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engineering report

Dallas Division | Collins Radio Company, Dallas, Texas

Design Analysis - [illegible]

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28 October 1964

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engineering report

Design Analysis - Unified S-Band System for Apollo Network

Volume 1, Parts I and II

Contract NAS5-9035

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part I

introduction

This report presents a design analysis of the physical and performance characteristics of equipment for the Unified S-Band System for Apollo being provided by Collins Radio Company under contract NAS 5-9035. The characteristics that are described apply directly to the complete 30-foot stations, but may be readily extrapolated to other partial systems.

Part II describes the physical configuration and electrical performance parameters for each of the subsystems of the 30-foot station. The appropriate subsystem performance parameters are then combined in Part IV to provide an estimate of the overall system performance. Part III describes the integration of the subsystems into the partial systems.

Part V, Appendices, contains the following information:

(1) Appendix a, Specification 126-0429, Signal Data Demodulator

(2) Appendix b, Specification 126-0427, High Power Combiner

(3) Appendix c, Reliability Analysis Report, containing information on:

  (a) Antenna Position Programmer

  (b) Tracking Data Processor, Single

  (c) Tracking Data Processor, Dual

  (d) Timing System.

(4) Appendix d, Reliability Analysis Report, Encoding System

(5) Appendix e, Specification 511-4524, Error Code Generator

(6) Appendix f, Specification 270-2175, Message Encoder Unit.

part II

subsystem descriptions

The following sections contain detailed descriptions of the Unified Apollo S-Band Subsystems. The subsystems are divided into sections for clarity. A comprehensive table of contents is contained in the front matter of this report.

section 1

antenna subsystem

1.1 GENERAL.

The antenna subsystem is separated into eight major subassemblies:

(1) Y-wheel house assembly

(2) Secondary reflector support structure

(3) Reflector panels and backup structure

(4) Y-axis bearing supports

(5) X-wheel and bearing assemblies

(6) X-axis bearing supports

(7) Pedestal platform and support structure

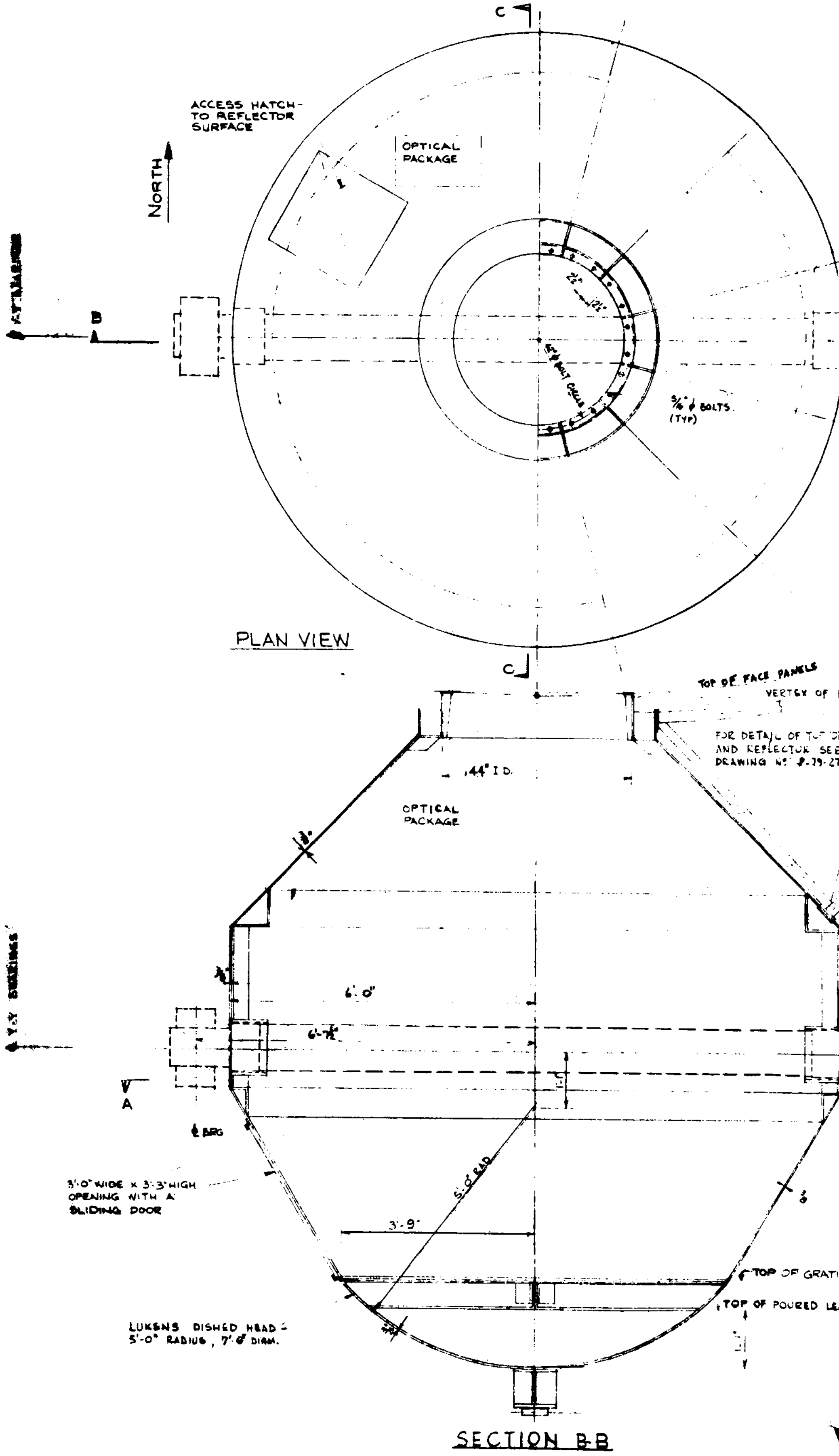
(8) Equipment house (located beneath the pedestal support structure).

The design of each subassembly is described in the following sections. It should be noted that the structural detailing is not completed and that the drawings shown in this report are subject to revision.

1.2 DESCRIPTION OF SUBASSEMBLIES.

The Y-wheel house assembly, as shown in figure 1-1, is a welded assembly consisting of 3/8-inch steel plate, rolled angle stiffening rings, poured lead counterweight, Y-axis shaft, Y-axis bearing assemblies, supporting surface for the axis gear segments, and the feedcone mounting ring.

The Y-wheel house is the enclosure for the antenna mounted electronic equipment. At the present time, the exact requirements of the equipment to be mounted in the wheel house is unknown. To provide optimum space and implement the interface


ACCESS HATCH-
TO REFLECTOR
SURFACE
OPTICAL
PACKAGE
NORTH
5/8" ⌀ BOLTS
(TYP)
PLAN VIEW
TOP OF FACE PANELS
44" I.D.
OPTICAL
PACKAGE
6'-0"
3'-0" WIDE x 3'-3" HIGH
OPENING WITH A
SLIDING DOOR
5'-0" RAD
3'-9"
TOP OF GRATI
TOP OF POURED LE
LUKENS DISHED HEAD -
5'-0" RADIUS, 7'-6" DIAM.
SECTION B-B

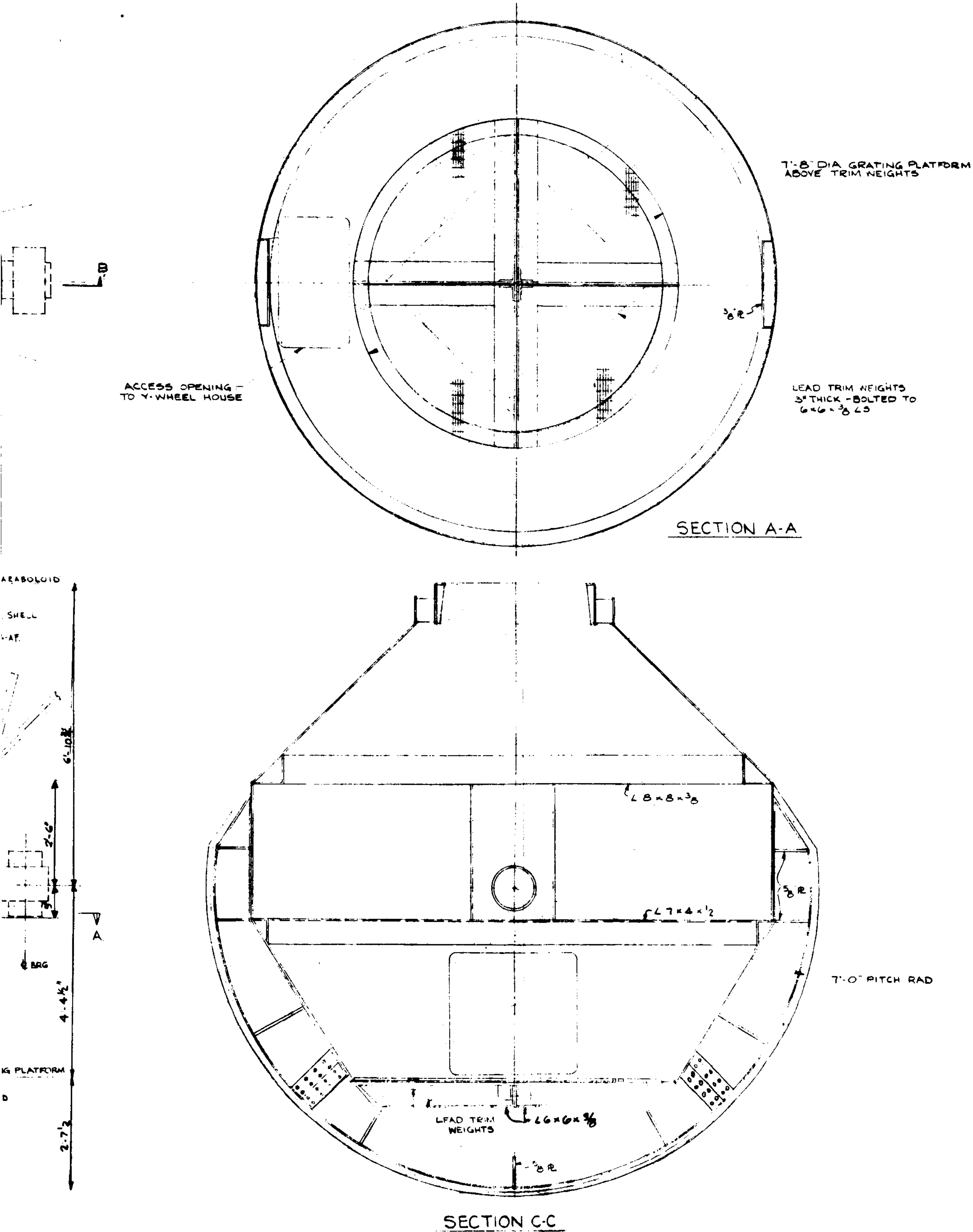


Figure 1-1. Y-Wheel House Assembly

2#

between the structure and the government furnished electronic equipment, it has been decided to build a full scale wooden mockup of the interior portion of the Y-wheel house. It is presently planned that special 19-inch electronic rack frames will be used in the Y-wheel house. Figure 1-2 represents a preliminary layout of the special racks. The wooden mockup is under construction and will be finished about 15 November.

The Y-axis encoder package is located inside the east end of the axis. The input shaft of the encoder is coupled to a stationary stub shaft. This stub shaft is independently adjusted to the axis of rotation and doweled in place at the time of erection. The encoder mounting surface is machined in the axis at the factory.

The Y-axis synchro package will be mounted outboard of the east end of the axis. A stub shaft is coupled to the synchro input shaft and, unlike the encoder package, the synchro shaft rotates with the Y-axis while the synchro housing is held stationary. Figure 1-3 depicts the details of the encoder and synchro mounting arrangement.

The west end of the Y-axis contains the provisions for mounting the r-f rotary joint, which is discussed elsewhere in this report.

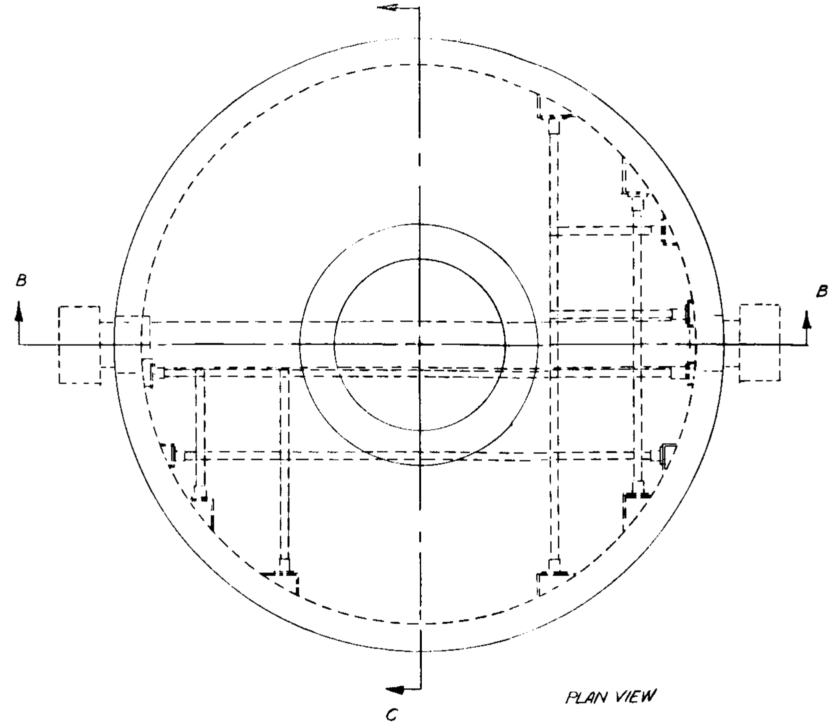
The mounting arrangement for the GFP optical package has not been decided upon at this time.

The reflector design is shown in figure 1-4. This drawing shows details of the adjusting provisions for the reflector panels as well as the radial truss design.

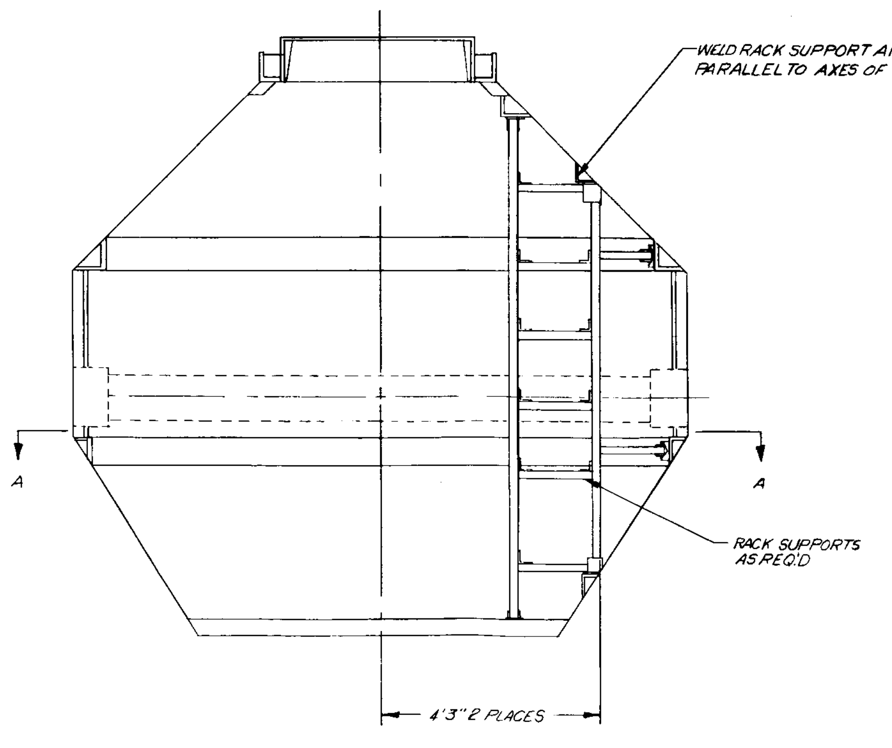
The integration of the Y-axis hydraulic power supply into the X-wheel is being closely coordinated to allow maximum utilization of space and, at the same time, optimize the structural configuration. The access to the X-wheel is located on the periphery of the wheel and not on the side as originally planned.
Provisions have been made such that the hydraulic power supply can be removed as an assembly from the X-wheel.

The pedestal and equipment house layout is shown in figure 1-5. Figure 1-5 shows that there is adequate work room around the hydraulic power supply and also in the equipment house.

The hydraulic power supply was located as shown in figure 1-5 to minimize the hydraulic line lengths to the motors.

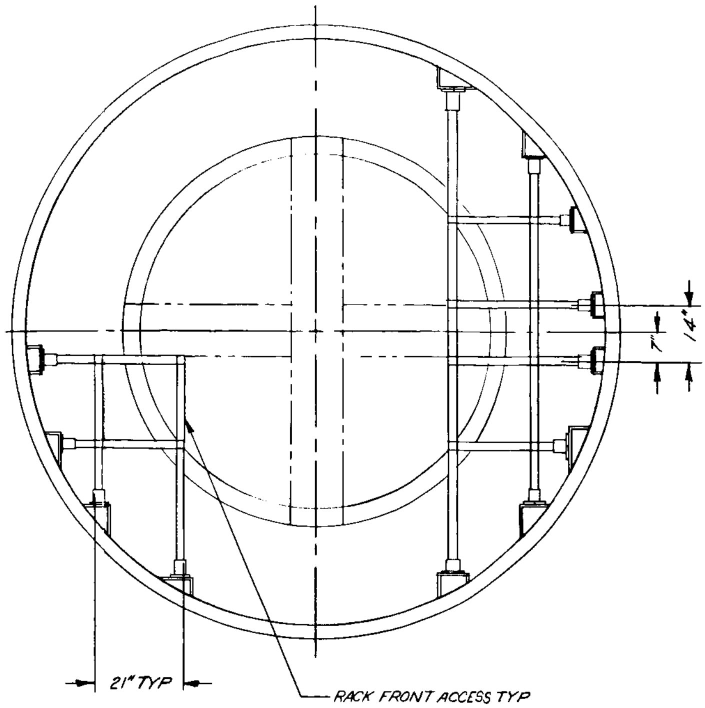


PLAN VIEW

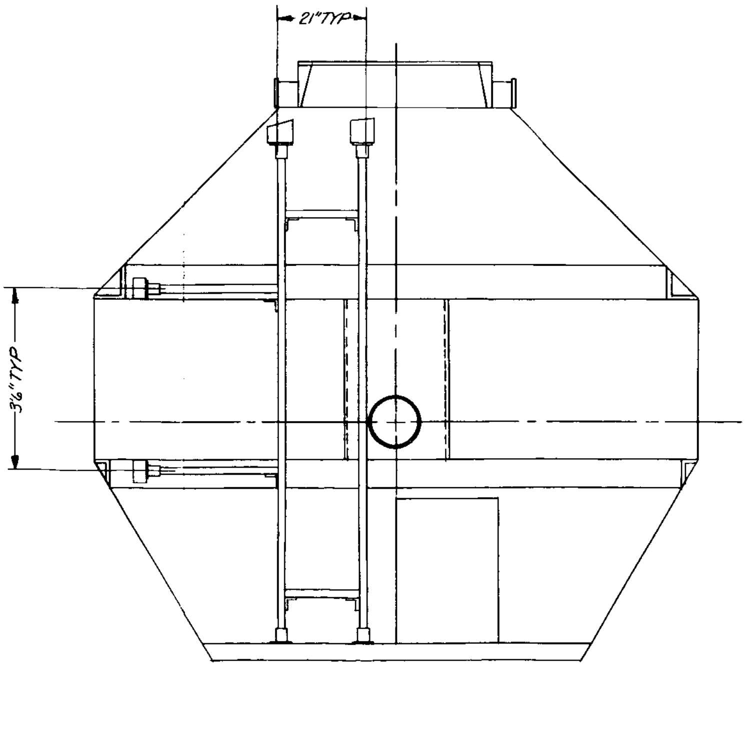


SECTION BB

II-1-4



SECTION AA



SECTION CC

Figure 1-2. Rack Layout, 30-Foot Shell Mockup (Preliminary)

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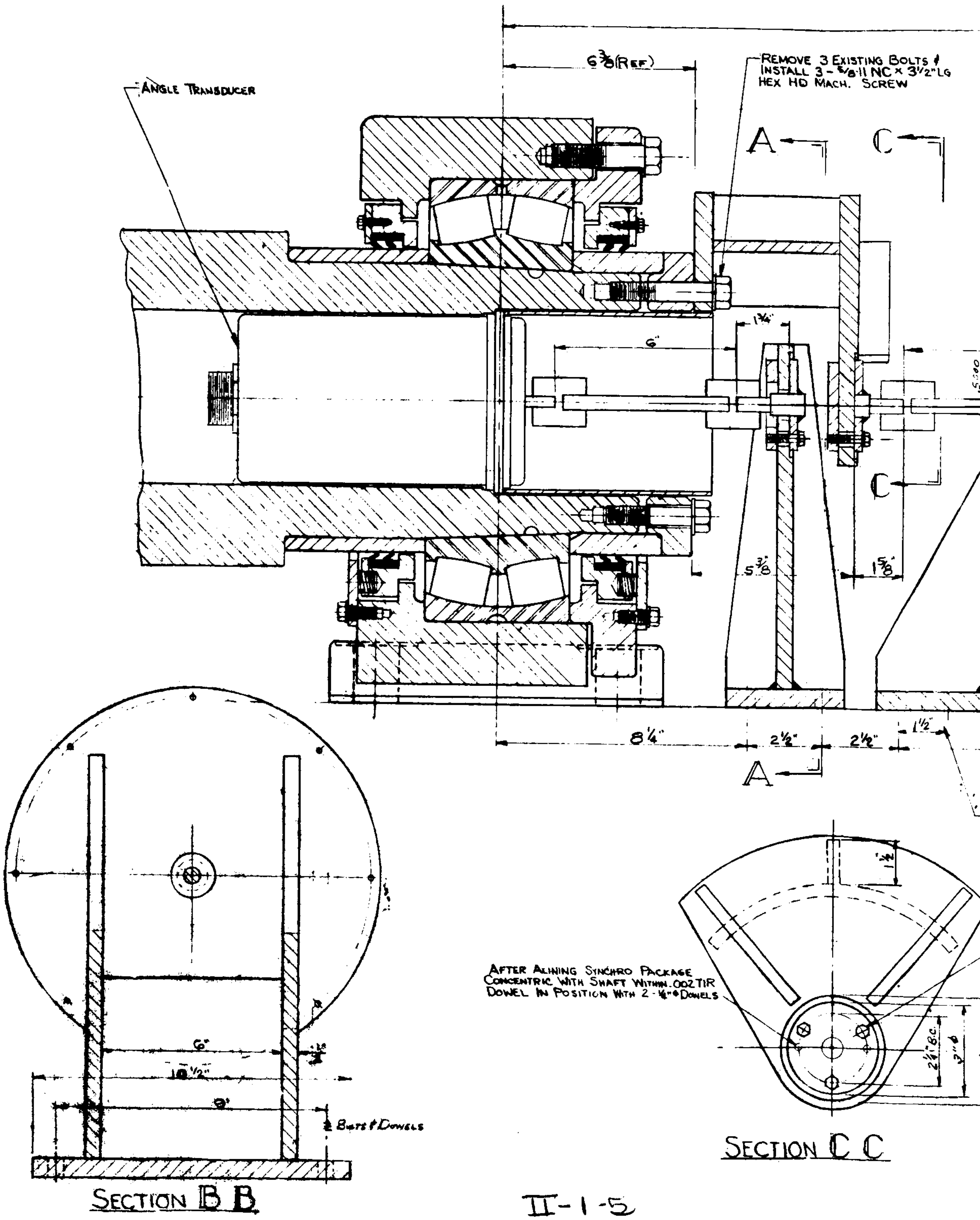


ANGLE TRANSDUCER
6 3/8 (REF)
REMOVE 3 EXISTING BOLTS & INSTALL 3 - 5/8-11 NC × 3 1/2" LG HEX HD MACH. SCREW
A
C
1 3/4"
6"
5 3/8
1 5/8
8 1/4"
2 1/2"
2 1/2"
1 1/2"
6"
10 1/2"
8"
BOLTS & DOWELS
SECTION B B
AFTER ALINING SYNCHRO PACKAGE CONCENTRIC WITH SHAFT WITHIN .002 TIR DOWEL IN POSITION WITH 2 - 1/8" Ø DOWELS
SECTION C C

1#

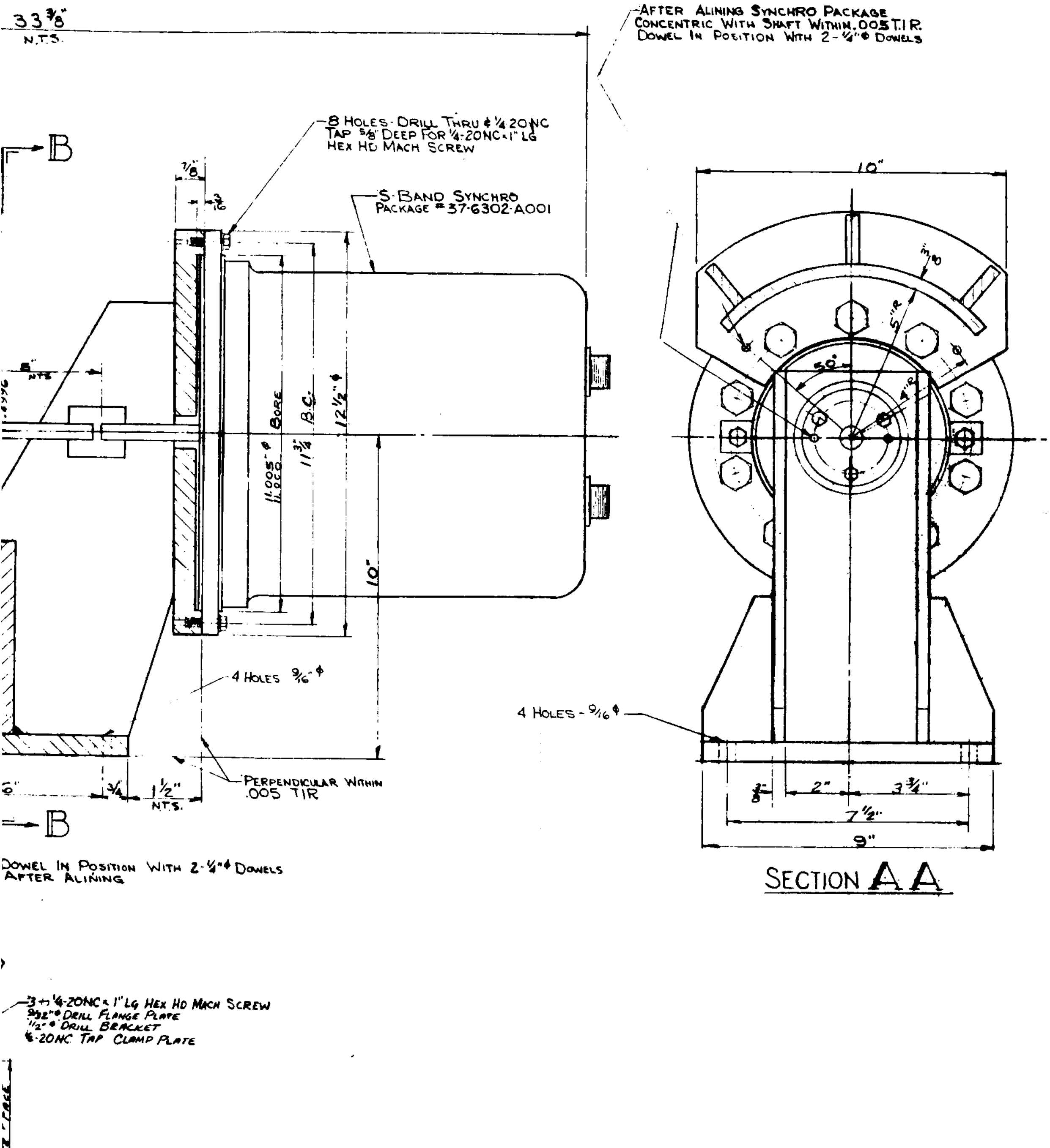
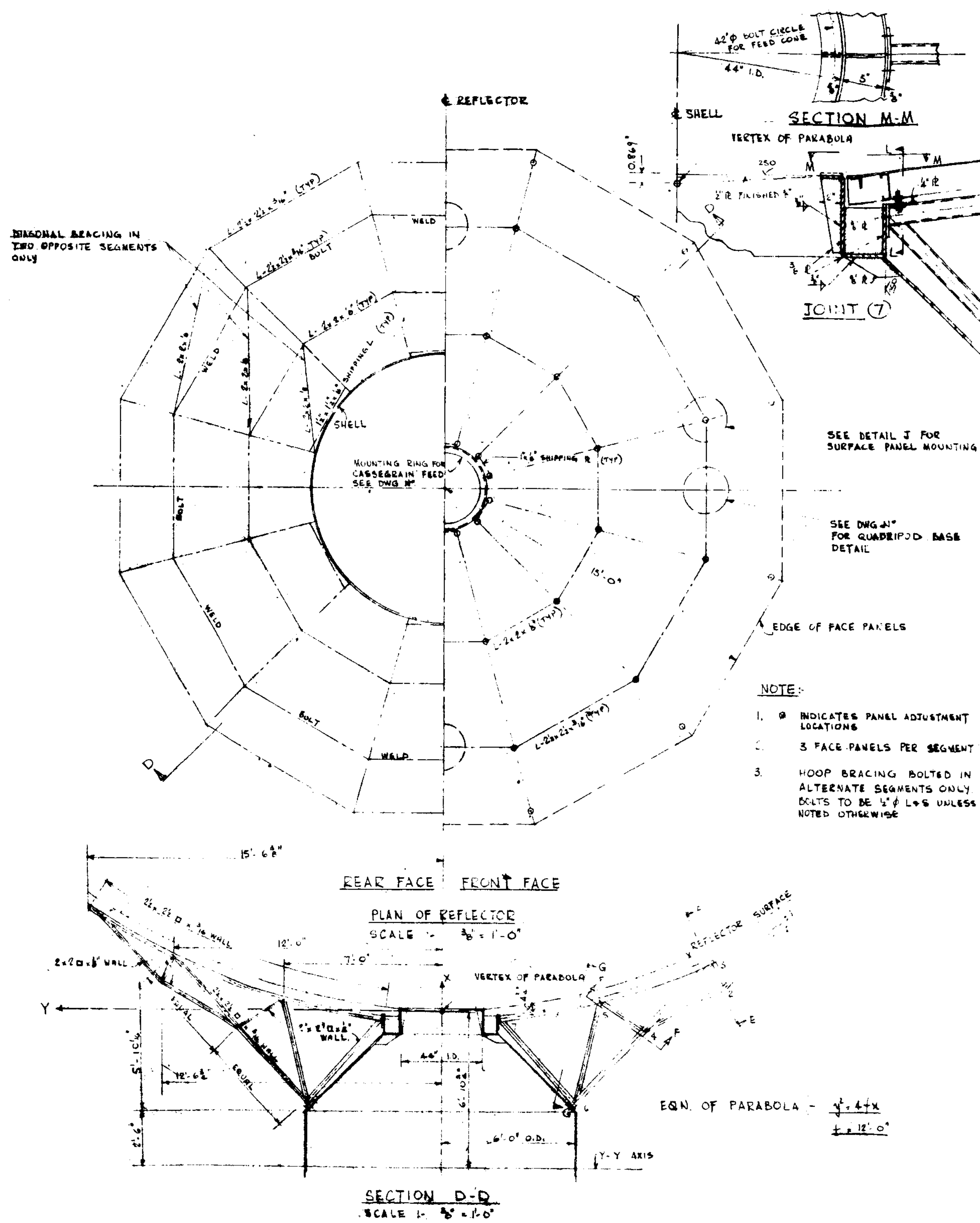


Figure 1-3. Encoder and Synchro Mounting Arrangement



42" φ BOLT CIRCLE FOR FEED CONE
44" I.D.
SECTION M-M
℄ REFLECTOR
℄ SHELL
VERTEX OF PARABOLA
JOINT (7)
DIAGONAL BRACING IN TWO OPPOSITE SEGMENTS ONLY
WELD
BOLT
SHELL
MOUNTING RING FOR CASSEGRAIN FEED SEE DWG
SEE DETAIL J FOR SURFACE PANEL MOUNTING
SEE DWG FOR QUADRIPOD BASE DETAIL
EDGE OF FACE PANELS
NOTE:-
1. INDICATES PANEL ADJUSTMENT LOCATIONS
2. 3 FACE PANELS PER SEGMENT
3. HOOP BRACING BOLTED IN ALTERNATE SEGMENTS ONLY. BOLTS TO BE ½" φ L+S UNLESS NOTED OTHERWISE
15'-0"
15'-6⅝"
REAR FACE
FRONT FACE
PLAN OF REFLECTOR
SCALE :- ⅜" = 1'-0"
REFLECTOR SURFACE
VERTEX OF PARABOLA
12'-0"
7'-0"
44" I.D.
6'-0" O.D.
Y-Y AXIS
EQN. OF PARABOLA - $y^2 = 4fx$
$f = 12'$-$0"$
SECTION D-D
SCALE :- ⅜" = 1'-0"

1#

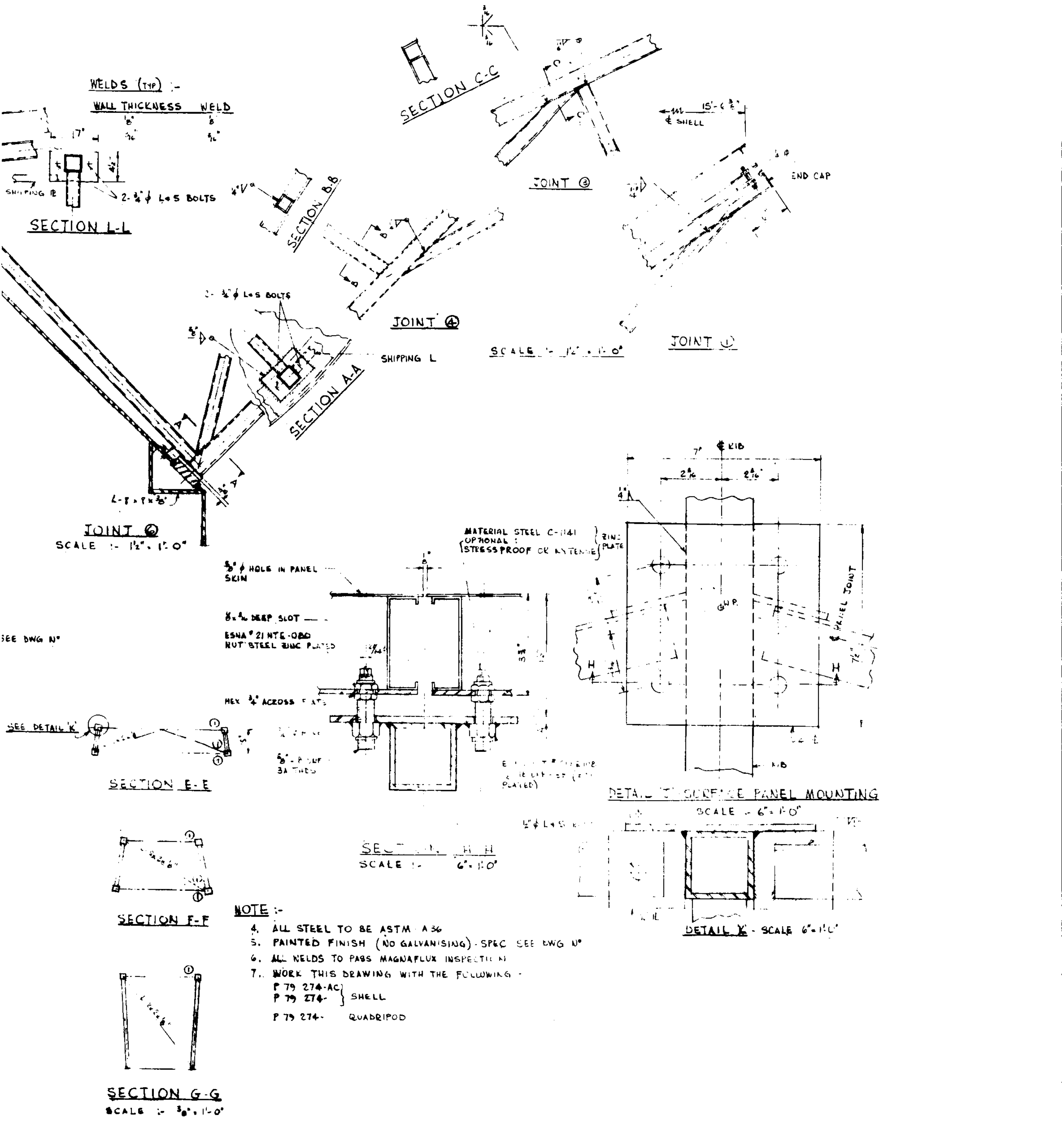
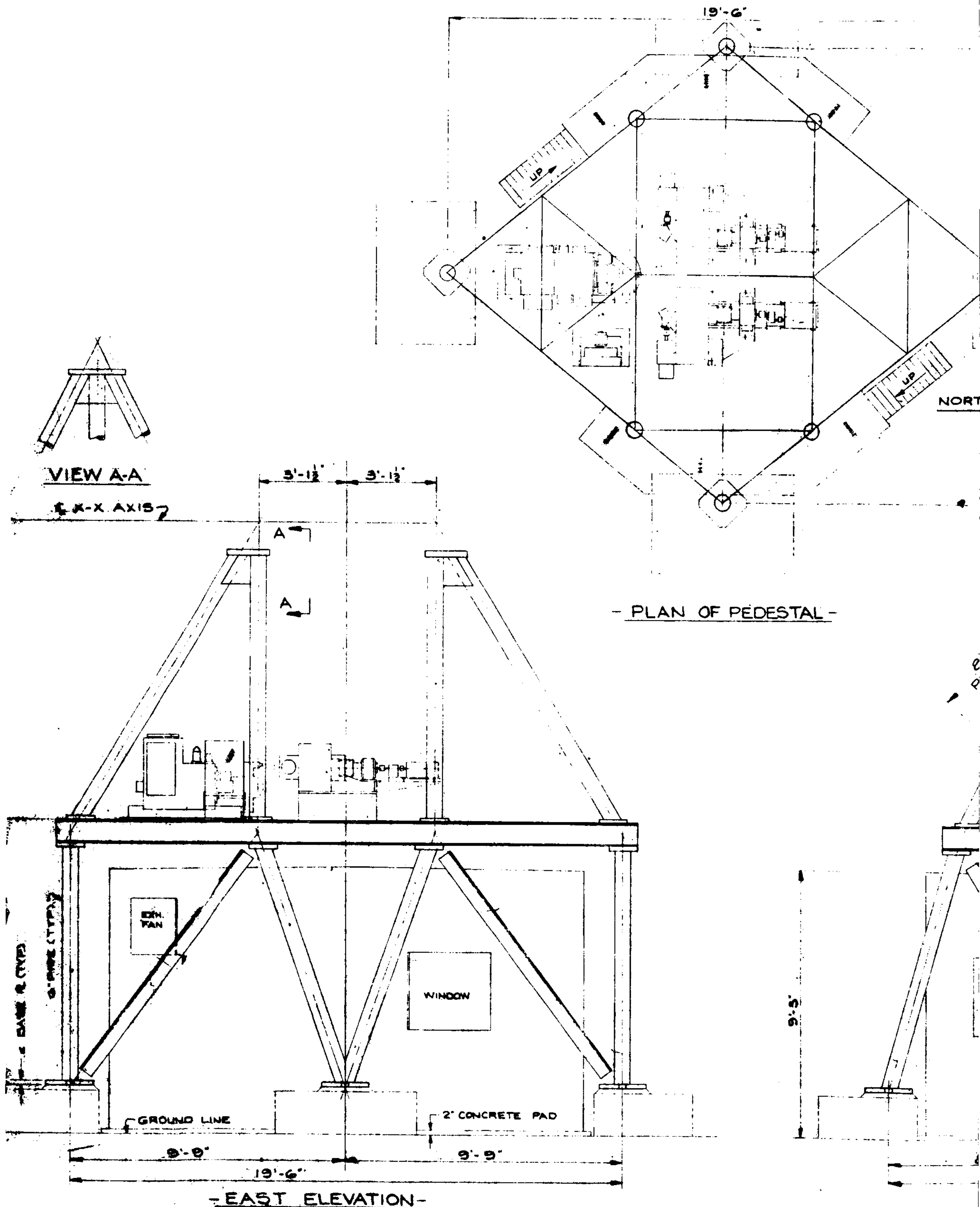


Figure 1-4. Reflector Design


19'-6"
UP
UP
NORT
- PLAN OF PEDESTAL -
VIEW A-A
℄ X-X AXIS
3'-1½"
3'-1½"
A
A
EXH. FAN
WINDOW
GROUND LINE
2" CONCRETE PAD
9'-9"
9'-9"
19'-6"
9'-5"
- EAST ELEVATION -

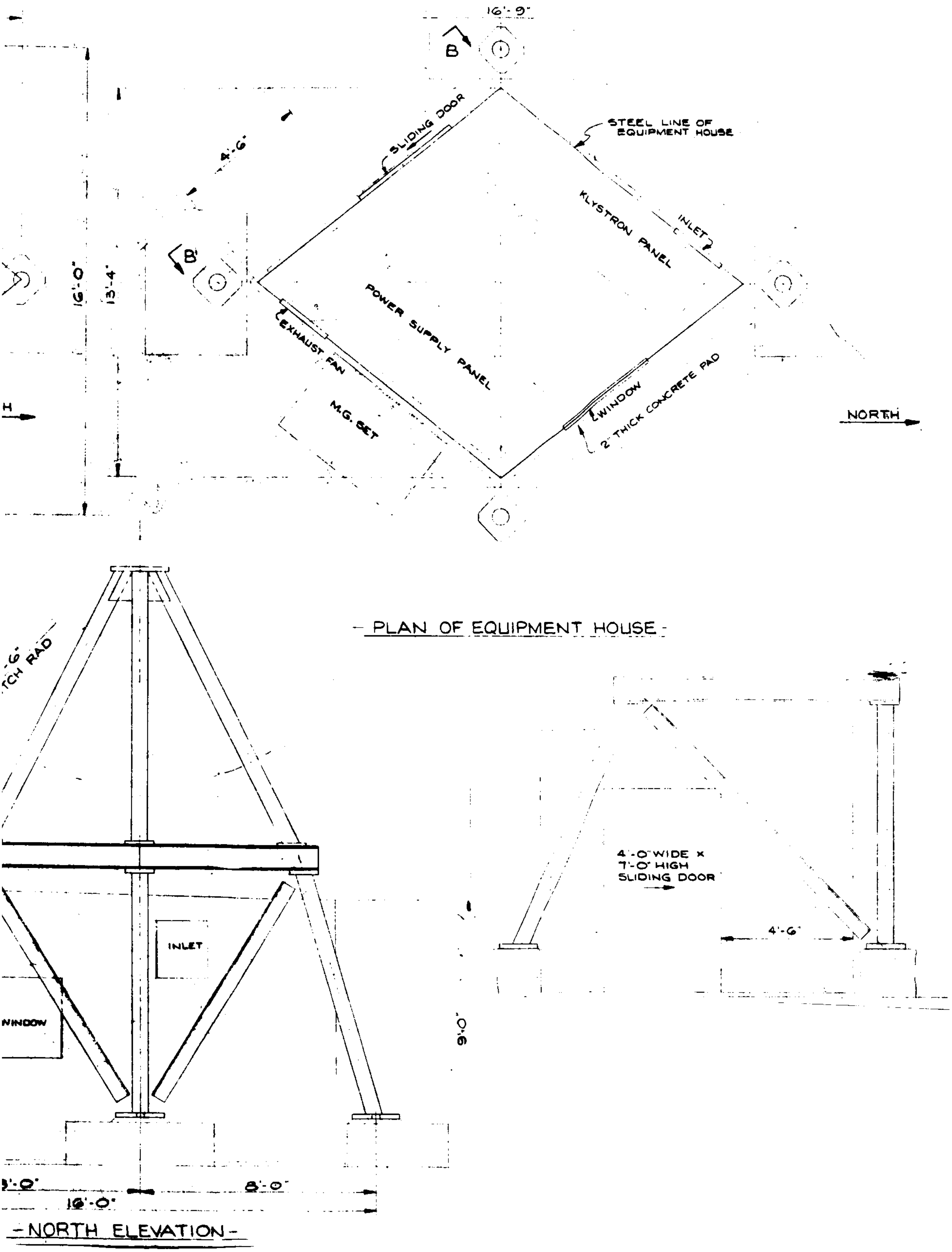


Figure 1-5. Pedestal and Equipment House Layout

2#

It is suggested that the acquisition antenna be located at the junction of the secondary reflector support structure. Figure 1-6 depicts the typical mounting arrangement. Some of the reasons for selecting this particular mounting arrangement are:

(1) Achievement of symmetrical loading on the primary reflector support structure for all antenna attitudes

(2) The additional weight of the acquisition antenna causes the top of the hyperbola to rotate away from the parabola whereas, without this additional weight, the top of the hyperbola rotates toward the parabola, increasing the r-f boresight shift. The net result, from locating the acquisition antenna at the quad tip, is to reduce the r-f boresight shift due to hyperbola rotation.

(3) The location of the collimation tower at each site would not be critical.

(4) The affect of the acquisition antenna on lateral deflections of the quadripod amounts to approximately 5 percent of the total.

1.3 BEARING LIFE.

A summary of bearing loads is given in table 1-1. The basic dynamic load rating of the X and Y axes bearings led to selecting of identical bearings for both axes. The bearing selected is SKF #23144CK/C2. The following indicates the method used in determining the life and reliability of the selected bearings.

Y-Axis Dynamic (+15%): Radial maximum = 15,000 lbs.

axial maximum = 47,200 lbs.

for 20,000 hour life @ mean velocity of 0.166 rpm

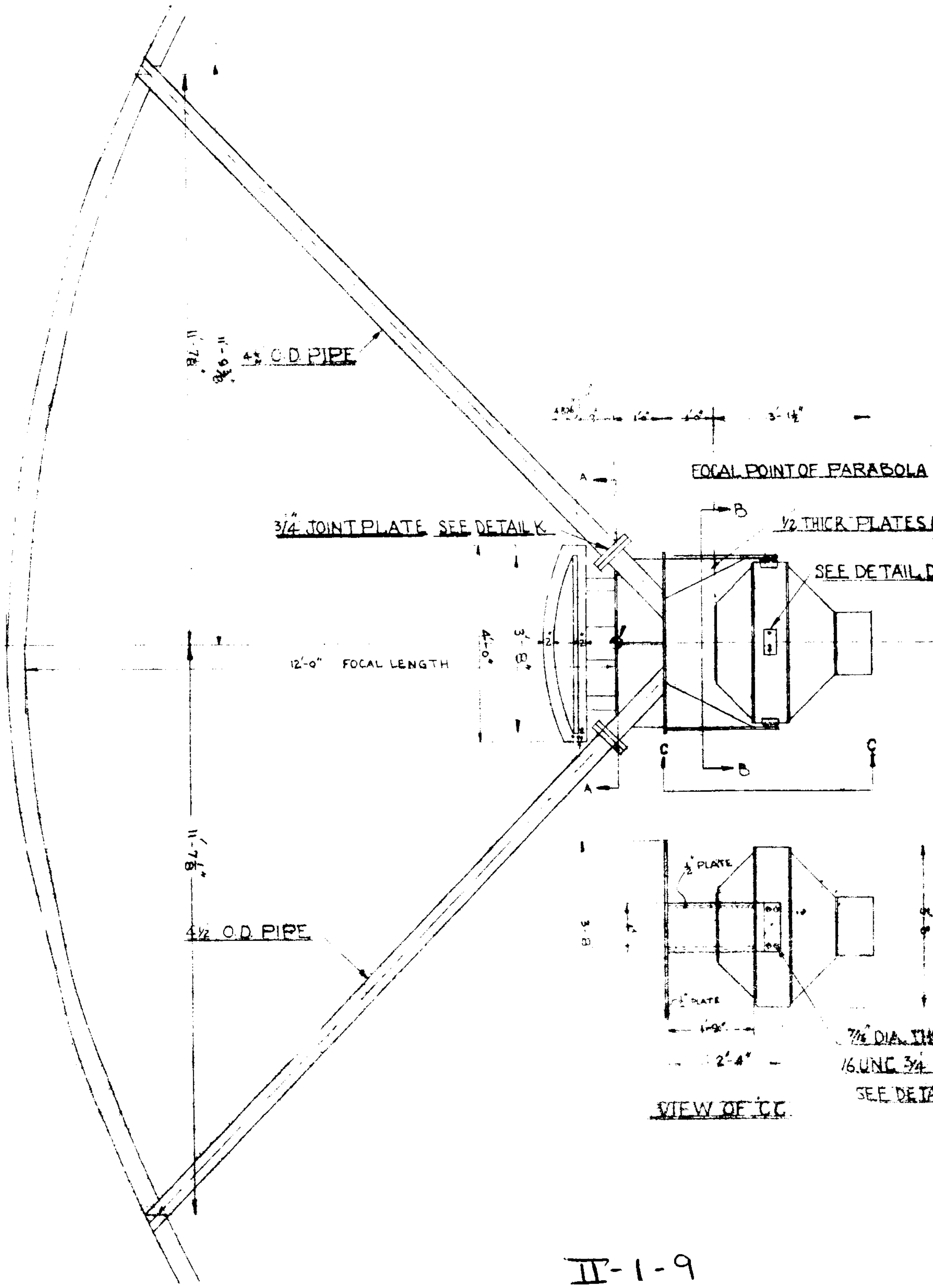
$$20,000 \times 60 \times 0.166 = 200,000 \text{ rev. (Life)}$$

The 200,000 revolutions is based on 90% of the bearings exceeding the 200,000 rev. before first evidence of fatigue develops. To provide a higher reliability, say 99.999%, a "reliability factor" of 30 is used thus:

$$30 \times 200,000 = 6 \times 10^6 \text{ rev. (Life)}$$

Following the procedure outlined in the SKF catalog, it is found that C (basic dynamic load rating) for the selected bearing is:

$$C = 294,000 \text{ lbs.}$$


4½ O.D PIPE
FOCAL POINT OF PARABOLA
3/4" JOINT PLATE SEE DETAIL K
1/2 THICK PLATES
SEE DETAIL
12'-0" FOCAL LENGTH
4'-0"
3'-8"
3'-1½"
11'-7⅞"
4½ O.D PIPE
½" PLATE
2'-4"
VIEW OF C-C

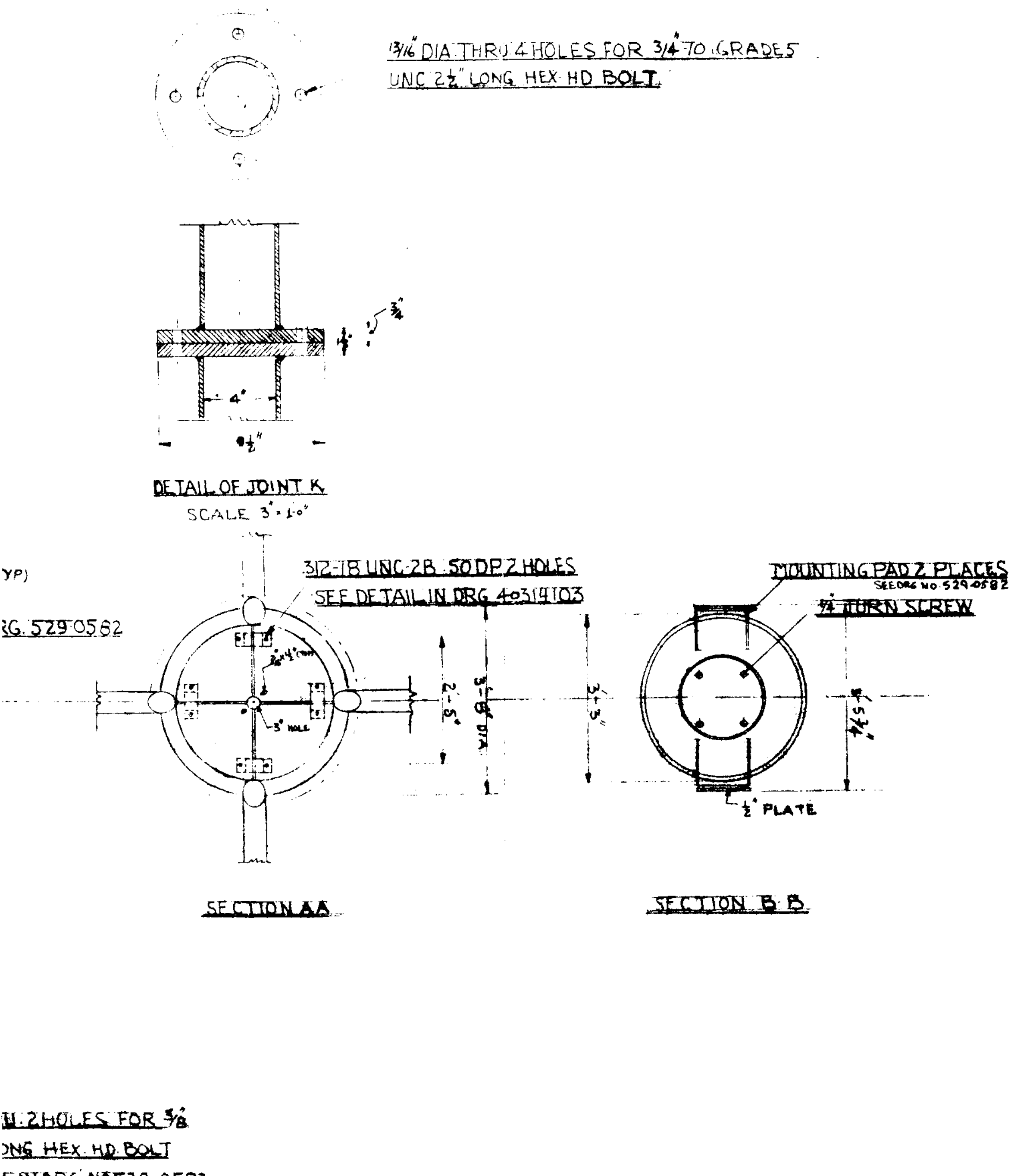


Figure 1-6. Acquisition Antenna, Typical Mounting Arrangement

TABLE 1-1. SUMMARY OF AXIS BEARING LOADS

Y-Axis	BRG #1 (Radial (lbs.))	BRG #2 (Radial (lbs.))	BRG #1 (Axial (lbs.))	BRG #2 (Axial (lbs.))
140 mph, 90° to Y-axis	34,300	34,300	-	-
140 mph, 0° to Y-axis	12,800	37,200	4,870	19,480
60 mph, $5°/sec^2$, Y-vertical	13,100	13,100	10,180	40,900
30 mph, $3°/sec^2$, Y-vertical	4,170	4,170	10,000	40,000
X-Axis				
140 mph, 90° to X-axis	82,000	82,000	-	-
140 mph, 0° to X-axis	21,600	128,400	6,620	26,480
60 mph, Y-axis vertical	82,200	82,200	5,490	21,790
60 mph, Y-axis horizontal	41,040	108,960	4,090	20,650
60 mph, Y at 45°	74,000	76,500	8,270	2,080
30 mph, $3°/sec^2$, Y-horizontal	63,940	85,660	1,320	6,500

Y-Axis

Dynamic: Radial maximum = 13,000 lbs.
Axial maximum = 41,000 lbs.

Static: Radial maximum = 37,200 lbs.
Axial maximum = 19,500 lbs.

X-Axis

Dynamic: Radial maximum = 109,000 lbs.
Axial maximum = 21,800 lbs.

Static: Radial maximum = 128,400 lbs.
Axial maximum = 26,500 lbs.

The basic dynamic load rating (C) for the actual loading is 284,000 pounds; therefore, the Y-axis bearings should have a reliability of 99.999 percent for 20,000 hours of operation.

$$\text{Factor of Safety (FS)} = \frac{294,000}{284,000}$$

$$\text{FS} = 1.04$$

Similarly:

For Y-axis maximum static, FS = 3.97

For X-axis maximum dynamic, FS = 1.875

For X-axis maximum static, FS = 1.66

1.4 ANTENNA SUBSYSTEM RELIABILITY.

Table 1-2 is a listing of the expected reliability for the various components of the antenna subsystem.

The maximum probable downtime of 56.3 hours indicates a total subsystem reliability of about 99 percent.

TABLE 1-2. EXPECTED RELIABILITY FOR VARIOUS ANTENNA SUBSYSTEM COMPONENTS

COMPONENT	QTY/SYSTEM	FAILURE RATE PER 5000 HRS.		HOURS DOWN TIME PER FAILURE	MAXIMUM PROBABLE DOWN TIME PER 5000 HOURS
		EACH	TOTAL		
X-Axis Brgs.	2	0.001	0.002	200	0.4
Y-Axis Brgs.	2	0.003	0.006	100	0.6
X-Reducer Brgs.	20	0.010	0.200	25	5.0
Y-Reducer Brgs.	20	0.010	0.200	100	20.0
Brakes	4	0.100	0.400	2	0.8
Couplings	12	0.080	1.000	2	2.0
Limit Switches	4	0.125	0.500	5	2.5
Motors-Pumps	2	0.500	1.000	3	3.0
Pinions	4	0.010	0.040	100	4.0
Gear Segments	10	0.010	0.100	100	10.0
Miscellaneous					8.0
					56.3

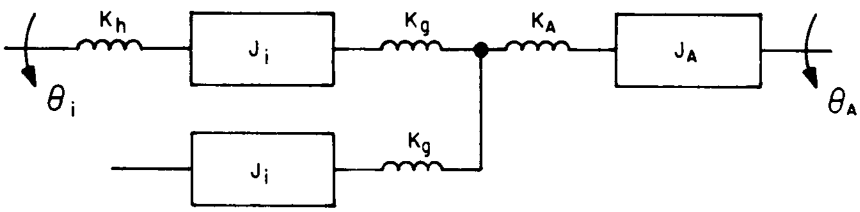
1.5 DISCUSSION OF RESONANT FREQUENCY.

Determination of natural frequencies of the antenna structure indicates that the lowest resonance will occur when the X-axis is at 90° and the Y-axis is at 0°.

The lowest calculated natural frequency of the structure, with the gear reducer input shaft locked, is 4.73 cps. The locked pinion resonance is approximately 10 percent higher, or 5.2 cps. The lowest resonance occurs about a vertical axis and would be excited by the Y-axis drive system. Design is continuing in an effort to increase the lowest resonance to at least 5 cps.

Figure 1-7 is a plot of the relationship of coupled resonant systems to the uncoupled parameters of the same system. The equations, from which the curves are a result, were obtained from an analysis assuming no energy losses due to heat, friction, etc.

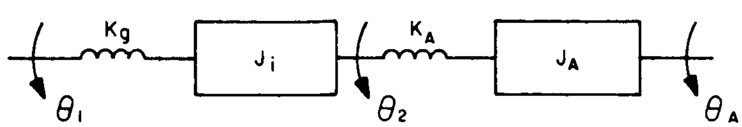
The antenna and drive system is represented by the following schematic:



(1)

where:
- K_h = Hydraulic spring constant
- J_i = Inertia of motor, gear reducer, brake, coupling and misc.
- K_g = Gear reducer spring constant
- K_A = Antenna spring constant
- J_A = Antenna Inertia
- $\theta_i - \theta_A$ = Relative motion of output to input

Total inertia (J_T) = $2 J_i + J_A$ (normalized to the same speed shaft). To simplify (1) and also to arrange the system such that the derived curves of figure 1-7 may be utilized, consider the following:



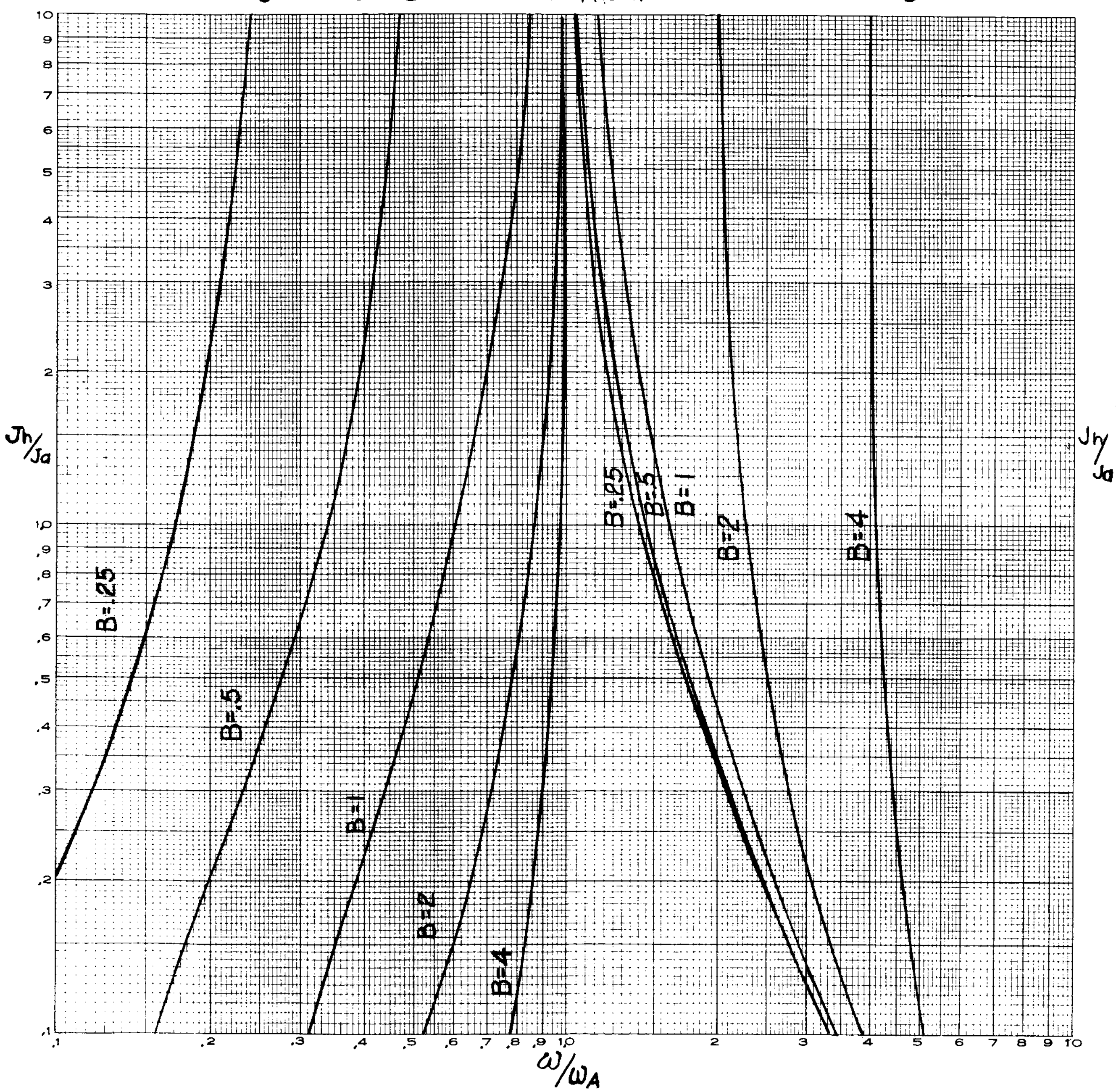
(2)

SYSTEM 1 SYSTEM 2

$\theta_{i_1} \xrightarrow{K_h} \boxed{J_h} - \theta_{o_1}$ $\theta_{i_2} \xrightarrow{K_A} \boxed{J_A} - \theta_{o_2}$

$\omega_h = \sqrt{\frac{K_h}{J_h}}$ $\omega_A = \sqrt{\frac{K_A}{J_A}}$

$$\frac{\theta_{i_3}}{\theta_{o_3}} = \frac{1}{\omega_A^2 \omega_h^2}\left\{S^4 + \left[\omega_h^2 + \left(\frac{J_A}{J_h}\right)\left(\frac{\omega_A}{\omega_h}\right)^2 \omega_h^2 + \omega_A^2\right] S + \omega_A^2 \omega_h^2\right\}$$



$B = \frac{\omega_h}{\omega_A}$ $A = \frac{J_h}{J_A}$

$$\omega^2 = \frac{\omega_A^2}{2A}\left\{\left[A(B^2+1)+1\right] \pm \sqrt{A^2(B^2-1)^2 + 2A(B^2+1)+1}\right\}$$

Figure 1-7. Relationship of Coupled Resonances to Uncoupled Parameters)

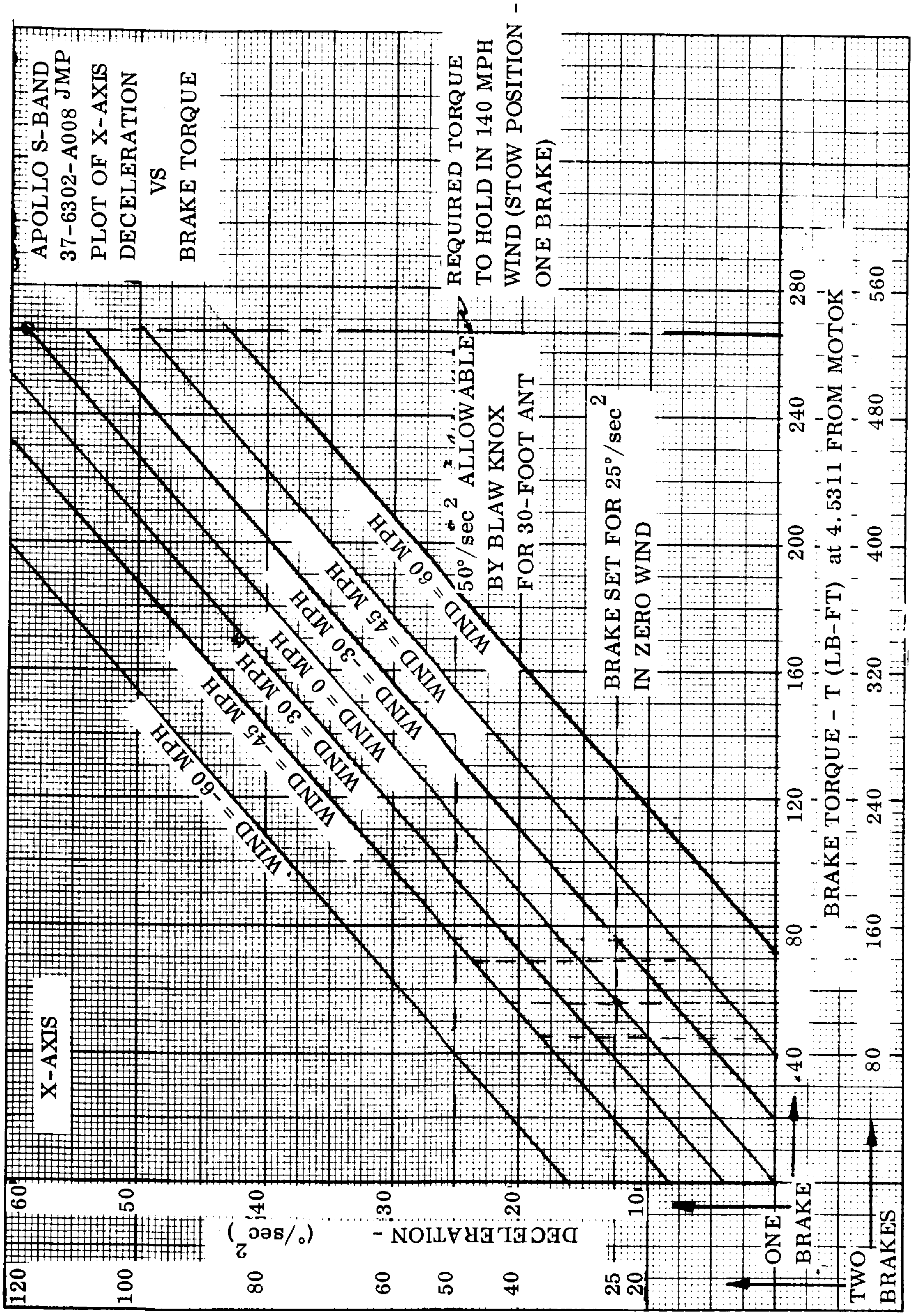
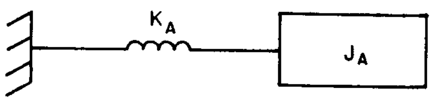


Figure 1-8. Plot of X-Axis Deceleration Vs. Brake Torque

System (2) is equalivent to locking the input shaft of one gear reducer and reflecting the inertia (J_i) of the other gear to the pinion level. The reason for only one J_i, in (2) is because the most significant inertia of the gear reducer is at the input shaft which is locked.

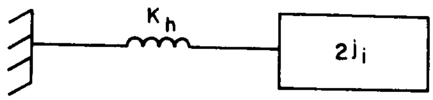
The system represented by (2) can be further simplifier, thus:



$$\omega_A \text{ (locked pinion)} = \frac{K_A}{J_A} \tag{3}$$

$$\omega_A = 5.2 \text{ cps (described above)}$$

The remaining portion of (2) is shown as:



(4)

whose resonance is:

$$\omega_g = \frac{K_g}{J_i} \quad \text{(normalized @ same shaft)}$$

$$\omega_g = \frac{18 \times 10^6 \text{ in-lb/rad}}{0.0267 \text{ in-lb-sec}^2\ (216)^2}$$

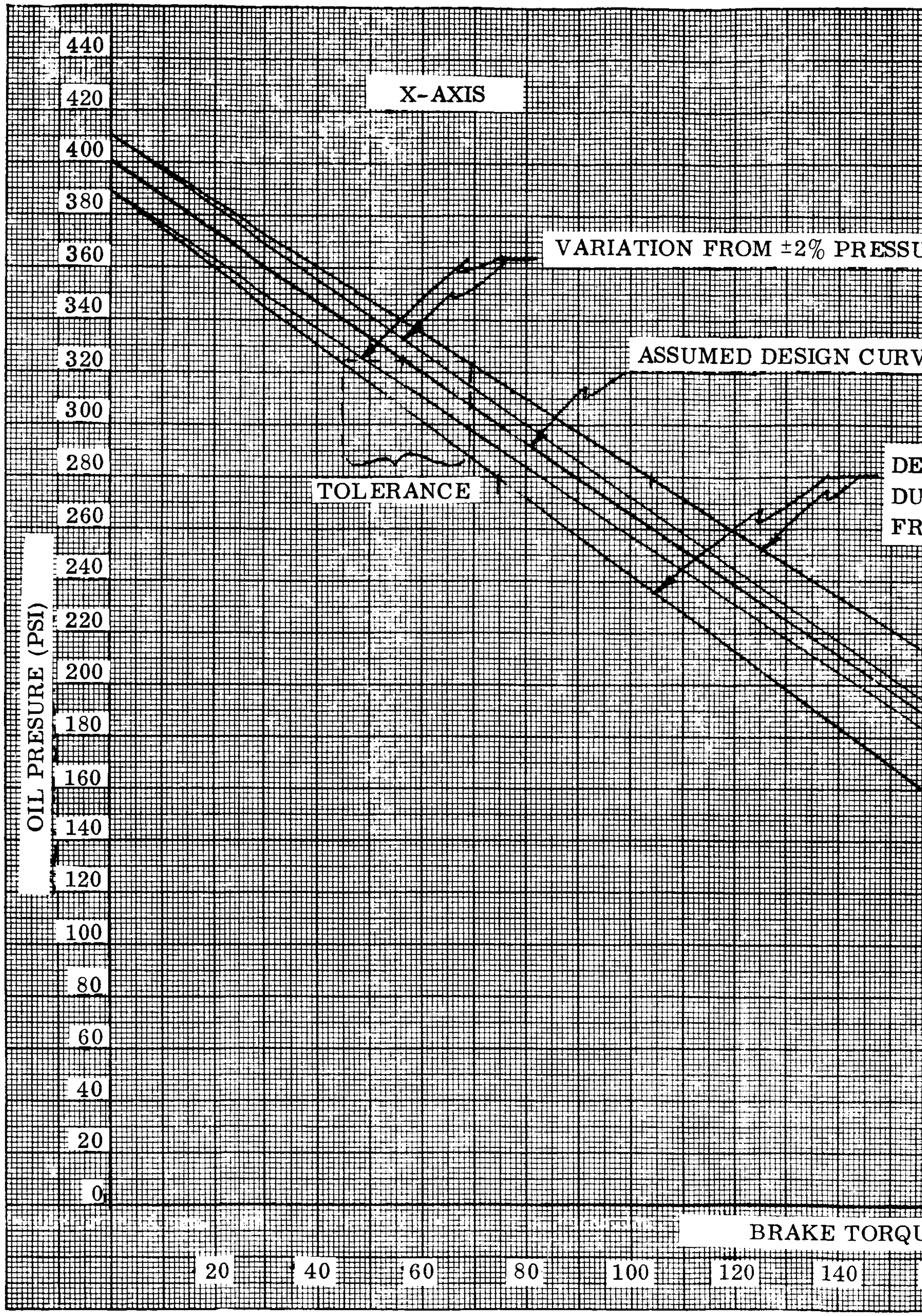
$$\omega_g = 19.2 \text{ cps}$$

The uncoupled systems (3) and (4) exhibit two resonant frequencies ω_g and ω_a. When these systems are coupled as shown in (2), then two new resonances will occur. The two new resonances are again found by using the curves of figure 1-7.

$$B = \frac{\omega g}{\omega A} \qquad A = \frac{J_i}{J_A}$$

$$B = \frac{19.2}{5.2} \qquad A = \frac{(0.0267)\ (216)^2}{18 \times 10^6/(28)^2} \quad \text{(normalized to pinion)}$$

$$B = 3.7 \qquad A = 0.198$$


X-AXIS
VARIATION FROM ±2% PRESSU
ASSUMED DESIGN CURV
TOLERANCE
DE
DU
FR
OIL PRESURE (PSI)
440
420
400
380
360
340
320
300
280
260
240
220
200
180
160
140
120
100
80
60
40
20
0
BRAKE TORQU
20
40
60
80
100
120
140

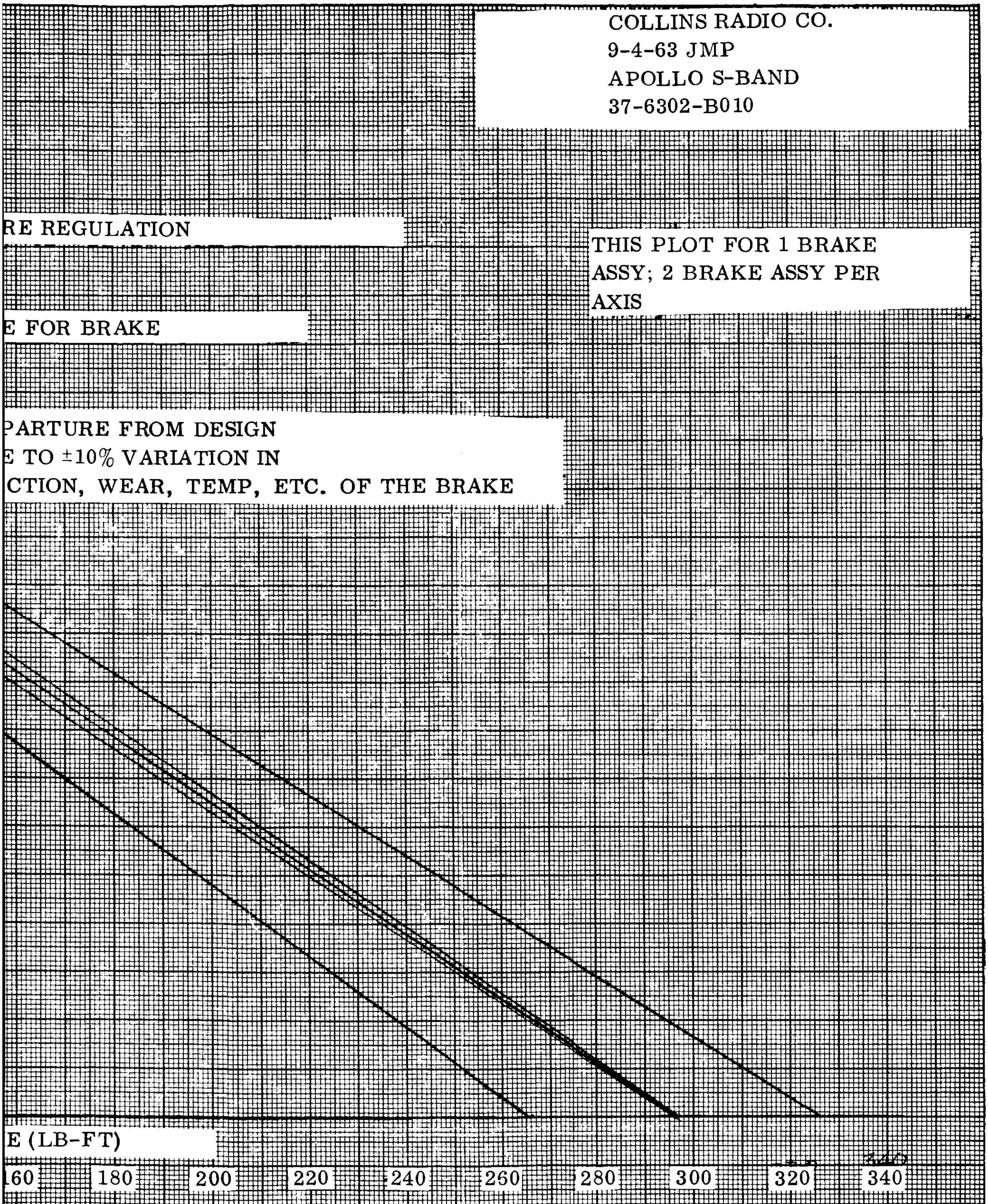


Figure 1-9. Plot of Brake Cylinder Pressure Vs. Brake Torque (One Complete Brake)

From figure 1-7

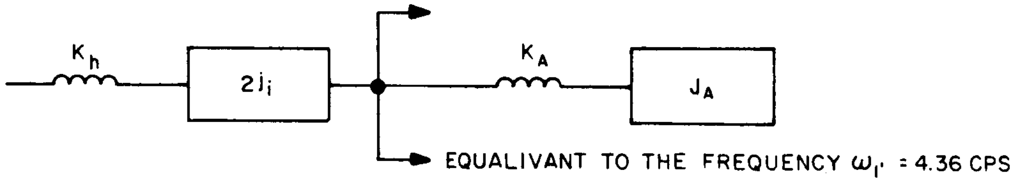
$$\frac{\omega_{1'}}{\omega_A} = 0.84 \qquad \frac{\omega_{2'}}{\omega_A} = 4.4$$

$$\omega_{1'} = 5.2\ (0.84) \qquad \omega_{2'} = 5.2\ (4.4)$$

$$\omega_{1'} = 4.36 \text{ cps} \qquad \omega_{2'} = 22.9 \text{ cps}$$

The above calculations indicate a system such as shown in (2) would have a lowest resonant frequency of 4.63 cps and the next resonance occuring at 22.9 cps.

The hydraulic system may now be coupled to the systems already described thus:



(5)

The inertia, $2J_i$ is lumped as shown because $K_g >> K_A$.

The hydraulic resonance is found from

$$\omega_h = K_{mt} \pm \sqrt{\frac{B}{(2J_i)\ (V)}}$$

where: ω_h = hydraulic resonance

K_{mt} = motor torque constant

B = Bulk modules of hydraulic oil

V = total entrapped volume of oil

$$\omega_h = 0.15 \pm \frac{2 \times 10^5}{(0.0534)\ (20)}$$

$$\omega_h = 8.3 \text{ cps}$$

The two uncoupled resonant frequencies (4.36 and 8.3 cps) when coupled together give the following final resonant system.

$$B = \frac{\omega_h}{\omega_{1'}} \qquad A = \frac{2J_i}{J_A}$$

$$B = 1.9 \qquad A = 3.24$$

Using the values of A and B calculated above and the curves of figure 1-7 gives:

$$\frac{\omega_1}{\omega_{1'}} = .93 \qquad \frac{\omega_2}{\omega_{1'}} = 2$$

or

$$\omega_1 = 4\ 36(.93) \qquad \omega_2 = 4.36(2)$$

$$\omega_1 = 4.06 \text{ cps} \qquad \omega_2 = 8.72 \text{ cps}$$

Where ω_1 is the lowest resonant frequency of the system shown in (1) above.

1.6 ACCESS PROVISIONS.

Access to the pedestal platform and X-drive assembly is accomplished with stairway type ladders located on the southwest and northeast sides of the pedestal. A stepdown walkway is provided to allow walking past the X-wheel at the pedestal level. The access to the Y-drive assembly (located in the X-wheel) is through an opening on the periphery of the X-wheel. A ladder on the inside of the X-wheel allows access to the Y-wheel house. A sliding door on the Y-wheel house is accessible when the Y-axis is approximately 0°.

The normal access to the rotating portions of the antenna system (X-wheel, Y-wheel reflector, etc.) will be when the antenna is at the zenith position, which is also the normal service position.

1.7 ANTENNA BRAKE SYSTEM.

Each gear reducer will be supplied with a hydraulic disk brake assembly. The hydraulic pressure for releasing the brakes is obtained from the axis hydraulic power supply. Normal braking is accomplished through the servo control system, which limits the axis deceleration to 10° per second. For braking other than normal, such as emergency stops, the hydraulic pressure to the brakes would be lowered to a predetermined level and held for approximately two seconds and then vented to zero. The predetermined level would be based on a no wind condition and $25°/\text{sec}^2$ deceleration rate.

Because of the wide range of torque caused by the wind (acting with or against the direction of motion) and the variations of the brakes (friction, wear, etc.), it is felt that a higher deceleration rate be allowed to adequately cover the worst condition (maximum overhauling wind with only one brake operational at minimum torque). Figures 1-8 and 1-9 are graphs showing the conditions and variations from wind and typical brakes for the antenna system. Figure 1-10 is a graph showing maximum loading versus distance from the axis of rotation for various axis accelerations.

1.8 ANTENNA SUBSYSTEM ERRORS.

The systematic and random errors for the antenna structure are shown in table 1-3. The deflections causing the systematic errors are the result of analysis performed to date on the overall structure. As the results of the analysis evolve, the portions of the structure causing excessive errors are redesigned and error results are again determined. The final design is expected to be complete in November; however, the errors shown in table 1-3 are not expected to change appreciably.

To arrive at the systematic error caused by structural deflections of the reflector assembly (the reflector assembly being the Y-wheel house, radial trusses, parabola, hyperbola support, quadripod and feed support ring), one must realize that the translations and rotations of the various portions of the reflector assembly may cause additive or compensating effects with respect to the axis angle readout and rf boresight axis. More specifically, the following relationships have been established:

(1) If the hyperbola translation is downward (+) relative to the best fit parabola axis, the resulting rf beam shift will be upward (+).

(2) If the best fit parabola axis rotates downward relative to the ideal parabola, the resulting rf beam shift will be downward (-).

(3) If the hyperbola rotates negative (top of hyperbola moves closer to parabola surface), the resulting rf beam shift will be downward (-), assuming the best fit parabola axis rotates downward.

(4) If the feed horn phase center translates upward (-) relative to the hyperbola vertex and the best fit parabola, the resulting rf beam shift will be upward (+).

