N70-19890
NASA CR-62076

NASA-CR-62076

# PRE-PROCESSING OF WALLOPS STATION AN/FPQ-6 GEOS-II DATA



Edited By

R. L. Brooks
J. R. Vetter

DISTRIBUTION OF THIS REPORT IS PROVIDED IN THE INTEREST OF INFORMATION EXCHANGE. RESPONSIBILITY FOR THE CONTENTS RESIDES IN THE EDITORS OR ORGANIZATION THAT PREPARED IT.

PREPARED UNDER CONTRACTS

NAS 6-1467 AND NAS 6-1628

FEBRUARY 1970

BY

Wolf Research and Development Corporation
Riverdale, Maryland

FOR

National Aeronautics and Space Administration
Wallops Station
Wallops Island, Virginia

# PRE-PROCESSING OF WALLOPS STATION AN/FPQ-6 GEOS-II DATA

CONTRIBUTORS

Wolf Research and Development Corp.
Applied Sciences Division
Space and Planetary Sciences Department
Riverdale, Maryland

NASA - Wallops Station
GEOS-B C-Band System Project Group
Wallops Island, Virginia

Radio Corporation of America
Missile and Surface Radar Division
Moorestown, New Jersey

February 1970

## GLOSSARY (Cont.)

| | | |
|---|---|---|
| msec | - | millisecond |
| NAD | - | North American Datum (1927) |
| NGSP | - | National Geodetic Satellite Program |
| pps | - | pulses per second |
| PRF | - | Pulse Repetition Frequency |
| PW | - | Pulse Width |
| R | - | Range |
| $\dot{R}$ or RDOT | - | Range Rate |
| RCA | - | Radio Corporation of America |
| RF | - | Radio Frequency |
| RMS | - | root mean square |
| SAO | - | Smithsonian Astrophysical Observatory |
| S/N | - | signal-to-noise ratio |
| SR | - | Slant Range |
| TOD | - | Time of Day |
| TODG | - | Time of Day Generator |
| USC & GS | - | U.S. Coast & Geodetic Survey |
| USNO | - | U.S. Naval Observatory |
| UTC | - | Universal Time corrected for seasonal variations |
| yd | - | yard |
| Zulu | - | Universal Time |

TABLE OF CONTENTS

## LIST OF FIGURES

# LIST OF TABLES

# SECTION 1.0
# INTRODUCTION

## 1.1 PRE-PROCESSING

The calibration of the Wallops Station AN/FPQ-6 C-Band radar system is currently being performed by two independent methods; hardware system and sub-system testing, and analysis of the measurement residuals from data reduction of the GEOS-II satellite tracking data. Both methods have as their objective the elimination of all systematic errors discovered during the evaluation phase. Hardware analysis basically compares theoretical system parameters with the actual measured values and uses this as a measure of system performance. Software analysis utilizes statistical techniques in a data reduction process to compare the computed radar measurements with the actual measurements.

Accurate analysis of radar tracking data by means of data reduction techniques requires the pre-processing of the raw radar data. Radar data pre-processing in this context involves:

a. Identifying the operating and data acquisition characteristics of the system hardware; and

b. Quality control, software data corrections, and assumptions pertinent to qualifying the data for a data reduction process.

Data quality control checks are necessary for comparisons of actual radar operational modes with mission requirements, and the verification of their specific mode of operation (e.g., beacon track, skin mode, doppler tracking, etc.). Data correction is required to correct for known systematic errors such as droop, non-orthogonality, mis-level, and encoder bias and effects of tropospheric refraction. Figure 1 presents a generalized flow chart for the AN/FPQ-6 data pre-processing used at Wallops Island.

The on-site RCA 4101 computer program is used to apply the static corrections (pedestal mis-level, droop, non-orthogonality, encoder bias, encoder non-linearity, and skew) to the raw data. The dynamic lag corrections to the data are not applied at this point. However, these corrections which are calculated by the 4101 program are recorded. The 4101 output tape is then processed through the PASS 1 program which applies a time tag correction to the data, converts the data from radar bits to range in feet, and azimuth and elevation in decimal degrees. The PASS 1 program also reformats the data from 4101 format to the GE-625 compatible format. The PASS 1 output is then used to perform the following operations. First the R, Az, El, $\dot{R}$ calibration (pre and post) are analyzed and calibration corrections are computed. The PASS 2 program applies a transit time correction, nominal beacon delay correction, refraction correction and range calibration correction to the data.

## 1.2 WALLOPS STATION AN/FPQ-6 RADAR

### 1.2.1 General Measurement Information

The Wallops Station AN/FPQ-6 is a pulsed radar capable of non-ambiguous range measurements of up to $\sim$ 32,000 nautical miles. In addition to range measurements, the AN/FPQ-6 also provides azimuth and elevation angle measurements to the target. Using coherent signal processing (CSP) it provides range rate measurements.

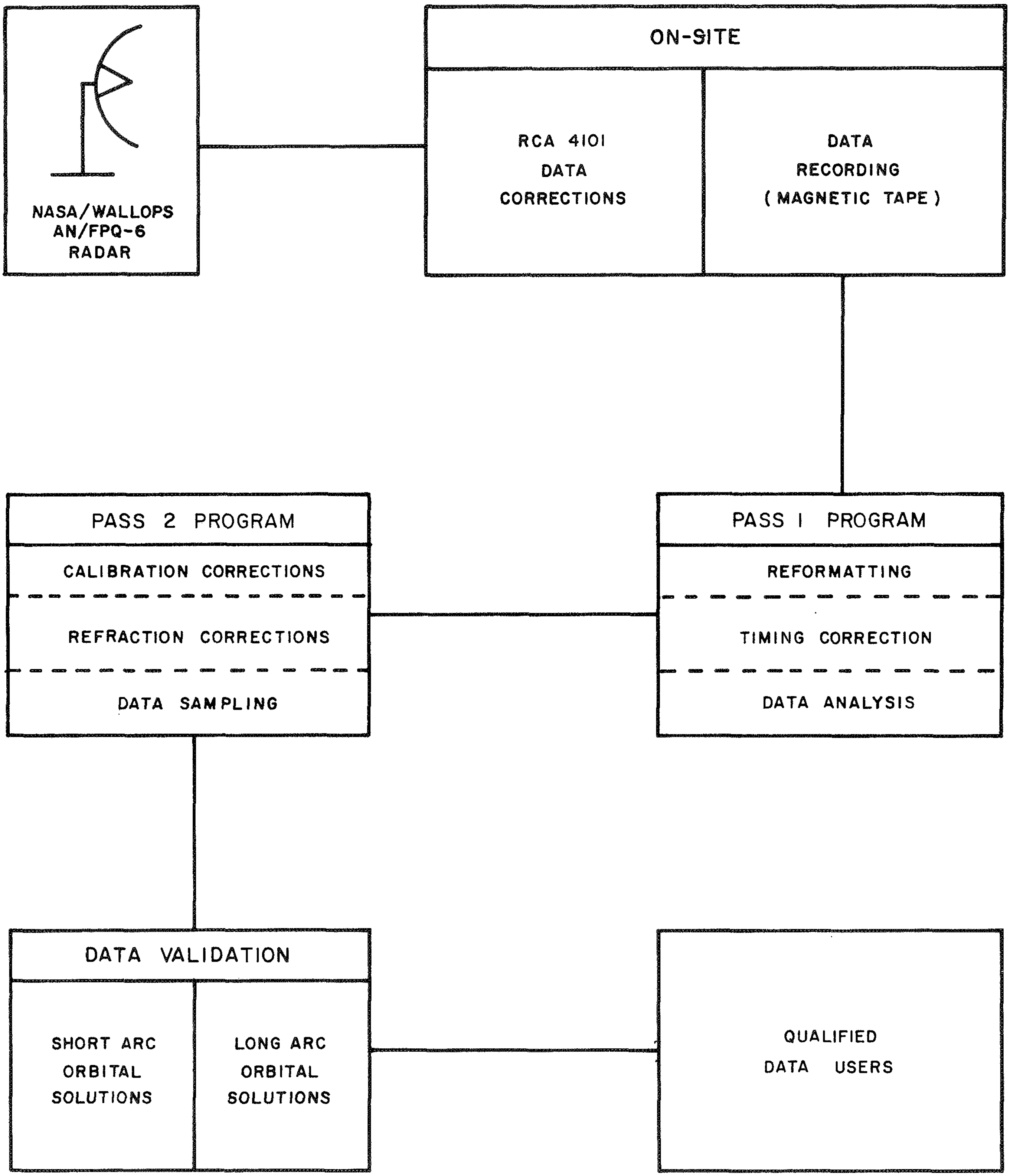



Figure 1

Generalized Flow Chart
AN/FPQ-6 DATA PRE-PROCESSING

For this project, CSP can only be used in the skin track mode since a coherent beacon is not available on GEOS-II. The AN/FPQ-6 provides:

| Measurement | Binary Bits | Least Count (Approx.) |
|---|---|---|
| Range Data | 25 | 1.95 yards |
| Range Rate Data | 20 + sign | 0.03125 yds/sec. |
| Azimuth/Elevation Data | 20 | 1.24 arc-sec. |

### 1.2.2 Site Survey Information

The AN/FPQ-6 site is located within the NASA Wallops complex in northern Accomack County, Virginia (see map, Figure 2).

#### 1.2.2.1 North American Datum

1.2.2.1.1 Survey. The Wallops AN/FPQ-6 site was most recently surveyed in March of 1968 by the Field Facilities Branch, STADAN Operations Division, NASA - Goddard Space Flight Center. The position and description of the AN/FPQ-6 site as determined by this survey appears in Figure 3.

Reference 1 states that the survey was performed at night using Wild T-3 theodolites to measure the horizontal angles and an AGA Model 6 Geodimeter to measure the distances between the stations.

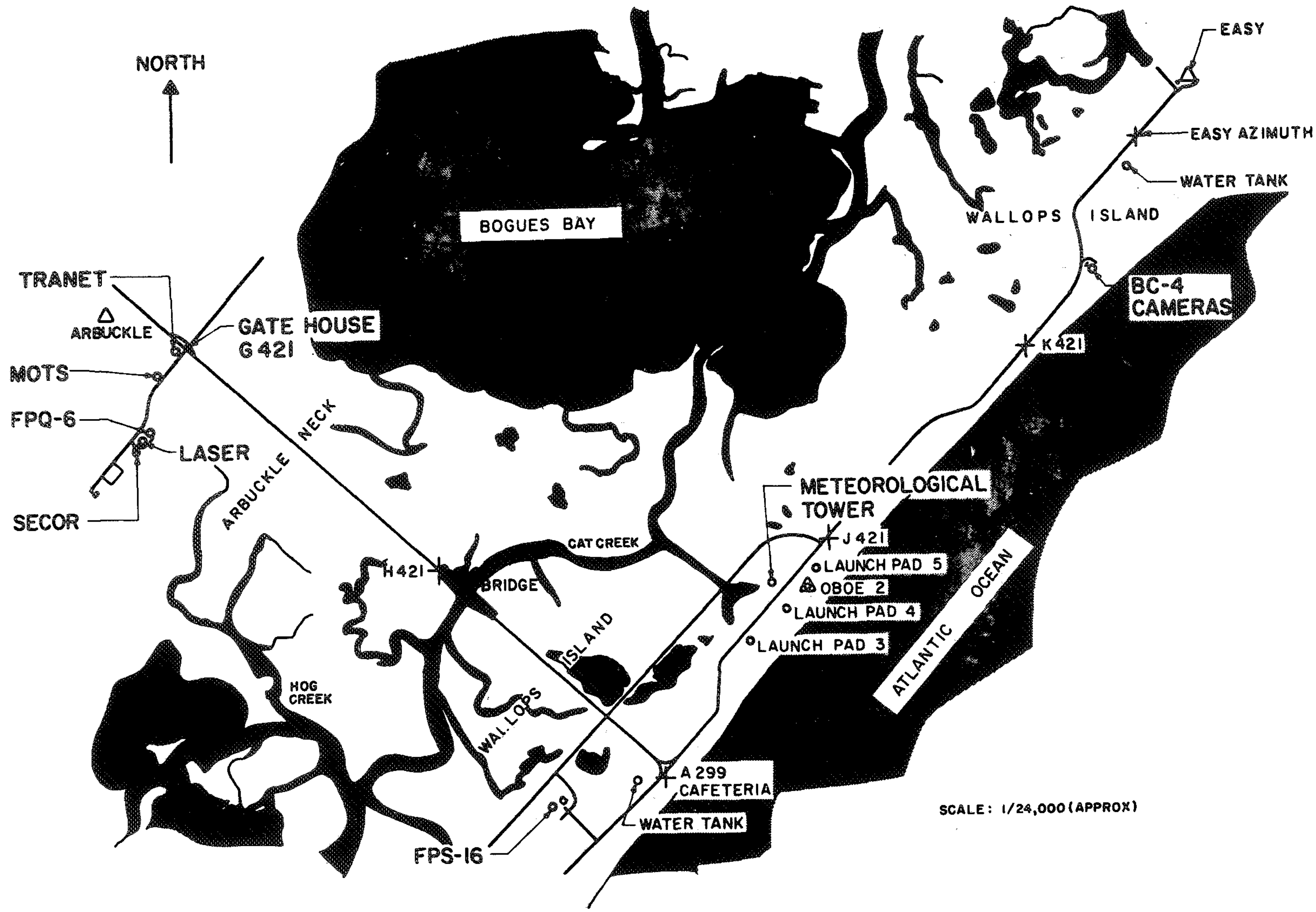



Figure 2 Layout of Wallops Island Collocation Experiment Systems and Geodetic Control

POSITION AND DESCRIPTION OF SURVEY STATION

| COUNTRY | TYPE OF MARK | STATION | |
|---|---|---|---|
| United States | Center of Rotation | NASA/Wallops FPQ-6 Pulse Radar First Order | |
| LOCALITY: Wallops Island, Va. | STAMPING ON MARK: None | AGENCY (CAST IN MARK): None | ELEVATION: 49.060 FEET / 14.953 METERS |
| LATITUDE: N 37° 51' 36".509 | LONGITUDE: W 75° 30' 34".764 | DATUM–ELLIPSOID: NAD 1927 Clarke 1866 | ORDER: Third |
| LATITUDE | LONGITUDE | DATUM–ELLIPSOID | DATUM: SLD 1929 |
| NORTHING | EASTING | GRID AND ZONE | ESTABLISHED BY – AGENCY – DATE: NASA/GSFC 3/68 |
| NORTHING | EASTING | GRID AND ZONE | |

TO OBTAIN GRID AZIMUTH, ADD

| OBJECT | (GEODETIC) AZIMUTH | BACK AZIMUTH | GEOD. DISTANCE (M) | GRID DISTANCE (M) (FT) |
|---|---|---|---|---|
| Bridge | 297-59-02.43 | 117-59-44.75 | 1908.898 | |
| | | | | |
| ARBUCKLE | 159-56-42.39 | 339-56-36.39 | 696.220 | |
| | | | | |
| | | | | |
| | | | | |
| | | | | |
| | | | | |
| | | | | |
| | | | | |
| | | | | |
| | | | | |
| | | | | |

NASA/Wallope FPQ-6 Pulse Radar is located at the FPQ-6 facility of the NASA Wallops Island, Va. facility. The station is the centers of rotation of the azimuth and elevation axes of the antenna.

To reach from the main gate of the Wallops Island facility proceed south-west 0.35 mile along blacktop road to the entrance to the FPQ-6 facility on the southeast side of the road. The antenna is located at the north-east end of the FPQ-6 operations building.

FIGURE 3

The geodetic survey diagram is superimposed on the locale map, Figure 2. The survey was tied into USC & GS first-order triangulation stations EASY, TESTCELL, and ARBUCKLE, using Assateague Lighthouse as an azimuth check. Station BRIDGE was established during this latest survey to provide intervisibility between stations TESTCELL, EASY, and the AN/FPQ-6 site. The NASA-GSFC Field Facilities Branch's position and description of station BRIDGE appears in Appendix A. The USC & GS positions, descriptions, and recovery notes for stations TESTCELL, EASY, and ARBUCKLE also are contained within Appendix A.

For height determination at the intersection of the azimuth and elevation axes, level lines were carried from USC & GS benchmarks "G 421 1963", "A 299 1949", "NACA 3 2 1963" and "K 421 1963". Appendix A contains the heights and descriptions of these benchmarks.

1.2.2.1.2 Positional Accuracy. Although survey stations EASY and TESTCELL were in very good agreement, closures at station ARBUCKLE were all in error approximately 11 centimeters in latitude and 7 centimeters in longitude indicating that the station marker may have been disturbed. Consequently, the geodetic position for the AN/FPQ-6 site was obtained by traverse circuits from EASY and TESTCELL. The evaluation of the accuracies for this computation is as follows:

| | |
|---|---|
| Maximum adjustment to geodimeter distances | 5.55 cms |
| Average adjustment to geodimeter distances | 1.45 cms |
| Probable Error | 1.45 cms |

| | |
|---|---|
| Maximum adjustment to angles | 2.50 sec |
| Average adjustment to angles | 0.90 sec |
| Probable Error | 0.80 sec |

1.2.2.1.3 Ellipsoidal Height. The geoid separation at this latitude and longitude is -2.0 meters, interpolated from Fischer's (1967) geoid contour maps for the North American Datum (see reference 2). Therefore, the geodetic coordinates on the Clarke 1866 ellipsoid for the AN/FPQ-6 radar at the intersection of the azimuth and elevation axes are:

| | |
|---|---|
| Latitude | 37° 51' 36".509 |
| Longitude (E) | 284° 29' 25".236 |
| Height (meters) | 12.95 |

1.2.2.2 SAO C-5 Datum

For the purpose of long - and short-arc reduction and data validation, the NAD position was transformed (see reference 3) to the SAO C-5 datum:

| | |
|---|---|
| Latitude | 37° 51' 36".353 |
| Longitude (E) | 284° 29' 25".851 |
| Height (meters) | -42.27 |

1.2.2.3 Mercury Datum

For completeness, the NAD position was transformed to the MERCURY datum:

| | |
|---|---|
| Latitude | 37° 51' 36".825 |
| Longitude (E) | 284° 29' 26".481 |
| Height (meters) | 16.40 |

### 1.2.3 General Radar Capabilities

The AN/FPQ-6 radar was designed and built by RCA specifically for precision/long range tracking detection, acquisition and precise continuous non-ambiguous measurement of the position in space of missiles and space vehicles. The primary function of this instrumentation radar is to supply highly accurate spherical coordinate information on long range high velocity targets.

This system is integrated with the Wallops range instrumentation complex and has the capability to reformat digital information to be transmitted via high and low speed teletype lines to a world wide tracking network.

Data obtained from this installation is utilized at Wallops for three main purposes. First for range safety target trajectory analysis, real-time impact prediction computations, and plotboard data display. Second for data acquisition as prescribed by the various range users. And third, for furnishing in-flight acquisition data to other Wallops instrumentation.

The plan view of the AN/FPQ-6 radar main enclosure at Wallops Station is shown in Figure 4.

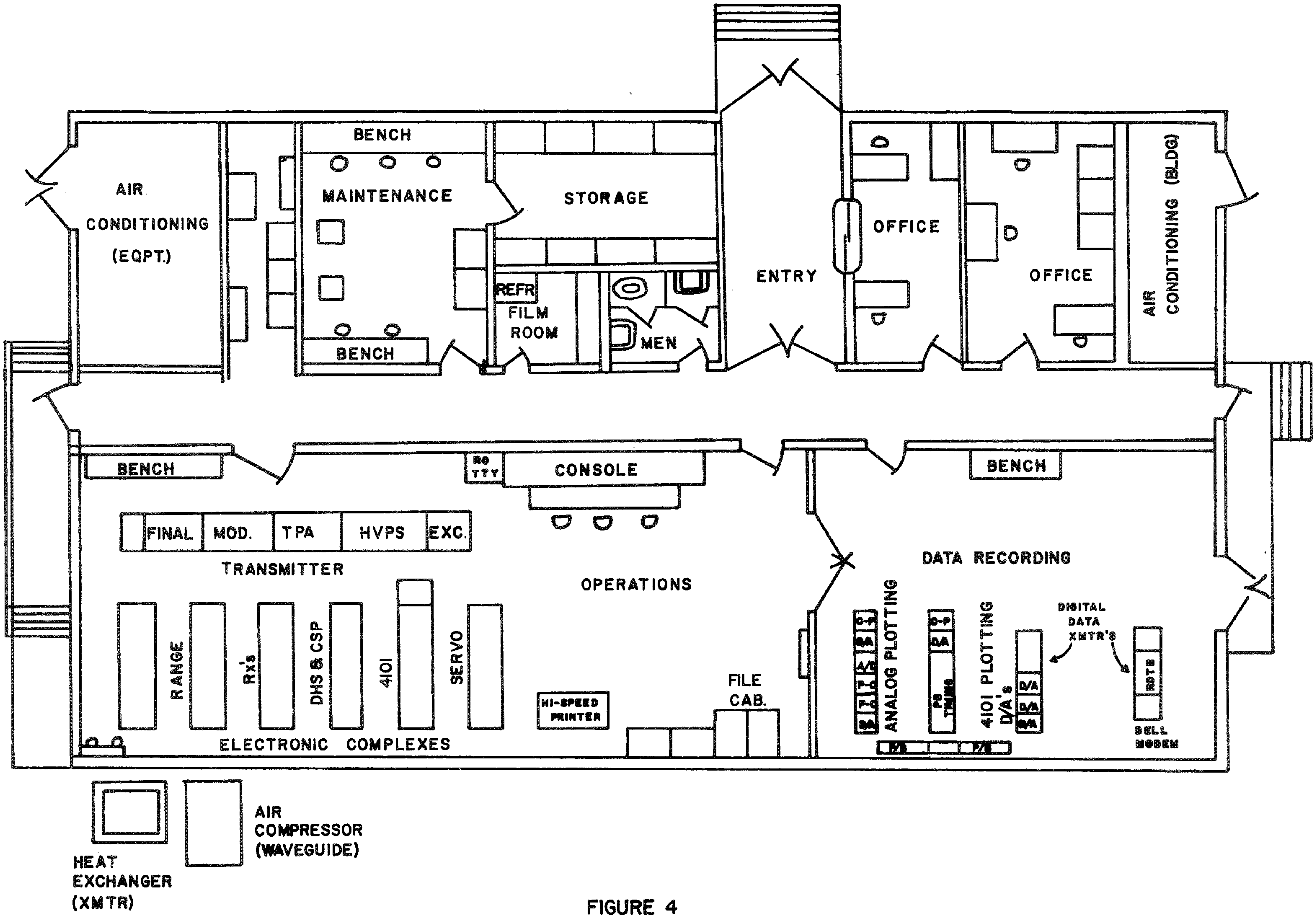



FIGURE 4
AN/FPQ-6 RADAR
**MAIN ENCLOSURE**

# SECTION 2.0
# RADAR OPERATIONS

## 2.1 AN/FPQ-6 TECHNICAL CHARACTERISTICS

### 2.1.1 Transmitting System

| | |
|---|---|
| Frequency: | C-Band 5400 to 5900 MHz |
| Frequency Accuracy: | 1 Part in $10^9$ Per Day |
| Frequency Resolution: | 243 KHz |
| Peak Power Output: | 3 Megawatts |
| Output Power Tube: | SAC-225 Klystron |
| Pulse Width: | 0.25, 0.5, 1, and 2.4 Microseconds |
| Pulse Shape: | Rectangular |
| PRF: | 160 and 640 Normal Nth Time Track<br>142, 233, 285, 341, 366, 1280, and 1707 Available |
| Coding Capability: | 1 to 5 Pulses |
| Power Programmer: | 0 to 30 db |
| Line Loss: | 2.6 db |
| VSWR: | 1.25 |
| Duty Cycle: | 0.0018 Maximum |

### 2.1.2 Receiving System

| | |
|---|---|
| Frequency: | C-Band 5400 to 5900 MHz |
| I.F.: | 30 MHz |
| Bandwidth: | 4.8, 2.4, 1.6, 0.5 Automatically Selected as a Function of PW or Manually Selected |
| Dynamic Range: | 120 db |
| Noise Figure: | 4 db |

| | |
|---|---|
| Sensitivity: | -113 dbm |
| Type: | Superheterodyne |
| Low Noise Device: | Parametric |
| Image Rejection: | Yes (Mixer) |
| Power Programmer: | 0 to 50 db |
| Line Loss: | 2.3 db |
| Tracking Gates: | 0.75, 1, 1.7, 4.0 Microseconds |

2.1.3 Antenna System

| | |
|---|---|
| Reflector: | 29-foot Cassegrainian Parabola |
| Beamwidth: | 0.4° (Half Power Points) |
| Focal Length: | 8 Feet |
| Beam Crossover: | 0 db |
| Gain: | 51 db |
| Capture Area: | 14.88 Square Meters |
| First Side Lobe Location: | 11 Mils Approx. |
| Second Side Lobe Location: | 24 Mils Approx. |
| First Side Lobe Height: | 16.5 db Down |
| Null Depth: | 35 db (Minimum) |
| Polarization: | Vertical or Circular |
| Antenna Temperature: | 26° K (Dark Sky) |
| Type Scan: | Monopulse |
| Type Feed: | 5 Horn |
| Type Transmission Line: | Rectangular Waveguide RG-49u |
| Azimuth Coverage: | 360° Continuous |
| Elevation Coverage: | -2° to +182° |
| Azimuth Tracking Rate: | 28°/Sec. |
| Elevation Tracking Rate: | 28°/Sec. |
| Azimuth Slew Rate: | 28°/Sec. |
| Elevation Slew Rate: | 28°/Sec. |

