WDL-TR7835
15 May 1978

JPL LARGE ADVANCED ANTENNA STATION ARRAY STUDY

FINAL REPORT

In Response to:
Contract No. 954973

Submitted to:

California Institute of Technology
Jet Propulsion Laboratory
4800 Oak Grove Drive
Pasadena, California 91103

Ford Aerospace & Communications Corporation
Western Development Laboratories Division

3939 Fabian Way
Palo Alto, California 94303

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SECTION 1

INTRODUCTION

Ford Aerospace & Communications Corporation, WDL Division, submits this report in compliance with Jet Propulsion Laboratory (JPL) contract number 954973. In accordance with study requirements, two antennas are described: a 30-meter standard antenna and a 34-meter modified antenna, along with a candidate array configuration for each. Modified antenna trade analyses are summarized, risks analyzed, costs presented, and a final antenna array configuration recommendation made.

1.1 ANTENNA AND ARRAY DEFINITIONS

The standard antenna is based upon the standard WDL wheel and track Intelsat antenna. The modified antenna is a direct outgrowth of the standard antenna with the aperture increased in proportion to differences between the original standard antenna wind specifications and JPL wind specifications. The modified antenna has several design improvements over the standard antenna: counterweight placed outboard of the elevation bearings to improve rms surface accuracy; a tripod subreflector support structure instead of a quadripod to reduce structural blockage; a simplified concrete foundation design; and many additional minor modifications to improve performance, increase maintainability, and increase component reliability. Figure 1-1 illustrates the major differences between the modified and the standard antenna.

The WDL 30-meter antenna was selected because it meets the contract requirements of an off-the-shelf antenna and the 34-meter modified antenna fulfills the requirements of an antenna comprised of existing, proven components. The selected antennas are evolutionary descendents of the first wheel and track antenna designed by WDL 8 years ago and they incorporate all cost, performance, maintenance, and operational design improvements obtained during that time.

Two key design features, found in both WDL antennas, add significantly to better performance and reduced maintenance: (1) a single elevation bull gear is utilized so that torsional forces are not applied to distort the reflector, (2) a three wheeled design is utilized which is more tolerant of track aging because torsional forces due to track misalignments are not applied to distort the antenna structure.

1.1.1 Standard and Modified Antenna Design Comparison

Table 1-1 summarizes design differences between the standard antenna and the modified antenna.

1.1.2 Standard and Modified Antenna Array Comparison

Table 1-2 shows estimated array performance for both the 30-meter standard antenna and the 34-meter modified antenna.

1.1.3 Trade Analyses

The selected 30-meter standard antenna is the most cost effective existing WDL design that meets LAAS requirements. Smaller antennas were less cost effective due to fixed electronics costs per array element. A larger antenna is more cost effective until the difference in cost for one antenna exceeds the fixed electronics costs; it is believed this happens near a 6 or 7-element configuration which corresponds (approximately) with that for 38 or 41-meter reflector diameters respectively. The 34-meter modified antenna was selected by WDL as the reflector size that most nearly approached the minimum cost array, and yet met the criteria of a low risk change to an existing WDL design.

After preliminary investigations of both king post and hour angle/declination mounts, the wheel and track mount was selected as most cost effective. After studying counterweight effects, the counterweights were moved outboard of the elevation bearings, partially counteracting reflector surface rms deterioration due to gravitational loads on the larger reflector. Increased backstructure stiffness and other structural modifications were also studied to improve reflector rms surface accuracy; however, when such extensive redesign was evaluated, costs for the 34-meter antenna grew out of proportion to performance gains.

Blockage was investigated and it was found that slightly narrower legs in a tripod configuration provided a low risk solution to reduced blockage. Further narrowing of the legs would require extensive redesign which does not meet the low risk intent of the LAAS study. Bipods have been utilized on small reflectors but they have lateral low frequency resonance which could cause servo instability and are therefore not recommended for the modified antenna.

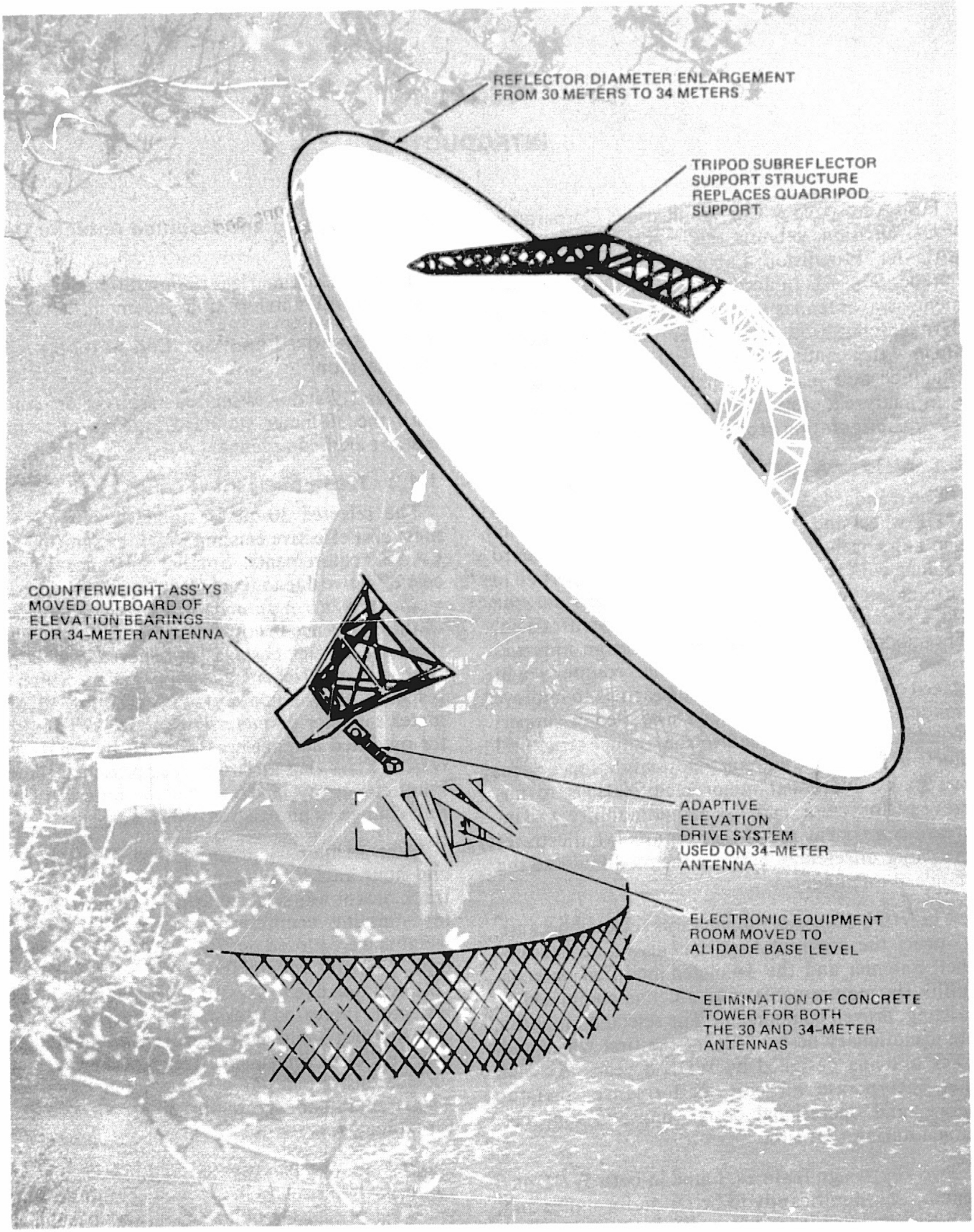

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Figure 1-1. 30-Meter Standard Antenna with 34-Meter Antenna Modifications Outlined for Comparison

Table 1-1. Standard Antenna and Modified Antenna Design Differences

Item Description	Standard Antenna	Modified Antenna
Reflector size	30 meter	34 meter
Subreflector support	Quadripod	Tripod
Counterweight	On elevation wheel	Outboard of elevation bearings
Reflector RMS	0.054 inch	0.040 inch
Elevation drive	Foot mounted	Adaptive
EER location	Upper access level	Base of Alidade
EER size	50 ft^2	200 ft^2
Antenna components in EER	None	Cable wrap, pintle bearing azimuth encoder
Alidade height to elevation bearing	37 ft	46 ft
X-band gain	66.4 dB	68.1 dB
S-band gain	55.6 dB	56.9 dB

Table 1-2. Standard Antenna and Modified Antenna Array Performance Estimates

Parameter	Array Performance			
	30-Meter Antenna		34-Meter Antenna	
	Characteristics	Margin	Characteristics	Margin
Number of Array Elements	13		9	
Array Gain				
X-Band	77.6 dB	-0.1 dB	77.6 dB	-0.1 dB
S-Band	66.8 dB	+1.1 dB	66.4 dB	+0.7 dB
Array G/T				
X-Band	65.6 dB/K	+0.3 dB/K	65.6 dB/K	+0.3 dB/K
S-Band	54.1 dB/K	+0.8 dB/K	53.7 dB/K	+0.4 dB/K

An adaptive drive configuration was selected for the elevation drive system to improve elevation gear reliability and maintainability.

A zenith stow mode was implemented, in that stow is at 89.5 degrees elevation. Specified tracking coverage required 88.5 degrees elevation, so there is no cost advantage available for lower stow angles.

1.2 RISK ANALYSIS

Because the standard antenna is an off-the-shelf product line of WDL and the modified antenna consists of all proven design components, potential risk elements are only in the areas of recommended design improvement features. The effect of these risk elements in the areas of design, manufacturing, and installation are discussed in the following paragraphs.

The tripod is a direct extension of an existing design, and worst case design risk is very low. The reflector extension and counterweight changes were analyzed with proven computer programs that have provided accurate reflector performance estimates for many years and are therefore very low design risks. Adaptive drives have been utilized by WDL on other antennas and are a proven design. Dual dc drives have been used by WDL for over 10 years; 25 units of the proposed design have been delivered to other customers. Based on similar units delivered by WDL for other antennas, the pintle bearing diameter is enlarged. The EER is a change of an existing design, from one with a complex rotating seal to a simple portable building.

Manufacturing of all major components will be accomplished on precision fixtures which will be developed first; parts will then be fabricated from these fixtures and inspected. All interface or performance problems found during checkout will be corrected in this tooling; no additional tests or proof assembly will be required. Manufacturing of all components to this tooling will dramatically lower manufacturing risks for both the standard and modified antennas. Fewer elements to be manufactured means fewer possibilities for error; therefore the modified antenna has the lowest total manufacturing risk.

All installation and alignment functions will be performed by dedicated and specialized work crews to take maximum advantage of learning curves and to reduce risks. There is no real installation difference between the antennas except for size, which has very little associated risk (if any) for the small size differences between the standard and the modified antennas. Again however, as in manufacturing, fewer array elements lowers the probability of problems, simply on an exposure basis; therefore, the array for the modified antenna has the lower installation risk.

1.3 COSTS

Costs for the standard antenna are based upon the most recent vendor quotations updated by the Material Activity to July of 1978. New design items such as the EER and encoder have costs based upon telephone conversations with vendors, together with good engineering judgement and past experience applied. Costs for the modified antenna structure are based upon engineering estimates of the weight change and the cost per pound added to standard structural costs. In every case, costs have been reviewed by the Material Activity to provide a third party check of all material and subcontract cost data. Labor hours are estimated in the normal manner by the organization that would perform the tasks involved, and labor costs are based upon approved bidding rates for the categories of employees involved. All costs were reviewed at three management levels to ensure accuracy. Table 1-3 summarizes the cost data generated for both the standard and modified antennas.

Table 1-3. Cost Summary for the Standard and Modified Antennas

Cost	Hours	Description
STANDARD ANTENNA COSTS (13 REQUIRED)		
787,543	1,814	Structure
564,101	3,577	Installation and Checkout
162,205	2,132	Antenna Control
53,030	268	Antenna Electrical Furnishings
127,904	3,099	PMO
44,219	1,244	Quality Assurance
1,176	26	Reliability/Maintainability
642	11	Manpower Research
5,424	105	RF Engineering
1,106	24	Human Engineering/Safety
26,239	887	Manuals
299,120	881	Shipping
2,072,709	14,068	30-Meter Antenna
MODIFIED ANTENNA COSTS (9 REQUIRED)		
928,833	2,634	Structure
649,779	4,335	Installation and Checkout
184,983	3,084	Antenna Control
54,868	322	Antenna Electrical Furnishings
184,740	4,480	PMO
63,852	1,795	Quality Assurance
1,714	38	Reliability/Maintainability
583	16	Manpower Research
7,884	153	RF Engineering
1,608	35	Human Engineering/Safety
38,002	1,285	Manuals
377,221	1,272	Shipping
2,494,067	19,449	34-Meter Antenna

1.4 SUMMARY AND RECOMMENDATION

Reviewing current WDL antenna designs, and roughly estimating costs, the 30-meter wheel and track antenna was selected as the best WDL standard antenna design for the LAAS. The 30-meter antenna is the product of 8 years design evolution, and 11 identical systems have been delivered to other customers; improvements in performance, reliability. and maintainability have been incorporated to achieve a better antenna for the LAAS.

A second antenna, which is a further development of the standard antenna, was designed to comply with the modified antenna requirements defined in the study contract. RF performance of the modified antenna has been significantly improved by use of a tripod subreflector support and outboard counterweights to offset gravity-caused reflector rms errors.

Modified antenna maintainability has been improved by moving the EER to the lowest alidade level for easy access, and by enclosing the cablewrap and encoder in the EER so all maintenance functions on these components are performed in a controlled environment. Dual aiding/opposing adaptive drives increase reliability of the modified antenna by lowering gear tooth loads and by adaptive adjustment for gear wear and misalignment.

Risks were examined and it was found that while the standard antenna offers slightly lower risk, neither antenna (standard or modified) has any significant design or performance risks associated with it.

Superior in performance, reliability, and maitainability, the modified antenna array is best suited to LAAS requirements; at worst it is only slightly higher in risk than the standard antenna array, but significantly lower in cost. Therefore, WDL recommends the 9-element, 34-meter modified antenna array for the LAAS approach.

Sections 2 through 7 provide detailed descriptions of the standard and modified antenna configurations, typical site installation and checkout procedures, the program implementation plan and schedule, and various program support functions. RF performance data, structural/mechanical analyses, and maintainability information are provided in Appendixes A through D.

SECTION 2

ANTENNA DESCRIPTIONS

This section describes the structural and mechanical features of both the 30-meter standard antenna and the 34-meter modified antenna. Each of these is described for the "receive only" configuration and then the differences between the S-band transmit and X-band transmit configurations are briefly discussed.

Both the standard antenna with a 13-element array, and the modified antenna with a 9-element array, meet all LAAS performance requirements. RF performance data are summarized in Appendix A, and subreflector support structure blockage calculations are contained in Appendix B. Appendix C contains structural/mechanical analyses and includes reflector rms surface calculations for various pointing angles.

2.1 THE 30-METER STANDARD ANTENNA

The WDL 30-meter standard antenna, shown in a dual configuration in Figure 2-1, is modified slightly to comply with JPL LAAS specifications and also to improve maintainability. The major differences between the standard antenna and the JPL LAAS antenna are as follows:

- AC slew/dc drive system is replaced by a field proven dc drive system
- Cyclo-drive speed reducers are replaced by planetary drives manufactured by The Gear Works of Seattle
- Pintle bearing diameter is larger
- Electronic Equipment Room (EER) is simplified
- Concrete pedestal room is eliminated
- Encoder is replaced
- Limit switch mechanism is modified.

The standard antenna uses ac motors in the slew mode and small dc motors in the autotrack mode. For increased performance, dual 10-horsepower dc drive motors are used in the LAAS application. The servo, SCR amplifier, and drive motor components are nearly identical to the drive subsystem components supplied for 23 USASCA Heavy Terminals and exceed the 1000-hour MTBF design goal many times over.

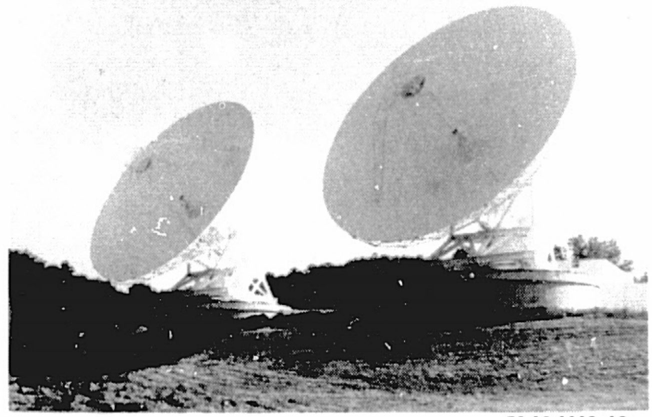


Figure 2-1. Dual 30-Meter Antennas at the AT&T Earth Station near Hanover, Illinois

The Cyclo-drive speed reducers from Sumitomo have been replaced by planetary gear speed reducers manufactured by The Gear Works of Seattle. The Gear Works is an excellent manufacturer from whom WDL has procured many speed reducers, including the highly reliable units supplied for the 23 USASCA Heavy Terminals.

The pintle bearing diameter has been increased to allow added clearance for cable runs to meet JPL requirements.

The EER has been modified to eliminate the rotating elevation seal and thereby increase system reliability. The selected EER is a prefabricated modular unit which can be completely assembled prior to being lifted into place.

The room built into the concrete pedestal has been eliminated, simplifying the antenna foundation design.

The encoder has been replaced with a 21-bit unit in accordance with LAAS requirements.

The limit switch mechanisms have been relocated to a 15-foot radius on the elevation axis, and a 30-foot radius on the azimuth axis for better accessibility and ease of adjustment.

The standard antenna consists of a reflector, pedestal, and mechanical assembly as shown in Figures 2-2 and 2-3. Each of these is described for the "receive only" configuration and then the differences between the S-band transmit and X-band transmit configurations are briefly discussed. A summary of the 30-meter standard antenna's performance is presented in Table 2-1.

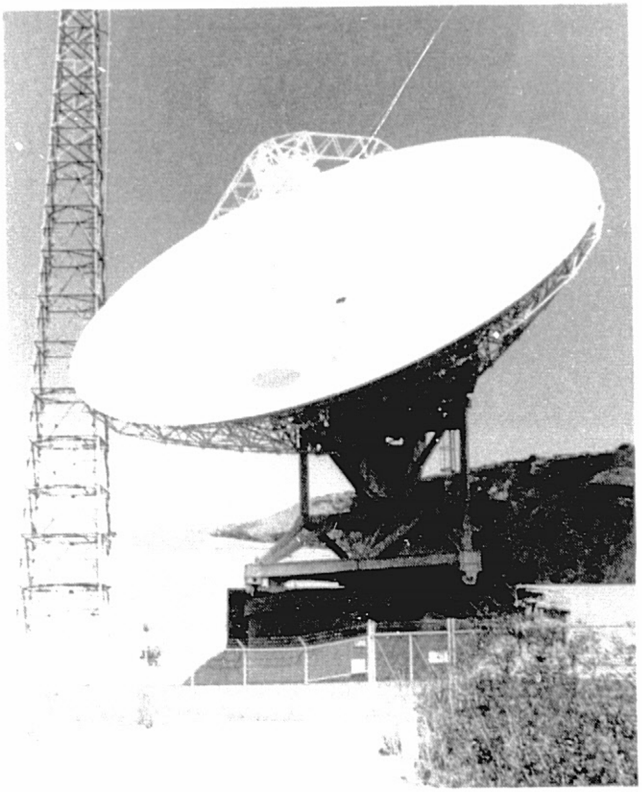


Figure 2-2. WDL 30-Meter Standard Antenna, AT&T Earth Station, Three Peaks, California

2.1.1 Reflector Assembly

The reflector assembly consists of the subreflector, subreflector support structure, reflector panels, reflector backup structure, elevation wheel, and elevation bearings.

The subreflector has been modeled as a 115-inch diameter solid aluminum, quasi-hyperbolic surface spun to rough shape and machined to the final 0.010-inch rms surface accuracy. The subreflector is supported by a lightweight, high strength, fiberglass and foam backup structure in which the subreflector mounting plates are embedded.

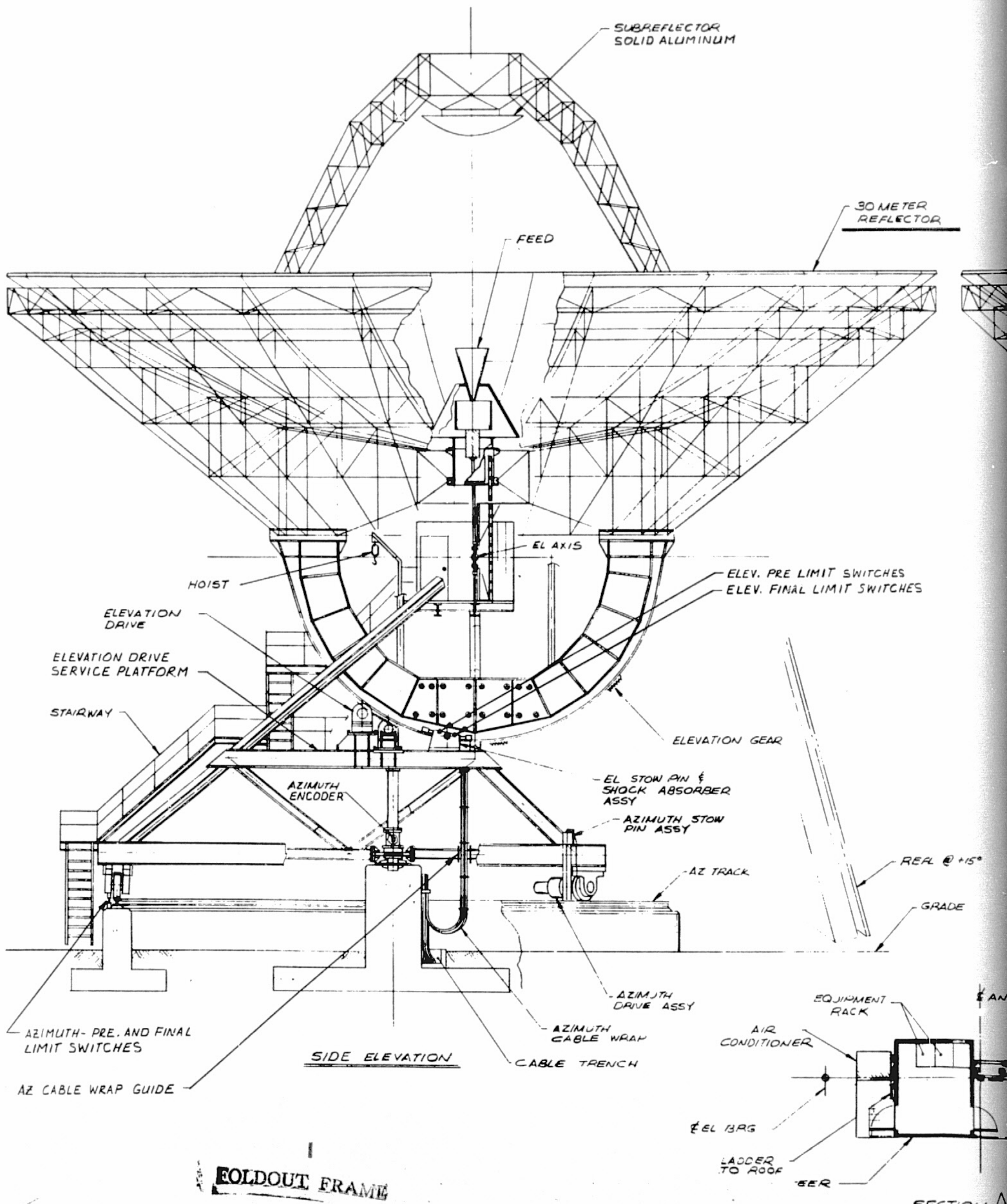
The subreflector support structure is an open truss quadripod. The truss legs are of welded square tube construction, canted near the subreflector to reduce secondary shadowing. The shadowing calculated for the subreflector support structure is 4.1% (see Appendix B). At the quadripod apex, behind and supporting the subreflector, is a space frame structure which provides easy access for subreflector adjustment. The subreflector adjustment mechanism consists of an adjustable plate mounting subassembly for lateral adjustment and threaded rods for axial adjustment; the mechanism is locked by jam nuts following final adjustment.

The reflector surface is made up of 228 panels of six different sizes. Each panel is a riveted aluminum assembly with a 0.060-inch thick, sheet-aluminum surface. The sheet-aluminum surface is supported by contoured zee-shaped sections and is designed to withstand a 300-pound "shoe load" without permanent deformation. Panels are manufactured to a 0.020-inch rms surface accuracy and are finished with high reflectance paint which scatters visible and infrared radiation. A special panel with a hatch door provides access to the reflector surface. The hatch door has a lock assembly and a safety interlock; if the door is not closed and locked, drive power cannot be applied.

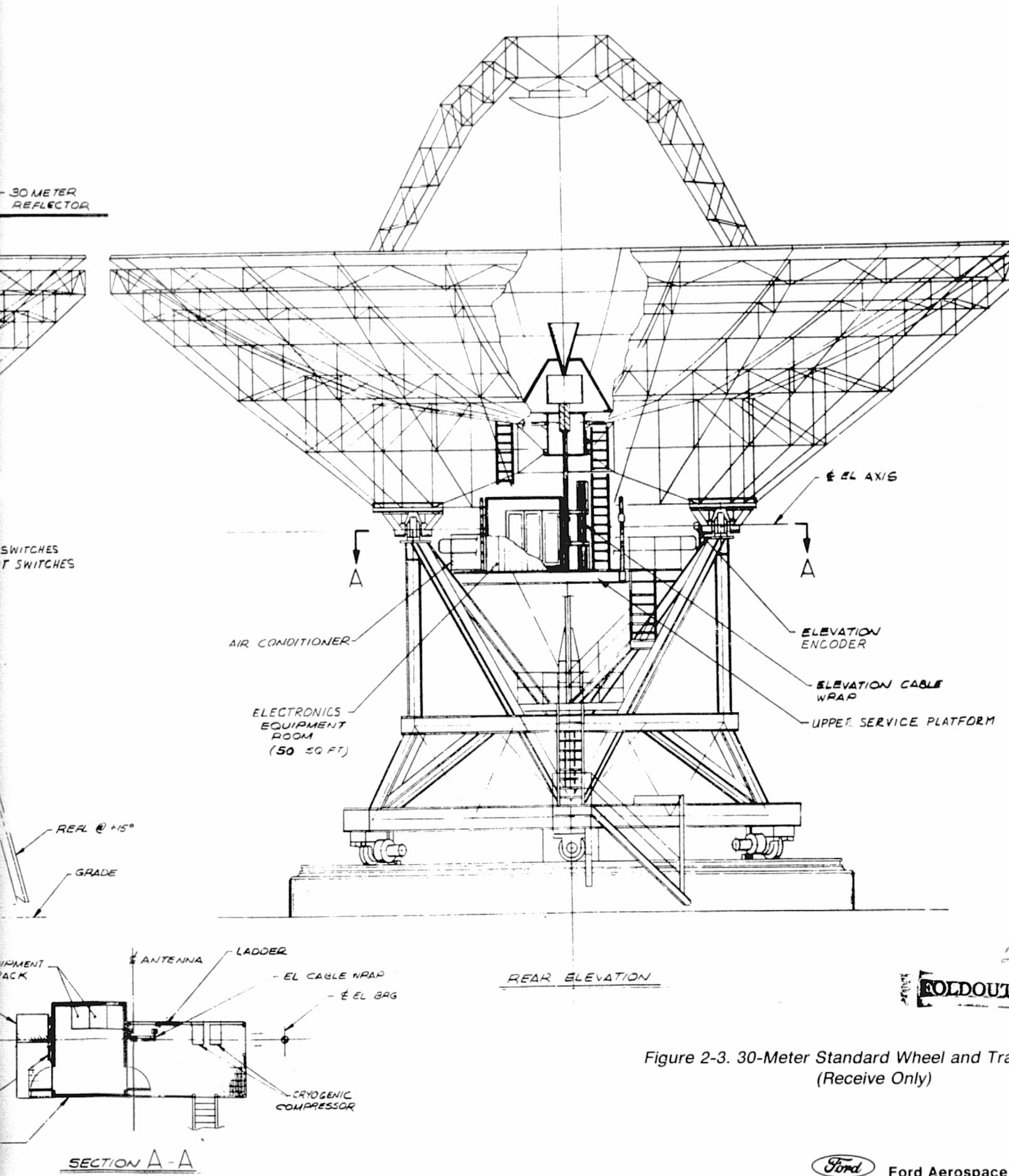
The reflector backup structure is a steel space frame of welded and bolted double angle construction. WDL has a series of proprietary computer programs which are used as design tools in the analysis of gravity and wind load deflection characteristics of three-dimensional space frame structures at selected pointing angles (see Appendix C).

