monitor location. The monitor essentially averages the dwell above threshold and compares the average to the "zero" angle. Changes in beam symmetry, above the 6 dB points, cause error accumulation.

In the event no pulses are received at the monitor digital assembly for a period of approximately 2 seconds, an alarm is sounded.

## 2-C2. ANGLE PROCESSING

A processing flow diagram for the angle field monitor is shown in Figure 2-C2. Pulses arriving at the monitor digital assembly are first synchronized with an 8 MHz processing clock and then the time intervals between pulses are measured. The timing process determines the type of information being received (azimuth or elevation) and the angle value of the monitor's position. The measured angle interval is compared to a reference



6-2172

Figure 2-C2. Processing Flow Diagram - Field Monitors-Angle

interval which represents the angle the monitor expects to receive, plus or minus the tolerance.

Gross deviations from the reference interval are rejected as invalid data. This prevents both random pulses (short intervals) and dropped pulses (long intervals) from being accepted. Invalid data, continuing for 1 second will cause an alarm to be sounded.

The monitor accumulates the difference between each data interval and the reference interval while the beam is sweeping the sector defined by the thresholding. The accumulation is at the rate of one count per 1/16-degree difference.

At turn on, the reference interval is arbitrarily set at the upper limit ( $\theta + \text{tolerance}$ ). Subsequently, the reference is determined by the sign of the accumulated error.

After the entire beam passage, the error accumulator will have a residual error. This error is the resultant obtained from comparing all the intervals that exceeded the threshold to the reference. In the case of exact alignment of transmitter and monitor, the error will be equivalent to the tolerance (1/8 degree). The actual count would be given by multiplying the average error by the number of counts per degree (16) and by the total number of data intervals received.

Assuming that 50 data intervals exceed the threshold during the beam passage, the count would be  $1/8 \text{ degree} \times 16 \text{ counts/degree} \times 50 \text{ intervals} = 100 \text{ counts}$ . For the first beam passage, the reference angle is set by the automatic adjust to the upper limit. The error accumulator will have a number which is viewed as negative (reference angle - measured angle). This negative residual will cause the automatic adjust to shift the reference to the lower limit. The next beam passage will generate a positive residual into the error accumulator. The net effect, under ideal conditions, is cancellation of the residual error accumulation.

In the case of a small, in tolerance, error (say  $+1/16$  degree), the first beam passage will yield a negative residual of 50 counts (equivalent to  $-1/16$  degree average error). The second beam passage, referenced to the lower limit by the negative residual, will yield a positive error of 150 counts ( $+3/16$  degree average error) for a net accumulation of +100 counts. The third beam passage, referenced to the upper limit by the positive residual, will yield a negative error of 50 counts ( $-1/16$  degree average error). This leaves a net error count of +50. The fourth passage, referenced to the upper limit by the positive residual, again yields a negative error of 50 counts ( $-1/16$  degree average error) which gives us zero net accumulation. The cycle repeats with the fifth passage.

The alternating sequence occurs only while the measured angle falls inside the tolerance window. If a positioning error (beyond the tolerance limit) occurs, the error will have the same sign for either limit and will yield an increasing residue in the accumulator. Angle positions less than the lower limit cause the accumulator to count in a negative direction only. Angle positions greater than the upper limit cause the error accumulator to count in a positive direction only. Both conditions are sampled at 1024 error counts, which is the alarm condition.

### 2-C3. DETAILED HARDWARE DESCRIPTION

Detected pulses that exceed the preset threshold at the pole-mounted RF unit are routed to the identity decoder. The video pulses are first synchronized with the 8-MHz processing clock. After synchronization the pulse is routed through a series of shift registers which are tapped at points providing the proper delay for the identity pair spacing expected. Coincidence between the next pulse received and the delayed pulse yields an identified video pulse. This identified video pulse initiates the angle decoding process with the following sequence. The reference clock is stopped, two strobe pulses are generated, and the reference clock is restarted. The identified video pulse, the two strobe pulses, and the timing pulse train (reference clock) are routed to the error detector.

The strobe pulses preset the reference counter to a number representing the monitor's position. The number includes allowances for the delay in data processing (6  $\mu$ s) and the tolerance window. The delay due to processing is a fixed offset. The tolerance window is applied via the automatic adjust, which determines the sign of the accumulated error, and applies the upper or lower boundary as described above. After the minimum interval (for validity) the processing clock is gated into the early/late error counter. This counter is preset to the minimum interval (6  $\mu$ s only) and increments until the next identified video pulse is received. If the second identified video pulse is received before the reference interval, an early control signal is produced; if after the reference interval, a late control signal is produced. The early/late control determines the direction of counting when the contents of the early/late counter are transferred to the error accumulator. The transfer takes place simultaneously with the timing of the next data interval.

#### 2-C4. EFFECT OF GROUND STATION SWITCHOVER ON FIELD MONITORS

One aspect of field monitor operation to consider is its transient behavior at switchover. Specifically, switchover can occur asynchronously, at any point in the backup systems cycle, possibly while one of the backup angle antennas is pointing directly at its respective field monitor. The net result of such a set of circumstances would be an error computed by the monitor for that particular scan. The effects of this error on overall field monitor operation must therefore be assessed.

The DME field monitor does not exhibit the same type of transient behavior as does the angle field monitor. All field monitor circuits (DME and angle) are reinitialized at switchover. While the angle monitors can act on new data immediately after switchover, possibly decoding an incomplete beam, the DME field monitor must wait for the solicit signal from the

ground station. Reception of solicits ensures synchronization of DME field monitors with the backup system.

Switchover from the primary to backup system can occur anywhere in the backup systems scan cycle. For approximately 9.1 milliseconds out of every 200 milliseconds, either the azimuth or elevation antenna is looking directly at the field monitors. Four and one-half percent of the time, therefore, an incomplete beam will be processed by the field monitors at switchover.

To compute the approximate number of error counts at switchover, the following procedure is followed. For azimuth, assuming that a whole beam was intercepted, the difference between the average decoded angle and the upper error bound should be 0.125 degree (assuming no boresighting error). On the average, for each interval between pulse pairs,  $0.125 \times 16 = 2$  error counts are generated. For a 5-degree azimuth monitor position, approximately 66 pulse pairs are intercepted (assuming a tracking level of 6 dB below beam peak). The total error count after the first beam should, therefore, be approximately 132.

Error count due to an incomplete beam is computed in a similar manner. The truncated beam appears to be in error in average decoded angle. It also contains a fewer number of pulse pairs. The difference between this average angle, and the error bound multiplied by 16 and by the number of pulse pairs, yields the approximate error count at the end of that beam.

The 6-dB azimuth antenna beam width is approximately 3.2 degrees. If the instantaneous pointing angle of the antenna is anywhere between 3.4 and 6.6 degrees at switchover, a transient error count will result at the field monitor (positioned at 5 degrees). Figure 2-C3 shows the worst case magnitude of this transient as a function of azimuth switchover angle for ground station boresighting errors of 0, 1/16 and 1/8 degrees. For a

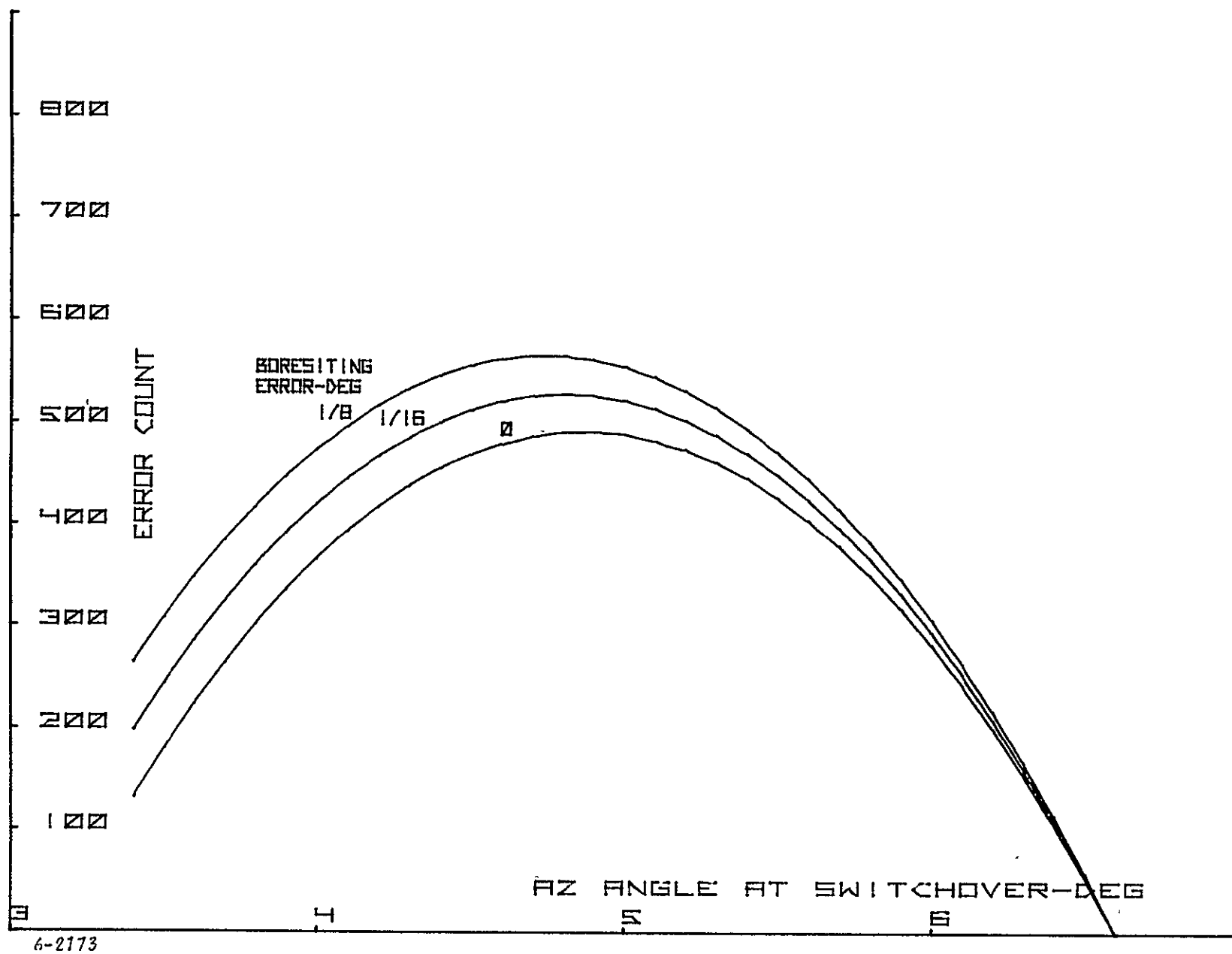


Figure 2-C3. Transient Response of Azimuth Field Monitor at Switchover

switchover angle of 3.4 degrees (assuming the antenna is scanning toward increasing angle) the whole beam is intercepted and the error count after the beam's passage is shown to be 132 (0-degree boresighting error). As the switchover angle increases, the error count likewise increases. At an angle of 4.43 degrees, a maximum transient of 490 error counts results. The elevation field monitors (positioned at 2 degrees) will exhibit a transient of 350 error counts if switchover occurs at an elevation angle of 1.88 degrees (Figure 2-C4).

If an in-tolerance ground station boresighting error exists, the transient error count may be somewhat higher. Worst-case for an azimuth 1/8-degree boresighting error, is an error count of 570. Worst-case elevation error count is 440.

The worst-case transient field monitor behavior at switchover is, therefore, an increase from a nominal 132 to 490 error counts after the first scan. This number of error counts is well below the 1024 count alarm trigger point so that false alarm should not be a problem. Assuming that the ground station is boresighted in tolerance, the transient error count will be "forgiven" at a rate of approximately 100 counts per scan so that field monitor operation should be back to normal 0.6 second after switchover.

It appears, therefore, that the transient behavior of the angle field monitors at switchover should not hamper their operation.

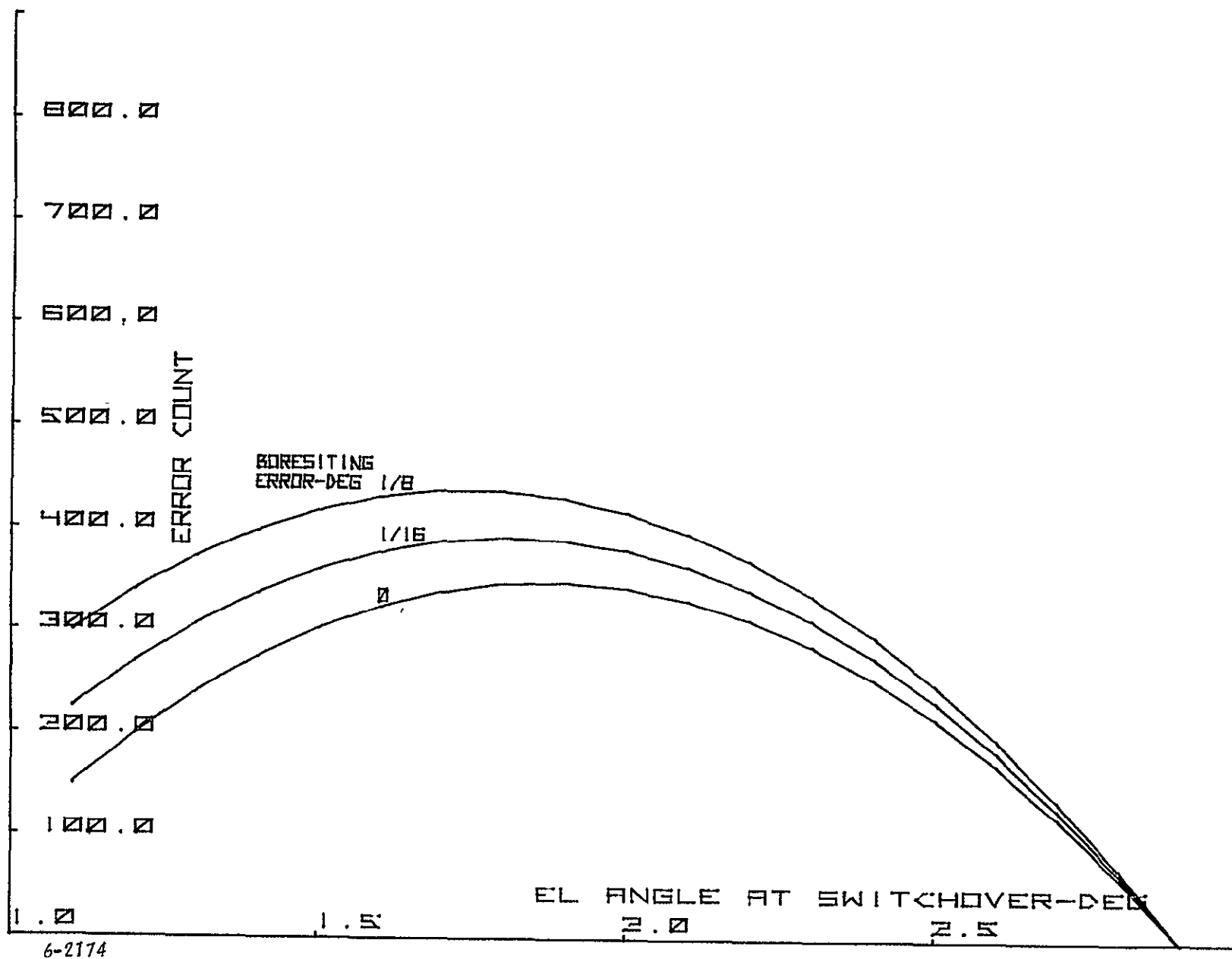


Figure 2-C4. Transient Response of Elevation Field Monitor at Switchover

75-1 TASKS 03 AND 05

PART D

MSBLS NAV SET SEARCH, TRACK, INTERROGATE,  
AND PROCESSING MODES

W. WONG

TECHNICAL REPORT Y220-10

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## 2-D1. NAVSET ANGLE DATA TRACKING AND PROCESSING

2-D2. INTRODUCTION. Angle guidance is provided to the Orbiter by the Nav Set which uses the pulse pairs above a tracking threshold on the angle beam to find the beam's central angle (Figure 2-D1). It is the purpose of this section of the report to discuss the following aspects of this operation:

- a. Time interval tracking
- b. Decoding and accumulation of angle data
- c. Computing the central angle
- d. Checking the number of data intervals

Since the Nav Set processes the azimuth and elevation beams in the same manner, the following discussion refers only to the azimuth function, but applies to the elevation function as well.

2-D3. TIME INTERVAL TRACKING. The Nav Set (NS) tracks the data pulses it finds exceeding the track level threshold. Stretched identified video (SIVD), TTL logic pulses  $0.125 \mu\text{s}$  wide, are generated to mark the occurrence of the track level RF data pulses. Figure 2-D2 shows n SIVD's generated across the track level of the azimuth beam. Two-microsecond track gates (TG) are generated to track SIVD's, starting with the third SIVD. Normally n-1 track gates would be generated across the beam.

The position of the track gate is determined by the tracking interval. The time delay from an SIVD to the center of the track gate is equal to the previously measured validated time interval (Figure 2-D3). Interval validation is discussed later on. Basically, tracking consists of measuring each time interval ( $\Delta t_1, \Delta t_2, \dots, \Delta t_k \dots \Delta t_{n-1}, \Delta t_n$ ) and then using it to position the next track gate.

Since no angle tracking information is stored from one beam to the next, the first step is to acquire the first tracking interval. This initial phase is called the search mode.

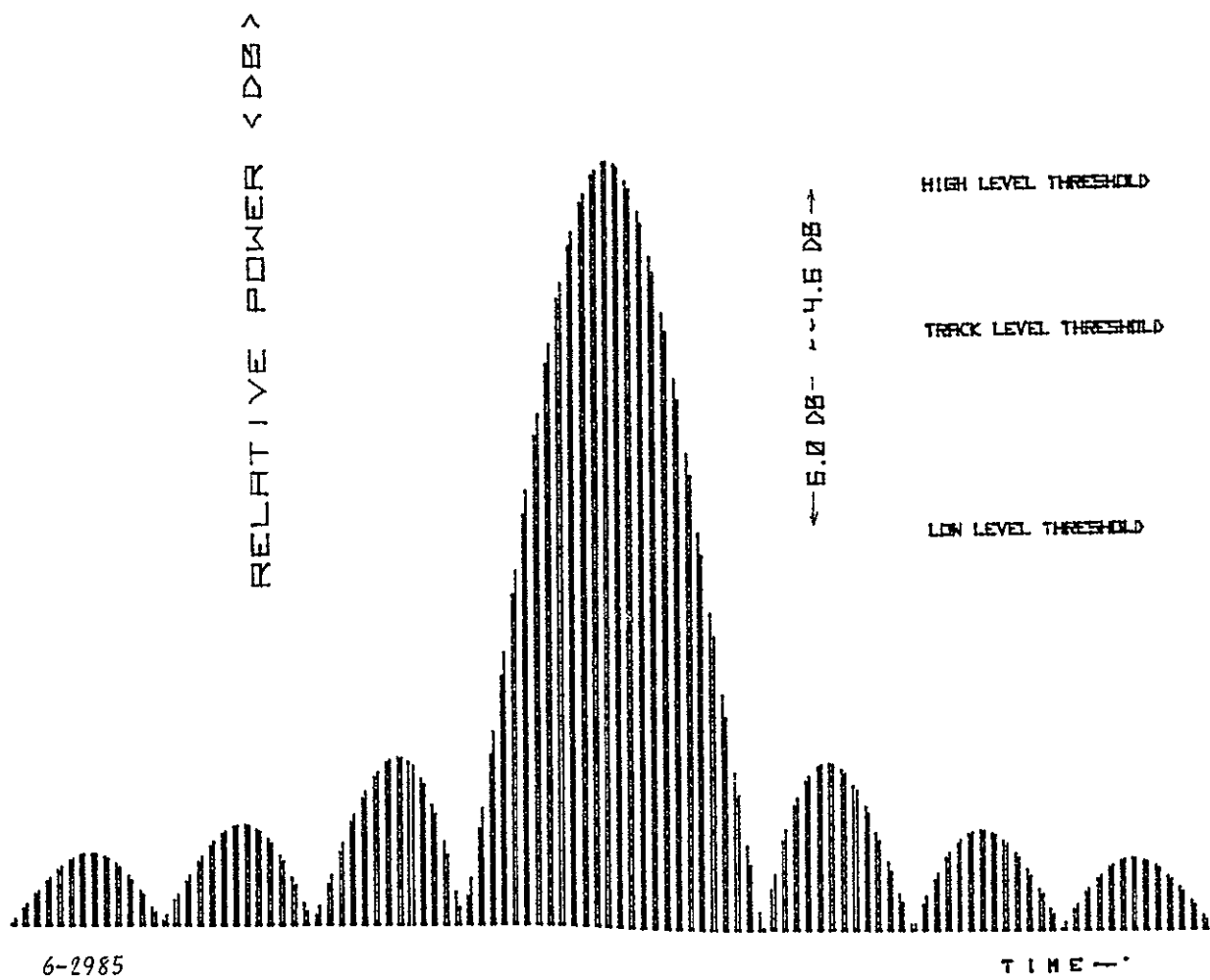


Figure 2-D1. Azimuth Beam Received by Nav Set

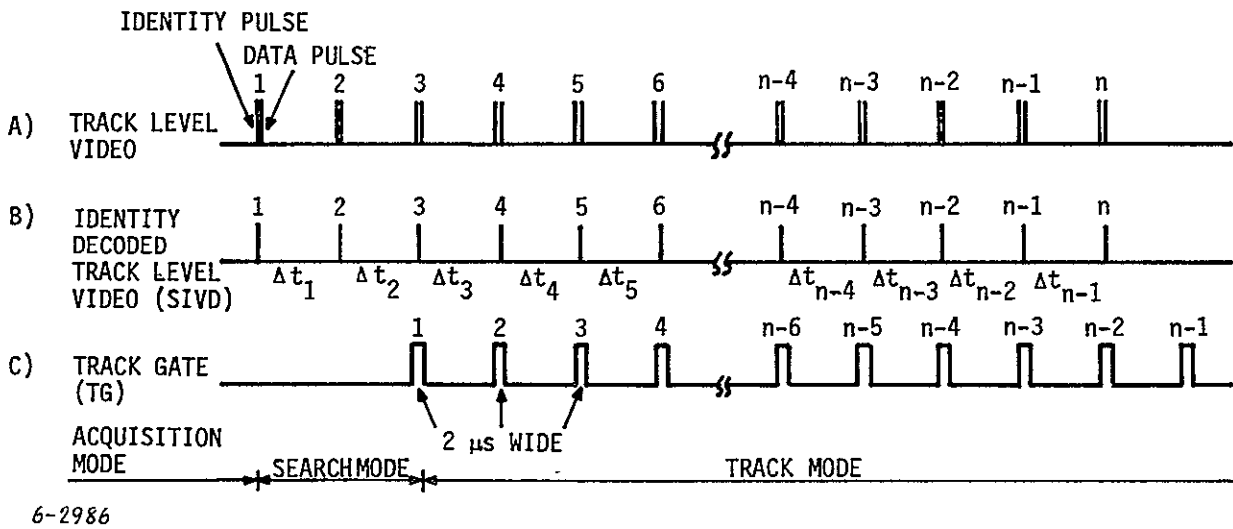
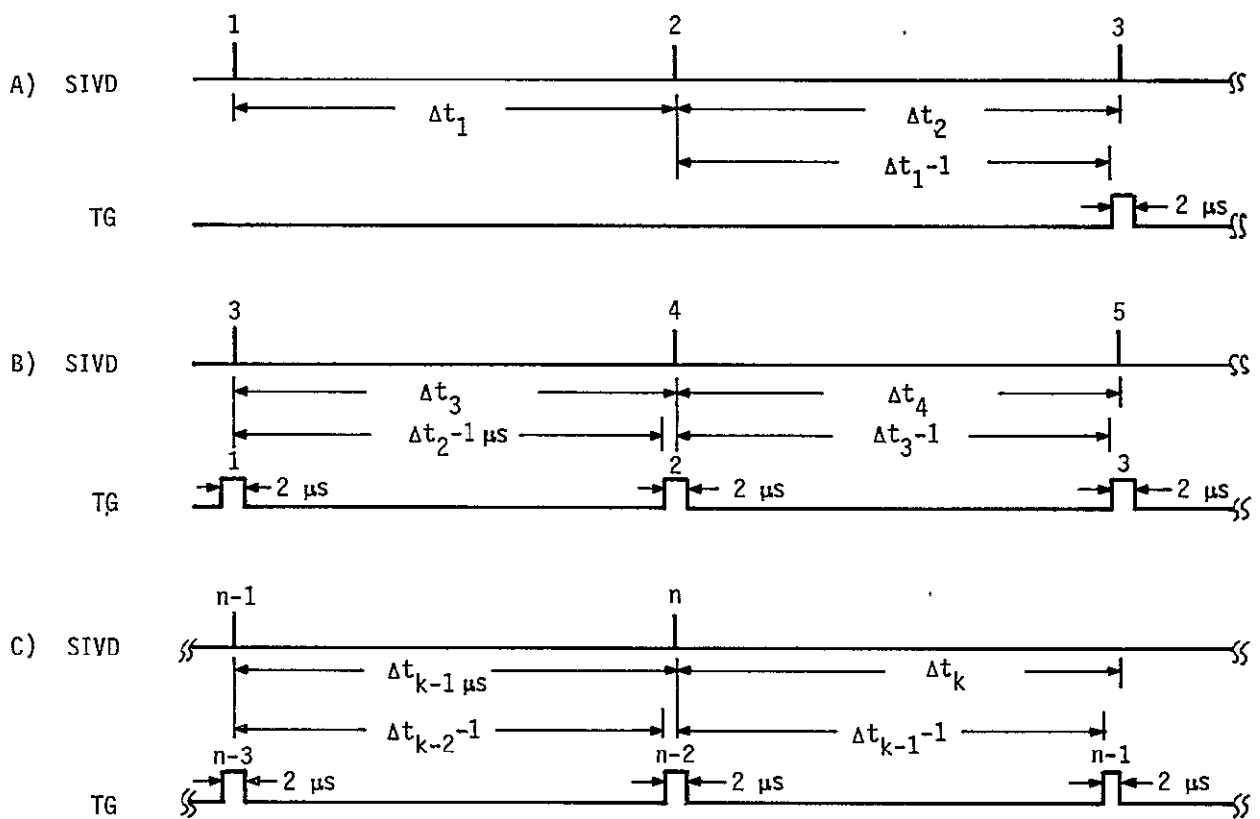


Figure 2-D2. Tracking the Data Pulse With a Two Microsecond Track Gate



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Figure 2-D3. Track Gate Timing

2-D4. SEARCH MODE. It is important to acquire the first tracking interval properly, for it essentially establishes the acceptable time intervals for the beam. When the first interval,  $\Delta t_1$ , is measured, it is accepted as a tracking interval if it falls between 59 and 119  $\mu s$  (Figure 2-D4).

When the second time interval,  $\Delta t_2$ , between SIVD<sub>2</sub> AND SIVD<sub>3</sub> is measured, tracking is validated if SIVD<sub>3</sub> falls inside the track gate and  $\Delta t_2$  exceeds 59  $\mu s$ . An acceptable tracking interval is now established and tracking continues across the beam (track mode).

If either of these two conditions are not met during the search mode, the Nav Set returns to the acquisition mode (Figure 2-D4). When the next SIVD is detected from the same beam, the search mode procedure is repeated. If an acceptable validated tracking interval has not been established after four attempts through the search mode, further tracking of beam is inhibited until the present beam ends and the next beam appears.

2-D5. CONTINUED TRACKING (TRACK MODE). Figures 2-D2 and 2-D3 show that after the second time interval,  $\Delta t_2$ , has been validated by the first track gate (TG<sub>1</sub>), additional track gates (TG<sub>2</sub> through TG<sub>n-1</sub>) are generated to track and validate the remaining intervals. Validated time intervals are decoded for angle data which are later used to compute the beam central angle. Also, the tracking interval is updated for each validated interval.

Let us examine how tracking is affected if an SIVD is missing from the beam. This is demonstrated in Figure 2-D5 with SIVD<sub>12</sub> missing. An attempt is made by track gate No. 12 to locate an SIVD. With no SIVD falling in the 2  $\mu s$  track gate, further measurement of the time interval is inhibited until the appearance of the next SIVD (No. 13). Also, the tracking interval is not updated and angle data is not decoded from the time interval. The next track gate is generated to track SIVD<sub>14</sub>. The tracking interval is 66.25  $\mu s$  which was taken from the last validated time interval (between SIVD<sub>10</sub> and SIVD<sub>12</sub>).

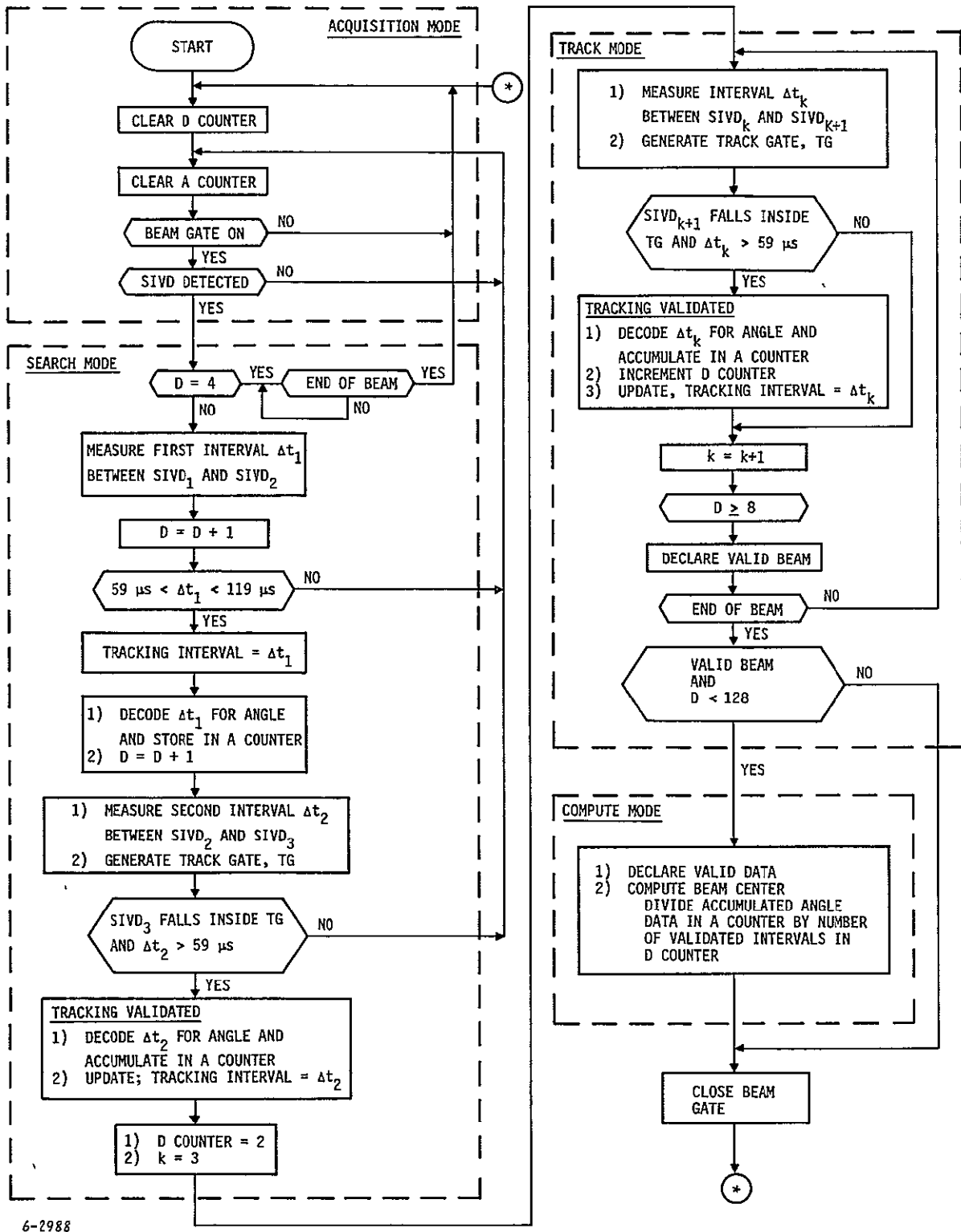


Figure 2-D4. Acquisition Search, Track, and Compute Mode Flow Diagram

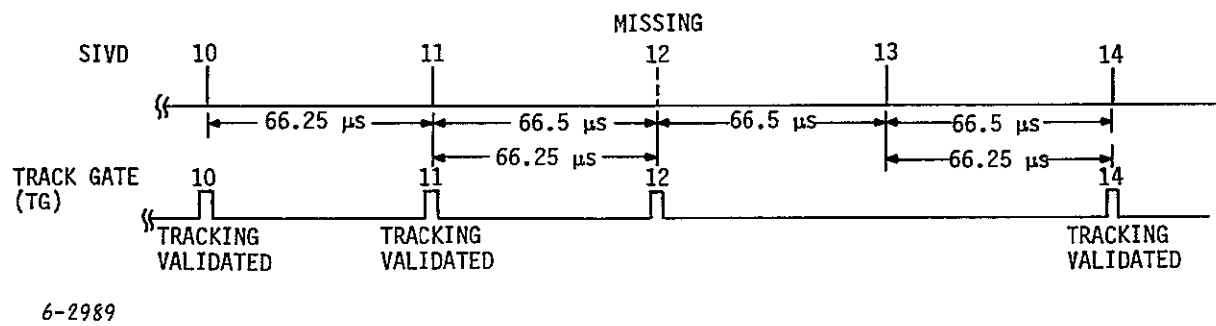


Figure 2-D5. Track Gate Validation

2-D6. GROUND STATION ANGLE DATA VARIATIONS AND TRACK GATE WIDTH. The position and width of the track gate is such that the next data interval cannot differ by more than  $\pm 1 \mu s$  (Figure 2-D6). In terms of angle, this time translates to  $\pm 0.5$  degree. The  $2 \mu s$  width of the track gate is compatible with the expected ground station angle data changes. The maximum angle the ground station ADP can change during the timing of the data interval is 0.058 degree for azimuth, and 0.038 degree for elevation, which can be approximated by finding the maximum angle change from:

$$\theta_{AZ} = 44 \cos 5\pi t \text{ degrees}$$

$$\frac{1}{\text{prf}} = \left( 60 + 2 \left| \theta_{AZ} \right| \right) \times 10^{-6} \text{ seconds}$$

$$\text{ADP Angle Change} = \Delta \theta_{AZ} \cong \dot{\theta}_{AZ} \frac{\text{deg}}{\text{sec}} \times \frac{1}{\text{prf}} \text{ sec}$$

$$\cong 220 \pi \cos \left( \sin^{-1} \frac{\theta_{AZ}}{44} \right) \left( 60 + 2 \left| \theta_{AZ} \right| \right) 10^{-6} \text{ degrees}$$

$$-15 \text{ degrees} \leq \theta_{AZ} \leq 15 \text{ degrees}$$

$$\theta_{AZ} = \text{Azimuth Angle}$$

$$\text{prf} = \text{Pulse Rate Frequency}$$

for azimuth angle and,

$$\theta_{EL} = 15 + 24 \cos 5\pi t \text{ degrees}$$

$$\Delta\theta_{EL} = 120 \pi \cos \left( \sin^{-1} \frac{\theta_{EL} - 15}{24} \right) (60 + 2 \theta_{EL}) 10^{-6} \text{ degree}$$

$$\theta_{EL} = \text{Elevation Angle}$$

for elevation angle.

As a result, the ground station transmitted data interval either changes  $0.25 \mu s$  (corresponding to one-eighth of a degree ADP angle increments) or remains the same from one interval to the next. If the data interval changes  $0.25 \mu s$ , a margin of  $0.75 \mu s$  remains, allowing for time shifts due to propagation delays and synchronization delays characteristic of TTL digital systems, and motion of Orbiter.

2-D7. DECODING AND ACCUMULATING DATA ANGLES. Angle data is encoded in the data spacing  $\Delta t_K$  with the format

$$t_K = 60 \mu s + c\theta_K \quad K = 1, 2, \dots n-1$$

$$\theta_K = \text{encoded angle in degrees}$$

$$c = 2 \mu s/\text{degree}$$

The time interval  $c\theta_K$  is proportional to the encoded angle. Each time an interval is validated, a logic signal AGATE,  $c\theta_K$  in duration, is generated. AGATE enables a binary up/down counter (A Counter in Figure 2-D7) to

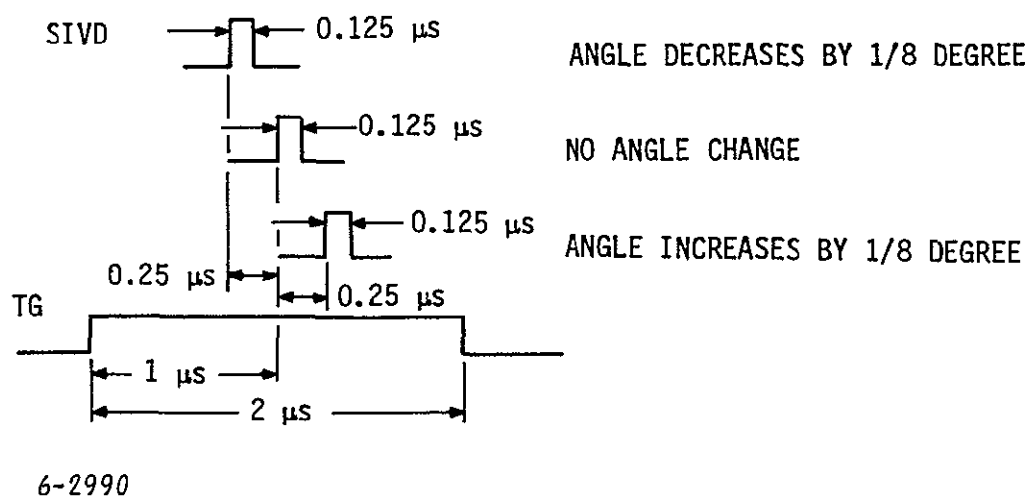


Figure 2-D6. Effect of Incremental Angle Data Changed on Tracking

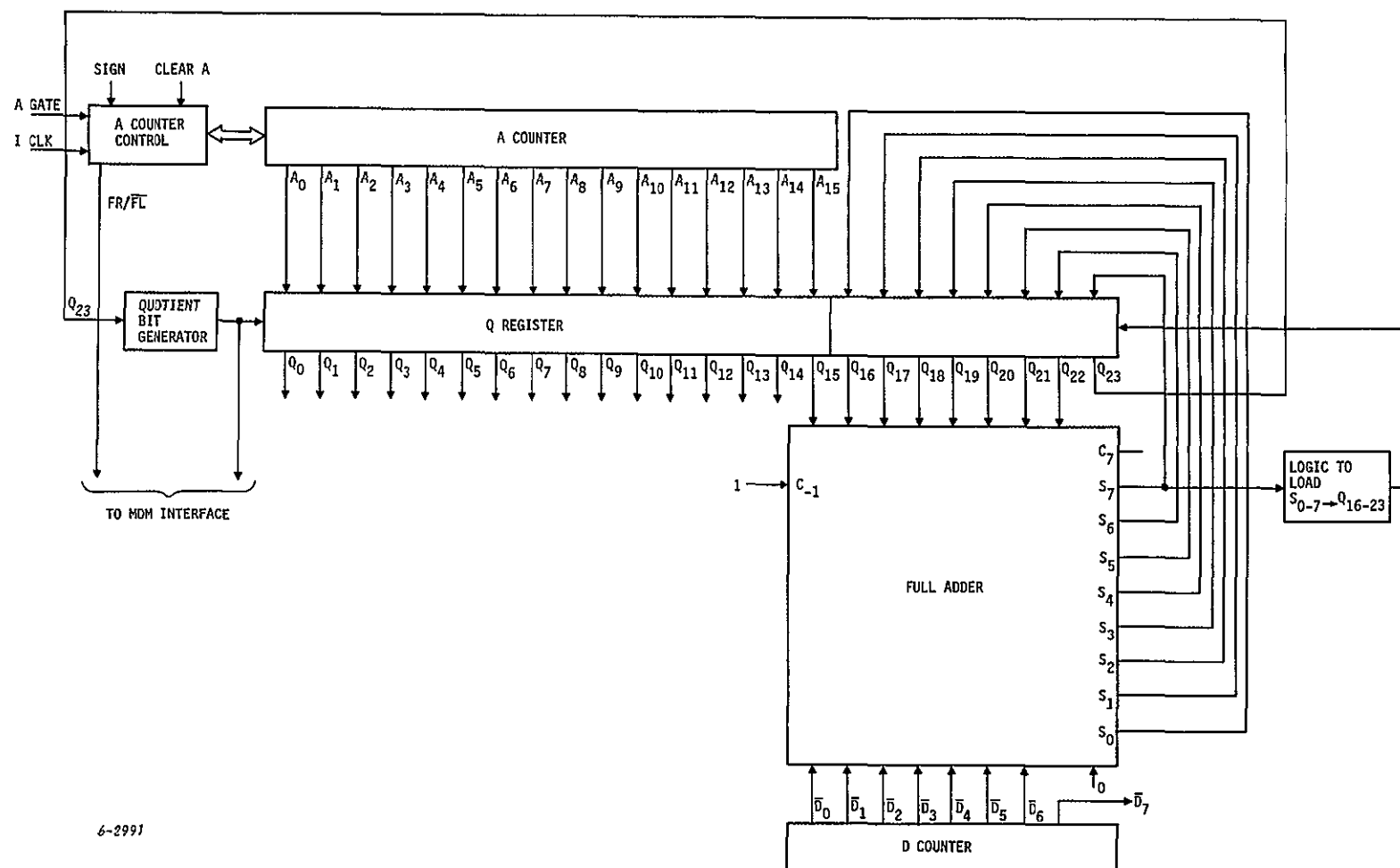


Figure 2-D7. Functional Block Diagram of Angle Data Processor

measure angle data by counting 8 MHz clock pulses (ICLK's). The angle measured by the A Counter after each clock pulse is given by:

$$\text{Angle Measured Per Clock Pulse} = \frac{0.125 \frac{\mu\text{s}}{\text{clock} \cdot \text{pulse}}}{2 \frac{\mu\text{s}}{\text{deg}}} = 0.0625 \frac{\text{deg}}{\text{clock} \cdot \text{pulse}}$$

The resulting output of the A Counter is a binary number which indicates the sum of all tracked angle data intervals in degrees (Figure 2-D8).

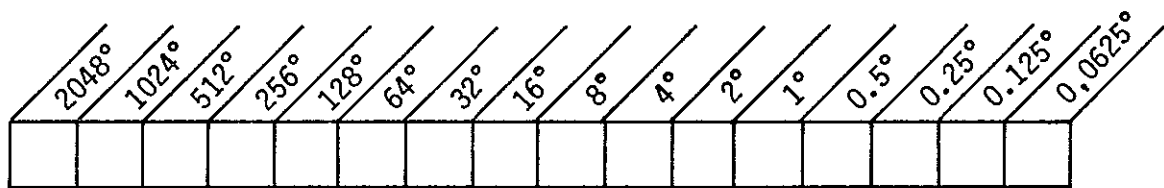
The A Counter is initialized to zero during the acquisition mode before the track level of the beam is reached. During the beam's passage, the A Counter accumulates angle data corresponding to valid time intervals:

$$\text{A Counter} = \sum_{k=1}^{n-1} \theta_{KV} \text{ degrees}$$

$$\theta_{KV} = \text{angle data encoded in validated time interval } \Delta t_K$$

Recalling the previous discussion, validated intervals are those which are successfully tracked.

The A Counter is only used to measure the absolute value of the sum of the angle data. Normally the A Counter is only counting up. However, the A Counter will also count down if both right and left azimuth angles are received. In this case, the net result in the counter is the difference between the sum of the right azimuth angles and the sum of the left azimuth angles. The sign of the accumulated azimuth angles is indicated separately by the FR/F $\bar{\text{L}}$  (fly right/fly left) signal.



6-2992

Figure 2-D8. A Counter Angle Format

The maximum angle sum the A Counter can accumulate is 4096.9375 degrees when all its outputs are logic ones. This upper limit is sufficient to hold the maximum expected angle sum of 3810 degrees when 127 30-degree angles are taken from an elevation beam.

A binary counter (D Counter in Figure 2-D7) counts the number of validated data intervals received across the track level of the beam. Counting is done in one's complement to facilitate the binary division which is discussed below. The total number of intervals counted is checked to ensure that it falls within specified limits. A beam is declared valid (VLBM) if there are at least eight tracked intervals. Data is declared valid (EVLDT) if there are at least eight and not more than 127 tracked intervals.

If data is declared valid once the beam has passed, a binary division operation is performed with a 16-bit dividend ( $A_0$  through  $A_{15}$ ) from the A Counter, and a 7-bit divisor ( $\bar{D}_0$  through  $\bar{D}_6$ ) from the D Counter. The hardware divider uses the 24-bit shift register (Q Register) and the 12-bit full adder shown in Figure 2-D7. One input to the adder comes from the Q Register, the other input comes from the D Counter. Division starts by first loading the Q Register with the dividend, which is then shifted right in a series of 0.25- $\mu$ s division cycles. During each such cycle, a trial subtraction is performed. If the subtraction results in a negative result, a quotient bit of zero is generated and the dividend is shifted right. If a positive number results from the subtraction, a quotient bit of one is generated, the output of the adder is loaded into the Q Register, and the Q Register is shifted right. This continues until the entire 13-bit quotient is generated from the most significant bit to the least significant bit. Each bit so generated is loaded in the left most bit position of the Q Register as it is shifting right and sent serially to the MDM interface to be included in the MDM data word.

Subtraction is performed using two's complement arithmetic. As indicated previously, the divisor is in one's complement form. By letting the

LSB carry into the adder to be one, the two's complement of the divisor is formed.

An example of the binary division algorithm is shown in Figure 2-D9. The number 215.125 is divided by 45. Binary division using "normal" subtraction is shown in Figure 2-D9, part B, while binary division using two's complement is shown in Figure 2-9, part C.

#### 2-D8. DME INTERROGATION, TRACKING AND SIGNAL PROCESSING

2-D9. GENERAL. The MSBLS DME (distance measuring equipment) is a pulsed interrogator-transponder system operating in the 15.412 to 15.688 GHz band. The interrogator function is performed by three MSBLS Nav Sets operating simultaneously from the shuttle Orbiter. The transponder function is provided by the ground station azimuth/DME primary or backup unit (Figure 2-D10).

The DME system can operate on one of 10 channels. The channel assignment of frequencies and pulse codes are given in Table 2-D1.

Interrogations from the three Orbiter interrogators are answered by the ground transponder, and the elapsed time between interrogation and reply is converted to indicate slant range in nautical miles. Each Nav Set automatically recognizes only the replies to its own interrogation.

This section describes the digital ranging techniques by which range information is processed by the Nav Sets.

2-D10. DME SIGNAL FORMAT. The DME signals consist of pulse pairs with  $0.3 \mu s$  pulse widths. The first pulse is called the identity pulse. The second pulse is called the data pulse.

2-D11. DME SOLICIT SIGNAL. The solicit signal transmitted by the MSBLS Ground Station consists of a series of 14 pulse pairs with an  $8 \pm 0.1 \mu s$  intra-pair spacing. The interval between adjacent pulse pairs is  $160 \mu s$ .

- A) DECIMAL FORM  $215 \div 45 = 4.780555$   
 B) BINARY DIVISION  $(215 \div 45)_{\text{BASE } 10} = (1101 \ 0111 \ 0010)_{\text{BASE } 2}$   
 $(45)_{\text{BASE } 10} = (010 \ 1101)_{\text{BASE } 2}$

100. 1100 0111 = 4.7734 QUOTIENT

```

010 1101 ) 1101 0111 0010 0000
           -1011 01
           -----
             10 0011 0
             - 1 0110 1
             -----
               1100 10
               -1011 01
               -----
                 1 0110 00
                 - 1011 01
                 -----
                   1010 110
                   - 101 101
                   -----
                     101 0010
                     - 10 1101
                     -----
                       10 0101 FINAL REMAINDER
  
```

- C) BINARY DIVISION USING 2's COMPLEMENT ARITHMETIC WHEN SUBTRACTING

-45  $\xrightarrow{\text{2's COMPLEMENT}}$  101 0011

0 0100 . 1100 0111 = 4.7734 QUOTIENT

```

0101 0010 ) 0000 1101 0111 0010 0000
             +0101 0011
             -----
             0110 0000
             000 1101 0
             +010 1001 1
             -----
             011 0110 1
             00 1101 01
             +01 0100 11
             -----
             10 0010 00
             0 0010 001
             +0 1010 011
             -----
             0 1100 100
             0010 0011
             +0101 0011
             -----
             0111 0110
             010 0011 0
             +010 1001 1
             -----
             100 1100 1
             000 1100 10
             +01 0100 11
             -----
             10 0001 01
             0 0001 011
             +0 1010 011
             -----
             0 1011 110
             0001 0110
             +0101 0011
             -----
             0110 1001
             001 0110 0
             +010 1001 1
             -----
             011 1111 1
             01 0110 00
             +01 0100 11
             -----
             10 1010 11
             0 1010 110
             +0 1010 011
             -----
             1 0101 001
             0101 0010
             +0101 0011
             -----
             1010 0101 FINAL REMAINDER
  
```

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Figure 2-D9. Binary Division Operation

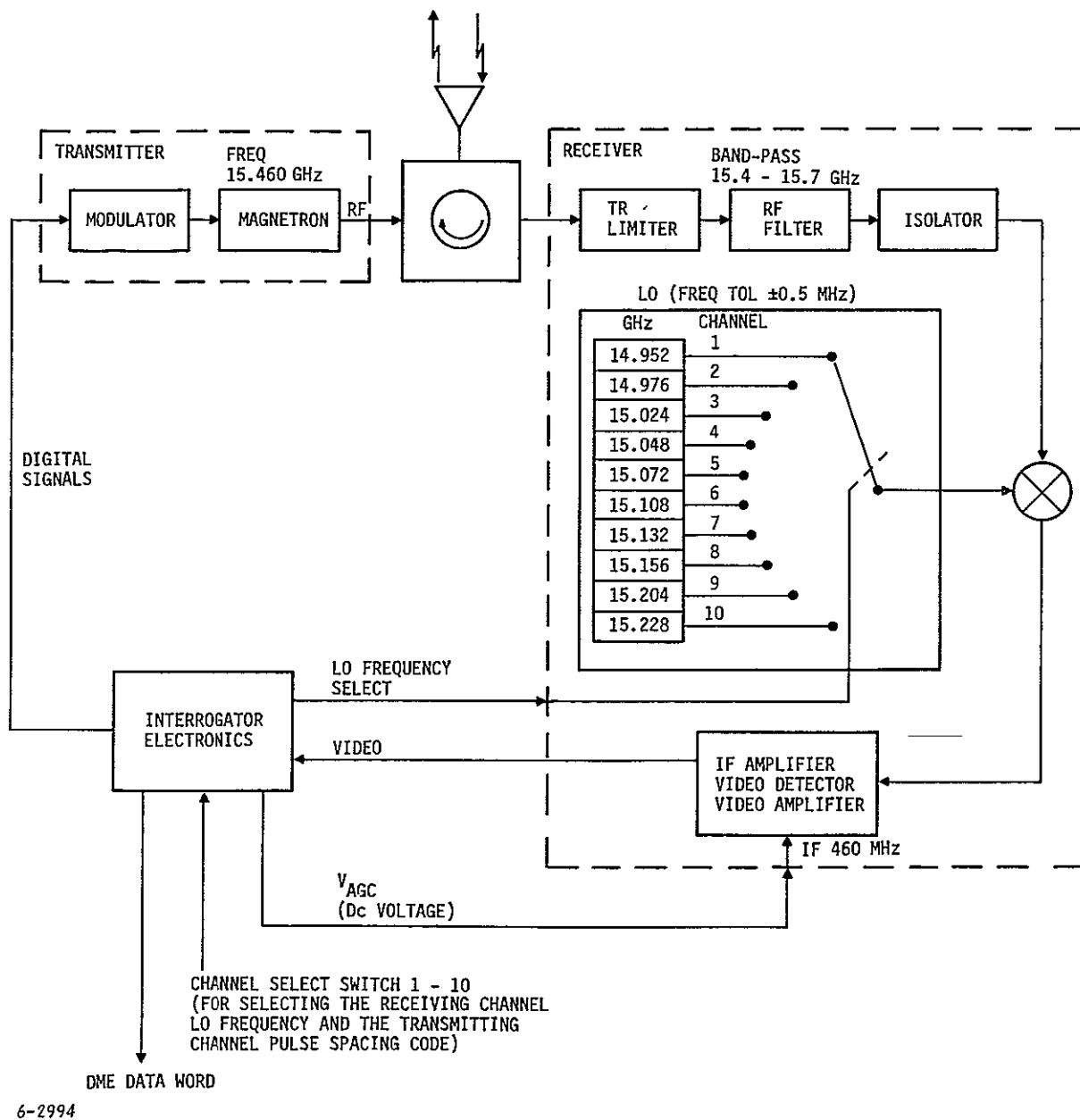


Figure 2-D10. Interrogator, Functional Block Diagram

Table 2-D1. MSBLS DME Channeling and Pairing

| Channel   | Airborne<br>Interrogating<br>Frequency | Airborne<br>Interrogating<br>Pulse Code | Ground<br>Reply<br>Frequency | Ground<br>Reply<br>Pulse Code |
|-----------|----------------------------------------|-----------------------------------------|------------------------------|-------------------------------|
|           | GHz                                    | Microseconds                            | GHz                          | Microseconds                  |
| 1         | 15.460                                 | 11                                      | 15.412                       | 8                             |
| 2         | 15.460                                 | 13                                      | 15.436                       | 8                             |
| 3         | 15.460                                 | 15                                      | 15.484                       | 8                             |
| 4         | 15.460                                 | 17                                      | 15.508                       | 8                             |
| 5         | 15.460                                 | 19                                      | 15.532                       | 8                             |
| 6         | 15.460                                 | 21                                      | 15.568                       | 8                             |
| 7         | 15.460                                 | 23                                      | 15.592                       | 8                             |
| 8         | 15.460                                 | 25                                      | 15.616                       | 8                             |
| 9         | 15.460                                 | 27                                      | 15.664                       | 8                             |
| 10        | 15.460                                 | 29                                      | 15.688                       | 8                             |
| Tolerance | -                                      | $\pm 0.1 \mu s$                         | $\pm 2.5 \text{ MHz}$        | $\pm 0.1 \mu s$               |

2-D12. DME INTERROGATION SIGNAL. The DME interrogation signal transmitted by the Nav Set consists of a series of 16 pulses with the channel of operation encoded in the intrapair pulse spacing given in Table 2-D1. The spacing between adjacent pulse pairs is nominally  $1670 \mu s$  jittered by  $\pm 500 \mu s$ .

2-D13. DME REPLY SIGNAL. The ground station transponder decodes the intrapair spacing of the coded interrogation and generates a reply if the encoded channel agrees with the channel selected for ground station. The reply is a transmitted pulse pair spaced  $8 \pm 0.1 \mu s$  apart and occurring at  $80 \pm 0.125 \mu s$  following each received interrogate pulse pair.

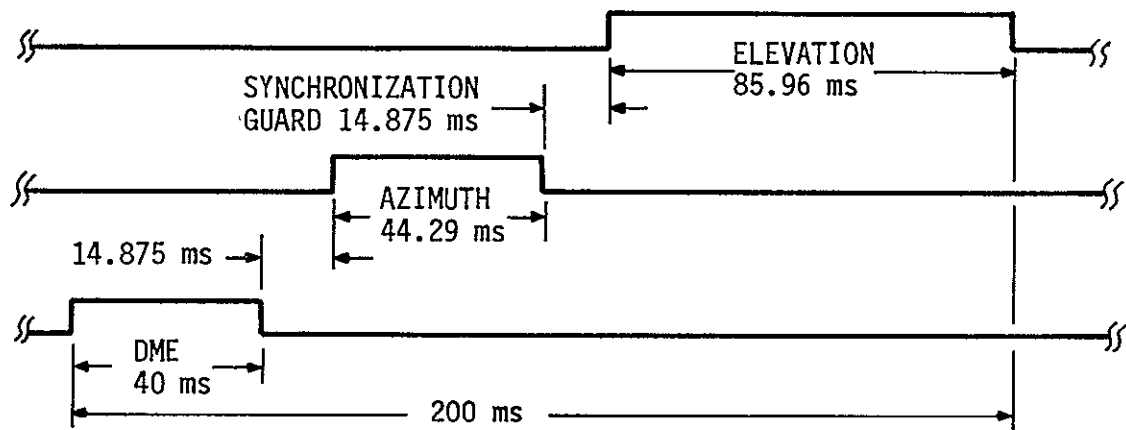
2-D14. SYSTEM TIMING. DME operation is time multiplexed with azimuth and elevation operation as shown in the ground station system timing given in Figure 2-D11. Every 200 ms, the ground station establishes a 40 ms time period during which DME operation is to occur. At the beginning of each DME period the ground station transmits the solicit signal which signals the Orbiter interrogators to begin their interrogations.

2-D15. NAV SET PROCESSING OF SOLICIT SIGNAL. When the airborne receiver first intercepts the solicit signal, its sensitivity is set at maximum by the squitter AGC voltage. According to the Rockwell Navigation Set specification, paragraph 3.21.12.7, the maximum sensitivity should be at least -77 dBm. The receiver sensitivity is established at its video output by a "low level threshold" (LLT, 1 volt video). Also, a "high level threshold" (HLT, 3.2 volt video), 10.6 dB above the LLT is used for AGC correction (Figure 2-D12).

After the Nav Set has identified three solicit pulse pairs exceeding the LLT, the distance beam gate turns on signifying DME operation. The distance beam gate switches the AGC voltage from the squitter AGC to the distance AGC. The distance AGC tries to maintain the ground station DME signals at a 3.2 volt video level (Figures 2-D12 and 2-D13).

Once the distance gate switches on, the Nav Set continues to look for seven additional solicit pairs to verify DME beam reception and to determine whether the distance AGC needs correction.

Beam verification takes the form of continued solicit signal identification and interval tracking. Two-microsecond track gates are generated to anticipate the occurrence of the solicit data pulses. The tracking scheme involves measurement of the time interval between solicit data pulses (SIVD's), validation of the interval and use of the validated interval to position a fixed 2- $\mu$ s track gate. Every time a solicit data pulse falls inside a track gate, the interval to the preceeding solicit data pulse is validated.

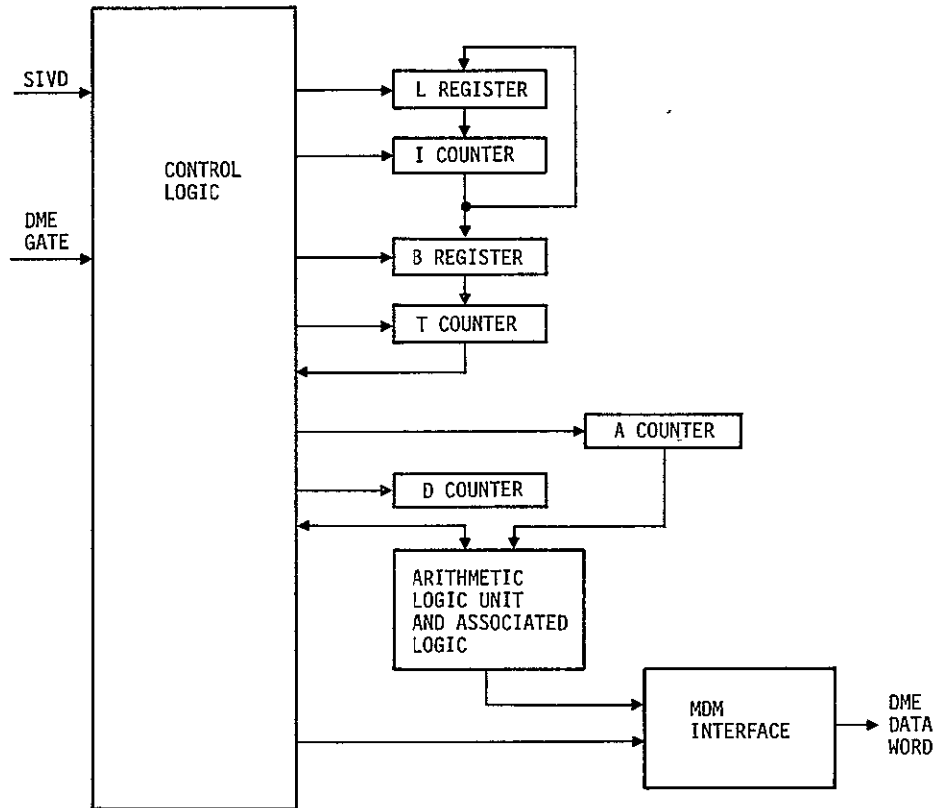
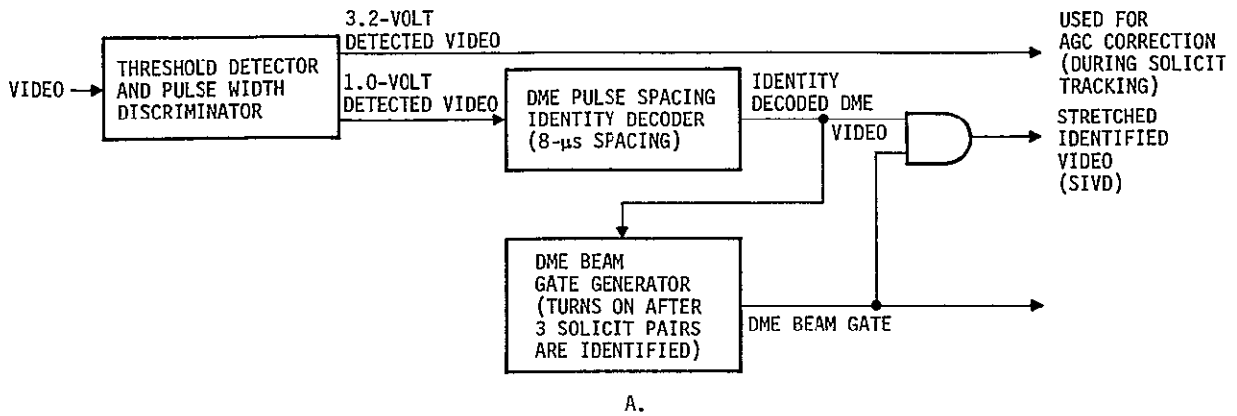


NOTE:

FROM TECHNICAL SPECIFICATION FOR  
MSBLS-GS 8/13/75, FIGURE 2

6-2995

Figure 2-D11. MSBLS-GS Timing and Sequence Format



6-2996

Figure 2-D12. Processing of DME Replies

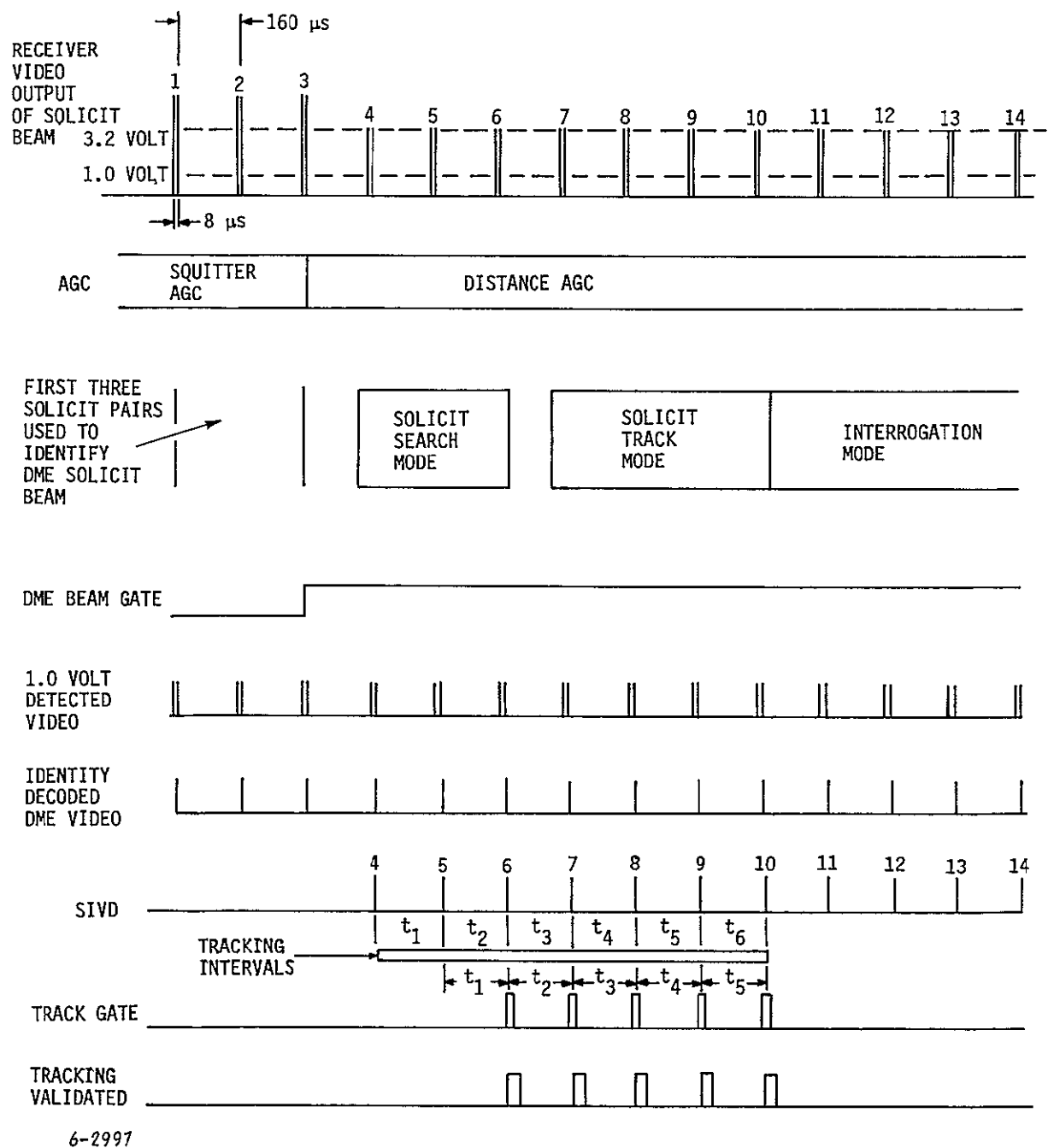


Figure 2-D13. Timing Diagram of Solicit Signal Processing

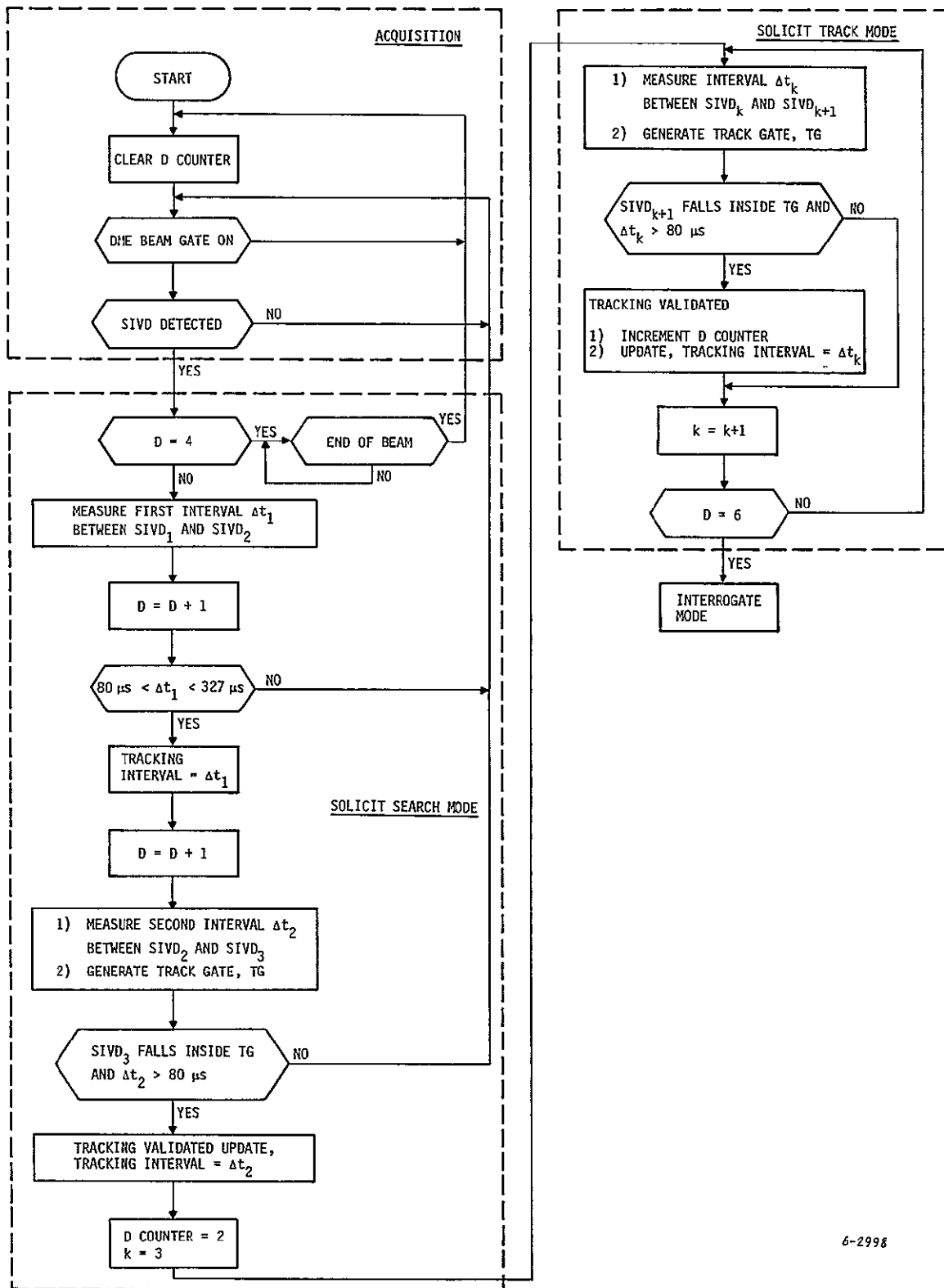
The solicit tracking function is basically implemented using three counters and one register performing the following roles:

- a. I Counter. Measures the time (data interval) between adjacent data pulses (SIVD).
- b. B Register. Holds the last validated data interval.
- c. T Counter. Generates the timing to position the track gate.
- d. D Counter. Counts the number of tracking attempts during solicit search mode and counts the number of validated intervals during solicit track mode

Solicit tracking consists of two parts; a solicit search mode followed by a solicit track mode. Three solicit pulse pairs are processed during search, four solicit pulse pairs are processed during track.