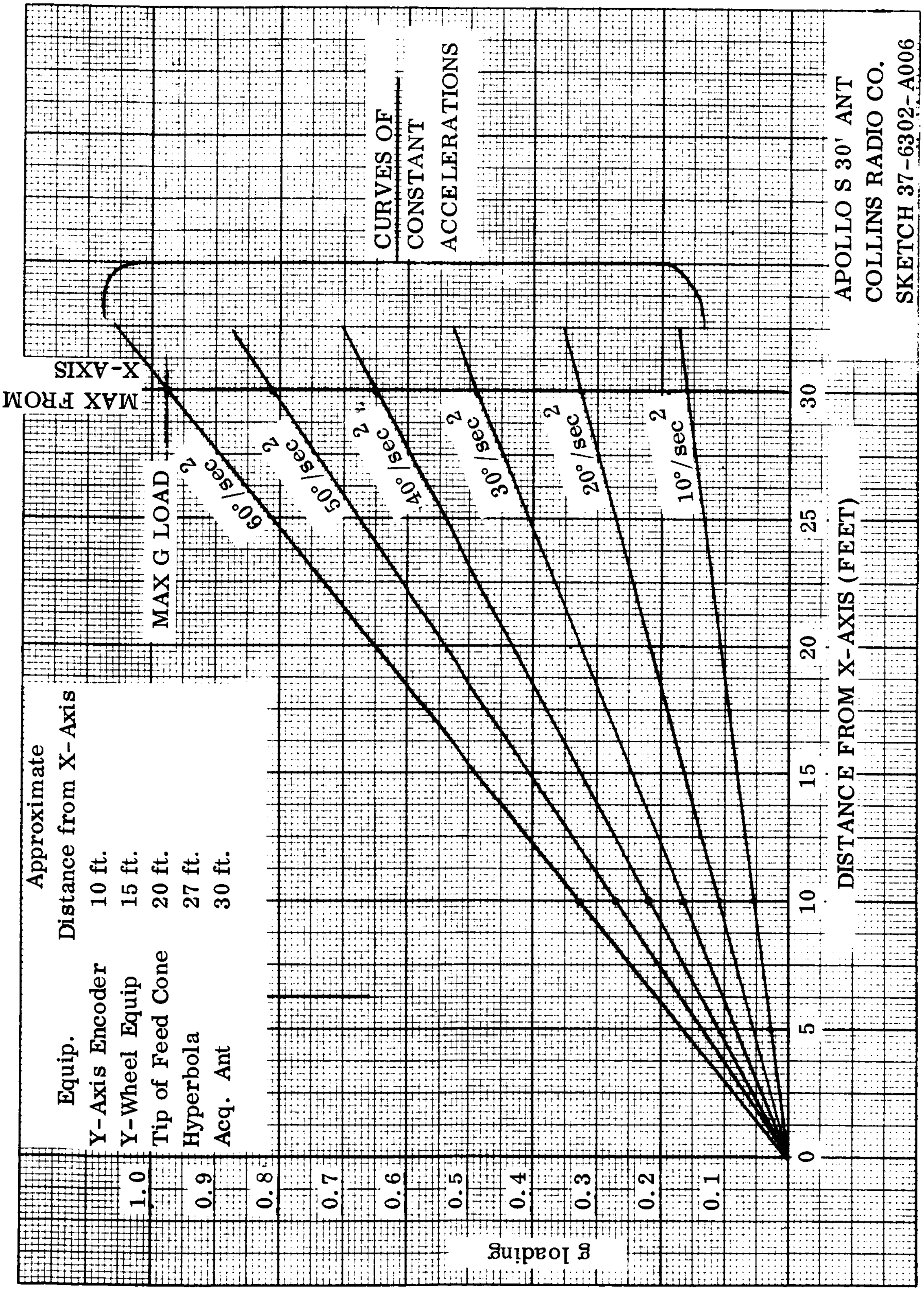


Figure 1-10. G Loading Vs. Distance from X-Axis for Various Decelerations

TABLE 1-3. ERRORS RELATIVE TO X- AND Y- AXES ANGLE READOUT SHAFT

TABULATION OF ERRORS RELATIVE TO X-AXIS ANGLE READOUT SHAFT		
ANTENNA POSITION: X AT 90°E., Y at 0°		
ACCELERATION: 5°/sec^2		
WIND FROM WEST: 20 mph		
(1) Systematic Errors		Peak Errors (3σ)
Error Source:		
(a) Installation errors		
X-axis alignment		5
Y-axis orthogonality		0
Reflector axis orthogonality		5
(b) Dead load deflections		
Reflector assembly		23.5
X-wheel		6.0
Pedestal		0
		39.5 arc seconds
(2) Random Errors		
Error Source:	3σ	$(3\sigma)^2$
(a) Wind load deflections		
Reflector assembly	6	36
X-wheel	4	16
Pedestal	4	16
(b) Bearings		
X-axis	10	100
Y-axis	10	100
(c) Acceleration load deflection		
Reflector assembly	6	36
X-wheel	4	16
Pedestal	6	36

TABLE 1-3. ERRORS RELATIVE TO X- AND Y- AXES ANGLE READOUT SHAFT (Cont)

(d) Thermal		
Reflector assembly	20	400
X-wheel	20	400
		Σ = 1126
		PEAK RMS = 34 SEC.

TABULATION OF ERRORS RELATIVE TO Y-AXIS ANGLE READOUT SHAFT

ANTENNA POSITION: X at 0°, Y at 80°N

ACCELERATION: $5°/sec^2$

WIND FROM SOUTH: 20 mph

(1) Systematic Errors		
Error Source:		Peak Errors (3σ)
(a) Installation errors		
X-axis alignment		5
Y-axis orthogonality		5
Reflector orthogonality		5
(b) Deal load deflections		
Reflector assembly		23.5
X-wheel and pedestal		0
		38.5 arc seconds
(2) Random Errors	3σ	$(3\sigma)^2$
Error Source:		
(a) Wind load deflections		
Reflector Assembly	6	36
X-wheel	10	100
Pedestal	6	36
(b) Bearings		
X-axis	10	100
Y-axis	10	100

TABLE 1-3. ERRORS RELATIVE TO X- AND Y- AXIS ANGLE READOUT SHAFT (Cont)

(c) Thermal		
Reflector	20	400
X-wheel and pedestal	20	400
		Σ = 1260
		PEAK RMS ERROR = 35.6 ARC SEC.

An analysis of the rf optics of a cassegrain antenna system [1] yields the following formulas for determining the maximum beam deviation as a result of items (1), (2), (3), and (4) above.

$$\psi_{\delta H} = \frac{\delta_H}{F} \left(20.6 \times 10^4\right) \tag{1}$$

$$\psi_{\gamma} = \frac{Lv \tan}{F} \tag{2}$$

$$\psi_{\delta F} = \frac{\delta_F}{F} \left(\frac{e-1}{e+1}\right) \left(20.6 \times 10^4\right) \tag{3}$$

$$\psi_{BFP} = \alpha_{BFP} \tag{4}$$

where:

ψ_{δ} = rf beam deviation (in seconds of arc) caused by a lateral translation of the hyperbola with respect to the feed cone phase center.

ψ_{γ} = rf beam deviation (in seconds of arc) caused by an angular tilt of the hyperbola axis with respect to the focal axis of the parabola.

[1] Final technical report for Advanced Antenna Study Program prepared for JPL by the Blaw-Knox Company with Alpha Corporation (Subsidiary of Collins Radio Company) and the Dalmo Victor Company, 8 May 1961.

$\psi_{\delta F}$ = rf beam deviation (in seconds of arc) caused by a lateral translation of the feed cone phase center with respect to the hyperbola. This effect is the same as the hyperbola translation, only reduced by the magnification factor of the system.

ψ_{BFP} = rf beam deviation (in seconds of arc) caused by departure to best fit parabola axis from undeflected parabola axis.

δ_H = translation of hyperbola vertex relative to the best fit parabola axis. (inches)

δ_F = translation of the feed cone phase center relative to the hyperbola vertex (inches)

α_{BFF} = angle the best fit parabola axis makes with the undeflected parabola axis.

F = Parabola focal length (in inches)

L_V = Position of hyperbola vertex to focus of parabola (in inches)

γ = angular tilt of hyperbola axis relative to the focal axis of the parabola (seconds of arc)

e = hyperbola eccentricity (in inches)

From the cassegrain geometry shown in section 2, figure 2-3,

L_V = 15.0637 inches

e = 1.7195 inches

F = 144 inches

The analysis from the antenna structure yields the following:

δ_H = 0.012 inches (downward)

δ_F = 0.0356 inches (upward)

γ = 70 seconds (negative)

α_{BFP} = 46 seconds (downward)

Substituting in equation (1) $\psi_{\delta H} = \frac{0.0119}{144} \quad (20.6 \times 10^4)$ (5)

$\psi_{\delta H}$ = 16.5 seconds upward

Substituting equation (2) $\psi_{\gamma} = \dfrac{15.0637 \tan 70''}{144}$ (6)

$$\underline{\underline{\psi_{\gamma} = 7.4 \text{ seconds downward}}}$$

Substituting in equation (3) $\psi_{\delta F} = \dfrac{0.0356}{144} \left(\dfrac{1.7195-1}{1.7195+1}\right)\left(20.6 \times 10^{4}\right)$ (7)

$$\psi_{\delta F} = \underline{\underline{13.5 \text{ seconds upward}}}$$

Substituting in equation (4) $\psi_{BFP} = \alpha_{BFP}$ (8)

$$\underline{\underline{\psi_{BFP} = 46 \text{ seconds downward}}}$$

An algebraic summation to determine the efforts on rf beam deviation and using the relationships stated in equations (5) through (8) above yields:

$$\psi_m = \psi_{\delta H} + \psi_{\gamma} + \psi_{\delta F} + \psi_{BFP}$$

where

ψ_m = maximum rf beam shift resulting from the reflector assembly

ψ_m = (-16.5) + (7.4) + (13.4) + (46)

ψ_m = 23.5 seconds (downward)

section 2

cassegrain feed system

2.1 GENERAL.

The cassegrain feed system consists of the hyperboloid subreflector, feed housing cone, multimode feed assembly, and the diplexer/filter subassembly. Figure 2-1 is a block diagram of the cassegrain feed system showing major components and method of polarization selection.

In the following paragraphs, the major assemblies of the cassegrain feed system are discussed along with performance predictions of the feed in the 30-foot antenna system.

2.2 CASSEGRAIN GEOMETRY.

Figure 2-2 defines the parameters and table 2-2 lists the formulas relating to cassegrain geometry. The paraboloid parameters of 30 feet in diameter and 12 feet in focal length are given. The parameters to select are hyperboloid diameter and focal length. The surface tolerance has already been established at 0.016 inches rms.

2.2.1 SUBREFLECTOR DIAMETER.

The subreflector should be as small as possible to reduce blocking of the radiation from the paraboloid, thus reducing gain and increasing sidelobes. There is a minimum size below which the feed aperture, in order to illuminate the subreflector, becomes large enough that it determines the unusable part of the paraboloid. The formula given below gives the minimum diameter.

$$D_{s\ min} = \sqrt{2\ \lambda\ F_m} = 40.3274 \text{ inches}$$

F_m = 12 ft. = 144 inches $\qquad \lambda$ = 5.6469 at 2090 mc

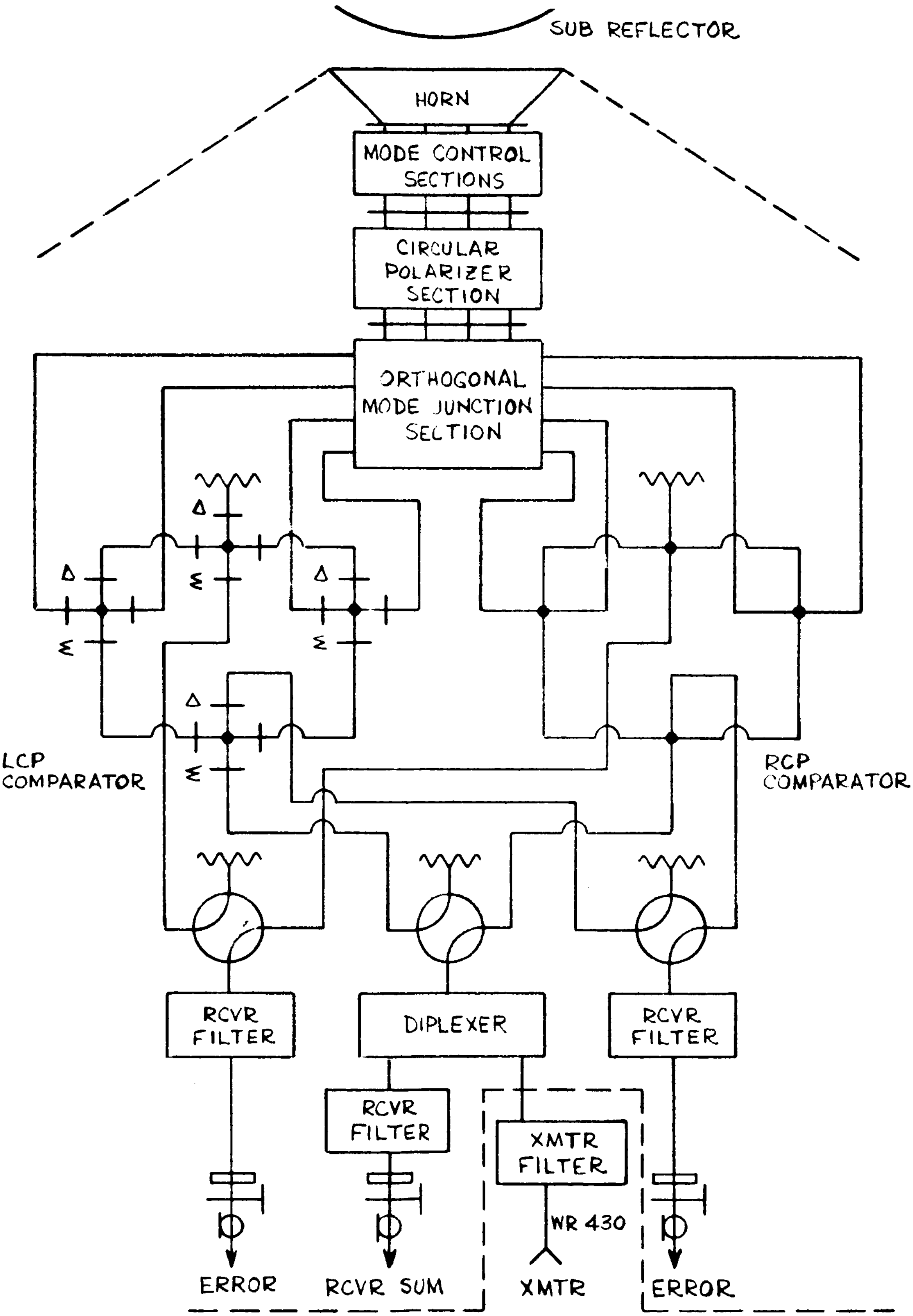


Figure 2-1. Cassegrain Feed System, Block Diagram

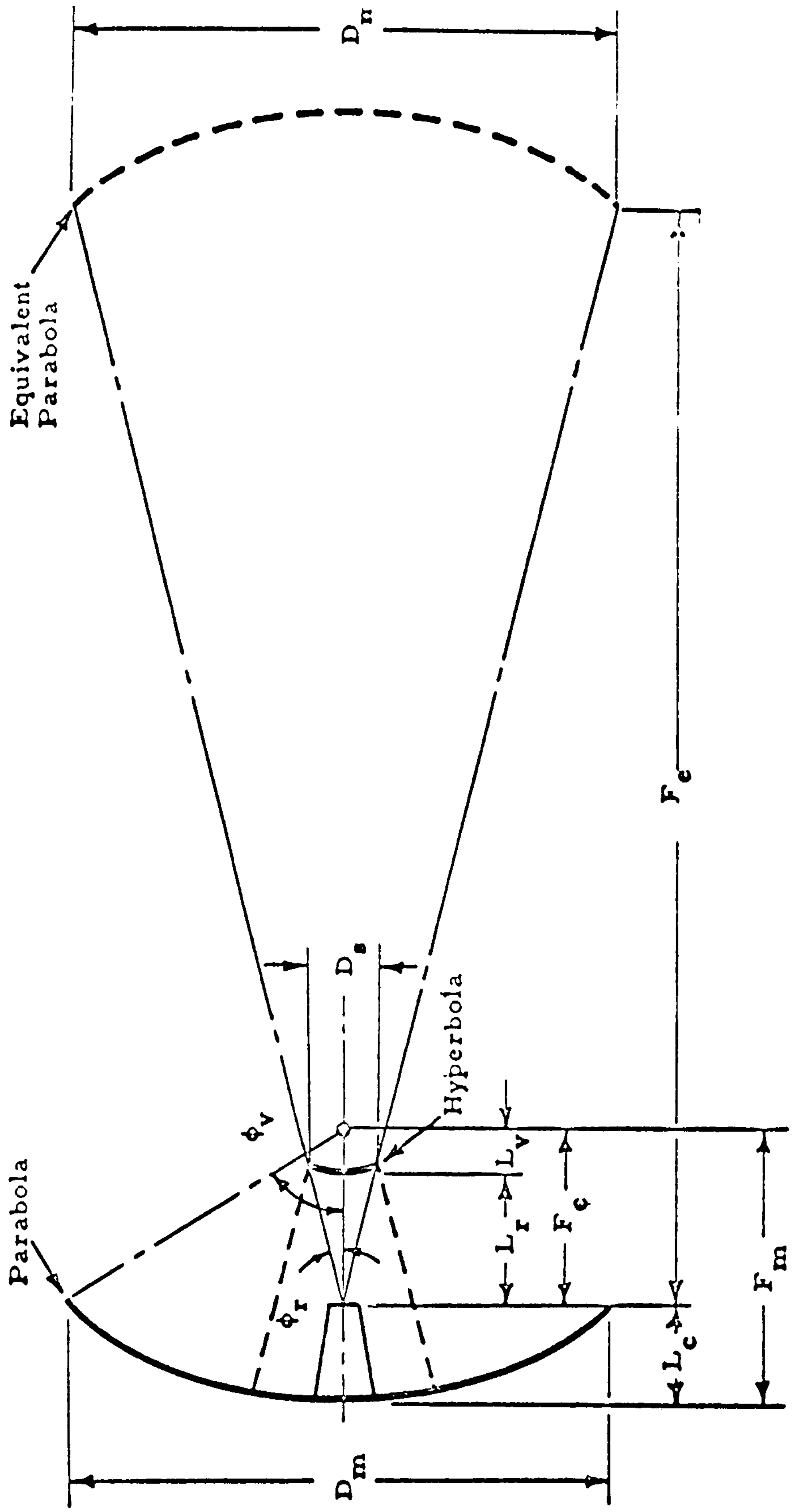


Figure 2-2. Cassegrain Geometry

Since the formula depends on the feed effective aperture = feed blocking aperture (and the feed effective aperture is usually slightly less) D_s should be selected slightly larger than the preceding. Accordingly,

$$D_s = 42.000 \text{ inches}$$

This is equivalent to assuming

$$\frac{\text{Effective aperture}}{\text{Blocking aperture}} = 0.92$$

2.2.2 SUBREFLECTOR FOCAL LENGTH.

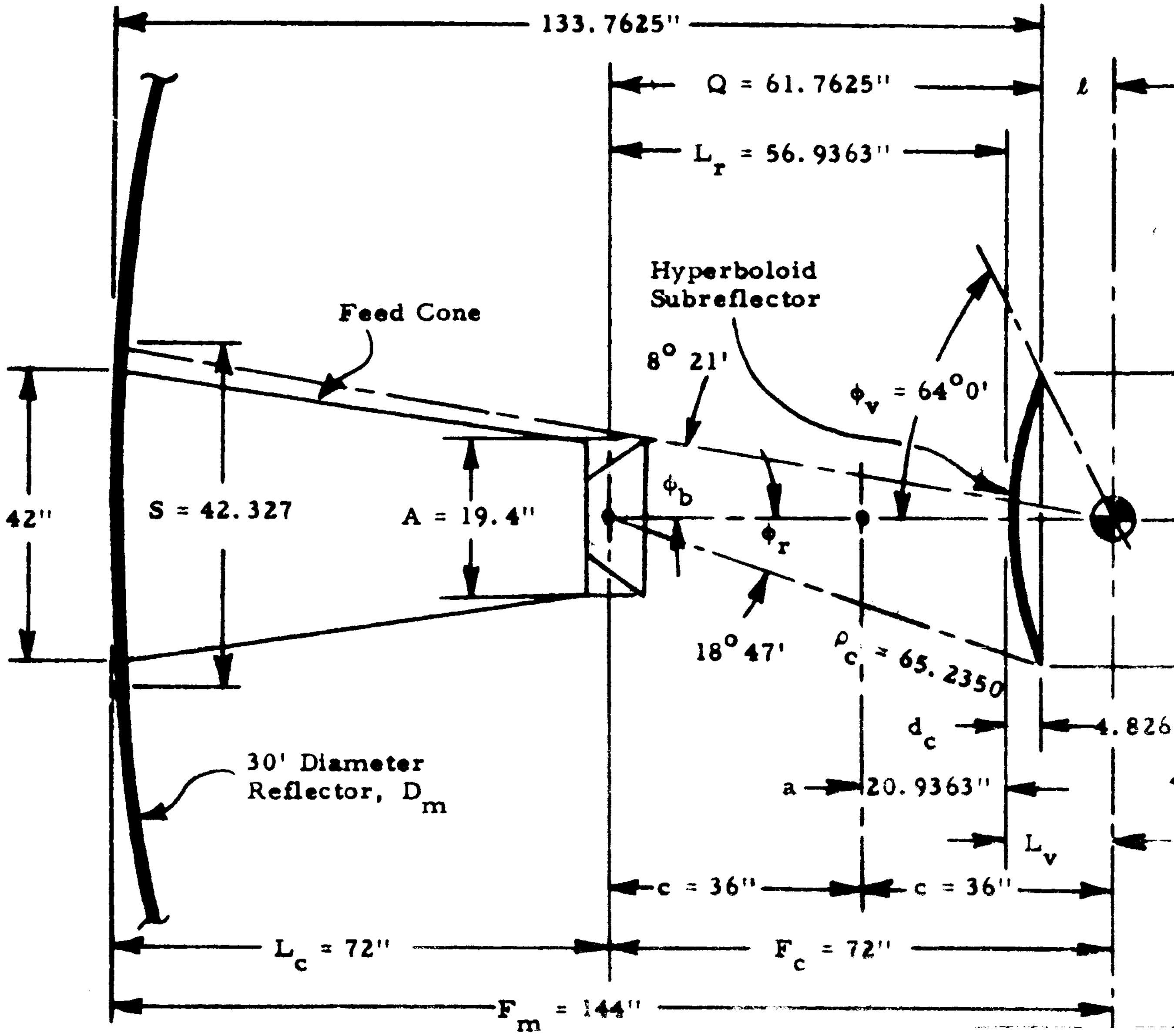
The considerations are feed location such that there is room for feed components, subreflector in far field of feed and mechanical support of feed under wind and dynamic conditions. The far field criterion does not, as might be thought, dictate moving the feed further from the subreflector, as its increased aperture to illuminate the smaller angle as it moves away makes d^2/λ increase faster than L_r. Table 2-1 shows some of the parameters for different F_c values. A tentative choice of 6 foot and resulting parameters are shown in Rantec Drawing 40314102 (figure 2-3). Notice that the feed shadow diameter is slightly larger than the subreflector diameter.

TABLE 2-1. CASSEGRAIN EQUATIONS

EQUATION	ITEM
$\tan \frac{1}{2} \phi_v = \frac{1}{4} \frac{D_m}{F_m}$	Paraboloid half angle
$\rho = F_m \sec^2 \frac{\phi}{2}$	Paraboloid polar surface equation
$y^2 = \Delta F_m x$	Paraboloid rectangular surface equation, original at vertex
$d_m = \frac{D_m^2}{16 F_m}$	Depth of paraboloid

TABLE 2-1. CASSEGRAIN EQUATIONS (CONT)

EQUATION	ITEM
$\cot \phi_r = 2 \frac{F_c}{D_s} - \cot \phi_v$	Hyperboloid half angle
$e = \frac{\sin \frac{1}{2} (\phi_v + \phi_r)}{\sin \frac{1}{2} (\phi_v - \phi_r)}$	Hyperboloid eccentricity
$M = \frac{e+1}{e-1} = \frac{L_1}{L_v} = \frac{\tan \frac{1}{2} \phi_v}{\tan \frac{1}{2} \phi_r}$	Magnification
$F_e = MF_m$	Focal Length of equivalent paraboloid
$a = \frac{F_c}{2e}$	Semi-tranverse axis
$b = a\sqrt{e^2 - 1}$	Semi-conjugate axis
$c = \sqrt{a^2 + b^2} = ae = \frac{F_c}{2}$	Semi-focal distance
$\frac{x^2}{a^2} - \frac{y^2}{b^2} = 1$	Hyperboloid rectangular surface equation
$\rho = \frac{a(e^2 - 1)}{1 + e \cos \phi} = \frac{L_v (e+1)}{1 + e \cos \phi}$	Hyperboloid polar surface equation, origin at paraboloid focus
$L_v = \frac{F_c}{2} \left(\frac{e-1}{e}\right) = a(e-1)$	Hyperboloid position
$d_c = L_v - \frac{D_s}{2} \cot \phi_v$	Depth of hyperboloid

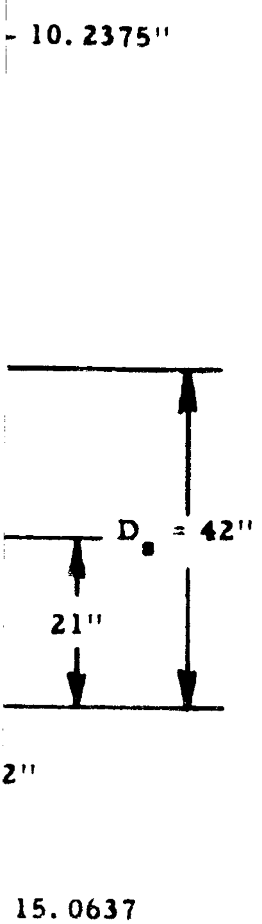


HYPERBOLOID SURFACE EQUATION:

$$\frac{X^2}{a^2} - \frac{Y^2}{c^2 - a^2} = 1;$$

$$\therefore \quad \frac{X^2}{(20.9363)^2} - \frac{Y^2}{(36^2 - 20.9363^2)} = 1;$$

1#



CASSEGRAIN GEOMETRY EQUATIONS:

ϕ_r = Hyperboloid Half Angle = $18^\circ\ 47'$

ϕ_v = Paraboloid Half Angle = $64^\circ\ 0'$

F_c = Focal Length = 72"

D_s = Hyperboloid Subreflector Dia = 42"

M = Hyperboloid Magnification = 3.77969"

e = Hyperboloid Eccentricity = 1.71950"

a = Semi-Transverse Axis = $\frac{F_c}{2e}$ = 20.9363"

b = Semi-Conjugate Axis = $a\sqrt{e^2-1}$

c = Semi-Focal Distance = $\frac{F_c}{2}$ = 36"

ℓ = 10.2375"

Q = 61.7625"

ρ_c = 65.2350"

L_v = Hyperboloid Position = $a(e-1)$ = 15.0637"

d_c = Depth of Hyperboloid = $L_v - \ell$ = 4.8262"

= $L_v - (\frac{D_s}{2} \cot \phi_v)$ = 4.8262"

L_r = 56.9355"

F_m = 144"

D_m = Parabola Diameter = 30 ft = 360"

S = 42.327

ϕ_b = $8^\circ\ 21'$

A = 19.4"

Figure 2-3. Cassegrain Geometry

TABLE 2-2. VARIOUS PARAMETERS VS F_c, 30-FOOT ANTENNA

D_m = 30 feet			F_m = 12 feet			D_s = 42 feet	
F_c	ϕ_r	e	Lr	A	A^2/λ	$\frac{Lr}{A^2/\lambda}$	ϕ_b
72	18° 47'	1.719	56.9	19.4	73	1.28	9.7°
66	20° 41'	1.822	51.0	17.6	60	1.18	9.8°
60	22° 52'	1.955	43.4	15.9	49	1.08	10.2°
54	25° 41'	2.147	39.6	14.3	40	1.01	10.4°
48	30° 28'	2.540	33.4	12.0	28	0.84	10.4°

2.3 CONE AND SUBREFLECTOR.

2.3.1 CONE (FEED HOUSING).

2.3.1.1 REQUIREMENTS. The function of the feed housing is to support, position, and protect the composite feed, diplexer, filters, and other related components mounted within it. The feed housing takes, naturally, a truncated conical shape (with the vertex of the cone at the focal point of the parabola) since this provides a simple shape of greatest volume for minimum aperture blocking. Based on a 44-inch diameter base (comparable to the subreflector diameter), this feed housing has a half-angle of 8° 45'.

In supporting the internal components, the structure of the feed housing must carry loads arising from:

(1) Acceleration

(a) Gravity - 32 ft./sec^2

(b) Antenna Drive - 10°/sec^2

(2) Wind - 140 mph (Equivalent Pressure Loading - 54 psf)

(3) Additional dead weight - One 300 pound man.

In positioning the internal components, the structure of the feed housing must carry the following operating loads while maintaining the feed horn position within 0.010 of its theoretical position in order to preserve tracking accuracy:

(1) Acceleration - in any lateral direction

(a) Gravity - 32 ft./sec^2

(b) Antenna Drive - 10°/sec^2

(2) Wind - 45 mph (Equivalent Pressure Loading - 5 psf).

In protecting the internal components, the feed housing must keep out rain, snow, dust, insects, etc. However, the protection must be removable so that access to the components is available for maintenance.

2.3.1.2 DESCRIPTION. The structural configuration of the feed housing is a simple box frame.

The longerons carry the tension and compression components of the bending load and the diagonals carry the shear components. A ring is provided at the base to mate with the mounting ring supplied by the antenna manufacturer. The mounting bolts for this attachment are aligned with the load-carrying longerons for efficient transfer of load.

Preliminary analysis indicates that the maximum load to be carried is around 75,000 pound-inches bending moment, made up about equally of acceleration and wind loads. The spread between the longerons is approximately 30 inches. Hence, the load in each longeron is approximately $\frac{75,000}{30 \times 2} = 1250$ pounds. Based on a design stress of 10,000 psi (providing a 100 percent overload margin for welded 6061-T6 aluminum members), the longerons each must provide about $\frac{1,250}{10,000} = 0.125 \text{ in.}^2$ of crossection areas.

This is an impractically small member, (for example, a tube 0.50 inches in diameter with .095-inch wall thickness) hence, the members will be sized more on the basis of column buckling and fabrication and handling ease. A likely member size is 2-inch diameter aluminum (6061-T6) tubing with approximately 0.15 inch wall thickness.

This configuration provides a relatively open structure which should permit good access to the feed components. Additional access can be provided, if especially needed in a particular location, by making one of the diagonals removable. By using tapered pins for the connection, the diagonal can be replaced with no loss of structural integrity.

With regard to deflection, a first approximation can be made considering the housing as a uniformly loaded cantilever, for which the end deflection is:

$$r = \frac{wL^4}{8EI}$$

The equivalent I of the frame is:

$$I_{Equiv} = 4 \text{ (tubes) } (1.07 \text{ in.}^2) \text{ area } (15 \text{ in.})^2 \text{ (Distance from neutral axis)}$$

$$= 960 \text{ in.}^4$$

The loading,

$$w = \frac{500 \text{ lb (dead weight) } (1.5 \text{ g}) + 100 \text{ lb (Wind)}}{70 \text{ inches Cone Length}}$$

$$= \frac{850}{70} = 12.2 \text{ lb/in.}$$

$$r = \frac{(12.2)\ (70)^4}{(8)\ (10 \times 10^6)\ (960)} = 0.0038 \text{ in. approximate}$$

This is a tolerable deflection.

The feed components are attached to the structure with numerous brackets. Those brackets connect between the longerons and diagonals, thereby forming bulkheads and distributing loads into the main members without introducing bending.

A sheet metal cover provides weather protection to the feed components. A portion of this is removable to provide access to the interior of the housing. The removable portion has captivated fasteners and is gasketed. A collar completes the closure around the feed horn, and the base of the housing likewise is closed.

2.3.1.3 TOOLS. In addition to an interface template, the following items of tooling are anticipated:

(1) Assembly Fixture. To position structure parts of housing for welding.

(2) Alignment Fixture. To align difference axes of feed with mounting axes of housing.

2.3.2 SUBREFLECTOR.

2.3.2.1 REQUIREMENTS. The function of the subreflector is to present a hyperbolic reflecting surface.

2.3.2.2 DESCRIPTION. The subreflector is an aluminum spinning. A flange turned at the edge stiffens the spinning and a hat-shaped ring attached on the back of the reflector completes the stiffening by forming a closed torsion ring. Lightening holes in the webs of this ring provide numerous lifting locations.

Four attach pads are fastened on the stiffening ring. These receive the ball ends of the adjusting and supporting studs.

The studs are mounted in brackets clamped to the quadrapod tubes. The studs are threaded, and adjustable in the brackets in the direction of the focal axis of the antenna. Adjusting the studs simultaneously adjusts the focal position of the subreflector. Adjusting the studs differentially adjusts the squint of the subreflector. No lateral adjustment is provided, since the angular adjustment is considered more effective in positioning the boresight axis.

2.4 ELECTRICAL SPECIFICATIONS.

The electrical specifications are given in terms of secondary radiation pattern characteristics (see table 2-3). The task to be executed, however, is the development of the primary illuminator for the main reflector. The main reflector is a 30-foot diameter paraboloid. This main reflector is illuminated by a 42-inch diameter hyperboloid subreflector. The subreflector design is treated in paragraph 2.3.2.2. The illumination of the subreflector is achieved by the feed assembly. This section will describe the factors in the design of this feed assembly. The primary patterns generated by the feed assembly must indicate a capability of ultimately producing the required gain and secondary patterns. It will be shown that a multimode horn type feed is necessary to insure meeting the gain specification.

TABLE 2-3. SPECIFICATION FOR COMPLETE ANTENNA

ITEM	TRANSMIT FUNCTION	RECEIVE FUNCTION
Frequency	2090-2120 mc	2270 to 2300 mc
VSWR	1.2 maximum	1.2 maximum at Sum Channel Terminals of Feed Assembly
Gain	43.0 db minimum	44.0 db minimum
Sidelobe Level	-18 db maximum	-18 db maximum in region within 20° of boresight axis. -30 db maximum in region within 80° of boresight axis, but beyond 20° from boresight axis. -40° maximum outside of 80° half angle cone about boresight axis
Null Depth	- -	-35 db maximum
Pre-Comparator Unbalance	- -	0.2 db maximum
Boresight Shift with Polarization	- -	3.0% of sum beamwidth 0.5% design goal
Cross Coupling of Error Channels	- -	10% maximum in 0.25° half angle cone about boresight axis
Beamwidth	- -	0.8° minimum 1.3° maximum
Polarization	RCP or LCP Remotely Selectable	RCP or LCP Remotely Selectable
Axial Ratio	1.0 db maximum	1.0 db maximum
Power Capability	20 kw average 30 kw peak	- - - -
Channels	Sum	Sum X-error Y-error

TABLE 2-4. GAIN LOSS

ITEM		LOSS
(1)	I^2R Losses in Feed and rf Network:	0.5 db
(2)	Aperture Efficiency Loss from $(1-r^2)$:	
	Taper - - - -10 db Edge Illumination:	0.4 db
(3)	Aperture Blockage Loss:	0.3 db
(4)	Paraboloid and Hyperboloid Surface Tolerance Loss:	0.1 db
(5)	Spillover Loss:	1.0 db
(6)	Phase Error Loss:	0.3 db
(7)	Polarization Loss:	0.1 db
	Total Losses	2.7 db

2.4.1 DESIGN CONSIDERATIONS.

2.4.1.1 GAIN. The gain of an ideal, uniformly illuminated circular aperture of 30 feet in diameter is 46.0 db and 46.7 db at the lower ends of the transmit and receive bands, respectively. In either band, the overall antenna will suffer various losses as shown in table 2-3.

The conclusion, then, is that 43.3-db and 44.0-db gains may be expected at the transmit and receive frequencies, respectively. Each of the seven items in the table 2-4 has a tolerance on its value. It is conceivable that an accumulation of the tolerances could lead to a somewhat greater value for total losses. The likelihood of this is low because the individual values are believed to include worst-case tolerance allowances.

The design of the feed must be optimized at the receive frequency since there is less margin available there. At the lower frequency, the spillover loss should increase because of the broadening of the primary pattern; however, this will be offset by an increase in secondary aperture efficiency since the broadening of the primary pattern increases the edge illumination on the paraboloid. Thus, the loss table should apply to both frequency bands. Items 2 and 5 in table 2-4 are computed on the basis of a circular cross section for the beam of the primary illuminator. Furthermore, -18 db sidelobes were assumed for the maximum sidelobe level.

The spillover and aperture efficiency parameters are major sources of loss. It follows, therefore, that the primary pattern must be well tailored. The generation of equal E-plane and H-plane beamwidths may be accomplished by the use of a finned square horn, operated in the TE_{01} mode (plus the TE_{10} mode in quadrature to achieve circular polarization). The single mode finned horn, however, does not suppress E-plane sidelobes and would force the use of a higher figure for Item 5 of table 2-4. A further disadvantage of the finned horn is that it does not allow the use of the maximum aperture as required for difference pattern efficiency. The multimode horn can be designed to avoid the problems of high E-plane sidelobes and low efficiency of the E-plane difference patterns.

Analysis of multimode horns establishes that the sacrifice of some H-plane beam shape control leads to a design which is more manageable over the bandwidth of interest. A good compromise is as follows:

(1) Accept the unmodified H-plane amplitude variation of the TE_{10} mode for H-plane sum beam shaping.

(2) Use the combined effect of the TE_{10} modes, and specially induced TE_{12} modes for E-plane beam broadening and sidelobe suppression.

(3) Use the TE_{20} mode for the H-plane difference beam.

(4) Use the naturally occurring TE_{11} and TM_{11} modes for the E-plane difference pattern.

This compromise leads to horn throat dimensions which can be far from cutoff (for bandwidth) for the TE_{12}/TM_{12} modes yet not pass the TE_{22}/TM_{22} modes. This approach allows great freedom in selecting from numerous techniques for generating the TE_{12}/TM_{12} modes. Attempts to further shape the H-plane sum patterns require modes with mode numbers higher than the TE_{22}/TM_{22}.

2.4.1.2 SIDELOBE LEVEL. The near-in sidelobes are controlled by the secondary aperture taper and degraded by the extent and nature of the aperture blockage. The taper and the relatively small subreflector indicate that -18 db sidelobes will be obtained in the majority of space. In the plane of the subreflector support legs, the sidelobes will depend on the size and angle of these supports.

2.4.1.3 NULL DEPTH. The use of magic tees throughout in the generation of the sum and difference patterns bodes well for achieving the amplitude and phase balance required for good primary pattern null depths. The mechanical tolerance to be involved will be very modest since a rather long wavelength is involved. The -35 db secondary pattern null depth is attainable.

2.4.1.4 VSWR. The feed design will employ low Q elements in waveguide well above cutoff for all modes of interest. Matching over the two ±0.75 percent bands should present little difficulty.

2.4.1.5 AXIAL RATIO. The axial ratio is a function of the circular polarizer, and, in multimode feeds, the equality of phase path in the E-plane and H-plane mode sets assigned to a given beam function.

For the design planned, the sum beam modes are the TE_{10} mode at one instant, and the TE_{10} plus the TM_{12} and TE_{12} one-quarter rf period later. There are no fundamental obstacles to achieving the required phase equalization within some multiple of 2π as required. The 1-db axial ratio specification is realizable.

2.4.2 MISCELLANEOUS.

The specifications on power handling, boresight shift with polarization, and crosstalk, allow sufficient tolerances in the light of other specifications. No special problems are envisioned in these areas.

2.4.3 TRACKING AND POINT ACCURACY.

Static pointing accuracy is interpreted as the alignment between the geometrical (mechanical or optical) axis of the antenna system and the rf (electrical) axis. The sources of error are:

(1) Distortion of the main reflector,

(2) The subreflector and quadripod support,

(3) The vertex cone feed housing and feed support due to wind and as a function of azimuth and elevation position

(4) Fixed errors due to the precomparator amplitude unbalance

(5) Pre and postcomparator phase errors in the tracking feed rf circuitry,

(6) Random errors due to noise.

2.4.3.1 STATIC POINT ERRORS. To analyze the problems, assume the following parameters:

Paraboloid Diameter:	D_m = 30 ft.
Paraboloid Focal Length:	F_m = 12 ft.
Hyperboloid Diameter:	D_s = 42 inches
Hyperboloid Focal Length:	F_c = 6 ft.
Length of Feed Cone including Horn:	L_c = 6 ft.

The following equations (some approximate) can be used in estimating pointing errors:

$$\tan \theta_f = \frac{\epsilon_f}{MF_m}$$

$$\tan \theta_r = \frac{2F_c \beta_r}{F_m (M + 1)}$$

$$\tan \theta_h = \frac{(M - 1) \epsilon_h}{MF_m}$$

θ_f = error due to feed lateral displacement, ϵ_f

θ_r = error due to hyperboloid rotation around its vertex, β_r

θ_h = error due to hyperboloid lateral displacement, ϵ_h

M = magnification

For the assumed geometry this would result in $\theta_f = 0.4\ \widetilde{sec}/0.001''$ and $\theta_h = 1\ \widetilde{sec}/.001.''$ The effect of hyperboloid rotation $\theta_r = .209\ \beta_r$, is normally in the opposite direction of θ_h and θ_f.

2.4.3.2 ERROR CHANNEL SLOPE. Error channel slope, K, is defined as the rate of change with angle of the error received signal at boresight normalized to unit voltage at the sum channel output. Thus, the units will be volts per volt per degree. For a 30-foot antenna at 2.3 gc, the maximum theoretically possible slope (optimum illumination, no spillover or losses) is 1.90 volts/volt/degree. Estimating 3 db due to illumination efficiency, losses and spillover, the estimated slope becomes 1.37 volts/volt/degree. This will be used in subsequent analyses.

2.4.3.2.1 COMPARATOR AMPLITUDE UNBALANCE. Equation (1) is a relation for boresight shift due to amplitude unbalance, where α is the voltage unbalance ratio. The balance in db is 20 log

$$\theta = \frac{1}{K}\ \frac{1 - \alpha}{1 + \alpha} \tag{1}$$

If the amplitude unbalance can be less than 0.1 db, the resulting boresight error is 15 seconds or 0.42 percent of the beamwidth.

2.4.3.2.2 PHASE ERRORS. Simultaneous precomparator and postcomparator phase errors are required to produce a boresight shift. An approximate formula for this boresight shift is

$$\theta = \frac{1}{2K} \sin \phi_1 \tan \phi_2 \tag{2}$$

Where ϕ_1 = precomparator phase unbalance

ϕ_2 = postcomparator phase unbalance

For ϕ_1 = 2 degrees, ϕ_2 = 2 degrees, θ = 1.6 seconds, for example.

2.4.4 POWER HANDLING CAPACITY.

The power handling capacity shall be 20 kw, cw with 30 kw peaks. For the waveguide size and frequency band, this is not exceptionally high power. The design will require normal precautions but no extreme measures. The temperature rise in WR430 waveguide is theoretically less than 20°C for this power and no cooling will be required. Design precautions required to prevent arcs will be avoidance of sharp edges, corners, or small gaps.

section 3

acquisition antenna

3.1 GENERAL.

This section presents an analysis of the basic requirements of the acquisition antenna along with error and performance predictions to show design compliance with GSFC-TDS-ANT-31 and system compatibility. A block diagram is shown in figure 3-1.

3.2 GAIN.

Paragraph 7.2.5 of the specification requires 22 db of gain. Although the predicted performance is marginal, this requirement can be met. The gain is calculated as follows:

$$G_o = 10 \log 0.55 \left(\frac{4\pi A}{\lambda^2}\right)$$

$$= 10 \log 0.55 \left(\frac{4\pi (1020)}{26.7}\right)$$

$$= 24.2 \text{ db gain}$$

where: 0.55 = 55% efficiency

A = area of 3 foot dish

λ = operating wavelength

Losses:

RF Circuitry	0.5 db
Cables	0.3 db
Radome	0.1 db
Horn	0.1 db

Feed Horn Blockage	0.7 db
Strut Blockage	0.5 db
Total effective losses	2.2 db

Expected Gain = G_o - losses

$$= 24.2 - 2.2 = \underline{22 \text{ db}}$$

This analysis assumes the blocked energy from the feed and struts is out of phase with the energy radiated from the parabola; therefore, this is a worst case condition.

3.3 SIDELOBE LEVEL.

The level of the first sidelobe must be at least 15 db below the maximum of the sum pattern and more than 30° from the boresight axis must be 30 db below the sum pattern maximum. The calculations presented below show that the estimated level of the first sidelobe is 14.4 db. Again, this is a pessimistic value since the blocked energy is assumed to be out of phase with the direct energy. In practice, a value of 15 db can probably be obtained. The level of the first sidelobe is calculated as follows:

$$\frac{E_s}{E_r} = 1.55 \left(\frac{w}{d_r}\right) \left(\frac{4}{5}\right)$$

where: E_s/E_r = maximum field intensity of the strut pattern relative to the max intensity of the unperturbed aperture.

$$\frac{E_f}{E_r} = 2\left(\frac{d_f}{d_r}\right)^2$$

$$\frac{E_s}{E_r} = 1.55 \left(\frac{0.75}{36}\right) (4/5)$$

$$= 0.0257 \text{ (struts)}$$

E_s/E_r = maximum field intensity of the feed blockage pattern relative to the max intensity of the unperturbed aperture.

$$\frac{E_f}{E_r} = 2\left(\frac{7.25}{36}\right)^2 = 0.081$$

D_r = diameter of the reflector = 36 inches, W = width of struts, d_f = blocking diameter of the feed.

Sidelobe for unperturbed aperture with $(1-r^2)$ illumination is 24.6 db or 0.059

4/5 = modification factor so that strut blockage in the area of the feed is not included twice.

Thus $\frac{E_s 1}{E_r} = 0.059$

	To be added to first sidelobe	To be subtracted from main beam	Source
	0.081	0.081	feed
	0.026	0.052 (2 sets of struts)	struts
Totals	0.107	0.133	

Sidelobe level with blockage

$$= 20 \log \left(\frac{Es1/Er + 0.107}{Er - 0.133}\right)$$

$$= 20 \log \left(\frac{0.059 + 0.107}{1 - 0.133}\right)$$

$$= \underline{14.4 \text{ db}}$$

No difficulty is anticipated in meeting the 30-db requirement beyond 30° from the boresight axis.

3.4 NULL DEPTH.

The depth of the central null in each acquisition error channel shall be 25 db below the beam maximum. The null depth level is affected mainly by phase errors.

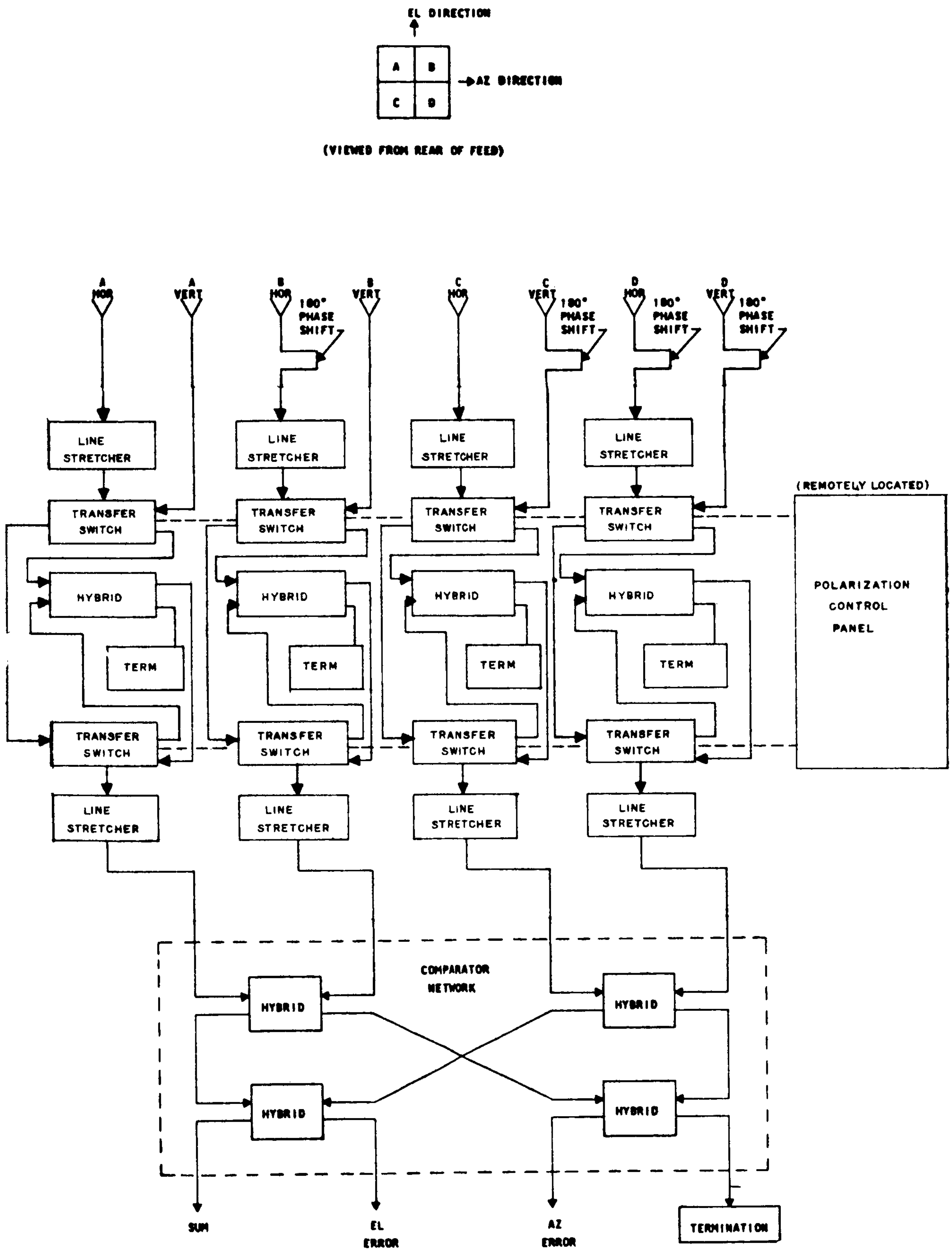


Figure 3-1. Acquisition Antenna, Block Diagram

The Collins design will incorporate phase shifters to compensate for manufacturing tolerances and other sources of phase errors. Therefore, no difficulty is anticipated in meeting the 25-db specification.

3.5 PRECOMPARATOR AMPLITUDE UNBALANCE.

Due to the symmetrical nature of the 4-horn feed and the nearly equal line lengths between this horn and the comparator, no difficulty is anticipated in meeting the required precomparator amplitude unbalance of 0.2 db.

3.6 BORESIGHT SHIFT VERSUS POLARIZATION.

A boresight shift with polarization is primarily a function of precomparator amplitude unbalance. Theoretically, an amplitude difference of 0.2 db results in a boresight shift of 0.6 percent of the sum channel beamwidth. Thus, if the precomparator amplitude unbalance specification is met, the boresight shift with polarization will be less than 1 percent of the sum channel beamwidth, assuming that there are no post detector phase shifts. Precomparator phase errors will have negligible effect on the boresight shift with polarization.

3.7 CROSS COUPLING OF THE ERROR CHANNELS.

Since the requirement for 10 percent or less crosstalk between error channels amounts to approximately 20 db of isolation, which is fairly easy to achieve, the crosstalk of the acquisition antenna should be within the specification. It is pointed out, however, that particular attention should be given to the measurement technique for verifying this specification. Normally, the collimation antenna for an X-Y mount system is positioned either due east or due west of the station, with the desired coordinates for checking cross coupling being an X angle of ±90° and a Y angle of 0°. Since it is not always possible to have the collimation antenna positioned at the proper X and Y angles, orthogonality measurements for any other coordinates might indicate more cross coupling than that actually present. Coupling measurements will be made during the acceptance test so that both the ground reflections and the coordinate system can be controlled.

3.8 ISOLATION.

Isolation of 160 db between the outputs of the acquisition antenna and the transmit feed of the 30-foot antenna is required. This specification can be met with filtering. Because of the near field effects and the possibility of several ray paths, calculation of the exact isolation between the two antennas is difficult. To estimate the isolation to a probable accuracy of 10 db, the following equation was used:

$$\text{Isolation} = \frac{G_t G_a \lambda^2}{16\pi^2 R^2}$$

Where: G_t = gain of the transmit antenna in the direction of interest.

G_a = gain of the receive antenna in the direction of interest.

λ = operating wavelength

R = the separation between the antennas in the direction of interest.

Considering several possible ray paths, the worst possible isolation was calculated to be 66 db with the acquisition antenna mounted on the perifery of the 30-foot dish. Considering the accuracy of the calculations, it was decided to provide 120 db of filtering in each of the output channels on the acquisition antenna. The supplied filters are the waveguide-beyond-cutoff type that have an insertion loss of approximately 0.1 db at the receive band. With the acquisition antenna placed near the focal point of the 30-foot dish (end of quadrapod) the isolation between these antennas improve. The improvement factor is calculated to be about 25 db, that is, the isolation is on the order of 85 db compared to the 66 db calculated above . Thus, it is recommended that the acquisition antenna be placed at the apex of the quadrapod (see section 2 for a mechanical discussion).

3.9 BORESIGHT SHIFT FROM ELECTRICAL OR MECHANICAL INSTABILITY.

Even though the requirement for the instability to be less than 2 percent of the half power beamwidth was deleted, the boresight shift calculated for mechanical deflections within the acquisition antenna is found to be approximately 1/2 percent of the half power sum channel beamwidth. Assuming that the deflections of the interface mountings are minimized, the mechanical stability should be well within the 2 percent figure.

section 4

parametric amplifier

4.1 GENERAL.

Basically, the parametric amplifier is a radio-frequency amplifier. Located directly behind the antenna, the parametric amplifier utilizes inherent low noise properties to increase the sensitivity of the receiving system. The parametric amplifier and associated power supply are enclosed in a pressurized container weighing approximately 50 pounds. A control panel located up to 200 feet away is supplied for remote operation. The parametric amplifier is controlled from the remote panel.

Figure 4-1 illustrates the parametric amplifier system in block diagram form. The various components and the associated functions are described in the following paragraphs.

4.2 SYSTEM DESCRIPTION.

4.2.2 DIRECTIONAL COUPLER.

The directional coupler has a phase versus frequency characteristic identical with that of a length of coaxial line and an insertion loss of approximately 0.1 db at the receive frequency. The directional coupler functions as a test signal injection point and is calibrated for a coupling factor of 20 db ± 0.5 db.

4.2.3 CIRCULATOR.

The circulator is a 5-port circulator with the second port terminated. The termination provides 45 db minimum isolation between the input and the first stage parametric amplifier. This isolation is necessary to eliminate effects of a changing input vswr; however, an extra 0.1 db is added to the noise figure as a result. Varactor diode holders are mounted to the third and fourth ports. The fifth port is connected to the power divider.

4.2.4 POWER DIVIDER.

The power divider provides five equal outputs with a 25-db minimum isolation between channels. An additional 25-db isolation is obtained from individual output isolators. Insertion loss from the input to either of the five outputs is approximately 7 db.

4.2.5 OUTPUT ISOLATORS.

An individual isolator (3-port circulator) is attached to each of the five power divider outputs. The isolators provide a minimum isolation of 25 db, which satisfies two requirements: first, to obtain 50-db isolation between outputs; and second, to insure that performance of the amplifier is not degraded because of output mismatch.

4.2.6 PARAMETRIC AMPLIFIER.

The block identified as parametric amplifier in figure 4-1 is actually a diode holder. The diode holder provides for connection to the circulator, appropriate bias arrangement, and connection to the pump circuit. The parametric amplifier, or diode holder, is the interchangeable replacement part for the system.

4.2.7 VARIABLE ATTENUATOR.

A manually operated attenuator in each arm of the pump circuit is used as a coarse gain adjustment. The fine gain adjustment is remotely controlled and is discussed later. The attenuator controls the amount of pump power incident on the diode.

4.2.8 POWER DIVIDER.

The power divider divides the output power of the klystron into two equal parts and, with the variable attenuators, provides sufficient isolation between the two pump arms.

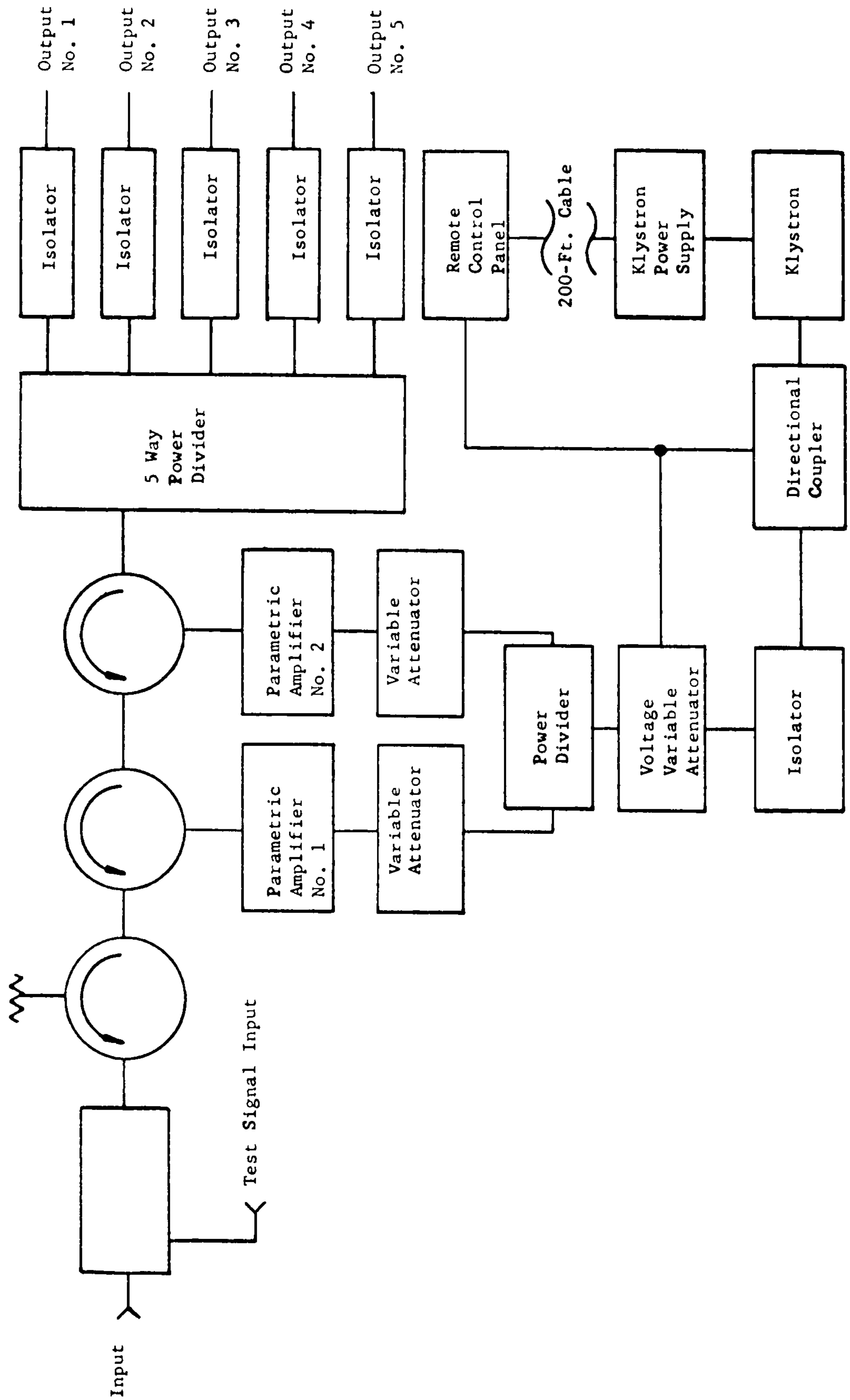


Figure 4-1. System Block Diagram

4.2.9 VOLTAGE VARIABLE ATTENUATOR.

The voltage variable attenuator is controlled from the remote control panel and provides a means of adjusting the gain of the amplifier assembly.

4.2.10 PUMP ISOLATOR.

The pump isolator provides comparatively constant inpedance termination to the klystron.

4.2.11 KLYSTRON.

The klystron is a reflex type and may be tuned from the center frequency by approximately ± 100 mc. No adjustment is necessary in the field; however, some adjustment may be required after replacement of a klystron.

4.3 PACKAGING DESCRIPTION.

The enclosure is of cast aluminum and is basically two identical half-shells. The inner volume of 8 by 12 by 18 inches is sufficient to house both power supply and amplifier assembly. Thermostatic control maintains the temperature at $120^{\circ} \pm 10^{\circ}$ F. A ribbed type design is used for strength and heat dissipation requirements. Four topped bosses on both the bottom and top are used for surface mounting as desired. Removal of fabricated cross members fastened to the bottom bosses allows the enclosure to be attached directly to a shelf. All heat is transferred to the walls through heat sinks. The power supply is located in a separate partition.

4.4 AMPLIFIER DESIGN.

The parametric amplifier is designed for a pump frequency of 15.5 kmc and a center frequency of 2285 mc. A silicon varactor diode with the following characteristics is used on the parametric amplifier:

$C_{jo} = 0.53$ pf

$f_{co} = 100$ kmc

$\gamma = 0.2$

$Q = 43.5$ at the signal frequency

The following pump, idler, and signal frequencies and ratios are fixed:

f_s = signal frequency = 2.285 gc

f_p = pump frequency = 15.5 gc

f_i = idler frequency = 13.215 gc

$$\frac{f_p}{f_s} = 6.8 \quad \frac{f_s}{f_p} = .1472$$

$$\frac{f_s}{f_i} = .173$$

The optimum pump frequency for this diode is approximately:

f_p = 19.8 gc

Using a pump frequency of 15.5 gc and assuming a figure of merit:

$Q = 8.7 \; (\gamma^2 Q^2 = 75.7$

$$F = \frac{(\gamma Q)^2}{\left(1-\omega_s/\omega_p\right)\left[(\gamma Q)^2 - \omega_p/\omega_s + 1\right]}$$

$$F = \frac{75.7}{.853 \times 69.86} = 1.27$$

F = 1.05 db noise figure

NOTE

A change in γ to 0.3 would result in a diode noise figure of 0.95 db

The value of R_g/R_d required to achieve the 1.05 db noise figure, is found from the equation:

$$F = (1 + R_d/R_g)\,(1 + \omega_1/\omega_2)$$

$$R_d/R_g = \frac{F}{(1 + \omega_1/\omega_2)} - 1$$

or

$$R_g/R_d = 12.5$$

Where:

ω_1 = 2 x signal frequency

ω_2 = 2 x idler frequency

R_d = effective diode series resistance

R_g = generator resistance

While this ratio appears to be a reasonable value, such loading will not permit infinite gain. Therefore, from the equation for gain in terms of diode parameters and pump and idler frequencies:

$$G = \frac{1 + (\gamma^2 Q^2 \omega_1/\omega_2 - 1) R_d/R_g}{1 - (\gamma^2 Q^2 \omega_1/\omega_2 - 1) R_d/R_g}$$

G = 2420

G = 38.4 db

The system will be operating in an ambient temperature environment of $120^\circ \pm 10^\circ$ F or $49^\circ \pm 5.5^\circ$ C for purpose of gain stabilization. This elevated temperature degrades the noise figure by the ratio of temperatures. The effect of temperature on other losses is:

(1) Circulator-coupler = 0.35 db

(2) Filter = 0.10 db

(3) Second paramp = .01 db

(4) Paramp = 1.05 db

0.35 db at 54.5° C = 327.5/290 (0.084) = 0.39 db

0.1 db at 54.5° C = 327.5/290 (0.022) = 0.11 db

1.05 db at 54.5° C = 327.5/290(0.274) = 1.17 db

0.01 db at 54.5° C = $\frac{0.01 \text{ db}}{1.68 \text{ db}}$

Therefore, taking into consideration a diode with the minimum Q and average γ, a noise figure of 1.68 db for the parametric amplifier system can be realized.

4.4.1 COMPONENTS SELECTION.

There are no standard varactor diodes capable of meeting replaceability requirements. To achieve a measure of uniformity, the silicon chips used in making the diodes will be cut from one block of silicon. Since the diode holder forms the most critical part of the amplifier, the unit will be of cast construction to minimize the number of operations required in fabrication. Through careful design, the holder can be cast with a minimum number of waveguide bends and twists.

4.4.2 TOLERANCE LIMITATIONS.

4.4.2.1 GAIN. The gain of the parametric amplifier is determined by diode loading and power available. Predicted loading of the diode, compatible with a good noise figure, is 12.5:1. With this value of loading, the achievable gain from an individual amplifier is 38.4 db. The two amplifiers in cascade would gheoretically give 76.8 db of gain. A more realistic value of gain based on experience would be 45 db before oscillation occurred. A gain of 30 db without oscillation is well within the practical limits of operation.

4.4.2.2 BANDWIDTH. Bandwidths in excess of 500 mc and 15-db gain have been achieved consistently and no problem in meeting the 30-mc bandwidth has been experienced.

section 5

converter design

5.1 GENERAL.

The block diagram in figure 5-1 shows the 3-channel S-band down converter system supplied by Microwave Physics Corporation (MPC). Three identical channels are fed by the same local oscillator (LO) producing either of two frequencies which are distributed by a power divider to the mixer of each channel. The following paragraphs will describe the design of the amplifier/mixer channels and the LO multiplier chain, and give details of how each functional specification will be met.

5.2 AMPLIFIER/MIXER CHAIN.

This unit consists of a directional coupler, preselector, and mixer, integrated in a single stripline package configuration and a 2-stage, solid-state if. amplifier which is mounted on one side of the strip-line assembly. The amplifier/mixer will be supplied to Microwave Physics Corporation by LEL Incorporated.

The if. chain has an overall noise figure of 10 db. Maximum phase shift between any two channels is 4°, or less, and the maximum gain difference is 1 db.

5.2.1 DIRECTIONAL COUPLER.

The coupling factor and directivity are both 20 db over the frequency range from 2270 to 2300 mc. The dynamic range is from thermal noise to -30 dbm.

5.2.2 MIXER.

The solid-state mixer employs two diodes in a balanced configuration which assumes a rejection of the incoming rf signal at the LO port of greater than 20 db.

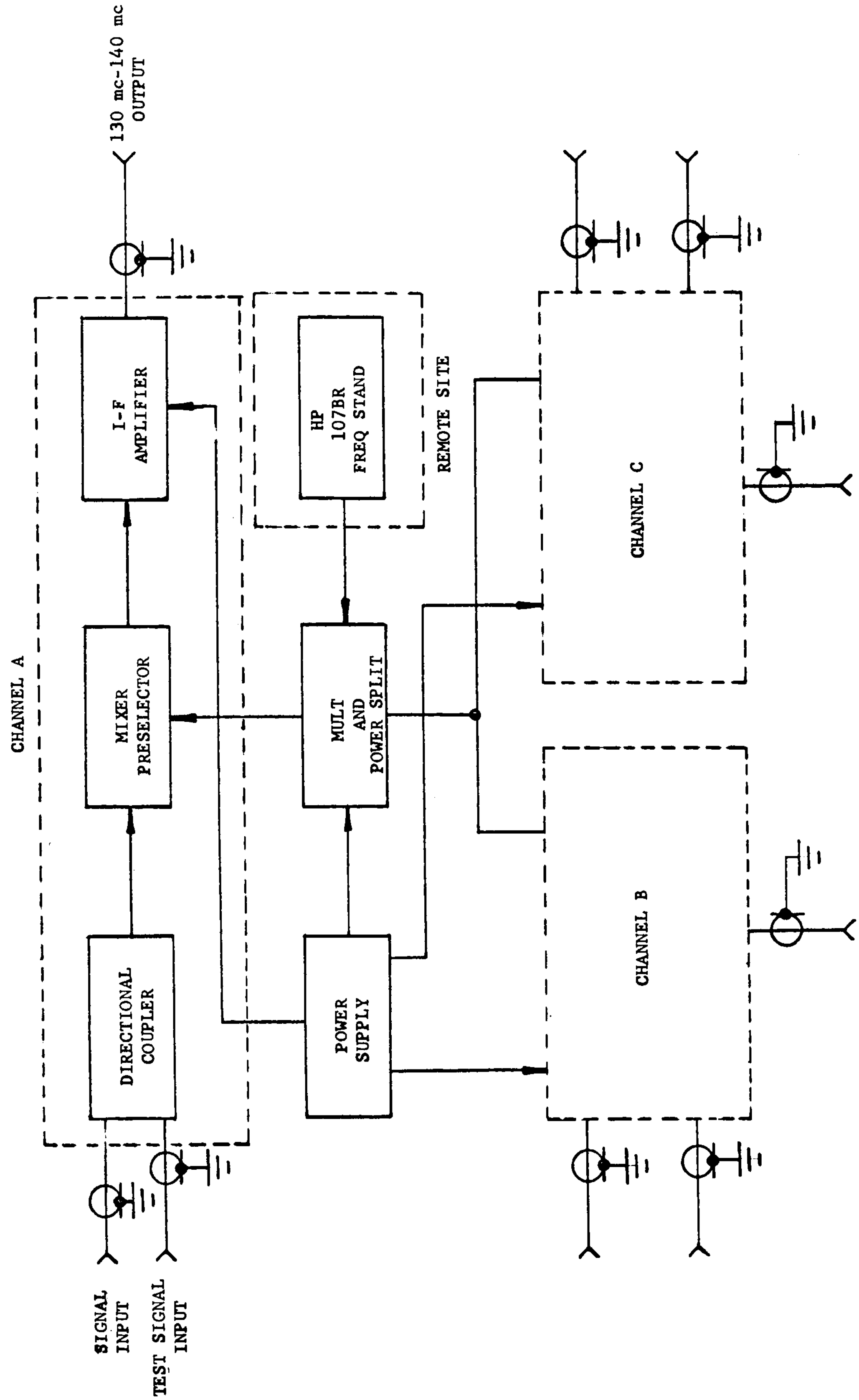


Figure 5-1. Converter, Block Diagram

The device is adjustable for an LO drive of from 1 to 4 mw and is equipped with terminals for monitoring the crystal voltage at the remote control.

5.2.3 PRESELECTOR STAGE.

The preselector is a 3-stage filter with a 30-mc bandwidth at the 1-db points and a 40-mc bandwidth at the 3-db points. Rejection of the image frequency and if. signals is greater than 60 db.

5.2.4 IF AMPLIFIER.

A gain of from 8 ± 0.5 db to 11 ± 0.5 db is produced by the output amplifier. The bandwidth is 10 mc between 2-db points, with a skirt slope of 24 db per octave.

5.3 LO/MULTIPLIER CHAIN.

The LO/multiplier chain consists of a Hewlett-Packard 107 BR frequency standard (located in the operations room) that drives an integrated 2-channel multiplier, coaxial relay, and power splitter, all supplied to MPC by Microstate, Inc. A block diagram of the LO/multiplier chain, beginning with the frequency standard outputs, is given in figure 5-2.

The first multiplication-amplification stages are an off-the-shelf design by Microstate and will be adapted to the chain. The first stage amplifier contains a lumped constant filter and the output filter is a cylindrical cavity harmonic device.

The power splitter is made of 3 port coaxial circulators, each having one port terminated. A minimum of 20-db isolation through these devices is provided between channels in the band from 2280 to 2300 mc. The use of the filters gives a maximum allowable spurious of -131 dbm in the range of frequencies from 130 to 140 mc. on either side of the LO output frequencies. All others outside the range of image frequencies will be 40 db down. Output power is in the range from 1 to 4 mw per channel and is adjustable.

5.4 ENCLOSURE.

A pressure tight, cast aluminum enclosure that consists of two identical ribbed halves is provided. The base half is machined for connectors, pressure valve, and "O" ring groove. Four bosses on each half are used as mounting points. The

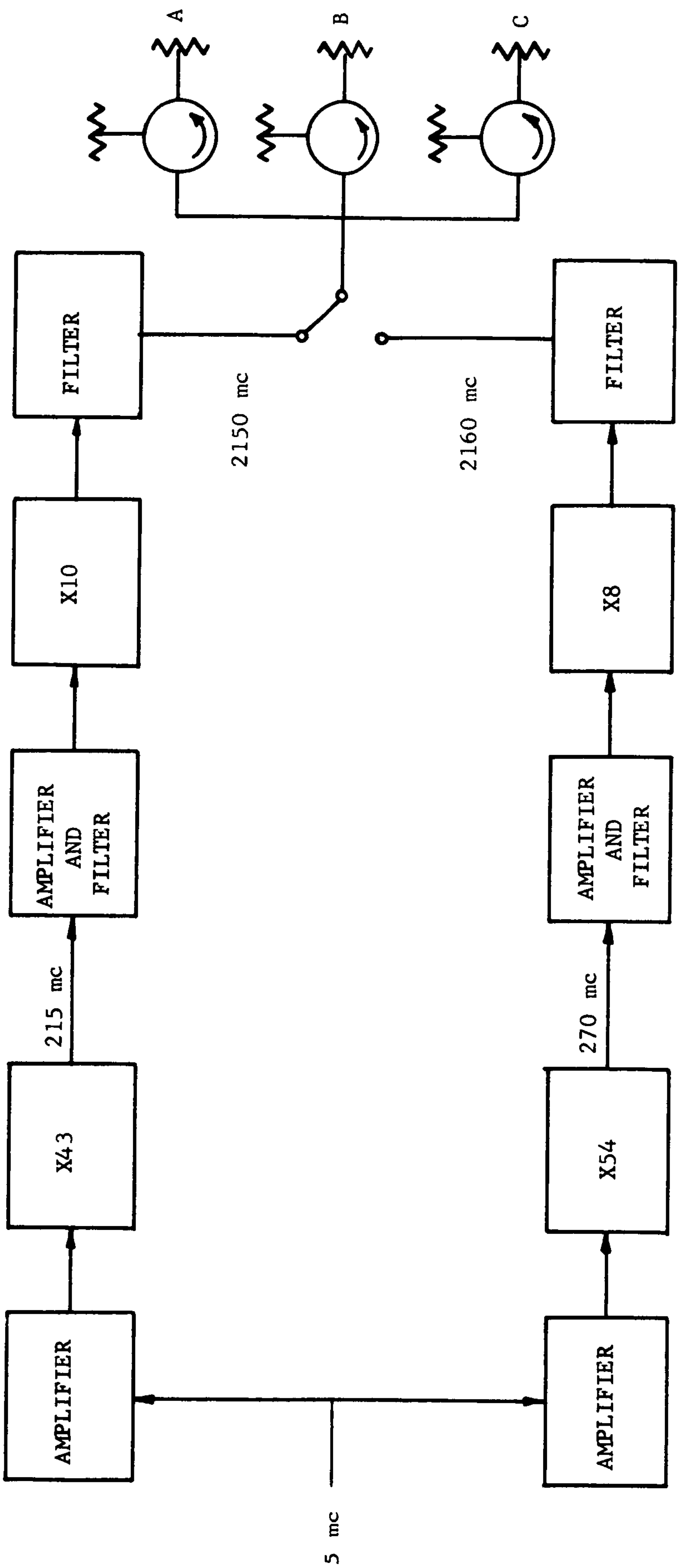


Figure 5-2. LO/Multiplier Chain

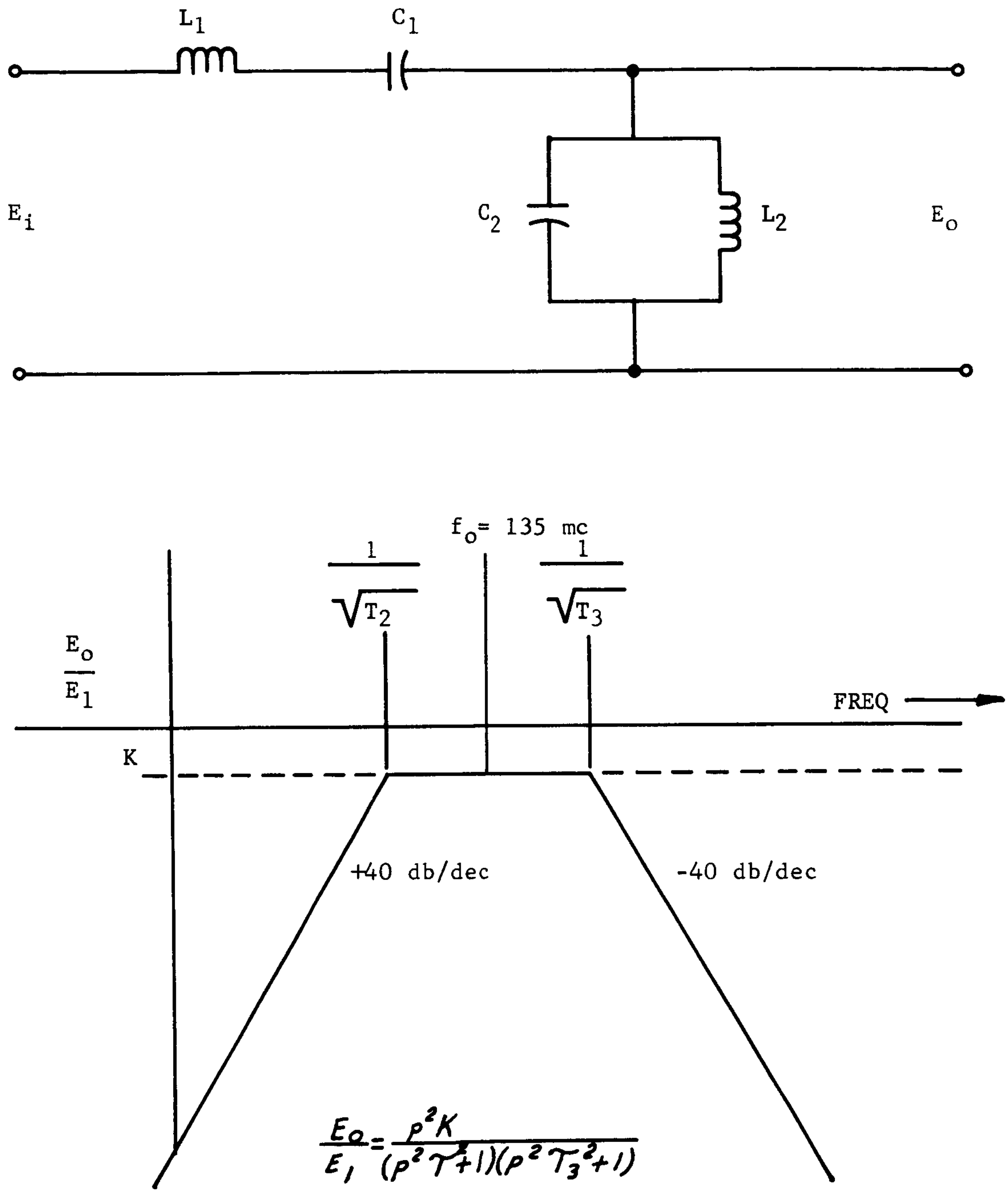


Figure 5-3. Constant K Filter and Passband

upper half has the bosses untopped and the bottom half has the bosses tapped to take two cross-braces which are required for surface mounting.

Rf leakage is controlled through use of a neoprene "O" ring impregnated with metal (monel) to seal the junction between the two halves of the enclosure.

Thermostatic control of heating elements restricts the temperature inside the enclosure to a range of 110^{o} to 130^{o} F.

To facilitate accurate control of the enclosure temperature, it is necessary to place the converter power supply in a separate, insulated compartment and provide a heat sink to the outside wall. All heat producing components are mounted to a heat sink to insure that the heaters are the most significant source of heat within the enclosure. About 60 watts is required to operate the heaters. The outside dimensions are approximately 20 by 14 by 10 inches and the entire parametric amplifier weighs about 28 pounds.

5.5 SPECIFICATION ANALYSIS.

5.5.1 ISOLATION.

The required isolation of 50 db minimum is accomplished by the combination of 20 db from the input to the LO port of one channel through the power divider to another channel. Thus, the total isolation at signal frequencies is 60 db.

5.5.2 BANDWIDTH AND GAIN.

The required 10-mc minimum bandwidth and 11-db maximum gain is accomplished in the transistorized amplifier and output filter in the if. stage of the converter.

5.5.3 NOISE FIGURE.

The 10-db noise figure is provided through use of a IN21E diode, which has a specified maximum noise figure (F_1) of 7.0 db when tested with an amplifier having a 1.5 db noise figure. No data is given as to the conversion loss (L_e) or the noise ratio (N_R) of this diode. However, by extrapolating the data given on the IN21D diode, which does give these values and has a noise figure of 7.3 db overall, system noise figure can be determined since the IN21E is a IN21D. The IN21E diode was selected because of its lower noise figure. By solving the noise figure equation for L_e and N_R, using the 7.0 db noise figure and substituting both into the noise figure equation with if. amplifier noise figure, the worst case is determined to be as follows:

$$L_e N_R + (F-1)\, L_e = F_R \tag{1}$$

where:

L_e = conversion loss ratio of diode

N_R = noise ratio of diode

F = noise figure of amplifier

F_R = specified noise figure for IN21E diode

the resulting equations are for the IN21E

$$L_e\,(1.3) + (1.41-1)\; L_e = 5 \tag{2}$$

and

$$(3.16)\; N_R + (1.41-1)\; 3.16 = 5 \tag{3}$$

The results are

$L_e = 2.93$ and $N_R = 1.17$

Substitution of the above values for L_e and N_R separately into equation (1), where $F = 3.0$ db (the noise figure of the if. amplifier), gives $F_1 = 8.24$ db and $F_2 = 8.33$ db for the change in L_e and N_R, respectively.

Taking $F_2 = 8.33$ db and adding the expected 1-1 db contribution of the preselector and directional coupler, the overall system noise figure is 9.4 db. The 3-db noise figure of the amplifier is conservative and can be as low as 2.4 db.

5.5.4 SPURIOUS SIGNALS.

The major problem in spurious suppression is the rejection of signals in the band from 130 to 140 mc, which could originate in the multiplier chain. The specification permits no more than -131 dbm at any output of the power splitter in this range of signals. The mixer LO signal port rejection of signals to the output is 20 db and the if. gain is 11 db maximum. This results in a signal of -140 dbm at the output as a maximum if the power splitter spurious output is as high as -131 dbm. The rejection between the mixer LO port and the output is 20 db. With an if. gain of 11 db, the maximum LO multiplier spurious output is -131 dbm.

5.5.5 IMAGE AND IF REJECTION.

The use of a 3-cavity filter in the preselector portion of the mixer/amplifier chain achieves the required 60 db of rejection at both the image and intermediate frequencies.

5.5.6 RF LEAKAGE.

The use of RFI gaskets and power line filters will control all radiated leakage.

The chief source of conducted leakage is usually from the LO generator chain. Control of leakage to the input circuit is accomplished through a combination of 20-db mixer rejection and a 33 db or greater preselector rejection to signals at the LO frequency.

5.5.7 DIFFERENTIAL GAIN AND PHASE SHIFT.

Proper location of heating elements, use of a circular fan, and the inherent similarity of all channels controls the differential phase shift and gain. The fact that the LO multiplier chain and power splitter are included in the controlled environment contributes to the differential phase stability.

section 6

ITT Federal Laboratories tracking receiver

6.1 GENERAL.

The ITTFL (ITT Federal Laboratories) acquisition tracking receiver described in the following paragraphs is presently intended to be used only during an interim testing period. The final acquisition tracking receiver to be used in the ground stations will be GFP.

6.2 GENERAL CHARACTERISTICS.

This 3-channel receiver is completely self-contained in a package capable of being mounted in a standard rack. All normal operator controls are readily accessible from the front panel. With the exception of the headset jack, all signal and power connections are made from the rear.

This solid-state receiver is capable of operating in either a phase-lock-loop mode or in an open-loop mode. In either mode, the receiver provides tracking signals for use by a servo system in positioning an antenna. Two data outputs at 50 mc and 10 mc are available from the receiver sum channel for use by an external analog data demodulator. In addition there are signal outputs giving the operating condition of the receiver for a digital data system.

6.3 ELECTRICAL CHARACTERISTICS.

6.3.1 OPERATING FREQUENCIES.

The receiver input frequency is continuously tunable from 130 to 140 mc. Since the intended use of this receiver is at S-band, the illuminated front-panel frequency readout is calibrated to read between 130 and 140 mc. The choice of readout is selected by a switch. The dynamic range of signal level into the preamplifier converter system intended for use ahead of this receiver is from -60 dbm to threshold.