Radial trusses are supported from a central hub and are interconnected by hoop and diagonal braces. Surface panels are connected to the backup structure by adjustable supports which permit alignment of the reflector surface. Final reflector panel alignment is made at the elevation angle selected to minimize surface errors due to gravity deflection.

A single elevation wheel is supported from the reflector structure. The elevation wheel consists of a welded steel plate girder on which the counterweight and elevation gear segments are mounted. The stow pin receptacle and the shock absorber strikers are also on the elevation wheel. The elevation wheel has a 20-foot radius at the rim of the wheel. A steel plate counterweight is bolted to the wheel weldment to balance the reflector assembly about the elevation axis.



SIDE ELEVATION



2

FOLDOUT FRAME

Figure 2-3. 30-Meter Standard Wheel and Track Antenna (Receive Only)

Table 2-1. 30-Meter Standard Antenna Performance Summary

Type of Antenna	Azimuth-Elevation Wheel and Track
Total Weight of Antenna	530 kips
Reflector Diameter	30 meters
Focal Length of Main Reflector	11.1 meters (approximate)
Type of Main Reflector Panels	Aluminum Skin + Zee Stiffeners
Type of Subreflector Support	Quadripod – Trussed Legs
Type of Subreflector	Aluminum Skin
Subreflector Diameter	3.4 meters
Aperture Efficiency	63.3%
Surface Accuracy (rms)	
– Manufacturing and Alignment	0.026 inch
– Manufacturing + Align + Gravity	0.054 inch
– Manufacturing + Align + Gravity + Wind	0.058 inch
RF Boresight Performance	
– Gain X-Band	66.42 dB
– Gain S-Band	55.65 dB
System Temperature °K (Zenith/30° Elevation)	
– X-Band	15.88/19.52 K
– S-Band	18.76/21.66 K
Figure of Merit G/T	
– X-Band	54.41 dB/K
– S-Band	42.92 dB/K
Cable Wrap-up System	
– Azimuth	Cable Loop
– Elevation	Flex Bend
Cable Wrap-up Capacity	
– Azimuth	25 1-inch diameter Cables
– Elevation	40 1-inch diameter Cables
Drive System	Dual Electric Torque Biased
Drive System Power Requirements	60 kVA

Slew Rates	
– Azimuth	0.25°/s
– Elevation	0.25°/s
Acceleration Rates (no wind)	
– Azimuth	$0.25°/s^2$
– Elevation	$0.25°/s^2$
Minimum Tracking Velocity	
– Azimuth	0.001°/s
– Elevation	0.001°/s
Axis Alignment (Orthogonality)	20 arc seconds
System Natural Frequency (Locked Rotor)	
– Azimuth Motion – Reflector @ Zenith	2.1 Hz
– Azimuth Motion – Reflector @ Horizon	2.2 Hz
– Elevation Motion	2.4 Hz
Azimuth Position Readout Type	Inductosyn
– Resolution	21 bits (0.00017°)
– Repeatable Errors	+0.00068°
– Nonrepeatable Errors	+0.001°
Pointing Accuracy	
– 20 mi/h wind steady	0.007°
Pointing Accuracy	
– 40 mi/h wind steady	0.027°
Drive to Stow (wind)	50 mi/h
Survival at Stow (wind)	100 mi/h
Operational Temperature Range	-18°C to 49°C 0°F to 120°F
Rain	2 inch/hour
Snow	1 ft at Stow
Ice	1/2 inch Radial
Sand and Dust	Wind Carried
Humidity	0 to 100%
Salt Atmosphere	Coastal Environments
Seismic	0.25 g
Travel Range	
– Azimuth	±125°
– Elevation	15° to 90°

Elevation bearing support brackets are mounted to the reflector structure. Welded plate girder construction is utilized in a straddle mount concept to achieve a symmetrically loaded shaft. The elevation bearing pillow blocks are mounted on machined surfaces on the support structure. The elevation bearings are 12-inch bore, spherical roller assemblies, preloaded to eliminate clearance and increase stiffness. The elevation bearing and support brackets are shown in Figure 2-4 The bearings are grease lubricated.

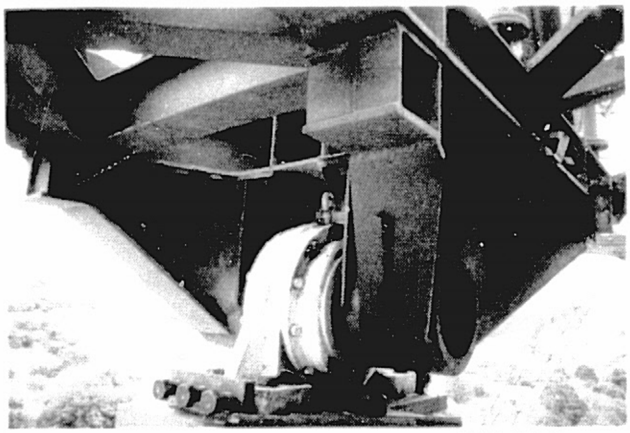

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Figure 2-4. Elevation Bearing and Reflector Support Assembly

2.1.2 Pedestal Assembly

The pedestal assembly consists of the alidade, pintle bearing assembly, azimuth wheel assemblies, azimuth track, electronic equipment room, and antenna access provisions.

The alidade (an open space frame of I-beam construction) is the main structural framework of the pedestal assembly. It provides support for the reflector assembly, elevation drives, electronic equipment room, and antenna access stairways, walkways, and platforms. The alidade is supported by three azimuth wheel assemblies which travel on the machined surface of a circular, 58-foot diameter crane rail. The three wheel configuration was selected because it avoids the structural stress problems inherent in four wheel mounts.

Two of the azimuth wheels are driven and have drive components mounted on them while the third wheel is an idler. The wheels are 36-inch diameter crane wheels, hardened to 360 Bhn minimum. Wheel faces are machined conical for true rolling action on the plane, circular track. Spherical roller bearing pillow blocks are used in the wheel assemblies. The wheel assemblies are adjusted for correct axle inclination and radial alignment, and accuracy of alignment is verified under full load. An azimuth wheel and drive assembly is shown in Figure 2-5.

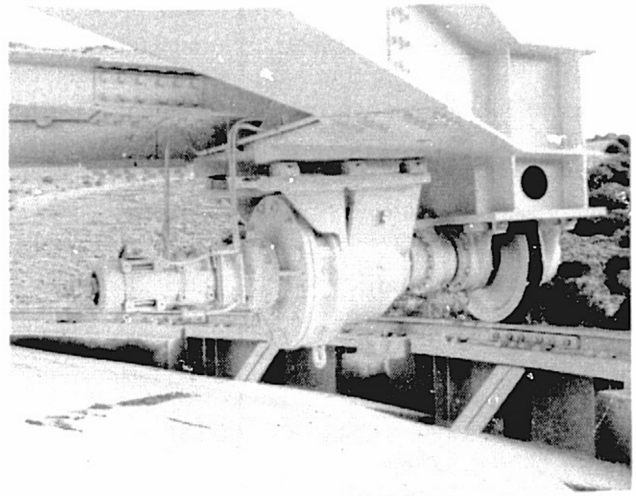
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Figure 2-5. Azimuth Wheel and Drive Assembly

A pintle bearing is used to take all shear and uplift loads, even under survival uplift conditions. The pintle bearing is a 24-inch bore, grease lubricated, spherical roller assembly. The inner shaft is attached to the foundation and the outer housing to the alidade structure through spokes. The azimuth encoder is mounted on the pintle bearing assembly.

The azimuth track consists of 12 segments of 171-pound-per-yard crane rail hardened to 320 Bhn minimum. The track is rolled to a 58-foot diameter and Blanchard ground for flatness The track is fastened to the concrete foundation with anchor bolts, and is grouted with a 3-inch thick, 10,000 lb/in^2 ultimate strength grout. Machined splice bars are provided at track joints. The track is aligned in the horizontal plane within 0.060 inches.

An EER is located inside the elevation wheel near the feed enclosure at the elevation bearing access level. A minimum of 50 square feet of floor space is provided in the EER. The EER walls are capable of supporting a 4000-pound load; the floors are capable of supporting a 2000-pound concentrated load. Access is provided through a man door. The EER is off the azimuth axis to allow clearance for the azimuth cable run and, in the S-band transmit configuration,

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to allow room for the waveguide run and elevation rotary joint.

Access is provided to all maintenance and working levels of the antenna as shown in Figure 2-3. Stairs lead from the ground to the elevation drive service platform; stairs are provided from there to the upper platform on which the EER is mounted. Ladders are provided from the EER level to the feed enclosure and from the EER roof to reflector surfaces. A quadripod leg provides access to the subreflector. The upper service platform is used to provide elevation bearing access and to mount cryogenic compressors. A 1000-pound davit hoist is provided at the EER platform level for equipment handling.

The foundation is 5 feet above grade and is constructed of reinforced concrete with embedded anchor bolts. A 58-foot diameter track mounting surface is provided by a reinforced circular concrete ring with spread footing. A central concrete pier is provided for mounting the pintle bearing.

2.1.3 Mechanical Assemblies

Mechanical assemblies include the elevation gear, elevation drives, azimuth drives, elevation stow lock, elevation shock absorbers, azimuth stow lock, and travel limit mechanisms.

The elevation gear is fabricated in 6 segments to 320 Bhn hardness. Each segment is shimmed and bolted to the elevation wheel. Segments are keyed together. Gears are 2-inch deep, 25-degree pitch angle, involute stub with 240-inch pitch radius and 8-inch face width. Lubricaton is provided by open gear lubrication grease.

The elevation drives (Figures 2-6 and 2-7) utilize grease lubricated, planetary gear speed reducers in a dual aiding/opposing configuration. Drives are of the in-line type, foot mounted with adjustable wedge jacks for alignment. Each drive output pinion is supported by an outboard bearing. A machined flange is provided on the drive assembly for motor mounting. Each speed reducer is driven by a single 10-horsepower dc motor.

An azimuth drive is shown in Figure 2-5. The azimuth drive output shaft is coupled to the wheel axle; a flange is provided for mounting the drive motor. Coupling to the track is by friction with the two active wheels driven in an aiding/opposing configuration. Azimuth speed reducers are in-line planetary type, foot mounted, provided by The Gear Works of Seattle. Access to azimuth drive assemblies is from track level.

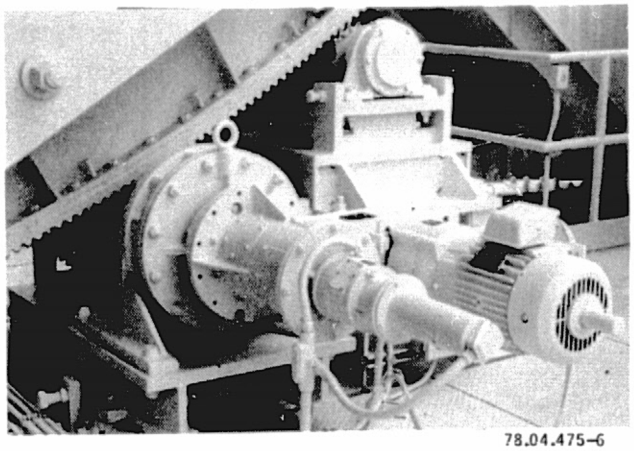

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Figure 2-6. Elevation Drive Assemblies

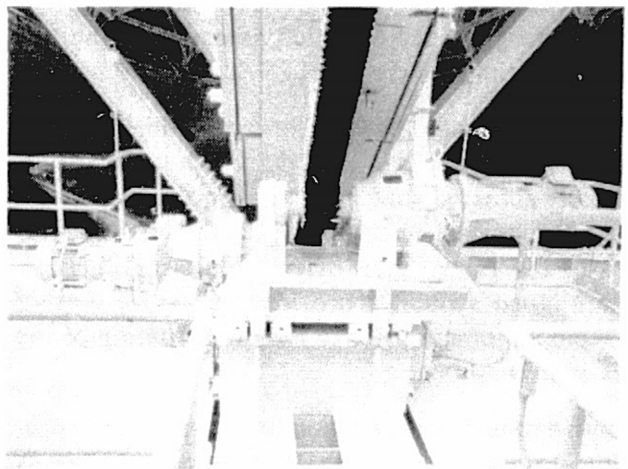

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Figure 2-7. Elevation Drive and Gear Arrangement

The elevation stow lock, shown in Figure 2-8, consists of a remotely actuated pin assembly mounted on the elevation drive platform. The elevation stow pin engages the elevation wheel. A stow pin aligned switch is provided to assure correct stow pin alignment prior to engagement. The antenna is stowed at zenith.

Four elevation shock absorber units are mounted on the elevation stow lock bracket as shown in Figure 2-8. Strikers are attached on either end of the elevation wheel to mechanically limit elevation travel between 14 degrees and 90.5 degrees. The eleva-

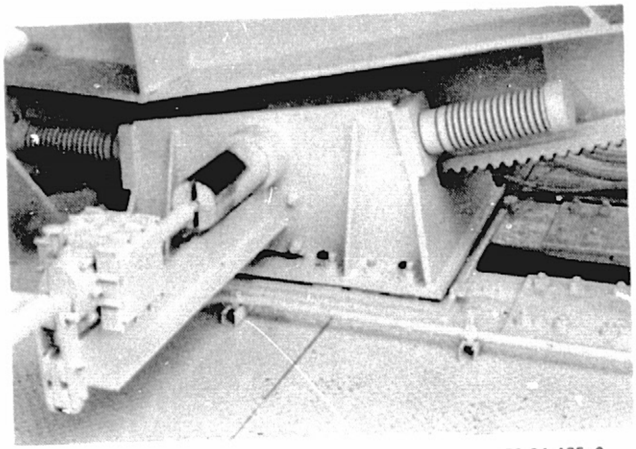

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Figure 2-8. Elevation Stow Pin and Shock Absorber Assembly

tion shock absorbers are capable of absorbing the kinetic energy of the elevation assembly at the full rated elevation velocity of 0.25 degree per second.

Mounted to one alidade corner weldment is the azimuth stow lock (Figure 2-9) which consists of a remotely actuated stow pin assembly that engages a stow pin receptacle mounted on the foundation adjacent to the track. Stow orientation is optional. A stow aligned switch is provided to assure correct stow pin alignment prior to remote actuation of the stow pin.

Both azimuth and elevation limit switches are provided. Azimuth travel is ±125 degrees, elevation is 15 degrees to 89.5 degrees prior to actuation of prelimit switches. Final limit switches are set at ±126 degrees in azimuth and 14.5 degrees and 90 degrees in elevation. For ease and accuracy of setting, elevation limit switches are located on an approximate 15-foot radius. Prelimit switches provide a servo stop command. Final limit switches deactivate the motors and apply the brakes. A pull connector provides a pseudomechanical stop in azimuth by disconnecting all antenna drive power at approximately ±130 degrees azimuth. Elevation shock absorbers serve as mechanical stops for elevation motion.

2.1.4 S-Band Transmit Configuration

The S-band transmit version of the modified antenna (Figure 2-10) is identical in all respects to the receive only antenna, except as follows:

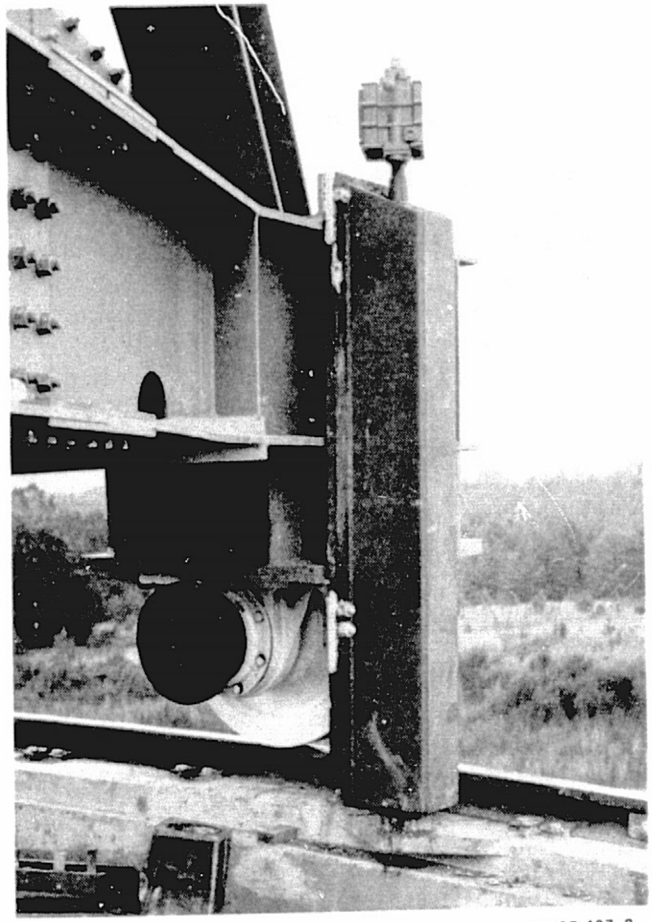

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Figure 2-9. Azimuth Stow Lock Assembly

- Waveguide rotary joints are mounted at both the azimuth and elevation axes
- EER floor space is increased to 80 square feet
- EER walls are designed for a 5000-pound load

2.1.5 X-Band Transmit Configuration

The X-band transmit version of the modified antenna (Figure 2-11) is identical in all respects to the receive only antenna except as follows:

- The reflector center hub is enclosed and enlarged for the high power amplifier
- EER floor space is increased to 100 square feet
- EER walls are designed for a 5000-pound load

S BAND

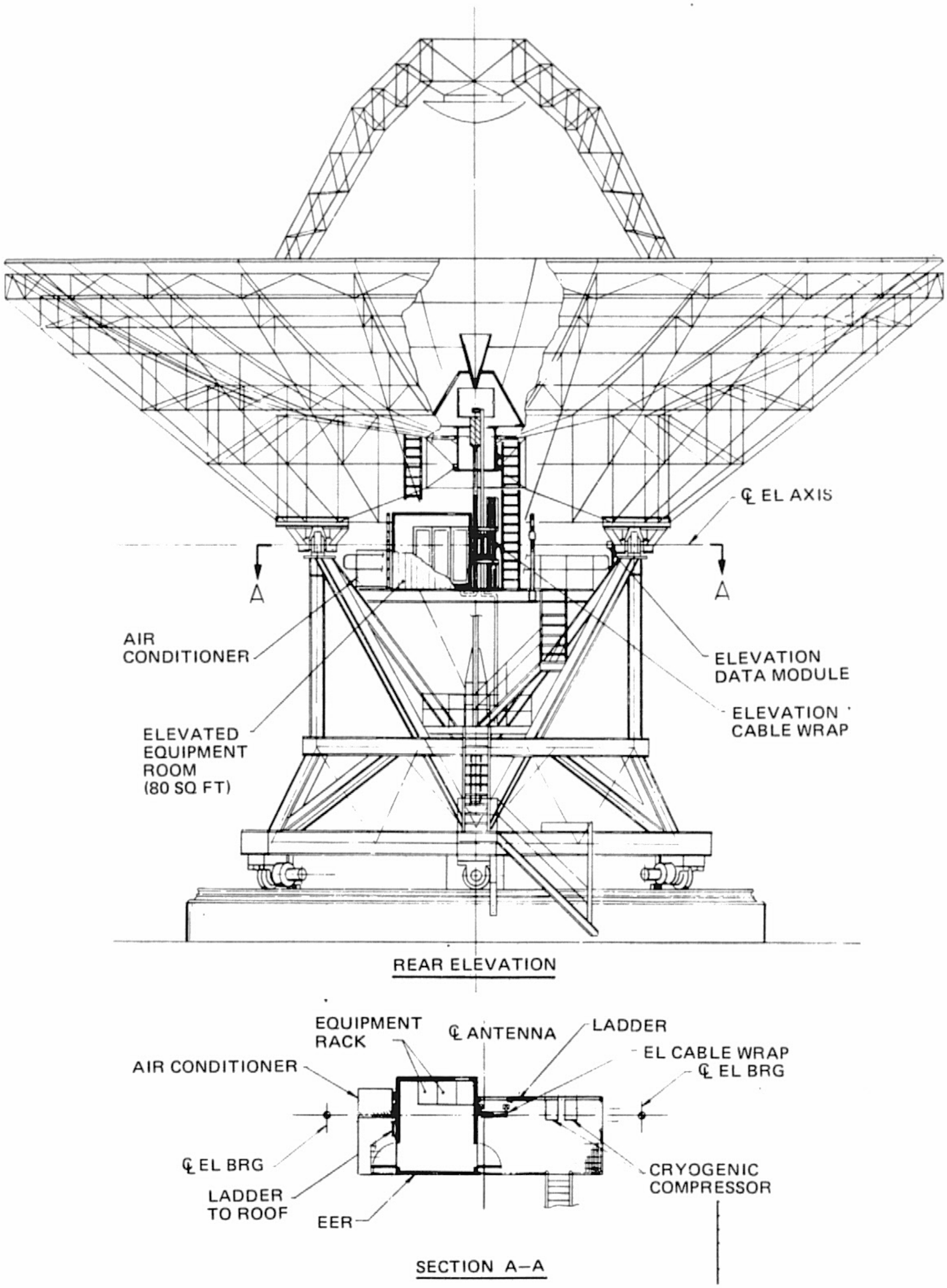


Figure 2-10. 30-Meter S-Band Transmit Configuration

- The X-band transmitter heat exchanger is mounted on the upper access platform
- Lead lining is provided in the reflector hub where the transmitter is mounted

2.1.6 Paint

At the fabricator's facility, all parts will be cleaned and one coat of organic zinc rich primer, equivalent to Napco 2Z, will be applied. One coat of white vinyl paint, equivalent to Napko Duravin, will also be applied prior to shipping. In the field, one coat of white vinyl paint equivalent to Duravin will be applied.

2.2 THE 34-METER MODIFIED ANTENNA

The 34-meter modified antenna is a direct outgrowth of the 30meter standard antenna; the reflector has been enlarged to account for the difference in the 30-meter standard antenna 120 mi/h survival wind design loads and the required 100 mi/h Goldstone survival wind design loads. The rms surface accuracy would normally degrade by direct extension of the reflector. However, counterweights were moved outboard to redistribute gravity deflections for a net improvement over the standard antenna in reflector surface rms accuracy. The standard antenna quadripod was changed to a tripod configuration on the modified antenna to reduce blockage and improve performance. The EER has been moved to the base of the alidade to provide greater accessibility. A self-aligning elevation drive feature has been added to this modified antenna configuration.

The solid aluminum reflector surface, 3-wheeled azimuth mount, and other key design features of the standard antenna were retained on the modified antenna. Planetary gear boxes made by The Gear Works of Seattle are utilized for the drives.

The modified antenna (receive only) is shown in Figure 2-12. The reflector, pedestal assembly, mechanical assemblies, S-band transmit configuration, X-band transmit configuration, and paint are discussed in the following paragraphs. A summary of 34-meter modified antenna performance is shown in Table 2-2.

2.2.1 Reflector Assembly

The reflector assembly consists of the subreflector, subreflector support structure, reflector panels, reflector backup structure, counterweights, elevation wheel, and elevation bearings.

The subreflector has been modeled as a 150-inch diameter, solid aluminum surface, high efficiency, shaped quasi-hyperbola. The subreflector is spun to approximate contour and machined to achieve the final 0.012-inch rms surface accuracy. The subreflector is supported by a fiberglass and foam backup structure in which the subreflector mounting plates are embedded.

The subreflector support structure is an open truss tripod. The truss legs are of welded square tube construction and are canted near the subreflector to reduce secondary shadowing. The shadowing calculated for the subreflector support legs is 2.9% (see Appendix B). At the apex, behind and supporting the subreflector, is a space frame structure providing easy access to the subreflector adjustment mechanism. The subreflector adjustment mechanism consists of an adjustable plate mounting assembly which, after adjustment, is locked by jam nuts.

The number of reflector surface panels is increased to 276; 48 more than the standard antenna. Each panel is a riveted aluminum assembly with a 0.060-inch thick, sheet-aluminum surface. The sheet-aluminum surface is supported by contoured zee-shaped sections and is designed for a 300-pound "shoe load". Panels are manufactured to a 0.020-inch rms surface accuracy and are finished with high reflectance paint which scatters visable and infrared radiation. A special panel with a hatch door is provided for reflector surface access. The hatch door has a lock assembly and a safety interlock; if the door is not closed and locked, drive power cannot be applied.

The reflector backup structure is a steel space frame of bolted double angle construction. WDL has a series of proprietary computer programs to analyze a three dimensional space frame which provides accurate gravity and wind load deflection data at selected pointing angles (see Appendix C). Radial trusses are supported from a central hub. Cross braces are added to provide torsional rigidity. The center hub is enclosed on three sides and has a floor to provide feed access. Adjustable panel supports are provided for reflector surface alignment. Provisions are made for mounting the surface alignment tooling in the hub. Final reflector panel alignment is made at the elevation angle selected to minimize surface errors due to gravity loads.

Two counterweight structures are used: one outboard of each elevation bearing. This counterweight configuration was selected to counteract gravity loads and improve the reflector rms surface accuracy. Surface accuracy generally deteriorates as reflector size increases; however, the selected counter-

X BAND

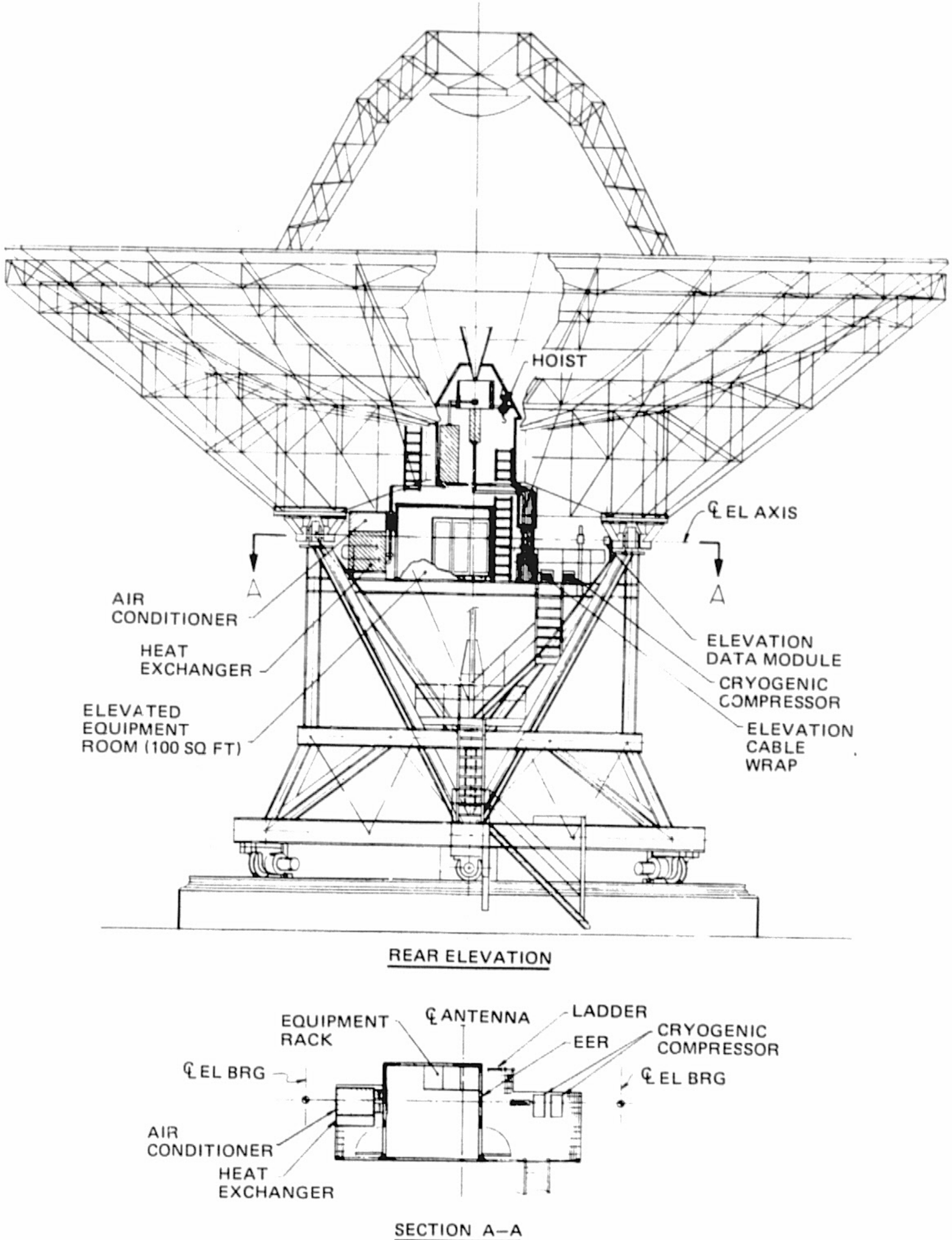


Figure 2-11. 30-Meter X-Band Transmit Configuration

weight configuration actually provides an improvement over the standard antenna (standard antenna 0.054-inch rms to the modified antenna 0.042-inch rms). The counterweights are supported from the reflector by a steel space frame terminated in a counterweight box with poured-in-place heavy concrete containing crushed cast steel aggregate. Steel trim weights are provided to achieve a completely balanced system.