The solicit search mode allows the first tracking interval to be acquired. At the start of the distance beam gate, the time  $t_s$  between the first two identified solicit data pulses is measured. If the interval falls between approximately 79 and 327  $\mu s$ , it is then used to set up a 2- $\mu s$  track gate centered  $t_s$  from the first solicit data pulse. If the next or third solicit data pulse falls inside this gate, tracking is validated and the solicit tracking is initiated. If the search mode is unsuccessful, three more attempts are made to acquire the first tracking interval. After the fourth unsuccessful attempt, the Nav Set considers the solicit signal invalid and stops further processing of the beam. A logic flow diagram of the above discussion is given in Figure 2-D14.

The D Counter is used to count the number of tracking attempts during the search mode. At the start of solicit tracking, the D Counter is preset to two, indicating two data intervals or three pulse pairs during the search mode. The counter is then used to count the number of validated data intervals.



6-2998

Figure 2-D14. Solicit Signal Processing Flow Diagram

During solicit tracking, the Nav Set continues to measure the time between solicit data pulses, and to generate track gates. Each time a solicit data pulse falls inside a track gate, the D Counter is incremented and the I Counter is loaded into the B Register. As previously indicated, the B Register stores the latest validated track interval. Just before T Counter starts timing out the next track gate position, it is loaded with the contents of the B Register. The T Counter counts down, and during some predetermined point in the count down sequence, the leading edge of the track gate is generated. The T Counter timing is such that the time from a solicit data pulse to the center of the track gate is equal the time from that same solicit data pulse to the previous solicit data pulse.

The solicit tracking scheme indicates that the Nav Set is expecting a fixed time interval between solicit pulse pairs or a change of no more than  $\pm 1 \mu\text{s}$ . The ground station solicit format conforms to this requirement since the spacing between adjacent pulse pairs is fixed at  $160 \pm 0.1 \mu\text{s}$ . The spacing also falls within the acceptable limits of 79 to  $327 \mu\text{s}$ .

When the D Counter equals six, indicating four tracked intervals during the solicit track mode, further solicit tracking stops and the interrogate mode flip-flop is set. After a delay from 1170 to  $2170 \mu\text{s}$ , the Nav Set starts transmitting the interrogate signal. This delay allows the remaining solicit pulse pairs in the solicit signal to be transmitted by the ground station before the Orbiter interrogators start transmitting. Normally the Nav Set requires only 10 of the 14 pulse pairs in the solicit signal: three for beam acquisition; three for solicit search; and four for solicit tracking.

During solicit tracking, the Nav Set also determines whether the distance AGC needs correction. As stated previously, the Nav Set tries to maintain the DME signals it receives from the ground transponder at a constant 3.2-volt video level. The 3.2-volt HLT and a  $0.0625\text{-}\mu\text{s}$  pulse width discriminator is used at the video output. Each time a video pulse at least

0.0625  $\mu$ s wide and exceeding 3.2 volts is detected, a digital pulse is generated. Each pulse is used to increment a counter. If eight such pulses are counted during solicit tracking, a flip-flop is set, indicating that the video level is too high. In this case, the gain of the receiver will be decreased for the next DME time period. Conversely, if less than eight high level video pulses are detected during the solicit tracking period, the Nav Set will increase the gain of the receiver for the next DME cycle, in order to bring the video down to 3.2-volt level.

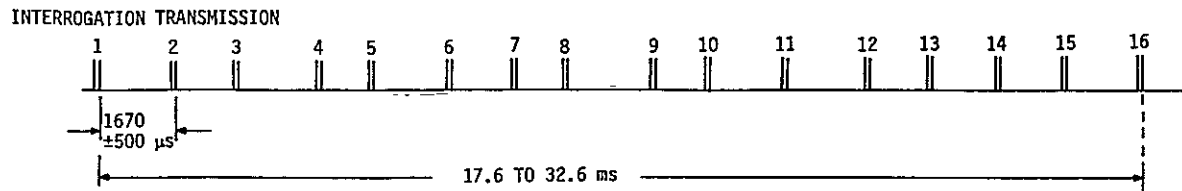
Since there are four pulse pairs, eight pulses are normally processed during solicit tracking. All the solicit tracking pulses must exceed 3.2 volts in order for the receiver gain to be decreased.

A more detailed discussion of the Nav Set decoding of each solicit pulse pair, and of the AGC scheme can be found in report Y220-01, Examination of the MSBLS Nav Set Operation During the Acquisition Mode.

2-D16. INTERROGATE PERIOD. Following the solicit signal, the Nav Set(s) interrogates the ground transponder 16 times. The time between interrogations is 1670  $\mu$ s, randomly jittered by  $\pm 500$   $\mu$ s, in conjunction with a range tracking scheme, the jitter enables each Nav Set to recognize the range replies to its own interrogation signal and to blank out those intended for other Nav Sets (Figure 2-D15).

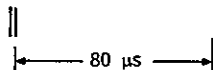
The interrogation pulse pair spacing is encoded with a spacing of 11 to 29  $\mu$ s corresponding to the Nav Set selected channel. The ground station transponder decodes the pulse pair spacing and replies if the spacing corresponds to the channel selected for the transponder. The reply is transmitted 80  $\mu$ s after the reception of the interrogation. The transponder receiver sensitivity is at least -77 dBm.

Some of the Nav Set interrogation pulse pairs may not be replied to if the ground station is responding to a number of interrogators, because the

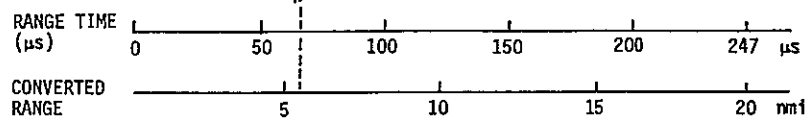


A. INTERROGATION TRANSMISSION

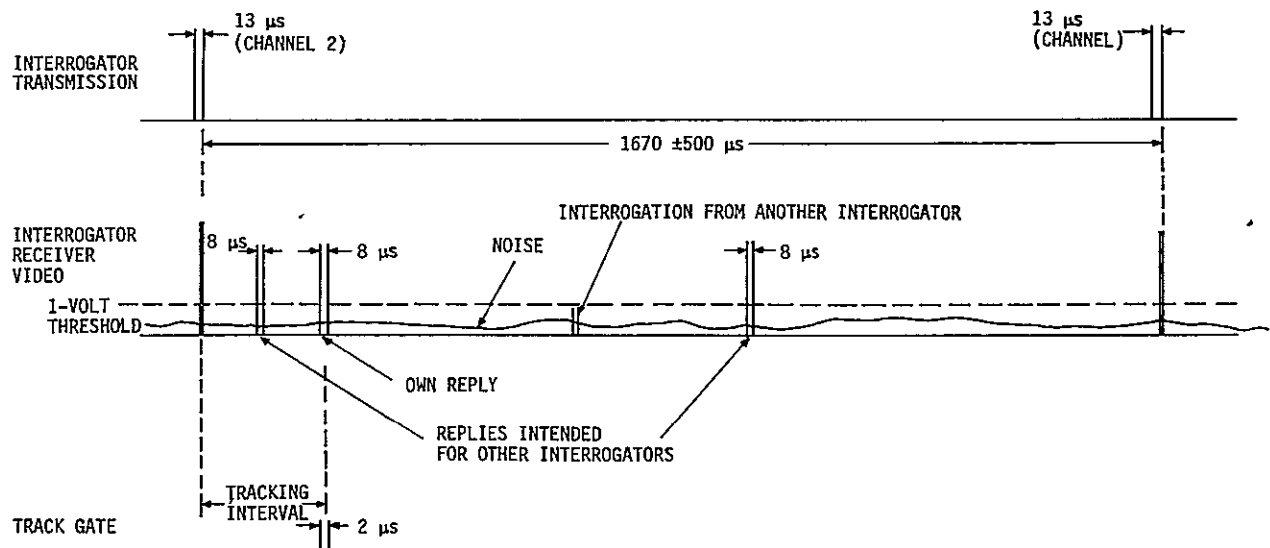
TRANSMITTED REPLY



RECEIVED REPLY



B. RANGE CONVERSION



C. INTERROGATOR TRANSMISSION AND RECEPTION OF DME PULSES

6-2999

Figure 2-D15. Interrogation and Range Conversion

ground station transmitter is inhibited for  $60\ \mu\text{s}$  after it has emitted a reply pulse pair (to protect the transmitter from overload). If the  $80\ \mu\text{s}$  delay for a received pulse pair ends during the  $60\ \mu\text{s}$  inhibit period, the ground station cannot emit a reply pulse pair. This means that interrogations from different Nav Sets must be at least  $60\ \mu\text{s}$  apart in order for the ground station to reply to all interrogations.

A valid reply can also be blanked out if it occurs  $5.25\ \mu\text{s}$  after a Nav Set receives a reply intended for another Nav Set. The Nav Set circuit turns on a  $5.25\text{-}\mu\text{s}$  echo guard gate whenever one volt video is detected. The gate effectively blanks out detected video for  $5.25\ \mu\text{s}$ .

During the interrogation period, the Nav Set digital ranging circuits measure the time from a transmitted RF interrogation data pulse to the received RF reply data pulse, and subtracts the  $80\ \mu\text{s}$  dead time to obtain an indication of slant range. After all 16 interrogations have been transmitted, the Nav Set will compute the arithmetic mean of all the slant ranges, if at least eight interrogations have been answered. The average slant range is then sent to MDM computer interface.

The Nav Set uses a  $2\text{-}\mu\text{s}$  track gate to look for a reply to an interrogation. The track gate enables the Nav Set to distinguish the desired reply from replies meant for other Nav Sets. The tracking scheme is similar to the one used for solicit tracking. The digital hardware is the same with the following changes:

- a. I Counter. Measures the elapsed time from the leading edge of the interrogation data pulse to the leading edge of the reply data pulse (data interval).
- b. B Register. Holds the last validated data interval measured by the I Counter.
- c. T Counter. Generates the necessary timing to position the track gate.

d. L Register. Between beams, the register holds the last validated interrogation to reply from the previous DME time period.

e. D Counter. Counts the number of validated data intervals measured by the I Counter.

f. A Counter. Serves as an accumulator to sum the validated range data converted from the validated data intervals measured by the I Counter.

The use of the L Register to store the previously validated data interval from the previous DME period, obviates the need for a search period which is required for solicit and angle tracking. As noted previously, a search time is generally needed to acquire the first tracking interval. For interrogations, tracking can begin simultaneously with the transmission of the first interrogation pulse. This is accomplished by preloading the B Register with the contents of the L Register before the start of interrogation. The T Counter then generates the timing for the track gate for the expected reply.

Digital ranging begins when the leading edge of the interrogation data pulse is used to start the digital circuits. The interrogation data pulse sets a flip-flop to start the I Counter counting the clock pulses from an 8 MHz crystal oscillator, and the reply pulse is used to reset the flip-flop to stop the counting. The number of cycles counted, minus the 80  $\mu$ s delay, provides a measure of distance. Each 0.125- $\mu$ s clock pulse translates to approximately 0.0101 nautical miles. The maximum limit for the measured time is 320  $\mu$ s or 19.4 nautical miles.

The interrogation data pulse is also used to load tracking interval into the T Counter, and to start the T Counter timing, to position the track gate for the expected reply. The time from the interrogation to the center of the track gate is set to the last validated interrogation-to-reply time as measured by the I Counter. If the reply falls inside the track gate, the interval measured by the I Counter is validated. The validated interval is then used to update the B Register and L Register with the latest tracking interval.

The A Counter is used to accumulate the distance information from each validated interrogation-to-reply interval. Since the T Counter is pre-loaded with validated interval after each interrogation, its track gate timing is used to generate a distance interval equal to interrogation-to-reply interval minus  $80\ \mu\text{s}$ . While the distance interval is on, the A Counter counts an 8 MHz clock. As noted before, each clock cycle represents 0.0101 nautical miles. The D Counter is used to count the number of accumulated intervals. After the last interrogation, the Nav Set computes the average slant range by performing a binary division operation with the A Counter contents as the dividend and D Counter as the divisor.

Since the digital ranging method requires the T Counter timing, the slant range for the last or 16th interrogation is never used to compute the final average range.

Should the Nav Set lose tracking, meaning that the replies do not fall inside the track gate during the interrogation period, the distance flag is set. The Nav Set then attempts to re-establish tracking during the next interrogation period using its slew/hold circuits. The scheme used can be explained using the timing diagram in Figure 2-D16. Assume that the track gate is set at 5 nautical miles ( $141.7\ \mu\text{s}$ ). First, three attempts are made to track the first three reply pulses with the 5 nm gate. After the third failed attempt, the track gate is extended from 5 nm to the maximum range of 20.0 nm ( $327\ \mu\text{s}$ ). If the reply fails to fall in the extended track gate, a wide track gate from zero range ( $80\ \mu\text{s}$ ) to 20.0 nm ( $327\ \mu\text{s}$ ) is generated for the next reply. Either the extended track gate or the wide track gate should re-establish tracking. The slew/hold circuits also establish range tracking when the transmitted uplink and downlink DME signals become strong enough to be received by the interrogator and transponder receivers.

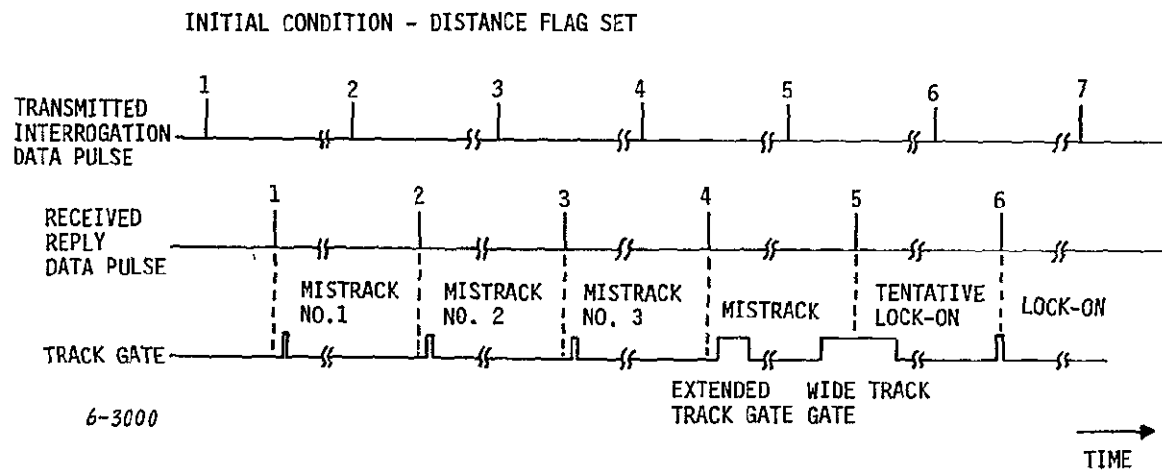


Figure 2-D16. Timing Diagram for a Full Slew/Hold Cycle

## 2-D17. REFERENCES

- a. AIL, "Technical Specification for Microwave Scanning Beam Landing System - Ground Station," Rev A, 22 December 1975.
- b. Rockwell International Corporation, Space Division, Specification for "Navigation Set, Microwave Scan Beam Landing System," Rev B04, 9 June 1975.
- c. "Manual for MSBLS Navigation Set," PDRD No. TG01A, Prepared for Rockwell International Corp. by AIL, Rev B, May 1976.
- d. DME Identity Decoder Schematic Diagram, AIL Drawing Number 502402, Rev A, 11 August 1975.
- e. Clock and Video Processor Schematic Diagram, AIL Drawing Number 502283, 11 August 1975.

75-1 TASKS 03 AND 05

PART E

MSBLS TRANSPONDER OPERATION

W. WONG

TECHNICAL REPORT

Y220-13

FINAL

AUGUST 1976

## 2-E1. INTRODUCTION

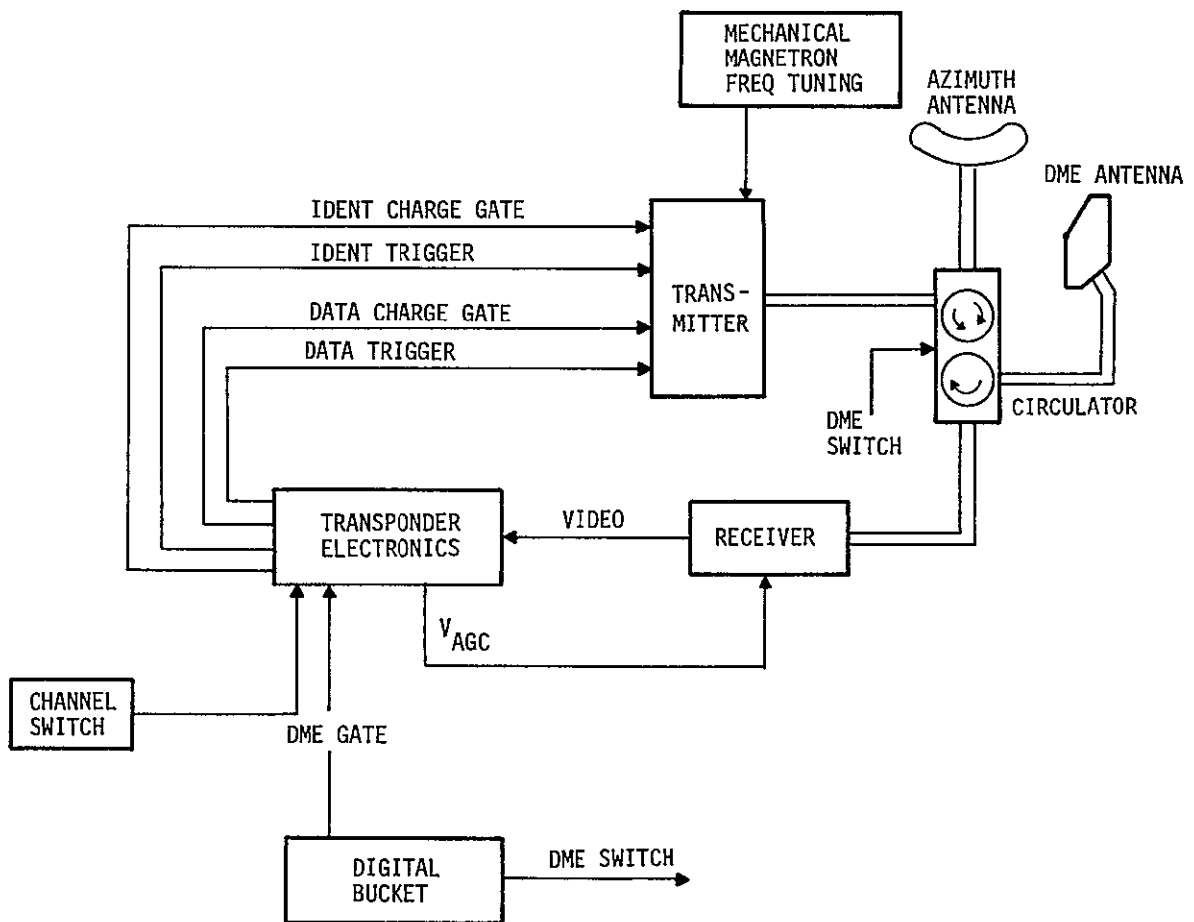
The MSBLS transponder is a transponder-receiver triggered by an interrogation. The purpose of this report is to describe this operation with emphasis on the signal processing of the transponder electronics.

A functional block diagram of the transponder is shown in Figure 2-E1. The transponder operates only during the time period allocated to DME operation. As shown in the timing diagram in Figure 2-E2, the DME operates every 200 ms during a 40 ms time period. During this time, the DME gate and DME switch signals are turned on. The DME switch signal directs the transmitter RF output (solicits and replies) to the DME antenna and directs the incoming RF interrogations from the DME antenna to the receiver. The DME gate activates the transmitter electronics during the DME period.

## 2-E2. CHANNELIZATION

The MSBLS transponder is capable of operating on any one of 10 channels using 10 frequencies. Each channel is identified by both operating frequency and DME pulse spacing. The frequencies and DME pulse spacings assigned to each channel are as follows:

| Channel<br>No. | Transmitting Channels<br>Pulse Spacing - 8 $\mu$ s<br>Frequency - Listed Below | Receiving Channels<br>Pulse Spacing - See Below<br>Frequency - 15.460 GHz |
|----------------|--------------------------------------------------------------------------------|---------------------------------------------------------------------------|
| 1              | 15.412 GHz                                                                     | 11 $\mu$ s                                                                |
| 2              | 15.436 GHz                                                                     | 13 $\mu$ s                                                                |
| 3              | 15.484 GHz                                                                     | 15 $\mu$ s                                                                |
| 4              | 15.508 GHz                                                                     | 17 $\mu$ s                                                                |
| 5              | 15.532 GHz                                                                     | 19 $\mu$ s                                                                |
| 6              | 15.568 GHz                                                                     | 21 $\mu$ s                                                                |
| 7              | 15.592 GHz                                                                     | 23 $\mu$ s                                                                |
| 8              | 15.616 GHz                                                                     | 25 $\mu$ s                                                                |
| 9              | 15.664 GHz                                                                     | 27 $\mu$ s                                                                |
| 10             | 15.688 GHz                                                                     | 29 $\mu$ s                                                                |



6-3001

Figure 2-E1. Transponder, Functional Configuration

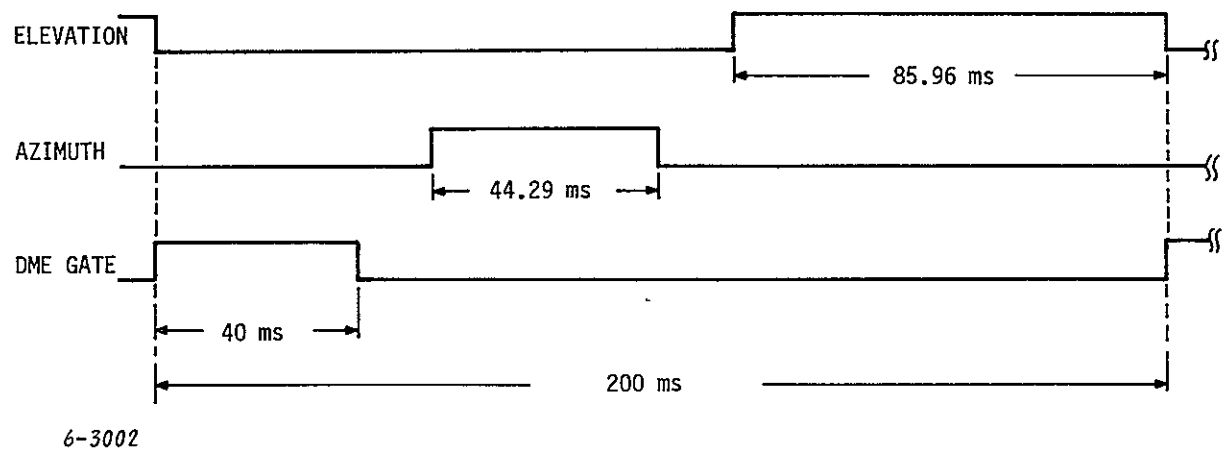


Figure 2-E2. MSBLS Ground Station Information Cycle

The transmitting frequency is obtained by mechanically tuning the transmitter magnetron to the proper channel frequency.

### 2-E3. TRANSPONDER ELECTRONICS

The transponder electronics performs the following functions (Figure 2-E3):

- a. Decodes video pulse spacings.
- b. Generates signals to the transmitter to generate the solicit signal and replies to interrogations.
- c. Generates squitter AGC voltage ( $V_{AGC}$ ) to set the video decoding threshold sufficiently above rms noise.

A detailed description of transponder electronics follows.

2-E4. VIDEO DETECTION. As shown in Figures 2-E4 and 2-E5, video from the receiver is detected by a comparator with a 2-volt threshold. When video crosses above the threshold a synchronized video pulse (SYNVD) is generated. The leading edge of SYNVD, which is synchronized to a 4 MHz system clock, marks the time of arrival of the received pulse. However, due to clock synchronization, SYNVD is offset from the actual time of arrival by less than one clock period or  $0.25 \mu s$ .

When the transponder is being interrogated, two SYNVD's are generated. The first SYNVD, corresponding to the identity pulse, establishes a time reference for the identity decoding process described later. The second SYNVD corresponds to the data pulse. If the (data) SYNVD occurs within the proper time from the first SYNVD, it is used to trigger or start the timing for the reply signal.

2-E5. SOLICIT PULSE TRIGGER GENERATOR. The solicit pulse trigger generator consists of the solicit pulse generator, solicit gate generator, and solicit pulse counter shown in Figure 2-E4. At the beginning of the 40 ms

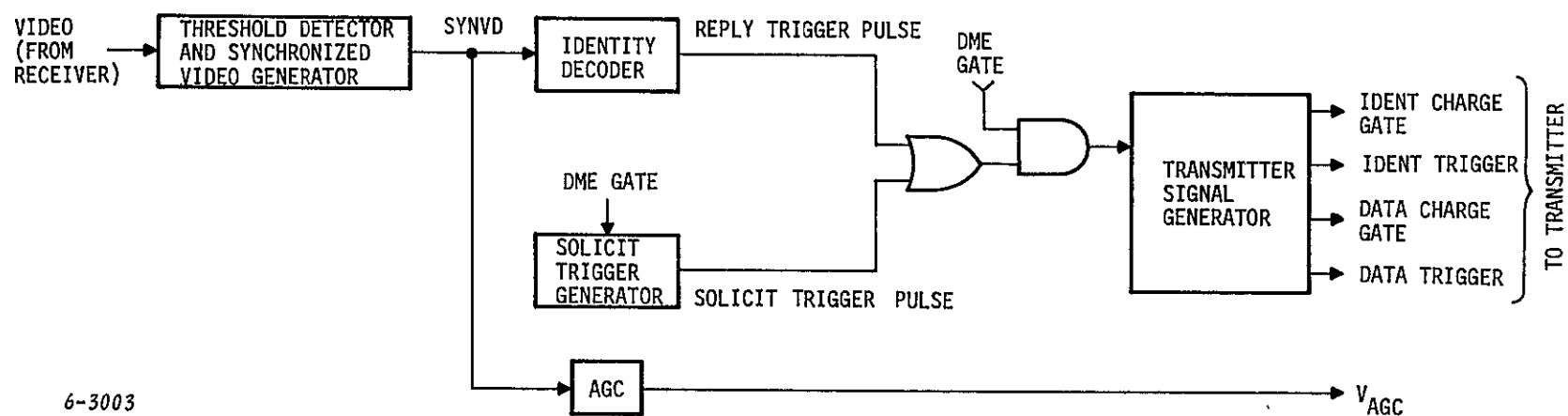
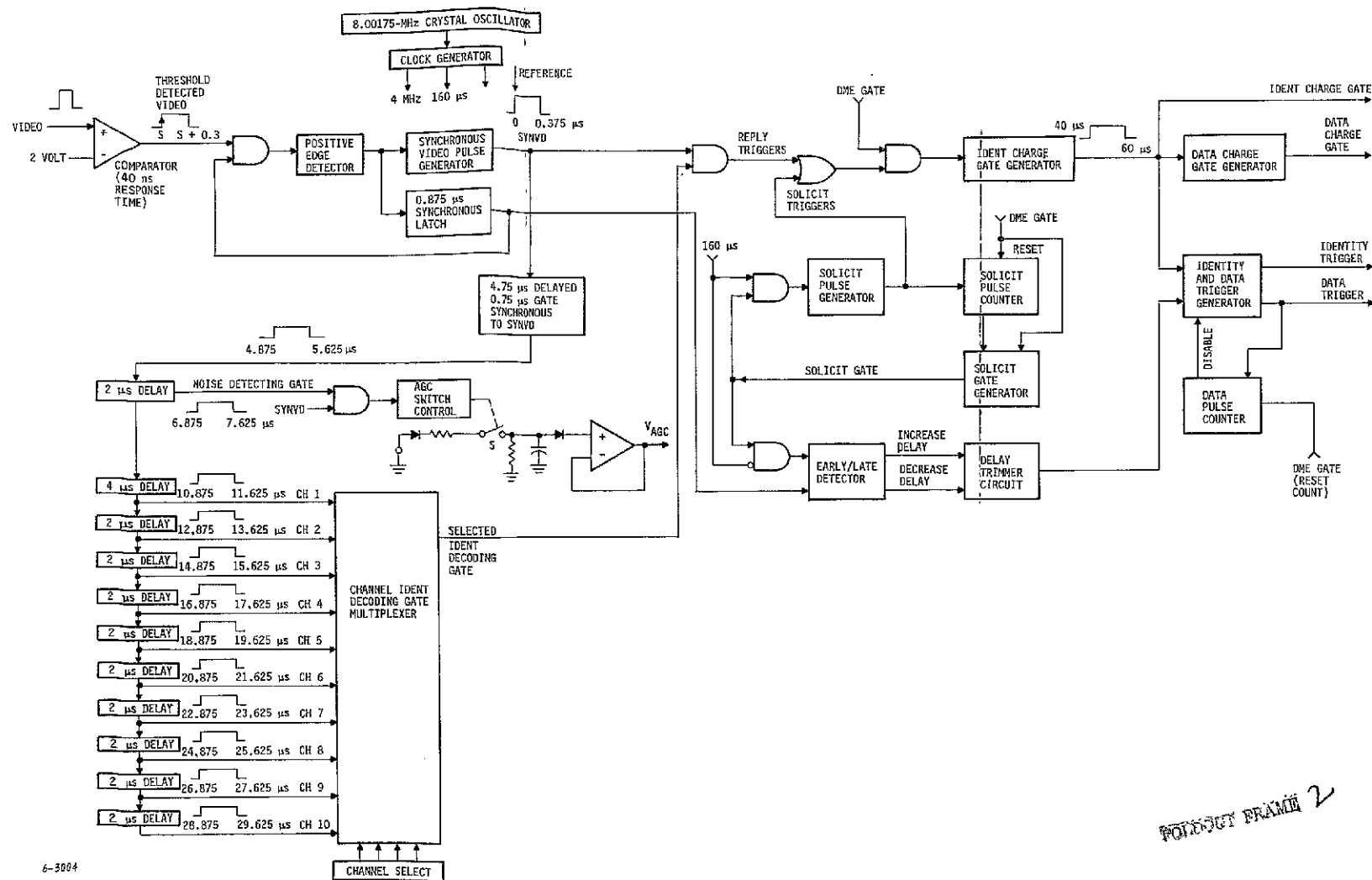


Figure 2-E3. Transponder Electronics, Simplified Block Diagram



6-3004

Figure 2-E4. Transponder Electronics, Block Diagram

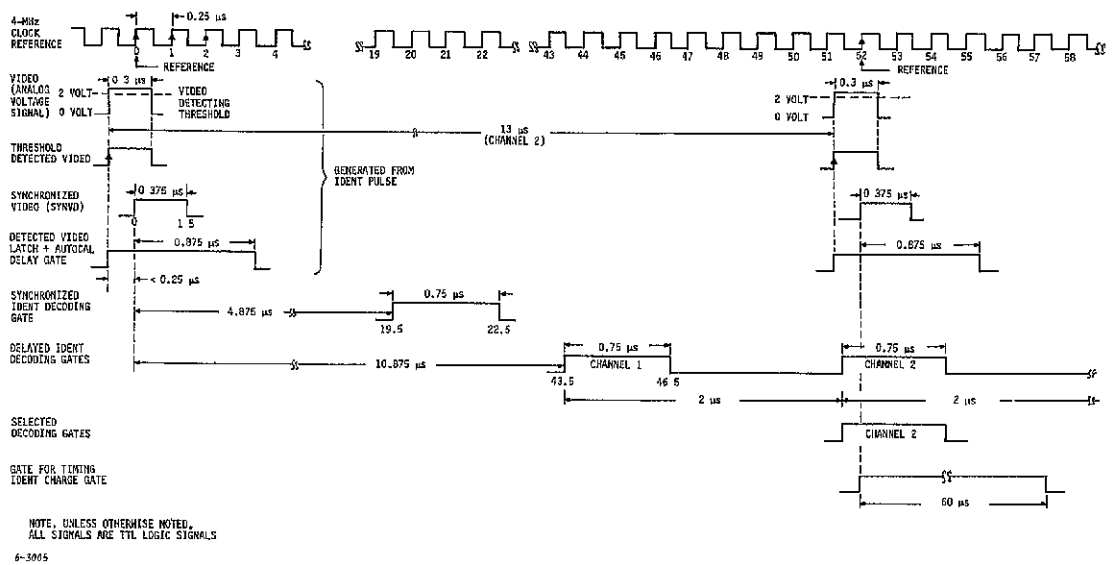


Figure 2-E5. DME Electronics, Timing

DME period the solicit gate turns on, permitting 14 solicit triggers (SOP), spaced  $160\ \mu\text{s}$  apart, to be generated. See Figure 2-E6.

Each SOP directs the transmitter signal generator to generate the transmitter signals to produce a pair of  $0.3\text{-}\mu\text{s}$  pulses spaced  $8\ \mu\text{s}$  apart. See Figure 2-E6.

2-E6. TRANSPONDER CHANNEL IDENTITY DECODING. Interrogations received by the transponder consist of pulse pairs with a channel identity code spacing. The transponder answers only those interrogations with the selected channel spacing.

The transponder recognizes or decodes the interrogation channel spacings with the use of  $0.75\text{-}\mu\text{s}$  identity decoding gates as shown in the timing diagram in Figure 2-E7 and the block diagram in Figure 2-E4. The first pulse (identity pulse) of the interrogation signal causes a SYNVD pulse to be generated, which in turn starts the timing for the 10 decoding gates. A channel selector selects one of the 10 gates to be used to detect the appearance of the next SYNVD (data pulse). If the next SYNVD occurs inside the selected decoding gate, a valid interrogation is recognized, resulting in a reply trigger being generated to start the timing for the transmitter signals.

2-E7. TRANSMITTER SIGNAL GENERATOR. The transmitter signal generator generates the necessary logic signals, which are sent to the transmitter so that the transmitter can produce pairs of  $0.3\text{-}\mu\text{s}$  RF pulses spaced  $8\ \mu\text{s}$  apart. The generator is activated by an input trigger signal. At the beginning of the DME period the generator receives 14 such triggers (SOP's) from the solicit pulse generator in order to produce the RF solicit signal. Thereafter, further triggers (SYNVD's) are generated in response to Orbiter interrogations as shown in Figure 2-E8. Near the end of the DME period, after the Orbiter has finished its interrogation, field monitor interrogations are also answered with RF replies.

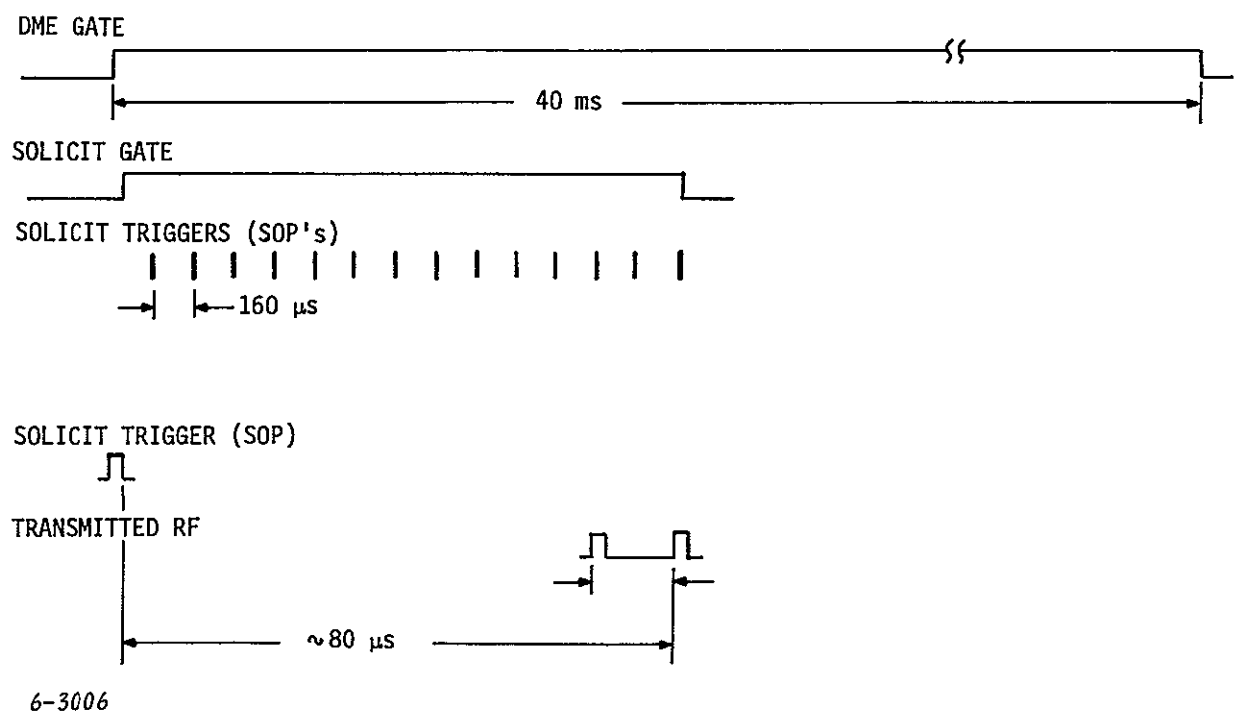
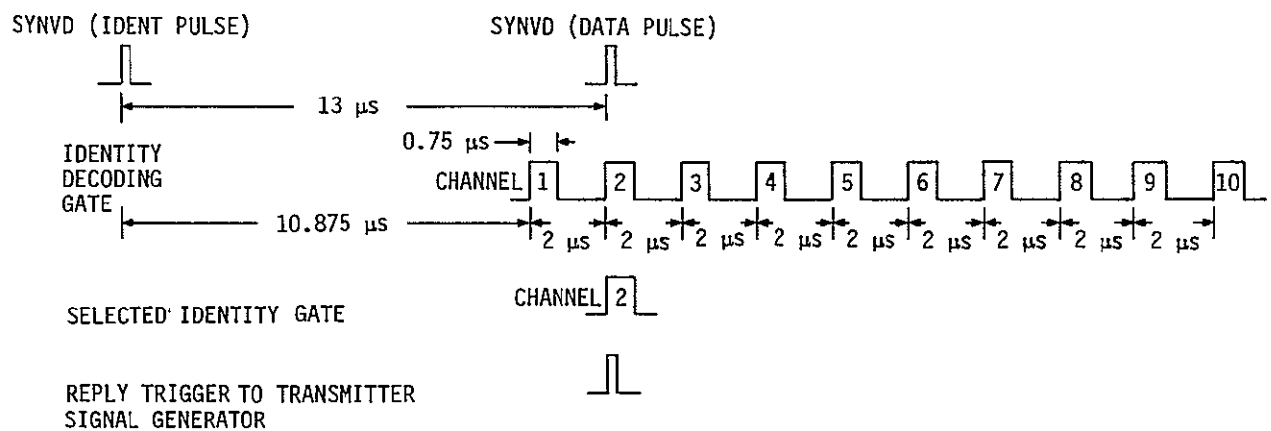


Figure 2-E6. Solicit Signal



6-3007

Figure 2-E7. Transponder, Identity Decoding

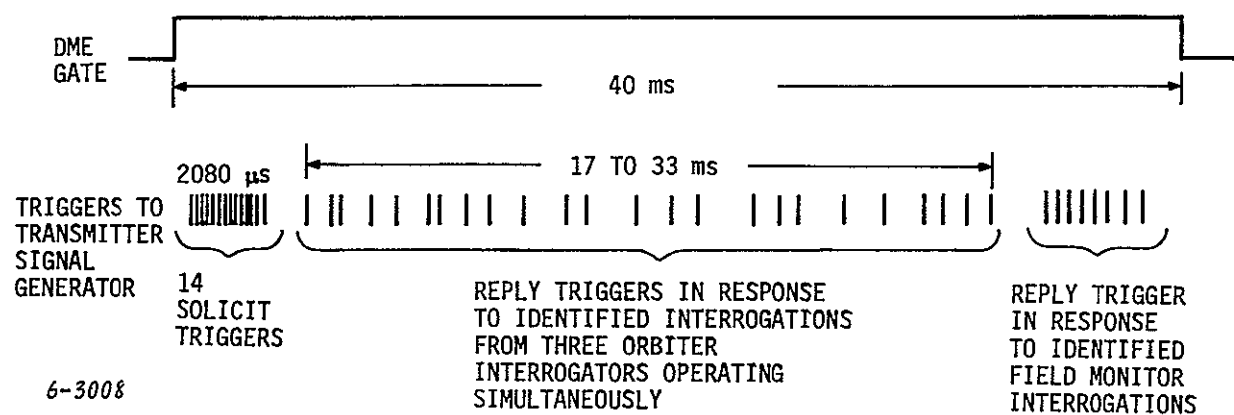
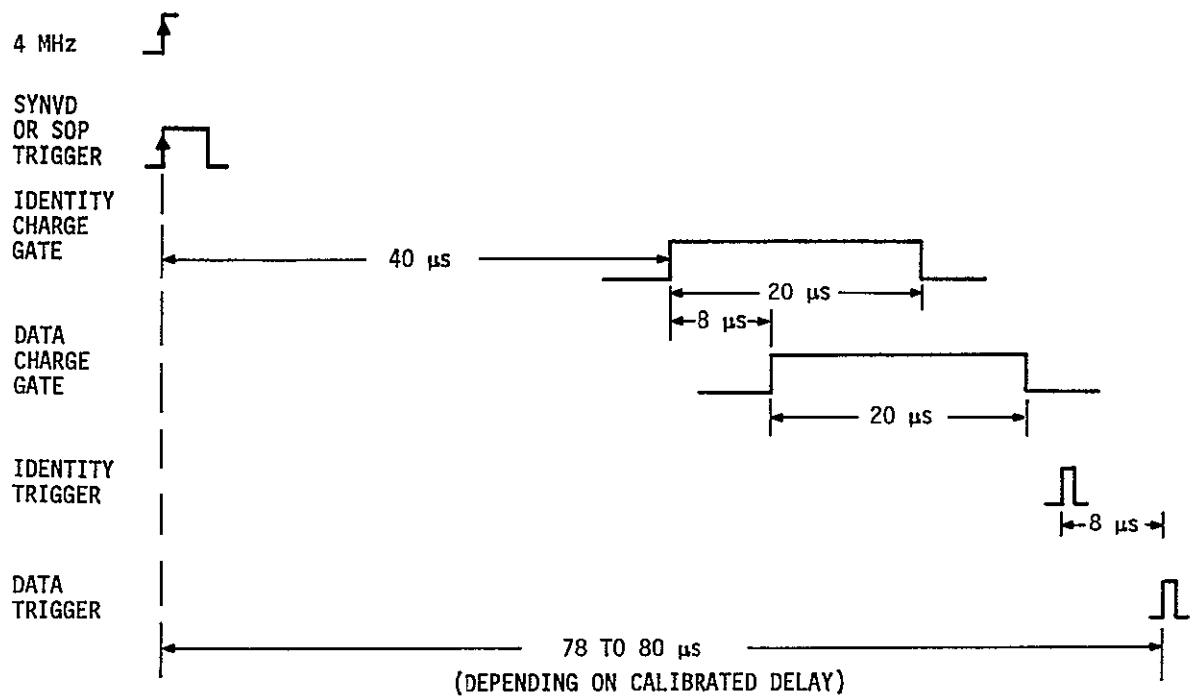


Figure 2-E8. Triggers to the Transmitter Signal Generator

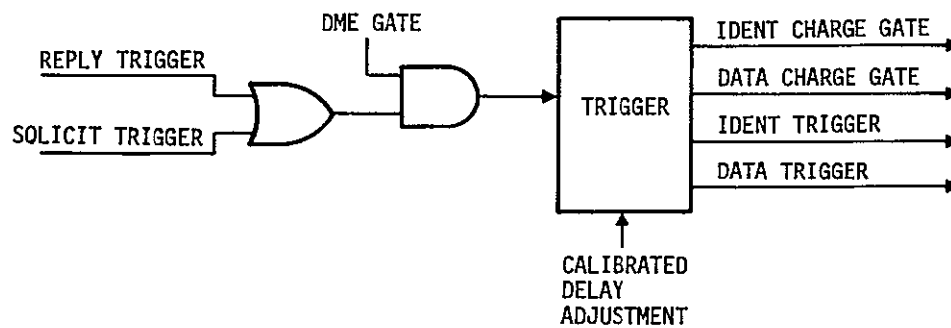
The timing for the logic signals sent to the transmitter is shown in Figure 2-E9. Each RF pulse generated by the transmitter requires a  $20\ \mu\text{s}$  charge gate command to charge up the modulator, followed by a trigger pulse to release the stored energy to fire the magnetron. The identity charge gate and the identity trigger pulse are used to produce the RF identity. The data charge gate and data trigger pulse are used to produce the RF data pulse  $8\ \mu\text{s}$  later.

When the transponder is transmitting a reply in response to an interrogation, the time delay from a received interrogation to a transmitted reply should be  $80 \pm 0.5\ \mu\text{s}$  (one sigma) as specified by the ground station specification. This specification dictates the timing for the transmitter charge gates and transmitter trigger pulses. As shown in Figure 2-E9, the transponder electronics uses the leading edge of SYNVD as the reference point. The position of the two charge gates are fixed at  $40\ \mu\text{s}$  and  $48\ \mu\text{s}$  from the reference. In order to compensate for the transponder system delays shown in Figure 2-E10, the time delay introduced by the transmitter signal generator is set to less than  $80\ \mu\text{s}$ . This delay is automatically adjusted to the proper time by a control loop which operates during solicit transmission. During the solicit period, the SOP trigger sets off the signals to the transmitter, the transmitter generates the RF pulse, the RF then passes through the receiver to the transponder electronics, and then a comparison is made of the time from SOP to the received data pulse. From this comparison, the transmitter signal generator trims the variable delay by the proper amount. The early/late detector and delay trimmer circuits shown in the block diagram in Figure 2-E4 are used for the delay adjustment.

Due to the configuration of the transmitter signal generator circuitry, once a trigger has been received, another trigger cannot be processed for a period of  $60\ \mu\text{s}$ . For this reason, if the DME antenna receives two interrogations within  $60\ \mu\text{s}$  of each other, the second interrogation will be ignored.

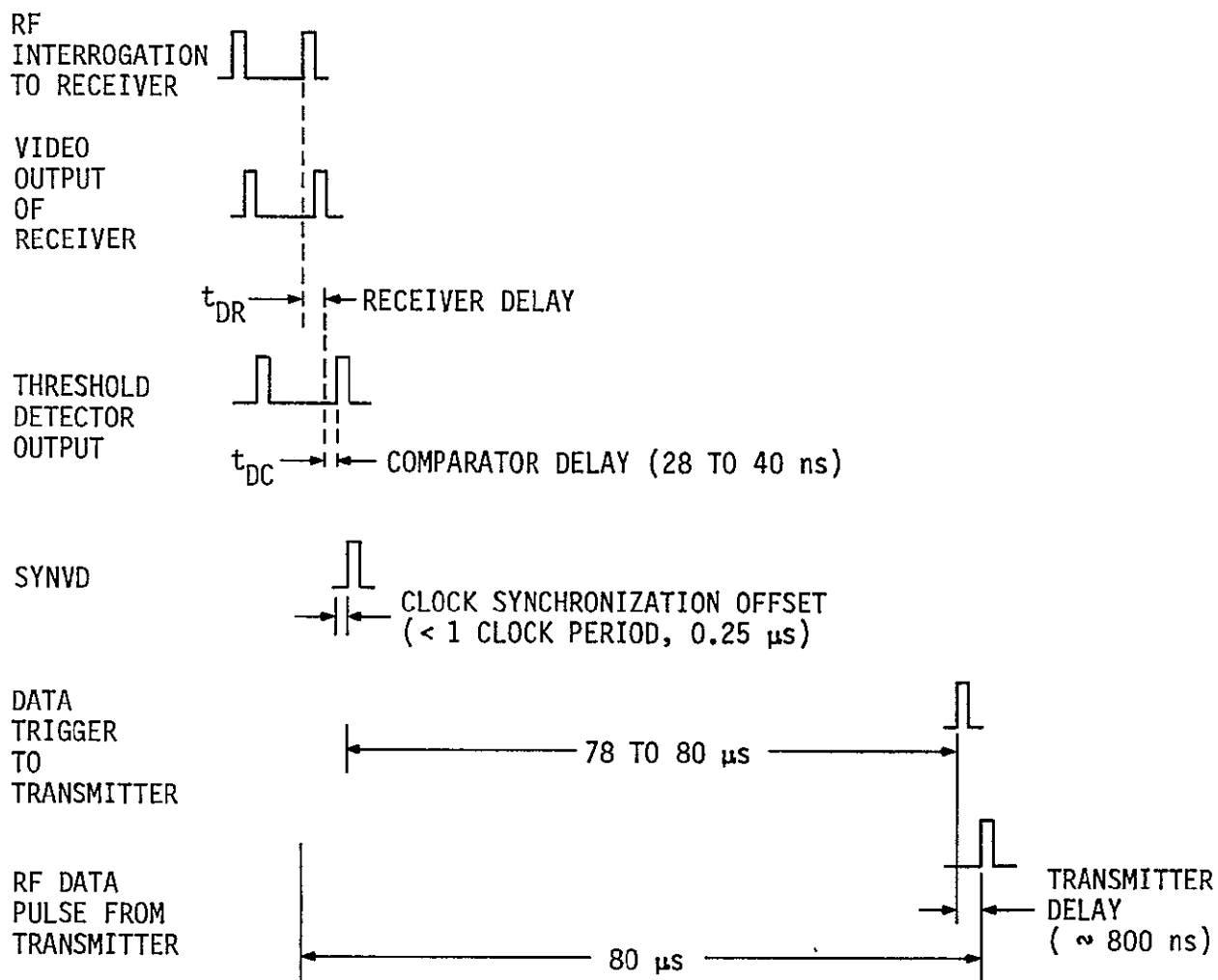


A. SIGNAL TIMING



B. INPUT/OUTPUT SIGNALS

Figure 2-E9. Transmitter Signal Generator



6-3010

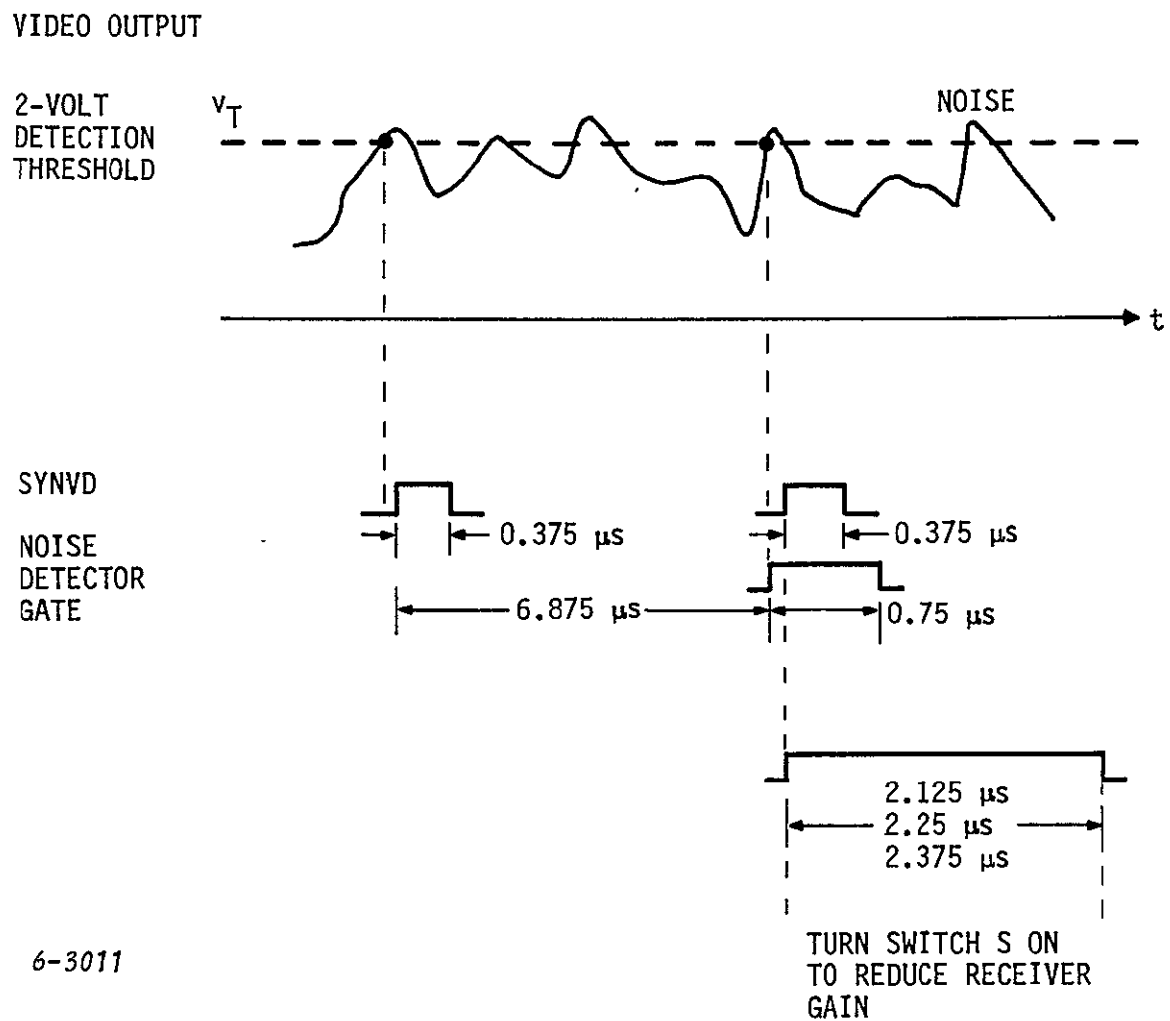
Figure 2-E10. Identifying Transponder Systems Delay

2-E8. TRANSPONDER AGC. The transponder receiver sensitivity is determined by a squitter AGC loop which tries to maintain the amplitude of the noise appearing at the video output sufficiently below the detecting threshold, so that it does not interfere with normal DME signal processing. As shown in Figure 2-E11, noise pulses exceeding threshold can be detected. Should a pair of noise pulses be detected with a spacing corresponding to the selected DME channel spacing ( $11\ \mu\text{s}$  for channel 1,  $13\ \mu\text{s}$  for channel 2,  $15\ \mu\text{s}$  for channel 3, etc.), a false interrogation is recognized, causing a DME reply to be transmitted. If such false interrogations become excessive, the transponder may fail to recognize valid interrogations if they are received within  $60\ \mu\text{s}$  following a false interrogation.

The AGC scheme shown in Figure 2-E12 uses a noise detector and an AGC capacitor memory circuit to produce a dc voltage to set the receiver gain. In order to differentiate noise from valid interrogation signals, the noise detector looks for detected video separated by  $7.25 \pm 0.75\ \mu\text{s}$ , a spacing which does not fall within any of the DME channel pulse spacing codes. The AGC capacitor memory is an RC circuit shown in Figure 2-E13. The voltage  $V_{\text{AGC}}$ , equal to the capacitor voltage, controls the receiver gain. The receiver gain is maximum when  $V_{\text{AGC}}$  equals zero and decreases with  $V_{\text{AGC}}$  at a rate of approximately 17 dB per volt.

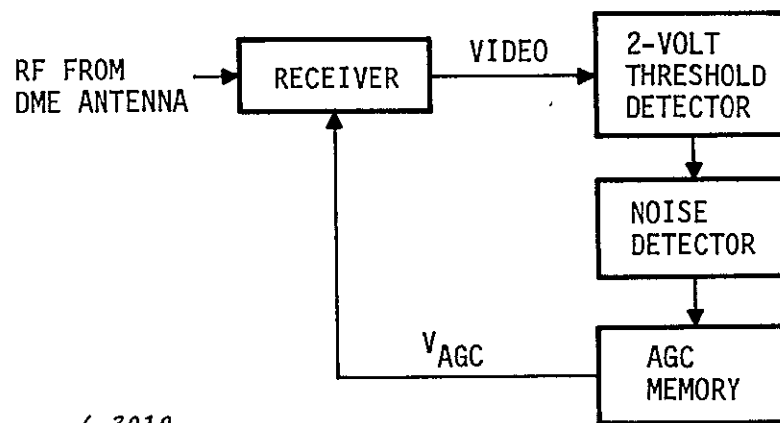
Initially, the capacitor voltage equals zero and switch S is open. When the noise detector detects excessive noise appearing at the video output, switch S closes for approximately  $2\ \mu\text{s}$ , increasing  $V_{\text{AGC}}$ , decreasing the receiver gain, and thereby reducing the noise output. As noise continues to be detected,  $V_{\text{AGC}}$  increases each time until output noise is finally reduced to an acceptable level.

By keeping the transponder sensitivity high, it is able to detect signals from close-in and far interrogators. In the MSBLS the transponder is interrogated by the close-in field monitors and the three Orbiter Nav Sets.



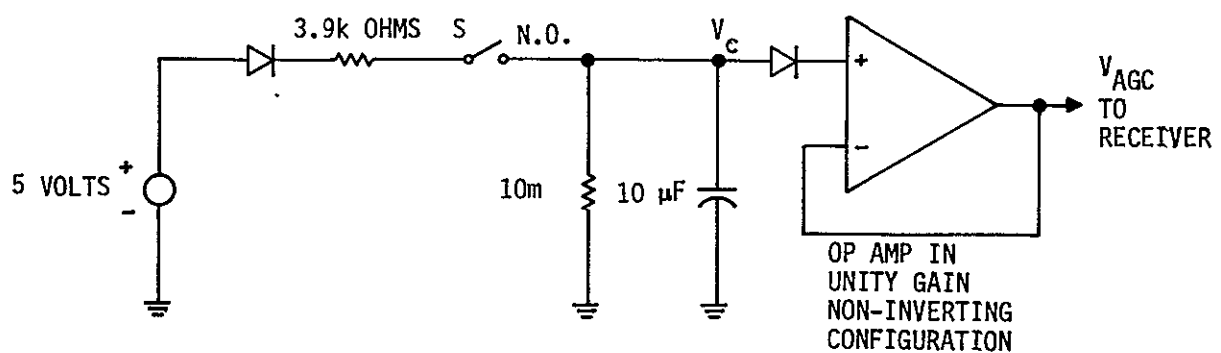
6-3011

Figure 2-E11. Noise Detector



6-3012

Figure 2-E12. Transponder AGC, Block Diagram



NOTES:

1. SWITCH S IS NORMALLY OPEN
2. SWITCH S CLOSSES FOR  $\sim 2 \mu$ s WHENEVER A NOISE PULSE PAIR IS DETECTED
3. THE OPERATIONAL AMPLIFIER SERVES AS A BUFFER PROVIDING HIGH INPUT IMPEDENCE AND LOW OUTPUT IMPEDENCE

6-3013

Figure 2-E13. Transponder AGC Memory

2-E9. DATA TRIGGER COUNTER. The data trigger counter, shown in Figure 2-E4, counts the number of data triggers generated during the DME period. If more than 511 data triggers are counted, a signal is generated to inhibit further transmitter triggers from being generated during the present DME period. The purpose of setting an upper limit is to prevent the transmitter from being overloaded.

If 511 data triggers are spaced equally apart during the 40 ms DME period, the time between data triggers is  $78\ \mu\text{s}$ . Recalling the presence of a  $60\ \mu\text{s}$  inhibit period following a received interrogation, it would appear that the  $60\ \mu\text{s}$  period would probably prevent the transponder transmission from ever reaching 511.

The 511 upper limit is well within requirements. The ground station is specified to be able to operate with a maximum of 10 interrogators. A tabulation of the maximum number of data triggers the transponder expects to transmit is given below:

|                                               | Number of Data Triggers |
|-----------------------------------------------|-------------------------|
| Solicit signal                                | 14                      |
| Ten interrogators<br>(16 interrogations each) | 160                     |
| Field monitors                                | <u>21</u>               |
|                                               | 195                     |

PART F

DESCRIPTION OF MSBLS-GS ANTENNA  
DRIVE AND SYNCHRONIZATION

W. WONG

TECHNICAL REPORT Y220-18

FINAL  
MARCH 1977

## 2-F1. INTRODUCTION

The azimuth and elevation ground station antennas both oscillate in a manner which allows transmission of azimuth, elevation, and DME information to be multiplexed in a 200 millisecond period. As shown in Figure 2-F1, the information sequence is azimuth, elevation, and then DME. The azimuth antenna scans sinusoidally  $\pm 44$  degrees from 0-degree azimuth centerline, or centerscan, and transmits only while the antenna is scanning  $\pm 15$  degrees. The elevation antenna scans sinusoidally  $\pm 24$  degrees from 15 degrees elevation angle and transmits only while the antenna is scanning  $\pm 15$  degrees from 15 degrees elevation (0 to 30 degrees elevation angle).

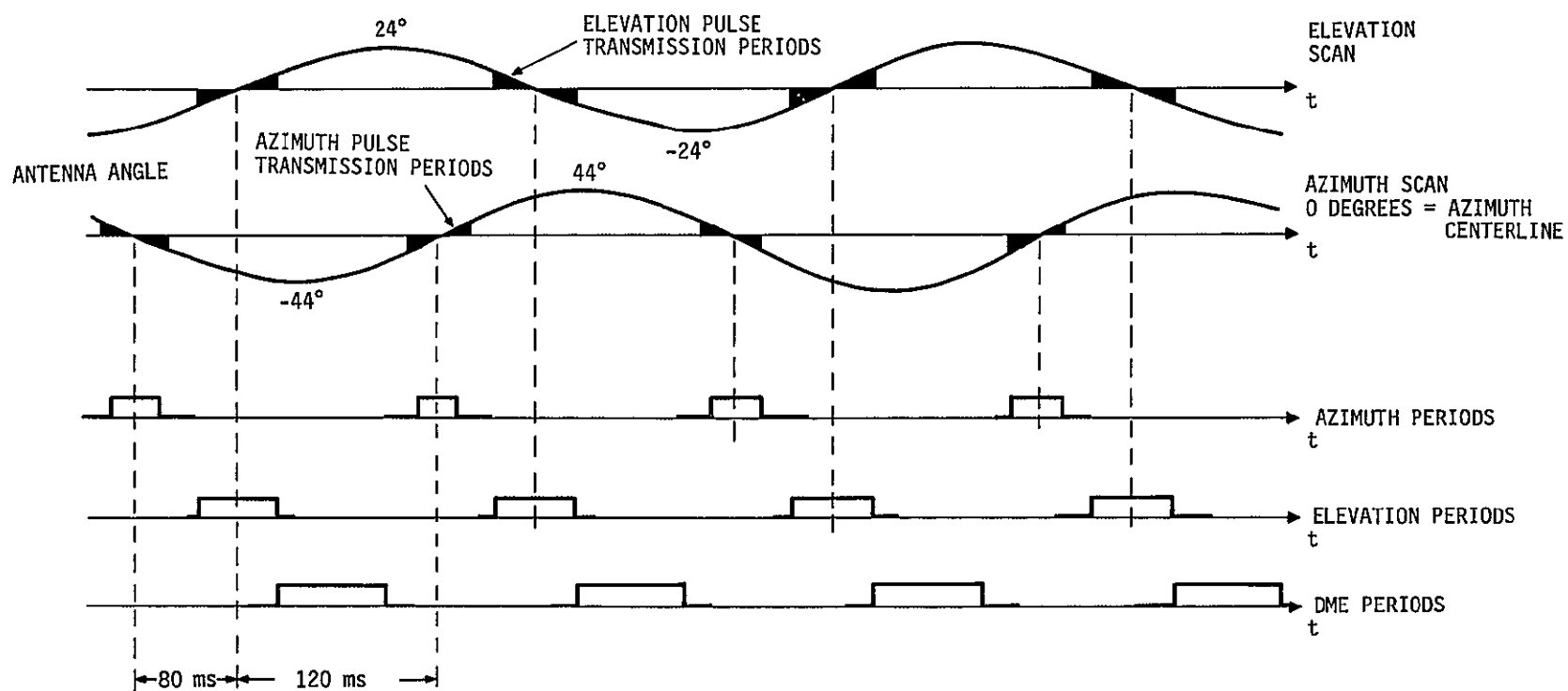
In order to prevent any overlapping of the information periods, the elevation and azimuth antennas are synchronized so that the azimuth scan lags the elevation scan by 120 milliseconds as shown in Figure 2-F1. The discussion which follows describes the antenna drive system which:

- a. Starts the antenna scanning.
- b. Maintains the antenna's oscillatory period and amplitudes at their design values.
- c. Keeps the proper phasing between the elevation and azimuth antenna scans.

## 2-F2. BASIC ANTENNA DRIVE CONFIGURATION

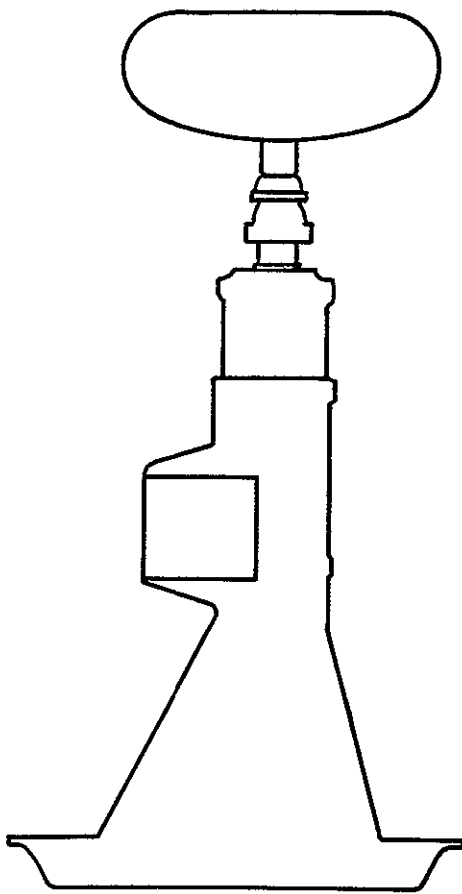
The antenna scanner for azimuth and elevation are similar. Each basically consists of a transmitting antenna, angle data pickoff (ADP), torque motor, drive amplifier, drive timing, overscan switch, and torsion bar. The structures of the scanners are shown in Figures 2-F2 and 2-F3. One end of the torsion bar is connected to the scanner housing while the opposite end is connected to the ADP shaft. The torque motor rotor shaft and antenna are also connected along the same axis.

Block diagrams illustrating the relative roles of the drive system elements are shown in Figures 2-F4 and 2-F5.