6.3.2 BANDWIDTH AND SENSITIVITY.

A wide selection of bandwidths is available in this receiver. Table 6-1 lists these bandwidths and corresponding thresholds. The tabulated sensitivities are based on use of a preamplifier with 25-db gain and 4-db noise figure.

TABLE 6-1. RECEIVER BANDWIDTHS

CLOSED-LOOP MODE	
BANDWIDTH	LOOP SENSITIVITY*
30 CPS	-144 dbm
100 CPS	-139 dbm
300 CPS	-134 dbm
1000 CPS	-129 dbm
OPEN-LOOP SENSITIVITY	
BANDWIDTH	ERROR CHANNEL THRESHOLD**
10 KC	-130 dbm
30 KC	-125 dbm
100 KC	-120 dbm
300 KC	-115 dbm

* Defined as the input level where the phase noise in the loop reaches 0.35 radian rms.

** Defined as the input level required to maintain the error detector output voltage within 6 db of that required for maximum angular error for a level of -60 dbm into the sum preamplifier. A tolerance of 2 db is allowed.

6.3.3 AGC AND AFC.

Provision for both coherent and non-coherent agc has been made. The agc is derived from the sum channel and is applied to all three channels. A choice of four response times is available: 3 seconds, 300 milliseconds, 30 milliseconds, and 3 milliseconds.

An afc circuit is available to compensate for doppler shift in the open-loop mode.

6.3.4 ACQUISITION.

An acquisition sweep circuit is provided to automatically lock the receiver to an incoming signal provided it does not exceed the maximum tracking rates. An oscilloscope is provided as an acquisition aid. For further details concerning the receiver refer to the block diagram, figure 6-1.

6.4 MECHANICAL CHARACTERISTICS.

6.4.1 OPERATING CONTROLS AND DISPLAYS.

Figure 6-2 shows the arrangement of the controls and visual displays on the front panel of the receiver. This panel is painted number 26440 gray per Federal Standard 595.

6.4.2 MOUNTING.

The receiver will be capable of mounting in a standard rack by use of the provided tilt rack slides.

6.4.3 OPERATING ENVIRONMENT.

The receiver is capable of operating between +32 to +120°F, 20 to 80 percent relative humidity, and 0 to 15, 000 feet MSL without degraded performance.

6.5 DESIGN ANALYSIS.

The design analysis is presented in this report as a four part discussion relating to the following pertinent areas:

(1) Gain-Bandwidth Considerations

(2) The Frequency Synthesis

(3) Control Loop Considerations and Calculations

(4) Data Channels

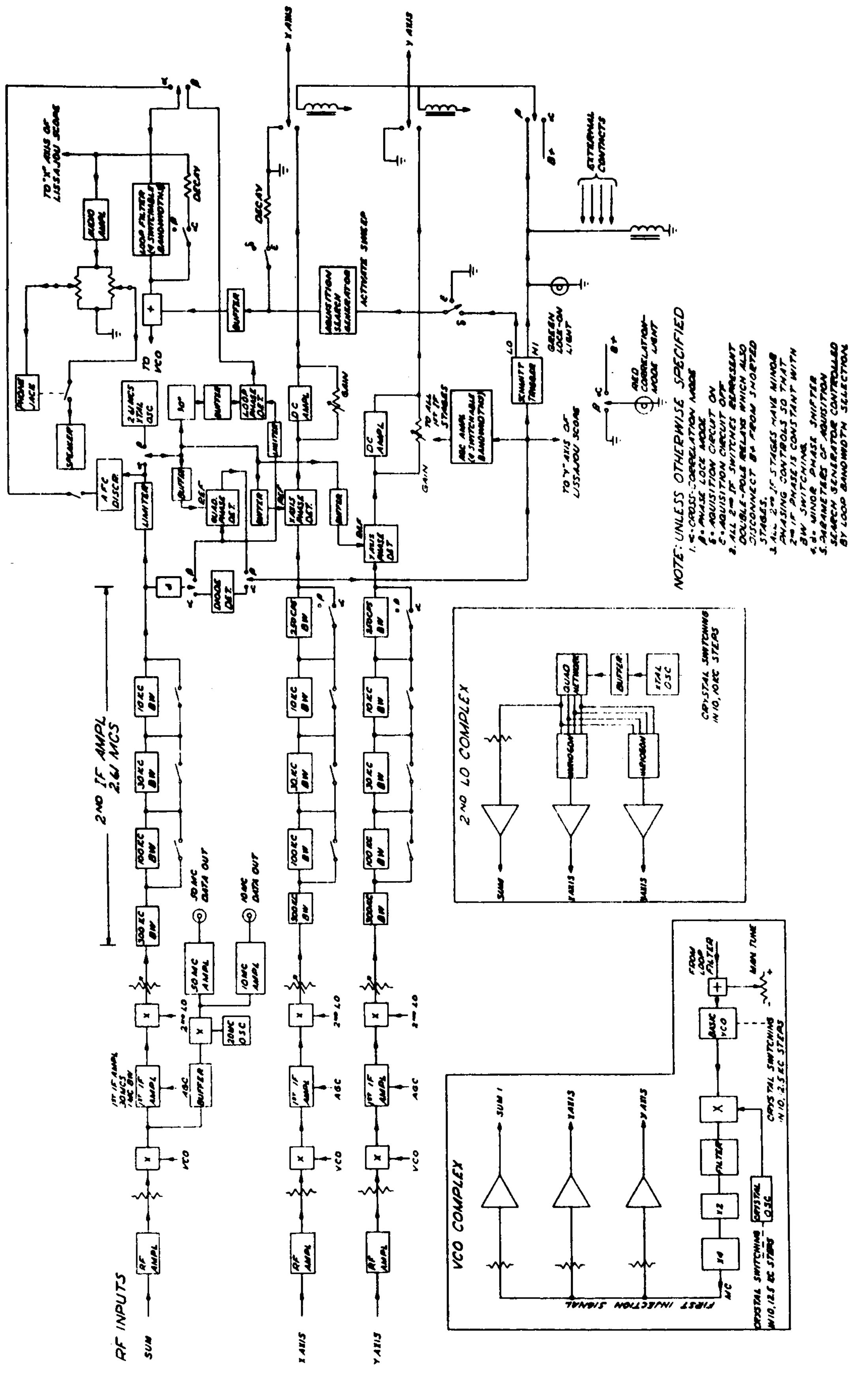


Figure 6-1. Acquisition Receiver, Block Diagram

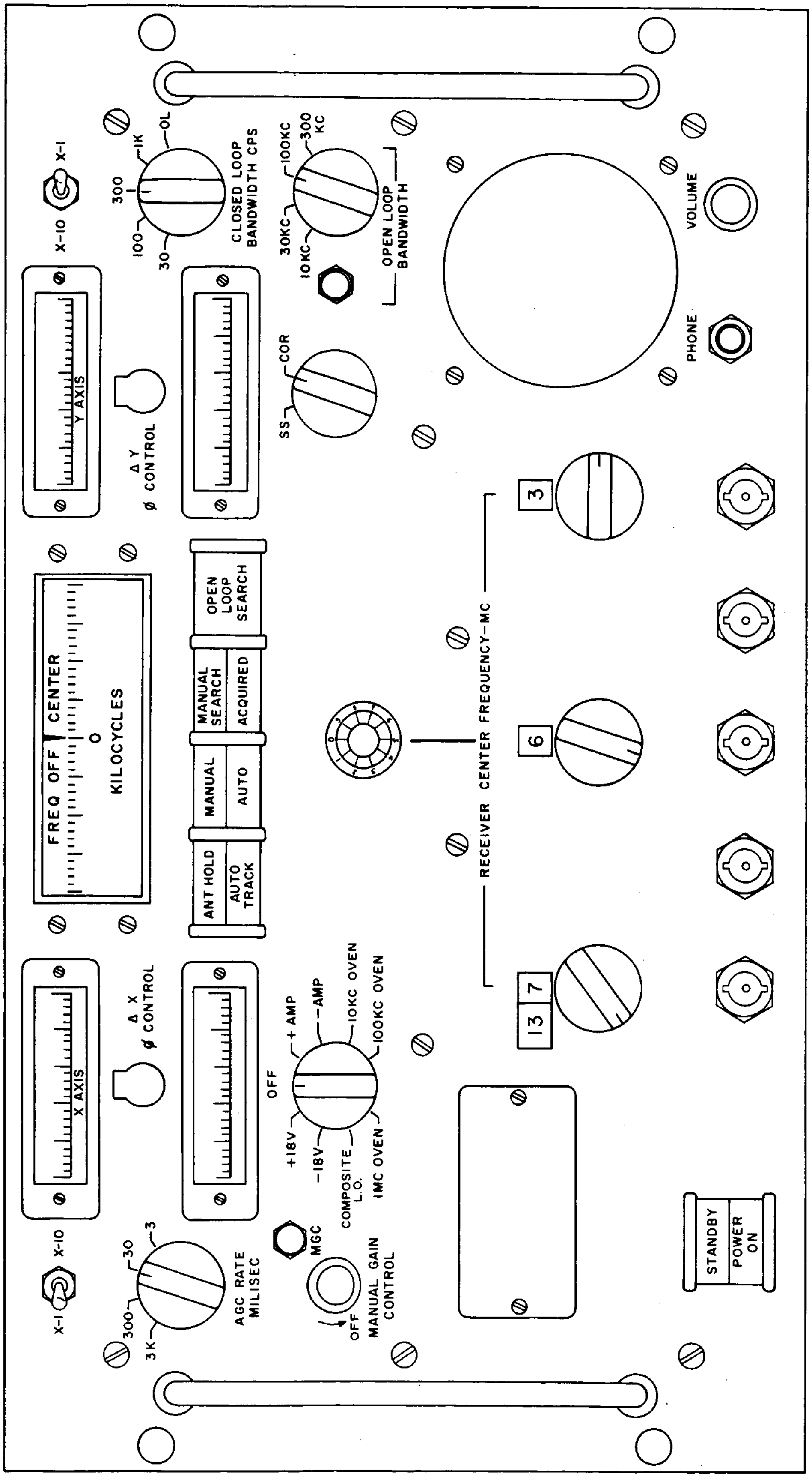


Figure 6-2. Acquisition Receiver, Front Panel

The design analysis which is presented represents a specific application of methods and techniques which are either currently in use in existing equipment or are currently being evaluated in a breadboard system. The current activities are centered around module-level design and preparing specifications for subcontracted items. The items or subassemblies to be subcontracted are as follows:

(1) Decade oscillator (Green Ray Industries)

(2) Crystal filters (Mc Coy Electronics)

(3) Crystal discriminator (J. Knight or Niederman-Sherholl)

(4) Temperature compensated oscillators (Bendix)

(5) Power supplies (AC/DC Electronics)

The above referenced items have been used in previous systems or are currently being evaluated in the breadboard system.

6.5.1 GAIN-BANDWIDTH CONSIDERATIONS.

The rf, if., and bandpass circuits in the receiver have been designed to ensure, among other things, that no limiting because of high noise levels occurs in the detector driver amplifiers. The noise figure is established at the preamplifier and is not degraded anywhere in the if. strip where video amplifiers have been employed. Figure 6-3 presents a complete tabulation of the calculated signal and noise levels through the receiver.

Starting at the front end, the preamplifier has a noise figure of 4 db and a gain of 300. This gain limits the noise figure contribution by the second stage to a value on the order of 0.01 db. The 290 degree noise temperature of the first stage sets the noise power level at -174 dbm per cycle of bandwidth. The 3-db bandwidth (BW_3) of the first stage is 20 mc and permits a noise power level of -97 dbm to enter the preamplifier. The minimum signal input to the receiver in the phase locked mode is -144 dbm. After the preamplifier, the signal level is -119 dbm minimum and the noise is -72 dbm, a signal-to-noise ratio of -47 db. This signal-to-noise ratio prevails until the if. filter module is reached. It should be pointed out that the if. filter module is the first attempt to narrow the bandwidth to eliminate some of the noise

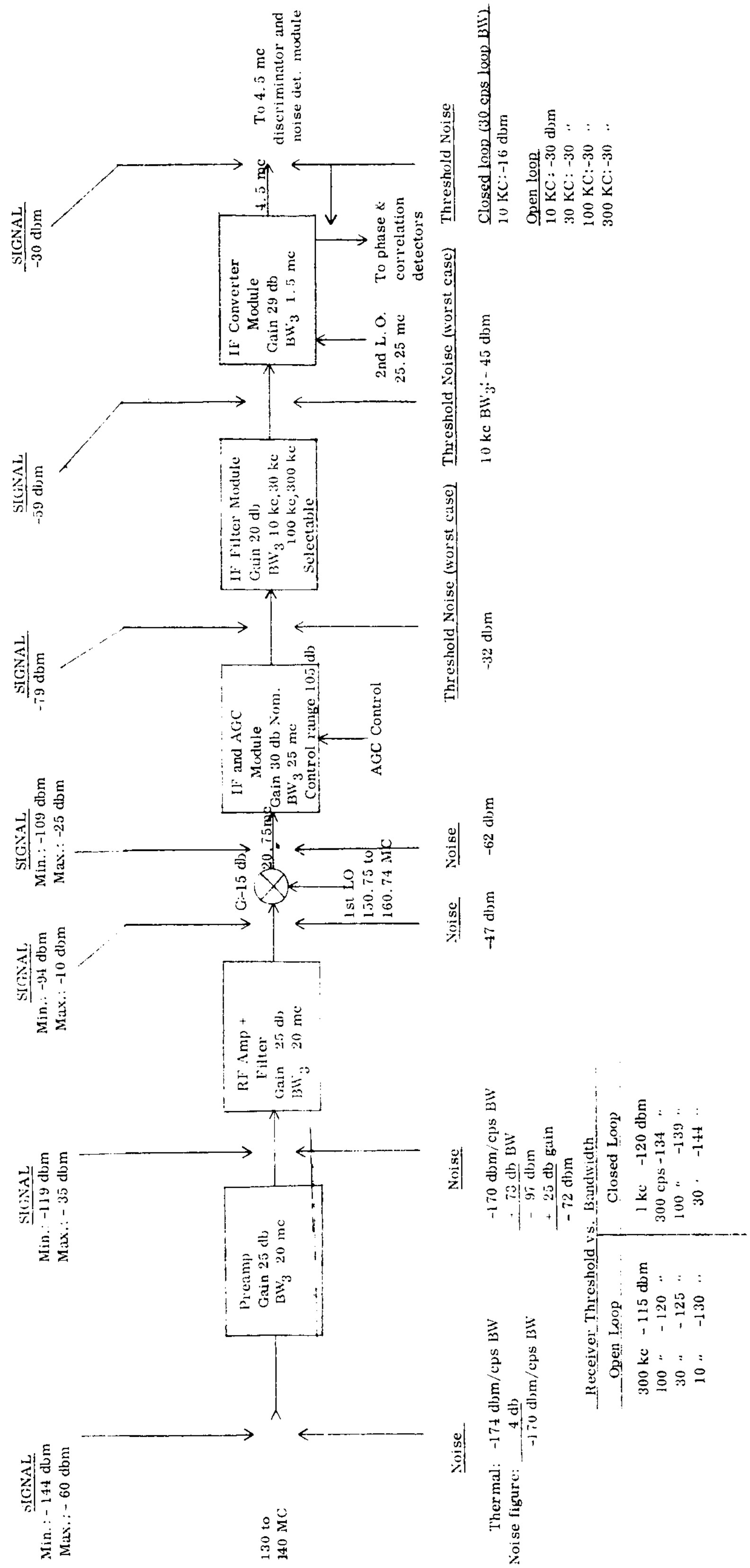


Figure 6-3. Tabulation of Calculated Signal and Noise Levels Through The Receiver

power in either open or closed loop operation. At the if. filter input, the noise has reached a -32 dbm level. The narrowest (10 kc) if. filter output has a front end noise level of -75 dbm. The noise generated by the amplifier immediately after is: -174 dbm/cps + 71 db (12 mc BW_3) + 6 db (noise figure) = -97 dbm.

Therefore, the amplified front end noise is considerably greater than the noise generated by the 12-mc if. amplifier following the if. filter.

All of the agc action is accomplished in the 20.75-mc if. strip, where 105 db of control has been placed in four passive, voltage controlled attenuators. There is also about 30 db excess gain in the if. amplifiers in the if. and agc module.

In open loop tracking, any one of the four if. filters may be selected. In closed loop or phase locked tracking, only the 10-kc if. filter is used. The loop bandwidth is then selectable from among the 30-, 100-, 300-, and 1000-cps filters. Receiver thresholds required in these various bandwidths are tabulated in figure 6-3.

After a second conversion to 4.5 mc, the if. output is further amplified and divided to an output signal level of -30 dbm to the various detector driver amplifiers. The corresponding if. noise level to these amplifiers in the various if. bandwidths is tabulated under "threshold noise" at the output. The 10-kc bandwidth position presents the maximum noise level of -16 dbm. The detector drivers show no effective limiting at levels as high as 0 dbm.

6.5.2 FREQUENCY SYNTHESIS.

The selection of the frequencies to be used in the various decade oscillators and the single frequency oscillators is based on an educated trial and error method with the aid of a spurious response chart. The spurious response chart is not included since this classic information appears in various literature. The spurious response chart used indicates spurious up to ninth order products, which are generally regarded as being at least 60 db down in any mixer circuit. Besides selecting frequencies which, in themselves, are clear of spurious, the frequencies of the nearest spurious were checked to make sure they were far enough removed from the desired band to enable them to be effectively filtered out. Included in this discussion is a tabulation of spurious frequencies that appear relatively close to the desired frequency. These spurious frequencies are a major influencing factor in the selection of filtering to be used in this synthesis scheme. The generalized method employed in the system is depicted in figure 6-4. It should be noted that both sum and difference mixing is used, which should enhance the stability of receiver tuning. This prediction can be made assuming the temperature characteristics of the frequency sources are similar.

During the initial system configuration planning, it was decided that all of the variable frequencies involved in the system would be combined and impressed on the first frequency conversion of the receiver system. The major advantage in this type of design is that the intermediate frequencies (if. 's) would remain at a fixed frequency and, therefore, simplify the if. design. Obviously, this trade-off somewhat complicates the frequency synthesis for combining four variable frequencies across a 10-mc band. During the initial design engineering, it became apparent that a fair degree of difficulty would be encountered if the decade oscillator plus the vco signals were combined directly into a 10-mc band of frequencies. The technique used to overcome this situation was to perform the decade switching at one-tenth of the required frequency intervals and frequency multiply the compositie signal by a factor of 10 to the desired frequency. This allowed the mixing to be performed at relatively narrow bandwidth and caused fewer undesired frequencies at band edges and, in general, an easier method of controlling undesired mixing products. This, however, required the vco (voltage controlled oscillator) frequency to be divided by a factor of 3 if the existing vco circuitry was to be used. This direction with relation to the vco was taken since a long development cycle might be involved if the vco circuitry were redesigned. The major problem would be involved with the crystal discriminator used to stabilize the oscillator.

The general description of the technique used is well defined in figure 6-4. Figure 6-4 indicates the decade frequencies, the mixing method (sum or difference), the band frequencies, and the filtering. The most serious potential problem anticipated with the indicated synthesis will probably be with relation to the 10-kc decade frequency feeding directly into the 10 multiplier. If precautions are not taken, it will

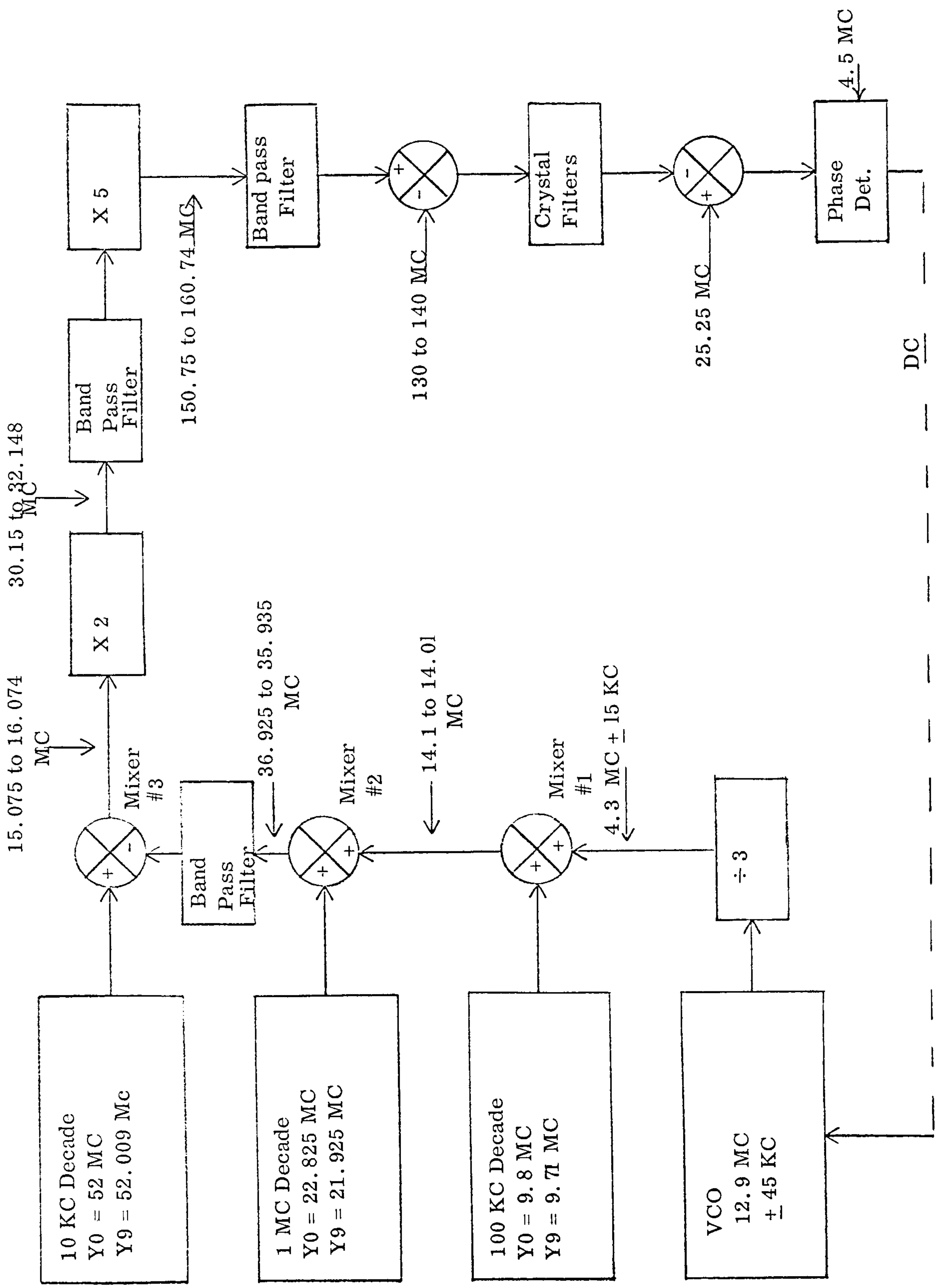


Figure 6-4. General Frequency Synthesis, Block Diagram

supply an undesired product directly into the 150-to 160-mc distribution circuitry. A similar problem was encountered in previous equipments; however, this type feed-through can readily be reduced to a satisfactory minimum once the problem is recognized. The other undesired products are defined in table 6-2. These frequencies are in the general proximity of the desired, frequency band, but not in the frequency band of interest. Therefore, they can be filtered out. Since these are both eighth order products, their levels will be in the order of 40 to 45 db below the desired signal. At least 20 db of additional rejection will be required. Refering to the block diagram, figure 6-4, there are two filters which can perform this requirement. The bandpass filter following mixer 2 and the bandpass filter following the X 2 multiplier. The closest spurious is 1 mc from the desired band edge.

Since the filter bandwidth is 1 mc, it should be possible to provide at least 10-db reduction of this frequency in each filter, thereby bringing the level down to a maximum of 60 db below the desired output. While the second filter is at a point where the frequency has been doubled, it has to have twice the bandwidth and the spurious will be twice the distance from the band edge. Thus, the attenuation will be similar for each filter.

TABLE 6-2. MIXER PRODUCTS

LOCATION	DESIRED FREQ. BAND	UNDESIRED FREQ.
Mixer 2	36.925 35.935 mc	34.9, 38.95 mc $(4F_2, 4F_1)$ $(6F_2, 2F_1)$
Mixer 3	15.075 16.074 mc	*17.1, 13.05 mc

* These products are involved with the undesired frequencies previously indicated in mixing with the 10-kc decade.

6.5.3 CONTROL LOOP CONSIDERATIONS AND CALCULATIONS.

6.5.3.1 PHASE-LOCK LOOP FILTER. The design of the phase lock loop tracking filter for the receiver represents an accumulation of experience gained in the development of filters for several receivers previously designed by ITT Federal Laboratories.

This filter provides a third order phase lock loop with a low order of phase velocity and phase acceleration error. The loop filter consists of a passive lead-lag network followed by an active filter using a differential operational amplifier.

The phase lock loop signal path may be traced on the block diagram of the receiver. However, the important functional components of this loop are shown in the simplified loop block diagram, figure 6-5.

The phase lock loop filter and the essential quantities in the open loop transfer function, G (S), are shown in figure 6-6.

The open loop transfer function is

$$G(S) = \frac{K}{S} \frac{(S+\omega_2)(S+\omega_b)}{(S+\omega_1)(S+\omega_a)}, \quad S = j\omega$$

where: $$\frac{K}{S} = K_1 \; K_2 \; \frac{K_3}{S} \; K_4 = \frac{1}{4} \times \frac{\omega_1}{\omega_2} \times 2\pi \frac{6.43}{S} \times 10^3 \times 3.33$$

$$= \frac{3.37 \times 10^4}{S} \times \frac{\omega_1}{\omega_2}$$

K_1 is the phase detector sensitivity; 0.25 v/rad.

K_2 is the high frequency divider ratio of the passive filter.

(note the active filter gain is unity at high frequencies)

$K_{3/S}$ is the vco transfer function

K_4 is the phase gain due to the freq. dividers and multipliers

The values of the break frequencies and the filter components are given in table 6-3.

A log modulus sketch of the open loop transfer function is presented in figure 6-7.

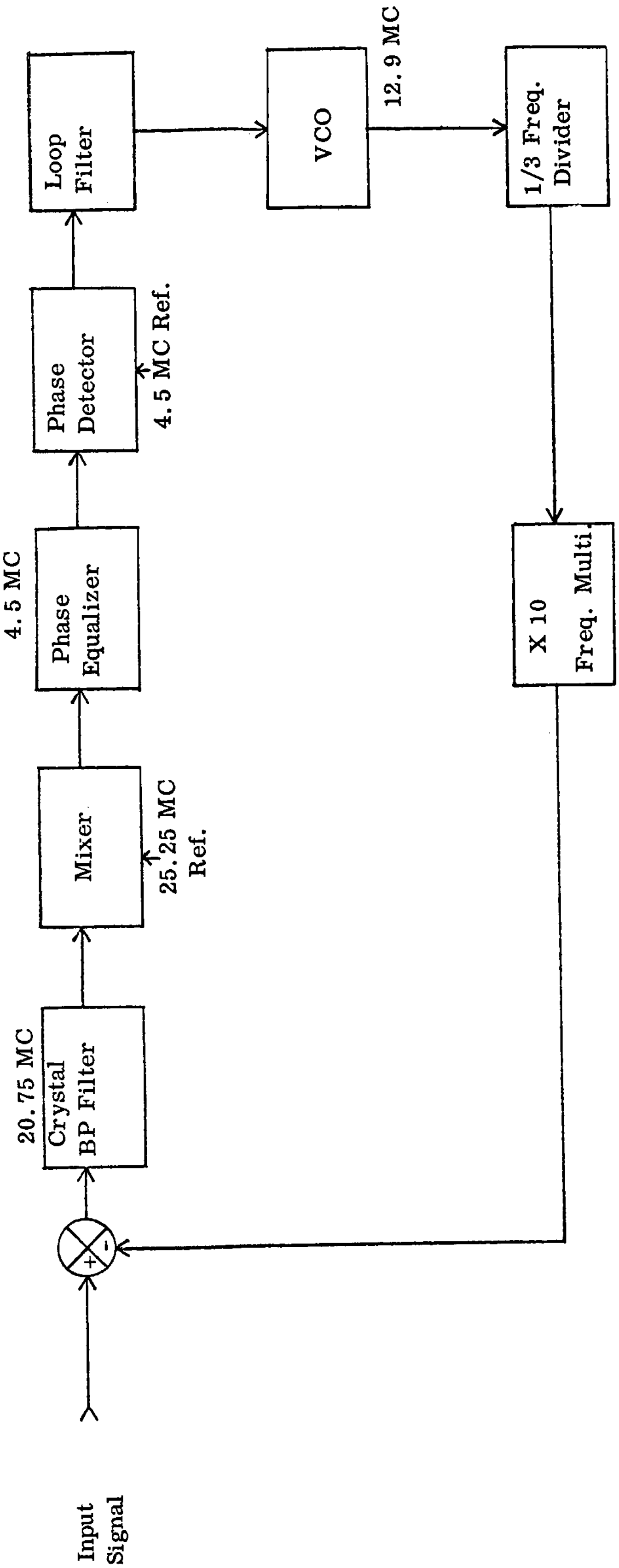


Figure 6-5. Block Diagram of Phase-Lock Loop

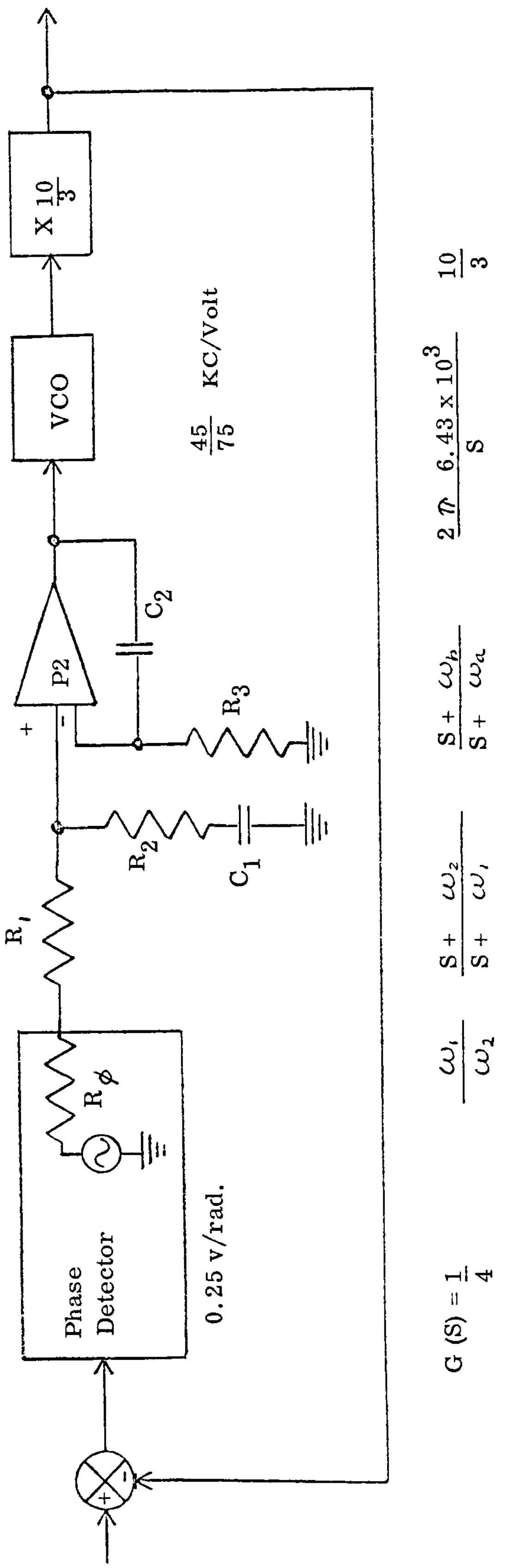


Figure 6-6. Detail of Phase-Lock Loop Filter Showing The Open Loop Transfer Function, G (S)

TABLE 6-3. CHART OF PHASE-LOCK LOOP PARAMETERS

NOISE BW CPS	DAMPING FACTOR	K	ω_2	ω_b	ω_1/ω_2	ω_1	R_2	R_1	R_3
30	.7	37.8	12.6	6.3	1.12×10^3	0.0141	7.94K	7.08M	159K
100	.7	125.6	41.8	20.9	3.72×10^3	0.156	2.4K	643K	48K
300	.7	378	126	63	11.2×10^3	1.41	794	70.8K	15.9K
1000	.7	1256	418	209	37.2×10^3	15.6	240	6430	4.8K

C_1 = 10 uf

C_2 = 1.0 uf

$R_1 = R_1 + R_2 + R_\emptyset$

$R_\emptyset = 5000\Omega$, impedance of phase detector output

$\omega_a = \dfrac{\omega_b}{K_d}$

K_d = gain of operation amplifier (about 40,000)

Bandwidth and Damping Factor

The following equation gives the video noise bandwidth for a two-lag network:

$$B_2 = \frac{\pi K}{2}\left[\frac{K(\omega_b + \omega_2) + \omega_b^2 + \omega_b\omega_2 + \omega_2^2}{K(\omega_b + \omega_2) - \omega_b\omega_2}\right]$$

and since the r-f noise bandwidth, ω_{NB}, is twice B_2

$$\omega_{NB} = \pi K\left[\frac{K(\omega_b + \omega_2) + \omega_b^2 + \omega_b\omega_2 + \omega_2^2}{K(\omega_b + \omega_2) - \omega_b\omega_2}\right]$$

evaluating ω_{NB} for

$K = 37.8$

$\omega_2 = 12.6$

$\omega_b = 6.3$

gives $\omega_{NB} = 29.55$ cps

The damping factor used in the loop is 0.7.

6.5.3.2 AFC LOOP. The automatic frequency control loop consists of a frequency discriminator, an amplifier and filter, and the voltage controlled oscillator used in the phase lock loop. The frequency divider multiplier chain which gives a 10/3 frequency deviation gain must also be considered in this loop.

The input frequency variation is ±150 kc. An error of ±1 kc is allowed to control the vco.

The frequency discriminator characteristic is 0.15 volts per kc which must be amplified to about 7 volts to force the LO to follow with only a 1-kc error.

A dc amplifier with a gain of 46 is required. It is planned to connect the P2 amplifier used in the active section of the phase lock loop filter to provide the required gain. A low pass filter will be used to assure stability of the afc loop. The loop bandwidth is tentatively set at 1 cps; however, final selection of this characteristic cannot be evaluated thoroughly until data is available from the breadboard system.

Care must be taken to prevent interaction between the agc and the afc loops. No difficulty is apparent using ideal functions (ripple-free passbands, linear discriminator, etc); however, in the actual circuitry, imperfections in these functions can cause difficulty.

6.5.4 DATA CHANNELS.

The data channel signal is obtained from the sum receiver at the output of the if. and agc module. This pick-off point is used since the bandwidth of the if. and agc is sufficient to supply the required spectral bandwidth. In addition, the level into the data channels will be of constant amplitude by virtue of agc action. The signal level available at the output of the if. and agc for processing in the data channels is -85 dbm; the maximum noise level is -37 dbm.

The bandwidth required at the output frequency of the data channels is 5 mc in one case and 10 mc in the other. It is readily apparent that with the gain required to raise the signal level to that specified (0 dbm for the 5-mc bandwidth and -10 dbm for the 10-mc bandwidth) would be totally unrealistic. An amplifier chain with a sufficient gain bandwidth product to accommodate the noise power that would be present when processing signal levels near threshold of the phase-locked receiver (-145 dbm) is extremely difficult. If this were to be the design criteria, the noise levels that would be present would be approximately +47 dbm. This corresponds to approximately 20 watts of power into a 50-ohm output impedance.

If the assumption is made that the data channel outputs are usable with a signal-to-noise ratio of 1, then whenever the noise level presented to the data channels from the sum receiver if. and agc exceeds unity, the data channels would be incapacitated as a result of the noise levels. As previously indicated, the signal level is -85 dbm and the maximum noise is -37 dbm. Therefore, from these considerations it is apparent that the minimum usable level into the receiver system occurs when (85-37=48 db) or more, gain control has been achieved in the agc circuits. Therefore, the minimum usable level into the receiver system is -97 dbm or greater (-145 + 48 = -97). It is apparent that noise limiting will occur at signal levels much below -97 dbm.

The frequency synthesis is required to yield reasonably spurious-free frequencies at the output of the data channels was adequately discussed previously. However, a recap of these discussions follows. The basic circuit configuration is shown in figure 6-8.

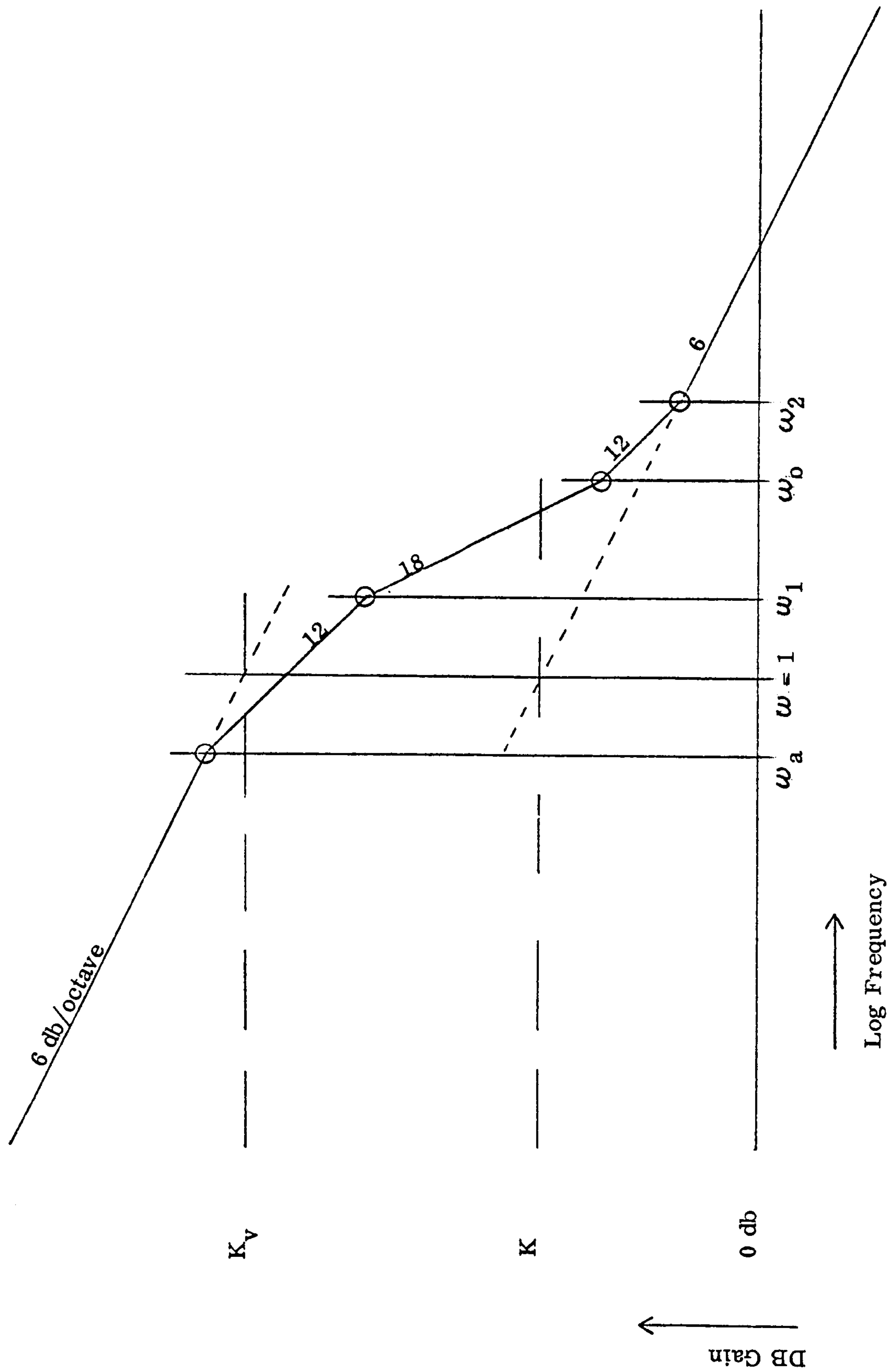


Figure 6-7. Log Modulus Plot of Open Loop

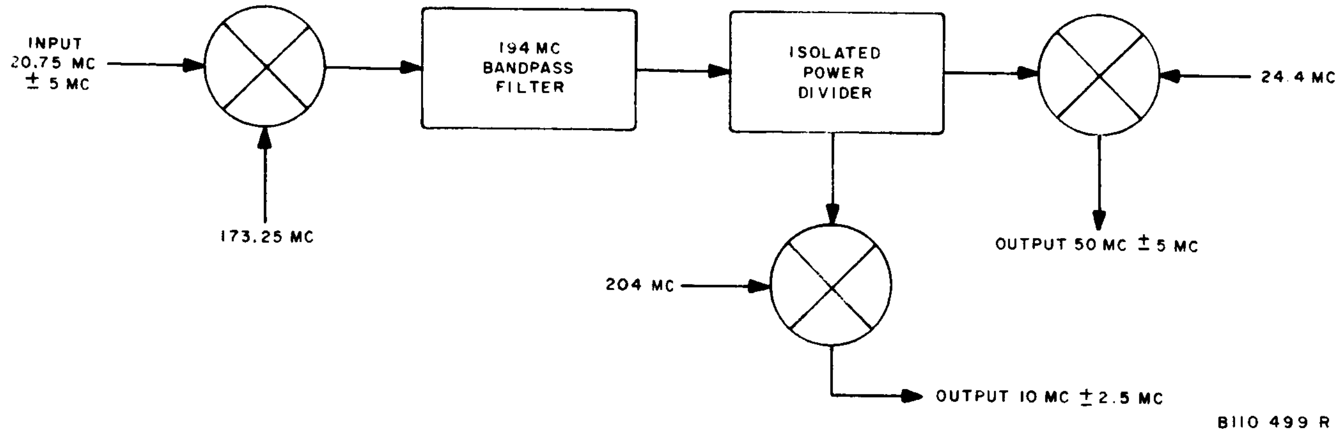


Figure 6-8. Basic Circuit Configuration of Data Channels

A problem results because of the conversion of relatively wideband spectrum from one frequency to another. An insurmountable problem would exist if an attempt were made to convert directly from 20±5 mc to 10±2.5 and 50±5 mc. The basic approach displayed in figure 6-8 somewhat relieves the problem by up-conversion to a more suitable frequency (194 mc) before processing to the required frequencies of 10 and 50 mc. The problem with this technique is that 7th order undesired products can appear in the output frequency bandwidth when both the input signal and converter signals are present. Laboratory tests to simulate the condition have been conducted and the results indicate that 40-db suppression of the undesired products can be achieved. It must be emphasized that these undesired frequencies are present only when signal is impressed on the receiver. The locally generated undesired products shall be down a minimum of 60 db.

section 7

signal data demodulator

7.1 GENERAL.

The signal data demodulator accepts phase-modulated signals centered at 10 mc or frequency-modulated signals centered at 50 mc from the tracking or range and range-rate (R and RR) receiver. These signals are demodulated and the various components, such as voice, television, etc, are separated. The voice and telemetry components that have been modulated onto subcarriers are demodulated, and all signals are amplified for recording or for presentation to the operating personnel. A subsystem block diagram is shown in figure 7-1. More detailed block diagrams are referenced in the following paragraphs.

7.2 EQUIPMENT SPECIFICATIONS.

A study has been conducted to determine the design parameters that would be used in developing the demodulator. The results of this study are given in appendix g. * The signal conditions for which the subunits have been designed are summarized in table 7-1 and are based on the results of appendix g. The stated thresholds are the signal-to-noise ratios in the corresponding noise bandwidths which cause the units to have the specified internal noise conditions for threshold. These characteristics and other parameters given in appendix g, table 1-3, are used in part IV, paragraph 4. 1. 2, to calculate maximum ranges at which these threshold conditions will occur for each Apollo mode.

*Appendix g is being prepared as a separate volume because of its length. Six preliminary copies were informally submitted to GSFC on 11 July 1964; revisions to incorporate the latest specification are currently being prepared.

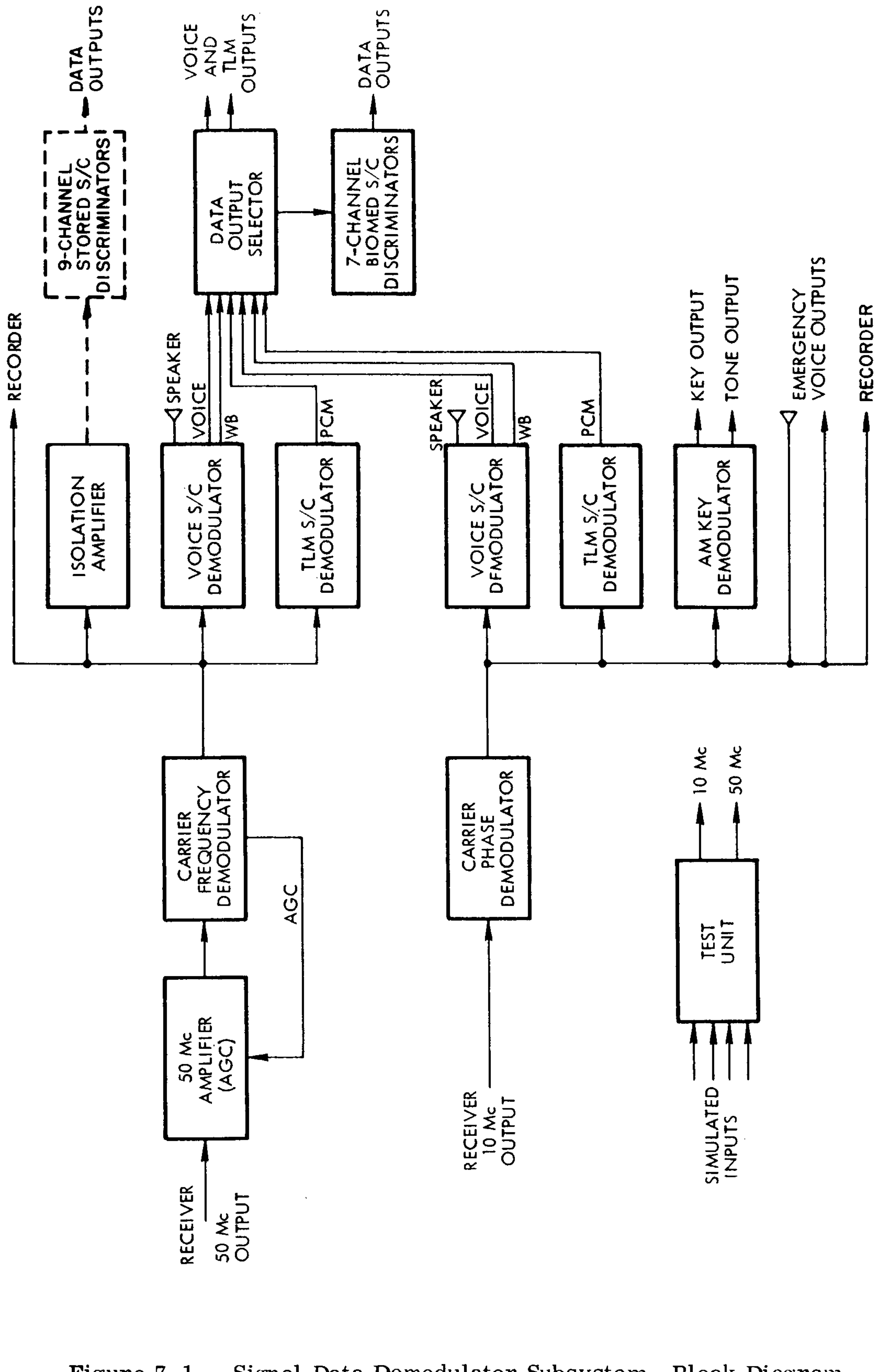


Figure 7-1. Signal Data Demodulator Subsystem, Block Diagram

TABLE 7-1. DATA DEMODULATOR INPUT SIGNAL CHARACTERISTICS

Demodulator Sub-Unit	Frequency (mc)	Level		Threshold S/N (db) in Noise Bandwidth	Noise Bandwidth
		Minumum	Maximum		
(1) Carrier		(dbm)			
Carrier Phase	10	-75	-65	6.0	200 cps (*1)
				6.0	60 cps (*1)
Carrier Frequency	50	-31.3	+15	5.3 (*2)	11 mc (*1)
		-32.2	+15	8.8 (*3)	4 mc (*1)
(2) Subcarrier		(Volts)			
Telemetry	1.024	0.1	1.0	8.5	6 kc (*4)
				8.5	150 kc (*4)
				8.5	600 kc (*4)
Voice	1.250	0.1	1.0	4.7	50 kc (*1)
A. M. Key	0.512	0.707	1.414	-4.0 (*5)	1 kc (*5)

*NOTES:
(1) Phase Lock Loop
(2) Mode E (Television, Voice and Telemetry)
(3) Mode D-1 (Voice and Telemetry)
(4) If filter 3-db bandwidth
(5) Human Operator, 98% intelligibility

Some of the Apollo modulation parameters have been changed during the program. The major changes in the demodulator are described in the following paragraphs.

7.2.1 CARRIER PHASE DEMODULATOR.

A block diagram of the PM carrier demodulator is shown in figure 7-2. The PM demodulator will accept and demodulate phase modulated 10-mc signals from the R and RR receivers. These signals will include emergency voice, as well as all non-emergency PM data.

It was planned originally to frequency modulate the emergency voice signal directly onto the rf carrier. This now has been changed. The emergency voice is to be

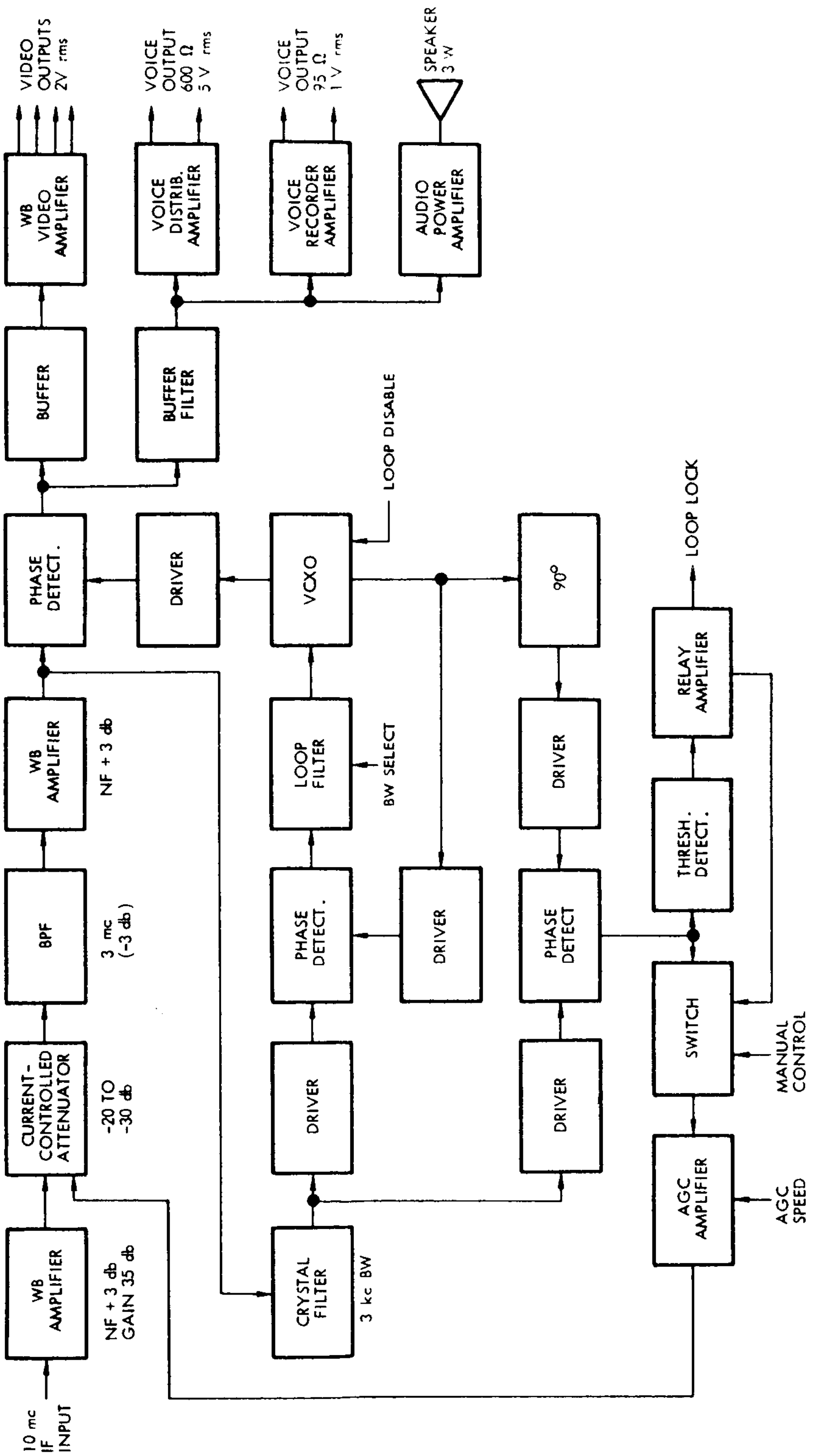


Figure 7-2. Carrier Phase Demodulator, Block Diagram

phase modulated directly onto the rf carrier. This change eliminates a separate, 50-mc fm demodulator for emergency voice.

Using a wideband phase demodulator for demodulation of a narrow band signal requires careful design to assure that the noise bandwidth of the phase lock loop in which the PM demodulator reference signal is derived does not become excessively wide when the signal-to-noise ratio is high. Since the portion of the PM signal within the noise bandwidth of the reference loop will be tracked by the loop, it will not be detected by the phase detector. If the loop bandwidth becomes 1 or 2 kc under strong signal conditions, the demodulator could not be used to demodulate a voice signal.

The loop bandwidth problem is solved in the circuit to be used here, by the addition of a crystal filter prior to the loop input. The effect of the filter is discussed in more detail in appendix g.

The requirement for agc in the carrier PM demodulator has been deleted, since the agc will control the output level (carrier component) of the R and RR receivers to within ±1 db over the dynamic input range. It will be possible to eliminate static differences between receiver outputs of 0 to 7 db by attenuators in the patching lines.

7.2.2 CARRIER FREQUENCY DEMODULATOR.

A block diagram of the fm carrier demodulator is given in figure 7-3. The function of this unit has not changed significantly from that described in the original specification. Circuit design criteria have changed only in that the IRIG subcarriers (see paragraph 7.2.6) will not be present on the input.

The 50-mc if. amplifier and the fm demodulator specified in RFS-226 have been combined in the Collins specification because they operate as a unit, providing agc action to allow demodulation of the fm signal over an input dynamic range of -40 to 0 dbm or greater. Maximum level of the 50-mc signal from the receivers was originally given as +15 dbm. The level will probably not exceed 0 dbm because of output circuit limitations.

7.2.3 TELEMETRY SUBCARRIER DEMODULATOR.

A block diagram of the telemetry subcarrier demodulator is given in figure 7-4. The unit is required to demodulate a 1.024-mc subcarrier that has been phase

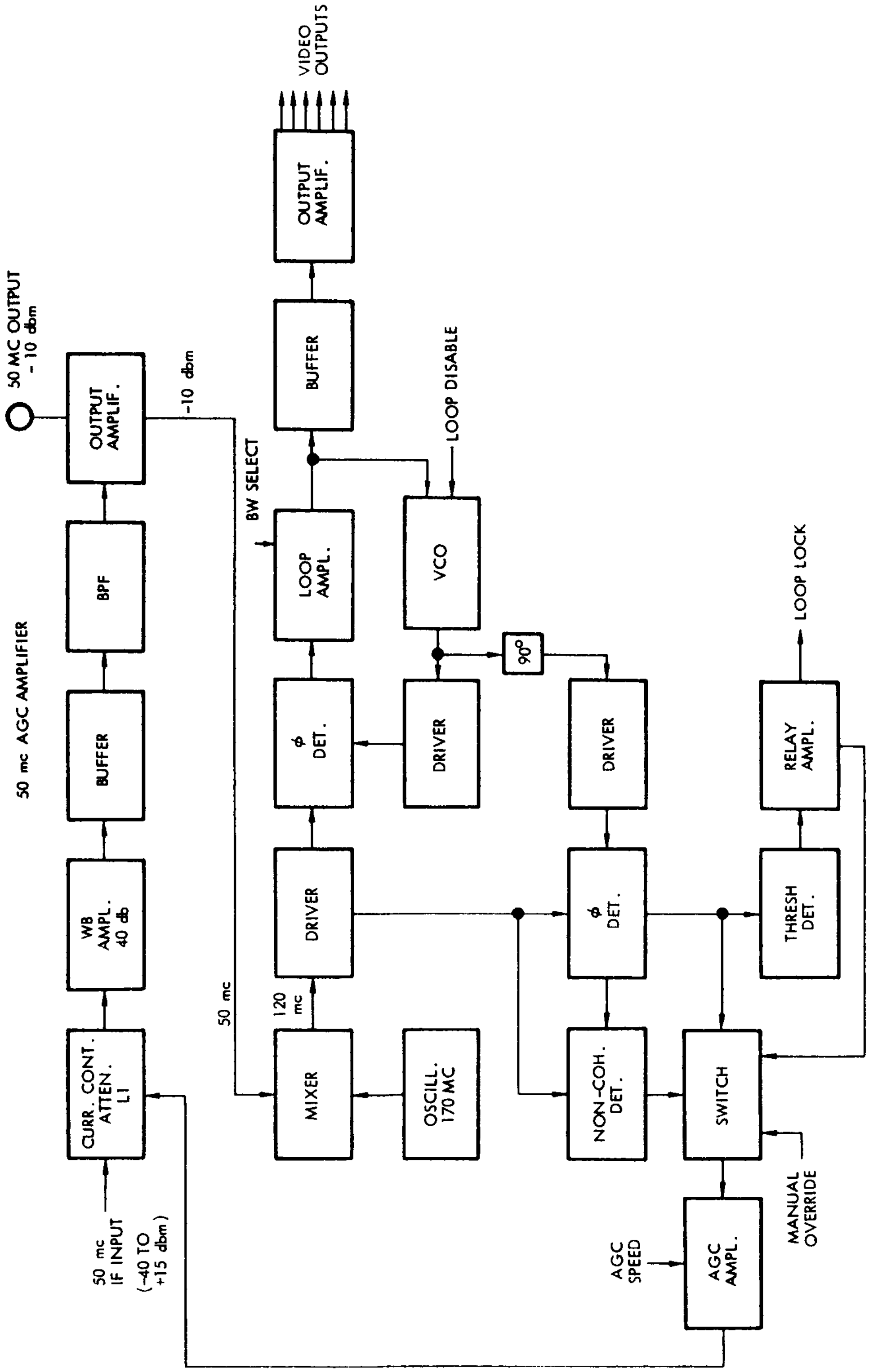


Figure 7-3. Carrier Frequency Demodulator, Block Diagram

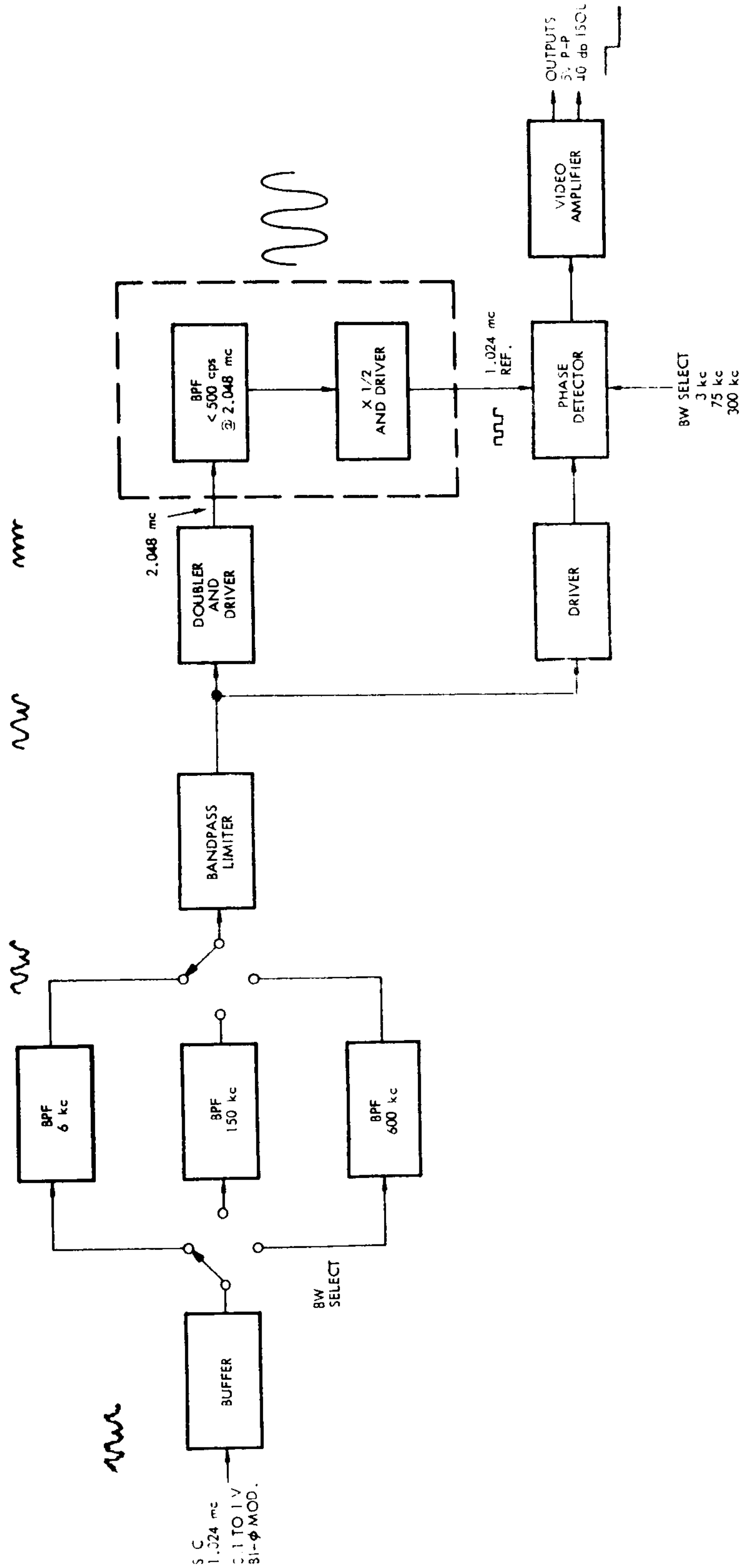


Figure 7-4. Telemetry Subcarrier Demodulator, Block Diagram

modulated by a PCM signal. The method of modulation is ±90° phase-shift switching. To derive a reference carrier for the phase modulator, it is necessary to double (square) the incoming signal, filter the result, and divide by two. Several methods of providing the filtering function were considered. Passive crystal filters and phase locked loops were analyzed to determine if they would be suitable for this function.

A wide range of bitrates is involved (100 bps to 200 kpbs, later changed to 1 kbps to 200 kbps) and the expected doppler shift of the subcarrier is specified to be as much as ±50 cps.

A crystal filter, with a bandwidth of 500 cps or less, as shown in figure 7-4, was selected to simplify circuitry and to reduce acquisition time.

7.2.4 VOICE SUBCARRIER DEMODULATOR.

This demodulator, figure 7-5, is a phse-locked loop discriminator to demodulate the signals on the 1.25-mc voice subcarrier. The demodulator output in the wideband channel or prior to filtering in the voice channel is a voice signal, linearly summed with seven biomedical subcarriers. The biomedical subcarriers have center frequencies between 4 and 12.4 kc. An attenuation of 20 db at 4 kc has been specified for the low pass voice output filter to reduce the level of the 4-kc subcarrier to which the operators must listen. Modulation parameters for the biomedical subcarriers were not given in RFS-226. Recommended values for these have been derived (see appendix g) for simultaneous threshold of all of the subcarriers, assuming the use of phase lock loop subcarrier discriminators. This type of discriminator will be supplied in the subsystem. The phase-locked loop discriminators will provide at least a 6-db advantage over the pulse-averaging type and this advantage could be increased if the Apollo modulation indices are changed to provide simultaneous threshold of carrier and subcarriers. See appendix g.

7.2.5 AM KEY SUBCARRIER DEMODULATOR.

This unit is required to detect a 512-kc keyed subcarrier, available at the output of the PM carrier demodulator. It will be built as shown in the block diagram of figure 7-6. The AM key demodulator specified in RFS-226 consisted of a phase locked loop, providing the reference for a coherent AM detector. A square-law detector was

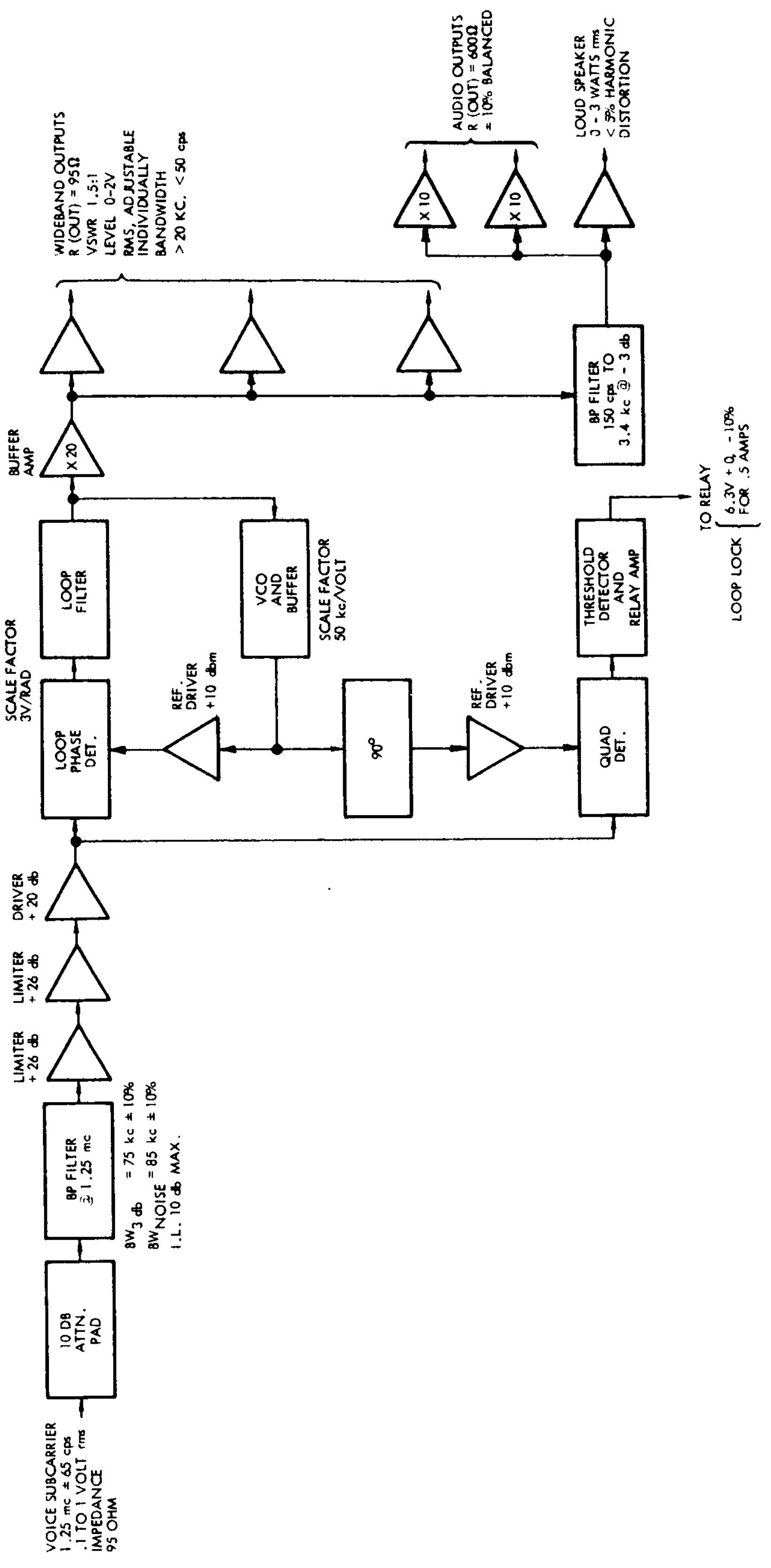


Figure 7-5. Voice Subcarrier Demodulator, Block Diagram

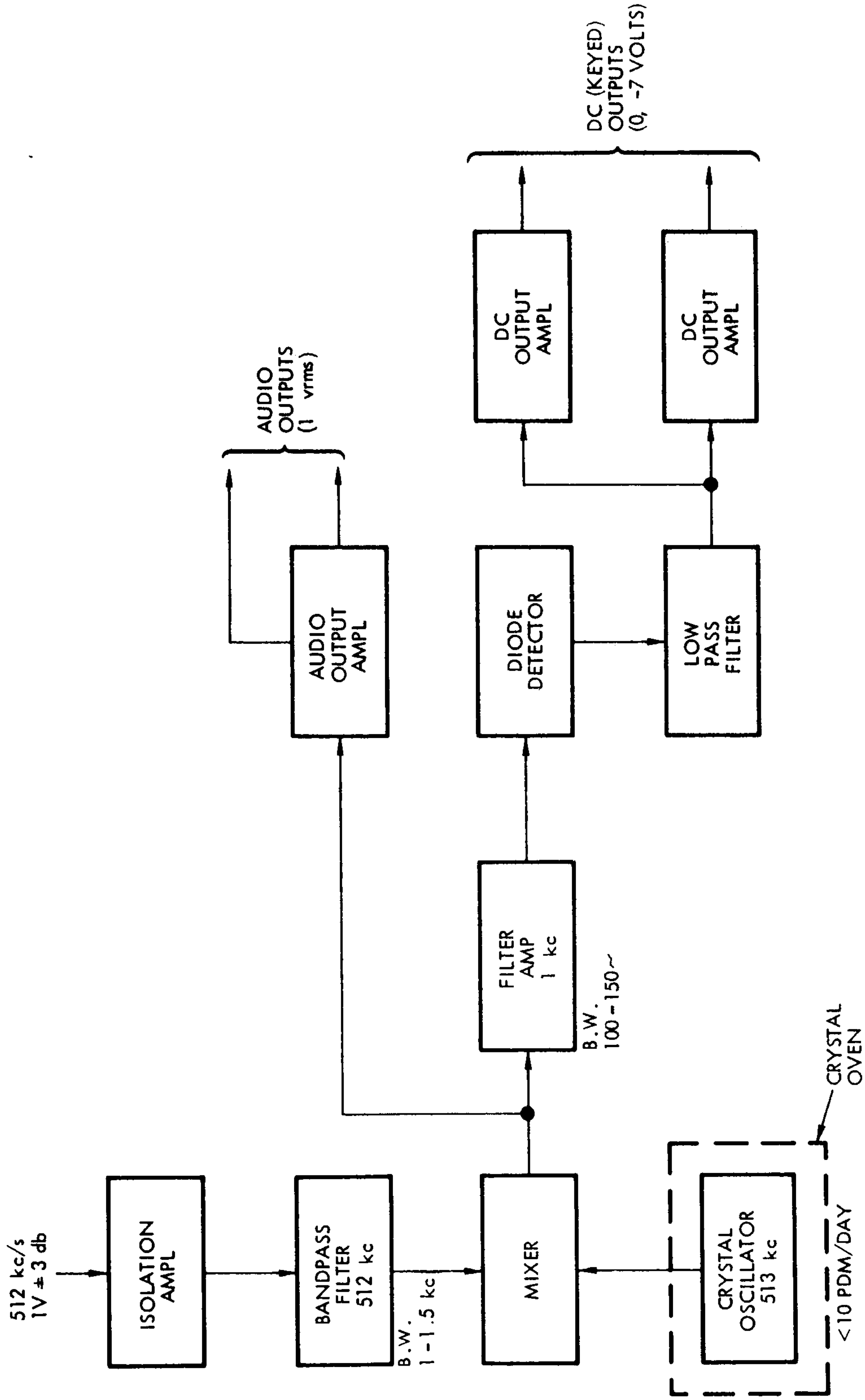


Figure 7-6. AM Key Demodulator, Block Diagram

also specified as backup. The circuit to be provided is different in several respects. It will operate on the "BFO" principle, wherein the subcarrier is converted from 512 kc to 1 kc for audio monitoring by an operator. In this form, the signal is suitable for recording without dc-response circuitry.

It will be noted that no filtering of the 1-kc audio output is provided. As indicated in appendix g, studies have shown that the human listener will act as a tracking filter with a bandwidth of 50 to 100 cps and a threshold below 0 db signal-to-noise. It was also found that this threshold was not improved by bandpass filtering of the audio signal.

To provide a dc or keyed output, the 1-kc signal (rather than the 512-kc signal) is detected with a square-law device. The frequency of 1 kc provides better bandpass control with simpler filter designs than 512-kc.

The square-law device provides one additional advantage over the phase locked loop synchronous detector. The keyed subcarrier would have to be re-acquired by the phase-locked loop at the beginning of each tone burst, presenting an acquisition time problem. The loop bandwidth would have to be wide (25 cps or greater) to acquire rapidly enough, and the normal phase-locked loop advantage of very narrow bandwidth would be lost.

7.2.6 STORED-DATA FM/FM SUBCARRIER DISCRIMINATORS.

These discriminators, specified in RFS-226, were required to demodulate 9 IRIG subcarriers from the Apollo fm carrier. These subcarriers, which would have carried analog operational data, have been removed from the Apollo down-link signal, and the discriminators for them will not be supplied. This decision was a recent one, and the analysis of the FM carrier demodulator in appendix g includes some material on these subcarriers.

7.2.7 TEST UNIT.

A test unit will be provided as a part of the subsystem. Such a unit was not specified in RFS-226 but is required to satisfy other descriptions of station function. A block diagram is given in figure 7-7. Most of the characteristics of the receiver outputs can be simulated by the unit. Most inputs and outputs of the subunits are patchable and all

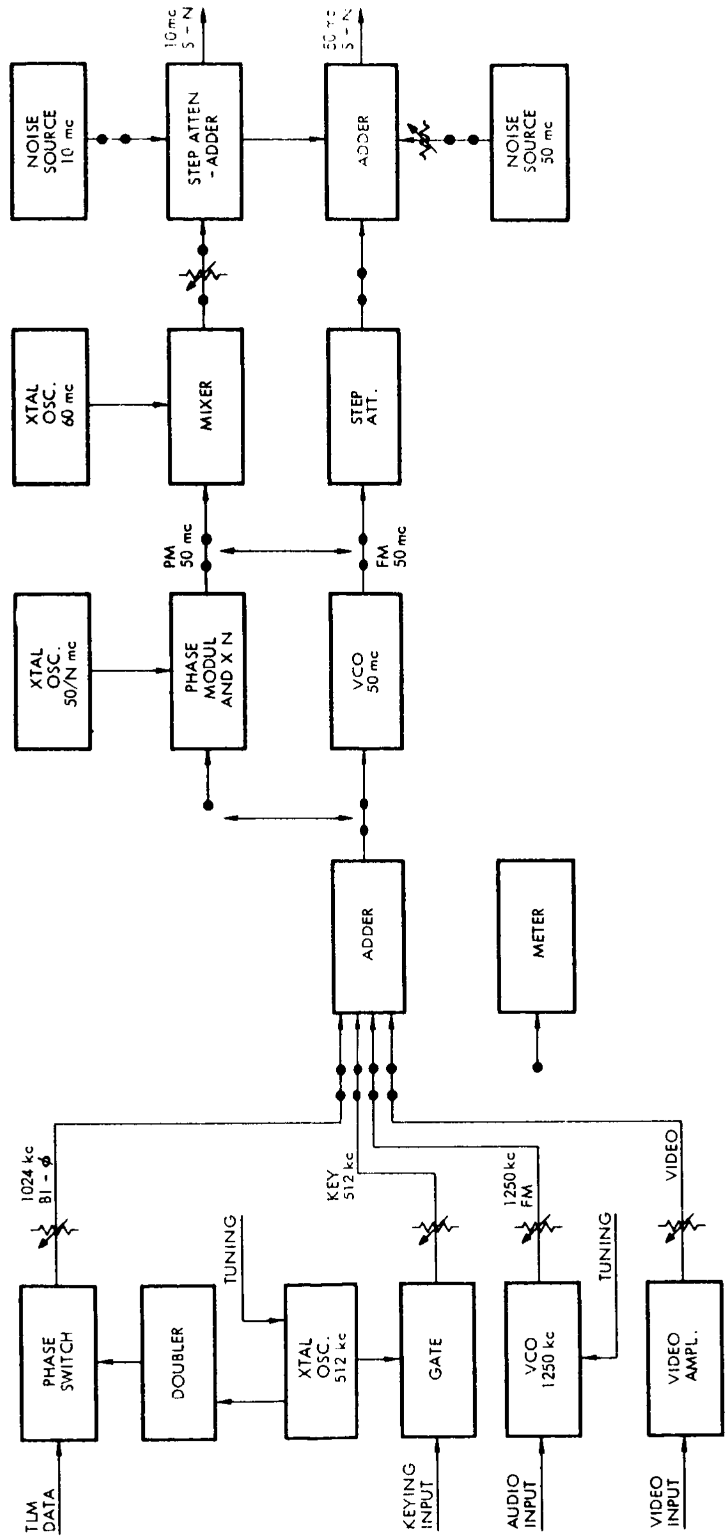


Figure 7-7. Test Unit, Block Diagram

inputs for the data demodulator subsystem and outputs from the three R and RR receivers are available on the patch panel.

7.3 MECHANICAL CHARACTERISTICS.

Figure 7-8 shows the packaging technique that will be used for the data demodulator subsystem.

The module housing consists of a flat aluminum plate and two die cast aluminum shells, one on the dc side and one of the rf side. All of the circuits will be assembled on the flat plate. The flat plate will be assembled to the dc side which will contain the dc connectors and the rf connectors. The shields on the rf leads will be carried through the plate and terminated on the rf side. The dc shell contains two small cavities, one or both of which can be used for line filters.

The rf shell contains several cavities that provide the interstage shielding. A flat plastic gasket that is silver-loaded and die cut to the same egg crate arrangements as the rf shell will be attached to the flat plate and will seal all edges when the rf shell is attached.

This design provides maximum accessibility for assembly and for servicing. All assembly can be accomplished on the flat plate, except for attaching the leads from the connectors. When the rf shell is removed, all parts are accessible for test and repair. When interstage shielding is required during testing, a dummy rf cover will be provided with the necessary openings for adjustments.

It is planned to use this standard design for all of the modules of the demodulator system. To maintain this standard, no attempt will be made to fill every available space in each module. Some modules may be completely full and some may be half full. The modules will be mounted in standard rack panel type drawers. Each drawer will be identical mechanically and will contain a standard mounting for the modules. The modules will be mounted on edge across the drawers, with the cables running along the side of the drawer to each module. Again, some drawers may be full and some may not. Standard mounting will add flexibility as additional modules can be added for changes to the system. A module can be serviced in the drawer by disconnecting the cables, rotating the module 180°, reconnecting the cables, and placing

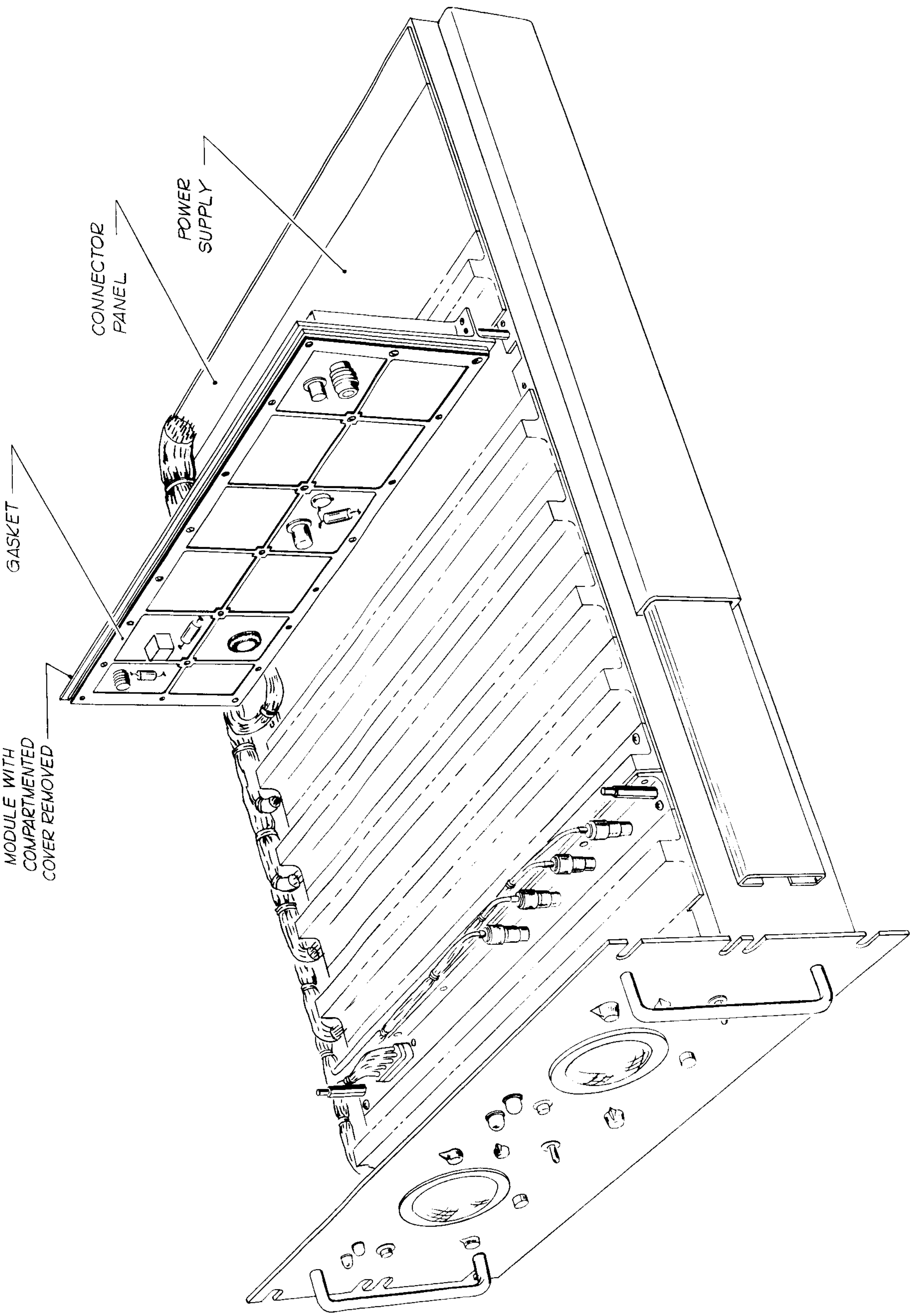


Figure 7-8. Signal Data Demodulator Packaging Technique

the module guide pins in the side of the drawer that will hold the module in an elevated accessible position.

The subsystem, with blowers and power supplies, will require one standard rack.

section 8

antenna position encoding system

8.1 GENERAL.

The function of the antenna position encoder subsystem is to measure accurately the antenna axis shaft position. This subsystem includes shaft position transmitters (resolvers, coupler, mounting hardware) which are attached to the axis of the antenna, and rack mounted (in the Instrumentation Building) shaft position receiving units that supply the station with X and Y real angle information. A 10-pps command readout pulse is supplied, and the angle existing at the time is locked up as the binary output within 100 microseconds. The angles are stored until the next pulse.