### 2.1.4 Ranging System

| | |
|---|---|
| Maximum Range: | 32,768 Nautical Miles (Nonambiguous) |
| Minimum Range: | 600 Yards |
| Master Oscillator Frequency: | 81.96427 KHz |
| Oscillator Stability: | 1 Part in $10^7$ |
| Tracking Gates: | 0.75, 1, 1.7, 4.0 Microseconds |
| Range Tracking Rate: | 20 K Yards/Sec. |
| Range Slew Rate: | 240 K Yards/Sec. |
| Bandwidth: | 16 Hz Maximum |
| Acceleration: | 20 K Yards/$Sec^2$ (Range) |
| Range Tracking: | Manual, Automatic, Rate Aided and Coast |

### 2.1.5 Other System Facts

| | |
|---|---|
| Skin Track Range (1 Sq. Meter) | 708 Naut Miles |
| Range Precision: | $\pm$ 3 Yards (RMS) |
| Angle Precision: | $\pm$ 0.05 Mils (RMS) |
| Synchro Output (Angles): | Size 23: 1:1, 1:1, 1:16, 1:36 |
| Synchro Inputs (Angles): | Size 23: 1:1 |
| Boresight System: | TV Camera with 40" or 80" FL |
| Target Acquisition Systems: | Open Sight (Mark 51),<br>Digital Designate from other radar systems<br>Milgo Analog Slaving from other radar systems<br>Orbital Elements Designation from 4101 Computer |

### 2.1.6 Data Systems

| Digital | Magnetic Tape Recorder |
|---|---|
| Range (Digital): | 25-bits Binary |
| Range Rate: | 20-bits Binary |
| Azimuth Encoder: | 20-bits Binary |
| Elevation Encoder: | 20-bits Binary |
| Timing: | Wallops Fast Time Code (36-bit BCD) |
| TTY Time, Range, El, Az, Events: | 10 Frames/Min. |
| High Speed Data: | 10 Frames/Sec. |
| Sample Rate: | 1, 10, and 20 pps |
| Range Granularity: | 1.953125 Yards |
| Range Rate Granularity (Doppler): | 0.03125 Yards/Sec. |
| Angle Granularity: | 0.006103515625 Mils |
| AGC Voltage: | 7 bits Binary Plus Sign |
| Azimuth Error Voltage: | 9 bits Binary Plus Sign |
| Elevation Error Voltage: | 9 bits Binary Plus Sign |
| AGC Voltage Granularity: | 0.061035472 Volts |
| Azimuth Error Voltage Granularity: | 0.061037182 Volts |
| Elevation Error Voltage Granularity: | 0.061037182 Volts |
| Angle Error Voltage Gradient: | 10 Volts per Mil |

| Analog | Sanborn Strip Chart |
|---|---|
| AGC Voltage: (Gross) | 0 db Signal/Noise Ratio to Saturation |
| (Fine Line) | -12 db to noise |
| Azimuth Error Voltage: | ±1 Mil Full-Scale |
| Elevation Error Voltage: | ±1 Mil Full-Scale |

| <u>Analog</u> | <u>Sanborn Strip Chart</u> |
|---|---|
| Timing: | Wallops Slow Time Code (28-bit BCD) |
| Events: | 24 Channels |
| Chart Speed: | 0.25 to 100 mm/Sec. in 9 Steps |
| Radar Mode: | Auto (Channel #11) |

## 2.2 TIMING

### 2.2.1 Introduction

The Wallops Station master clock system generates coded timing pulse trains which are transmitted by telephone lines to the AN/FPQ-6 and other Wallops Station sites. Figure 5 illustrates the timing flow from the master clock to the AN/FPQ-6 site.

### 2.2.2 Wallops Station Master Clock System

The master clock system, also known as the Time-of-Day Code Generator, is physically located in building N-159 of Wallops Station. The generated time can be derived from either a cesium beam standard or an ultra-stable quartz crystal oscillator synchronized with WWV emitted (UTC).

The cesium beam standard clock has been initially synchronized with the U.S. Naval Observatory timing system and is within ± 50 microseconds of USNO time. It serves as the reference oscillator for the Wallops Time-of-Day system or it may also be transported to a remote site for timing purposes. The cesium beam standard is transported to the U.S. Naval Observatory at approximately three-month intervals to insure that the oscillator drift has not been sufficient to cause significant biases in the Wallops timing system. Previous tests conducted with the USNO atomichron have indicated a drift of approximately 1 μsec per month in the Wallops Station cesium beam standard.

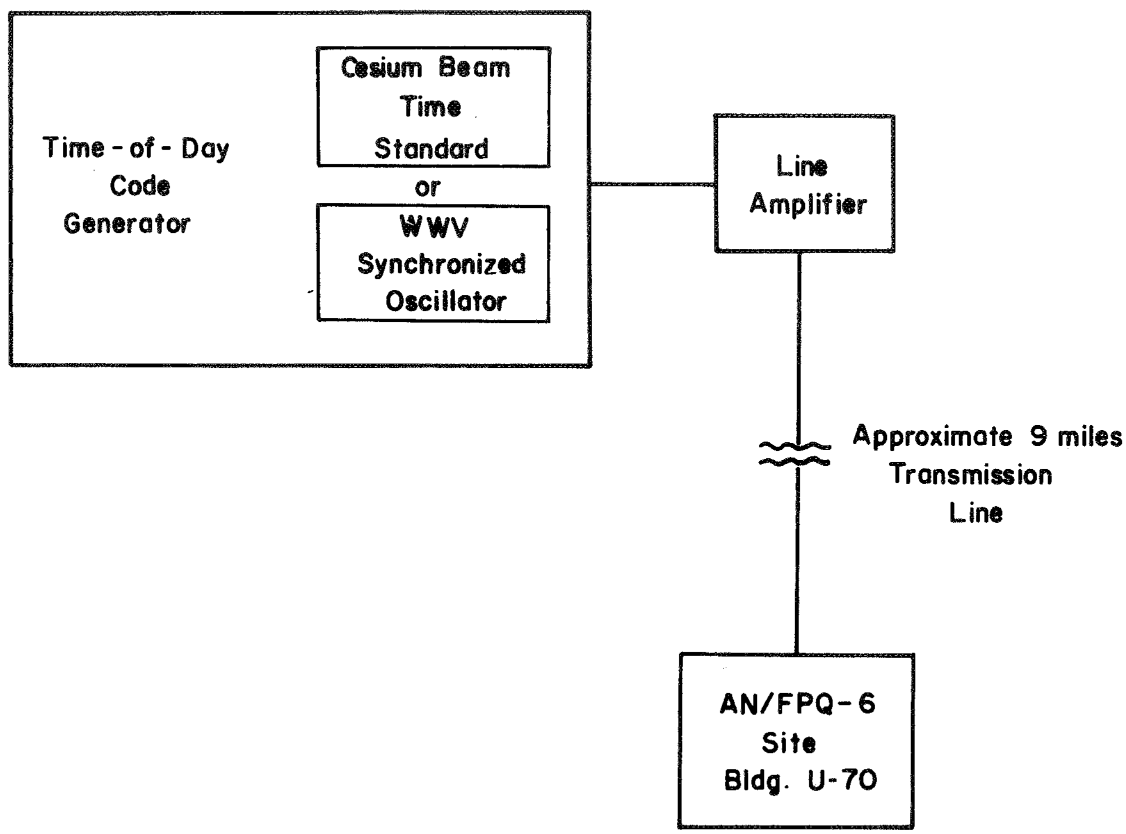



FIGURE 5

TIME FLOW AT WALLOPS STATION

The WWV - synchronized oscillator has a nominal WWV propagation delay of 9.0 milliseconds applied to the generated time. Whenever this oscillator is employed as the reference for the Time-of-Day Code Generator, the offsets between it and the cesium beam clock are recorded daily.

These two reference oscillators are capable of generating the following two time codes to be transmitted serially to the various remote sites:

a. Fast Code - 36 bit 100 pps time of year code (UTC) in seconds, minutes, hours, and day of year.

b. Slow Code - 28 bit 2 pps time of year code (UTC) in minutes, hours, and day of year.

Both the above codes are on a modulated 1000 Hz carrier using 3:1 amplitude-width modulation in binary form. The time code formats are shown in Figure 6. The time codes are transmitted approximately nine miles to the AN/FPQ-6 site.

### 2.2.3 Data Time Tags

At the AN/FPQ-6 site (Bldg. U-70), the Slow Code time pulses are used in auxiliary equipment, such as the Sanborn strip chart recorder (see reference 4).

The time tags on the digitally recorded radar data measurements are generated from the Fast Code time pulse which have been altered by the radar timing hardware. The AN/FPQ-6 radar range, azimuth, elevation, and range-rate

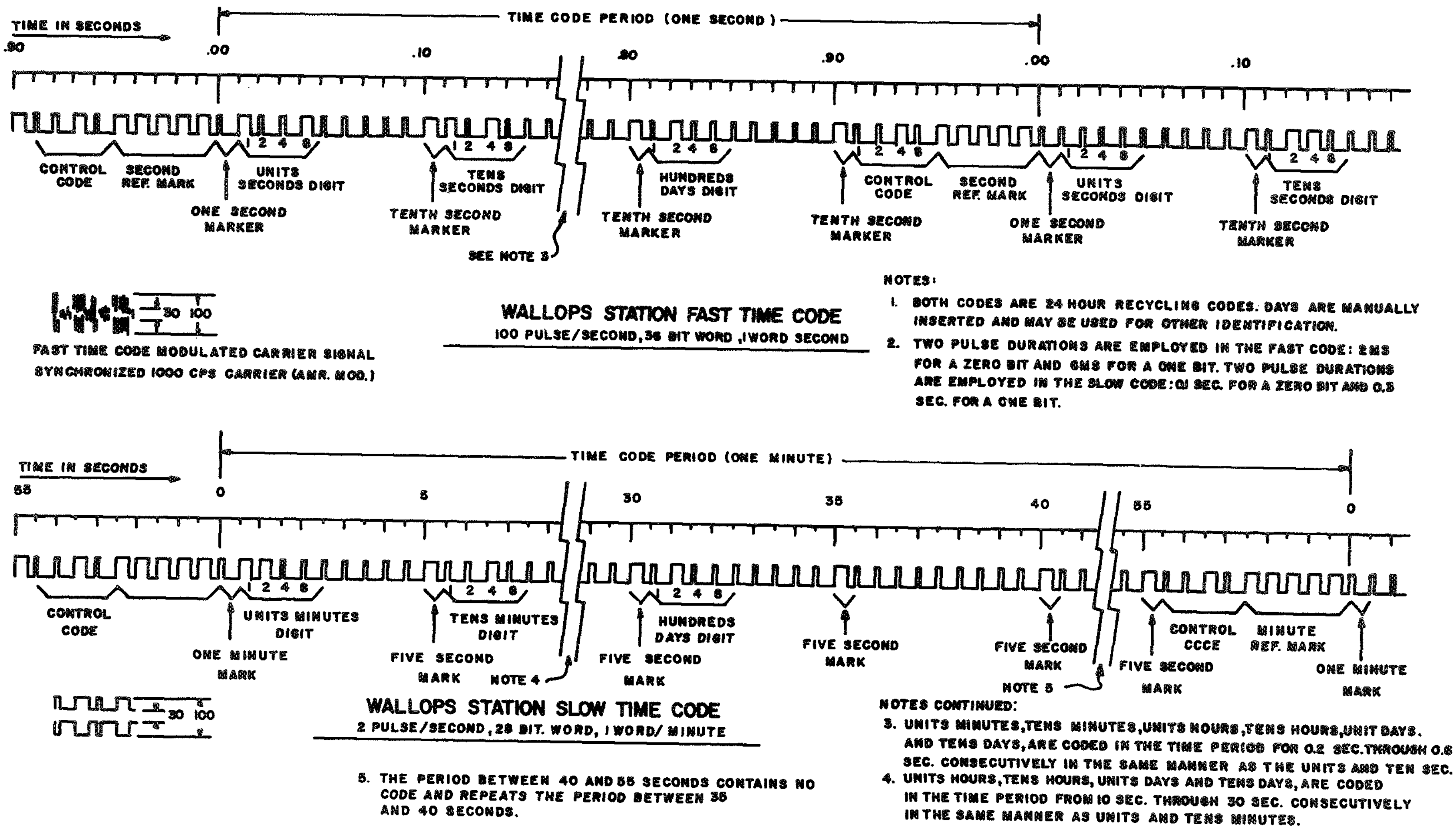


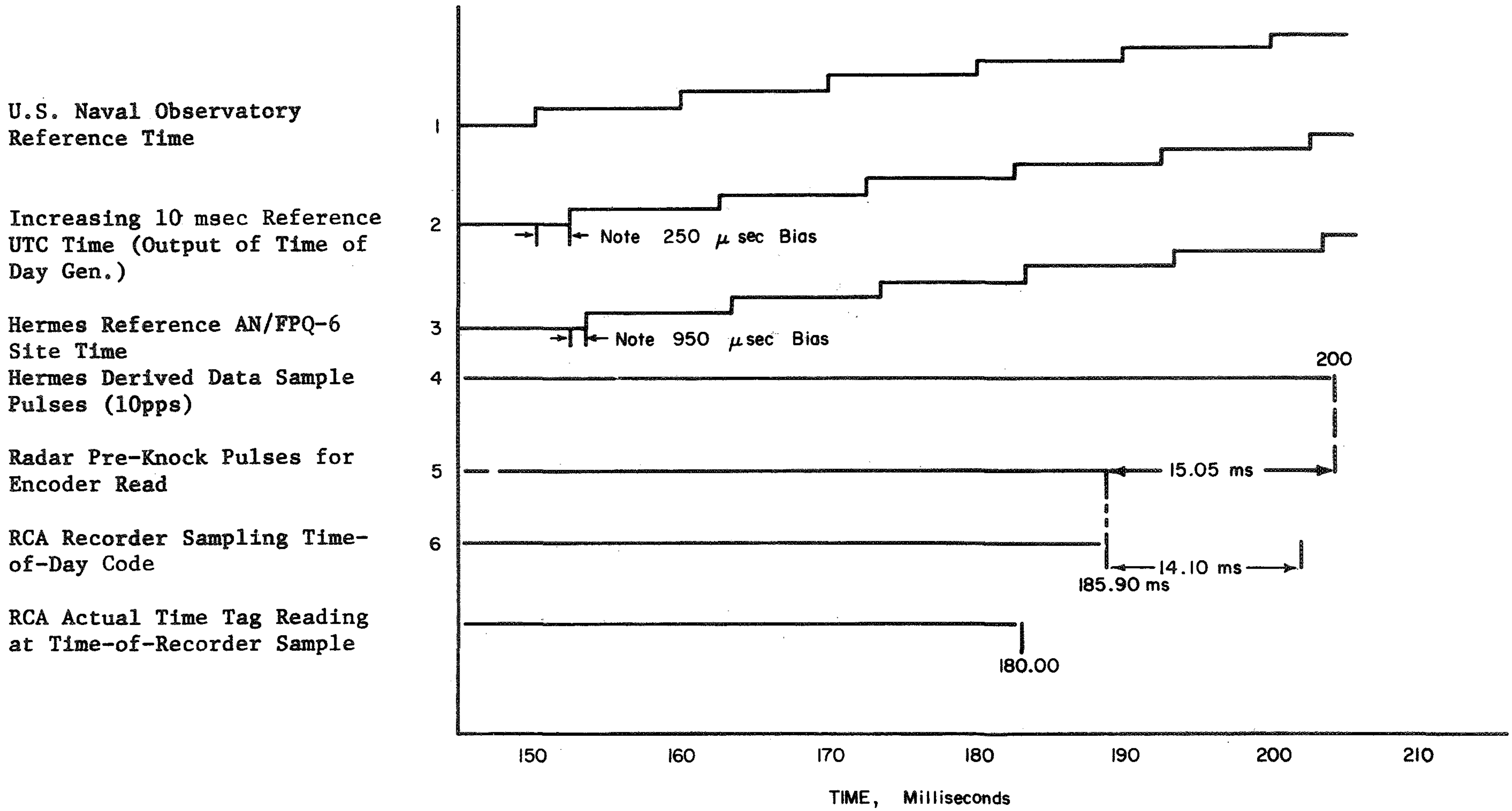

Figure 6 TIME-CODE FORMATS

data are recorded on magnetic tape. This data is normally sampled at 100 millisecond intervals and is correlated with concurrently recorded time information. There are two systems for recording the data, each with unique timing considerations. The preferred system employs the RCA recorder; and the alternate system utilizes the MILGO recorder. Only the RCA recorder system is discussed in this report.

The received TOD pulse is used by the AN/FPQ-6, 4101 Hermes system to time tag the R, Az, El data at the site. The procedures and circuitry used in tagging data biases the time tag by -5msec. ± 5μsec. See AN/FPQ-6 Timing Diagram, Figure 7. The time is further biased by -0.9msec., the transmission delay between the TOD and the AN/FPQ-6 site. These two biases have been accurately determined and are properly accounted for in the PASS 1 program (see Section 3.2).

Diurnal variations are measured and recorded daily at the master site by direct comparison of the TOD oscillator and the cesium beam standard. The log indicates that this variation can range from 43 to 300μs (measurement accuracy ± 3 μsec). At GEOS-II satellite ranges, this time tag error could cause up to ≅ 1 yd. error in range. The diurnal variations are not accounted for in the pre-processing.

The known AN/FPQ-6 timing errors and their sources are presented in Table 1.




## FPQ-6 TIMING DIAGRAM

Figure 7

NOTE:

1. Since all encoders are read at pre-knock time all recorded time should be corrected to the UT-C Time-of-pre-knock, i.e.:
   RCA True Time = RCA Recorded Time + 5.9 msec.

2. Under the conditions where 4101 Computer corrections are not desired data may be recorded without pre-knock.

TABLE 1
AN/FPQ-6 TIMING ERRORS

| TIMING ERRORS | REFERENCE | BIAS (Approximate) | NOISE | MEASUREMENT INTERVAL |
|---|---|---|---|---|
| U.S. Naval Observatory Wallops Cesium Standard | Errors are systematic but until trends can be fully studied they will be considered as noise. The Cesium standard is carried to the U.S. Naval Observatory for bias comparison. | 0μsec | ±1μsec | Quarterly |
| Wallops Time of Day Generator | Bias shifts each time the Cesium standard is removed and re-inserted as the reference oscillator to the Time of Day Generator. The ±1μsec is the variation in the Time of Day Generator circuitry comparing its output with the Cesium standard input. | 50μsec | ±1μsec | Daily |
| Cable Delay and Pre Knock Delay | The total delay from the output of the Time of Day Generator to the encoder sample pulses. These same pulses sample Time of Day for recording and are late by the bias indicated. The bias is measured by taking the Cesium standard out to the site and comparing it with the encoder sample pulses in a Time Delay Interval Unit. When this is done the Time of Day Code Generator is referenced back to its internal oscillator. The bias of the Time of Day Code Generator is measured with the Cesium standard before it is taken out to the radar site. | 5910μsec | ±5μsec | Monthly |
| FPQ-6 Time Correction | Total | 5960μsec | ±7μsec | |

## 2.3 CALIBRATION PROCEDURES

### 2.3.1 Mission By Mission Calibrations

Static calibration of the AN/FPQ-6 radar is performed prior to, and immediately following each mission. Identical calibration procedures are followed in both pre- and post-mission calibration. A detailed description of the mission calibration procedures is given in Reference 5.

The 4101 Recorder is used during each pre- and post-mission calibration with a standard sampling rate of 10 pps. The 4101 Recorder records model number, ID word, time, range, azimuth, elevation, range rate, AGC Voltage, $V_a$ and $V_e$ (lag error corrections). This 4101 format is described in Appendix B.

It is assumed that the antenna is properly aligned prior to mission setup. This means that the RF Axis is aligned parallel to the Optical Axis and the Optical Axis is aligned with the Mechanical Axis. The 4101 Recorder is run for approximately 10 seconds (100 data points) in each of the following positions:

- Boresight Tower Normal - electrically locked to the boresight tower (BST) in azimuth and elevation. Static correctors are on.

- Boresight Tower Plunged - same set-up as for BST Normal except antenna in plunged mode. Static correctors are on.

- Range Target Skin Gate - lock onto the range target using the skin L.O. The skin gate range displays should indicate surveyed range.

Range Target Beacon Gate - If a transponder track is planned, the proper delay compensation is set into the beacon gate range system. The beacon gate range displays should then read the surveyed range minus the beacon gate.

The digital recorder code sheet, Figure 8, identifies the appropriate model numbers for the pre/post calibration data to be used for subsequent data analysis and correction.

In conjunction with the normal range and angle calibration procedures, an AGC step calibration is normally performed for each pre- and post-mission. The calibration is referenced to a zero db signal (i.e., one whose power is equal to that of the noise power). Although zero db is determined using a CW signal from the signal generator, the pulse mode is used for the actual recorder step-calibration. Basically, the method employs a power meter as an indicator, and a 3 db pad as the actual calibrating device. A measurement is taken on the power meter of the noise energy from the receiver without any signal applied. The 3 db pad is then added to the input to the power meter, and the CW signal applied to the receiver. A precision variable attenuator at the boresight tower is adjusted until the power meter again indicates the same level measured on noise alone. Next a reference reading is taken of AGC voltage with the console digital voltmeter. The boresight signal generator is switched to pulse mode, and with the radar locked on to the pulsed signal, the attenuator at the boresight tower is adjusted to give the same

FIGURE 8

DIGITAL RECORDER CODE SHEET

RADAR____________________ MODEL #______________ DATE__________________

1) Record minimum of 100 samples for each function.
2) Prior to running each function, set Model number as per code below.
3) After running each function, circle code number with pen or pencil.
4) Enclose this sheet, inside tape can, as part of mission data.
5) After each lock-on of tower, delay recording of data for 5 seconds to allow for the servo to settle out.

ROUTINE CALIBRATIONS (PRE CAL - 100 SERIES/POST CAL 200 SERIES)

| PRE | POST | FUNCTION | PRE | POST | FUNCTION |
|---|---|---|---|---|---|
| 101 | 201 | LOCK-ON-NOISE | 125 | 225 | RANGE TARGET - SKIN GATE |
| 102 | 202 | 0 DB | 126 | 226 | RANGE TARGET - BEACON GATE |
| 103 | 203 | 3 DB | EOF | | |
| 104 | 204 | _______________ DB | 127 | 227 | AZIMUTH - ONE MIL LEFT |
| 105 | 205 | 5 DB | 128 | 228 | AZIMUTH - ONE MIL RIGHT |
| 106 | 206 | 6 DB | 129 | 229 | ELEVATION - ONE MIL BELOW |
| 107 | 207 | _______________ DB | 130 | 230 | ELEVATION - ONE MIL ABOVE |
| 108 | 208 | _______________ DB | EOF | | |
| 109 | 209 | _______________ DB | 131 | 231 | XMTR - ATTN OUT |
| 110 | 210 | 10 DB | 132 | 232 | XMTR - _____ % PWR |
| 111 | 211 | 15 DB | 133 | 233 | XMTR - _____ % PWR |
| 112 | 212 | 20 DB | EOF | | |
| 113 | 213 | 25 DB | 134 | 234 | RCVR - ATTN OUT |
| 114 | 214 | 30 DB | 135 | 235 | RCVR - _____ DB ATTN IN |
| 115 | 215 | 35 DB | 136 | 236 | RCVR - _____ DB ATTN IN |
| 116 | 216 | 40 DB | 137 | 237 | RCVR - _____ DB ATTN IN |
| 117 | 217 | 45 DB | EOF | | |
| 118 | 218 | 50 DB | 138 | 238 | TEST ROCKET |
| 119 | 219 | 55 DB | EOF | | |
| 120 | 220 | 60 DB | 139 | 239 | SPHERE TRACK |
| 121 | 221 | 65 DB | EOF | | |
| 122 | 222 | 70 DB | 140 | 240 | CSP PLUS ONE LINE |
| EOF | | | 141 | 241 | CSP MINUS ONE LINE |
| 123 | 223 | BORESIGHT TOWER NORMAL | 142 | 242 | __________________ |
| 124 | 224 | BORESIGHT TOWER PLUNGED | 143 | 243 | __________________ |
| EOF | | | 144 | 244 | __________________ |

COMMENTS:

AGC voltage as was obtained in CW mode. The resultant attenuator setting represents zero db, or S/N = 1. The S/N is stepped-up to 70 db (see Figure 8) using model numbers 101 - 122 for pre mission calibration. The above procedures are repeated for post-mission calibration using model numbers 201 - 222.