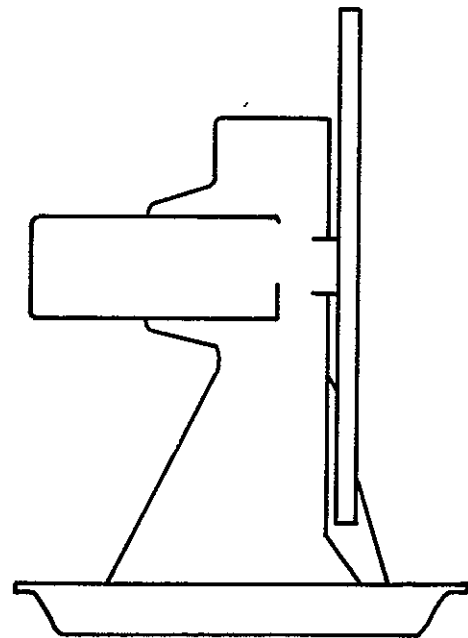
7-979

Figure 2-F1. Nominal Phasing Diagram for Azimuth, Elevation, and DME Information Periods, and for Elevation and Azimuth Scans



AZIMUTH SCANNER  
FRONT VIEW

7-980



ELEVATION SCANNER  
FRONT VIEW

Figure 2-F2. Azimuth and Elevation Scanners

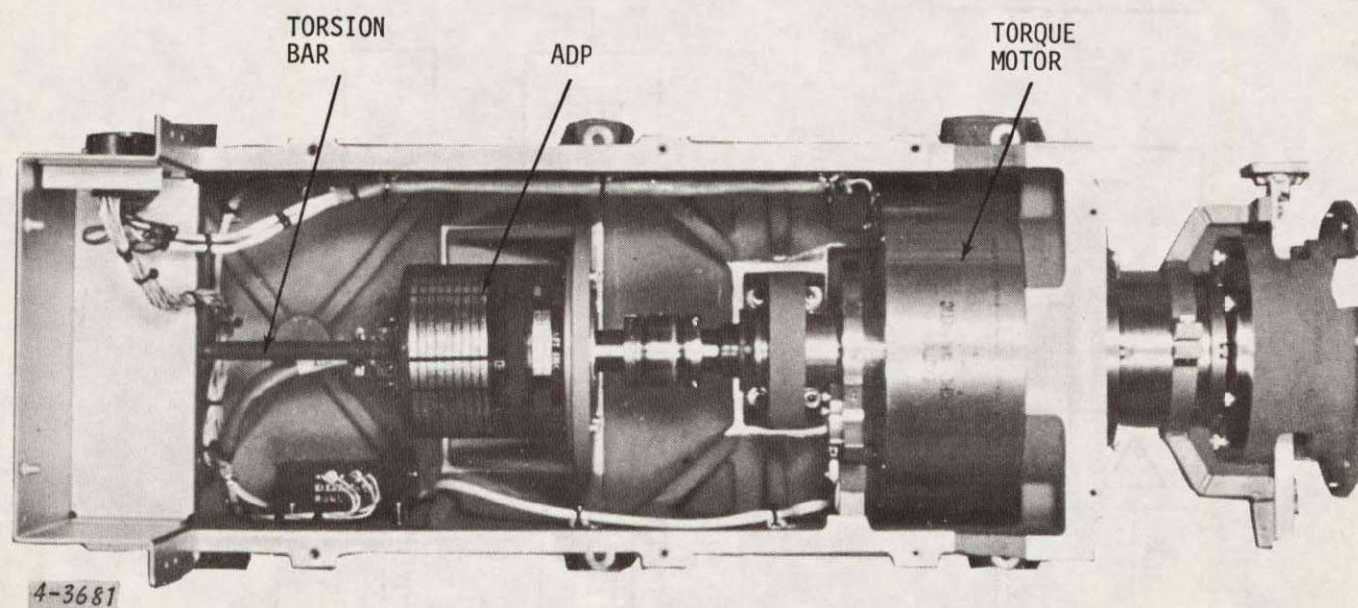


Figure 2-F3. Antenna Drive Scanner Assembly (Less Antenna)

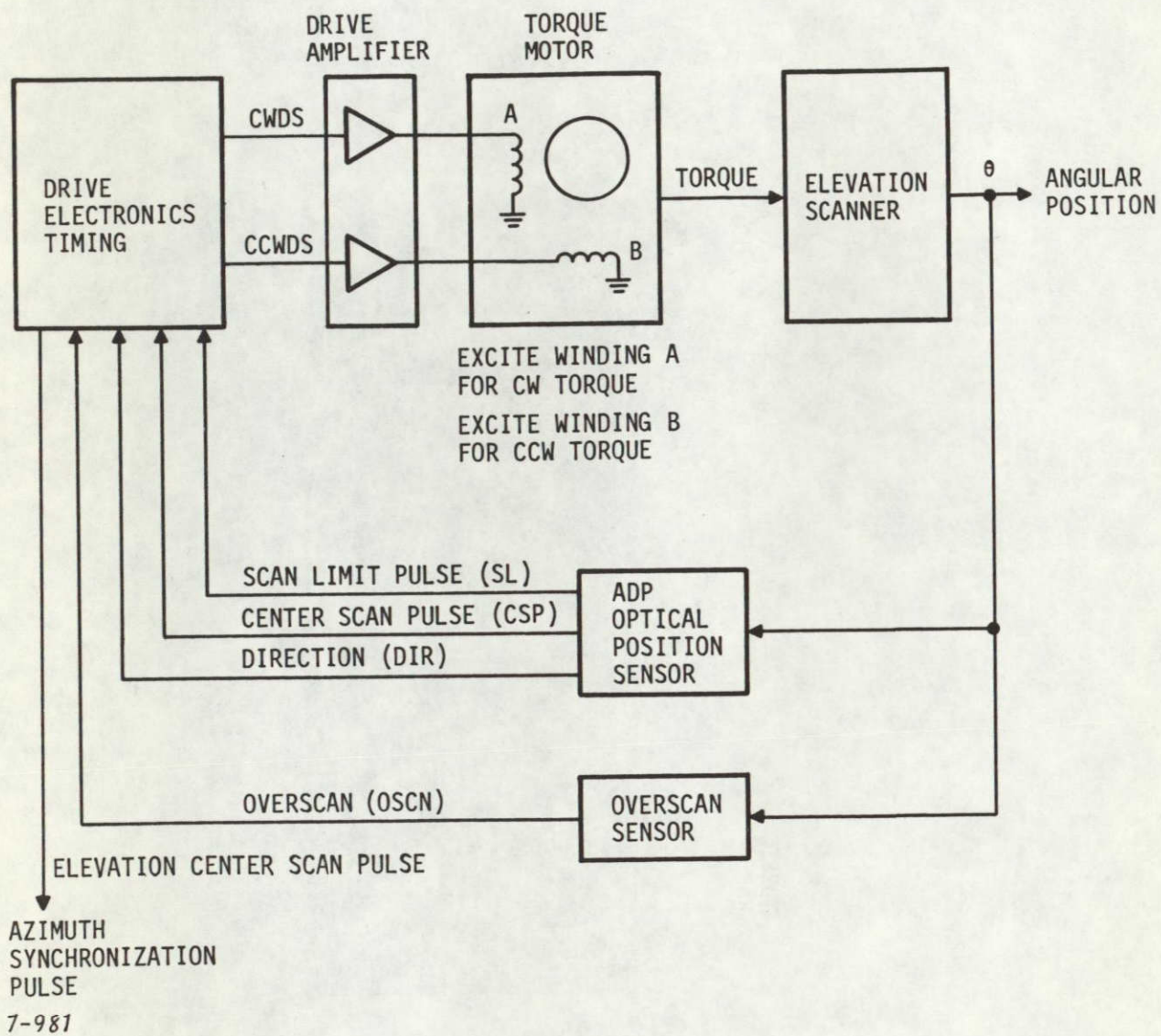
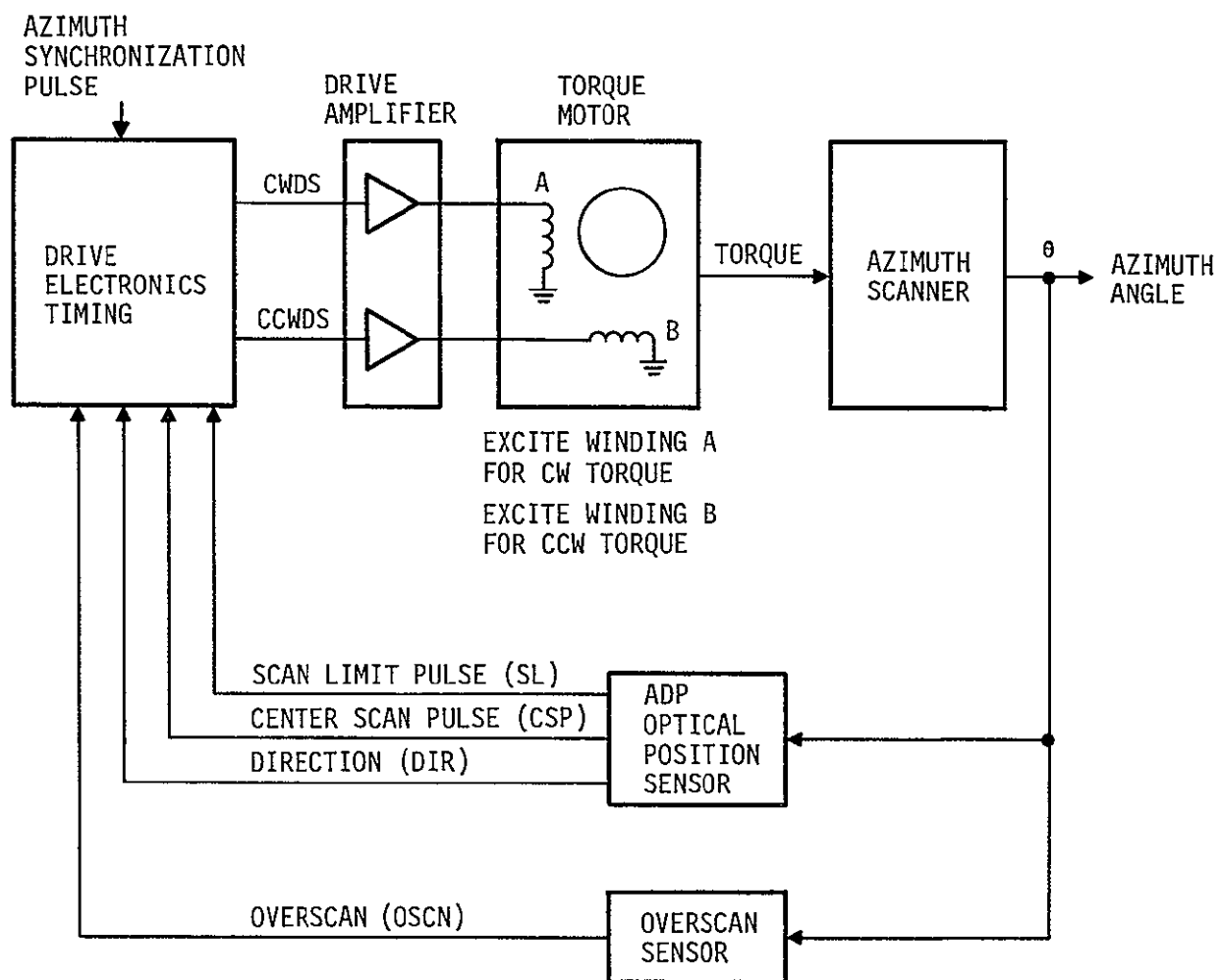


Figure 2-F4. Elevation Scanner, Block Diagram



7-982

Figure 2-F5. Azimuth Scanner, Block Diagram

2-F3. ANGLE DATA PICKOFF (ADP). The ADP is an optical-mechanical transducer which generates a logic signal which senses antenna angular position. These signals enable the drive timing to generate the proper drive signals to obtain the correct antenna scans. The ADP signals used by the drive system are:

a. Center Scan Pulse (CSP). The center scan pulse is generated whenever the antenna shaft rotates through its equilibrium position.

b. Scan Limit (SL). The scan limit signal is high when the elevation antenna shaft position is greater than  $\pm 23$  degrees ( $\pm 42$  degrees for azimuth) of the equilibrium position.

c. Direction (DIR). The direction signal is high when the antenna shaft is rotating clockwise, and low when the shaft is rotating counterclockwise. The elevation direction is referenced looking into the shaft axis from the side on which the antenna is mounted, while the azimuth direction is referenced looking down into the shaft axis from the top of the azimuth scanner.

2-F4. TORQUE MOTOR AND DRIVE AMPLIFIER. The motor is a brushless dc motor with two separate excitation windings for delivering torques of opposite polarity. The drive amplifier sends a constant excitation to only one of the motor windings at any given time, subject to the command signals from the drive timing.

2-F5. TORSION BAR. The torsion bar provides a spring constant to the mechanical system such that the natural oscillatory frequency is 2.5 Hz.

#### 2-F6. ELEVATION DRIVE

The elevation drive timing generates two logic drive signals to turn on the drive amplifier. When the clockwise drive signal (CWDS) is high, the drive amplifier excites one of the torque motor windings so that a constant clockwise torque is applied to the scanner. Likewise, when the counterclockwise drive signal (CCWDS) is high, the drive amplifier excites the other motor winding for counterclockwise torque.

2-F7. DRIVE PULSE DURATION. The elevation drive timing controls the drive signals in several ways. The duration of the drive signal is regulated such that from 0 to 24 degrees scan amplitude, the torque duration is long enough to impart sufficient power to the scanner in order to exceed the frictional losses. This allows the scan amplitude to build up. The drive signal duration characteristic is shown in part A of Figure 2-F6. From 0 to 23 degrees, the drive signal duration  $\Delta t_{DS}$  is 50 milliseconds (Figure 2-F7). From 23 degrees on (Figure 2-F8), the drive signal duration is regulated by the ADP scan limit pulse duration which provides a measure of the scan amplitude. The equations which relate elevation drive signal duration to scan limit pulse duration, and scan limit pulse duration to scan amplitude are:

$$\Delta t_{DS} = \begin{cases} 50 & \text{ms} & 0 < \theta_M < 23^\circ \\ 28 - \frac{\Delta t_{SL}}{2} & \text{ms} & 23^\circ < \theta_M < 25.4^\circ \\ 0 & & \theta_M > 25.4^\circ \end{cases} \quad (7a)$$

$$\Delta t_{SL} = \begin{cases} 0 & 0 < \theta_M < 23^\circ \\ 200 - 127.3 \sin^{-1} \frac{23}{\theta_M} & \text{ms} & \theta_M > 23^\circ \end{cases} \quad (7b)$$

where

$\theta_M$  = scan amplitude in degrees

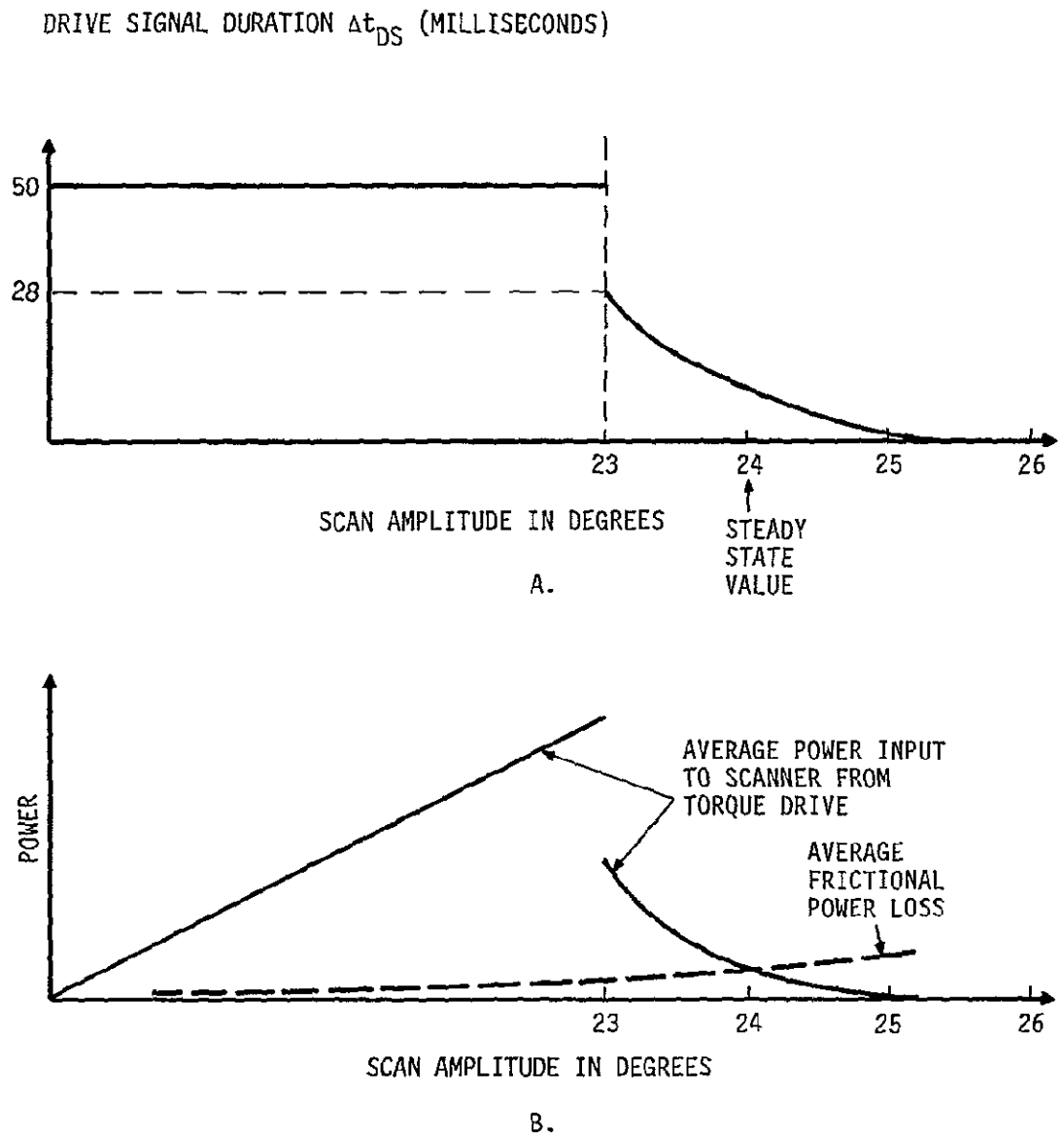
$\Delta t_{DS}$  = drive signal duration in milliseconds

$\Delta t_{SL}$  = scan limit pulse duration in milliseconds

The dimensions of  $\sin^{-1} \frac{23}{\theta_M}$  is radians. At 23 degrees, with zero scan limit duration, the drive signal duration is 28 milliseconds. As the scan amplitude continues to increase from 23 degrees, the scan limit pulse duration increases and the drive signal duration decreases. Eventually, when the scan amplitude reaches 24 degrees, the power imparted to the scanner by the applied torque is just equal to the frictional losses of the scanner, and the scan amplitude stabilizes at 24 degrees. Should the scan amplitude overshoot the steady state value, the drive duration decreases to bring down the scan amplitude. Part B of Figure 2-F6 illustrates how the power balance is obtained.

2-F8. DRIVE PULSE TIMING. The timing between the drive signals CWDS and CCWDS is designed so that the scanner oscillates with a 400 millisecond period. During start-up from 0 to 23 degrees, the drive signal alternates between clockwise and counterclockwise drive every 200 milliseconds as shown in Figure 2-F7.

For scan amplitudes greater than 23 degrees, the drive signals are centered to coincide with the equilibrium scan position, and torque is applied to the scanner in the same direction it is rotating. As shown in Figure 2-F8, the ADP center scan pulse (CSP) and direction (DIR) signals are used for generating the necessary timing. The elevation drive timing synchronizes its digital timing circuits to the CSP, so that the drive signal is centered 200 milliseconds from the CSP. For proper torque direction, the clockwise drive signal is generated when DIR is high and the counterclockwise drive signal is generated when DIR is low.



7-983

Figure 2-F6. Drive Signal Characteristic, and Power Input and Frictional Losses

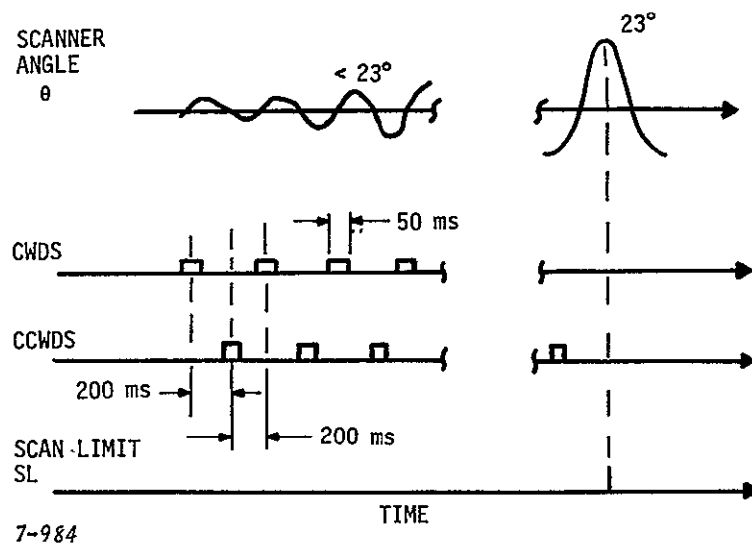


Figure 2-F7. Elevation Drive Start-Up Timing

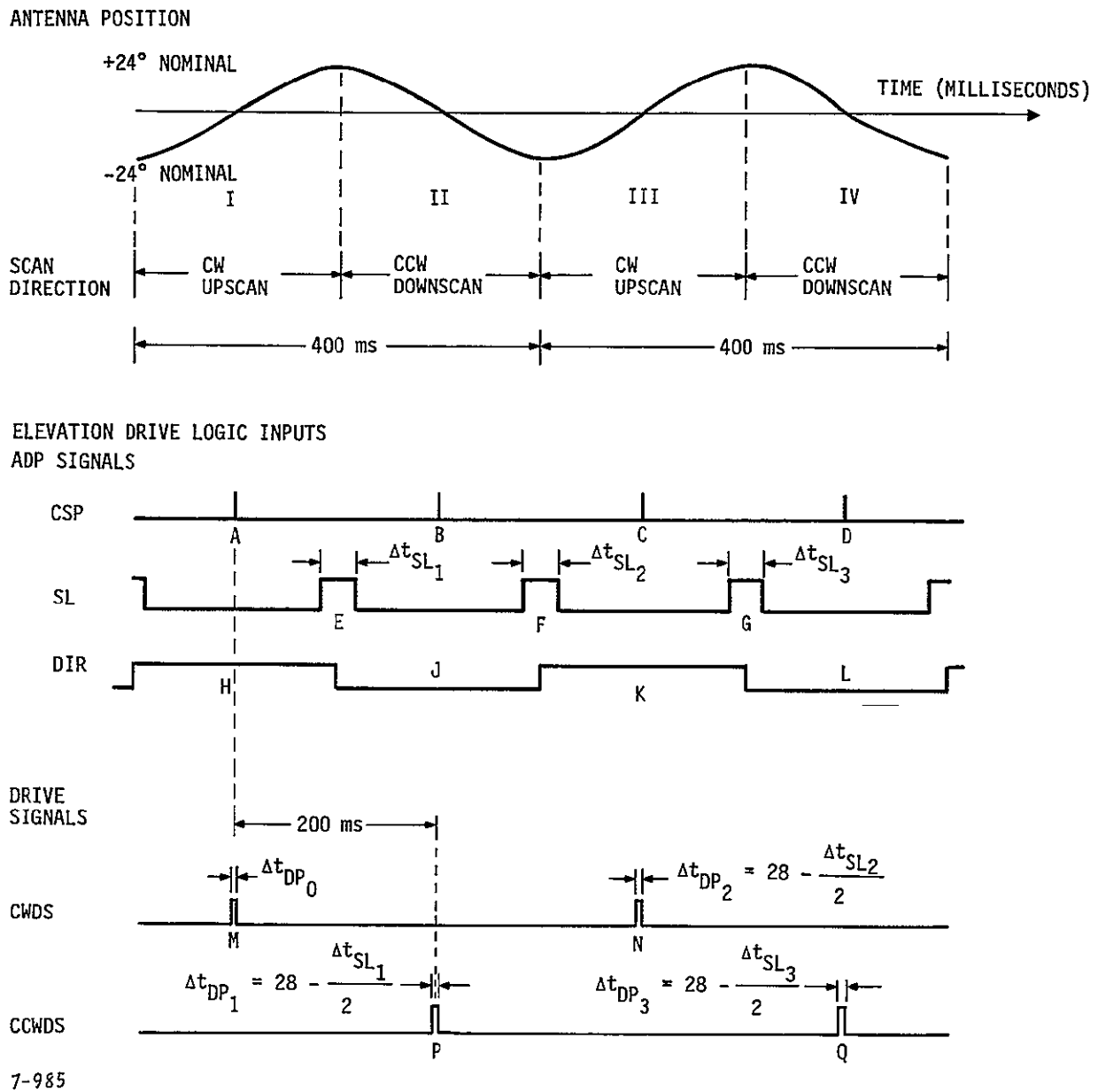


Figure 2-F8. Elevation Drive Timing for Scan Amplitudes Greater Than 23 Degrees

2-F9. **OVERSCAN PROTECTION.** In order to protect the scanner from mechanical damage, should the scan amplitude exceed 28 degrees due to some failure, the system contains an optical switch to sense the condition. When the scan exceeds 28 degrees, the optical switch generates the over-scan signal (OSCN in Figure 2-F4) to the elevation drive timing to inhibit the generation of drive signals.

#### 2-F10. AZIMUTH DRIVE

The azimuth drive signals are the same as those for the elevation drive.

2-F11. **DRIVE SIGNAL DURATION.** The control of the azimuth signal duration is similar to that described for the elevation drive with the following differences. The drive signal duration is 50 milliseconds from 0 to 42 degrees scan amplitude. For scan amplitudes greater than 42 degrees the drive signal duration is modulated by the scan limit pulse duration according to the relationship:

$$\Delta t_{DS} = \begin{cases} 50 & \text{ms} & 0 < \theta_M < 42^\circ \\ 45 - \frac{\Delta t_{SL}}{2} & \text{ms} & 42^\circ < \theta_M < 48^\circ \end{cases} \quad (11a)$$

where

$\Delta t_{DS}$  = drive signal duration in milliseconds

$\Delta t_{SL}$  = scan limit duration in milliseconds

$\theta_M$  = scan amplitude in degrees

The equation which relates scan amplitude and scan limit pulse duration is:

$$\Delta t_{SL} = \begin{cases} 0 & 0 < \theta_M < 42^\circ \\ 200 - 127.3 \sin^{-1} \frac{42}{\theta_M} & \theta_M > 42^\circ \end{cases} \quad (11b)$$

where

$\Delta t_{SL}$  = scan limit duration in milliseconds

$\theta_M$  = scan amplitude in degrees

The dimension of  $\sin^{-1} \frac{42}{\theta_M}$  is radians.

2-F12. DRIVE SIGNAL TIMING AND SYNCHRONIZATION. The azimuth drive signal functions in a manner similar to that described for the elevation drive with the additional requirement that the azimuth scan nominally lags the elevation scan by 120 milliseconds plus or minus 2 milliseconds as shown in Figure 2-F1. Correct synchronization is determined by measuring the time lag between the azimuth center scan pulse and the elevation center scan pulse. If the time lag falls between 118 and 122 milliseconds, correct synchronization exists and the azimuth timing does not differ from the elevation timing scheme. The drive signal is centered about the scanning equilibrium position and the torque is directed in the direction of rotation, as before.

If the time lag is less than 118 milliseconds, the azimuth center scan is leading its correct position and the scan must be advanced. This is accomplished by advancing the drive signal to the right of the azimuth center scan pulse as shown in Figure 2-F9.

If the time lag is greater than 122 milliseconds, the drive signal is delayed so that it falls to the left of the center scan pulse as shown in Figure 2-F9.

2-F13. OVERSCAN PROTECTION. The azimuth overscan signal is generated when the azimuth scan reaches 48 degrees. The signal inhibits the generation of drive signals.

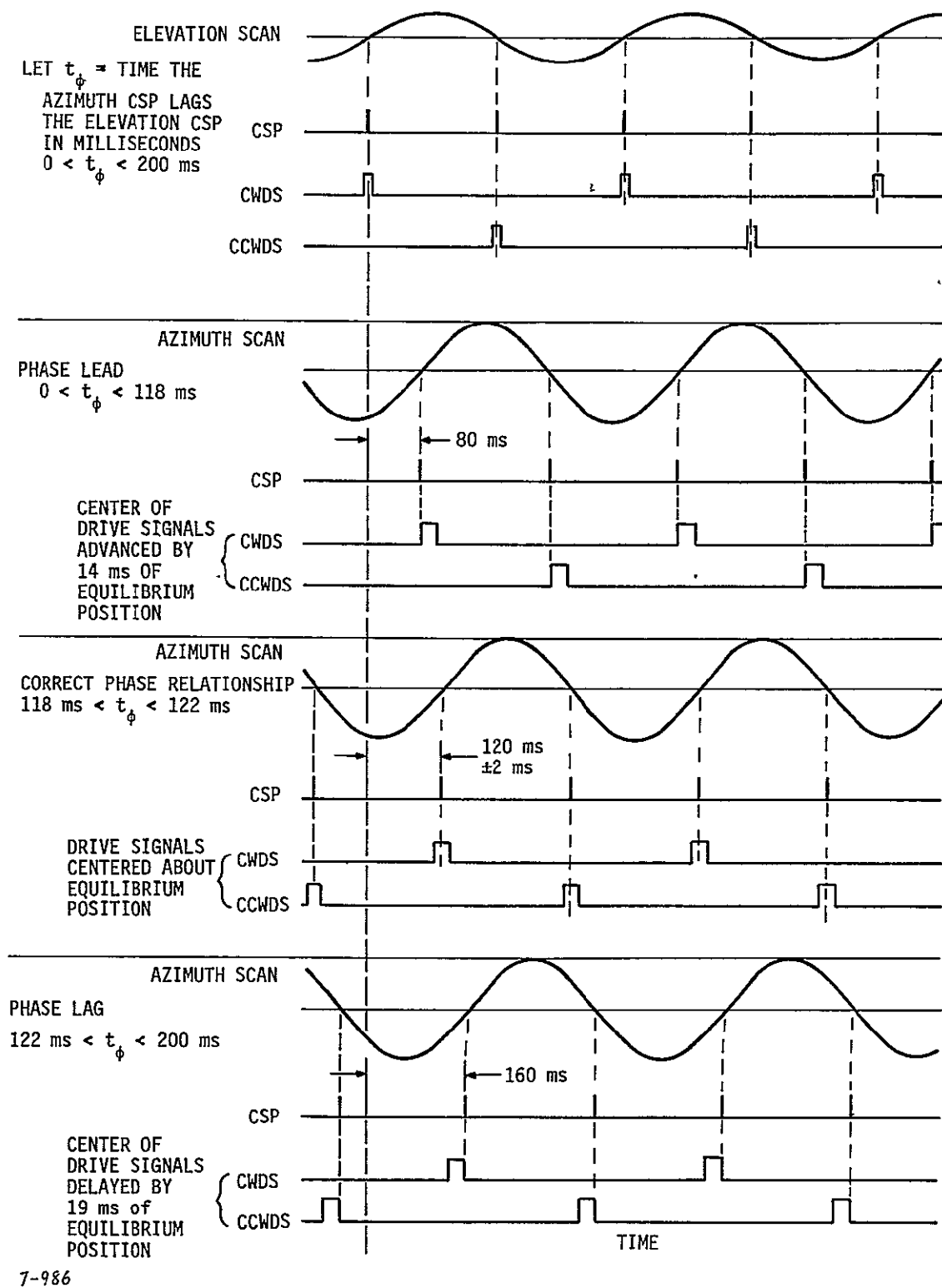


Figure 2-F9. Timing for Synchronizing the Azimuth Scan to the Elevation Scan

SECTION III  
LINK MARGIN PREDICTIONS  
(TASK 06)

PART A  
LINK MARGIN PREDICTIONS

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P. ANZALONE  
A. CHARYCH

TECHNICAL REPORT Y220-17

FINAL  
APRIL 1977

### 3-A1. INTRODUCTION

This report presents a set of graphs which predict selected azimuth, DME, and elevation uplink margins for the OFT-1, ALT-2, and ALT-3 trajectories. The elevation tracking response for the OFT-1 and ALT-3 trajectories are also given in this report. The source of data for the graphs was obtained from computer runs (references a, b, c, d, e, f, and g) of programs developed by Lockheed Corporation.

These programs computed the spherical coordinates of the Orbiter in a ground station (azimuth/DME or elevation) centered coordinate system and computed azimuth, DME, and elevation link margins from the OFT-1, ALT-2, and ALT-3 trajectory tapes.

For each trajectory, plots were made of X, Y, and Z position from runway threshold as a function of time; and link margins as a function of time and X position from runway threshold. These graphs are presented in paragraph 3-A7. The elevation tracking response plots are found in paragraph 3-A11. For the link margin plots, 0, 10, 20, 30, 40, and 50 mm/h rain rates were considered. Paragraph 3-A6 describes the ETAC rain model used to compute the decrease in link margin due to rain attenuation along the propagation path. This model is more realistic than homogeneous rainfall, but does not necessarily typify expected conditions.

Paragraph 3-A2 briefly describes the data base used in the Lockheed program runs. Paragraph 3-A5 describes the coordinate transformation to convert from the antenna centered spherical coordinates system, to the runway threshold centered rectangular coordinate system.

### 3-A2. LOCKHEED PROGRAM RUNS

Data for plotting the graphs in this report were obtained from seven Lockheed program computer runs. Each run contains tabulated time records of Orbiter position (slant range, azimuth angle, and elevation angle) and of a

single link margin (azimuth, elevation, or DME) for the three trajectories. Table 3-A1 provides a description of each run. The method for computing the link margins is given in detail in reference k.

3-A3. GROUND STATION GAIN (REFERENCE 10). The azimuth ground station antenna gain is obtained from interpolation between measured antenna values (reference m). The DME ground antenna gain is obtained from a combination of measured values and a model (reference l). The elevation ground antenna pattern is defined by a model only (reference n).

3-A4. ORBITER ANTENNA GAIN. The orbiter antenna gain is computed from interpolations between measured values taken from NASA Document EE33-77-103 (reference o). This document contains preliminary gain measurements of the Orbiter Vehicle 102 (OV102) airborne antenna, with thermal protection in place.

Although the ALT trajectories are flown by Orbiter Vehicle 101 (OV101), all the link margins presented in this report use the OV102 antenna patterns. The OV101 is fitted with a boom which may make its antenna pattern different from the OV102 antenna pattern.

#### 3-A5. COORDINATE SYSTEM TRANSFORMATION FOR A RUNWAY THRESHOLD CENTERED COORDINATE SYSTEM

The Lockheed program runs provide orbital coordinates from either an azimuth or elevation centered coordinate system. The coordinate transformation involves two steps. First, the slant range, azimuth, and elevation angles are converted to X, Y, Z components. The trigonometric conversion equations can be derived from Figures 3-A1 and 3-A2. The second step involves translating the antenna centered coordinate system to runway threshold from knowing the location of the two antennas relative to runway threshold. The azimuth antenna is located 16,300 feet back from runway threshold and 300 feet

Table 3-A1. Summary of Lockheed Program Runs Used in the Link Margin Plots

| Flight Path or Trajectory | Lockheed Program Computer Run No. | Run Date | Link       | Frequency (GHz) | Orbiter Antenna Gain (dB) | Transmitter Output (dB) | Ground Antenna Gain (dB)            | Orbiter Loss (dB) | Polarization Loss (dB) | Ground Station Loss (dB) | Receiver Threshold (dBm) | Wind Condition  |
|---------------------------|-----------------------------------|----------|------------|-----------------|---------------------------|-------------------------|-------------------------------------|-------------------|------------------------|--------------------------|--------------------------|-----------------|
| OFT-1                     | 30                                | 3-2-76   | Azimuth Up | 15.415          | EE33-75-103 (1)           | 62                      | Measurement Interpolation           | 3.8               | (2)                    | 2.5                      | -74                      | 99 pct Headwind |
|                           | 37                                | 3-16-76  | Elev Up    | 15.415          | EE33-75-103 (1)           | 62                      | Model                               | 3.8               | (2)                    | 2.5                      | -74                      | No Wind         |
| ALT-2                     | 27                                | -        | Azimuth Up | -               | EE33-75-103 (1)           | 62                      | Measurement Interpolation           | 2.5               | (2)                    | 3.7                      | -74                      | No Wind         |
|                           | 4                                 | 12-11-75 | DME Down   | 15.46           | EE33-75-103 (1)           | 62                      | Model and Measurement Interpolation | 3.8               | (2)                    | 2.5                      | -77                      | No Wind         |
| ALT-3                     | 10                                | -        | Azimuth Up | -               | EE33-75-103 (1)           | 62                      | Measurement Interpolation           | 3.8               | (2)                    | 2.5                      | -74                      | No Wind         |
|                           | 8                                 | 12-11-75 | DME Down   | 15.46           | EE33-75-103 (1)           | 63                      | Model and Measurement Interpolation | 3.8               | (2)                    | 1.7                      | -77                      | No Wind         |
|                           | 48                                | 1-24-77  | Elev Up    | 15.508          | EE33-75-103               | 62                      | Model                               | 3.8               | (2)                    | 2.5                      | -74                      | No Wind         |

(1) Preliminary OV 102 Configuration (Reference 5)

(2) Included in Orbiter Antenna Gain

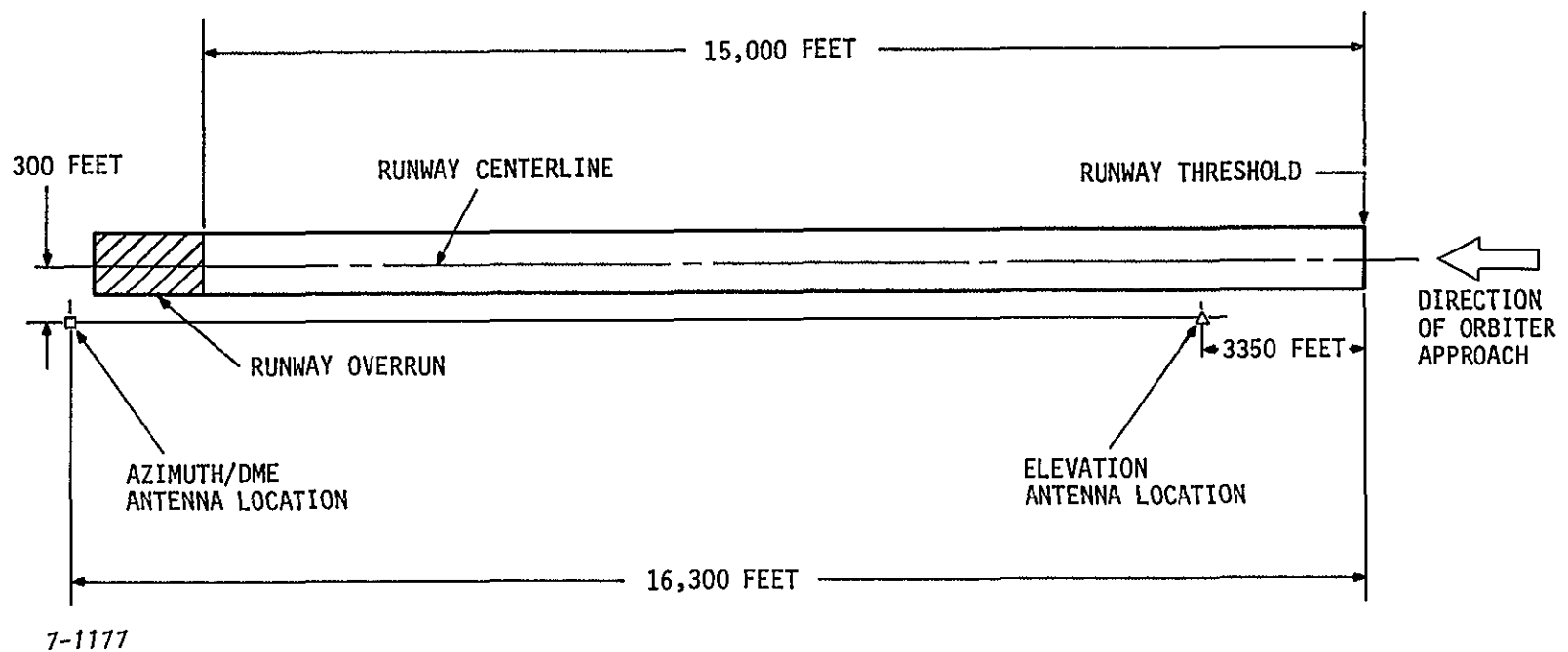


Figure 3-A1. Azimuth/DME and Elevation Station Locations With Respect To Runway

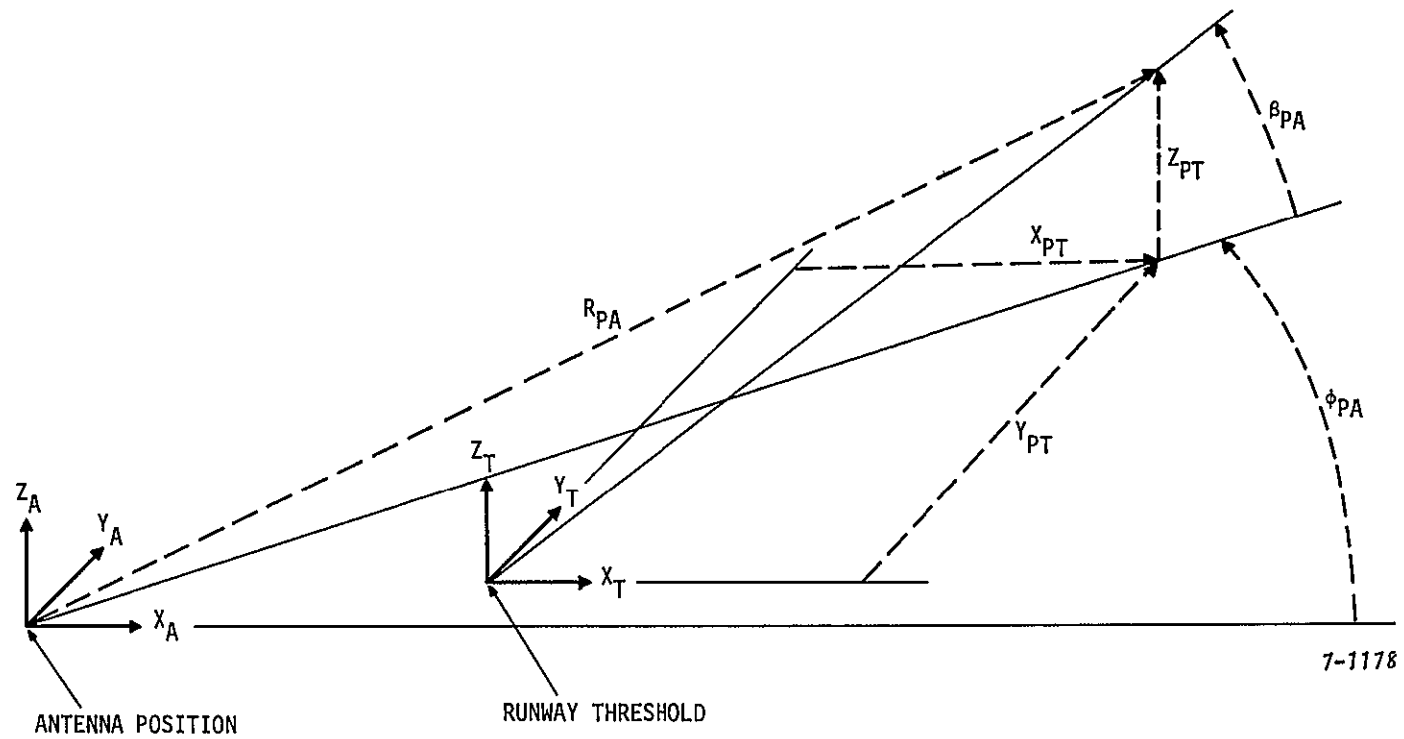


Figure 3-A2. Orbiter Coordinates at Point P ( $R_{PA}$ ,  $\phi_{PA}$ , and  $\beta_{PA}$ ) Converted to Rectangular Coordinates

to the side of the runway centerline as shown in Figure 3-A1. The elevation antenna is located 3,350 feet back from runway threshold and offset 300 feet from the runway centerline (reference i).

The transformation equations to convert from the azimuth or DME antenna centered coordinates to runway threshold coordinates are:

$$X_T = R_A \cos \beta_A \cos \phi_A - 16,300 \text{ feet}$$

$$Y_T = R_A \cos \beta_A \sin \phi_A - 300 \text{ feet}$$

$$Z_T = R_A \sin \beta_A$$

Antenna centered coordinates:

$R_A$  = Slant range from azimuth antenna in feet

$\phi_A$  = Azimuth angle from azimuth antenna in feet

$\beta_A$  = Elevation angle from azimuth antenna in feet

Runway threshold centered coordinates:

$X_T$  = X component from threshold in feet

$Y_T$  = Y component from threshold in feet

$Z_T$  = Z component from threshold in feet

The transformation equations to convert from elevation centered coordinates to runway centered coordinates are:

$$X_T = R_E \cos \beta_E \cos \phi_E - 3350 \text{ feet}$$

$$Y_T = R_E \cos \beta_E \sin \phi_E - 300 \text{ feet}$$

$$Z_T = R_E \sin \beta_E$$

The subscript E signifies that  $R_E$ ,  $\phi_E$ , and  $\beta_E$  are referenced from the elevation antenna location.

### 3-A6. ETAC RAIN MODEL

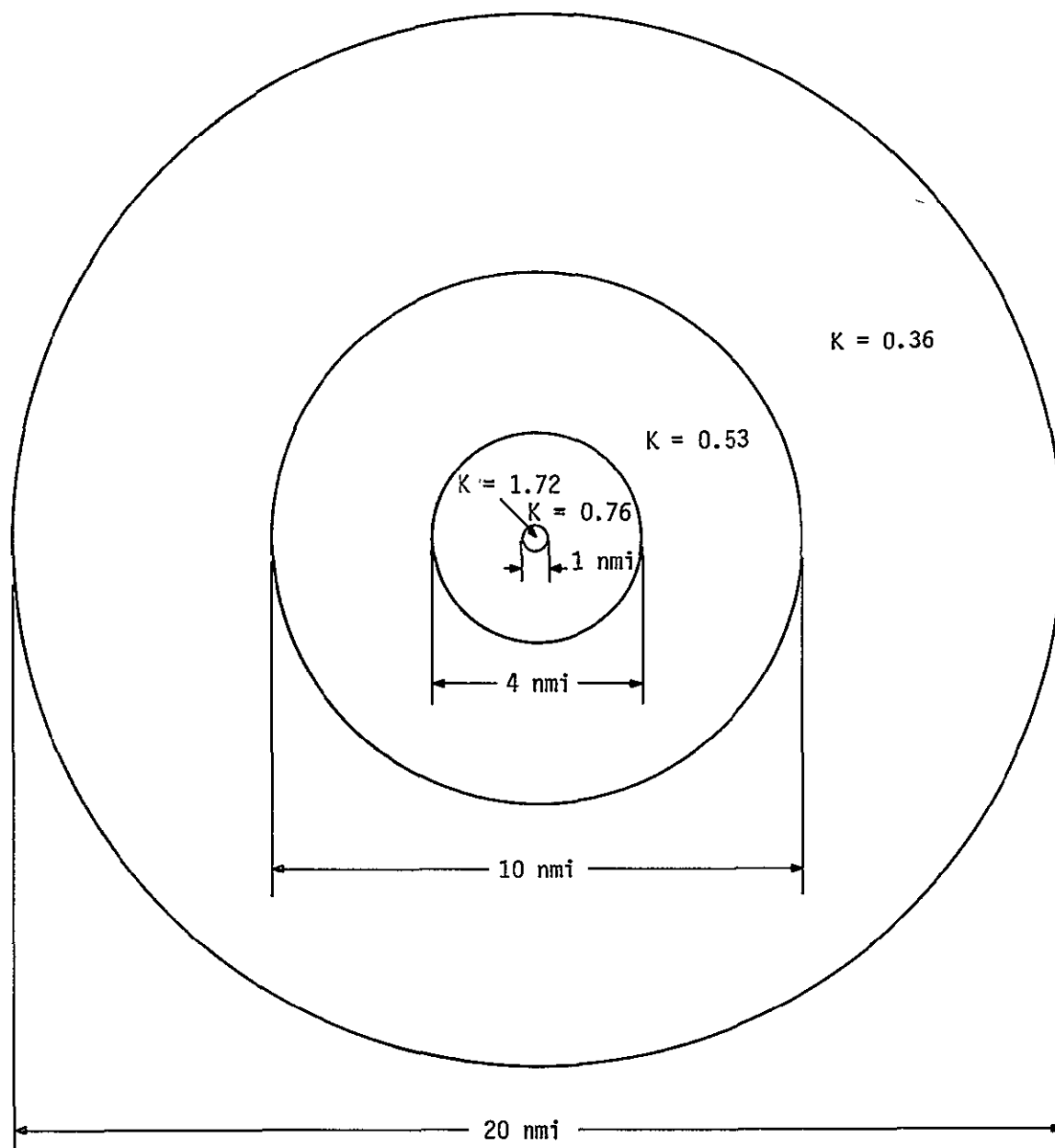
Attenuation due to rain is calculated using the ETAC rain model. The ETAC model localizes the rain storm within a 10 mile radius from the storm center. As shown in Figure 3-A3, the storm area is divided into four regions, a 1 nmi diameter inner cylinder surrounded by three coaxial cylindrical shells whose diameters are 4, 10, and 20 nmi. Each of the four regions is assigned a rain attenuation rate in decibels per kilofeet with the highest attenuation rate assigned to the inner cylinder and decreasingly lower rates assigned to the outer regions as the region moves further from the center. The equation which defines the attenuation rate for each region is:

$$A = 0.0107 (K R_N)^{1.15} \text{ dB/Kfeet}$$

$R_N$  = nominal or point rate in mm/h

$$K = \begin{cases} 1.72 & \text{for the 1st region or the inner cylinder} \\ 0.76 & \text{for the 2nd region} \\ 0.53 & \text{for the 3rd region} \\ 0.36 & \text{for the 4th region or the outer shell} \end{cases}$$

For 10 mm/h nominal rain rate, the rain from the inner to outermost region is 0.28 dB/Kfeet, 0.110 dB/Kfeet, 0.073 dB/Kfeet and 0.047 dB/Kfeet, respectively.



NOTE:

THE ETAC RAIN MODEL DEFINES FOUR CYLINDRICAL REGIONS. WITHIN EACH REGION THE RF SIGNAL IS ATTENUATED AT RATES OF  $0.0107 (K R_N)^{1.15}$  dB/KILOFEET (FREQUENCY = 15.50 GHz).  $R_N$  IS THE NOMINAL RAIN RATE IN mm/h. 7-1179

Figure 3-A3. ETAC Rain Model Definition

In the present application of the ETAC rain model, the center of the rain storm is placed 5 nautical miles away from runway threshold along a straight line which extends from runway centerline. As a simplification to the model, the regions are assumed to be separated by vertical planes tangent to the cylinders at the point they cross the centerline extension. As shown in Figure 3-A4, the limits to each region are then defined by a value of X from runway threshold of 3, 4.5, 5.5, 7, 10, and 15 nautical miles.

As an example of the computations for attenuation due to rain, assume the Orbiter is located 50,000 feet from the azimuth station with a 10-degree azimuth angle and a 20-degree elevation angle. In order to calculate the rain attenuation, it is necessary to determine the propagation path or slant range through each region, multiply it by the attenuation rate for that region, and finally, summing the attenuations to find the total attenuation in dB. This is done in the chart below with the path through each region computed using the equation:

$$\frac{X_A \text{ (upper value)} - X_A \text{ (lower value)}}{\cos \phi_A \cos \beta} \text{ feet}$$

| Region<br>(feet)         | Propagation<br>Path<br>Through<br>Region<br>(kilofeet) | Rain<br>Attenuation<br>Rate<br>(dB/Kft) | Rain<br>Attenuation<br>Through<br>Region (dB) |
|--------------------------|--------------------------------------------------------|-----------------------------------------|-----------------------------------------------|
| $0 < X_A \leq 16300$     | 17.61                                                  | 0.0467                                  | 0.822                                         |
| $16300 < X_A \leq 34528$ | 19.70                                                  | 0.0728                                  | 1.434                                         |
| $34528 < X_A \leq 43642$ | 9.85                                                   | 0.1102                                  | 1.086                                         |
| $43642 < X_A \leq 49719$ | 6.57                                                   | 0.282                                   | 1.853                                         |
| $49719 < X_A \leq 50000$ | 0.304                                                  | 0.1102                                  | <u>0.034</u>                                  |
| $R_N = 10 \text{ mm/h}$  |                                                        |                                         | 5.229                                         |
| $\phi_A = 10^\circ$      |                                                        |                                         | $\approx 5.23 \text{ dB}$                     |
| $\beta_A = 20^\circ$     |                                                        |                                         |                                               |

For the location given here, the rain attenuation through the propagation path is 5.23 dB.

In the link margin plots given in this report, with rain rates ranging from 10 to 50 mm/h, the rain attenuation is similarly calculated for each location of the Orbiter and then subtracted from the corresponding link margin to obtain the link margin which includes the attenuating effects of rain.

### 3-A7. TRAJECTORY AND LINK MARGIN PLOTS

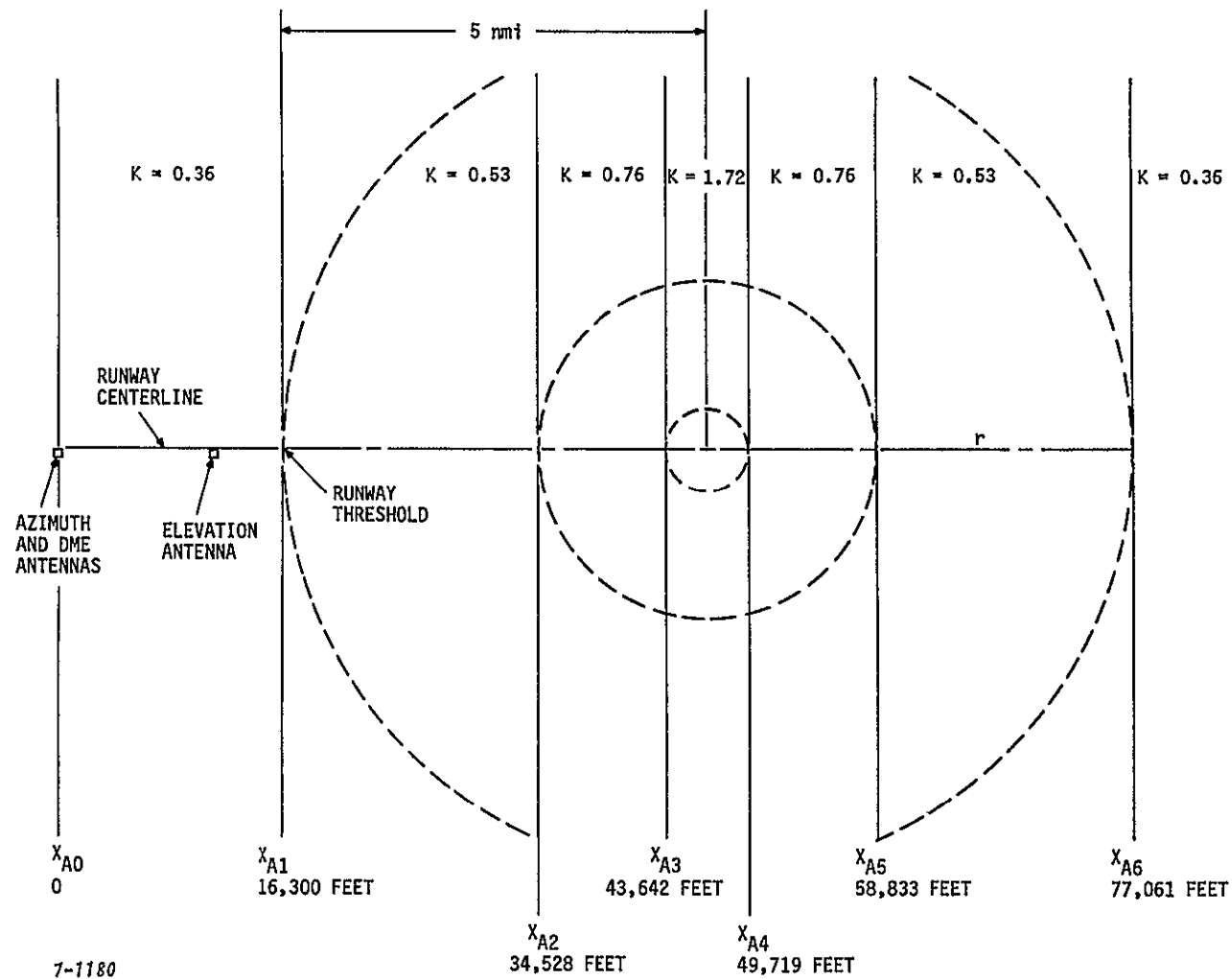
Trajectory and link margin plots for the OFT-1, ALT-2, and ALT-3 trajectories are given in this section. The plots for each trajectory include: X, Y, Z plots from runway threshold as a function of time; and azimuth uplink, DME downlink, or elevation uplink as a function of time, and also as a function of X position from runway threshold.

Data for each link is obtained from one of the Lockheed program runs listed previously in Table 3-A1. The reader can refer to this table in order to identify the parameters which are used for the particular link.

3-A8. OFT-1 PLOTS. Figures 3-A5, 3-A6, and 3-A7 provide plots of X, Y, Z from threshold as a function of time. Azimuth uplink and elevation uplink plots are given in Figures 3-A8 through 3-A11 using runs 30 and 37, respectively.

3-A9. ALT-2 PLOTS. Figures 3-A12, 3-A13, and 3-A14 provide plots of X, Y, Z from runway threshold as a function of time. Azimuth uplink and DME downlink plots are given in Figures 3-A15 through 3-A18 using runs 27 and 4, respectively.

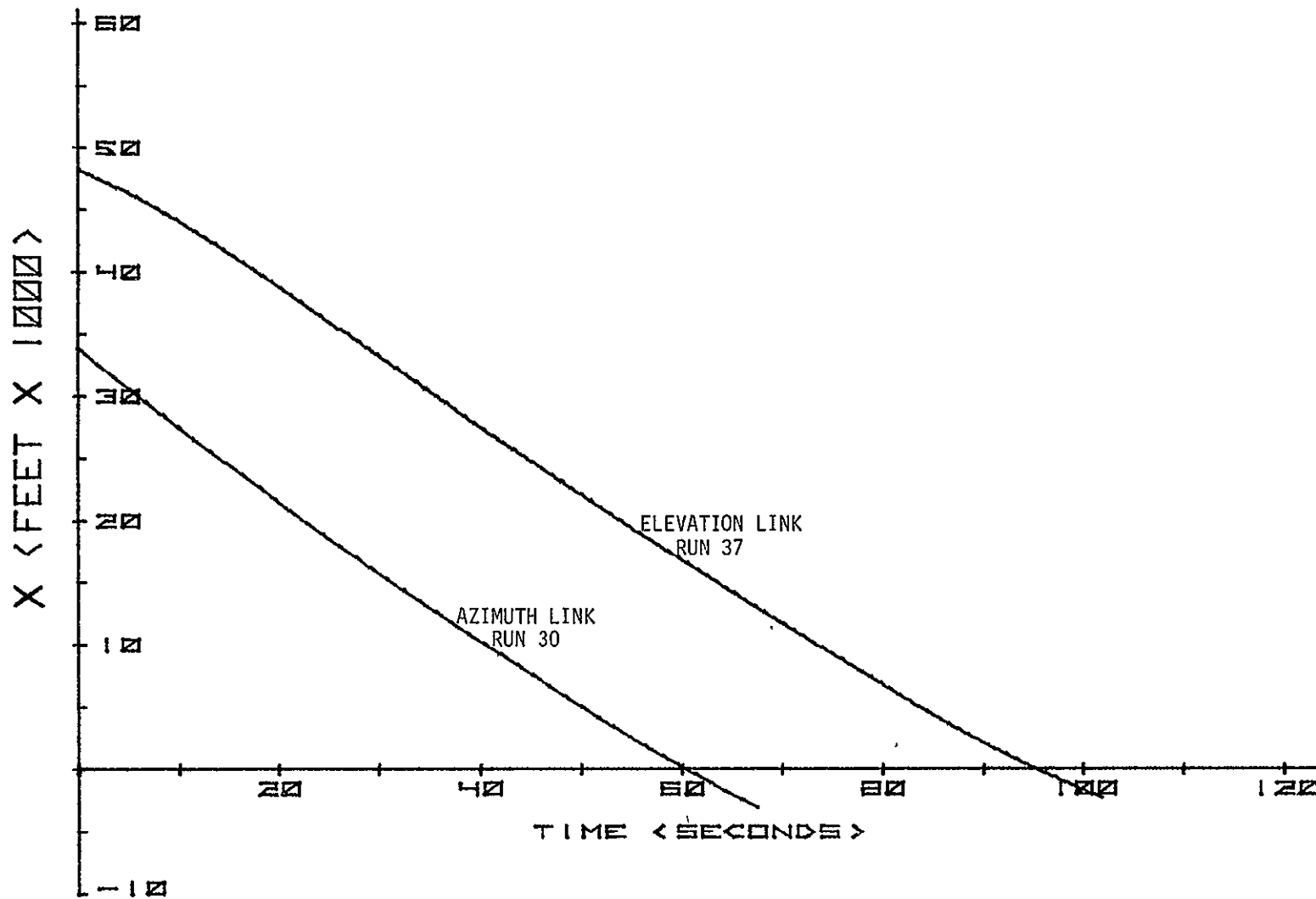
3-A10. ALT-3 PLOTS. Figures 3-A19, 3-A20, and 3-A21 provide plots of X, Y, Z from threshold as a function of time. Azimuth uplink, DME downlink and elevation uplink plots are given in Figures 3-A22 through 3-A27 using runs 10, 8, and 48, respectively.



## NOTE:

THE CENTER OF THE ETAC RAIN MODEL IS PLACED 5 NAUTICAL MILES FROM RUNWAY THRESHOLD ALONG THE LINE EXTENDING FROM RUNWAY CENTERLINE. THE VERTICAL LINES MARK THE BEGINNING AND END OF EACH RAIN REGION FOR THE SIMPLIFIED VERSION OF THE ETAC MODEL.