8.2 ELECTRICAL DESCRIPTION.

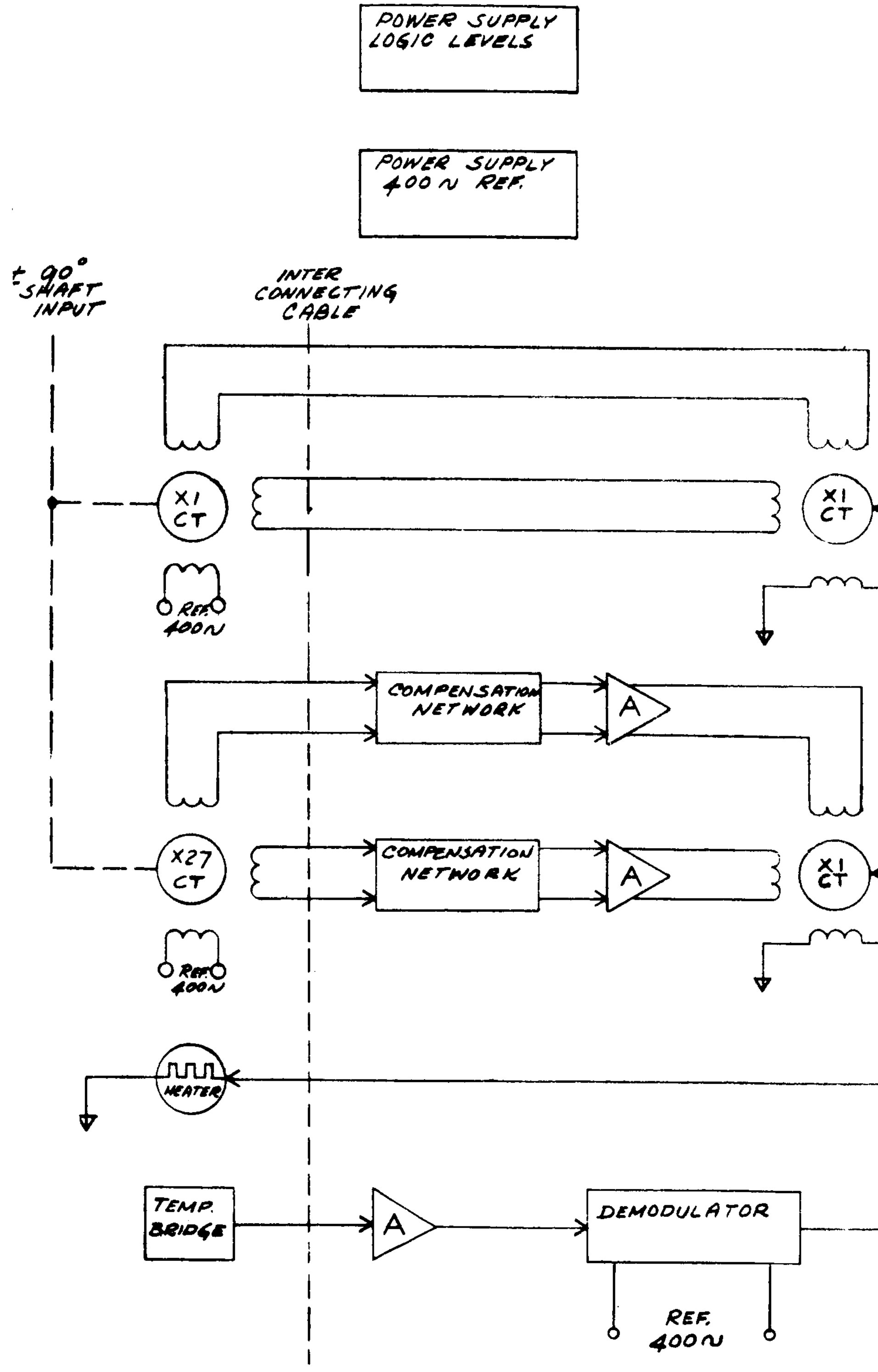
8.2.1 GENERAL DESCRIPTION.

A description of the encoding system is given as follows (see figure 8-1):

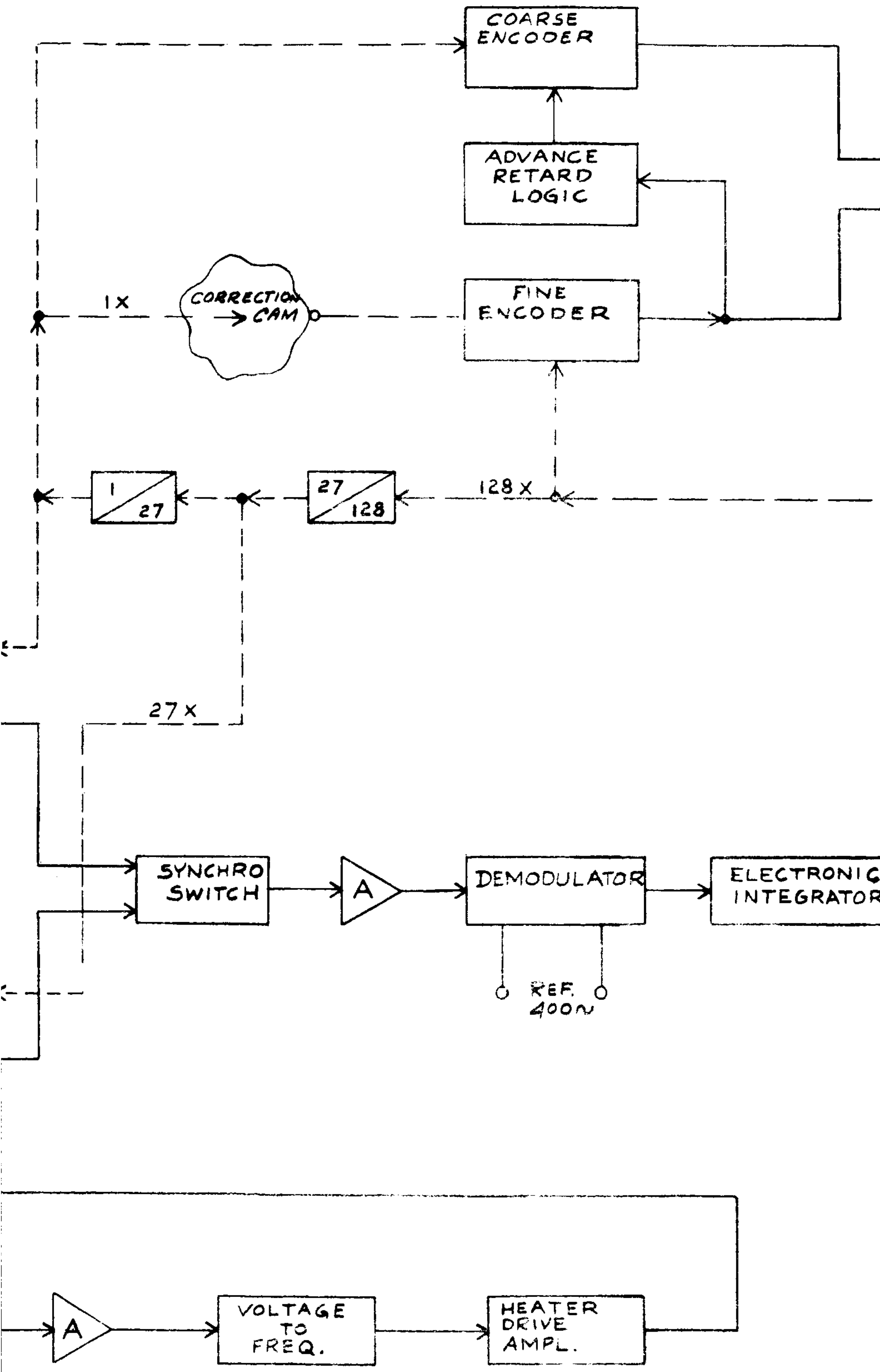
Transducers are mounted on the antenna and coupled to the X and Y axes. By means of an instrument servo, the transducers position the rack-mounted encoders (located in the control building) as the antenna is moved. The servo repeater unit repeats the antenna position and by means of a motor and gearing drives the encoder unit itself. Logic circuits are provided to give a straight binary output. Indicator display lights are provided for each binary bit.

8.2.2 ELECTRICAL PARAMETERS.

Resolution:	Seventeen bits for rotation of 0° to 90° (plus 1 bit for sign). The least significant bit (least count) is equal to 2.47 arc seconds or 0.006°. The most significant bit is equal to 45°.

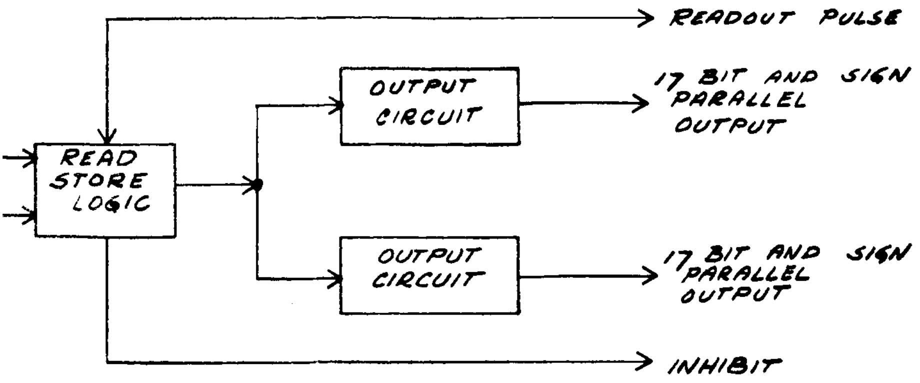

POWER SUPPLY
LOGIC LEVELS
POWER SUPPLY
400 ~ REF.
± 90°
SHAFT
INPUT
INTER
CONNECTING
CABLE
X1
CT
X1
CT
REF.
400 ~
COMPENSATION
NETWORK
A
X27
CT
COMPENSATION
NETWORK
A
X1
CT
REF.
400 ~
HEATER
TEMP.
BRIDGE
A
DEMODULATOR
REF.
400 ~

1


COARSE ENCODER
ADVANCE RETARD LOGIC
FINE ENCODER
1X
CORRECTION CAM
128 X
27/128
1/27
27 X
SYNCHRO SWITCH
A
DEMODULATOR
REF. 400~
ELECTRONIC INTEGRATOR
A
VOLTAGE TO FREQ.
HEATER DRIVE AMPL.

II-8-2-A

2



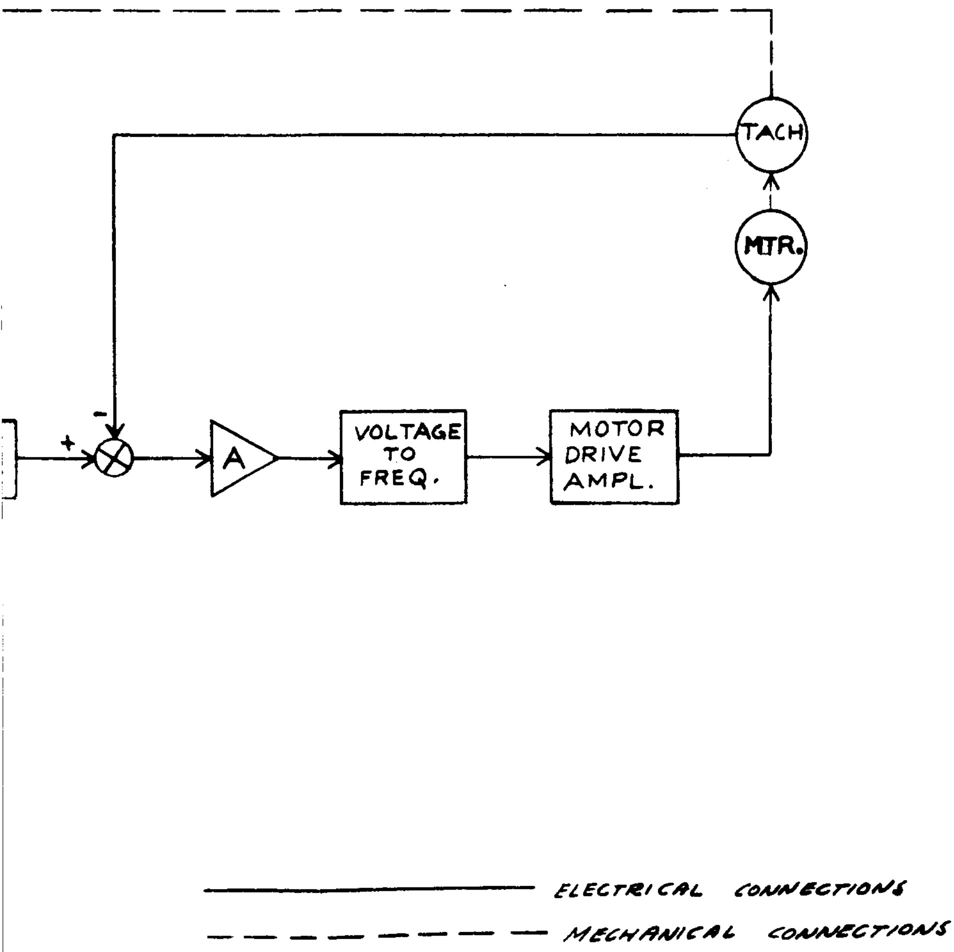


Figure 8-1. Encoder System, Block Diagram

Peak Accuracy:	The accuracy of the antenna position encoding system is ±15 arc seconds (three sigma) under any combination of the following conditions:

(1) Throughout the temperature range of -25° to +130°F on the transmitter, coupling mounting hardware and cable (from the encoder transmitter on the antenna to the encoder receiver in the Instrumentation Building).

(2) Throughout the entire antenna velocity of 0.002 to 4 degrees per second

(3) With encoder coupling deformation of:

(a) axial, ±0.030 inches

(b) Radial, ±0.005 inches

(c) angular, 5 arc minutes

Readout cycles:	Unlimited
Readout:	Parallel
Maximum readout speed:	4° per second maximum antenna speed
Repeatability:	2.47 arc seconds

8.2.3 INPUT SIGNAL CHARACTERISTICS.

Rotation of the X and Y antenna axes

Readout pulse:	Storage will be initiated on receipt of a command pulse with the following characteristics.
Amplitude:	Positive pulse, -6 volts to 0 volt
Rise time:	2.0 microseconds
Width:	10 to 20 microseconds between 6-db points
Rate:	10 pulses per second
Input impedance:	5 ma max. short circuit current to ground.

8.2.4 OUTPUT SIGNAL CHARACTERISTICS.

Output Form: Both X and Y axis position is defined by a straight binary number readout in parallel upon command with a maximum readout rate of 10 per second. The output for both X and Y axes is as follows:

	17 bits	binary angle
	1 bit	sign
Total	18 bits	X axis
	18 bits	Y axis

X Axis Range:	The output in 17 bit straight binary form is from 0 to $\pm 2^{16}$ (131,072) per ±90°angular rotation.
Y Axis Range:	The output in 17 bit straight binary form is from 0 to $\pm 2^{16}$ (131,072) per ±90° angular rotation.
Logic Levels:	The binary 1 is 0.0 ±0.5 volts and the binary 0 is -6.0 ±0.5 volts dc. Output logic is capable of driving a 1000 ohm resistive load to -18 volts dc.
Sign Bit:	The sign bit shall consist of a binary 1 for positive angles and a binary 0 for negative angles.
Inhibit Output:	Readout will be in transition during the inhibit pulse
Amplitude:	Negative pulse, 0 to -6 volts
Duration:	Between 50 and 100 microseconds
Output Impedance:	1 K connected to -18 volts
Visual Displays:	A binary light display shall be provided on the rack-mounted receiving units representing each antenna axis position. One light will be provided for each binary bit (including sign) with the most significant bit displayed on the left. The purpose of these readouts is to provide an aid in testing and troubleshooting the encoder system and will not be used for normal station operation. The display indicators will be located on the front panel of the encoder rack-mounted receiving units. The lamps will be grouped by 3's starting from the least significant bit on the right providing easy reading in octal pattern.
Isolated Outputs:	Two outputs, isolated electrically, are provided for each axis.

8.2.5 POWER REQUIREMENTS:

The electrical power requirements for the X-Y antenna position encoding system are as follows:

Voltage (steady state):	120 volts ±10% single phase

Voltage tolerances:	
Maximum fluctuation in voltage:	±2%
Maximum rate of change of voltage:	±2.5% per second
Frequency (steady state):	60 cps ±5%
Frequency tolerances:	
Maximum fluctuation in frequency:	±1%
Maximum rate of change of frequency:	±2.5% per second
Deviation factor:	10%
Current (steady state):	5.0 amperes
Power (steady state):	480 watts

8.2.6 HEAT DISSIPATION.

The heat dissipation for the encoding system is 480 watts.

8.3 MECHANICAL DESCRIPTION.

8.3.1 ANTENNA MOUNTED EQUIPMENT (SEE FIGURE 8-2.)

The transmitter package is sealed and provided with heaters for temperature control. This unit is identical to the equipment supplied to GSFC for the Rosman II station.

8.3.2 RACK-MOUNTED EQUIPMENT.

The rack-mounted equipment (standard 19") will be comprised of 4 units (see figure 8-3):

(1) X servo repeater and logic circuits

(2) Y servo repeater and logic circuits

(3) 400 cycle solid state converter

(4) Low voltage power supply

The above four units require 36-1/4 inches of rack space. All units are front rack-mounted (no rear mounted 400 cycle converter as on previous stations).

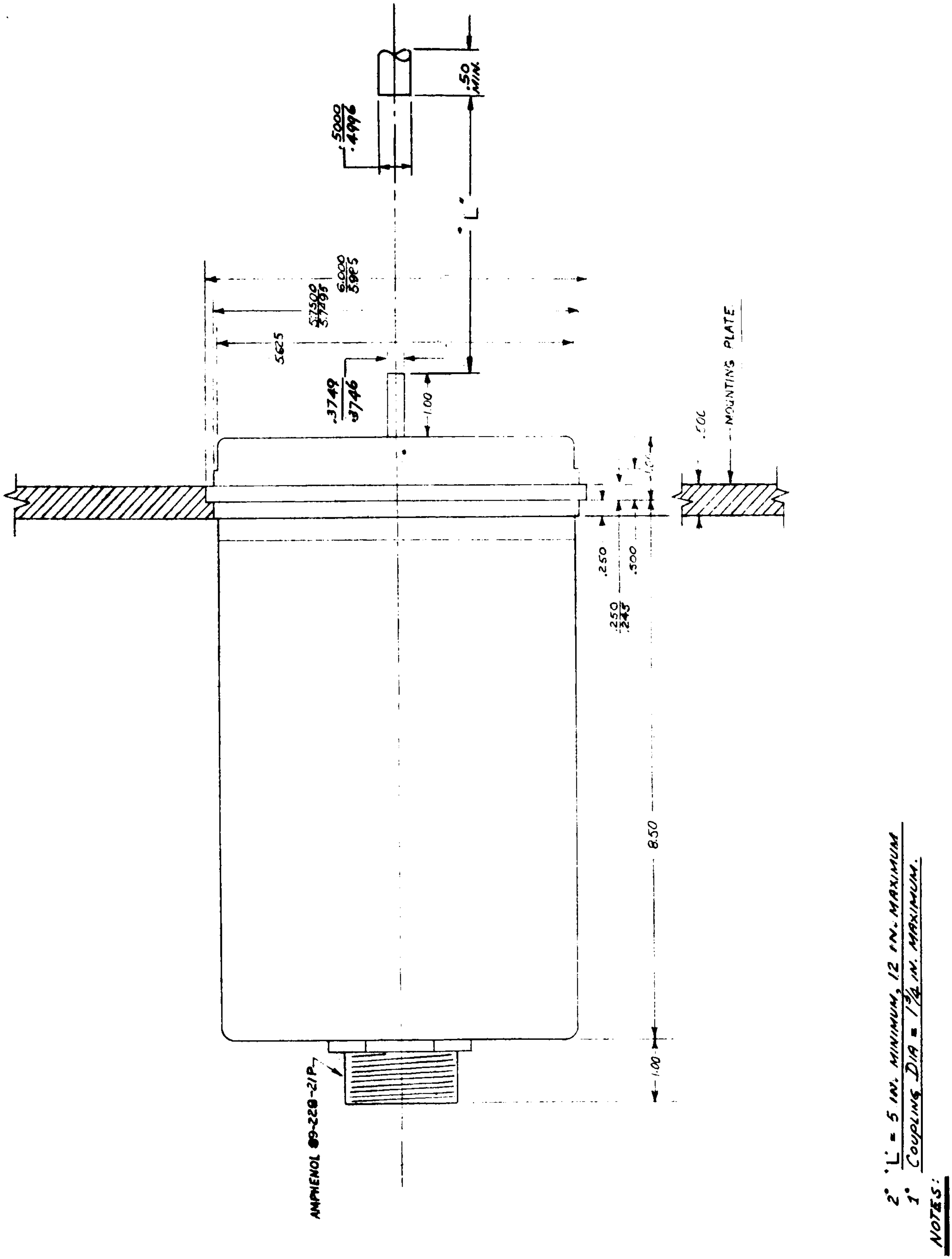
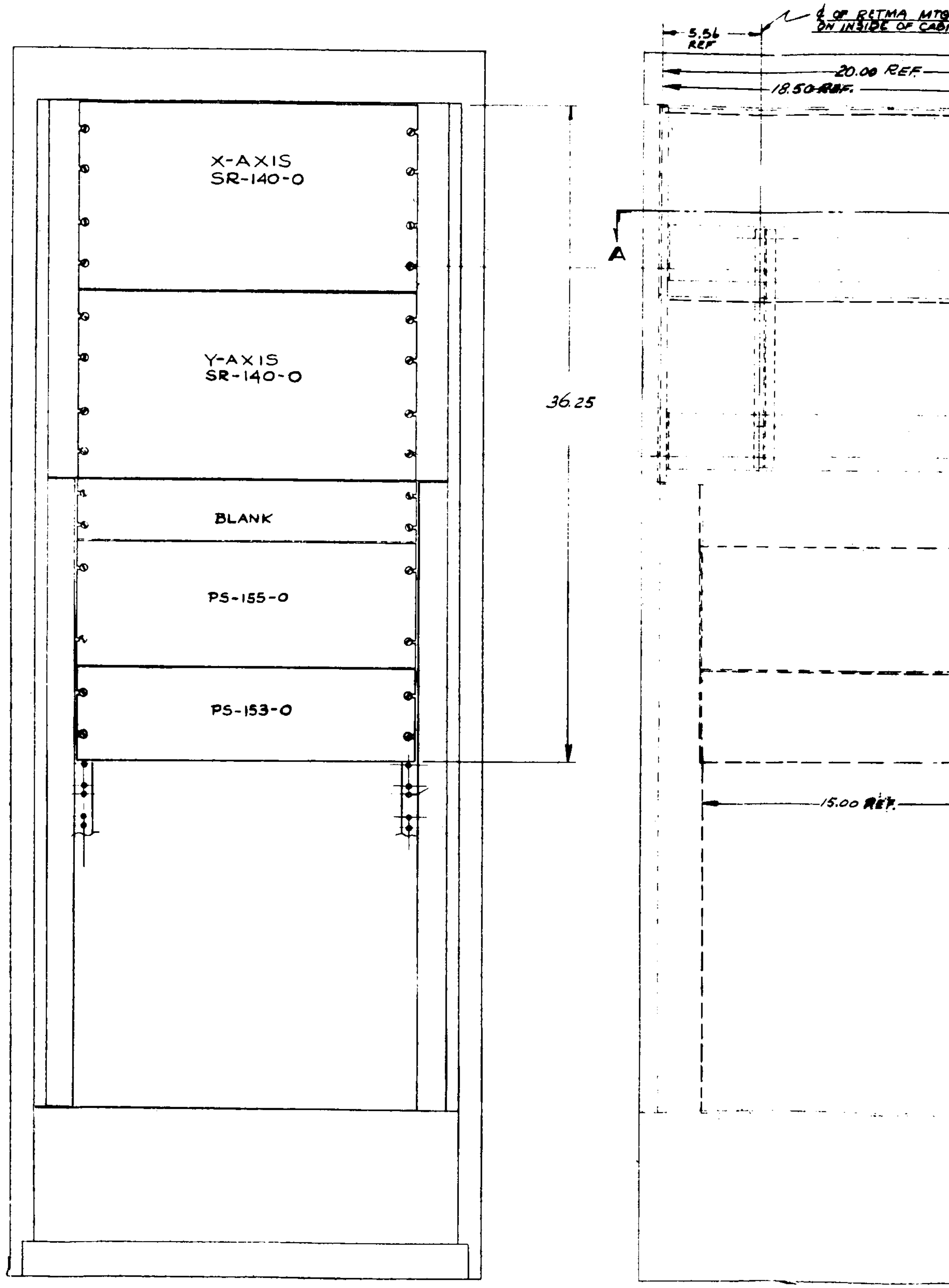


Figure 8-2. Precision Angle Transducer


X-AXIS
SR-140-0
Y-AXIS
SR-140-0
BLANK
PS-155-0
PS-153-0
36.25
A
5.56 REF
20.00 REF
18.50 REF.
15.00 REF.

1#

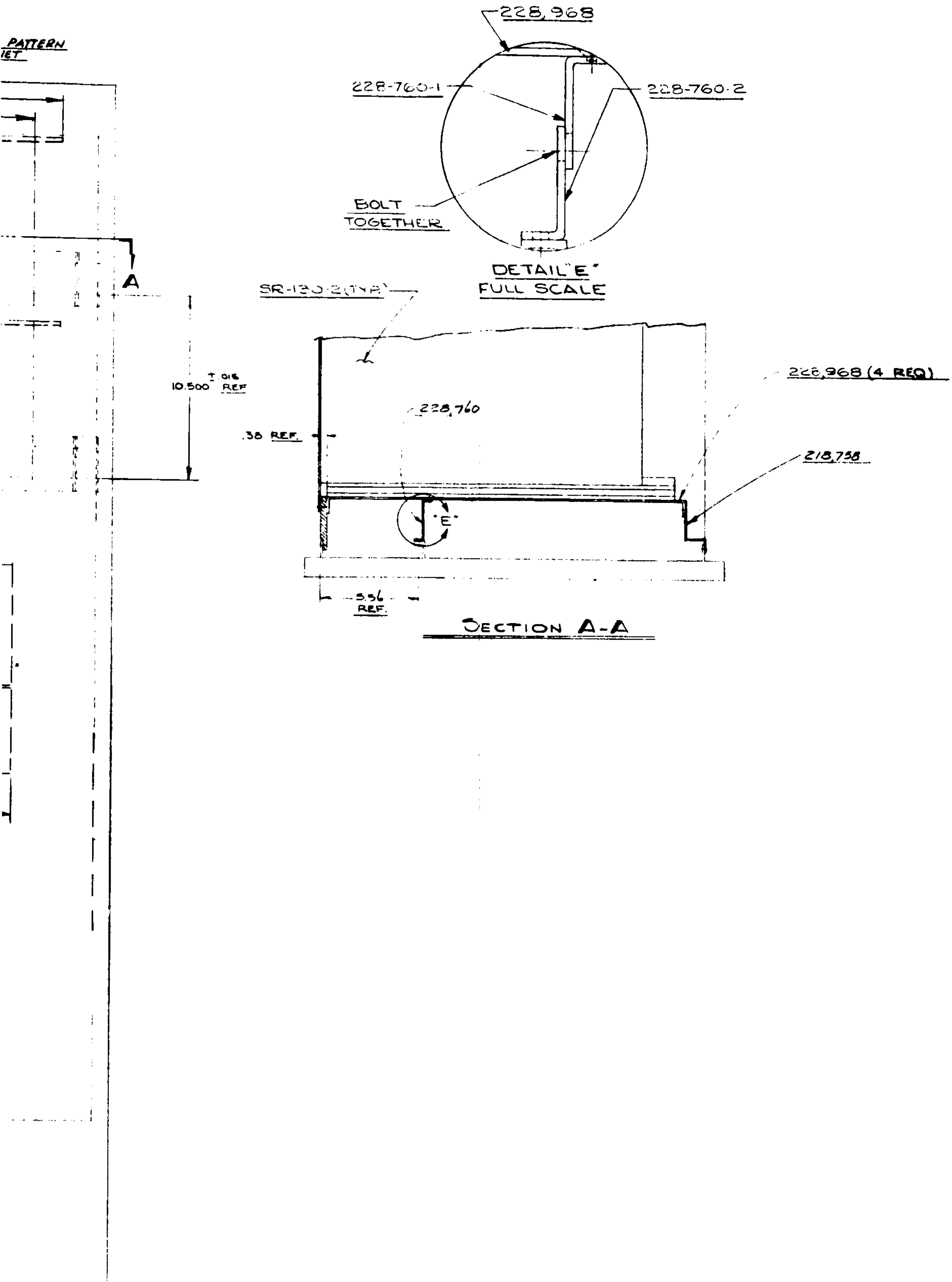


Figure 8-3. Units Installed in Standard Rack

8.4 PERFORMANCE PREDICTION.

The performance prediction is calculated as follows:

(1) The system MTBF is calculated at 7950 hours (M_S).

(2) The probability that the system will go through a continuous mission cycle of 8800 hours without a failure is 33.1% (R_{S1}).

(3) The probability that the system will go through a continuous mission cycle of 4400 hours without any failure is 57.5% (R_{S2}).

(4) Reference: Appendix d, "Reliability Analysis X-Y Antenna Position Encoding System."

8.5 ERROR ANALYSIS.

(1) Combined static, resolution and repeatability error component:	±4.94 arc second
(2) Combined temperature and coupling component:	±10 arc second
(3) Velocity error component:	±0.06 arc second
Total error (arithmetic addition):	±15 arc second
Total error (RSS addition):	±11.2 arc second

NOTES:

(1) All above errors are worst case

(2) 500 feet of cable between transmitter and receiver is also temperature cycled and its effect included in the temperature test.

section 9

antenna position programmer

9.1 GENERAL DESCRIPTION.

The antenna position programmer system performs the following principal functions:

The programmer subsystem accepts spacecraft predictional data (after processing by the station computer) transmitted from GSFC to the station. This predictional data defines spacecraft position through the entire pass. The term "pass" is defined as the spacecraft transit across the station's visible sky region.

The programmer reads in the command information from the drive tape or from the computer at a word rate of 1 per second or 1 per 10 seconds. Real X and Y angles are read from the antenna position encoding subsystem at a rate of 10 ps. The programmer compares the real X with the desired or command X (same for the Y angle) and generates an analog voltage at a rate of 10 per second for usage by the antenna control and drive system to drive the antenna.

The antenna position programmer system shall also provide visual displays for time, X and Y angular information.

9.2 ELECTRICAL DESCRIPTION.

9.2.1 DEFINITIONS.

The X and Y angles are defined to be zero at zenith with increasing positive X angles toward the East and increasing positive Y angles toward the North. Increasing negative X angles will be measured moving West, and increasing negative Y angles will be measured moving South. To avoid confusion in the meaning of various performance characteristics, error measurement quantities are defined as follows:

(1) Resolution - the degree to which a measurement or reading can be separated, or the degree to which two readings can be differentiated or distinguished.

(2) Accuracy — the degree of correctness or closeness to the reference or true value.

(3) Real time is defined as that timing information from the Apollo Timing System which will be set to Greenwich Mean Time (GMT).

(4) Real X and Y angles are defined as actual antenna angles, as measured by the antenna position encoder system.

(5) Command time is associated with command X and Y angles and is that time when the antenna will be pointing with a predetermined X and Y angular configuration.

(6) Command X and Y angles are associated with command time and represent predetermined orbital parameters.

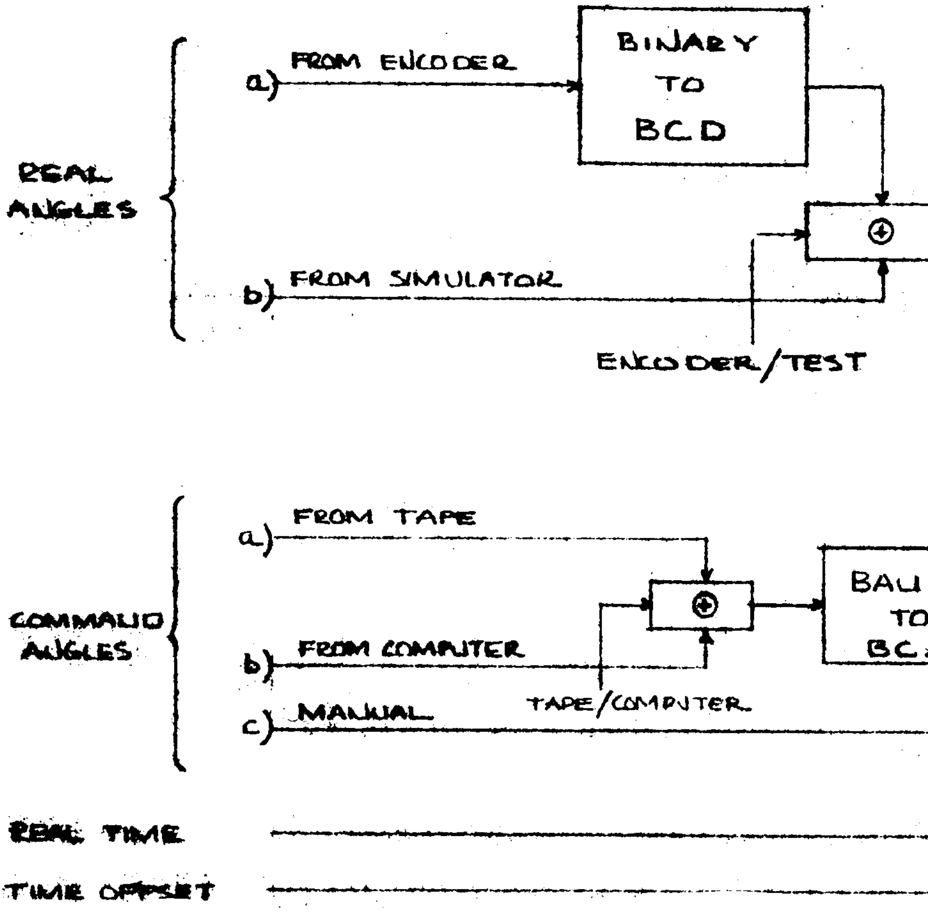
9.2.2 SYSTEM OPERATION.

The operation of the programmer is described as follows (refer to figure 9-1):

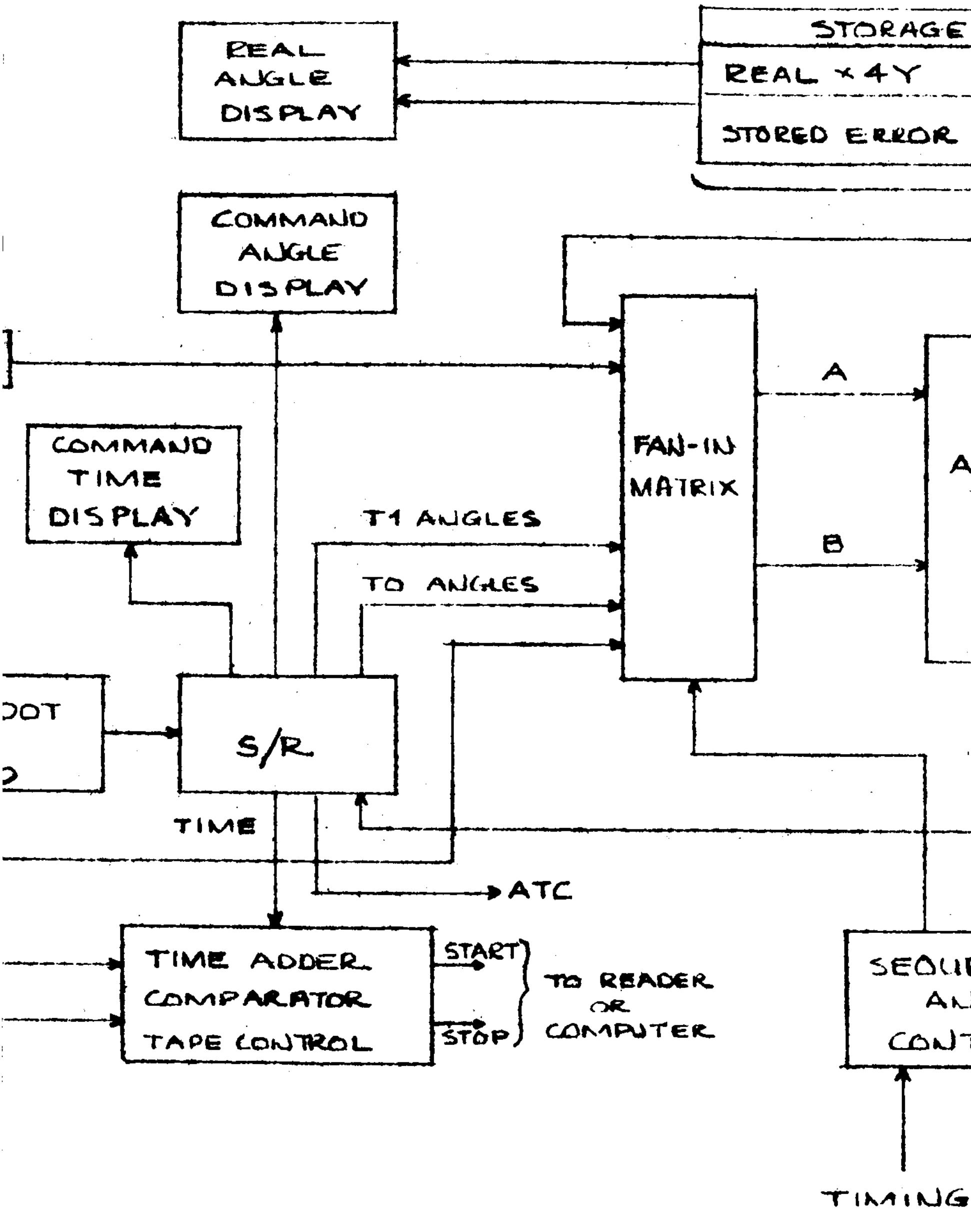
9.2.2.1 GENERAL. The function of the programmer subsystem is to accept command (obtained from a precomputed orbit) or desired time, X and Y angular information, and compare this with real time (GMT), X and Y angular information. The programmer subsystem then generates analog signals from these differences (for both X and Y axes) to be used by the servo system for antenna steerage. The real (GMT) time will always come from the Apollo Timing System. The real X and Y angles will always come from the antenna position encoding subsystem.

Command time, X and Y angles are obtained from either punched tty drive tape, the station computer, or manual switches (located on the programmer remote control panel). The programmer will sample tracking angles during autotrack, and in the event of signal loss, will direct the antenna based on angles from tty drive tape (or computer) up-graded by a sample taken during previous autotrack. The corrections added to the drive tape input will be constant and will be based on the last sample taken in autotrack mode.

ANTENNA POSITION PROGRAMMER
(APP)



CYCLE NO.	FUNCTION	OPERATOR CONTROL
1.	ADD INCREMENT	NO
2	ADD OFFSET	YES
3	ADD ERROR	YES
4	BINARY TO BCD	
5	COMPUTE ERROR	
6	FIND NEXT INCREMENT	


STORAGE
REAL ANGLE DISPLAY
REAL × 4Y
STORED ERROR
COMMAND ANGLE DISPLAY
FAN-IN MATRIX
A
B
COMMAND TIME DISPLAY
T1 ANGLES
TO ANGLES
S/R
TIME
ATC
TIME ADDER
COMPARATOR
TAPE CONTROL
START
STOP
TO READER OR COMPUTER
TIMING

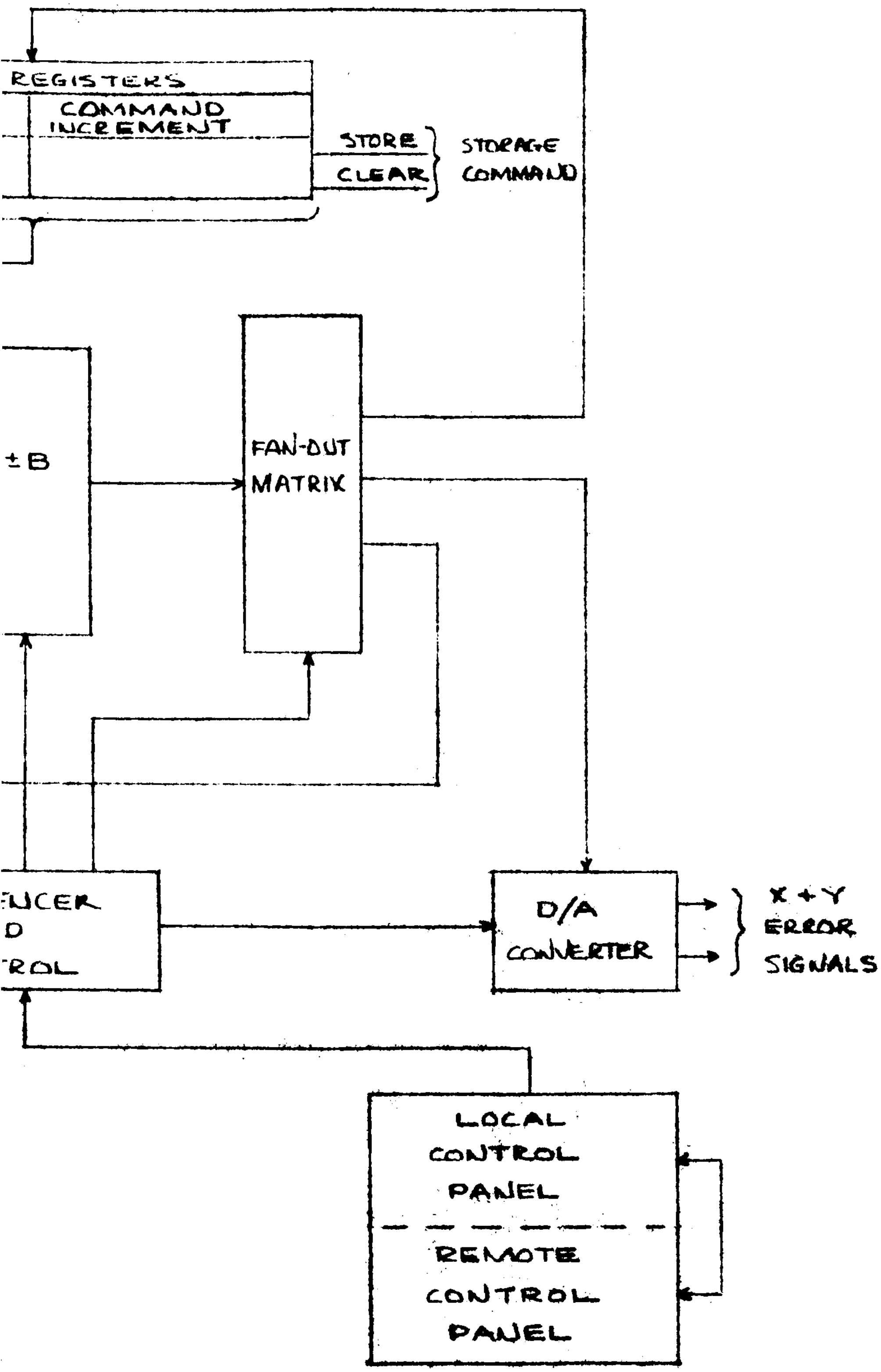


Figure 9-1. Programmer, Block Diagram

At operator discretion, a particular sample may be desired, therefore, the programmer has the capability of storing this sample for use in up-dating the tty drive tape (or computer signal). The programmer has the capability of deleting the stored error (operator discretion) when in program mode. The programmer has the capability of permitting the operator to insert X and Y command angles manually in the absence of drive tape. The programmer will also permit the operator to use the manual insertion to add or subtract X and Y angles to the command angles from tape (or computer).

Provisions are made to add known hours, minutes, and seconds to each time on the tape. This is accomplished by digit selector controls. A contact closure is supplied which enables this addition. A search switch is provided, which will cause the tape reader to advance the drive tape at maximum speed until the drive tape time coincides with real time, as supplied by the time standard.

9.2.2.2 AUTOTRACK MODE. The autotrack mode exists when the tracking receiver system outputs are utilized to direct the motion of the antenna. During this mode, the programmer compares at a 10 ps rate, the real X and Y information with the corresponding command X and Y information. This comparison utilizes either corrected or original drive tape time, and X and Y angles. X and Y difference signals are generated and displayed on analog meters which give an indication of the magnitude of error between actual orbit and drive tape (or computer) orbit.

9.2.2.3 PROGRAM MODE. The program mode exists when the programmer subsystem outputs (the X and Y axis servo control signals) are utilized to direct the motion of the antenna. This is a backup mode and will, in general, only be used when loss of tracking signal occurs. During this mode, the programmer compares the real X and Y angular information at a 10 per second rate with the corrected or original command X and Y antenna position. The command information is fed into the programmer subsystem at a 1 per second or 1 per 10 second rate. Linear interpolation is used to generate the command X and Y angles for the 1/10th second comparisons. Real time is supplied to this system for reference. The signals provided by the programmer are velocity signals which will cause the antenna to reach the desired position in 0.1 second.

9.2.2.4 LINEAR INTERPOLATION.

(1) The analog voltage linearly related to the difference between the command angle and the real angle is supplied to the scale of 1 volt per one degree. Linear interpolation is used in both autotrack mode and program mode to generate the command X and Y angles for the 1/10th second comparisons. One tenth second interpolation is provided for both the 1 per second and 1 per 10 second command information rates.

Linear interpolation is provided in the following manner:

The last command position is subtracted from the next command position and divided by either 10 or 100 (corresponding to a command rate of 1 per second or 1 per 10 seconds respectively) to determine the interpolation increment. This interpolation increment is then added to the last command to find the desired position 0.1 seconds later. A new desired position is determined at each 0.1 second interval by again adding the interpolated increment.

(2) Program Mode. In the program mode, the difference between the command position and the measured position is equivalent to the distance that the antenna must travel during the next 0.1 second interval. This difference is utilized to drive the digital to analog converter which provides the servo velocity command.

(3) Autotrack Mode. In the autotrack mode, the programmer will obtain the command position at the same time as the measured position; and the difference is equivalent to the error in the program with respect to the actual vehicle being tracked.

(4) Manual Correction. Provisions are made in the programmer to add corrections to X and Y angles. The analog outputs to either the velocity servo or to the error display reflect the effects of these corrections.

9.2.3 ELECTRICAL PARAMETERS.

X and Y Axis Servo Control Signal:	An analog voltage linearly related to the difference between the command X angle and the real X angle is supplied to the scale of 1 volt per one degree. A positive voltage will cause the X angle to increase. This signal is fed to the antenna control and drive system at a 10 per second rate. The characteristics of the servo control signal are as follows:
Resolution (minimum increment): *	10 millivolts dc (0.01°)
Accuracy:	±0.05% of the digitized value, ±4 millivolts dc
Maximum voltage:	10 volts dc (10°)

9.2.4 INTERFACE REQUIREMENTS.

9.2.4.1 INPUTS.

9.2.4.1.1 COMMAND DATA INPUT.

(1) Drive tape signals. The primary input method shall be by antenna drive tape. The drive tape will be a 5-level, Baudot, non-chadless (fully perforated) paper tape generated by the station computer.

The command data format is given in table 9-1.

---

* The minimum increments will be 10 millivolts, rather than 50 millivolts as required by GSFC specifications for the following reasons:

(1) To meet the servo control requirement of "position" resolution of ±0.005°.

(2) To keep the servo system limit cycle amplitude low, especially in the auto-program mode.

Reference is made to paragraph 4.2.3 of this design review. The Y axis servo control voltage is identical to the X axis servo control voltage. The programmer is capable of driving a 10k ohm (minimum) resistive load. This signal is single ended and grounded at the programmer.

TABLE 9-1. DRIVE TAPE FORMAT

CHARACTER	FUNCTION
1	CR
2	LF
3	Sign, X Angle *
4	Tens of Degrees, X Angle
5	Units of Degrees, X Angle
6	Tenths of Degrees, X Angle
7	Hundredths of Degrees, X Angle
8	Thousandths of Degrees, X Angle, to 0.001 degree
9	Space
10	Sign, Y Angle *
11	Tens of Degrees, Y Angle
12	Units of Degrees, Y Angle
13	Tenths of Degrees, Y Angle
14	Hundredths of Degrees, Y Angle
15	Thousandths of Degrees, Y Angle, to 0.001 degree
16	Space
17	Figures
18	Tens of Hours
19	Units of Hours
20	Tens of Minutes
21	Units of Minutes
22	Tens of Seconds
23	Units of Seconds

* The digit one will represent a + (positive) sign, and the digit zero will represent a - (negative) sign.

(2) Computer Signals. The second method of command data insertion is by the station computer with the identical format as contained in (1) above; the computer will furnish a 0.0 ±0.5 volt dc level for hole information and a -6.0 ±0.5 volt dc level for no-hole information.

The computer (GFP) will supply the following signals to the programmer:

5 signal lines (representing Baudot code)	"hole data" - 0.0±0.5 vdc "no-hole data" - -6.9±0.5 vdc
1 sprocket hole line (representing timing)	
2 lines for start and stop signals	logic of 0 and -6 volts dc
2 lines for computer Ready signal	dry contact closure

(3) Manual. The third method of command data insertion is by means of digit switches which are located on the programmer remote control panel at the servo console. X and Y angles only (not time) are inserted by these switches.

9.2.4.1.2 ENCODER SIGNALS INPUT. The encoding subsystem supplies X and Y antenna axis position in straight binary form at a rate of 10 per second. The antenna position signal characteristics (0 to ±90°) are described as follows:

17 binary bits X angle
1 binary bit X sign
17 binary bits Y angle
1 binary bit Y angle

binary 1 = 0.0±0.5 volts dc
binary 0 = -6.0±0.5 volts dc
sign bit = binary 1 positive angles
binary 0 negative angles

Two isolated data outputs are provided for each axis.

Inhibit Pulse

Readout will be in transition during the inhibit pulse. The pulse characteristics are as follows:

Amplitude:	Negative pulse, 0 to -6 volts dc
Duration:	Between 50 and 100 microseconds

9.2.4.1.3 TIMING INPUTS. Timing signals are provided by the timing system. The characteristics of these signals are not included in this report. Reference is made to Collins Specification No. 126-0436-001.

9.2.4.2 OUTPUTS.

(1) Servo Control Signals. 0 to ±10 volts in 10 millivolt increments capable of driving a 10k ohm (minimum) resistive load.

(2) Decimal Visual Displays. The programmer will supply decimal readouts of:

Command time:	units and tens of hours, minutes, and seconds
Real X angle:	0° to ±89.999°
Real Y angle:	0° to ±89.999°
Command X angle:	0° to ±89.999°
Command Y angle:	0° to ±89.999°

9.2.4.3 REMOTE CONTROL PANEL. A remote control panel is provided to control the programmer modes and functions during a tracking mission from the servo console. The remote control panel is designed to operate at a distance up to 100 feet (cable length) from the programmer. The remote control panel contains switches and light indicators for the following functions (see figure 9-2):

(1) Command Data Mode
- (a) Drive Tape Control
- (b) Computer Control
- (c) Manual (Test) Control

(2) Add Error

(3) Store Error

(4) Add Time Delay

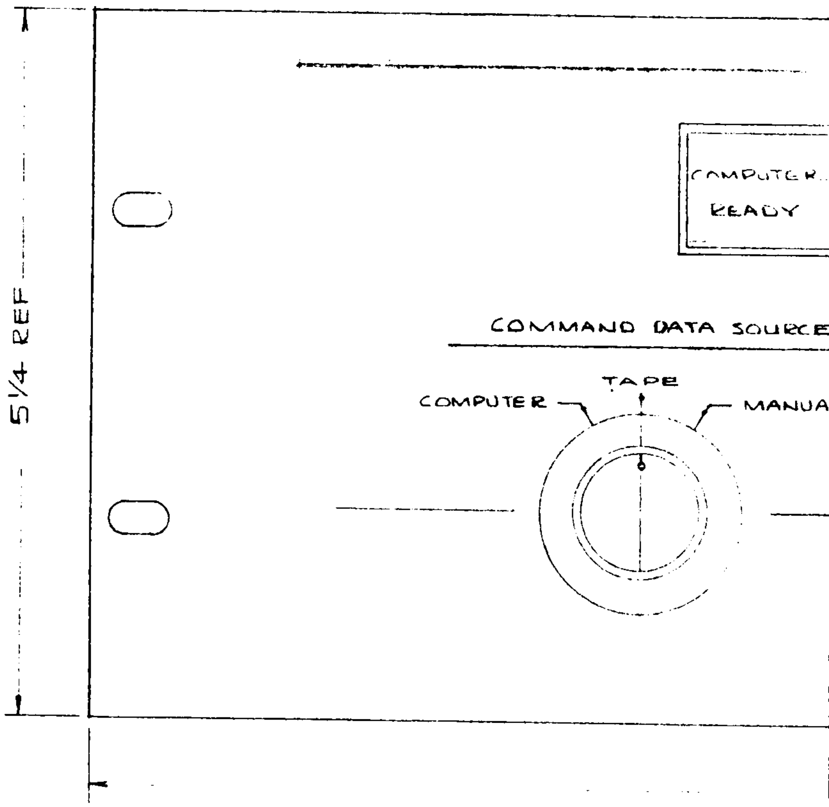
(5) Offset Angles

(6) Digiswitches (for manual X and Y angle control)

(7) Local/Remote Control

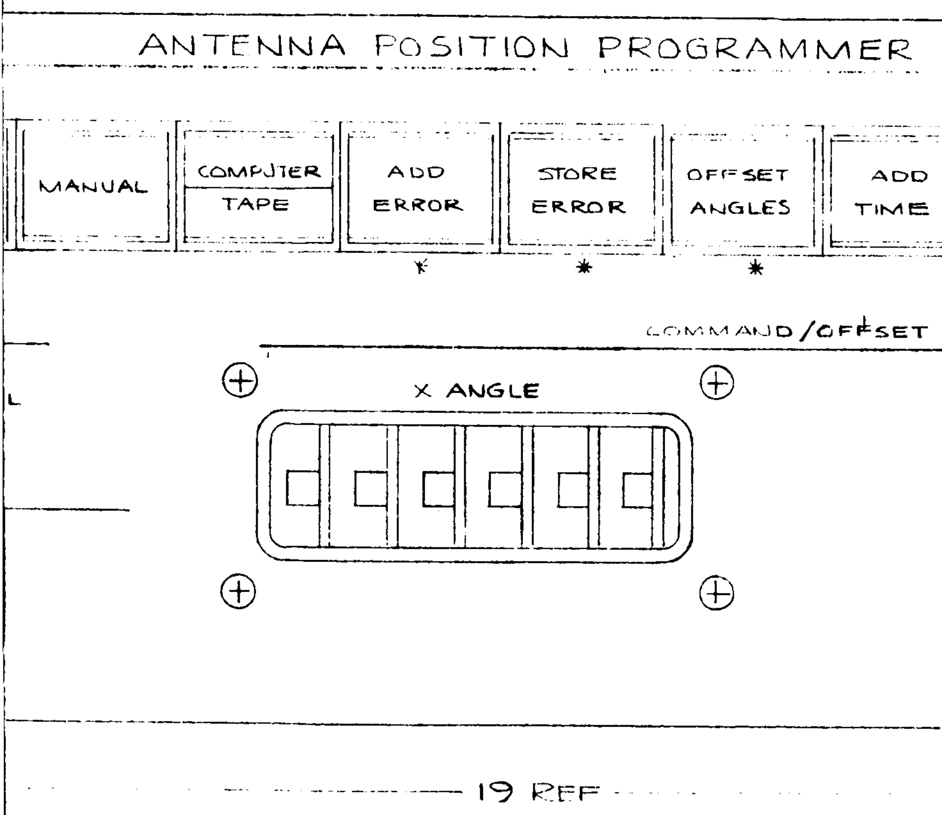
9.2.4.4 POWER REQUIREMENTS. The input power requirements for the programmer is:

34 amps @ 110 volts ac single phase



COMPUTER
READY
COMMAND DATA SOURCE
TAPE
COMPUTER
MANUA
5 1/4 REF

1A


ANTENNA POSITION PROGRAMMER
MANUAL
COMPUTER
TAPE
ADD
ERROR
STORE
ERROR
OFFSET
ANGLES
ADD
TIME
COMMAND/OFFSET
X ANGLE
19 REF

II-9-10-A

2#

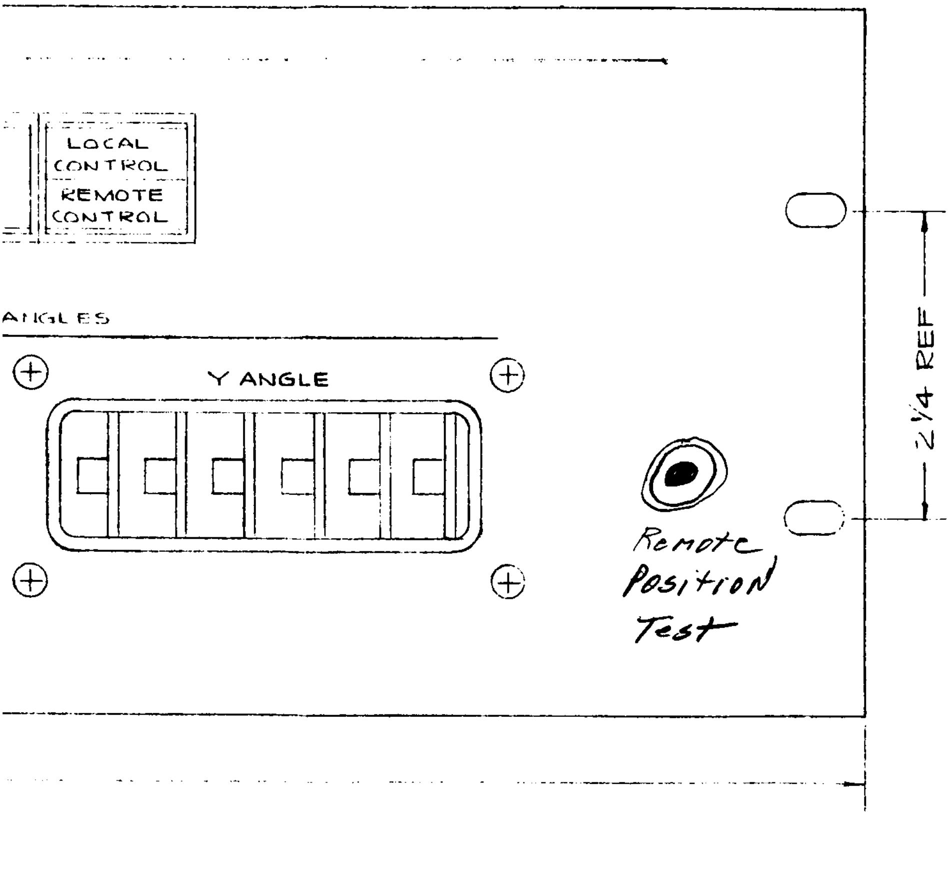


Figure 9-2. Programmer Remote Control Panel

9.2.4.5 HEAT DISSIPATION. The heat dissipation for the programmer is 3740 watts.

9.3 MECHANICAL DESCRIPTION.

9.3.1 RACKS.

The antenna position programmer will be housed in 3-1/2 racks, (see figure 9-3). Since the programmer and tracking data processor are combined into one system, rack four is shared with the TDP. (See figure 9-4.) The programmer system racks are 69 inches high, 26 inches deep and 9 feet wide. The combined programmer and tracking data processor racks are approximately 15 feet, 6-3/4 inches wide.

9.3.2 FINISH.

The finish for the exterior racks will be semi-gloss Federal Standard 595 grey, number 26440. Front panels and control panels will be painted the Collins standard color scheme used on TE-404 and other data systems supplied to GSFC.

9.3.3 COOLING.

The programmer racks will use standard Collins computer type forced-air cooling which has been used on Collins TE-404 and other data systems supplied to GSFC. The blowers are mounted at the bottom rear and intake air from the control room through filters.

9.3.4 RACK CABLE ENTRY.

The Collins programmer racks have been designed to provide for signal cable entry from the bottom (through the floor). A cable access area of 3-1/4 inches x 9 inches is available from the bottom where two racks adjoin and an access area of 1-5/8 inches x 9 inches is available on the outer sides of the end racks.

9.3.5 CONTROL PANEL LAYOUT.

The programmer control panel layout is shown in figure 9-5. Master Specialities Company "Twist-lite" series 10 switches and indicators have been standardized and are used through the data system.

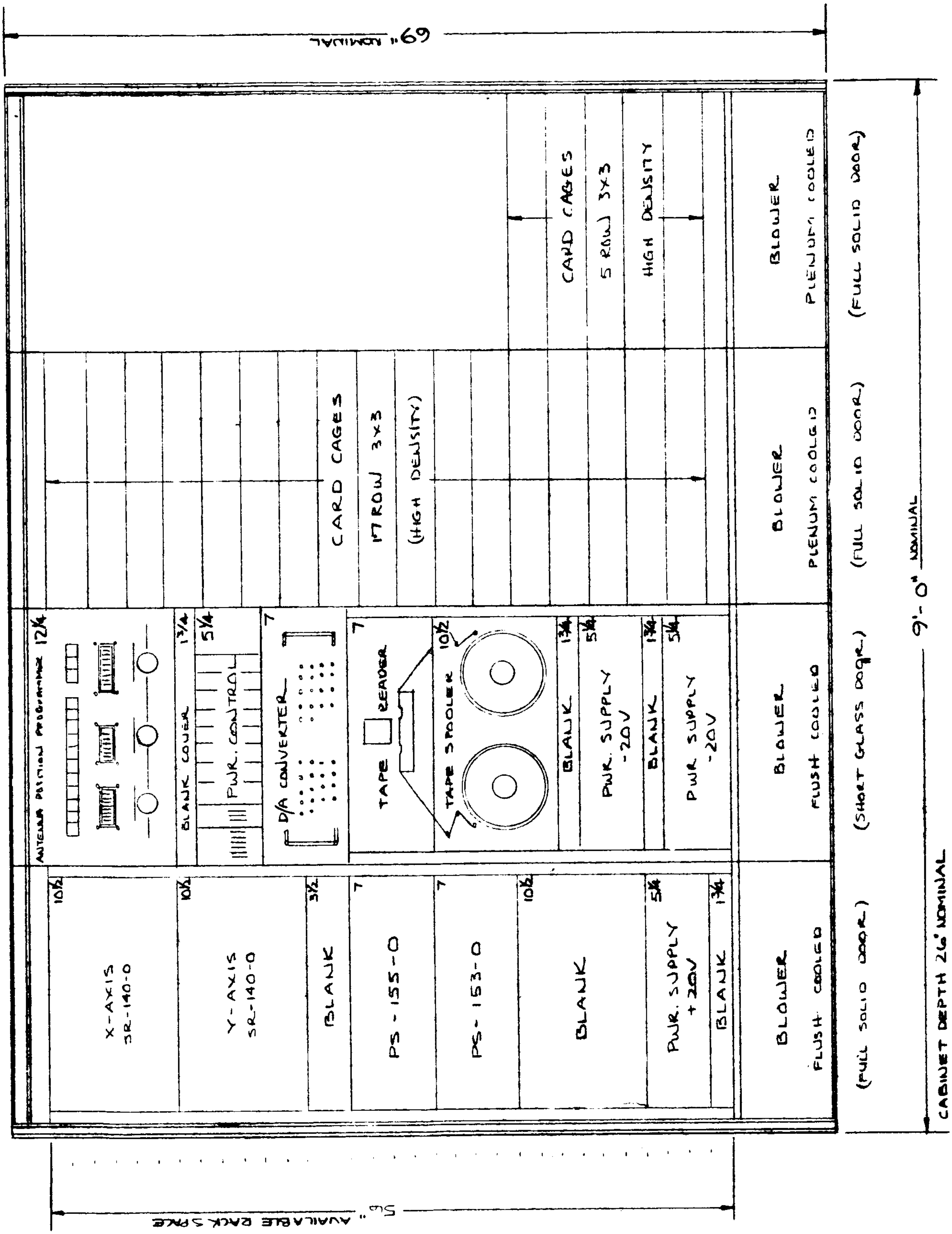
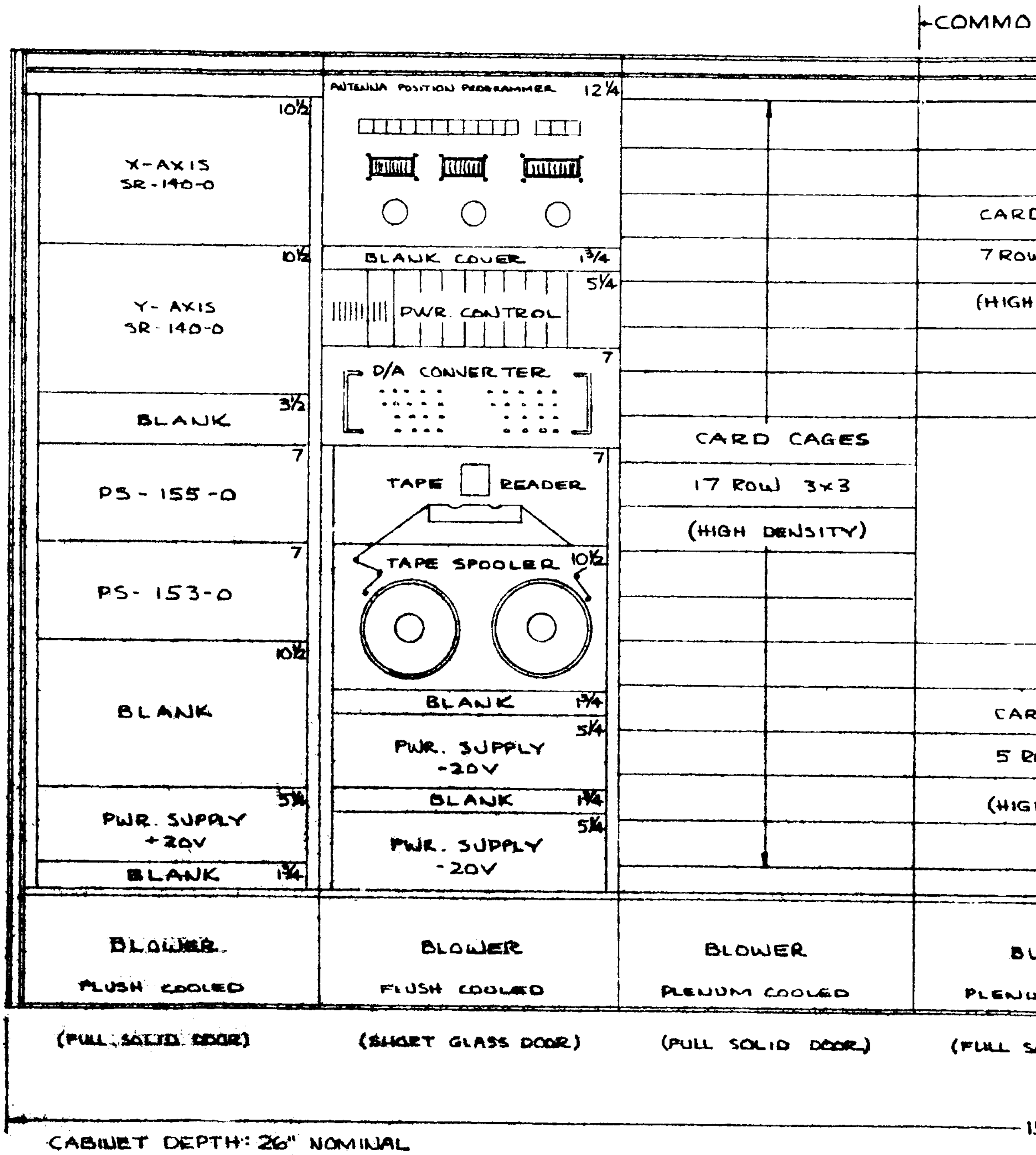


Figure 9-3. Bay Layout TE-409 Antenna Position Programmer

ANTENNA POSITION PROGRAMMER



1#

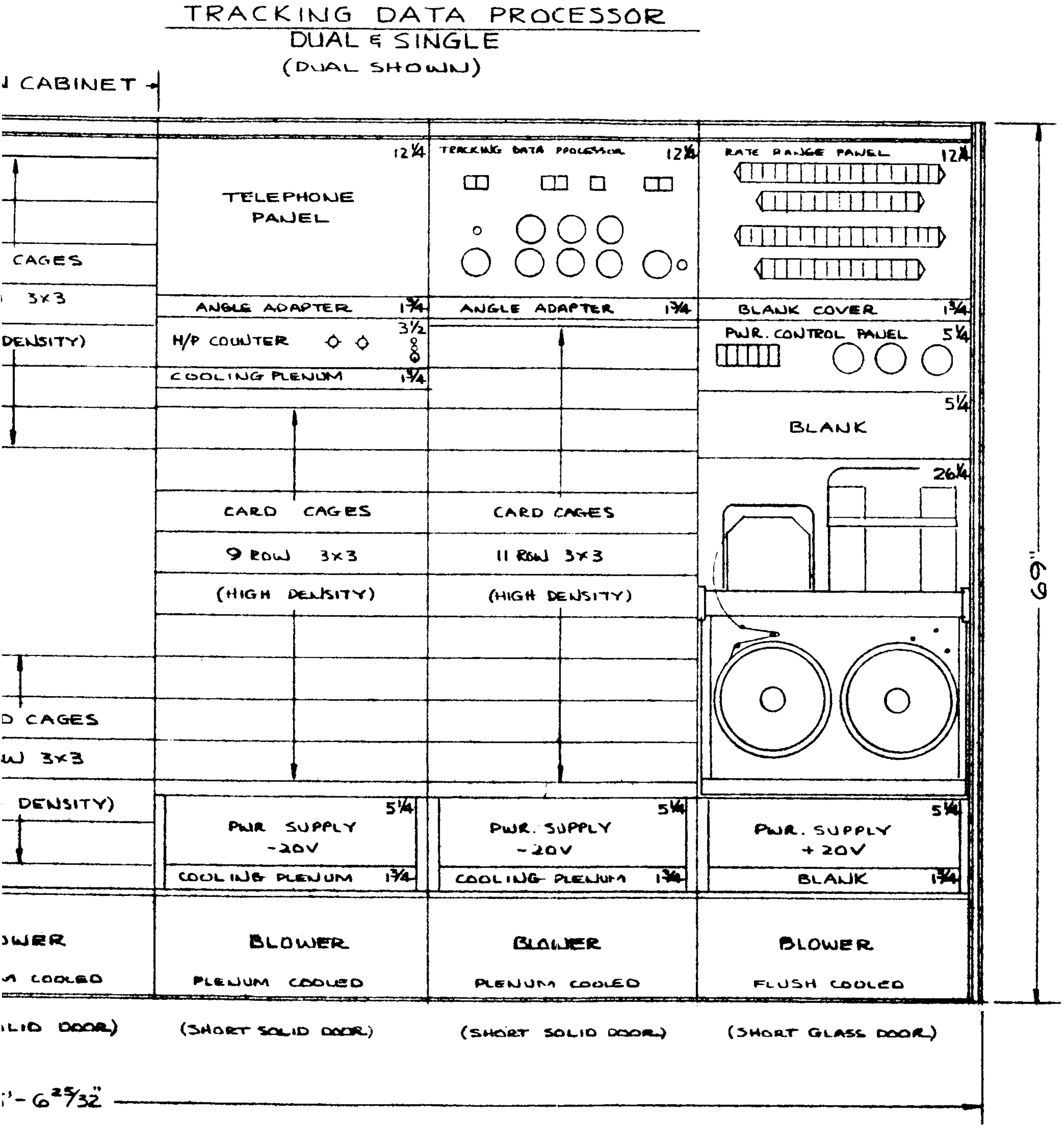
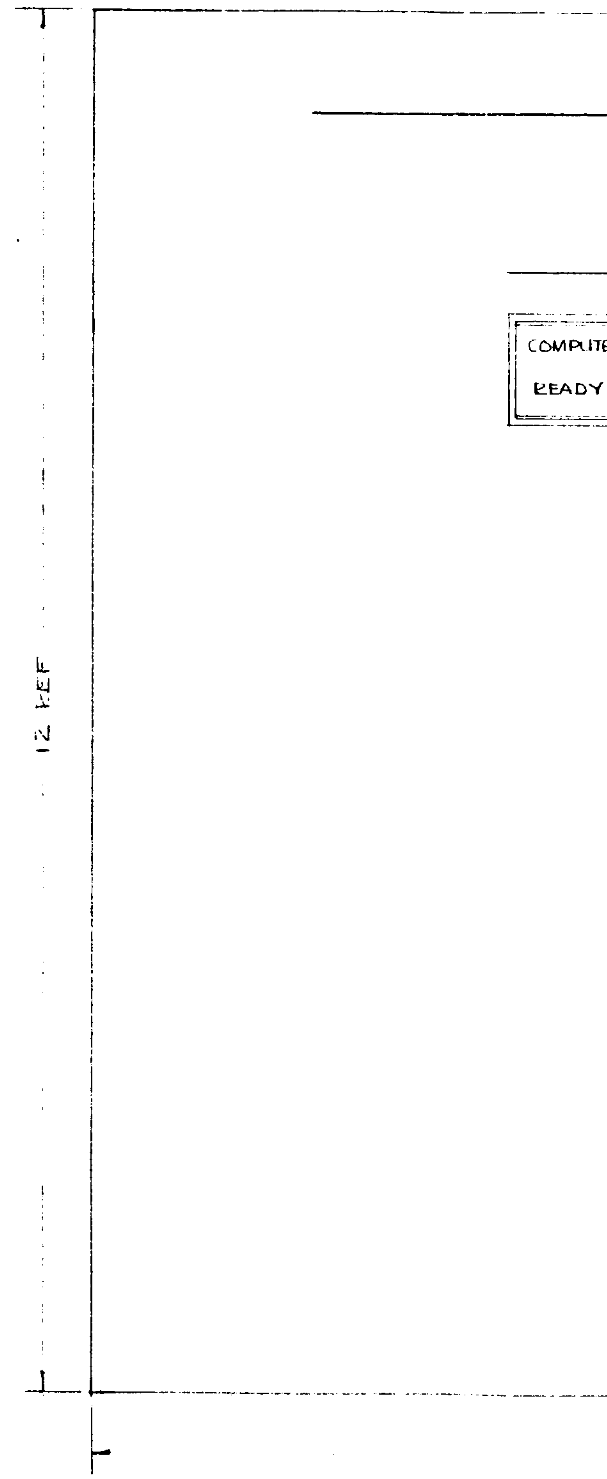
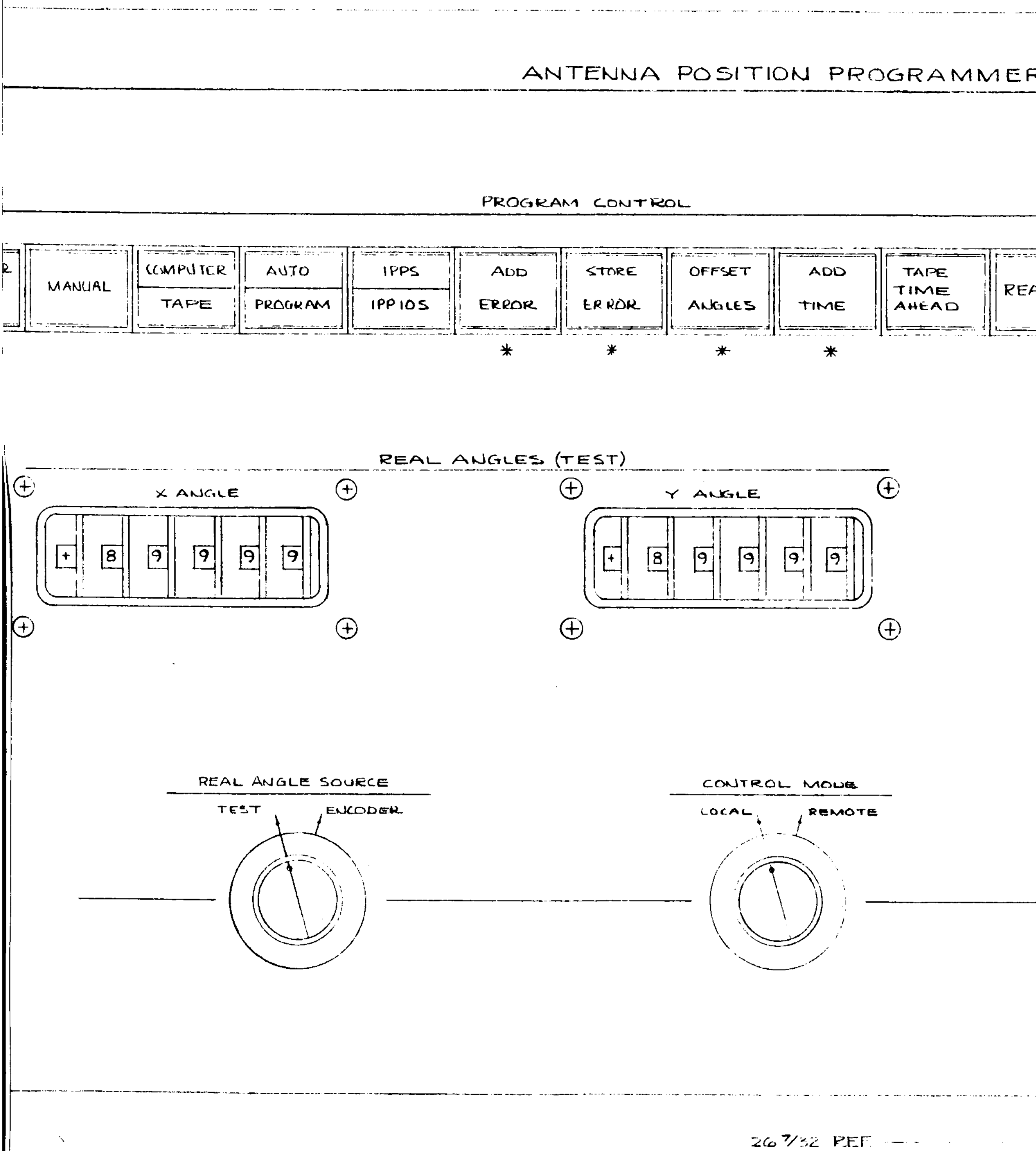


Figure 9-4. Bay Layout TE-409 Antenna Position Programmer and TE-410/410A Tracking Data Processor Combined Systems

2#


12 REF
COMPUTE
READY

,#


ANTENNA POSITION PROGRAMMER
PROGRAM CONTROL
MANUAL
COMPUTER
TAPE
AUTO
PROGRAM
1PPS
1PP10S
ADD
ERROR
STORE
ERROR
OFFSET
ANGLES
ADD
TIME
TAPE
TIME
AHEAD
REAL ANGLES (TEST)
X ANGLE
+ 8 9 9 9 9
Y ANGLE
+ 8 9 9 9 9
REAL ANGLE SOURCE
TEST
ENCODER
CONTROL MODE
LOCAL
REMOTE
26 7/32 REF

II-9-14-A

2#

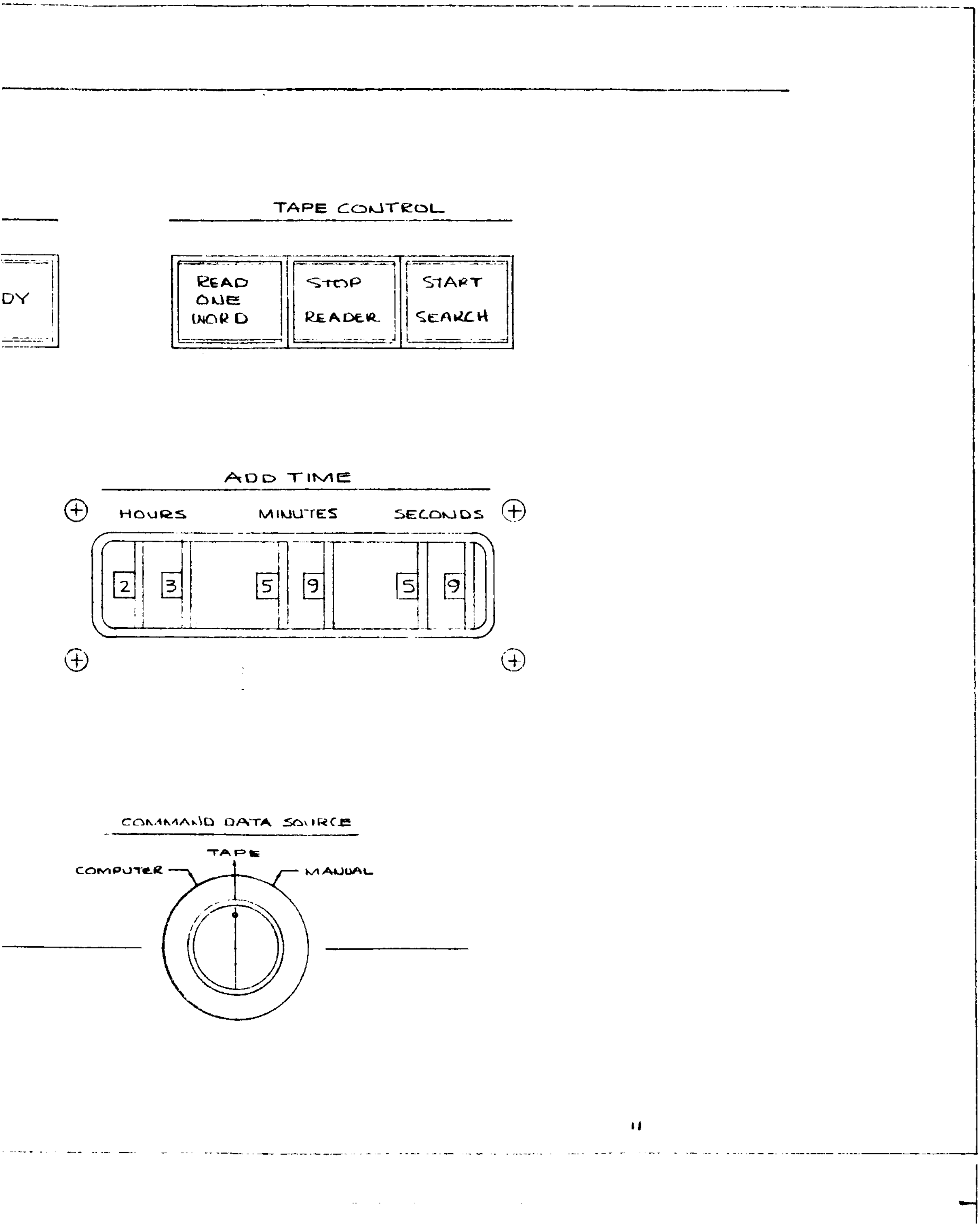


Figure 9-5. Control Panel, Antenna Position Programmer

9.4 RELIABILITY ANALYSIS.

Reference is made to appendix c, "Preliminary Reliability Analysis Report" dated 30 September 1964, for an analysis. A brief summary of this report is given as follows.

9.4.1 BASIC ASSUMPTION AND SOURCES OF DATA.

(1) The programmer subsystem is comprised entirely of equipment that is functionally in an on-line status. The reliability analysis is that of a pure series model for all parts, cards and purchased equipment.

(2) The failure rates for the C-8000 circuit cards have been obtained primarily from operating experience at the Collins Cedar Rapids Computer Terminal. These cards have undergone a total of 150 million circuit card operating hours. They have experienced an average failure rate of 0.064 percent per 1000 hours per card over all card types for the last 108 million hours of operation.

(3) The quantities used for parts and circuit cards are preliminary and are thus subject to some change as the detailed design becomes firm. These changes are expected to be relatively minor, however.

(4) The failure rate values for all purchased equipment are rough approximations since suppliers have not been selected at this time. These will be up-graded as supplier estimates are received and as detailed analyses are submitted subsequent to contract awards.

9.4.2 FAILURE RATE ANALYSIS (Inlet Temperature 85°F).

Quantity	Item Description	Subtotal Failure Rate %/1000 hours
1100	Circuit cards subtotal	78.93%
11	Purchased equipment subtotal	* 59.0 %
81	Miscellaneous parts subtotal	2.43%
Subsystem total failure rate		140.36%/1000 hours
Subsystem MTBF		** 712 hours

* Indicates preliminary estimate, subject to revision after supplier selection has been made.