### 2.3.2 Periodic Calibrations

The following calibration procedures are performed on a periodic basis:

- Receiver gain calibration (monthly).
- Dynamic lag calibration (monthly).
- Azimuth encoder is checked for possible bias by observing the star, Polaris (yearly).
- Pedestal leveling (monthly).
- RF axis calibration (yearly).

The calibration procedures pertinent to each calibration are described in more detail in Reference 5.

## 2.4 RADAR OPERATING MODES

### 2.4.1 Normal Radar Parameter Settings

Our present operational set-up includes three modes of operation, one for beacon mode tracking, the second for passive tracking and the third to be used when both beacon and skin track data are to be gathered on a single pass of GEOS-II. It should be emphasized that changes in the operational set-up are made only after a careful analysis of the data and the hardware system indicate that such a change will enhance the C-Band radar performance. The rationale for the current GEOS-II tracking set-up is described in the following paragraphs.

We selected a wide transmitter pulsewidth (2.4 μsec) for skin tracking since it provides signal to noise enhancement and increases the reliability of CSP tracking. For the beacon portion of beacon/skin missions we reduced the pulsewidth to 1 μsec since in the wider pulsewidth, the coding required would have caused the radar transmitter to approach its maximum duty cycle. Switching from single to double pulse operation while the radar is in this condition often causes transmitter overload. Therefore, the 1 μsec pulsewidth makes the beacon-to-skin-to-beacon transition more reliable. The AN/FPQ-6 has the capability of dual presentation of skin and beacon returns. This was omitted for all tracks and calibrations except the beacon-skin case where continuous mode was used to facilitate switching from beacon-to-skin-to-beacon.

Since the parametric amplifier systems (paramps) at the Wallops AN/FPQ-6 can be pre-set and pre-phase delay corrected to provide instantaneous switching between two frequencies, they are used in all tracking applications to avoid the possibility of changes in system alignment which may be caused by bypassing the paramps.

TABLE 2

WALLOPS ISLAND AN/FPQ-6 PRESENT RADAR SETUP

| SYSTEM PARAMETER | BEACON ONLY | BEACON/SKIN MODE | |
|---|---|---|---|
| | | SKIN PORTION | BEACON PORTION |
| PARAMPS | ON | ON | ON (BOTH) |
| PULSE WIDTH | 0.5 μsec | 2.4 μsec | 1 μsec |
| POLARIZATION | LINEAR VERTICAL | LINEAR VERTICAL | LINEAR VERTICAL |
| PRF | 160 | 640 | 160 |
| BEACON AFC | ON | OFF | ON |
| BEACON DELAY COMPENSATION | 809 yds | N/A | 809/123 yds as appropriate |
| SKIN AFC | OFF | ON | ON |
| RANGE BANDWIDTH | 4 Hz | 4 Hz | 4 Hz |
| ANGLE BANDWIDTH | Pos. #9 3.2 Hz | Pos. #9 3.2 Hz | Pos. #9 3.2 Hz |
| DATA CORRECTOR BANDWIDTH | 2 Hz | 2 Hz | 2 Hz |
| DATA RATE | 10 PPS | 10 PPS | 10 PPS |
| RECEIVER BANDWIDTH | 2.4 MC | 0.6 MC | 1.6 MC |
| BEACON GATE | ON | OFF | ON |
| BEACON LO | ON | OFF | ON |
| SKIN GATE | OFF | ON | ON |
| SKIN LO | OFF | ON (COHERENT) | ON (COHERENT) |
| DOPPLER SYSTEM BANDWIDTH | N/A | 160 Hz | 40 Hz |
| DOPPLER LO LOOP BANDWIDTH | N/A | WIDE | WIDE |
| POSITION TRACK | N/A | GROSS | GROSS |
| DOPPLER SYSTEM | N/A | ON | ON (SKIN) |
| PULSE CODER | On 2 Pulse 8 sec | OFF | On 2 Pulse 8 sec (both) |

Atmospheric phenomena can often cause conflicting re-polarization (signal fading) when systems are operated with like polarizations. To avoid the possibility of these deep signal fades, the radar is operated in linear-vertical although the transponder antenna polarization is circular.

When tracking the transponder, the radar automatic frequency control (AFC) loop uses the transponder return frequency as its reference. In the skin portion of the beacon/skin mode, the AFC references the range rate from the range system until the CSP acquires track whereupon the pulse doppler controls the loop.

The pulse repetition frequency (PRF) is held at 160 for all tracks and calibrations except skin tracking. In skin track, the 640 rate is used, since it furnishes significantly better track at low signal to noise ratio (S/N).

The general reasoning for selecting the operating servo bandwidths was based upon minimizing the combined thermal noise and dynamic lag errors in each coordinate.

The 4 Hz range-servo bandwidth was selected as the available bandwidth most closely approaching the optimum (minimum combined thermal noise and dynamic lag errors) range servo bandwidth for both the skin and beacon tracks modes of operation. Other bandwidths would have provided lower errors on specific passes but the selected bandwidth provides the best available compromise for all expected tracking conditions. The selection of a single range servo bandwidth for all tracks was deemed desirable from a data reduction and analysis point of view.

The use of single angle servo bandwidth was also deemed desirable from radar set-up and data reduction/analysis points of view. Since the primary track mode was expected to be the beacon track mode, the beacon track bandwidth requirements were first investigated. It was calculated that a minimum single-hit I.F. S/N ratio greater than 30 db would exist on all beacon tracks above 20° elevation. Under these high S/N conditions the optimum angle servo bandwidth is merely that bandwidth (servo position #9 or B.W. ≃ 3.2 Hz) which minimizes the dynamic lag error. Next, the optimum angle servo bandwidth for the skin track case was investigated (only skin tracks above 60° elevation were possible from signal-to-noise considerations). This investigation indicated that the optimum available single servo bandwidth for the skin track mode would be 1.0 Hz (B.W. position #6). The increased thermal noise error introduced by using the higher beacon track bandwidth during a relatively few skin-tracks was deemed preferable to accepting an increased dynamic lag error during beacon-tracks. This decision was consistent with the decision to avoid real-time lag-error corrections. Thus, the wide bandwidth was selected for use on all GEOS-B missions.

Throughout all operations, every effort has been made to maintain the radar set-up outlined. Any deviations from the recommended set-up in either track or calibration operations is documented so that the possible effect on the data can be evaluated and applied to the data as necessary.

### 2.4.2 Known Range Errors

#### 2.4.2.1 Effects of Parameter Settings on Radar Track

Since an important aspect of the calibration mission is the identification of sources of systematic errors, we have performed a series of radar experiments designed to assist us in determining the magnitude and sign of systematic errors in the range data. The results of these experiments are described below, and a tabulation of the errors defined to date is given in Table 3 (see ref 6). It should be noted that this tabulation is by no means comprehensive or general in nature. It defines errors which we have discovered and measured at Wallops. Some of the errors are inherent in the procedures used to gather and process the data. We are continuing the experiments to further define additional sources and expect to update our tabulation as the results of these experiments become available and are analyzed.

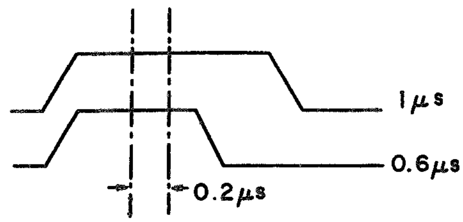
2.4.2.1.1 Pulse Width Matching. Since the AN/FPQ-6 radar is a centroid tracker, any difference in the pulsewidth used for calibration and the pulsewidth experienced in tracking will result in a range bias error. For example, for GEOS-II beacon/skin missions, the AN/FPQ-6 was calibrated using a 1 μsec pulsewidth; the beacon portion of the mission was tracked using 1 μsec pulsewidth while the actual transponder reply was 0.6 μsec. As shown below, the difference between

TABLE 3

SUMMARY OF RANGE ERROR CORRECTIONS --- - COLLOCATION TESTS 1-109
(Dependent on Wallops Calibration Methods)

| TEST DESCRIPTION | AN/FPQ-6 RADAR | | | | | | AN/FPS-16 RADAR | | REMARKS |
|---|---|---|---|---|---|---|---|---|---|
| | SKIN TRACK | | BEACON TRACK | | BEACON PORTION of Beacon/Skin Track | | BEACON TRACK | | |
| | Bias | Variation | Bias | Variation | Bias | Variation | Bias | Variation | |
| 1. RANGE OSCILLATOR DRIFT | | ± 1 yd | | ± 1 yd | | ± 1 yd | | ± 1 yd | (a) oscillator frequency measured (b) effect on Range calculated |
| 2. CALIBRATION PULSEWIDTH versus TRACK PULSEWIDTH | | | - 8.2 yds | ± 2 yds | + 31.1 yds | ± 2 yds | | | (a) Range Bias calculated from pulsewidths measured |
| 3. REFRACTION CORRECTION for Calibration (Range Target) | + 3 yds | ± 0.5 yd | + 3 yds | ± 0.5 yd | + 3 yds | ± 0.5 yd | | | (a) calculated error from normal weather conditions |
| 4. RANGE DRIFT (Warmup) | | ± 1 yd | | ± 1 yd | | ± 1 yd | | | (a) measured on Range Target |
| 5. Difference between: TRANSPONDER DELAY vs. INTERROGATION SIGNAL STRENGTH -and- DELAY VALUES used in Data Reduction — Serial No.5 (Short Delay) | | | + 0.8 yd | ± 1 yd | + 0.8 yd | ± 1 yd | | | (a) Interrogation Signal Strength computed from measured radar received signal strength (b) Delay picked from preflight measured delay curves |
| Serial No.6 (Long Delay) | | | + 0.3 yd | ± 1 yd | + 0.3 yd | ± 1 yd | | | |
| 6. UNCERTAINTY in Delay Curve Orgin | | | | ± 2 yds | | ± 2 yds | | | (a) value obtained from preflight transponder test data |
| 7. P R F CHANGE 160 (for Calibration) versus 640 (for Track) | + 4.5 yds | ± 1 yd | | | | | | | (a) measured on Range Target |
| 8. LOCAL OSCILLATOR CHANGE Continuous (for Calibration) versus Off (for Track) | | | | | + 0.5 yd | ± 0.1 yd | | | (a) measured on Range Target |
| 9. TIMING | | ± 1 yd | | ± 1 yd | | ± 1 yd | | | (a) Timing Bias measured (b) effect on Range calculated |
| 10. RECEIVER BANDWIDTH (Mismatch) | | | | | | ± 1 yd | | | (a) measured on Range Target |
| **TOTAL CORRECTIONS:** SKIN TRACK | + 7.5 yds | ± 2.1 yds | | | | | | | |
| SHORT DELAY TRANSPONDER | | | - 4.4 yds | ± 3.5 yds | + 35.4 yds | ± 3.7 yds | | | |
| LONG DELAY TRANSPONDER | | | - 4.9 yds | ± 3.5 yds | + 34.9 yds | ± 3.7 yds | | | |

the two centroids is 0.2μsec when the same leading edge is referenced.




The radar range system references the leading edge when establishing zero range with the transmitter trigger; however, the centroid is referenced when establishing target range. The 0.2μsec difference thus results in a range bias which, at the radar propagation velocity of 327.8 yards/μsec, represents 32.8 yards of range error (accounting for round-trip times) that must be added to the data to maintain calibration.

When supporting pure beacon missions, the AN/FPQ-6 was calibrated using a 0.5μsec pulsewidth, which, when compared to the transponder return of 0.6μsec, results in a range bias of -8.2 yards. A further error of the same nature could develop if the actual radar pulsewidth were different from that indicated. For example, the actual pulsewidth could be 0.98μsec when the mode selector indicates 1 μsec. This possible source is currently being investigated.

2.4.2.1.2 PRF Dependent Error. A consistent -4.5 yard difference in range between skin and beacon tracking is attributable to the fact that we calibrate at a Pulse Repetition Frequency (PRF) of 160 cps and track at 640 cps during skin missions. This dependence on PRF is possibly caused by frequency sensitivity of the radar circuitry.

2.4.2.1.3 Local Oscillator Mode Dependent Error. The radar has two independent local oscillators (LO) and range tracking gates which can be either simultaneously or independently used for skin and beacon tracking. During the pre and post mission calibration it is desirable to make measurements in both skin and beacon; therefore, the "continuous" (both LO on) condition is used. During the tracking mission only one LO is required; therefore, the "off" (one LO on) condition is selected. In this condition, the selection of the track mode chooses the appropriate local oscillator. Measurements taken on the range target indicate that this procedure produces, under certain circumstances, a range error. The cause and stability of this error have not been determined but are under study at this time.

2.4.2.1.4 Receiver Bandwidth Mismatch. The receiver bandwidth is known to be mismatched in the beacon portion of beacon/skin missions. The error caused by this mismatch has been investigated. Although detailed measurements have not been carried out, preliminary analysis has indicated that this mismatch contributes less than 1 yd. error to the beacon portion of the mission.

We have tabulated in Table 3 all of the errors investigated to date along with their sign and probable uncertainty. We must emphasize that this tabulation is not yet complete. We are continuing investigations into other probable sources of error, and we will continue to update the table as our investigations indicate.

From time to time we will evaluate the validity of the total correction by applying it to data which has already been processed and analyzed to see whether, in fact, the application of these corrections does improve the fit of the data over short and long arc passes.

2.4.2.2 Effects of Other Range Errors

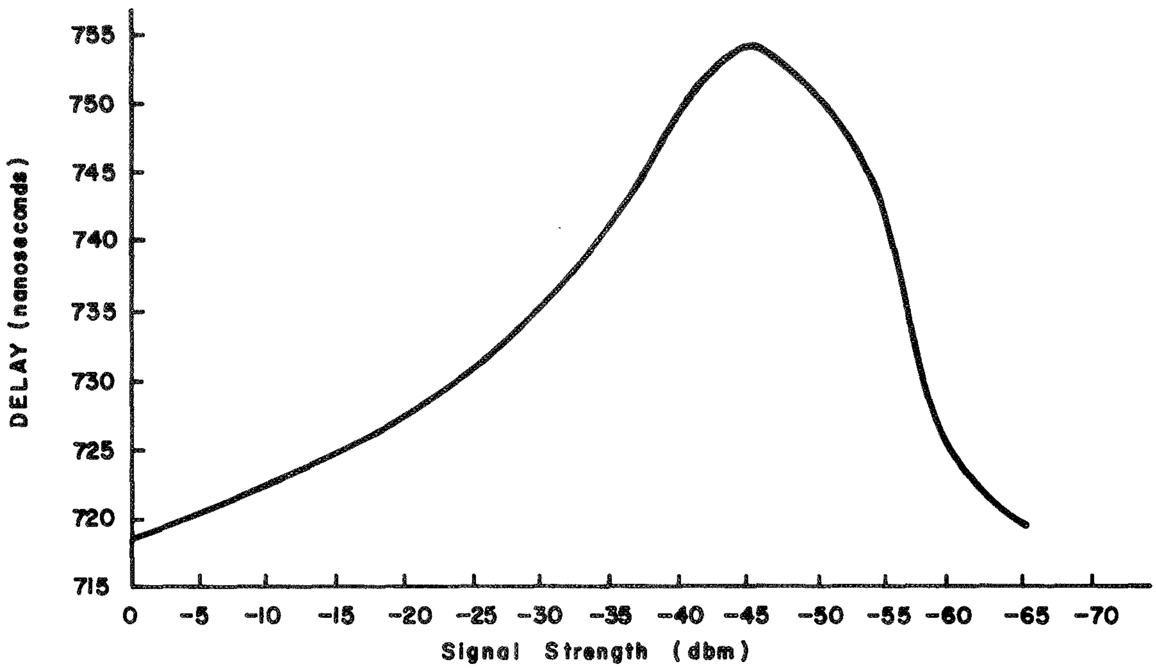
2.4.2.2.1 Timing Errors. There is a small, variable error in the time lag of the radar data which has not been accounted for in our reductions thus far. This error is due to the fact that we do not correct for diurnal variations in the "time-of-day-generator" (TODG) oscillator at the master timing site.

2.4.2.2.2 Transponder Delay vs Interrogation Signal Strength. The C-Band transponders aboard GEOS-II have delays which vary as a function of the strength of the interrogation signal. The nominal delay vs signal strength curves for each transponder are shown in Figure 9. In the pre-processing of the radar data to date we chose nominal values from the smoothed beacon curves to serve as first approximations to the true delay value. These nominal values correspond to range corrections of 123 yds. and 809 yards. The same delays were used for the AN/FPQ-6 and they correspond to range corrections of 123 yds. for the short delay transponder and 809 yds. for the long delay transponder. These delays are within the uncertainty in the shape of the delay curves (± 1 yd.).

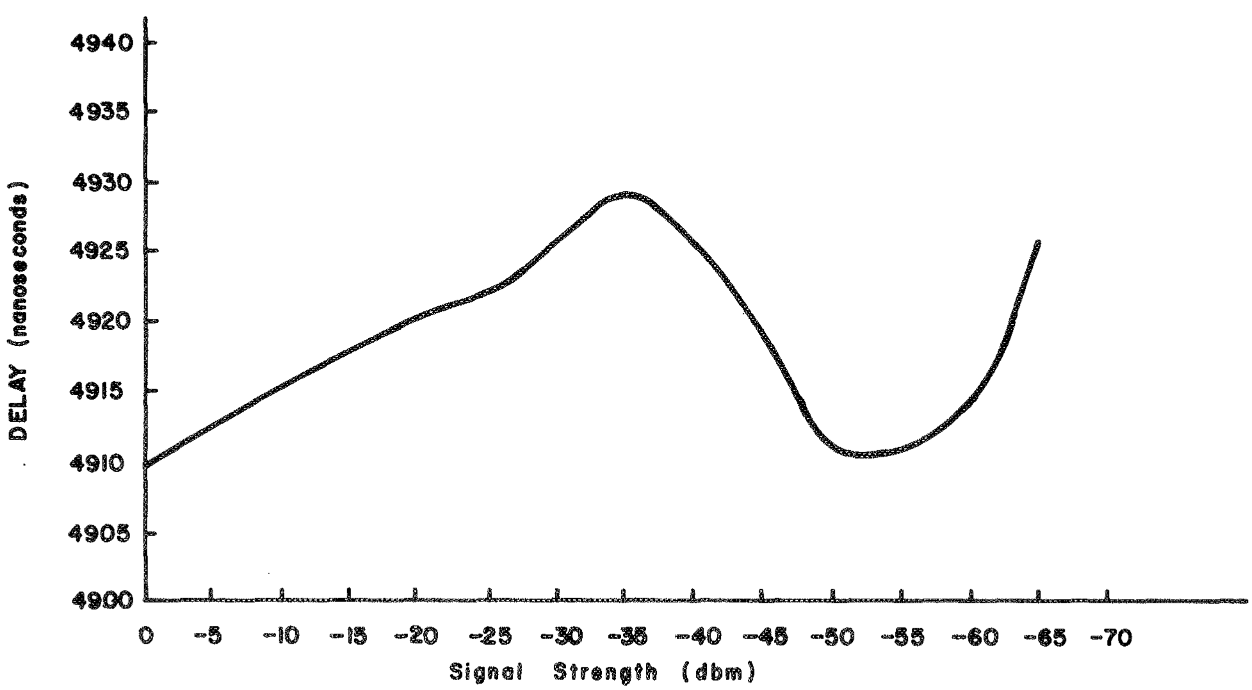
Since the same transponder, transponder antenna, radar antenna, and atmospheric losses occur in both the transmission and receiving paths of the radar track, a

FIGURE 9

TRANSPONDER DELAY CURVES




SHORT DELAY TRANSPONDER SN#5 (Beacon I)




LONG DELAY TRANSPONDER SN# 6 (Beacon 2)

better estimate of the interrogation signal strength can be obtained by studying the radar received signal strength, assuming that the transponder power output is known. We have performed this study, and the corrections indicated on Line 5 of Table 3 are the differences between the original delay estimates and the newly determined delays. Only the originally determined delay estimates have been used to date.

2.4.2.2.3 Uncertainty in Delay Curve Origin. Although the shape of the delay curves are well defined (± 1 yd.), the total delay with respect to the leading edge of the interrogation pulse was not well defined. Data taken during the flight qualification of the transponders indicates an uncertainty of ± 2 yds. in the Odbm delay point. It has not been determined whether this is a transponder problem or a limitation in the test equipment used to measure the transponder characteristics. We hope to reduce this error through the reduction and analysis of a sufficient number of AN/FPQ-6 beacon/skin tracks.

2.4.2.2.4 Refraction. The survey distance to the range target is 26,880 ft. at an elevation of .3°. At this range and elevation the distance to the range target should measure approximately 3 meters ± .5 meters longer than survey because of the effect of atmospheric refraction. No attempt has been made to correct for the error.

In addition to this error, refraction corrections to range and elevation were made using only nominal values to calculate the refractive index. No attempt has been made to use any actual meteorological data to correct for refraction errors.

2.4.2.2.5 <u>Range Drift</u>. We have compiled the pre- and post-mission range target calibration data for 109 AN/FPQ-6 tracks taken during the course of the collocation experiments at Wallops Station. Investigation of this data reveals that the pre-mission range calibrations average approximately 2 yards longer than the post-mission calibrations. We assumed that this variation was attributable to "warm-up" of the circuitry in the range system. In order to verify this assumption, an experiment was performed whereby apparent target range versus time was monitored for a period of 19 hours on 16 July 1968. The data from this experiment is plotted in Figure 10. We did not use the data obtained during the first two hours of the experiment since the radar is always warmed up for at least two hours prior to any tracking mission.

This significance of this plot is the magnitude of the drift which can occur during the time interval (approximately 1 hour) between pre- and post-calibrations. From the curve we can see that in the worst case, a 3 yard change could occur. Since we are currently averaging pre- and post-mission calibration data, the peak error will be approximately 1.5 yards.

A refined technique for weighting the pre- and post-mission calibration data as a function of their proximity to the track time should reduce this error to less than ± 0.5 yds.

2.4.2.2.6 <u>Range Oscillator Drift</u>. The AN/FPQ-6 range reference oscillator is designed to provide 2000 International yards per cycle. In order to ascertain the actual frequency of the oscillator in the AN/FPQ-6,

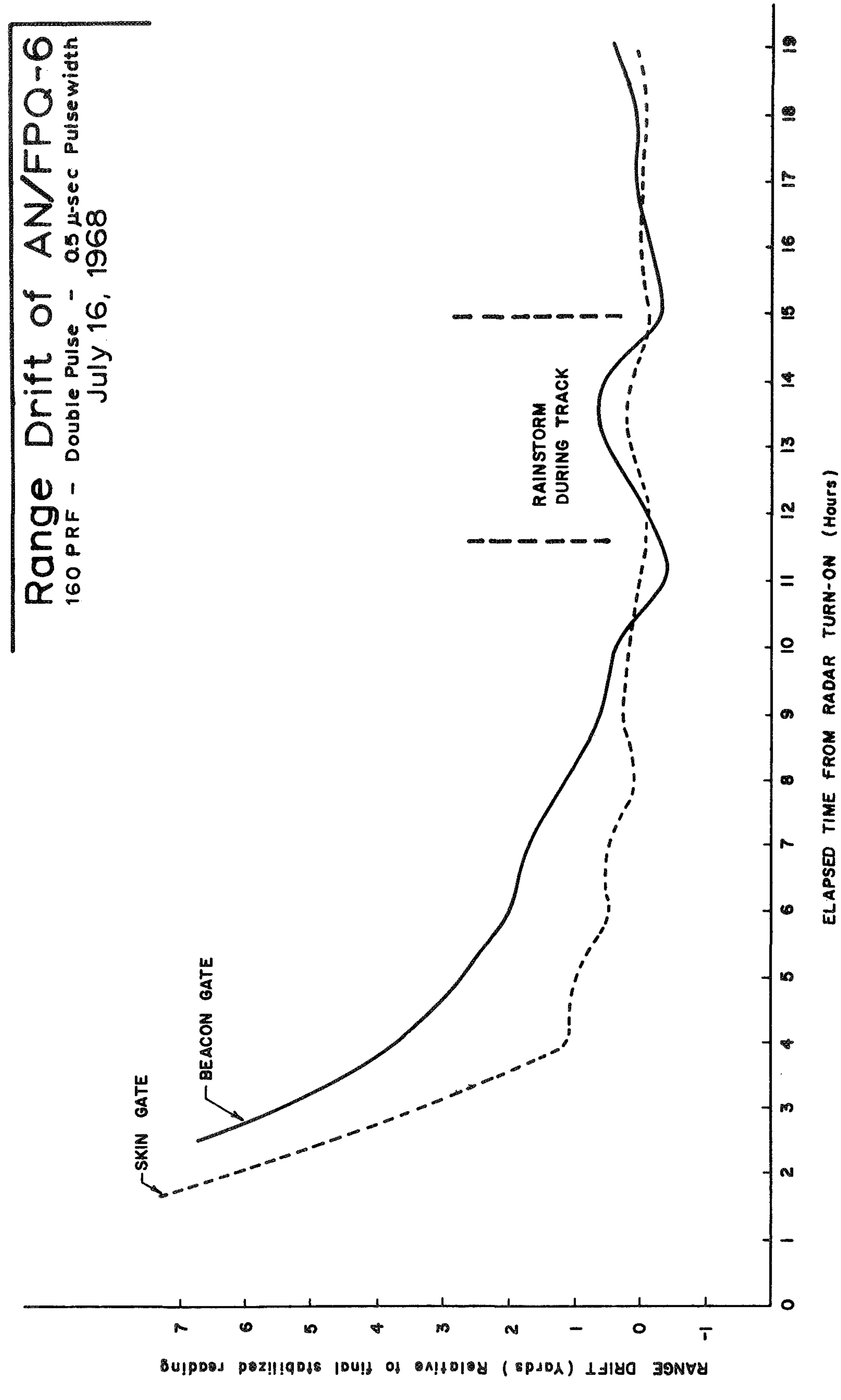

Range Drift of AN/FPQ-6
160 PRF - Double Pulse - 0.5 µ-sec Pulsewidth
July 16, 1968
SKIN GATE
BEACON GATE
RAINSTORM DURING TRACK
ELAPSED TIME FROM RADAR TURN-ON (Hours)
RANGE DRIFT (Yards) Relative to final stabilized reading

Figure 10

it was compared to the Wallops cesium beam standard. These measurements indicate that the AN/FPQ-6 oscillator rate is 81,964.$\overline{28}$* cps. These measurements are limited by the resolution of the time interval available at Wallops. We hope to make additional measurements in the future using a more precise counting technique. Since the design frequency (based on the speed of light in vacuo = 327,857,0$\overline{64}$ $\pm$ 4$\overline{37}$ yds/sec (see reference 7) is 81,964.2$\overline{66}$ cps, an error approximately 1 yard in 1000 nautical miles is possible with the knowledge of the oscillator frequency. This range is typical for GEOS-II passes.