A single elevation wheel is supported from the reflector structure. The elevation wheel consists of a welded steel plate girder that provides the elevation gear mounting surface; the stow pin receptacle and bumpers for the shock absorber mechanism are also on the elevation wheel. The elevation wheel has a 20-foot radius at the rim of the wheel.

Elevation bearing support brackets are mounted to the reflector structure. Welded plate girder construction is utilized in a straddle mount concept to achieve a symmetrically loaded shaft. A machined surface is provided to mount the elevation bearing pillow blocks. The elevation bearing is a 12-inch bore, spherical roller assembly, preloaded to eliminate clearance and increase stiffness. The elevation bearings are grease lubricated.

2.2.2 Pedestal Assembly

The pedestal assembly consists of the alidade, pintle bearing assembly, azimuth wheel assemblies, azimuth track, electronic equipment room, and antenna access stairways, walkways and platforms.

The alidade is an open space frame assembly of plate girder construction. The alidade provides support for the reflector assembly, elevation drives, azimuth drives, electronic equipment room, and antenna access stairways, walkways, and platforms. The wheel, track, and pintle bearing configuration is the same as that of the 30-meter standard antenna except that uplift restraint lugs are provided at the stow-position wheel locations for additional protection against overturning forces encountered under survival wind conditions.

An EER is located at the alidade base for easy access. Approximately 200-square feet of floor space is provided. The EER walls are capable of supporting a 4000-pound load; the floors are capable of supporting a 2000-pound concentrated load. Access is provided through a man door. The EER encloses the azimuth cable wrap, azimuth encoder, and pintle bearing.

Access is provided to all maintenance and working levels of the antenna as shown in Figure 2-13. Stairs lead from the ground to the elevation drive service platform; ladders are provided from there to the upper feed enclosure platform and from the elevation drive service platform to the reflector surface. From the reflector surface, rungs on the tripod provide access to the subreflector. An access walkway to the EER is provided at the alidade base. The upper service platform is used to provide elevation drive access and to mount cryogenic compressors. A 1000-pound davit hoist is provided at the upper platform for equipment handling.

The foundation is 4 feet above grade and is constructed of reinforced concrete with embedded anchor bolts. A 58-foot diameter track mounting surface is provided by a reinforced circular concrete ring with spread footing. A central concrete pier is provided for mounting the pintle bearing.

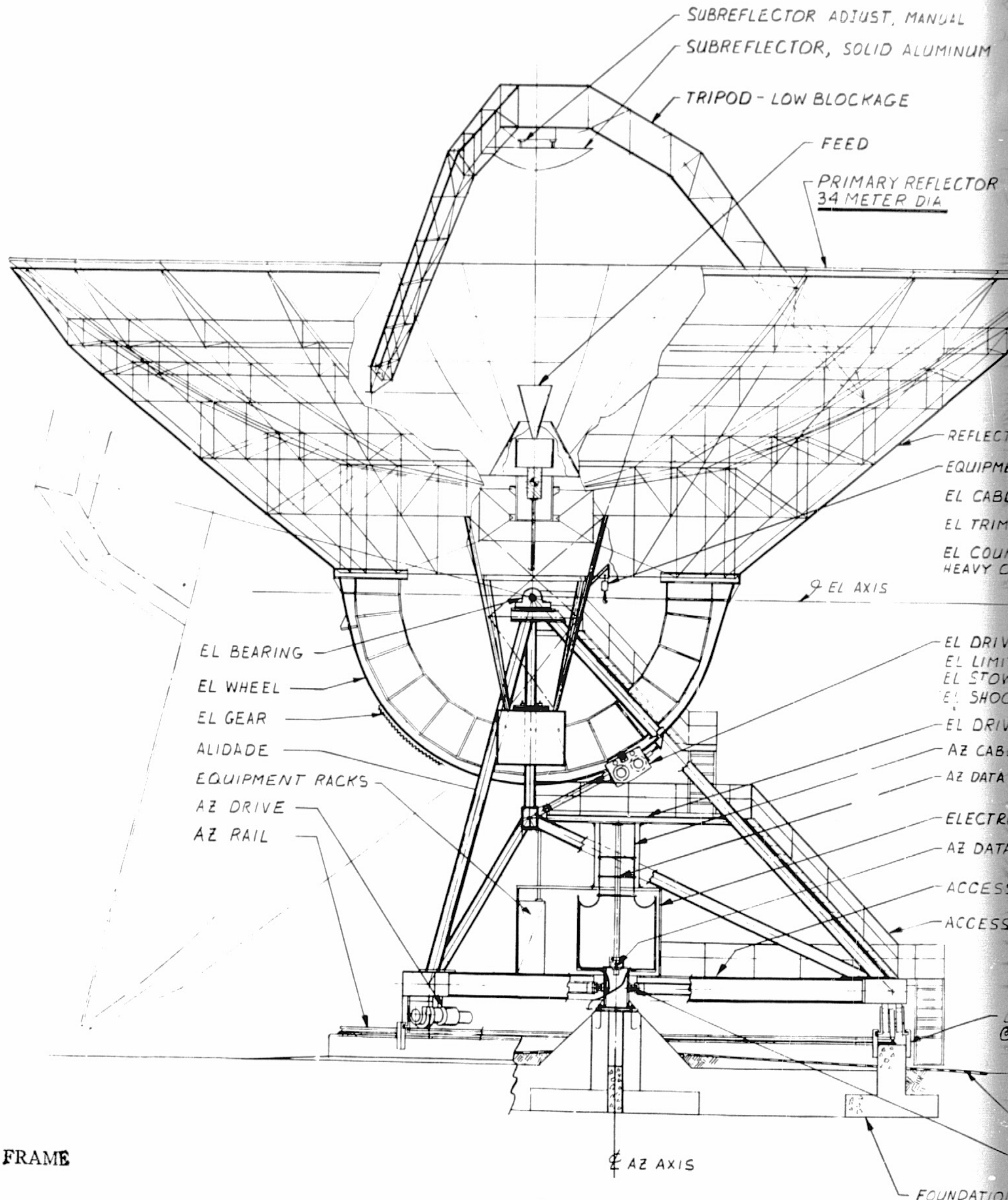
2.2.3 Mechanical Assemblies

Mechanical assemblies include the elevation gear, elevation drives, azimuth drives, elevation stow lock, elevation shock absorbers, azimuth stow lock, and travel limit mechanisms.

The elevation gear is fabricated in 6 segments to 320 Bhn hardness. Each segment is shimmed and bolted to the elevation wheel. Segments are keyed together. Gears are 2-inch deep, 25-degree pitch angle, involute stub with 240-inch pitch radius and 9-inch face width. A flange of controlled thickness is provided for the adaptive drive rollers. Lubrication is provided by open gear lubrication grease.

The elevation drive assembly is a self-aligning unit supported by rollers on the back surface of the segmented elevation gear and tied to the alidade structure by articulating struts. This drive arrangement maintains near-perfect gear mesh alignment by adapting to imperfections in gear alignment, thereby minimizing tooth stresses for improved gear life. The self-aligning drive is shown in Figure 2-14. The elevation speed reducers are planetary type from The Gear Works of Seattle.

Azimuth drives are of the in-line type, and are foot mounted. The output is coupled to the wheel axle. A flange is provided on the drive assembly for mounting the drive motor. Coupling to the track is by friction. Azimuth gear boxes are planetary type provided by The Gear Works of Seattle. Access to azimuth drive assemblies is from track level.



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SIDE ELEVATION

WDL-TR7835

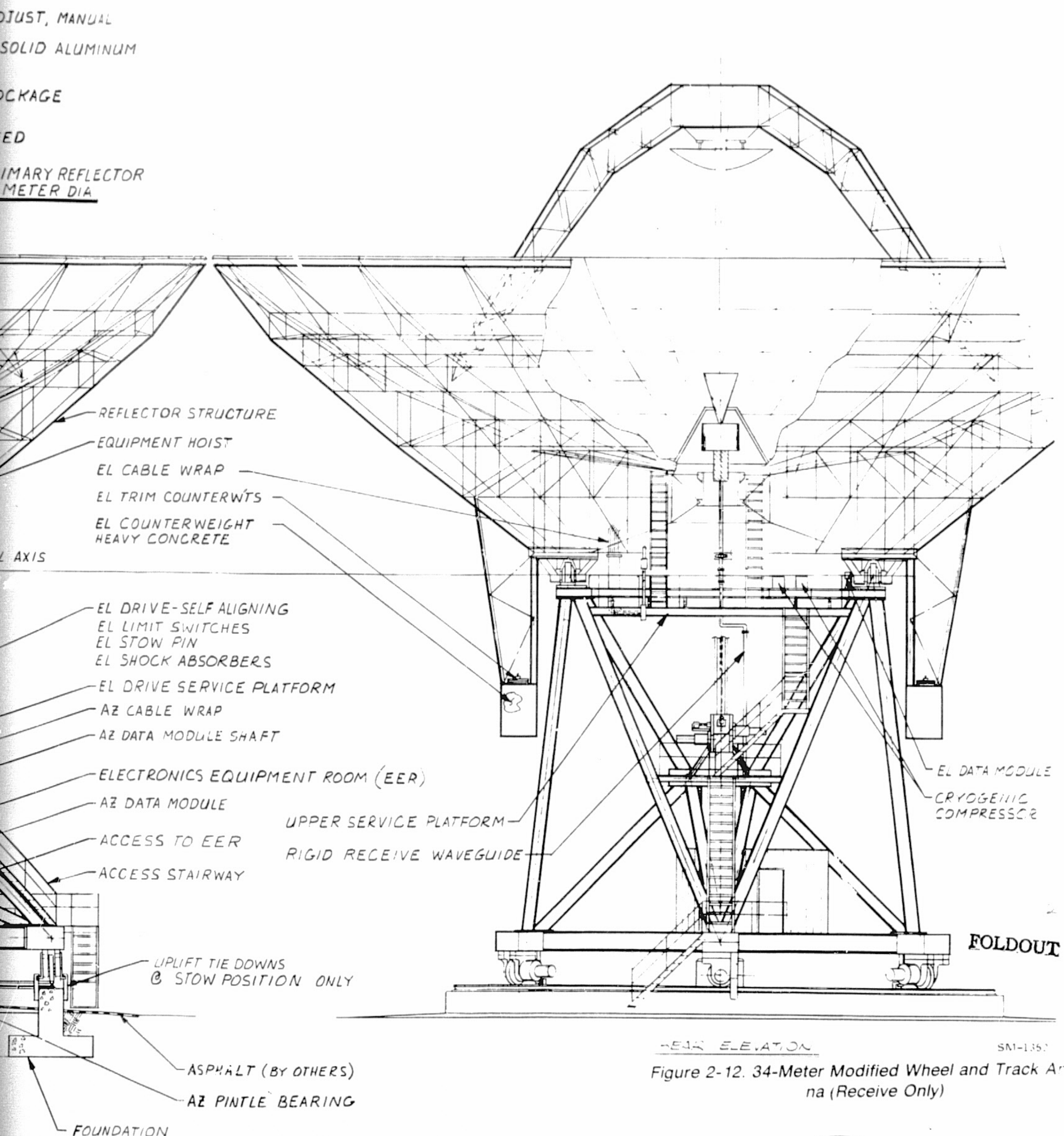

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Figure 2-12. 34-Meter Modified Wheel and Track Antenna (Receive Only)

Table 2-2. 34-Meter Modified Antenna Performance Summary

Type of Antenna	Azimuth-Elevation Wheel and Track
Total Weight of Antenna	620 kip
Reflector Diameter	34 meters
Focal Length of Main Reflector	11.1 meters (approximate)
Type of Main Reflector Panels	Aluminum Skin + Zee Stiffeners
Type of Subreflector Support	Tripod - Trussed Legs
Type of Subreflector	Aluminum Skin
Subreflector Diameter	4 meters
Aperture Efficiency	68.5%
Surface Accuracy (rms) (15° - 90° Elevation)	
– Manufacturing and Alignment	0.026 inch
– Manufacturing + Align + Gravity	0.040 inch
– Manufacturing + Align + Gravity + Wind (20 mi/h mean)	0.045 inch
RF Boresight Performance (One Antenna)	
– Gain X-Band	68.07 dB
– Gain S-Band	56.86 dB
System Temperature °K (Zenith/30° Elevation)	
– X-Band	15.88/19.52 K
– S-Band	18.76/21.66 K
Figure of Merit G/T (One Antenna)	
– X-Band	56.06/57.17 dB/K
– S-Band	44.13/43.50 dB/K
Cable Wrap-up System	
– Azimuth	Maypole Type
– Elevation	Flex Bend
Cable Wrap-up Capacity	
– Azimuth	25 1-inch diameter Cables
– Elevation	40 1-inch diameter Cables
Drive System	Dual Electric Torque Biased
Drive System Power Requirements	60 kVA
Slew Rates	
– Azimuth	0.25°/s
– Elevation	0.25°/s

Acceleration Rates (no wind)	
– Azimuth	$0.25°/s^2$
– Elevation	$0.25°/s^2$
Minimum Tracking Velocity	
– Azimuth	0.001°/s
– Elevation	0.001°/s
Axis Alignment (Orthogonality)	20 arc seconds
System Natural Frequency (Locked Rotor)	
– Azimuth Motion - Reflector @ Zenith	1.6 Hz
– Azimuth Motion - Reflector @ Horizon	1.7 Hz
– Elevation Motion	1.8 Hz
Azimuth Position Readout Type	Inductosyn
– Resolution	21 bits 0.00017°
– Repeatable Errors	+0.00068°
– Nonrepeatable Errors	+0.001°
Elevation Position Readout Type	Inductosyn
– Resolution	0.00017°
– Repeatable Errors	+0.00068°
– Nonrepeatable Errors	+0.001°
Pointing Accuracy	
– 20 mi/h Wind Steady	0.009°
Pointing Accuracy	
– 40 mi/h Wind Steady	0.034°
Drive to Stow (wind)	50 mi/h
Survival at Stow (wind)	100 mi/h
Operational Temperature Range	-18°C to 49°C 0°F to 120°F
Rain	2 inches/hr
Snow	1 ft at Stow
Ice	1/2 inch Radial
Sand and Dust	Wind Carried
Humidity	0 to 100%
Salt Atmosphere	Coastal Environments
Seismic	0.25 g
Travel Range	
– Azimuth	±125°
– Elevation	15° to 90°

2.2.3 Mechanical Assemblies

The elevation stow lock consists of a remotely actuated pin assembly mounted on the adaptive drive assembly. The elevation stow pin engages the elevation wheel. A stow pin aligned switch is provided to assure correct stow pin alignment prior to engagement. The antenna is stowed at zenith.

Two elevation shock absorber units are mounted on the elevation adaptive drive assembly. Strikers are attached on either end of the elevation wheel to mechanically limit elevation travel between 14 degrees and 90.5 degrees. The elevation shock absorbers are capable of absorbing the kinetic energy of the elevation assembly at the full rated elevation velocity of 0.25 degree per second.

Mounted to one alidade corner weldment is the azimuth stow lock which consists of a remotely actuated stow pin assembly that engages a stow pin receptacle mounted on the foundation adjacent to the track. Stow orientation is optional. A stow-aligned switch is provided to assure correct pin alignment prior to remote actuation of the stow pin.

Both azimuth and elevation limit switches are provided. Azimuth travel is ±125 degrees, elevation is 15 degrees to 89.5 degrees prior to actuation of prelimit switches. Final limit switches are set at ±126 degrees in azimuth and 14.5 degrees and 90 degrees in elevation. For ease and accuracy of setting, elevation limit switches are located on an approximate 15 foot radius; azimuth on an approximate 30-foot radius. Prelimit switches provide a servo stop command. Final limit switches deactivate the motors and apply the brakes. A pull connector is provided in azimuth that disconnects all antenna drive power at approximately ±130 degrees.

2.2.4 S-Band Transmit Configuration

The S-band transmit version of the modified antenna (Figure 2-15) is identical in all respects to the receive only antenna except as follows:

- Waveguide rotary joints are mounted at both the azimuth and elevation axes
- EER floor space is increased to 250-square feet
- EER walls are designed for a 5000-pound load

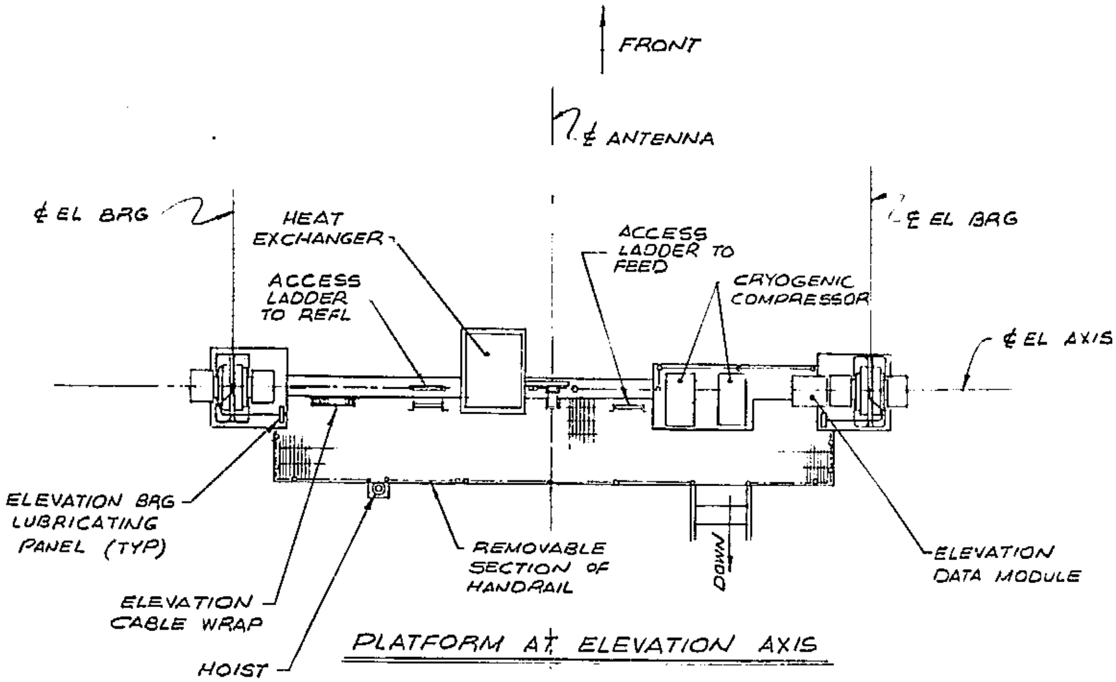
2.2.5 X-Band Transmit Configuration

The X-band transmit version of the modified antenna (Figure 2-16) is identical in all respects to the receive only antenna except as follows:

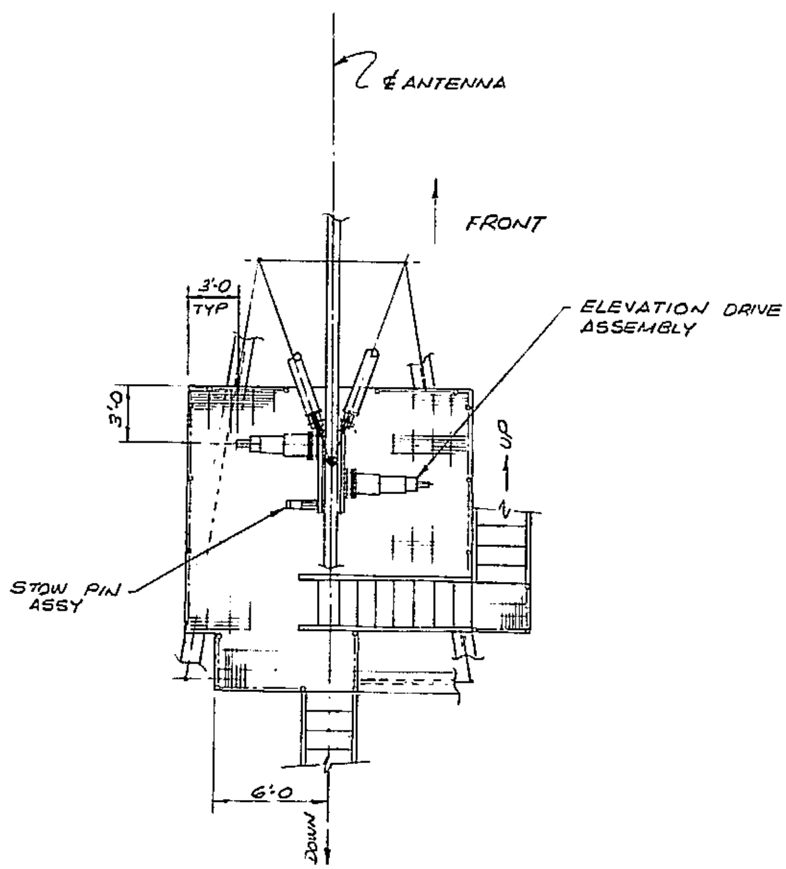
- The reflector center hub is enclosed and enlarged for the high power amplifier
- EER floor space is increased to 250-square feet
- EER walls are designed for a 5000-pound load
- The X-band transmitter heat exchanger is mounted on the upper access platform

2.2.6 Paint

At the fabricator's facility, all parts will be cleaned and one coat of organic zinc rich primer, equivalent to Napko 2Z, will be applied. One coat of white vinyl paint, equivalent to Napko Duravin, will also be applied prior to shipping. In the field, one coat of white vinyl paint equivalent to Duravin will be applied.



PLATFORM AT ℄ ELEVATION AXIS



PLATFORM AT ELEVATION DRIVE

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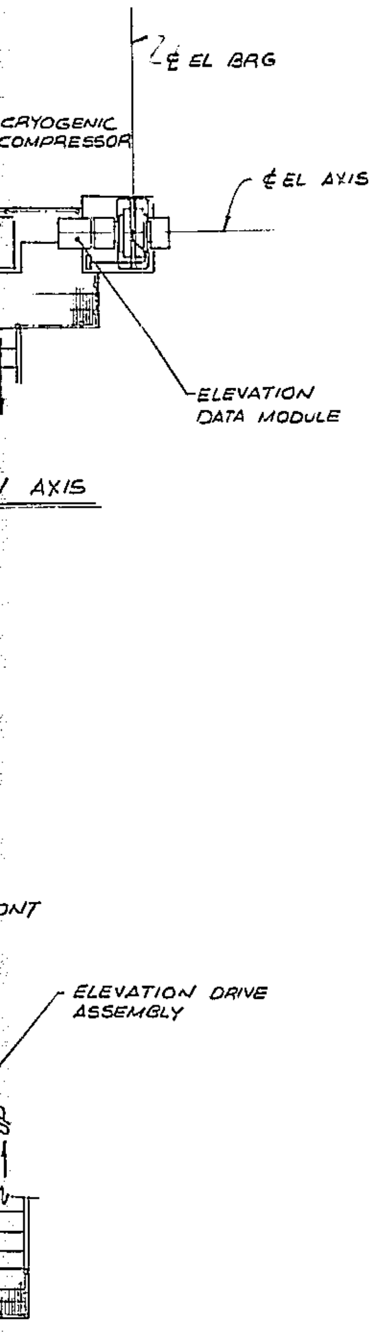