** $\text{MTBF} = \dfrac{10^5}{\text{F.R. \%/1000 Hr.}}$

section 10

tracking data processor

10.1 GENERAL DESCRIPTION.

The tracking data processor (TDP) system performs the following functions:

(1) Provides as an output, time, X and Y angles, range and range rate information, in serial form compatible with two types of communications links - high speed (2400, 2000, 1200, or 600 bits per second) and low speed 100 wpm teletype. Arranges this data in proper format and adds the station identification and other functional information in the process. Sources of the data are the ranging system, the antenna shaft angle encoding system, the timing system, and the servo system.

(2) Accepts range rate data in analog form and processes this data varying the sampling rates and measurement periods and generating doppler destruct and doppler non-destruct modes.

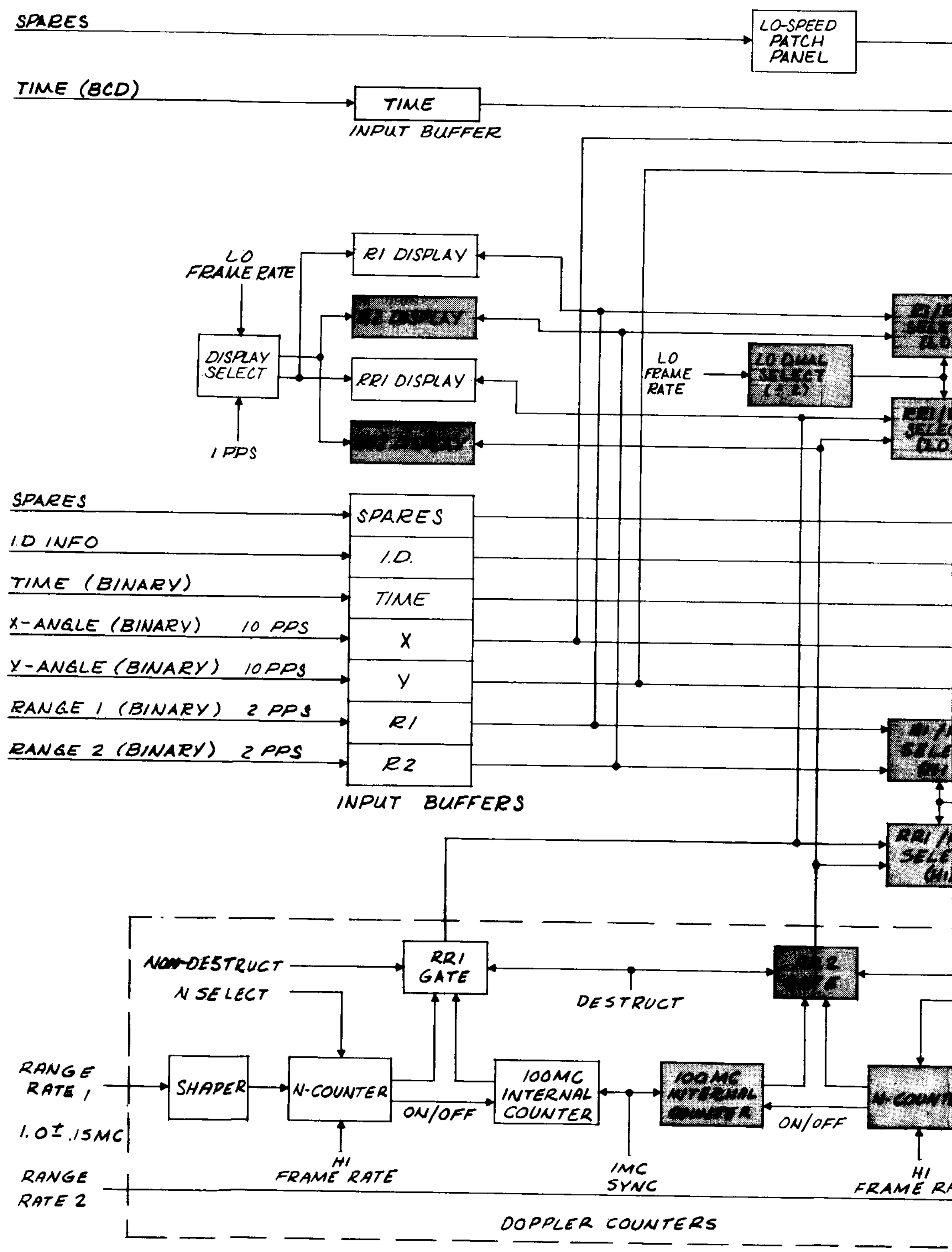
(3) Provides for the recording of the high speed data on a GFE magnetic tape recorder in the event of communications failure enabling data recovery in post real time.

(4) Converts the slow speed data from straight binary to octal. Also records this slow speed data on punched paper tape.

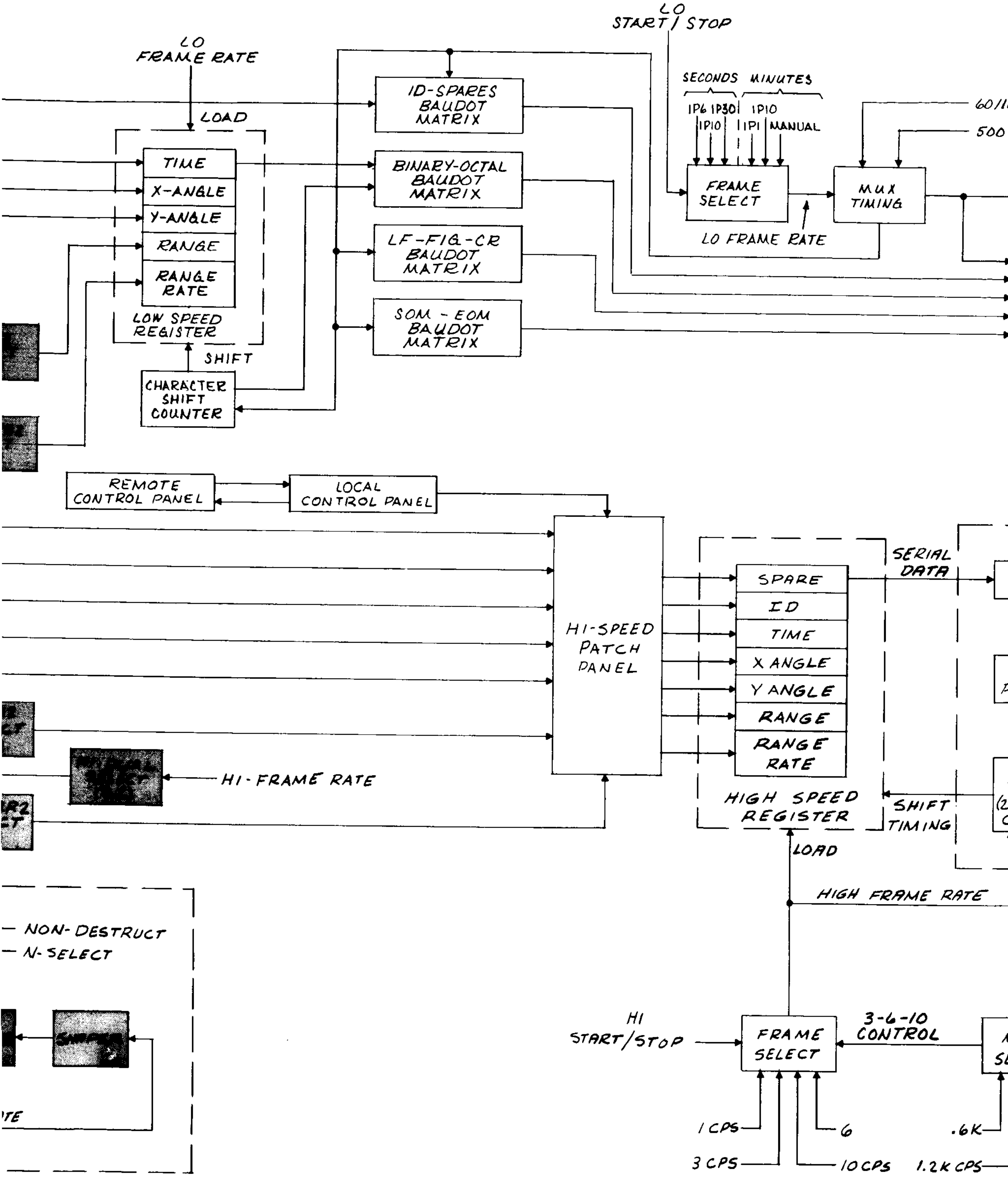
10.2 ELECTRICAL DESCRIPTION.

10.2.1 GENERAL.

A description of the TDP is given as follows (see figure 10-1).


SPARES
LO-SPEED PATCH PANEL
TIME (BCD)
TIME
INPUT BUFFER
LO FRAME RATE
R1 DISPLAY
DISPLAY SELECT
RR1 DISPLAY
1 PPS
LO FRAME RATE
SPARES
I.D INFO
TIME (BINARY)
X-ANGLE (BINARY) 10 PPS
Y-ANGLE (BINARY) 10 PPS
RANGE 1 (BINARY) 2 PPS
RANGE 2 (BINARY) 2 PPS
SPARES
I.D.
TIME
X
Y
R1
R2
INPUT BUFFERS
NON-DESTRUCT
N SELECT
RR1 GATE
DESTRUCT
RANGE RATE 1
1.0± .15MC
SHAPER
N-COUNTER
ON/OFF
100MC INTERNAL COUNTER
ON/OFF
HI FRAME RATE
1MC SYNC
HI FRAME RA
RANGE RATE 2
DOPPLER COUNTERS

1#


LO FRAME RATE
LOAD
TIME
X-ANGLE
Y-ANGLE
RANGE
RANGE RATE
LOW SPEED REGISTER
SHIFT
CHARACTER SHIFT COUNTER
ID-SPARES BAUDOT MATRIX
BINARY-OCTAL BAUDOT MATRIX
LF-FIG-CR BAUDOT MATRIX
SOM - EOM BAUDOT MATRIX
LO START / STOP
SECONDS MINUTES
IP6 IP30 IP10 IP10 IP1 MANUAL
FRAME SELECT
LO FRAME RATE
MUX TIMING
60/1
500
REMOTE CONTROL PANEL
LOCAL CONTROL PANEL
HI-SPEED PATCH PANEL
HI-FRAME RATE
SPARE
ID
TIME
X ANGLE
Y ANGLE
RANGE
RANGE RATE
HIGH SPEED REGISTER
SERIAL DATA
SHIFT TIMING
LOAD
HIGH FRAME RATE
NON-DESTRUCT
N-SELECT
HI START/STOP
FRAME SELECT
3-6-10 CONTROL
1 CPS
3 CPS
6
10 CPS
.6K
1.2K CPS

2#

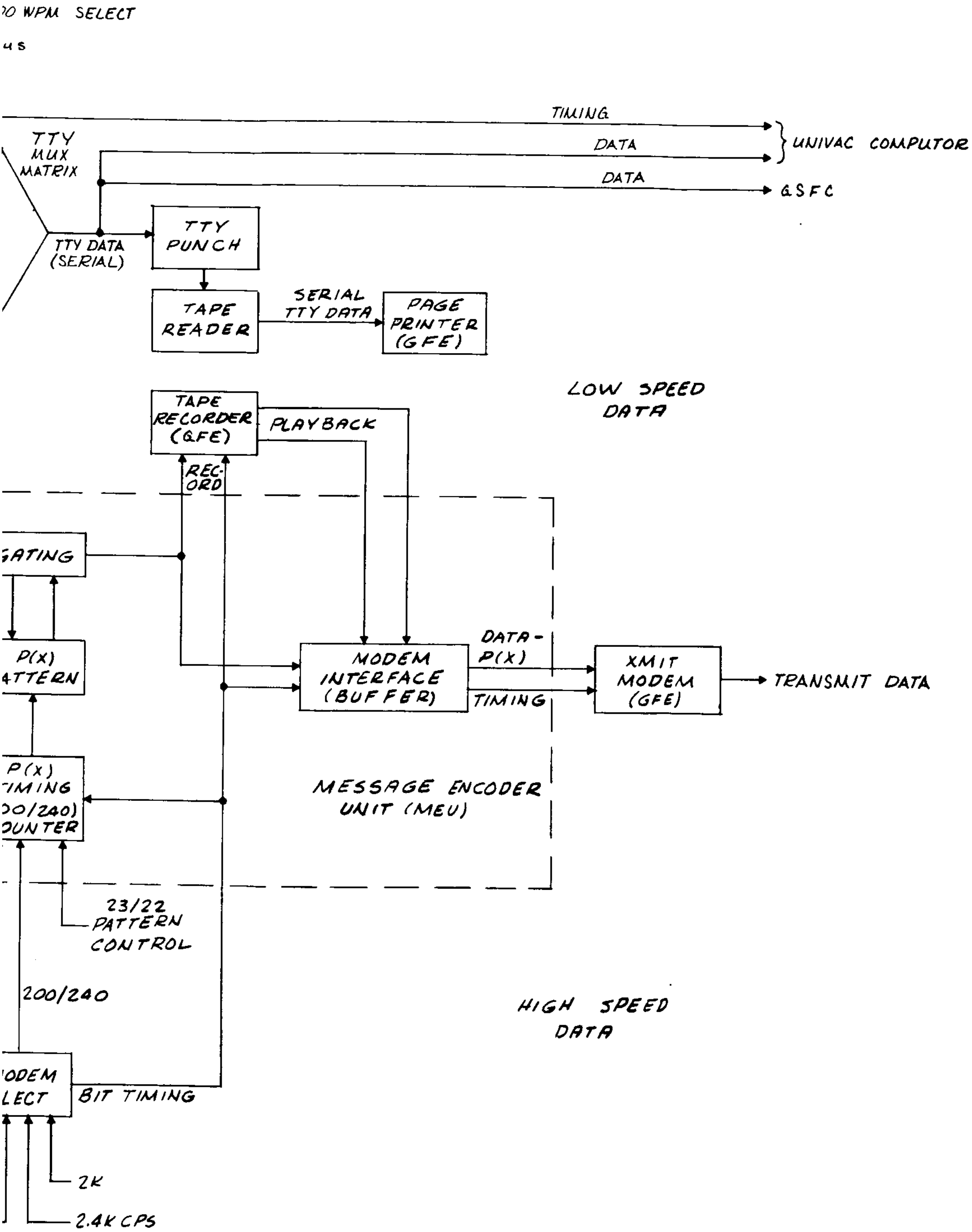


Figure 10-1. Tentative Block Diagram, Tracking Data Processor (TDP)

External data for processing, recording, and transmitting is supplied to the TDP, as follows:

PARAMETER	SUPPLIED FROM
Time:	The timing system
X & Y real angles:	The antenna position encoding system
Range:	The range and range rate system
Range rate (doppler):	The range and range rate system
Autotrack switch contacts:	The servo system

The above data is processed, stored, coded, read out in a serial binary bit stream (high speed format) for transmission by a high speed data link. The data is also converted to octal form and transmitted in Baudot on a low speed tty link. The high speed format is recorded on magnetic tape and the low speed format is recorded on punched paper tape.

10.2.2 ERROR DETECTION CODE GENERATOR.

The design of the error detection code generator is described in Collins specification no. 511-4524. See appendix e.

10.2.3 DUAL RANGE AND RANGE RATE CAPABILITY.

For the dual range and range rate capability, one tracking data processor is provided which is designed to process range and doppler information from two vehicles simultaneously in the non-destruct mode and alternately in the destruct mode. Range and range rate for LEM and CSM will be transmitted on alternate data frames for both the high speed and low speed tty transmitting links.

10.2.4 SYSTEM IMPROVEMENTS.

The tracking data processor has been designed to increase reliability in two areas:

(1) Deletion of RI register (Figure II of GSFC specification). As shown in Figure II, time, angles, and range are stored in RI for 0.1 seconds or 1 second (depending on the rate selected) during the period required to count the doppler word. The data is then transmitted with a one-time frame lag which the GSFC computer compensates for.

Collins/ISC design deletes the RI register. The doppler word is read first and at the end of the counting period, time, angles, and range are read out and the format is then transmitted or recorded in real time with no time lag. This approach increases reliability since fewer circuit cards and components are required.

(2) Doppler 100-mc Counter. The Hewlett-Packard 100 mc counter, model 5275A, required by the present specification, provides an output in BCD form. Since the high speed format is transmitted in binary form, a BCD to binary converter must be provided. Collins/ISC design uses a 100 mc counter providing an output in binary form, rather than BCD form. This approach deletes the requirement for a BCD to binary converter, thereby increasing reliability since fewer circuits and components are required.

10.2.5 DOPPLER COUNTER SUBSYSTEM, SINGLE.

(Single capability) for shipboard use. A separate doppler counter subsystem, single capability, is provided for shipboard installation. Basically, the doppler counter performs the same functions as the ground station systems. The doppler output signal is in serial straight binary form. Sync pulses are provided with the readout. Both destruct and non-destruct counts are available.

This equipment will be designed for shipboard use and will meet the requirements of Enclosure I to Exhibit F of NASA RFP 10001, dated 18 November 1963.

The equipment will be designed for standard 19-inch rack mounting in accordance with SE-102, Electronic Industries Association Standard, Panel Mounted Racks, Panels and Associated Equipment.

10.2.6 DOPPLER COUNTER SUBSYSTEM, DUAL.

(Dual capability) for shipboard use. A separate doppler counter subsystem, dual capability, is provided for shipboard installation. This equipment provides the capability to readout doppler information from two vehicles simultaneously. The data rate is expected to be less than two samples per second for each vehicle.

The requirements for the dual capability doppler counter subsystem are the same as outlined in paragraph 10.2.5.

10.2.7 INPUT SIGNAL CHARACTERISTICS.

The following signals are provided to the TDP. (NOTE: Since Collins/ISC is designing and integrating the TDP, programmer and timing system into one data system the signals supplied between these subsystems are not described.)

(1) Antenna position (From Encoding System)

X angle:	17 binary bits (parallel)
X angle sign:	1 binary bit
Y angle:	17 binary bits (parallel)
Y angle sign:	1 binary bit
binary 1:	0.0 ±0.5 volts
binary 0:	-6.0 ±0.5 volts
positive angles:	binary 1
negative angles:	binary 0

(2) Range. [From Range and Range Rate System (GFP)]

(a) Range:	30 binary bits (parallel)
	binary 1 = 0.0 ±0.5 volts
	binary 0 = -6.0 ±0.5 volts
(b) Range acquisition (R_A):	1 binary bit
R_A acquired:	binary 1 (contact closure)
R_A not acquired:	binary 0 (open contacts)
(c) Range data quality (R_{DQ}):	1 binary bit
R_{DQ} good data:	binary 1 (contact closure)
R_{DQ} bad data:	binary 0 (open contact)

NOTE: the dry contact closures for R_A and R_{DQ} are to be provided on 2 wires each.

(3) Range Rate (Doppler) [From Range and Range Rate System (GFP)]

(a) Doppler:	analog signal, 1 volt rms
	1 ±0.15 mc

(b) Range rate data quality (RR_{DQ}): 1 binary bit

RR_{DQ} good data: binary 1 (contact closure)

RR_{DQ} bad data: binary 0 (contacts open)

(c) Object number: 1 binary bit

LEM: binary 1 (contact closure)

CSM: binary 0 (contact open)

NOTE: the dry contact closures for RR_{DQ} and object number are to be provided on 2 wires each.

(4) On-track from servo control system

On-track: 1 binary bit

Autotrack: binary 1 (contact closure)

Other: binary 0 (contact open)

NOTE: this signal (dry contact closure) will be provided on 2 wires.

(5) Frequency standard selection from frequency standard system (GFP)

Frequency standard identification: 1 binary bit

Primary standard: binary 1 (contact closure)

Secondary standard: binary 0 (contacts open)

NOTE: the dry contact closure for frequency standard identification will be provided on 2 wires.

10.2.8 OUTPUT SIGNAL CHARACTERISTICS.

The output of the tracking data processor consists of 2 formats:

High speed format: 200 binary bits

Low speed format: 60 characters Baudot code

10.2.8.1 HIGH SPEED FORMAT. The high speed format consists of 200 bits for transmission at rates of 600, 1200, or 2000 pps by the MODEM (GFE). Provisions are made to transmit a 240-bit format at a rate of 2400 pps.

The 200-bit high speed format is given in table 10-1.

TABLE 10-1. HIGH SPEED FORMAT

BIT NUMBER	BIT DESCRIPTION	BIT LOGIC *
1	Start of Frame	
2	Start of Frame	
3	Start of Frame	
4	Start of Frame	
5	Start of Frame	
6	Start of Frame	
7	Start of Frame	
8	Station Identification	
9	Station Identification	
10	Station Identification	
11	Station Identification	
12	Station Identification	
13	Range Rate Destruct/Non-Destruct	Destruct = Binary 1 Non-Destruct = Binary 0
14	Range Rate N_1/N_2	N_1 = Binary 1 N_2 = Binary 0
15	Range Rate 10 ps/1 ps	10 ps = Binary 1 1 ps = Binary 0
16	Real/Test Data	Real Data = Binary 1 Test Data = Binary 0
17	Spare	
18	Spare	
19	Object Number	LEM = Binary 1 Command = Binary 0
20	On-Track	Autotrack = Binary 1 Other = Binary 0
21	Manual Good/Bad Data	Data Good (Manual) = Binary 1 Data Bad (Manual) = Binary 0

TABLE 10-1. HIGH SPEED FORMAT (CONT)

BIT NUMBER	BIT DESCRIPTION	BIT LOGIC *
22	Doppler Mode	One Way = Binary 0 Two Way = Binary 0 Multiple = Binary 1 Spare = Binary 1
23	Doppler Mode	One Way = Binary 0 Two Way = Binary 1 Multiple = Binary 0 Spare = Binary 1
24	Frequency Standard Identification	Primary = Binary 1 Secondary = Binary 0
25	Spare	
26	Time (T_{29}) most significant bit	
27	(T_{28})	
28	(T_{27})	
29	(T_{26})	
30	(T_{25})	
31	(T_{24})	
32	(T_{23})	
33	(T_{22})	
34	(T_{21})	
35	(T_{20})	
36	(T_{19})	
37	(T_{18})	
38	(T_{17})	
39	(T_{16})	

TABLE 10-1. HIGH SPEED FORMAT (CONT)

BIT NUMBER	BIT DESCRIPTION	BIT LOGIC *
40	Time(T_{15})	
41	(T_{14})	
42	(T_{13})	
43	(T_{12})	
44	(T_{11})	
45	(T_{10})	
46	(T_9)	
47	(T_8)	
48	(T_7)	
49	(T_6)	
50	(T_5)	
51	(T_4)	
52	(T_3)	
53	(T_2)	
54	Time (T_1) least significant bit	
55	Antenna Angle X sign	Positive X angles = Binary 1 Negative X angles = Binary 0
56	Antenna Angle (X_{17}) most significant bit	
57	(X_{16})	
58	(X_{15})	
59	(X_{14})	

TABLE 10-1. HIGH SPEED FORMAT (CONT)

BIT NUMBER	BIT DESCRIPTION	BIT LOGIC *
60	Antenna Angle (X_{13})	
61	(X_{12})	
62	(X_{11})	
63	(X_{10})	
64	(X_9)	
65	(X_8)	
66	(X_7)	
67	(X_6)	
68	(X_5)	
69	(X_4)	
70	(X_3)	
71	(X_2)	
72	Antenna Angle (X_1) least significant bit	
73	Antenna Angle Y sign	Positive Y angles = Binary 1 Negative Y angles = Binary 0
74	Antenna Angle (Y_{17}) most significant bit	
75	(Y_{16})	
76	(Y_{15})	
77	(Y_{14})	
78	(Y_{13})	
79	(Y_{12})	

TABLE 10-1. HIGH SPEED FORMAT (CONT)

BIT NUMBER	BIT DESCRIPTIONC	BIT LOGIC *
80	Antenna Angle (Y_{11})	
81	(T_{10})	
82	(Y_9)	
83	(Y_8)	
84	(Y_7)	
85	(Y_6)	
86	(Y_5)	
87	(Y_4)	
88	(Y_3)	
89	(Y_2)	
90	Antenna Angle (Y_1) least significant bit	
91	Range Data Quality (R_{DQ})	R_{DQ} good data = Binary 1 R_{DQ} bad data = Binary 0
92	Range Acquisition (R_A)	R_A acquired = Binary 1 R_A not acquired = Binary 0
93	Range (R_{30}) most significant bit	
94	(R_{29})	
95	(R_{28})	
96	(R_{27})	
97	(R_{26})	

TABLE 10-1. HIGH SPEED FORMAT (CONT)

BIT NUMBER	BIT DESCRIPTION	BIT LOGIC *
98	Range (R_{25})	
99	(R_{24})	
100	(R_{23})	
101	(R_{22})	
102	(R_{21})	
103	(R_{20})	
104	(R_{19})	
105	(R_{18})	
106	(R_{17})	
107	(R_{16})	
108	(R_{15})	
109	(R_{14})	
110	(R_{13})	
111	(R_{12})	
112	(R_{11})	
113	(R_{10})	
114	(R_{9})	
115	(R_{8})	
116	(R_{7})	
117	(R_{6})	
118	(R_{5})	

TABLE 10-1. HIGH SPEED FORMAT (CONT)

BIT NUMBER	BIT DESCRIPTION	BIT LOGIC *
119	Range (R_4)	
120	(R_3)	
121	(R_2)	
122	Range (R_1) least significant bit	
123	Spare	
124	Spare	
125	Spare	
126	Spare	
127	Spare	
128	Spare	
129	Spare	
130	Spare	
131	Range Rate Data Quality (RR_{DQ})	RR_{DQ} good data = Binary 1 RR_{DQ} bad data = Binary 0
132	Range Rate (RR_{35}) most significant bit	
133	(RR_{34})	
134	(RR_{33})	
135	(RR_{32})	
136	(RR_{31})	
137	(RR_{30})	
138	(RR_{29})	

TABLE 10-1. HIGH SPEED FORMAT (CONT)

BIT NUMBER	BIT DESCRIPTION	BIT LOGIC *
139	(RR_{28})	
140	(RR_{27})	
141	(RR_{26})	
142	(RR_{25})	
143	(RR_{24})	
144	(RR_{23})	
145	(RR_{22})	
146	(RR_{21})	
147	(RR_{20})	
148	(RR_{19})	
149	(RR_{18})	
150	(RR_{17})	
151	(RR_{16})	
152	(RR_{15})	
153	(RR_{14})	
154	(RR_{13})	
155	(RR_{12})	
156	(RR_{11})	
157	(RR_{10})	
158	(RR_{9})	

TABLE 10-1. HIGH SPEED FORMAT (CONT)

BIT NUMBER	BIT DESCRIPTION	BIT LOGIC *
159	(RR_8)	
160	(RR_7)	
161	(RR_6)	
162	(RR_5)	
163	(RR_4)	
164	(RR_3)	
165	(RR_2)	
166	Range Rate (RR_1) least significant bit	
167	Error Code (EC_{33}) most significant bit	
168	(EC_{32})	
169	(EC_{31})	
170	(EC_{30})	
171	(EC_{29})	
172	(EC_{28})	
173	(EC_{27})	
174	(EC_{26})	
175	(EC_{25})	
176	(EC_{24})	
177	(EC_{23})	
178	(EC_{22})	
179	(EC_{21})	

TABLE 10-1. HIGH SPEED FORMAT (CONT)

BIT NUMBER	BIT DESCRIPTION	BIT LOGIC *
180	Error Code (EC_{20})	
181	(EC_{19})	
182	(EC_{18})	
183	(EC_{17})	
184	(EC_{16})	
185	(EC_{15})	
186	(EC_{14})	
187	(EC_{13})	
188	(EC_{12})	
189	(EC_{11})	
190	(EC_{10})	
191	(EC_{9})	
192	(EC_{8})	
193	(EC_{7})	
194	(EC_{6})	
195	(EC_{5})	
196	(EC_{4})	
197	(EC_{3})	
198	(EC_{2})	
199	Error Code (EC_{1}) least significant bit	

TABLE 10-1. HIGH SPEED FORMAT (CONT)

BIT NUMBER	BIT DESCRIPTION	BIT LOGIC *
200	Communications Synchronization	Binary 1 - does not exist Binary 0 - hard wired

* Logic

All data in the high speed format is in straight binary form. A binary 1 is represented by 0.0 ±0.5 volts dc and a binary 0 is represented by -6.0 ±0.5 volts dc.

10.2.8.2 LOW SPEED FORMAT.

The low speed format consists of 60 characters of 5 level tty Baudot code. Rate, control characters, angles, range and range rate, object number and range and range data quality are octal numbers obtained from the high speed binary bit format. The low speed format is given in table 10-2.

TABLE 10-2. LOW SPEED DATA FORMAT

CHARACTER NUMBER	DESCRIPTION	CHARACTER NUMBER	DESCRIPTION
1	LF	13	T Day-Tens
2	Figs	14	T Hour-Tens
3	Station-ID-Tens	15	T Hour-Units
4	Station-ID-Units	16	T Minute-Tens
5	Rate 8^1	17	T Minute-Units
6	Rate 8^0	18	T Second-Tens
7	DCC 8^1	19	T Second-Units
8	DCC 8^0	20	Spare 2
9	Object 8^0	21	X Angle 8^5
10	Spare 1	22	X Angle 8^4
11	T Day-Hours	23	X Angle 8^3
12	T Day-Units	24	X Angle 8^2

TABLE 10-2. LOW SPEED DATA FORMAT (CONT)

CHARACTER NUMBER	DESCRIPTION	CHARACTER NUMBER	DESCRIPTION
25	X Angle 8^1	43	R 8^2
26	X Angle 8^0	44	R 8^1
27	Spare 3	45	R 8^0
28	Y Angle 8^5	46	Spare 5
29	Y Angle 8^4	47	RR 8^{11}
30	Y Angle 8^3	48	RR 8^{10}
31	Y Angle 8^2	49	RR 8^9
32	Y Angle 8^1	50	RR 8^8
33	Y Angle 8^0	51	RR 8^7
34	Spare 4	52	RR 8^6
35	R-RR DQ	53	RR 8^5
36	R 8^9	54	RR 8^4
37	R 8^8	55	RR 8^3
38	R 8^7	56	RR 8^2
39	R 8^6	57	RR 8^1
40	R 8^5	58	RR 8^0
41	R 8^4	59	Spare 6
42	R 8^3	60	CR

10.2.8.3 HIGH-SPEED DATA INTERFACE REQUIREMENTS. The interface requirements of the TDP with the MODEM (GFE) and magnetic tape recorder, FR-600 (GFE) are described in Collins specification no. 270-2175. See appendix f.

10.2.8.4 COMPUTER INTERFACE FOR SMOOTHING HIGH-SPEED FORMAT. Collins will provide the high-speed format in serial form along with sync pulses. Collins will not provide buffers or storage registers. It is assumed the computer will be capable of accepting serial data at logic levels of 0 and -6 volts. Collins equipment will not be required to drive over 100 feet of cable.

10.2.8.5 LOW SPEED TTY INTERFACE. The TDP is designed to operate with either 60wpm or 100 wpm teletype transmission links (GFE). This format is in 5-level Baudot code. The battery (loop current) for the tty loop will be supplied GFE.

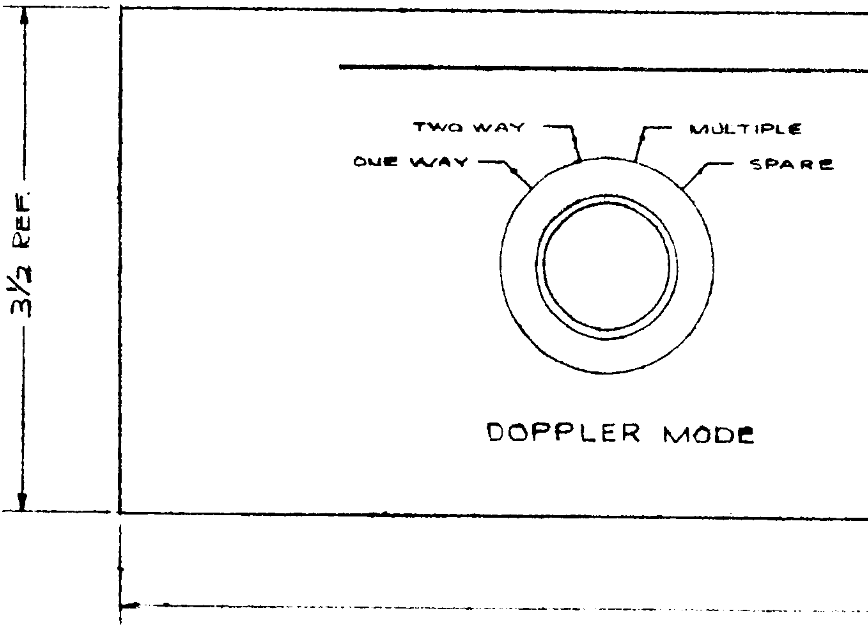
10.2.8.6 PAGE PRINTER (GFP) INTERFACE. The page printer for printing out the low speed tty format will be supplied GFP. The battery (loop current) will also be GFP. The page printer will accept the output of the punched tape transmitted by the "transmitter distributor" in 5 level Baudot standard tty code.

10.2.8.7 HIGH-SPEED PUNCH. The punch to record the low-speed tty format will be a 100 wpm punch since the system does not require the use of a high-speed punch like the BRPE-9 or BRPE-11. The punch will provide 5-level, Baudot code, nonchadless (fully perforated) tape.

10.2.8.8 VISUALS DISPLAYS. The tracking data processor will provide as an output Range and Doppler displayed in octal form. The octal display rate will change with the low-speed format rate selected. For dual stations, displays will be provided for both LEM and CSM vehicles.

10.2.8.9 REMOTE CONTROL PANEL. A remote control panel is provided to be located at the servo control console. The following TDP controls and indicators are made available to the servo operator (see figure 10-2):

(1)	Doppler Mode:	one way
		two way
		multiple
		spare
(2)	High-Speed Data:	start
		stop
(3)	Low-Speed Data:	start
		stop
(4)	Good/Bad Data Mode	
(5)	Local/Remote Control Mode	



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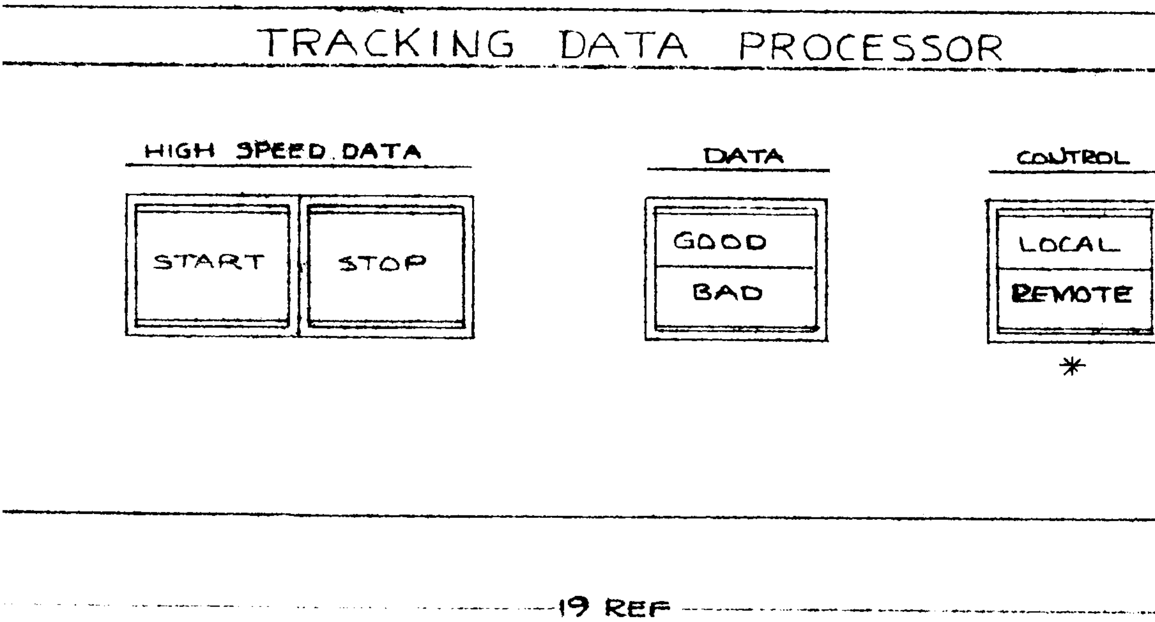

TRACKING DATA PROCESSOR
HIGH SPEED DATA
START
STOP
DATA
GOOD
BAD
CONTROL
LOCAL
REMOTE
*
19 REF

2#

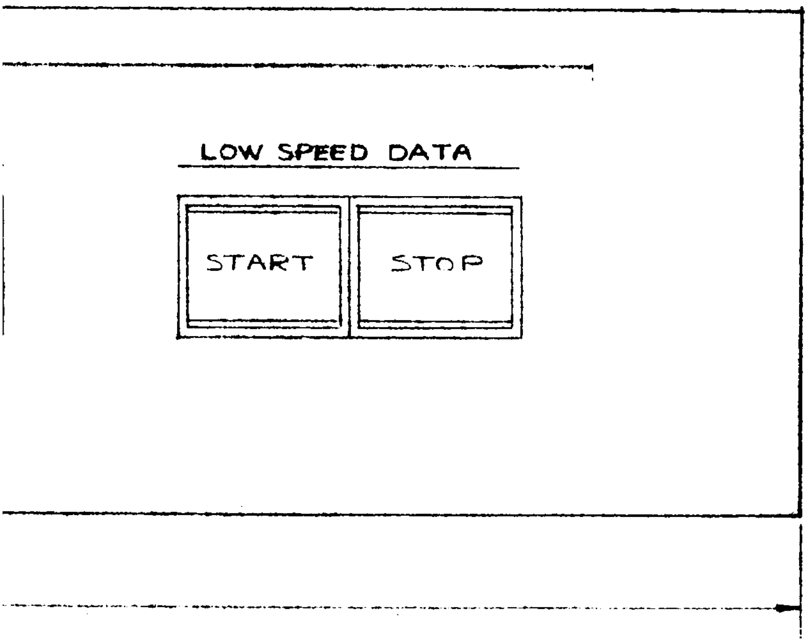


Figure 10-2. TDP Remote Control Panel

10.2.9 POWER REQUIREMENTS.

The input power requirements for the TDP are:

Single TDP:	22 amps @ 110 volts ac single phase
Dual TDP:	24 amps @ 110 volts ac single phase
Doppler counter ships (dual):	9 amps @ 110 volts ac single phase
Doppler counter ships (single):	7 amps @ 110 volts ac single phase

10.2.10 HEAT DISSIPATION.

The heat dissipation for the TDP is as follows:

Single TDP:	2420 watts
Dual TDP:	2640 watts
Doppler counter ships (dual):	990 watts
Doppler counter ships(single):	770 watts

10.3 MECHANICAL DESCRIPTION.

10.3.1 RACKS.

The tracking data processor will be housed in 3-1/2 racks (see figure 10-3 for the dual TDP and figure 10-4 for the single TDP). Since the TDP and programmer are combined into one system, rack 1 is shared with the programmer (see figure 9-4).

The tracking processor racks are 69 inches high, 26 inches deep and 9 feet wide. The single and dual stations use the same number of racks. Extra blank rack space is available on the single TDP. It is noted that the telephone panel (GFE) is located on the TDP rack 2. This telephone will be shared with the programmer. (A second telephone, GFE, is located on the timing system.) The GFE telephone panel will be painted to blend in with the Collins color scheme.

10.3.2 FINISH. (See Section 9)

The finish for the TDP will be the same as for the programmer.

10.3.3 COOLING. (See section 9)

Cooling provisions for the TDP are the same as for the programmer.

10.3.4 RACK CABLE ENTRY. (See section 9)

Cabling provisions for the TDP are the same as for the programmer.

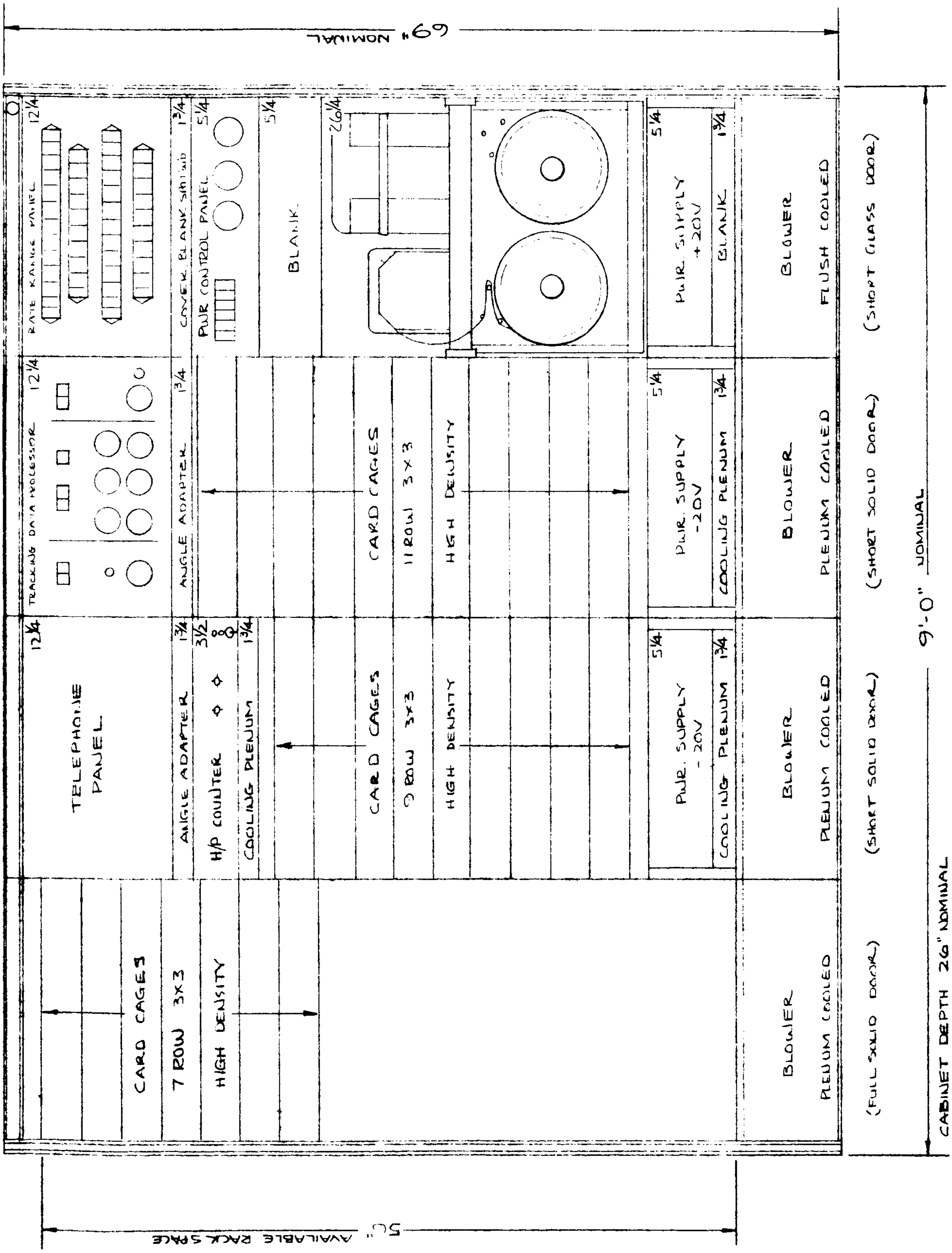


Figure 10-3. Bay Layout TE-410 Tracking Data Processor (Dual)

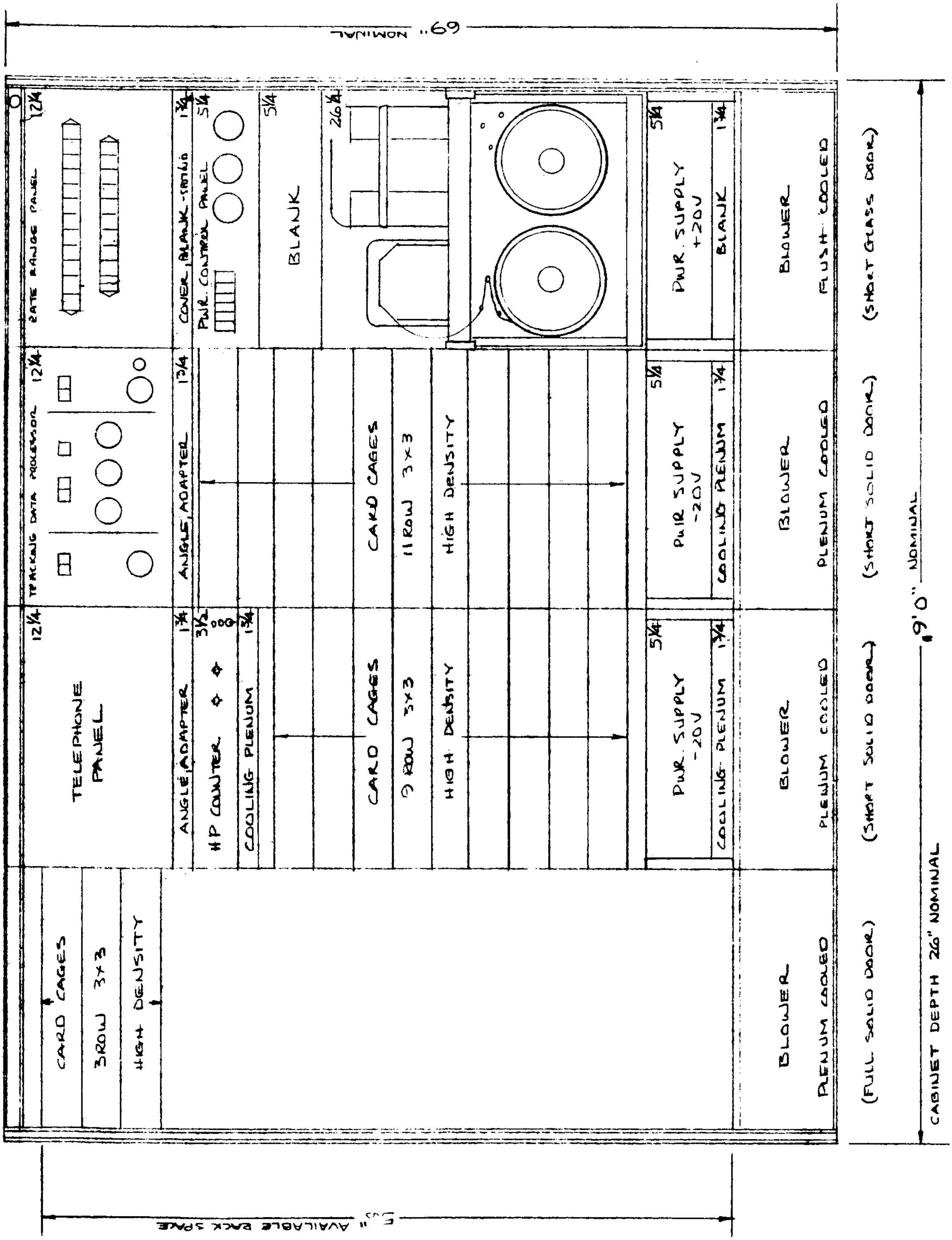


Figure 10-4. Bay Layout TE-410A Tracking Data Processor (Single)

10.3.5 LOCAL CONTROL PANEL LAYOUT. The TDP local control panel layout is shown in figure 10-5 for the dual TDP and figure 10-6 for the single TDP. Controls, switches, and indicators are the same type as used on the programmer.

Reference is made to appendix c, "Preliminary Reliability Analysis Report," dated 30 September 1964, for an analysis.

10.4 TRACKING DATA PROCESSORS.

10.4.1 TRACKING DATA PROCESSOR, SINGLE.

10.4.1.1 GENERAL. The introductory remarks of section 9 also apply to the TDP subsystem. The TDP has low- and high-speed outputs which represent a form of redundancy. The reliability analysis is made for all outputs functioning however, and thus neglects this fact of redundant signals.

10.4.1.2 FAILURE RATE ANALYSIS. (Inlet Temperature 85°F)

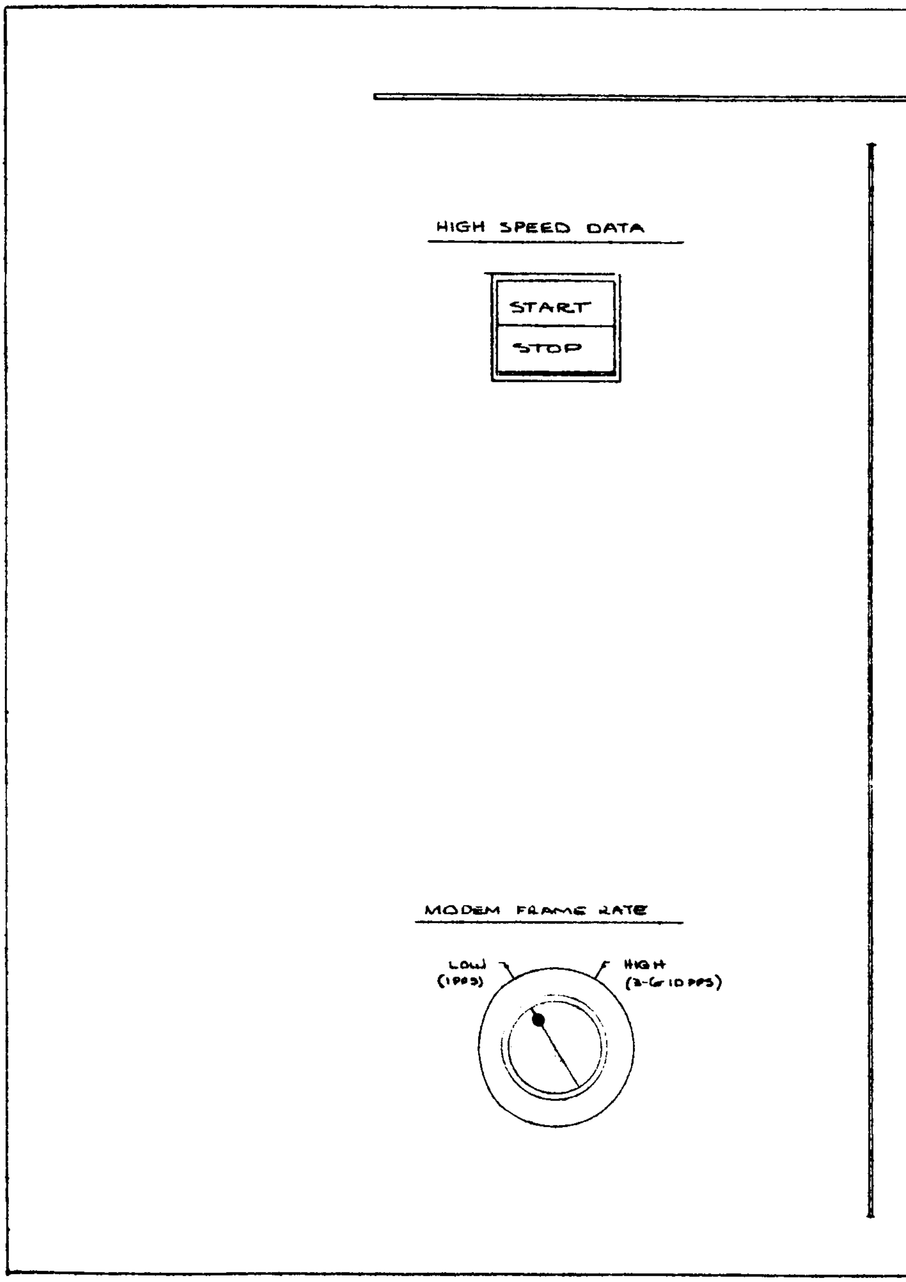
Quantity	Item Description	Subtotal failure rate %/1000 hours
1100	Circuit cards subtotal	77.75%
13	Purchased equipment subtotal	45.5 %
271	Miscellaneous parts subtotal	6.0 %
Subsystem total failure rate		129.25%
Subsystem MTBF		774 hours

10.4.2 TRACKING DATA PROCESSOR, DUAL

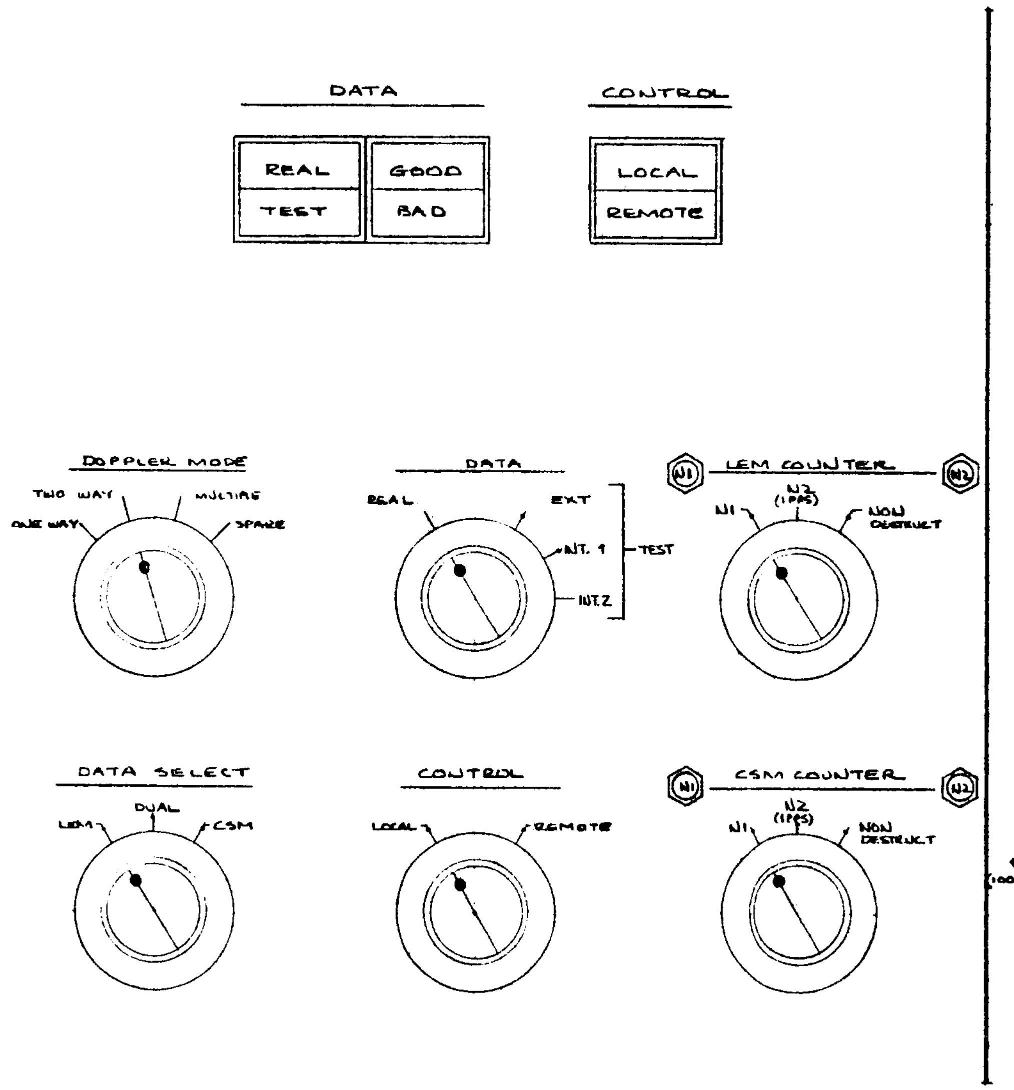
10.4.2.1 GENERAL. The only difference between the single and dual TDP subsystems is an increase in circuit card and purchased equipment quantities for the dual version. The reliability analysis is similar to that for the single doppler case.

10.4.2.2 FAILURE RATE ANALYSIS

Quantity	Item Description	Subtotal failure rate %/1000 hours
1350	Circuit cards subtotal	98.36%
17	Purchased equipment subtotal	57.5 %
271	Miscellaneous parts subtotal	6.0 %
Subsystem total failure rate		161.86%
Subsystem MTBF		618 hours


HIGH SPEED DATA
START
STOP
MODEM FRAME RATE
LOW
(1PPS)
HIGH

TRACKING DATA PROCESSOR



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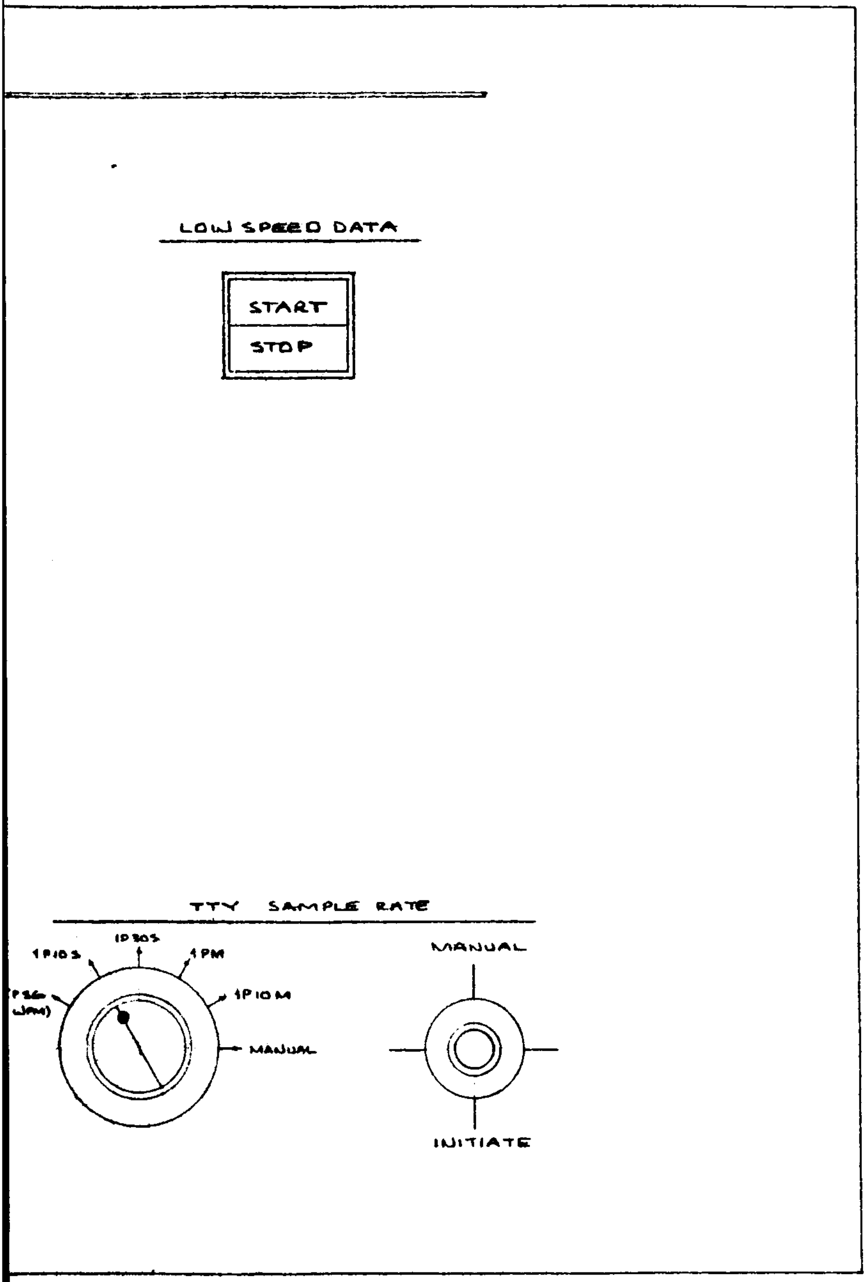
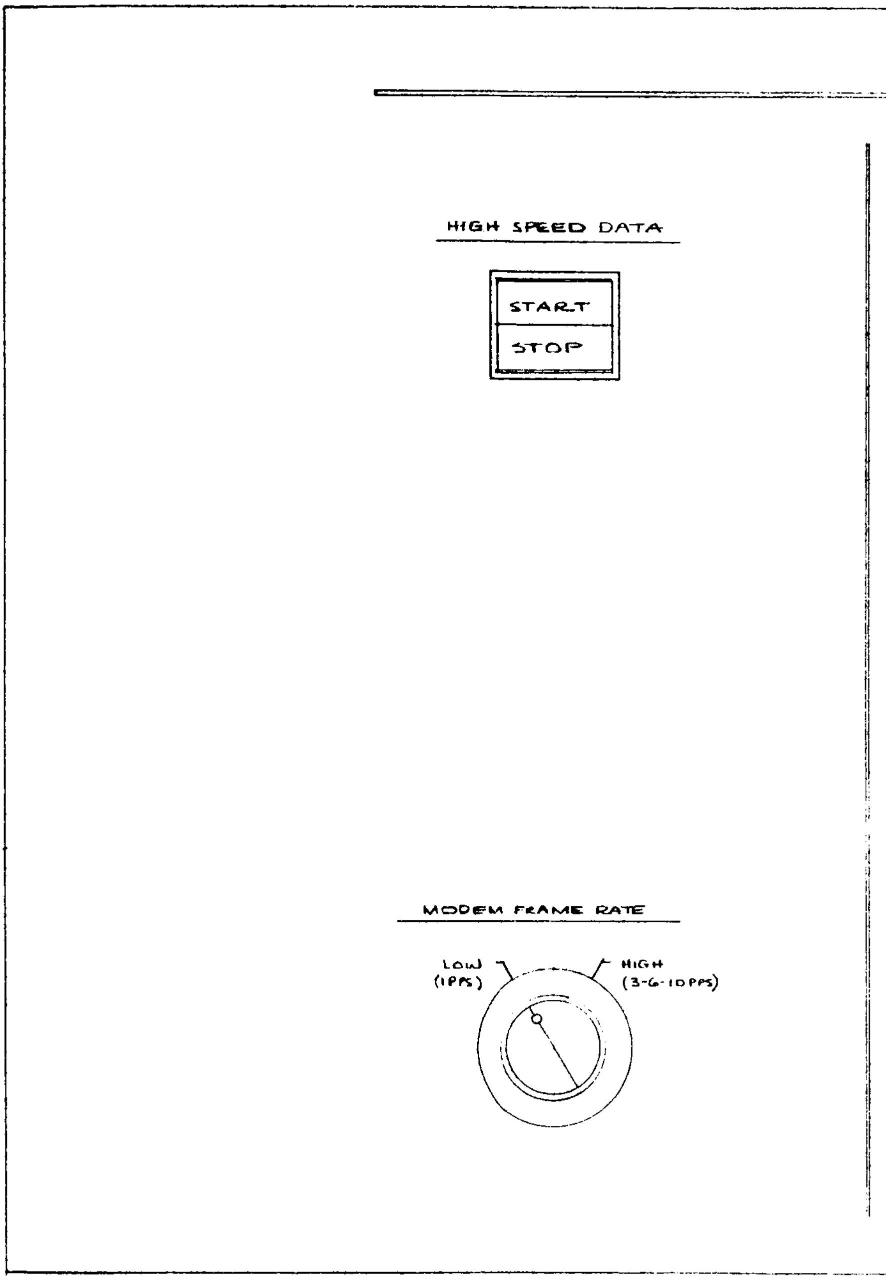
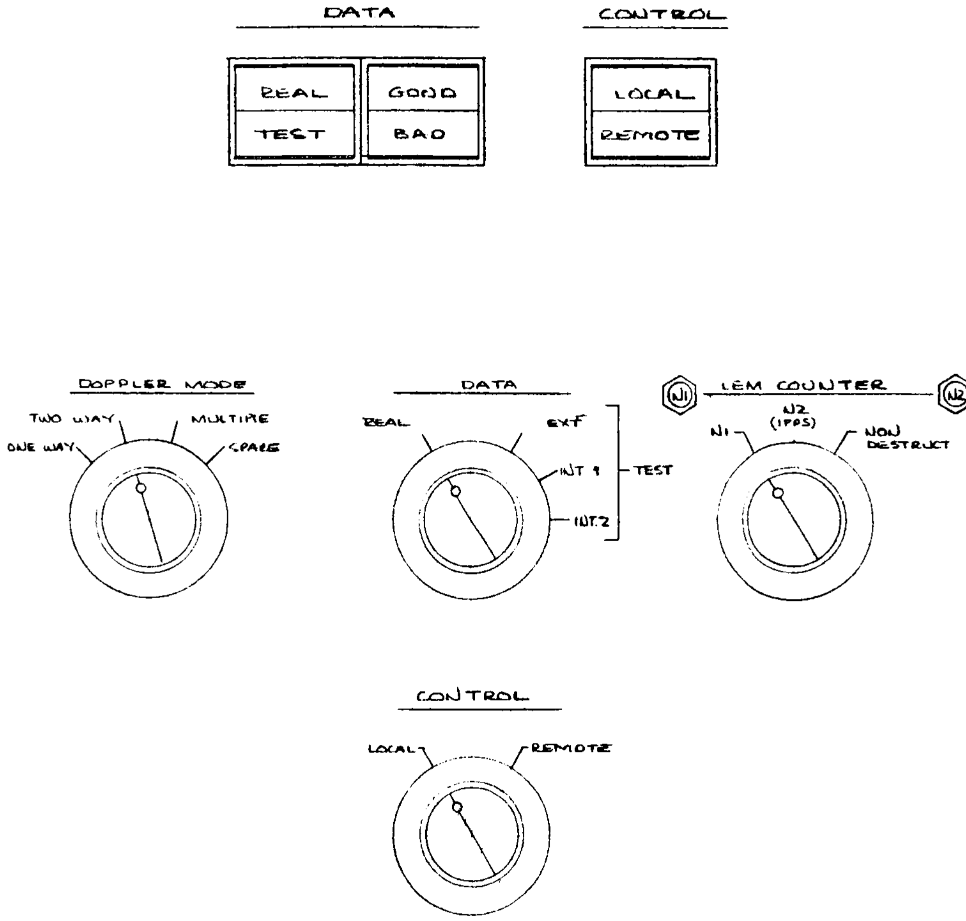


Figure 10-5. Local Control Panel Layout for TDP (Dual)


HIGH SPEED DATA
START
STOP
MODEM FRAME RATE
LOW
(1PPS)
HIGH
(3-6-10PPS)

#

TRACKING DATA PROCESSOR



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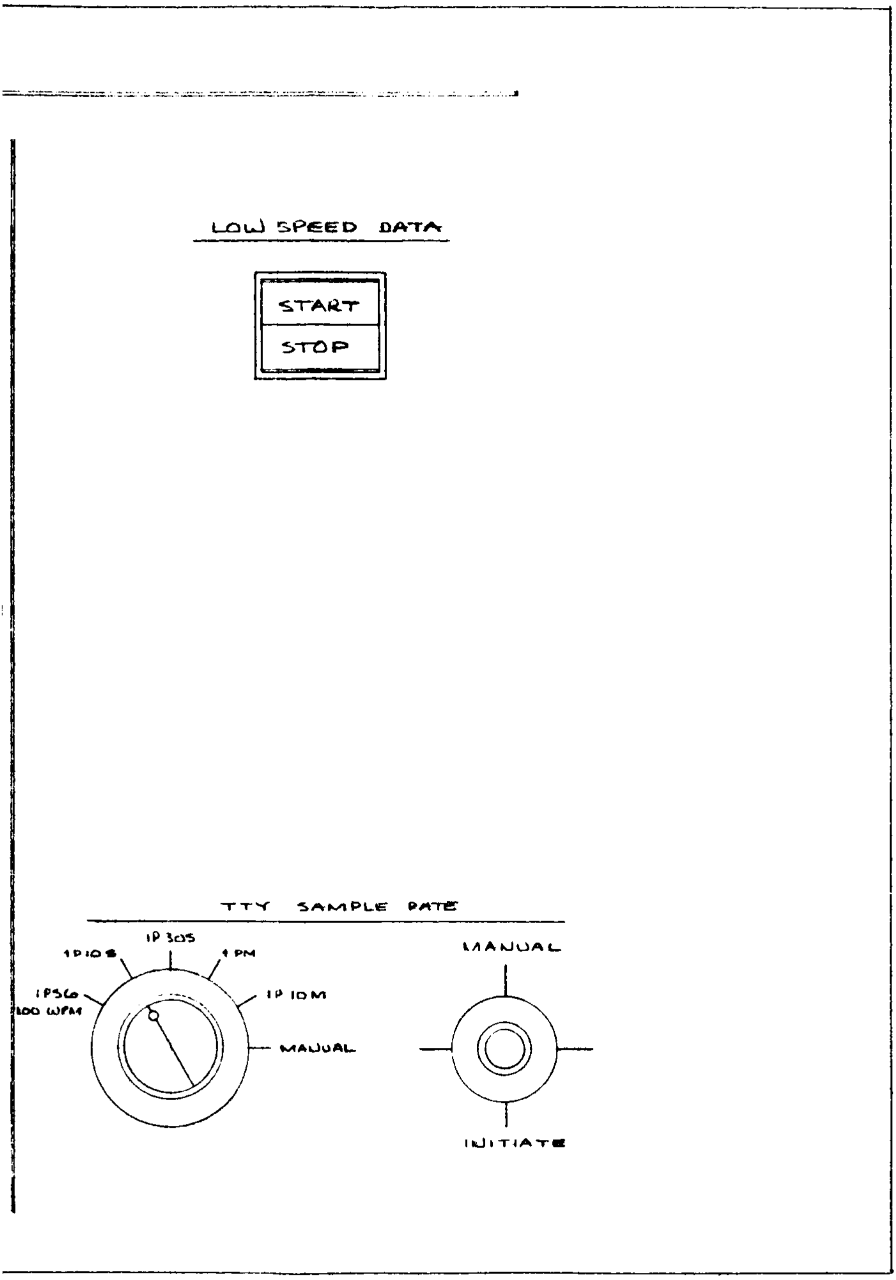


Figure 10-6. Local Control Panel Layout for TDP (Single)

3#

section 11

timing system

11.1 GENERAL DESCRIPTION.

The prime function of the timing system is to provide the Apollo S-Band tracking station with accurate real time (GMT). The timing system supplies the needs of all subsystems of the station including GFE subsystems. The secondary function of the timing system is to provide a countdown/elapsed time and hold time system to meet the needs of the station.

11.2 ELECTRICAL DESCRIPTION.

11.2.1 GENERAL.

The timing system is described as follows (see figure 11-1):

The frequency standard is supplied GFE and is not a part of the Collins design. The GFE frequency standard supplies 2 sets of identical 1-mc signals to the frequency divider. The frequency standard also supplies 5-mc, 1-mc, and 100-kc signals to the distribution amplifier to provide isolation and distribution to the station. The timing system is designed to provide back-up capability. This consists of supplying 2 each of the following units.

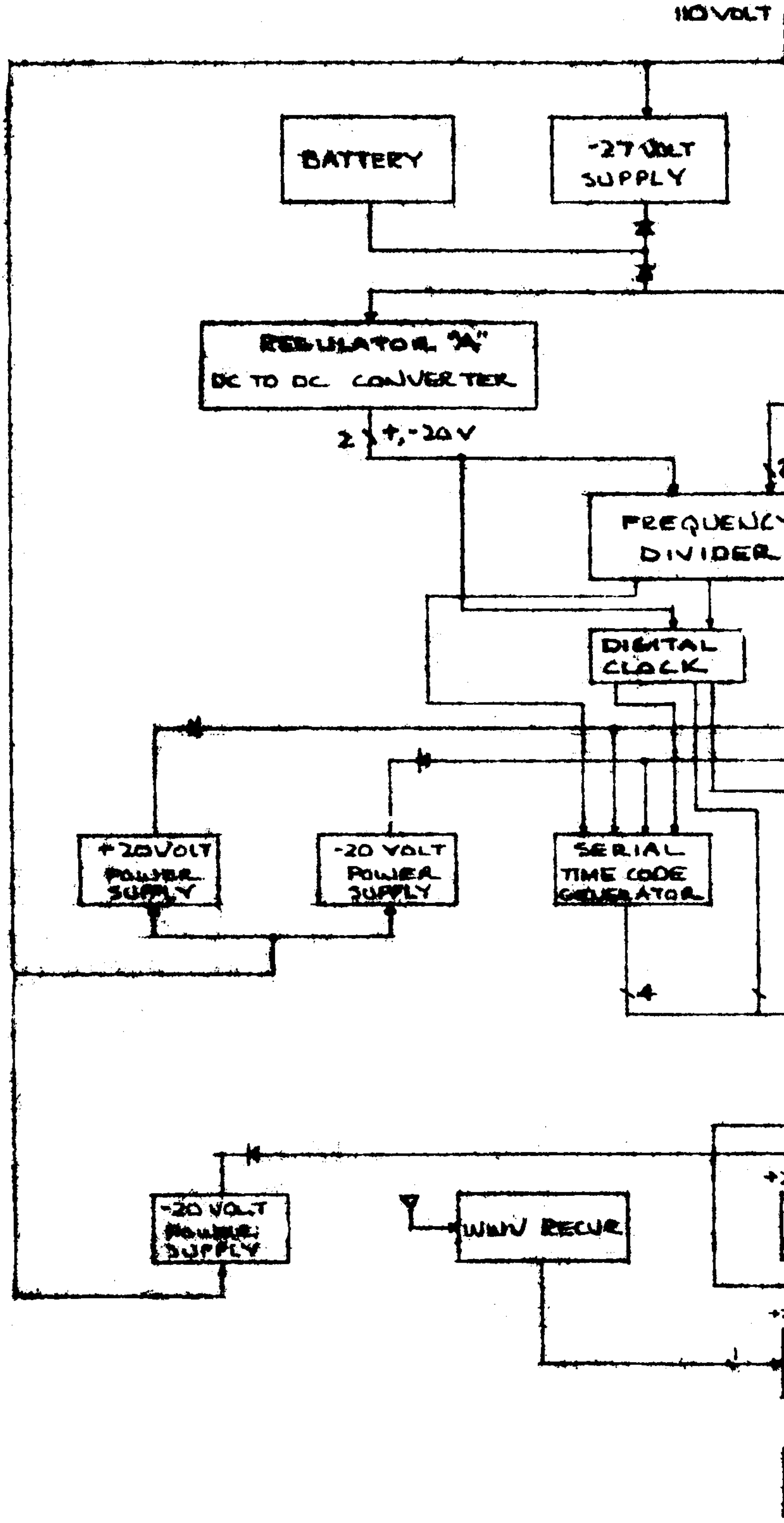
(1) Frequency divider

(2) Digital clock

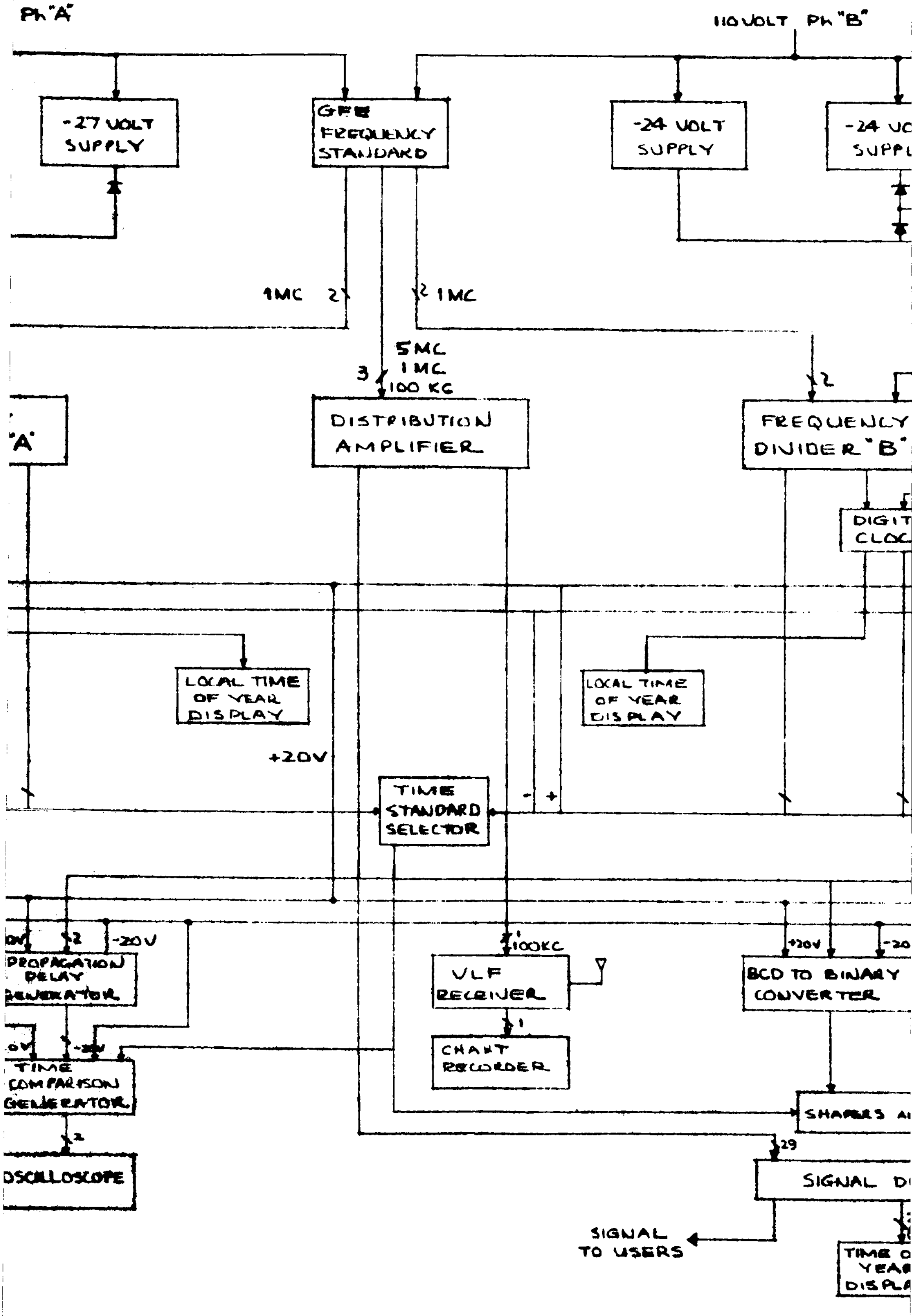
(3) Time code generator

(4) Power supplies.

Provisions are made for automatic switchover between A and B systems in case of failure.


110 VOLT
BATTERY
-27 VOLT SUPPLY
REGULATOR "A" DC TO DC CONVERTER
2
+,-20 V
FREQUENCY DIVIDER
DIGITAL CLOCK
+20 VOLT POWER SUPPLY
-20 VOLT POWER SUPPLY
SERIAL TIME CODE GENERATOR
4
-20 VOLT POWER SUPPLY
WWV RECVR

1#



Ph "A"
110 VOLT Ph "B"
-27 VOLT SUPPLY
GFE FREQUENCY STANDARD
-24 VOLT SUPPLY
-24 VO SUPPL
1MC 2
2 1MC
5MC 1MC 100 KC
3
2
"A"
DISTRIBUTION AMPLIFIER
FREQUENCY DIVIDER "B"
DIGIT CLOC
LOCAL TIME OF YEAR DISPLAY
LOCAL TIME OF YEAR DISPLAY
+20V
TIME STANDARD SELECTOR
- +
2
-20V
PROPAGATION DELAY GENERATOR
100KC
VLF RECEIVER
+20V
BCD TO BINARY CONVERTER
1
CHART RECORDER
-20V
TIME COMPARISON GENERATOR
SHAPERS A
2
29
OSCILLOSCOPE
SIGNAL D
SIGNAL TO USERS
TIME O YEAR DISPLA

II-11-2-A

2#

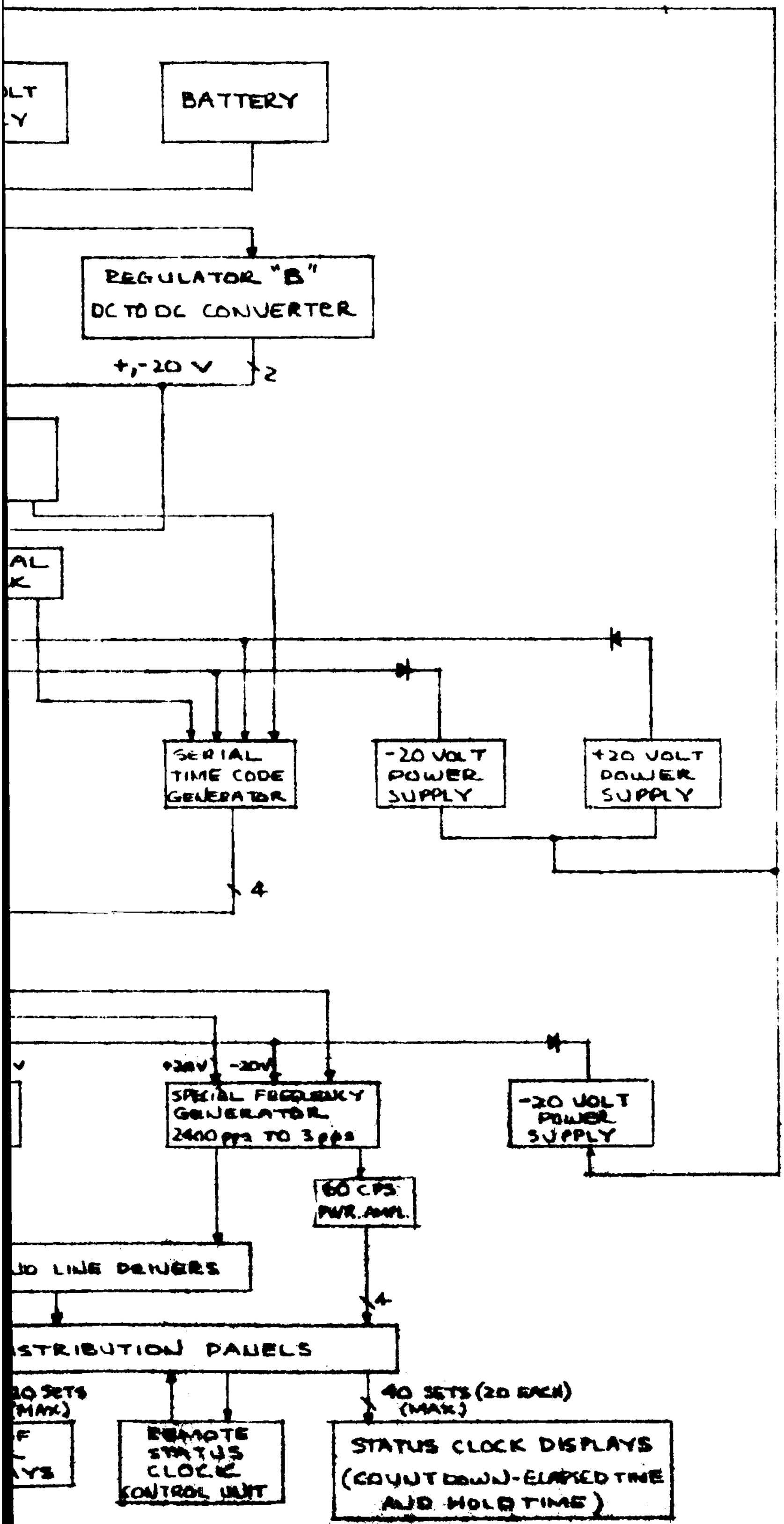


Figure 11-1. Timing System Block Diagram with Power Distribution

3#

The frequency divider accepts the 1-mc signal and through a series of decade dividers, divides this frequency down to 1 pps. The various pulse rates developed in this division process are delivered to the time code generator and to the signal distribution unit for distribution to users.

The digital clock receives the 1-pps signal from the frequency divider and divides this signal down to 1 pulse every 100 days. The clock provides time in seconds, minutes, hours, and days.

Provisions are made for synchronizing the time standard to WWV or other references.

The time code generator provides the NASA time codes from the parallel time of year information.

A BCD to binary converter is supplied for the parallel time of year information.

An emergency power system is supplied which will operate the frequency divider and digital clock units for a period of 5 hours in the event of primary power failure.

A system patch panel is provided to patch signals to any user. The timing system provides remote readouts of GMT time, countdown/elapsed time, and hold time.