Figure 3-A4. ETAC Rain Model Placed 5 Nautical Miles From Runway Threshold



7-1181

Figure 3-A5. X Position Referenced From Runway Threshold as a Function of Time for OFT-1 Trajectory

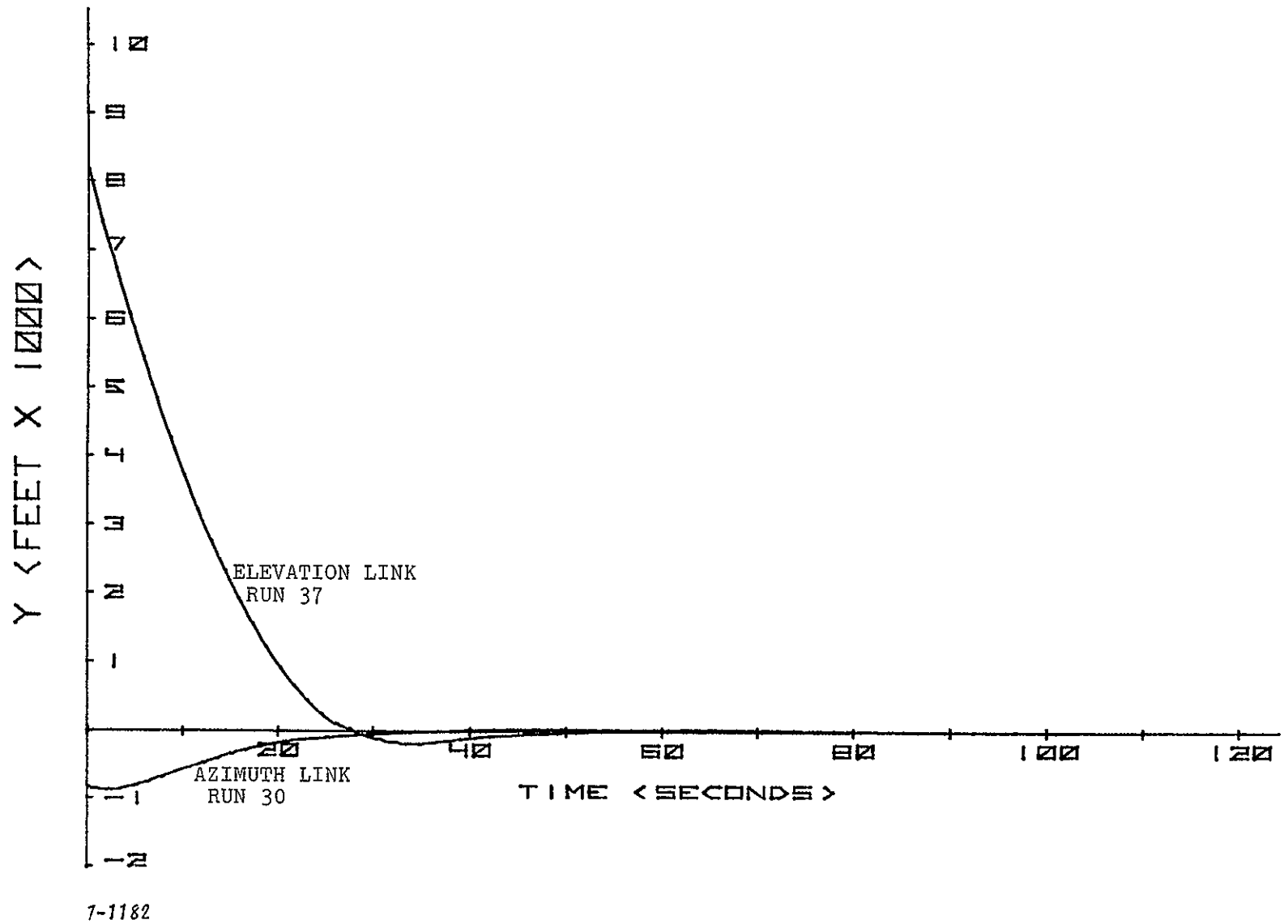
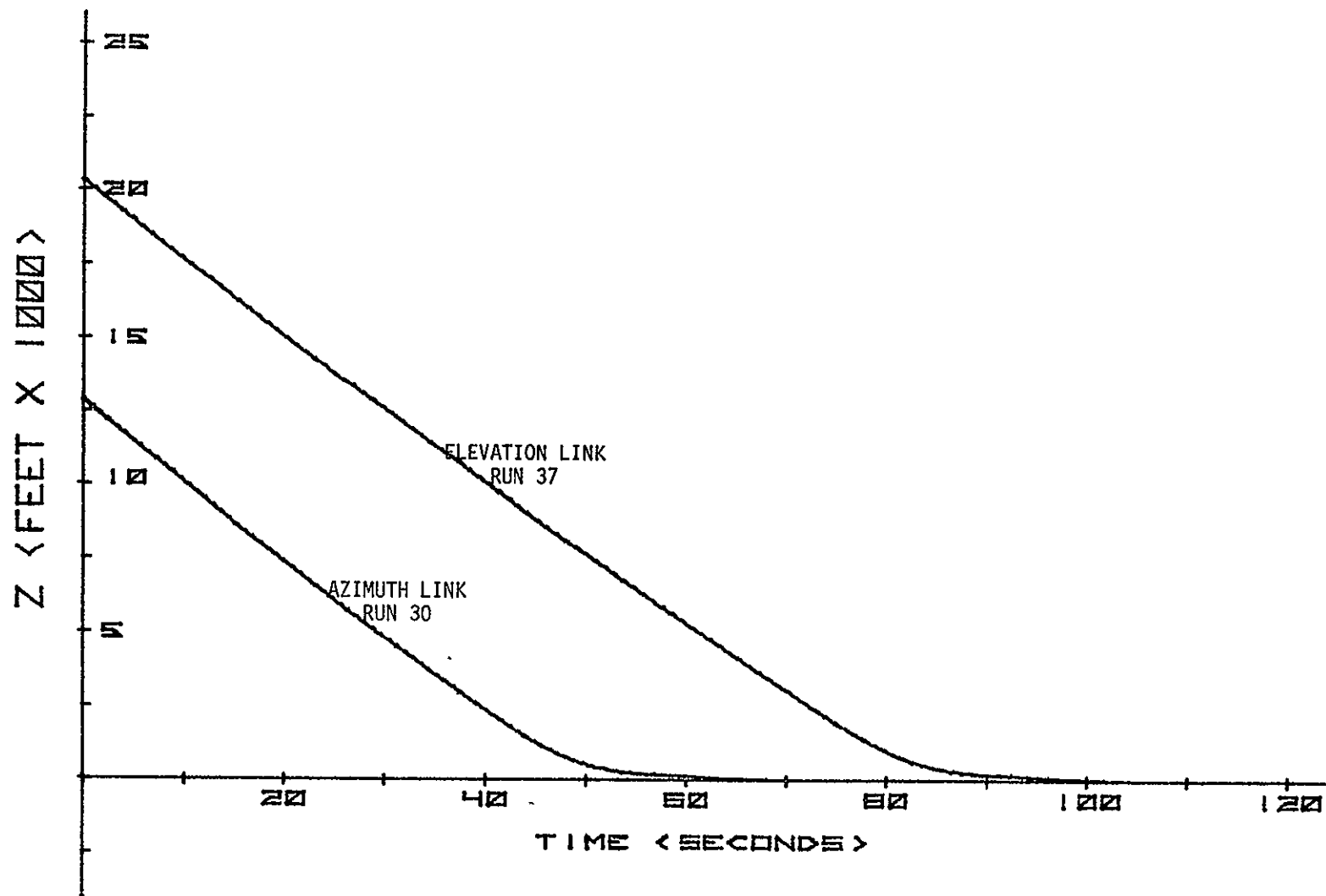


Figure 3-A6. Y Position Referenced From Runway Threshold as a Function of Time for OFT-1 Trajectory



7-1183

Figure 3-A7. Z Position Referenced From Runway Threshold as a Function of Time for OFT-1 Trajectory

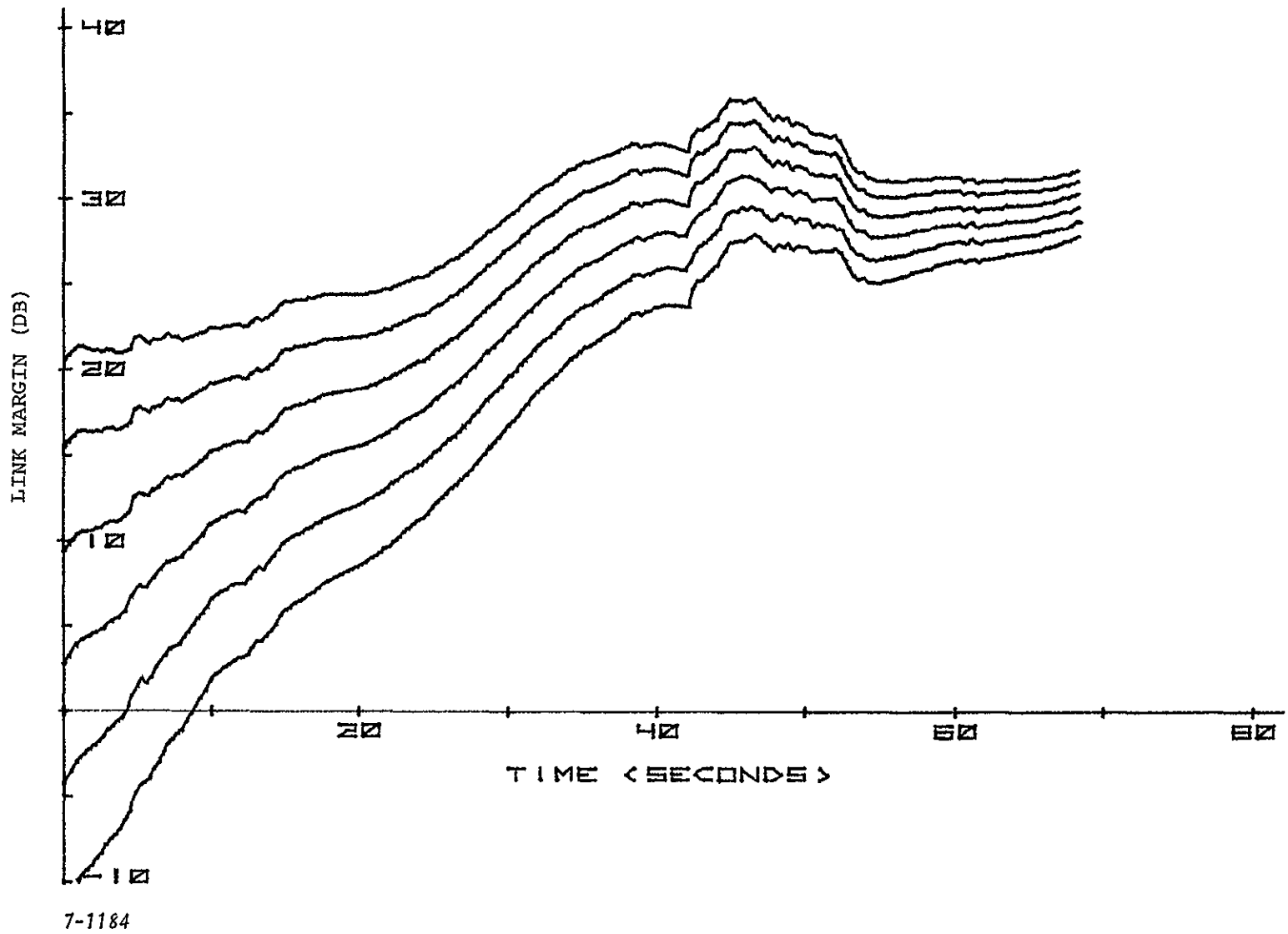


Figure 3-A8. Azimuth Link Margin as a Function of Time for OFT-1 Trajectory at Rainfall Rates of 0, 10, 20, 30, 40, and 50 mm/h Using the ETAC Rain Model

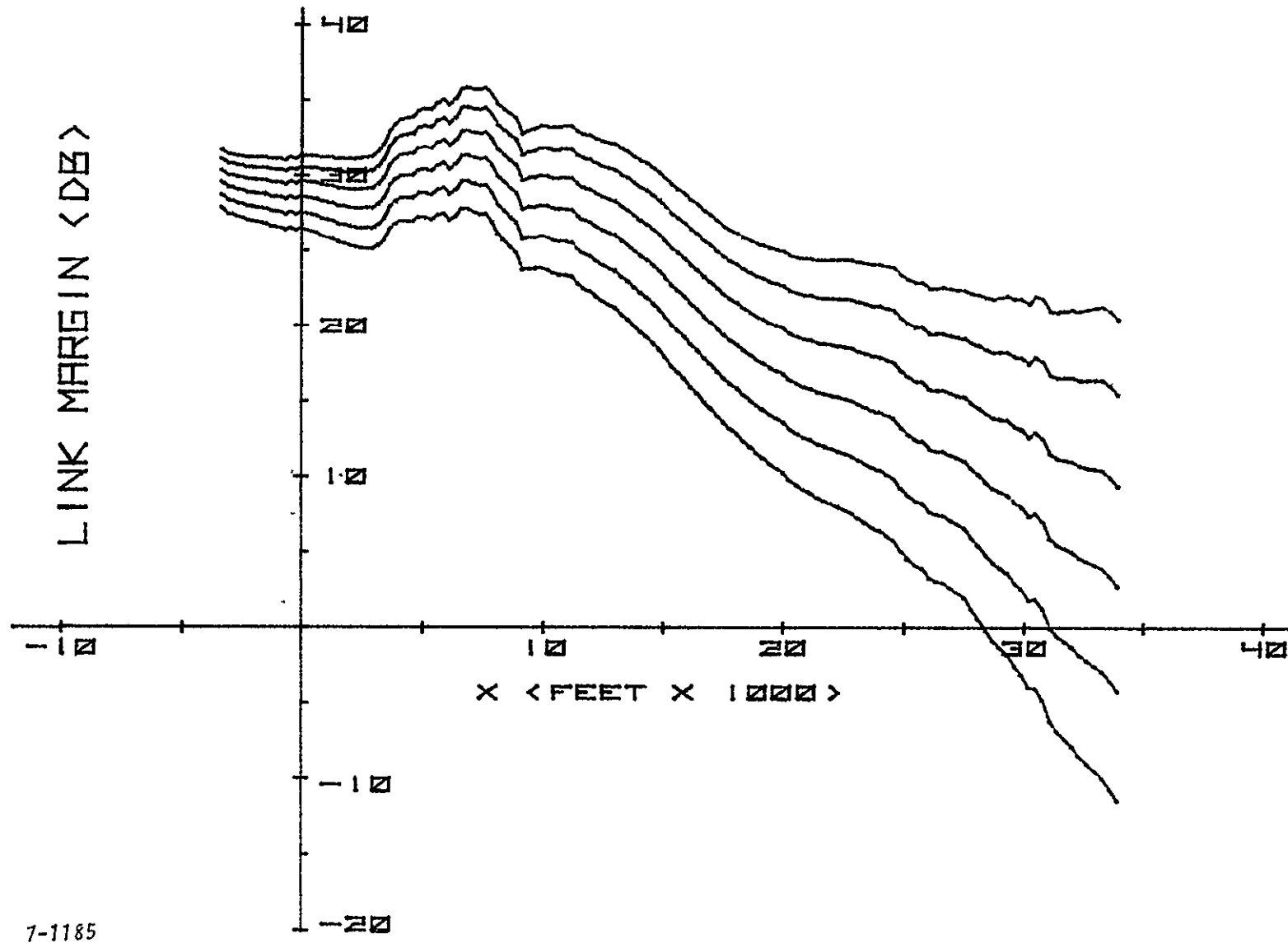


Figure 3-A9. Azimuth Link Margin as a Function of X for OFT-1 Trajectory at Rainfall Rates of 0, 10, 20, 30, 40, and 50 mm/h Using the ETAC Rain Model

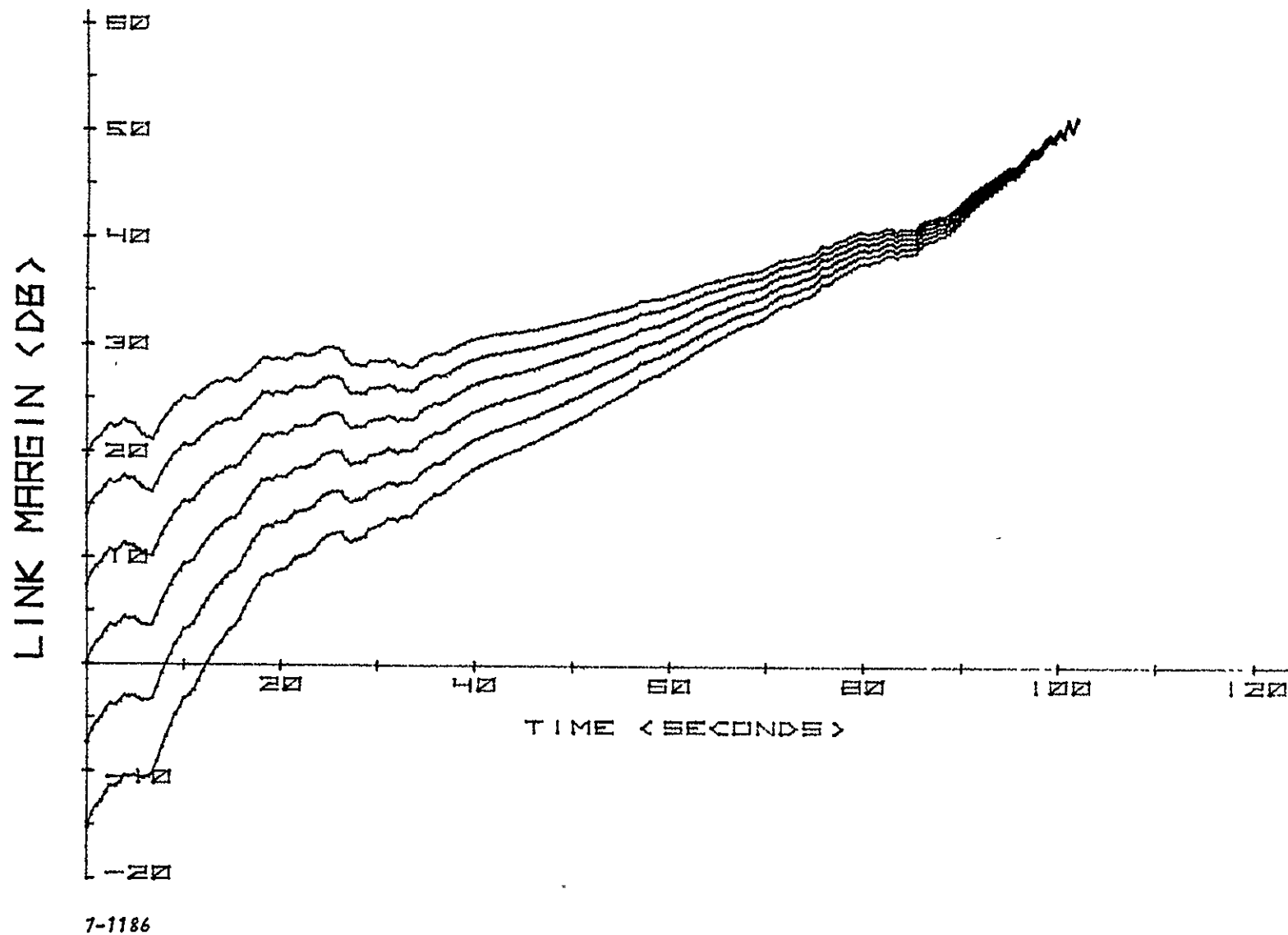


Figure 3-A10. Elevation Link Margin as a Function of Time for OFT-1 Trajectory at Rainfall Rates of 0, 10, 20, 30, 40, and 50 mm/h Using the ETAC Rain Model

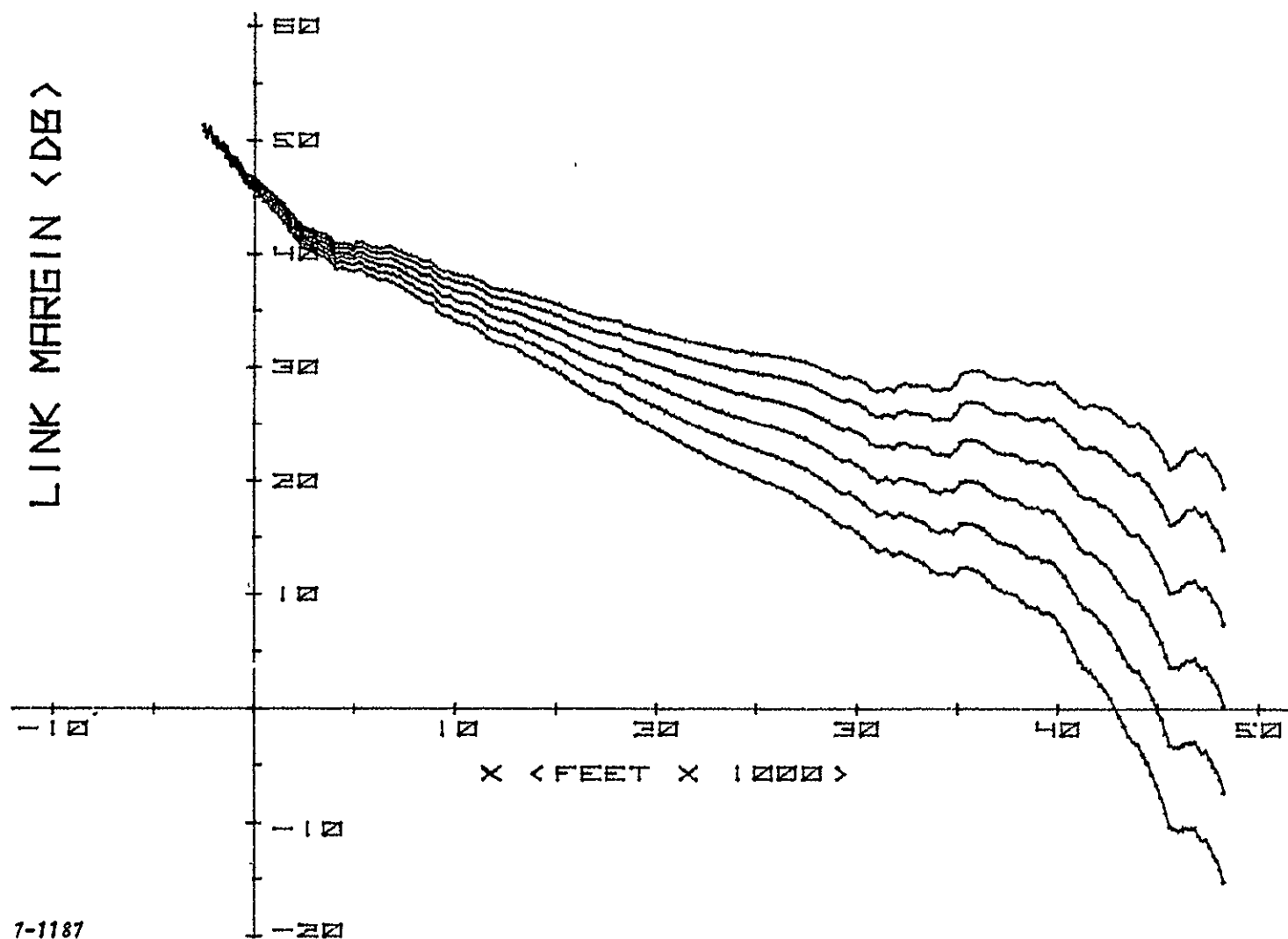


Figure 3-A11. Elevation Link Margin as a Function of X for OFT-1 Trajectory at Rainfall Rates of 0, 10, 20, 30, 40, and 50 mm/h Using the ETAC Rain Model

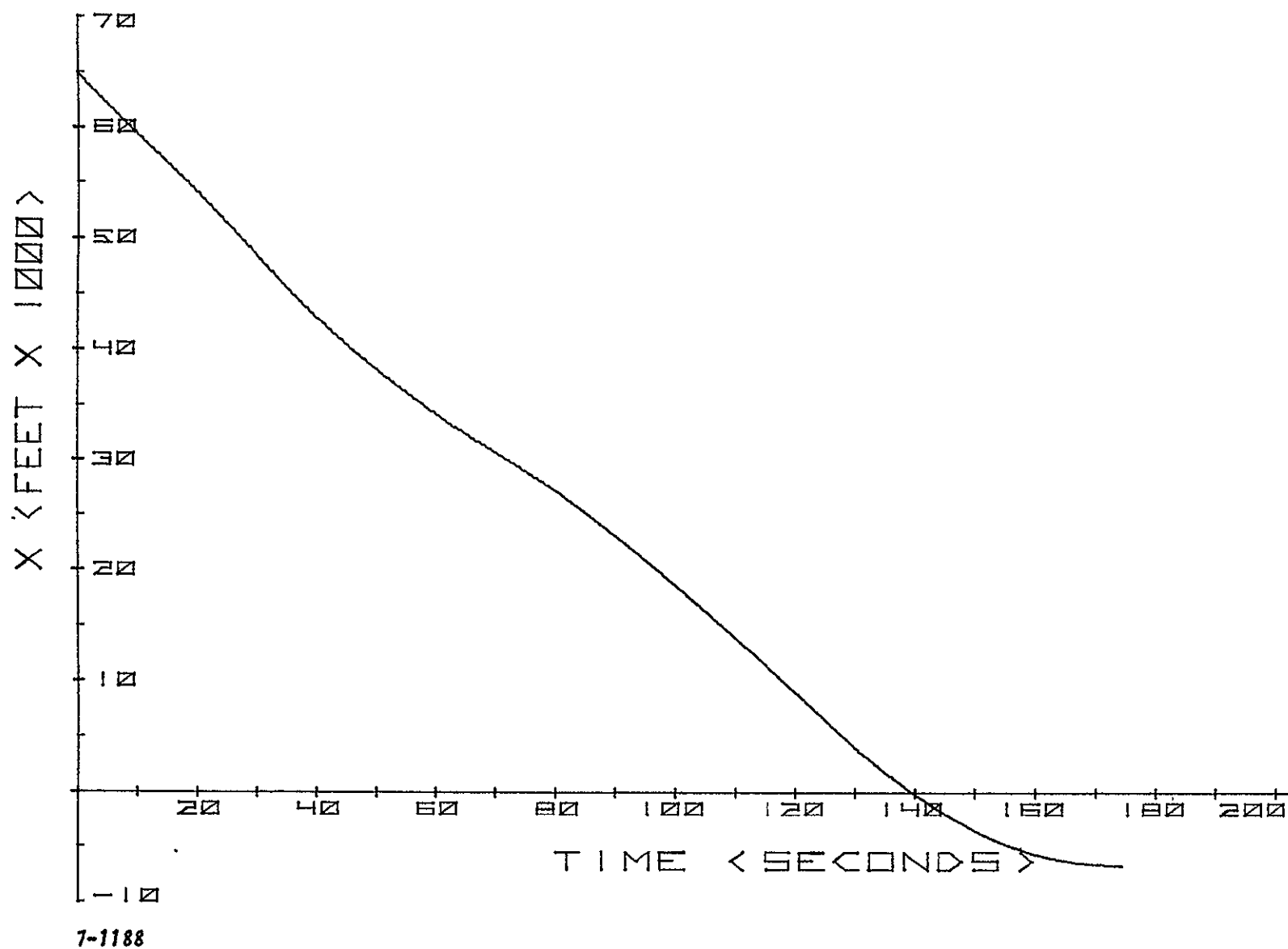
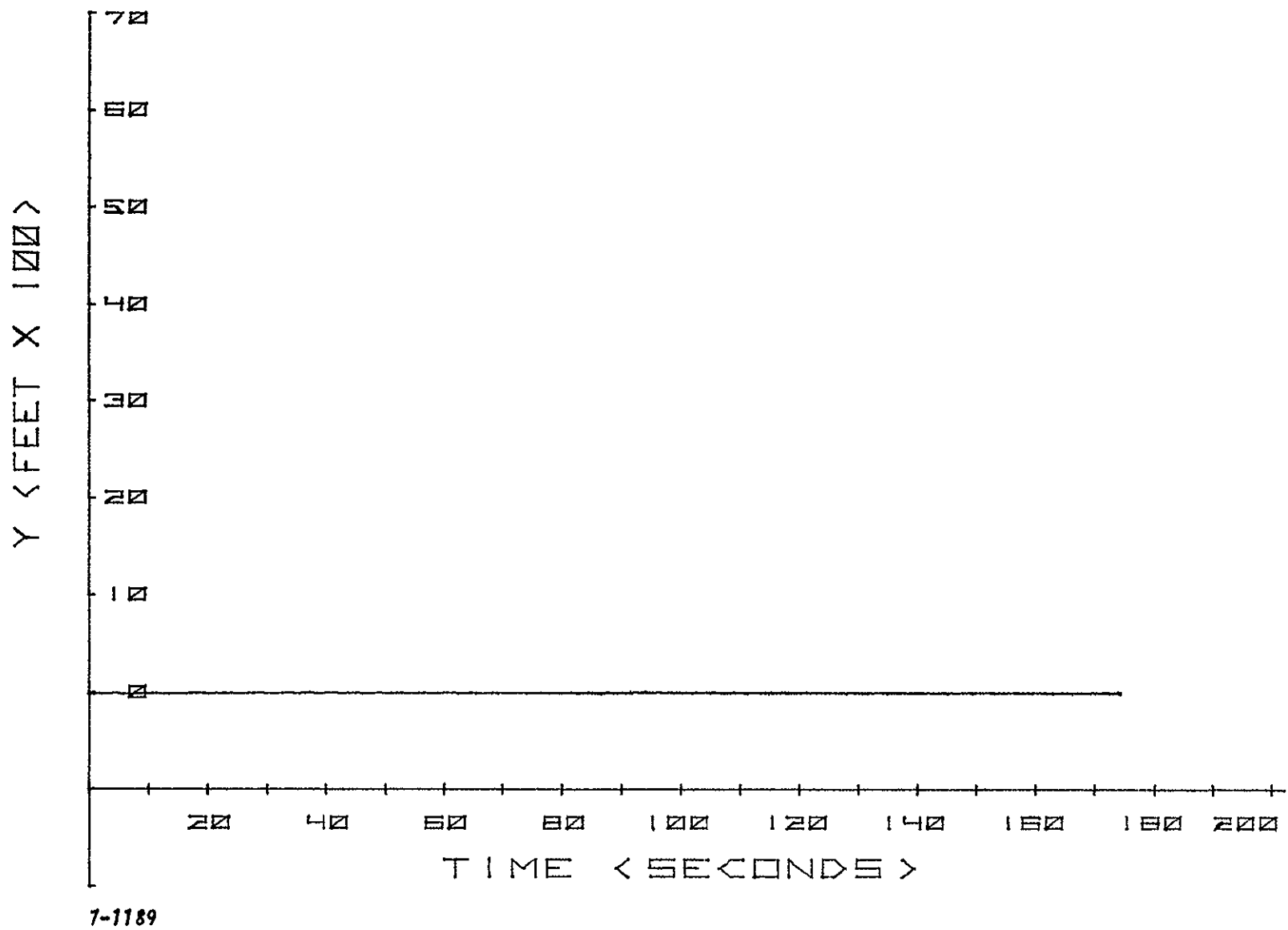


Figure 3-A12. X Position Referenced From Runway Threshold as a Function of Time for ALT-2 Trajectory



7-1189

Figure 3-A13. Y Position Referenced From Runway Threshold as a Function of Time for ALT-2 Trajectory

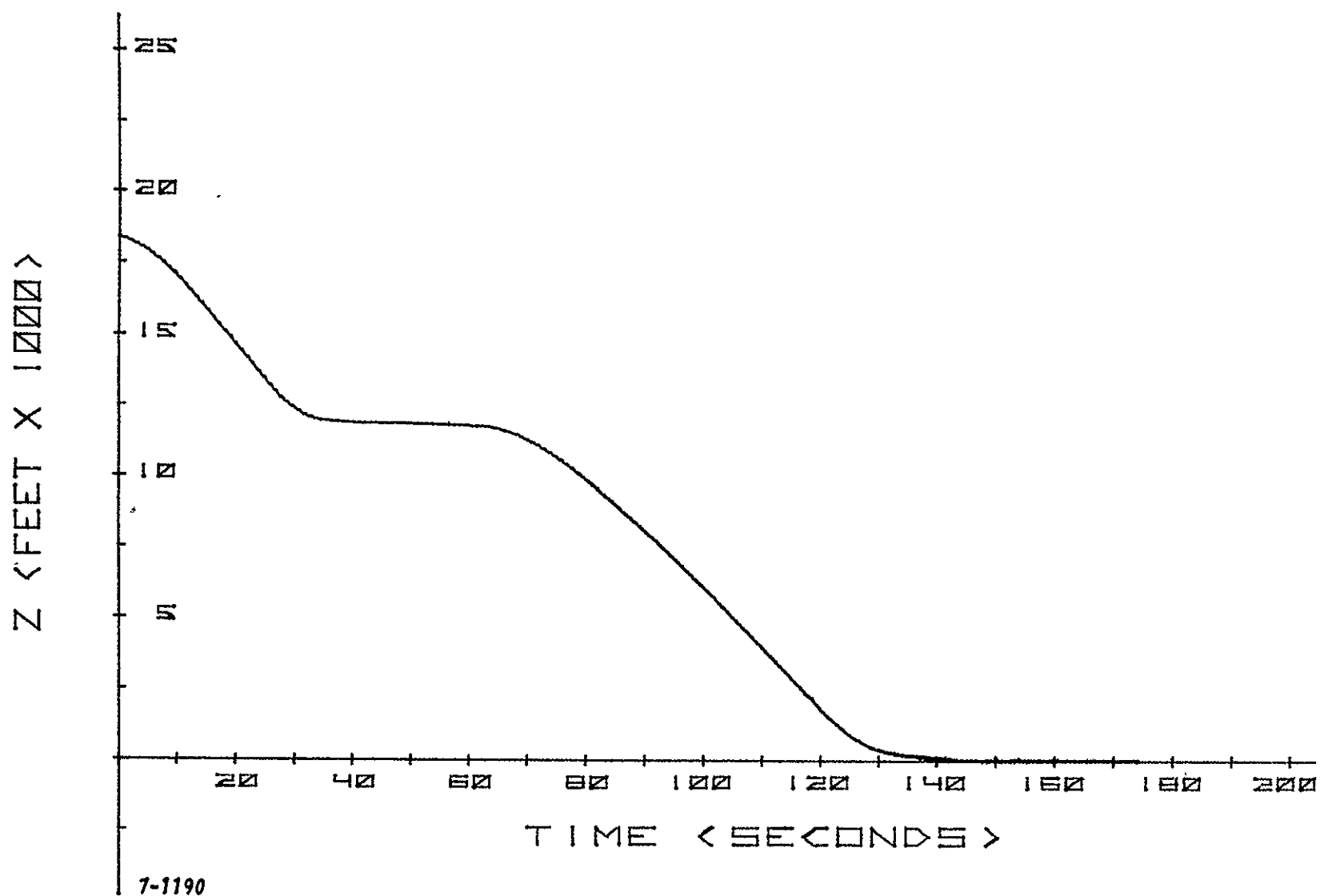


Figure 3-A14. Z Position Referenced From Runway Threshold as a Function of Time for ALT-2 Trajectory

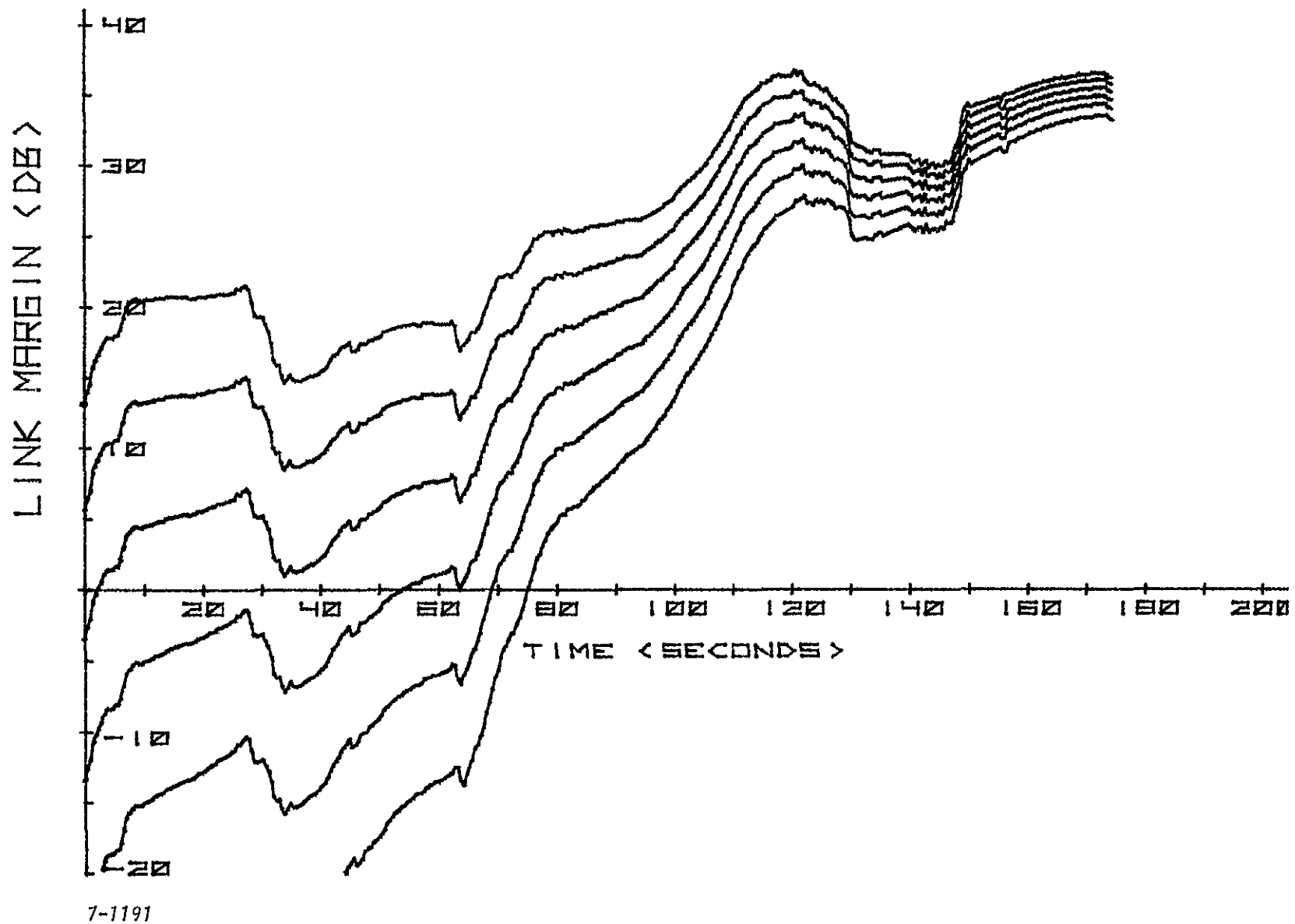


Figure 3-A15. Azimuth Link Margin as a Function of Time for ALT-2 Trajectory at Rainfall Rates of 0, 10, 20, 30, 40, and 50 mm/h Using the ETAC Rain Model

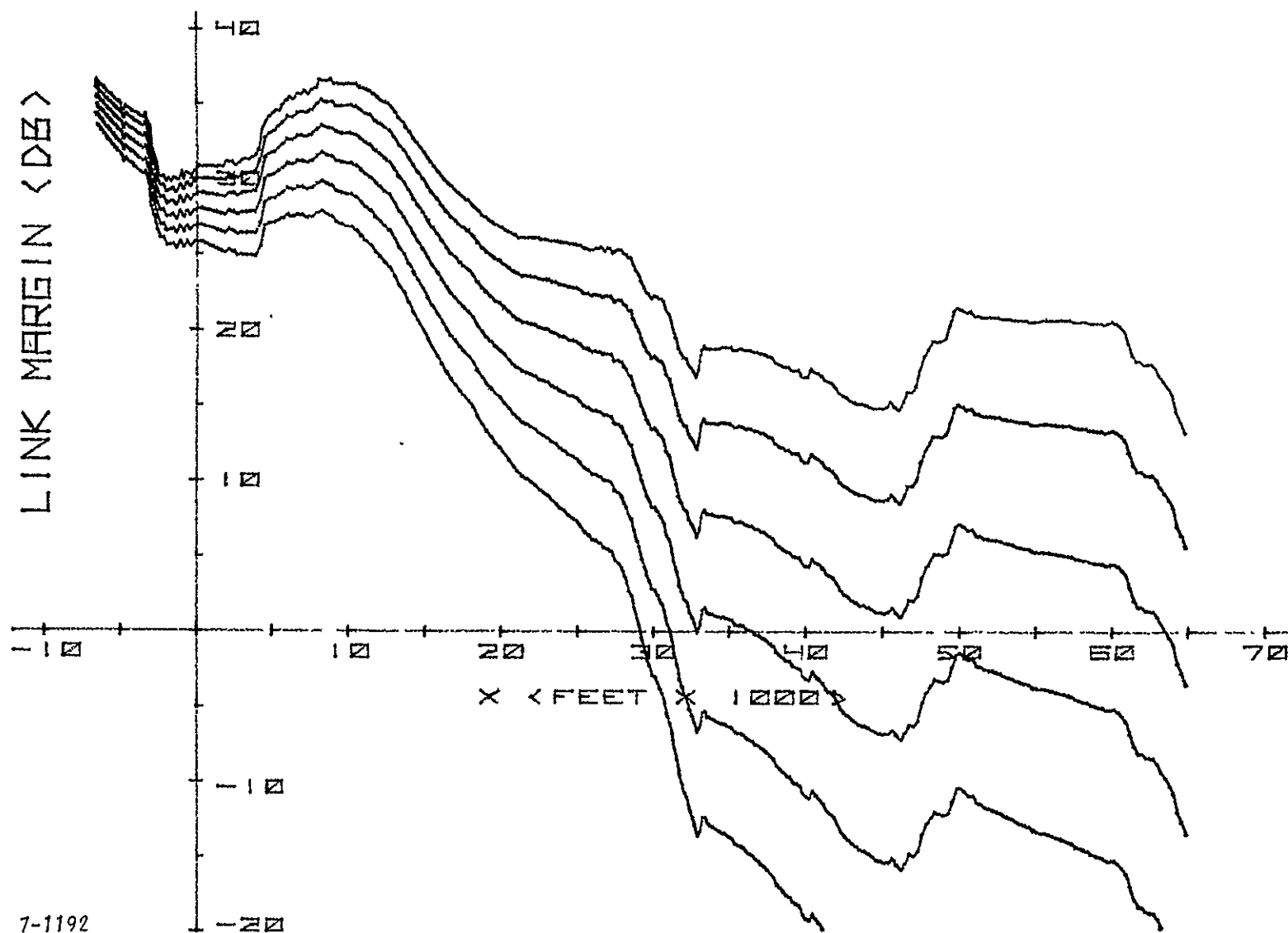


Figure 3-A16. Azimuth Link Margin as a Function of X for ALT-2 Trajectory at Rainfall Rates of 0, 10, 20, 30, 40, and 50 mm/h Using the ETAC Rain Model

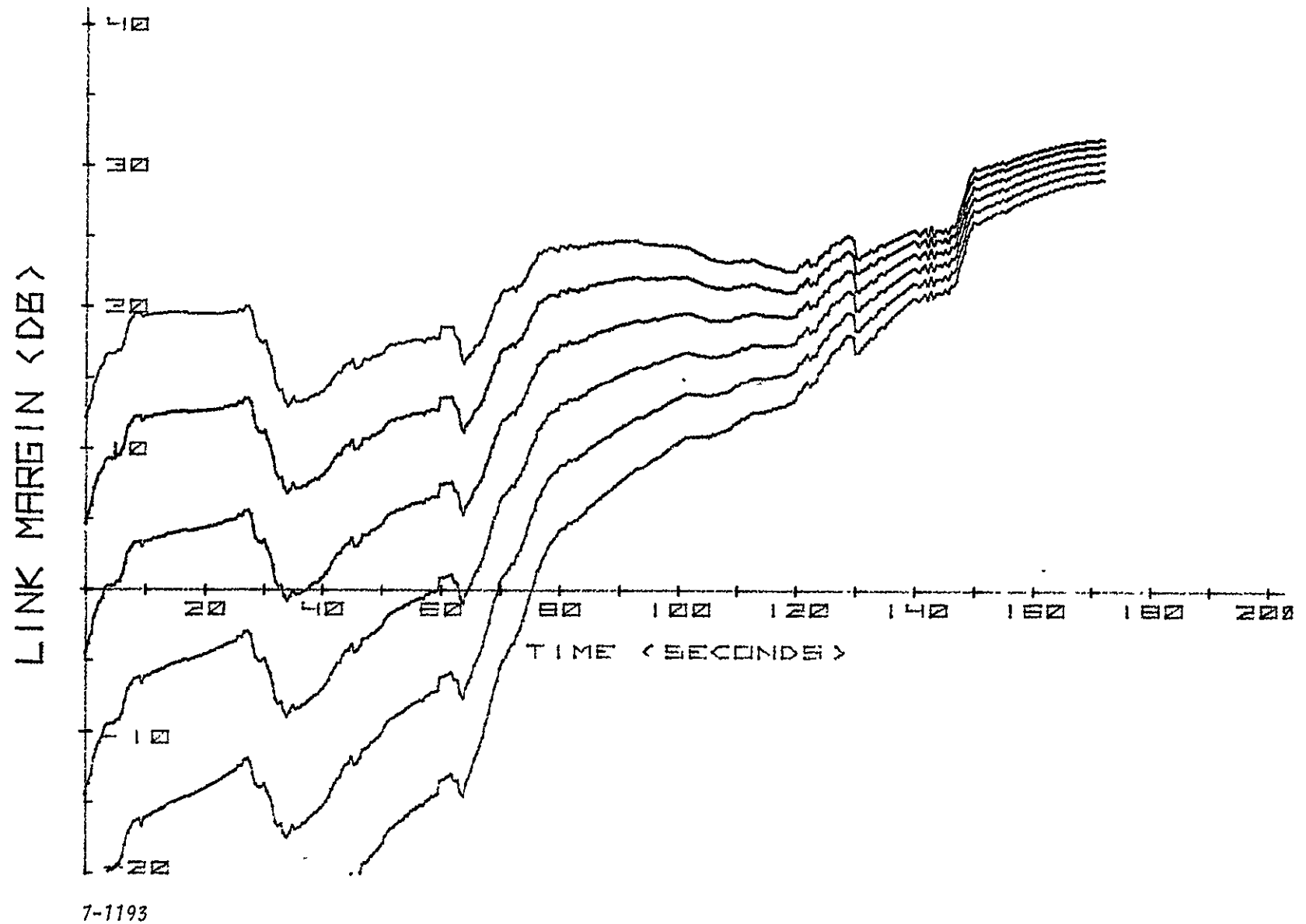


Figure 3-A17. DME Downlink Margin as a Function of Time for ALT-2 Trajectory at Rainfall Rates of 0, 10, 20, 30, 40, and 50 mm/h Using the ETAC Rain Model

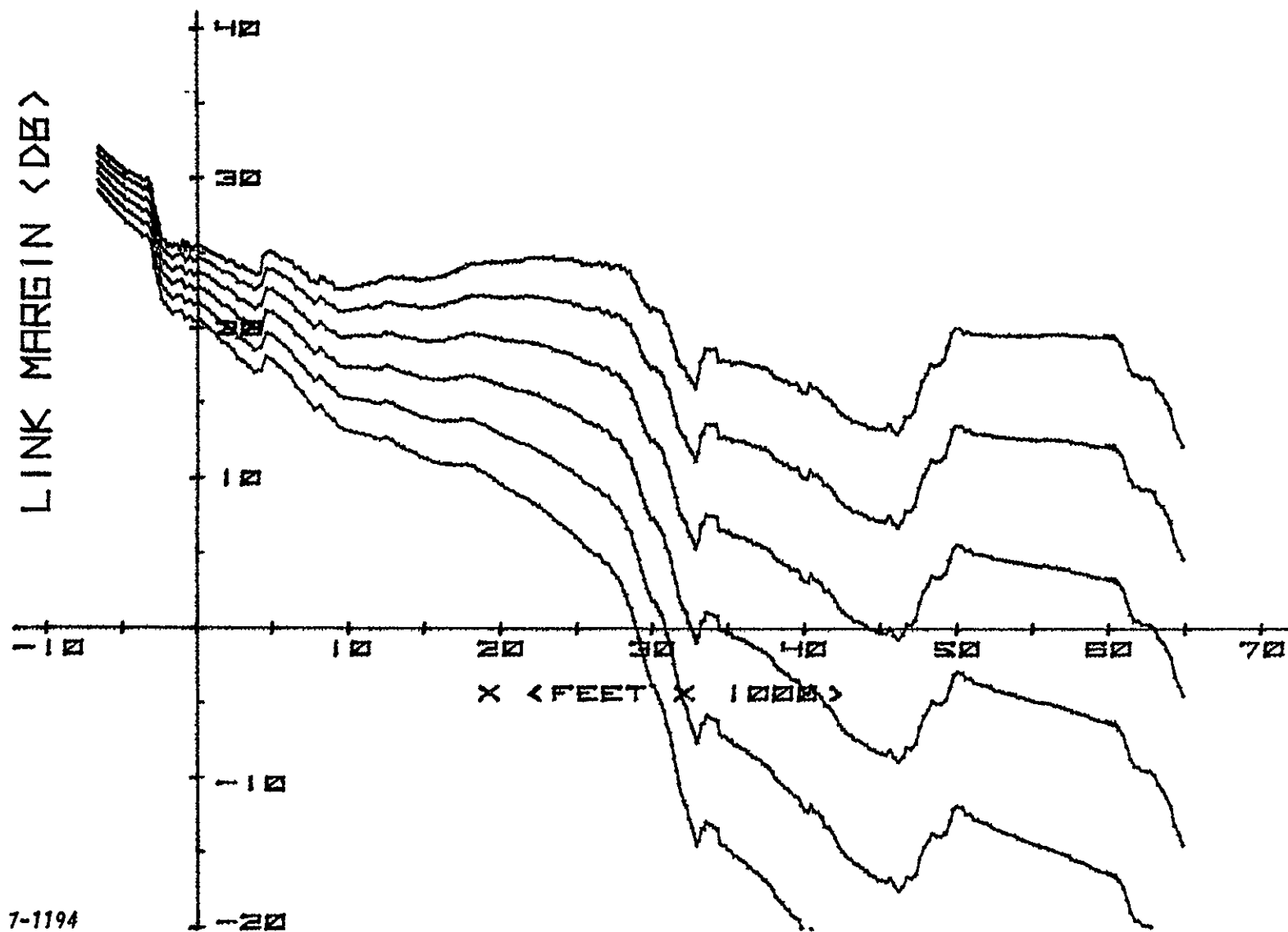


Figure 3-A18. DME Downlink Margin as a Function of X for ALT-2 Trajectory at Rainfall Rates of 0, 10, 20, 30, 40, and 50 mm/h Using the ETAC Rain Model

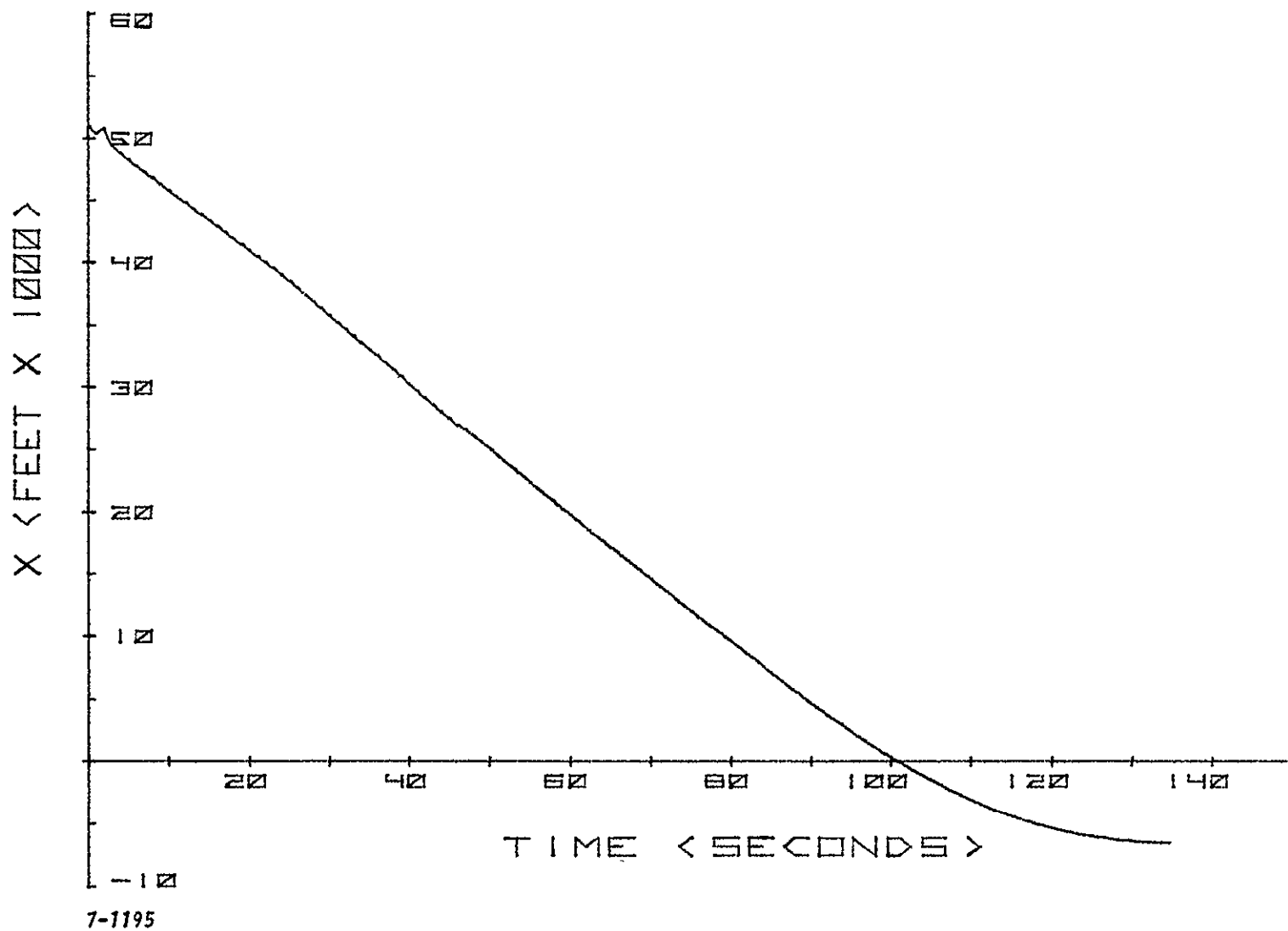


Figure 3-A19. X Position Referenced From Runway Threshold as a Function of Time for ALT-3 Trajectory

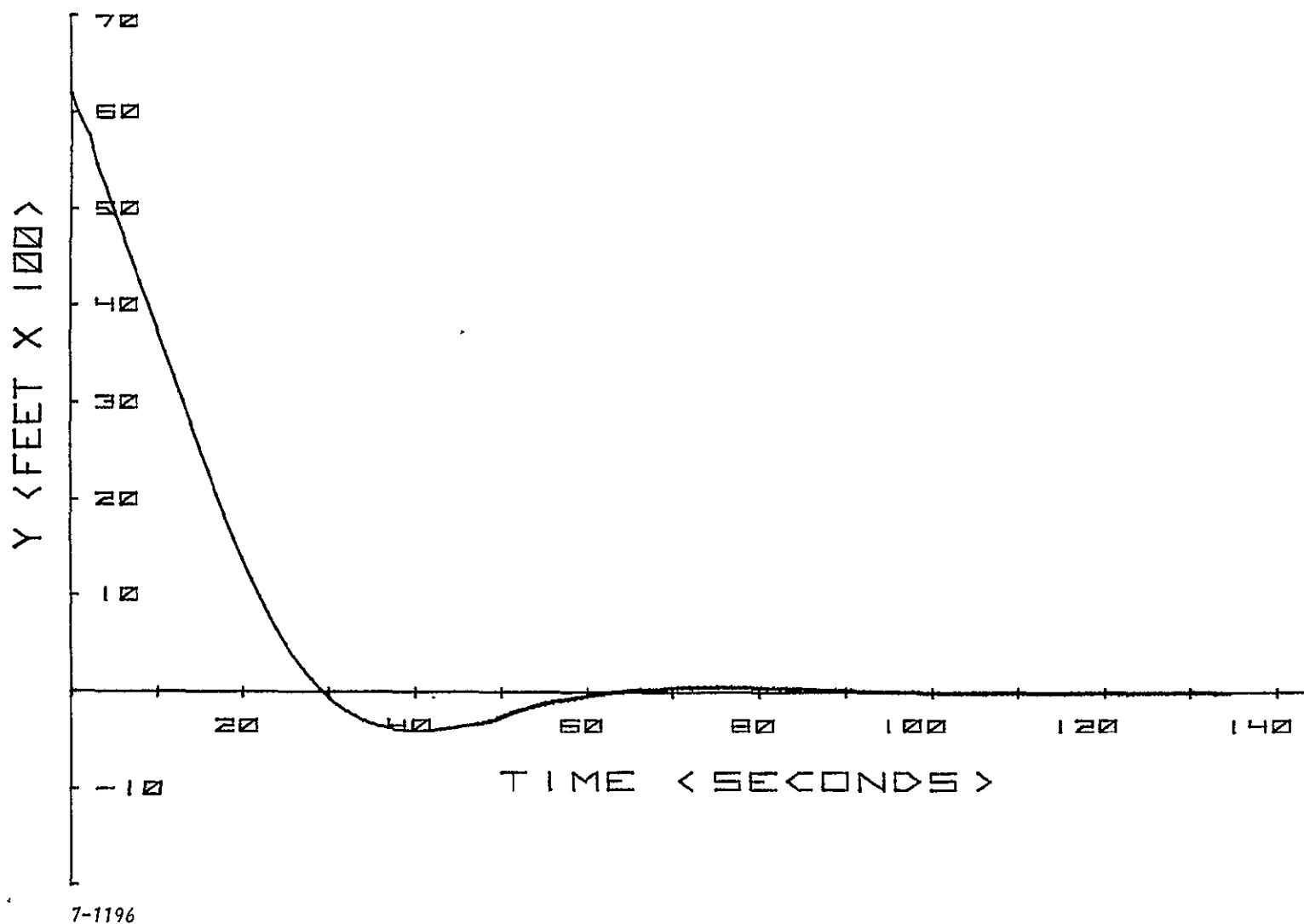


Figure 3-A20. Y Position Referenced From Runway Threshold as a Function of Time for ALT-3 Trajectory

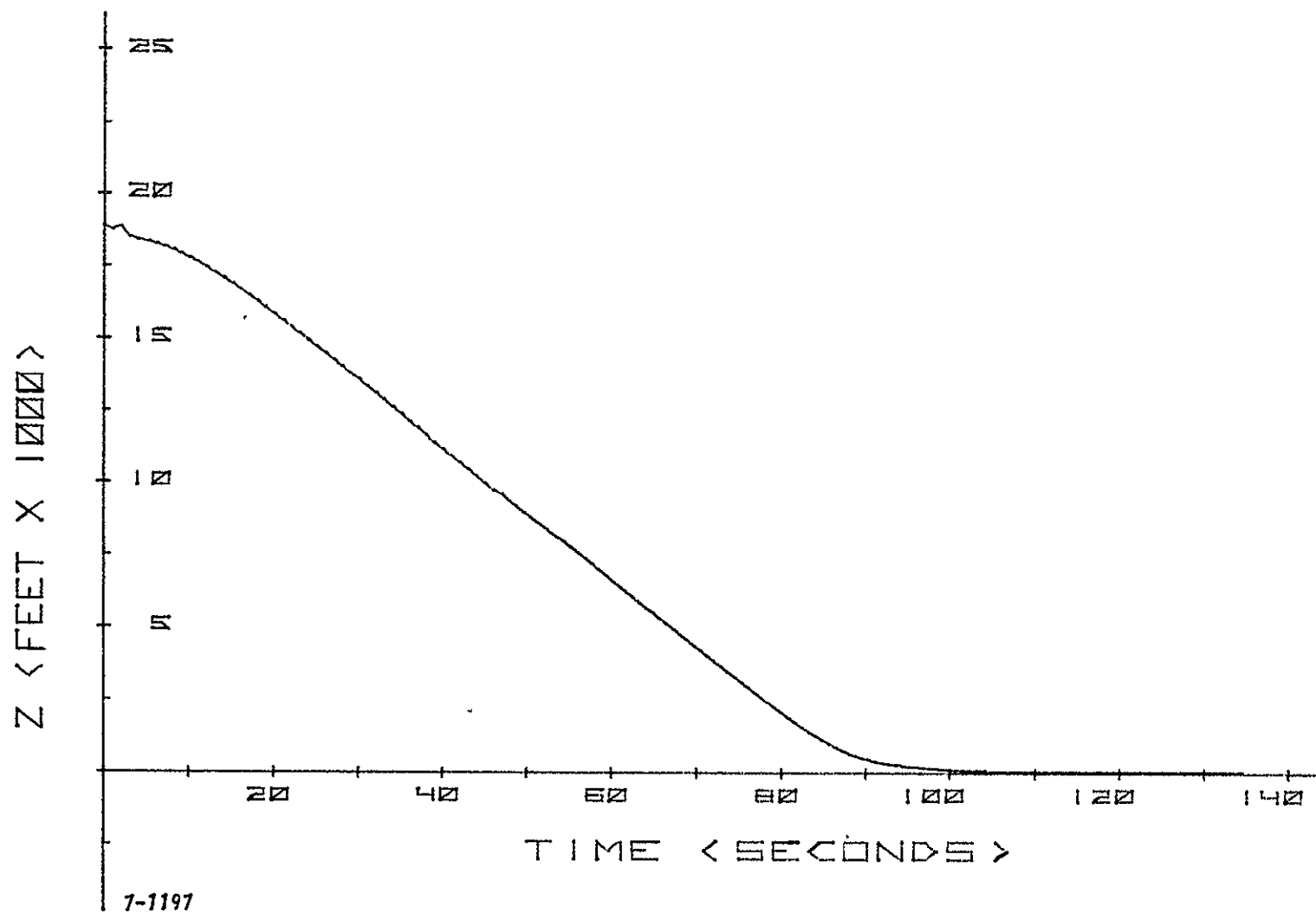
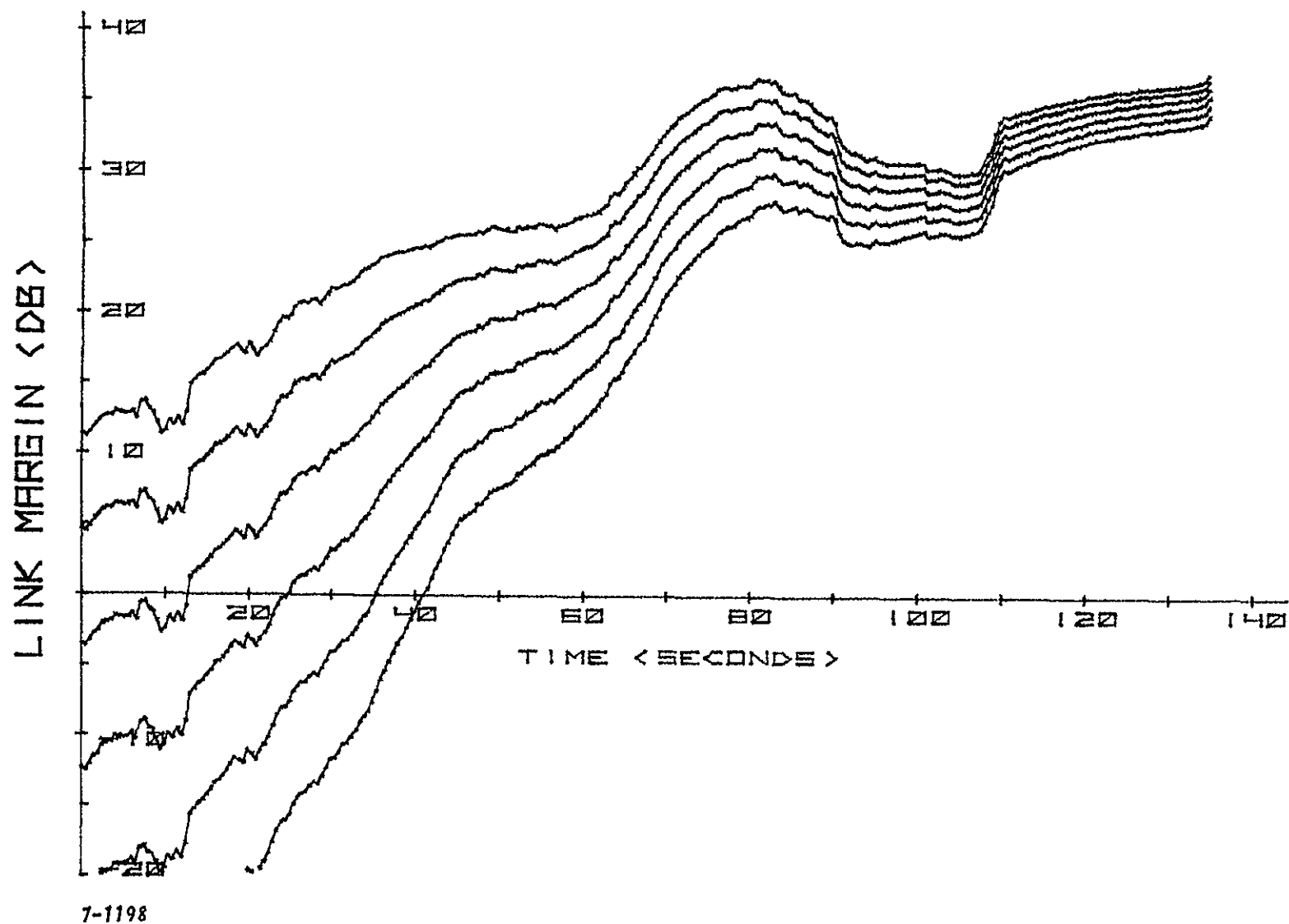
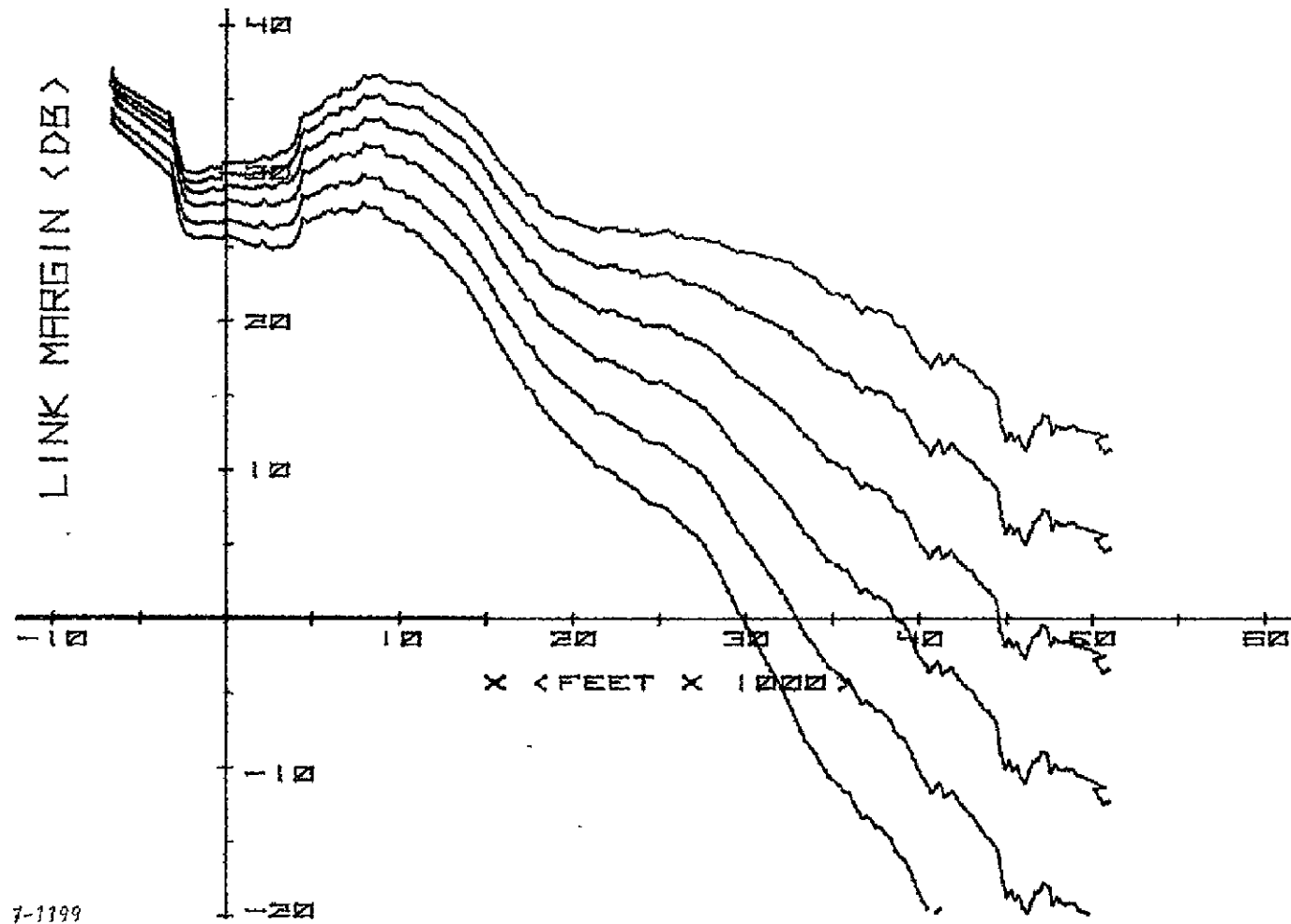


Figure 3-A21. Z Position Referenced From Runway Threshold as a Function of Time for ALT-3 Trajectory



7-1198

Figure 3-A22. Azimuth Link Margin as a Function of Time for ALT-3 Trajectory at Rainfall Rates of 0, 10, 20, 30, 40, and 50 mm/h Using the ETAC Rain Model



7-1199

Figure 3-A23. Azimuth Link Margin as a Function of X for ALT-3 Trajectory at Rainfall Rates of 0, 10, 20, 30, 40, and 50 mm/h Using the ETAC Rain Model

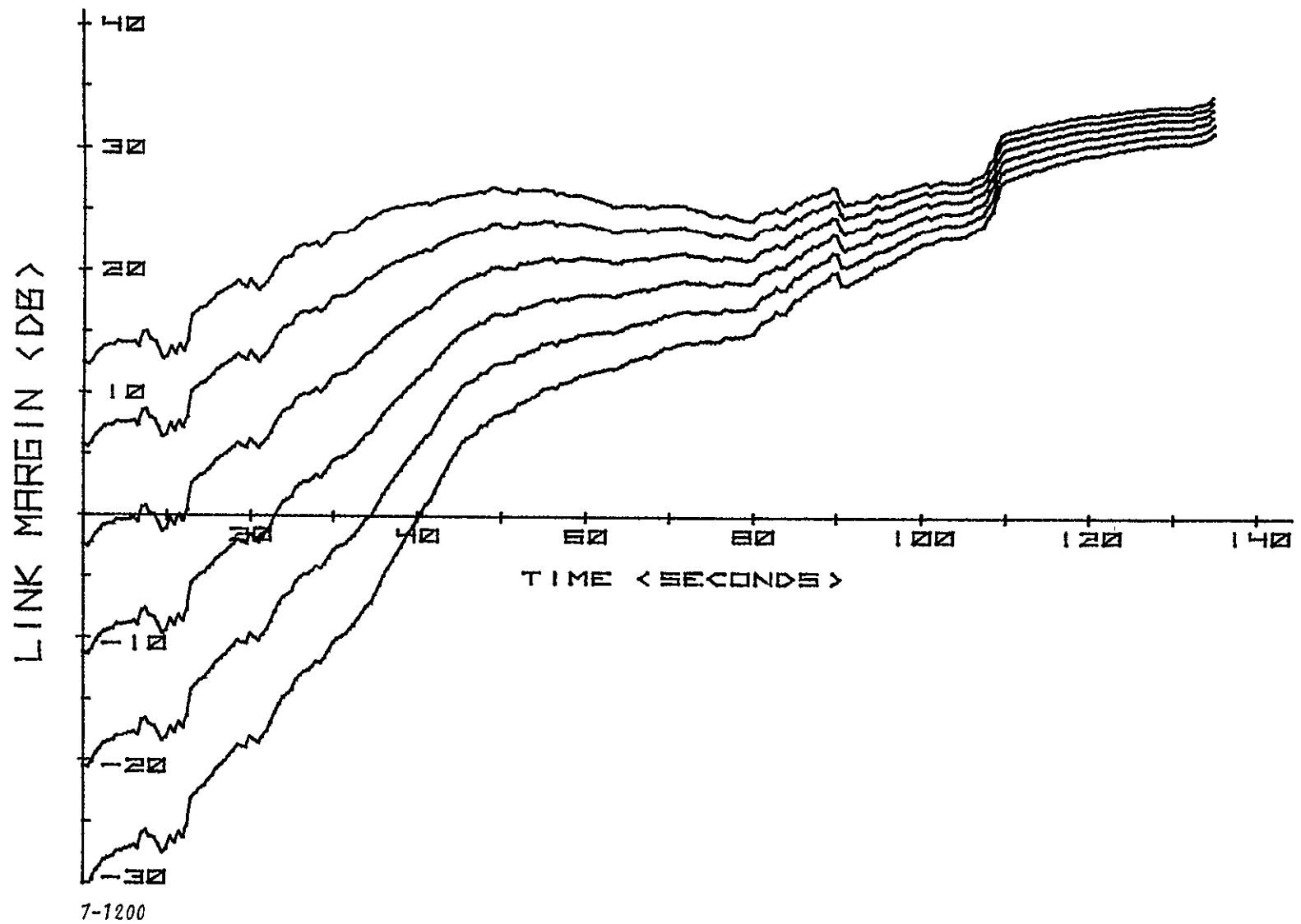
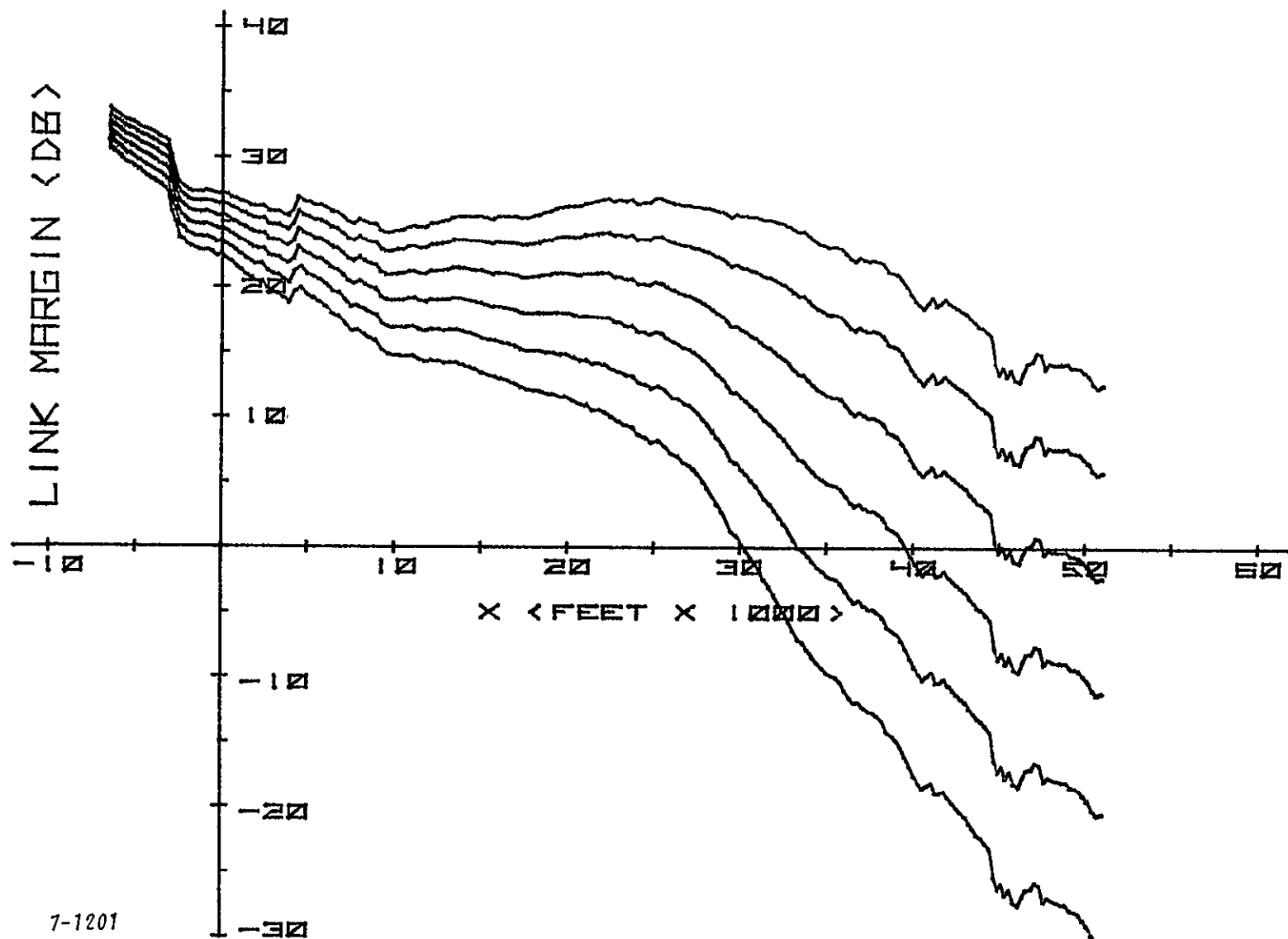