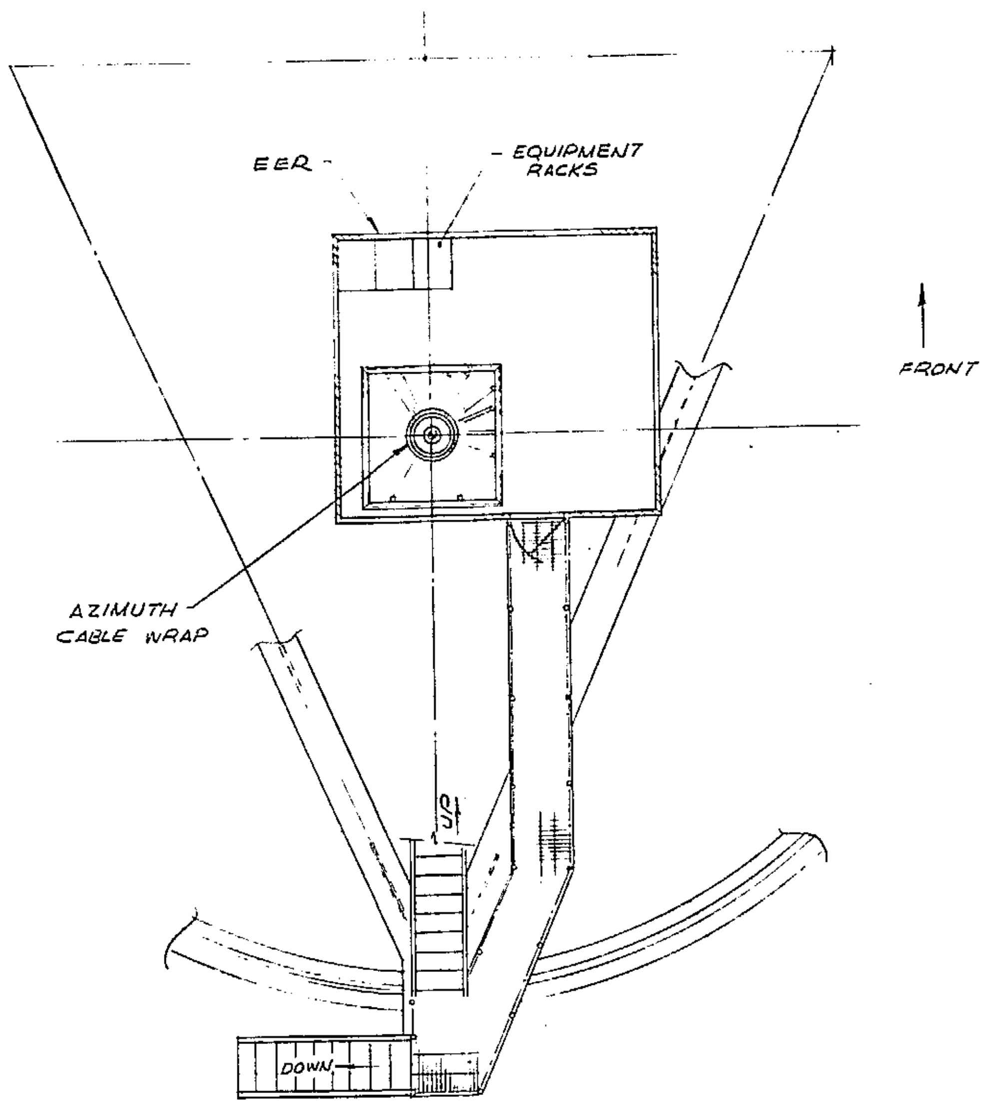

PLATFORM AT AZIMUTH AREA

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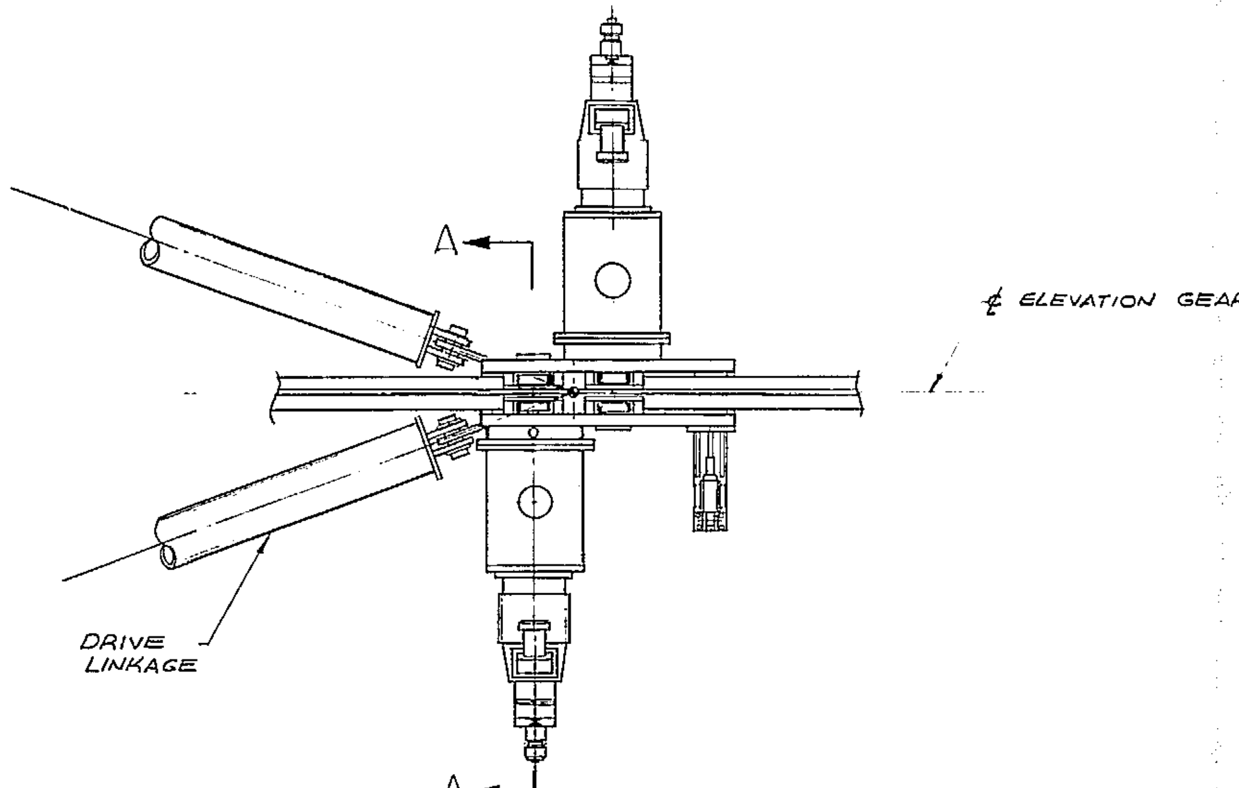
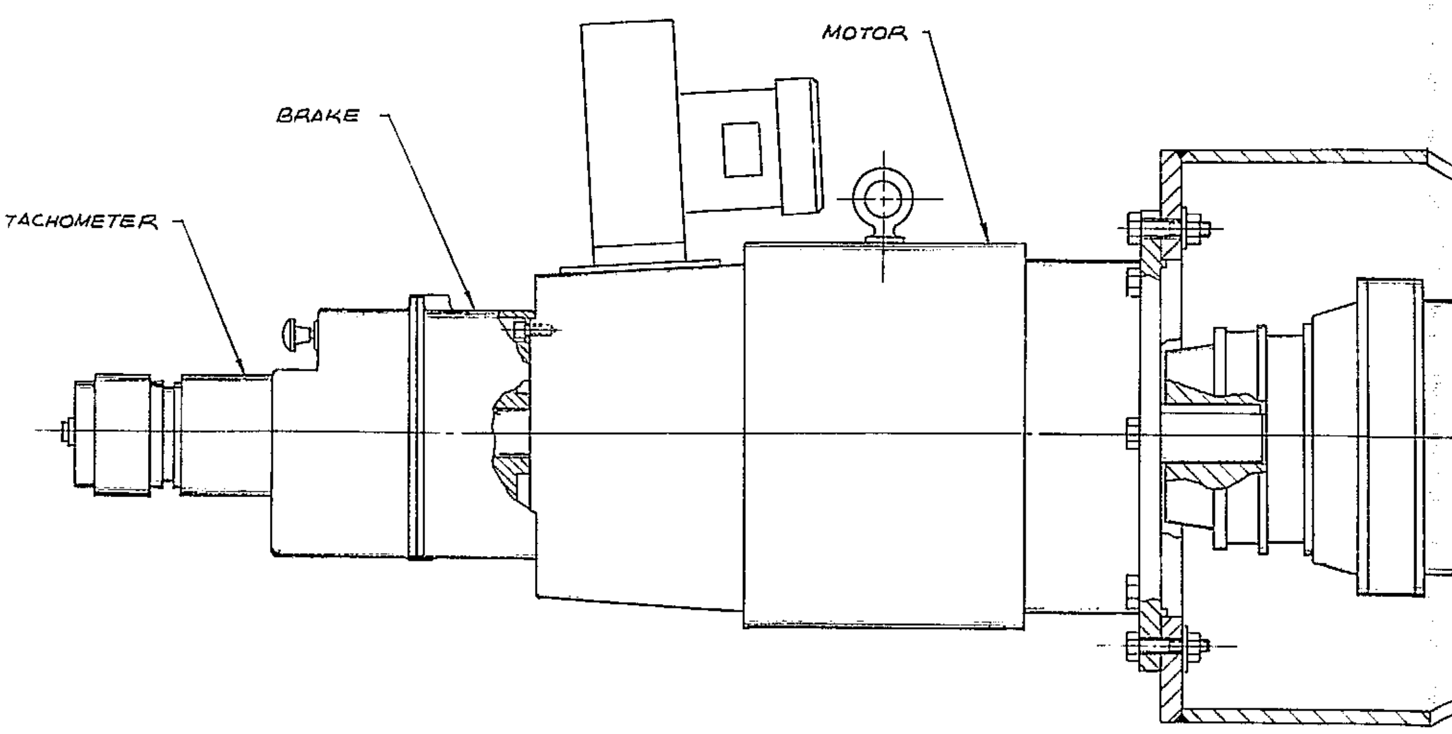
Figure 2-13. 34-Meter Modified Antenna Access Arrangement



PLAN



SECTION A–A

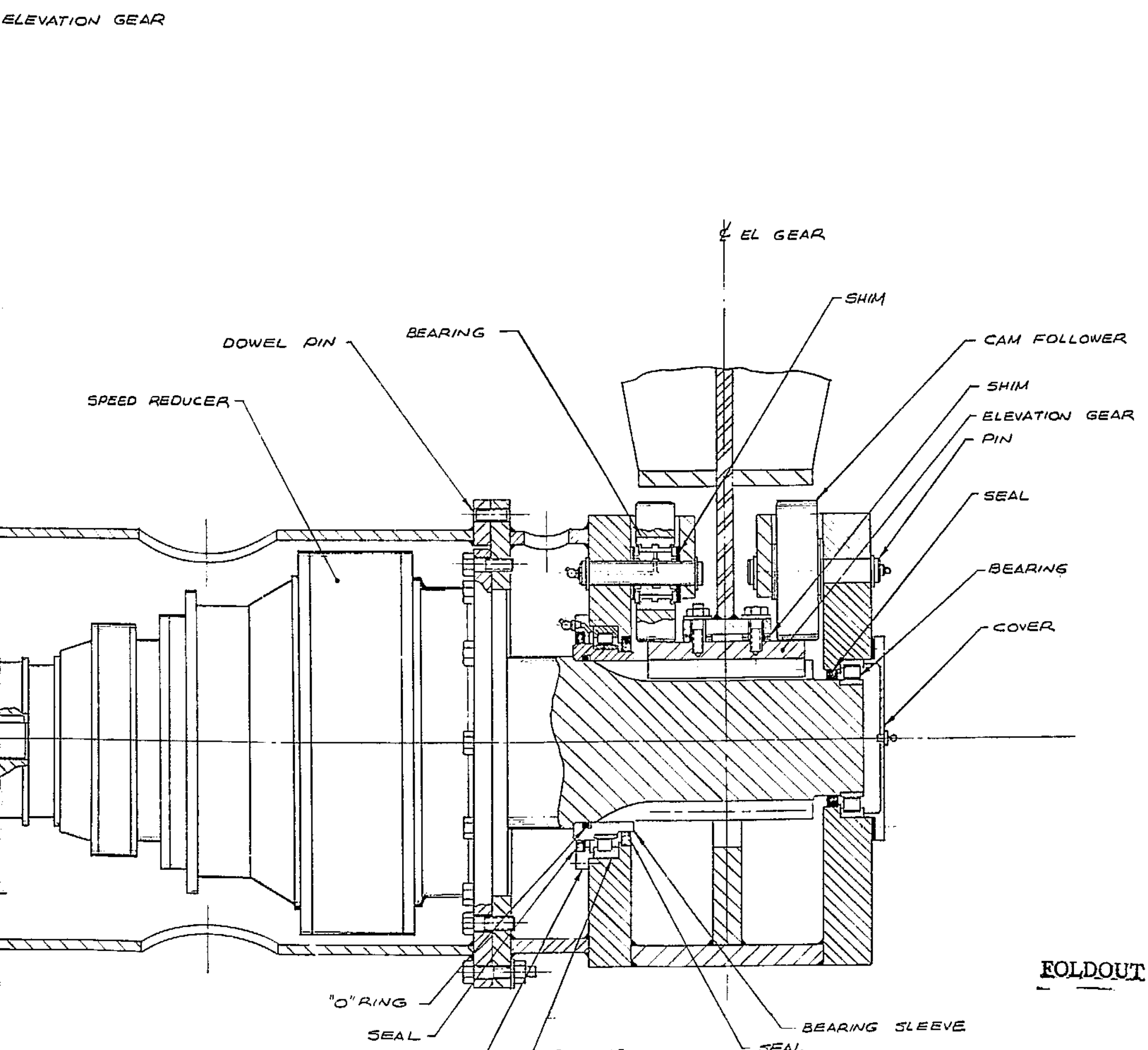


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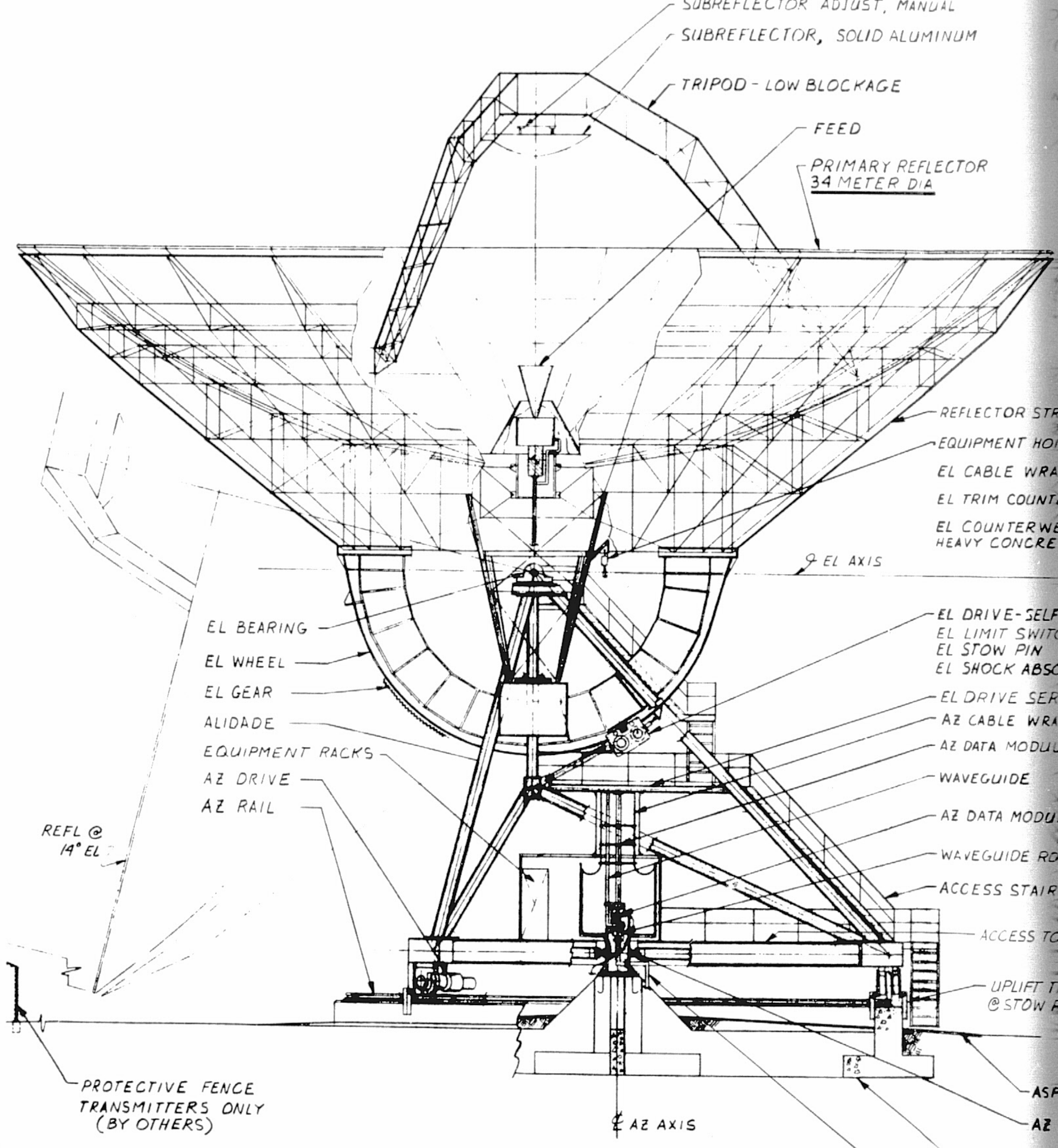
Figure 2-14. 34-Meter Modified Antenna Elevation Drive Configuration



SIDE ELEVATION

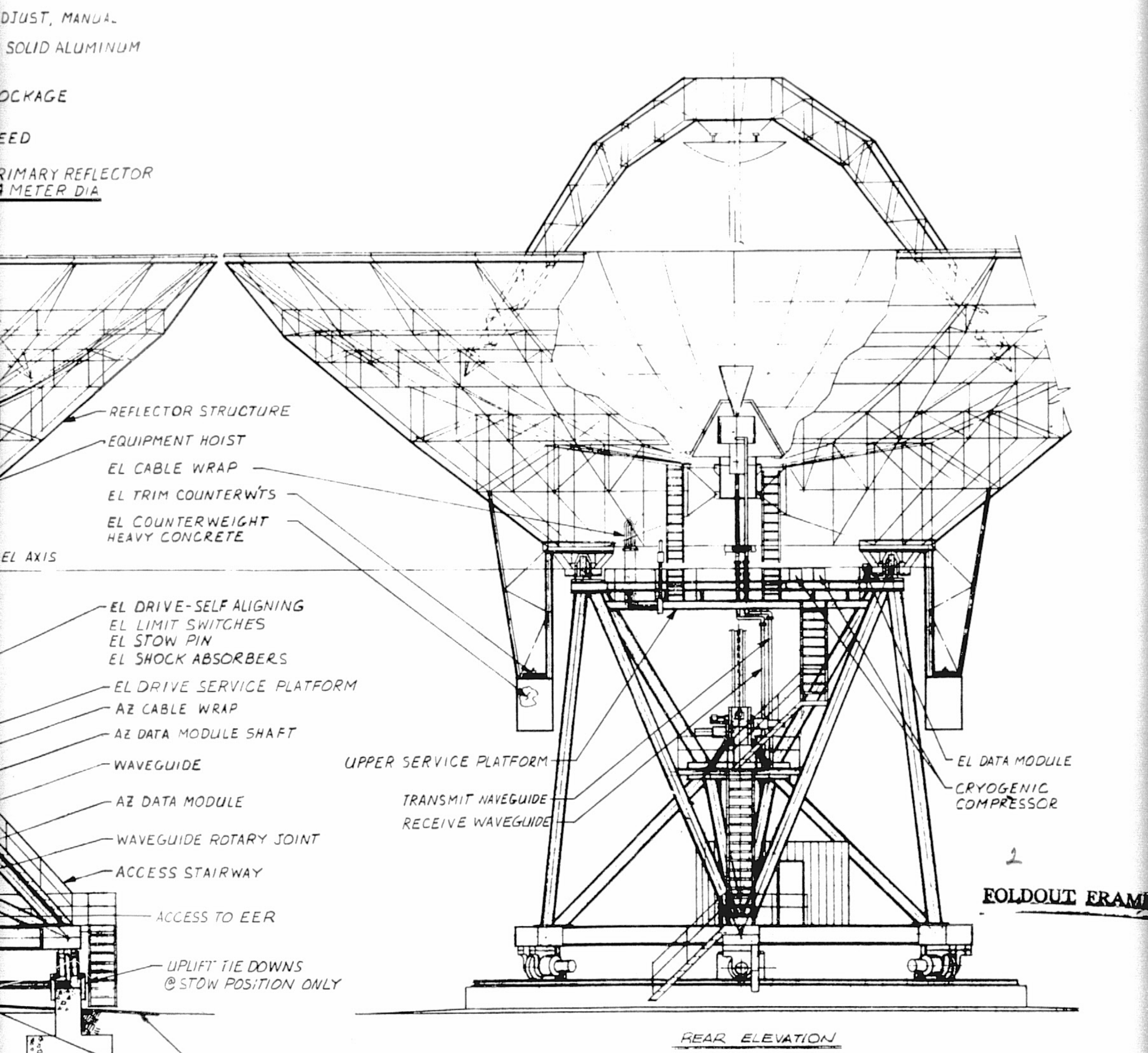


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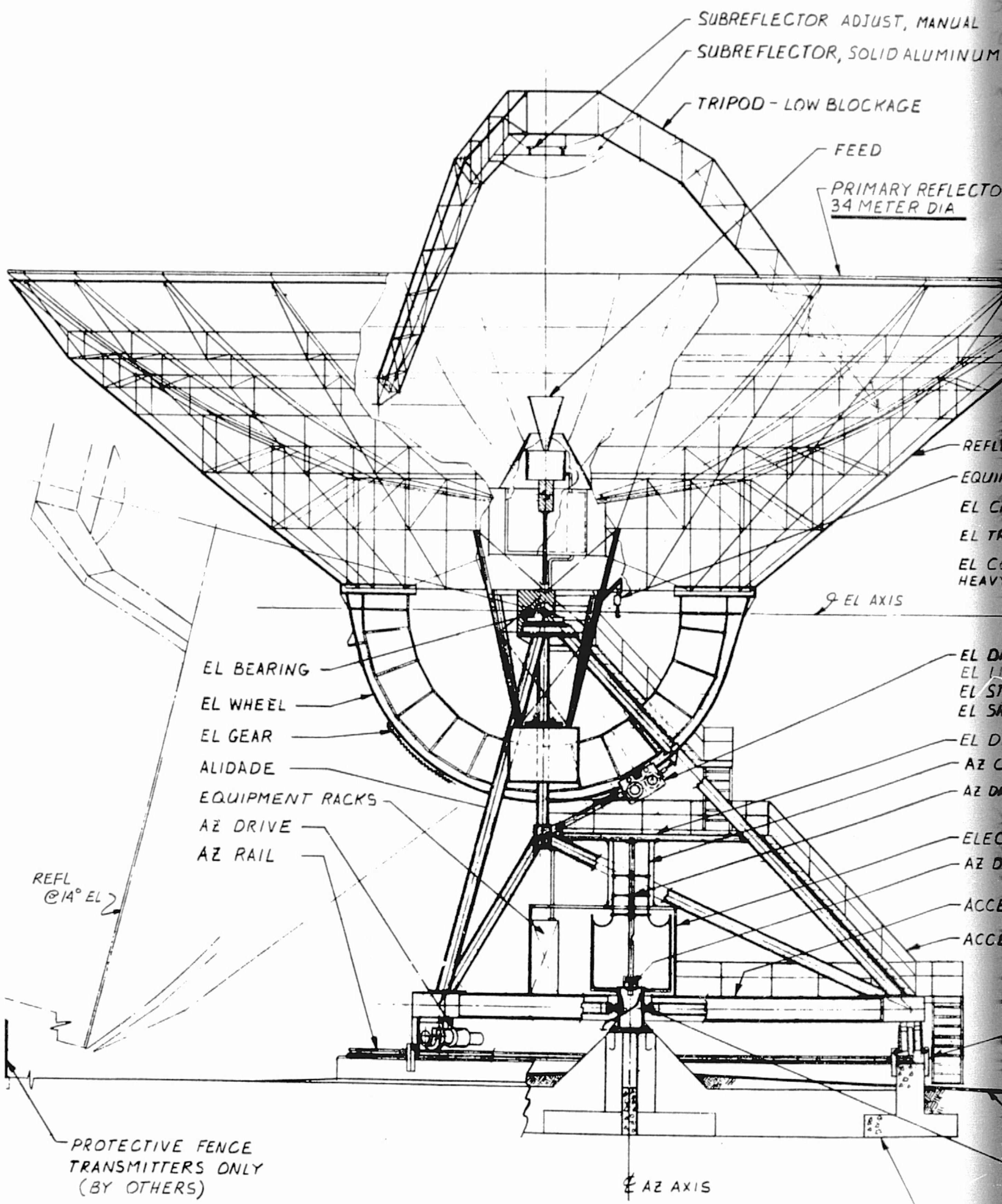
Figure 2-15. 34-Meter Modified Wheel and Track Antenna (S-Band Transmit)



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SIDE ELEVATION

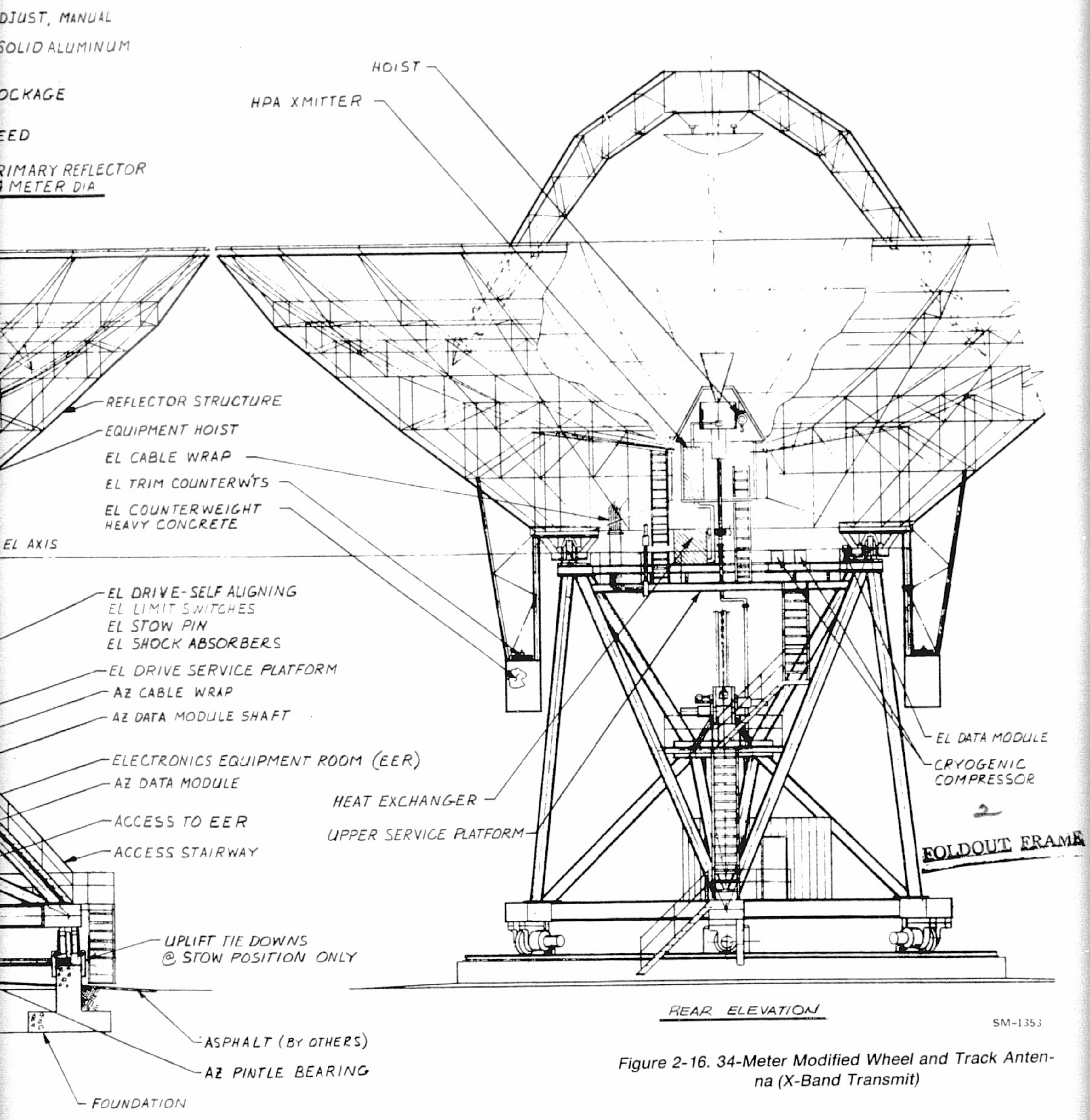

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Figure 2-16. 34-Meter Modified Wheel and Track Antenna (X-Band Transmit)

Ford Aerospace & Communications Corporation

SECTION 3

ANTENNA CONTROL EQUIPMENT

The antenna control equipment is identical for the standard and modified antennas; it consists of four drive motor assemblies (including brakes, blowers and tachometers), drive controllers, a 21-bit encoder system, and a local operator control and status panel.

Each axis utilizes two 10-horsepower dc drive motor assemblies in an aiding/opposing antibacklash configuration. The motors are capable of driving the antenna at 0.25 degree per second in both azimuth and elevation, and forced air cooling of the motors enables continuous operation at stall in maximum operating winds. The fail-safe brakes are applied when power is removed.

One drive cont:oller, consisting of the servo and SCR components, is required per axis. All servo and SCR components for both axes are mounted in a single cabinet located in the EER. The servo controller receives digital commands from the tracking subsystem, converts the digital command words to analog, and utilizes them to drive the antenna. The servo has both velocity and acceleration limits for safety, and features fault isolation equipment. The SCR amplifier is a three-phase, half-wave, phase-controlled, bidirectional amplifier designed for dc shunt motors.

The 21-bit encoder subsystem consists of the encoder, power supply, and position readout panel. Axis angle measurement is accomplished by an inductosyn directly coupled to the axis. This measurement is converted to TTL-compatible BCD within a single electronic chassis. Measurement resolution is 0.00017 degree and nonrepeatable errors are 0.001 degree. An electrical offset is provided for fine alignment. Encoder position is displayed to three decimal places on the encoder position panel in the local control cabinet in the EER.

The local control equipment provides digital and slew position controls, status lights for limit switches, and fault isolation status lights. Local control is primarily for maintenance functions. The antenna is commanded from the control center during normal operation.

Four operational modes are provided: standby, manual, slew, and program. In the standby mode, low level electronics are energized, drive power is off, and axis brakes are applied. In the manual mode, the local digital position control loop is enabled at the local control panel. In the slew mode, proportional bidirectional slew control is enabled. In the program mode, local control is disabled and the antenna is controlled by digital position commands from the site control center. Digital switches are provided on the local control panel for digital position commands. A slew control is provided for each axis. Status lights include antenna mode indicators, limit switch status, and drive controller summary fault status.