11.2.2 EMERGENCY POWER SYSTEM.

The selection of lead calcium batteries rather than nickel cadmium as specified by GSFC, was chosen for the design of the emergency power system as a result of a thorough battery survey of all types of batteries. The reasons for this choice and the advantages of lead calcium batteries on float service are as follows:

(1)	State of charge determination:	Easily determined by hydrometer reading.
(2)	Maintenance:	Requires water once every 1 to 3 years.
(3)	Equilization:	Not required if floated at 2.20 to -2.25 volts.
(4)	Life expectancy:	25 years or better.
(5)	Gassing*:	Less than 0.0009 cubic feet/hour at +60° C on float charge.
(6)	Cell reversal:	Not a problem as with nickel cadmium.

* Venting is not required with lead calcium batteries since there is no problem with corrosion or danger to personnel from fumes.

11.2.3 TIME CODE GENERATOR.

The frame markers on the BCD serial code signals will be capable of being coded through patching. Connectors are provided for each of the three time codes (1 second, 1 minute, and 1 hour time codes) for four data bits. An open circuit (no input) represents a logic zero.

11.2.4 BCD TO BINARY CONVERTER.

The serial time of year outputs from the BCD to binary converter will be provided with clock pulses in addition to serial data. Clock pulses will be provided for the binary seconds of the year, binary one-tenth seconds of the year, and milliseconds of the year serial time outputs. A checkout method is also provided for testing the BCD to binary converter. This is done by opening the input and by means of digiswitches, programing a fixed pattern into the converter and providing monitor lights for registers.

11.2.5 PROPAGATION DELAY GENERATOR.

The propagation delay generator will provide delays in 10 microsecond intervals of 0 to 1 second rather than 0 to 0.1 second. This will provide a readout of 999.99 milliseconds.

11.2.6 VLF RECEIVER.

The VLF receiver will:

(1) Be provided with an electronic servo.

(2) Not be provided with the built-in chart recorder, since a chart recorder is provided as a separate unit.

(3) Not be provided with the 60-kc channel option.

11.2.7 WWV ANTENNA.

A Rohn model 45 tower will be provided instead of Rohn model 25 as specified. The model 45 tower will meet the requirements of the Mosley WWV-33 antenna. This tower will be 44 feet high and will be provided with a bolt-on base. A concrete tower foundation, with mounting bolts, will be required at each site.

11.2.8 SYSTEM PATCH PANELS.

Patch panels will be provided for all outputs except parallel BCD time of year outputs, which will be provided on rear mount connectors (same type as Rosman).

11.3 INPUT SIGNAL CHARACTERISTICS.

The input signals to the timing system are obtained from the frequency standard (GFP) as follows:

Description	Quantity	Specification
5 mc	1	1 volt, rms, 50 ohms
1 mc	5	1 volt, rms, 50 ohms
100 kc	1	1 volt, rms, 50 ohms

11.4 OUTPUT SIGNAL CHARACTERISTICS.

Since the timing system is designed by Collins/ISC and is integrated with the programmer and tracking data processor, the timing signals required for these subsystems are not included in this report. Table 11-1 includes all timing signals provided at the signal distribution unit available for station use.

TABLE 11-1. SIGNAL DISTRIBUTION UNIT, TIMING SIGNALS

SIGNAL	QUANTITY	SPECIFICATION
2400 pps	2	All pulses to be at 0 and -6 volts logic levels, 50-ohm outputs
2000 pps	2	
1200 pps	2	
600 pps	2	
10 pps	1	
6 pps	2	
3 pps	2	
1 pps	1	
1 pp 6 sec	2	
1 pp 10 sec	2	
1 pp 30 sec	2	
1 pp min	2	
1 pp 10 min	3	

TABLE 11-1. SIGNAL DISTRIBUTION UNIT, TIMING SIGNALS (CONT)

SIGNAL	QUANTITY	SPECIFICATION
5 mc	10	50-ohms output impedance
1 mc	10	1 vrms, -0 ± 3 db
100 kc	10	50 db cross talk, channel to channel 60 db harmonic distortion 80 db non-harmonic distortion
500 kc	2	
10 kc	10	
1 kc	10	
60 cps	10	50 ohms 1 vrms 1% distortion
BTC 1/sec (1kc)	10	
BTC 1/sec (10 kc)	2	
BTC 1/min	2	
BTC 1/hour	2	
SDTC (1 kc)	10	
SDTC (10 kc)	2	
100 kpps	4	
50 kpps	2	
10 kpps	4	
5 kpps	2	
1 kpps	8	50 ohms Voltage output at 0 and -6 logic level
500 pps	2	
100 pps	8	
50 pps	2	
10 pps	8	
5 pps	2	
1 pps	8	
BTC 1/sec	5	

TABLE 11-1. SIGNAL DISTRIBUTION UNIT, TIMING SIGNALS (CONT)

SIGNAL	QUANTITY	SPECIFICATION
BTC 1/min	5	
BTC 1/hour	5	
SDTC	5	
Binary sec. of the year (serial)	2	
Binary 1/10 sec. of the year (serial)	2	
Binary milliseconds of the year (serial)	2	
Parallel time of year year (BCD) for GMT displays (10 GMT display units to be provided for each system)	20	Output signal will be compatible with the display unit, 0 and -3 volts logic level
Parallel time of year (BCD)	2	Outputs will be similar to logic levels (inverter output)
BCD outputs (tens of microseconds to hundreds of milliseconds)	2	Outputs will be similar to logic levels (inverter output)
Binary seconds of the year (parallel)	2	
Binary 1/10 sec of the year (parallel)	2	Outputs will be similar to logic levels (inverter output)
Binary millisec of the year (parallel)	2	
60 cps (high level)	4	Output from the 60-cps power amplifier 115 volts ± 10%

All pulse signals will be provided on 50-ohm line drivers at logic levels of 0 and -6 volts. The output drivers are designed to meet the following requirements.

At the end of 200 feet of 50-ohm cable (RG 58, or equivalent) properly terminated in 50 ohms, the rise time will be 0.2 microseconds maximum and the fall time will be 0.3 microseconds maximum.

11.5 POWER REQUIREMENTS.

The input power requirement for the timing system is:

38 amps 110/208 volts ac single phase

NOTE: This does not include the GFE frequency standards.

11.6 HEAT DISSIPATION.

The heat dissipation for the timing system is 4180 watts.

NOTE: This does not include the GFE frequency standard.

11.7 MECHANICAL DESCRIPTION.

11.7.1 TIMING SYSTEM.

The timing system will be housed in 6 racks (see figure 11-2). The timing system racks are 69 inches high, 26 inches deep, and 13.5 feet wide. These racks do not provide space for mounting the GFE frequency standard. The GFE frequency standards will be supplied in Collins type racks to be compatible with the rest of the timing system. Provisions are made for mounting the 10-1/2 inch GFE telephone panel.

11.7.2 FINISH.

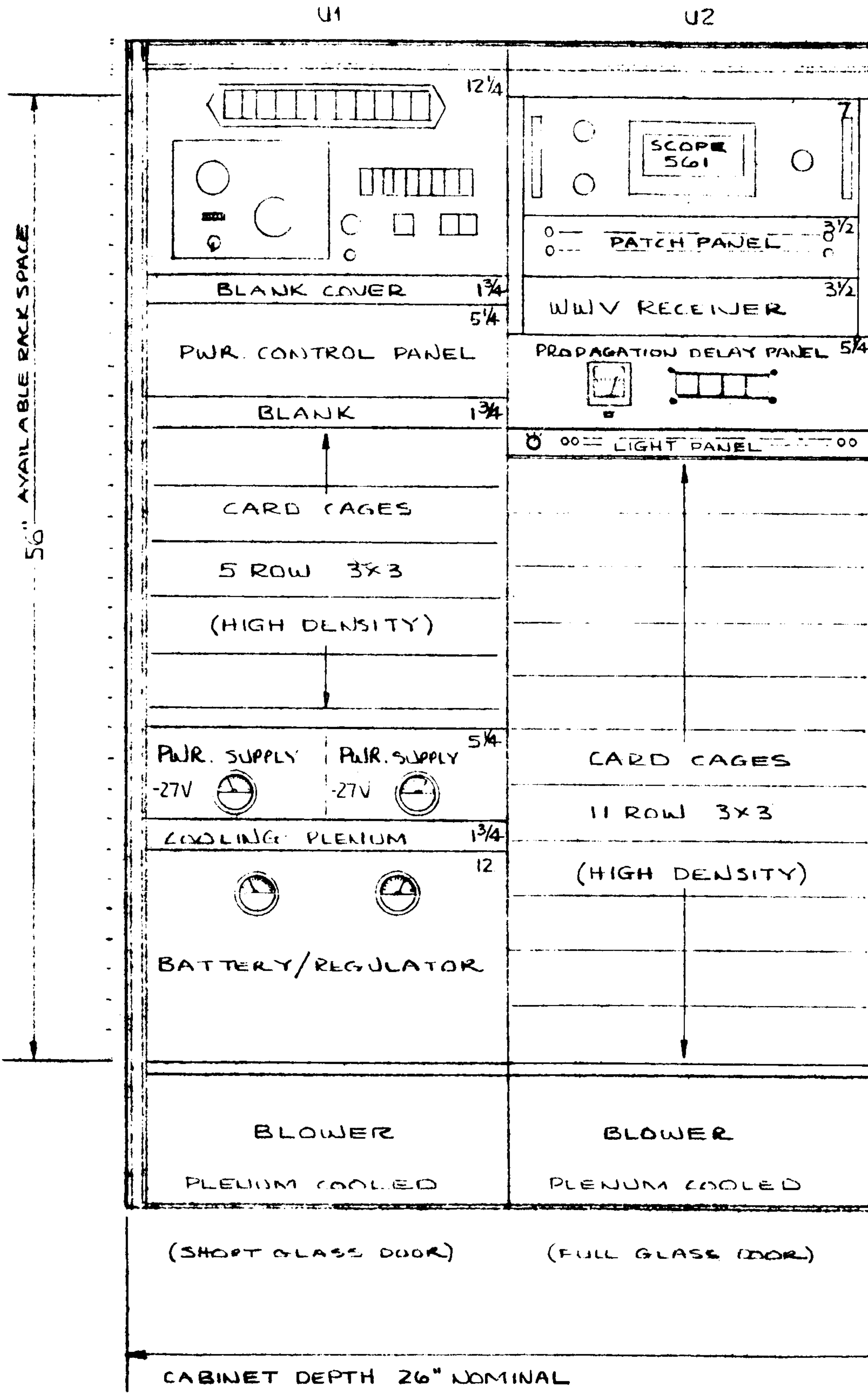
The finish for the timing system will be the same as for the programmer (see Section 9).

11.7.3 COOLING.

Cooling provisions for the timing system are the same as for the programmer (see Section 9).

11.7.4 RACK CABLE ENTRY.

Cabling provisions for the timing system are the same as for the programmer (see Section 9).


U1
U2
56" AVAILABLE RACK SPACE
12¼
BLANK COVER
1¾
5¼
PWR. CONTROL PANEL
BLANK
1¾
CARD CAGES
5 ROW 3×3
(HIGH DENSITY)
PWR. SUPPLY
-27V
PWR. SUPPLY
-27V
5¼
COOLING PLENUM
1¾
12
BATTERY/REGULATOR
BLOWER
PLENUM COOLED
(SHORT GLASS DOOR)
7
SCOPE 561
PATCH PANEL
3½
WWV RECEIVER
3½
PROPAGATION DELAY PANEL
5¼
LIGHT PANEL
CARD CAGES
11 ROW 3×3
(HIGH DENSITY)
BLOWER
PLENUM COOLED
(FULL GLASS DOOR)
CABINET DEPTH 26" NOMINAL

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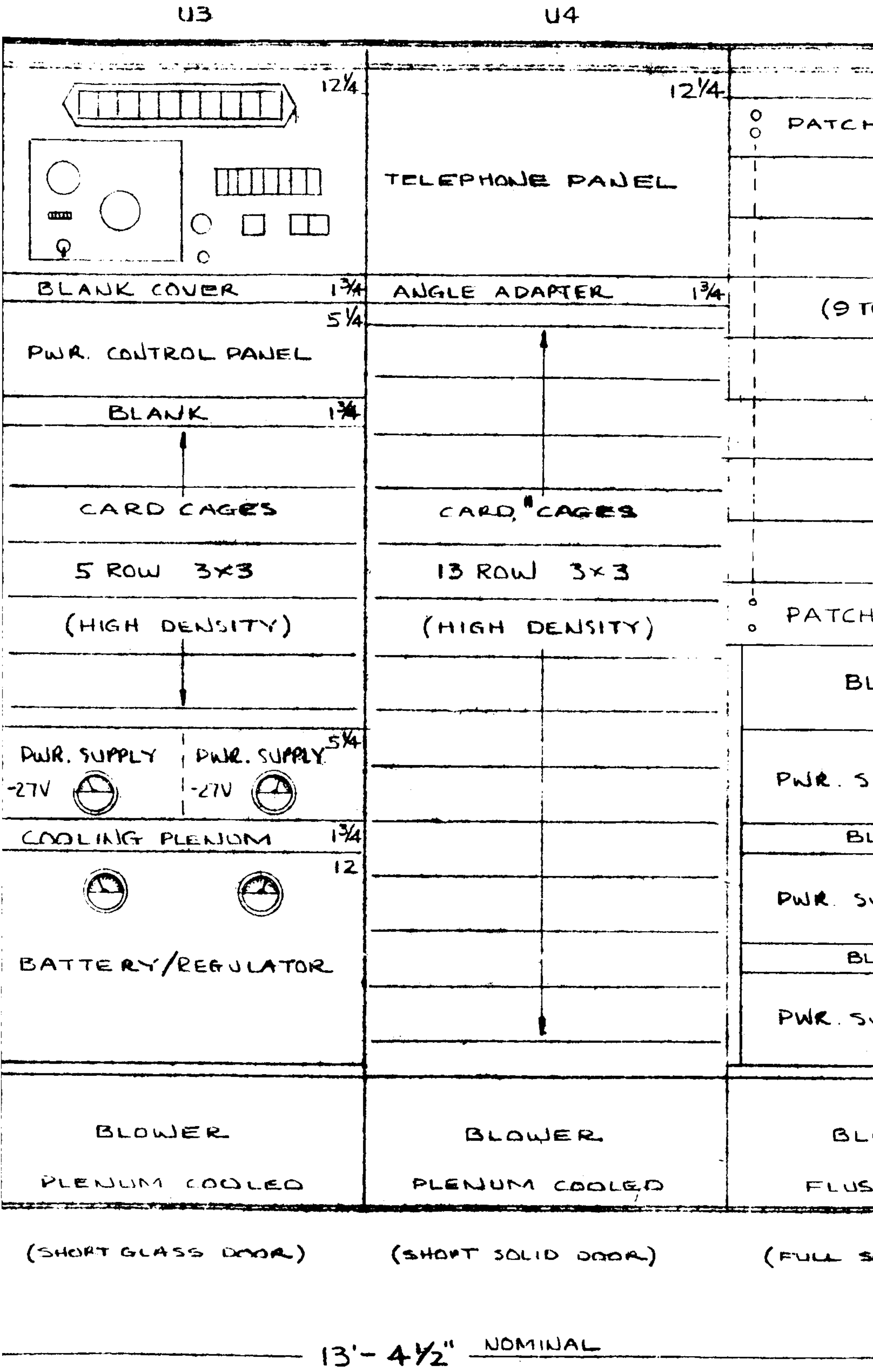

U3
U4
12¼
BLANK COVER
1¾
5¼
PWR. CONTROL PANEL
BLANK
1¾
CARD CAGES
5 ROW 3×3
(HIGH DENSITY)
PWR. SUPPLY
-27V
PWR. SUPPLY
-27V
5¼
COOLING PLENUM
1¾
12
BATTERY/REGULATOR
12¼
TELEPHONE PANEL
ANGLE ADAPTER
1¾
CARD CAGES
13 ROW 3×3
(HIGH DENSITY)
PATCH
(9 T
PATCH
BL
PWR. S
BL
PWR. S
BL
PWR. S
BLOWER
PLENUM COOLED
BLOWER
PLENUM COOLED
BL
FLUS
(SHORT GLASS DOOR)
(SHORT SOLID DOOR)
(FULL S
13'-4½" NOMINAL

2#

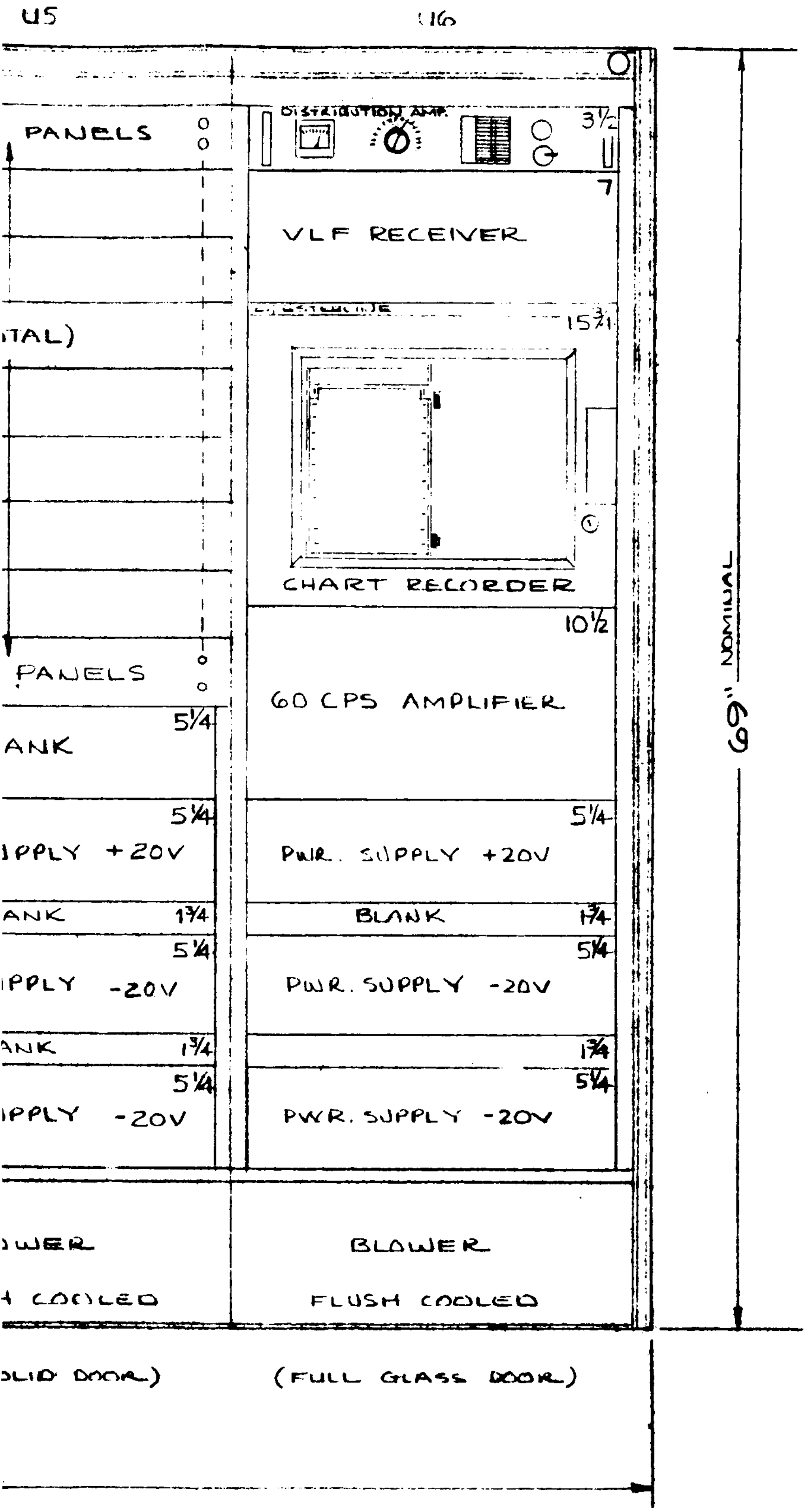


Figure 11-2. Bay Layout, TE-411 Timing System

11.7.5 CONTROL PANELS.

Control panels for the timing system are shown in the following figures:

Digital Clock Timing System	Figure 11-3
Count Down/Elapsed Time	
Clock Remote Control Panel	Figure 11-4
Power Control Panel	Figure 11-5
Maintenance Panel	Figure 11-6

Controls, switches, and indicators will be the same type as used on the programmer.

11.8 RELIABILITY ANALYSIS.

11.8.1 GENERAL.

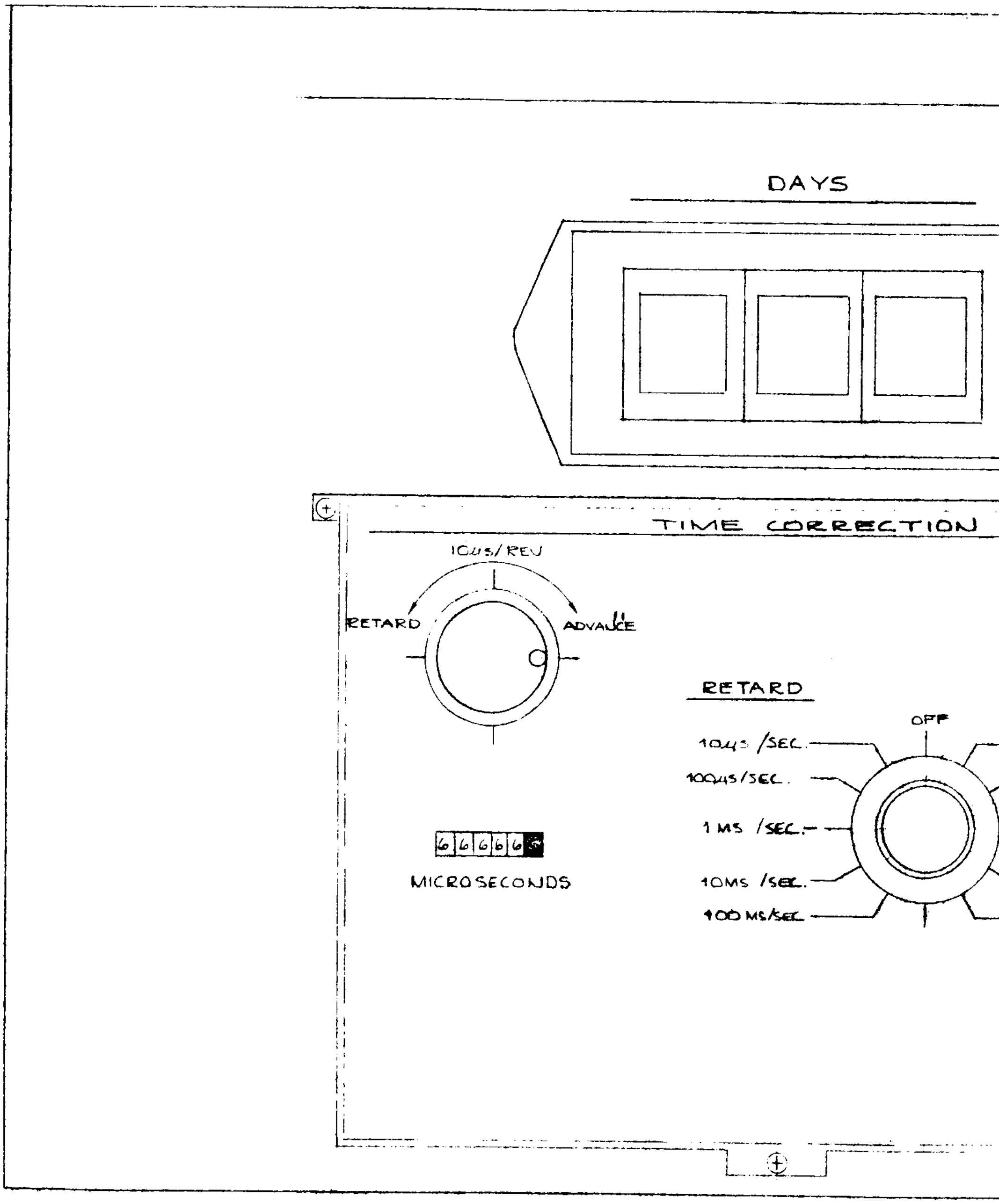
Reference is made to appendix c, "Preliminary Reliability Analysis Report", dated 30 September 1964, for an analysis. The reliability analysis of the timing subsystem is rather complex since several branches of the equipment have intentionally been made redundant. Specifically, the basic time standard generation sections have need for extremely high dependability and thus utilize equipment redundancy as well as an emergency power source. In addition, all power supplies for this subsystem are individually redundant.

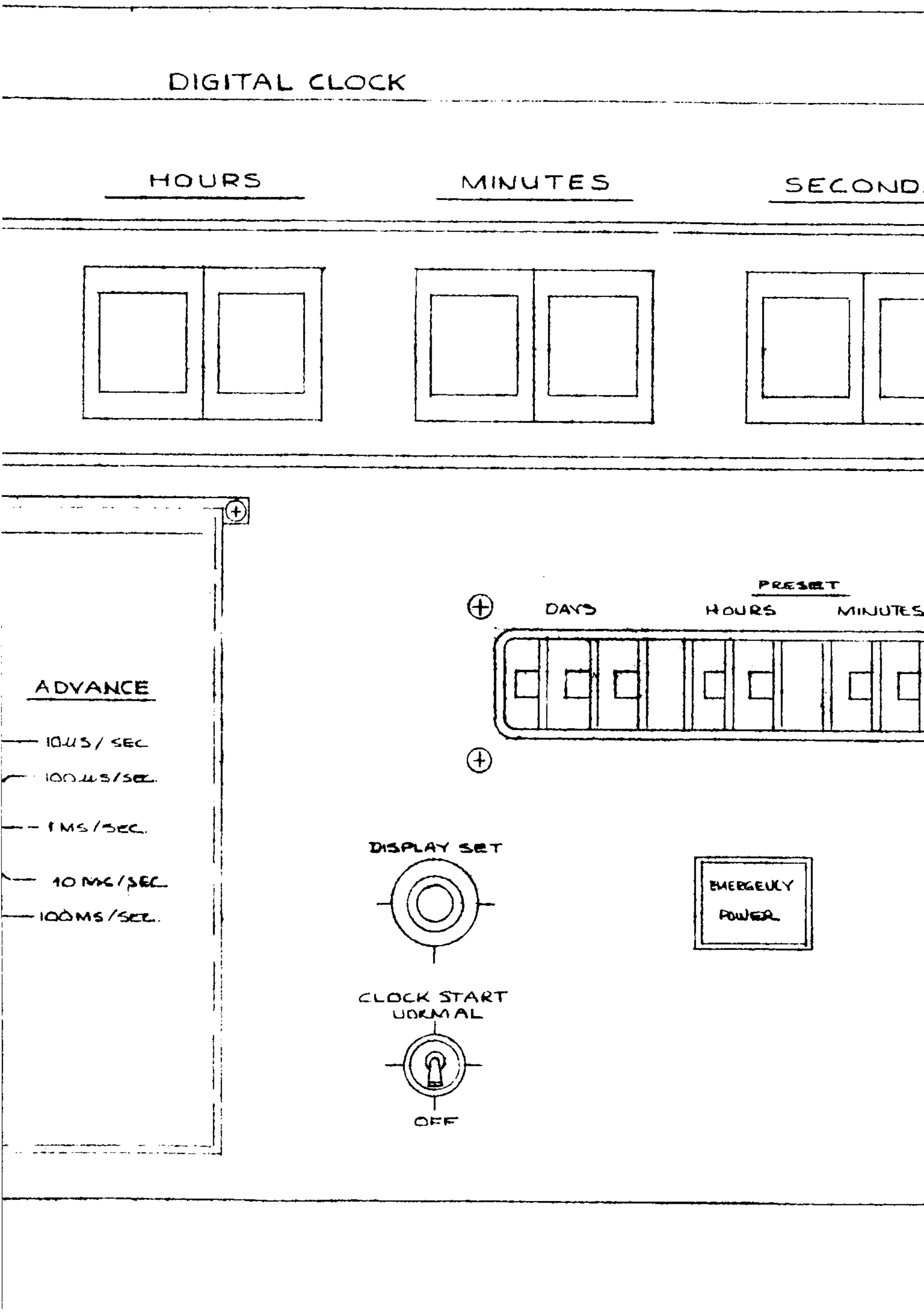
11.8.2 FAILURE RATE ANALYSIS.

Subsystem failure rate analysis is as follows:

	With periodic inspection	Without periodic inspection
Subsystem total failure rate	93.1%	*
Subsystem MTBF	1074 Hr.	920 Hr.

* Subsystem failure rate without repair is not easily computed.


DAYS
TIME CORRECTION
10µs/REV
RETARD
ADVANCE
MICROSECONDS
RETARD
OFF
10µs /SEC.
100µs/SEC.
1 MS /SEC.
10MS /SEC.
100 MS/SEC.


DIGITAL CLOCK
HOURS
MINUTES
SECOND
ADVANCE
10 μS / SEC
100 μS/SEC
1 MS/SEC
10 MS/SEC
100MS/SEC
PRESET
DAYS
HOURS
MINUTES
DISPLAY SET
EMERGENCY
POWER
CLOCK START
NORMAL
OFF

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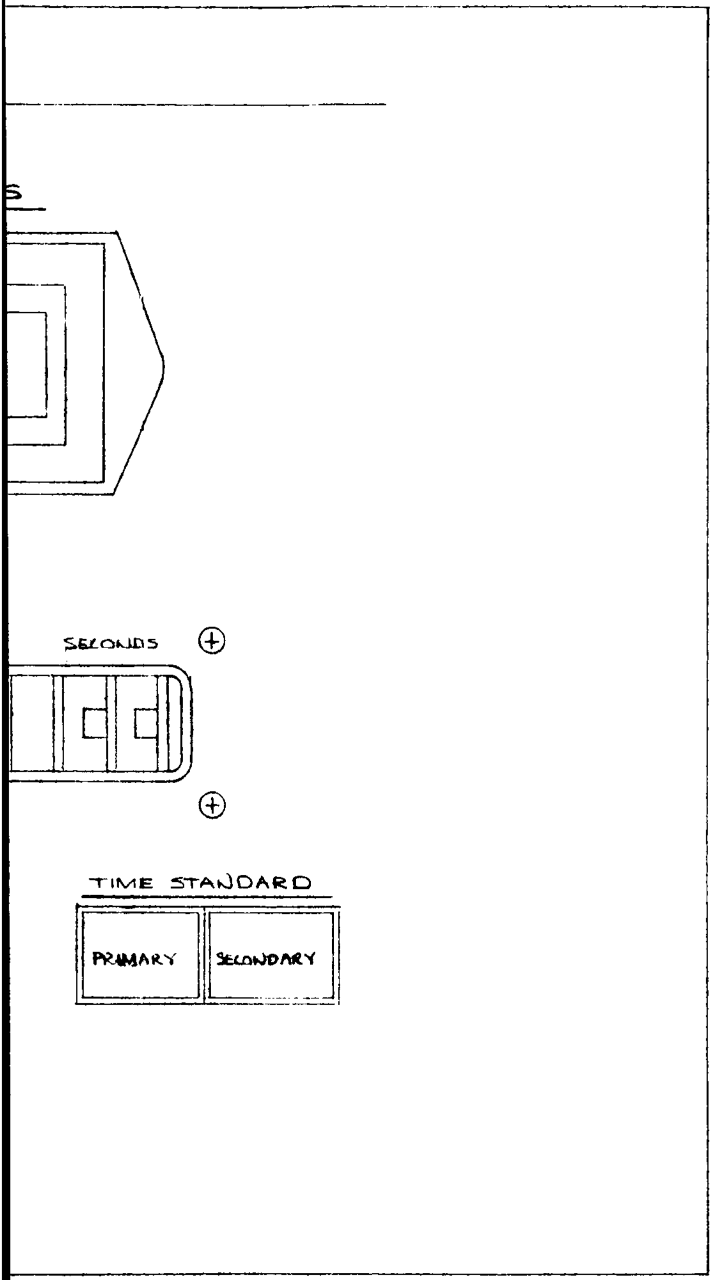


Figure 11-3. Digital Clock Timing System

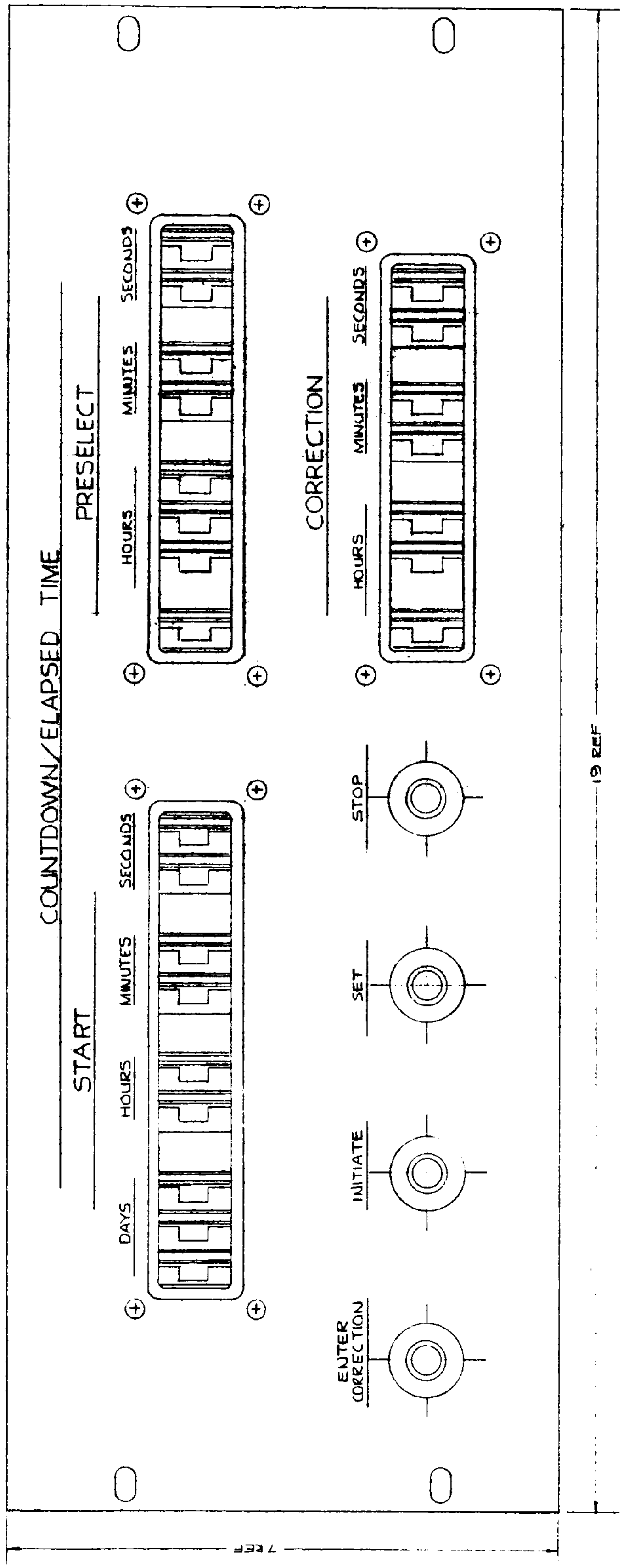
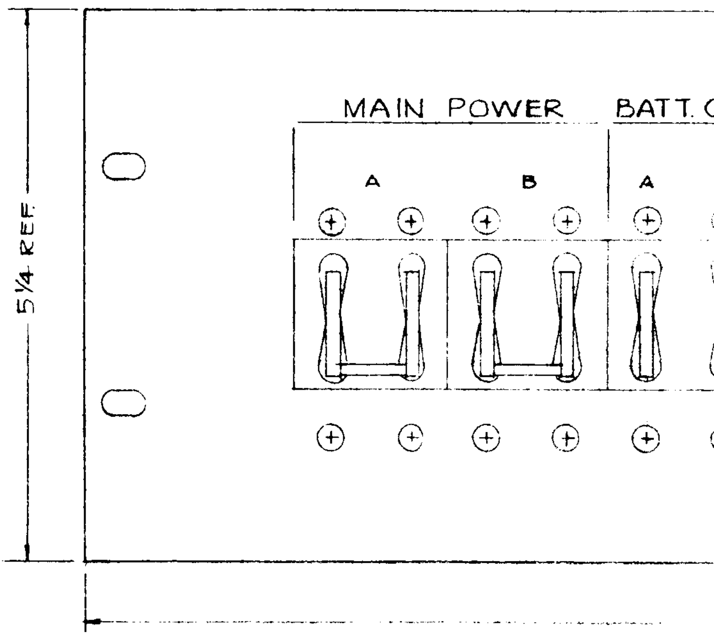


Figure 11-4. Timing System Count Down Clock/Elapsed Time Remote Control Panel



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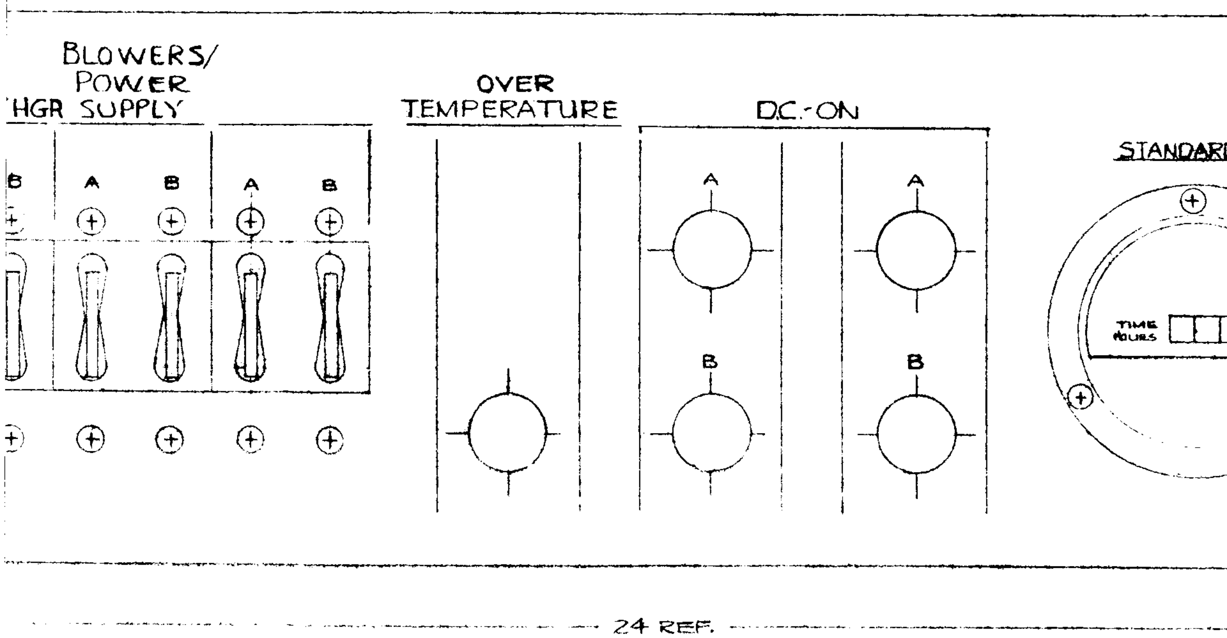

BLOWERS/
POWER
HGR SUPPLY
B
A
B
A
B
OVER
TEMPERATURE
D.C.-ON
A
A
B
B
STANDARD
TIME
HOURS
24 REF.

II-11-13-A

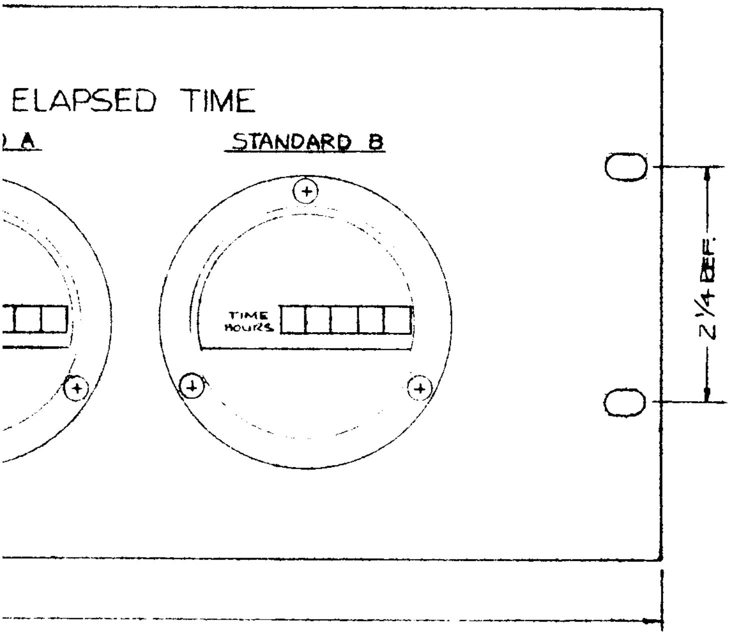
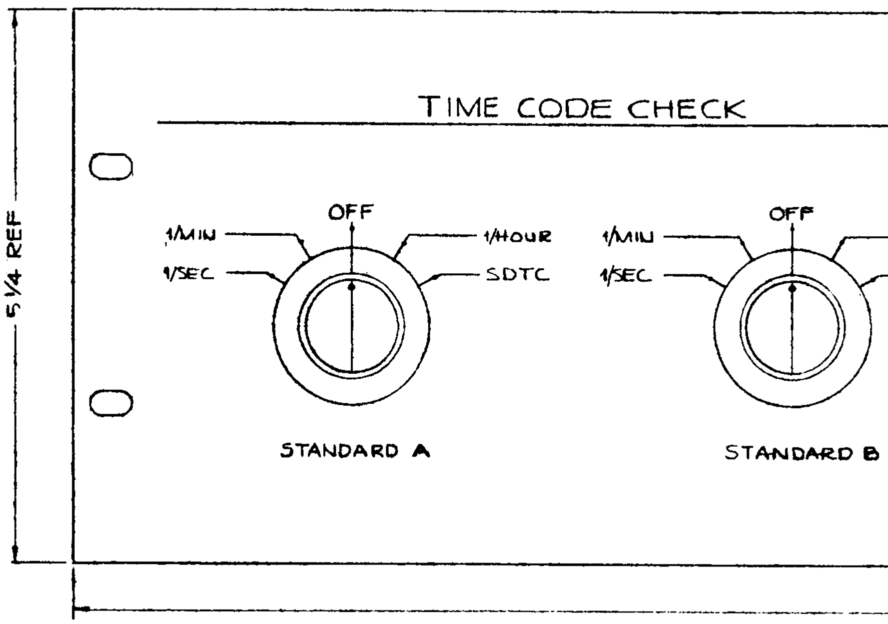
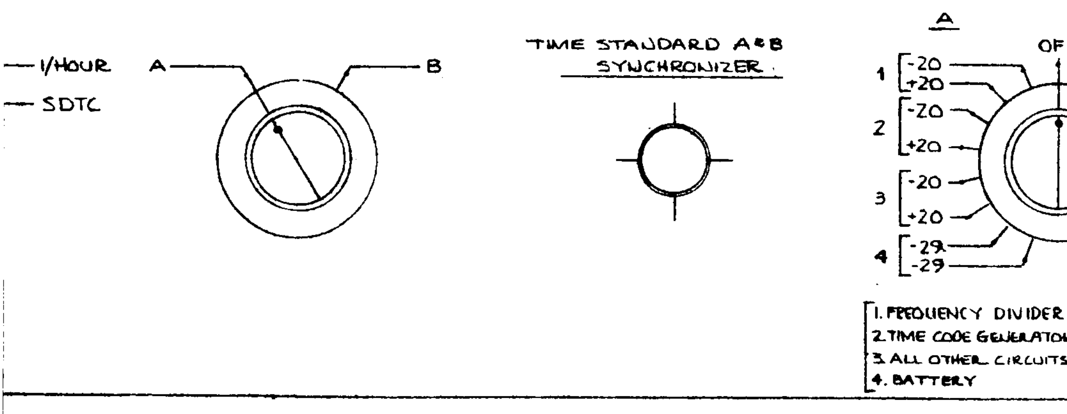


Figure 11-5. Power Control Panel
Timing System


TIME CODE CHECK
5 1/4 REF
OFF
1/MIN
1/SEC
1/HOUR
SDTC
STANDARD A
OFF
1/MIN
1/SEC
STANDARD B

1#

TIME STANDARD



24 REF.

II-11-14-A

2#

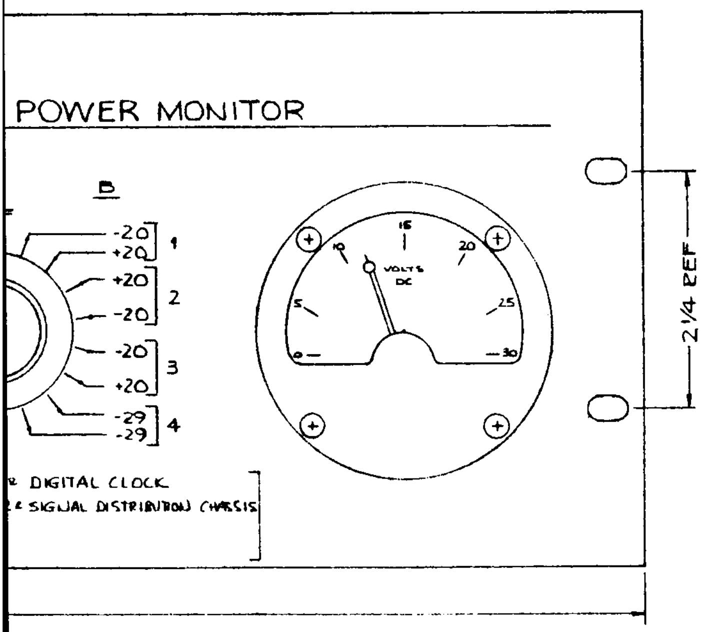


Figure 11-6. Maintenance Panel
Timing System

7#

section 12

servo control and drive subsystem

12.1 SYSTEM REQUIREMENTS.

Table 12-1 summarizes the system requirements and gives the Collins proposed characteristics.

TABLE 12-1. SYSTEM REQUIREMENTS

CHARACTERISTIC	SPECIFICATION REQUIREMENTS	COLLINS PROPOSED	COLLINS DESIGN
Antenna Control:			
Velocity	±0.002 to ±4°/sec	±0.002 to ±4.4°/sec	Same
Acceleration	0 to ±5°/sec^2	0 to ±5°/sec^2 in winds to 45 mph	Same
	10°/sec^2 max	0 to ±10°/sec^2 max: control drive or brake deceleration	10°/sec^2 max in drive control
Stow	Stow from any position in winds to 60 mph	Stow from any position in winds to 60 mph	Same
Antenna Operation:			
Modes	Manual Position	Manual Position	Same
	Manual Velocity	Manual Velocity	Same
	Slave	Slave	Same
	Programmer	Programmer	Same

TABLE 12-1. SYSTEM REQUIREMENTS (Cont)

CHARACTERISTIC	SPECIFICATION REQUIREMENTS	COLLINS PROPOSED	COLLINS DESIGN
	Acquisition Track	Acquisition Track	Same
	Auto-Track	Auto-Track	Same
		Auto-Program	Same
Submodes	Brake	Brake	Same
	Scan-Spiral	Scan-Spiral	Spiral, Circle Raster, Line Offset
Test Modes	Position-Collimation Tower	Position-Collimation Tower	Same
	Acquisition Track	Acquisition Track	Same
	Auto-Track	Auto-Track	Same
	Programmer	Programmer	Same
Antenna Stow	Stow	Stow (zenith position)	Same
Allowable Errors:			
Position repeatability	not more than $\pm 0.01°$ in winds to 20 mph	not more than $\pm 0.01°$ in winds to 20 mph	Same
	NMT ± 0.02 in winds 20 to 30 mph	NMT ± 0.02 in winds 20 to 30 mph	Same
	NMT ± 0.04 in winds 30 to 45 mph	NMT ± 0.04 in winds 30 to 45 mph	Same
Static dead zone	NMT $\pm 0.002°$	NMT $\pm 0.002°$	Same
Acquisition tracking (overall system axis tracking)	NMT 12 min of arc ($0.2° = 3\sigma$) in winds to 20 mph; max s/n ratio	NMT $0.2° = 3\sigma$ in winds to 20 mph; s/n ratio max	Servo errors exclusive of rf noise $3\sigma = 0.009°$ for widest bandwidth
Auto tracking (overall system axis tracking)	NMT 1.5 min of arc ($0.025° = 3\sigma$) max s/n ratio (includes antenna and encoder errors)	dynamic errors NMT $0.018° = 3\sigma$ gear noise, variations in friction, cogging noise, etc. NMT $0.015° = 3\sigma$	Servo errors exclusive of rf noise $3\sigma = 0.009°$ for widest bandwidth

TABLE 12-1. SYSTEM REQUIREMENTS (Cont)

CHARACTERISTIC	SPECIFICATION REQUIREMENTS	COLLINS PROPOSED	COLLINS DESIGN
	NMT $0.05° = 3\sigma$ winds 20 to 30 mph, NMT $0.1° = 3\sigma$ winds 30 to 45 mph	Wind induced noise NMT $0.004° = 3\sigma$ for 20 mph wind NMT $0.05° = 3\sigma$ NMT $0.1° = 3\sigma$	servo errors do not include antenna or encoder errors.
Slave tracking	Not specified	Not specified	$\pm 0.2°$ goal
Locked Motor Resonance	4 cps or greater	min 4 cps; goal 6 cps	Same
Transient Response:			
Manual mode overshoot	overshoot NMT 40% setting to within 5% of final value within 1.5 sec. for unsaturated step command	NMT 30% setting time 1.5 sec	NMT 40%
Velocity constant	at least 80	$K_v >> 80$, type II servo	Same
Velocity mode overshoot	not stated	NMT 1.3X input command	Same
Setting time	1.5 sec	1.5 sec	Same
Tracking mode overshoot	40%	NMT 40% for type II NMT 30% for type I tracking	NMT 40%

12.2 DESCRIPTION OF SYSTEM.

The servo control and drive subsystem consists of transistorized electronic servo amplifiers which control a hydraulic drive system on each axis. A block diagram of the servo subsystem is shown in figure 12-1. The servo bill of materials is listed in table 12-2.

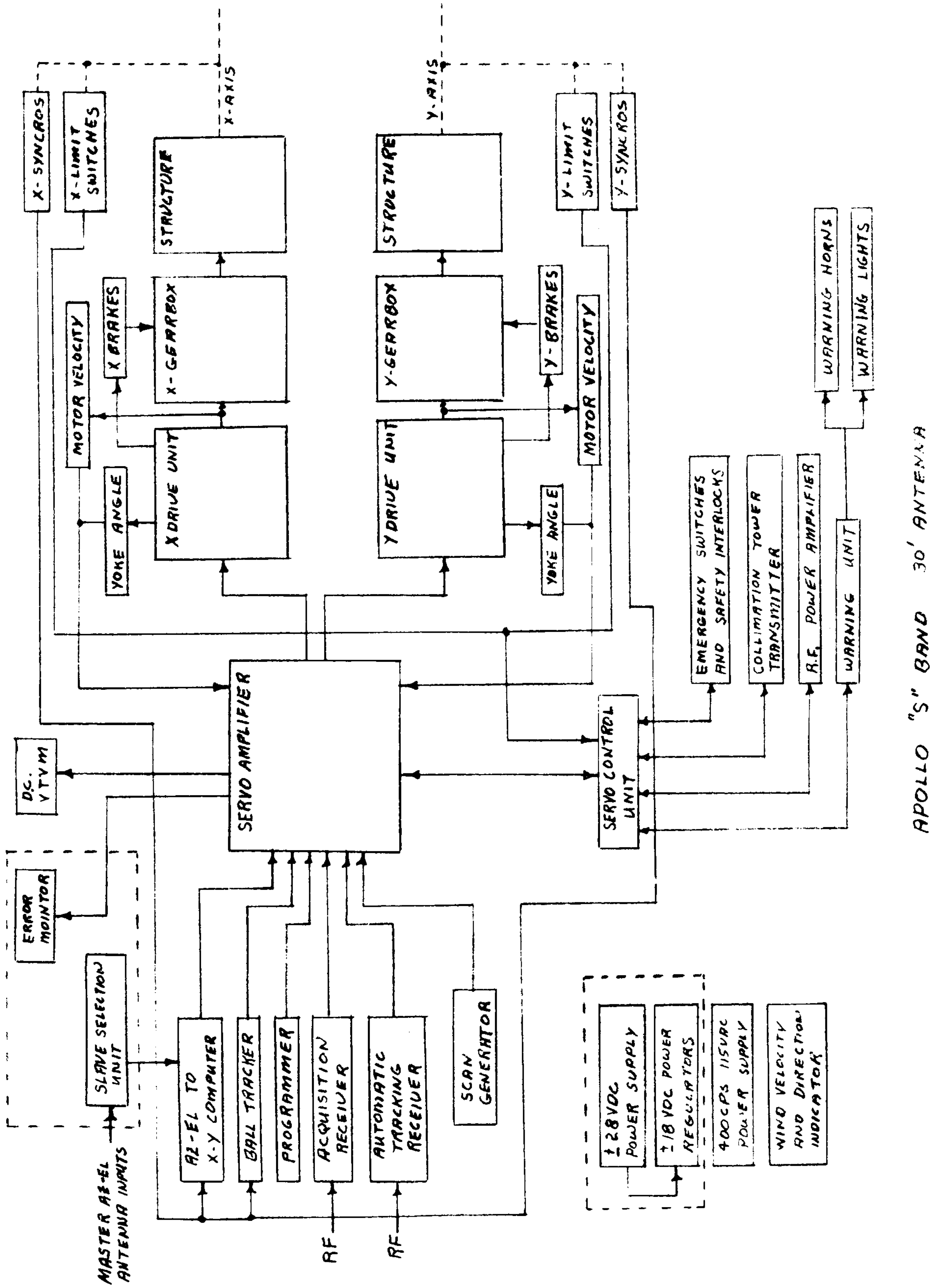


Figure 12-1. Servo and Drive Systems, Block Diagram

TABLE 12-2. SERVO BILL OF MATERIALS

UNIT	QUANTITY
CONSOLE MOUNTED UNITS	
Servo Control	1
Scan Generator	1
Error Monitor-Slave Selector	1
Warning Control	1
Ball Tracker	1
Wind Direction and Velocity Indicator	1
RACK MOUNTED UNITS	
Dual Axis Amplifier	1
AZ-EL to X-Y Computer	1
DC Power Supply	1
400 cps Power Supply	1
DC VTVM	1
Rack Terminal Unit	1
AUXILIARY	
Rack Wiring Kit	
Antenna Wiring Kit	
ANTENNA MOUNTED UNITS	
Axis Warning System	1
Emergency Interlock System	1
X-Axis Servo Box	1
Y-Axis Servo Box	1
X-Axis Tachometer Box	2

TABLE 12-2. SERVO BILL OF MATERIALS (Cont)

UNIT	QUANTITY
Y-Axis Tachometer Box	2
X-Axis Synchro Box	1
Y-Axis Synchro Box	1
Dual Axis Hydraulic Drive including heat exchanger and hydraulic installation kits	2

The console layout of the servo subsystem is shown in figure 12-2 and the final layout of the servo control unit, ball tracker, scan generator, error monitor-slave selector unit, and antenna axis servo box are shown in figures 12-3 through 12-7, respectively. Figure 12-8 is the servo subsystem cable diagram.

12.3 SERVO DESIGN.

The Apollo S-Band 30-foot X-Y antenna tracking system must search for, acquire, and track satellite beacons in orbits as low as approximately 130 miles high. It must also operate in an environment including wind torque induced noises as well as rf thermal noises which cause position errors. The servo subsystem must, therefore, provide sufficient loop gain to minimize errors because of relative satellite to antenna dynamics, it must have sufficient low frequency gain, and sufficient high frequency bandpass to minimize the effects of wind noise and yet a minimum bandwidth to minimize received rf noise which causes position jitter. For example, when tracking a low altitude spacecraft in high winds requires a wide bandwidth, while tracking a satellite at long ranges when the wind is negligible requires a minimum bandwidth because of thermal rf noise. To track under high variable wind conditions plus high rf noise conditions, requires a wide servo loop for the wind noise and a small servo bandwidth for the tracking signal. Consequently, a combined mode such as wide bandwidth programmed pointing plus a narrow bandwidth tracking signal channel may be required.

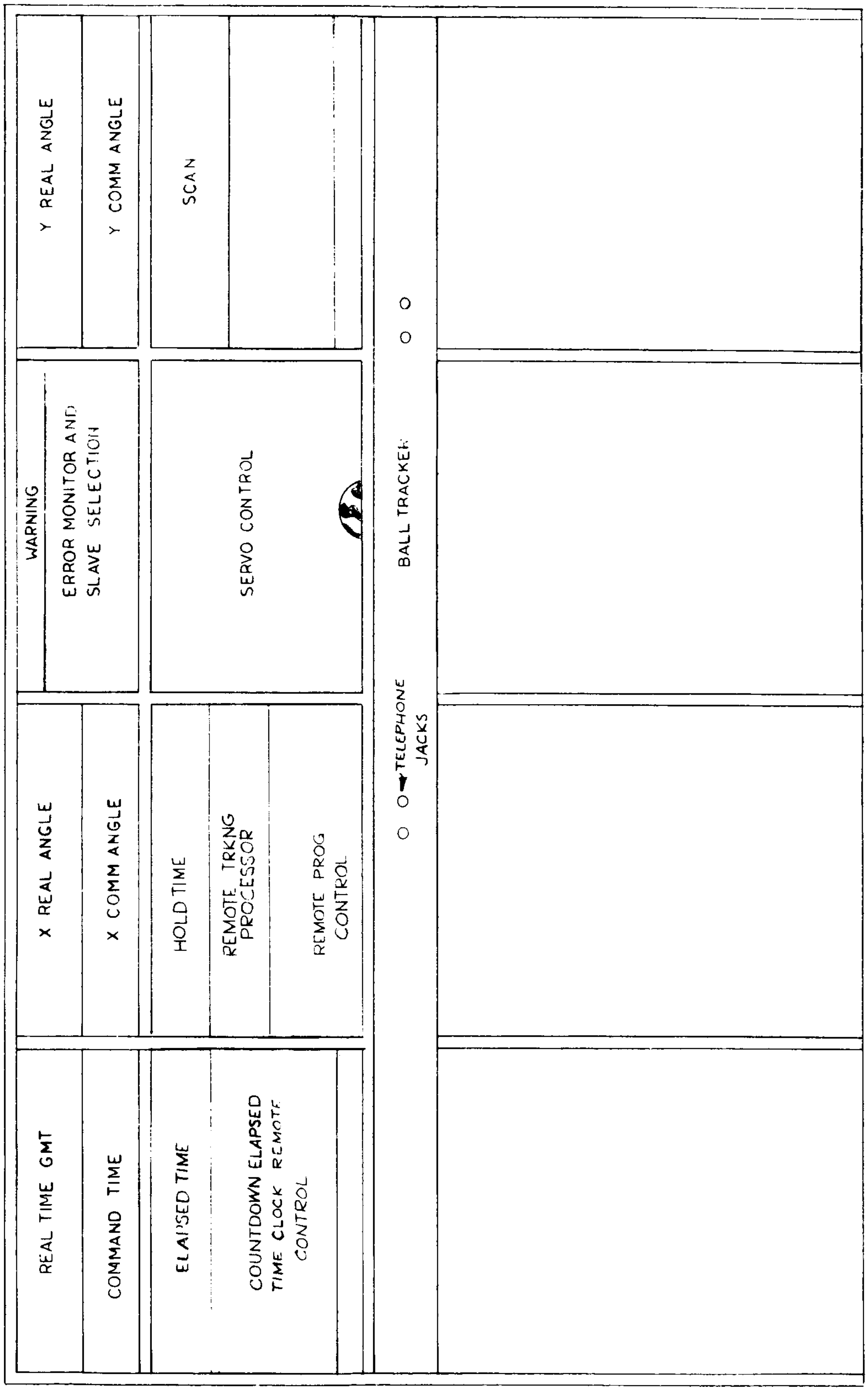


Figure 12-2. Control Console Layout

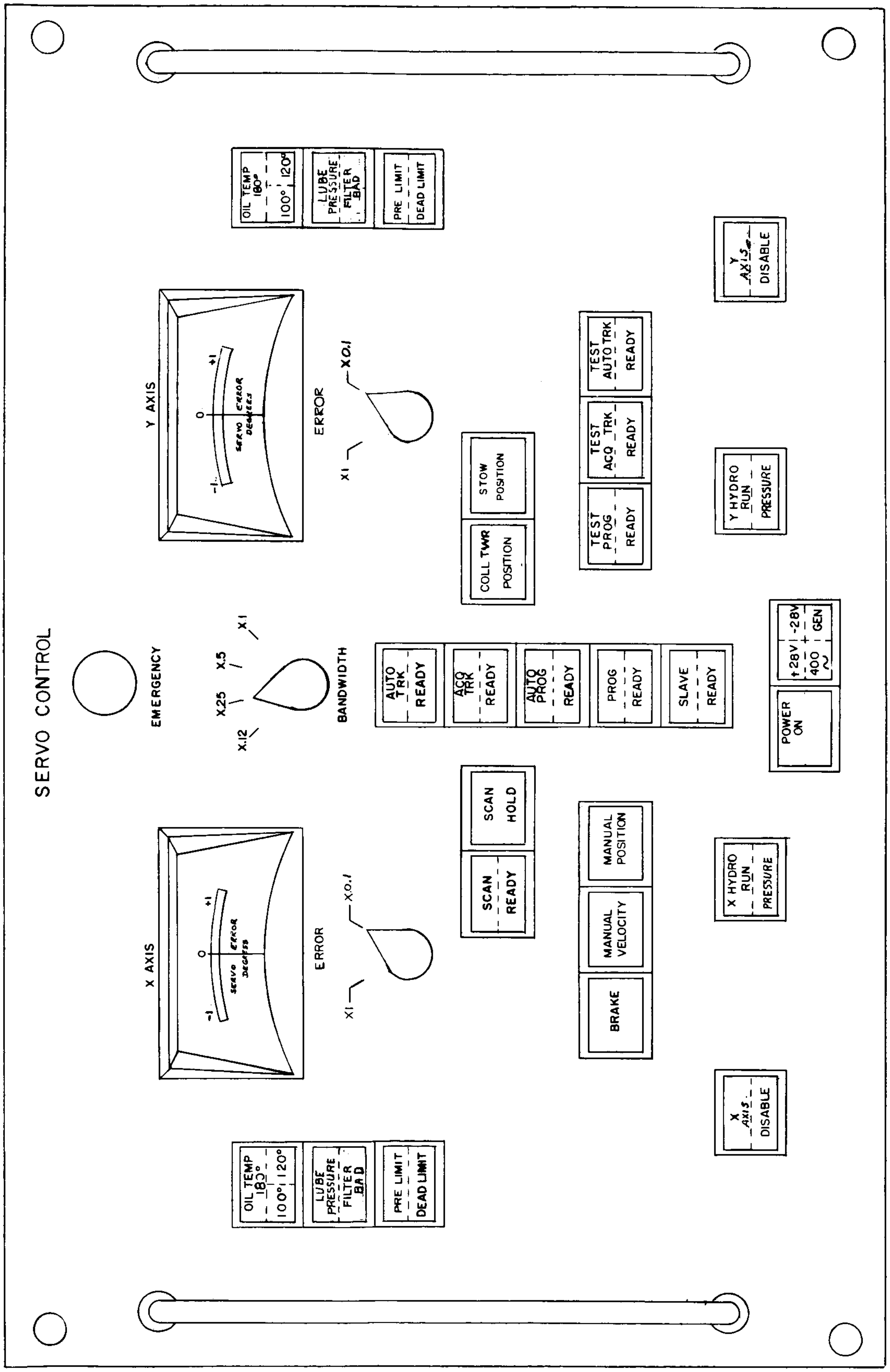


Figure 12-3. Servo Control Unit

Figure 12-4. Top View of Ball Tracker

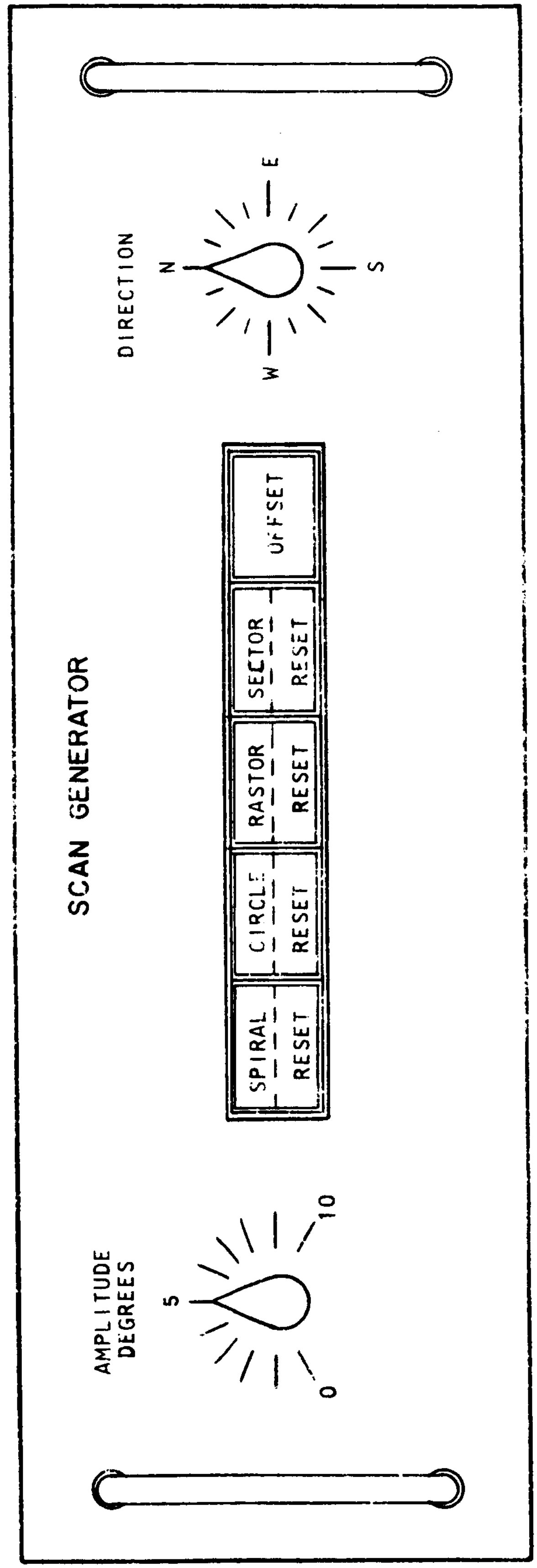


Figure 12-5. Scan Generator

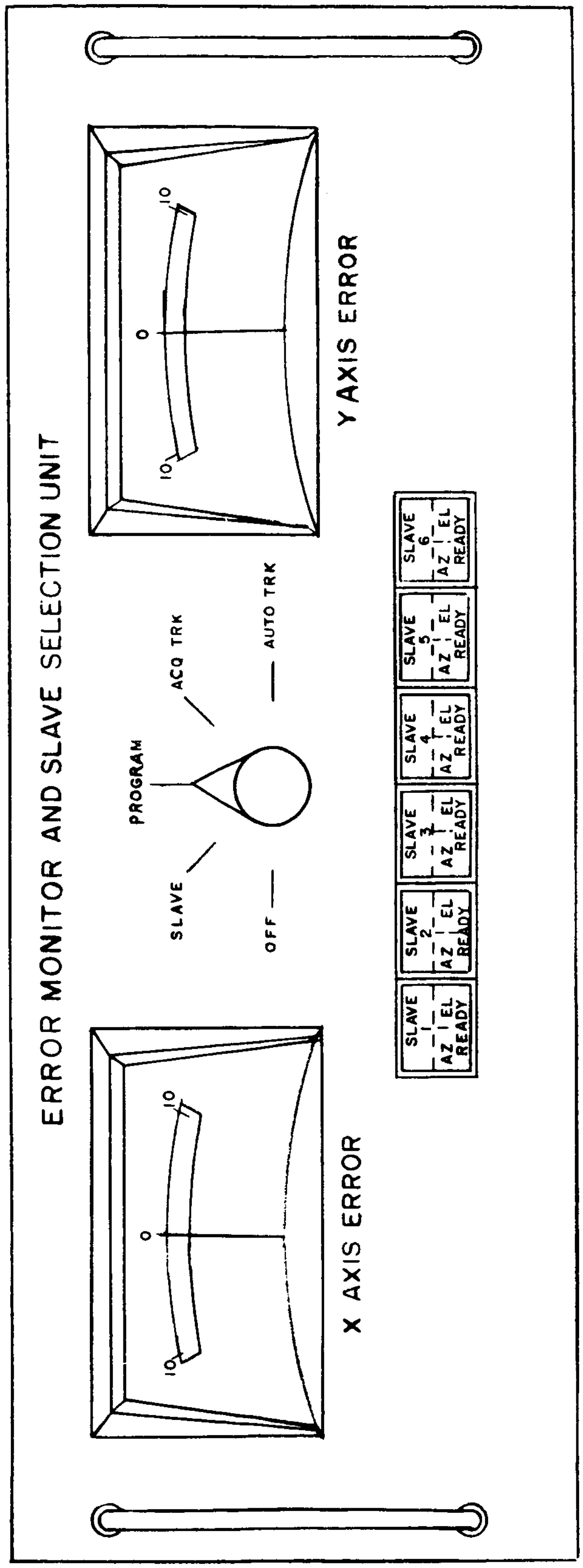


Figure 12-6. Error Monitor and Slave Selection Unit

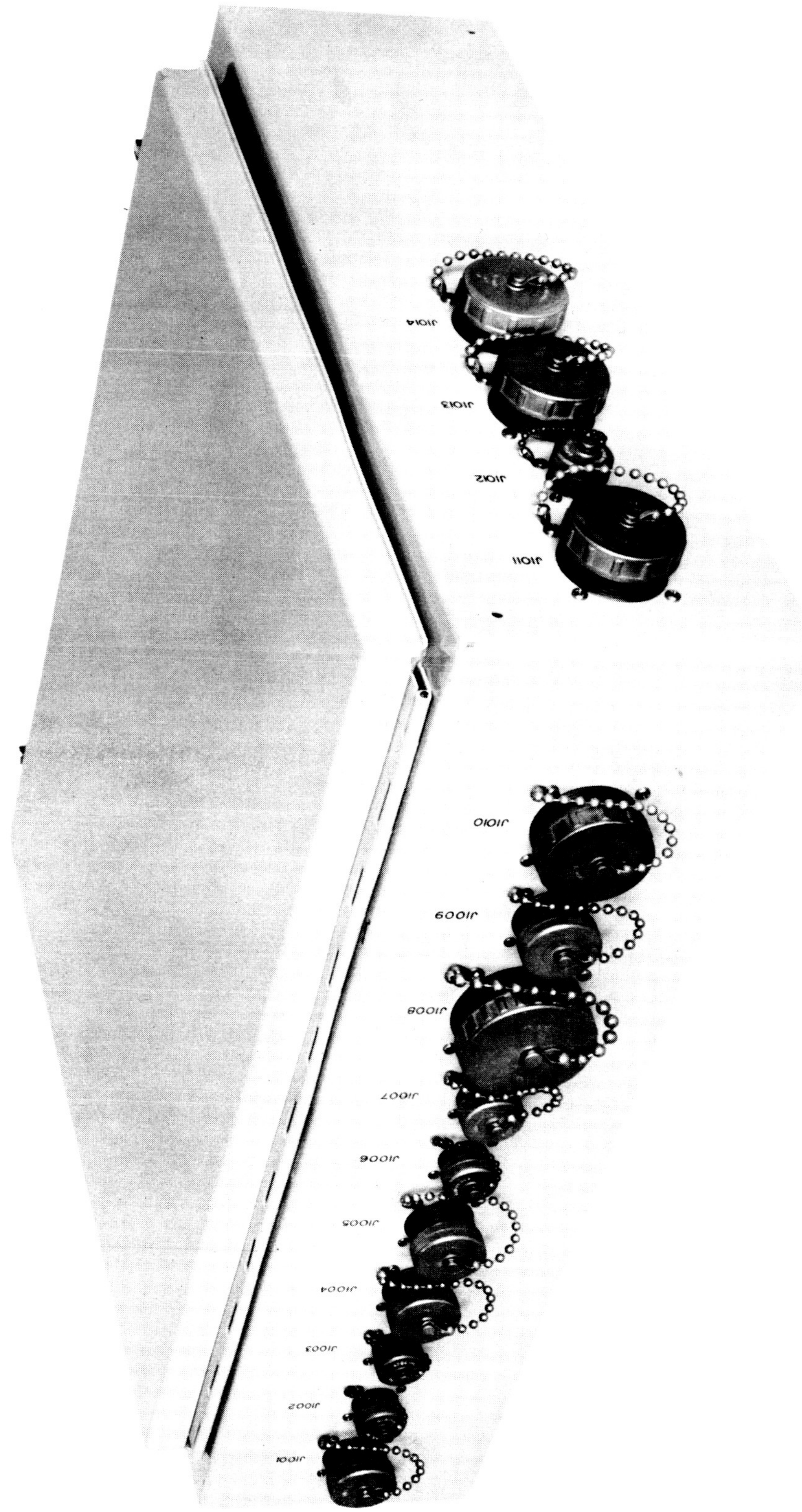


Figure 12-7. Antenna Axis Servo Box

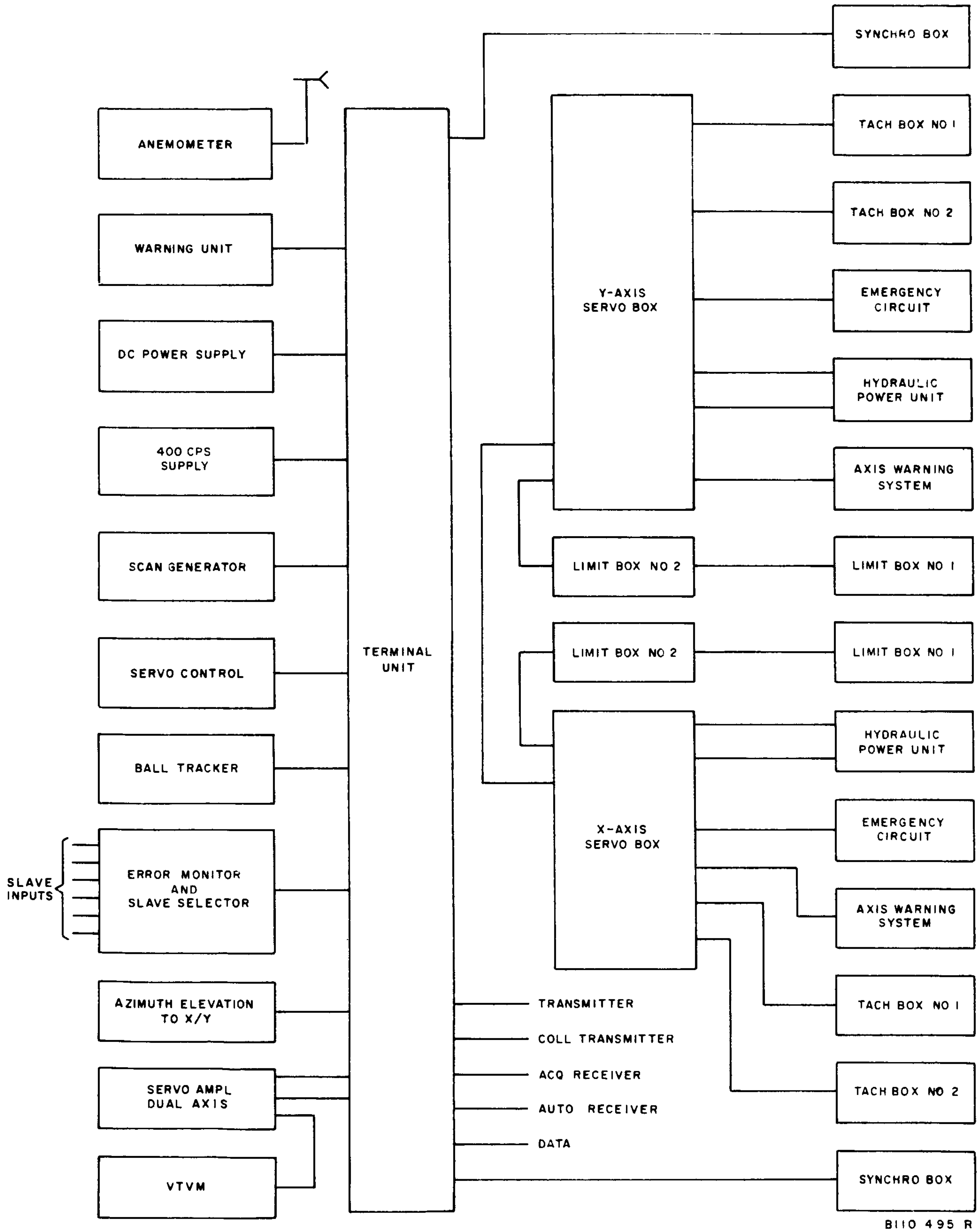


Figure 12-8. Servo Cable Diagram

The criteria for designing the servo system is based, in part, on the Goddard Space Flight Center Specification GSFC-TDS-SRV-30, which gives the tracking conditions for strong rf signal conditions. Figure 12-9 gives a brief qualitative examination of how the system tracking error increases as the signal strength decreases since the thermal rf noise increases. The design is also based on providing bandwidth switching to allow an operator to choose the optimum bandwidth for the conditions previously discussed and also on providing a combined auto-track programmer mode (aided tracking) for tracking low level rf signals under high wind conditions. Also position resolutions in some modes are improved over those in the GSFC specifications, i.e., programmer mode, servo system analogs, and saturation levels have been chosen to use the full dynamic range of amplifiers. In addition, interface areas not apparent in the servo specification require optimization; for example, the acquisition receiver output analog is believed to be no more than 0.3 volt per degree and not 0 to 10 volts per degree adjusted to 3 volts per degree as stated in the servo specification.

In general, the servo tracking loop design is based on providing a type II servo for tracking from about 0.002 to 4 degrees per second antenna axis angular velocity with axis tracking errors minimized by the servo operator selecting the optimum bandwidth for the particular mission and mode of operation.

The proposed servo system tracking loop is shown in figure 12-10. A Bodie plot is shown in figure 12-11. A locked rotor frequency of 4 cps is used with a velocity servo -3 db bandwidth of approximately 2 cps. Bandwidth selection is provided and the compensation for each bandwidth is selected to optimize transient response. An analog computer study is presently being performed to determine the optimum compensation. For this report, a ratio between the open loop unity gain crossover frequency and the acceleration error coefficient is as follows:

$$\omega_c^2 = K_\alpha \sqrt{6}$$

Where: ω_c is in radians/sec

K_α is the acceleration error coefficient in $\frac{1}{\text{sec}^2}$ units

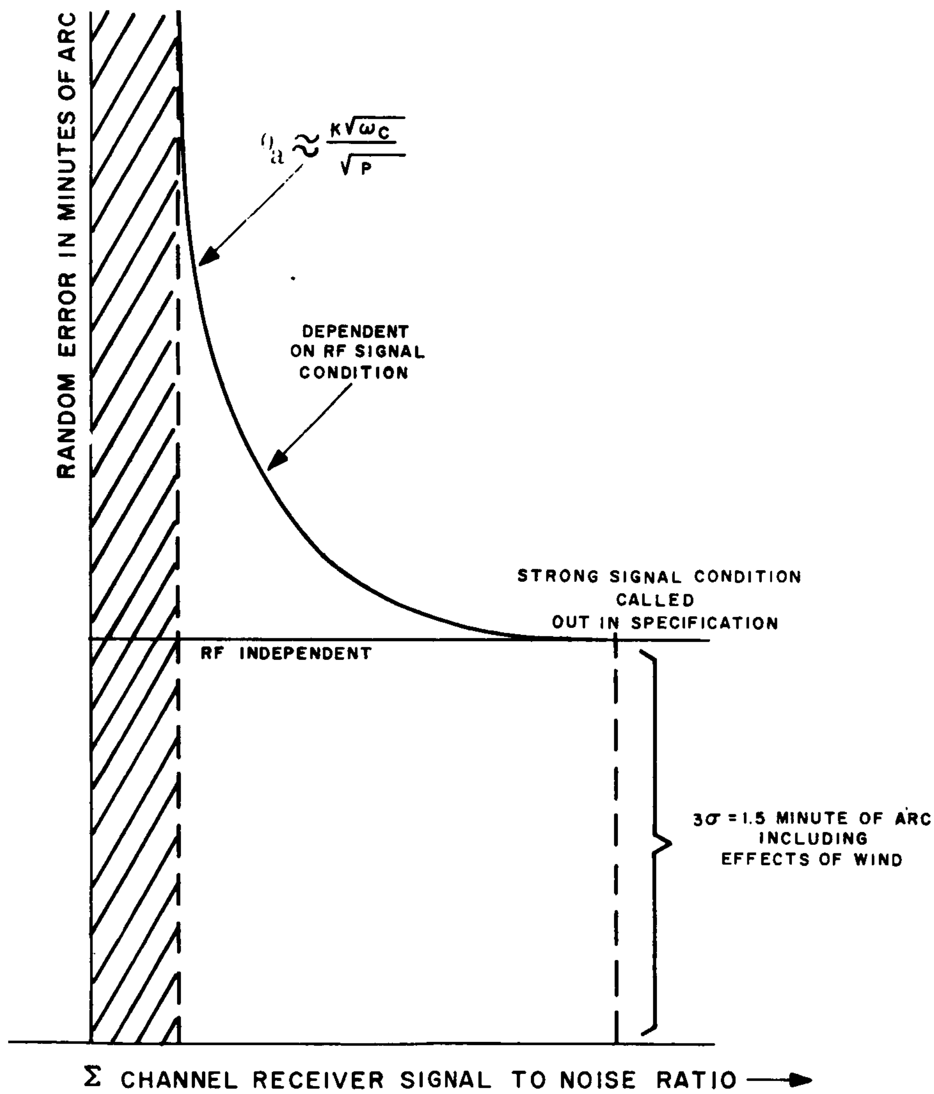


Figure 12-9. Axis Random Error as a Function of Signal-to-Noise Ratio for a Given Servo Bandwidth

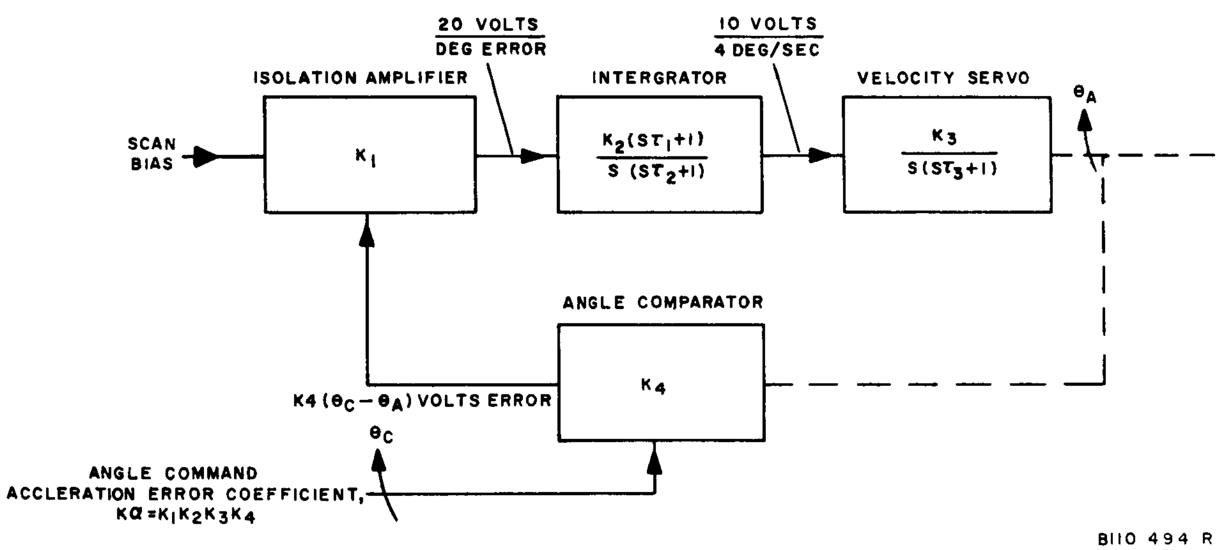


Figure 12-10. Axis Position Loop, Simplified Block Diagram

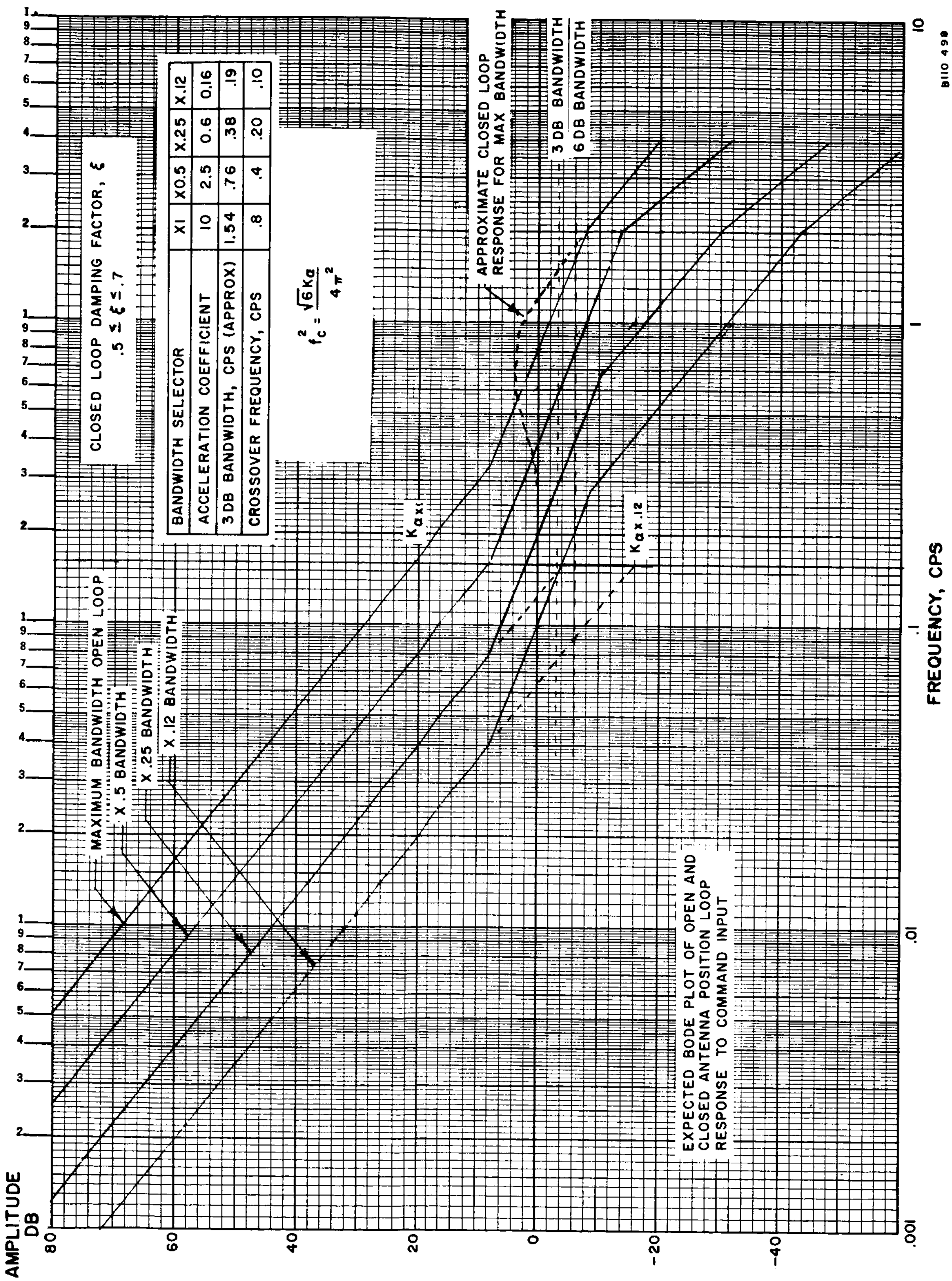


Figure 12-11. Expected Bode Plot of Open and Closed Response to Command Input

The velocity servo, which controls the axis velocities of the antenna from $0.002°$/sec to $4°$/sec with a closed loop -3 db bandwidth of approximately 2 cps, is shown in figure 12-12. Yoke velocity commands are controlled to insure an antenna acceleration of not more than $10°/sec^2$ under all load conditions. The velocity servo tachometer feedback and the high spring constants of the gear reducers insure that the bull gear drive pinion spring rate is extremely high for wind torque fluctuations on the antenna.