The error in range is represented by:

$$\varepsilon_R = 2000 \text{ yds} - \frac{C}{2fr} \cdot \left[\frac{\text{Target Range (yds)}}{2000 \text{ yds}}\right]$$

where

C = velocity of light in vacuo (yds/sec)

fr = Range Reference Oscillator Frequency (Hz)

The Wallops Station AN/FPS-16 radar oscillator is more stable than that of the AN/FPQ-6, and we therefore adjust the AN/FPQ-6 oscillator prior to each mission until the range rate between the AN/FPQ-6 and AN/FPS-16

*The bar over the final digit(s) indicates that this is a non-significant number carried in the calculation to prevent rounding errors.

is under 20 yards/sec. At 1000 nautical miles (12,202 μsec) range, the range error between the two radars is less than 0.25 yds.

Since this error is systematic and proportional to range, it could be further reduced if we were able to precisely measure the oscillator frequencies prior to, during, or after track. This is not possible with our present test equipment. Until better equipment is available for these measurements, the radars will be maintained to within 20 yds/sec of each other and the absolute oscillator frequencies will be assumed more precise than our capability to measure them.

### 2.4.3 Angle Tracking Loop

The AN/FPQ-6 angle tracking loop, as depicted in Figure 11, illustrates the real-time sequence from the instant of receiving a C-Band pulse at the antenna, to the driving of the antenna dish to follow the target, and the data recording (see reference 8).

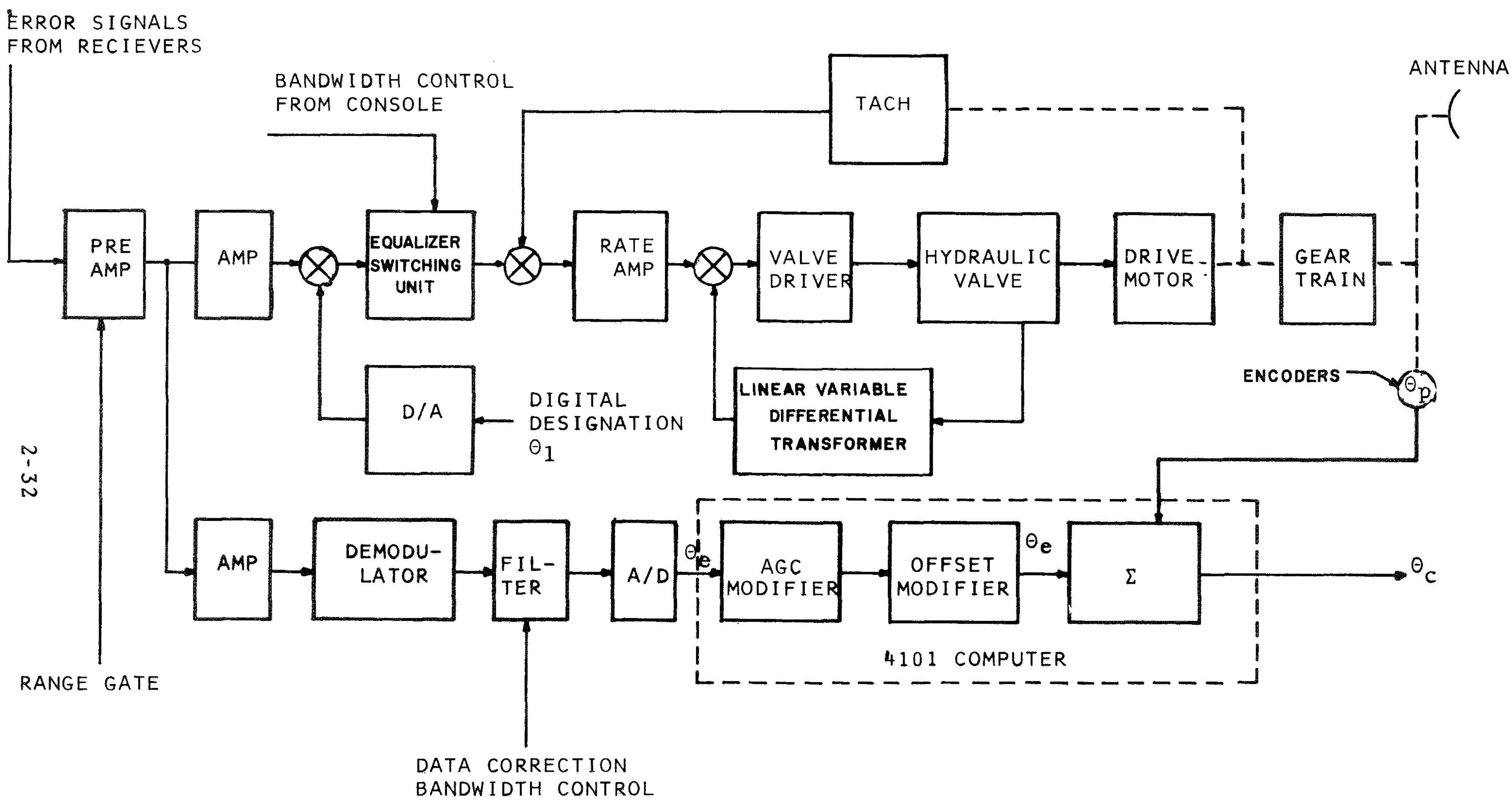



FIGURE 11
AN/FPQ-6 TRACKING LOOP

# SECTION 3.0
# DATA PREPROCESSING

## 3.1 DATA HANDLING AT AN/FPQ-6 SITE

### 3.1.1 Data Correction and Recording

#### 3.1.1.1 General

The AN/FPQ-6 instrumentation includes an RCA 4101 general purpose computer which permits radar system maintenance, calibration, and operational testing independent of other external systems. The computer is adaptable to user requirements, such as data correction and real-time data recording on magnetic tape in 4101 format (Appendix B) at a 10 or 20 sample per second rate.

#### 3.1.1.2 Data Correcting

The nature and the forms of the error corrections within the 4101 program are shown in Figure 12. As indicated, the elevation and azimuth measurements are corrected for:

a. Servo Lag (optional)

b. RF Axis Shift

c. Encoder Bias

d. Droop (applied to elevation only)

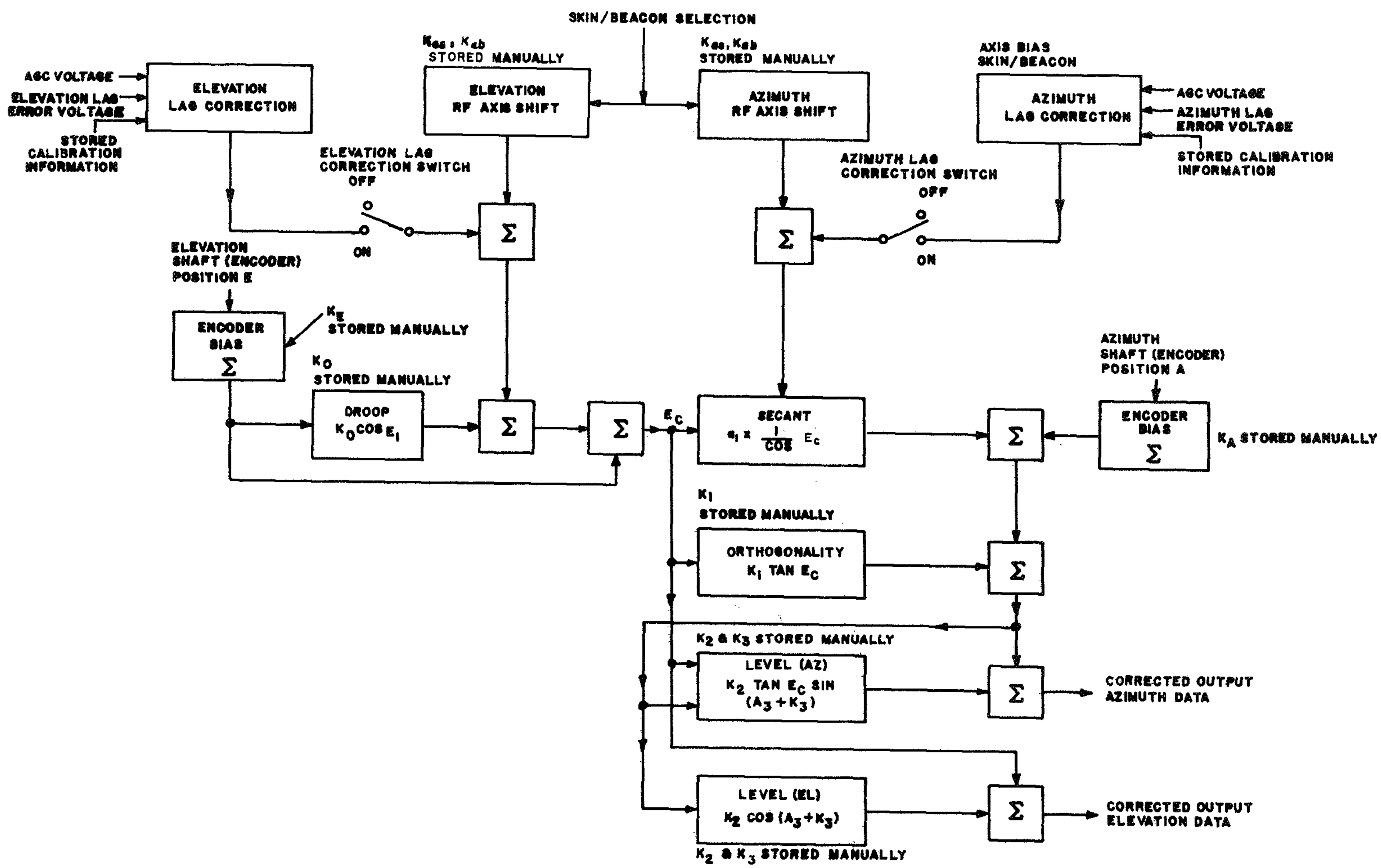



FIGURE 12

FLOW DIAGRAM OF THE ERROR CORRECTION PROGRAM

e. Secant Error (applied to azimuth only)

f. Non-Orthogonality

g. Pedestal Mislevel

It is noteworthy that no corrections to range are made within the 4101 program, and that no mission-by-mission calibration corrections are applied at the radar site. Appendix C describes the Wallops Island AN/FPQ-6 instrumentation radar system error model for the GEOS-II program.

#### 3.1.1.3 Data Recording

The calibration and track data, after processing by the 4101 Error Corrector Program, is recorded on magnetic tape in the 4101 format. This format is described in Appendix B.

### 3.1.2 Data Transmittal

A standard data package is sent from the radar site to the Wallops Computing Center. This package consists of:

a. Magnetic tape, described in 3.1.1.3 above.

b. Radar Log.

c. Calibration Code Sheet.

d. Meteorological Data Log.

### 3.1.2.1 Radar Log

A sample Radar Log is shown in Figure 13. This log is required for each radar that is scheduled for GEOS-B support. A description of the entries of the Radar Log shown in Figure 13 is given below:

Item 1. Enter Zulu date of pass at horizon time.

Item 2. Enter expected acquiring horizon time in Zulu to nearest minute, taken from prediction data.

Item 3. Enter local site name or number, plus GEOS Site ID number.

Item 4. Enter local mission, test, or model number.

Item 5. Circle or enter all pulse widths used during mission.

Item 6. Circle or enter all PRF's used during mission.

Item 7. Circle or enter all receiver bandwidths used during mission.

Item 8. Enter the transmitter frequency measured near mission time.

Item 9. Enter the beacon receiver frequency as read from the beacon L.O. during or after the mission and before it is readjusted.

## RADAR LOG

| 1 DATE | 2 PRED. HOR. TIME | 3 SITE | 4 MISSION NUMBER |
|---|---|---|---|
| | | | |

OPERATING PARAMETERS

| 5 PW | 6 PRF | 7 RCVR. BW | 8 XMTR. FREQ. | 9 RCVR. FREQ. | 10 XMTR. PWR.% | 11 XMTR.PWR. |
|---|---|---|---|---|---|---|
| 1.0 2.4 ___ us. | 160 640 ___ PPS | 1.6 0.6 ___ MHz | ___ MHz | ___ MHz | 100 ___ PERCENT | 2.5 2.0 ___ MW |

| 12 POLARIZATION | 13 NOISE FIGURE | 14 INSERTED BCN.DLY | 15 PULSE CODE | 16 SYSTEM K |
|---|---|---|---|---|
| CIRC LIN | REF___ AZ___ EL___ db | ___ N/A YARDS | ___,___ N/A NBR us | ___ |

| 17 SEC POT | 18 TCKING GATE | 19 BEACON TRACKED | 20 DATE OF LAG ERROR CORRECTION CALIBRATION | 21 EL Pos During Calibration |
|---|---|---|---|---|
| IN OUT | SKIN BEACON | LONG SHORT DELAY | ___ | Manual Locked-on |

22 MEASURED ERROR GRADIENT
AZIMUTH___
ELEVATION___

23 SERVO BANDWIDTH SW POS VRS BW HZ

| | POS 6 | POS 7 | POS 8 | POS 9 | POS 12 |
|---|---|---|---|---|---|
| ELEVATION | ___ | ___ | ___ | ___ | ___ |
| AZIMUTH | ___ | ___ | ___ | ___ | ___ |
| RANGE | ___ | ___ | ___ | ___ | ___ |

24 TRACK $K_v$
AZIMUTH___
ELEVATION___
mils/sec

25

| | | |
|---|---|---|
| $K_0$___ | $K_a$___ | $K_{es}$___ |
| $K_1$___ | $K_e$___ | $K_{ab}$___ |
| $K_2$___ | $K_{as}$___ | $K_{eb}$___ |
| $K_3$___ | | |

26 CALIBRATION SURVEY
BORESIGHT TWR AZ ___
BORESIGHT TWR EL ___
RANGE TARGET RNG ___

27 COMMUTATION FREQUENCY

28 DATA CORRECTION BANDWIDTH

OPERATION DATA

| 29 ACQUISITION USED | 30 PREDICTED PCA | 31 SIGNAL CHARACTERISTICS |
|---|---|---|
| ___ | EL___ DEGREES<br>RNG___ KYDS<br>TIME___ ZULU | STEADY LOBING WITH DB NULLS<br>REMARKS___ |

32 ORIGINAL ON___Z OFF___Z ON___Z OFF___Z TRACKING TIMES

ON___Z OFF___Z ON___Z FINAL OFF___Z

33 REMARKS:___

FIGURE 13

Item 10. Circle or enter the transmitter power used, normally 100%.

Item 11. Circle or enter the measured transmitter power. Measurement should be as close to mission time as possible.

Item 12. Circle the polarization used.

Item 13. Enter the receiver noise figure taken from all three tracking receivers.

Item 14. If beacon delay compensation has to be used, the digital recorded range, in yards, is entered here.

Item 15. Enter the number of pulses used for pulse coding, plus the measured spacing, in microseconds.

Item 16. Enter the measured system K, if available.

Item 17. Circle whether the secant correction was IN or OUT.

Item 18. Circle either or both Skin or Beacon tracking gates used.

Item 19. If transponder was tracked, circle whether Short or Long Delay.

Item 20. Enter date of last lag error correction calibration.

Item 21. During pre- and post-calibration, circle indicating that elevation was locked-on or manually (optically) positioned to boresight tower track point.

Item 22. Enter actual measured error gradient used for mission, nominally 10 volt per mil.

Item 23. Enter, from latest periodic check, the measured bandwidths for azimuth, elevation, and range over the switch positions listed.

Item 24. Record the Track Kv value for both azimuth and elevation.

Item 25. For FPQ-6 type radars, list the static correction values used:

$K_0$ - Droop

$K_1$ - Orthogonality

$K_2$ - Level Error

$K_3$ - Level Error

$K_a$ - Azimuth Bias

$K_e$ - Elevation Bias

<u>Null Shift Corrections</u>

$K_{as}$ - Az (Skin)

$K_{es}$ El (Skin)

$K_{ab}$ - Az (Beacon)

$K_{eb}$ El (Beacon)

Item 26. Enter the latest survey position to the radars reference targets, in mils and yards.

Item 27. Enter commutation frequency.

Item 28. Enter data correction bandwidth.

Item 29. Enter acquisition source used to acquire track.

Item 30. Enter information taken from track data, if possible.

Item 31. Circle whether target signal was steady or lobing. If lobing, indicate lobe null depth. Enter pertinent remarks on signal characteristics.

Item 32. List all On and Off track time (up to number of spaces given), to the nearest second.

Item 33. All pertinent remarks.

3.1.2.2 Calibration Code Sheet

A sample Calibration Code Sheet is shown in Figure 8, page 2-15. The digital codes are divided into two sections. The first section covers Routine Calibrations such as normal Pre-Calibration (100 Series) and Post Calibration (200 Series) recordings.

The intent is that each calibration step will be keyed with the code (from the sheet) applicable to it by inserting the code into the digital word. This code is added, either at the radar site or by post-reduction processes.

For quick-look information, each time the codes are added, a copy of the code sheet is marked by circling each event recorded. The code sheet then becomes a part of the data package.

Codes 101 through 122 and 201 through 222 apply to AGC calibration. The db value refers to a signal level above 0 db. Codes 104, 204, 107, 207, 108, 208, 109, and 209 can be used for any additional levels recorded that are not noted elsewhere.

Codes 123 through 126 and 223 through 226 are used when locked-on to the boresight tower and range target to record their survey bearing and/or range.

Codes 127 through 130 and 227 through 230 show calibration values when error voltages (azimuth and elevation) are recorded. The amplitudes recorded correspond to the error generated by displacing the antenna 1 mil in the direction shown.

Codes 131 through 133 and 231 through 233 are for recording calibration of the transmitter attenuator with the radar lock-on to a stable skin return; 131 and 231 will show the AGC voltage with the attenuator fully out (100% power). Codes 132, 133, 232, and 233 can be used for any values of attenuation expected to be used. The code sheet should be marked with the applicable values.

Codes 134 through 137 and 234 through 237 are for recording calibration of the receiver attenuator. With the attenuator fully out, codes 134 and 234 show the AGC level when locked-on to a stable return. The remaining codes can be used for any value of receiver attenuation expected to be used during pre-calibration (135, 136, 137) or during post-calibration (235, 236, 237). The Code Sheet should be marked with the applicable attenuation values.

Codes 138 and 238 are used to record the track of system evaluation test rockets.

Codes 139 and 239 are used to record the track of a pre- or post-mission calibration sphere.

The second section (300 Series) calibrations are used to obtain information that, in conjunction with mission-recorded AGC and raw azimuth and elevation servo errors, may be used to determine antenna position lag. The lag error is then added to the antenna position recorded during the mission. Also these 300 Series calibrations are used to record how well the three receiver channels track together (the error channel amplitudes are monitored as a function of AGC) and the actual error amplitude, as generated by the receiver as a function of physical antenna displacement from a zero error condition.

### 3.1.2.3 Meteorological Data Log

A sample Meteorological Data Log is shown in Figure 15. This log is required on all tests in which either optical or radar data is taken.

## ZERO TIME WEATHER OBSERVATION
WALLOPS ISLAND, VIRGINIA

| | |
|---|---|
| WALLOPS MODEL NO. | HK-720 |
| VEHICLE | GEOS-B |
| OTHER MODEL NO./REV. | |
| PASS DATE | |
| PASS TIME | Z |

**DISTRIBUTION**

| | |
|---|---|
| P.C. | |
| R.I.B. | |
| RADAR | |

| | | |
|---|---|---|
| CLOUD COVER (BASES IN HUNDREDS OF FEET) | | |
| VISIBILITY (IN STATUTE MILES) AND WEATHER | | |
| SEA LEVEL BAROMETRIC PRESSURE | millibars | |
| TEMPERATURE AND DEW POINT (DEGREES F.) | | |
| SURFACE WIND (30 FEET ABOVE GROUND, BLDG. X-85) | °/ | MPH |

REMARKS:

| | | | | | | |
|---|---|---|---|---|---|---|
| Data in Support of Radar: (GEOS Designation/Designations) | FPQ-6 4860 | FPS-16 4840 | | | | |
| Distance from Observation Site to Radar Site/Sites: | | | | | | |
| Direction from Observation Site to Radar Site/Sites: | | | | | | |
| Height of Observation Site Relative to Radar Site/Sites: | | | | | | |

SUPPORT RADIOSONDE

| Ascent No. | Release Time | Termination Pressure | Termination Altitude | Reason for Termination |
|---|---|---|---|---|
| | | | ft. | |
| | | | ft. | |

Other Data or Remarks: ____________________

____________________

____________________

____________________

FIGURE 14

## 3.2 PASS 1 "RAW DATA" PROGRAM

### 3.2.1 Program Description

The purpose of this program is to:

a. Apply appropriate bit weights to the information on the data tapes received from the radar site.

$$SR = SR \times K1$$
$$AZ = AZ \times K2$$
$$EL = EL \times K3$$
$$RDOT = RDOT \times K4$$

b. Compute first differences of the raw data.

$$DR = SR_i - SR_{i-1}$$
$$DA = AZ_i - AZ_{i-1}$$
$$DE = DE_i - DE_{i-1}$$

c. Correct radar data time tags by adding +5.9 msec as per timing discussion in Section 2.2.

d. Output the data in a standard format suitable for further computer processing. This format is outlined below.

e. Perform data analysis. This analysis includes time intervals of track data; and times, variate differences, and measurements where "bad" data occurs.

### 3.2.2 Program Flow Chart

A generalized PASS 1 program flow chart comprises Figure 15.

### 3.2.3 PASS 1 Output

An output tape is generated with the data in the format presented in Table 4.

Pre- and post-mission calibration measurements are printed as a part of the output (sample output, Figure 16). A summary is also printed (Figure 17).

## 3.3 PASS 2 PROGRAM

### 3.3.1 Purpose

The PASS 2 Program has five interrelated functions. These are:

a. Range measurements are corrected for nominal satellite transponder delays, if applicable, and corrected for range bias, as indicated by the pre- and post-mission calibrations.

b. Every $n^{th}$ record is selected from the PASS 1 output tape for processing and later reduction, where n is a function of the radar sampling rate and the desired data rate for reduction.