The antenna control system includes elements required for automatic and manual control of the antenna main-beam steering axes (azimuth and elevation). Tracking is achieved by providing a computer derived digital command word to the antenna. The major elements of this system are as follows:

a. Antenna drive components
b. Drive controller
c. Motor drive amplifiers
d. Antenna position readout
e. Local operator control and status panel

Functional operation of the antenna control system is as shown in the block diagram, Figure 3-1.

3.1 ANTENNA DRIVE SYSTEM

The electric drive system proposed is the result of evolutionary improvements to the drive system originally designed in 1966 for the 90-foot Telespazio antenna and modified for use on terminals for USASCA where it exceeds its 1,000-hour MTBF design goal many times over, achieving nearly a 12,000-hour MTBF. The electric drive utilizes a torque aiding/opposing dual dc motor system. The input to the drive system is an analog velocity command signal, which is normally a D/A conversion of a digital command word from computer control and tracking equipment.

Shown graphically in Figure 3-2, the aiding/opposing drive configuration is achieved by equal and opposite dc bias commands to the individual motor torque loops. Aiding/opposing drive is made possible by closedloop torque control and has the following advantages:

a. Provides antibacklash operation of overall drive system

SINGLE AXIS FUNCTIONAL BLOCK DIAGRAM

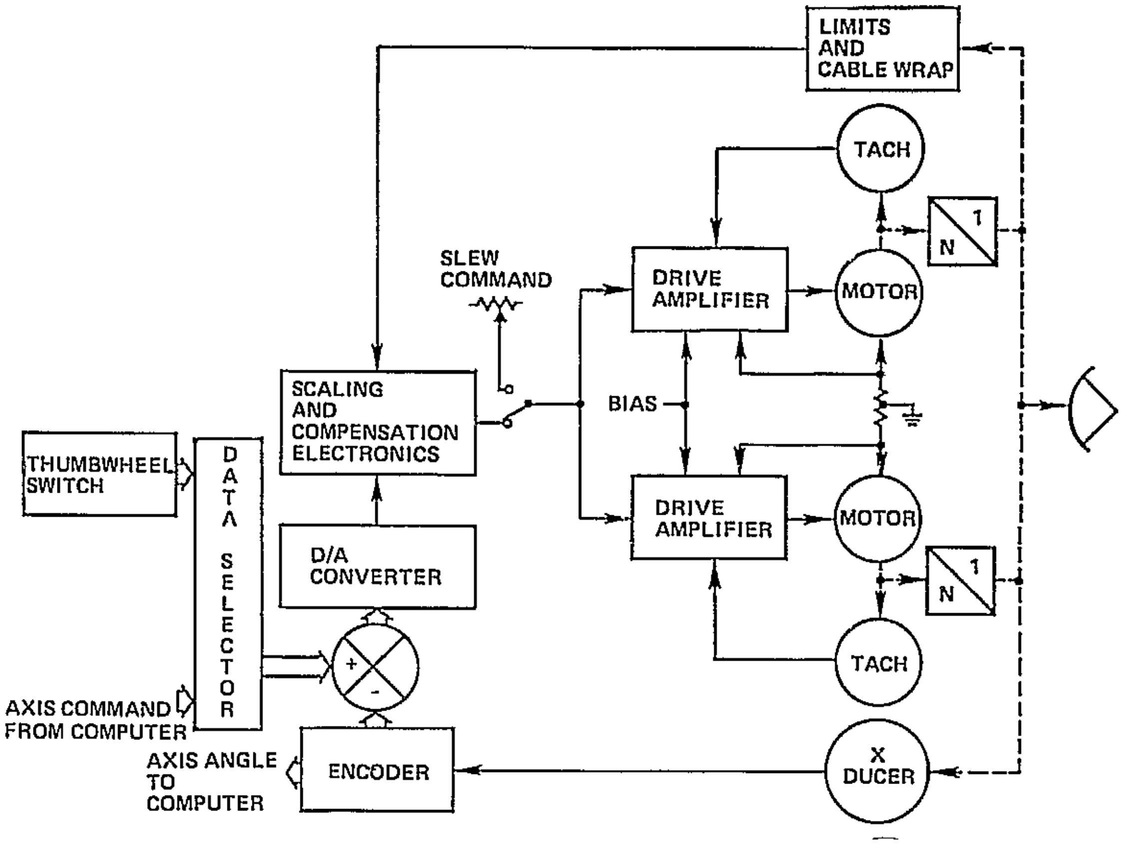

Figure 3-1. Single Axis Antenna Control System Functional Block Diagram

b. Prevents limit cycle oscillation due to backlash nonlinearity without sacrificing system performance

c. Reduces individual gear tooth loading, thereby reducing the size of gear teeth required

The antenna drive motors have the following features:

a. **10 hp, totally enclosed, air over (TEAO)**
b. 1750 r/min
c. 240 V dc field
d. 240 V dc armature
e. Air over blower assembly (1/3 hp, 3-phase, 480-V motor, totally enclosed)
f. 5 BC 42 tachometer, totally enclosed
g. D flange mount
h. Conduit junction box containing rfi filters and electrical terminal boards.
i. Thermostat
j. Special paint

The motor is designed to operate with 250% overload for one (1) minute up to 15,000 ft. But ambient at maximum altitude is restricted to 10 degrees centigrade.

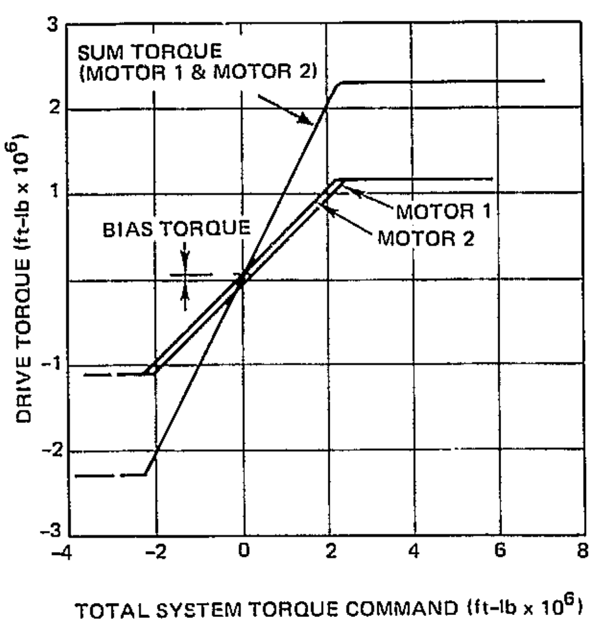

Figure 3-2. Two-Motor Aiding/Opposing Drive System Command-Output Torque Relationship

Table 3-1 summarizes antenna drive horsepower requirements for the standard and modified antennas, respectively. The horsepower required for tracking in 40 mi/h winds is calculateu for both the azimuth and elevation axes.

It can be seen that drive to stow requirements at the full rated velocity of 0.25 degrees per second in each axis establishes the horsepower needed. Assuming a net gearing and aiding/opposing bias efficiency of 40%, the available horsepower on each axis is 60% of the two 10-horsepower motors or 12 horsepower. The maximum horsepower required is 5.9 horsepower for the standard antenna and 8.5 horsepower for the modified antenna; hence, both motors are conservatively rated and will provide a long, reliable life.

The drive controller was designed to meet the 1,000-hour MTBF requirements of the Heavy Terminal (AN/FSC-78) program for the U.S. Army and has exceeded that requirement many times over. Design of the drive controller expresses WDL's consideration for maintenance and repair should any component become inoperative. With exception of the inductors, all major components are modular and may be readily replaced. The SCR modules have been removed and replaced during production test in less than 15 minutes using common tools. Spare fuses have been incorporated into the drive controller in consideration of MTTR requirements.

3.2 DRIVE CONTROLLER

The drive controller for each axis consists of a torque loop, bias circuitry, and a velocity loop. The torque developed by each motor is sensed by measuring the voltage drop across a shunt in the motor armature circuit. Since the developed torque is proportional to motor current, this voltage drop can be used to implement feedback control of torque output. The motor current signal is fed back and compared to the command, and any resulting torque error signal is integrated and supplied to the SCR power amplifier controller. The torque loop is a high-gain, Type 0 system, which provides a fast-response, wide bandwidth driving plant.

To provide the torque aiding/opposing configuration, the torque command to one motor circuit is positively biased while the torque command to the other motor circuit is negatively biased with equal magnitude. Utilization of closed-loop torque control enables the bandwidth inherent in the motors to be increased significantly.

The velocity control loop, which is closed around the torque loop, provides accurate velocity control. Velocity, sensed by precision tachometers on each of the motors, is fed back and compared with the velocity command signal to produce a velocity error signal; the velocity error signal is the torque loop command The type 2 velocity loop exhibits minimum steady-state wind torques. An additional loop which nulls the difference of the two motor velocities is also incorporated. This loop serves to eliminate the problem of drive system resonances encountered in high-gear-ratio systems. The basic WDL rate loop design has a closed-loop bandwidth of 2 Hz and an open-loop dc gain of $100/\text{sec}^2$ with a phase margin of 45 degrees and a gain margin in excess of 9 dB.

The drive controller (Figure 3-3) components are enclosed in a single rfi-tight NEMA 12 cabinet measuring 24 inches deep x 36 inches wide x 90 inches high, weighing approximately 1800 pounds. The cabinet has full-access, key-lockable doors both front and rear. The rear door is interlocked to the power distribution center 480-V contactor and to the controller cabinet 120-V relay to provide personnel safety. The interlock can be overridden to allow work on the unit and resets upon closing the rear door. There are no high voltages (greater than 29 V dc) exposed inside the controller front door. The cabinet is cadmium plated and fully rfi gasketed with rfi door clamps. All input/output conduit and connectors are on top of the controller. The front door contains an emergency stop switch, local/remote key switch, and remote control connector. The drive controller components are described in the following paragraphs.

Power Control Panel

The motor control panel mounts the power supplies required for the servo electronics and SCR gates. Also included are the field power supplies and associated fuses, including the standby field supply, field loss sensing resistors, circuit breaker for power supplies, ac convenience outlet, and 120-V ac safety interlock relay. Terminal strips on the front of the panel are for low level signals, while those on back are for high voltage signals.

Motor Control Panels

Two motor control panels provide complete power control; one panel for each axis. The two dc motors for each axis are arranged in a torque-aiding configuration with a bias opposing torque for anti-backlash control. A single, easily removable, PC card is mounted on the front of the panel; this card contains all required electronics, test points, and

Table 3-1. Axis Horsepower Requirements.

Parameter	30 Meter	34 Meter
Track in 40 mi/h winds		
• Elevation:	$\frac{520 \times 10^3 \times 0.0055}{6 \times 5250} = 0.10$ hp	$\frac{740 \times 10^3 \times 0.0055}{6 \times 525\text{[illegible]}} = 0.14$ hp
• Azimuth:	$\frac{640 \times 10^3 \times 0.21}{6 \times 5250} = 4.3$ hp	$\frac{890 \times 10^3 \times 0.\text{[illegible]}1}{6 \times 5250} = 6.0$ hp
Stow in 50 mi/h winds		
• Elevation:	$\frac{810 \times 10^3 \times 180^\circ/12\ \text{min}}{360 \times 5250} = 5.9$ hp	$\frac{1160 \times 10^3 \times 180^\circ/12\ \text{min}}{360 \times 5250} = 8.5$ hp
• Azimuth:	N/A	N/A
Drive Motor Rating		
• Gearing efficiency	60%	60%
• Motor rating	10 hp each motor	10 hp each motor
• Available rated horsepower	(2 motors X 60%) 12 hp	12 hp

fault monitoring LED's for convenient inspection and troubleshooting. Also included are the timing reference transformer, associated fuses, and terminal strips for all low level signal interfaces. Six SCR bridges, motor thermal overload relays, and motor current sensing shunts are mounted on the back of the panel. The SCR bridges include a gate firing module, snubber protective circuitry, and overvoltage protectors. Each bridge is easily removable as a unit for any required maintenance or replacement.

Armature Inductors

The armature inductors mount to the bottom of the enclosure behind a safety panel. One inductor is used for each motor and consists of a dual section, connected between the positive and negative SCR bridge. The resultant circulating currents provide linear torque loop gain through zero motor current. The choke also improves the form factor of the dc current.

Power Line RFI Filter

The power line rfi filter consists of three sections plus neutral. Each section is a double L-C filter with the inductor on the output to prevent di/dt damage to the SCR's. In addition, the three filters have line-to-line capacitors which attenuate the majority of noise due to SCR line commutation. The filter is mounted on the top of the enclosure and includes an rfi-tight compartment for input terminations.

3.3 MOTOR DRIVE AMPLIFIERS

The motor drive power amplifiers consist of a 3-phase, half-wave, bidirectional choke-isolated SCR bridge with continuous conduction at null to provide linear zero speed control of the drive motor. The timing signals for the SCR gates are line-derived cosines which provide linear speed control over the entire range of firing angles, both motoring and regenerating.

The torque command to one bridge of each axis is inverted so that when one bridge is positive in output, the other bridge is negative in output. Since the torque commands to both motors are equal and opposite, the ac power line sees the equivalent load of a full wave bridge with no dc component. Furthermore, the main core-type 3-phase transformer will handle the dc component if a single motor per axis is used.

3.4 ANTENNA POSITION READOUT

Pointing angles of each axis are provided by the antenna position readout equipment. This equipment comprises 21-bit on-axis transducers and in-

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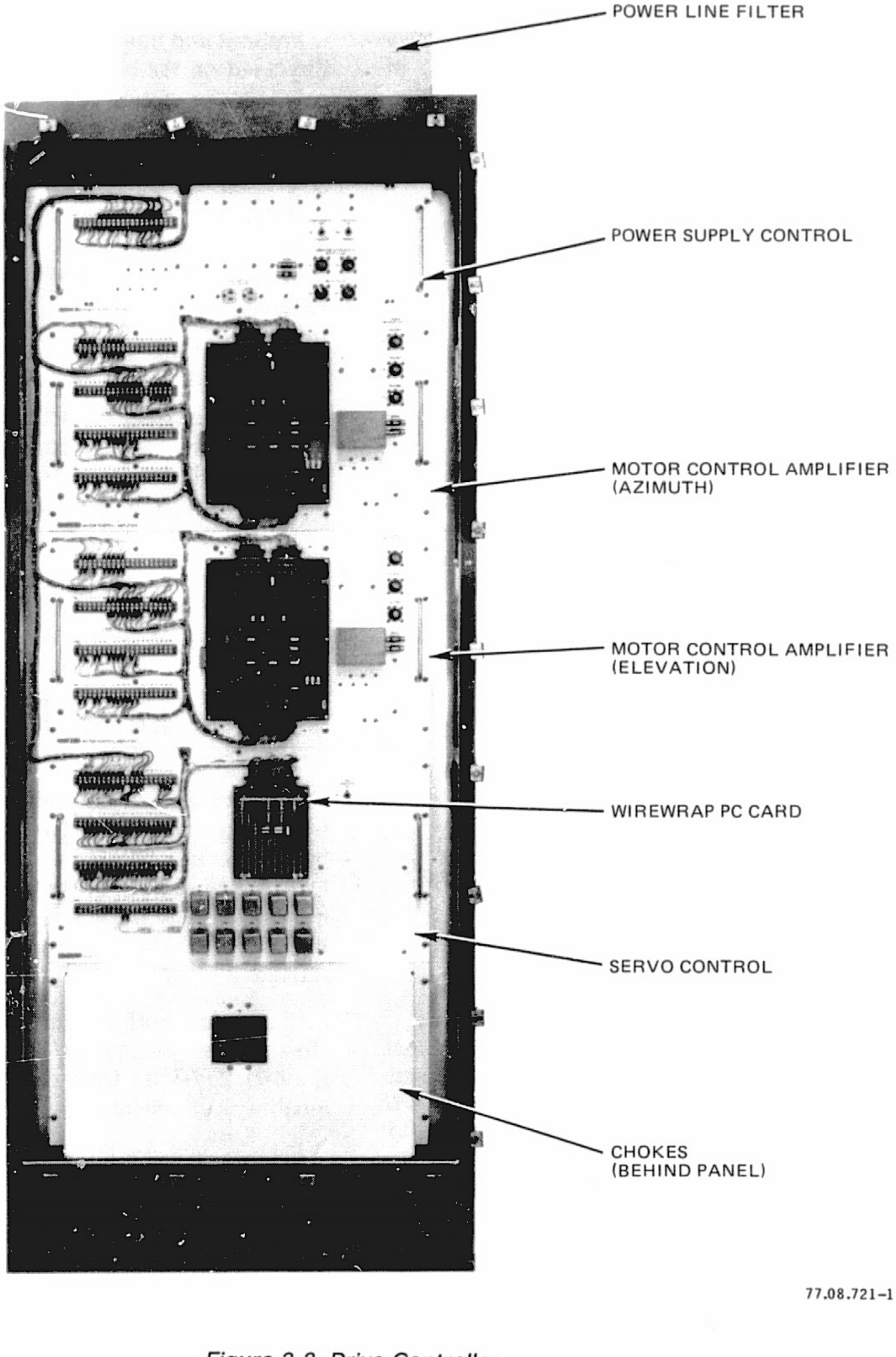

Figure 3-3. Drive Controller

terconnecting cabling to the EER for each axis. Each transducer consists of a single-speed and multispeed precision resolver within a single sealed enclosure directly coupled to the antenna axis without the use of intermediate gearing. The converter chassis contains solid state resolver-to-digital conversion electronics, and provides a decimal numeric display of each axis position to an absolute accuracy of 0.001 degree. The readouts are six-decimal digital with 0.001 degree resolution. The encoder operates on internally generated 400 and 1200 Hz carriers that serve as the single-speed and multispeed resolver reference signals. The azimuth and elevation conversions are multiplexed and provide drive to the displays at an update rate of 500 per second. The encoder provides an angular output in both axes with a resolution of 21 binary bits in TTL compatible BCD. The encoder is a proven design of which many similar units have been reliably utilized by WDL on numerous earth stations over the past years.

3.5 LOCAL OPERATOR CONTROL AND STATUS PANELS

Local operator control and status panels are provided on each antenna: in the SCR control cabinet on the standard antenna, and in the EER on the modified antenna. The local control provides a panel enable switch which may not be overridden at the central control console. The panels have the following controls and displays:

- Panel Enable Control
- Off Control
- Standby Control
- Manual Control
- Slew Control
- Stow Pin Control
- Prelimit Display (each axis)
- Final Limit Display (each axis)
- Summary Fault Display (each axis)

The *panel enable* switch activates the local control panel and provides an antenna maintenance status indication to the array central control console. *Off* deenergizes the servo and drive subsystem. *Standby* energizes low level electronics but the drives are deenergized and brakes are set; this is an interim mode prior to entering one of the operational modes. *Manual* enables the digital switch position command and allows the antenna to be driven to a specific azimuth and elevation angle. *Slew* enables the slew potentiometers and allows the antenna to be slewed at a rate proportional to the setting of the slew control.

Stow pin controls are included for each axis. The azimuth and elevation axis stow pin controls are interlocked such that the pin cannot be inserted unless the axis is at the stow position. When aligned, the *Stow Pin Aligned* indicator will be illuminated.

Prelimit and final limit indicators for each axis are displayed on the control panel. When a prelimit is reached, the motion of the antenna is restricted in the direction of the prelimit; however, motion in the opposite direction is permitted. When a final limit is reached, the brakes are applied and the drives are deenergized. The final limit can only be reached as a result of a fault condition, and hence it is desirable to require handcranking to remove the antenna from the final limit zone.

3.6 PROTECTIVE CIRCUITRY AND INTERLOCKS

Protective circuitry includes phase reversal and phase loss protection, electronic power supply sensing, and field loss sensing. If loss of a bridge fuse occurs, the current limit is reduced, allowing continued, but degraded operation.

Fault status indications are provided for bridge fuses, field loss, phase reversal or loss, motor overload, and power supply loss. These indications are individually displayed on the amplifier PC card. Fault status is also summed for isolated contact closure remote status and for display on the local control panel.

Interlock circuitry is used to ensure that the SCR bridges are not gated "on" unless the axis drive brakes are fully released and all other required interlocks are closed. All integrators are fully caged during the standby mode and whenever interlocks are broken, for circuit protection and to ensure a smooth startup.

In addition, both the emergency off interlock circitry and the console on/off command disconnects the 480/277-V ac from the controller cabinet and auxiliary equipment.

Each drive motor is protected with a thermal overload relay. Actuation of an overload relay only shuts down the affected motor and allows continued drive operation at degraded performance levels in emergencies.

Short circuit and instantaneous overcurrent protection is provided by semiconductor-type fuses on each bridge input.

In addition to the above safety interlocks and protective circuitry, the following safety features apply to the SCR drive control electronics.

a. *Current Limit.* The current limit is set by fixed electronic limits sized to the motor and load. Fixed limits preclude the possibility of equipment damage by misadjustment.

b. *Field Supplies.* The field supplies for each axis provide automatic operation at 100-V dc whenever the 277-V ac is turned off. This ensures that the drive motors are continuously warm without excessive field dissipation. Drive motor field current is individually sensed and statused on the PC board.

c. *Analog Control Input.* The analog control input to the controller is buffered by a differential input operational amplifier to prevent ground loops between equipment or from the central control console. Any velocity command will be acceleration and velocity limited by electronics on the servo control PC board.

d. *RFI Filtering.* The majority of rfi noise generated by the SCR amplifier is due to SCR line-to-line comutation currents. The magnitude of this noise is directly proportional to the motor dc current, that is, the most noise is generated at the high currents associated with acceleration and deceleration and very little noise is generated during steady state tracking. Since the majority of noise is associated with the power line, filters are provided to effectively eliminate rfi interference. The steel controller cabinet provided has an rfi gasket which provides effective attenuation of any radiated rfi. Conduit and shielded cables are used for all control and status signals and have proven effective in noise control. Since the reliability of signal level rfi filters is low, rfi filters are not used.

SECTION 4

ANTENNA MECHANICAL AND ELECTRICAL FURNISHINGS

The miscellaneous mechanical furnishing items, safety equipment, power distribution subsystems, cable wraps, and equipment locations are generally identical for both the standard 30-meter antenna and the 34-meter modified antenna; The equipment layouts and cable routings are slightly different for the receive only, S-band transmit, and X-band transmit configurations on both types of antennas. This section describes these furnishings.

4.1 MAJOR FURNISHINGS

The following is a listing of the major antenna furnishings:

- Elevation stow pin actuator
- Azimuth stow pin actuator
- Azimuth limit switches
- Elevation limit switches
- Emergency stop switches
- Reflector hatch interlock switch
- Azimuth and elevation stow-aligned switches.
- Elevation axis travel limit shock absorbers
- Emergency lights
- Fire detector
- Technical grounding
- EER lighting
- Equipment hoist
- Personnel warning switch

4.1.1 Stow Pin Actuators

Azimuth and elevation axes are equipped with remotely operated stow locks for use when high winds are anticipated. The stow pin is designed to survive 120 mi/h wind loads, and is actuated by an electric linear actuator assembly consisting of motor, brake, speed reducer, screw actuator, travel limit switches, and a manual crank to insert or remove the stow pin when electric power is not available. The elevation and azimuth stow pin assemblies are mounted on the alidade structure. They engage receivers on the elevation wheel and the azimuth track respectively.

4.1.2 Limit Switches

Limit switches are provided for both azimuth and elevation. Both the azimuth and elevation axes have prelimit and final limit switches. The prelimit switches give motors a servo stop command, and the final limit switches remove drive power and apply the brakes. The elevation final limit switches are set to operate just prior to shock absorber action.

4.1.3 Emergency/Safety Stop Switches

Emergency and safety stop switch units are provided at each axis drive area and at other critical points so that the antenna drive system may be disabled by pressing an emergency button.

4.1.4 Reflector Hatch Interlock

The hatch in the reflector access panel is interlocked to prevent operation of axis drives when the hatch is open.

4.1.5 Stow-Aligned Switches

An electrical interlock switch is provided to prevent stow pin actuation when the antenna is not in the stow position. A springset, electrical-release brake is also provided on the stow pin actuator to assure that the stow pin does not move when actuator power is off.

4.1.6 Elevation Shock Absorbers

The elevation axis is equipped with shock absorbers at each extreme limit of travel. The shock absorbers are mounted on the alidade structure and are engaged by strikers attached at either end of travel on the elevation wheel (14° and 90.5°). These shock absorbers are capable of absorbing the kinetic energy of the rotating assemblies when impacted at 0.25°/s without damaging the antenna structure or related components.

4.1.7 Emergency Lights

Battery operated emergency lights in the EER provide automatic illumination in the event of a utility power failure.

4.1.8 Fire Detector

A fire detector which can be connected to the station fire alarm system is provided in the EER .

4.1.9 Technical Ground

An insulated technical ground cable is provided to the EER for use with critical electronic equipment. This ground is connected to the station grounding system at the antenna base.

4.1.10 Electronic Equipment Room Lighting

The EER equipment area is illuminated to a nearly uniform lighting intensity of 50 foot-candles (measured at a level 30 inches above the floor) by means of wall switch controlled fluorescent lighting fixtures. Access areas of the antenna base will be illuminated to 30 foot-candles.

4.1.11 Equipment Hoist

An electric hoist having a lift capacity of 1,000 pounds and a 50-foot lift capability is provided to assist in moving technical equipment to and from the EER.

4.1.12 Personnel Warning Switch

A personnel warning switch provides a display panel indication of personnel on the antenna.

4.2 ANTENNA POWER DISTRIBUTION

Each antenna is provided with two separate power distribution systems, the technical power distribution system and the utility power distribution system.

4.2.1 Technical Power Distribution System

The technical power distribution system is designed to supply an estimated 14 kVA to critical communications loads consisting of the low noise amplifiers and associated cryogenics, rain deflection blower, polarization drive, and receptacle outlets for general purpose communications test equipment. This system derives power from the ac power supply at the antenna base, and it consists of: a feeder from the splice point in the antenna base to the distribution panelboard, and branch circuit wiring to the designated technical equipment.

4.2.2 Utility Power Distribution System

The utility power distribution system is designed to supply 76.0 kVA to noncritical communications loads consisting of the antenna drive controllers, equipment hoist, antenna base lights and receptacles, EER lights and receptacles, and stairway lights.

The system consists of two power distribution panelboards, two lighting panelboards, a 15 kVA dry type transformer, interconnecting feeders, and branch circuit wiring. This system derives power from a 480/277-volt feeder provided to the antenna base by JPL.

4.3 CABLE WRAP

Two types of cable wrap are utilized; a loop type in elevation and a Maypole design in azimuth. Because of the limited elevation motion, a simple loop of cables is made to provide the needed motion of 15 to 90 degrees. A Maypole design is used in azimuth for plus or minus 125 degree motion. A series of tests performed at WDL indicated bending of cables over large radii caused no cable deterioration; however, twisting of cables caused an immediate deterioration of the VSWR which became worse with the number of twist cycles. The deterioration was caused by failure of outer shields. Therefore, the Maypole cable wrap was conceived to eliminate all detrimental cable twisting actions. In the Maypole, cables are supported from the top and cable support down the length of the azimuth cable wrap is achieved with rings as shown in Figure 4-1. A cable loop is left at the bottom of the cable wrap. As the antenna turns, the rings control cable bending; most of the cable flexure is taken by the lower loop which is shortened as azimuth motion is increased. The Maypole design allows very little torsional twist of cables, thereby protecting cable shields.

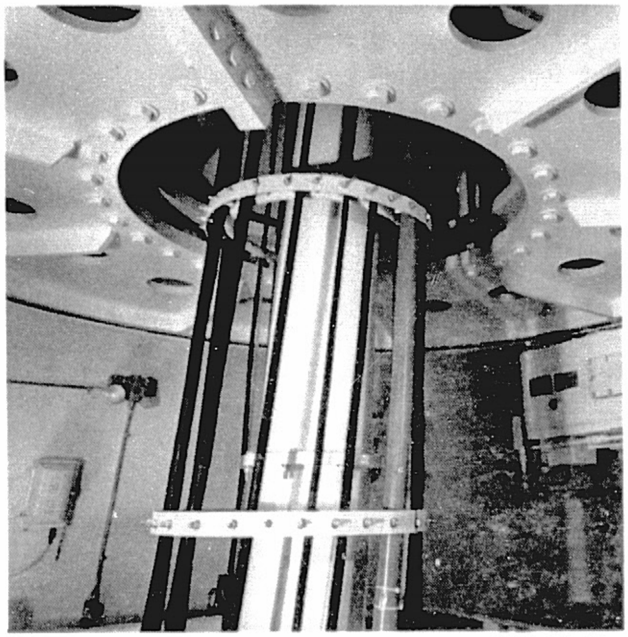

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Figure 4-1. Maypole Type Cable Wrap Assembly

Allowance for 25 one-inch cables has been made in the azimuth axis cable wrap and 40 one-inch cables in the elevation cable wrap. The S-band transmit line crosses the azimuth axis through a waveguide rotary joint.