The basic position resolution of the antenna axis motion controlled by the servo tracking loop will be no less than $\pm 0.002°$. Positive anti-backlash control is used for the antenna gearing and stiction levels are sufficiently low to permit this resolution. The pump yoke angle potentiometer has a resolution equivalent to 4×10^{-4} degree per second of antenna velocity. The motor tachometers have resolutions sufficient to control an antenna velocity better than $0.001°$/sec. See figure 12-13. The effects of stiction, wind torque, and tachometer feedback, as shown in figure 12-14, reveal that a tachometer loop gain of 18.4 minimum is necessary. Since a type I tachometer loop is planned, the loop gain will be sufficiently large to insure a velocity resolution of $\pm 0.002°$/sec.

12.4 HYDRAULIC DRIVE.

Table 12-3 is a summary of drive and antenna parameters. In the hydraulic schematic, figure 12-15, it will be noted that the primary relief valve in the replenishing circuit (set at 100 psi) has been positioned to insure a positive flow of 5 gpm from the replenishing vane pump through the servo pump relief loop. This will provide a constant change of oil in this loop and will insure against overheating of the pump valve plate and barrel assembly should the antenna be driven against set brakes causing the servo pump relief valves to lift. This condition could quickly overheat the small amount of oil in the relief loop. Pump cooling when the unit is in standby operation should also be improved.

Although it is not apparent from the schematic, improved pump cooling will be obtained by passing the 5 gpm replenishing vane pump flow twice through the pump case. One pass will flow over and around the pump valve plate and barrell assembly, while the second pass will be over the yoke assembly.

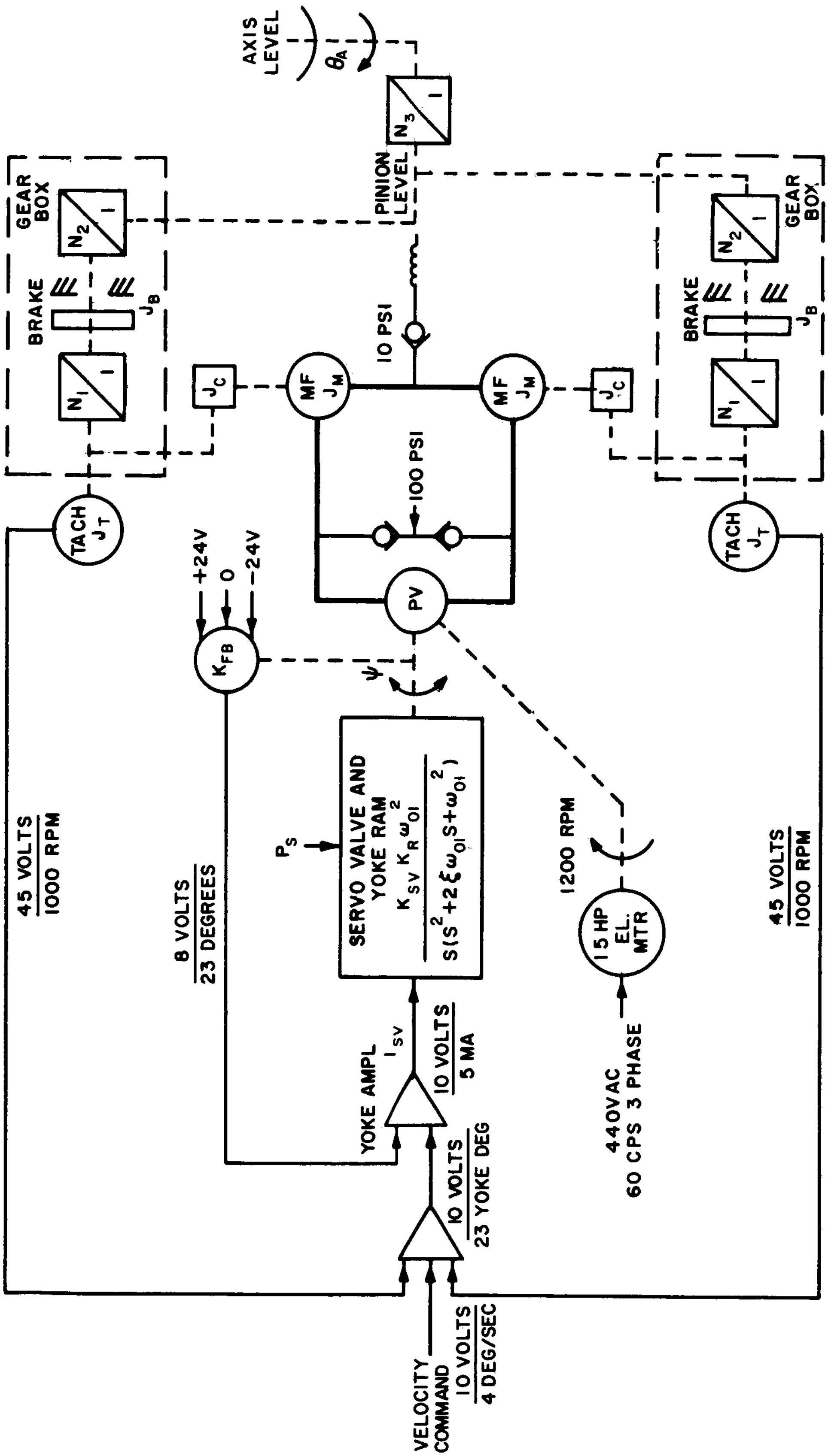


Figure 12-12. Axis Velocity Servo, Simplified Block Diagram

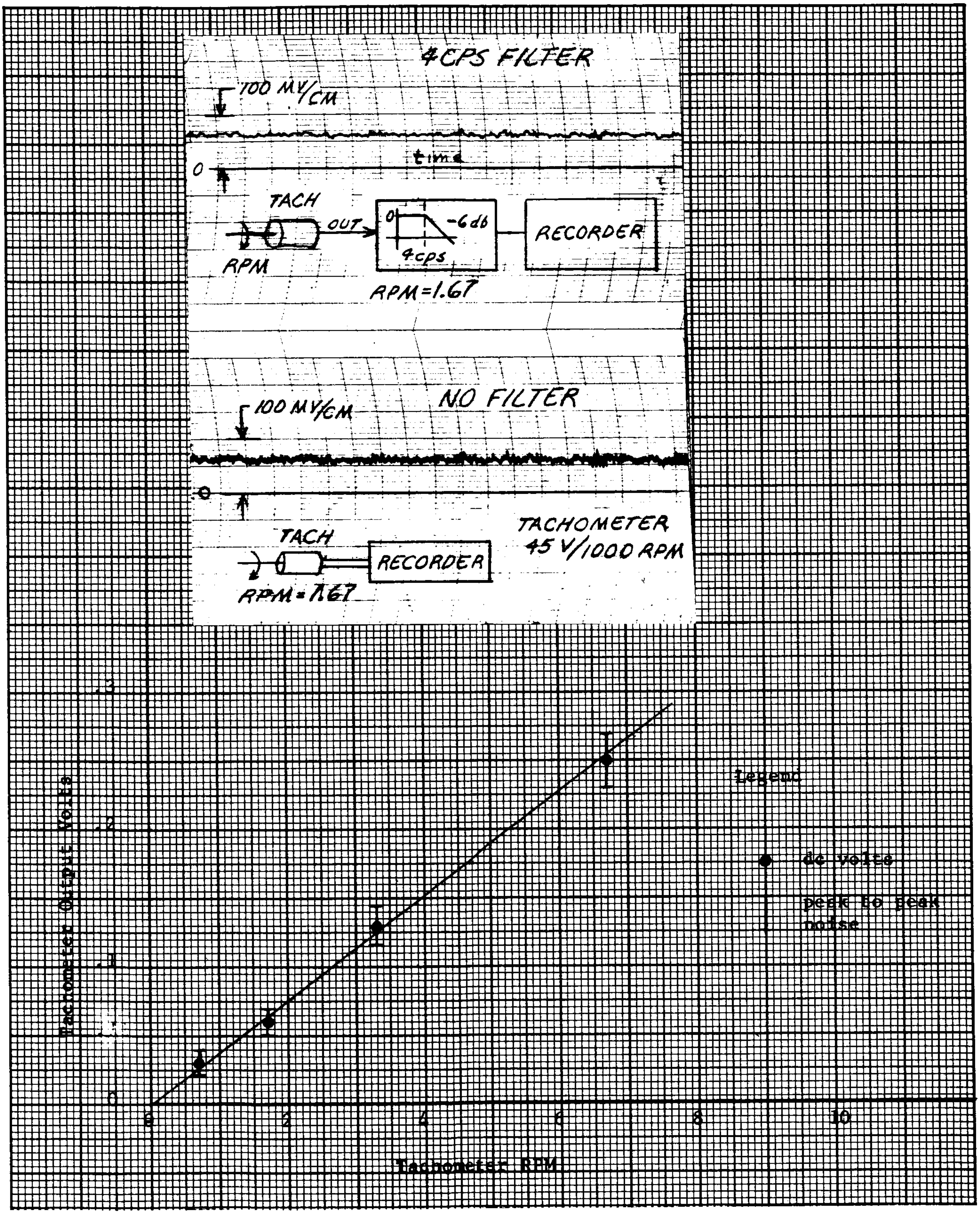


Figure 12-13. Tachometer Output Versus RPM

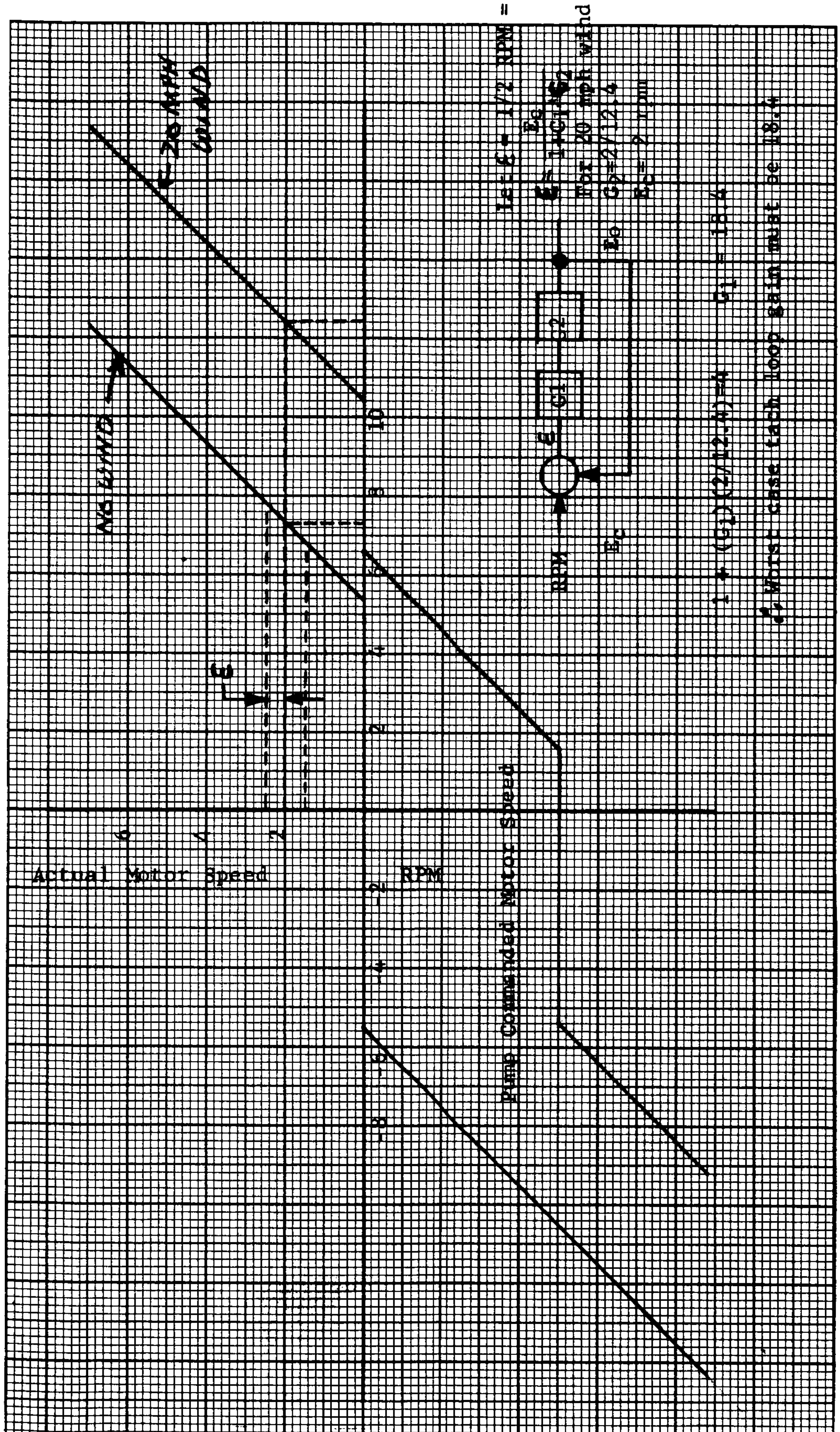


Figure 12-14. Actual Motor Speed Versus Pump-Commanded Motor Speed

TABLE 12-3. HYDRAULIC DRIVE PARAMETER CHART

COMPONENT	X-AXIS	Y-AXIS	UNITS
Hydraulic Pump-Denison	Series 700	Series 700	
Servo Valve	Atchley 410	Atchley 410	
Hydraulic Motor-Vickers	MFA-2003-30-15	MFA-2003-30-15	
Brake-Goodyear			
Rating Per Unit	290	130	Ft-Lb (Static)
J_b (Max) Motor Level	.005	.005	In-Lb Sec^2
Gear Reducer			
J_r (Max.) Motor Level	.018	.015	In-Lb Sec^2
G_{mp} (N_1 N_2) Overall	180:1	216:1	
N_1 (Motor to Brake Level)	4.5:1	4.5:1	Min. Ratio
K_{s2} (at Drive Pinion)	1.5×10^6	1.5×10^6	Ft-Lb/Radian
Motor Level Stiction	6	6	In-Lbs
Pinion to Bull Gear	34:1	28:1	Ratio
Axis Spring Constant	2.2×10^8	1.2×10^8	Ft-Lb/Radian
Antenna Inertia About Axis	200,000	50,000	Ft-Lb Sec^2
Motor to Gear Reducer Coupling, J_c	.002	.002	In-Lb Sec^2
Motor Inertia, J_m per Motor	.005	.005	In-Lb Sec^2
Total Inertia at Motor Level: J_i	.060	.054	In-Lb Sec^2
Volume of Hydraulic Oil Under Compression (Max.)	20	20	In^3
Expected Hydraulic Resonance	8.2	8.3	Cycles/Sec
Expected Resolution of Pump Yoke Angle	.0023	.0023	Degrees
Motor Displacement Constant	0.153	0.153	In^3/Radian

TABLE 12-3. HYDRAULIC DRIVE PARAMETER CHART (Cont)

COMPONENT	X-AXIS	Y-AXIS	UNITS
Expected Resolution of Motor Velocity	0.5	0.5	RPM
Hydraulic Oil	MIL-F-17111	MIL-F-17111	
Oil Filtration Per MIL-H-8815A	1.5-15	1.5-15	Micron
Filter Area in Excess of Flow Rating	448-560	448-560	Percent
Normal Heat Load with 120° Ambient Air	3	3	Horsepower
Heat Exchanger Capacity with 120° Ambient Air	6	6	Horsepower
Electric Drive Motor (1200 RPM,440 V,60 cps,3 ∅)	15	15	Horsepower

Secondary relief valves have been placed between the vane pump outlets and the nonbypass type filters as a safety measure. The filters used here contain elements designed to withstand extremely high pressure differentials. If a clogged element were left unattended, the increased pressure drop across the filter element could conceivably exceed the rated pressure of the vane pump and cause the pump to fail from over-pressure if no relief were present.

12.4.1 MECHANICAL LAYOUT.

The mechanical layout of the hydraulic drive unit is shown in figure 12-16. Access is possible to the Y-axis drive unit from only one side because of the confines of the X-wheel. For servicing purposes, all hydraulic components requiring inspection, servicing, or adjustment are mounted on the accessible side.

Because of space limitations and for purposes of servicing, both the X and Y-axes heat exchangers, associated temperature switches, and thermometers will be contained on a separate mounting on each axis and connected to the hydraulic drive unit during field installation. Heat exchanger air will exhaust to the outside.

Vibration:

The design for operating conditions shall be based on the equipment being subjected to vibration as specified under paragraph 3.11.8.1 of MIL-E-16400 (NAVY).

14.4.3.4 OTHER INFORMATION.

Drawings:	Certified parameters of motor-generator to be sent to ENERGY SYSTEMS 10 days ARO. Certified drawings to be sent 30 days ARO.
Documentation:	Certified copy of test results to be serialized, identified, and shipped with motor-generator Thirteen copies of the full operating instructions shall be delivered with each unit, including complete parts list. A preliminary instruction book shall be submitted and approved prior to issuing final book.
Reliability:	Long life and high reliability shall be a prime requirement; reliability shall be defined as the ability of the equipment to function properly and continuously under all conditions specified herein. The vendor shall exercise such quality control methods as to insure extremely high quality and reliability.
Life:	The equipment specified herein shall be designed for a minimum operating lifetime of 1 year of continuous operation at full power.
Final Acceptance:	Final acceptance will be based upon satisfactory performance in accord with these specifications.
Interference:	To meet MIL-I-26600. Test not required.

14.4.4 RADIO TRANSMITTER COOLING UNIT SPECIFICATIONS.

14.4.4.1 GENERAL.

Quantity:	Twenty units.
Type:	The cooling unit shall be vertical air discharge liquid-to-air heat exchanger for outdoor operation. Fourteen of the twenty units will be nonpressurized, but shall be designed for a minimum working pressure of 30 psig on the low side. The other six units shall be designed for a minimum working pressure of 75 psig.

Service:	The cooling unit shall be designed to cool a single stream of ethylene glycol-distilled water solution which will absorb the heat with high-powered electronic equipment, either ground-mounted or antenna-mounted. Fifteen units will be installed ashore, five units will be installed aboardship. None of the shipboard units will be pressurized. All equipment shall be selected for outdoor operation under the environmental conditions specified herein.
Equipment:	The cooling unit shall consist of one skid-mounted assembly of the following equipment: Radiator core, core guard screen, steel frame, plenum chamber, fan, fan guard screen, fan shroud ring, fan motor, pump, pump motor, reservoir, temperature control valve, flow switch, temperature switch, air flow switch, liquid level switch, 10-kw immersion heater, inlet and outlet temperature and pressure gauges, valves, piping, fittings, and nitrogen pressure regulator. The above assembly shall be skid-mounted; skid is to be equipped with forklift slots.
Layout:	The cooling system layout shall be similar to Figure 14-4, Heat Exchanger Flow Schematic.

14.4.4.2 MECHANICAL.

Heat Transfer Rate:	238,910 Btu/hr (70 kw)
Coolant:	50% uninhibited ethylene glycol; 50% distilled water solution.
Coolant Flow Rate:	32 gpm
Maximum Coolant Inlet Temperature:	154.1° F
Maximum Coolant Exit Temperature:	137°F

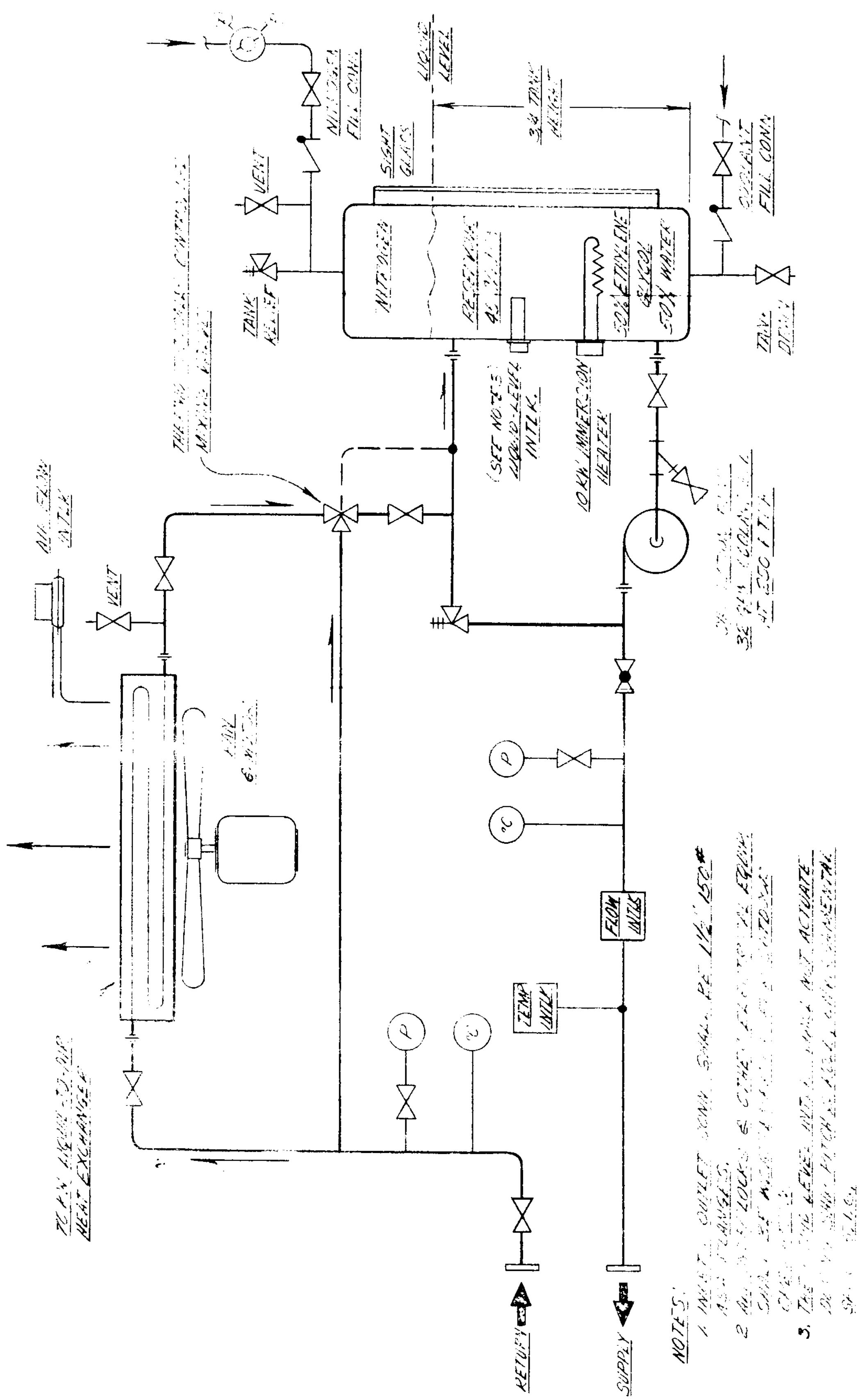


Figure 14-4. Heat Exchanger Flow Schematic

Maximum Air Inlet Temperature:	120° F
Minimum Air Inlet Temperature:	0° F
Set Point Temperature:	132° F
Set Point Regulation:	±5° F
Pressure Drop:	The maximum pressure drop through the cooling unit at normal operating temperatures shall not exceed 10 psi.
System Static Pressure:	
Pressurized Unit:	75 psig (6 units)
Nonpressurized Unit:	30 psig (14 units)
Coolant Circuit:	The coolant circuit will be a closed loop pressurized with nitrogen. Materials in contact with the coolant are to be limited to copper, bronze, brass, and stainless steel. Brass shall be used as sparingly as possible. All solder joints shall be silver-soldered with solder containing a minimum of 45 silver and with a melting point of at least 1100° F.
Coolant Connections:	Supply and return connections shall be 1-1/2 inches, 150# ASA flanges. Cooling unit inlet and outlet connections shall be side-by-side located near the ground.
Fan Noise:	Fan noise shall be limited to 83 db at 18 feet in front of the fan. No test required.
Vibration:	Rotating parts shall be in static and dynamic balance to minimize vibration during operation.
Degreasing:	All interior surfaces of the cooling unit - heat exchanger, pump, reservoir, pipe, and fittings - which come in contact with the coolant shall be degreased with a solvent or detergent. All trash, dirt, and other foreign material shall be flushed from the

coolant passages prior to delivery. The interior surfaces of the cooling unit shall be dry and clean upon delivery.

Leak Test:	The contactor shall guarantee that the cooling unit will show no visible leakage when tested with coolant, as specified, at the set point temperature, 132° F, at one and one-half times the operating pressure. Repairs required to enable the system to meet this test will be at the contractor's expense. The test will be performed at ENERGY SYSTEMS within a reasonable time after delivery.
Operating Test:	All fans, motors, and pump shall be tested for porper operation and rated performance after the cooling unit is fully assembled and prior to delivery. Certification of the vendor's pump capacity test shall be provided with each cooling unit at delivery.
Witnessed Pump Test:	A capacity test shall be performed on the circulation pump used in the first unit delivered. ENERGY SYSTEMS shall be notified 2 days prior to this test so that cognizant personnel may be on hand as witnesses. Copies of the certified data from this test shall be provided with the unit at the time of delivery.
Painting:	After all machining, welding, and brazing operations are completed, all surfaces shall have all rust or other visible corrosion products and flux removed; shall be thoroughly cleaned of all grease, oil, and dirt by solvent wiping, vapor degreasing, or caustic washing and rinsing' and shall then be painted as follows:
Primer:	One coat of synthetic paint primer 0.0008 inch thick per TT-P-636.
Enamel:	GSDS gray, air dry #422281 per MIL-E-15090, Type II, Class 2 (order paint from the Trail Chemical Co., El Monte, Calif.).

Operating Instructions:	Thirteen copies of the full operating instructions shall be delivered with each unit. A preliminary instruction book shall be submitted and approved prior to issuing final book.
Parts List:	Thirteen copies of the full parts list shall be delivered with each unit.
Life:	Life expectancy of the equipment shall be for 1 year of continuous operation at full power during the 1-year period following the delivery date.

14.4.4.3 ELECTRICAL.

Primary Power:	440 volts, ±10%3-phase, 3-wire, 60 ±3 cps.
Control Power:	26 volts dc.
Electrical Components:	NEMA MG-1-1955.
Wiring Connections:	All wiring connections shall enter the weathertight control receptacle through the bottom.
Motor Controls:	The quotation shall include the cost of units with motor controls and units without motor controls. Motor controls and circuit breakers shall be weathertight for outdoor operation.
Switches:	All switches shall be weatherproof for outdoor operation.
Wiring Diagrams:	Thirteen copies of complete wiring diagrams shall be supplied with each unit.

14.4.4.4 EQUIPMENT

Enclosure:	Total enclosure is not required; however, the heat exchanger must operate under any and all environmental conditions in accordance with the performance specifications outlined herein. The unit shall be skid-mounted and shall be provided with forklift slots. Slots

	shall be 2-1/2 in. deep by 10 in. wide on 54 in. centers. The unit shall also be provided with four lift eyes suitable for crane handling.
Reservoir:	
Pressurized:	The reservoir shall be 45-gallon capacity and shall be built, tested, and stamped per ASME code, for 75-psig working pressure. The reservoir shall be complete with 10-kw immersion heater, relief valve, drain valve, vent valve, sight glass, liquid level switch, coolant high temperature switch, inlet and outlet connections, and a 1/4-inch NPT nitrogen connection with shutoff valve. The coolant return line shall discharge coolant in the reservoir below the liquid level.
Non-pressurized:	Same as above except delete ASME code stamp and design for a minimum working pressure of 30 psig. Note: The reservoir in the non-pressurized system will serve as an expansion tank and will experience some pressure as the coolant expands.
Circulation Pump Coolant:	The pump shall be a centrifugal or turbine type with mechanical seal. The motor shall be TEFC, shall comply with NEMA standards, and shall be wound for 208 volts ±10%, 3-phase, 60 ±3cps. The pump shall have a capacity of 32 gpm at 250 FTDH when pumping coolant per para. 2.2, at 137° F.
Fan and Coil:	The fan and coil shall be mounted for vertical air discharge. The fan motor or motors shall be TEAO, shall comply with NEMA standards, and shall be wound for 208 volts, ±10%, 3-phase, 60 ±3 cps. Total horsepower of the fan or fans shall not be greater than 5.
Pressurized Coil:	Coils for pressurized units shall have a working pressure of at least 85 psig.
Unpressurized Coil:	Coils for unpressurized units shall have a working pressure of at least 35 psig.

Temperature Control Valve:	The temperature control valve shall be a self-contained thermostatically operated mixing valve with adjustable set point and shall be capable of maintaining the coolant temperatures at the set point within the set point regulation of ±5° F.
Gauges:	Coolant temperature and pressure gauges shall be panel-mounted. Temperature gauge dials shall read in °C. Each pressure gauge shall be provided with a gauge cock per Figure 14-4.
Controls:	Controls shall be weatherproof for outdoor operation. All thermostats, control switches, control valves, motors, and other control equipment shall be adjusted and placed in complete operating condition by the contractor.
Mechanical Protection:	Guards shall be provided to protect personnel from moving parts such as fans, couplings, belt driven mechanisms, etc. Edges and corners shall be rounded for the protection of operating personnel.
Mechanical Design:	All effort shall be made to design an equipment which maximizes performance, is physically rugged, and facilitates servicing and adjustment. The piping layout shall be such that it facilitates removal of components, contains a minimum number of bends, and is properly supported to prevent sway and vibration during operation. This unit shall be adequately provided with vents to facilitate filling and draining.
Nitrogen Pressure Regulator:	The nitrogen pressure regulator shall be a 2-stage regulator for cylinder service.
Nitrogen Cylinder Brackets:	The unit shall be provided with brackets capable of holding a 227 ft^3 nitrogen cylinder during the nonoperating environmental conditions outlined in para. 14.4.4.5, Nonoperating Environment.
	Note: The nitrogen cylinder is to be supplied by the customer.

14.4.4.5 ENVIRONMENTAL.

Operating Environment:

Temperature:	The cooling unit shall operate in accordance with the requirements of the specification within the ambient temperature range of 0° to 120° F.
Elevation:	From sealevel to 15,000 feet.
Humidity:	From 0 to 100% relative humidity through the operating temperature range.
Corrosion Resistance:	Materials and corrosion resistant materials shall be employed in accordance with specification MIL-E-16400 (Navy). In addition, the requirements concerning dissimilar materials shall apply. The salt spray test referred to in MIL-E-16400 (Navy) shall be applicable to all equipment intended for installation on weather decks and exposed to weather.
Vibration:	The design for operating conditions shall be based on the equipments being subjected to vibration as specified under para. 3.11.8.1 of MIL-E-16400 (Navy).
Pitch and Roll of the Ship:	The design for operating conditions shall be based on ship motions resulting from pitching in a sinusoidal manner with peak amplitudes of 0° to 5° and a minimum period of 6.25 seconds and sinusoidal roll with peak amplitudes of 0° to 15° and a minimum period of 12 seconds.

Nonoperating Environment:

Temperature:	-40° to +160° F.
Shock and Vibration:	Nonoperating vibration conditions which this equipment shall withstand shall be in accordance with specification MIL-E-16400 (Navy), para. 3.11.8.1. The equipment shall be capable of withstanding, when suitably packed and packaged, the shocks encountered in handling, shipping, and installation.

Pitch and Roll of the Ship:	The design for nonoperating conditions shall be based on ship motions resulting from a sinusoidal pitch with peak amplitudes of 0° to 10° and a minimum period of 6.25 seconds and sinusoidal roll with peak amplitudes of 0° to 30° and a minimum period of 12 seconds.

14.4.4.6 OTHER INFORMATION.

Size and Weight:	Final size and weight shall be specified within 30 days ARO.
Submittal Drawings:	Submittal drawings shall be sent to ENERGY SYSTEMS within 14 days ARO. The submittal drawings shall be accompanied by two copies of the heat exchanger calculations, pump and fan capacity curves and data, and make and model of the coil, pump, fan, temperature control valve, interlocks and gauges.
Changes and Waivers:	There shall be no verbal changes or waivers to any part of this specification unless generated by cognizant ENERGY SYSTEMS personnel, and implemented by a change in the purchase order.
Reliability:	Long life and high reliability shall be a prime requirement; reliability shall be defined as the ability of the equipment to function properly and continuously under all conditions specified herein. The vendor shall specify such quality control methods as to insure extremely high quality and reliability.
Life:	The equipment specified herein shall be designed for a minimum operating lifetime of 1 year of continuous operation at full power during the 1 year period following the delivery date.
Tests:	Two days advance notice of all tests specified herein shall be given to ENERGY SYSTEMS so that cognizant personnel may be on hand as witnesses.

Quality Control:	ENERGY SYSTEMS reserves the right to in-process quality control and inspection of all major components specified herein.

14.4.4.7 TECHNICAL INFORMATION.

The single point of contact on this specification for technical information is L. H. Groh, Senior Mechanical Engineer, ENERGY SYSTEMS, INC.

14.4.5 LINE VOLTAGE REGULATOR SPECIFICATIONS.

14.4.5.1 ELECTRICAL.

Frequency:	60±3 cps.
Unregulated Input:	208 volts ±10%, 3-phase, 4-wire.
Regulated Output:	208 volts, 3-phase, 4-wire, ±1% maximum.
Load Power	7.5 kva.
Waveform Distortion:	Not to exceed 1%.
Protection:	Line circuit breakers to be provided by ENERGY SYSTEMS.

14.4.5.2 MECHANICAL.

Packaging:	Unenclosed, to be mounted by ENERGY SYSTEMS.
Sand, Dust and Fungus:	Per MIL-E-5272. Test not required.

14.4.5.3 ENVIRONMENTAL.

Shipping and Storage:

Temperature:	-65° to +160° F.
Altitude:	0 to 35,000 feet.

Operation:

Temperature:	55°C maximum.
Altitude:	15, 000 feet maximum.
Relative Humidity:	0° to 100%.

14.4.5.4 OTHER INFORMATION.

Reliability:	Long life and high reliability shall be a prime requirement; reliability shall be defined as the ability of the equipment to function properly and continuously under all conditions specified herein. The vendor shall exercise such quality control methods as to insure extremely high quality and reliability.
Drawings:	Three copies of certified outline drawings to be furnished by vendor within 30 days of receipt of Purchase Order.
Final Acceptance:	Final acceptance will be conditional upon satisfactory performance in accordance with tests to be performed by ENERGY SYSTEMS personnel.

14.4.6 CABINET BLOWER SPECIFICATIONS.

14.4.6.1 ELECTRICAL.

Frequency:	60±3 cps.
Voltage:	208 volts, ±10%, 3-phase.

14.4.6.2 PERFORMANCE.

Delivery, Free Air:	1500 cfm.
Delivery, 1-inch Static Pressure:	1000 cfm.

14.4.6.3 ENVIRONMENTAL.

General Specifications:	Per MIL-E-4158B, except as noted below.
Temperature:	-55° to +71°C.
Altitude:	
Storage:	0 to 35,000 feet
Relative Humidity:	0 to 100%.
Radio Interference:	Per MIL-I-26600.

14.4.6.4 MECHANICAL.

IMC type BC3820F, 10-inch propeller fan, or equivalent. Must be supplied with Venturi ring and personnel-protecting screen over blades.

14.4.7 HIGH-POWER ABSORPTIVE-TYPE WAVEGUIDE FILTER SPECIFICATIONS.

14.4.7.1 ELECTRICAL.

Passband:	
Frequency Range:	2.05 to 2.19 gc
Insertion Loss:	0.15 db maximum.
Input VSWR:	1.05:1 maximum, when terminated in a load whose vswr is 1.02:1 maximum.
Output VSWR:	1.1:1 maximum, when terminated in a load whose vswr if 1.05:1 maximum.
Power Transmission Capacity:	20 kw cw maximum.
Stop Bands:	
Frequency Range:	4.1 to 4.36 gc, 6.15 to 6.54 gc.
Attenuation:	60 db minimum, 50 db minimum.

Power Absorbing Capacity:	200 watts, 100 watts
Input VSWR:	1.5:1 maximum for all propagating modes in stop band 1. Measurements to be made at least for TE10 and TE01 modes. 2:1 maximum for all propagating modes in stop band 2. Measurements to be made at least for TE10 and TE01 modes.

14.4.7.2 MECHANICAL.

Input and Output Flanges:	To meet ENERGY SYSTEMS standards, drawing 50003C2 (UG-437A/U Flange Assembly).
Cooling:	Air convection cooling.
Exterior Finish:	To be specified. Paint furnished by ENERGY SYSTEMS if other than flat black.
Dissimilar Metals:	Per MIL-F-14072.

14.4.7.3 ENVIRONMENTAL.

Temperature:	-35° to +65°C.
Shock and Vibration:	1G, 5 through 100 cps, triaxial. Tests to be performed by ENERGY SYSTEMS after delivery of completed filter.
Operating Altitude:	0 to 15,000 feet.
Waveguide Pressure:	1.0 psig.
Orientation:	Any.
Fungus:	As per MIL-E-5272. No test required.
Protective Coating:	Must not chip, crack, or scale with age or extremes of climate or environment.
Humidity:	0 to 100 percent, including condensation due to temperature changes.

Location:	Will be mounted in movable antenna waveguide run exposed to weather.

14.4.7.4 OTHER INFORMATION.

Reliability:	Long life and high reliability shall be a prime requirement; reliability shall be defined as the ability of the equipment to function properly and continuously under all conditions specified herein. The vendor shall exercise such quality control methods as to insure extremely high quality and reliability.
Drawings:	Three copies of certified outline drawings to be furnished by vendor within 30 days of receipt of purchase order.
Final Acceptance:	Final acceptance will be conditional upon satisfactory performance in accordance with high-power tests to be performed by ENERGY SYSTEMS personnel. Vendor to furnish results of low-power tests.

14.4.8 WAVEGUIDE SWITCH SPECIFICATIONS.

14.4.8.1 ELECTRICAL.

Frequency Range:	2.0 to 2.2 gc.
Power:	25 kw cw.
Input VSWR:	1.05 maximum
Output VSWR:	1.1 maximum each arm.
Insertion Loss:	0.1 db maximum.
Isolation:	50 db minimum.

14.4.8.2 MECHANICAL.

Waveguide size:	WR-430.
Input and Output Flanges:	In accordance with ENERGY SYSTEMS drawings 50003E2 and 50003C1.

Waveguide Pressurization:	10 psig.
Drive Power:	120 volts, 60 cps ac, or 26 volts dc.
Interlocks:	Dpdt sensitive position switches.
Mechanical Life:	10,000 operations without degradation of mechanical or electrical performance.
Drive:	Motor-positioning, latching.

14.4.8.3 ENVIRONMENTAL.

Temperature:	-35° to +65°C.
Shock and Vibration:	1G, 5 through 100 cps, triaxial.
Operating Altitude:	0 to 15,000 feet.
Orientation:	Any.
Fungus:	As per MIL-E-5272. No test required.
Protective Coating:	Must not chip, crack, or scale with age or extremes of climate or environment.
Humidity:	0 to 100%, including condensation due to temperature changes.

14.4.8.4 OTHER INFORMATION.

Reliability:	Long life and high reliability shall be a prime requirement; reliability shall be defined as the ability of the equipment to function properly and continuously under all conditions specified herein. The vendor shall exercise such quality control methods as to insure extremely high quality and reliability.
Drawings:	Certified drawings to be furnished 30 days after purchase order is received.

14.4.9 HIGH POWER ISOLATOR SPECIFICATIONS.

14.4.9.1 ELECTRICAL.

Frequency Range:	2080 to 2130 mc.
Isolation:	10 db minimum.
Insertion Loss:	0.3 db maximum.
Input VSWR:	1.05 maximum.
Output VSWR:	1.1 maximum.
Average Power Rating:	25 kw cw. Load vswr will not exceed 1.6 to 1 in the fundamental frequency range.
Harmonoc Power Level:	Second harmonic, 200 watts; third harmonic, 100 watts; the sum of all other harmonics not to exceed 50 watts.
VSWR Input and Output for all Harmonic Power:	1.5:1 objective; vendor load vswr design choice to be specified 30 days ARO.
Operating Pressure:	1.0 psig in isolator electrical structure maximum.

14.4.9.2 MECHANICAL.

Waveguide Size:	WR430; compatible with copper cooling system and aluminum waveguide flanges. (See below.)
Input and Output Flanges:	To mate with flanges shown in ENERGY SYSTEMS drawing 50003C2 (UG-437A/U Flange Assembly).
Maximum Dimensions:	Overall length, 18 inches; height, 6 inches; width, 12 inches; all maximum.
Weight:	100 lb maximum; 75 lb objective; vendor's design choice to be specified 30 days ARO.
Cooling Medium:	50% aqueous solution of ethylene glycol; 70 psig; 38° to 60°C.

Flow Rate:	1 gpm maximum; vendor design flow to be specified 30 days ARO.
Pressure Drop:	5 lb objective; 7 lb maximum; vendor design choice to be specified 30 days ARO.
Exterior Finish:	To be specified.

14.4.9.3 ENVIRONMENTAL.

Temperature:	-35° to +65°C.
Shock and Vibration:	1 G, 5 through 100 cps, triaxial.
Operating Altitude:	0 to 15,000 feet.
Water Spray:	Up to 1 inch per hour.
Orientation:	Any.
Fungus:	As per MIL-E-5272. No test required.
Sand and Dust:	As per MIL-E-5272. No test required.
Protective Coating:	Must not chip, crack, or scale with age or extremes of climate or environment.
Humidity:	0 to 100%, including condensation due to temperature changes.

14.4.10 HIGH POWER DIRECTIONAL COUPLER SPECIFICATIONS.

14.4.10.1 ELECTRICAL.

Frequency Range:	2.0 to 2.2 gc.
Mainline Power:	25 kw cw maximum.
Mainline VSWR:	1.1 to 1 maximum.
Mainline Insertion Loss:	0.5 db maximum.
Directivity:	30 db minimum.
Secondary Arms:	Type N female.

Coupling Factors:	
Incident:	50 db ±1
Incident:	40 db ±1 power split $\begin{cases} -50 \\ -50 \end{cases}$
Incident:	65 db ±1
Reflected:	53 db ±1
Reflected:	53 db ±1
Auxiliary Coupler:	To be mounted on waveguide furnished by ENERGY SYSTEMS.
Reflected:	47 db ±1
Flatness:	±0.1 db maximum over range (calibration curve to be provided for each unit).

14.4.10.2 MECHANICAL.

Waveguide Material:	Aluminum, WR430.
Input and Output Flanges:	In accordance with ENERGY SYSTEMS drawings 50003E2 and 50003E3.
Finish:	Alodine 1200 or equivalent. Outside paint TBS.
Dissimilar Metals:	Per MIL-F-14072.
Length:	Not to exceed 9 inches.

14.4.10.3 ENVIRONMENTAL.

Temperature:	-35° to +65°C.
Operating Altitude:	0 to 15,000 feet.
Waveguide Pressure:	0.5 psig maximum.
Humidity:	0 to 100%, including condensation due to temperature changes.
Fungus:	As per MIL-E-5272.

14.4.4.10.4 OTHER INFORMATION.

Drawings:	Certified drawings to be sent to ENERGY SYSTEMS 30 days ARO.
Documentation:	Certified copy of test results to be serialized, identified, and shipped with each coupler.
Reliability:	Long life and high reliability shall be a prime requirement; reliability shall be defined as the ability of the equipment to function properly and continuously under all conditions specified herein. The vendor shall exercise such quality control methods as to insure extremely high quality and reliability.
Final Acceptance:	Final acceptance will be based upon satisfactory performance in accordance with these specifications at 25 kw cw, to be performed by ENERGY SYSTEMS personnel.

14.5 DESIGN OF WAVEGUIDE SYSTEM.

The waveguide system will consist of rigid waveguide, flexible waveguide, one harmonic filter, one transmitter filter, and two rotary joints. For pressurization considerations, the feed will also be included. The harmonic filter is a part of the PA, and the transmit filter is a part of the feed subsystem.

14.5.1 WAVEGUIDE.

The waveguide used is type WR430, made of aluminum. The flanges are type 437A/U, with Neoprene seals. An estimate of the length of rigid waveguide, number of bends, and quantity of flexible waveguide necessary for the run from the PA output to the feed input has been made. The quantities were derived using the Blaw-Knox preliminary drawings of the antenna. The estimate of the quantities to be used is as follows:

(1) 44 feet rigid waveguide (includes length added by 11 bends).

(2) 6 feet flexible waveguide (2 each 2-foot sections; 2 each 1-foot sections).

Using the above estimates of waveguide to be used, an insertion loss for the rigid and flexible waveguide components computes to be 0.230 db. This value is derived using the theoretical loss for this type waveguide. In practice, the loss is usually about 20 percent greater, or 0.276 db.

14.5.2 ROTARY WAVEGUIDE COUPLER.

Two identical rotary couplers will be used; one to pass the waveguide over the X-axis, and the other to pass the waveguide over the Y-axis. Although the coupler supplier has not yet been determined, there will be no problems involved in securing a unit that will meet all the following specifications:

Configuration:	U type.
Frequency Range:	2.08 to 2.14 gc.
VSWR:	1 to 10 maximum.
Insertion Loss	0.5 db maximum.
WOW:	0.05 db maximum/360° rotation.
VSWR Rotation Effect:	0.03 maximum/360° rotation.
Power Average:	20 kw cw.
Pressurization:	10 psig.
Pressurization Leakage Rate:	3 psig/24 hr.
Starting Torque	2 ft/lb maximum.
Waveguide Flange Type:	U6-437A/U.
Material:	Aluminum.
Weight:	30 lb maximum.

The overall size of the coupler has been kept to a minimum to lessen interference with the antenna structure during extreme deflections of the antenna. The approximate dimentions of this unit will be 14 inches in length by 8 inches in diameter. A bracket will be supplied by Blaw-Knox on both the X-axis and Y-axis for mounting the couplers. The mounting arrangement has been shown in the pictoral drawing of the antenna, figure 14-5.

14.5.3 TOTAL INSERTION LOSS FOR SYSTEM.

In determining the total loss for the waveguide system, the harmonic filter is considered as a part of the PA. Ths loss for the rigid waveguide, bends, and flexible waveguide has been given as 0.276 db. To this will be added a loss of 0.2 db for the two rotary couplers. The loss in the transmitter filter will be a maximum of 0.1 db. By adding these values, a total insertion loss of 0.576 db for the waveguide system is found. This value is slightly greater than the 0.5 db design goal. It is hoped, however, that each of the components will have a loss somewhat less than the maximum allowable loss. With reductions in these areas, plus a possible reduction in waveguide length, the value of 0.5 db total insertion loss should be achieved.

14.5.4 WAVEGUIDE PRESSURIZATION SYSTEM.

The waveguide, rotary couplers, and feed will be pressurized with dry nitrogen at a maximum pressure of 0.5 psig. This pressure will be regulated approximately between 0.3 and 0.5 psig.

The regulator assembly will be supplied by National Cylinder Gas, a division of Chemetron Corporation. This unit, in three stages, reduces the inlet pressure of approximately 2200 pounds to an output pressure of 0.5 psig maximum. A dual stage regulator, model 5868, reduces the pressure to approximately 20 pounds, then the final regulator, model 24032B, regulates the pressure to the desired output of 0.5 psig maximum.

The nitrogen supply will be furnished by a 280-cubic-foot bottle. This supply bottle will be located in the equipment house near the PA cabinet. This leakage rate for the entire waveguide system is not expected to exceed 2-cubic feet per 24 hours. Consideration should be given to connecting several bottles in parallel to allow uninterrupted operation for periods of 1 year or longer. The pressure regulation system is shown in figure 14-6.

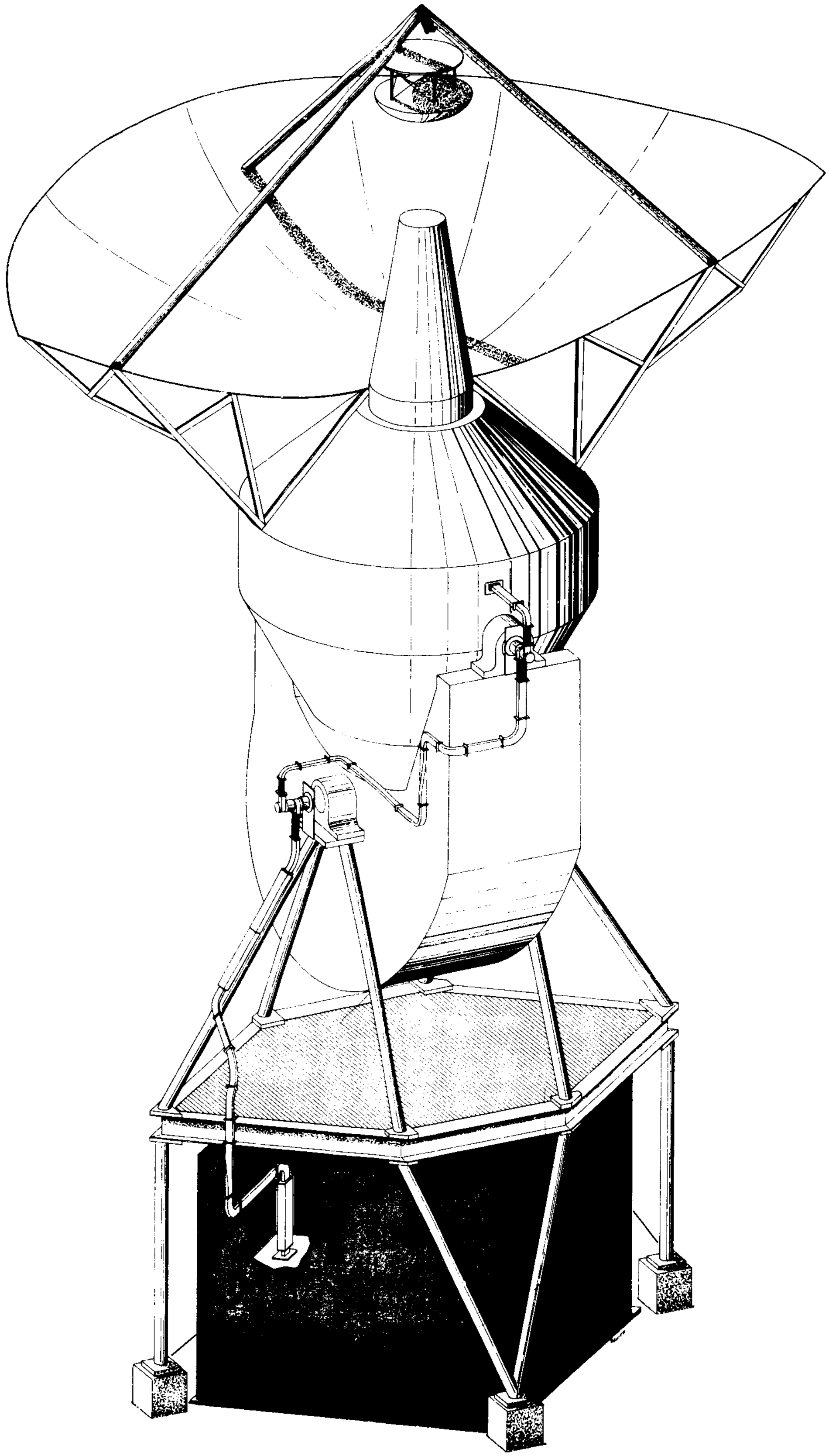


Figure 14-5. Pictorial Drawing of the Antenna

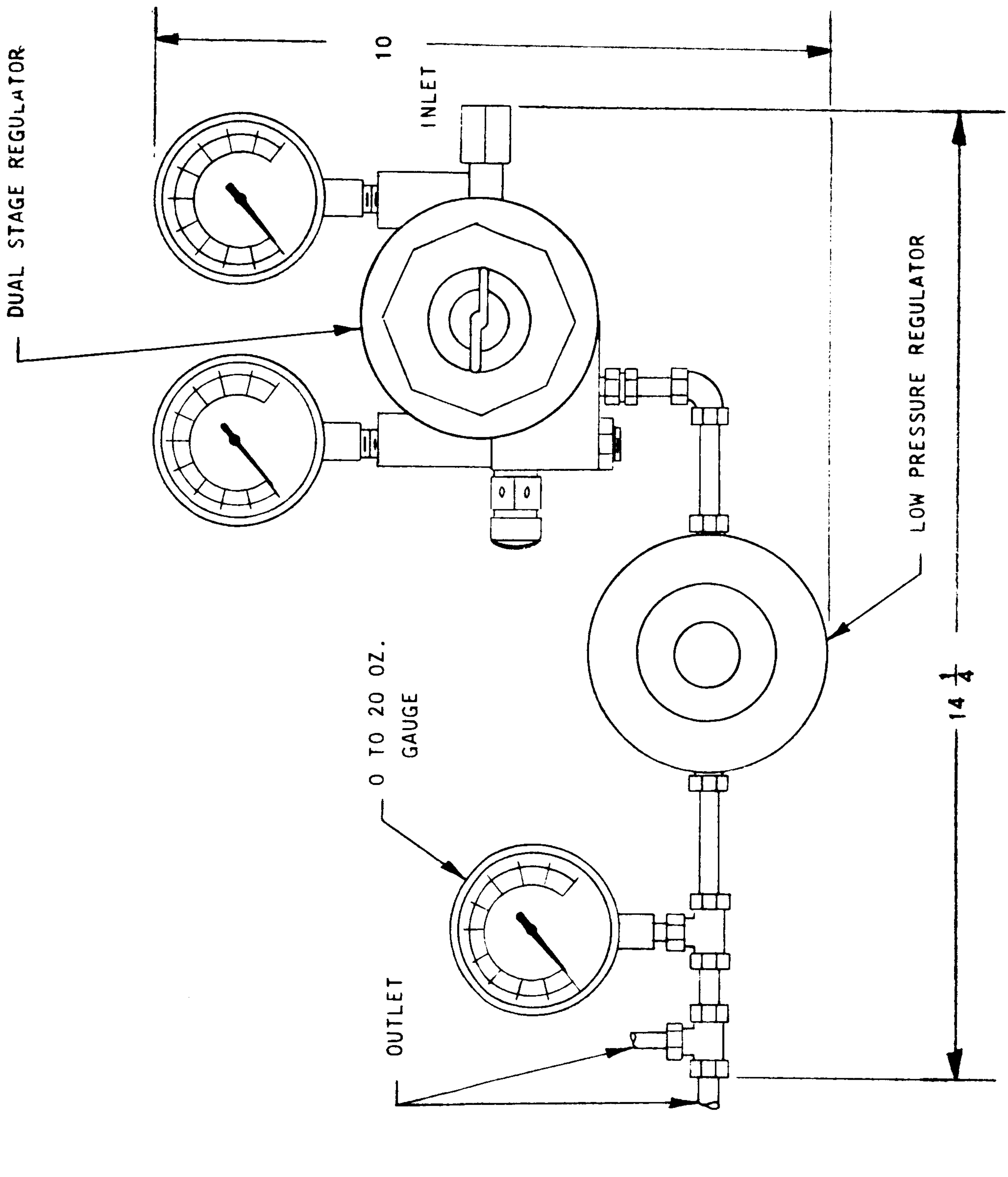


Figure 14-6. Waveguide Pressure Regulator Assembly

A warning system with indications for overpressure and underpressure conditions will be included. The indicators will consist of lights located in the console area in the instrumentation building. These lights will be actuated by a pressure switch mounted on the nitrogen feedline leading to the waveguide connection.

The pressure switch for operating the pressure warning lights will be supplied by Meletron Corporation. The switch, model 2276E-5A, has two switching elements. The switches are independently adjustable over a range of -3 to +20 inches of water and have an actuation value of 0.85+0.65 inch of water. One of these switches will be adjusted to actuate at 0.5 psig for overpressure indication; the other will be adjusted to actuate at 0.3 psig for underpressure indication.

The beam supply of the PA will be interlocked through a third pressure switch located in the waveguide. This interlock will prevent operation of the PA whenever a loss of pressure occurs and is a part of the PA interlock chain.

14.6 SAFETY AND OPERATIONAL INTERLOCKS.

Distinction must be made between those interlocks provided for protection of personnel and equipment from malfunctions and those provided for operational control. As a general rule, the safety interlocks protect from equipment failure and unauthorized operation of the PA, while operational interlocks allow system operation in varying modes.

Inspection of figure 14-2 shows the following safety interlocks, each one of which will deenergize the beam voltage and in some instances also remove rf input drive.

(1) Cabinet air flow

(2) Cabinet doors (may be manually cheated at the switch location; however, warning lights are provided to indicate the presence of voltages in excess of 300 volts)

(3) Heat exchanger flow and temperature

(4) Coolant flow through the magnet

(5) Coolant flow through the tube body

(6) Coolant flow through the tube collector

(7) Coolant flow through the rf load

(8) Coolant flow through the waveguide isolator

(9) Klystron filament air flow

(10) Klystron filament under current

(11) Klystron filament time delay

(12) Magnet under current

(13) Beam high-voltage phase failure

(14) Beam high-voltage 60-cps line overcurrent

(15) Beam high-voltage overvoltage

(16) Beam high-voltage overcurrent

(17) Klystron body overcurrent

(18) Rf output power forward

(19) Rf output power reflected

(20) Arc detector

(21) Waveguide pressure

(22) External (use described below)

(23) Beam voltage lowering

(24) Spare.

Item (22) in the above list is utilized to provide emergency interlock on the antenna structure and is primarily a safeguard against personnel hazard. One such interlock is provided, for instance, on the Y-axis wheel house door and operates in such a manner that the tripped switch can only be reset from outside the wheelhouse. In order to operate the PA with a person in the wheelhouse, a second person would be required to reset the door interlock. Other interlock switches that operate through the system of item (22) are located on the antenna structure and are manually operated. In most cases, operation of one of these interlock switches will also deenergize the hydraulic system.

The operational interlocks do not work through the safety interlock system. They do, however, remove the rf input drive to the klystron as do some of the safety interlocks. Two areas require operational interlocks,

(1) The antenna when operating near the horizon

(2) Waveguide switching in the feed to effect polarization changes.

It is not considered desirable in these cases to deenergize the beam supply voltage since a period of several minutes is required to restore this voltage. Also, since all personnel will be adequately warned of the existence of high-power rf during operation, the removal of the beam voltage is deemed unnecessary. Therefore, when polarization switching is required, a switching logic is followed that first removes rf input drive and grounds the klystron input prior to accomplishing the waveguide switching. After the switching cycle is completed, the rf drive is reapplied automatically. The switching scheme shown in figure 14-7 illustrates the fail-safe feature of this method.

Also furnished in the operational interlock is the facility to operate near the horizon without untimely loss of beam voltage and yet accomplishing personnel protection. For each site, a horizon profile will determine at which level the rf radiation is hazardous. Limit switches on the antenna will be set to remove rf drive to the klystron when these limits are reached. This will allow operation very near the rf horizon without fear of losing beam voltage. Provisions will be made to manually override these limit switches if required in the conduction of a mission.

14.7 HIGH-POWER S-BAND DIPLEXER (COMBINER) FOR GSFC 85-FOOT STATIONS.

The proposed S-band diplexer will be designed to receive two 20-kw cw signals separated by approximately 5-mc in the frequency range from 2090 to 2120 mc with an input vswr of less than 1.5:1 for antenna loads of the same limits. At least 30-db isolation between input ports will be provided, and third-order intermodulation non-linearities will be at least 30 db below either input signal level. The diplexer will be a waveguide hybrid circuit compatible with WR-430 waveguide, capable of pressurization to 10 psig, and furnished with directional couplers at each port for indication and control of forward and reflected power at a remote panel. The mechanical and environmental requirements of Collins specification number 126-0427 will be fulfilled. See appendix b.

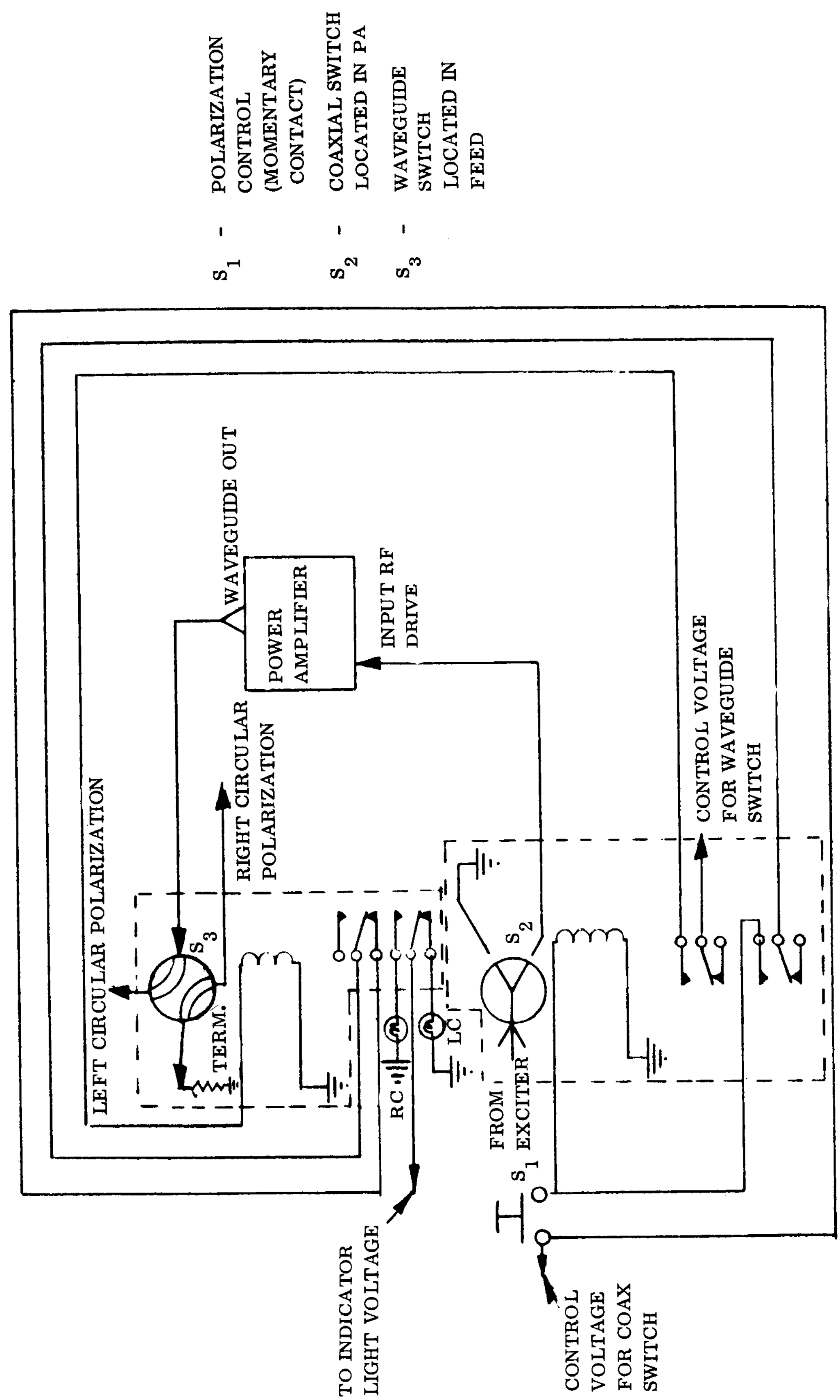


Figure 14-7. Operational Interlock

The basic principle of this diplexer is the realization of phase cancellation at dummy-load and opposing-transmitter ports while obtaining in-phase recombination at the antenna port of two signals which must be divided, phase shifted, and maintained at equal amplitudes. The diplexer circuit will consist of two broadband short-slot waveguide hybrids, a line stretcher for phase control, a fixed waveguide attenuation section, and other connecting and transition waveguides. See figure 14-8. The two transmitter waveguides will be connected to two ports of the input hybrid. The remaining two ports of the input hybrid are connected to two ports of the output hybrid by:

(1) A relatively short length of waveguide constructed for higher unit attenuation than that of WR-430

(2) A relatively long length ("d" approximately 75 feet) of waveguide, including a line stretcher.

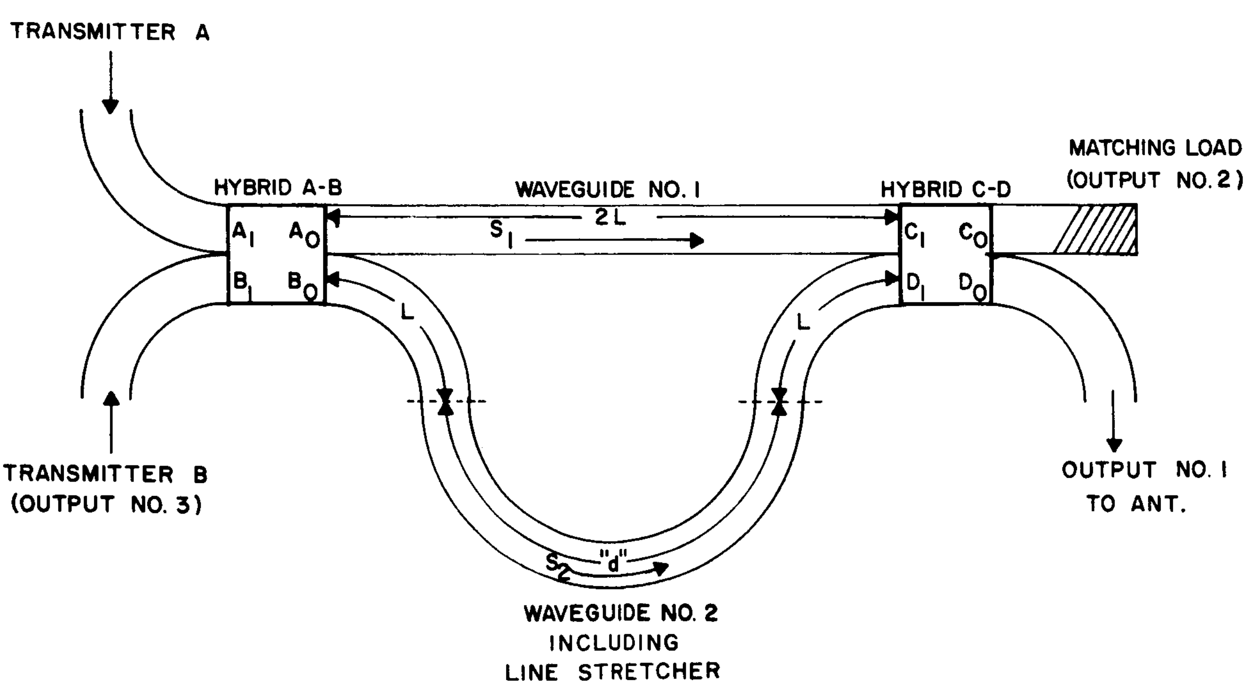


Figure 14-8. High-Power S-Band Diplexer Connections

The remaining two ports of the output hybrids are connected to the antenna and to a 5-kw waveguide load. The line stretcher will be set so that the difference in guide wavelength between the lines connecting the hybrids is an integral number of wavelengths at one transmitter frequency and an odd multiple of half wavelengths at the other transmitter frequency.

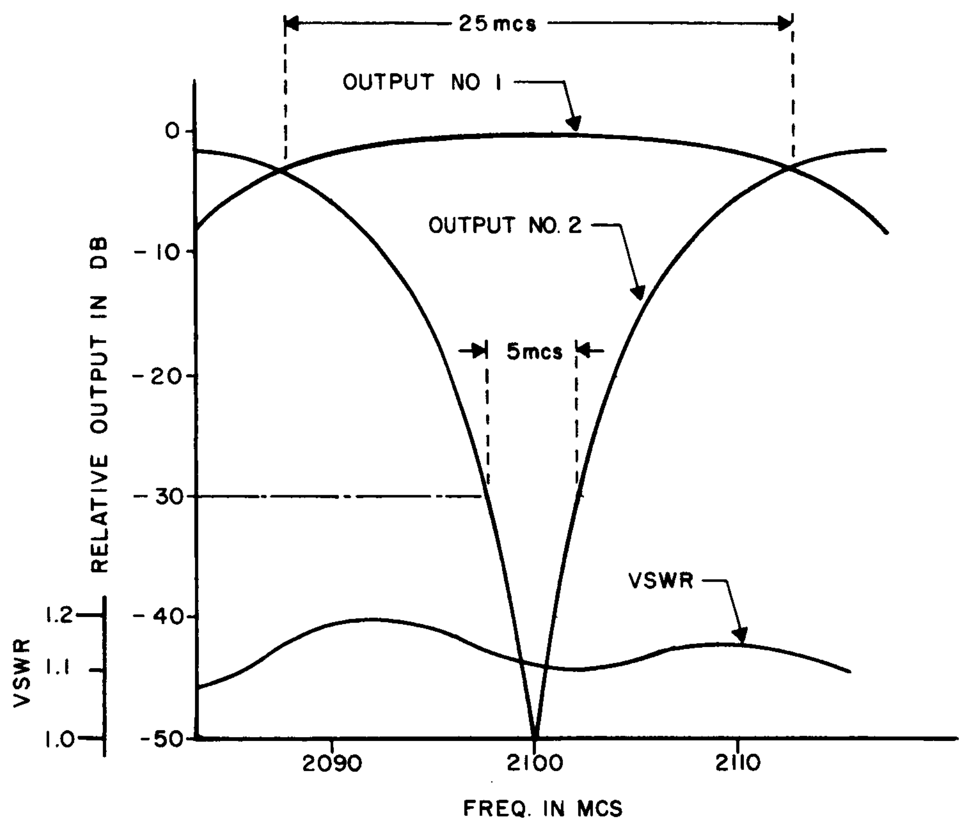
The design area requiring the most intensive control is that related to signal phase variations due to environmental and dissipative thermal effects in the waveguide system. Considerations pertinent to the above are:

(1) The need to maintain signal amplitude equality in intra-hybrid lines of vastly different length

(2) The important but unrelated variation in signal phase of the relatively long waveguide because of environmental and dissipative thermal changes.

The scope of this work includes analysis and measurement of these and other significant parameters and provision of such automatic adjustments as required to maintain the specified performance under all stated conditions.

Figure 14-9 shows a test connection and typical data obtained by varying the frequency at the input port. The curves indicate that the passband width is about 1.2 percent, the isolation bandwidth is 0.2 percent wide at the -30 db level, and the vswr in the passband is flat. The sharp isolation notch at port 2 will provide an excellent correction signal to automatically adjust the line-stretcher length for the correct value of "d" given in figure 14-8. The following sample calculations indicate the necessary values of "d" and how d changes as a signal pair separated by 5 mc is relocated 25 mc up the band.



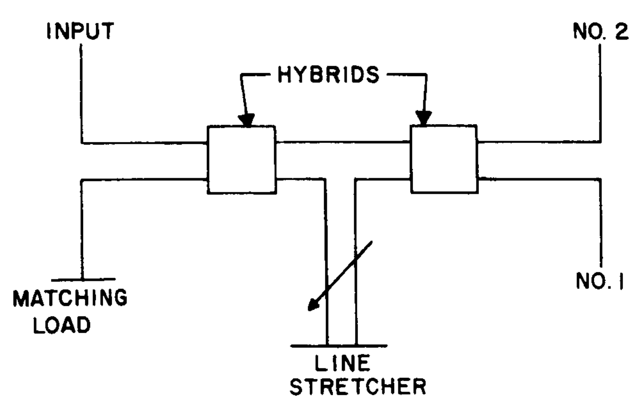


Figure 14-9. Typical Combiner Performance

14.7.1 SAMPLE CALCULATIONS FOR S-BAND DIPLEXER.

From reference (a) : $d = \frac{V}{2\left(f_1 - f_2\right)} \frac{\lambda}{\lambda_g}$

where $\frac{\lambda}{\lambda_g} = \sqrt{1 - \left(\frac{f_c}{f}\right)^2}$, $f = \frac{1}{2}(f_1 + f_2)$

$v = 118.11 \times 10^8$ inches/sec.

then $d = \frac{118.11 \times 10^8}{2\,(f_1 - f_2)} \sqrt{1 - \left(\frac{f_c}{f}\right)^2}$ inches (1)

Example 1

Given: $f_1 = 2095$ mc, $f_2 = 2090$ mc

$f_c = 1372$ mc (forWR-430 waveguide)

$$d = \frac{118.11 \times 10^8}{10^7} \sqrt{1 - \left(\frac{1372.0}{2092.5}\right)^2} = 1181.1 \times 0.755$$

Answer: d = 891.7 inches = 74.3 feet

Example 2

Given: $f_1 = 2120$ mc, $f_2 = 2115$ mc, $f_c = 1372$ mc

$$d = \frac{118.11 \times 10^8}{10^7} \sqrt{1 - \left(\frac{1372.0}{2117.5}\right)^2} = 1181.1 \times 01762$$

Answer: d = 900 inches = 75.0 feet

Using equation (1) above:

$$\frac{\partial d}{\partial f} = \frac{V}{2(f_1 - f_2)} \frac{1}{2} \frac{-2\left(\frac{f_c}{f}\right)\left(-\frac{f_c}{f^2}\right)}{\sqrt{1 - \left(\frac{f_c}{f}\right)^2}}$$; substitute equation (1):

$$\frac{\partial d}{\partial f} = \frac{V^2 f_c^{\,2}}{4(f_1 - f_2)^2\, d\, f^3} \qquad (2)$$

Example 3

Given: $f_c = 1372$ mc, $(f_1 - f_2) = 5$ mc;

and d = 896 inches, f = 2105 mc, nominal.

$$\frac{\partial d}{\partial f} = \frac{(1.1811)^2 \times 10^{20} \times (1.372)^2 \times 10^{18}}{10^{14} \times .896 \times 10^3 \times (2.105)^3 \times 10^{27}} = \frac{2.626 \times 10^{38}}{8.357 \times 10^{44}} \frac{\text{inches}}{\text{cps}}$$

Answer: $\frac{\partial d}{\partial f} = 0.314$ inches/mc (3)

Comparison: Between examples 1 and 2, the mean frequency, f, shifted 25 mc.

$$\Delta d \approx \frac{\partial d}{\partial f} \Delta f = 1.315 \times 25 = 7.85 \text{ inches}$$

The difference found in d was: $\Delta d = 900 - 891.7 = 8.30$ inches

Therefore, equation (2) gives a good slope approximation over a limited range and equation (3) gives the approximate rate of change in line stretcher adjustment for fixed spacing.

[Reference Teeter and Bushore, "A Variable-Ratio Microwave Power Divider and Multiplexer," IRE Transactions MTT October 1957, pp. 227-229. Note: Equation (1) page 229 omits a term. See equation (5).]

The initial Collins proposal indicated that the combiner would consist of wave-guide hybrids with appropriate loads suitably connected to combine the outputs of two power amplifiers. Its main advantage is that this combiner is not frequency sensitive; however, 3 db of the total power must be dissipated; i.e., 20 kw when radiating 10 kw in each of two frequencies. The method outlined here is frequency sensitive but provides approximately 3 db improvement in system performance. The device can be tuned to any desired frequency within the required bandwidth. The method is straightforward and Collins is confident of satisfactory performance. Accordingly, it is recommended that this method be utilized.

section 15

up-data verification receiver

15.1 GENERAL.

The up-data verification receiver design configuration is shown in figure 15-1. The receiver is used in the Unified S-Band system to provide verification of the data transmitted to the spacecraft. The unit receives a signal from a directional coupler located at the output of the 10-kw power amplifier. The receiver operates over the frequency band of 2040 to 2120 mc.

15.2 DESCRIPTIONS.

The verification receiver is a Vitro Type R-1037A telemetry receiver that has been modified to meet the special requirements of the specification. Two Airpax RDS 30 subcarrier demodulators are mounted on a separate panel. This panel also contains the line driver amplifiers required to divide each subcarrier output into two channels.

The receiver is a standard double conversion, superheterodyne, fm telemetry receiver, except that the normal discriminator is followed by an integrator to provide phase demodulation of the carrier. FM demodulation of the 30- and 70-kc subcarriers is accomplished following the phase demodulator.

15.2.1 MAIN CHASSIS.

The chassis of the standard Vitro 1037A receiver is modified by adding a fixed 30-db attenuator at the signal input to provide a signal level to the receiver compatible with the low noise input stages normally found on a receiver of this type. In accordance with specification requirements, provision for remote control of frequency has been

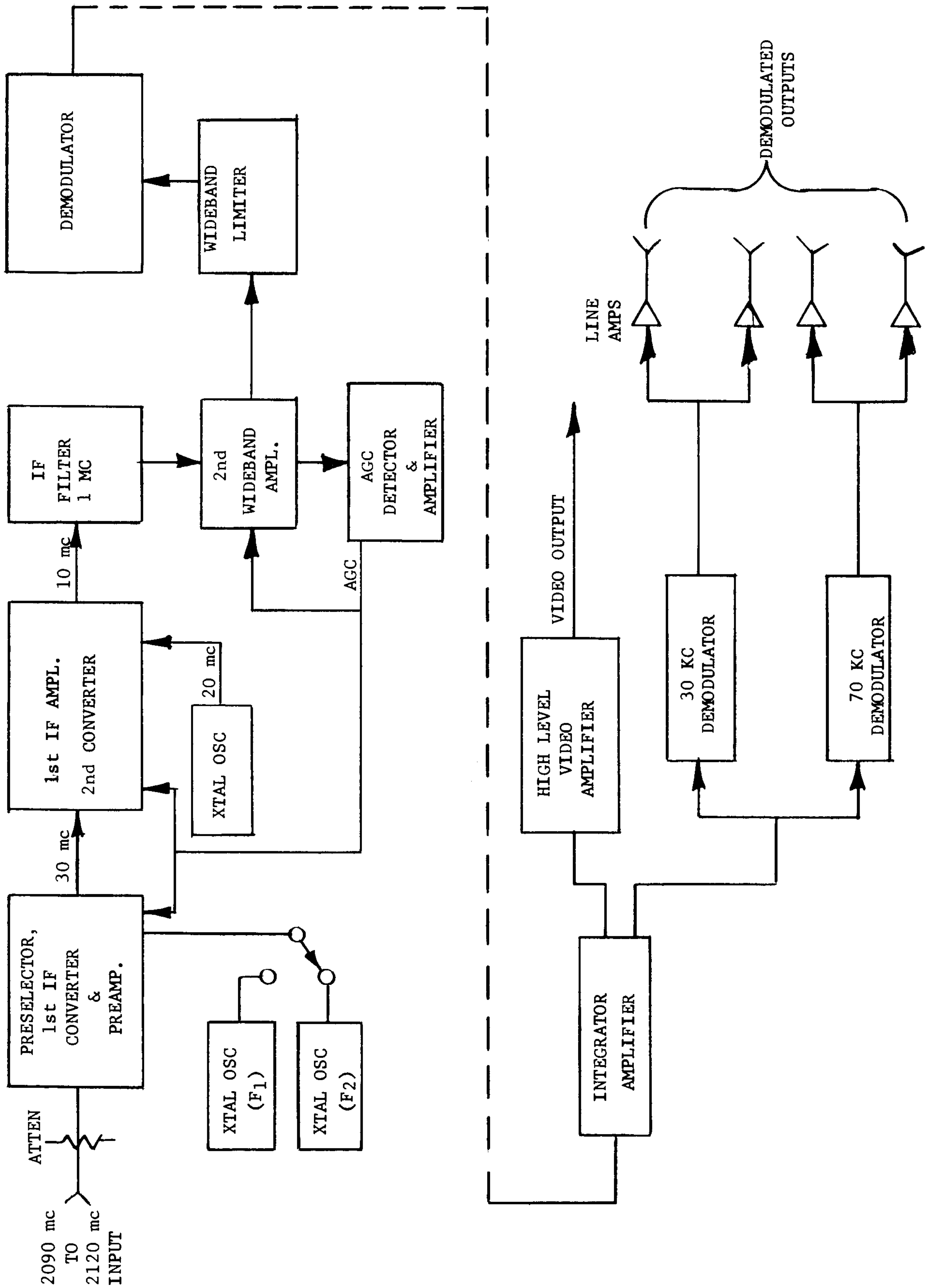


Figure 15-1. Verification RCVR Block Diagram

added to the unit. A choice of two frequencies is possible through remote selection of the appropriate crystal.