Figure 3-A24. DME Downlink Margin as a Function of Time for ALT-3 Trajectory at Rainfall Rates of 0, 10, 20, 30, 40, and 50 mm/h Using the ETAC Rain Model



7-1201

Figure 3-A25. DME Downlink Margin as a Function of X for ALT-3 Trajectory at Rainfall Rates of 0, 10, 20, 30, 40, and 50 mm/h Using the ETAC Rain Model

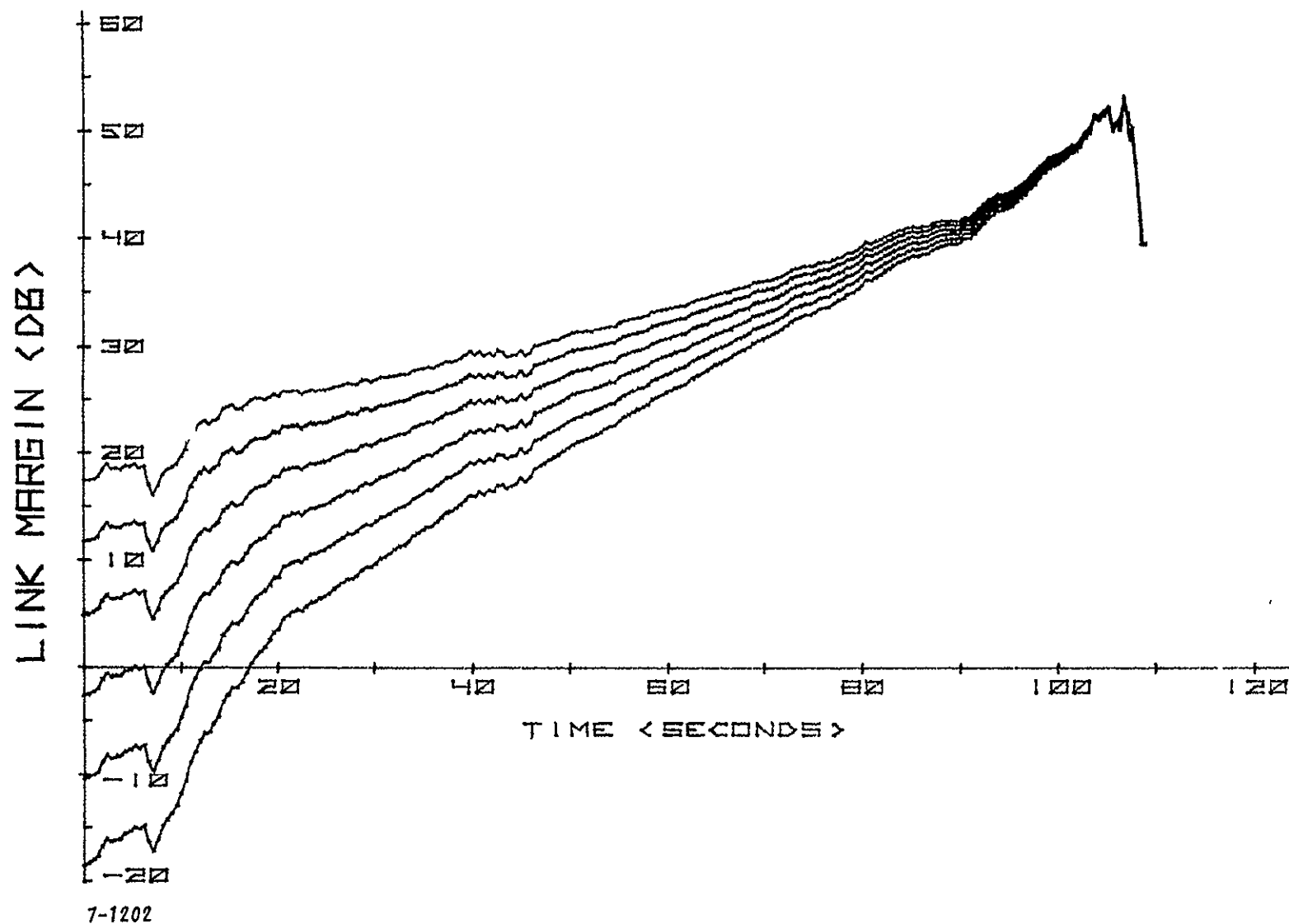


Figure 3-A26. Elevation Link Margin as a Function of Time for ALT-3 Trajectory at Rain-fall Rates of 0, 10, 20, 30, 40, and 50 mm/h Using the ETAC Rain Model

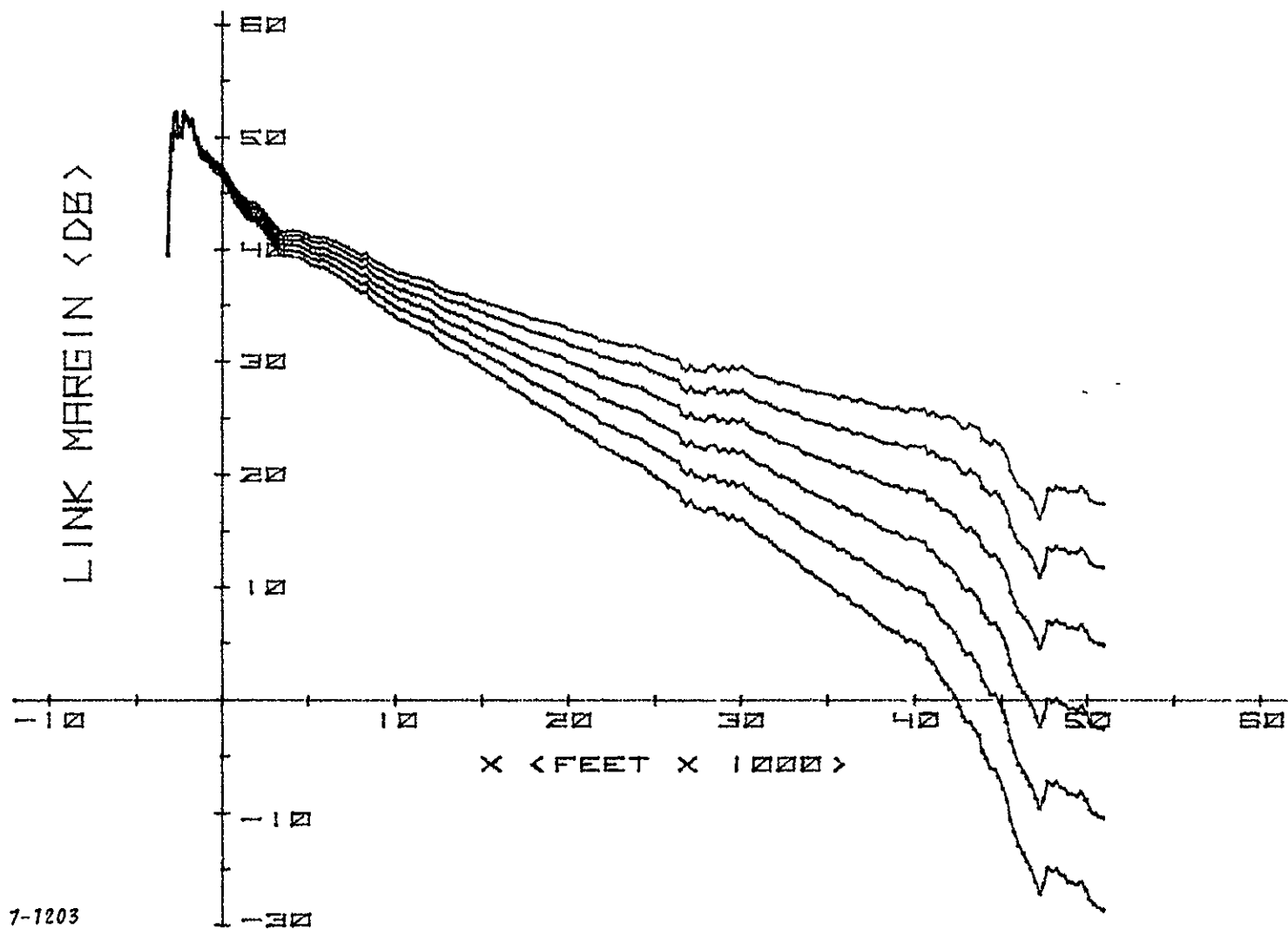


Figure 3-A27. Elevation Link Margin as a Function of X for ALT-3 Trajectory at Rainfall Rates of 0, 10, 20, 30, 40, and 50 mm/h Using the ETAC Rain Model

### 3-A11. DETERMINING THE POSITION OF ORBITER WHEN ELEVATION DATA DROPOUT OCCURS FOR THE ALT-3 TRAJECTORY

In this section, the point in the ALT-3 trajectory when elevation data dropout occurs is predicted. The Orbiter expects to lose elevation data some time after it flies over runway threshold and starts to pass the elevation station. The dropout point is found by using a program (reference p) which simulates the Nav Set tracking response in conjunction with run 48, which contains ALT-3 elevation link data. The simulation shows that elevation data dropout occurs when the orbiter is -3059 feet from runway threshold and 45.3 degrees in azimuth off from the elevation station as shown in Figure 3-A28. The elevation station is located 3350 feet back and 300 feet to the side of runway threshold. The method of arriving at the result is described below.

Figure 3-A29 shows the Nav Set elevation tracking response to the ALT-3 signal trajectory. For most of the trajectory the Nav Set tracks 4 to 5 dB below the peak of the elevation beam. Data dropout occurs at the end of the trajectory, between 100 and 110 seconds. This section of time is expanded in Figure 3-A30. It should be explained at this time that for run 48, the orbiter antenna gain is undefined from 108.16 seconds on, when the azimuth angle to the elevation antenna exceeds 39.20 degrees. For the purpose of this simulation, the Orbiter antenna gain is held fixed at the last defined Orbiter antenna gain value of 1.98 dB for the time after 108.16 seconds.

Figure 3-A30 contains four plots as functions of time from 100 to 110 seconds. From top to bottom, the ordinates for the plots are X from threshold in kilofeet, azimuth angle from the elevation antenna, elevation signal in dBm to the Orbiter including the Orbiter antenna gain, and Nav Set elevation tracking level in dB. From Figure 3-A30, part a, we can

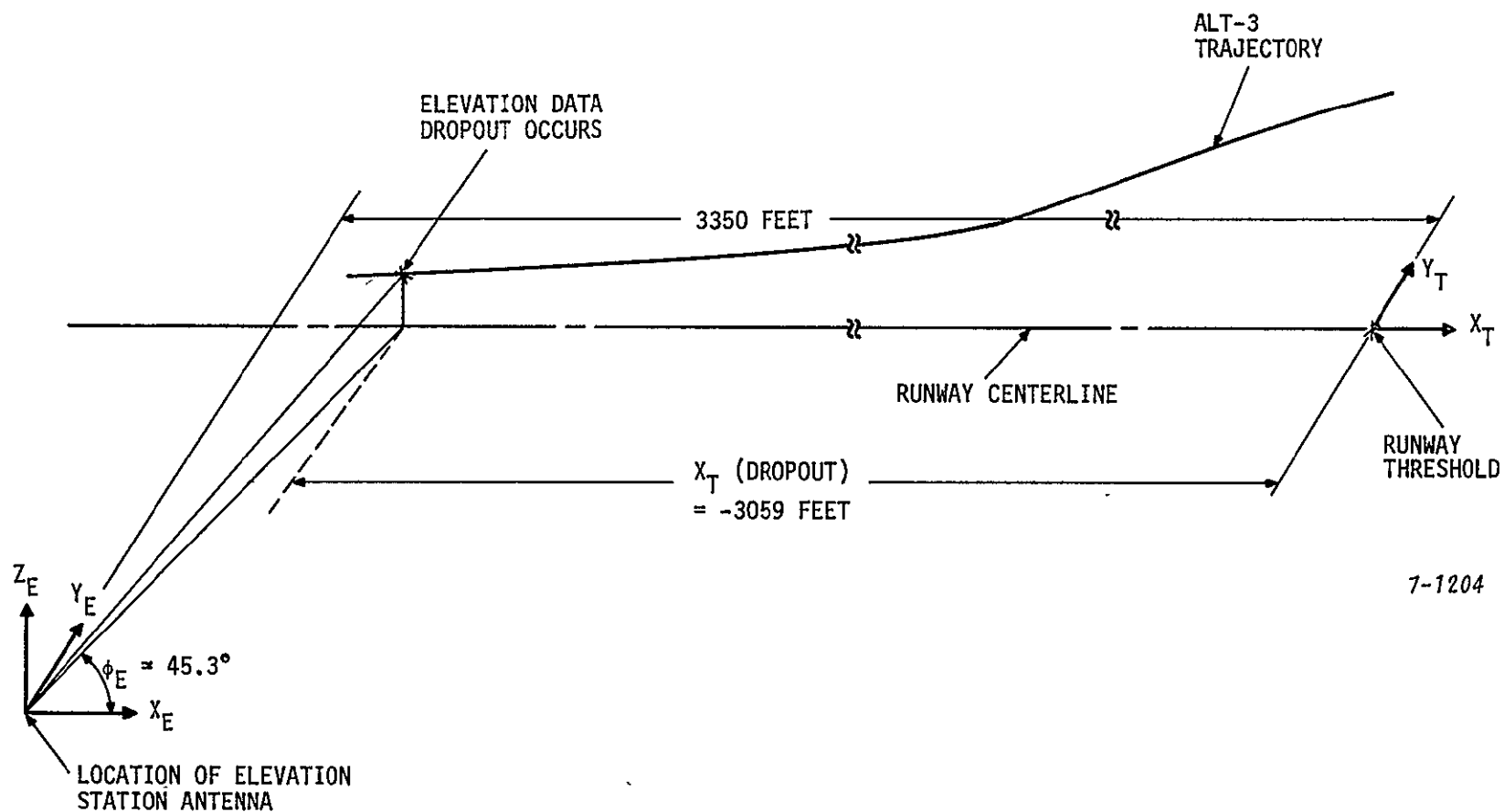


Figure 3-A28. Geometry Illustrating Location of Orbiter When Elevation Data Dropout Occurs

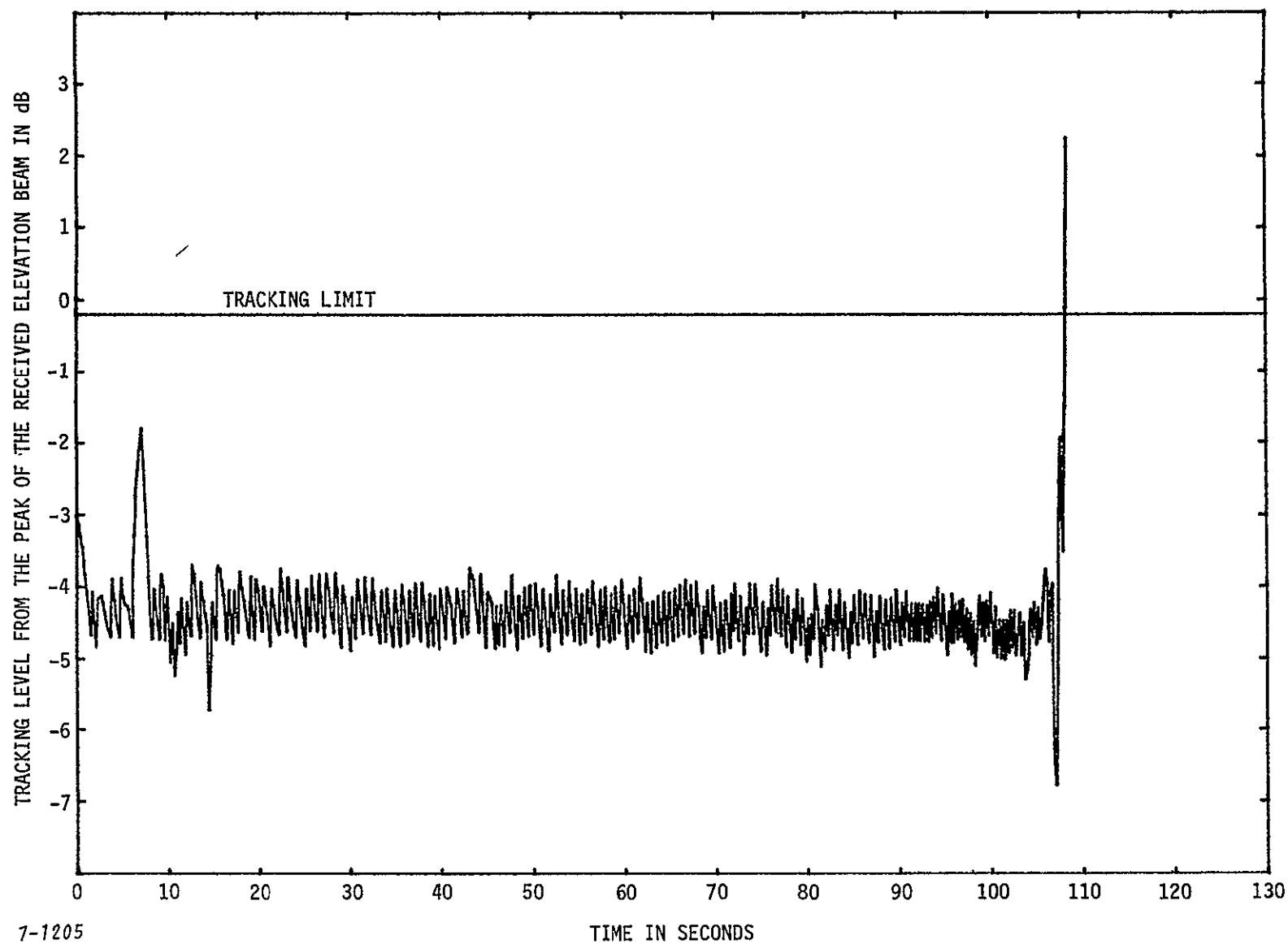


Figure 3-A29. Nav Set Tracking Response for Elevation ALT-3 Signal

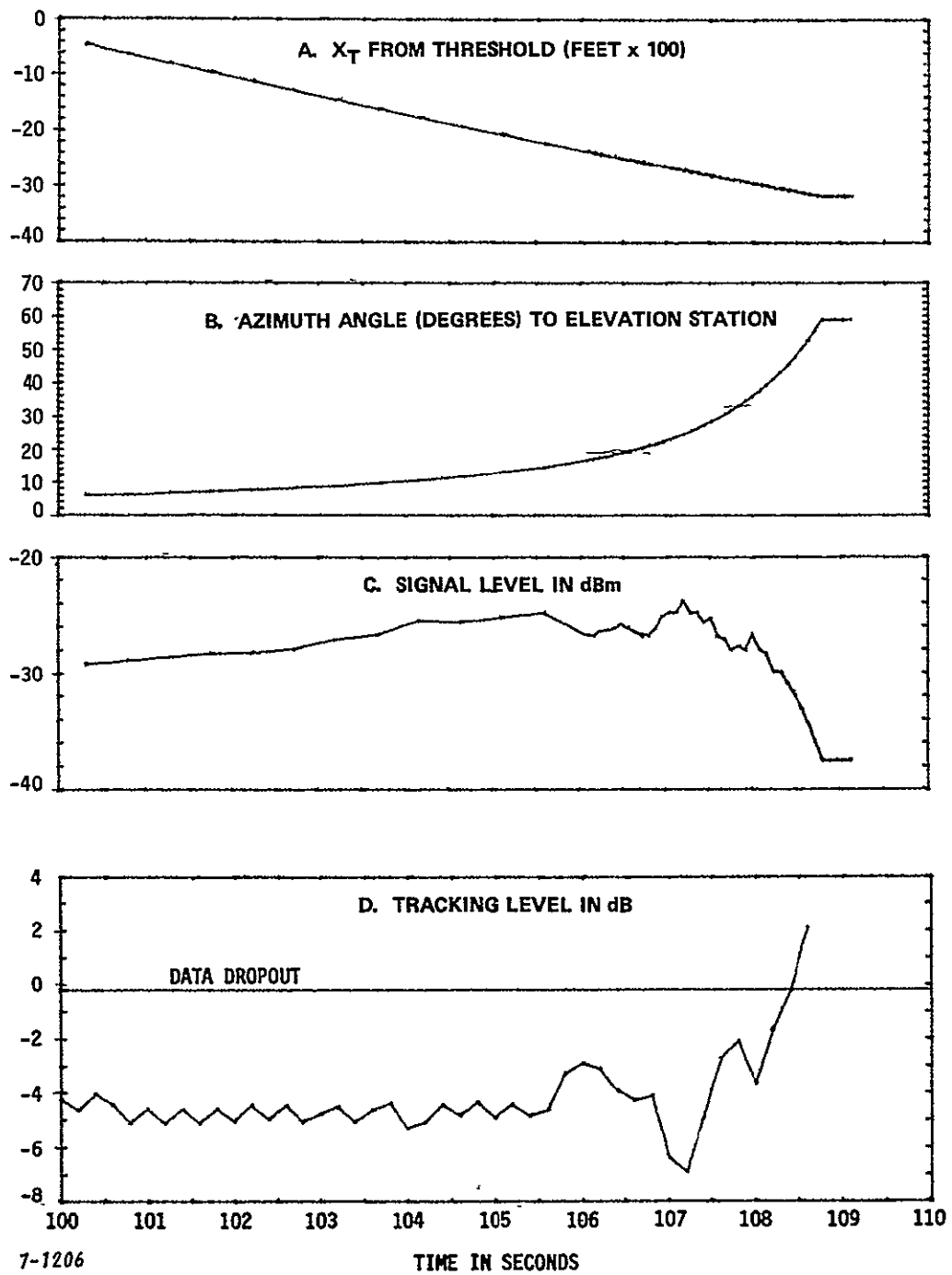


Figure 3-A30. Orbiter Position, Nav Set Signal Level, and Nav Set Tracking Level From 100 to 110 Seconds

see that the value of X is negative, signifying that the Orbiter is past runway threshold and over the runway. As the Orbiter flies toward the end of the runway, the azimuth angle increases rapidly. The signal level increases slowly until the Orbiter goes past the elevation station, when the signal level decreases rapidly resulting in data dropout as the Nav Set tracking limit is reached as shown in Figure 3-A30, part d. The precise time of data dropout of 108.4 seconds is easily obtained from Figure 3-A31, with an expanded plot of the tracking response from 107 to 109 seconds. The corresponding location of the Orbiter is: X position from threshold of -3059 feet, azimuth angle from the elevation antenna of 45.3 degrees, and elevation angle of 2.8 degrees.

### 3-A12. REFERENCES

- a. MSBLS Flight Performance Data Run No. 30, Azimuth OFT-1 Trajectory with 99 Percent Headwind, March 2, 1976 Run Date.
- b. MSBLS Flight Performance Data Run No. 37, Elevation OFT-1 Trajectory, March 16, 1976 Run Date.
- c. MSBLS Flight Performance Data Run No. 27, Azimuth ALT-2 Trajectory.
- d. MSBLS Flight Performance Data Run No. 4, DME ALT-2 Trajectory, December 11, 1975 Run Date.
- e. MSBLS Flight Performance Data Run No. 10, Azimuth ALT-3 Trajectory.
- f. MSBLS Flight Performance Data Run No. 8, DME ALT-3 Trajectory, December 11, 1975 Run Date.
- g. MSBLS Flight Performance Data Run No. 48, Elevation ALT-3 Trajectory, January 1, 1977 Run Date.

h. Microwave Scanning Beam Landing System Handbook, NASA, Houston, Texas, Second Edition, January 1976.

i. ibid, Chapter 5, Ground Station Locations, Section 5.2 Edwards Air Force Base Locations.

j. MSBLS Signal Level Computations, J.O. 16-619 Lockheed Electronics Company, Inc., Aerospace Space Division, Houston, Texas, Contract No. NAS 9-12200.

k. ibid, Chapter 2, Equations for MSBLS Link Signal Levels, p 2-5.

l. ibid, Section 6.1, DME Downlink Signal Levels, p 6-4.

m. ibid, Section 6.3, Azimuth Uplink Signal Levels, p 6-24, 6-33.

n. ibid, Section 6.4, Elevation Uplink Signal Levels, p 6-49.

o. MSBLS Antenna Pattern Data Computer Program To Calculate Gain Gradient and Pattern Ripple, NASA Document EE33-75-103, October 28, 1975.

p. A. Charych, Report No. Y220-02, Evaluation of MSBLS Nav Set AGC Tracking Capability As a Function of Received Signal, June 1976.

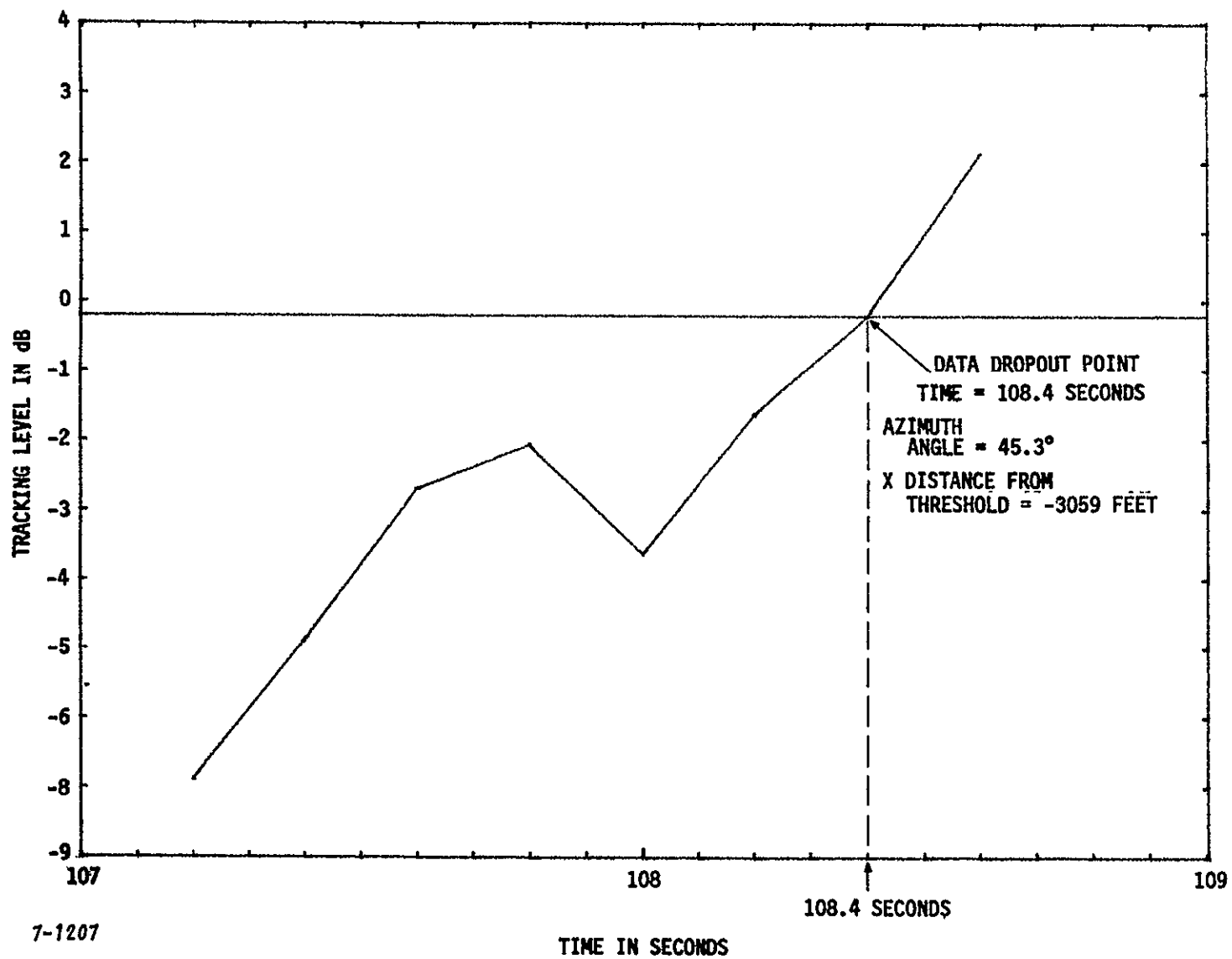


Figure 3-A31. Elevation Data Dropout

SECTION IV  
SYSTEM ACCURACY  
(TASK 07)

PART A  
MSBLS ERROR  
CLASSIFICATION AND SUMMARY

F. BATTLE

TECHNICAL REPORT Y220-09  
INTERIM - FEBRUARY 1976

FINAL  
APRIL 1976

#### 4-A1. INTRODUCTION

A theoretical error analysis of the angular and distance functions of the MSBLS has been presented in Technical Note A980-18, in which assumed or known magnitudes of the various error-causing effects ("source errors") were stated, and in which formulas were derived to evaluate the corresponding partial resultant errors. However, the combined effects of such errors on overall azimuth, elevation or DME system accuracy were illustrated only by inclusion of computer print-out examples.

Summary lists of the formulas for resultant error effects are presented here, together with lists of source error magnitudes, and system parameter values that affect translations of source effects to resultant guidance errors. The individual translation formulas are given in terms involving such system parameters, and also in simpler and more numerical forms that result from substituting the presently assigned values of those parameters.

In addition, separate formulations are tabulated for the evaluations of bias and random errors attributable to ground stations, airborne Nav Sets, and path effects.

Some minor changes and corrections are included here with respect to previously computed and reported error evaluations, but overall resultant values are not significantly affected. Slight changes in some results are due to assuming a Gaussian rather than  $\sin x/x$  beam shape, which simplifies many calculations. In practice, the MSBLS beamshapes appear to fall between these two theoretical models, and at least as close to the Gaussian as to the  $\sin x/x$ .

#### 4-A2. ANGLE GUIDANCE ERRORS

Source errors in the angle guidance subsystems, as correspondingly numbered and described in Technical Note A980-18, are here designated with the presently estimated magnitudes ( $1\sigma$ ) and with units of measure:

| <u>Error</u> | <u>Description</u>                   | <u>Azimuth<br/>Value</u> | <u>Elevation<br/>Value</u> |
|--------------|--------------------------------------|--------------------------|----------------------------|
| $e_1$        | Fan beam roll                        | 0.015 deg                | 0.015 deg                  |
| $e_2$        | Aperture/scan axis roll misalignment | 0.009 rad                | 0.009 rad                  |
| $e_3$        | Scanner pitch                        | 0.03 deg                 | 0.01 deg                   |
| $e_4$        | Scanner yaw                          | 0.01 deg                 | 0.03 deg                   |
| $e_5$        | Angle pickoff bias                   | 0.01 deg                 | 0.01 deg                   |
| $e_6$        | Encoder clock frequency              | $3 \times 10^{-5}$       | $3 \times 10^{-5}$         |
| $e_7$        | Decoder clock frequency              | $5 \times 10^{-5}$       | $5 \times 10^{-5}$         |
| $e_{10}$     | Beam-center angle shift/dB           | 0.0075 deg               | 0.0075 deg                 |
| $e_{14}$     | Angle pickoff increment              | 0.125 deg                | 0.125 deg                  |
| $e_{15}$     | Angle pickoff jitter                 | 0.025 deg                | 0.025 deg                  |
| $e_{16}$     | Encoder clock increment              | 250 nsec                 | 250 nsec                   |
| $e_{17}$     | Pulse transmission jitter            | 15 nsec                  | 15 nsec                    |
| $e_{18}$     | Decoder clock increment              | 125 nsec                 | 125 nsec                   |
| $e_{19}$     | Decoder timing jitter                | 20 nsec                  | 20 nsec                    |
| $e_{20}$     | Decoder output increment (LSB)       | 0.0039 deg               | 0.0039 deg                 |

Symbols for various angle system parameters, and some numerical values as presently used in the MSBLS, are as follows:

| <u>Symbol</u>   | <u>Description</u>                                                                               |
|-----------------|--------------------------------------------------------------------------------------------------|
| $\theta$        | Azimuth absolute value in degrees relative to either scanner.                                    |
| $\phi$          | Elevation in degrees relative to either scanner.                                                 |
| $\omega_{\max}$ | Maximum angular scan rate (at center of guidance sector): azimuth 691 and elevation 377 deg/sec. |
| B               | Half-power beam width: azimuth 2 and elevation 1.3 deg.                                          |
| K               | Angle encoding scale factor: $2 \mu s/\text{deg}$ .                                              |
| L               | Decoding threshold level below beam peak: 4 dB.                                                  |
| M               | Multipath/direct signal amplitude ratio.                                                         |
| P               | Receiver input power (at peak of beam as it is intercepted) in dBm.                              |
| N               | Pulse code intervals ("hits") per beam dwell time.                                               |

It should be noted that the number "91" that appears in some of the equations to follow represents the equivalent input noise power of the Nav. Set receiver, which is nominally -91 dBm.

#### 4-A3. AZIMUTH ERRORS

Resultant azimuth guidance errors (in degrees) due to various source errors are individually calculated as follows:

$$e_1 \tan \phi \cos^2 \theta = 0.015 \tan \phi \cos^2 \theta \quad (3a)$$

$$\cos^{-1} \left\{ \frac{e_2 \tan \phi \sin (2 \theta)}{2[1 - e_2 \tan \phi \sin (2 \theta)]} - \sqrt{\frac{1 + \cos (2 \theta)}{2[1 - e_2 \tan \phi \sin (2 \theta)]}} \right\} - \theta \quad (3b)$$

$$\frac{1}{2} e_3 \tan \theta' \sin (2 \theta) = 0.015 \tan \theta' \sin (2 \theta) \quad (3c)$$

$$e_4 = 0.01 \quad (3d)$$

$$e_5 = 0.01 \quad (3e)$$

$$e_6 (30 + \theta) \approx 0.0011 (@ \theta = 7.5^0; \text{assumed constant}) \quad (3f)$$

$$e_7 (30 + \theta) \approx 0.0012 (@ \theta = 7.5^0; \text{assumed constant}) \quad (3g)$$

$$\text{Beam pulse density imbalance--compensated} \approx 0 \quad (3h)$$

$$(0.627 \text{ MB}) \exp (0.115L)/\sqrt{L} = 0.993M \approx M \quad (3i)$$

$$e_{10}/\sqrt{2} = 0.0053 \quad (3j)$$

$$0.627B10^{-(P+91)/20} \exp (0.115L)/\sqrt{L} = (2.8) 10^{-5-P/20} \quad (3k)$$

$$(0.05)10^{-(P+91)/20} = (1.41) 10^{-6-P/20} \quad (3l)$$

$$\frac{(60 + K\theta) 10^{-6}}{\sqrt{24}} \omega_{\max} \sqrt{1 - (\theta/44)^2} \quad (3m)$$

$$\approx 10^{-3} \sqrt{72 + 4.8\theta + 0.043\theta^2 - 0.0025\theta^3}$$

$$e_{14}/(N \sqrt{12}) = 0.036/N \quad (3n)$$

$$e_{15}/\sqrt{N} = 0.025/\sqrt{N} \quad (3o)$$

$$e_{16}/(2000 N \sqrt{12}) = 0.036/N \quad (3p)$$

$$\sqrt{2} e_{17}/(2000 N) = 0.011/N \quad (3q)$$

$$(\text{synchronism with ground clock}) \approx 0 \quad (3r)$$

$$\sqrt{2} e_{19}/(2000 N) = 0.014/N \quad (3s)$$

$$e_{20}/\sqrt{12} = 0.0011 \quad (3t)$$

The expressions for resultant azimuth errors, as given in Table 4-A1, are obtained by combining into sets the above-listed individual resultants that are numbered as follows:

|                | <u>Bias</u>        | <u>Random</u>          |
|----------------|--------------------|------------------------|
| Ground Station | 3a, 3c, 3d, 3e, 3f | 3m, 3n, 3o, 3p, 3q     |
| Nav Set        | 3g                 | 3j, 3k, 3l, 3r, 3s, 3t |
| Path           | -                  | 3i                     |

It should be noted that error No. 3b is omitted, because the individual equation has not been reduced to an appropriately simple form. It can be separately evaluated and combined (RSS) as another component of ground station bias, or it can be neglected, since its estimated value is typically less than 0.002 degree. Error No. 3h is omitted for similar reasons. In addition, compensatory adjustments to remove most of this error are possible, but the means of adjustment (hence the exactness) have not yet been fully determined.

Table 4-A2 gives numerical results for a sample, nearly worst-case, condition of azimuth measurement.

#### 4-A4. ELEVATION ERRORS

Resultant elevation guidance errors (in degrees) due to various source errors are individually calculated as follows:

$$e_1 \tan \theta \cos^2 \phi = 0.015 \tan \theta \cos^2 \phi \quad (4a)$$

$$\cos^{-1} \left\{ \frac{e_2 \tan \theta \sin (2\phi)}{2[1 - e_2 \tan \theta \sin (2\phi)]} - \sqrt{\frac{1 + \cos (2\phi)}{2[1 - e_2 \tan \theta \sin (2\phi)]}} \right\} - \phi \quad (4b)$$

$$e_3 = 0.01 \quad (4c)$$

$$\frac{1}{2} e_4 \tan \theta \sin (2\phi) = 0.015 \tan \theta \sin (2\phi) \quad (4d)$$

$$e_5 = 0.01 \quad (4e)$$

$$e_6 (30 + \phi) \approx 0.0012 (@ \phi = 10^0; \text{assumed constant}) \quad (4f)$$

$$e_7 (30 + \phi) \approx 0.0020 (@ \phi = 10^0; \text{assumed constant}) \quad (4g)$$

$$\text{Beam pulse density imbalance--compensated} \approx 0 \quad (4h)$$

$$(0.627 \text{ MB}) \exp (0.115L)/\sqrt{L} = 0.646 \text{ M} \quad (4i)$$

$$e_{10}/\sqrt{2} = 0.0053 \quad (4j)$$

$$0.627B 10^{-(P+91)/20} \exp (0.115L)/\sqrt{L} = (1.82) 10^{-5-P/20} \quad (4k)$$

$$(0.05)10^{-(P+91)/20} = (1.41) 10^{-6-P/20} \quad (4l)$$

$$\frac{(60 + K\phi)}{\sqrt{24}} \omega_{\max} \sqrt{1 - [(\phi - 15)/24]^2} \quad (4m)$$

$$\approx 10^{-3} \sqrt{18.8 + 1.59 \phi + 0.032 \phi^2 - 0.00037 \phi^3}$$

$$e_{14}/(N \sqrt{12}) = 0.036/N \quad (4n)$$

$$e_{15}/\sqrt{N} = 0.025/\sqrt{N} \quad (4o)$$

$$e_{16}/(2000 N \sqrt{12}) = 0.036/N \quad (4p)$$

$$\sqrt{2} e_{17}/(2000 N) = 0.011/N \quad (4q)$$

$$(\text{Synchronism with ground clock}) \approx 0 \quad (4r)$$

$$\sqrt{2} e_{19}/(2000 N) = 0.014/N \quad (4s)$$

$$2_{20}/\sqrt{12} = 0.0011 \quad (4t)$$

The expression for resultant elevation errors, as given in Table 4-A3, are obtained by combining into sets the above-listed individual resultants that are numbered as follows:

|                | <u>Bias</u>        | <u>Random</u>          |
|----------------|--------------------|------------------------|
| Ground Station | 4a, 4c, 4d, 4e, 4f | 4m, 4n, 4o, 4p, 4q     |
| Nav Set        | 4g                 | 4j, 4k, 4l, 4r, 4s, 4t |
| Path           |                    | 4i                     |

Table 4A-4 gives numerical results for a nearly worst-case condition of elevation measurement.

#### 4-A5. DME ERRORS

Source errors in the DME subsystem, as correspondingly numbered and described in Technical Note A980-18, are here designated with the presently estimated magnitudes ( $1\sigma$ ) and with units of measure:

| <u>Error</u> | <u>Description</u>                  | <u>Value</u>       |
|--------------|-------------------------------------|--------------------|
| $e_1$        | System delay offset                 | -7.52 nsec         |
| $e_4$        | Threshold uncertainty (air)         | 0.122              |
| $e_5$        | Video level (AGC) uncertainty (air) | 0.189              |
| $e_6$        | Clock frequency (ground)            | $3 \times 10^{-5}$ |
| $e_7$        | Clock frequency (air)               | $5 \times 10^{-5}$ |
| $e_8$        | Circuit delay (ground)              | 10 nsec            |
| $e_9$        | Circuit delay (air)                 | 15 nsec            |
| $e_{13}$     | Clock increment (ground)            | 125 nsec           |
| $e_{14}$     | Clock increment (air)               | 125 nsec           |
| $e_{15}$     | Transmission jitter (ground)        | 15 nsec            |
| $e_{16}$     | Circuit jitter (air)                | 10 nsec            |
| $e_{17}$     | Output increment (LSB)              | 15.37 ft           |

Symbols for various DME system parameters, and some numerical values as presently used in the MSBLS are as follows:

| <u>Symbol</u> | <u>Description</u>                                            |
|---------------|---------------------------------------------------------------|
| F             | Threshold/RMS noise (ground receiver): 4.47                   |
| G             | Threshold/normalized amplitude (air): 0.333                   |
| n             | Replies per DME period: $15/[1 + 0.036 (\text{No. a/c} - 1)]$ |
| P             | Receiver input peak pulse power in dBm                        |

| <u>Symbol</u> | <u>Description</u>                      |
|---------------|-----------------------------------------|
| R             | Range in nautical miles                 |
| X             | Multipath/direct signal amplitude ratio |
| t             | Video pulse rise time: 110 nsec         |

Resultant DME errors (in feet) due to various source errors are individually calculated as follows (with 0.492 round-trip ft/nsec representing the speed of light):

$$0.492 e_1 = -3.70 \quad (5a)$$

$$0.492 t F 10^{-(P+91)/20} = + (0.0068) 10^{-P/20} \quad (5b)$$

$$0.492 t G = + 18.04 \quad (5c)$$

$$0.492 t G e_4 = 2.20 \quad (5d)$$

$$0.492 t G e_5 = 3.41 \quad (5e)$$

$$492 (80 \text{ usec}) e_6 = 1.18 \quad (5f)$$

$$492 (80 + 12.35R) e_7 = 1.97 + 0.304 R \quad (5g)$$

$$0.492 e_8 = 4.92 \quad (5h)$$

$$0.492 e_9 = 7.38 \quad (5i)$$

$$\begin{aligned}
0.492 t G (0.122) + 0.492 t F \left[ \frac{x}{(1-x^2)} \right] 10^{-(P+91)/20} \\
= 2.20 + 6800 \left( \frac{x}{1-x^2} \right) 10^{-6-P/20}
\end{aligned} \quad (5j)$$

$$0.492 \pm 10^{-(P+91)/20} / \sqrt{n} = (0.00153) 10^{-P/20} / \sqrt{n} \quad (5k)$$

$$(0.00153) 10^{-P/20} / \sqrt{n} \quad (5l)$$

$$0.492 (e_{13} / \sqrt{12}) / \sqrt{n} = 17.75 / \sqrt{n} \quad (5m)$$

$$0.492 (e_{14} / \sqrt{12}) / \sqrt{n} = 17.75 / \sqrt{n} \quad (5n)$$

$$0.492 e_{15} / \sqrt{n} = 2.50 \quad (5o)$$

$$0.492 e_{16} / \sqrt{n} = 1.67 \quad (5p)$$

$$e_{17} / \sqrt{12} = 4.44 \quad (5q)$$

The expressions for resultant DME errors, as given in Table 4-A5, are obtained by combining into sets the above-listed individual resultants that are numbered as follows:

|                | <u>Deterministic</u> | <u>Bias</u>    | <u>Random</u>  |
|----------------|----------------------|----------------|----------------|
| Ground Station | 5a, 5b               | 5f, 5h         | 5k, 5m, 5o     |
| Nav Set        | 5c                   | 5d, 5e, 5q, 5i | 5l, 5n, 5p, 5q |
| Path           | -                    | -              | 5j             |

Table 4-A6 gives numerical results for a sample, nearly worst-case, condition of distance measurement.

Table 4-A1. Predicted Azimuth Errors in Degrees

| Source          | <u>Type of Error</u>                                                                   |                                                                                                                      |
|-----------------|----------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------|
|                 | <u>Bias (1 <math>\sigma</math>)</u>                                                    | <u>Random (1 <math>\sigma</math>)</u>                                                                                |
| Ground Station* | $10^{-3} \sqrt{201 + \{113 [1 + \cos (2\theta)] + 169 \sin^2 2\theta\} \tan^2 \phi}$   | $10^{-3} \sqrt{72 + 4.8\theta + 0.043\theta^2 - 0.0025\theta^3 + 2717/N^2 + 625/N}$                                  |
| Nav Set         | 0.0022                                                                                 | $10^{-3} \sqrt{29.4 + (8.8) 10^{-4-P/10} + 140/N^2}$                                                                 |
| Path            | 0                                                                                      | M                                                                                                                    |
| Total System    | $10^{-3} \sqrt{202 + \{113 [1 + \cos (2\theta)] + 225 \sin^2 (2\theta)\} \tan^2 \phi}$ | $10^{-3} \sqrt{101 + 4.8\theta + 0.043\theta^2 - 0.0025\theta^3 + 2857/N^2 + 625/N + (8.8) 10^{-4-P/10} + 10^6 M^2}$ |

\* Scan axis/beam misalignment and pulse density imbalance omitted.

Notes:

$\theta$  = Azimuth, deg.

$\phi$  = Elevation, deg.

P = Receiver input, dBm

M = Multipath/direct Ampl. ratio

N = code hits/dwell  $\approx 1000 / \sqrt{322 + 22\theta + 0.2\theta^2}$

Table 4-A2. Approximate Worst-Case Limits of Azimuth Errors in Degrees

| <u>Source</u>  | <u>Bias (1 <math>\sigma</math>)</u> | <u>Type of Error</u>                  |  |
|----------------|-------------------------------------|---------------------------------------|--|
|                |                                     | <u>Random (1 <math>\sigma</math>)</u> |  |
| Ground Station | 0.0142                              | 0.0126                                |  |
| Nav Set        | 0.0022                              | 0.0423                                |  |
| Path           | 0                                   | 0.0158                                |  |
| Total System   | 0.0144                              | 0.0468                                |  |

Notes:

Vehicle at 12,000 ft altitude,  $8.85^{\circ}$  elev.,  $14^{\circ}$  az, from azimuth station;  
 -36 dB multipath; 10 MM/HR rain.

$$\theta = 14^{\circ}$$

$$R = 12.7 \text{ nmi}$$

$$N = 39$$

$$\phi = 8.85^{\circ}$$

$$P = -63 \text{ dBm}$$

$$M = 0.0158$$

Table 4-A3. Predicted Elevation Errors in Degrees

| Source          | Type of Error                                                                                         |                                                                                                                                   |
|-----------------|-------------------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------|
|                 | Bias (1 $\sigma$ )                                                                                    | Random (1 $\sigma$ )                                                                                                              |
| Ground Station* | $10^{-3} \sqrt{201 + \left\{ 113 [1 + \cos (2\theta)] + 169 \sin^2 (2\theta) \right\} \tan^2 \theta}$ | $10^{-3} \sqrt{19 + 1.6\emptyset + 0.032\emptyset^2 - 0.00037\emptyset^3 + 2717/N^2 + 625/N}$                                     |
| Nav Set         | 0.0022                                                                                                | $10^{-3} \sqrt{29.4 + (3.3) 10^{-4-P/10} + 140/N^2}$                                                                              |
| Path            | 0                                                                                                     | 0.64 M                                                                                                                            |
| Total System    | $10^{-3} \sqrt{202 + \left\{ 113 [1 + \cos (2\theta)] + 169 \sin^2 (2\theta) \right\} \tan^2 \theta}$ | $10^{-3} \sqrt{49 + 1.6\emptyset + 0.032\emptyset^2 - 0.00037\emptyset^3 + 2857/N^2 + 625/N + (3.3) 10^{-4-P/10} + 4.1 M^2 10^5}$ |

Notes:

 $\theta$  = Azimuth, deg. $\emptyset$  = Elevation, deg

P = Receiver input, dBm

M = Multipath/direct ampl. ratio

 $N = \text{code hits/dwell} \approx 1000 / \sqrt{138 + 21\emptyset + 0.6\emptyset^2 - 0.026\emptyset^3}$ 

\*Scan axis/beam misalignment and pulse density imbalance omitted.

Table 4-A4. Approximate Worst-Case Limits of Elevation Errors in Degrees

| <u>Source</u>  | <u>Type of Error</u>                |                                       |
|----------------|-------------------------------------|---------------------------------------|
|                | <u>Bias (1 <math>\sigma</math>)</u> | <u>Random (1 <math>\sigma</math>)</u> |
| Ground Station | 0.0150                              | 0.0073                                |
| Nav Set        | 0.0022                              | 0.0218                                |
| Path           | 0                                   | 0.0286                                |
| Total System   | 0.0152                              | 0.0367                                |

Notes:

Vehicle at 12,000 ft altitude,  $10.7^{\circ}$  elev.,  $17.3^{\circ}$  az, from elevation station;  
 -27 dB multipath; 10 MM/HR rain.

$$\theta = 17.3^{\circ}$$

$$R = 10.4 \text{ nmi}$$

$$N = 50$$

$$\phi = 10.7^{\circ}$$

$$P = -61.3 \text{ dBm}$$

$$M = 0.0447$$

Table 4-A5. Predicted DME Errors in Feet

| Source         | Type of Error                 |                                 |                                                                                                                                                           |
|----------------|-------------------------------|---------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------|
|                | Deterministic                 | Bias (1 $\sigma$ )              | Random (1 $\sigma$ )                                                                                                                                      |
| Ground Station | $(0.0068) 10^{-P/20} - 3.70$  | 5.06                            | $\sqrt{\frac{370 + (2.33) 10^{-6-P/10}}{n}}$                                                                                                              |
| Nav Set        | +18.04                        | $\sqrt{71 + (1.97 + 0.304R)^2}$ | $\sqrt{4.44 + \frac{339 + (2.33) 10^{-6-P/10}}{n}}$                                                                                                       |
| Path           | 0                             | 0                               | $2.20 + 6800 \left( \frac{X}{1 - X^2} \right) 10^{-6-P/20}$                                                                                               |
| Total System   | $14.34 + (0.0068) 10^{-P/20}$ | $\sqrt{97 + (1.97 + 0.304R)^2}$ | $\left\{ 19.7 + \left[ 2.20 + 6800 \left( \frac{X}{1 - X^2} \right) 10^{-6-P/20} \right]^2 + \left[ 709 + (4.66) 10^{-6-P/10} \right] / n \right\}^{1/2}$ |

Notes:

P = Receiver input in dBm

n = Replies/period

R = Range in nmi

X = Multipath/direct amplitude ratio

Table 4-A6. Approximate Worst-Case Limits of DME Errors in Feet

| <u>Source</u>  | <u>Deterministic</u> | <u>Type of Error</u>                |                                       |
|----------------|----------------------|-------------------------------------|---------------------------------------|
|                |                      | <u>Bias (1 <math>\sigma</math>)</u> | <u>Random (1 <math>\sigma</math>)</u> |
| Ground Station | +36.81               | 5.06                                | 7.21                                  |
| Nav Set        | +18.04               | 10.25                               | 7.27                                  |
| Path           | 0                    | 0                                   | 29.31                                 |
| Total System   | +54.85               | 11.43                               | 31.29                                 |

Notes:

Vehicle at 12,000 ft altitude,  $8.85^{\circ}$  elev.,  $14^{\circ}$  az, from DME station;  
 -6 dB multipath; 10 MM/HR rain; 21 interrogators

P = -75.5 dBm                      n = 8.7 replies  
 R = 12.7 nmi                        X = 0.5012

PART B

GROUND STATION ENCODER ACCURACY

A. CHARYCH

TECHNICAL REPORT Y220-07

INTERIM - DECEMBER 1975  
JANUARY 1976  
MARCH 1976

FINAL

APRIL 1976

#### 4-B1. INTRODUCTION

The ground station encoder generates the necessary angular code which is transmitted, via the scanning antenna, to the orbiter's Nav Set. The Instantaneous angle code is dependent upon the position of the scanning antenna as determined by an optical shaft encoder (angle data pickoff). The angular code is subject to certain quantization and bias effects due to the nature of the encoding process. The accuracy of the coded data, when averaged over an angular antenna beamwidth, represents the best accuracy the MSBLS can attain. This is so, because other sources of MSBLS error, such as anomalies in ground antenna pattern and effects of electromagnetic propagation, are not included.

Performing encoder accuracy measurements and simulations will ascertain that the class of MSBLS errors pertaining to the encoder falls within the analytic error budget assigned to these sources. The analytic error model, in turn, could be updated if the measured and simulated data warrants a change. Determining the encoder accuracy will also be useful as a way of separating classes of MSBLS errors when system accuracy tests are being performed.

#### 4-B2. APPROACH

The approach to evaluate encoder accuracy is:

- a. Measurement
- b. Simulation
- c. Comparison to analytic error budget

Accuracy measurements will be performed on the encoders built for the DVTU system. This data will then be compared to the output of a software simulation. The reason for performing measurement and simulation is to verify that the simulation is operating correctly. Once confidence exists in

the simulated results, simulations could be performed for worst-case (specification limit) parameter tolerances. Simulation and measurement accuracy will then be compared to the analytic error budget to determine agreement with encoder accuracy predictions.

The parameters which describe encoder accuracy are provided in paragraphs 4-B3, 4-B4, and 4-B5.

4-B3. ENCODER BIAS. This is a fixed offset in measured or simulated data when compared to the center of the angular sector over which the data is decoded. An offset which is independent of angular position and direction of antenna scan is not of interest because it will be compensated for in any system boresighting procedure. An offset which changes with angle position (slope bias) can be eliminated only at the boresighting angle and, therefore, contributes to system error at any other angle. A bias which changes with direction of antenna scan (hysteresis) will manifest itself as an additional system random noise component (unless adjacent scan integration is performed).

4-B4. ENCODER RANDOM NOISE ERROR. This is a 1 sigma value of fluctuations about the mean decoded angle. This random noise is caused by several quantizing effects in the encoding process.

4-B5. PEAK ANGULAR DEVIATION. Since the encoder random noise error is made up mostly of several quantization effects which are uniformly distributed, the composite random noise component is not quite Gaussian. Peak deviation of decoded angle gives a good insight into its statistics.

#### 4-B6. DVTU ELEVATION ENCODER BIAS ERROR

4-B7. MEASUREMENT TEST SET UP. The test setup for measurement of encoder accuracy is shown in Figure 4-B1. A test fixture, called the beam generator, monitors the pointing angle of the DVTU scanning antenna via the ADP outputs of the DVTU optical shaft encoder. By the use of programming

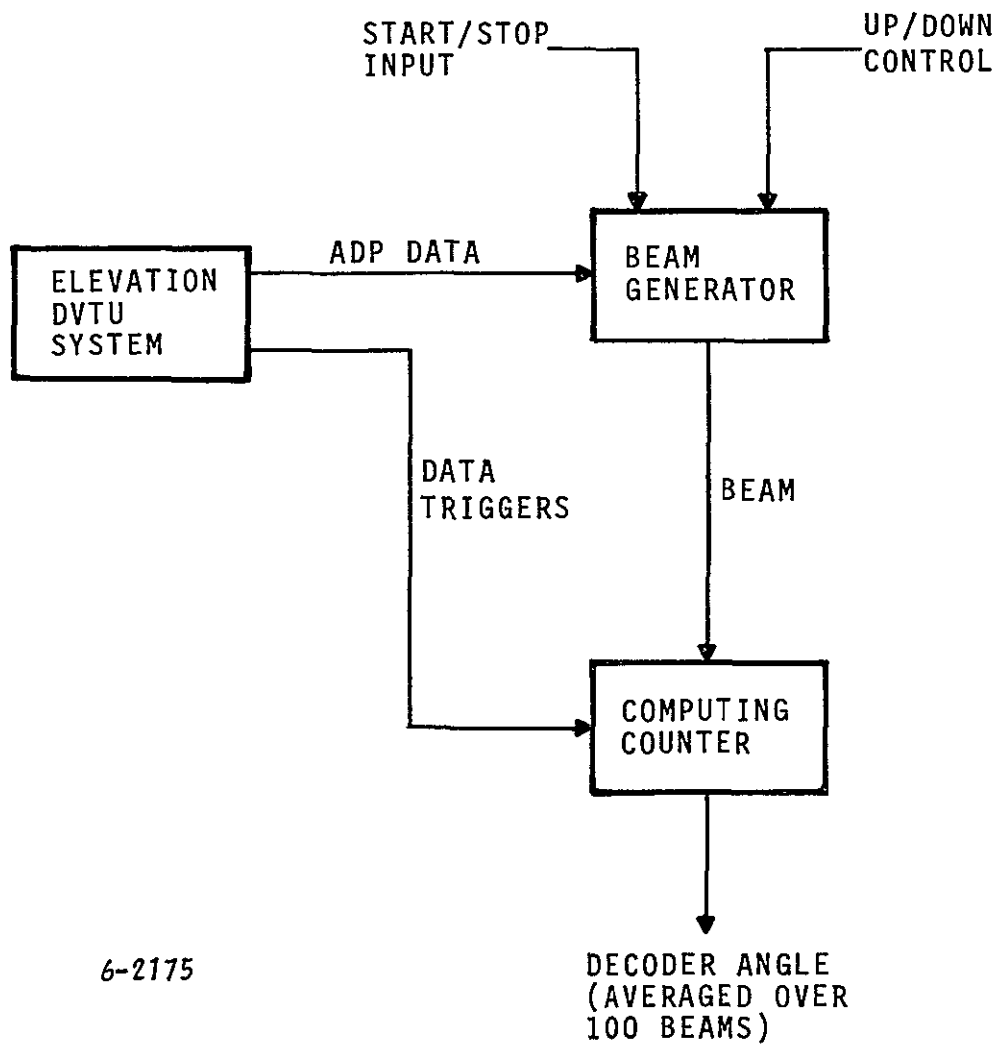


Figure 4-B1. Test Setup for Encoder Accuracy Measurement

switches, the beam generator can output a pulse which covers any angular sector within the scanning beam coverage. The beam output allows a computing counter to average DVTU system data triggers over its width, in order to determine the average data interval, which in turn, directly corresponds to the decoded beam central angle.

Time interval measurement done with the counter differs slightly from the way the Nav Set decodes data, so that a correction to the counter measurement is required. This correction is done using the counters computing capability (Figure 4-B2).

The counter starts a time interval measurement at the first data trigger after the beginning of the beam. The measurement continues until the first interval after the end of the beam. The Nav Set, however, does not use the last data interval in decoding the beam's central angle. In order to correct the measured results, the computing counter subtracts a fixed number which corresponds to the last data interval (the number is known since the last interval occurs at a predetermined angle). The counter also decrements the total number of measured data intervals by one, and performs division in order to compute the average interval (and, therefore, the beam's central angle) across the beam.

The counter is capable of averaging anywhere from 10 to 1000 decoded beams in order to accurately compute bias and random noise errors. A separate switch on the beam generator allows beams to be decoded only during the upscan or the downscan portion of the antenna cycle, so that any hysteresis in the decoded angle could easily be spotted.

4-B8. ELEVATION DVTU ENCODER BIAS MEASUREMENTS. Test data performed on the elevation DVTU encoder is shown in Figure 4-B3. The data shows practically no difference between upscan and downscan bias (no hysteresis), but shows an appreciable change in bias as a function of elevation angle (slope error). The difference in bias between the low angles and the

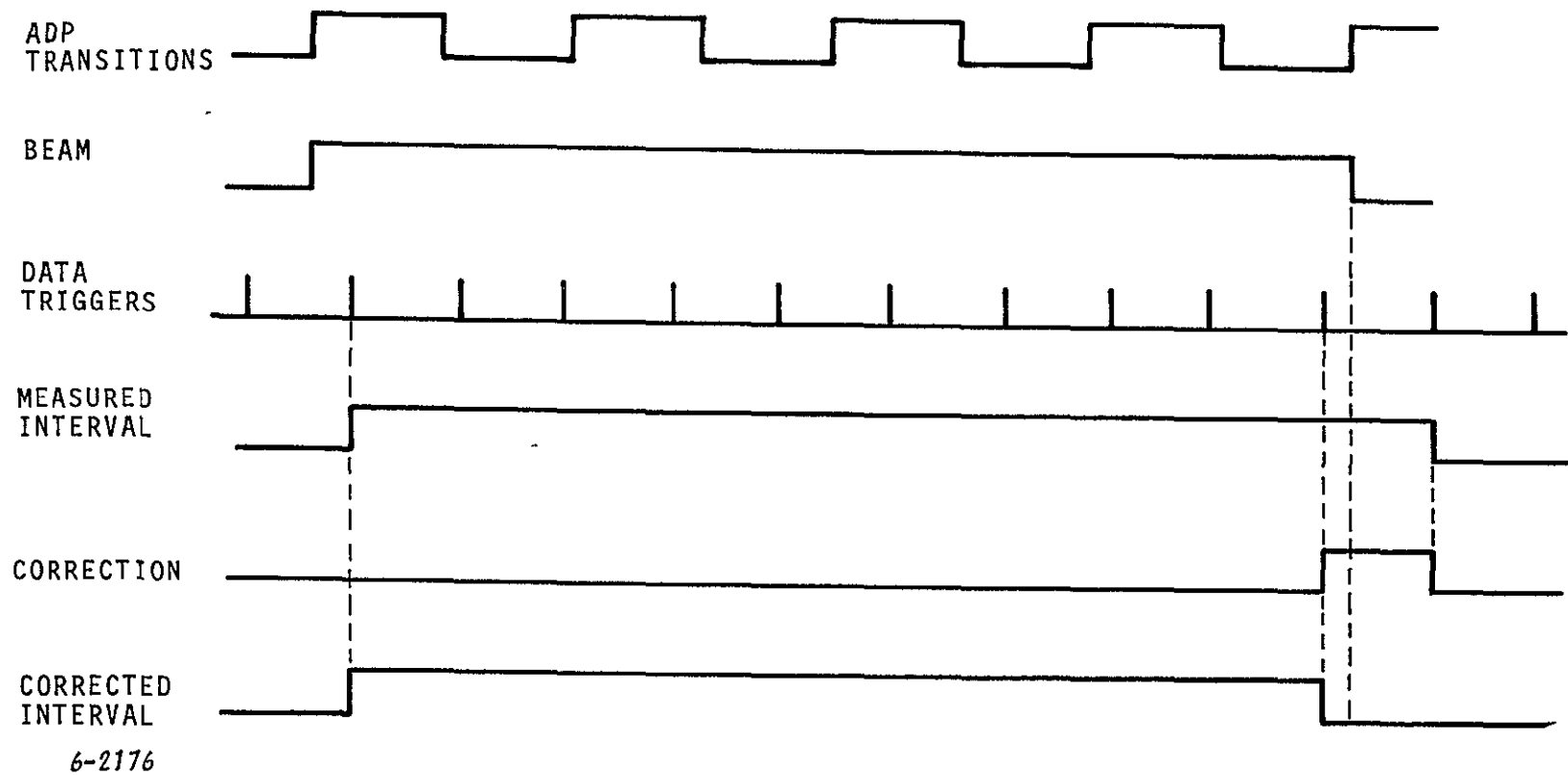


Figure 4-B2. Encoder Accuracy Measurement Waveforms

C-5

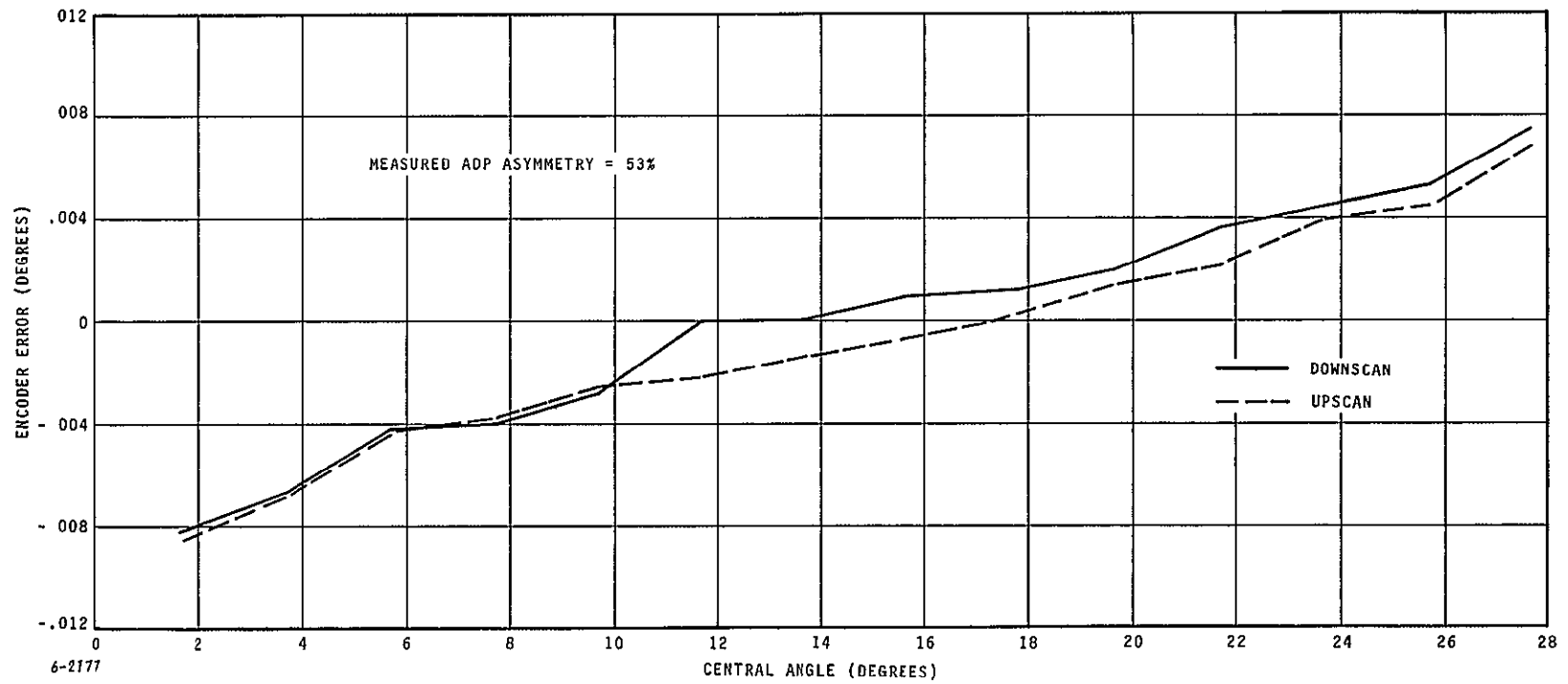


Figure 4-B3. Measured Elevation DVTU Encoder Bias Error

high angle is seen to be approximately 0.015 degree. This means that if the elevation scanner is boresighted at an angle of say 3 degrees, the decoded angle at 30 degrees will be too high by slightly less than 0.015 degree.

A look at the analytic error model reveals that a slope error in the elevation channel is due to "beam pulse density imbalance." The difference in bias between the low and the high angles for an elevation beam width of 1.5 degrees, however, is computed to be no more than 0.003 degree (Figure 4-B4). The measured slope error is not accounted for in the analytic error model.

4-B9. ELEVATION ENCODER SIMULATION. A software simulation of encoder operation was developed a little over a year ago in order to study hysteresis effects in the scanning beam encoding process. A look at the DVTU encoder measured data indicates that very little hysteresis exists in the encoded data.

This simulation was updated with DVTU encoder circuit peculiarities which could possibly have an influence on the encoded angle. The specific shape of the elevation DVTU Angle Data Pickoff (ADP) waveform was also programmed into the simulation. An ideal ADP waveform would be as shown in Figure 4-B5, part A. The waveform is a square wave with each leading and trailing edge signifying 1/8-degree change in scanning antenna position. The actual elevation DVTU waveform (Figure 4-B5, part B) is not square, but was measured to have a ratio of pulse width to period of 53 percent. The ADP specification (AIL No. 502030) allows the ratio to be  $50 \pm 10$  percent.