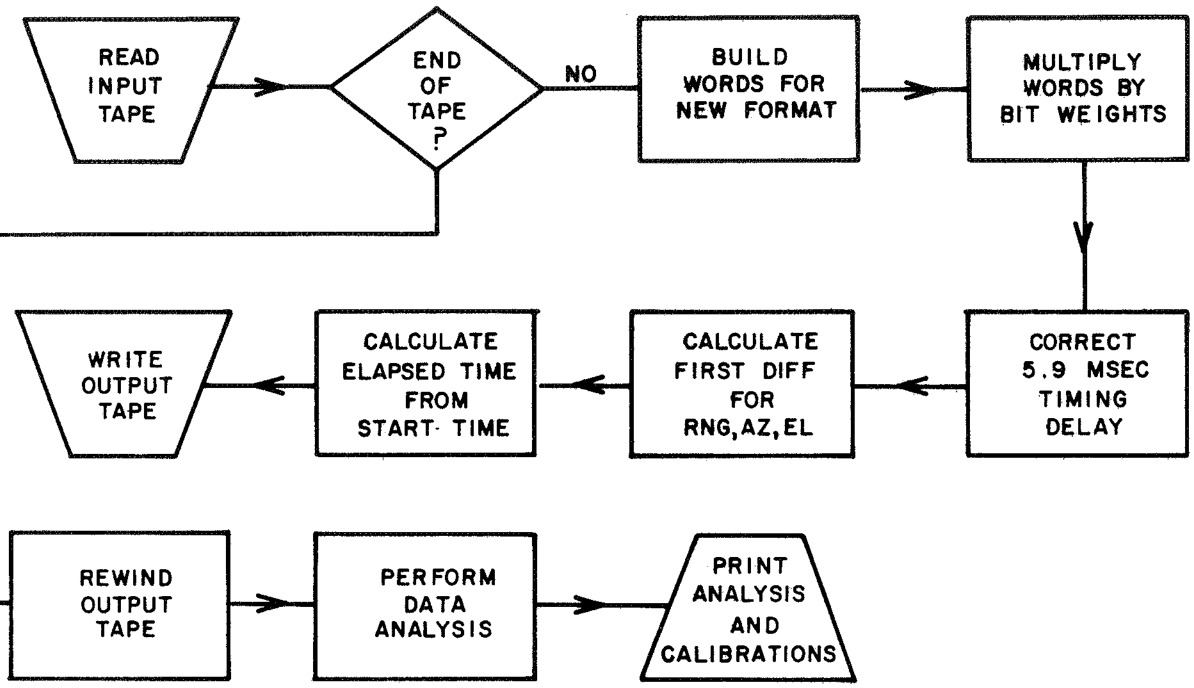



FIGURE 15

PASS 1 PROGRAM FLOW CHART

TABLE 4

Mode of Writing: Binary    Density: 800 BPI

Words/Record: 34

Explanation of Record:

Each word consists of 36 bits:

| | | |
|---|---|---|
| 1 | I | Run Number |
| 2 | A | Radar Number (0-11); Model Number (12-35) |
| 3 | A | Radar Mode (0-5) |
| 4 | A | Control Mode |
| 5 & 6 | DP | Time (hours) |
| 7 & 8 | DP | Azimuth (degrees) |
| 9 & 10 | DP | Elevation (degrees) |
| 11 & 12 | DP | Slant Range (feet) |
| 13 & 14 | DP | Delta Azimuth (degrees) |
| 15 & 16 | DP | Delta Elevation (degrees) |
| 17 & 18 | DP | Delta Slant Range (feet) |
| 19 | I | Azimuth Error (bits) |
| 20 | I | Elevation Error (bits) |
| 21 | I | Range Rate (feet per sec x 10000) |
| 22 | I | Velocity of Propagation (feet per sec) |
| 23 | I | Doppler Freq Counter (megahertz) |
| 24 | I | Transmitter Freq (Hertz) |
| 25 | I | Blank |
| 26 | I | Blank |
| 27 | I | Blank |
| 28 | I | AGC (bits) |
| 29 & 30 | DP | Elapsed Time (hours) |
| 31 | O | $\dot{R}$ Bits (33-35) |
| 32 | O | FPQ-6 Status Bits (0-20); Milgo Aux Bits Recorded and Transmitted Bits (31-35) |
| 33 | A | Azimuth Lag Correction Bit (bit 5) |
| 34 | A | Elevation Lag Correction Bit (bit 5) |

I = Integer
A = Alphanumeric
DP = Double Precision
O = Octal

PRE - FLIGHT ROUTINE CALIBRATIONS

AGC CALIBRATIONS

| | |
|---|---|
| NOISE | 4 BITS |
| 0 DB | 0 BITS |
| 5 DB | -4 BITS |
| 10 DB | -7 BITS |
| 15 DB | -11 BITS |
| 20 DB | -14 BITS |
| 25 DB | -18 BITS |
| 30 DB | -21 BITS |
| 35 DB | -24 BITS |
| 40 DB | -27 BITS |
| 45 DB | -30 BITS |
| 50 DB | -33 BITS |
| 55 DB | -37 BITS |

| | | | | |
|---|---|---|---|---|
| BORESIGHT TOWER NORMAL | AVG AZ | 24.2827 DEG | AVG EL | 3.4169 DEG |
| BORESIGHT TOWER PLUNGED | AVG AZ | 204.2746 DEG | AVG EL | 176.5911 DEG |
| RANGE TARGET - SKIN GATE | AVG SR | 26882. FEET | | |
| RANGE TARGET - BEACON GATE | AVG SR | 24452. FEET | | |

Figure 16

SAMPLE LISTING OF PRE-FLIGHT CALIBRATION DATA

RADAR NUMBER 05

MODEL NUMBER 0720

| | |
|---|---|
| FIRST TIME ON MODEL | 06-06-55.74 |
| FIRST AUTO MODE ON MODEL | 06-07-02.34 |
| LAST TIME ON MODEL | 06-25-07.94 |
| TOTAL NUMBER OF RECORDS | 10923 |
| PERCENTAGE OF RECORDS IN AUTO MODE | 98 |
| PERCENTAGE OF AUTO WITH S/N GREATER THAN 10 DB | 98 |
| NUMBER OF TIMES RADAR ACQUIRED TRACK | 1 |
| NUMBER OF TIMES RADAR LOST TRACK | 1 |
| NUMBER OF TIME DISCREPANCIES | 0 |
| NUMBER OF RANGE VARIATE DIFFERENCES GREATER THAN THRESHOLD | 74 |
| NUMBER OF AZ VARIATE DIFFERENCES GREATER THAN THRESHOLD | 10 |
| NUMBER OF EL VARIATE DIFFERENCES GREATER THAN THRESHOLD | 27 |

Figure 17

DATA SUMMARY SHEET

c. Radar range and elevation measurements are refraction corrected.

d. Measurement time tags are corrected for the pulse transit time from the satellite to the radar site.

e. Thermal noise equations are used to compute *a priori* uncertainties for each measurement.

### 3.3.2 Method

#### 3.3.2.1 Selection of Every $n^{th}$ Record

A variable which is called IPICK is input to the program for the selection of data records to be processed. An internal counter is incremented until the number of records equals IPICK. The data on the selected record is then pre-processed; the counter is set back to zero, and the process continues. However, a record does not increment the counter unless the range exceeds $2 \times 10^6$ feet (to eliminate the calibration data), the elevation angle exceeds a variable input value, and the observation is in the auto-track mode.

#### 3.3.2.2 Refraction Corrections

The tropospheric refraction correction applied to Wallops radar data during preprocessing uses a measured surface index of refraction and a cosecant dependence upon elevation angle. A refraction correction based upon the ray path integration using a measured vertical refractive index profile has an expected error on the order of 2-4%. The use of a correction procedure based upon a surface index only should introduce a few percent additional error, as should the flat earth approximation (i.e., the csc E dependence). Taking into account the fact that the location of the radar near the land-sea boundry where atmospheric conditions are quite difficult to predict, a residual refraction error of 10% is an approximate upper limit to the error which could be expected.

The refractive index, μ, for radar is computed as follows (see ref 9):

$$\mu - 1 = \left[ \frac{103.49\ (P-e)}{T} + \frac{86.26}{T} \left(1 + \frac{5748}{T}\right) e \right] \times 10^{-6},$$

where

P = total atmospheric pressure (mm Hg),

e = partial pressure of water vapor (mm Hg),

and

T = absolute (C) temperature

If temperature, pressure, and relative humidity are not known, a nominal value of $0.2919 \times 10^{-3}$ (see reference 10 and 11) for μ-1 is pre-set in the program.

The refraction corrected elevation angles and ranges are computed by:

$$E_c = E_o - \cot E_o (\mu - 1)$$

$$R_c = R_o - [(\mu - 1)(s)/\sin E_c]$$

where

$E_c$ = corrected elevation angle measurement

$E_o$ = observed elevation angle measurement

$R_c$ = corrected range measurement

$R_o$ = observed range measurement

$s$ = scale height of the atmospheric refractive index, $\mu$, approximately 7.6 km (see ref 9)

3.3.2.3 Time Tag Correction

The measurement time tags are corrected to the time the radar pulse left the satellite by

$$T_c = T_o - R_c/C$$

where

$T_c$ = corrected observation time (seconds)

$T_o$ = sampled time at radar

$C$ = velocity of light = 299792.5 km/sec

### 3.3.2.4 Range Measurement Corrections

3.3.2.4.1 Range Calibration Corrections. Using the approximately 100 range pre-mission calibration measurements (10 seconds of radar Range Target data taken at 10 p.p.s) the mean difference of radar and survey measurements and the standard deviation about this mean are computed. A $3\sigma$ editing routine is used to eliminate rogue data points in the calibration.

A mean difference between the radar post-mission range and survey measurements, and the standard deviation about this mean, are then computed.

If the difference in pre- and post-mission range calibrations exceeds a pre-set value, post-calibration data is used and data is flagged as questionable. The post-calibration data is used since post-calibration is generally performed closer to the actual track time. This comparison is done with a statistical significance test.

We compute the Z statistic

$$Z = \frac{\sqrt{mn/(m + n)} \qquad (\overline{X}_1 - \overline{X}_2)}{\left(\Sigma(X_{1i} - \overline{X}_1)^2 + \Sigma(X_{2j} - X_2)^2 / m + n-2\right)^{1/2}}$$

where

$m$ = the pre-calibration sample size

$n$ = the post-calibration sample size

$$\overline{X}_1 = \Sigma \frac{X_{1i}}{m}$$

$$\overline{X}_2 = \Sigma \frac{X_{2i}}{m}$$

$X_{1i}$ = $i^{th}$ reading of the pre-calibration

$X_{2i}$ = $i^{th}$ reading of the post-calibration

Since m and n are usually large (approximately 100 samples) the computed quantity Z is normally distributed with zero mean and unit variance. Therefore, if Z is less than 2.54, the means are judged to be not significantly different at the 95% confidence level and the pre- and post-calibration results are averaged. If Z is greater than 2.54, the post-calibration data is used as described above and the data flagged as questionable.

3.3.2.4.2 <u>Satellite Transponder Delays</u>. Nominal satellite transponder delays are converted to equivalent range corrections for beacon-track data. The range correction values for the GEOS-B satellite are presented and discussed in Section 2.4.2.2 of this document.

3.3.2.4.3 <u>Combined Range Corrections</u>. The total AN/FPQ-6 range correction is calculated algebraically as follows:

$$R_{TC} = R_s - R_c - R_T - R_R$$

where

$R_{TC}$ = total range correction

$R_s$ = surveyed range to calibration target

$R_c$ = measured range to calibration target

$R_T$ = nominal transponder delay

$R_R$ = refraction correction (Section 3.2.2.2 above)

3.3.2.5 Data Uncertainty Computations

The thermal noise equations are used to compute range, azimuth, elevation, and range-rate uncertainties for each data point for use in the weighting scheme.

THERMAL NOISE EQUATIONS

Azimuth

$$\sigma_A = \frac{\theta}{\sqrt{\frac{2S}{N} \quad \frac{fr}{\beta n}}} \sec(EL)$$

$\theta$ = radar half beam-width (radians)

fr = repetition rate (pps)

$\beta n$ = servo bandwidth (Hz)

$\frac{S}{N}$ = signal to noise power ratio

Elevation

$$\sigma_E = \frac{\theta}{\sqrt{\frac{2S}{N} \quad \frac{fr}{\beta n}}}$$

Range

$$\sigma_r = \frac{\tau}{\sqrt{\frac{S}{N} \quad \frac{fr}{\beta n}}}$$

$\tau$ = pulsewidth (1μsec = 500 ft.)

Range Rate

$$\sigma_{\dot{r}} = \frac{\lambda \, \beta fL}{4.0 \sqrt{\frac{S}{N} \; \frac{fr}{\beta n}}}$$

$\lambda = \frac{C}{f}$

C = speed of light

f = frequency of transmission ($5690 \times 10^6$)

$\beta fL$ = fine line bandwidth (160)

The computed uncertainties for the range and angle measurements are plotted in Figures 18 and 19 as a function of the signal-to-noise ratio in db.

### 3.3.3 PASS 2 Output

The pre-processed data is output on (optional) data cards or magnetic tape. The output format (Appendix D0 is suitable for further data reduction and is compatible with the format prescribed for data submission to the data bank of the National Geodetic Satellite Program.

FIGURE 18

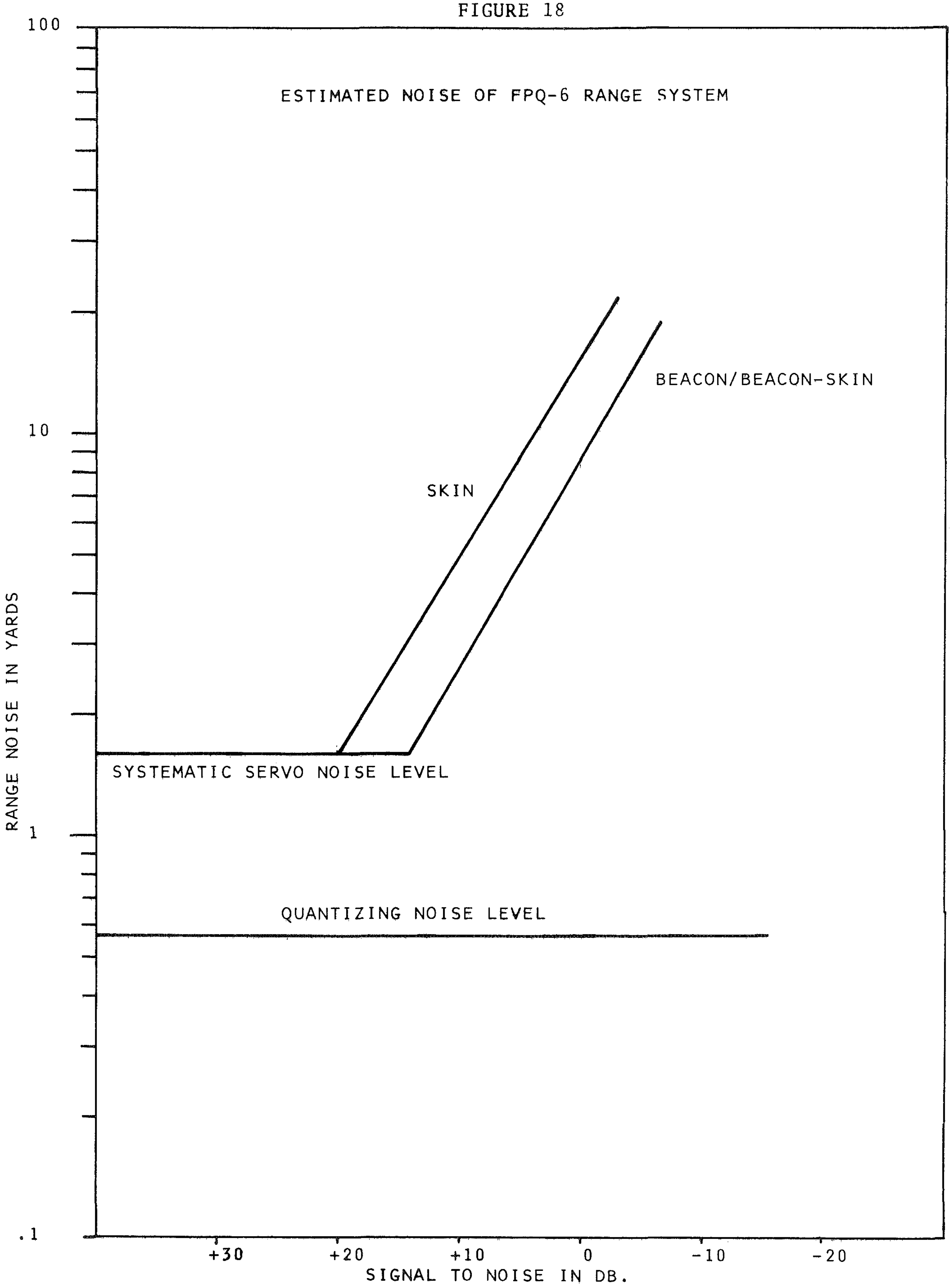
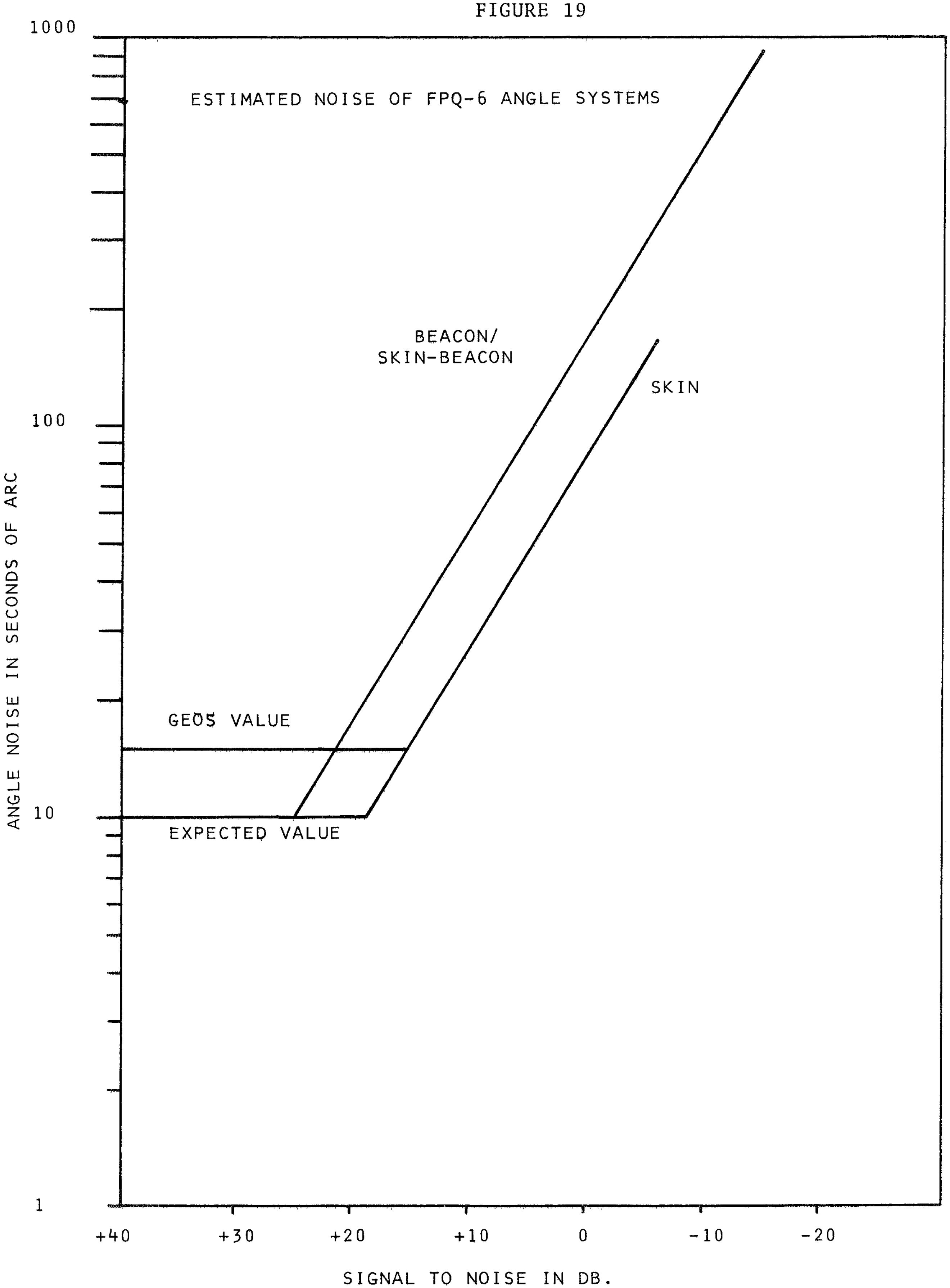

ESTIMATED NOISE OF FPQ-6 RANGE SYSTEM
100
10
1
.1
RANGE NOISE IN YARDS
BEACON/BEACON-SKIN
SKIN
SYSTEMATIC SERVO NOISE LEVEL
QUANTIZING NOISE LEVEL
+30
+20
+10
0
-10
-20
SIGNAL TO NOISE IN DB.

FIGURE 19



ESTIMATED NOISE OF FPQ-6 ANGLE SYSTEMS
1000
100
10
1
ANGLE NOISE IN SECONDS OF ARC
BEACON/
SKIN-BEACON
SKIN
GEOS VALUE
EXPECTED VALUE
+40
+30
+20
+10
0
-10
-20
SIGNAL TO NOISE IN DB.

# REFERENCES


1. Geodetic Survey Report of the Tracking Systems in the Collocation Experiment of the GEOS Observation Systems Intercomparison-Investigation, Field Facilities Branch, STADAN Operation Division, NASA-GSFC, April 1968.

2. Fischer, I., M. Slutsky, F.R. Shirley, and P.Y. Wyatt, New Pieces in the Picture Puzzle of an Astrogeodetic Geoid Map of the World, AMS, September 1967.

3. Lerch, F.J., J.G. Marsh, M.D. D'Aria, and R.L. Brooks, GEOS-I Station Tracking Positions on the SAO Standard Earth (C-5), NASA X-552-68-70, December 1967.

4. Wallops Station Handbook, NASA, Wallops Station, Wallops Island, Virginia, April 1964.

5. AN/FPQ-6 Operation Procedures, NASA, Wallops Station, Wallops Island, Virginia, August 1968.

6. Calibration and Evaluation of the Wallops AN/FPQ-6 Radar Utilizing the GEOS-II Satellite, NASA DOC. X-16-68-1, August 1968.

7. "IRIG Standard for Pulse Repetition Frequencies and Reference Oscillator Frequency for C-Band Radars", Document 103-65, Secretariat, Range Commander's Council, White Sands Missile Range, New Mexico, Nov. 1965.

8. Final Report, Missile Precision Instrumentation Radar Sets AN/FPQ-6 and AN/TPQ-18, Contract Number w61-0428d, RCA Missile and Surface Radar Division, July 1964.

9. Martin, C.F., Tropospheric Refraction Corrections and Their Residual Errors, Technical Document Report Number MTC-TDR-64-3, Air Force Systems Command, Patrick AFB, Florida, February 1964.

10. Bomford, Brig. G., Geodesy, Clarendon Press, 1962.

11. American Institute of Physics, American Institute of Physics Handbook, 1957.

# APPENDIX A
# SURVEY INFORMATION

POSITION AND DESCRIPTION OF SURVEY STATION

| | | | |
|---|---|---|---|
| COUNTRY<br>United States | TYPE OF MARK<br>Brass Tablet | STATION<br>BRIDGE | First Order |
| LOCALITY<br>Wallops Island, Va. | STAMPING ON MARK<br>BRIDGE 1968 | AGENCY (CAST IN MARK)<br>NASA/GSFC | ELEVATION 48.143 FEET<br>14.674 METERS |
| LATITUDE<br>N 37° 51' 07".452 | LONGITUDE<br>W 75° 29' 25".811 | DATUM-ELLIPSOID<br>NAD 1927 Clarke 1866 | ORDER<br>Third |
| LATITUDE | LONGITUDE | DATUM-ELLIPSOID | DATUM<br>SLD 1929 |
| NORTHING | EASTING | GRID AND ZONE | ESTABLISHED BY- AGENCY-DATE<br>NASA/GSFC 3/68 |
| NORTHING | EASTING | GRID AND ZONE | |

TO OBTAIN GRID AZIMUTH, ADD

| OBJECT | (GEODETIC) AZIMUTH | BACK AZIMUTH | GEOD. DISTANCE (M) | GRID DISTANCE (M) (FT) |
|---|---|---|---|---|
| Secor CW Radar | 114-25-06.77 | 294-24-22.42 | 1940.321 | |
| Laser Pulse Radar | 116-28-53.38 | 296-28-09.90 | 1935.018 | |
| FPQ-6 Radar | 117-59-44.75 | 297-59-02.43 | 1908.898 | |
| Walmot # 7078 | 126-25-00.88 | 306-24-19.61 | 2042.731 | |
| TRANET Doppler | 131-23-36.56 | 311-22-58.04 | 2045.384 | |
| TESTCELL | 197-22-47.15 | 17-24-01.94 | 9955.006 | |
| EASY | 236-40-37.37 | 56-42-19.97 | 4889.117 | |
| Oboe 2 | 270-56-37.42 | 90-57-24.47 | 1874.828 | |
| FPS-16 Radar | 339-43-44.59 | 159-43-55.75 | 1283.715 | |
| Savage Bridge | 353-47-28 | 173-47-28 | 8.641 | |
| | | | | |
| | | | | |
| | | | | |

Station Bridge is located on the highest part of the bridge over Cat Creek leading to Wallops Island, Va. The station is a brass tablet grouted into the walkway on the north side of the bridge. The center is marked by a punch hole at the intersection of an etched cross.

To reach station from the cafeteria at Wallops Island (Bldg. 5005) proceed northwest along blacktop road 0.9 mile to high point in bridge and station.

Savage Bridge was used as a reference mark and is a 1/2-inch metal plug in the eastbound lane of road.