15.2.2 RF TUNER.

The rf tuner consists of an oscillator-tripler, a tripler, and an amplifier. The latter two units are Nuvistor operated devices. The oscillators operate over a frequency range of 39.2592 to 39.8148 mc, depending upon the crystal selected. Two crystal frequencies are provided; however, any other frequency in the band indicated can be chosen by insertion of the proper crystal. After multiplication, the local oscillator provides drive to a hybrid ring mixer. The mixer output is centered at 30 mc and is followed by a 3-stage pre if. amplifier in the tuner unit.

15.2.3 IF FILTER AND DEMODULATOR.

The if. filter and demodulator is a plug-in module and is a modification of the Vitro Type FSD 108A. The addition of an integrator permits use of this discriminator in demodulation of phase modulated signals.

15.3 DESIGN ANALYSIS.

15.3.1 POWER LEVELS.

The fixed attenuator at the receiver signal input reduces the input level from the specified range of -10 dbm through +20 dbm to -40 dbm through -10 dbm. The receiver is designed for a maximum input level of -7 dbm. In the event that it is found necessary to extend the dynamic range (signals below -80 dbm for instance), the 30 db attenuator may be bypassed.

15.3.2 INTERMEDIATE FREQUENCY.

Selection of i-f bandwidth is determined by considerations of maximum phase deviations, maximum modulating frequency, phase detector linearity, and signal-to-noise ratio.

Tests performed on a 1037A receiver operating with a prototype tuner and demodulator indicate that a 1-mc if. bandwidth is the best choice. An analysis of the noise in the system proves that, even with a 1-mc bandwidth, a sufficiently high signal-to-noise ratio can be maintained. The power amplifier when operating at 10-kw cw produces less than -130 db per cycle below carrier in the 2-kc to 5-mc band about the carrier. With a 50-db factor at the coupled arm of the power amplifier directional coupler, the following noise power is present at the up-data verification receiver input:

Let P_T = 10 kw = +70 dbm, Power amplifier output,

P_N = 130 db/cycle below P_T, noise power out of the power amplifier,

L_C = 50 db, coupling factor

L_T=16 db, transmission line losses

L_A = 30 db, input attenuator

NF = 11 db, receiver noise figure

BW = 1 mc, receiver if. bandwidth.

Noise power from the power amplifier present at the receiver input terminals is:

$$P_{IN} = - P_N + BW + P_T + L_C + (L_T + L_A) \text{ in dbm}$$

$$P_{IN} = -130 + 60 + 70 - 50 - (46) \text{ in dbm}$$

$$P_{IN} = -96 \text{ dbm in a 1 mc band}$$

Noise power because of losses associated with the receiver are L_T and L_A. Thus noise P_R due to these sources is:

$$P_R = kT_{290^oK} + (L_T + L_A)$$

$$P_R = -174 + 46 \text{ dbm/cycle}$$

$$P_R = -128 \text{ dbm/cycle or } -68 \text{ dbm over 1 mc band.}$$

Noise power caused by losses is much greater than noise from the power amplifier: therefore, noise contributed by the latter can be neglected. With an 11-db receiver noise figure, and maximum signal present at the coupler output, (+ 20 dbm), the receiver input signal-to-noise ratio is 77 db.

The if. filter is a 7-pole LC Butterworth with a 2.8 shape factor (6 to 60 db).

15.3.3 OSCILLATOR STABILITY.

Both final and second local oscillators are crystal controlled. Stability for the worst case (first local oscillator) is ±0.0005 percent, or 5 ppm. This yields a maximum drift of ± 10.6 kc at 2120 mc. Phase instabilities of the crystal oscillators will contribute no more than 3° peak-to-peak phase jitter.

15.3.4 PHASE DEMODULATOR.

The discriminator followed by an integrator has a response of 1db from 10 kc to 100 kc. Since the discriminator has no dc response, linearity is determined by plotting the family of curves generated when signals of from 10 to 100-kc, which phase modulate the carrier with phase deviations of up to 1 radian, are demodulated. Amplitude of the demodulated signal is in the same ratio as the modulating signal with respect to phase deviation when the modulation process is linear.

section 16

collimation system

16.1 GENERAL.

The collimation system consists of the following equipment: the collimation tower and tower equipment, collimation antenna and feed system; the polarization rotator and controls; the remote attenuator; the rf power monitor; and the optical target and optical target illumination control.

16.2 COLLIMATION TOWER, SHELTER, EQUIPMENT, AND OPTICAL TARGET.

16.2.1 COLLIMATION TOWER.

The tower will be 78 feet high with a base measuring 6 by 4 feet and made up of tubular aluminum sections. The tower is provided by the Up-Right Tower Company. In compliance with current regulations, the tower will be painted international orange and white and non-aluminum parts that are subject to rust and corrosion are constructed with stainless steel. The structure will meet the enviornment conditions outlined in GSFC-TDS-RFS-688. The guys will be Alumaweld cable and each will be equipped with an individual tensiometer. An antitwist guy system is used at the 72 foot level. A 45° inclined stairway is provided within the structure. The tower will withstand wind of 120 mph without ice and 100 mph with 1-inch of radial ice without permanent damage. The lateral deflection of the top of the tower in 30-mph wind will not exceed 2 inches and will not twist more than 1°.

16.2.2 TOWER EQUIPMENT.

A top platform with a 42-inch guard rail is provided for working and equipment installation; a second platform with guard rails stands off the 6-foot side of the tower at approximately the 72-foot level. This platform provides a convenient work area for antenna installation, etc. A manual hoist and full lighting protection equipment is provided as are aircraft warning lights with automatic photoelectric control. Adjustable floor lights using PAR 38, 150-watt lamps are provided at the base of the tower and on the work platform for tower and work area illumination. A telephone outlet jack connected to the telephone in the shelter is installed at the top of the tower.

Three or more weather-proof 115 -volt, single-phase, 15-ampere electrical outlets are provided at the top platform; one or more electrical outlets will be provided at the base of the tower.

16.2.3 SHELTER AND SHELTER EQUIPMENT.

Collins will provide and install standard relay racks and rack electrical outlets in the collimation shelter. The shelter will serve as a housing for boresight sources and remote control equipment.

16.2.4 OPTICAL TARGET AND TARGET LIGHT.

An optical target is provided for each collimation system. The center of the optical target will be positioned to have the same relationship to the collimation transmitting antenna as the center of the boresight lens has to the center of the feed of the cassegrain antenna. The target will be a white cross on a black background painted on a metal panel mounted to an adjustable arm. The size of the target and the width of the white cross will be contingent on the distance between the prime antenna and the collimation site. In general, the width of the white line should subtend approximately 12 seconds of arc when viewed from the prime antenna. A light mounted behind a hole in the center of the target will provide a nightime optical source. A remote intensity control for the target light will operate from off to full bright.

Below is a brief tabulation of recommended target sizes, white line width, and target light hole sizes recommended for various distances between the prime antenna and the collimation site.

DISTANCE (ft.)	TARGET SIZE (ft.)	LINE WIDTH (inches)	DIAMETER OF HOLE (inches)
3,000	1 by 1	2	1-1/2
5,000	1-1/2 by 1-1/2	3	1-1/2

DISTANCE (ft.)	TARGET SIZE (ft.)	LINE WIDTH (inches)	DIAMETER OF HOLE (inches)
15,000	3-1/2 by 3-1/2	10	3
2,500	5 by 5	15	4

16.3 COLLIMATION SYSTEM RF.

16.3.1 GENERAL.

The collimation r-f system comprises a 3-channel, 2300-mc transmitter; a variable, 0- to 120-db transmit attenuator; a transmit-receive antenna system; a GFE transponder; an rf receive level monitor; and a local/remote control system. The boresight source provides a highly stable cw or 1000 cps modulated rf signal on one of three fixed frequencies. The 0- to 120-db remote controlled attenuator is in series with the transmit antenna, providing a wide range of transmit level adjustment. The GFE transponder input and the rf receive level monitor are permanently connected to the receive antenna, and the transponder output (normally terminated) can be switched to the transmit antenna line. The local/remote control system provides complete control and status indication of the collimation equipment at the collimation shelter and the instrumentation building.

16.3.2 BORESIGHT SOURCE.

The boresight source is provided by Defense Electronics, Inc. (DEI) of Rockville, Maryland. The transmitter, a modification of the Model BST-3 used on the Rosman Data Acquisition Facility, will be designated by DEI as the BST-4. The BST series Collimation transmitters are low power units which provide a high degree of frequency stability for boresighting and testing of tracking antenna systems. Frequency is crystal-controlled in an oscillator which is followed by a multiplier chain to acheive the desired output. Selection of one of three frequencies is made at a remote control panel. Provisions are made for amplitude modulation to 50 percent with an internal 1000-cps oscillator, which is also controlled by a remote panel. The output rf power is monitored at the transmitter and indications of pre-established power levels are remoted to the control panel.

The boresight transmitter is a rack mounted unit that is located at the collimation tower site.

The modification of the BST-3 consists of:

(1) Change of crystal oscillator frequencies from the 17.7- to 17.8-mc range to the 17.8- to 17.9-mc range, and retuning of subsequent stages through the time 8 multiplication

(2) Substitution of two doubler and one quadrupler stages (142.8 x 16 = 2300 mc) for the BST-3 tripler-quadrupler chain (142 x 12 = 1700 mc)

(3) Change of 1700-mc output stages to 2300 mc

(4) Change output level requirement from 0±3 dbm to 0 dbm adjustable to at least +3 dbm

(5) Change control and indicator scheme to actuate all switching functions by application of remote grounds, and require all status indications to be in the form of grounds supplied through duplicate contacts on the end-actuated switching relays

(6) Ensure that control and indicator functions operate reliably when activated over a cable having between 0 and 500 ohms resistance, and that all other parameters specified by GSFC-TDS-RFS-224 and GSFC-TDS-RFS-208 are met or exceeded.

The modifications referred to in items (1), (2), and (3) above provide the desired output frequencies. Item (4) modifies specification GSFC-TDS-RFS-224 to eliminate a possible 6-db variation between units so that all site interfaces may be standardized. This also provides an adjustment range so that each unit may be adjusted to a uniform antenna level despite small installation differences from one site to another. In this manner the attenuator readout may be calibrated in dbm directly, avoiding the necessity for operator calculations. Items (5) and (6) ensure a compatible interface with the collimation local/remote control panels, and provide command verification by ensuring that status indications are obtained directly from the end-actuated switch rather than from some intermediate device.

Table 16-1 lists the significant electrical parameters. Figure 16-1 is a block diagram of the transmitter indicating the modifications discussed above.

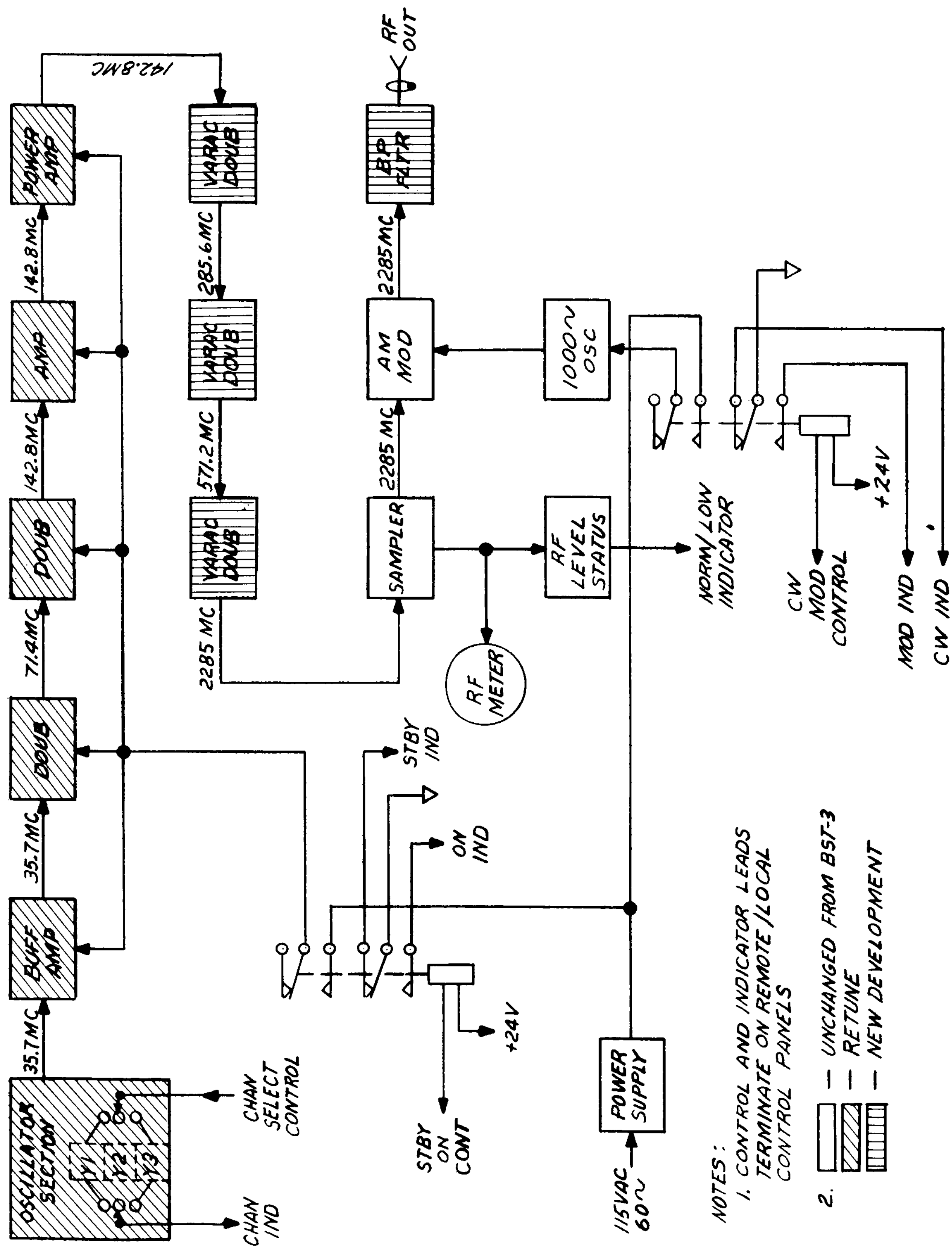


Figure 16-1. BST-4 Block Diagram

TABLE 16-1. SUMMARY OF DESIGN SPECIFICATIONS.

ITEM	REQUIREMENT	REMARKS
Frequency Band	2270-2300 mc	Select crystal only for channel
F1	2282.500	Channel 1, as equipped
F2	2285.000 mc	Channel 2, as equipped
F3	2287.500 mc	Channel 3, as equipped
Stability	1.0 ppm for 8 hours	Constant enviornment
	3.0 ppm	Over enviornmental range
	10° p-p maximum PM	Above 3 cps in non-vibratory condition
Modulation	1000±20 cps, 50±5% AM	Less than 3° p-p PM at 50% AM
RF Leakage	-140 dbm radiated	Detected within 2 feet of unit
	-90 dbm conducted	Detected on power and control lines
Output Z	50 ohms	Nominal
VSWR	1.5:1 maximum	Over 2270-2300 band
Output Power	0 dbm	Adjustable to at least +3 dbm
Output Stability	Within ±1.0 db	Over entire enviornment range
	Within ±0.5 db	For three hours under constant enviornmental range

TABLE 16-1. SUMMARY OF DESIGN SPECIFICATIONS (Cont)

ITEM	REQUIREMENT	REMARKS
Spurios Outputs	80 db below carrier	Between 2270 and 2300 mc
Remote Controls	STANDBY/ON	Verified status indications
	MOD/CW	Verified status indications
	NORM/LOW (output)	Verified status indications
	F1/F2/F3 (frequency)	Verified status indications
Connectors	Type N	RF
	MS enviornmental	Power, control, and indicator
Mechanical	5-1/4 by 19" by 19" 40 lbs.	Rack mounted

16.3.3 REMOTE CONTROLLED ATTENUATOR.

Three methods of providing the 0- to 120-db variable attenuator have been pursued, each capable of yielding performance consistant with GSFC-TDS-RFS-223. They are:

(1) Selective combinations of fixed pads yielding 5-db incremental steps from 0- to 120-db

(2) A motor-driven, continuously variable attenuator yielding infinite resolution over the range

(3) A voltage-variable (semiconductor) attenuator, also yielding infinite resolution over the range.

Method (1) has several disadvantages in addition to the obvious shortcoming of the stepped range: first, the number of pads in combination varies from 0 to 4 over the range. Thus, the tolerances of individual pads (±0.5 db) combine to produce an error pattern which will vary according to the number of pads (not the total attenuation) and this pattern will be peculiar to each installation. Next, the signal path in every instance is through series contacts of 5 coaxial switches, increasing the probability of failure accordingly. Finally, the control system between sites requires five cable pairs; five relays; and a 5-deck, 25-position switch; as well as an equally complex command-readback-readout system to provide verification.

In summary, method (1) imposes a reliability problem because of the number of separate components required and the switching complexity Method (2) has the advantages of complete range coverage, position control and verification with few components, and the necessity for only two control and indicator pairs. The Narda model 784 variable attenuator can provide attenuation over the entire range with an absolute accuracy of 0. 4 db. This unit is easily fitted with a reversible drive motor which can be controlled from the instrumentation building. The readout indicator would be a dc milliammeter calibrated in db. Particulars regarding the control and indicator design are discussed in paragraph 16. 4. Several suitable motor drive systems have been explored. The accuracy of the system will exceed, by a good margin, the ±2 db requirements of GSFC-TDS-RDS-223. Method (3) also has the advantages of complete range coverage, few parts, and the necessity for only two control pairs. Several manufacturers market voltage-variable semiconductor attenuators that provide adequate range for the application. The control circuit involves only adjustment of the applied voltage to the device as monitored by the readout voltmeter (calibrated in db). A disadvantage apparent in this sytem is the fact that the attenuation vs. voltage curve for this type device is not linear, resembling a narrow S-curve. Presumably the readout meter can be calibrated to fit the curve to eliminate the difficulty, however, at this time none of the suppliers have been able to provide positive assurance that curves for individual production units will be identical within the tolerances required for readout accuracy of ±2 db over the range. Two suppliers have furnished curves for 1 gc units with ranges considerably below 120 db; however, both have promised to supply supplementary data to allow a more complete evaluation of this application. It appears that the voltage-variable attenuator, although offering greater simplicity, does not yet offer off-the-shelf availability for this particular application.

In summary, the motor-driven attenuator offers the best combination of simplicity, reliability, and compliance with the specification, and therefore, this system is recommended for use in the Unified S-Band System.

16.3.4 COLLIMATION ANTENNA SYSTEM.

The collimation antenna system consists of two, 4-foot diameter parabolic antennas mounted facing the tracking antenna. The receive antenna has a fixed linear polarization and operates over a 30-mc band centered at 2105 mc. The transmit antenna operates over a 30-mc band centered at 2285 mc with linear polarization, orientation to be rotatable through a total angle of at least 360°. The antennas have gain in excess of 22 db and a vswr not exceeding 1.3:1 over the bands noted. Isolation between transmit antenna input and receive antenna output shall exceed 80 db over both bands.

The antenna systems will be purchased to a Collins specification, embodying all provisions of GSFC-TDS-ANT-29 and additional requirements pertaining to interface with Collins equipment. Each assembly will include complete hardware for tower mounting; the total weight of both antennas will be 350 pounds.

The transmit antenna has as an integral part of the feed horn assembly a rotating joint between the coaxial input to the horn and the coaxial input to the feed system. A reversible motor drives the horn through a total angle of at least 360° to provide polarization orientation rotation. The motor also drives a precision potentiometer that provides position information by changing the current in a compensated loop between sites. The control and indicator arrangement is discussed in paragraph 16.4.

Aside from the operating frequencies and the provisions for rotation of the transmit antenna feeds, the two antennas are identical. Three-point mounting to the tower structure is provided and provision will be made for slight adjustment of elevation and azimuth during installation. The gain is approximately 24 db with an anticipated side lobe level on the order of 18 db below main lobe. To achieve isolation of 80 db between feedpoints, both antennas will be equipped with radiation shields consisting of a short cylinder enclosing the dish perimeter. The shields will be lined with a microwave absorber material.

Connections to both antennas will be by means of 7/8" type N connectors on flexible coaxial cable. The loss in the cable will be approximately 2 db. The boresight transmitter will be adjusted to compensate for this loss so that a 1-milliwatt level will be achieved at the antenna input.

16.3.5 RF MONITOR.

The rf monitor provides a continuous transmitter level indication corresponding to the level received at the receive antenna located at the collimation tower.

Since it is anticipated that from 1 to 10 kw will be transmitted from the tracking antenna to the collimation tower, a monitor has been designed with a single scale reading from 1 to 10 kw (in terms of the transmitter power). The monitor will be initially calibrated to give full scale deflection for a 10-kw transmission from the tracking antenna.

For the 30-foot system, the expected power levels are calculated as follows:

P_T = Transmit power = 10 kw = +70 dbm

G_T = Transmit Gain - = +46 db

G_R = Receiver/Gain = +24 db

G_P = Path gain = 70 + 46 + 24 = 140 db

L_P = Path loss =[37 + 20 log F_{mc} + 20 log D_{mi}] db

[37 + 20 log 2200 + 20 log 0.5] db

[37 + 66 + (-6)] db

= 97 db

P_R = Received Power = (140 - 97) dbm = 43 dbm at 10 kw radiated (33 dbm at 1 kw)

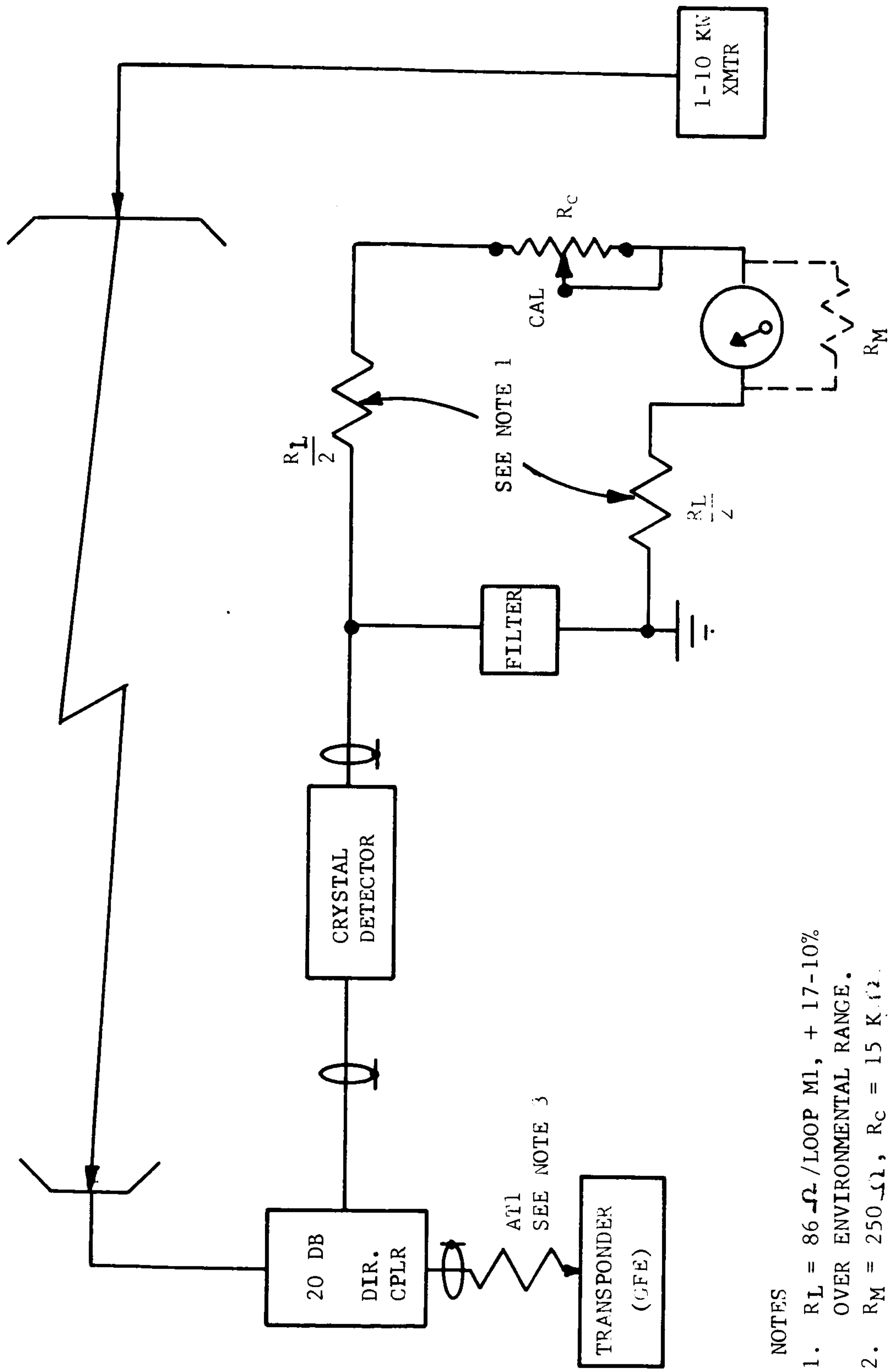
P_M = Monitor power = 43 - 20 = 23 dbm using 20 db directional coupler.

= .2 watts at 10 kw radiated

or (.02 watts at 1 kw)

Figure 16-2 illustrates the power monitor circuit. As a rule, output from a crystal detector depends upon the power levels, frequency, and the type crystal used. Therefore, the dc levels are not precisely calculated. The levels will be plotted experimentally and a meter scale will be tailored to fit the response of the type detector used.

Assuming a linear response curve, a source resistance of the detector-filter combination of 200 ohms, and that there is a 1/2 power loss in the detector, the



NOTES

1. R_L = 86 Ω/LOOP M1, + 17-10%
   OVER ENVIRONMENTAL RANGE.
2. R_M = 250 Ω, R_C = 15 KΩ
3. 85 db FOR TRANSPONDER INPUT OF -42 dbm.

Figure 16-2. RF Monitor System Block Diagram terminal voltage across the line will be on the order of 4.5 volts for a 10-kw transmission. For full-scale deflection at 10 kw with a 0.5 milliammeter, a total circuit resistance of 9000 ohms is required. Resistor R_c will be adjusted with the transmitter keyed to initially calibrate the system. A 1-kw transmission would then yield a deflection of approximately 30 percent full scale.

The cable resistance (assuming #19 AWG) will vary with temperature from a nominal value of 52 ohms to between 45 and 60 ohms for the 30-foot stations. Thus, the error from this source will be negligible (0.1%). For the 85-foot far field installations, the error due to the cable will be approximately 10 times as great, or 1 percent. Allowing for a meter accuracy of 1 percent, additional errors totaling 3 percent can be tolerated and still achieve a monitoring system accurate to within ±5 percent. No problems are anticipated in exceeding this accuracy requirement with the system described.

It should be noted that, with the power levels anticipated, considerable attenuation is required in the receiver line to prevent damage to the transponder unit (approximately 85 db is required to reduce the transponder input to -42 dbm).

16.4 COLLIMATION LOCAL/REMOTE CONTROL SYSTEM.

16.4.1 GENERAL.

The collimation local/remote control system provides the following collimation equipment control and indicating functions for both the collimation shelter (local) and the instrumentation building (remote):

(1) Optical Target illumination control (INC/HOLD/DEC)

(2) Received power level indicator (0 to 10 kw)

(3) Variable attenuator control and indicator (INC/HOLD/DEC)

(4) Transmit antenna polarization orientation rotator control and indicator (CW/HOLD/CCW)

(5) Boresight transmitter controls and indicators

- (a) Power (ON/STANDBY)
- (b) Output Monitor (NORMAL/LOW)
- (c) Frequency selection (F1/F2/F3)
- (d) Modulation control (MOD/CW)

(6) Mode Selection (COLLIMATE/TRANSPOND)

(7) Control priority (INSTRUMENTATION BLDG/COLLIMATION SITE)

(8) Calibration adjustments for indicators (2), (3), and (4) above.

Figure 16-3 illustrates the collimation control panel layout. The panels at both sites are identical in appearance, however, the circuits differ somewhat to provide control priority at the instrumentation building. Thus, the PRIORITY window on the panel in the instrumentation building contains a transfer switch for relinquishing control to the collimation shelter, but the same window on the Panel in the collimation shelter contains only an indicator. In addition, the BORESIGHT TRANSMITTER ON/STBY switch function is extended (in parallel) to an identical switch on the servo control panel within the instrumentation building.

Indicators for TRANSMITTER LEVEL, BORESIGHT LEVEL, and BORESIGHT POLARIZATION are illuminated projection-type meters providing high accuracy and resolution (Weston 1209 PMS, 0.5 percent, equivalent of 8-inch scale). The ROTATOR, ATTENUATOR, and OPTICAL TARGET LIGHT controls are center-off, momentary-on, double-throw switches with limit indicators for controlling reversible motors. The FREQUENCY selector control is a wafer switch with adjacent lamps to provide verification. The remaining controls are of the pushbutton indicator type. All indications are obtained as readbacks from the end-controlled device to provide positive status verification.

16.4.2 CONTROL SIGNALS.

Figure 16-4 is a functional block diagram of the collimation system showing schematic detail for the controls and indicators. Relays K1 and K2, located at the collimation site, provide for transfer of priority to the collimation site. Relay K1 is held operated through the PRIORITY switch contacts at the instrumentation building control panel. All control lines from the instrumentation building are routed through the N. C. contacts of relay K1, as are indicator lines for PRIORITY status indicators. Operation of the PRIORITY switch to the COLLIMATION SITE position releases K1, opens all control lines from the instrumentation building, closes all control lines at the collimation site, and provides COLLIMATION SITE PRIORITY status indications

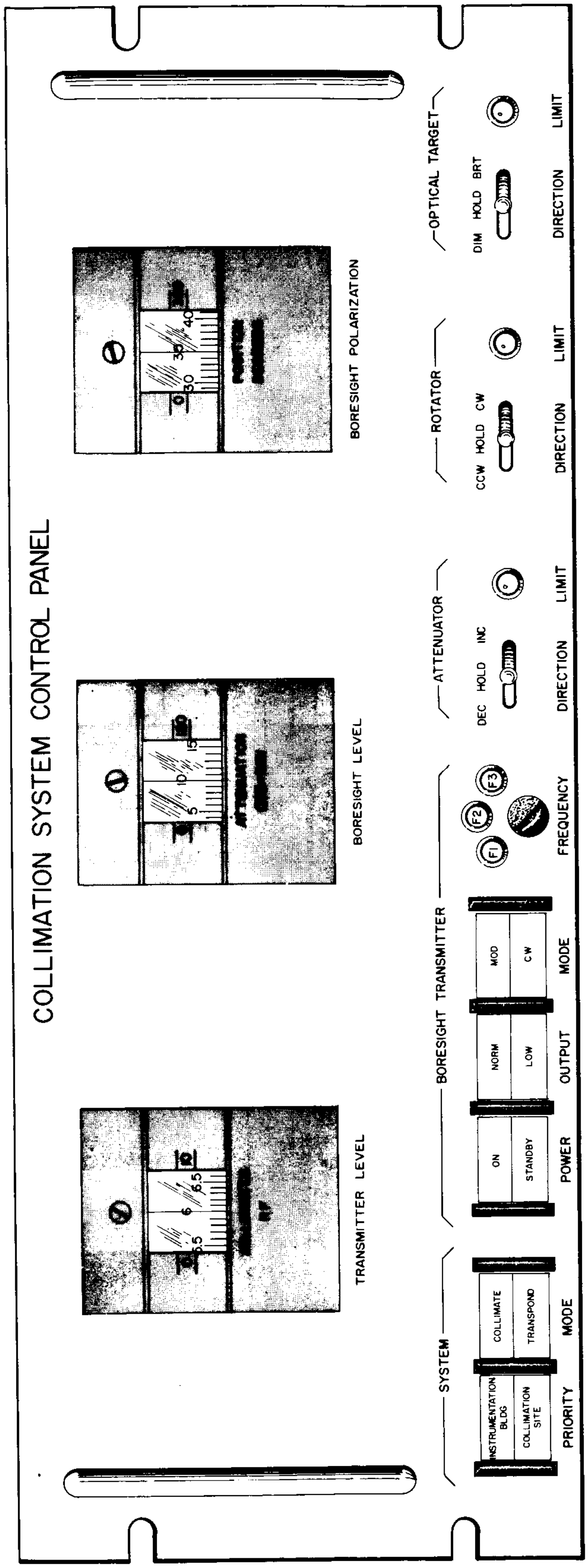
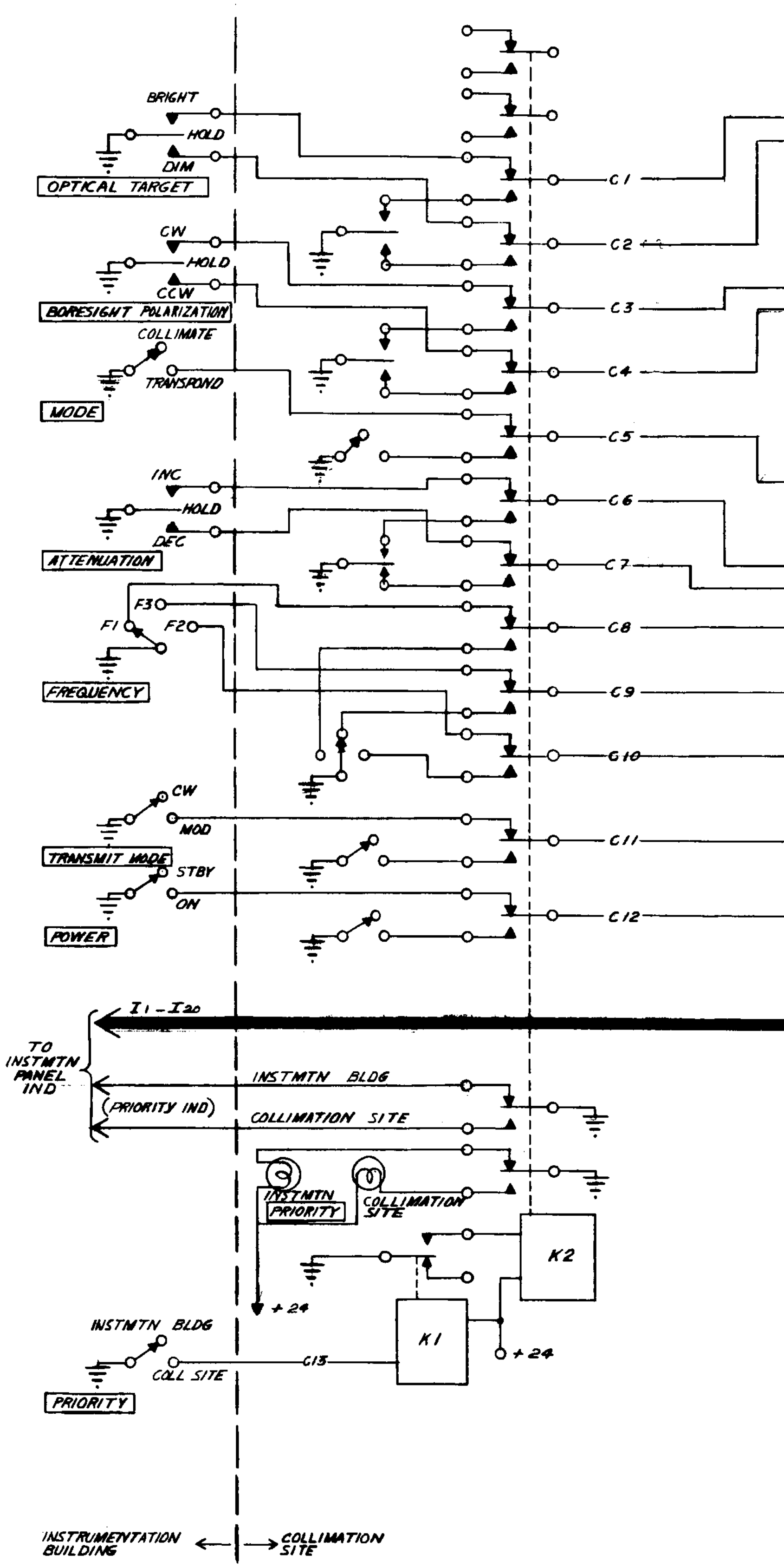


Figure 16-3. Collimation Local/Remote Control Panel



BRIGHT
HOLD
DIM
OPTICAL TARGET
CW
HOLD
CCW
BORESIGHT POLARIZATION
COLLIMATE
TRANSPOND
MODE
INC
HOLD
DEC
ATTENUATION
F1
F2
F3
FREQUENCY
CW
MOD
TRANSMIT MODE
STBY
ON
POWER
C1
C2
C3
C4
C5
C6
C7
C8
C9
C10
C11
C12
$I_1 - I_{20}$
TO INSTMTN PANEL IND
INSTMTN BLDG
(PRIORITY IND)
COLLIMATION SITE
INSTMTN PRIORITY
COLLIMATION SITE
K2
+24
K1
+24
INSTMTN BLDG
COLL SITE
C13
PRIORITY
INSTRUMENTATION BUILDING
COLLIMATION SITE

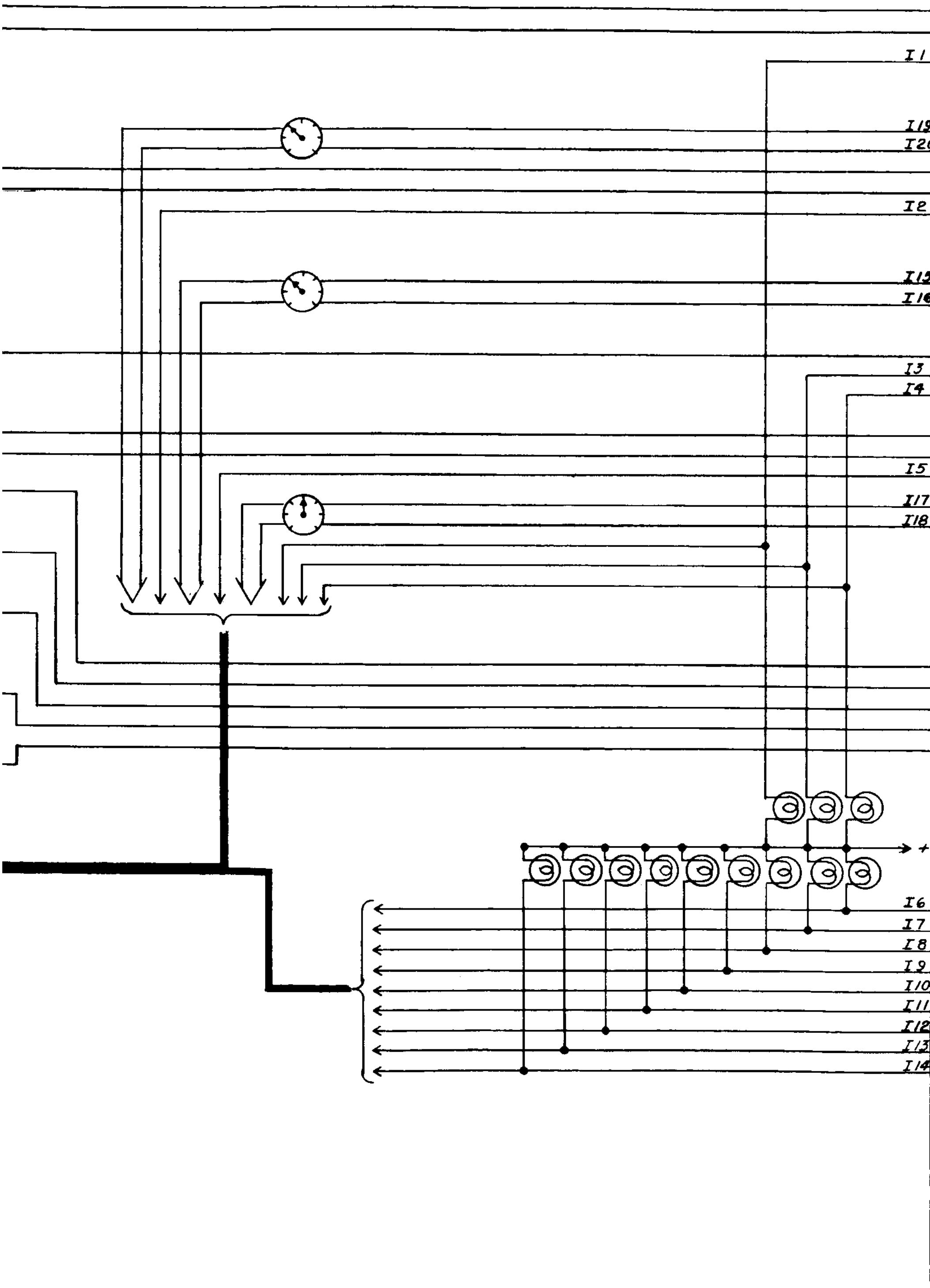
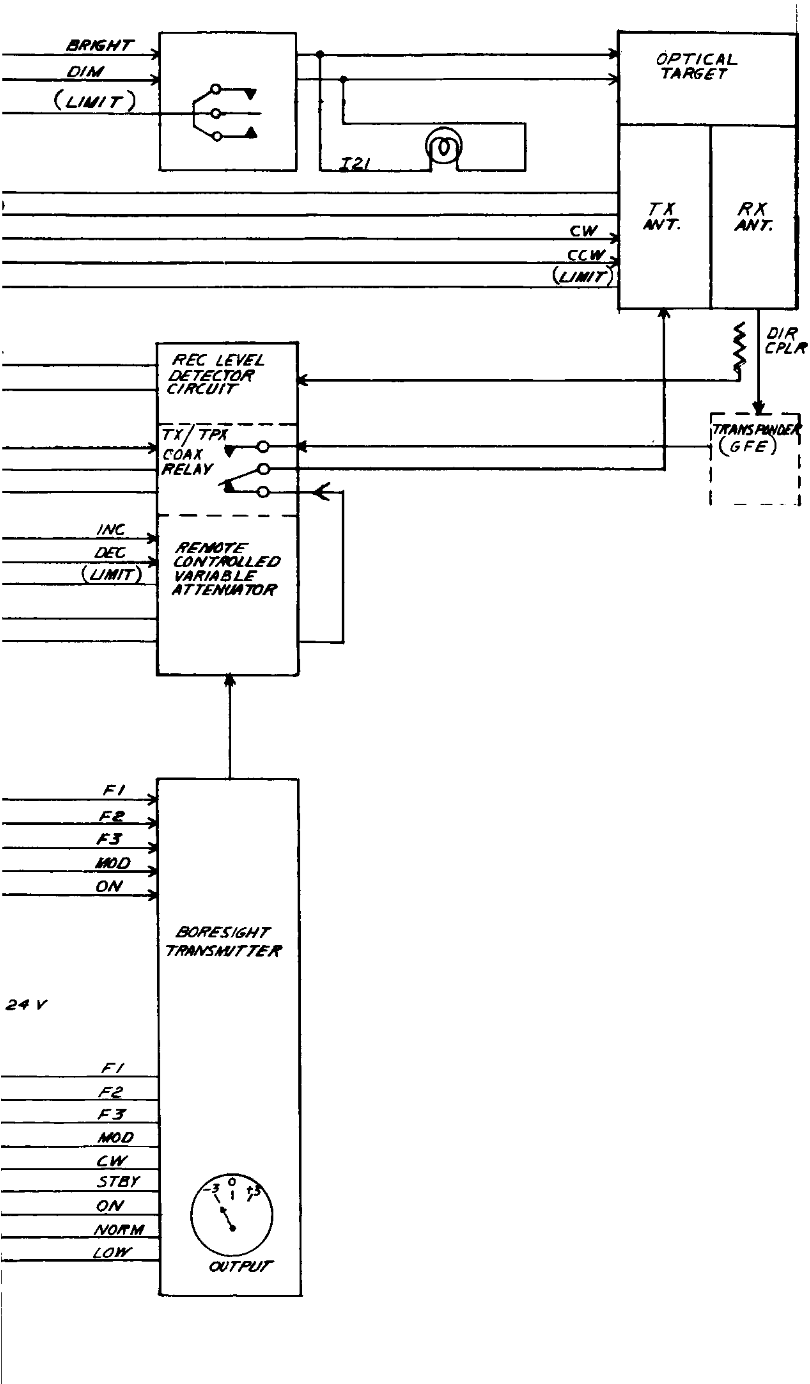


Figure 16



-4. Collimation System, Functional Block Diagram at both sites. It should be noted that the instrumentation building operator can resume or relinquish control at any time.

Thirteen control lines (C1 through C13) are shown between sites. In each case, a ground is applied to actuate a low current relay in the controlled device. The ground return lead between sites must be adequate to carry the operating currents for all 13 relays without interaction. Specific relays have not been selected for these control functions because, in some instances, they are part of subcontractor furnished equipment. However, Collins specifications in all instances require the subcontractor to choose relays with low current and provide at least a 2 to 1 operating voltage range, subject to approval by Collins Radio Company. It is anticipated that the worst case current requirement for all control lines will not exceed 125 ma. Assuming #19- AWG cable, the worst-case (maximum temperature) resistance will be 50 ohms for a control pair (117% x 86 Ω / loop mile) between sites for the 30-foot stations (3000 feet). Thus, a single 19-gauge conductor would provide an adequate return for the control system. Instead, the cable shield will be used for an added margin. In the case of the 85-foot far-field towers (6 miles) the ground return should not exceed 70 ohms for reliable operation under worst-case conditions. Thus, the cable shield must have conductivity equivalent to 10 parallel 19-gauge conductors. This seems a safe assumption; however, spare cable conductors will be available in the 25-pair cable and these can be utilized as required to augment the return path.

16.4.3 INDICATOR SIGNALS.

Twenty indicator leads (I_1 through I_{20}) extend between sites, and one indicator is used only at the collimation site (I_{21} provides local indication of optical target illumination. This can be monitored by the TV camera at the instrumentation building). Indicator leads I_1 through I_{14} provide grounds to operate panel lamps. A separate ground path will be provided for I_1, I_2, and I_5 (120 ma maximum); for I_3/I_4, I_9/I_{10}, and $I_6/I_7/I_8$ (120 ma maximum); and for I_{11}/I_{12} and I_{13}/I_{14} (80 ma maximum). This will provide adequate performance for the 30-foot installations, however, the 85-foot far-field installations will require the addition of a relay bank of 10 sensitive relays to control indicators indirectly. The meter indications $I_{15} - I_{16}$, $I_{17} - I_{18}$, and $I_{19} - I_{20}$ will be carried on three separate pairs.

Total requirements for the control lines (10 pairs maximum) and the indicator lines (10 pairs maximum) will be 20 pairs or less, leaving 5 pairs in the cable for communications between sites.

16.4.4 ATTENUATOR AND POLARIZATION ROTATOR CONTROL CIRCUITS.

The BORESIGHT LEVEL and BORESIGHT POLARIZATION indicators are the readouts for the two open-loop control systems for positioning the remote attenuator and the rotatable transmit antenna feed. The discussion which follows applies to either system.

While it is possible to use a relatively simple synchro system for accurate angular position indications over short cable lengths, reliability of such a system is questionable over a length of 3000 feet, as in the 30-foot installations. When the length is increased to 6 miles, as in the 85-foot far-field installations, a compensated 2-speed system employing servo amplifiers is recommended. Such a system requires carefully balanced lines to achieve an accuracy on the order of 1 percent, and may require a separate synchro cable. A potentiometer system, on the other hand, can provide comparable accuracy with improved reliability owing to simplicity, provided care is exercised in the design. Additionally, a single design is appropriate to either the 30-foot installations or the 85-foot far-field installations. Only the cable resistance need be considered to extend the distance between sites, and the design for the greater length will always suffice for any shorter distance without modification. The advantage of a uniform control system for all sites is apparent.

Figure 16-5 is a schematic representation of the control and indicator system. The graph plots the percent error versus shaft angle It can be seen that the error is symmetrical, maximizing near 90° and 270° to approximately 0.15 percent. The determination of error follows:

$$\% \text{ error} = \frac{V_o - aV_{max}}{V_{max}}$$

where V_o = output voltage

V_{max} = maximum output voltage

a = ratio of shaft angle to total angle

Let $R_c + R_L + 2R_M = R_o$, the total output resistance

$R_o = k_1 R_A$, and $R_B = k_2 R_A$

Then[1]

$$\% \text{ error} = \frac{(a-a^2)k_2 - (a^2-a^3)}{k_1+k_1k_2 + ak_2 + (a-a^2)} \times 100$$

Thus, where $k_2 = 0.5$ and $k_1 = 10$, substitution in the above equation yields a numerator of 0 for a = 0, 1/2, or 1. The fraction reduces to + 1/327 at a = 1/4, and to -1/332 at a = 3/4. The constant k_1 may be made larger to further reduce error (for $k_1 = 20$, the fraction reduces to +1/647 and -1/652 at the same points, halving the error). There is a limit to this process, however, because it is necessary to maintain a reasonable line current, and the step function of the potentiometer (turn to turn) becomes increasingly important.

With k_2 chosen at 20, a line current of 0.5 ma is obtained which is adequate to avoid susceptability to control line transients elsewhere in the cable, if reasonable suppression techniques are used. A further consideration is the resistance versus temperature change of the cable pair. Assuming 19 gage AWG cable, the resistance is 86 Ω/loop mile, +17% and -10%, over the environmental range. Thus, for the 85-foot far-field installation the line resistance (R_L) will vary between 465Ω and 605Ω. It can be seen that the error contribution because of cable temperature change varies inversely with k_2. For $k_2 = 20$, the maximum error because of temperature is the ratio between the maximum resistance deviation ΔR_L (referenced to the resistance at 20°C) to R_o. In this instance, ΔR_L = (605-515) = 90Ω; $R_o = 20R_A$ = 32KΩ; and the maximum error will be 0.28%. For the 30-foot installations the error due to Δ R reduces by a factor of 10, owing to the short cable length.

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1 John G Truxall, Control Engineer's Handbook, pp 17-25.

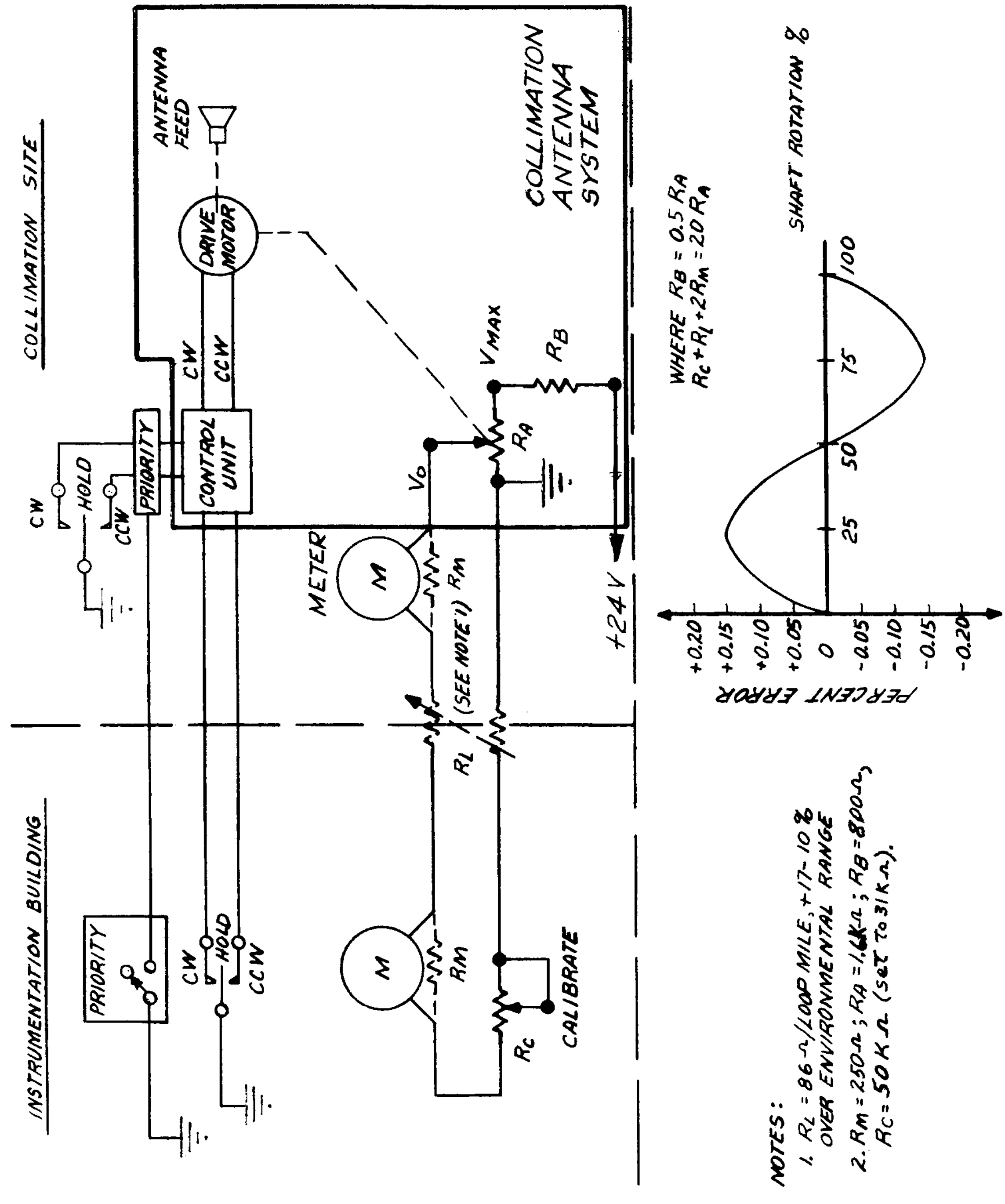


Figure 16-5. Control and Indicator System

The potentiometer R_A and series resistor R_B also represent error sources; however, units are now available which exhibit tolerances of 0.2 percent, linearities to 0.1 percent, and resolutions of 0.1 percent or better. Careful selection of these components limits the error from this source to a negligible amount.

In summary, this design lends itself to this application because of its flexibility and simplicity. The accuracy of the system is limited by the following:

(1) Readout device; accurate to ±0.5%

(2) Potentiometer circuit ±0.15%

(3) Cable resistance change (ΔR), +0.28%, -0.16%

Under worst-case conditions, the overall accuracy should approximate 1 percent, with the greatest limitation being the ability to interpret the readout absolutely. This limitation would also apply to a synchro readout device and, in this respect, the Weston projection meter excells because the pointer and image are in the same plane, thereby eliminating parallax.

section 17

noise figure and test signal subsystem

17.1 GENERAL.

The noise figure and test signal subsystem consists of the following items:

(1) Test signal generator (GFE) located in the instrumentation building

(2) Noise source located at the antenna

(3) Noise modulator located at the antenna

(4) Noise figure meter located in the instrumentation building

(5) Control and indicator panel, located at the instrumentation building, containing controls and indicators for items (1) through (4)

(6) Equipment panel at antenna, mounting items (2) and (3), and the switching and coupling devices controlled by item (5)

The controls are arranged to provide: (1) injection of the noise signal into any individual rf channel, and simultaneous connection of the nose figure meter to the if. output of the same channel; or, (2) injection of the test signal into all three rf channels of either receiver simultaneously. Controls are interlocked so that the test transmitter is off when noise measurements are being made, and the noise generator is off (and noise meter disconnected) when the test transmitter is on. A single control initiates all operations, and indicators provide readback verification from the end-operated device. One position of the control (NORM) disables both test systems. See figure 17-1.

17.2 DESCRIPTION.

Figure 17-2 is a functional block diagram of the subsystem, with control functions indicated schematically. Control switch S1 is a 9 by 5 wafer switch. Section A generates the command indications and sections D and E complete the verification indicator

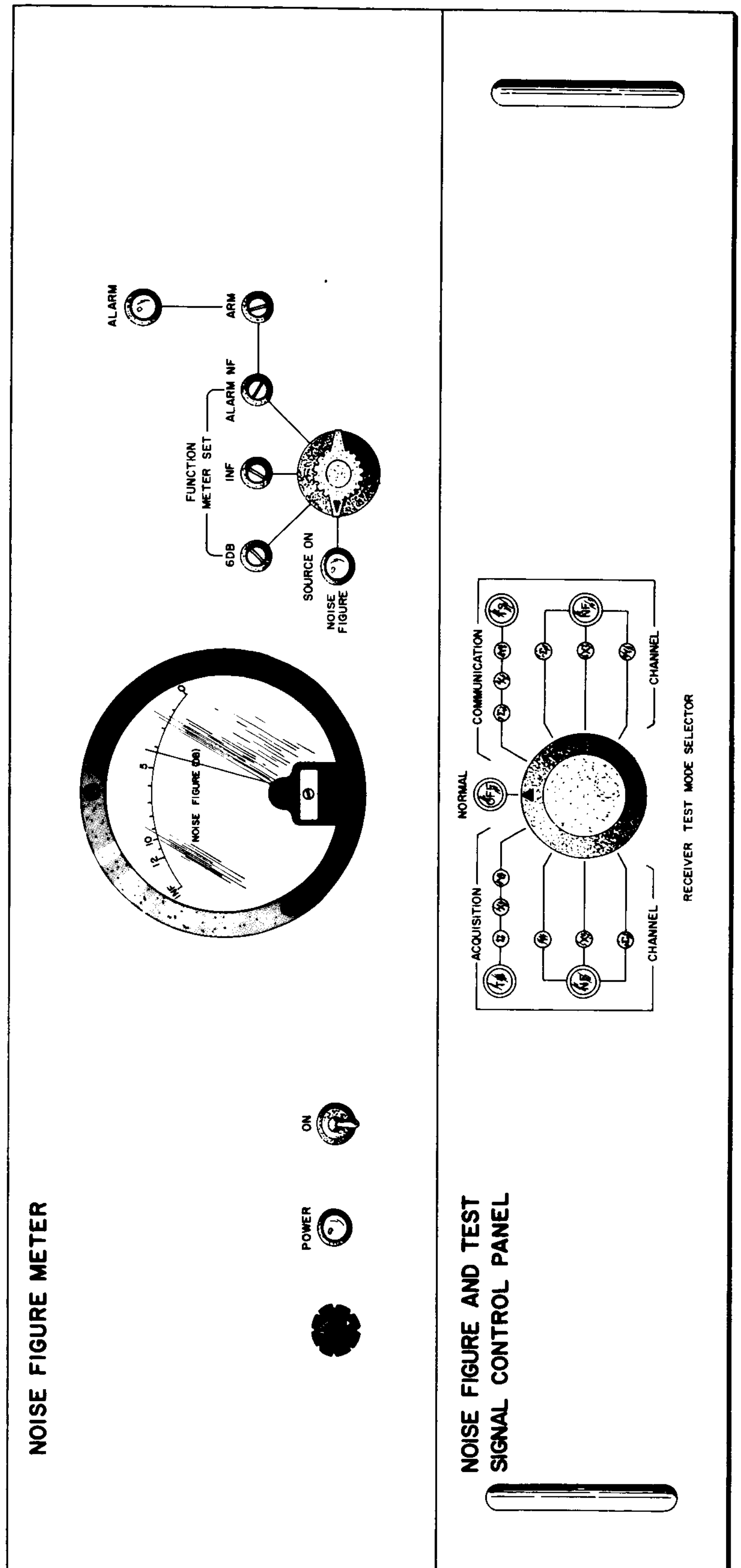
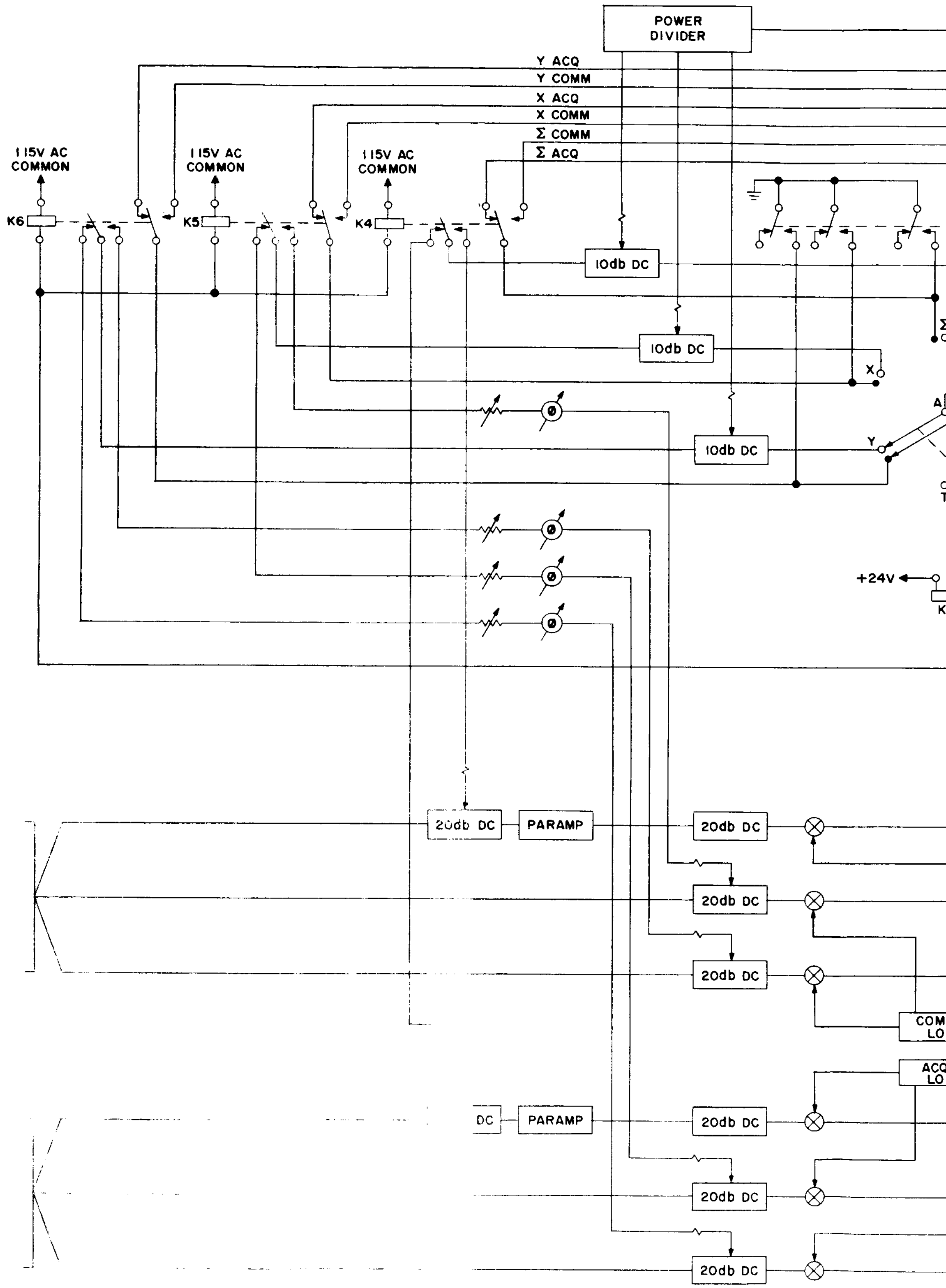
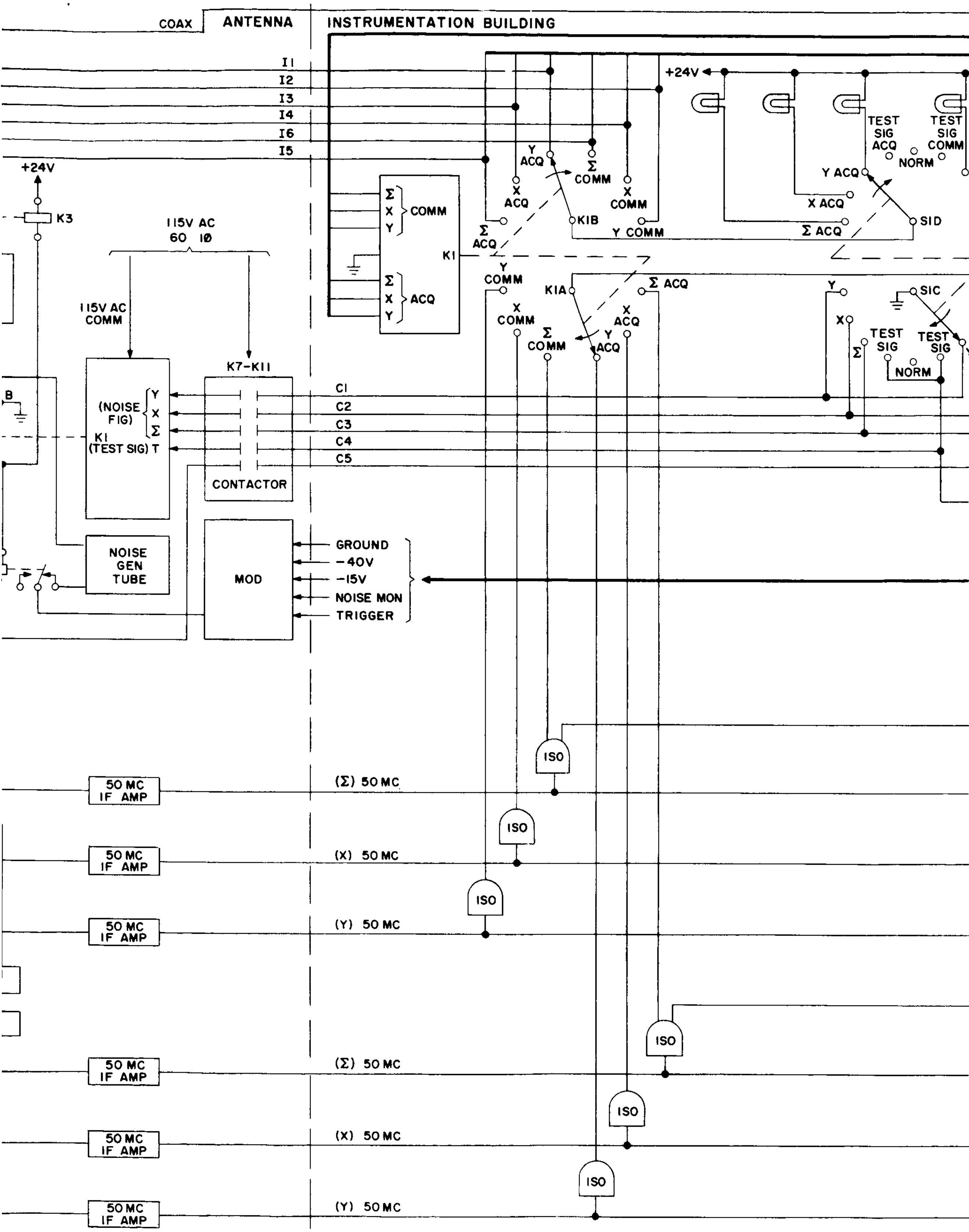


Figure 17-1. Noise Figure and Test Signal Control Panel, Pictorial



POWER DIVIDER
Y ACQ
Y COMM
X ACQ
X COMM
Σ COMM
Σ ACQ
115V AC COMMON
115V AC COMMON
115V AC COMMON
K6
K5
K4
10db DC
10db DC
10db DC
X
Y
A
+24V
20db DC
PARAMP
20db DC
20db DC
20db DC
COM LO
ACQ LO
DC
PARAMP
20db DC
20db DC
20db DC



COAX
ANTENNA
INSTRUMENTATION BUILDING
I1
I2
I3
I4
I6
I5
+24V
K3
115V AC
60 1Ø
115V AC
COMM
K7-K11
(NOISE FIG)
K1
(TEST SIG)
Y
X
Σ
T
CONTACTOR
NOISE GEN TUBE
MOD
C1
C2
C3
C4
C5
GROUND
-40V
-15V
NOISE MON
TRIGGER
COMM
ACQ
K1
K1A
K1B
Y ACQ
X ACQ
Σ ACQ
Y COMM
X COMM
Σ COMM
TEST SIG ACQ
TEST SIG COMM
NORM
SIC
SID
TEST SIG
ISO
50 MC IF AMP
(Σ) 50 MC
(X) 50 MC
(Y) 50 MC

2

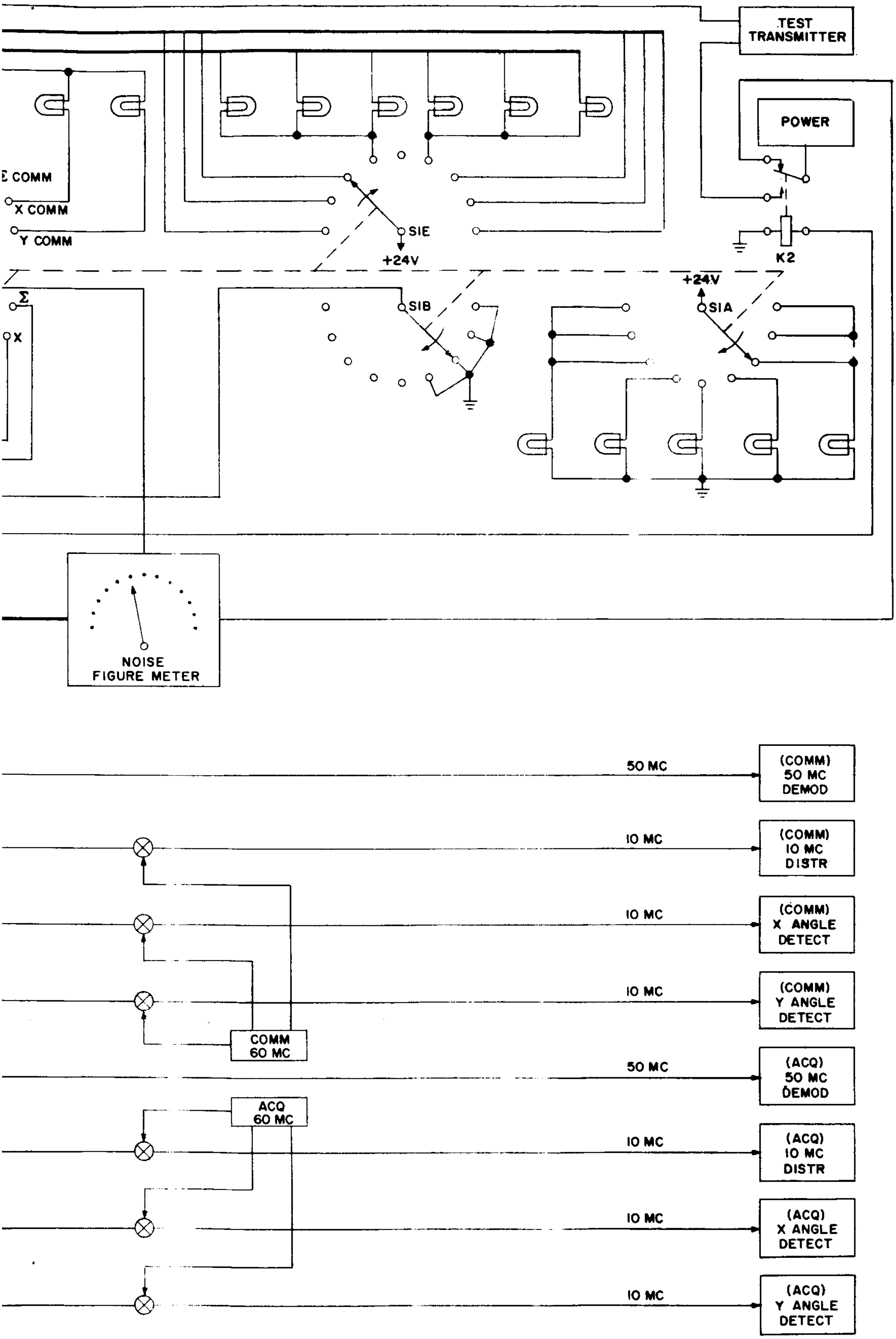


Figure 17-2. Noise Figure and Test Signal System, Block Diagram

paths. Section E also generates control signals for the noise-measuring modes, causing motor-actuated relay K1 to connect the noise figure meter to the appropriate isolation amplifier if. output (through ports on K1A). Switch section S1C operates contactors K7 to K10 to position motor-actuated relay K1 at the antenna for the selected rf channel noise tests (or to shut down the noise system and energize the test signal generator for the test signal mode). Receiver channel selection (Σ, X, Y) at the antenna is determined by motor-actuated relay K1, and the receiver system selection (ACQ or COMM) is determined by relays K4, K5, and K6, which are operated by K11 under control of S1B at the control panel.

Relay K2 at the instrumentation building, controlled by switch section S1C, energizes the test transmitter. The test signal is split three ways in the power divider at the antenna, and each output is connected through the coupled arm of a 10-db directional coupler. The directional coupler outputs are connected to the three receiver channels through receiver selector relays K4, K5, and K6. Phase and amplitude adjustment network will be inserted in the angle channels (X and Y) to compensate for the path differentials, if necessary.

17.3 CONTROL AND INDICATOR LINES.

Indicator contacts that follow the positions of K1, K3, K4, K5, and K6 at the antenna provide positive verification at the instrumentation building that the desired switching action has occurred. Assuming a 16-gauge AWG control and a 350-foot indicator cable, six lines are required for the verification indicators (I_1 through I_6) and a seventh line will serve as the return ground (maximum current of 160 ma).

Control lines C1 through C5 operate contactors for the motor-driven switch. Five no. 16 leads will be used, and a sixth will serve as the return ground (maximum current of 250 ma).

17.4 TEST SIGNAL AND NOISE FIGURE CABLES.

The test transmitter located in the instrumentation building must deliver a level of at least -60 dbm to the receiver input, when the signal generator output is 0 dbm. A 3/8-inch flexible coax line will be used between the antenna and the test transmitter (350 feet). This cable loss is 5 db/100 feet for a total loss of 17.5 db. Other losses in the path are 9.6 db (power divider), 10 db (network directional coupler), and 20 db (receiver directional coupler). Total path loss will be approximately 57 db - well within the requirement.

Cabling between locations for the noise figure measuring system requires special attention. All power and signals to operate the modulator are derived from the noise figure meter chassis. Table 17-1 lists the cables required and important parameters. All wire sizes and resistance values are in accordance with Hewlett-Packard recommendations for this application, and are based on a maximum run of 400 feet.

TABLE 17-1. NOISE FIGURE SYSTEM CABLING DATA

SIGNAL	CABLE TYPE	MAX. RESISTANCE (ohms)	REMARKS
MODULATOR OUTPUT TO NOISE TUBE	RG 59/U		Max. length -
-15 volts	#16 Shielded	4	
-40 volts	#8 Shielded	0.5	
Ground	(equivalent to #8)	0.5	(Consists of overall cable shield and four individual cable shields.)
Control Pulse	#16 Shielded	15	
Noise Source Monitor	#16 Shielded	15	

17.5 OPERATION.

The noise figure measurement system consists of the following Hewlett-Packard instruments:

(1) Dymec H70-344A Rack-mounted Noise Figure Meter, 50-mc if., 0- to 15-db range

(2) Dymec 344A-78G Modulator (antenna-mounted)

(3) Dymec H01-349 Noise Source (antenna-mounted)

In addition to the special cabling requirements previously mentioned, the system requires that the receiver gain be between 40 and 80 db. Referring again to figure 17-2, it can be seen that this requirement is adequately met since the gain of the receiver is specified as at least 50 db (including the coupling factor of the directional coupler).

The noise figure meter is scaled from 0 to 15 db with readings accurate within 0.5 db from 0 to 5 db, and within 1 db from 5 to 10 db. A discussion of measurement principles follows[1]:

Noise figure is a measure of the reduction of a signal-to-noise ratio caused by the internal generation of noise in an active network (receiver or amplifier) under consideration. If the network were an ideal, noiseless network, the signal-to-noise ratio would be unchanged by the network. In this ideal case, the ratio (F) of the signal-to-noise ratio at the input to the signal-to-noise ratio at the output would be 1 and the noise figure, NF = (10 log F), would be zero db. However, all electronic devices add noise to a signal as the signal passes through, reducing the signal-to-noise ratio at the output. Mathematical expressions for the above are:

$$F = \frac{S_i/N_i}{S_o/N_o}$$

$$NF = 10 \log F$$

$$= 10 \log \left(\frac{S_i/N_i}{S_o/N_o} \right)$$

$$= 10 \log (S_i/N_i) - 10 \log (S_o/N_o)$$

where:

NF = noise figure (db)

S_i/N_i = input signal-to-noise power ratio

S_o/N_o = output signal-to-noise power ratio

1 Hewlett-Packard Company, Operating and Service Manual, Model 344A/AR Noise

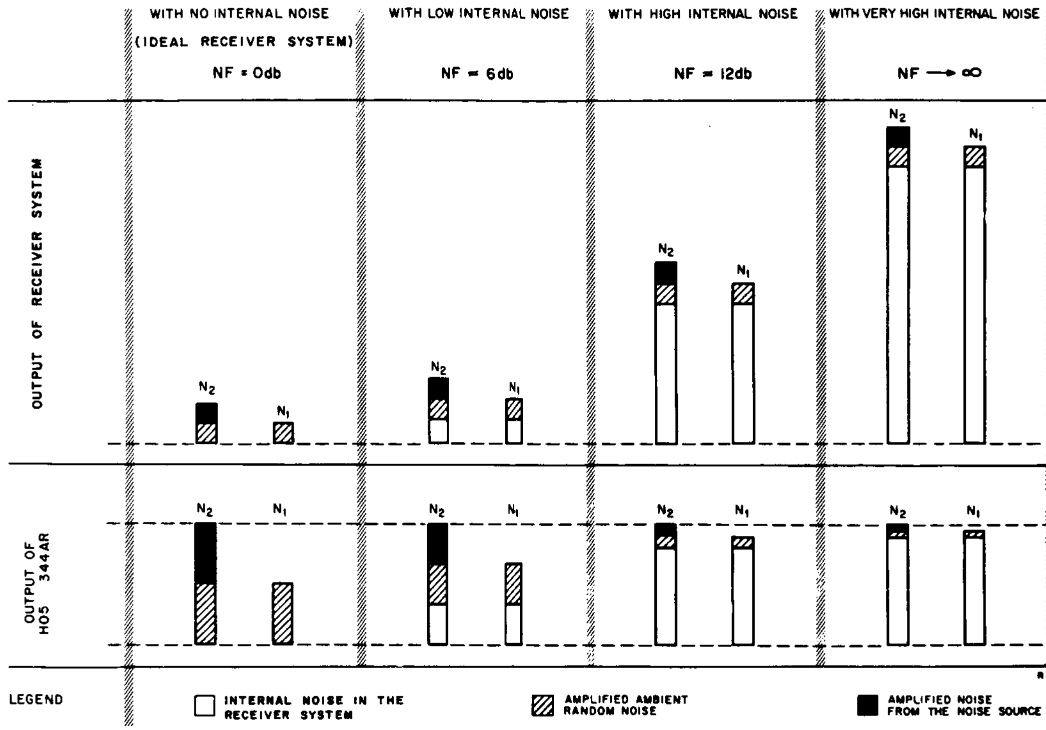


Figure 17-3. Principle of Measurement Diagram

In actual practice, it is not possible to separate the signal from the noise at the output of a network and to measure them separately because noise is always present. Therefore it is necessary to measure noise figure using a different technique.

$$F = \frac{S_i N_o}{S_o N_i} = \frac{S_i N_o}{(GS_i) N_i} = \frac{N_o}{GN_i}$$

where: G = gain of the network.

The output noise is then:

$$N_o = FGN_i$$

The available power generated by a noise source can be written as N KTB where:

K = Boltzmann's constant

T = absolute temperature of the source

B = effective bandwidth of the network.

Therefore:

$$N_o = FGKTB$$

Adding and subtracting GKTB

$$N_o = FGKTB + GKTB - GKTB$$

$$N_o = GKTB + (F-1)\,GKTB$$

This last equation shows that the noise output of any network comprises two contributions: GKTB, the amplified input noise, and (F-1)GKTB which must then be the additional noise generated by the network itself. The temperature, T, in each term is a function of each source of noise. For the second term, T is always the ambient temperature of the device being measured and, in calibrating the 344A/AR meter, is taken to be 290°K. When only random noise is present at the input of the network, T in the first term is also ambient temperature. In this case, the equation for output noise is:

$$N_1 = GKT_0B + (F-1)GKT_0B$$

where: T_0 = ambient temperature (290°K)

N_1 = output noise with random (ambient) input noise

If an external source of noise power is placed at the input to the network, the equation for the output noise (N_2) becomes:

$$N_2 = GKTB + (F-1)GKT_0B$$

where T is the effective temperature at the input created by the new noise power source. The temperature in the second term remains T_0, the ambient temperature of the device being measured.

Subtracting and adding GKT_0B at the first term of the last equation:

$$N_2 = GKTB - GKT_0B + (F-1)GKT_0B$$

$$N_2 = GK(T-T_0)B + GKT_0B \quad (F-1)GKT_0B$$

$$N_2 = GKT_0B(\frac{T}{T_0} - 1) + GKT_0B \quad (F-1)GKT_0B$$

As the final two terms of the last equation are N_1, the output noise with random input, the member

$$(\frac{T}{T_0} - 1)$$

of the first term can be considered an excess-noise ratio, D.

Taking the ratio of N_1 to N_2 and cancelling the term GKT_0B:

$$\frac{N_1}{N_2} = \frac{F}{D + F}$$

Solving for F:

$$FN_2 = N_1(D + F)$$

$$F(N_2 - N_1) = N_1D$$

$$F = \frac{N_1D}{N_2-N_1}$$

$$F = \frac{D}{(N_2/N_1) - 1}$$

Noise figure, NF, is 10 log F and:

$$NF = 10 \log \frac{D}{(N_2/N_1) - 1}$$

$$NF = 10 \log D - 10 \log (\frac{N_2}{N_1} - 1)$$

$$NF = 10 \log (\frac{T}{T_0} - 1) - 10 \log(\frac{N_2}{N_1} - 1)$$

In the operation of Model 344A/AR, the temperature T_0 is assumed to be constant at 290°K. With a specified noise source, the input noise power for the development of N_2 is known and the temperature T is therefore constant. The only variable then in the last equation is the ratio N_2/N_1.

To determine the noise figure of a system under test, with the Model 344A/AR, a calibrated noise source delivers a pulse of known noise level into the system in order to generate an N_2 pulse for measurement. The noise source is then deactivated and a portion of the random ambient noise from the system is sampled (N_1). The Model 344A/AR then measures the difference between these two pulses. In order to use this difference for the determination of NF, it is necessary to make this difference between the heights of these pulses be a function of their ratio. This is done by holding N_2 at a constant level, regardless of internal noise, by using AGC. The gain of the Model 344A/AR is get by AGC during the appearance of each N_2 pulse to maintain a predetermined level for the N_2 pulse at the detected output. The amount of this AGC is determined by the magnitude of the N2 pulse into the Model 344A/AR. This gain setting is then held constant for the appearance of the N_1 pulse. The difference in pulse heights is now a function of N_2/N_1 and the meter is appropriately calibrated to display noise figure directly in db.

This principle of measurement is illustrated in figure 17-3. Under any conditions, the N_2 output of the system is the same as the N_1 output with the addition of the amplified noise-source signal. AGC in the Model 344A/AR always brings the N_2 pulse to a constant level. To do this, the AGC must either expand or compress all the constituents of the system output. The amount of AGC used to perform this level setting is held during the appearance of the N_1 pulse. Thus the constituents of the system output during N_1 (the internal noise of the system and the amplified random ambient noise), after removal of the noise source signal, are acted upon in the same manner (expanded or compressed) to the same degree as those in N_2.

The difference between the heights of the N_2 and N_1 pulses, under a given set of conditions, is the amplified noise-source signal which was compressed, along with the other constituents of the N_2 pulse, to maintain a constant-level N_2 pulse. The more internal noise present in the system, the more the noise-source signal must be compressed. As the internal noise in the system increases, then, the higher will be the N_1 pulse at the output of the Model 344A/AR.

This difference in height (between N_2 and N_1) drives a meter calibrated directly in db of noise figure.