Initial simulation results showed a slope bias which did not conform to the measured results.

A review of the simulation procedure revealed that an approximation to real world conditions was used, which was thought to have minimal effect on encoded data. The velocity of the scanning antenna within the dwell time

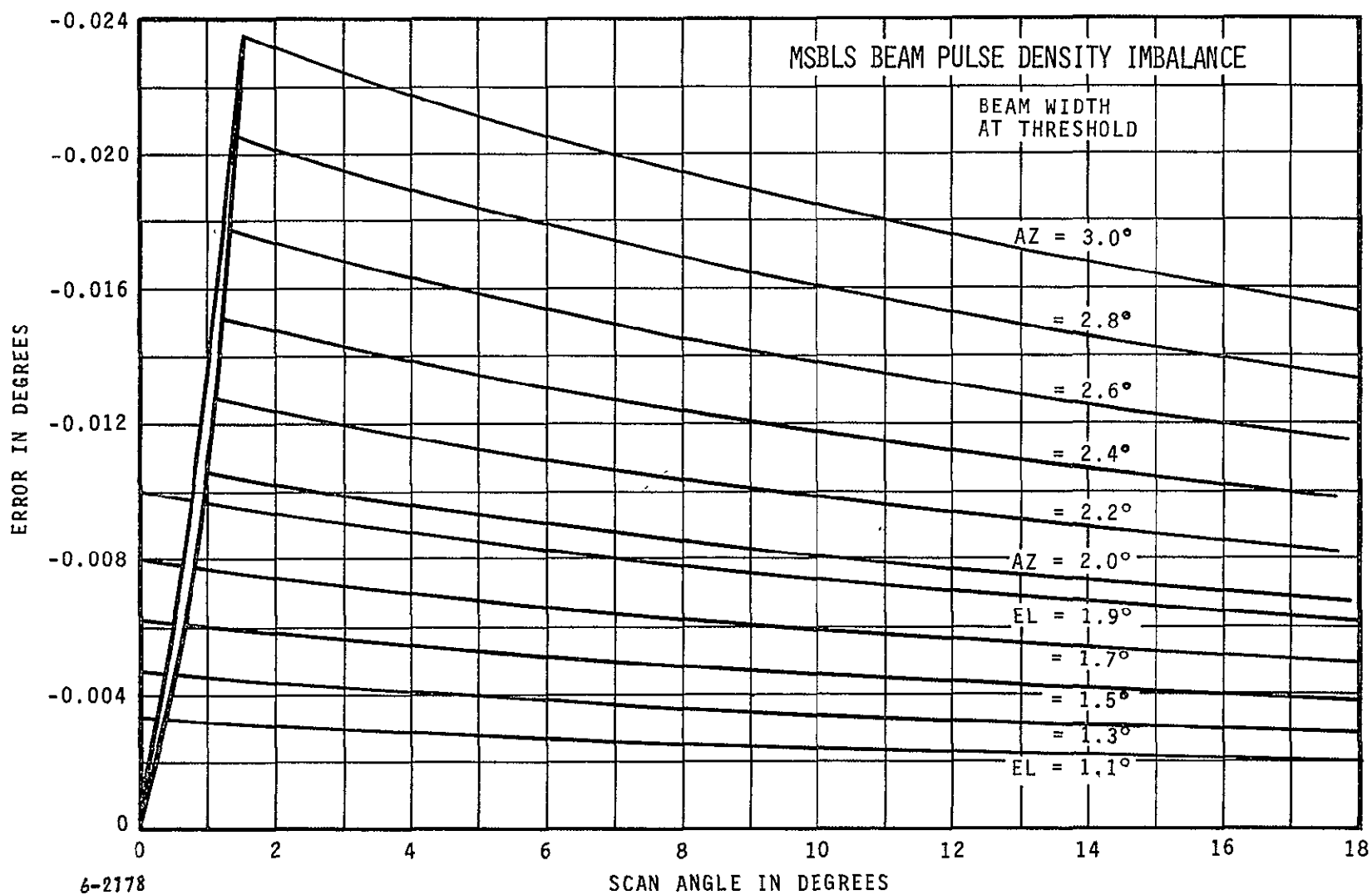
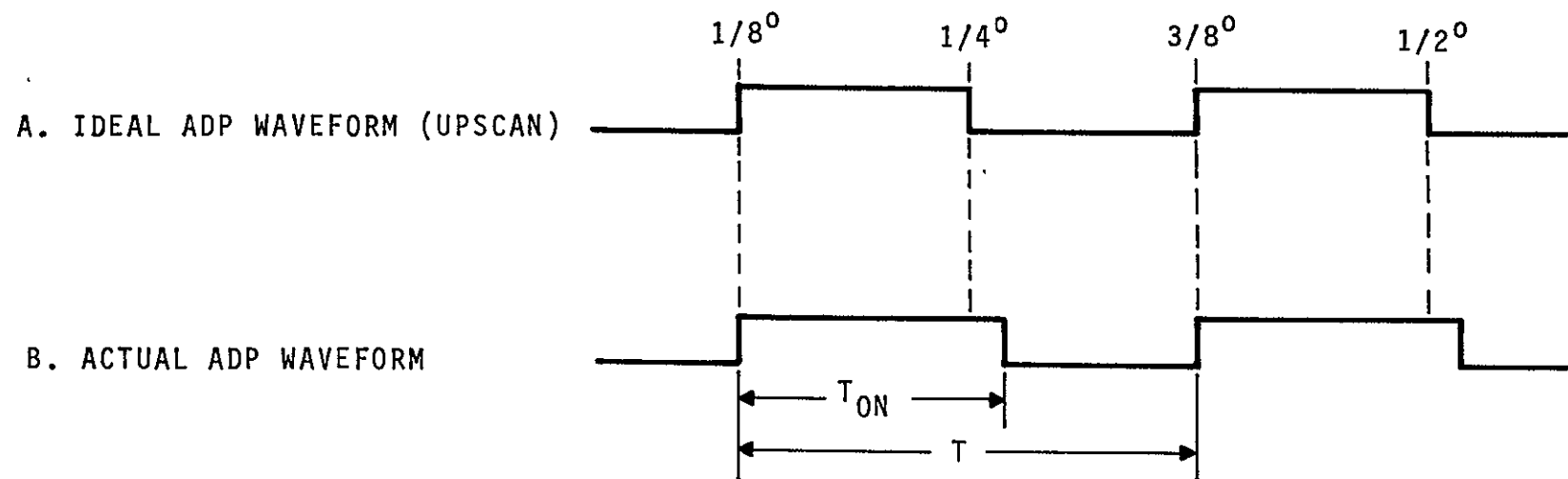


Figure 4-B4. Analytic MSBLS Encoder Slope Bias Error



6-2179 MEASURED PERCENT WAVEFORM ASYMMETRY =  $T_{ON}/T \times 100\% = 53\%$

Figure 4-B5. Elevation DVTU ADP Waveform Assymetry

of the intercepted beam was assumed to be constant. This approximation holds well for most torsion bar systems, including the MSBLS-GS azimuth scanner. The azimuth scanner mechanically scans through a sector of  $\pm 44$  degrees, transmitting only over a  $\pm 15$  degree sector. This is a fairly linear region. In any 2-degree segment (one beam width), antenna velocity can be considered constant. The elevation scanner, however, transmits over the same  $\pm 15$ -degree angular sector, but the mechanical scan is only  $\pm 24$  degrees. Near the edges of the transmission sector, antenna velocity changes sufficiently in a 1.5-degree beam width so that too many pulse pairs are intercepted in 1/2 of the beam, aggravating the error due to beam pulse density imbalance.

The derivation of beam pulse density imbalance for the analytic error model also assumed a constant antenna velocity within a beam dwell.

The simulation was next updated to allow the antenna velocity to change after each transmitted pulse pair. Comparison of simulated and measured data (Figure 4-B6) shows excellent correlation. Beam pulse density imbalance error for the analytic error model will, therefore, have to be updated.

4-B10. SIMULATION OF WORST-CASE ADP ASYMMETRY. Simulation of Figure 4-B6 was run with an ADP asymmetry (ratio of ADP pulse width to ADP period) of 53 percent, as was measured for the elevation DVTU encoder. Since the ADP specification allows the asymmetry to be  $50 \pm 10$  percent, a question arises as to what effect can be expected on encoded data with a worst-case ( $\pm 10$  percent) ADP asymmetry.

Simulation of encoder bias error for an ADP asymmetry of 60 percent (Figure 4-B7) shows that the average offset changes, but neither hysteresis nor slope error increases. Since the average offset is taken out during system boresighting, ADP asymmetry does not seem to have much effect on system accuracy.

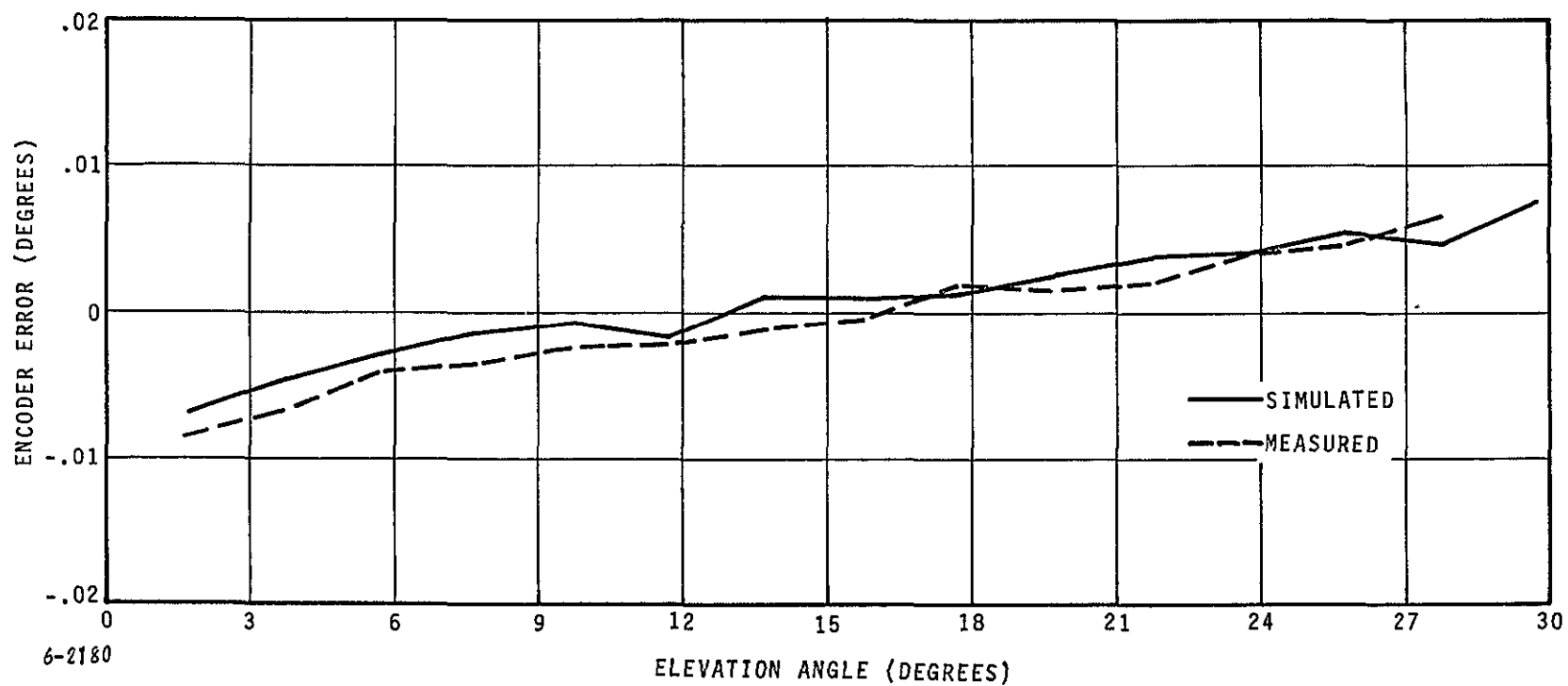


Figure 4-B6. Elevation Encoder Upscan Bias Error--Simulated Versus Measured Data (ADP Asymmetry = 53 Percent)

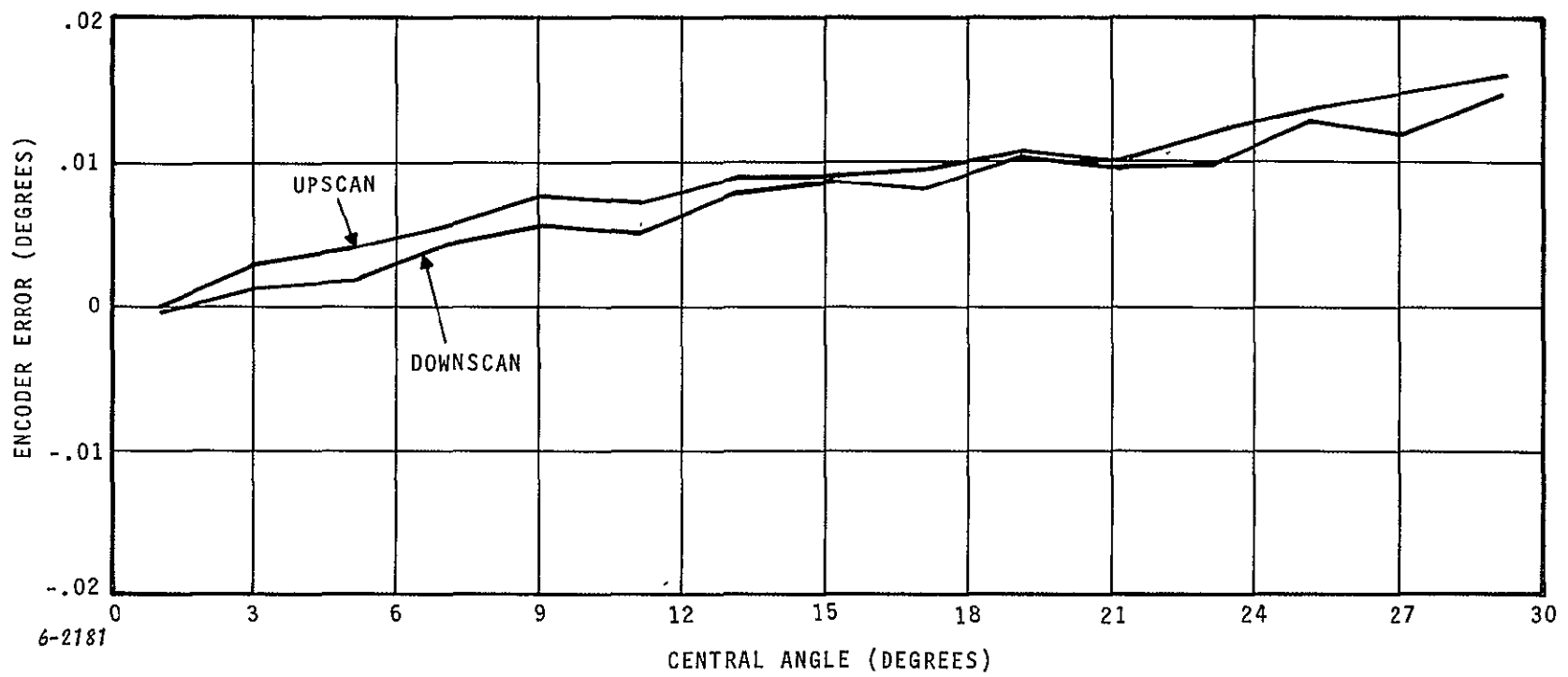


Figure 4-B7. Simulated Elevation Encoder Bias Error (ADP Asymmetry = 60 Percent)

#### 4-B11. AZIMUTH ENCODER BIAS

4-B12. AZIMUTH DVTU ENCODER BIAS ERROR MEASUREMENTS AND SIMULATION. The azimuth encoder bias error was measured utilizing the procedure described in the previous paragraphs. The measurement was performed by decoding beams only during one portion of the antenna scan; either clockwise or counterclockwise. The measurement beam width was set at 2.5 degrees.

Measurement results are shown in Figure 4-B8. The average encoder bias error (average between clockwise and counterclockwise scan) is seen to be approximately  $\pm 0.018$  degree. This agrees well with the analytically predicted value (Figure 4-B4). The average difference between clockwise and counterclockwise scan (hysteresis) was measured to be approximately 0.008 degree.

Simulation of azimuth encoder bias error (Figure 4-B9) follows approximate predictions of the analytic error model. On one side of centerline (positive azimuth angle) the bias error, mostly due to beam pulse density imbalance, is approximately -0.015 degree. On the other side of centerline (negative azimuth angle) this error is approximately +0.015 degree. Within one antenna beam width of centerline (+1 degree, -1 degree) expected bias changes by 0.03 degree. Outside the centerline region (1 degree to 15 degrees), some slope error exists, but it is relatively small (less than 0.005 degree). This simulation was performed at a tracking level of 4 dB below beam peak (beam width of 2.3 degrees). The results correlate well with the analytically predicted values (Figure 4-B4). The difference between measured and simulated results is primarily due to the difference in beam width, 2.3 versus 2.5 degrees.

The slope bias around 0 degree azimuth may prove to be a problem because it occurs right in the center of the shuttle's operational region. A look at the azimuth angle for the OV102 ALT-3 autoland trajectory reveals that

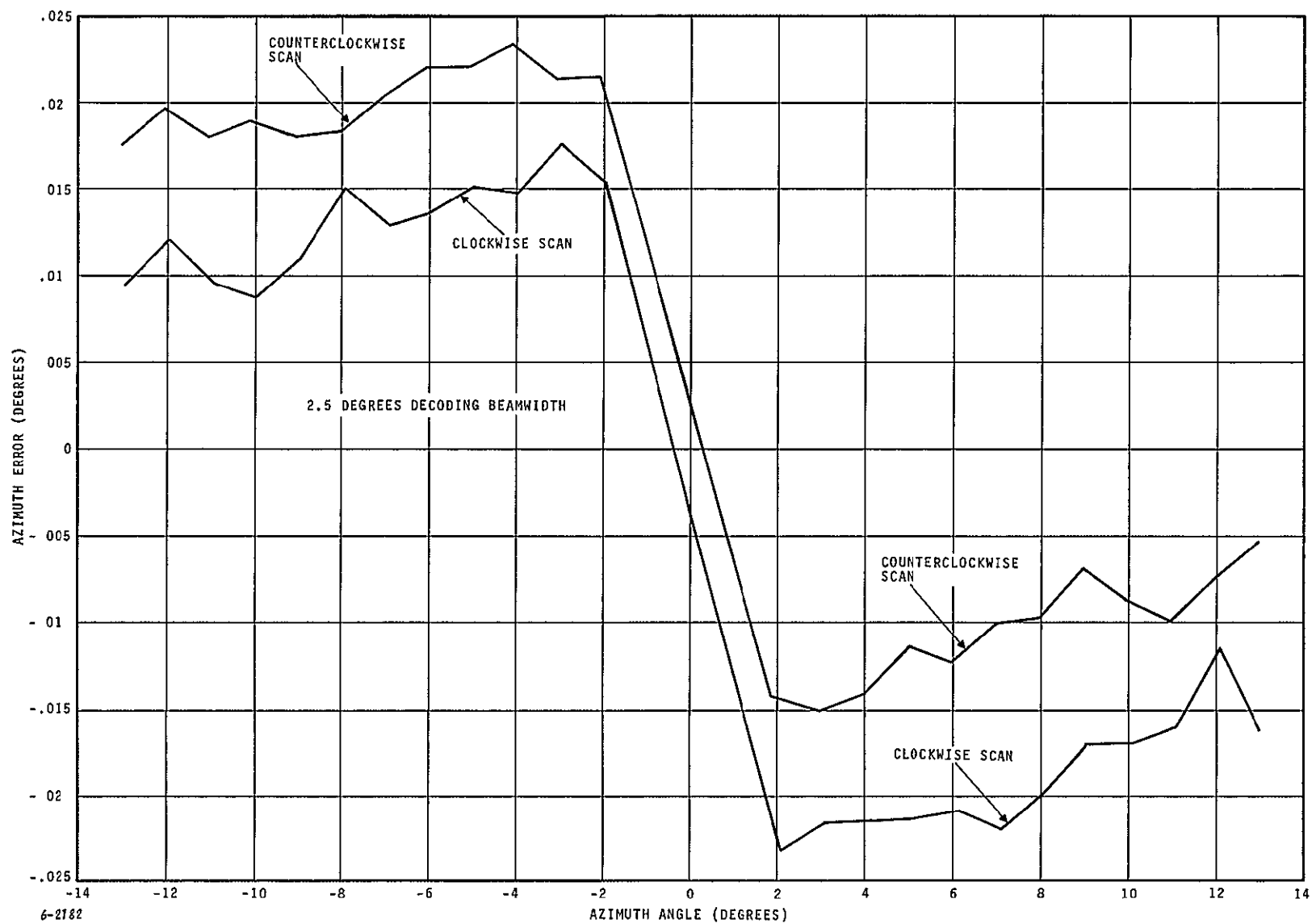


Figure 4-B8. Measured Azimuth Encoder Bias Error

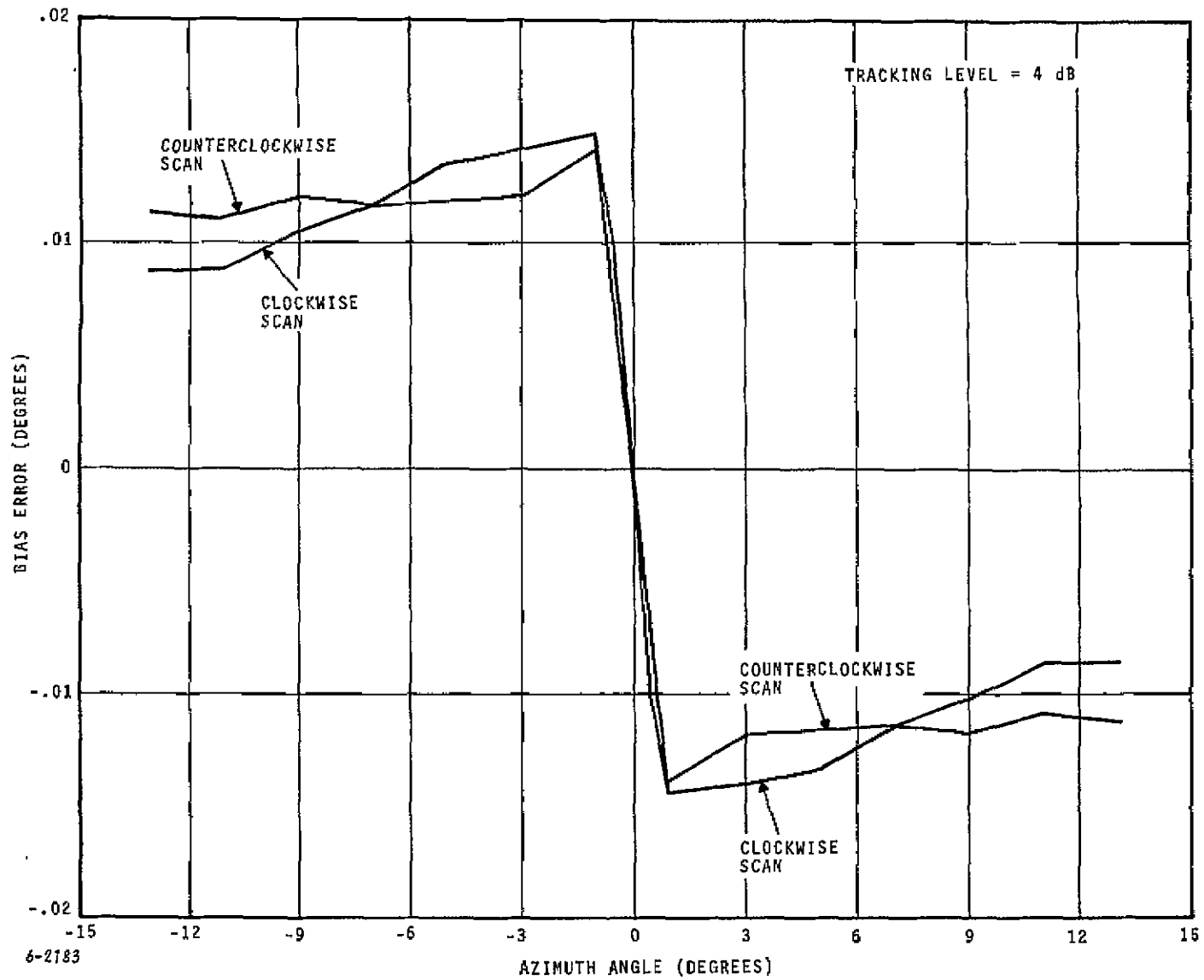


Figure 4-B9. Simulated Azimuth Bias Error

75 percent of the flight from separation to touchdown is inside the  $\pm 1$  degree sector. This bias cannot be boresighted out to occur in a nonoperational region as can be done with the elevation subsystem.

4-B13. FIRST ORDER ENCODER CORRECTION. A first order correction to the azimuth slope error can be mechanized within the encoding system. The correction can be set up such that best results are obtained at a nominal tracking level of 4 dB below beam peak. The correction requires each data spacing to be increased by approximately 0.03 microseconds in order to eliminate the slope error near 0 degree azimuth. Slope error in the 1 degree to 15-degree sector can be equalized by slightly changing the encoder clock frequency. Elevation slope error would also be equalized by a small frequency change.

Since the encoder is operating synchronously at a clock frequency of 4 MHz, there is no way to increase data spacing by anything other than one clock count, or  $0.25 \mu s$ . In order to realize a data spacing increase which is a fraction of this number, every  $n$ th data spacing can be increased by one clock count. This would average out to an effective increase of  $0.25/n \mu s$  per data spacing.

As an example, in order to equalize the slope error for elevation and in the 1-degree to 15-degree azimuth sector, a frequency change from 4 MHz to 4.0016 MHz is required. This new clock frequency would yield a zero angle spacing of  $59.976 \mu s$  instead of  $60 \mu s$ . A zero angle spacing of approximately  $60.03 \mu s$  is required to equalize the slope error in the  $\pm 1$ -degree azimuth sector. This implies that each data spacing must be increased by approximately  $0.054 \mu s$ . This is done by increasing every 5th data spacing ( $0.25/0.054 \approx 5$ ) by 1 clock count or  $0.25 \mu s$ . A simulation of azimuth bias error for a tracking level of 4 dB using the above correction (Figure 4-B10) shows that most azimuth encoder slope error has been eliminated.

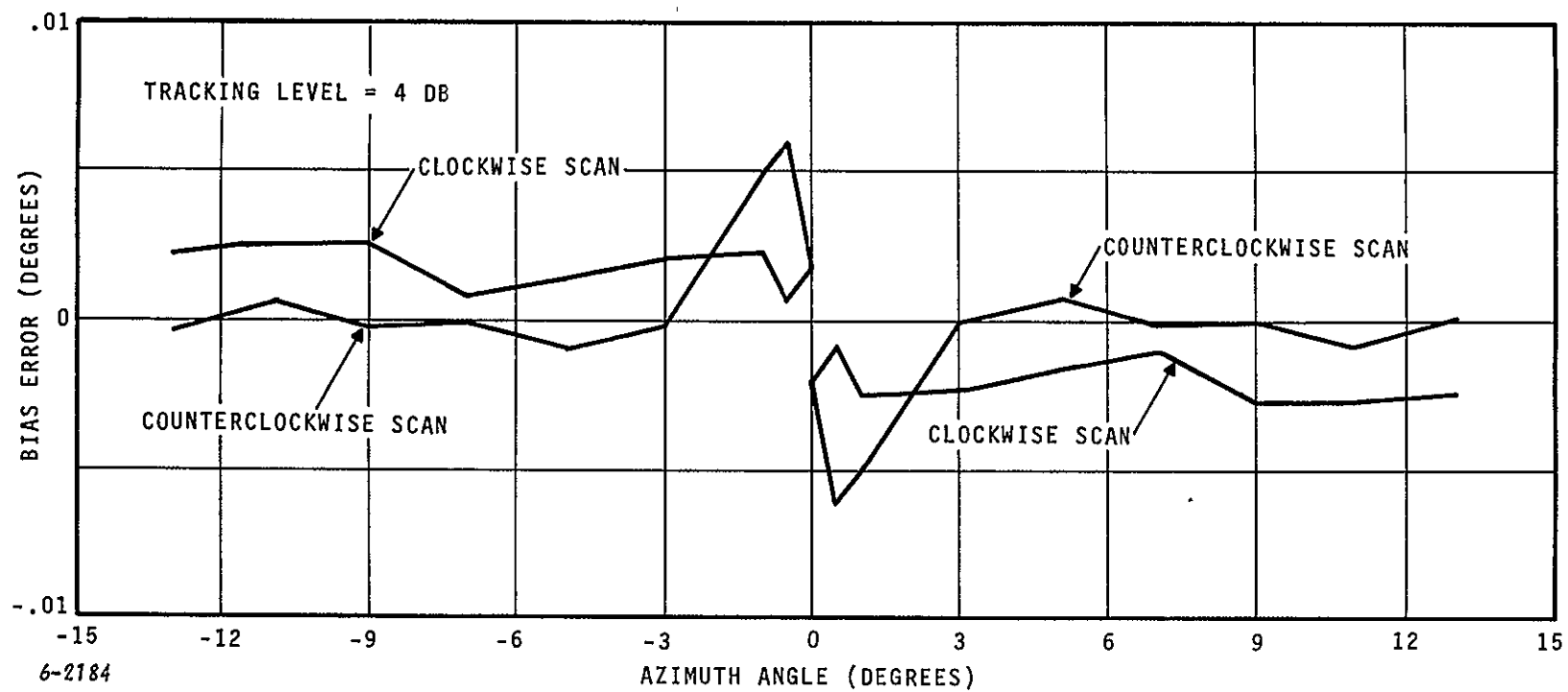


Figure 4-B10. Simulated Azimuth Bias Error, Modified Encoder

Tracking thresholds other than 4 dB will exhibit some slope error, but that will not manifest itself as a system bias. Due to AGC hunting, tracking level is fluctuating approximately  $\pm 1$  dB, so that the bias shift due to tracking level appears as a random noise component. Comparison of the relative shift of angle bias as a function of tracking level for the corrected approach versus an unmodified encoder, shows approximately the same shift in bias for a given change in tracking level.

Elevation slope error for the corrected encoder (Figure 4-B11) is very small (less than 0.002 degree) as compared to the 0.015 degree difference in bias between small and high elevation angles exhibited by the unmodified encoder.

Comparison of the random noise components for the unmodified versus corrected encoder showed no noticeable difference between the two.

4-B14. **HARDWARE IMPLEMENTATION OF ENCODER CORRECTION.** In order to implement the first order encoder correction, the present 8-MHz encoder clock must be changed to 8.0032 MHz. In addition, some artwork changes to the encoder board must be made, and some additional logic, which implements the data spacing increase every 5th pulse, must be included. The additional logic amounts to two integrated circuit packages.

The frequency change would have a minimal effect on timing functions (other than angle encoding) within the MSBLS-GS. The elevation identity spacing, for example, would change from  $12 \mu s$  to  $11.9952 \mu s$  ( $0.005 \mu s$  off). The airborne receiver will accept  $12 \pm 0.75 \mu s$ , so no problem exists there. Internal ground station alarms should not be affected by the frequency change.

A breadboard of the proposed encoder modification was built in order to test its feasibility. The modified encoder was plugged into the azimuth DVTU system and encoder accuracy measurements were performed. Figure 4-B12 shows the modified encoder bias error, measured separately for

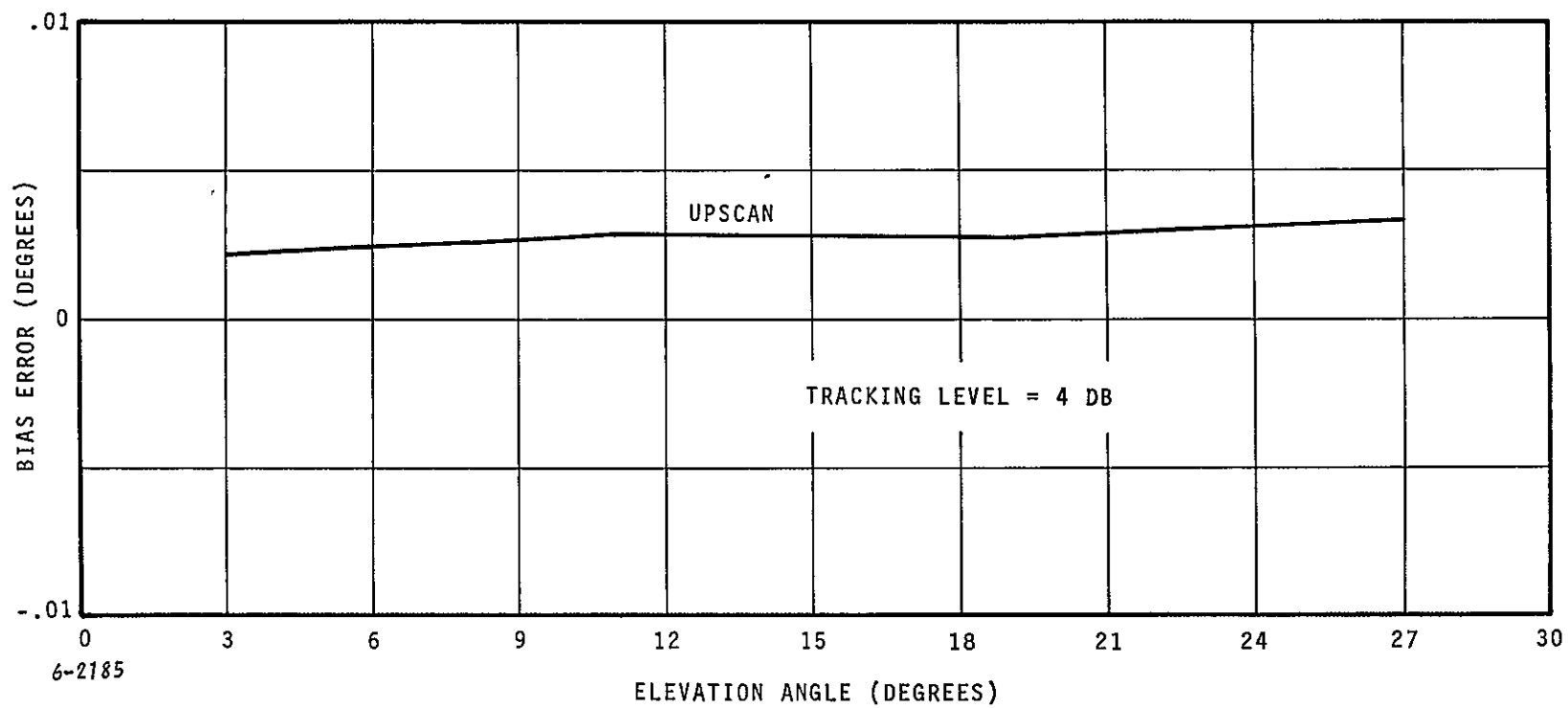


Figure 4-B11. Simulated Elevation Bias Error, Modified Encoder

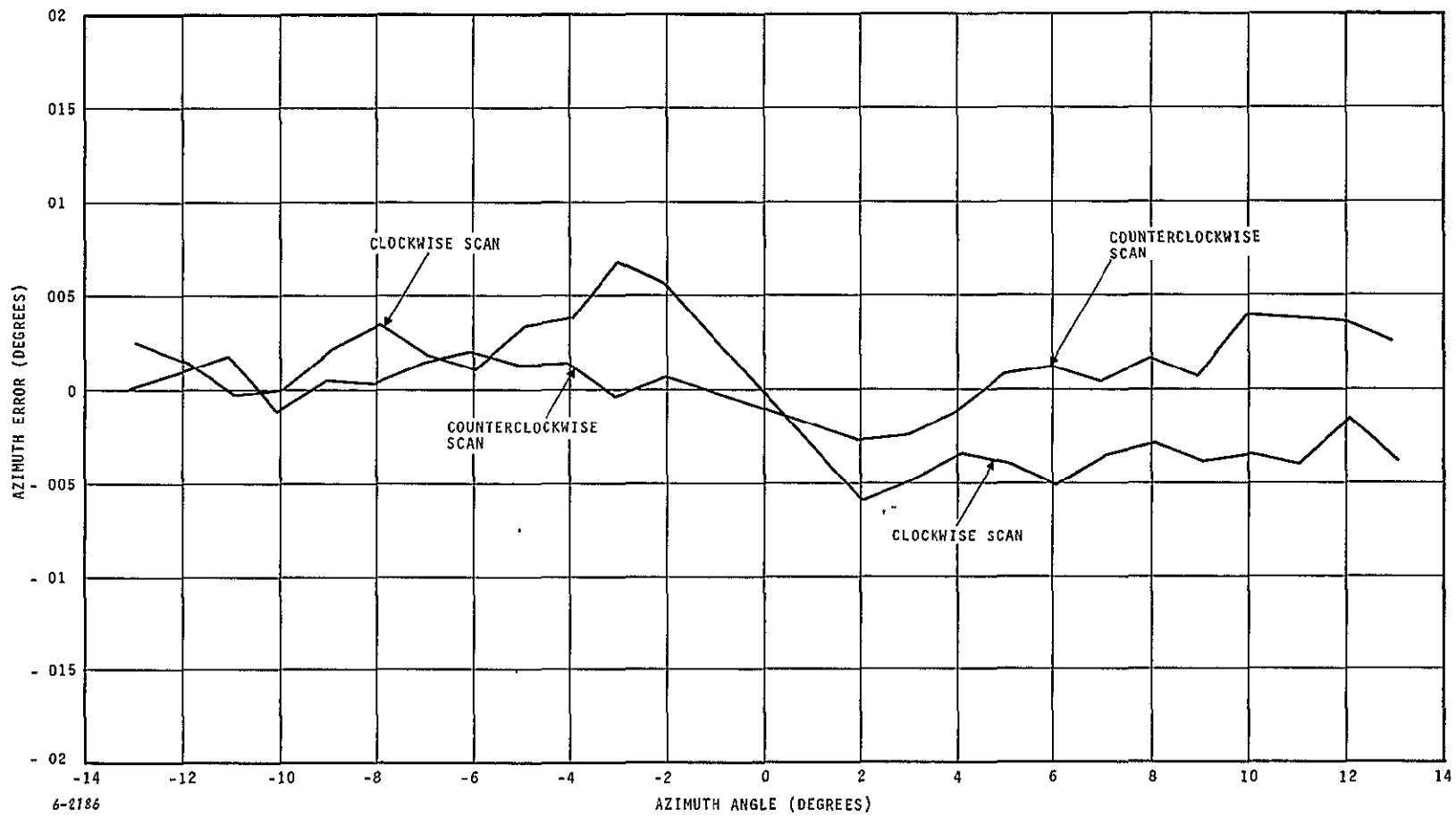


Figure 4-B12. Measured Modified Azimuth Encoder Bias Error (2.5-Degree Decoding Beam Width)

clockwise and counterclockwise scan. When compared to the unmodified encoder (Figure 4-B8), it is seen that most of the error due to beam pulse density imbalance has been compensated. The measurements were performed using a decoding beam width of 2.5 degrees. The actual operating beam width will be closer to 2.3 degrees. The narrower beam width will yield a slightly better compensation than the measurements of Figure 4-B12 indicate.

#### 4-B15. OTHER ENCODER ERROR PARAMETERS

Figures 4-B13 and 4-B14 show simulation results of the elevation and azimuth encoder 1-sigma random-noise components as a function of elevation and azimuth angle. These results are consistent with predicted encoder performance. Figures 4-B15 and 4-B16 show minimum and maximum error values recorded during these simulations.

#### 4-B16. ENCODER ANGULAR RESOLUTION

Resolution of the encoded angle is defined here as the smallest angular change which can be detected by a perfect decoding system.

In order to determine the encoder's resolution limits we have performed an encoder simulation at a given encoded angle, and computed the encoder bias error utilizing a perfect decoder. We then changed the encoded angle by 0.001 degree and recomputed the bias error. If the encoded angle could not be resolved to 0.001 degree, then the corresponding bias error would increase by 0.001 degree. If, on the other hand, the new angle could be resolved to 0.001 degree, the bias error would remain approximately constant.

A simulated demonstration of encoder resolution (Figures 4-B17 and 4-B18) shows the encoded angle resolution to be better than 0.001 degree. For the elevation encoder (Figure 4-B17), a change of 0.001 degree was always detected for an elevation angle of 5 to 5.02 degrees. The azimuth encoder performed somewhat worse (Figure 4-B18), but nevertheless was always able to resolve a 0.001 degree angle change for an azimuth angle of 3 to 3.02 degrees.

The MSBLS system resolution, therefore is expected to be approximately equal to the MSBLS Nav Set output data quantization of  $1/256$  (0.004) degree.

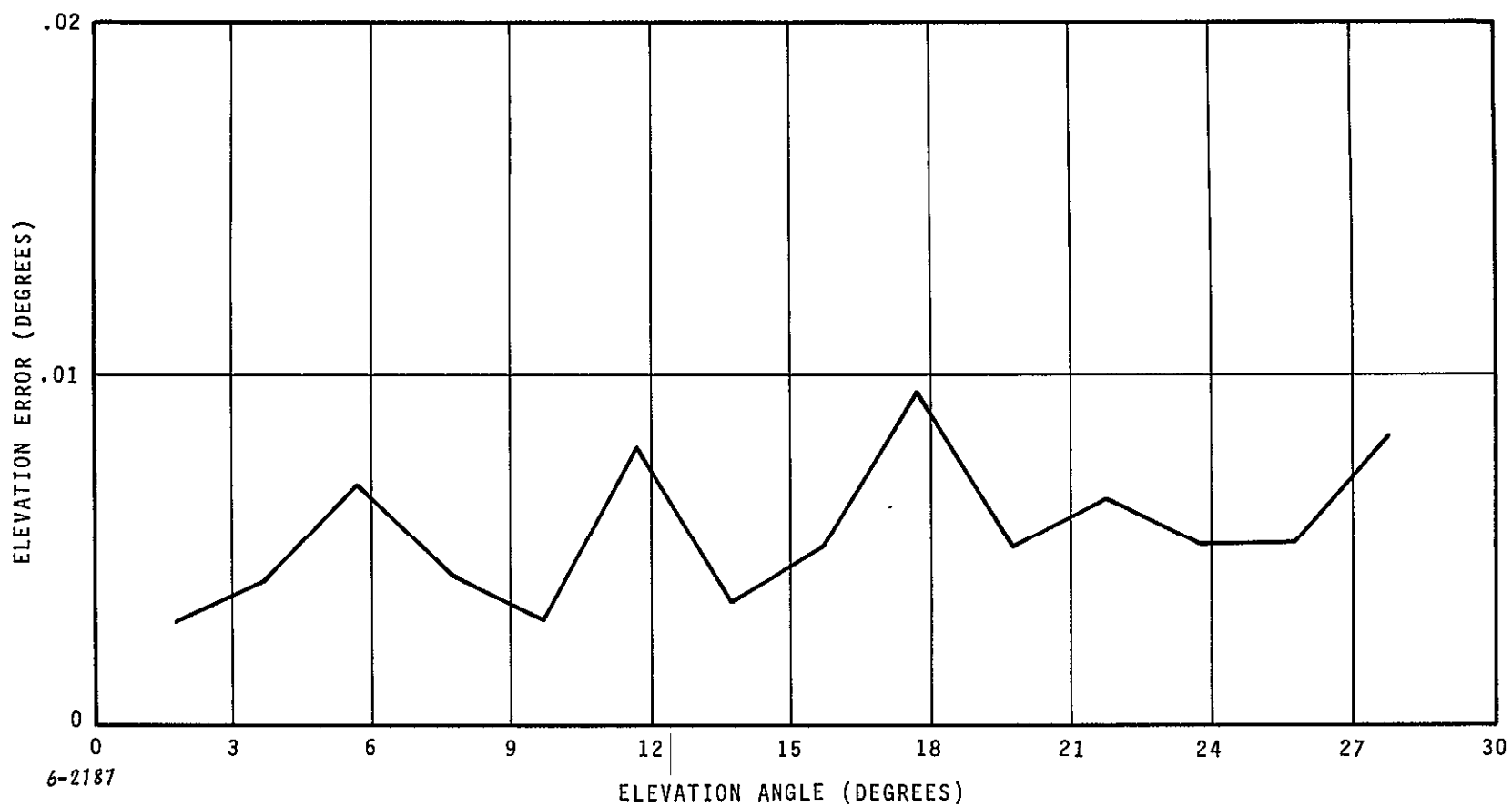


Figure 4-B13. Simulated Elevation Encoder ( $1\sigma$ ) Random Noise Error

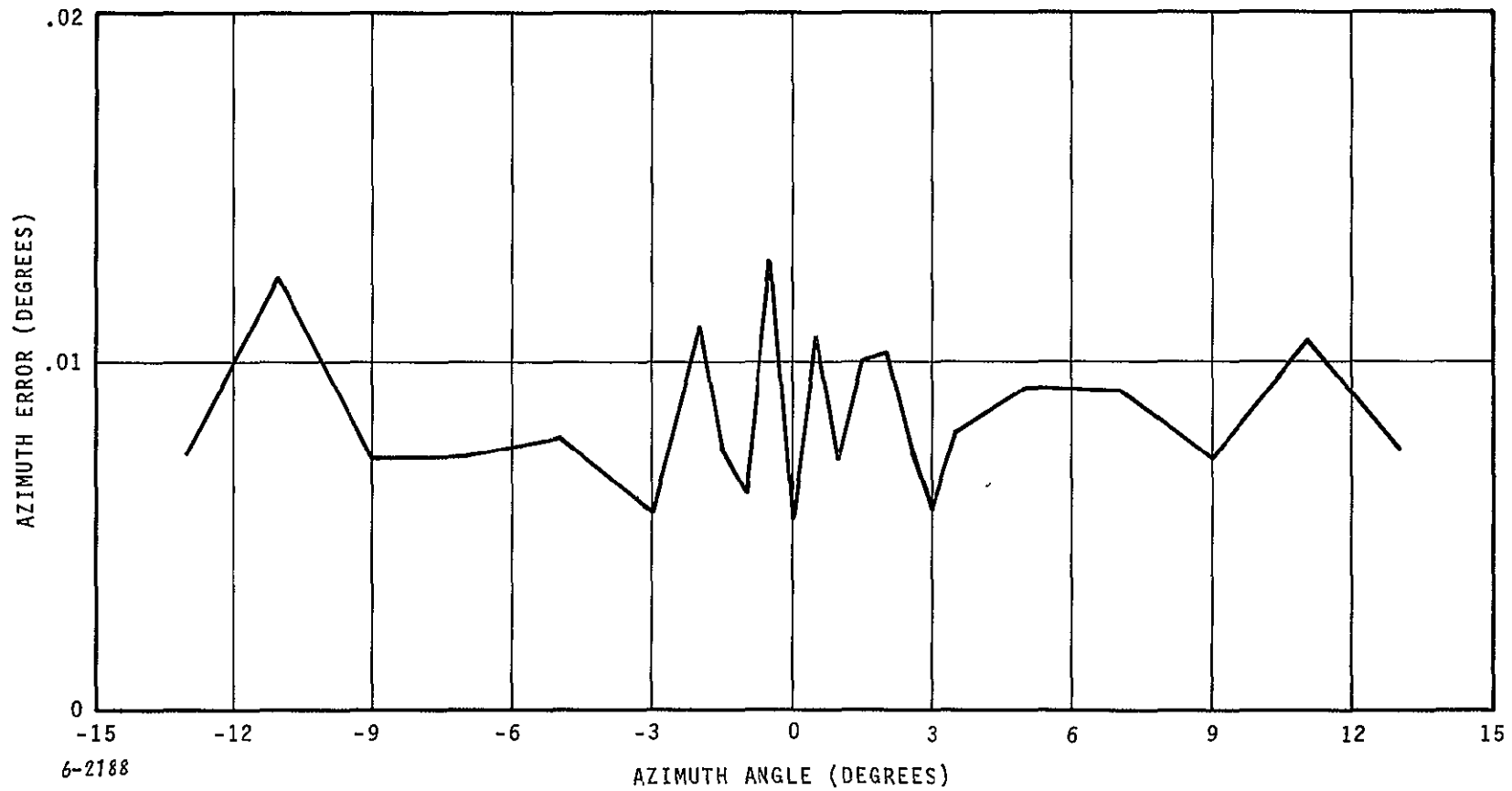


Figure 4-B14. Simulated Azimuth Encoder ( $1\sigma$ ) Random Noise Error

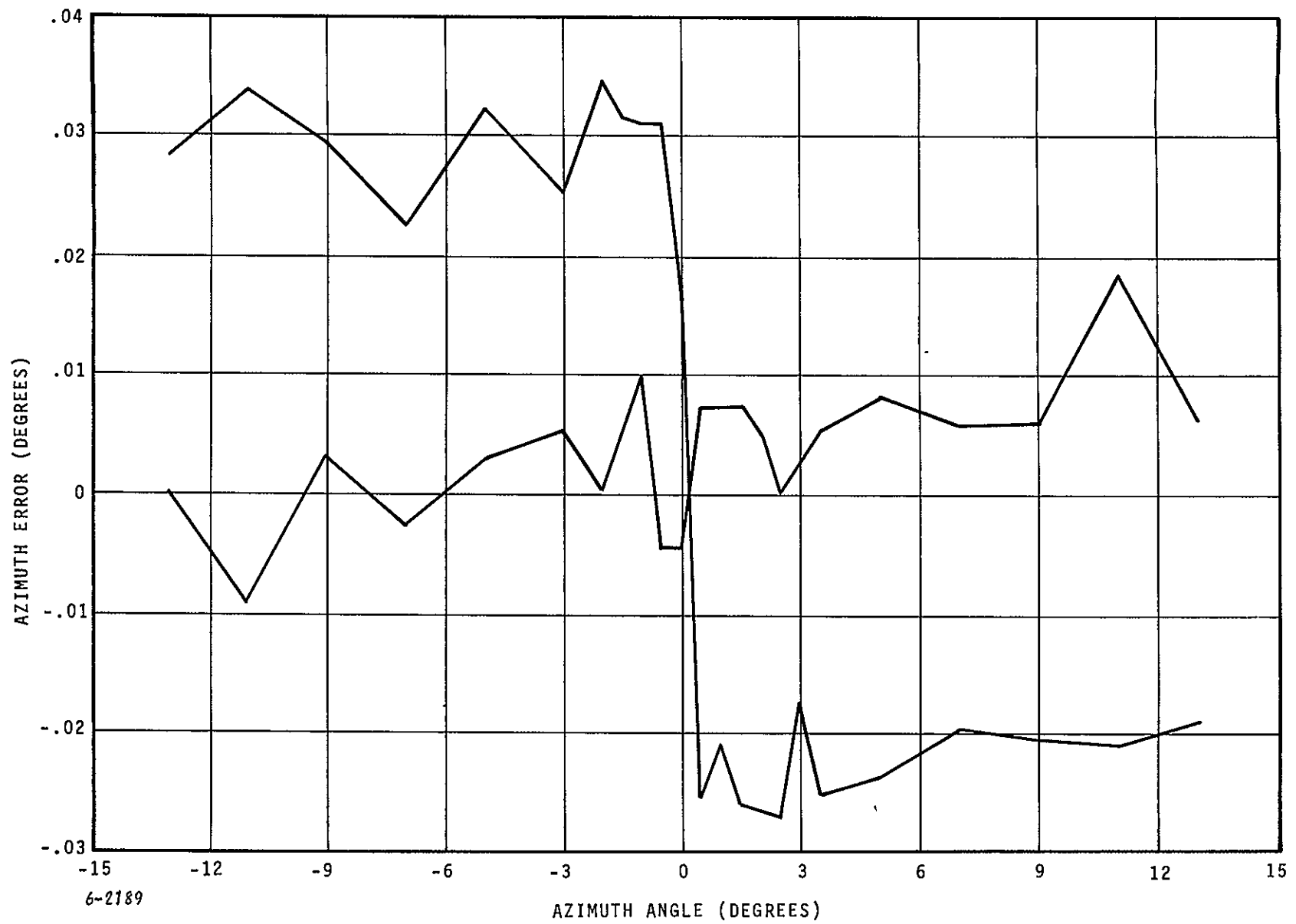


Figure 4-B15. Simulated Azimuth Encoder-Minimum/Maximum Error Values

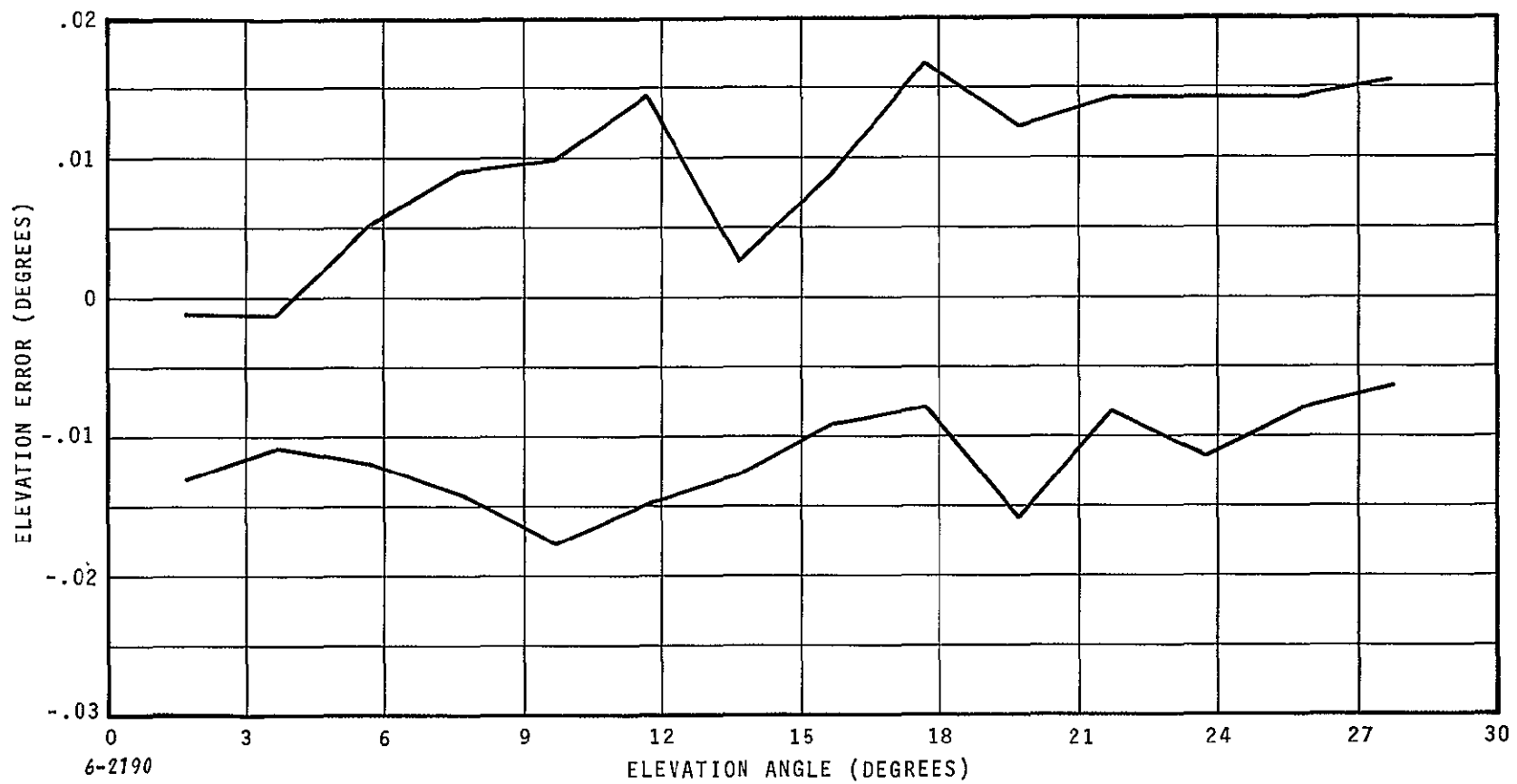


Figure 4-B16. Simulated Elevation Encoder Minimum/Maximum Error Values

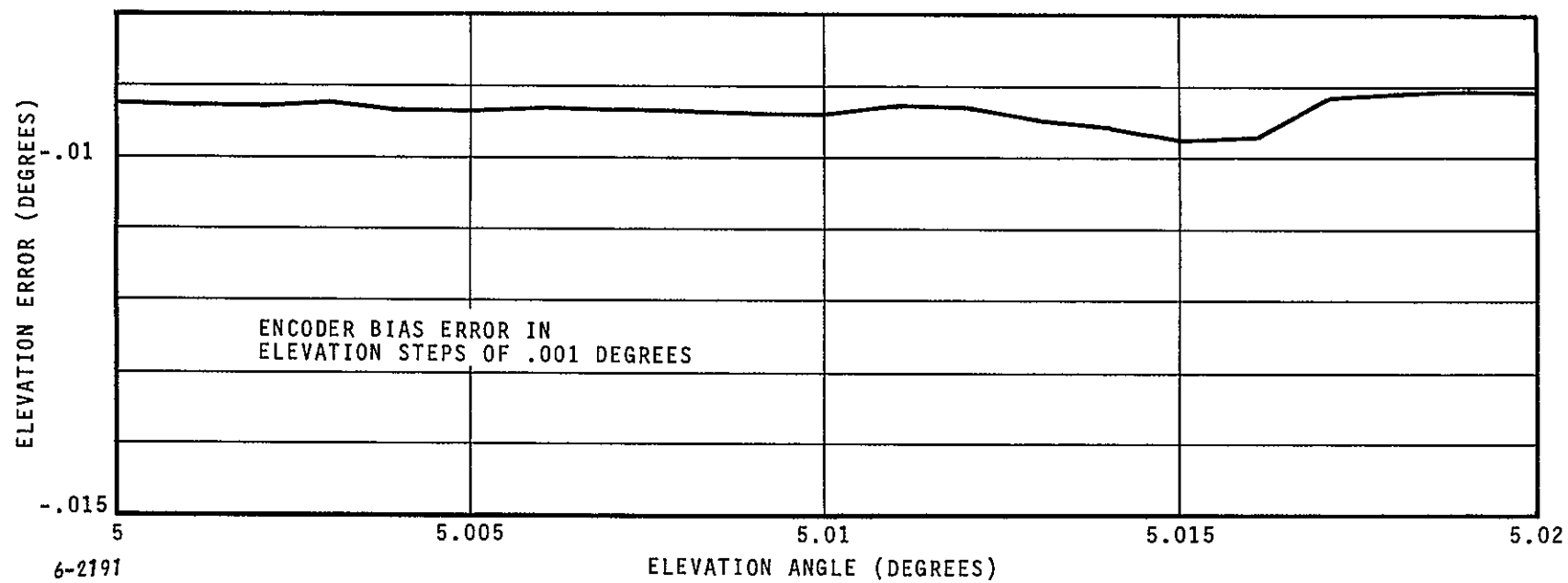


Figure B-17. Simulated Demonstration of Elevation Encoder Resolution

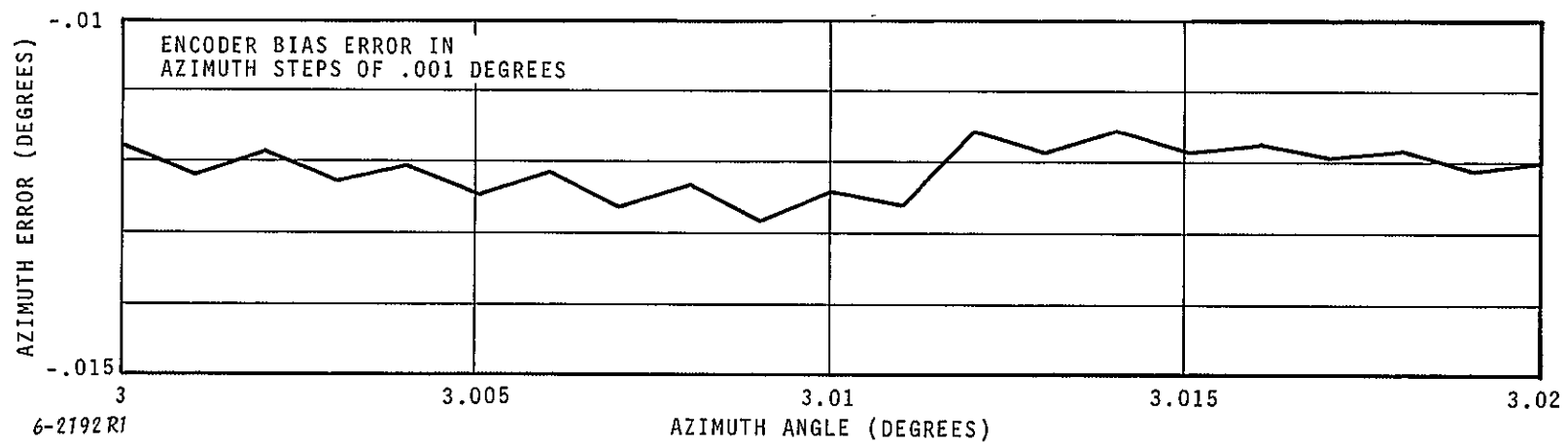


Figure 4-B18. Simulated Demonstration of Azimuth Encoder Resolution

#### 4-B17. SUMMARY AND RECOMMENDATIONS

Elevation measurement and simulation of the DVTU encoder bias error showed a slope bias of approximately 0.015 degree, which was not accounted for in the analytic error model. This error was found to originate from the nonlinearity of the elevation antenna angular velocity. The analytic error model assumed the velocity to be constant during a beam dwell time.

There was no evidence of upscan/downscan hysteresis in the measured and simulated data. Simulation of worst-case ADP asymmetry showed little apparent effect on the encoded data.

Azimuth encoder bias measurements and simulations showed the predicted error due to beam pulse density imbalance. This error is present throughout the whole azimuth coverage sector and is worst in the  $\pm 1$ -degree operational region.

A first order encoder correction was mechanized as an attempt to minimize this source of error. A modified encoder was built and tested within the azimuth DVTU system. Test results showed that most of the azimuth bias error was neutralized.

Measurements using the modified encoder in the elevation DVTU system were not performed, but simulation results also showed the elevation slope bias error to be neutralized by the encoder modification.

Simulation of other encoder error parameters, such as random noise error and minimum/maximum error values, conformed approximately to the analytic error model.

Simulations were also performed to determine the encoder's angular resolution limits. The angular resolution of both the azimuth and elevation encoder was found to be better than 0.001 degree. System resolution, therefore, is primarily determined by the Nav Set's output data quantization of 0.004 degree.

#### 4-B18. RECOMMENDATIONS

It is recommended that the analytic error model for the elevation subsystem be updated to take into account the slope bias error uncovered during this investigation.

It is further recommended that an evaluation of azimuth DVTU accuracy data be performed in order to decide whether the encoder modification ought to be incorporated into the baseline MSBLS-GS equipment. The evaluation should compare measured azimuth DVTU accuracy data to the 0.05-degree 1 sigma system error specification, bearing in mind that some accuracy degradation is expected when measurements are made under dynamic (flight) conditions.

#### 4-B19. REFERENCES

- a. Microwave Scanning Beam Landing System Ground Station Technical Specification, AIL No. 00752-502498.
- b. Navigation Set, Microwave Scan Beam Landing System MC409-0017 Rev C.
- c. Angle Data Pickoff Specification, AIL No. 00752-502030.

PART C

MEASUREMENT OF ADP ACCURACY

P. ANZALONE

TECHNICAL REPORT Y220-16

FINAL

MARCH 1977

#### 4-C1. INTRODUCTION

The MSBLS ground system transmits coded angular information to the airborne MSBLS Nav Set through the scanning azimuth and elevation antennas. The transmitter beam from each antenna contains the present pointing angle of the transmitting antenna. The MSBLS Nav Set, by intercepting this scanning beam, can then determine its relative angle (or position) to the ground centerline or horizon.

Encoding of the transmitter beam on the ground is accomplished by an angle data pickoff (ADP) and the encoder circuitry. The ADP is an opto-mechanical device that incrementally measures the mechanical pointing angle of the transmitting antenna. These incremental angular signals from the ADP are then processed by the ground encoder circuitry. The encoder circuitry calculates the absolute pointing angle of the antenna and provides the required signals to the transmitter to encode the transmitted beam.

The purpose of this report is to determine the sources (and magnitude) of errors that affect ADP accuracy and how they relate to the accuracy of the MSBLS system.

#### 4-C2. BACKGROUND

The ADP unit is contained in a sealed cylindrical case with a hollow drive shaft mounted through the center. A coupler on one end of the hollow shaft connects the ADP to the antenna drive shaft. The ADP outer case is rigidly mounted to the scanner frame by means of an L bracket. Internally, the ADP consists of a slotted disk mounted on the rotatable center shaft. An LED light source below the disk illuminates a photo cell above the disk through slots in the disk. Since the light source and photo cell are attached to the stationary center case, and the disk is attached to the rotatable center shaft, the ADP output signals are directly related to the disk slot pattern and the angular position of the center shaft. Four separate channels with outputs are provided as listed below.

4-C3. ANGLE INCREMENT PULSE (AIP). The AIP output is a square wave signal with each leading and trailing edge occurring every  $1/8$  degree of shaft rotation. These pulses are counted to calculate the angular displacement of the center shaft from a nominal center point.

4-C4. CENTER SCAN PULSE. The center scan pulse is generated whenever the shaft is at the nominal center point.

4-C5. SCAN SECTOR. The scan sector signal is active (high) whenever the center shaft is within  $\pm 15$  degrees of the center point.

4-C6. SCAN LIMIT. The scan limit signal is active (high) whenever the center shaft rotation is greater than 42 degrees (23 degrees for elevation) from the center point.

#### 4-C7. DIRECTION

The direction signal indicates the direction (CW or CCW) of rotation of the center shaft.

All outputs are provided as differential signals by thresholding and buffering circuits in the ADP, except the direction signal which is single ended. The center point of the scan is marked on the ADP outer case and its relative position to the shaft can be checked by rotating the outer case in its support bracket. Since each ADP contains both an azimuth and elevation sector on the disk, the selection of a particular sector can be accomplished by rotating the ADP outer case to the appropriate sector center line.

#### 4-C8. ACCURACY AND MEASUREMENT

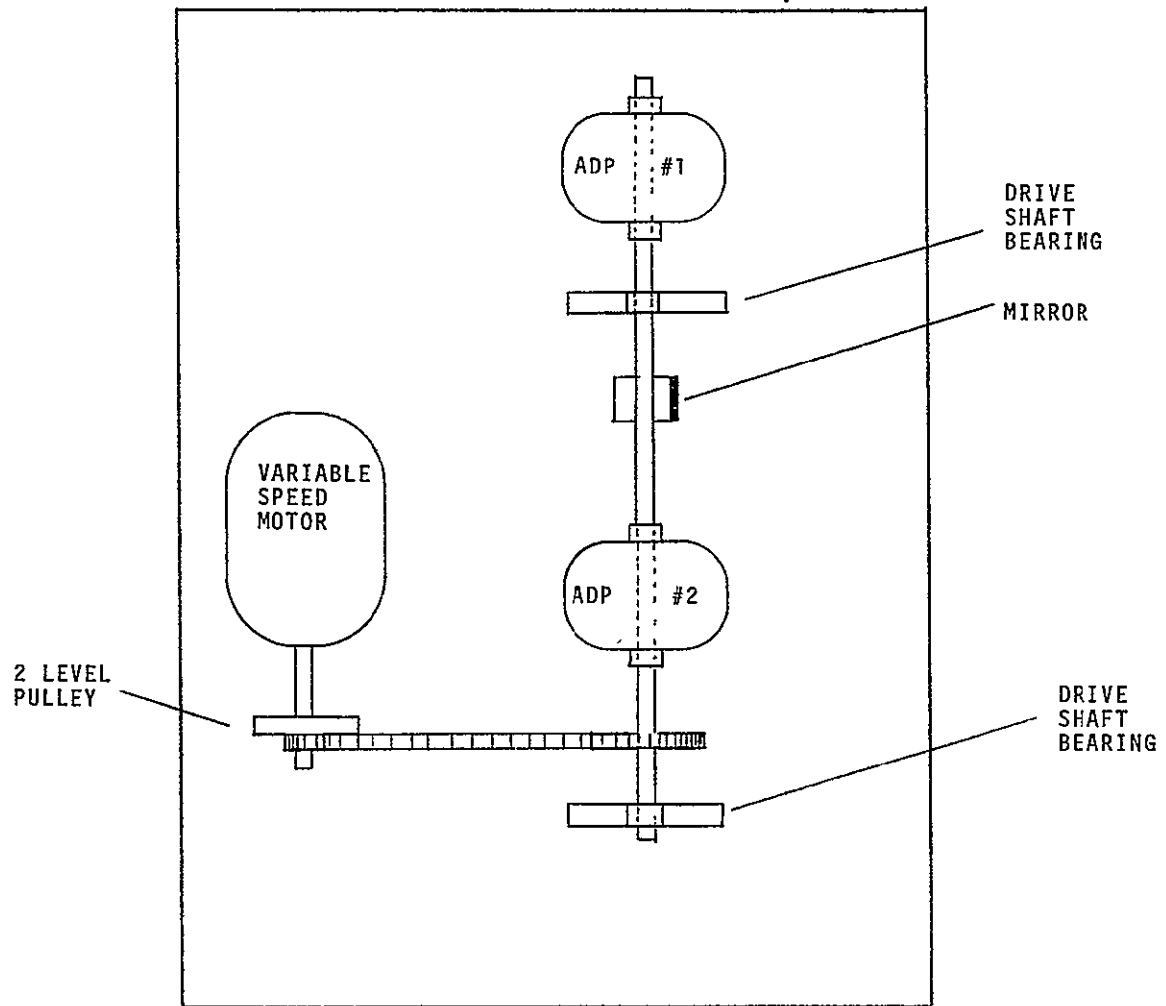
Since the MSBLS encoder circuitry counts only the AIP pulses to determine the antenna pointing angle, the remaining ADP output signals do not affect the angle accuracy. Hence, only the accuracy of the AIP signal will be investigated in this report.