# DESCRIPTION OF BENCH MARK

Designation: NACA NO. 3 2 1963

Nearest town: Wallops Island

Distance and direction from nearest town: On Wallops Island

Character of mark: A standard traverse-station disk

Established by: USC & GS

State: Virginia

County: Accomack

Chief of party: R. Gerrish

Leveling date: 2-5-63

Stamping: NACA NO. 3 2 1963

Detailed description:

On Wallops Island, Accomack County, within the National Advisory Council on Aeronautics Area, 30.9 feet northeast of station NACA NO. 3 1951, 17 feet southwest of a post with electrical outlet, 4 feet northwest of the edge of concrete apron, and set in the top of a concrete monument about 1 foot in diameter, flush with the ground.

| B.M. Description | Adjusted Elevation (Meters) | (Feet) |
|---|---|---|
| NACA NO. 3 2 1963 | 2.618 | 8.590 |

DESCRIPTION OF BENCH MARK

Designation: G 421

Nearest town: Wallops Island

Distance and direction from nearest town: 2.05 miles northwest

Character of mark: C & GS Bench Mark Disk

State: Virginia

County: Accomack

Chief of party: R. Gerrish

Leveling date: 7-63

Stamping: G 421 1963

Detailed description:

About 2.05 miles northwest along a black top road from the cafeteria (Bldg. 5005) within the National Aeronautics and Space Administration property at Wallops Island, at the sentry house (Bldg. F 10) at the main entrance to property, 37 feet southwest of center line of road junction leading southwest, 7.5 feet southeast of cyclone fence line, 6 1/2 feet southwest of a power pole, 1 1/2 feet above level of road, and set in the top of a concrete post projecting 3 inches.

Note: Mark may also be reached by going 2.1 miles southwest along Secondary State Highway 679 from the intersection of Secondary State Highway 7-2 at Atlantic, thence 1.0 mile southeast along Secondary State Highway 803.

| B.M. Description | Adjusted Elevation (Meters) | Adjusted Elevation (Feet) |
|---|---|---|
| G 421 | 5.319 | 17.451 |

# DESCRIPTION OF BENCH MARK

Designation: K 421

Nearest town: Wallops Island

Distance and direction from nearest town: At Wallops Island

Character of mark: C & GS Bench Mark Disk

Established by: C & GS

State: Virginia

County: Accomack

Chief of party: R. Gerrish

Leveling date: 7-63

Stamping: K 421 1963

Detailed description:

At Wallops Island, about 1.9 miles northeast along a black top road from the cafeteria (Bldg. 5005), within the National Aeronautics and Space Administration property, 18.5 feet northwest of center line of road, 93 feet southeast of east corner of explosive storage building W-224, 3 feet southwest of a power pole, 1.8 feet northeast of a steel witness post, 1/2 foot above level of road, and set in the top of a concrete post projecting 3 inches.

Note: Mark may also be going 1.15 miles southwest along a black top road from the U.S. Coast Guard lookout tower on Wallops Island.

| B.M. Description | Adjusted Elevation (Meters) | Adjusted Elevation (Feet) |
|---|---|---|
| K 421 | 1.854 | 6.083 |

RECOVERY NOTE, BENCH MARK

Designation: A 299

Nearest town: Wallops Island

Distance and direction from nearest town: At Wallops Island

Character of mark: C & GS Bench Mark Disk

Established by: C & GS

Present condition: Good

State: Virginia

County: Accomack

Chief of party: R. Gerrish

Leveling date: 5-63

Stamping: A 299 1949

Detailed description:

At Wallops Island, within the National Aeronautics and Space Administration property, at the cafeteria (Bldg. 5005), set on top of top step at northwest (main) entrance to cafeteria, 2 feet northwest wall of building, 12 feet south of power pole 1, 0.3 foot northeast of southwest wall of steps, and 1 1/2 feet above level of ground.

| B.M. Description | Adjusted Elevation (Meters) | (Feet) |
|---|---|---|
| A 299 | 3.095 | 10.154 |

# APPENDIX B
# 4101 DATA FORMAT

# MISSILE IDENTIFICATION

| 4101 Word 1 BIT | Bit Value |
|---|---|
| 00 | All Zeroes |
| 1 | |
| 2 | |
| 3 | |
| 4 | |
| 5 | |
| 6 | |
| 7 | |
| 8 | |
| 9 | $2^2$ |
| 10 | $2^1$ |
| 11 | $2^0$ |
| 12 | All Zeroes |
| 13 | |
| 14 | |
| 15 | |
| 16 | |
| 17 | |
| 18 | $2^{11}$ |
| 19 | $2^{10}$ |
| 20 | $2^9$ |
| 21 | $2^8$ |
| 22 | $2^7$ |
| 23 | $2^6$ |
| 24 | $2^5$ |
| 25 | $2^4$ |
| 26 | $2^3$ |
| 27 | $2^2$ |
| 28 | $2^1$ |
| 29 | $2^0$ |
| 30 | Always Zero |
| 31 | Always Zero |
| 32 | Always Zero |
| 33 | Always Zero |
| 34 | Always Zero |
| 35 | Always Zero |

# TIME

4101
Word 2

| BIT | Function | BCD Representation |
|---|---|---|
| 0 | Always Zero | |
| 1 | Always Zero | |
| 2 | Always Zero | |
| 3 | Always Zero | |
| 4 | Always Zero | |
| 5 | Always Zero | |
| 6 | Always Zero | |
| 7 | Always Zero | |
| 8 | Always Zero | |
| 9 | Always Zero | |
| 10 | Tens of Hours | (2) |
| 11 | Tens of Hours | (1) |
| 12 | Always Zero | |
| 13 | Always Zero | |
| 14 | Units of Hours | (8) |
| 15 | Units of Hours | (4) |
| 16 | Units of Hours | (2) |
| 17 | Units of Hours | (1) |
| 18 | Always Zero | |
| 19 | Always Zero | |
| 20 | Always Zero | |
| 21 | Tens of Minutes | (4) |
| 22 | Tens of Minutes | (2) |
| 23 | Tens of Minutes | (1) |
| 24 | Always Zero | |
| 25 | Always Zero | |
| 26 | Units of Minutes | (8) |
| 27 | Units of Minutes | (4) |
| 28 | Units of Minutes | (2) |
| 29 | Units of Minutes | (1) |
| 30 | Always Zero | |
| 31 | Always Zero | |
| 32 | Always Zero | |
| 33 | Always Zero | |
| 34 | Always Zero | |
| 35 | Always Zero | |

## TIME

4101
Word 3

| BIT | Function | BCD Representation |
|---|---|---|
| 0 | Always Zero | |
| 1 | Always Zero | |
| 2 | Always Zero | |
| 3 | Always Zero | |
| 4 | Always Zero | |
| 5 | Always Zero | |
| 6 | Always Zero | |
| 7 | Always Zero | |
| 8 | Always Zero | |
| 9 | Tens of Seconds | (4) |
| 10 | Tens of Seconds | (2) |
| 11 | Tens of Seconds | (1) |
| 12 | Always Zero | |
| 13 | Always Zero | |
| 14 | Units of Seconds | (8) |
| 15 | Units of Seconds | (4) |
| 16 | Units of Seconds | (2) |
| 17 | Units of Seconds | (1) |
| 18 | Always Zero | |
| 19 | Always Zero | |
| 20 | Tenths of Seconds | (8) |
| 21 | Tenths of Seconds | (4) |
| 22 | Tenths of Seconds | (2) |
| 23 | Tenths of Seconds | (1) |
| 24 | Always Zero | |
| 25 | Always Zero | |
| 26 | Hundredths of Seconds | (8) |
| 27 | Hundredths of Seconds | (4) |
| 28 | Hundredths of Seconds | (2) |
| 29 | Hundredths of Seconds | (1) |
| 30 | Always Zero | |
| 31 | Always Zero | |
| 32 | Always Zero | |
| 33 | Always Zero | |
| 34 | Always Zero | |
| 35 | Always Zero | |

# RANGE

| 4101 Word 4 | Bit Value (Yards) |
|---|---|
| 0 | 32,768,000 |
| 1 | 16,384,000 |
| 2 | 8,192,000 |
| 3 | 4,096,000 |
| 4 | 2,048,000 |
| 5 | 1,024,000 |
| 6 | 512,000 |
| 7 | 256,000 |
| 8 | 128,000 |
| 9 | 64,000 |
| 10 | 32,000 |
| 11 | 16,000 |
| 12 | 8,000 |
| 13 | 4,000 |
| 14 | 2,000 |
| 15 | 1,000 |
| 16 | 500 |
| 17 | 250 |
| 18 | 125 |
| 19 | 62.5 |
| 20 | 31.25 |
| 21 | 15.625 |
| 22 | 7,8125 |
| 23 | 3.90625 |
| 24 | 1,953125 |
| 25 | 0 |
| 26 | 0 |
| 27 | 0 |
| 28 | 0 |
| 29 | 0 |
| 30 | Always Zero |
| 31 | Always Zero |
| 32 | Always Zero |
| 33 | Always Zero |
| 34 | Always Zero |
| 35 | Always Zero |

# AZIMUTH

4101
Word 5

| BIT | Bit 0 - 19 Value (MILS) |
|---|---|
| 0 | 3200 |
| 1 | 1600 |
| 2 | 800 |
| 3 | 400 |
| 4 | 200 |
| 5 | 100 |
| 6 | 50 |
| 7 | 25 |
| 8 | 12.5 |
| 9 | 6.25 |
| 10 | 3.125 |
| 11 | 1.5625 |
| 12 | .78125 |
| 13 | .390625 |
| 14 | .1953125 |
| 15 | .09765625 |
| 16 | .048828125 |
| 17 | .0244140625 |
| 18 | .01220703125 |
| 19 | .006103515625 |
| 20 | 1 = lag corrected, 0 = no lag correction |
| 21 | Zero |
| 22 | Zero |
| 23 | Zero |
| 24 | Zero |
| 25 | Zero |
| 26 | Zero |
| 27 | Zero |
| 28 | Zero |
| 29 | Zero |
| 30 | Always Zero |
| 31 | Always Zero |
| 32 | Always Zero |
| 33 | Always Zero |
| 34 | Always Zero |
| 35 | Always Zero |

## ELEVATION, AUTOMATIC GAIN CONTROL

4101
Word 6 Bit 0 = 19 Value (MILS) Bit 23 - 29 Value (Volts)

| BIT | | |
|---|---|---|
| 0 | 3200 | |
| 1 | 1600 | |
| 2 | 800 | |
| 3 | 400 | |
| 4 | 200 | |
| 5 | 100 | |
| 6 | 50 | |
| 7 | 25 | |
| 8 | 12.5 | ELEVATION |
| 9 | 6.25 | |
| 10 | 3.125 | |
| 11 | 1.5625 | |
| 12 | .78125 | |
| 13 | .390625 | |
| 14 | .1953125 | |
| 15 | .09765625 | |
| 16 | .048828125 | |
| 17 | .0244140625 | |
| 18 | .01220703125 | |
| 19 | .006103515625 | |
| 20 | 1 = lag corrected, 0 = no lag correction | |
| 21 | Zero | |
| 22 | Sign Bit (o=Positive Voltage, 1=Negative Voltage) | |
| 23 | 3.90625 | |
| 24 | 1.953125 | |
| 25 | 0.9765625 | |
| 26 | 0.48828125 | AGC VOLTS |
| 27 | 0.244140625 | (7 Bits + Sign) |
| 28 | 0.1220703125 | |
| 29 | 0.06103515625 | |
| 30 | Always Zero | |
| 31 | Always Zero | |
| 32 | Always Zero | |
| 33 | Always Zero | |
| 34 | Always Zero | |
| 35 | Always Zero | |

## RADAR STATUS IDENTIFICATION

Word 7

| BIT | | | | |
|---|---|---|---|---|
| 0 | 1 = Recorder On | | 0 = Recorder Off | |
| 1 | 1 = Track Mode | | 0 = Non-track | |
| 2 | 1 = Acquisition Mode | | 0 = Non-acquisition | |
| 3 | 1 = Designation Mode | | 0 = Non-designation | |
| 4 | 1 = Target Detected | | 0 = Target not detected | |
| 5<br>6 | 1<br>0 = 160 PRF | 0<br>1 = 640 PRF | 0<br>0 = Other PRF | |
| 7<br>8 | 1<br>1 = B.W. 0.6 MC. | 0<br>1 = B.W. 1.6 MC. | 1<br>0 = B.W. 2.4 MC. | 0<br>0 = B.W. 4.8 MC. |
| 9<br>10 | 1<br>1 = P.W. 0.25 | 0<br>1 = P.W. 0.5 | 1<br>0 = P.W. 1.0 | 0<br>0 = P.W. 2.4 |
| 11 | 1 = AGC | | 0 = Not in AGC | |
| 12 | 1 = Angle Coast | | 0 = Not in Angle Coast | |
| 13 | 1 = Operate Status | | 0 = Test Status | |
| 14 | 1 = Circle Scan | | 0 = Not Circle Scan | |
| 15 | 1 = Spiral Scan | | 0 = Not Spiral Scan | |
| 16 | 1 = Rectangular Scan | | 0 = Not Rectangular Scan | |
| 17 | 1 = Raster Scan | | 0 = Not Raster Scan | |
| 18 | 1 = Angle Displays - Degrees | | 0 = Angle Displays - Mils | |
| 19 | | | | |
| 20 | 1 = Azimuth 2 KC BW Scan | | 0 = Not Azimuth 2 KC BW Scan | |
| 21 | 1 = Elevation 2 KC BW Scan | | 0 = Not Elevation 2 KC BW Scan | |
| 22 | 1 = Az. Data Lag Corrected | | 0 = Az. Data not Lag Corrected | |
| 23 | 1 = El. Data Lag Corrected | | 0 = El. Data not Lag Corrected | |
| 24 | 1 = Range Display - Yards | | 0 = Range Display in 100's of Yds | |
| 25 | 1 = Skin Track | | 0 = Beacon Track | |
| 26 | 1 = Digital Designate Mode | | 0 = Not in Digital Designate Mode | |
| 27 | 1 = Orbital Elements Mode | | 0 = Not in Orbital Elements Mode | |
| 28 | 1 = On Track Elements Mode | | 0 = Not in On Track Elements Mode | |
| 29 | 1 = Angle Designate | | 0 = Not in Angle Designate | |
| 30 | Always Zero | | | |
| 31 | Always Zero | | | |
| 32 | Always Zero | | | |
| 33 | Always Zero | | | |
| 34 | Always Zero | | | |
| 35 | Always Zero | | | |

## AZIMUTH ERROR CORRECTION AND ELEVATION ERROR CORRECTION

Word 8

| BIT | Bits 3 - 11 Value (Mils), Bits 21 - 29 Value (Mils) | |
|---|---|---|
| 0 | Zero | |
| 1 | Zero | |
| | Azimuth Correction (Track Mode) | Azimuth Correction (Designate or Acquire Mode) |
| 2 | Sign Bit (0=Positive Quantity, 1=Negative Quantity) | |
| 3 | 1.5625 | 100 |
| 4 | 0.78125 | 50 |
| 5 | 0.390625 | 25 |
| 6 | 0.1953125 | 12.5 |
| 7 | 0.09765625 | 6.25 |
| 8 | 0.048828125 | 3.125 |
| 9 | 0.0244140625 | 1.5625 |
| 10 | 0.01220703125 | .78125 |
| 11 | 0.006103515625 | .390625 |
| 12 | Zero | |
| 13 | Zero | |
| 14 | Zero | |
| 15 | Zero | |
| 16 | Zero | |
| 17 | Zero | |
| 18 | Zero | |
| 19 | Zero | |
| | Elevation Correction (Track Mode) | Elevation Correction (Designate or Acquire Mode) |
| 20 | Sign Bit (0=Positive Quantity, 1=Negative Quantity) | |
| 21 | 1.5625 | 100 |
| 22 | 0.78125 | 50 |
| 23 | 0.390625 | 25 |
| 24 | 0.1953125 | 12.5 |
| 25 | 0.09765625 | 6.25 |
| 26 | 0.048828125 | 3.125 |
| 27 | 0.0244140625 | 1.5625 |
| 28 | 0.01220703125 | .78125 |
| 29 | 0.006103515625 | .390625 |

Word 8 (continued)

| | |
|---|---|
| 30 | Always Zero |
| 31 | Always Zero |
| 32 | Always Zero |
| 33 | Always Zero |
| 34 | Always Zero |
| 35 | Always Zero |

NOTE 1: If sign bit is a logical "1" (negative), data will be in "one's" complement form.

NOTE 2: During the track mode the az and el correction represents the amount of lead or lag correction; during the designate or acquire mode the correction represents the difference between the designated pedestal position and the actual pedestal position.

## VELOCITY OF PROPAGATION AND CSP STATUS IDENTIFICATION

Word 9

| BIT | | | BCD Rep. |
|---|---|---|---|
| 0 | 10,000 Yds/Sec. Digit | | 8 |
| 1 | 10,000 Yds/Sec. Digit | | 4 |
| 2 | 10,000 Yds/Sec. Digit | | 2 |
| 3 | 10,000 Yds/Sec. Digit | | 1 |
| 4 | 1,000 Yds/Sec. Digit | | 8 |
| 5 | 1,000 Yds/Sec. Digit | | 4 |
| 6 | 1,000 Yds/Sec. Digit | | 2 |
| 7 | 1,000 Yds/Sec. Digit | | 1 |
| 8 | 100 Yds/Sec. Digit | | 8 |
| 9 | 100 Yds/Sec. Digit | | 4 |
| 10 | 100 Yds/Sec. Digit | | 2 |
| 11 | 100 Yds/Sec. Digit | | 1 |

NOTE: The actual Velocity of Propagation Constant equals the above number plus 327,800,000 Yds/Sec. when inserted manually at the console.

| | | |
|---|---|---|
| 12 | 1 = Vel. of Prop.-Console | 0 = Vel. of Prop.-Program |
| 13 | 1 = Simulation Ready | 0 = Not Simulation Ready |
| 14 | 1 = Simulation Start | 0 = Not Simulation Start |
| 15 | 1 = Coherent Position Track | 0 = Gross Position Track |
| 16 | 1 = Fine Line Lock-On | 0 = Not Fine Line Lock-On |
| 17 | 1 = Central Line Lock-On | 0 = Not Central Line Lock-On |
| 18 | Zero | |
| 19 | Zero | |
| 20 | Zero | |
| 21 | Zero | |
| 22 | Zero | |
| 23 | Zero | |
| 24 | Zero | |
| 25 | Zero | |
| 26 | Zero | |
| 27 | Zero | |
| 28 | Zero | |
| 29 | Zero | |
| 30 | Always Zero | |
| 31 | Always Zero | |
| 33 | Always Zero | |
| 33 | Always Zero | |
| 34 | Always Zero | |
| 35 | Always Zero | |

# DOPPLER FREQUENCY COUNTER

Word 10

| BIT | | |
|---|---|---|
| 0 | 1,048,576 | CPS |
| 1 | 524,288 | CPS |
| 2 | 262,144 | CPS |
| 3 | 131,072 | CPS |
| 4 | 65,536 | CPS |
| 5 | 32,768 | CPS |
| 6 | 16,384 | CPS |
| 7 | 8,192 | CPS |
| 8 | 4,096 | CPS |
| 9 | 2,048 | CPS |
| 10 | 1,024 | CPS |
| 11 | 512 | CPS |
| 12 | 256 | CPS |
| 13 | 128 | CPS |
| 14 | 64 | CPS |
| 15 | 32 | CPS |
| 16 | 16 | CPS |
| 17 | 8 | CPS |
| 18 | 4 | CPS |
| 19 | 2 | CPS |
| 20 | 1 | CPS |
| 21 | Zero | |
| 22 | Zero | |
| 23 | Zero | |
| 24 | Zero | |
| 25 | Zero | |
| 26 | Zero | |
| 27 | Zero | |
| 28 | Zero | |
| 29 | Zero | |
| 30 | Always Zero | |
| 31 | Always Zero | |
| 32 | Always Zero | |
| 33 | Always Zero | |
| 34 | Always Zero | |
| 35 | Always Zero | |

NOTE

Doppler Shift = 1 Megacycle $\pm$ 800 KC

(highest 1.8 MC)
(lowest 200 KC)

## TRANSMITTER FREQUENCY

Word 11

| BIT | | BCD Rep. |
|---|---|---|
| 0 | 10,000,000 CPS Digit | 8 |
| 1 | 10,000,000 CPS Digit | 4 |
| 2 | 10,000,000 CPS Digit | 2 |
| 3 | 10,000,000 CPS Digit | 1 |
| 4 | 1,000,000 CPS Digit | 8 |
| 5 | 1,000,000 CPS Digit | 4 |
| 6 | 1,000,000 CPS Digit | 2 |
| 7 | 1,000,000 CPS Digit | 1 |
| 8 | 100,000 CPS Digit | 8 |
| 9 | 100,000 CPS Digit | 4 |
| 10 | 100,000 CPS Digit | 2 |
| 11 | 100,000 CPS Digit | 1 |
| 12 | 10,000 CPS Digit | 8 |
| 13 | 10,000 CPS Digit | 4 |
| 14 | 10,000 CPS Digit | 2 |
| 15 | 10,000 CPS Digit | 1 |
| 16 | 1,000 CPS Digit | 8 |
| 17 | 1,000 CPS Digit | 4 |
| 18 | 1,000 CPS Digit | 2 |
| 19 | 1,000 CPS Digit | 1 |
| 20 | Zero | |
| 21 | Zero | |
| 22 | Zero | |
| 23 | Zero | |
| 24 | Zero | |
| 25 | Zero | |
| 26 | Zero | |
| 27 | Zero | |
| 28 | Zero | |
| 29 | Zero | |

NOTE: Actual Transmitter frequency is equal to the above number multiplied by 128 plus 426 MCS.

| | | |
|---|---|---|
| 30 | Always Zero | |
| 31 | Always Zero | |
| 32 | Always Zero | |
| 33 | Always Zero | |
| 34 | Always Zero | |
| 35 | Always Zero | |

# RANGE RATE

Word 12

| BIT | | |
|---|---|---|
| 0 | Sign Bit (0=Positive Quantity, 1=Negative Quantity) | |
| 1 | 16,384.0 | Yds/Sec. |
| 2 | 8,192.0 | Yds/Sec. |
| 3 | 4,096.0 | Yds/Sec. |
| 4 | 2,048.0 | Yds/Sec. |
| 5 | 1,024.0 | Yds/Sec. |
| 6 | 512.0 | Yds/Sec. |
| 7 | 256.0 | Yds/Sec. |
| 8 | 128.0 | Yds/Sec. |
| 9 | 64.0 | Yds/Sec. |
| 10 | 32.0 | Yds/Sec. |
| 11 | 16.0 | Yds/Sec. |
| 12 | 8.0 | Yds/Sec. |
| 13 | 4.0 | Yds/Sec. |
| 14 | 2.0 | Yds/Sec. |
| 15 | 1.0 | Yds/Sec. |
| 16 | 0.5 | Yds/Sec. |
| 17 | 0.25 | Yds/Sec. |
| 18 | 0.125 | Yds/Sec. |
| 19 | 0.0625 | Yds/Sec. |
| 20 | 0.03125 | Yds/Sec. |

NOTE: If the sign bit is a logical "1" (negative), the data will be in 2 complement form.

| | |
|---|---|
| 21 | 0.0156250 |
| 22 | 0.00781250 |
| 23 | 0.003906250 |
| 24 | 0.0019531250 |
| 25 | 0.00097656250 |
| 26 | 0.000488281250 |
| 27 | 0.0002441406250 |
| 28 | 0.00012207031250 |
| 29 | 0.000061035156250 |
| 30 | Always Zero |
| 31 | Always Zero |
| 32 | Always Zero |
| 33 | Always Zero |
| 34 | Always Zero |
| 35 | Always Zero |

# APPENDIX C

# WALLOPS ISLAND AN/FPQ-6 INSTRUMENTATION RADAR SYSTEM ERROR MODEL FOR THE GEOS-II PROGRAM

# INTRODUCTION

This document contains an error model for the Wallops Island AN/FPQ-6 Instrumentation Radar System when it is set up as directed in the GEOS-B Program's operating instructions. While the error terms presented herein are valid for all AN/FPQ-6 radars (with the exception of the Radial Range Rate errors which only apply to radars equipped with the RCA Coherent Signal Processor), the magnitude of the error terms have been specifically calculated for the Wallops Island AN/FPQ-6 radar. In addition, the errors presented herein assume that the Wallops Island radar is involved only in tracking the GEOS-B satellite. Finally, it should be noted that only the radar dependent errors are presented and it is assumed that non-radar errors such as site survey errors, propagation errors, and beacon dependent errors will be combined with the radar model terms prior to post-mission data reduction.