4.4 EQUIPMENT LOCATION

The Maser subsystem is supplied by JPL and installed within the feed cone. The elevated equipment room houses the receiving system and associated amplifier and cryogenic control panels. Space for cryogenic compressors and adsorber filters is provided on the upper EER landing in both the standard and modified antennas.

The equipment arrangement is shown in Figure 4-2. The feed extends from the feed cone into the reflector hub. Dual masers are attached to the feed assembly and located in the feed cone. The maser power supplies are mounted adjacent to the masers in the feed cone. Electronic and cryogenic lines cross the elevation axis and are routed within the EER in a floor-mounted duct.

The LNA compressors and their associated adsorbers are mounted on the antenna access grating near the EER. Installation and removal of the compressors is made by the use of a small davit-mounted hoist above the EER access grating outside the EER room. The use of an externally mounted cryogenic compressor has two advantages; reduction of noise levels in the EER, and compressor heat dissipation without the need for additional EER air-conditioning.

All cabling and waveguide, both transmit and receive, are brought into the EER via a cable tray below floor level and terminate in the equipment cabinets.

4.5 SAFETY EQUIPMENT

The protection of equipment and personnel safety have been prime considerations in the design of the JPL standard and modified antennas and safety criteria specified in the Occupational Safety and Health Administration (OSHA) standards have been incorporated into the design. Particular attention has been given to the following areas of the OSHA standards.

	Hazard	OSHA Paragraph
a.	Electrical Hazard	1910.308 and 1910.309 (National Electrical Code)
b.	Mechanical Hazard	1910.212, 1910.219(f) 1910.144, and 1910.145
c.	Personnel Accident Prevention	1910.22, 1910.36, 1910.212, and 1910.145
d.	Elevated platforms	1910.23, 1910.24, 1910.27, 1910.35 and 1910.37
e.	Fire Protection	Subpart L
f.	Antenna Operation and Control Center Control Coordination	1910.145
g.	Emergency Lightning	1910.308, 1910.309 (National Electrical Code)
h.	Equipment Hoist	1910.79

The recognized principles of human factors engineering have been applied to the planning, design, and development of the JPL standard and modified antennas. All subsystems and components meet the overall objectives of reliable and efficient operation and ease of maintenance. The following safety equipment is supplied in full compliance with the performance criteria:

a. Spring-set, electric-release brakes mounted on the axis drive motors, which are automatically applied when electric power is interrupted, final limits are reached, or interlocks are activated.

b. Stow locks for the azimuth and elevation axes which are remotely controlled but can be activated only when the antenna is in stow position. Manual stow lock operation capability is also provided.

c. Shock absorbers at both extremes of elevation travel.

d. Prelimit and final limit switches on both the elevation and azimuth axes.

e. Grounding of equipment, including an isolated technical ground from the EER to the JPL-supplied common ground.

f. An interlock at the reflector hatch which disables the antenna drives when the reflector hatch is open.

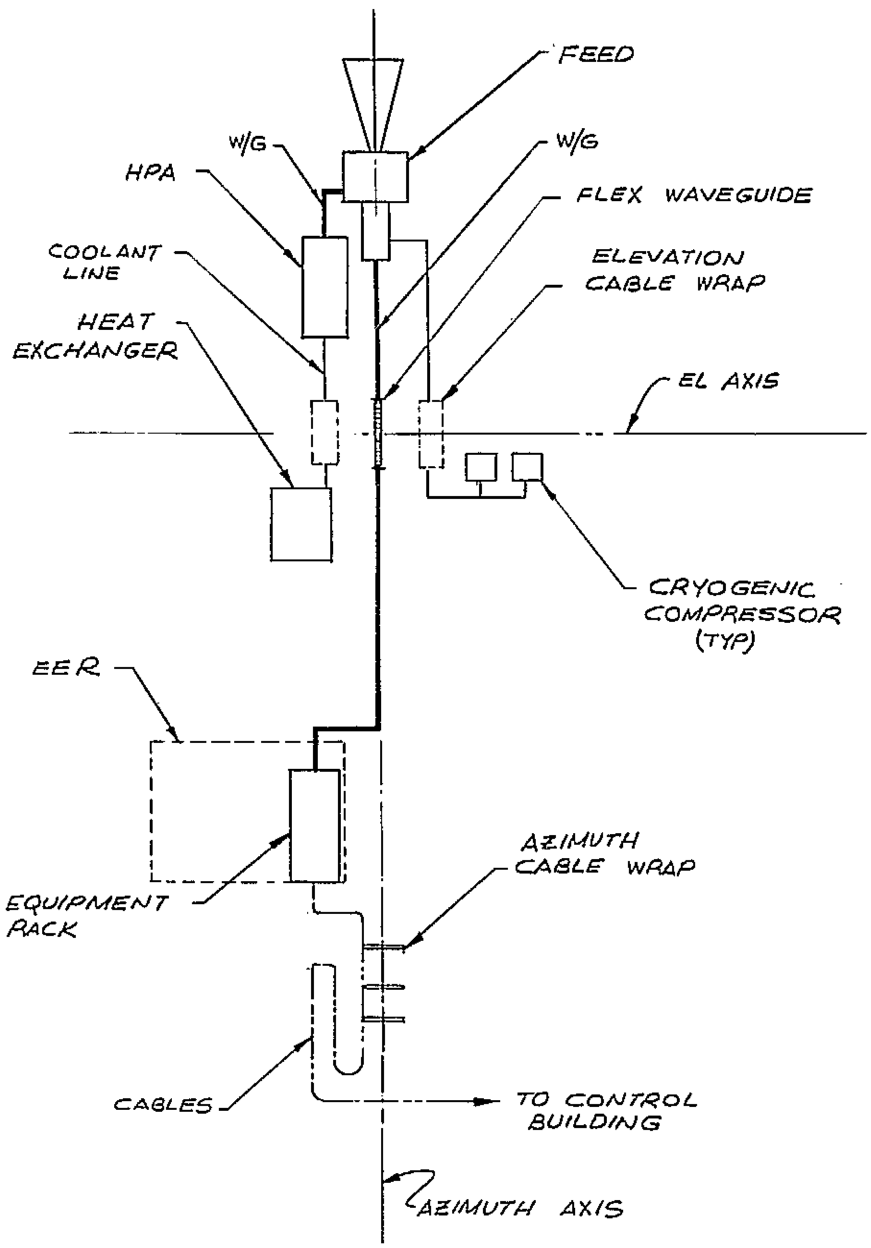
g. A fire detector in the EER.

h. Emergency lights in the EER.

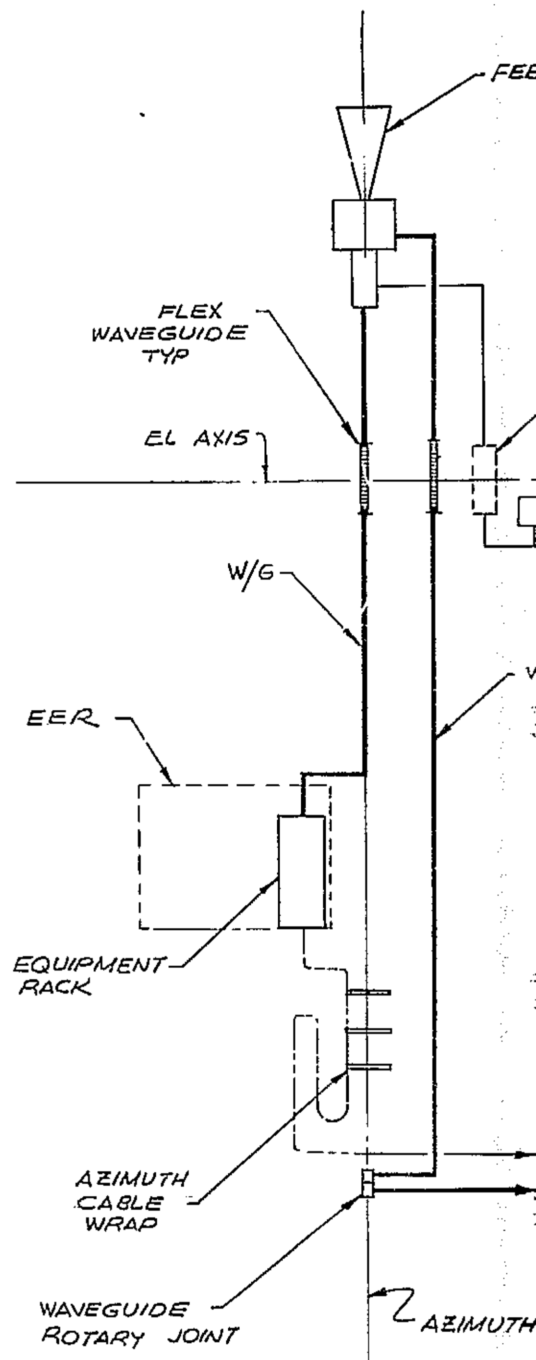
i. Safety rails on all grating used for personnel access.

j. Emergency stop switches for personnel use in the EER, at the elevation drive location, at both azimuth drive locations, and at the antenna base access stairway.

k. Redundant limit switches at both extremes of elevation and azimuth travel; these are completely independent of previously described limit switches.



X-BAND TRANSMIT



S-BAND TRAN

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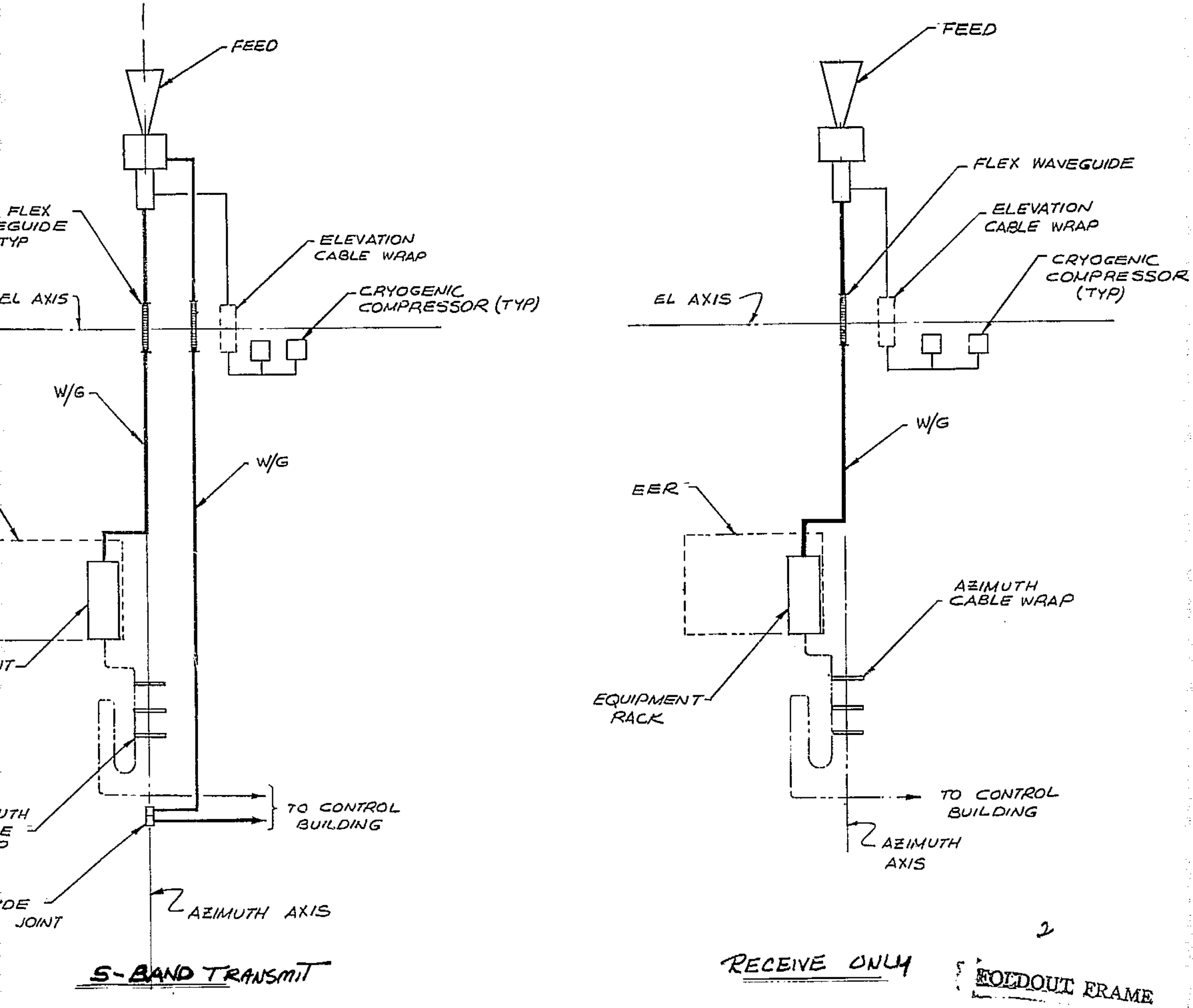

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Figure 4-2. 34-Meter Modified Antenna Equipment Configurations

SECTION 5

SITE IMPLEMENTATION PLAN

WDL maintains a department staffed with earth station equipment installation experts who have installed and integrated numerous earth stations and tracking stations for the U.S. Air Force, U.S. Army, NASA, COMSAT, AT&T, and other Government and civilian agencies throughout the world. As shown from past experience, WDL can easily accomplish the installation and testing of the antenna arrays within the time frame required.

This section describes the installation philosophy, some typical antenna alignments, the manpower and equipment requirements, tests to be performed and the implementation schedule. The basic site implementation plan does not change appreciably between the 30-meter standard antenna array and the 34-meter modified array. The philosophy discussed in the following paragraphs generally pertains to both array configurations.

The erection functions will be performed by a team of engineering personnel and skilled technicians from WDL, supplemented by local labor. The personnel will be supplied with all necessary installation tools, materials, and documentation required to accomplish their tasks in an expeditious manner. The following classifications of WDL personnel are proposed for the LAAS field implementation program:

a. Site Supervisor. This man will be a full time on-site representative in charge of all work at the site. He will be responsible for all liaison with JPL subcontractors, WDL, Palo Alto, etc., and will maintain schedule and control of all site work.

b. Logistician: The WDL logistician will receive, inventory, and separate all materials. He will maintain inside storage, kit equipment and maintain control of inventories.

c. Civil Engineer. A civil engineer will be on site under the supervision of the site supervisor whenever any earth work or foundation work is in process. He will assist the subcontractor in all anchor bolt alignments and track and pintle placement. Concrete and grout testing will be under his supervision.

d. Field Installation Engineers. Because of the division of work, there will be more than one on-site structural engineer during all phases of the antenna installation. Responsibilities will be divided so that each man covers a given area such as alidade, reflector subassemblies, reflector placement, miscellaneous furnishings, etc.

e. Alignment Engineer. An alignment engineer, skilled in optical alignment, will conduct and supervise all final alignments. He will reduce all data and maintain complete records.

f. Electrical Engineer. This man will be on site for all electrical installation. He will supervise the electrical subcontractor and assure that all items are to specifications and prevailing codes.

5.1 SITE STORAGE AND LAYOUT CONFIGURATION

The array configuration, as presently envisioned for the standard 30-meter configuration with on site storage and work areas, is shown in Figure 5-1.

5.1.1 Equipment Building

A temporary reusable building with 6,000 ft^2 of floor space will be erected on site for storage of delicate components, hardware, test equipment, etc. In addition to this building, two equipment vans will be used to house all working tools. A typical building for this use is shown in Figure 5-2.

5.1.2 Subassembly Fixtures

Four sets of foundations for reflector center hub ground assembly will be installed in order to permit erection of four reflector hubs to their respective alidades in a short time span (see Figure 5-1). These foundations will also locate the elevation bearings, reflector supports, and elevation wheel attachment points.

There will be one shop-fabricated and tested fixture to control the assembly of all outer main trusses. Combined with this truss fixture, there will be one jig for assembly and control of main trusses and intermediate trusses into "pie" sections. These sections will consist of a minimum of three main trusses and will reduce the work required in the air.

5.1.3 Logistics

FACC proposes to have a full time representative on site for the sole purpose of receiving, sorting, inventorying, and distributing all material. Material handling equipment and a temporary storage building fitted with racks, bins, pallets, etc., will be provided to assist in this effort.

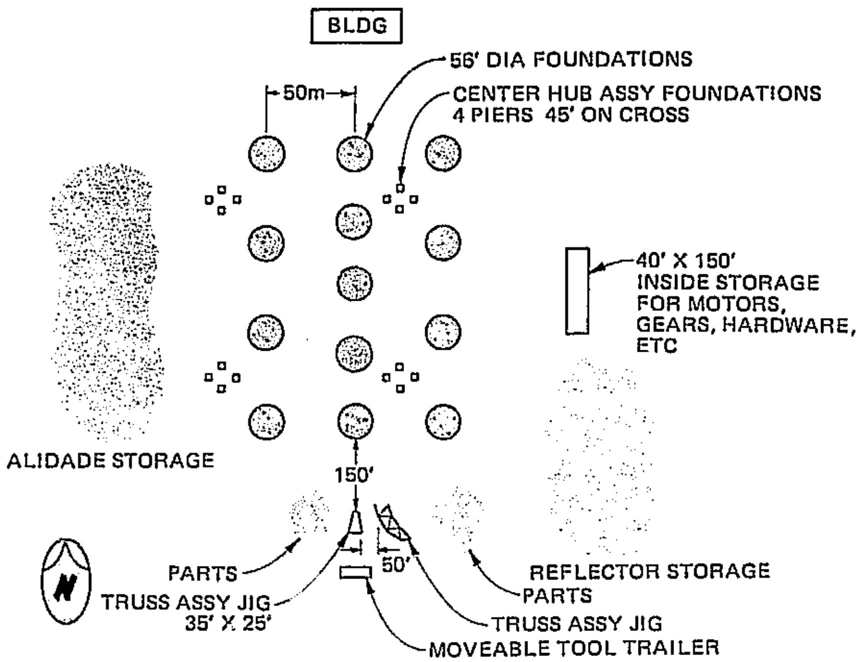


Figure 5-1. Site Storage and Layout Configuration

5.2 WORK PLAN AND SCHEDULE

Figure 5-3 shows a typical installation schedule for an array of eleven antennas in the 30 to 34-meter class. It depicts the sequence of installation tasks and the key manpower required. Actual schedules for installation of arrays of nine 34-meter or thirteen 30-meter antennas would not differ significantly from this schedule. The work plan is based on a study of similar WDL antenna installations, and is aimed at dividing the work so that the same job elements are performed repetitively by dedicated crews. This shortens the learning curve and increases overall efficiency. The schedule sequence provides for a smooth and efficient flow of work under the continuous supervision of qualified FACC engineers and technicians.

5.2.1 Basic Work Plan

The work has been divided into the following tasks:

a. Receiving, logistics, and material movement
b. Foundations
c. Pintle and track assembly
d. Alidade assembly
e. Reflector hub assembly (ground)
f. Reflector outer truss assembly (ground)
g. Reflector placement and panel installation
h. Alignments
i. Electrical power installation
j. Painting
k. Servo equipment installation
l. Subsystem checkout and test

The plan is to work these categories separately to a point where necessary interfacing of components can take place on three or four structures in succession.

5.2.2 Detail Schedule

Figure 5-3 depicts the overall schedule of all work on site. The schedule shows all overlapping work, engineering assistance, and start and stop times for the tasks of each antenna structure.

The schedule was devised from the expected time of hardware delivery and adding in known times for installation of this type of equipment. A degree of latitude exists in the schedule due to the fact that all antennas are to be installed at the same location using the same personnel.

5.3 ERECTION SEQUENCE

This discussion presents the sequence of steps for erecting one antenna structure. However, in practice each of these steps may be performed on three, four, or more antennas before proceeding to the next major task.

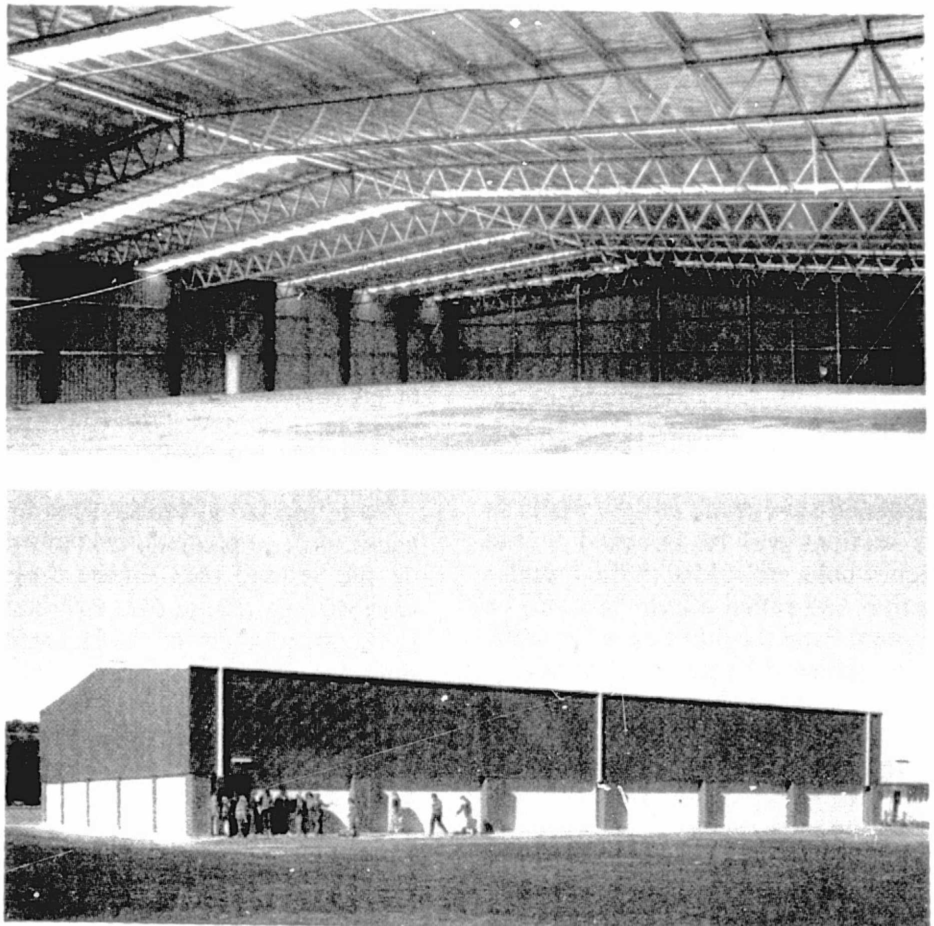


Figure 5-2. On-site Storage and Kitting Facility

5.3.1 Antenna Installation

The sequence of major steps necessary to complete installation of one antenna is as follows:

a. Concrete foundation installation

b. Base power installation

c. Pintle bearing installation, alignment, and grouting

d. Azimuth track installation, alignment, and grouting

e. Alidade base (with wheels) installation and alignment

f. Assembly of alidade tower with stairways

g. Installation of elevation and azimuth drive assemblies

h. Installation of elevation and azimuth stow pin assemblies

i. Elevation wheel placement on alidade

j. Installation of electronic equipment room

k. Assembly of reflector hub on ground

l. Assembly of reflector trusses on ground

m. Attachment and alignment of reflector hub structure to elevation wheel and elevation bearing pads

n. Rough alignment of elevation and azimuth drives

o. Installation and alignment of outer truss assemblies

p. Installation of subreflector support and subreflector

q. Installation of counterweights

r. Installation and rough alignments of reflector panels

s. Final alignment of elevation bearings and drives

t. Final alignment of reflector panels and subreflector

u. Feed installation

v. Final alignment of limit switches, stow pins, encoders, etc.

w. Painting

5.3.1.1 Concrete Foundation

WDL will subcontract the foundations to a local contractor. WDL will furnish the contractor with track and pintle post templates to ensure proper alignment. WDL will also have a qualified engineer on site to check all alignments and make all necessary tests of concrete to ensure specification compliance.

5.3.1.2 Azimuth Track and Pintle Post

Erection of the antenna will begin with installation of the azimuth track and pintle post on the concrete ring and center pier, respectively. The 58-foot diameter hardened-steel track will be made in 12 sections. The sections will be attached to the tower by steel anchor bolts embedded in the foundation. Circumferential and radial alignments will be made by measurement from the pintle post. Leveling of the track will be achieved by means of a double nut arrangement on the anchor bolts which permits the track to be raised or lowered as required. After final alignment, the track will be grouted to the foundation.

The pintle bearing post defines the azimuth center of rotation and it will be mounted directly to anchor bolts imbedded in the concrete foundation at the center of the azimuth track.

5.3.1.3 Azimuth Wheel and Alidade Installation

The alidade, which will support the reflector and elevation wheel at the elevation bearings, will be a spaceframe structure consisting of structural steel shapes terminating on three corner wheels at the base.

Construction of the alidade wil begin with the assembly of the triangular base frame and attachment of the three corner wheel assemblies that form the azimuth carriage. The radial bearing members will be installed next, along with the inner stiffening members.

Erection will continue with the upper assembly, consisting mainly of heavy structural sections, with connections to complete the alidade. All connections will be made with high-strength bolts, torqued to specified values.

5.3.1.4 Elevation Wheel and Reflector Structure Installation

The elevation wheel will be preassembled on the ground. The assembly will be lifted into place on the alidade structure, temporarily guyed and shored, and radially restrained by the elevation stow pin.

The EER is to be lifted and installed between the alidade tower supports as one assembly (see Figure 5-4).

The reflector hub section with elevation bearings attached (see Figure 5-5) will be lifted into place utilizing two cranes. When the bearings have been secured to their pedestals, the elevation wheel will be jacked up to the hub section and attached. After these sections have been connected and aligned, all bolts will be torqued.

To minimize assembly time in the air the radial trusses will be preassembled into eight "pie" sections on the ground (see Figure 5-6). The subreflector support (see Figure 5-7) will be installed just prior to the attachment of the last section. After all sections are attached to the center hub structure, the remaining circumferential structural bracing will be installed to complete the reflector backup structure.

5.3.1.5 Counterweight Installation

The counterweights and all trim weights will be installed from underneath the structure utilizing a hydraulic ram crane. All trim weights will be installed prior to adjusting the drives, to ensure a positive "tail-heavy" condition.