In order to investigate the accuracy of the ADP, a test fixture as shown in Figure 4-C1 will be utilized. The test fixture will contain two ADP units driven by a common, variable-speed motor. Preliminary MSBLS boresighting data tends to indicate that the azimuth AIP pulses may have a cumulative error that exceeds the specified maximum ( $\pm 0.02$  degree). This tends to be reinforced by flight data taken at DFRC. The azimuth data has been observed to contain an angle dependent error (slope error). By using the azimuth sector of one ADP and the elevation sector of the remaining ADP, a comparison between the AIP signals from the two sectors can be made.

In addition, the test fixture will also be utilized to test the absolute accuracy of the ADP as shown in Figure 4-C2. In order to measure the ADP accuracy, a means of accurately determining the drive shaft position is required. This will be accomplished by using a collimated laser light beam reflected by a small mirror mounted on the ADP drive shaft. The positions of the reflected beam can be determined visually and by means of a photocell detector mounted approximately 50 feet from the ADP. The mirror (drive shaft) angle can be easily calculated by measuring the angle between the laser source and the reflected beam. A theodolite will be used for measuring the resulting angles. The 50 foot moment arm will provide sufficient accuracy to determine the ADP shaft position. By comparing the shaft position to the AIP output signal, both static and dynamic error sources can be measured and evaluated.

The expected primary source of static error is caused by imperfections in the internal disk pattern of the ADP. A secondary source of error might be internal optical misalignment in the ADP. The static error for both sectors of the ADP will be measured.

Dynamic AIP accuracy will also be measured to investigate their sources and magnitudes. The variable speed motor will allow us to determine if there is any correlation between AIP accuracy and rotational speed. Hysteresis, acceleration, and power supply voltage variations shall also be measured to determine their effect on AIP accuracy.



1-1173

Figure 4-C1. ADP Test Fixture

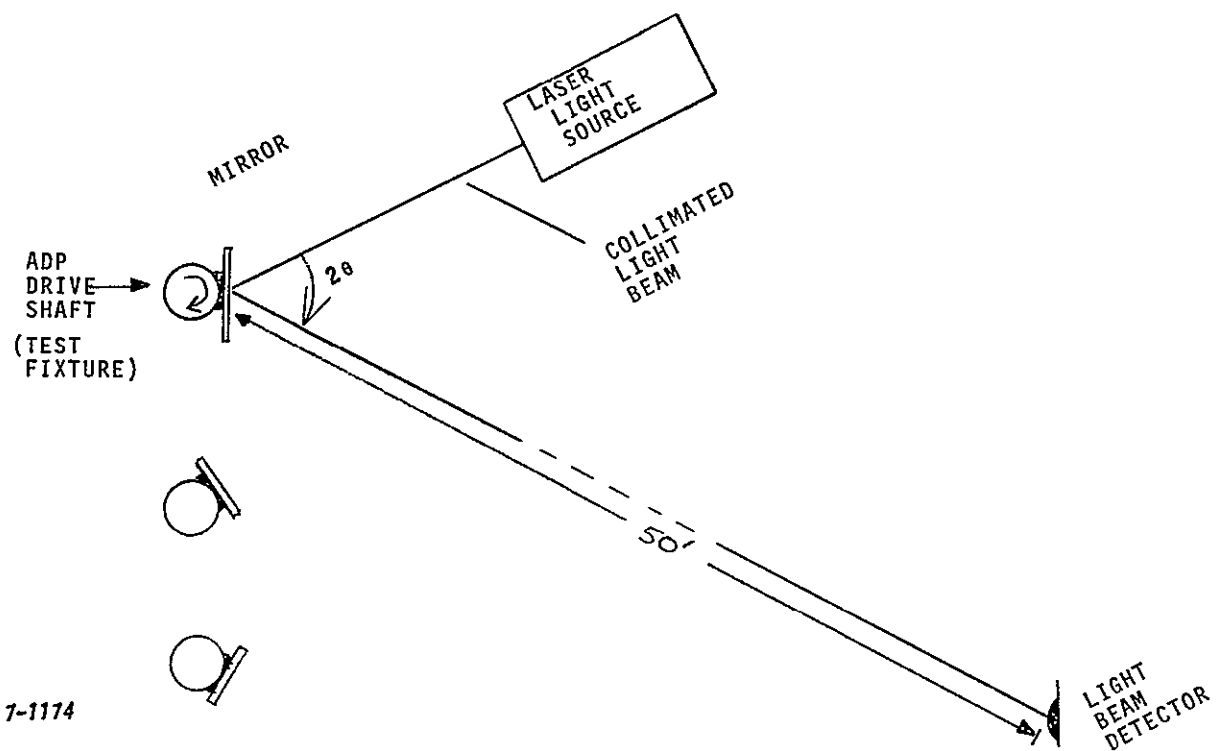


Figure 4-C2. ADP Accuracy Measurement

#### 4-C9. TEST RESULTS

The ADP test fixture, as illustrated in Figure 4-C1, was fabricated and utilized in the tests described below. The two ADP's tested were removed from the MSBLS DVTU for this test. A 4 milliwatt helium-neon laser with a collimating lens was utilized as a light source.

Observing the AIP pulses from both AIP's on an oscilloscope, revealed no sources of error. AIP pulses from both the azimuth and elevation sectors were compared. The maximum angular difference was found to be  $\pm 0.005$  degree within either sector. Neither rotational speed, nor direction had any effect on this observation. Varying the power supply voltage over the specified operating range of the ADP also resulted in no significant change.

The following tests were performed to dynamically measure the shaft position of the ADP. The laser, photo cell, and theodolite were utilized to optically measure the position of a mirror mounted on the ADP shaft. A correction factor was added to the observed angles to compensate for the thickness of the shaft mirror. The correction was approximated by the following formula:

$$\gamma = \sin^{-1} \left( \frac{D \sin (2\theta)}{\cos (\theta) \text{ Range}} \right) / 2$$

Where

D = thickness of the mirror (13/16 inches)

$\theta$  = measured angle between photocell and laser

Range = distance from mirror to photocell

$\gamma$  = shaft correction

The first test was performed to investigate the relationship between shaft rotational speed and ADP output data. Two runs were performed over a wide range of speeds as shown in Table 4-C1. The data as plotted in Figures 4-C3 and 4-C4 reveal that the ADP output is insensitive to changes in rotational speed. In actual use, the speed variation for the active (transmitting) elevation sector is only  $\pm 50$  degrees/second with a maximum speed of 350 degrees/second. Similarly, the azimuth sector experiences a variation of  $\pm 70$  degrees/second with a maximum speed of 700 degrees/second.

The second test that was performed was to determine the actual angle of the shaft at various points within the sector. Since an accurate centerline point was not available, all angles were measured with respect to the laser. The mirror correction factor is included in the data presented in Tables 4-C2, 4-C3, and 4-C4.

Figures 4-C5, 4-C6, and 4-C7 graphically illustrate the error in the AIP increments as measured by the laser technique described previously. The ADP performance is well within the  $\pm 0.02$  degree specification. This confirms the oscilloscope observations made previously utilizing the two AIP's.

Figures 4-C8 and 4-C9 show the absolute error between the ADP output data and the shaft position. Separate tests were performed for the azimuth and elevation sectors. As shown, the maximum error does not exceed  $\pm 0.006$  degree for either sector, well within the overall  $\pm 0.02$  degree specification.

#### 4-C10. SUMMARY AND RECOMMENDATIONS

The ADP performed as specified in AIL Specification 502030. We can conclude from the data observed that the ADP is not the source of the slope error seen in the DFRC flight data.

A similar test should be performed to investigate the azimuth drive assembly and antenna as a possible source of this error.

4-C11. REFERENCES

- a. MSBLS Angle Data Pickoff Detail Specification (AIL No. 502030).

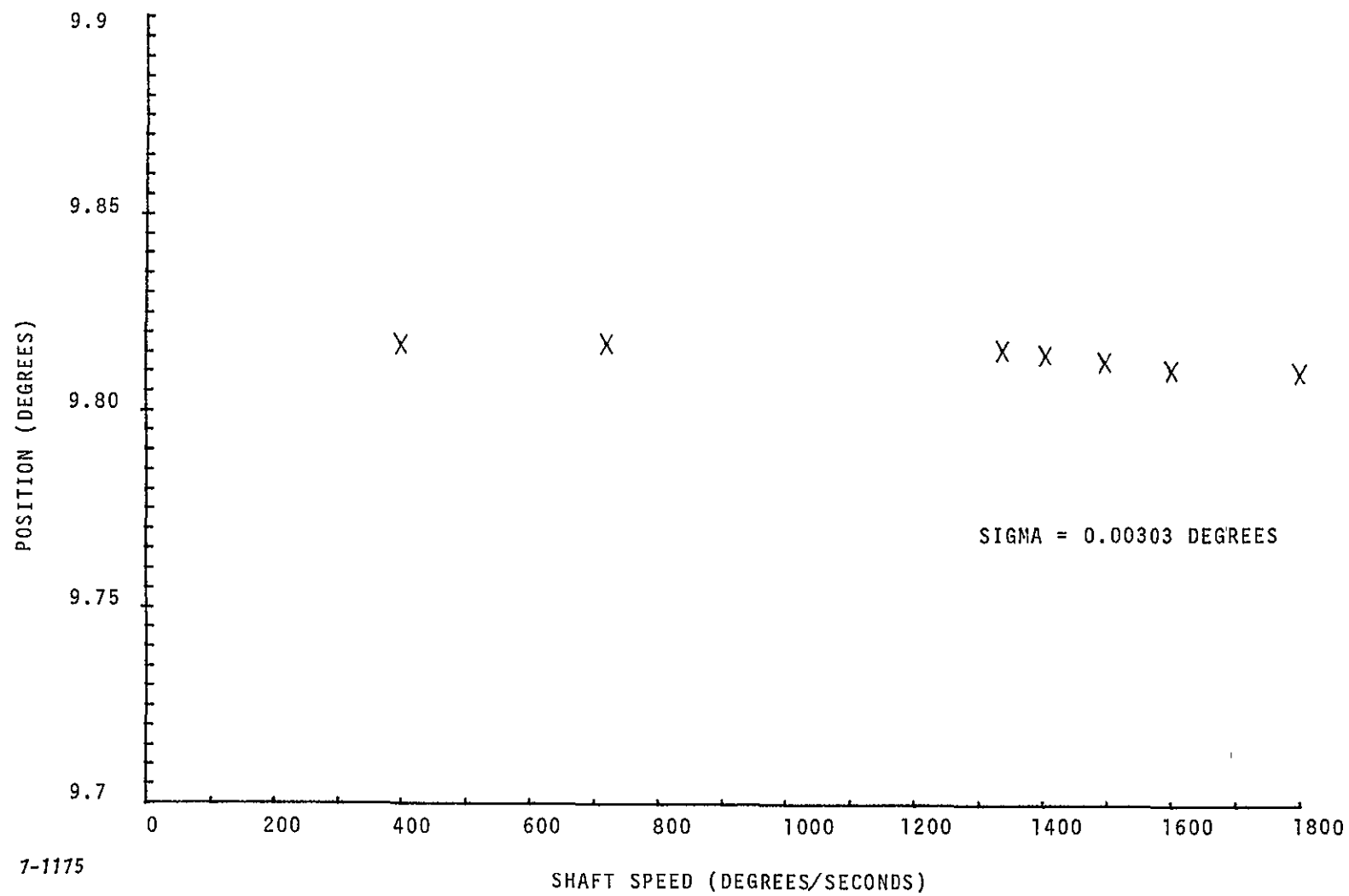
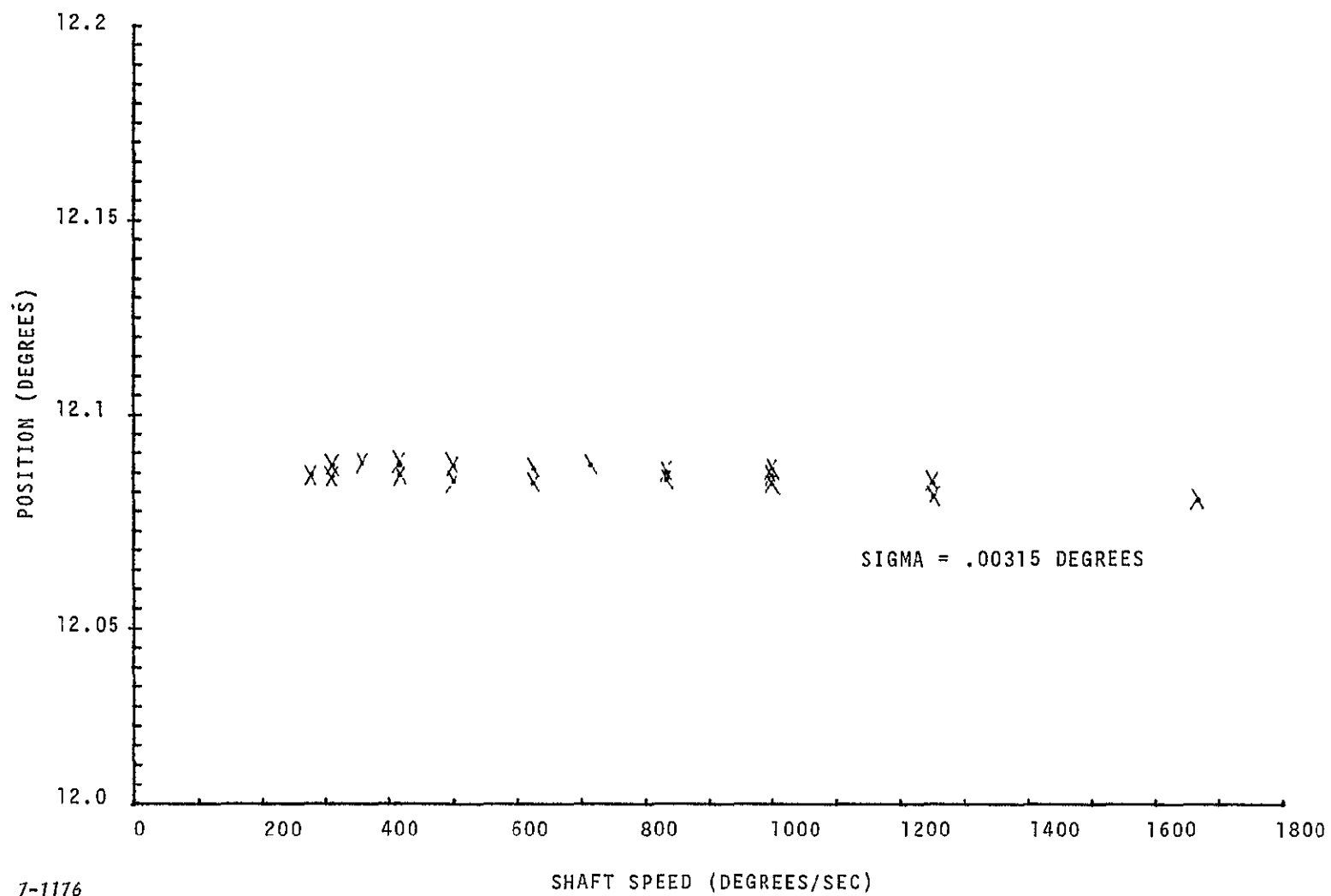


Figure 4-C3. Position Versus Speed, Run No. 1



7-1176

Figure 4-C4. Position Versus Speed, Run No. 2

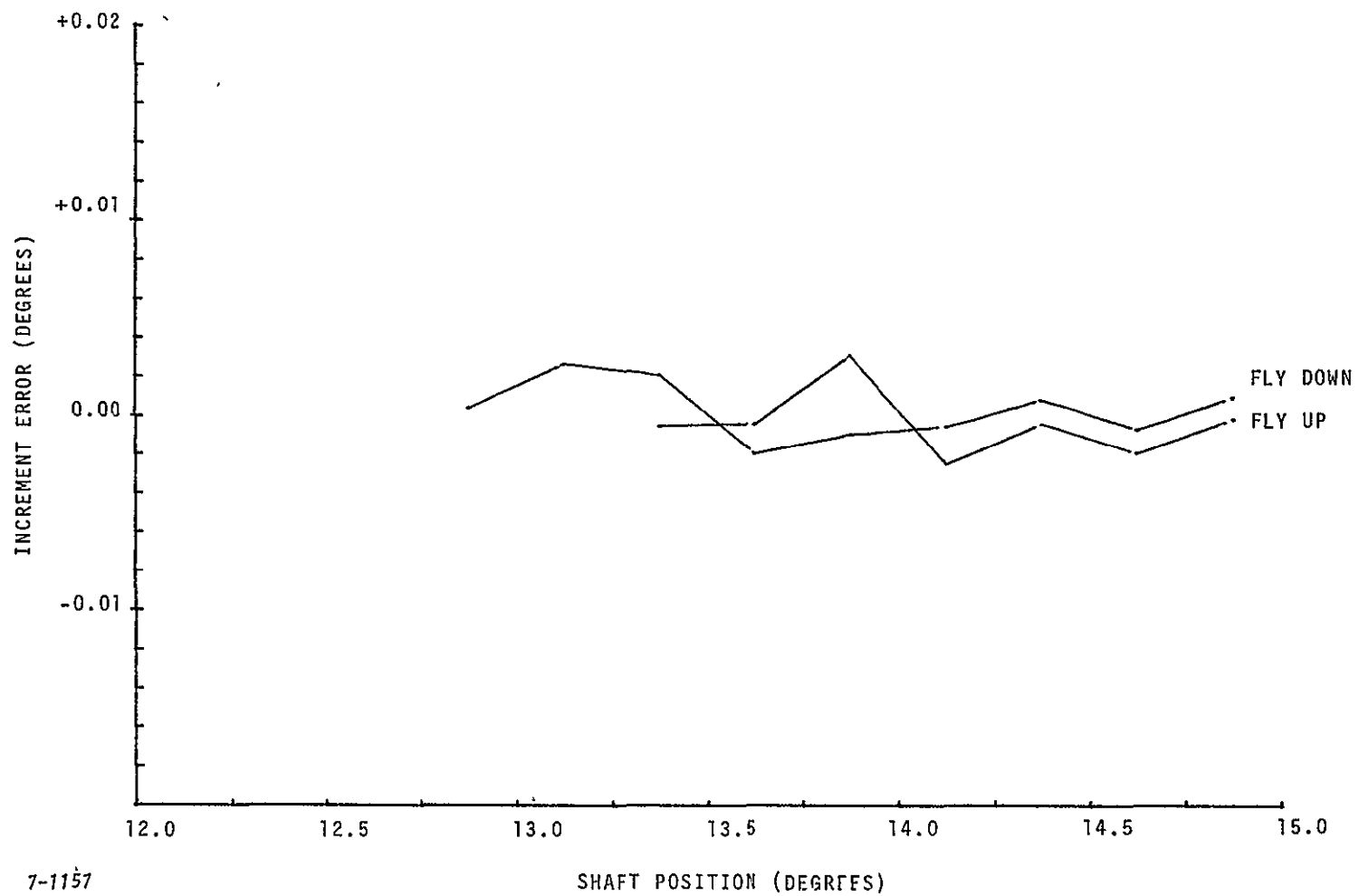


Figure 4-C5. Increment Error Versus Position, Elevation

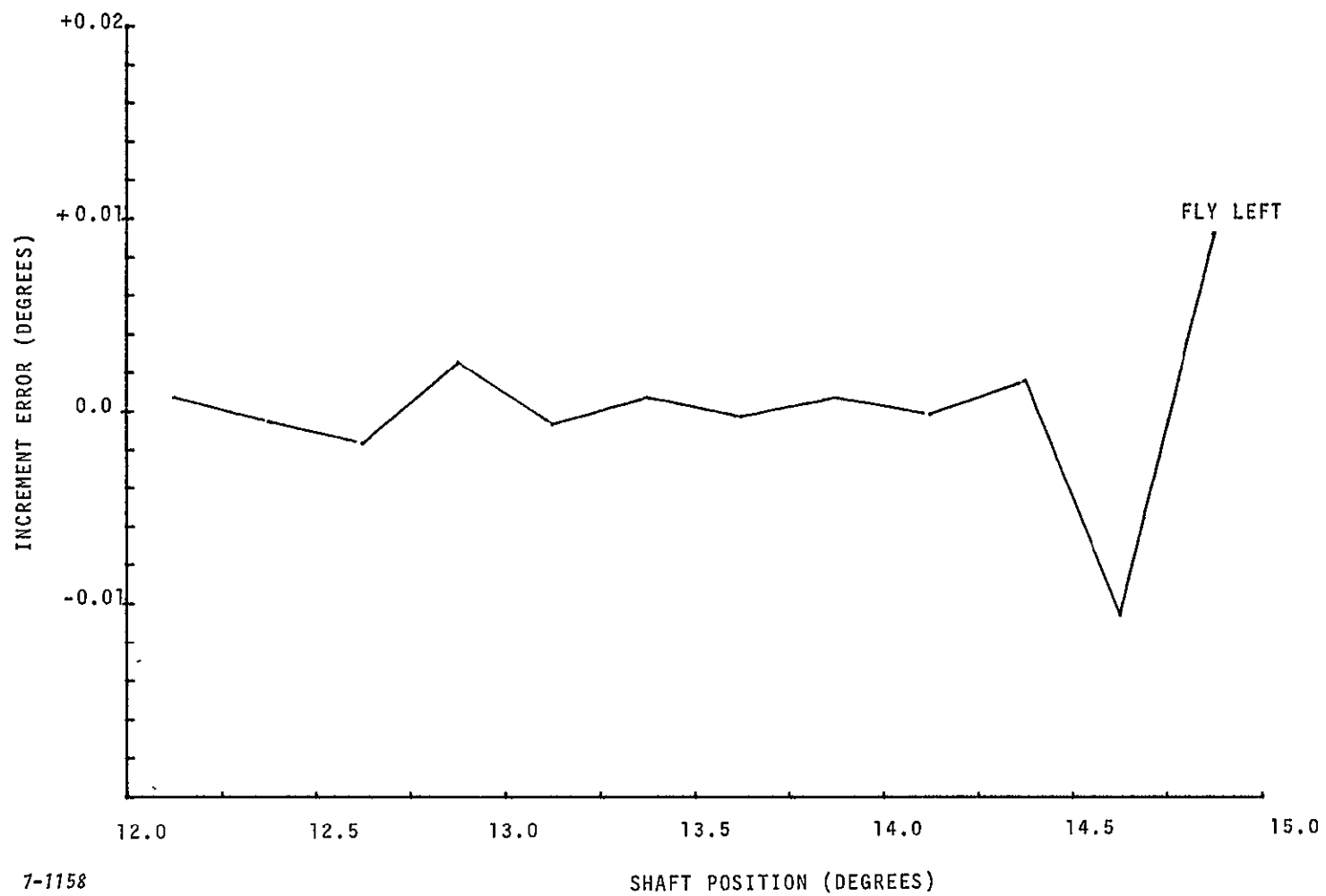


Figure 4-C6. Increment Error Versus Position, Azimuth, Run No. 1

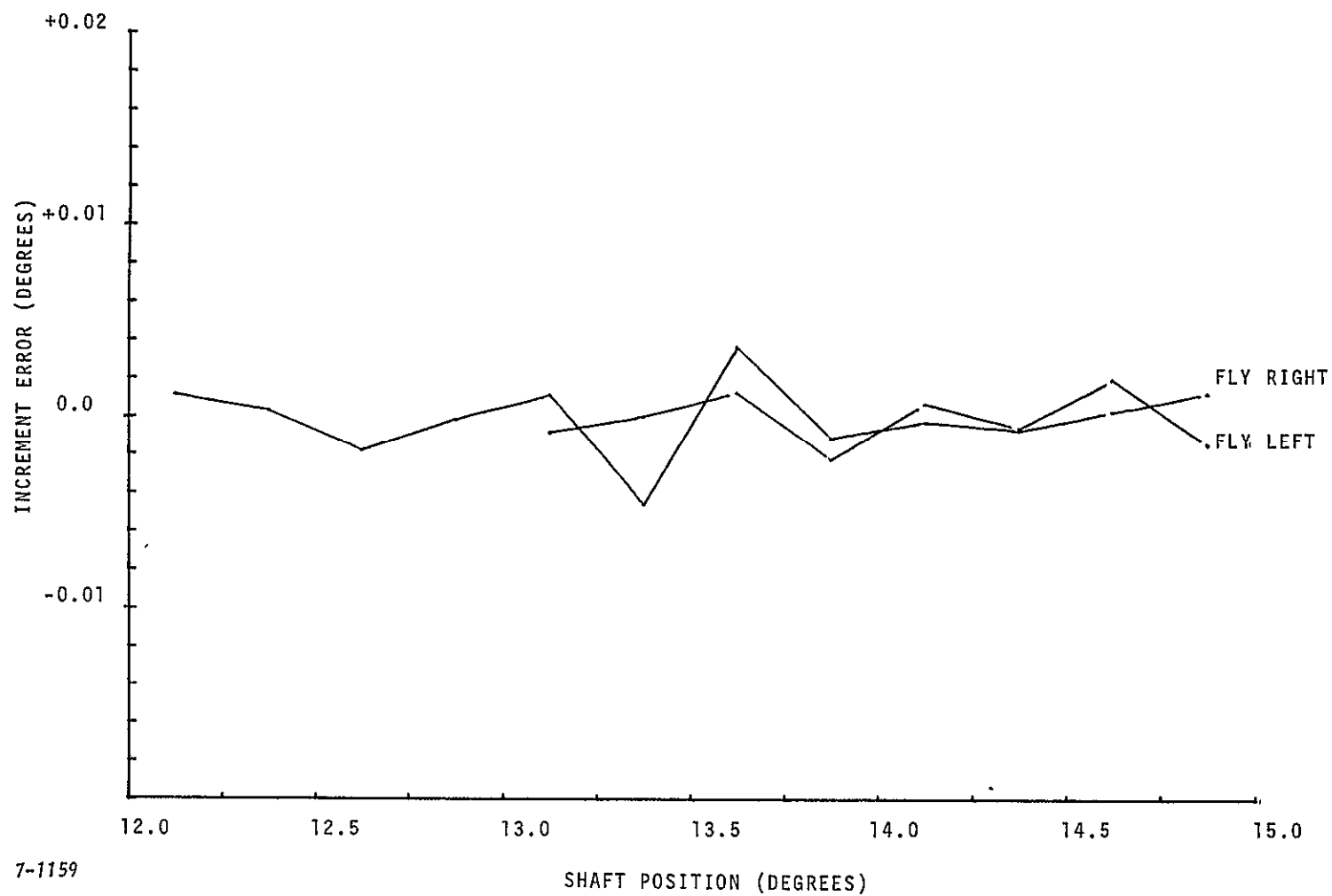


Figure 4-C7. Increment Error Versus Position, Azimuth, Run No. 2

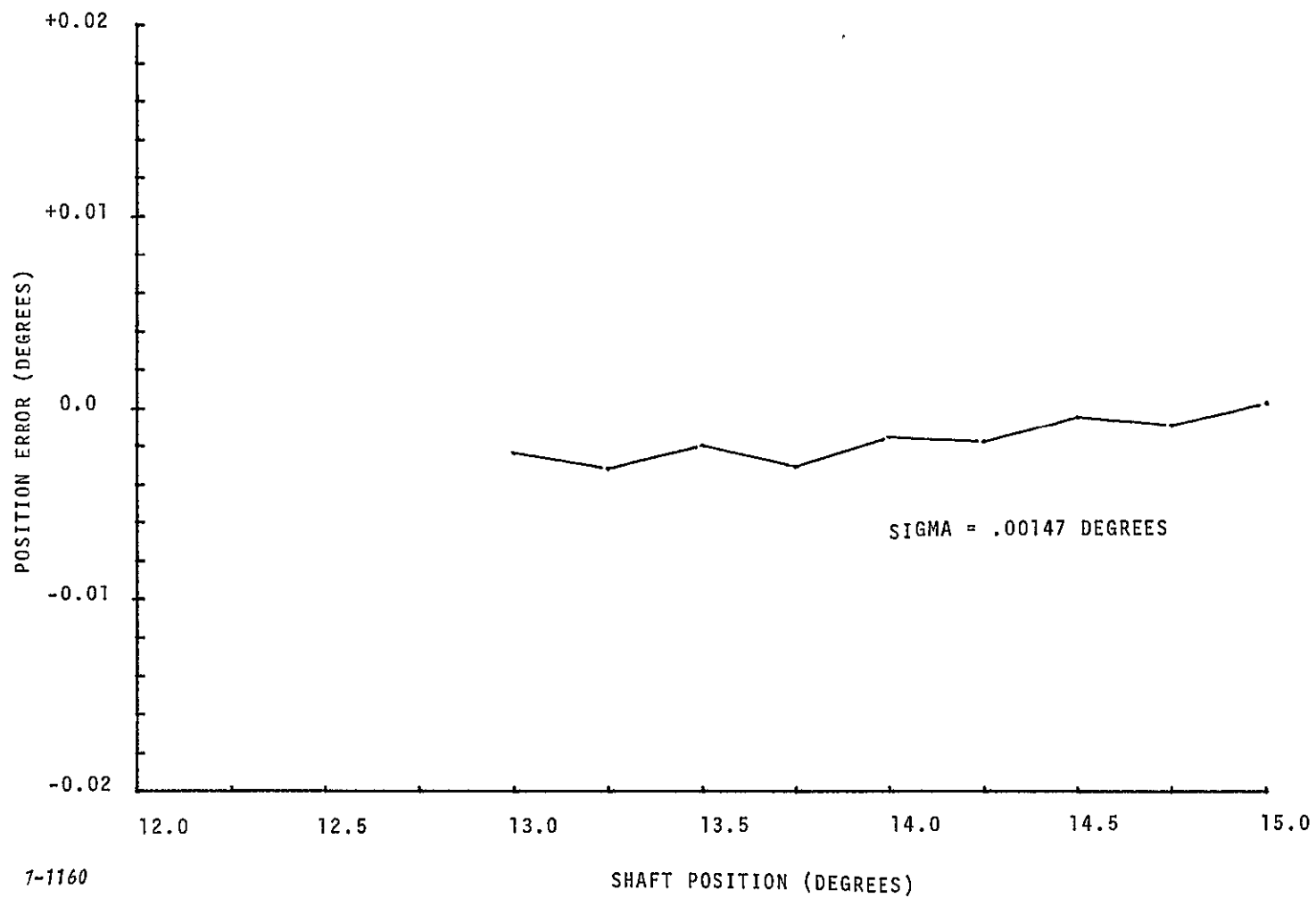


FIGURE 8

Figure 4-C8. Position Error Versus Position, Elevation

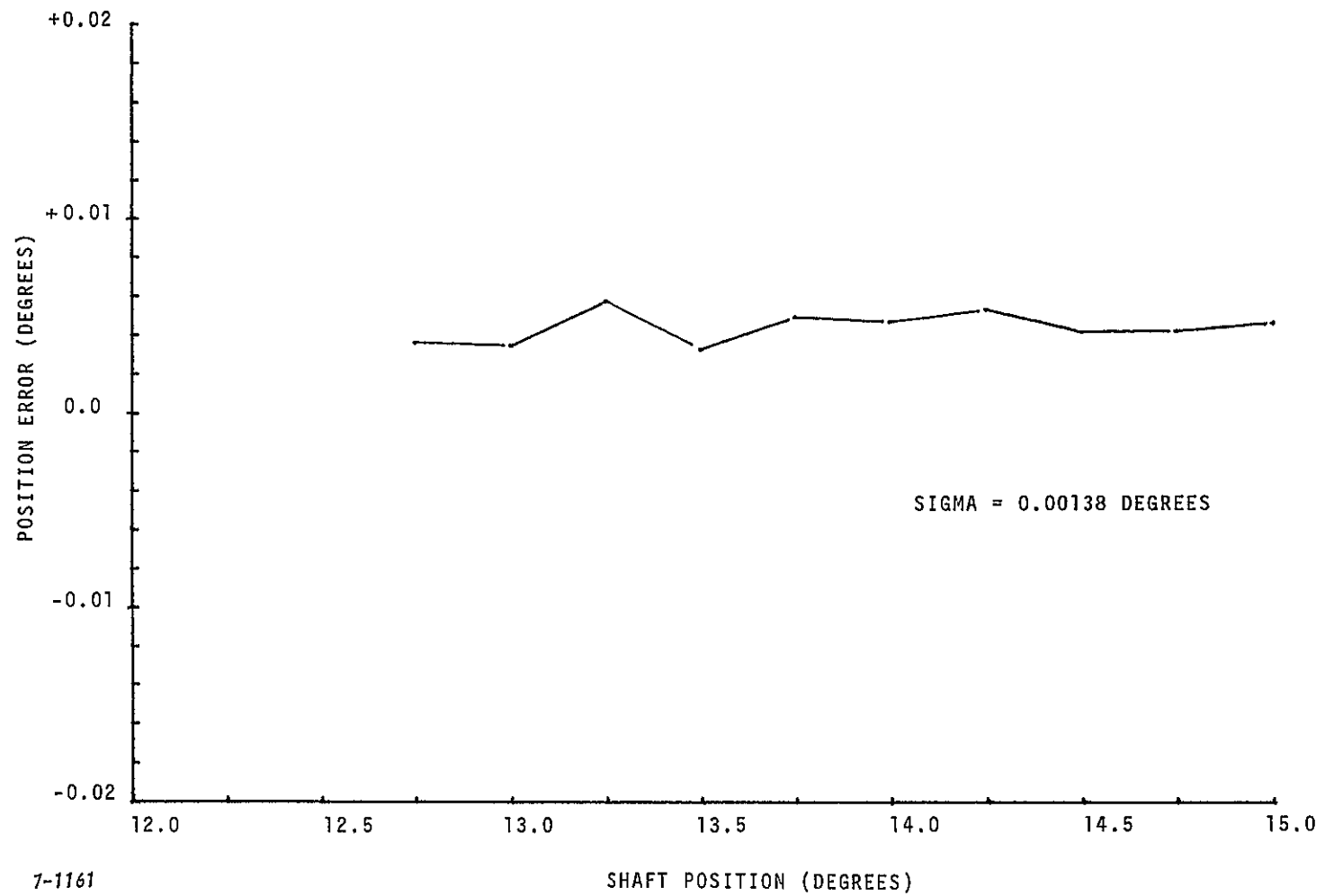


Figure 4-C9. Position Error Versus Position, Azimuth

Table 4-C1. Velocity Tests

| <u>Velocity Test 1</u>           |                                               |    |    |                                         |
|----------------------------------|-----------------------------------------------|----|----|-----------------------------------------|
| <u>Speed</u><br><u>(Deg/Sec)</u> | <u>Observed Angle</u><br><u>(Deg-Min-Sec)</u> |    |    | <u>Angle Offset</u><br><u>(Degrees)</u> |
| 1798                             | 53                                            | 21 | 14 | 9.81000257                              |
| 1600                             | 53                                            | 21 | 20 | 9.810837368                             |
| 1497                             | 53                                            | 21 | 35 | 9.812924359                             |
| 1404                             | 53                                            | 21 | 48 | 9.814733085                             |
| 1336                             | 53                                            | 21 | 59 | 9.816263545                             |
| 720                              | 53                                            | 22 | 07 | 9.817376607                             |
| 400                              | 53                                            | 22 | 07 | 9.817376607                             |

| Velocity Test 2             |                                              |    |    |                                    |
|-----------------------------|----------------------------------------------|----|----|------------------------------------|
| Speed<br>( <u>Deg/Sec</u> ) | Theodolite Reading<br>( <u>Deg/Min-Sec</u> ) |    |    | Offset Angle<br>( <u>Degrees</u> ) |
| 277                         | 57                                           | 53 | 42 | 12.08453018                        |
| 416                         | 57                                           | 53 | 42 | 12.08453018                        |
| 833                         | 57                                           | 53 | 34 | 12.08341713                        |
| 1250                        | 57                                           | 53 | 03 | 12.07910407                        |
| 1666                        | 57                                           | 52 | 56 | 12.07813016                        |
| 2500                        | 57                                           | 52 | 37 | 12.07548667                        |
| 1000                        | 57                                           | 53 | 53 | 12.08606062                        |
| 416                         | 57                                           | 53 | 58 | 12.08675627                        |
| 833                         | 57                                           | 53 | 48 | 12.08536496                        |
| 416                         | 57                                           | 54 | 03 | 12.08745193                        |
| 1000                        | 57                                           | 53 | 42 | 12.08453018                        |
| 312                         | 57                                           | 53 | 40 | 12.08425192                        |
| 500                         | 57                                           | 53 | 32 | 12.08313887                        |
| 1000                        | 57                                           | 53 | 26 | 12.08230408                        |
| 625                         | 57                                           | 53 | 27 | 12.08244321                        |
| 500                         | 57                                           | 53 | 59 | 12.0868954                         |
| 1250                        | 57                                           | 53 | 29 | 12.08272148                        |
| 312                         | 57                                           | 53 | 59 | 12.08689540                        |
| 833                         | 57                                           | 53 | 45 | 12.08494757                        |
| 357                         | 57                                           | 54 | 03 | 12.08745193                        |
| 625                         | 57                                           | 53 | 54 | 12.08619975                        |
| 714                         | 57                                           | 54 | 0  | 12.08703453                        |

Laser Location: 33° 46' 7"

Table 4-C2. Elevation Position Test

| <u>ADP Angle<br/>(Degrees)</u> | <u>Observed Angle<br/>(Deg-Min-Sec)</u> |    |    | <u>Angle Offset<br/>(Degrees)</u> |
|--------------------------------|-----------------------------------------|----|----|-----------------------------------|
| 15.0                           | 359                                     | 56 | 27 | 16.94359022                       |
| 14.75                          | 0                                       | 26 | 16 | 16.69469                          |
| 14.5                           | 0                                       | 56 | 20 | 16.44371                          |
| 14.25                          | 1                                       | 26 | 12 | 16.19439                          |
| 14.0                           | 1                                       | 56 | 15 | 15.943550                         |
| 13.75                          | 2                                       | 26 | 08 | 15.694095                         |
| 13.5                           | 2                                       | 55 | 58 | 15.44505                          |
| 13.25                          | 3                                       | 25 | 41 | 15.19699                          |
| 13.0                           | 3                                       | 55 | 53 | 14.94489                          |
| 12.75                          | 4                                       | 26 | 09 | 14.692236                         |
| 12.5                           | 4                                       | 56 | 09 | 14.44190581                       |
| -15.0                          | 59                                      | 50 | 03 | -13.055799                        |
| -14.75                         | 59                                      | 20 | 15 | -12.80703                         |
| -14.5                          | 58                                      | 50 | 19 | -12.557157                        |
| -14.25                         | 58                                      | 20 | 36 | -12.309087                        |
| -14.0                          | 57                                      | 50 | 42 | -12.0594866                       |
| -13.75                         | 57                                      | 21 | 03 | -11.81197                         |
| -13.5                          | 56                                      | 50 | 44 | -11.55889                         |
| -13.25                         | 56                                      | 20 | 50 | -11.309290                        |
| -13.0                          | 55                                      | 50 | 57 | -11.059827                        |
| -12.75                         | -                                       | -  | -  |                                   |
| -12.50                         | 54                                      | 51 | 17 | -10.561735                        |
| -12.25                         | 54                                      | 21 | 13 | -10.31074069                      |
| -12.0                          | 53                                      | 51 | 20 | -10.061276                        |

Laser Location: 33° 46' 7"

Table 4-C3. Azimuth Position Test 1

| <u>ADP Angle<br/>(Degrees)</u> | <u>Observed Angle<br/>(Deg-Min-Sec)</u> |    |    | <u>Angle Offset<br/>(Degrees)</u> |
|--------------------------------|-----------------------------------------|----|----|-----------------------------------|
| -15.0                          | 4                                       | 46 | 54 | -14.51902214                      |
| -14.75                         | 5                                       | 16 | 42 | -14.27026017                      |
| -14.5                          | 5                                       | 46 | 54 | -14.01815863                      |
| 15.0                           | 64                                      | 40 | 58 | 15.48429188                       |
| 14.65                          | 64                                      | 11 | 7  | 15.23511443                       |
| 14.5                           | 63                                      | 40 | 4  | 14.97591927                       |
| 14.25                          | 63                                      | 11 | 23 | 14.73647978                       |
| 14.0                           | 62                                      | 41 | 15 | 14.48493566                       |
| 14.75                          | 62                                      | 11 | 19 | 14.23506059                       |
| 14.5                           | 61                                      | 41 | 17 | 13.98435027                       |
| 14.25                          | 61                                      | 11 | 22 | 13.73461339                       |
| 13.0                           | 60                                      | 41 | 20 | 13.48390215                       |
| 13.75                          | 60                                      | 11 | 28 | 13.23458175                       |
| 13.5                           | 59                                      | 41 | 13 | 12.98206092                       |
| 13.25                          | 59                                      | 11 | 28 | 12.73371355                       |
| 12.0                           | 58                                      | 41 | 35 | 12.48425272                       |
| 12.75                          | 58                                      | 11 | 33 | 12.23353929                       |
| 12.5                           | 57                                      | 41 | 25 | 11.98199067                       |

Laser Location: 33° 46' 7"

Table 4-C4. Azimuth Position Test 2

| <u>ADP Angle<br/>(Degrees)</u> | <u>Observed Angle<br/>(Deg-Min-Sec)</u> |    |    | <u>Angle Offset<br/>(Degrees)</u> |
|--------------------------------|-----------------------------------------|----|----|-----------------------------------|
| 15.0                           | 59                                      | 54 | 07 | 13.07291282                       |
| 14.75                          | 59                                      | 24 | 25 | 12.82498300                       |
| 14.50                          | 58                                      | 54 | 19 | 12.57371362                       |
| 14.25                          | 58                                      | 24 | 20 | 12.32341774                       |
| 14.0                           | 57                                      | 54 | 28 | 12.07409536                       |
| 13.75                          | 57                                      | 24 | 33 | 11.82435518                       |
| 13.50                          | 56                                      | 54 | 44 | 11.57544940                       |
| 13.25                          | 56                                      | 24 | 21 | 11.32181276                       |
| 13.0                           | 55                                      | 54 | 57 | 11.07638450                       |
| 12.75                          | 55                                      | 24 | 42 | 10.82525148                       |
| 12.5                           | 54                                      | 54 | 56 | 10.57535027                       |
| 12.25                          | 54                                      | 25 | 12 | 10.32715831                       |
| 12.0                           | 53                                      | 55 | 13 | 10.07685901                       |
| 11.75                          | 53                                      | 25 | 08 | 9.82572457                        |
|                                |                                         |    |    |                                   |
| -15.0                          | 0                                       | 1  | 34 | -16.91771284                      |
| -14.75                         | 0                                       | 31 | 56 | -16.66642255                      |
| -14.5                          | 1                                       | 1  | 27 | -16.41783313                      |
| -14.25                         | 1                                       | 31 | 38 | -16.16587512                      |
| -14.0                          | 2                                       | 1  | 31 | -15.91642084                      |
| -13.75                         | 2                                       | 31 | 33 | -15.66571389                      |
| -13.5                          | 3                                       | 1  | 14 | -15.41792809                      |
| -13.25                         | 3                                       | 31 | 20 | -15.16666359                      |
| -13.0                          | 4                                       | 1  | 17 | -14.91665073                      |
| -12.75                         | 4                                       | 31 | 08 | -14.66747215                      |

Laser Location: 33<sup>0</sup> 48' 18"

SECTION V  
SPECIAL TESTS  
(TASK 08)

PART A  
NAV SET AGC TRACKING TEST

W. WONG

TECHNICAL REPORT Y220-06

INTERIM - MARCH 1976

FINAL  
APRIL 1976

## 5-A1. INTRODUCTION

This test is designed to find the maximum AGC tracking rate of the Nav Set in dB/sec as a function of increasing and decreasing signal strength from -30 dBm to -70 dBm. The AGC loop tries to maintain a constant track level below the beam peak. We want to know the maximum rate the beam peak may increase (or decrease) while still holding a constant relative track level. After these rates are found, they are compared with nominal rates calculated from an AGC mathematical model.

The approach to be used and the method for implementing the plan are discussed. Also the predicted tracking rates are derived.

## 5-A2. APPROACH

The maximum tracking rates are found by applying, to the receiver, a triangular input beam signal with a power that is increasing (or decreasing) with increasing rate (constant acceleration) in accordance with:

$$P = P_o \pm at^2 \text{ dBm} \quad (2a)$$

$$\dot{P} = \frac{dP}{dt} = \pm 2at \text{ dB/second}$$

where:

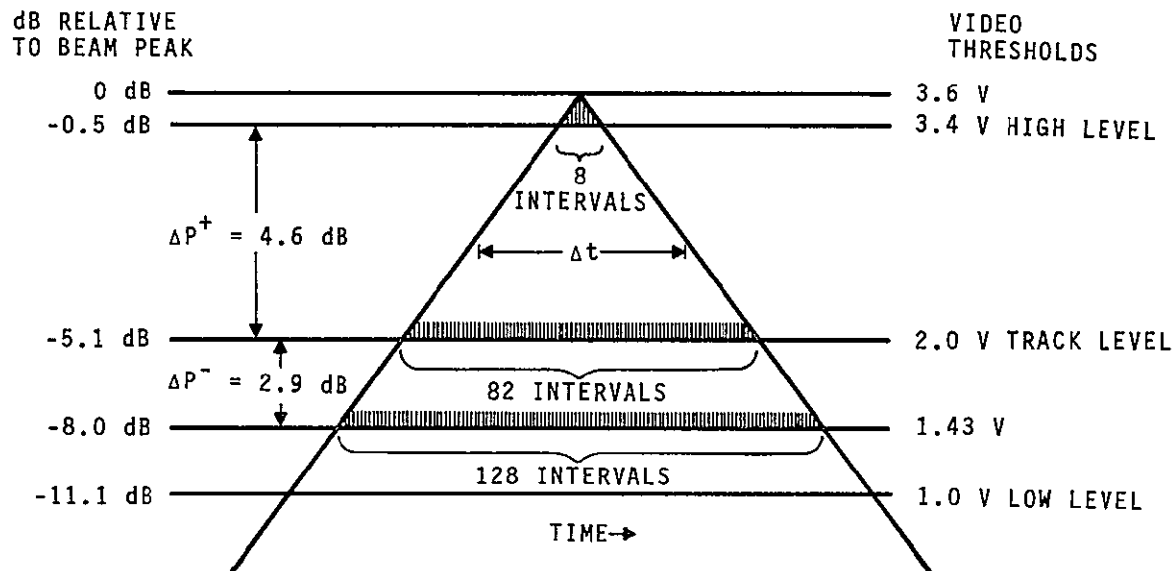
t = time in seconds

P = peak power of the triangular beam

a = acceleration constant

$\dot{P}$  = signal rate

The triangular beam shape is linear in dB per degree. The width of the triangular beam and the data spacing are selected to obtain 128 pulse pairs at 8 dB down from the peak. This puts 8 pulse pairs 0.5 dB down and fixes the other beam parameters as shown in Figure 5-A1.



### Triangle Beam Equations

Using some simple trigonometry the following equations are applicable to the triangle beam.

where:

$R$  = dB relative to beam peak

$n$  = number of data intervals

$\theta$  = data angle in degrees

$\Delta t$  = time across a beam cut (see figure)

$$R = \frac{n}{16} \text{ dB}$$

For:  $n = 128$  then,

$$R = -8 \text{ dB}$$

For:  $n = 8$  then,

$$R = -0.5 \text{ dB}$$

$$\Delta t = n(60 + 2\theta)10^{-6} \text{ seconds}$$

$$\Delta t = -16R(60 + 2\theta)10^{-6} \text{ seconds}$$

For  $\theta = 5$  degrees and  $n = 128$ , then  $\Delta t = 8.96 \text{ msec}$

Figure 5-A1. Triangle Beam

A triangular beam was chosen in order to make use of the validity bit from the receiver. Data is invalid if there are less than 9 or more 127 hits. Invalid data will set the validity bit to a logic one.

Consider the case for  $P$  increasing from  $P_0$  at time  $t_0$ . The AGC action would tend to hold the tracking threshold at -5.1 dB (Figure 5-A1) for the triangular beam for small  $P$  (Figure 5-A2). Initially, the tracking rate is fast enough to maintain the constant track level threshold. At time  $t_s$  the signal rate becomes equal to the maximum AGC tracking rate. As the signal rate increases further, the tracking threshold falls 2.9 dB until it gets down to 8 dB below the peak (128 hits) setting the validity bit to logic one at time  $t_D$ . Knowing  $t_D$  allows  $P(t_D)$  and  $\dot{P}(t_D)$  to be computed from equations 2a and 2b.

The case for  $P$  decreasing is similar. However, validity drop-out occurs when the tracking threshold rises 4.6 dB to 0.5 dB below the beam peak (8 hits).

The maximum tracking rate and the power input at which this rate occurs can be found for increasing signal power from the following analysis.

The change in track level from time  $t_s$  to time  $t_D$  is represented by:

$$\Delta P = \int_{t_s}^{t_D} (\dot{P} - \dot{S}) dt \text{ dB} \quad (2c)$$

or

$$\begin{aligned} \Delta P &= \int_{t_s}^{t_D} \dot{P} dt - \int_{t_s}^{t_D} \dot{S} dt \\ &= P(t_D) - P(t_s) - \int_{t_s}^{t_D} \dot{S} dt \end{aligned} \quad (2d)$$

where  $\dot{S}$  = maximum receiver AGC tracking rate in dB/sec.

(2e)

$$\Delta P = 2.9 \text{ dB (for increasing signal strength).}$$

At time  $t_s$ , the maximum tracking rate is attained and this rate is equal to the signal rate from equation 2b.

$$\dot{S} = \dot{P}(t_s) = 2a t_s \text{ dB/sec} \quad (2f)$$

If we assume  $\dot{S}$  is constant from  $t_s$  to  $t_D$  and substitute for the beam power from equation 2a, equation 2d becomes:

$$\Delta P = a t_D^2 - a t_s^2 - \dot{S} t_D + \dot{S} t_s \quad (2g)$$

$\dot{S}$  can be found in terms of  $t_D$ , by solving equation 2f for  $t_s$  and substituting into equation 2g with the result:

$$\dot{S}^2 - 4a t_D \dot{S} + 4a^2 t_D^2 - 4a \Delta P = 0 \quad (2h)$$

Solving the quadratic equation for  $\dot{S}$  and substituting for  $\Delta P$ , we have:

$$\dot{S} = 2a t_D - \sqrt{4a \Delta P} \quad (2i)$$

$$= 2a t_D - 3.41 \sqrt{a}$$

$$= \dot{P}(t_D) - 3.41 \sqrt{a}$$

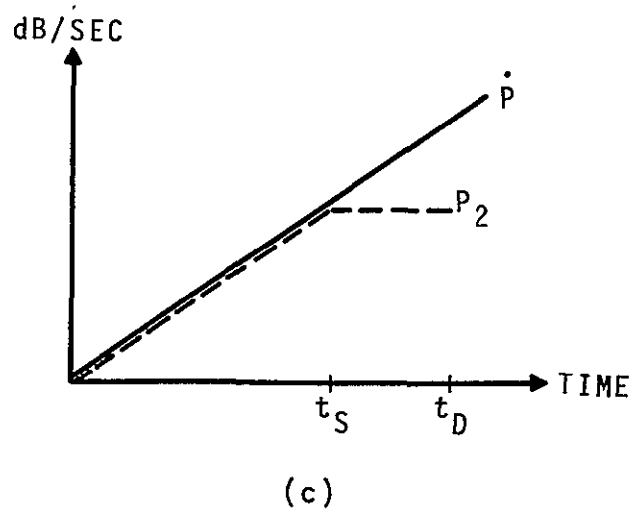
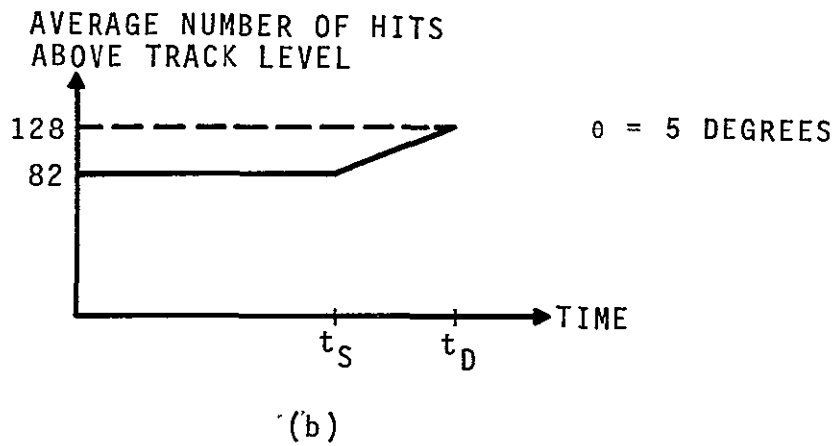
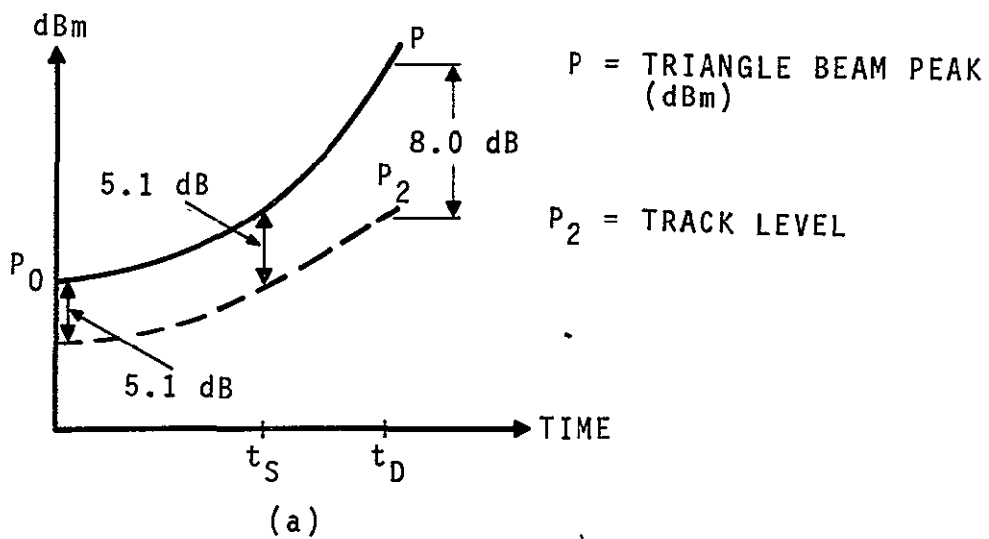


Figure 5-A2. Tracking for an Increasing Triangular Beam

Similarly for decreasing signal power:

$$\Delta P = -4.6 \text{ dB} \quad (2j)$$

$$\dot{S} = -2a t_D + 4.29 \sqrt{a} \quad (2k)$$

$$= \dot{P}(t_D) + 4.29 \sqrt{a}$$

Once  $\dot{S}$  is known,  $P(t_s)$  can be computed.

a. For increasing signal strength:

$$\dot{S} = 2a t_s$$

$$t_s = \frac{\dot{S}}{2a}$$

$$P(t_s) = P_O + a t_s^2 \text{ dBm}$$

b. For decreasing signal strength:

$$t_s = -\frac{\dot{S}}{2a} \text{ sec}$$

$$P(t_s) = P_O - a t_s^2 \text{ dBm}$$

If  $\dot{S}$  is plotted against  $P(t_s)$ , the graph would give the maximum tracking rate for a given signal strength input.

### 5-A3. TEST SETUP

The equation  $P = P_o \pm at^2$  is generated by using the RF generator of the Nav Set Test Set which is controlled by a pin diode attenuator. The attenuator nominally provides 20 dB of attenuation per volt. By testing the RF generator it was found that the equation--Attenuation =  $20.6 \nu_c + 1.0$  dB, where  $\nu_c$  = diode attenuator control voltage--can be used to model the diode attenuator. This equation was obtained from experimental data (Figure 5-A3) by using the technique of linear regression. The maximum RF generator power output is -9.6 dBm.

The power output as a function of control voltage is:

$$\begin{aligned} P &= 9.6 \text{--attenuation dBm} \\ &= -8.6 \text{--} 20.6 \nu_c \text{ dBm} \end{aligned} \tag{3a}$$

A voltage triangle generator with the following equation is used for the pin diode control voltage:

$$\nu_c = V_o \mp Kt^2 \tag{3b}$$

where:

$\nu_c$  = triangular voltage peak

K = constant

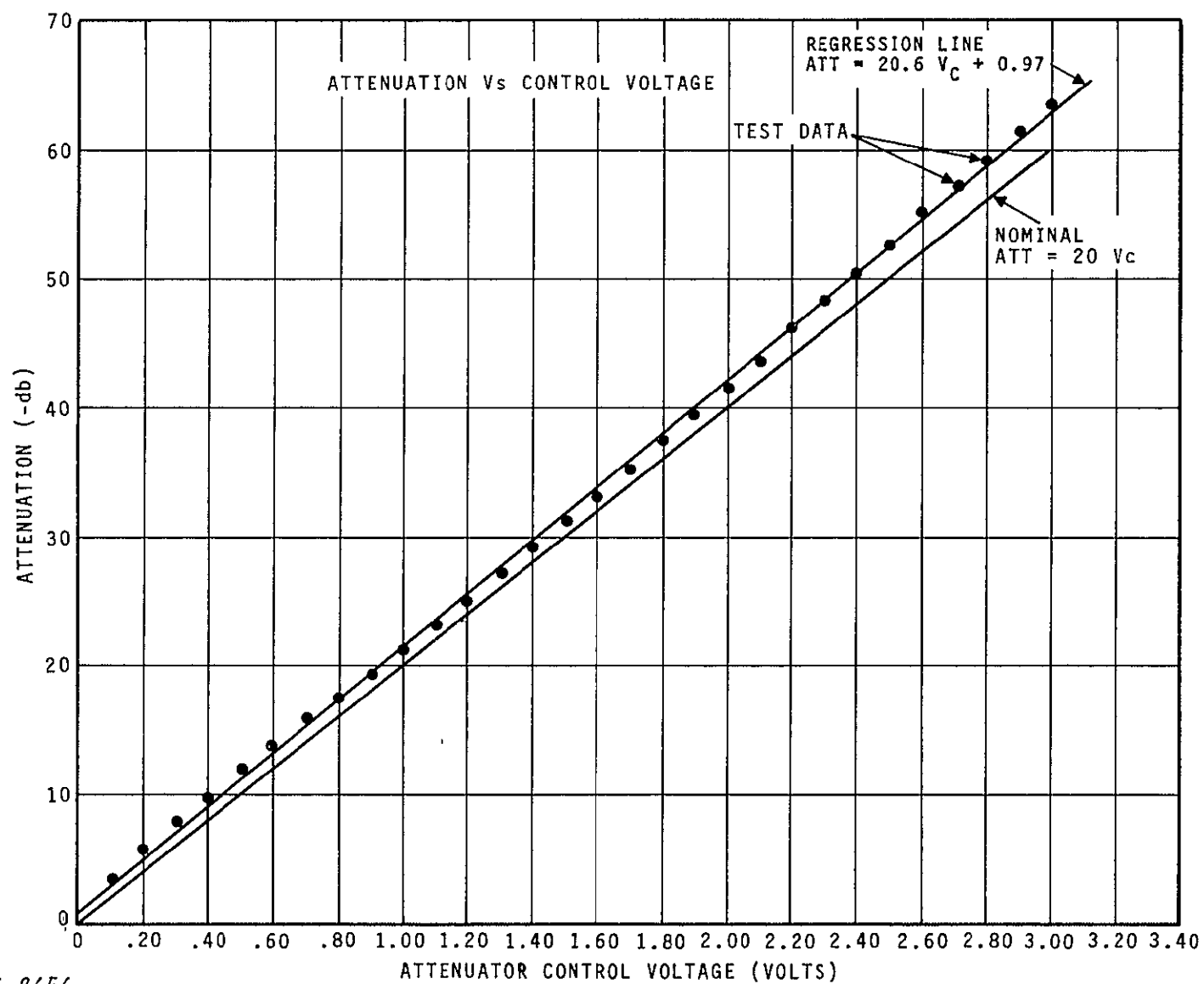
Finally substituting equation 3b into equation 3a:

$$P = (-8.6 - 20.6 V_o) \pm 20.6 Kt^2 \quad \text{dBm} \tag{3c}$$

$$\dot{P} = \pm 41.2 Kt \quad \text{dB/sec} \tag{3d}$$

$$P_o = -8.6 - 20.6 V_o$$

$$a = \pm 20.6 K$$



6-2656

Figure 5-A3. Attenuator Control Voltage (Volts)

Varying  $V_o$  allows the initial value of  $P_o$  to be set, and varying  $K$  allows the rate at which the beam peak is accelerating to be set. This set of equations plus those appearing in paragraph 5-A2 are used to reduce the data.

Since the azimuth, elevation, and DME circuits are identical, it is only necessary to test the elevation AGC function. Elevation is tested with a 5 degree data spacing.

A block diagram for the test scheme appears in Figure 5-A4. The three items required for this test (as shown in Figure 5-A4) are a Nav Set, a Nav Set Test Set (NSTS), and an AGC Tracking Test Set (ATTs).

The RF assembly of the MSBLS Nav Set is not needed since only the elevation AGC is tested.

The NSTS is used to supply power to the Nav Set and generates an RF pulse coded beam controlled by an external dc voltage. Also the NSTS provides access to the validity bit from the Nav Set.

The ATTs provides the following capabilities:

a. Generates a triangular voltage whose peak is a parabolic function, with  $K$  and  $V_o$  adjustable:

$$V_c = V_o + Kt^2 \quad (3b)$$

b. Monitors and displays the time  $t_D$  when the validity bit goes to a logic one to indicate less than 9 or more than 127 data intervals above the track level threshold.

#### 5-A4. PREDICTING THE MAXIMUM AGC TRACKING RATE

There are two tracking rates to be considered: positive tracking rate and negative tracking rate.

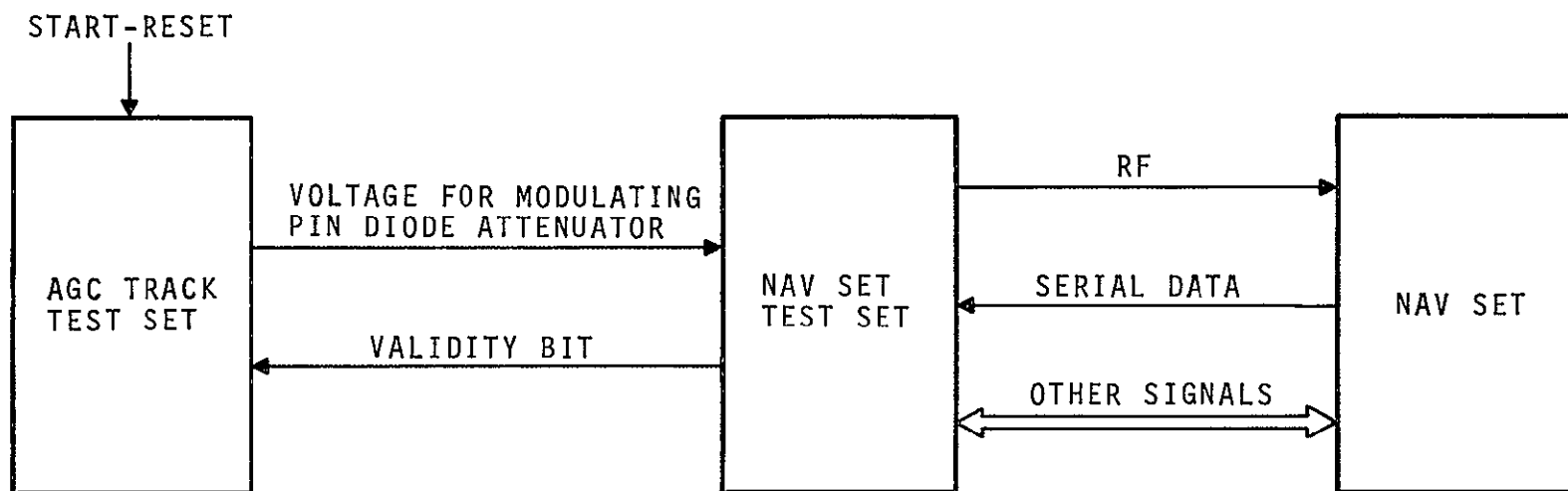


Figure 5-A4. Test Setup for AGC Tracking Test

From the specification for the IF amplifier and bit oscillator (SM-A-704023), the nominal equation relating the IF input to AGC voltage is:

$$P_2 = 17 V_A - 94 \text{ dBm} \quad (\text{at the IF input}) \quad (4a)$$

where:

$P_2$  = track level--input signal (dBm to the IF amplifier for a 2 volt video output)

$V_A$  = AGC voltage (volts)

In front of the IF amplifier is a mixer, a TR limiter, an RF filter, and an isolator. The mixer has a conversion loss of approximately 10 dB while the combination of the limiter, filter, and isolator contributes a 2 dB insertion loss. Translating equation 4a to the input of the receiver we have:

$$P_2 = 17 V_A - 82 \text{ dBm} \quad (\text{at the receiver input}) \quad (4b)$$

In order to represent the beam peak, we note that the beam peak is approximately 5 dB above the track level. Therefore, 5 dB is added to equation 4b:

$$P_P = 17 V_A - 77 \quad (\text{at the receiver input}) \quad (4c)$$

where:  $P_P$  = peak beam signal power

First consider increasing signal power. The AGC voltage,  $V_A$ , determines the gain of the IF amplifier. The gain decreases with  $V_A$  at a rate of 17 dB/volt. With increasing signal power  $V_A$  increases by:

$$\Delta V_A = -0.0086 V_A + 0.062 \text{ volts/scan} \quad (4d)$$

Note: See reference 5-A7g. for derivation of equation 4d.

The tracking rate is:

$$\begin{aligned} \frac{d P_2}{dt} &\approx \left( \frac{d P_2}{d V_A} \text{ dB/volt} \right) \left( \Delta V_A \text{ volts/scan} \right) (5 \text{ scans/sec}) \\ &\approx 85 \Delta V_A \text{ dB/sec} \end{aligned} \quad (4e)$$

$$\frac{d P_2}{dt} \approx -0.73 V_A + 5.27 \quad (4f)$$

Next solve for  $V_A$  in equation 4c and substitute into equation 4f for the positive tracking rate as follows:

$$\frac{d P_2}{dt} = -0.043 P_P + 1.96 \text{ dB/sec} \quad (4g)$$

As an example of equation 4g, assume a peak beam of -40 dBm, the maximum positive tracking rate of desensitizing rate is:

$$\frac{d P_2}{dt} = -0.043 (-40) + 1.96 = 3.68 \text{ dB/sec}$$

This corresponds to an increasing AGC voltage rate of 200 mV/sec.

The negative tracking rate can be derived in a similar manner to the positive tracking rate using a decreasing AGC voltage rate of:

$$\Delta V_A = -0.008 V_A \text{ volts/scan} \quad (4h)$$

Note: See paragraph 5-A7g. for derivation of equation 4h.

$$\frac{d P_2}{dt} = -0.040 P_P - 3.1 \text{ dB/sec} \quad (4i)$$

Equations 4g and 4i are graphed in Figures 5-A5 and 5-A6, respectively.

#### 5-A5. TEST RESULTS

The maximum positive tracking rate was obtained experimentally by increasing the beam power at a parabolic rate. The experimental results are plotted in Figure 5-A5 along with the predicted tracking rate. From -60 to -40 dBm, the experimental rate is higher than the predicted rate. From -40 to -30 dBm, the experimental rate is lower. The tracking rate decreases with increasing signal power as predicted.

The maximum negative tracking rate was obtained by decreasing the beam power. The results are plotted in Figure 5-A6. The experimentally determined tracking rate is found to be lower than the predicted rate. The tracking rate increases with increasing signal power as predicted.

#### 5-A6. GLOSSARY

- a. Track Level (Absolute)--Input signal to the receiver (dBm) for 2 volt output video.
- b. Relative Track Level--Absolute track level relative to the maximum signal power of a beam.
- c. Tracking Rate--Rate of change in dB/sec of the Track Level; equal to the negative of the rate of receiver gain.