# SECTION C1

## WALLOPS ISLAND AN/FPQ-6 RADAR ERROR MODEL

Tables 1 through 8 provide a listing of all applicable radar error terms including the functional form of the systematic error terms; the source of the errors; and the standard deviation of the errors which will exist in the output data from the radar. Qualifying and/or explanatory notes have been included to supplement the tabular data and supporting calculations have been placed at the end of this report. (see Section C2)

## General Comments

An attempt has been made in the accompanying tables to separate the radar dependent errors by coordinate (Azimuth, Elevation, Range and Radial Range Rate), by their frequency characteristics, and by their track mode dependency. For example, Table 1 lists those pure bias (zero frequency) and systematic (low frequency) error terms which must be considered during both beacon and skin tracking missions. Table 2 provides a separate breakout of the Azimuth systematic error terms which are track mode (beacon/ skin) dependent. Table 3 contains a listing of the Azimuth random errors. These latter errors are assumed to take the form of band-limited (by servo frequency response characteristics and/or by the effect of the discrete sampling frequency) random noise.

A comparison of the tables containing the systematic and bias error terms points out that several similar error terms (e.g., zero set bias, dynamic lag error, etc.) appear in the tables for each radar coordinate. Having noted the similarity of the error terms in each coordinate, it becomes quite easy to switch between tables since relatively few unique error terms appear in any particular table.

## Real-Time Data Correction

It will be noted that the magnitudes of certain error terms are associated with the comment; "Data correction is assumed." This comment refers to the real-time data correction capability which has been programmed into the RCA 4101 computers which form an integral part of the AN/FPQ-6 and AN/TPQ-18 Instrumentation Radar systems. This real-time data correction capability is restricted to the correction of certain systematic angular errors. Corrections can be applied in real-time for each of the following systematic errors:

| Azimuth Errors | Elevation Errors |
|---|---|
| Zero Set Bias | Zero Set Bias |
| Dynamic Lag | Dynamic Lag |
| Non-Orthogonality | Droop |
| Pedestal Leveling | Pedestal Leveling |
| Skin/Beacon Collimation | Skin/Beacon Collimation |
| Encoder Non-Linearity | Encoder Non-Linearity |

The mathematical error models used within the computer program are identical to the models presented in Tables 1 through 6. As stated above, no real-time corrections are applied to either the range or range-rate data.

The real-time data correction program assumes that accurate calibrations are carried out to determine the magnitudes of the error coefficients for each applicable error term. The accuracy of the corrections are therefore limited by the measurement uncertainties encountered during the calibration effort. The measurement uncertainty associated with each of the applicable error coefficients has been taken into account in generating the RMS errors which are listed in the error model tables. Thus, the listed error magnitudes refer to the estimated error residuals which will remain after real-time data correction has taken place.

All of the above listed error corrections are applied to the Wallops Island AN/FPQ-6 data obtained during GEOS-B tracking missions with the exception of the encoder non-linearity corrections, and the dynamic lag error corrections. The Azimuth and Elevation lag errors are computed in real-time but the results are recorded rather than applied in real-time. The recorded corrections can, of course, be applied during post-mission data reduction, and therefore, the lag error magnitudes presented in the tables are based upon the assumption that such a post-mission lag error correction will be carried out.

## Error Model Limitations

The error model presented has been based upon certain assumptions regarding the operational set-up of the radar and the dynamic characteristics of the mission.

The primary assumption made is that careful and accurate calibrations are performed to determine the error coefficient magnitudes for real-time data correction. This assumption implies that the applicable calibrations are performed on a pre and post mission basis for those errors which are known to be time dependent variables (e.g., range zero set error).

It is further assumed that GEOS-B tracks are not performed at low (< 5°) elevation angles. Such low angle tracks will introduce an additional multipath error into the angle data.

It is assumed that certain prescribed radar operating conditions are followed and that all calibrations are performed with the radar set-up in its operational state. It should be noted that the GEOS-B C-Band transponder transmits a nominal 0.5 microsecond pulse width. This imposes the requirement that all beacon-track range calibrations be performed with the radar set-up in the 0.5 microsecond pulse width mode even though a different pulse width may be used to interrogate the transponder. There is also a secondary effect introduced by the 0.5 microsecond beacon pulse width. The AN/FPQ-6 has been designed to optimally process only a 0.75 microsecond beacon return pulse width. The lower GEOS-B beacon reply pulse width will result in non-optimum processing which will show up primarily as a degradation in the dynamic response characteristics of the range servo. Specific effects of this mismatch are impossible to predict since they are greatly dependent upon operational set-up and adjustment procedures as well as upon the actual received beacon pulse width. Any differences between the 0.5 microsecond pulse width used for radar calibration and the actual pulse width received from the beacon will also introduce an apparent range zero set error.

It is assumed that a check and/or recalibration of the radar for dynamic angle lag error correction will be performed as often as necessary. Lag error calibration is affected by any adjustments which alter the relative gain and/or phase characteristics of the radar receiver's reference and angle error channels as well as by changes in the servo system's gain or bandwidth characteristics.

It is further assumed that the target characteristics are such that the radar is operating within the linear portion of its dynamic response characteristics. For a target such as GEOS-B, this assumption should be valid for beacon tracks with the possible exception of encountering a very short interval of elevation servo non-linearity due to stiction. This possibility will exist only at PCA (point of closest approach) and will affect only the elevation angle channel. There is also a possibility that the received beacon track signal strength will be sufficiently high (greater than approximately 40 dB) during high elevation passes to make the magnitude of the thermal noise small with respect to other random error components. In this event, the RMS value of the random errors for a particular coordinate will appear to remain fixed at a value which is approximately the RMS of the non-thermal random errors. The stiction problem may also occur during skin-tracks although increased thermal noise due to lower received signal strengths will tend to minimize the effects of this potential problem. The skin-track S/N ratio will be quite low (5 to 15 dB) and may result in radar operation within a signal strength region which is not covered by the assumptions inherent in the angle thermal noise equations. Therefore, the angle thernal noise equations may not adequately describe the random errors which will be present in angle tracking data obtained when the received single-hit IF signal to noise ratio is lower than approximately +10 to +12 dB. Finally, it is assumed that the angle tracking dynamics will be sufficiently low to permit the radar to maintain track in or near to the null of the antenna's error pattern. This assumption should be valid for an orbiting target such as GEOS-B when the radar is operated in the prescribed manner (wide angle bandwidths). Failure to maintain track at or near the antenna null could result in the introduction of unmodeled angle errors due to antenna dependent crosstalk and polarization effects.

Finally, the presented error model does not include error terms for scintillation (amplitude or angle) effects. These errors are introduced by target characteristics and are therefore considered to be non-radar dependent errors. The inclusion of such error terms would be meaningless since the effects of these errors will vary from pass to pass due to changes in aspect angle and beacon lobing characteristics.

TABLE 1

AZIMUTH SYSTEMATIC AND BIAS ERRORS WHICH ARE INDEPENDENT OF TRACK MODE

| ERROR TERM ($\mu_{Ai}$) | FORM OF ERROR | ERROR SOURCE | $\sigma_{Ai}$(Mils)* | REMARKS |
|---|---|---|---|---|
| $\mu_{A0}$ | $\mu_{A0}$ = Const. | $\mu_{A0}$ = $A_z$ Zero Set Error. | $\sigma_{A0-1}$ = unknown | See Note 1. |
| $\mu_{A1}$ | $\mu_{A1} = \Delta t \dot{A}$ | $\mu_{A-1}$ = Timing Error. | - - | See Note 2. |
| $\mu_{A2}$ | $\mu_{A2} = - \frac{1}{C} R\dot{A}$ | $\mu_{A2}$ = Transit Time Error. | - - | See Note 3. |
| $\mu_{A3}$ | $\mu_{A3} = \frac{\dot{A}}{K_v} + \frac{\ddot{A}}{K_a} + \frac{\dddot{A}}{K_j} + \ldots$ | $\mu_{A3}$ = Dyanmic Lag Error.<br>$K_v$ = Angle Servo Velocity Constant.<br>$K_a$ = Angle Servo Acceleration Constant.<br>$K_j$ = Angle Servo Jerk Constant. | 0.015 | Data correction and use of angle servo bandwidth position #9 are assumed. |
| $\mu_{A4}$ | $\mu_{A4} = K_5 \text{Sin}(A+\phi_A+180°)$ | $\mu_{A4}$ = Transducer Nonlinearity.<br>$K_5$ = Nonlinearity Amplitude.<br>$\phi_A$ = Nonlinearity Phase Angle. | 0.006 | From Site data. |
| $\mu_{A5}$ | $\mu_{A5} = K_1 \text{ Tan } (E)$ | $K_1$ = Non-Orthogonality of Axis.<br>E = Elevation Angle. | 0.01 | |

*Note: $\sigma_{Ai}$ Column provides the RMS residual error remaining after real-time data correction.

TABLE 1 (cont.)

| ERROR TERM ($\mu_{Ai}$) | FORM OF ERROR | ERROR SOURCE | $\sigma_{Ai}$(Mils)* | REMARKS |
|---|---|---|---|---|
| $\mu_{A6}$ | $\mu_{A6} = K_2 Sin(A+K_3) Tan(E)$ | $K_2$ = Pedestal Tilt Amplitude. | $\sigma_{K2} = 0.025$ | See Note 4. |
| | | $K_3$ = 270° - Pedestal Tilt Phase. | $\sigma_{K3} = 11.3°$ | |
| | | E = Elevation Angle. | = 200.89 Mil | |
| $\mu_{A7}$ | $\mu_{A7} = K_4 Sec\ E$ | $K_4$ = Antenna distortion errors (Dynamic deflection and solar heating) | unknown | See Note 5. |

*Note: $\sigma_{Ai}$ Column provides the RMS residual error remaining after real-time data correction.

TABLE 2

AZIMUTH SYSTEMATIC ERRORS WHICH ARE TRACK MODE DEPENDENT

| ERROR TERM ($\mu_{Ai}$) | FORM OF ERROR | ERROR SOURCE | $\sigma_{Ai}$ (Mils)* | REMARKS |
|---|---|---|---|---|
| $\mu_{A8}$ | $\mu_{A8} = K_{as/b} \text{ Sec}(E)$ | $K_{a\ s/b}$ = Skin/Beacon Collimation and boresight drift errors.<br>E = Elevation angle. | 0.01 | Data correction assumed. |

*Note: $\sigma_{Ai}$ is the estimated RMS residual error remaining after real-time data correction.

TABLE 3

AZIMUTH RANDOM ERRORS

| ERROR TERM | FORM OF ERROR | ERROR SOURCE | STAND. DEV. (MILS) SKIN | BEACON | REMARKS |
|---|---|---|---|---|---|
| $\sigma_{A-A}$ | Random error which is independent of trajectory and track mode | $\sigma_{A-a}$ = $A_z$ Bearing wobble. | | | |
| | | $\sigma_{A-b}$ = $A_z$ Servo noise. | 0.012 | 0.012 | |
| | $\sigma_{A-A} = \left[(\sigma_{A-a})^2 + (\sigma_{A-b})^2 + (\sigma_{A-c})^2\right]^{1/2}$ | $\sigma_{A-c}$ = Encoder quantizing error. | | | |
| $\sigma_{A-B}$ | $\sigma_{A-B} = \sigma_{\theta t} \mathrm{Sec} E$ | $\sigma_{\theta t}$ = Angle thermal noise. $= \dfrac{\theta}{k_m[S/N\ f_r/B_n]^{1/2}}$ | $\dfrac{0.45\ \mathrm{Sec}(E)}{\sqrt{S/N}}$ | $\dfrac{0.9\ \mathrm{Sec}(E)}{\sqrt{S/N}}$ | See Note 6. |
| | | E = Elevation angle. | | | |

TABLE 4

ELEVATION SYSTEMATIC AND BIAS ERRORS WHICH ARE INDEPENDENT OF TRACK MODE

| ERROR TERM ($\mu_{Ei}$) | FORM OF ERROR | ERROR SOURCE | $\sigma_{Ei}$ (Mils)* | REMARKS |
|---|---|---|---|---|
| $\mu_{E0}$ | $\mu_{E0} = \mu_{E0-1} + \mu_{E0-2} = \text{Const.}$ | $\mu_{E0}$ = El Zero Set Error. | $\sigma_{E0-1}$ = unknown | See Note 1. |
| $\mu_{E1}$ | $\mu_{E1} = \Delta t\dot{E}$ | $\mu_{E1}$ = Timing Error. | - - | See Note 2. |
| $\mu_{E2}$ | $\mu_{E2} = \frac{1}{C} R\dot{E}$ | $\mu_{E2}$ = Transit Time Error. | - - | See Note 3. |
| $\mu_{E3}$ | $\mu_{E3} = \frac{\dot{E}}{K_v} + \frac{\ddot{E}}{K_a} + \frac{\dddot{E}}{K_j} + \ldots$ | $\mu_{E3}$ = Dynamic Lag Error.<br>$K_v$ = Angle Servo Velocity Constant.<br>$K_a$ = Angle Servo Acceleration Constant.<br>$K_j$ = Angle Servo Jerk Constant. | 0.015 | Data correction and use of angle servo bandwidth position #9 are assumed. |
| $\mu_{E4}$ | $\mu_{E4} = K_6 \text{Sin}(E+\phi_E+180°)$ | $\mu_{E4}$ = Transducer Nonlinearity.<br>$K_6$ = Nonlinearity Amplitude.<br>$\phi_E$ = Nonlinearity Phase Angle. | 0.006 | From Site data. |

*Note: $\sigma_{Ei}$ is estimated RMS value of uncorrected error terms or the estimated RMS residual error for corrected errors.

TABLE 4 (cont.)

| ERROR TERM ($\mu_{Ei}$) | FORM OF ERROR | ERROR SOURCE | $\sigma_{Ei}$(Mils)* | REMARKS |
|---|---|---|---|---|
| $\mu_{E5}$ | $\mu_{E5} = K_0 \text{ Cos}(E)$ | $K_0$ = 0° El. Error due to Droop.<br>$E$ = Elevation angle. | 0.02 | Data correction is assumed. |
| $\mu_{E6}$ | $\mu_{E6} = K_2 \text{ Cos}(A+K_3)$ | $K_2$ = Pedestal Tilt Amplitude.<br>$K_3$ = 270° - Pedestal Tilt Phase. | | Same as $A_z$. See Table 1. |
| $\mu_{E7}$ | $\mu_{E7}$ = Const. = $K_4$ | Antenna distortion errors (Dynamic deflection and solar heating). | unknown | See Note 5. |

*Note: $\sigma_{Ei}$ is estimated RMS value of uncorrected error terms or the estimated RMS residual error for corrected errors.

TABLE 5

ELEVATION SYSTEMATIC ERRORS WHICH ARE TRACK MODE DEPENDENT

| ERROR TERM ($\mu_{Ei}$) | FORM OF ERROR | ERROR SOURCE | $\sigma_{Ei}$(Mils)* | REMARKS |
|---|---|---|---|---|
| $\mu_{E8}$ | $\mu_{E8}$ = Const. = $K_{e\ s/b}$ | $K_{e\ s/b}$ = Skin/Beacon Collimation and boresight shift errors. | 0.01 | Data correction assumed. |

*Note: $\sigma_{Ei}$ is estimated RMS residual error remaining after real-time data correction.

TABLE 6

ELEVATION RANDOM ERRORS

| ERROR TERM | FORM OF ERROR | ERROR SOURCE | STAND. DEV. (MILS) SKIN | BEACON | REMARKS |
|---|---|---|---|---|---|
| $\sigma_{E-A}$ | Random error which is independent of trajectory and track mode<br>$\sigma_{A-A} = \left[(\sigma_{E-a})^2 + (\sigma_{E-b})^2 + (\sigma_{E-c})^2\right]^{1/2}$ | $\sigma_{E-a} = E_{\ell}$. bearing wobble.<br>$\sigma_{E-b} = E_{\ell}$. servo noise.<br>$\sigma_{E-c}$ = Encoder quantizing error. | 0.012 | 0.012 | |
| $\sigma_{E-B}$ | $\sigma_{E-B} = \sigma_{Et}$ | $\sigma_{Et}$ = Angle thermal noise.<br>$= \dfrac{\theta}{k_m [S/N\ f_r/B_n]^{1/2}}$ | $\dfrac{0.45}{\sqrt{S/N}}$ | $\dfrac{0.90}{\sqrt{S/N}}$ | See Note 6. |

TABLE 7

RANGE MEASUREMENT ERRORS (RADAR DEPENDENT)

| ERROR TERM | FORM OF ERROR | ERROR SOURCE | $\sigma_{Ri}$ (Meters)* | REMARKS |
|---|---|---|---|---|
| $\mu_{R0}$ | $\mu_{R0} = \text{Const.} = \mu_{R0-1} + \mu_{R0-2} + \ldots$ | $\mu_{R0-1}$ = Zero Set Error.<br>$\mu_{R0-2}$ = Discriminator drift.<br>$\mu_{R0-3}$ = Servo unbalance. | 0.5 | RMS error is estimate assuming careful pre- and post-mission calibration. See Note 7. |
| $\mu_{R1}$ | $\mu_{R1} = \Delta t \dot{R}$ | Timing Errors. | unknown | See Note 2. |
| $\mu_{R2}$ | $\mu_{R2} = - \frac{1}{C} R \dot{R}$ | $\mu_{R2}$ = Transit time error. | - - | See Note 3. |
| $\mu_{R3}$ | $\mu_{R3} = \frac{\ddot{R}}{K_a} + \frac{\dddot{R}}{K_j} + \ldots$ | $\mu_{R3}$ = Dynamic Lag Error.<br>$K_a$ = Range Servo Acceleration Constant.<br>$K_j$ = Range Servo Jerk Constant | - - | See Note 8. |

*Note: $\sigma_{Ri}$ is estimated standard deviation of errors.

TABLE 7 (cont.)

| ERROR TERM | FORM OF ERROR | ERROR SOURCE | $\sigma_{Ri}$ (Meters)* | REMARKS |
|---|---|---|---|---|
| $\mu_{R4}$ | $\mu_{R4} = \left[\mu_{R4-1} + \mu_{R4-2}\right] R$ | $\mu_{R4-1}$ = Range Oscillator Frequency Error. | | |
| | | $\mu_{R4-2}$ = Velocity of light error. | unknown | See Note 9. |
| $\sigma_{R-A}$ | Random and independent of track geometry and track mode. | Range servo noise; range quantization; internal time jitter. | 0.75 | |
| $\sigma_{R-B}$ | $\sigma_{R-B} = \sigma_{Rt}$ | $\sigma_{Rt}$ = Range thermal noise. | $(\sigma_{Rt})_B = \frac{6.0}{\sqrt{S/N}}$ | See Note 6. |
| | | $= \frac{\tau}{k_r \sqrt{(S/N)\ f_r/B_n}}$ | $(\sigma_{Rt})_S = \frac{11.47}{\sqrt{S/N}}$ | |
| | | $\sigma_{Rt} = (\sigma_{Rt})_B$ for Beacon track. | | |
| | | $\sigma_{Rt} = (\sigma_{Rt})_S$ for Skin track. | | |

*Note: $\sigma_{Ri}$ is estimated standard deviation of errors.

TABLE 8

RANGE RATE MEASUREMENT ERRORS (RADAR DEPENDENT)

| ERROR TERM | FORM OF ERROR | ERROR SOURCE | $\sigma_{\dot{R}i}$ (Meters/sec.)* | REMARKS |
|---|---|---|---|---|
| $\mu_{\dot{R}0}$ | $\mu_{\dot{R}0} = \text{Const.} - \mu_{\dot{R}0-1}$ | $\mu_{\dot{R}0-1}$ = Discriminator drift. | | |
| | $+ \mu_{\dot{R}0-2}$ | $\mu_{\dot{R}0-2}$ = Environmental effects upon components. | 0.0380 | |
| $\mu_{\dot{R}1}$ | $\mu_{\dot{R}1} = \Delta t \ddot{R}$ | $\mu_{\dot{R}1}$ = Timing Error. | - - | See Note 2. |
| $\mu_{\dot{R}2}$ | $\mu_{\dot{R}2} = - \frac{1}{C} R \ddot{R}$ | $\mu_{\dot{R}2}$ = Transit Time Error. | - - | See Note 3. |
| | | $\mu_{\dot{R}3}$ = Dynamic Lag Error. | | |
| $\mu_{\dot{R}3}$ | $\mu_{\dot{R}3} = \frac{\dddot{R}}{K_a} + \frac{\ddddot{R}}{K_j} + \ldots$ | $K_a$ = Range Rate Servo Acceleration Constant. | - - | See Note 10. |
| | | $K_j$ = Range Rate Servo Jerk Constant. | | |

*Note: $\sigma_{\dot{R}i}$ is the estimated standard deviation of errors.

TABLE 8 (cont.)

| ERROR TERM | FORM OF ERROR | ERROR SOURCE | $\sigma_{\dot{R}i}$ (Meters/sec.)* | REMARKS |
|---|---|---|---|---|
| $\sigma_{\dot{R}A}$ | $\sigma_{\dot{R}A} = \left[(\sigma_{\dot{R}A-1})^2 + (\sigma_{\dot{R}A-2})^2 + \ldots\right]^{1/2}$ | $\sigma_{\dot{R}A-1}$ = Reference Oscillator Stability Error. = 2.46 $H_z$ RMS | | |
| | | $\sigma_{\dot{R}A-2}$ = Transmitter noise and and spurious effects $\leq$ 1.2 $H_z$. | 0.0727 | See Note 11. |
| | | $\sigma_{\dot{R}A-3}$ = Doppler quantizing error. = 0.29 $H_z$ RMS | | |
| | | $\sigma_{\dot{R}A-4}$ = Granularity of $\dot{R}$ readout. = 0.008 m/sec. | | |
| $\sigma_{\dot{R}B}$ | $\sigma_{\dot{R}B} = \sigma_{\dot{R}t}$ | $\sigma_{\dot{R}t}$ = Range rate thermal noise. $= \frac{\lambda/2\ B_{f_L}}{k_d \sqrt{S/N\ f_r/B_n}}$ | $\frac{0.527}{\sqrt{S/N}}$ | See Note 12. |

*Note: $\sigma_{\dot{R}i}$ is the estimated standard deviation of errors.

Notes Called Out in Tables 1 Through 8

Note 1: The Azimuth zero set error is a bias error which is considered to be a site survey error since the AN/FPQ-6 radar's data correction computer program can correct for any Azimuth bias error if some external Azimuth reference point is provided. It is hoped that an accurate estimate of this bias error term will be generated as a result of the GEOS-B Program.

Note 2: No timing error has been presented since the error of interest must include external (site timing) as well as internal radar timing errors. In addition, this term is felt to be negligibly small for the Wallops Island radar since considerable care has been taken in measuring the overall timing error and in applying the necessary time corrections to the data during post-mission data reduction.

Note 3: No transit time error has been presented since the post-mission data reduction of GEOS-B data includes a correction for this error. Rather than applying the correction in conformance with the mathematical form presented, this post-mission correction merely applies a time translation to the data by an amount equal to 1/2 of the transit time delay. The time tags associated with the final raw data permit this simplified form of correction to be made rather than the more complicated form which would be necessary if real-time corrections were attempted.

Note 4: The RMS leveling uncertainties given apply only to the Wallops Island radar and are considered to be very conservative. Monthly calibration of the radar for out-of-level error is presently being carried out which should lower the uncertainty in these terms by an order of magnitude.

Note 5: The antenna distortion errors are functions of environmental conditions and track geometry (direction, magnitude, and peridocity of wind) as well as track dynamics. Therefore, presentation of a fixed value for this error term for all missions would be meaningless.

Note 6: The formulae presented can be used for GEOS-B tracks by making use of the recorded AGC voltages and the pre mission receiver gain calibration data. However, it should be noted that amplitude and angle scintillation effects will not be predicted from such computations. If preferred, Section C2 provides theoretical calculations of the thermal noise errors as a function of slant range. However, beacon lobing and unexplainable skin track signal strengths observed during GEOS-B track make the usefulness of the theoretical computations questionable. It should also be noted that the other random errors listed in Table 3 will dominate the total RMS random error for S/N ratios greater than approximately +40 db. Also, the utilization of the angle thermal noise equation is limited to S/N ratios greater than approximately +12 db.

Note 7: Since transponder dependent errors are not included in the tables, the range zero set error has not been listed as a track mode dependent error. However, the zero set error will in practice vary between skin and beacon track calibrations. The given value for the estimated RMS error is felt to be valid for skin-track mode and should be approached for beacon track mode if allowances are made for differences between the actual beacon pulse width and the pulse width used during calibration. Uncertainties in the beacon time delay will also introduce apparent zero set errors into the beacon track data.

Note 8: No real-time corrections are made for range dynamic lag error. However, this error should be negligibly small (on the order of one foot max error for 80° Elevation pass) for a target such as GEOS-B if the range servo is properly adjusted and if the signal processing mismatch (see discussion of Error Model Limitations) does not introduce an unexpectedly large degradation of the range servo response characteristic.

Note 9: The range oscillator frequency error is unknown but present site attempts to measure this error by comparison to an atomic frequency standard may provide a reliable error estimate in the near future. It is thought that this error is negligible.

The velocity of light uncertainty is not a radar dependent error and is included only because its effects cannot be separated from the oscillator frequency effects.

Note 10: No estimated RMS error is given for the range rate dynamic lag error since no data is available on the magnitudes of the actual higher order range derivatives involved in this error term. However, the bandwidth (40 $H_z$) used during doppler tracking together with the type of target involved (relatively high altitude, orbiting object) will tend to make this error quite small (on the order of 0.005 m/sec max for 80° Elevation pass).