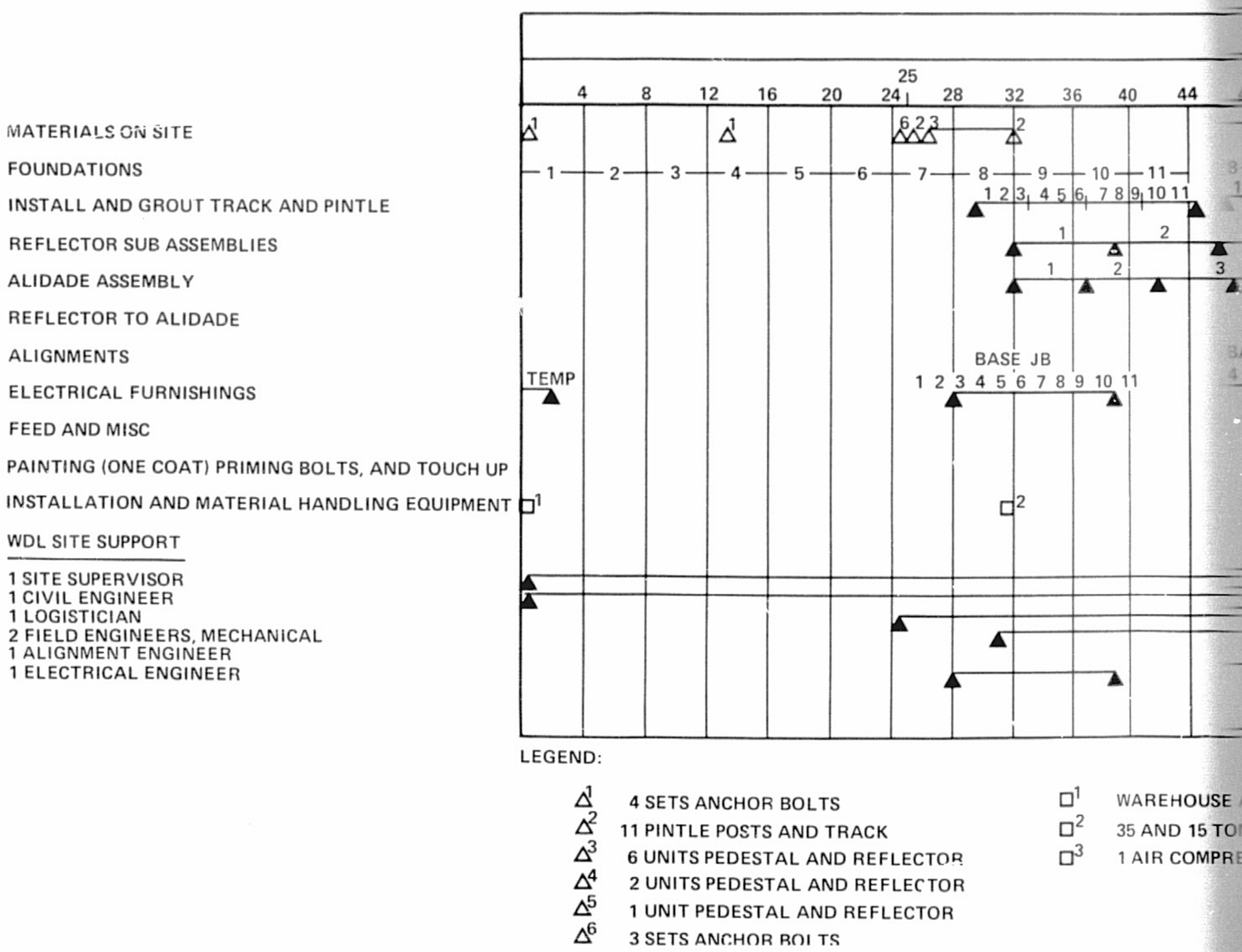
5.3.1.6 Panel Installation

Adjustable panel support brackets will be installed on the reflector backup structure. Before installing the panels, the panel support brackets will be aligned within a tolerance of 1/8 inch. The panels will be installed after completion of the reflector backup structure installation. The panels will be final aligned, with the antenna at the prescribed look angle, after installation of all heavy equipment that could significantly deflect the structure.

5.3.1.7 Mechanical Furnishings Installation

This effort can start as soon as the reflector structure is up, and it will continue in parallel with other installation efforts. Major mechanical furnishings to be installed include:

a. Azimuth and elevation cable wrap hardware
b. Limit switch mountings
c. Stow pins and actuators
d. Cable support brackets
e. Bearing ground straps
f. Azimuth and elevation transducer supports



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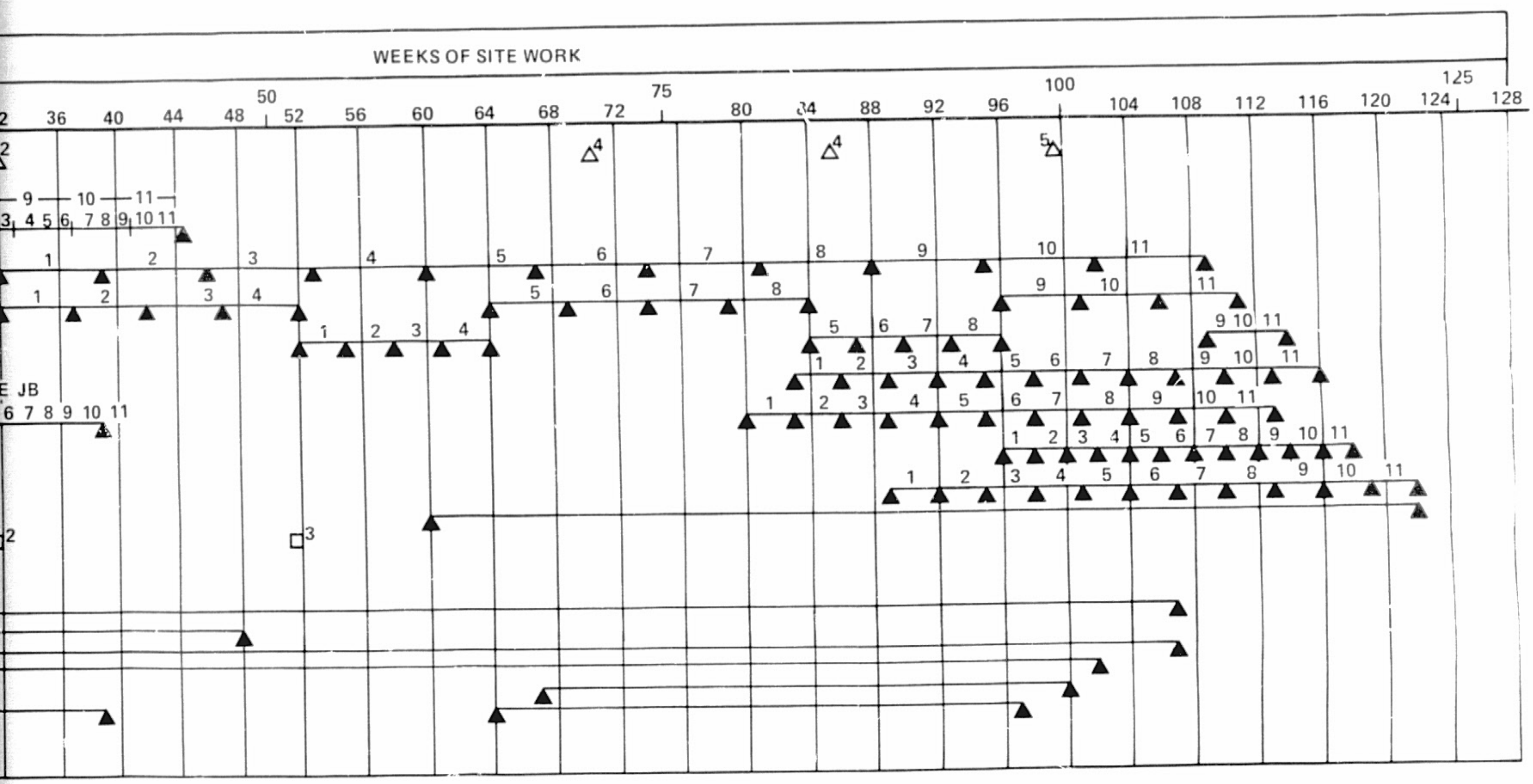

□[1] WAREHOUSE AND FORKLIFT
□[2] 35 AND 15 TON CRANES - 1 AIR COMPRESSOR - 1 TOOL SHED
□[3] 1 AIR COMPRESSOR - 2 WELDING MACHINES - 1 TOOL SHED

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Figure 5-3. Typical Installation Schedule

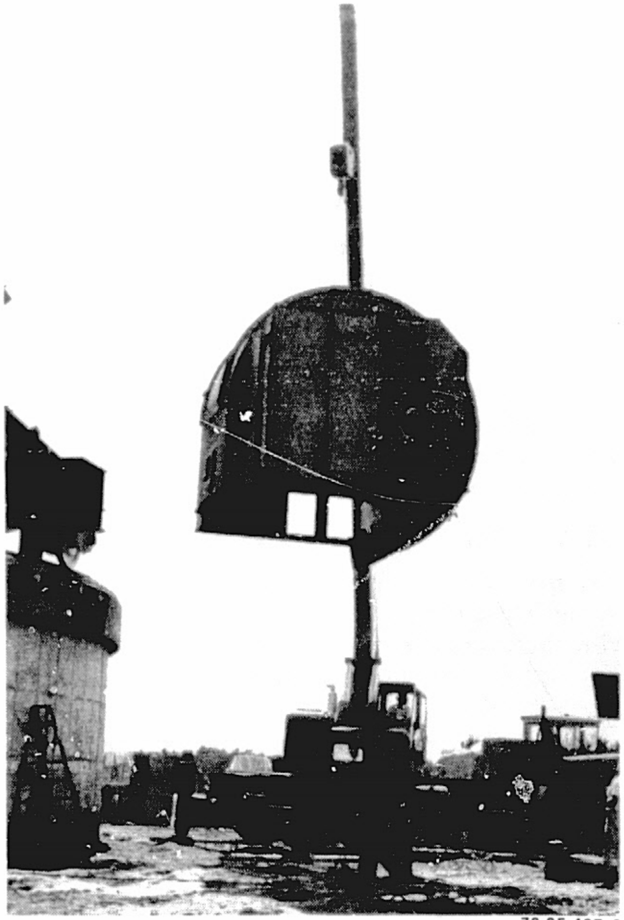
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Figure 5-4. Lifting the EER for Installation

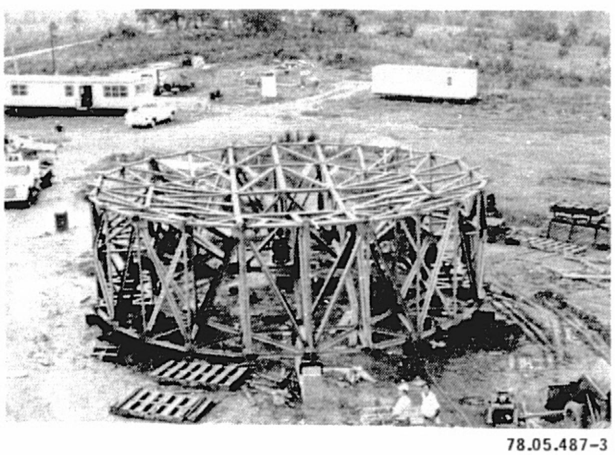
78.05.487-3

Figure 5-5. Assembling the Reflector Hub Section

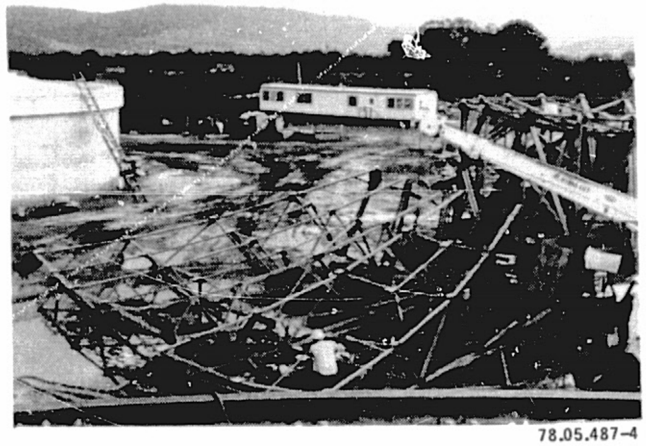
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Figure 5-6. Radial Truss Preassembly

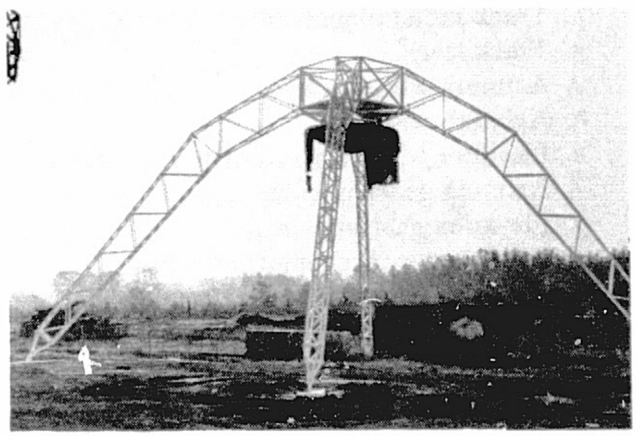

78.05.487-5

Figure 5-7. Assembled Subreflector Support

5.3.1.8 Electrical Furnishing Installation

Installation of the electrical furnishings will be in accordance with the National Electrical Code and applicable local regulations. Mechanical equipment will be installed and precisely aligned to WDL specified tolerances, and all final alignments will be verified by WDL engineers. During the antenna checkout and testing phases, limit switches and position transducers are precisely aligned. WDL engineers verify all settings and adjustments for each subsystem. All critically aligned components are keyed or doweled in their final positions to ensure proper realignment should any items require removal and replacement.

5.3.1.9 Field Painting

During erection, all damaged paint will be touched up with primer and one finish coat immediately after the damage occurs. After erection is completed, the alidade will receive one final top coat. After final panel alignment, the reflector surface will receive one final coat of high reflectance white paint.

5.4 STRUCTURAL/MECHANICAL ALIGNMENTS

Alignments will be performed, checked, and verified by a WDL engineer immediately upon completion of the installation of each component requiring alignment. In cases where components will be subjected to additional deflection as the erection sequence progresses, the components will be rough aligned at installation, and subsequently checked and readjusted after completing the erection. The basic alignments and adjustments that will be performed, either during or after erection, include:

a. Track radial alignment
b. Track level
c. Azimuth wheel camber
d. Azimuth wheel toe-in
e. Elevation/azimuth axis orthogonality
f. Azimuth gearbox alignment
g. Elevation gear alignment
h. Subreflector mechanical alignment
i. Reflector counterbalance
j. Reflector surface alignment

5.4.1 Track Radial Alignment

The track must be concentric with the pintle bearing within 0.25 inch T.I.R.; it must also be circular within 0.25 inch T.I.R. These tolerances are achieved by control of tolerances on placement of the anchor bolts, which are cast into the concrete foundation, and by provision of adequate clearance in the bolt holes in the track. The track, supported by nuts on the anchor bolts, can be readily adjusted to the prescribed tolerance.

5.4.2 Track Level Adjustment

With the track supported between the two nuts on each anchor bolt, the track is leveled with a precision optical level and optical scale. Segments are successively leveled until the track surface is within ±0.030-inch of a level plane, and at the proper elevation with respect to the pintle bearing.

5.4.3 Azimuth Wheel Camber Alignment

The camber misalignment angle is the relative angle of rotation between wheel and track, at the contact point, about an axis normal to the vertical plane containing the wheel turning axis. Since the wheel rim is conical to provide pure rolling action on the flat horizontal track, the wheel ideally should be tilted from the horizontal by half the included cone angle. This angle is easily checked by clamping a clinometer onto the rotating shaft with the level vial positioned approximately parallel to the wheel axis. Two readings are taken, one with the clinometer body above the axle and the other with the clinometer below the axle. These two positions are achieved by rotating the wheel axle through approximately 180 degrees. The inclination of the axle is then determined by averaging the two readings; any adjustment required is achieved by shimming above the wheel axle pillow-blocks.

5.4.4 Azimuth Wheel Toe-In Adjustment

Under ideal conditions, the conical wheel rolling on the planar track rolls about an axis coincident with the track centerline. If toe-in misalignment is present,the wheel tends to off-track as shown in Figure 5-8. Since the pintle bearing constrains the wheels to roll about the track centerline, continuous radial slippage occurs between wheel and track. The effect is a lateral load that occurs in a radial direction. This problem can be effectively eliminated by limiting the toe-in misalignment. Adjustment of each wheel is made by jacking the wheel off the track, sighting on a pintle bearing center target (using an on-axis mounted alignment telescope, K&E 71-2020 or equivalent, mounted on the wheel axle) and adjusting the entire wheel assembly, as required.

5.4.5 Elevation/Azimuth Axis Orthogonality

Orthogonality of the mechanical axes (azimuth-elevation) is aligned to within 20 seconds of arc. In the field, this is confirmed by examining the datum references representing the elevation bearing centers of motion. The relative displacement of these datums with respect to the orientation of the azimuth axis is examined by a precision optical level capable of sensing 2 to 3 seconds of arc. Measurements are performed with the antenna at two relative azimuth positions 180 degrees apart. The data is compared with measured verticality of the azimuth axis, and an average orthogonality is determined. Bearing pillow blocks are shimmed to obtain the required accuracy in orthogonality.

5.4.6 Azimuth Gearbox Alignment

The azimuth gearbox, mounted on the alidade structure is aligned coaxially to the wheel shaft by

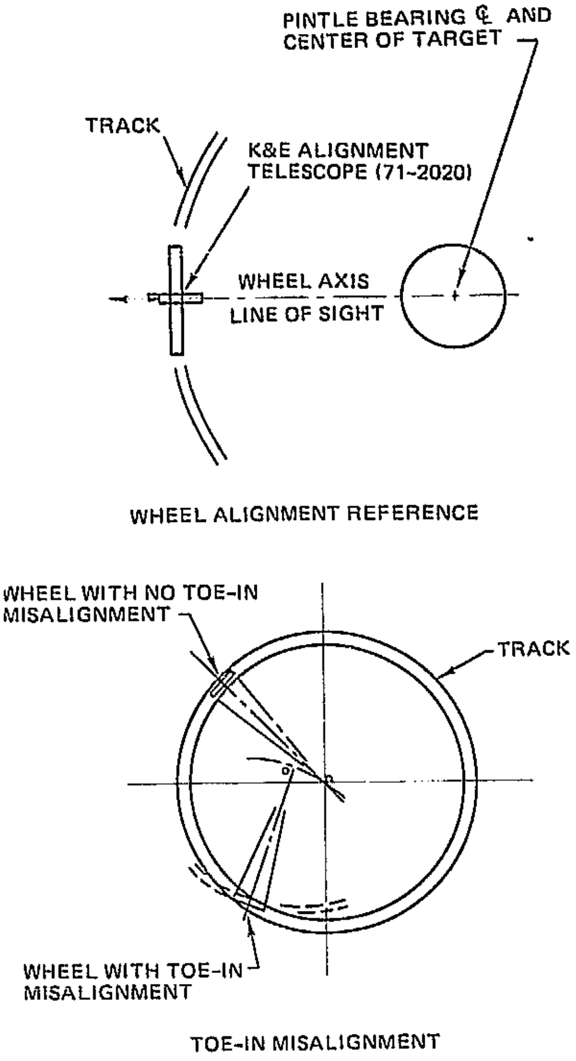


Figure 5-8. Azimuth Wheel Toe-In Alignment

means of machined wedge jacks. Once mounted and coupled to the wheel shaft, the gear box requires no further alignment or adjustment. There are no externally mounted gears in the aximuth drive power train.

5.4.7 Elevation Gear Alignment

The elevation gear segments are aligned until radial runout is within required limits. The elevation drives will be positioned and aligned so that the parallel misalignment between the gear and each pinion is less than 0.005 inch across the face and until the backlash of each pinion is between 0.010 inch and 0.030 inch over the total runout range.

5.4.8 Subreflector Alignment

The subreflector is aligned mechanically by locating the vertex and axis of the subreflector into described coincidence and axial relation with the primary reflector. This is performed with the reflector in the zenith orientation. A taping fixture is provided at the vertex to permit the subreflector to be accurately located to the desired position in the reflector. In addition, a mirror target on the subreflector will permit angular and lateral alignment of the subreflector to coordinates established by computer analysis of the actual reflector shape as determined by target readings.

5.4.9 Reflector Counterbalance

Counterbalance is checked by positioning the reflector to the near horizon position and noting the unbalance by antenna motion as the brakes are released. The antenna is counterweighted until it remains in position with all brakes released, in a no wind condition.

5.4.10 Reflector Surface Alignment

After the reflector structure and surface panels are installed, and after all significant masses are installed on the antenna. the individual panels are adjusted in the direction normal to the surface. Each corner of the four-sided panel is attached to an adjustable support, which is shared by four panel corners. Panel corner height is thus adjusted by turning the support screw, which is accessible from the under side of the reflector. The amount of adjustment required is determined as follows:

a. A theodolite, Hilger and Watts ST-48 or equal, is mounted on a fixture which places it on the reflector RF axis at a point slightly above the vertex.

b. Small optical targets (see Figure 5-9) are installed in holes in the panel supports. The holes are located with a strap gauge drill jig which lays on the panel surface and can be swept around the rf axis.

c. Theodolite elevation angles are pre-computed for each circumferential row of targets.

d. Theodolite elevation angles to the actual targets are then compared to the precomputed values and the supports are adjusted to raise or lower the targets to bring the elevation angle to the target within an acceptable range.

e. After all supports are adjusted, final theodolite angles to the targets are recorded; from this data, the rms surface error of the reflector can be computed.

5.5 ANTENNA SUBSYSTEM FUNCTIONAL TESTS

WDL will conduct antenna subsystem tests that

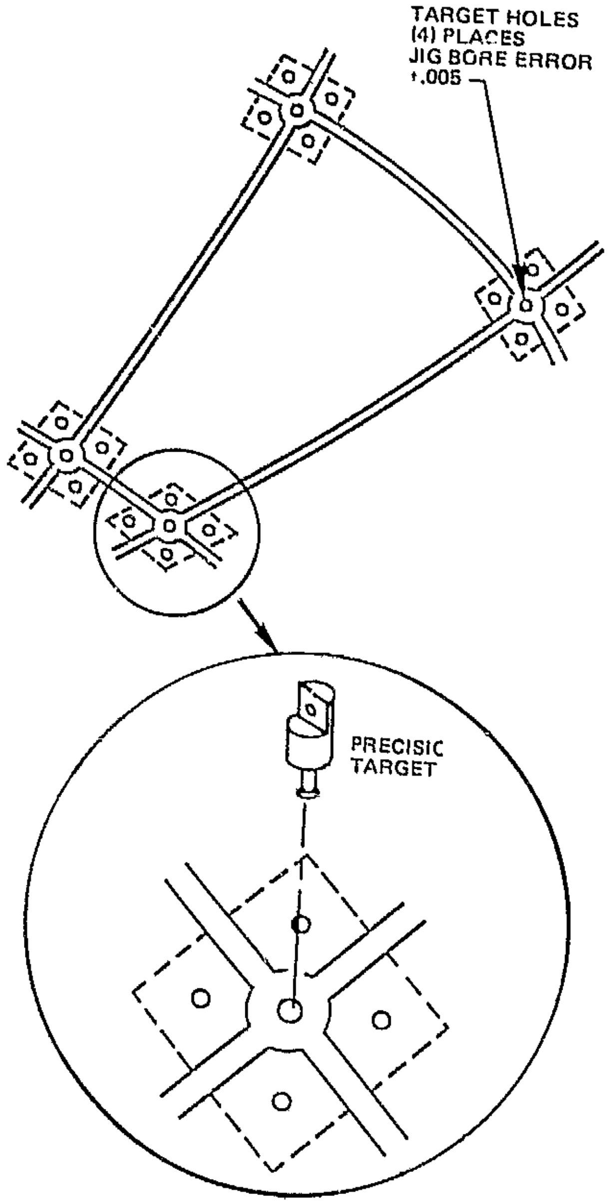


Figure 5-9. Typical Optical Target Mounting Holes

will demonstrate technical and contractual performance of its equipment, subcontracted equipment, and required interfaces with associated equipment. Acceptance test procedures will be developed and integrated into a consolidated antenna subsystem acceptance test document which will be submitted to JPL.

The test procedures for the acceptance test program will provide detailed instructions for accomplishing the proposed tests. Each test procedure will contain the following:

a. Test number
b. Test name
c. Applicable references
d. Performance criteria
e. List of test equipment required
f. Detailed instrumentation and test block diagram
g. Step-by-step procedure
h. Data sheets
i. Treatment and reduction of data

SECTION 6

PROGRAM IMPLEMENTATION AND SUPPORT

This section consists of a brief narrative as to how the overall program would be implemented, the WDL organization required to manage such a program, the various functions necessary to support a program of this magnitude and the software requirements to be fulfilled.

6.1 PROGRAM IMPLEMENTATION PLAN

Work will be accomplished in three phases: design, fabrication and installation. The structure, pintle bearing, EER, cable wrap, drive interfaces, access and ac wiring will be designed. Extensive use is made of computer programs to support design analyses and predict rf performance. After antenna geometry and surface coordinates are frozen, design will be concerned with updating drawings, writing alignment procedures and writing acceptance test procedures. Structural components are fabricated from design control drawings which the vendor utilizes to generate detailed parts drawings. Vendor drawings are reviewed and approved by WDL prior to the start of fabrication. After the final design review, fabrication is started.

Two types of fabrication control processes will be utilized: WDL fabrication and vendor fabrication. WDL engineering personnel procure all major components in both cases, providing all liaison necessary and witnessing approved test procedures as required. In-house fabrication personnel order all common components, kit them, and then fabricate, assemble, and test the finished equipment. Engineering personnel will witness all initial tests and selected production tests thereafter. Liaison engineers are provided to monitor major structural subcontracts. During critical phases, liaison personnel will be resident full time at the vendor's facility. During other program phases, near full time coverage will be obtained from a combination of engineering liaison and QA personnel.

Because of the number of components involved, it is planned to utilize extensive tooling. Tools will be manufactured to approved drawings, and will be critically inspected. The first parts manufactured using the tools will also be critically inspected. Finally, every major structural subassemblly will be proof assembled to check the tools. Problems found during proof test cycles will be corrected in the tooling. Further proof assembly of major components will not be necessary after successful completion of the first unit; parts will be fabricated using the verified tooling and the only inspection necessary will be for correctness of manufacture. The result will provide more uniform parts, fewer manufacturing errors, and reduced requirements for checking components.

To obtain benefit from specializing and to reduce human errors, installation will be performed with minimum sized, maximally specialized work crews. A concrete subcontractor will pour foundations, and after the alloted cure time, installation and alignment of the track and pintle bearings will start. A small crew will do one foundation at a time, moving from foundation to foundation until all track and pintle bearing installations are completed. Low personnel turnover will minimize training and associated errors. Erection of the alidades will progress one at a time. One crew will perform all preassembly work required on the ground, and then alidade assembly will start. Assembly of the alidade will be directly on the tracks. Reflectors will be preassembled on the ground and lifted into place for final panel alignment on the alidade at the correct elevation angle. Drives will be installed so the antenna can be moved and controlled from the local operator's panel.

An alignment crew will follow the installation crew and perform all necessary structural, reflector, and mechanical alignments. Crews will be specialized so that alignment work is performed in the same or slightly longer time than erection work, to assure a constant backlog of alignment work. Alignment will be performed to formal procedures provided by WDL engineering personnel. Satisfactory completion of alignment requirements will be witnessed by on site Quality Assurance (QA) personnel. After alignment, subsystem testing will start and continue smoothly through final acceptance testing. Start time and crew size will be selected to assure a backlog of work for the test crew, from their start until completion of the last antenna.

6.2 PROGRAM ORGANIZATION

A program manager will be assigned to this project; the program manager has direct access to the highest levels of WDL management on a routine basis through regular program schedule and progress reviews, and on a nonroutine basis as required. The program manager will be supported by up to 2 full time assistant program managers during the peak workload period. The program manager is directly responsible to WDL management for all facets of program performance and also provides the WDL customer interface. WDL utilizes a matrix organization. Reporting to the program manager in a matrix fashion will be the engineering managers, support managers, the installation manager and the program quality engineer.

Engineering managers are responsible for the design, documentation and procurement of equipment in their assigned areas. Engineering personnel support the program manager at all design reviews. Engineering managers are responsible for their respective schedules, documentation, and hardware procurement. Documentation includes drawing release and control, component test procedures, site alignment procedures, and the final on site acceptance test procedures. Hardware procurement responsibility includes part reliability, vendor schedules and warranty actions caused by component failures. All equipment not manufactured by WDL will be drop shipped to site by the vendor for inventory, kitting and control. The principal WDL manufactured component is the servo.

Support groups include rf engineering, manuals, logistics, and others as required. The program manager will task each support group to provide the support needed.

RF Engineering will provide design support for the antenna and will act on JPL's behalf for routine rf design decisions needed at WDL; the rf design will be presented by rf personnel at design reviews. Manual personnel will be responsible for preparing and delivering all manuals required. Logistics personnel will provide parts lists and recommended spares lists.

The installation manager will be responsible for all site activity including schedules, logistics, kitting, and testing. The installation manager will appoint WDL personnel to support him with his tasks. The site manager will reside at the site and supervise all site activities including installation, alignment, and acceptance tests. The site manager will arrive on site when foundation work begins and will remain until the final acceptance test is successfully completed. The logistican will move to site when the temporary storage building is complete and when parts start to arrive. He will be responsible for receipt of all parts, kitting parts, reporting shortages, and controlling inventory.