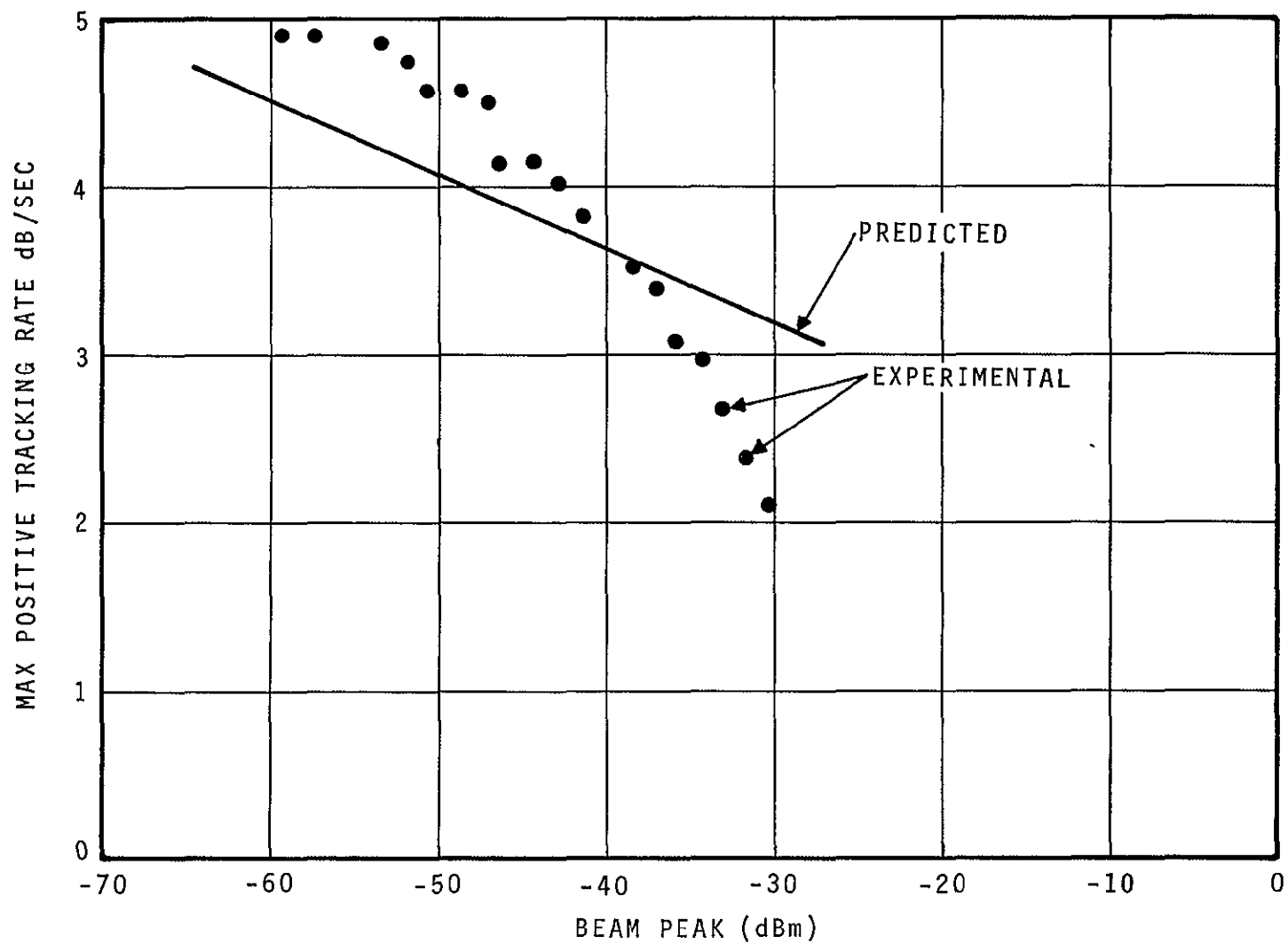


Figure 5-A5. Maximum Positive Tracking Rate

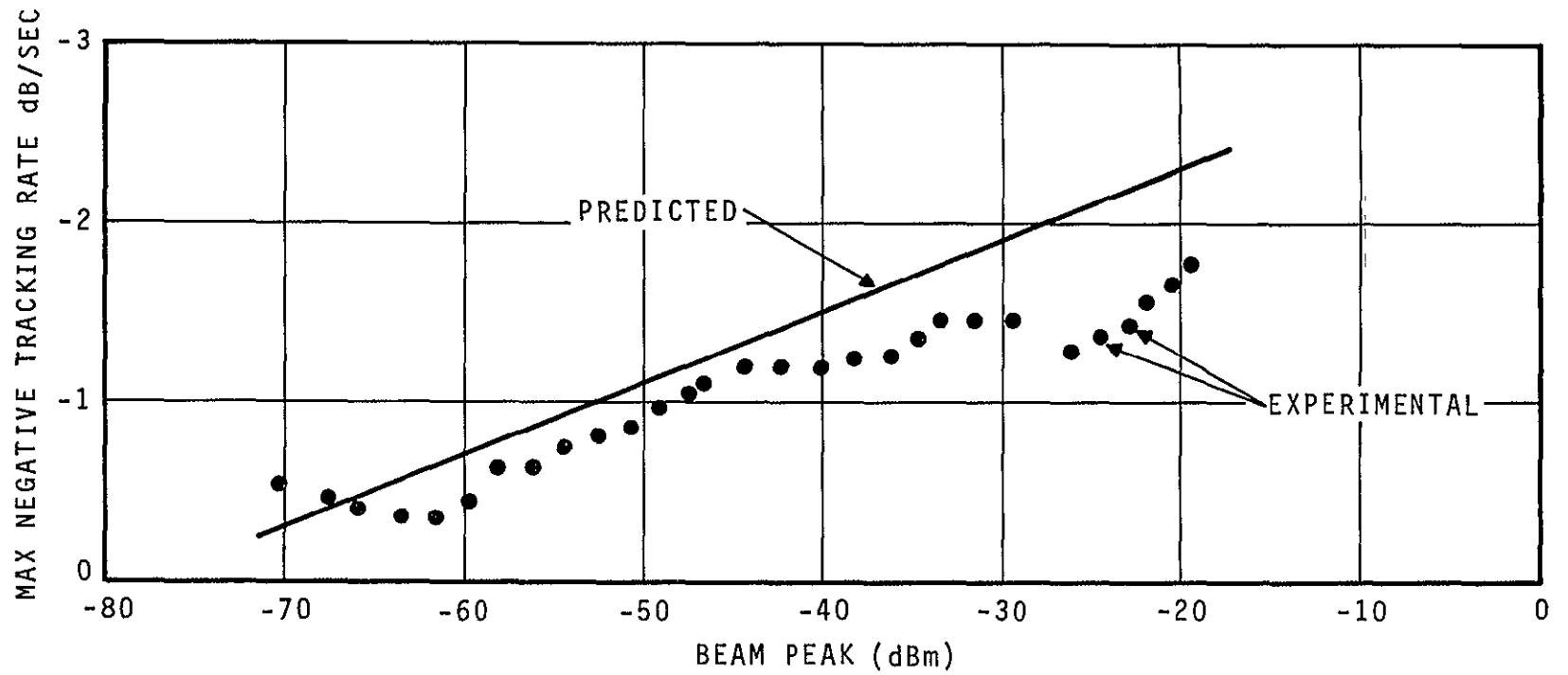


Figure 5-A6. Maximum Negative Track Rate

5-A7. REFERENCES

- a. AIL Specification Control Drawing No. SM-A-704023, "IF Amplifier and BIT Oscillator," p 13-14, 14 May 1975.
- b. A. Tatz, "Interference Tests and AGC Tracking Tests," Memo to Y220-08, 19 November 1975.
- c. A. Tatz, "Sequel on Interferences and AGC Tests," Memo to Y220-08, 26 November 1975.
- d. AIL Specification Control Drawing No, 501170, "TR Limiter," 16 June 1975.
- e. AIL Specification Control Drawing No. 501169, "Isolator," 7 February 1976.
- f. AIL Specification Control Drawing No. SM-A-72961, "Mixer," 27 June 1975.
- g. W. Wong, "Examination of the MSBLS NAVSET Operation During the Acquisition Mode," AIL Technical Report Y220-01, October 1975.

SECTION VI  
ENGINEERING ANALYSIS NO. 75-2

75-2  
CONTRACT: NAS9-14543

PART A

MSBLS FREQUENCY CHANNEL  
PERFORMANCE AND INTERFERENCE

J. SANTINI

TECHNICAL REPORT Y220-20

FINAL  
SEPTEMBER 1975  
UPDATED - MARCH 1977

## 6-A1. INTRODUCTION

The MSBLS can operate on a number of channels. In order to ensure no degradation in performance, the system should be operated on a channel such that there are no other similar systems operating on the same channel within the radius of detection. Also, system performance might vary from channel to channel because of slight differences in performance of RF components across the band.

As requested by NASA, this report will accomplish the following:

- a. Determine variations in end-to-end MSBLS performance from channel to channel.
- b. Determine the probability of interference between MSBLS and other landing systems (TRN-28, SPN-41, TLS, CO-SCAN, etc.) and plot their locations.
- c. Recommend optimum channels for KSC, FRC, and VAFB. Specify any channels to be avoided.

Because of the critical nature of the Orbiter's mission, worst-case conditions are examined such that no combination of circumstances can occur which would cause a reduction in MSBLS performance.

## 6-A2. VARIATIONS IN END-TO-END MSBLS PERFORMANCE FROM CHANNEL TO CHANNEL

MSBLS operates in the band of 15.4 to 15.7 GHz. This band is relatively narrow, so that the small frequency excursions possible from band edge to band edge do not have a large effect on overall system performance. The components affected by frequency changes are the transmitter, the antennas, the waveguide, and the receiver front end. These variations are not specified, so they can only be pointed out as typical. Minimums and maximums are usually specified for a particular device, but variations within the operating range are not covered in the specifications.

The transmitter output power varies slightly from the low end of the band to the high end. Power is typically 0.5 dB higher at the low end of the band than at the high end, although this difference is not accurately predictable.

The antenna patterns are fairly consistent from unit to unit. A check was made of 10 elevation antennas with the following results:

|                                     |         |
|-------------------------------------|---------|
| Maximum variation of maximum gain   | 0.4 dB  |
| Average variation of maximum gain   | 0.28 dB |
| Maximum variation of sidelobe level | 3.8 dB  |
| Average variation of sidelobe level | 2.06 dB |

The variations did not show a definite trend with frequency.

Waveguide losses decrease slightly as frequency increases. From 15.4 to 15.7 GHz, the change in attenuation is approximately 0.002 dB/foot. Assuming a total waveguide run of 35 feet, (including air and ground stations) this totals 0.07 dB.

Differences in signal propagation characteristics favor the low end of the band by about 0.15 dB.

Receiver performance also varies across the band. The noise figures of 7 mixers, along with an RF filter and the other components comprising a complete receiver front end, were measured. The noise figure was observed to increase as frequency increased. The average increase across the band was 0.63 dB, although one unit was observed to have a 1.6 dB differential.

The variation in system performance will be the sum of these individual variations, as summarized in Table 6-A1.

Table 6-A1. System Performance Variation

| Item                          | Variation (dB) |         | Band End Favored |
|-------------------------------|----------------|---------|------------------|
|                               | Maximum        | Average |                  |
| Transmitter                   | -              | 0.5     | Low              |
| Antennas { Gain<br>Side lobes | 0.4            | 0.28    | None             |
|                               | 3.8            | 2.06    | None             |
| Waveguide                     | -              | 0.07    | High             |
| Propagation                   | -              | 0.15    | Low              |
| Receiver                      | 1.6            | 0.63    | Low              |

Although the data in Table 6-A1 is incomplete and based on a relatively small sample of units, it is useful for estimating possible system variations across the frequency band. From the data in Table 6-A1, a worst-case differential of 2.2 dB could be observed between channel 1 and channel 10, with a typical differential of about 1.2 dB. As previously stated, this data was observed to be typical, but since it is not specified for individual components, it can not be specified as a system parameter.

This performance differential is small but significant, so that if a choice of interference-free channels is available, the channel corresponding to the lowest frequency would be preferred.

#### 6-A3. DETERMINING THE POTENTIAL FOR INTERFERENCE BETWEEN MSBLS AND SIMILAR LANDING SYSTEMS

In order to determine the susceptibility of the MSBLS to interference from other similar systems, it is necessary to compare the signal strength at the airborne receiver due to each station. The received signal power is

determined by summing the system gains with the path losses. Path attenuation results from two factors:

- a. Distance  $\left( \frac{1}{D^2} \right)$
- b. Obstruction (due to the curvature of the earth)

Interference to all three modes (Azimuth, Elevation, and DME) will be considered. System gains are summarized in Table 6-A2.

#### 6-A4. SIGNAL STRENGTH REQUIRED TO INTERFERE WITH NORMAL SYSTEM OPERATION

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The Orbiter receiver is most susceptible to interference before it begins tracking the MSBLS Ground Station. At that point (acquisition), the receiver gain is maximum, and the receiver is not yet expecting any particular beam.

The best possible receiver performance would enable a signal to be tracked at approximately -80 dBm (receiver noise level is -90 dBm). In order to determine maximum interfering range between MSBLS stations, therefore, it is necessary to determine a distance beyond which a ground station could not possibly produce a detectable signal (-80 dBm or greater) at an airborne receiver. Obviously, if no other ground stations are permitted to operate on the MSBLS channel within that radius, MSBLS performance will be optimum.

Once the receiver begins tracking the MSBLS-GS, it is much more difficult to interfere with proper system operation. The receiver's AGC circuit adjusts the receiver gain so that the beam is tracked nominally at the -4 dB level (4 dB down from the beam peak). An interfering signal would have to be comparable in strength to the MSBLS-GS signal for interference to be experienced. An interfering signal 6 dB below the MSBLS-GS signal would cause no noticeable interference.

Table 6-A2. MSBLS RF Gain Specifications

|                                                   | Azimuth                                                          | Elevation    | DME |
|---------------------------------------------------|------------------------------------------------------------------|--------------|-----|
| Power Output (dBm)                                | 63                                                               | 63           | 63  |
| Ground Antenna Gain (dB)                          | 31 (max) at 5° El<br>22 at 0° El                                 | 27           | 20  |
| Orbiter Antenna Gain<br>(Including 3 dB W/G Loss) | 2 dB on axis -3 dB at 50° points                                 |              |     |
| Receiver Sensitivity                              | Tracking -74 dBm min Noise Level -90 dBm<br>-80 dBm max (approx) |              |     |
| System Gain* (dB)<br>(Maximum)                    | 176 dB at 5° El<br>167 dB at 0° El                               | 172 at 0° Az | 165 |

\*Receiver sensitivity of -80 dBm, Orbiter antenna on axis. (Worst-case for interference.)

In summary, then, a signal of -80 dBm or more at the airborne receiver (worst-case before tracking is initiated) could be detected as a valid beam. Since we have chosen not to tolerate any detectable interfering signal, all signals of -80 dBm or more at the airborne receiver will be considered possible interfering signals. Consequently, it will not be necessary to consider the case in which the interfering signal is as strong as, or stronger than, the desired signal. This situation could occur, for instance, if there was a localized rainstorm between the Orbiter and the MSBLS-GS, and there was clear weather between the Orbiter and a more distant interfering station.

#### 6-A5. ATTENUATION DUE TO DISTANCE

The greater the distance, the greater the path attenuation. The equation for path loss is (assuming isotropic radiators - antenna gains calculated separately):

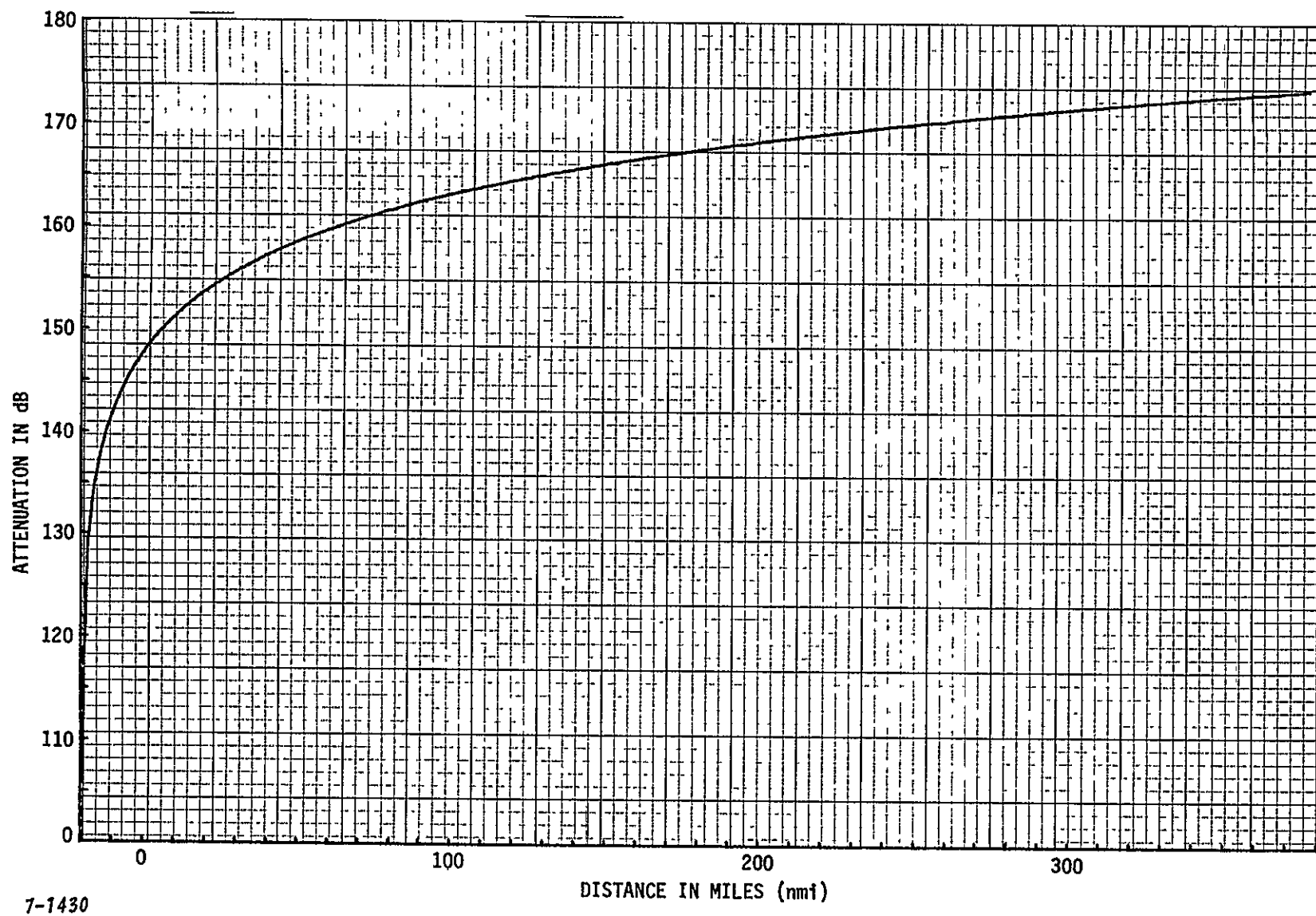
$$\text{Attenuation (dB)} = 10 \log \left[ \frac{(6.33 \times 10^{-3}) \lambda^2}{D^2} \right]$$

Figure 6-A1 shows the graphical solution to this equation.

System gain varies, depending on mode (Azimuth, Elevation or DME) and angle. At long distances, and therefore low angles, the maximum system gain of 172 dB occurs in the elevation mode (Table 6-A2). From the attenuation versus distance graph (Figure 6-A1) it can be seen that the distance at which path loss is about 172 dB is 330 nmi. This distance is the farthest possible distance at which a station could be detected in free space.

#### 6-A6. OBSTRUCTION DUE TO THE CURVATURE OF THE EARTH

The previous discussion of the attenuation due to distance assumed an unobstructed path between the Orbiter and the interfering station. At longer distances, the potential path becomes blocked by the earth (Figure 6-A2).



7-1430

Figure 6-A1. Attenuation Versus Distance at 15.55 GHz

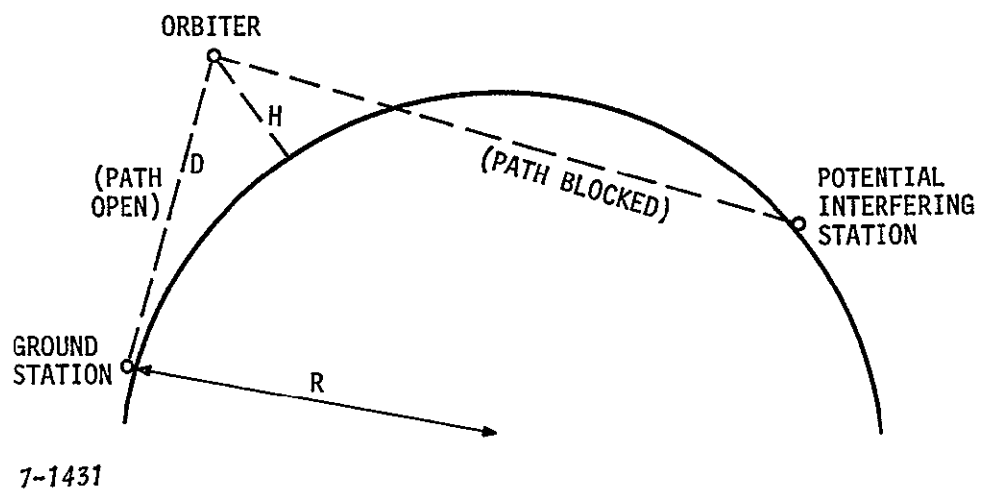


Figure 6-A2. Earth Curvature Obstruction

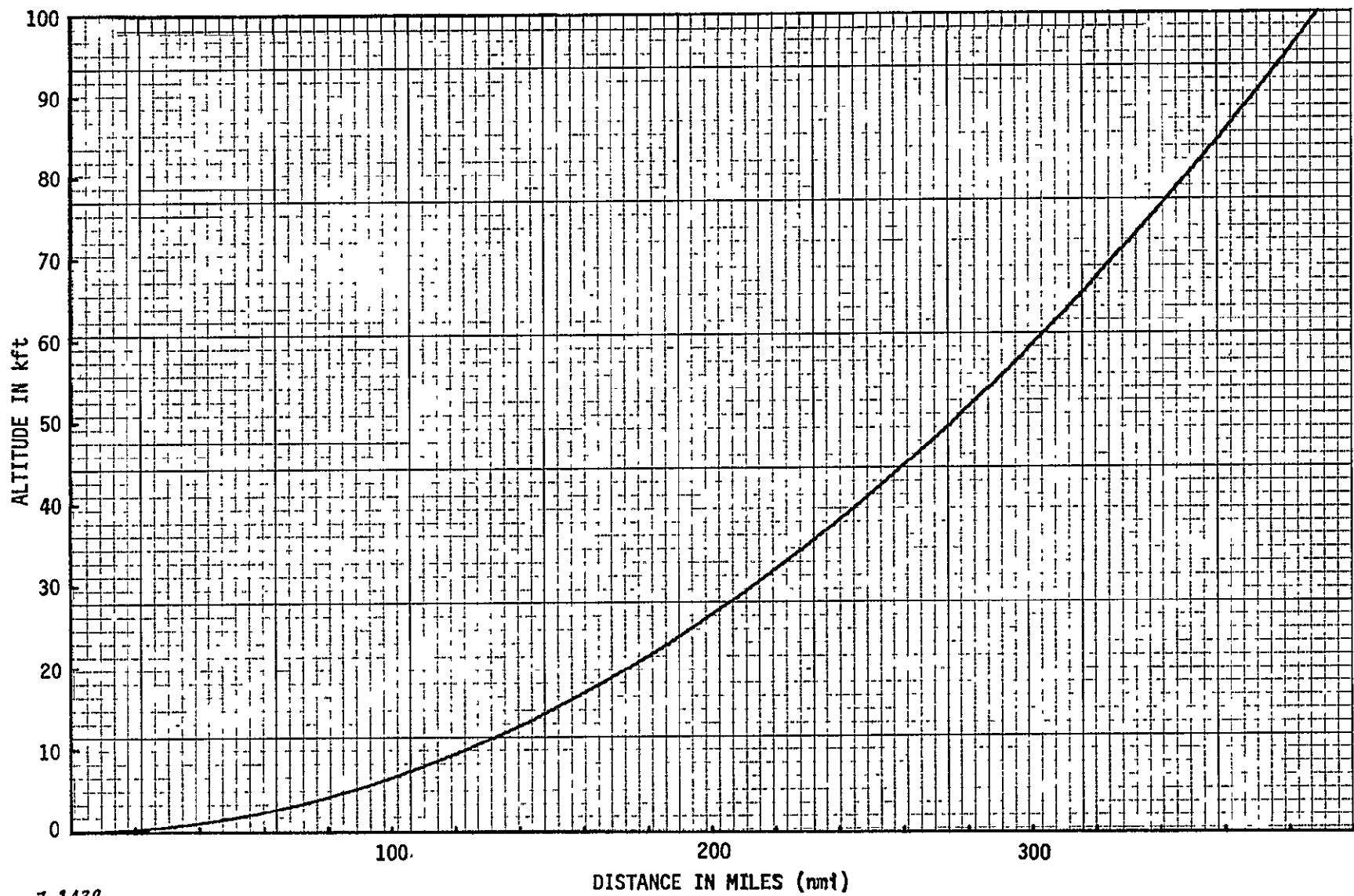
Since  $H \ll R$ :

$$D = \sqrt{2RH}$$

This equation relates altitude (H) to the distance to the horizon (D). Since radio waves are diffracted slightly by the atmosphere, the radius of the earth is usually increased by a factor of 4/3 in order to find the radio horizon (Figure 6-A3). For an altitude of 14,000 feet (Orbiter's altitude at MSBLS acquisition) this distance is approximately 145 nmi. At a distance of 200 nmi, the Orbiter would have to be above 26,000 feet to have an unobstructed path. This allows a 12,000 foot safety margin in altitude. Above 26,000 feet (line of sight) the path attenuation would be about 168 dB (Figure 6-A1), which would be too great to cause significant interference. Since the attenuation over paths beyond the radio horizon is generally considered infinite at Ku-band, an interfering station would have to be within about 200 nmi of the Orbiter (under the best possible propagation conditions) to cause any interference.

#### 6-A7. SIGNAL PROFILES

A program was written which would calculate the signal strength at the receiver at various altitudes and distances from a ground station. The program takes into account the attenuation due to distance (Figure 6-A1), the distance to the radio horizon (Figure 6-A3), the elevation angle from the ground station, and the azimuth and DME antenna gains at that angle (Figures 6-A4 and 6-A5). The gain figures are then added and plotted so that signal strength at the airborne receiver is shown as a function of distance and altitude (Figures 6-A6, 6-A7, and 6-A8). The profiles show the signal strength that would be seen by an observer flying from the ground station at a constant altitude. Various curves are shown for various altitudes. As the observer reaches the radio horizon (a function of altitude), the signal disappears.



7-1432

Figure 6-A3. Altitude Versus Distance to Radio Horizon

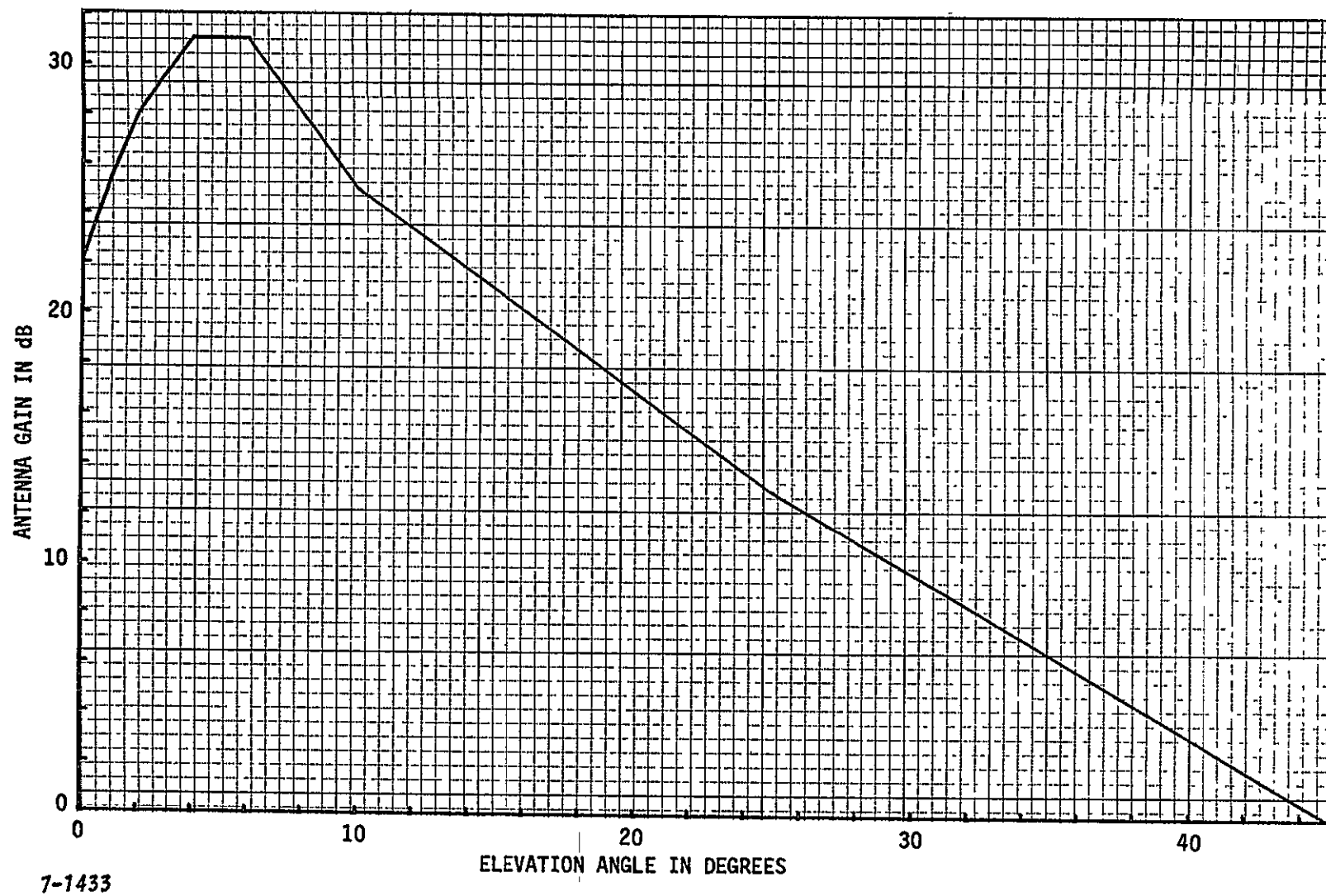
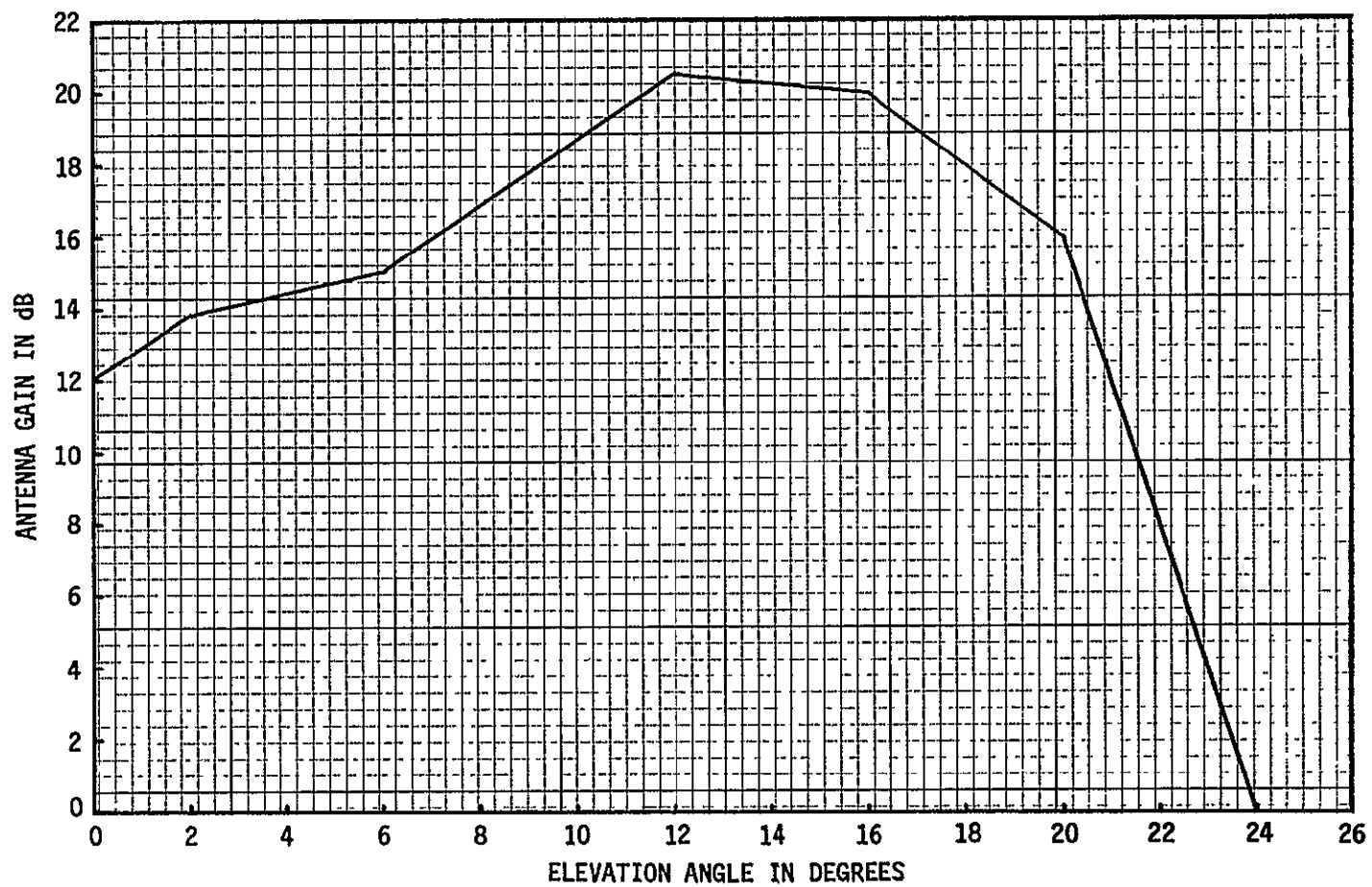


Figure 6-A4. Model Used to Approximate Radiation Pattern of Azimuth Antenna in the Vertical Plane



7-1434

Figure 6-A5. Model Used to Approximate Radiation Pattern of DME Antenna in the Vertical Plane

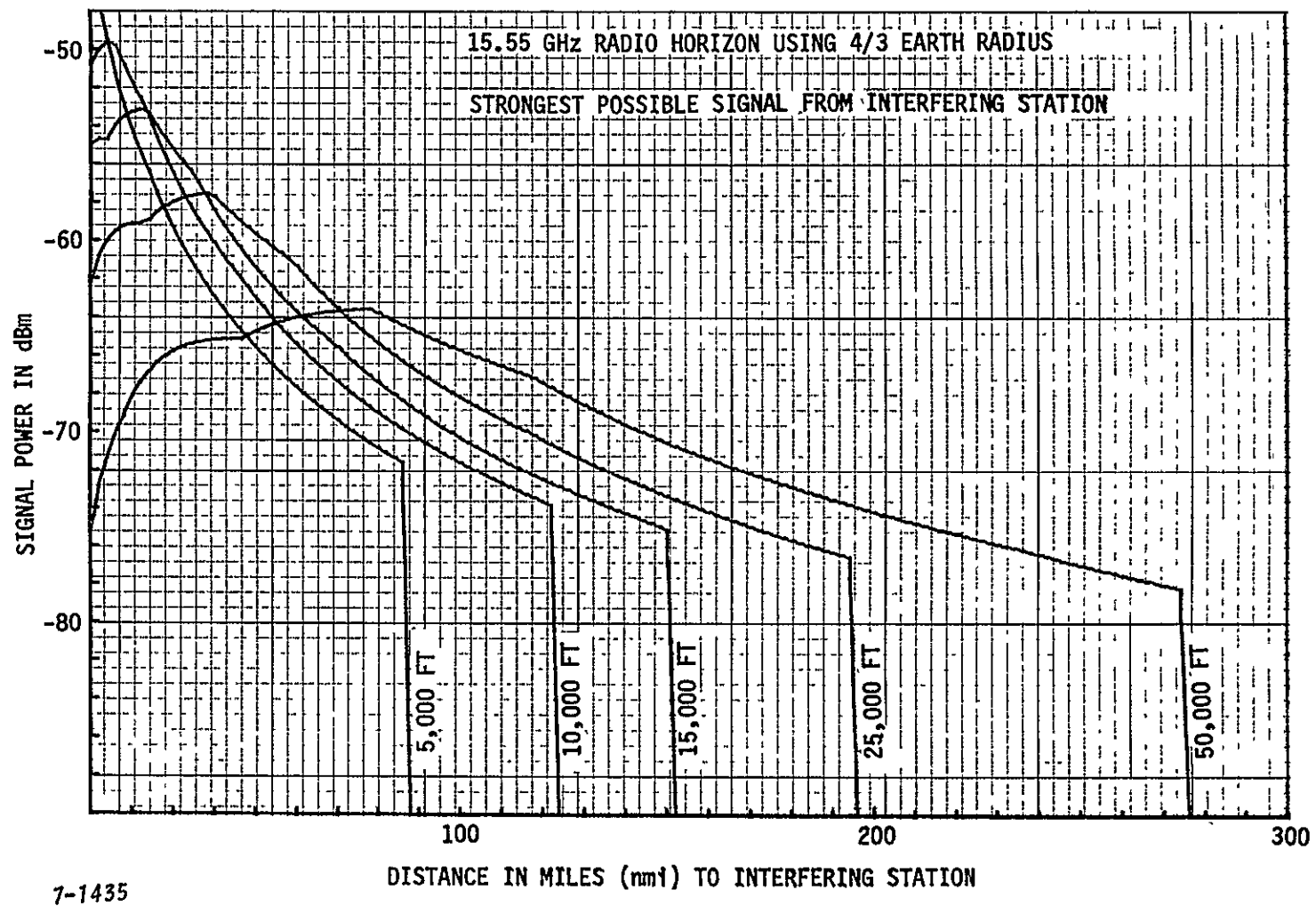
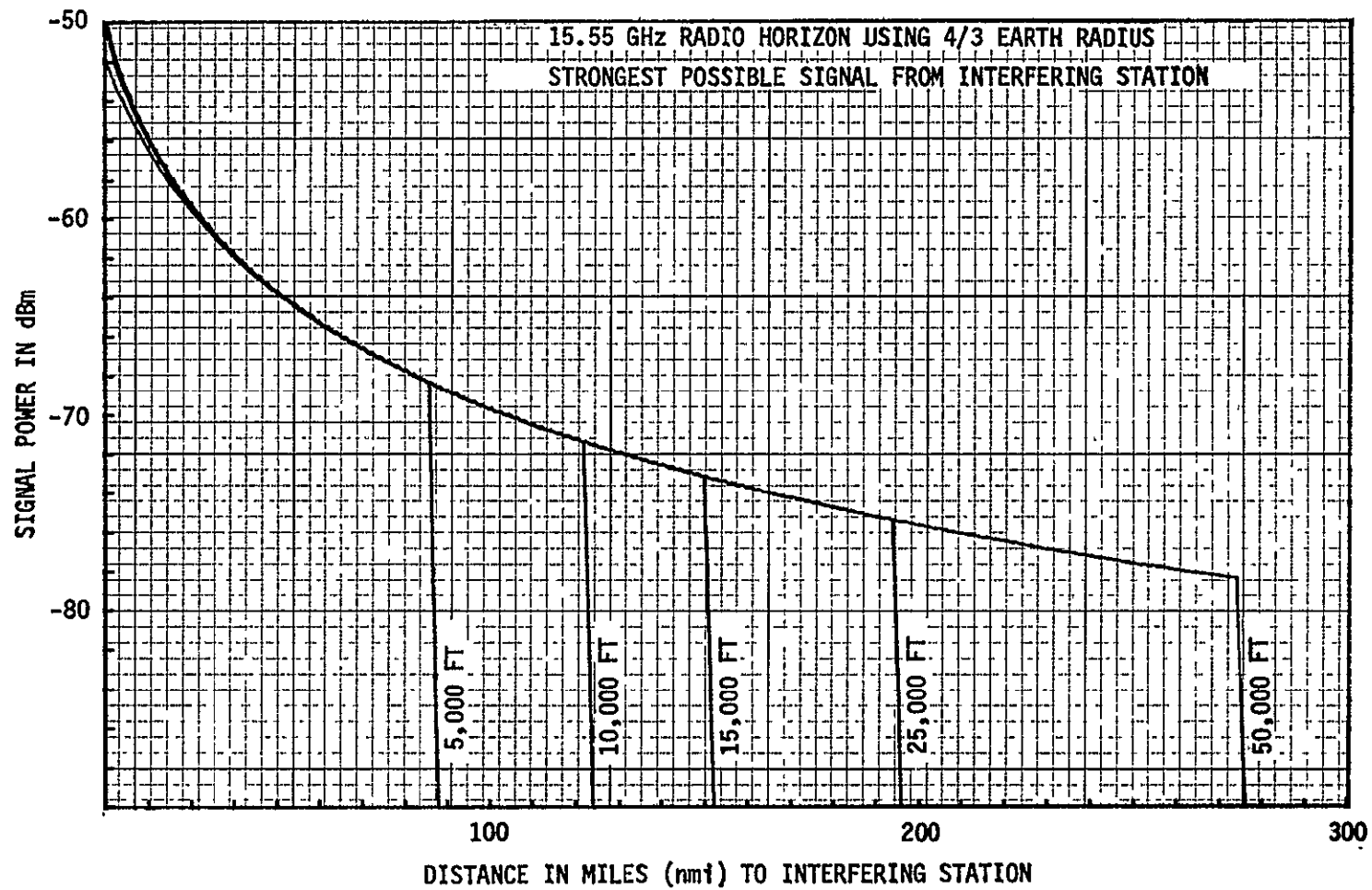
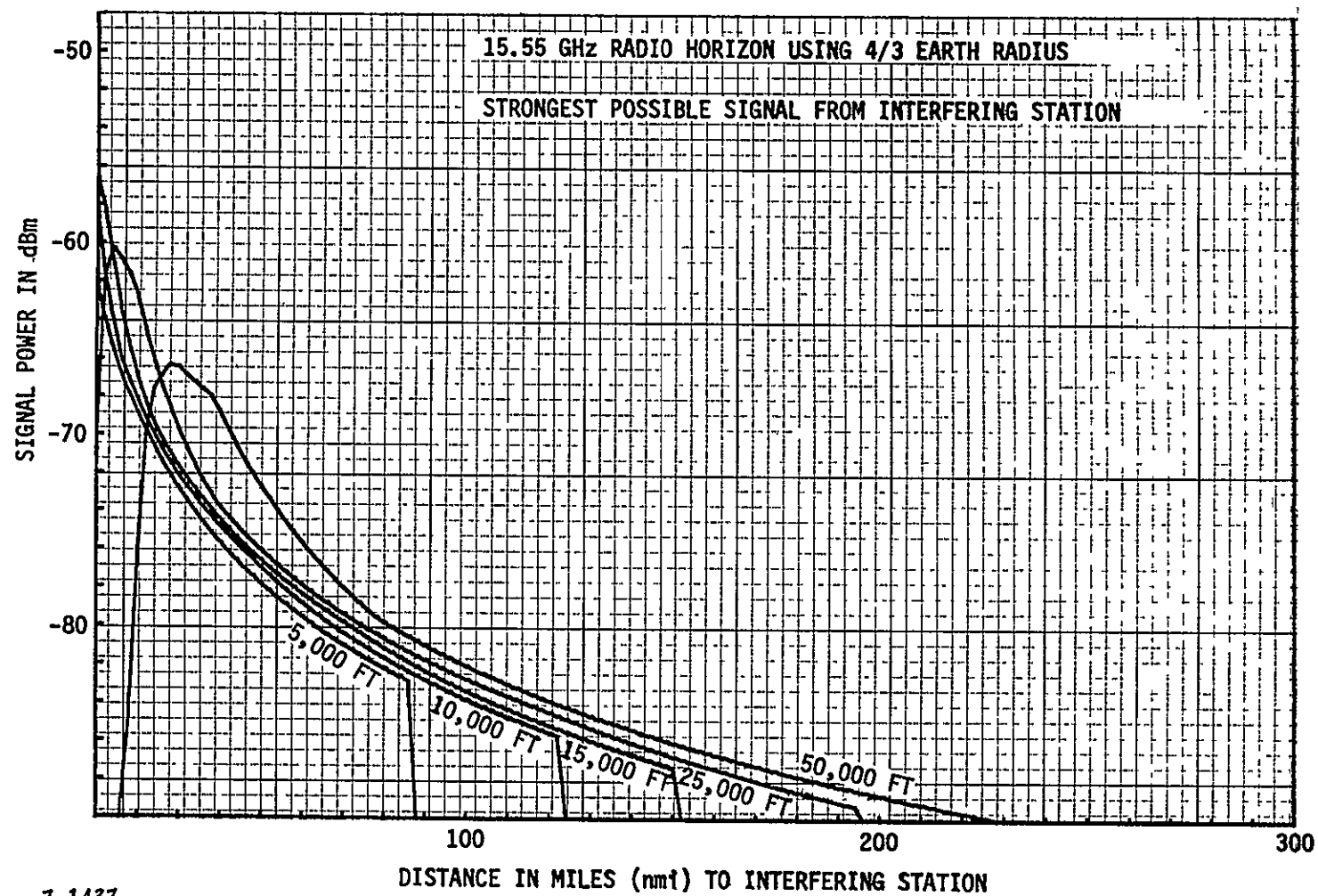


Figure 6-A6. Signal Profiles for MSBLS Azimuth Function



7-1436

Figure 6-A7. Signal Profiles for MSBLS Elevation Function



7-1437

Figure 6-A8. Signal Profiles for MSBLS DME Function

#### 6-A8. ADJACENT CHANNEL INTERFERENCE

The MSBLS operates on the 10 RF channels shown in Table 6-A3. In addition to these 10 RF channels, there are two airborne DME channels (between 2-3, 8-9) on different RF frequencies. Other systems, such as the SPN-41, use these 10 RF channels with two different sets of intrapair pulse spacings, yielding 20 operating channels. Channels 11 through 20 use the same RF frequencies but different intrapair spacings as channels 1 through 10.

Table 6-A3. Channel Frequencies

| Channel | Frequency<br>(GHz) |
|---------|--------------------|
| 1 (11)  | 15.412             |
| 2 (12)  | 15.436             |
| DME     | 15.460             |
| 3 (13)  | 15.484             |
| 4 (14)  | 15.508             |
| 5 (15)  | 15.532             |
| 6 (16)  | 15.568             |
| 7 (17)  | 15.592             |
| 8 (18)  | 15.616             |
| DME     | 15.640             |
| 9 (19)  | 15.664             |
| 10 (20) | 15.688             |

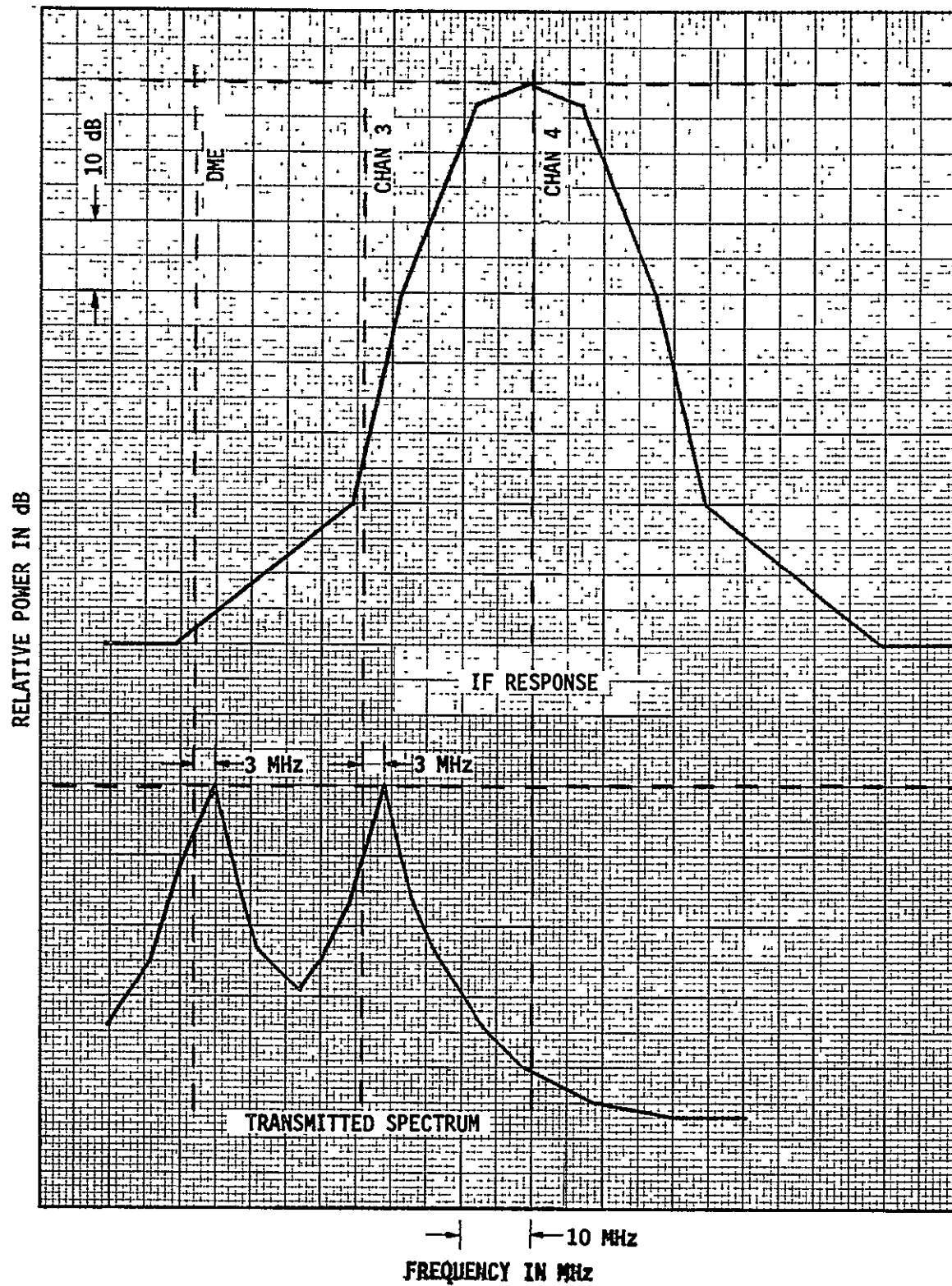
Note: Channels 11 through 20 (some systems) use same RF frequencies but different pulse coding.

Although the airborne receiver could not track an interfering station which was operating on the same RF channel, but with different intrapair pulse spacing, the individual pulses would be detected. Since these pulses would not be synchronized to the MSBLS, they would have an effect similar to noise on overall system operation. The system would still operate within specifications in this situation, however, lockup time is increased and accuracy is reduced slightly.

Since optimum performance and accuracy are desired for the Space Shuttle system, the MSBLS should operate on a channel such that no other system within the interference radius (200 nm) is operating on the same RF channel.

Another source of possible interference would be another system operating nearby on another RF channel. The frequency spectrum of a pulsed transmitter is relatively broad, and the receiver IF passband does not have infinite attenuation on adjacent channels. This results in a certain amount of leakage of RF energy from one channel to another. By examining the receiver's passband and the transmitter's frequency spectrum, the amount of adjacent channel rejection can be calculated.

Figure 6-A9 shows the worst-case situation. The receiver is operating on channel 4, but there is no signal being received from a channel 4 transmitter. Instead, there is a transmitter on channel 3 and a transmitter on the airborne DME frequency. These three channels are nominally 24 MHz apart, but worst-case frequency drift is shown. The two transmitters are shown 3 MHz high (maximum drift is specified at 2.5 MHz) and the receiver frequency is 0.5 MHz low (maximum specified LO drift). The transmitter spectrum was approximated by using a straight line approximation along the individual amplitude maximums of a typical spectrum.



7-1438

Figure 6-A9. IF Response and Transmitted Spectrum

Since an on-channel signal corresponds to the peak of the transmitted spectrum being coincident with the peak of the IF amplifier's response, the adjacent channel rejection is just the sum of the IF attenuation and the spectrum amplitude across the frequency band. This is shown in Figure 6-A10.

The maximum signal strength is at -37 dB. Zero dB corresponds to the IF center frequency response and the maximum transmitted power on its assigned channel, which would be an on-channel situation.

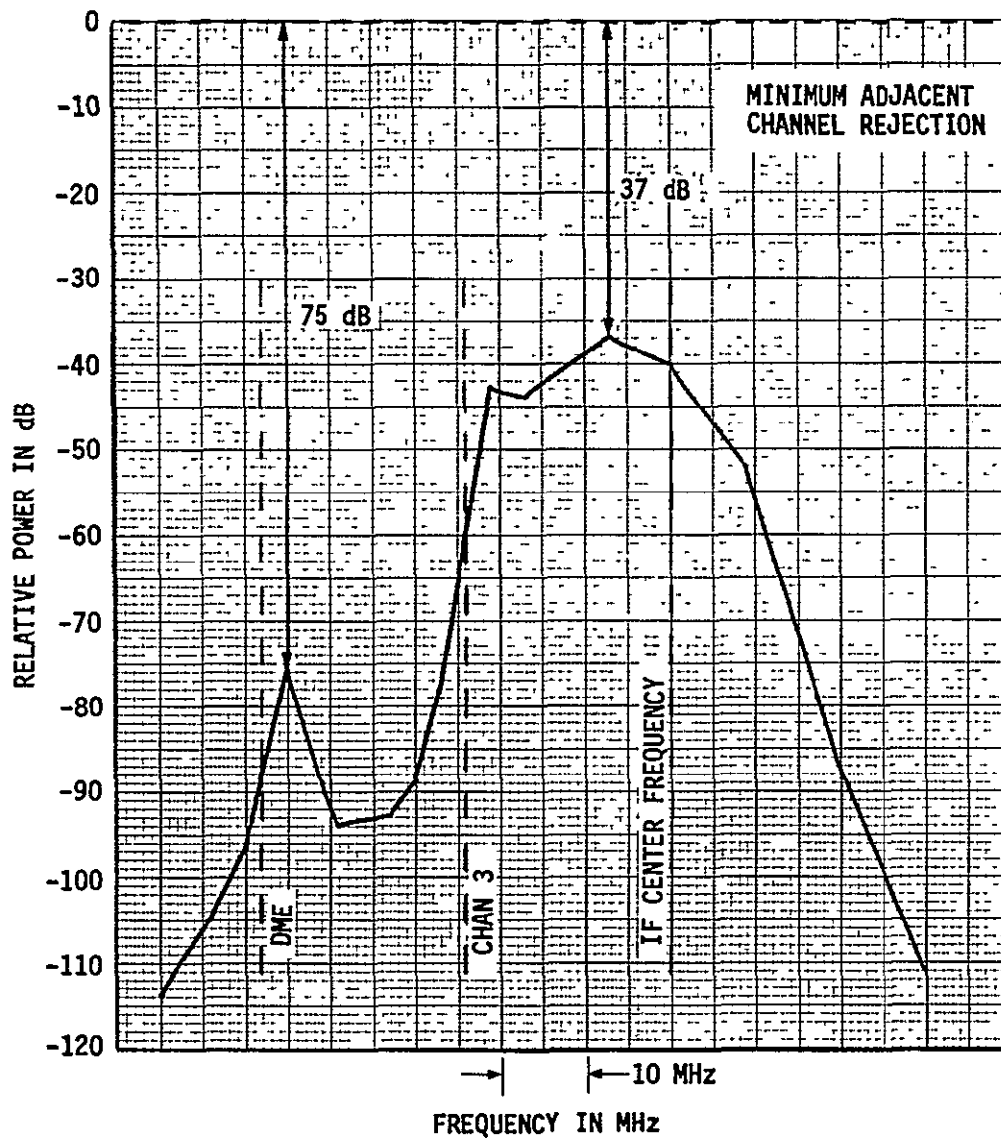
Referring back to Table 6-A2, it can be seen that the maximum system gain occurs in the azimuth mode at 5-degrees elevation. Using this as a worst-case figure, the system gain on an adjacent channel would be 37 dB lower, or 139 dB. From Figure 6-A10, the rejection two channels away (48 MHz) is -75 dB, giving a system gain of 101 dB at that point. From Figure 6-A1, the distance corresponding to a path loss of 139 dB is about 7 nmi, (7.4 nmi from equation) and the distance corresponding to a path loss of 101 dB is 565 feet.

Therefore, channels should be chosen such that there will be no possibility of the Orbiter flying within about 10 nmi of a ground station operating on an adjacent channel, or within 1,000 feet of a ground station two channels away.

#### 6-A9. OPERATION WITH TWO GROUND STATIONS

If two ground stations are to be located at each landing site (one for each direction), and two channel operation is desired, the preceding discussion of adjacent channel interference should be considered when choosing channels.

In order to assure no interference on the approach, adjacent channel operation should not be considered. Operation two RF channels apart (48 MHz) would assure a clear channel to within 565 feet of the interfering



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Figure 6-A10. Resultant IF Output

station, assuming a worst-case situation of the Orbiter approaching the other station head on (Figure 6-A11).

Since this case would correspond to the Orbiter being essentially at the runway, but flying in the wrong direction, a more realistic approach must be taken. Assuming the Orbiter will complete the final few thousand feet of the approach essentially on course, the ground station for the other direction of approach will have its back to the Orbiter. The front to back ratio for the antennas is greater than 30 dB and the shelter would also be shielding the Orbiter from the other station by more than 20 dB. This gives at least 50 dB attenuation, when the ground station is oriented in the opposite direction, in addition to the 75 dB attenuation due to the fact that the stations would be operating two channels apart. With this total of 125 dB attenuation, and using the maximum system gain of 176 dB, the Orbiter would have to be within 1.8 feet of the other ground station in order to experience any interference. As the Orbiter passed the interfering station on the runway, both ground stations (azimuth stations) would be pointing toward the Orbiter. However, the Orbiter would then be facing the on-channel ground station, and it would have its back toward the interfering station, so that the above calculations would also be approximately correct.

In summary, it is possible to instrument a runway such that each direction would have a separate ground station on a different channel (minimum of 48 MHz apart) with no significant interference.

#### 6-A10. CHANNEL ASSIGNMENTS OF ALL SIMILAR SYSTEMS

There are many microwave landing systems now in use which use the same channels and data formats as the MSBLS (Table 6-A4 and Figures 6-A12 and 6-A13). In order to eliminate interference problems, the MSBLS should not be operated on the same channel as another system located within 200 nmi, or within 10 nmi of a system on an adjacent channel. Referring to the map, Figure 6-A12, it can be seen that Cecil Field is within 200 nmi

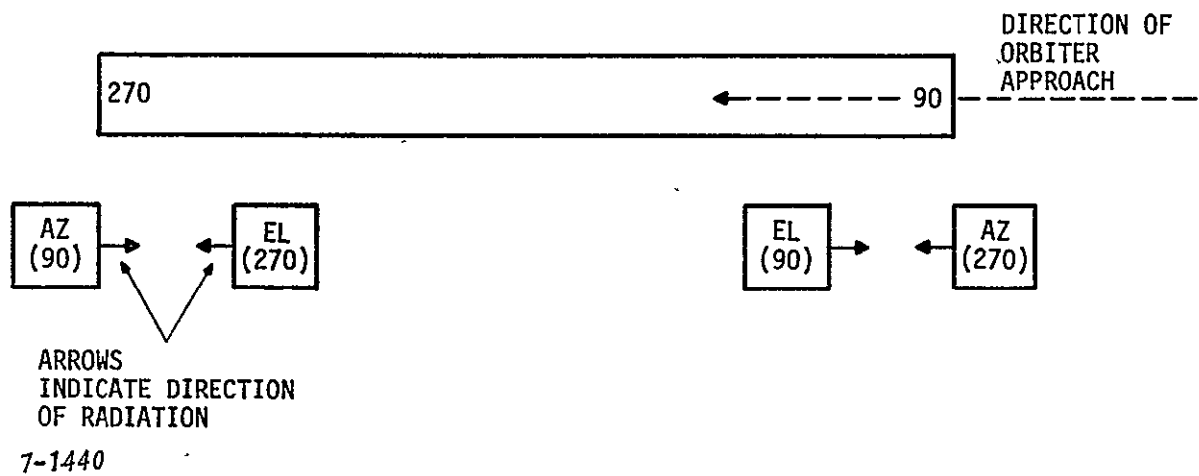


Figure 6-A11. Operation with Two Ground Stations

Table 6-A4. Channel Assignments of MSBLS-Type Systems

| Location             | Type          | Channel | Comments                 |
|----------------------|---------------|---------|--------------------------|
| Montreal, Canada     | CO-SCAN       | 4, 8    | 2 Systems                |
| Ottawa, Canada       | CO-SCAN       | 2, 6    | 2 Systems                |
| Eket, Nigeria        | CO-SCAN       |         |                          |
| Sweden               | TILS          | Note 1  |                          |
| Fort Rucker          | TLS           | --      | } 15 Units<br>in storage |
| Fort Hauchuca        | TLS           | --      |                          |
| Wright Patterson AFB | TLS           | --      | Under test               |
| NAS Glynco/Memphis   | SPN-41/TRN-28 | --      |                          |
| NAS Patuxent River   | SPN-41/TRN-28 | --      |                          |
| NAS Cecil Field      | TRN-28        | 19      |                          |
| NAS Lemoore          | TRN-28        | 3       |                          |
| NAS Miramar          | TRN-28        | 16      |                          |
| NAS Oceana           | TRN-28        | --      |                          |
| NAS Key West         | TRN-28        | --      | Planned                  |
| NAS Whidbey Island   | TRN-28        | --      | Planned                  |
| USS Hancock          | SPN-41        | Note 2  |                          |
| USS Oriskany         | SPN-41        | Note 2  |                          |
| USS Midway           | SPN-41        | Note 2  |                          |
| USS Coral Sea        | SPN-41        | Note 2  |                          |
| USS Forrestal        | SPN-41        | Note 2  |                          |

Table 6-A4. Channel Assignments of MSBLS-Type Systems (cont)

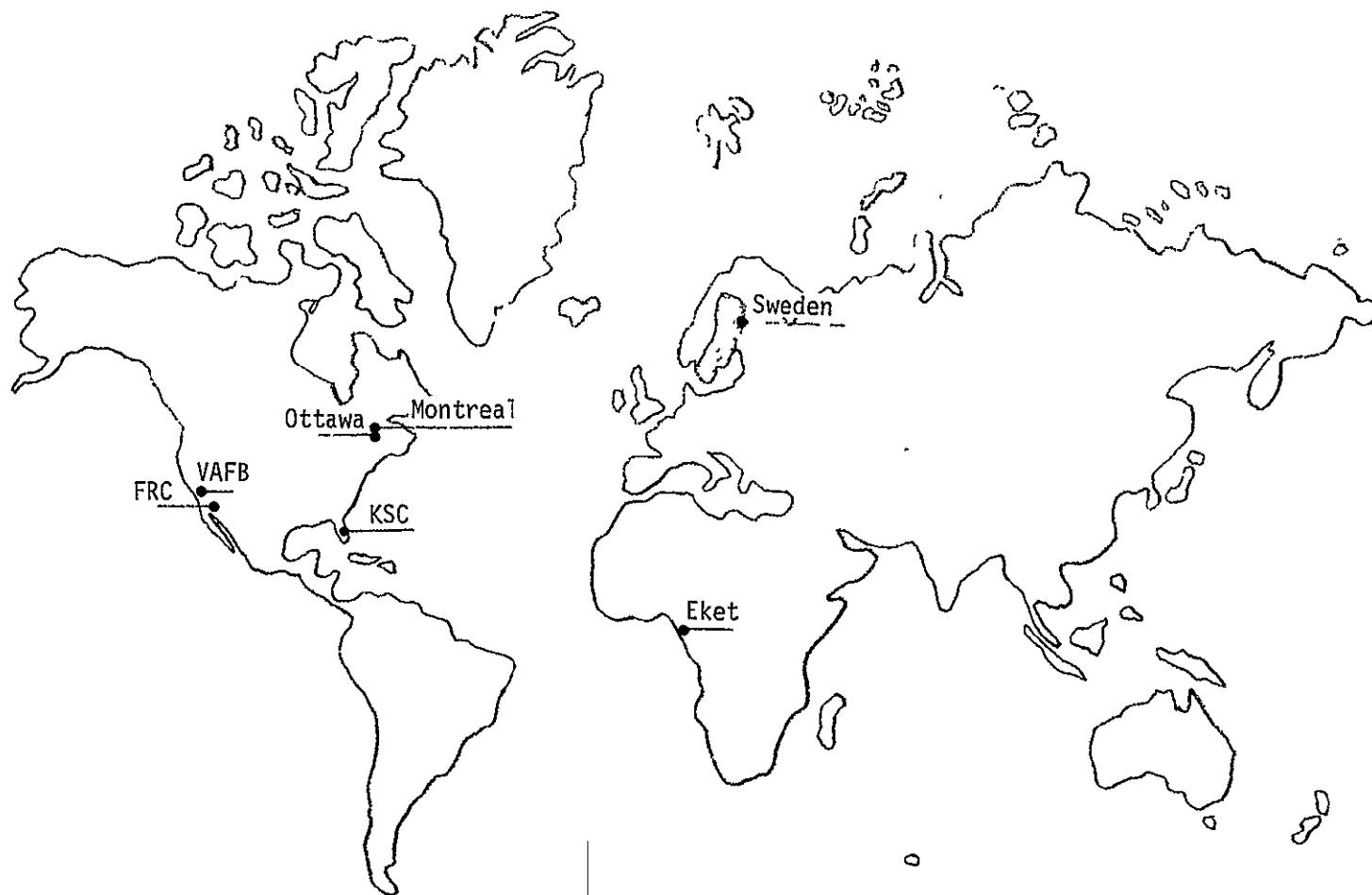
| Location          | Type   | Channel | Comments |
|-------------------|--------|---------|----------|
| USS Saratoga      | SPN-41 | Note 2  |          |
| USS Ranger        | SPN-41 | Note 2  |          |
| USS Independence  | SPN-41 | Note 2  |          |
| USS Kitty Hawk    | SPN-41 | Note 2  |          |
| USS Constellation | SPN-41 | Note 2  |          |
| USS Enterprise    | SPN-41 | Note 2  |          |
| USS America       | SPN-41 | Note 2  | Planned  |
| USS Kennedy       | SPN-41 | Note 2  | Planned  |
| USS Nimitz        | SPN-41 | Note 2  |          |
| USS Eisenhower    | SPN-41 | Note 2  | Planned  |
| USS Vinson        | SPN-41 | Note 2  | Planned  |

Note 1: Channel assignments are classified.

Note 2: All 10 RF channels have been reserved. Specific assignments were not made available to AIL.



Figure 6-A12. United States Locations of Similar Microwave Landing Systems



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Figure 6-A13. Worldwide Locations of Similar Microwave Landing Systems

of KSC, and Miramar and Lemoore are within 200 nmi of FRC and VAFB. These three stations have TRN-28 systems in operation. Also, many naval aircraft carriers have SPN-41 systems, and one of them could be within 200 nmi of the proposed MSBLS Ground Stations during landing operations.

Therefore, frequency coordination will be necessary in the operations area to ensure that siting interference does not occur. A contact with the joint frequency coordinating committee has been initiated through R. Brown (202) 755-2480. This operational area of coordination will be left for NASA, JSC to pursue further.

#### 6-A11. OPTIMUM CHANNEL ASSIGNMENTS FOR MSBLS

The channel assignments for the MSBLS should consider the following factors:

- a. The operating channel of the MSBLS should not be the same as that used by any similar system (TRN-28, SPN-41, CO-SCAN, etc.) within 200 nmi, or adjacent to a channel in use within 10 nmi.
- b. Preference should be given to the lower frequency channel, if a choice of interference-free channels is available.

Based on limited frequency information concerning other systems, AIL recommends the following frequencies for the MSBLS:

VAFB runway 30 - channel 5  
VAFB runway 120 - channel 2  
KSC runway 330 - channel 3  
KSC runway 150 - channel 1

It is understood that DFRC runways 17 and 22 will use channel 1 and runway 04 will use channel 4.

These frequencies are recommended based on the technical criteria summarized above, and frequency allocations as of March, 1977.

## 6-A12. CONCLUSIONS

In order for another ground station to interfere with an already acquired MSBLS Ground Station signal, it would have to be within about 4 dB of the MSBLS Ground Station, which would necessitate it being relatively close.

For the shuttle application, however, it is desirable to prevent any other signals from being detected. This will ensure optimum performance in the acquisition areas.

If no similar system is operating within 200 nmi, there would be no possibility of detecting it below an altitude of 26,000 feet. Therefore, we suggest operating on a channel such that no other similar system (TRN-28, SPN-41, etc.) within 200 nmi will be on the same channel.