Note 11: The value of 2.46 $H_z$ given for $\sigma_{\dot{R}A-1}$ was obtained from manufacturer's (Hewlett Packard) data on the fractional frequency deviation for the internal frequency standard of the H.P. 5100B/5110B frequency synthesizer. The specified RMS fractional frequency deviation is $6 \times 10^{-10}$ for the

50 $MH_z$ output over a 10 ms averaging time. The actual frequency used in the CSP system is 36 $MH_z$ so that a fractional frequency deviation of $(6 \times 10^{-10})\frac{(36)^2}{50} = 4.32 \times 10^{-10}$ was used in Table 8 which, when translated to the C-Band frequency of interest ($5690 \times 10^6$ $H_z$) results in the given RMS frequency error.

Note 12: The range rate thermal noise equation given in Table 8 is developed in Section C2. The value given for the standard deviation as a function of S/N is based upon the radar operational set-up used for the GEOS-B Program (i.3., a fine line filter bandwidth of 160 $H_z$, a PRF of 640, and a servo noise bandwidth of 40 $H_z$). For all available CSP nominal operating conditions (PRF of 640 pps is assumed) the followin equation applies:

$$\sigma_{\dot{R}t} = \frac{C}{\overline{S/N}} \quad (m/sec)$$

where the S/N ratio is the single hit Gross Spectrum receiver's I.F. S/N ratio and the values for the multiplying constant (C) are as listed below:

| $B_{fl}$ ($H_z$) | $B_n$ ($H_z$) | C |
|---|---|---|
| 5 | 0.7 | 0.002 |
| 15 | 3.0 | 0.014 |
| 40 | 10.0 | 0.066 |
| 160 | 40.0 | 0.527 |

## SECTION C2
## THEORETICAL SIGNAL TO NOISE RATIO (S/N) AND ANGLE THERMAL NOISE COMPUTATIONS

### Radar Range Equation for Beacon Track

From the radar range equation for Beacon tracks and matched filter operation:

$$(S/N)_B = \frac{P_t \, G_r \, G_B \, \lambda^2}{(4\pi)^2 \, R^2 \, k \, T_s \, B \, L_t \, L_a}$$

where

$P_t$ = Signal Power out of Beacon transmitter

$G_r$ = Gain of Radar Antenna relative to isotropic radiator

$G_B$ = Gain of Beacon Antenna relative to an isotropic radiator

$\lambda$ = Wavelength of transmitted signal = c/f

R = Slant range

k = Boltzman's constant = $1.38 \times 10^{-23}$ watts/°K/$H_z$

$T_s$ = Radar System noise Temperature referred to the antenna

$B$ = Receiver Noise Bandwidth in Hz ≈ 3 db bandwidth

$L_t$ = Beacon transmit losses

$L_a$ = Atmospheric losses

<u>Theoretical Computation of Beacon Track S/N for Constant $G_B$:</u>

All of the factors on the right hand side of the above equation are known with the exception of beacon antenna gain as a function of radar to satellite aspect angle (antenna pattern). However, assuming the beacon antenna has a nominal gain which is independent of aspect angle, the radar range equation can be fully evaluated as follows:

$P_t$ = 400 watts

$G_r$ = 51 db - 3 db (for receipt of circular polarization when in linear polarization mode)

= 48 db

$G_B$ = - 2 db

$$\lambda = \frac{3 \times 10^8}{5765 \times 10^6} = 5.2038 \times 10^{-5} \text{ Km}$$

$k = 1.38 \times 10^{-23}$

$B = 2.4 \times 10^{6}$ Hz

$L_t = 1$ db

also

$$T_s = T_a + T_o (L_r - 1) + T_o L_r (NF - 1)$$

$$= 50 = 290 (1.70 - 1) + (290) (1.70) (2.82 - 1)$$

$$= 1148° K$$

where

$T_a$ = Antenna Temperature $\approx$ 50°K for $E \geq 10°$

$T_o$ = 290° K

$L_r$ = receive losses = 2.3 db

$\overline{NF}$ = 4.5 db

and

$L_a$ = Atmospheric losses ≈ 0.2 db for $E \geq 10°$

After substituting these values into the radar range equation, the following expression is obtained for single hit radar I.F. S/N ratio:

$$S/N = \frac{5.45 \times 10^9}{R^2} \quad ; \text{ where R is in Km}$$

<u>Beacon Track Angle Thermal Noise for Constant $G_B$</u>

The expression relating angle thermal noise to specific radar parameters and to received S/N is:

$$\sigma_{\theta t} = \frac{\theta}{k_m \left[S/N \; f_r/B_n\right]^{1/2}}$$

where

$\theta$ = Half power Antenna beamwidth in MILS

$k_m$ = Angle Error Slope Factor in units of reference channel voltage per beamwidth error

$S/N$ = Received I.F. signal to noise ratio

$f_r$ = Pulse repetition rate

$B_n$ = Noise bandwidth of angle servo ≈ servo 3 db bandwidth

for the An/FPQ-6 radar set up for GEOS-B beacon track the above constants become:

$\theta$ = 7.0 MILS

$k_m$ = 1.1 volts/Beamwidth error

$f_r$ = 160 PPS

$B_n$ = 3.2 Hz

therefore, the theoretical angle thermal noise for an assumed constant gain beacon antenna is:

$$\left(\sigma_{Et}\right)_B = \text{Beacon Elevation Thermal Noise}$$

$$= \frac{7.0}{1.1\left[\frac{5.45 + 109}{R^2} \quad \frac{160}{3.2}\right]^{1/2}}$$

$$= 1.219 \times 10^{-5} \ R(\text{MILS})$$

$$\left(\sigma_{At}\right)_B = \text{Beacon Azimuth Thermal Noise} = Et \cdot \text{Sec } E$$

$$= 1.219 \times 10^{-5} \ R \cdot \text{Sec } E \ (\text{MILS})$$

where R is the slant range in Km.

Radar Range Equation for Skin Track

From the radar range equation for skin (echo) track and matched filter operation:

$$(S/N)_s = \frac{P_t \ (G_r)^2 \ \lambda^2 \ \sigma}{(4\pi)^3 \ k \ T_s \ B \ L_t \ L_a}$$

where all parameters are as defined in paragraph (1) above except for:

$P_t$ = Radar transmitter output power

$\sigma$ = Target radar Crossection

Theoretical Computation of Skin Track (S/N)

It it is assumed that the C-Band passive array is the only, or at least the primary, reflector for incident C-Band radar energy, it would be possible to utilize available array C-Band radar crossection information to compute the theoretical skin-track S/N and thermal noise. Unfortunately, however, existing GEOS-B skin track data obtained by the Wallops Island An/FPQ-6 radar shows a much higher skin track S/N (20 x 25 db max) than can be accounted for by using only the passive array's crossection (12 to 15 db max). It has also been found that the S/N received by the radar is as high or higher for linear vertical polarization as for circular polarization. In addition, no discernable improvement in signal strength lobing characteristics could be ascertained in the skin-track data with circular polarization relative to the skin-track data with vertical linear polarization. These skin tracking results all tend to indicate that the passive C-Band array is not the dominant C-Band reflector. Thus, it seems unrealistic to present a computation of theoretical S/N based upon only the radar crossection of the passive array. It is possible however to express the theoretical S/N and angle thermal noise terms as functions of both range and effective target C-Band cross-section. Then, once sufficient skin-track data is available, it will be possible to arrive at the target crossection empirically. Once this is done the theoretical thermal noise predictions can be computed as was done above for the beacon track case. The theoretical relationships and applicable parameters are printed below.

For the skin case:

$$P_t = 2.8 \times 10^6 \text{ (watts)}$$

$$(G_{R2})^2 = (1.259 \times 10^5)^2$$

$$\lambda^2 = \frac{(3 \times 10 \quad 10^5)^2}{5.69 \times 10^9} \text{ (Km)}^2$$

$\sigma$ = unknown ($10^{-6}$ x crossection relative to 1 sq. meter)

$$k = 1.38 \times 10^{-23}$$

$$B = 0.575 \times 10^6 \text{ Hz}$$

$T_s$ = 1123°K, referenced to Antenna

$L_t$ = 2.26

$L_a$ = 1.035 for $E \geq 40°$

R = variable = Slant range in Km

Substituting into the radar range equation:

$$(S/N)_s = 2.983 \times 10^{12} \frac{\sigma}{R^4}$$

for R in Km and $\sigma$ = crossection relative to one square meter.

<u>Skin Track Theoretical Angle Thermal Noise</u>

$$\sigma_{\theta t} = \frac{\theta}{k_m \left[S/N\ fr/B_n\right]^{1/2}}$$

where all terms are the same as defined previously. For the operating parameters used during GEOS-B skin tracking missions ($f_r$ = 640 pps, $B_n$ = 3.2 Hz).

$(\sigma_{Et})_s$ = Skin Elevation Thermal Noise

$$= 2.605 \times 10^{-7} \frac{R^2}{\sqrt{\sigma}} \text{ MILS}$$

$(\sigma_{At})_s$ = Skin Azimuth Thermal Noise

$$= 2.605 \times 10^{-7} \frac{R^2 \text{ Sec } E}{\sqrt{\sigma}} \text{ MILS}$$

where R is the slant range in Km and $\sigma$ is target crossection relative to one square meter.

Range Thermal Noise

The thermal noise appearing in the range measurement data can be computed by:

$$\sigma_R = \frac{\tau}{k \sqrt{(S/N)\ (f_r/B_n)}}$$

where

$\tau$ = The range interval encompassed by one pulse width

$k$ = Error constant for range discriminator

$(S/N)$ = Single hit I.F. S/N ratio

$f_r$ = P R F

$B_n$ = Range Servos Noise Bandwidth

Assuming a $k_r$ of 2.0 which will be accurate enough for present purposes we get:

(A) for Beacon Track:

The reference channel's IF S/N is known from the theoretical computation of the beacon track S/N for constant $G_B$:

$$(S/N)_B = \frac{5.45 \times 10^9}{R^2}$$

where R is slant range in Km, and the following parameters are known:

$$\tau = 0.5 \ \mu sec = 75 \text{ meters}$$

$$f_r = 160$$

$$B_n = 4.1 \text{ cps}$$

Substituting:

$$(\sigma_R)_B = \frac{75}{(2.0)\left[\frac{5.45 \times 10^9}{R^2} \quad \frac{160}{4.1}\right]^{1/2}}$$

$$= 8.131 \times 10^{-5} R \text{ (Meters)}$$

where slant range R is in units of Km.

(B) For Skin Track:

From the computations for skin track S/N:

$$(S/N)_s = 2.98 \times 10^{12} \frac{\sigma}{R^4}$$

So that:

$$(\sigma_R)_s = \frac{(150 \times 2.4)}{2.0\left[2.98 \times 10^{12} \frac{\sigma}{R^4} \frac{640}{2.6}\right]^{1/2}}$$

$$(\sigma_R)_s = 6.65 \times 10^{-6} \frac{R^2}{\sqrt{\sigma}} \text{ Meters}$$

where R is slant range in units of $K_m$ and $\sigma$ is target radar crossection relative to one square meter.

Range Rate Thermal Noise

Radial range rate measurements carried out as a part of the GEOS-B C-Band Radar experiment will, due to lack of a satellite borne coherent beacon, be associated with skin tracks of the GEOS vehicle. Further, present program plans do not call for closing the position loops (R, Az, and El) through the coherent signal processor (CSP) which is used to extract doppler information from the received signal. Therefore, the thermal noise computations as developed above for R, Az, and El remain valid even when doppler tracking is taking place.

For the signal strengths expected during skin tracks of the GEOS-B, the thermal noise appearing in the range rate measurements can be calculated from:

$$\sigma_{\dot{R}} = \frac{\lambda/2}{k_d \; T_c \sqrt{2(S/N) \; (f_r/B_{f_L}) \; (B_{f_L}/2B_n)}}$$

$$= \frac{\lambda \; B_{f_L}}{2k_d \sqrt{(S/N) \; f_r/B_n}}$$

where

$\lambda = \frac{c}{f}$ = wave length of signal in meters

$k_d$ = error slope factor for Doppler discriminator

$T_c$ = Coherent observation time interval. For properly designed system $T_c = \frac{1}{B_{f_L}}$ (where $B_{f_L}$ = fine line filter bandwidth)

S/N = Gross spectrum IF single hit signal to noise ratio (same as was used in previous thermal noise computations)

For the GEOS-B program and the Wallops Island CSP configuration:

$$\lambda \approx \frac{3 \times 10^8}{5690 \times 10^6}$$

$$B_{f_L} = 160 \text{ Hz}$$

$$k_d \approx 2$$

$S/N = 2.98 \times 10^{12} \dfrac{\sigma}{R^4}$ (from the range thermal noise equation)

$$f_r = 640$$

$$B_n = 40 \text{ Hz}$$

$\sigma$ = GEOS-B C-Band radar crossection relative to one square meter

$R$ = slant range to target in Km

Substituting:

$$\sigma_{\dot{R}} = 6.11 \times 10^{-7} \frac{R^2}{\sqrt{\sigma}} \text{ (Meters/sec)}$$

It should be noted that other sources of random range rate error must be taken into consideration in developing the overall RMS range rate random error. Table 8 (Section C1) lists the various random error sources and their budgeted error magnitudes.

# APPENDIX D
# NGSP DATA FORMATS

SECTION D1

NGSP FORMAT FOR

INTERAGENCY C-BAND

AZIMUTH AND ELEVATION MEASUREMENTS

| Field | Columns | Description |
|---|---|---|
| 1 | 1 - 6 | Satellite Identification* |
| | 1 - 2 | Year of Launch<br>68 = 1968 |
| | 3 - 5 | Order of Launch |
| | 6 | Component Identifier<br>1 = a |
| 2 | 7 | Type of Coordinates<br>7 = Azimuth and Elevation Angle |
| 3 | 8 | Observation Identifier<br>0 = (C-Band Tracking Transponder)<br>1 = (C-Band Skin Track) |
| 4 | 9 - 11 | Timing Standard Deviation |
| | 9 | Milliseconds |
| | 10 - 11 | .01 Milliseconds |
| 5 | 12 - 13 | Time Identifier<br>53 = UT-C Satellite Time |

* As per COSPAR numbering system.

| Field | Columns | Description |
|---|---|---|
| 6 | 14 - 18 | Station Number |
| | 14 | System Designator |
| | | 4 = Interagency C-Band |
| | 15 - 17 | Station Number |
| | 18 | Blank |
| 7 | 19 - 34 | GMT of Observation |
| | 19 - 20 | Year of Observation |
| | | 68 = 1968 |
| | | 69 = 1969 |
| | 21 - 22 | Month of Observation |
| | 23 - 24 | Day of Observation |
| | 25 - 26 | Hour of Observation |
| | 27 - 28 | Minute of Observation |
| | 29 - 30 | Second of Observation |
| | 31 - 34 | .0001 Second of Observation |
| 8 | 35 - 53 | Observation Data |
| | 35 - 37 | Azimuth degrees (arc), 0° North |
| | 38 - 39 | Azimuth minutes (arc) |
| | 40 - 41 | Azimuth seconds (arc) |
| | 42 - 44 | Azimuth |
| | | .001 seconds (arc) |
| | 45 | Blank |
| | 46 - 47 | Elevation degrees (arc) |
| | 48 - 49 | Elevation angle |
| | | minutes (arc) |
| | 50 - 51 | Elevation |
| | | angle, seconds (arc) |
| | 52 - 53 | Elevation |
| | | angle, .01 seconds (arc) |

| Field | Columns | Description |
|---|---|---|
| 9 | 54 - 59 | Date of Reduction |
| | 54 - 55 | Year of Reduction<br>68 = 1968<br>69 = 1969<br>etc. |
| | 56 - 57 | Month of Reduction |
| | 58 - 59 | Day of Reduction |
| 10 | 60 - 71 | Coded Information |
| | 60 - 61 | Supplementary Documentation<br>20 = Wallops C-Band Radar Preprocessing Report*<br>21 = AFETR C-Band Radar Preprocessing Report<br>22 = AFWTR C-Band Radar Preprocessing Report<br>23 = PMR C-Band Radar Preprocessing Report<br>24 = WSMR C-Band Radar Preprocessing Report<br>25 = NASA FRC C-Band Radar Preprocessing Report<br>26 = AFFTC C-Band Radar Preprocessing Report<br>27 = NASA GSFC C-Band Radar Preprocessing Report<br>30 = Wallops C-Band Optical Preprocessing Report<br>31 = AFETR C-Band Optical Preprocessing Report<br>32 = AFWTR C-Band Optical Preprocessing Report<br>33 = PMR C-Band Optical Preprocessing Report |

*Data was preprocessed in accordance with procedures contained herein.

| Field | Columns | Description |
|---|---|---|
| | 62 - 65 | Blank |
| | 66 - 67 | 67 = C-Band Radar |
| | 68 - 71 | Blank |
| 11 | 72 - 80 | Description of Random Error |
| | 72 | Standard deviation in Az (seconds of arc) |
| | 73 - 74 | Standard deviation in Az (.01 seconds of arc) |
| | 75 | Standard deviation in elevation angle (seconds of arc) |
| | 76 - 77 | Standard deviation in elevation angle (.01 seconds of arc) |
| | 78 - 80 | Covariance; sign in col 78(+), (-), decimal assumed between col 79 and 80 |

SECTION D2

NGSP FORMAT FOR

INTERAGENCY C-BAND

RANGE OBSERVATIONS

| Field | Columns | Description |
|---|---|---|
| 1 | 1 - 6 | Satellite Identification* |
| | 1 - 2 | Year of Launch |
| | | 68 = 1968 |
| | | etc. |
| | 3 - 5 | Order of Launch |
| | 6 | Component Identifier |
| | | 1 = a |
| 2 | 7 | Type of Coordinates |
| | | 2 = Range |
| 3 | 8 | Observation Identifier |
| | | 0 = C-Band (Tracking Transponder) |
| | | 1 = C-Band (Skin Track) |
| 4 | 9 - 11 | Timing Standard Deviation |
| | 9 | Milliseconds |
| | 10 - 11 | .01 Milliseconds |
| 5 | 12 - 13 | Time Identifier |
| | | 53 = UT-C Satellite time |
| 6 | 14 - 18 | Station Number |
| | 14 | System Designator |
| | | 4 = Interagency C-Band |
| | 15 - 17 | Station Number |
| | 18 | Blank |

* As per COSPAR numbering system.

| Field | Columns | Description |
|---|---|---|
| 7 | 19 - 34 | GMT of Observation |
| | 19 - 20 | Year of Observation<br>64 = 1964<br>65 = 1965<br>66 = 1966<br>67 = 1967<br>68 = 1968<br>etc. |
| | 21 - 22 | Month of Observation |
| | 23 - 24 | Day of Observation |
| | 25 - 26 | Hour of Observation |
| | 27 - 28 | Minute of Observation |
| | 29 - 30 | Second of Observation |
| | 31 - 34 | .0001 Second of Observation |
| 8 | 35 - 53 | Observation Data |
| | 35 - 50 | Range in Meters |
| | 51 - 53 | Range in .001 Meters |
| 9 | 54 - 59 | Date of Reduction |
| | 54 - 55 | Year of Reduction<br>68 = 1968<br>69 = 1969<br>etc. |
| 10 | 60 - 64 | Coded Information |
| | 60 - 61 | Supplementary Documentation<br>20 = Wallops C-Band Radar Preprocessing Report*<br>21 = AFETR C-Band Radar Preprocessing Report<br>22 = AFWTR C-Band Radar Preprocessing Report |

* Data was preprocessed in accordance with procedures contained herein

| Field | Columns | Description |
|---|---|---|
| | | 23 = PMR C-Band Radar Preprocessing Report |
| | | 24 = WSMR C-Band Radar Preprocessing Report |
| | | 25 = NASA FRC C-Band Radar Preprocessing Report |
| | | 26 = AFFTC C-Band Radar Preprocessing Report |
| | | 27 = NASA GSFC C-Band Radar Processing Report |
| | 62 - 63 | Instrumentation Type |
| | | 67 = C-Band Radar System |
| | 64 | Tropospheric Refraction Correction Indicator (TRC) |
| | | 1 = TRC applied to both range observation ROBS, Cols. 35 - 53) |
| | | 2 = TRC not applied to either Range Observation (ROBS) or Refraction Correction (REFCOR) |
| | | 3 = TRC included in ROBS but not REFCOR |
| | | 4 = TRC included in REFCOR but not ROBS |
| 11 | 65 - 70 | Description of Random Error |
| | 65 - 67 | Standard Deviation in meters |
| | | Standard Deviation in .001 meters |

*Data was preprocessed in accordance with procedures contained herein.

| Field | Columns | Description |
|---|---|---|
| 12 | 71 - 76 | Value of Refraction Correction (Refcor) Meters, xxx.xx |
| | 77 | Blank |
| 13 | 78 | Data Validity<br>0 or Blank = Data appears normal<br>1 = Data noisy<br>4 = Data not acceptable to reporting agency<br>5 = Support data questionable |
| | 79 | 0 or Blank = Used in solution<br>1 = Not used in solution<br>2 = Rejected from solution |
| 14 | 80 | Blank |

## SECTION D3
## NGSP FORMAT FOR INTERAGENCY C-BAND RANGE RATE OBSERVATIONS

| Field | Columns | Description |
|---|---|---|
| 1 | 1 - 6 | Satellite Identification* |
| | 1 - 2 | Year of Launch |
| | | 68 = 1968 |
| | 3 - 5 | Order of Launch |
| | 6 | Component Identifier |
| | | 1 = a |
| 2 | 7 | Type of Coordinates |
| | | 3 = Range Rate |
| 3 | 8 | Observation Identifier |
| | | 0 = C-Band (Tracking Transponder) |
| | | 1 = C-Band (Skin Track) |
| 4 | 9 - 11 | Timing Standard Deviation |
| | 9 | Milliseconds |
| | 10 - 11 | .01 Milliseconds |
| 5 | 12 - 13 | Time Identifier |
| | | 53 = UT-C   Satellite time |
| 6 | 14 - 18 | Station Number |
| | 14 | System Designator |
| | | 4 = Interagency C-Band |
| | 15 - 17 | Station Number |
| | 18 | Blank |

* As per COSPAR numbering system.

| Field | Columns | Description |
|---|---|---|
| 7 | 19 - 34 | GMT of Observation |
| | | 68 = 1968 |
| | | 69 = 1969 |
| | | etc. |
| | 21 - 22 | Month of Observation |
| | 23 - 24 | Day of Observation |
| | 25 - 26 | Hour of Observation |
| | 27 - 28 | Minute of Observation |
| | 29 - 30 | Second of Observation |
| | 31 - 34 | .0001 Second of Observation |
| 8 | 35 - 53 | Observational Data |
| | 35 | ± sign |
| | 36 - 50 | meters per second |
| | 51 - 53 | .001 meters per second |
| 9 | 54 - 59 | Date of Reduction |
| | 54 - 55 | Year of Reduction |
| | | 68 = 1968 |
| | | 69 = 1969 |
| | 56 - 57 | Month of Reduction |
| | 58 - 59 | Day of Reduction |
| 10 | 60 - 61 | Coded Information |
| | 60 - 61 | Supplementary Documentation |
| | | 20 = Wallops C-Band Radar Preprocessing Report* |
| | | 21 = AFETR C-Band Radar Preprocessing Report |
| | | 22 = AFWTR C-Band Radar Preprocessing Report |

* Data was preprocessed in accordance with procedures contained herein.

| Field | Columns | Description |
|---|---|---|
| | | 23 = PMR C-Band Radar Preprocessing Report<br>24 = WSMR C-Band Radar Preprocessing Report<br>25 = NASA FRC C-Band Radar Preprocessing Report<br>26 = AFFTC C-Band Radar Preprocessing Report<br>27 = NASA GSFC C-Band Radar Preprocessing Report |
| | 62 - 63 | Instrumentation Type<br>53 = C-Band Radar System |
| | 64 | Tropospheric Refraction Correction (TRC) Indicator<br>1 = TRC applied to both Doppler Observation (DOBS, Cols. 35 - 53) and to Refraction Correction (REFCOR, Cols. 67 - 72)<br>2 = TRC not applied to either DOBS or REFCOR<br>3 = TRC included in DOBS but not REFCOR<br>4 = TRC included in REFCOR but not DOBS |

*Data was preprocessed in accordance with procedures contained herein.

| Field | Columns | Description |
|---|---|---|
| | 65 - 66 | Identification of Frequency Pair and Method of Combination |
| 11 | 67 - 74 | Value of Refraction Correction |
| | 67 | ± sign for meters/second |
| | 68 - 69 | meters/second |
| | 70 - 72 | .001 meters/second |
| | 73 | 0 = C-Band (Tracking Transponder)<br>1 = C-Band (Skin Track) |
| | 74 | Blank |
| 12 | 75 - 77 | Description of Random Error |
| | 75 - 77 | Standard deviation in range rate, .001 meters/second |
| 13 | 78 - 80 | Blank |