The Product Assurance Program Engineer will establish all program inspection requirements, handle the disposition of nonconforming parts, approve all test procedures, provide vendor QA as needed, and maintain files for all quality documents, vendor test data, site alignment data, and site acceptance test procedures. The program quality engineer will provide the WDL single point contact for JPL quality personnel.

6.3 QUALITY CONTROL

WDL is a major contractor of command and control systems and data display system products, and maintains a comprehensive QA system, representative of modern product assurance philosophy for that technology. A commercial-level Quality Control (QC) program will be established under the direction of the QA manager for the JPL LAAS program.

WDL management recognizes the need for direct access to top-level management for effective implementation of the QA system. To attain this objective, Product Assurance is established as an activity organization reporting directly to the Operations Support Director who has responsibility vested by the Vice President and General Manager of the WDL Division to organize and direct the resources necessary for fulfillment of all objectives required by the program. The QA manager of the product assurance activity is responsible for the organization and implementation of the quality assurance functions.

Recognizing the need for direct access to the program manager and the need for orderly interfaces between the QA organization and others, a specific individual within the QA organization, ie, the product assurance program engineer, will be assigned to work as a member of the program manager's staff. The product assurance program engineer will also be the focal point for customer interfaces on program related QA activities. This arrangement will allow retention of the direct line to the General Manager, functional organization economics and the means for resolving specific program-oriented problems.

The product assurance program engineer will be responsible for defining, monitoring, and implementing (by way of the product assurance organization), all actions and requirements of the QA program.

6.3.1 Fabrication, Assembly, and Test Controls

Authorization and control of all internal manufacturing and test operations will be by a shop order. The shop order establishes the sequence of operations, including the QC inspection points. Quality Engineering (QE) personnel will participate in the production planning, and they will review and approve shop orders to assure the most economical, and effective quality control. At designated points in time, QC personnel will then perform inspections to the requirements of the appropriate drawings, specifications, and quality instructions.

Acceptance test procedures will be controlled, reviewed, and approved by QA personnel. The acceptance test procedure will be a comprehensive step-by-step test method and will include a detailed list of test and measuring equipment. Acceptance and rejection criteria, test equipment setup, preliminary checkout instructions, environmental conditions, and test sequences will be clearly stated in the acceptance test procedures.

Quality control personnel will assure that all acceptance tests meet the requirements of the acceptance test procedure and that the acceptance test procedure has been approved. Quality control personnel will assure that the controlling shop order and the inspection records reflect the correct revision of the acceptance test procedure used.

6.3.2 Control of Purchases

A detailed and comprehensive system for controlling the quality of purchased materials, equipment, and services is presently in operation on current contracts held by WDL. Quality requirements are conveyed to suppliers and subcontractors as a condition of procurement, and all procurement documents are reviewed by QA personnel before release. An integrated source inspection and incoming material inspection activity has been established to ensure conformance and to assist suppliers in resolving quality problems. A reporting and corrective action system, based upon lot receipt and rejection data, is maintained to monitor and improve the quality of material received from suppliers and subcontractors.

Quality engineering personnel will review all requisitions for procurement of deliverable material (supply requisitions) before they are released to a buyer for purchase placement. At this time, QA requirements, in the form of checkoff codes on a sheet of standard quality clauses, is inserted in the purchase order by the procurement organization.

6.3.2.1 Selection of Procurement Sources

The quality control organization is responsible for evaluating the quality potential of suppliers and subcontractors, and recommending preferred sources. The evaluation of suppliers and subcontractors will be based upon QA data from several sources, including quality history records from previous WDL purchases, surveys of supplier's facilities and inspection systems, WDL source inspections, etc.

6.3.2.2 Subcontractor Quality Programs

In conjunction with source inspection, the subcontractors QA and QC systems will be evaluated during the execution of their contracts to determine performance and compliance with the requirements of the program. Under the contract, designated WDL QA representatives will have the right to enter the subcontractor's facilities during working hours to inspect and review the plans, procedures, drawings, and records; with free access to their facilities, copies of pertinent documentation (eg, contracts, specifications, drawings, plans, procedures, inspection and test records, and any special requirements), and assistance for the conduct of this surveillance activity. The provisions of this paragraph also apply to designated WDL customer representatives, provided that such visits are coordinated with WDL. Subcontractors will be notified by WDL of any unsatisfactory conditions by means of quality deficiency reports which will require immediate initiation of corrective action.

6.3.2.3 Source Inspection

WDL will either provide for inspection at source, or require objective evidence that the supplier complies in detail with applicable requirements, when receiving inspection personnel cannot verify the quality of the procured article(s) because of any one of the following:

a. Articles being procured are at a level of assembly which prevents verification of quality when received.

b. In-process controls have such an effect on the quality of the articles that the quality cannot be determined solely by inspection or test of the completed articles.

c. Verification tests are destructive in nature, or the environments or special test equipment required cannot be reproduced feasibly and economically or made available at WDL.

d. The items are to be shipped directly from the supplier's plant to a customer facility.

6.3.2.4 Incoming Material Inspection

Incoming material inspection will be conducted in a well-equipped, self-contained, controlled access area. This inspection area has temperature, humidity, and dust control; adequate lighting levels; and a staff of trained technicians under the direction of an experienced supervisor. The inspection staff is supported by QE personnel, and the resources of other laboratories within WDL when specialized tests are required. In particular, the materials laboratory, environmental laboratory, and the standards laboratory regularly supply supplemental services.

6.3.3 Shipping Inspection

WDL shipping inspection personnel will provide verification of proper handling, preservation, packaging, marking, and accompanying documentation prior to shipping.

6.3.4 On-Site Receiving Inspection

Most of the material received on site will have had prior QA inspection and acceptance, either by inplant inspection acceptance or by WDL source inspection acceptance. Where this is the case, the material will be checked for identification, for possible damage, and for the evidence of prior QA acceptance.

All other material purchased for delivery to site will be procured by the WDL Material Organization in Palo Alto, California, where the procurement functions are subject to normal QA controls. Inspection of this incoming material will consist of identification, count, and damage.

6.3.5 Nonconforming Material

Nonconformances are identified and classified as either Type I or Type II. Type I covers material which departs from contract requirements involving safety, performance, durability, reliabity, physical or functional changeability, effective use or operation, weight, or appearance (where a factor). Type II covers material which departs from requirements in a manner which is insignificant and has no bearing on the effective use or operation of the item or related components for the intended application.

A log will be maintained in each nonconforming material hold area for the purpose of maintaining the status and location of the material, and assuring that disposition and corrective action is accomplished in a timely manner.

Type II nonconformances will be directly documented and corrected by means of an in-process quality discrepancy notice. These will normally include incomplete production operations, rework, repairs per approved standards, scrap, rework, reinspection to revised critiera, or return to vendor.

Type I nonconformances will be documented on a Discrepancy Notice and will be evaluated by a WDL quality engineer and an engineering representative for disposition. The advice of program management, manufacturing engineering, or other consultants may be solicited. The customer or his delegated representative will be advised of all Type I nonconformances.

The WDL QA organization may authorize material review authority to suppliers for disposition of minor nonconformances. This is normally accomplished in writing at the time of procurement, providing the supplier has an established material review system.

6.3.6 Corrective Action

Prompt detection of quality deficiencies, and the correction of assignable causes is a major consideration behind QA procedures. When discrepancies are detected, they will be recorded on a discrepancy notice which will require action to correct the discrepancy. Reinspection will be required prior to acceptance.

6.3.7 Indication of Inspection Status

Inspection stamps are used to indicate various types of acceptance or rejection, and the inspection status of material and work in process. Issue of all such stamps is controlled by the QA organization. Records are maintained to ensure that each stamp issued is traceable to the individual responsible for its use.

6.3.8 On-Site Assurance

For several years, WDL has been continuously engaged in operations at government station sites, including receipt of equipment and material, installation and checkout, acceptance testing, configuration accounting, operation and maintenance, and logistic support. As a result, WDL has a well-established and proven on-site system for these activities.

On-site QA functions may be delegated by the WDL QA manager to the site project supervisor.

6.4 DOCUMENTATION

Program documentation includes drawings, engineering change orders (ECO's), inspection procedures, alignment procedures and test procedures. Manuals are provided to facilitate maintenance and repair. Documentation is released and controlled to assure that all work is performed to documents of the latest revision. Changes to documentation are controlled by ECO's; periodically, the program manager requires document revision and incorporation of all outstanding ECO's. WDL fabrication is performed to manufacturing drawings. Modified off-the-shelf components are procured to specification drawings. Structural components are procured to design drawings which are detailed by the vendor for efficient production in his facility. Vendor detail drawings are checked and approved by WDL. Vendor parts are manufactured to released and controlled vendor drawings.

Formal alignment procedures are written to standardize on-site alignment work. The alignment procedure defines test equipment and test methods. Alignment adjustments are provided in a step-by-step manner. Data sheets are completed during on-site testing to provide a permanent record of test results obtained.

SECTION 7

RELIABILITY, MAINTAINABILITY, AND SPARES

This section discusses the anticipated reliability of the mechanical and electrical components comprising both the standard antenna array and the modified array. Maintainability requirements associated with the antenna array hardware, and recommendations for manning these stations (based on actual servicing data from other WDL antenna sites) are addressed. A brief description of the Operation and Maintenance (O&M) manuals and an antenna sparing recommendation is also presented.

7.1 RELIABILITY

Reliability and maintainability are inexorably entwined: those equipments which will not fail and do not need periodic adjustment or maintenance, require no access. Therefore, judgements as to the equipment requiring access are based upon reliability predictions and past experience.

Reliability predictions are based upon failure rates obtained from standard government and vendor sources. However, wherever possible, abstract reliability data has been replaced with actual field reliability data from the same or similar units under actual operating conditions. Reliability begins in the design with parts selection and derating factors for stress to strength ratios. But, reliability continues into the circuit design and circuit derating, and culminates in the stress factors for complete subsystems. During type tests, components are subjected to accelerated wear through tests and temperature extremes to provide further data. The result of such meticulous design and test procedures is equipment that operates for periods of time greatly in excess of those predicted.

The principal limited life items found on the antenna are as follows:

- Servo electronics
- SCR amplifier
- High voltage power supplies
- Encoders
- Drive motors
- Gear boxes
- Cable wrap

Servo electronics were designed by maintaining low component stresses to obtain component long life. Then, only the most reliable components were utilized to implement the design. Finally, at the subsystem level, the dual aiding/opposing drive subsystem provides a soft mode of failure because, essentially two motors, SCR amplifiers, and trigger circuits are in parallel for each axis. The low level signal circuits are not duplicated; having a MTBF of 61,800 hours based on field data for nearly identical equipment they are least likely to fail.

The SCR amplifier has been conservatively rated and close control on components has been maintained to achieve high reliability. Because the SCR amplifiers are high power devices, they are likely to fail; but, field data indicates an 11,940-hour MTBF.

The high voltage power supplies are most likely to fail because of the voltage stresses. However, this link (the weakest in a servo designed for a 1000-hour MTBF) has an 11,110-hour MTBF based on field data for a similar unit and assuming 4 SCR amplifiers in series.

Encoders are procured from vendors. For reliability, care must be taken to select only those encoders that have field proven reliability records. The encoder selected for the LAAS has an estimated 12,670 hour MTBF based on WDL data from the field for similar units.

Drive motors are always a reliability problem. It is assumed that normal maintenance has been kept up, brushes replaced, motors cleaned, and so on. Then, a failure is an unexpected requirement for maintenance replacement.

Motors operating near bearing life limits would normally be replaced during available downtime. Based on that definition of maintenance and failure, 100,000 hours between unexpected motor failure for 4 motors in series is expected.

Gear boxes seldom fail. Most gear box problems are associated with leaks due to seals. It is estimated that a 156,000-hour MTBF can be expected for 4 gearboxes in series.

The cable wrap is subjected to potential failures due to cable shield failure, broken wires, and wear due to rubbing. As explained in the cable wrap section, the Maypole cable wrap configuration employed in azimuth is designed to assure that cables do not rub, loops become shorter or longer; shields are not stressed by twist but take only long radius bending. The elevation cable wrap is also a loop to minimize twist stresses and to assure no rubbing. The cable wrap is therefore expected to have 156,000 hours between failures.

In summary, a 3089-hour MTBF from all causes is expected for a single antenna system as shown in Table 7-1.

Table 7-1. MTBF Predictions

Antenna Component	LAAS Count	MTBF Hours
Structure	1	2,000,000
Track	1	2,000,000
Wheel assemblies	3	1,000,000
Drive motor (sealed bearings)	4	100,000
Drive motor mounting	4	Infinite
Brakes	4	833,000
Gear drive seals and bearings	24	4,000,000
Gear boxes	4	156,000
Electric drive motor cooling units (maintenance free)	4	42,000 (estimated)
Major bearings (elevation and pintle)	4	5,000,000
Bullgear segments	4	1,000,000
Reflector surface		500,000
Cable wrap-up	Azimuth and elevation	156,000
Encoder	Azimuth and elevation	12,670
Drive power supply components	Azimuth and elevation	11,110
Servo	Azimuth and elevation	61,800
SCR's	Azimuth and elevation	11,940
Safety interlocks and limit switches	10	250,000
Stow pin actuators	Azimuth and elevation	250,000

MTBF = 3089 hours MTTR = 3.7 hours A $\approx$ 0.9988

Utilizing a 3.7-hour Mean-Time-To-Restore (MTTR) in both cases, the array of 13 standard antennas has a point availability of 0.984°, and the array of 9 modified antennas has a point availability of 0.989. However, it should be pointed out that the array degrades gracefully. Loss of a single element causes a 0.35 dB loss in the standard antenna array and a 0.51 dB loss in the modified antenna array.

Dual drives provide a similar graceful degradation. In a few minutes, the failed drive can be electrically bypassed; the resulting degradation in antenna performance is 0.14 dB for the standard antenna and 0.17 dB for the modified antenna. Therefore, the probability of 100% performance is less for the array than for a single antenna but the array degrades gracefully, element by element, without a catastrophic mission loss.

7.2 MAINTAINABILITY

Maintainability provides for adequate access to all antenna components subject to failure and insures that failed parts can be readily removed and replaced. Failure of the pintle bearing is so remote that no provision is made for its replacement either in spares or in design. The pintle bearing takes uplift and shear loads. Uplift loads are due to high winds which occur only a few days each year. Shear loads are also due to winds and seldom occur. Hence, the pintle bearing has an equivalent duty cycle of only a few percent. Therefore, the low probability of failure predicted by reliability personnel seems justified when critically examined.

The elevation bearings always support a load which increases under certain wind pointing angle conditions. So while the failure of an elevation bearing is a very low probability, such a failure seems more likely than failure of the pintle bearing. Elevation bearings are spared as a subassembly on the shaft with the attaching brackets. The philosophy is that a failed elevation bearing and bracket would be removed and replaced as a subassembly. Repair work to the bearing would be made off-line. A second elevation bearing is also spared so that a spare is available during the restocking cycle; bearings can be long lead items, depending upon the relationship with the next manufacturer's run of that bearing type. Access is provided to the elevation bearings for regular lubrication and inspection operations.

Drive motor, brake, tachometer, and blower motor form a single assembly. Blower motors, tachometers, brakes, and motor brushes may be readily removed and replaced. Access is provided to the motors so that these operations and regular inspections can be readily performed. Both the brake and tachometer are mounted on the rear of the motor so they can be removed and replaced without removing the entire motor.

Gear boxes and the elevation gear are accessible should replacement or repair be necessary. However, gear box replacement requires removal of dc motors in every case. Access from ground level is available for the azimuth drives. Platforms provide access to the elevation drives. A 1000-pound davit hoist is provided on the upper equipment level to facilitate installation and removal of components from the EER.

Fault isolation circuits are incorporated into the servo electronics and the SCR. Design criteria for the fault isolation circuitry was to maximize the equipment availability. Enough fault isolation was used to improve the MTTR without significantly degrading reliability. Spare fuses are mounted adjacent to the in-circuit fuse position to improve maintainability.

For preventive and corrective maintenance estimates, it has been assumed that in addition to all normal hand tools, cranes, heavy equipment handling devices, and heavy equipment tools are available on site. It has been assumed that the services of specialized machines such as grinding or gear cutting devices will be obtained from vendors. It has been assumed that air powered greasing equipment and other available labor saving devices will be utilized to minimize man-hours per task. Detailed preventive and corrective maintenance estimates are included in Appendix D.

Although a cover could be added to the elevation gear to reduce the intrusion of dirt and foreign matter, WDL initial investigations indicate this is not warranted. However, the design exists should cleaning and maintenance manpower requirements warrant such an addition.

7.3 MANNING

Antenna repair and maintenance studies were performed at WDL to provide supporting data for JPL estimates. WDL has been DSN contractor for 7 years and also has been O&M contractor for the USAF SCF nearly 20 years. WDL manpower research personnel have conducted manning and productivity studies for both the DSN and SCF. The SCF TT&C 46-foot antenna systems have been utilized as preventive and corrective maintenance models; the drive components are very similar to those proposed for the LAAS antennas and the antennas are operated 24 hours per day, 365 days per year.

The typical site O&M technician has 80 to 100 hours of classroom training on the 46-foot antenna and two or three years experience. A single depot team composed of experienced technicians with varying backgrounds is currently utilized to support eleven 46-foot and 60-foot antennas, in addition to as many smaller antennas.

Maintenance data is available for two periods: period 1 is worst case for new antennas covering the period 1972 and 1973; period 2 is a typical one year midequipment life span covering 1976 to 1978. During period 1, a total of 263 corrective maintenance man hours per year and 48 preventive maintenance man hours per year were required per antenna. During period 2, 199 corrective maintenance man hours per year and 48 preventive maintenance man hours per year were required per antenna. During period 1, a total of 311 maintenance man hours were required; during period 2, a total of 247 maintenance man hours were required.

Extending this data to the 13 element array and assuming no learning curves and no efficiency factors due to identical equipment, 4,043 maintenance man hours per year would be required when the array is new, and 3,211 maintenance man hours per year would be required during equipment midlife. Since the 46-foot antennas are utilized in a radome environment, an additional 260 hours per year is added for cleaning for a total of 3,471 required maintenance hours per year during equipment midlife.

Extending this data to the 9 element modified antenna array recommended, again assuming no learning curves and no efficiency factors due to identical equipment, 2800 maintenance man hours per year would be required when the array is new and 2,216 maintenance man hours per year would be required during equipment midlife. An additional allowance of 180 hours per year is added for cleaning for a total of 2396 required maintenance hours per year during equipment midlife.

These figures can be expected to climb again when the equipment reaches 15 to 20 years of age and approaches end of life conditions. The allowance for cleanup is entirely dependent upon the cleanliness criteria utilized. Here it is assumed that only those items affecting performance and wear, such as elevation gear teeth, need to be cleaned.

There is no reason to utilize WDL figures for vacation, sick, rest, and delay times nor is it necessary to provide crew size or shift data. These figures illustrate that approximately 2 men per year will be required for antenna maintenance of all types.

There are arguments to support any one of three crew configurations. Two men can be employed on a single day shift to provide all routine maintenance functions including normal repair work. The other shifts would be covered by multitalented personnel on call. Two shifts could be covered full time with a total of three men, and the third shift could utilize multitalented on-call personnel; a second man needed for support could be supplied from non-trained available pool personnel, or each shift could be manned with two men. Lastly, three shifts of coverage with four crews could be provided with either one or two men per crew.

The question of coverage is inevitably entwined with mission and program philosophy and cannot be simply unraveled by a contractor. Therefore, no recommendation will be made because it is believed that basically all three systems are utilized in various earth stations around the world. It is believed that commercial earth terminal operators favor a single maintenance shift. Military sites tend to use around the clock coverage with scheduled maintenance functions predominantly during the day shift. Other users no doubt use other techniques.

Because daylight productivity is higher, it is recommended that scheduled maintenance functions be normally scheduled for daylight hours. Scheduled maintenance includes all routine preventive maintenance, in addition to corrective maintenance on equipment having unsatisfactory performance but not threatening catastrophic failure (such as oil leaks). Other coverage requirements depend upon the mission.

7.4 MANUALS

After the final design reviews, work on the handbooks will start. However, completion of the handbooks will await actual site photographs. Initial handbook work emphasis will be on developing parts lists and recommended spares lists referenced to true manufacturer's part number. During the early installation phases, assembly of motors, gear boxes, gear alignment and wheel alignment will be photographed for inclusion in the manual as illustrations for the respective installation and alignment procedures.

Manuals will include a technical description of the antenna together with maintenance and repair data. Maintenance requirements will be tabularized. Removal, installation, alignment, and test information will be provided for each replaceable antenna component. Manuals will also include a list of all replaceable parts listed by true manufacturer's part number and will be annotated for spares recommendations. This O&M manual, which includes selected drawings, comprises the antenna documentation.

7.5 SPARES

Spare part recommendations are made based on the philosophy that failed modules will be replaced at the module level and repaired off-line. There are 9 identical antennas in the modified array, therefore it is recommended that every mechanical component be spared on the module level; for example, one spare gear box and one spare elevation gear. It is recommended that the servo be spared at the component level since fault isolation circuitry is included in the design to quickly isolate failures. In addition, it is recommended that a full complement of resistors, capacitors, transistors, IC's, SCR's, seals, brushes, and other simply replaced components be spared.

It is assumed that motors would be rewound or motor bearings replaced at a motor rewind shop or at the manufacturer's facility. It is also assumed that a major gearbox failure would be sent to the manufacturer for repair. It is assumed consumption of a major spare item like an elevation bearing would be the time at which that item would be reordered.

Those parts such as wheels and track sections that fail gracefully are normally not recommended for sparing because there is ordinarily enough lead time to order those parts after wear is noticed so they can be replaced before catastrophic failure occurs.. However, because there are 9 antennas, it is recommended that these components be spared. It is recommended that an elevation bearing/pillow block assembly be spared, but not the pintle bearing because of the low likelihood of pintle bearing failure.

Costs for all major components are generated from array cost data available. Costs for resistors and other small parts are based upon a factor applied to material costs. A list of recommended spares is shown in Table 7-2. Lubricants, paint and other expendables are not included in the recommended spares list.

Parts with long lead times are duplicated so that at least one spare will be available while a failed unit is reordered.

Table 7-2. Recommended Spares List

Item	Qty	Cost of Each (S)
Reflector Panels	10	500
Elevation Gear	2 segments	2,800
Rail	2 sections	2,500
Elevation Bearing Assy	2	5,750
Azimuth Wheel	2	2,300
Azimuth Drive Pillow Block	2	2,300
Elevation Speed Reducer	2	6,000
Azimuth Speed Reducer	2	10,000
Hoist	1	450
Brake Assy	2	900
Couplings	1 set	1,590
Actuator (Stow Pin)	2	1,200
Miscellaneous Seals, Electric Parts	1 set	2,000
Encoder 21, bit, assy	1	32,500
10 hp dc motor	2	9,560
Power Supply Components	2 sets	800
Pack for Long Term Storage	lot	11,500

7.5 TRAINING

No formal training program is proposed. It is believed that adequate on-the-job training will be available during the approximate 3-year site installation, erection, alignment, and test phase period.

APPENDIX A

LAAS RF PERFORMANCE DATA

Feed patterns given in contract Exhibit 2 were utilized to derive antenna performance. The given feed patterns were regenerated in a WDL version of the Potter Corrugated Horn Program from the data on Contract Exhibit 2 feed pattern plots (horn flare, aperature diameter, and groove depth). Feed patterns generated were for the S-band frequency of 2.295 GHz with Phi angles of 0 and 90 degrees (Figures A-1 and A-2) and for the X-band frequency of 8.450 GHz with Phi angles of 0 and 90 degrees (Figures A-3 and A-4). This data was then applied to a WDL version of the Ludwig Scatter Program to obtain the resultant subreflector distribution (see Figures A-5 through A-8). The scatter pattern was integrated to obtain antenna efficiency and noise temperature data to which manual corrections for surface tolerance and blockage were applied (see Tables A-1 through A-3).

The noise temperature program integrates scatter pattern data in three dimensions to obtain antenna noise temperature versus subreflector scatter pattern intercept angle. The scatter pattern was also integrated at various intercept angles to obtain antenna efficiency. The G/T was then found for both S-band and X-band and plotted against the subreflector intercept angle to optimize G/T performance at both bands. See Tables A-4 and A-5 and Figure A-9.

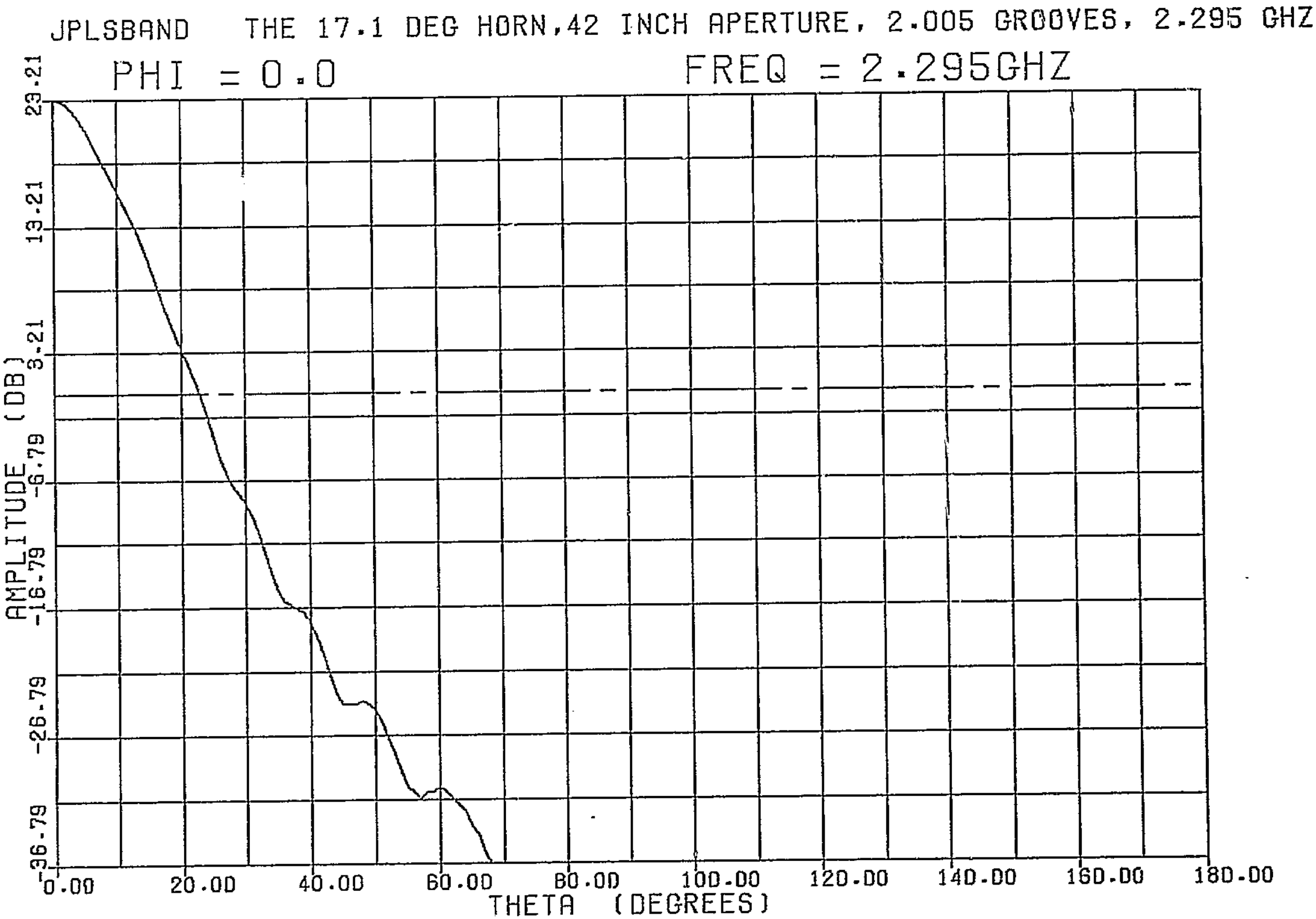


Figure A-I. S-Band Feed Pattern at 2.295 GHz (Phi = 0.0)

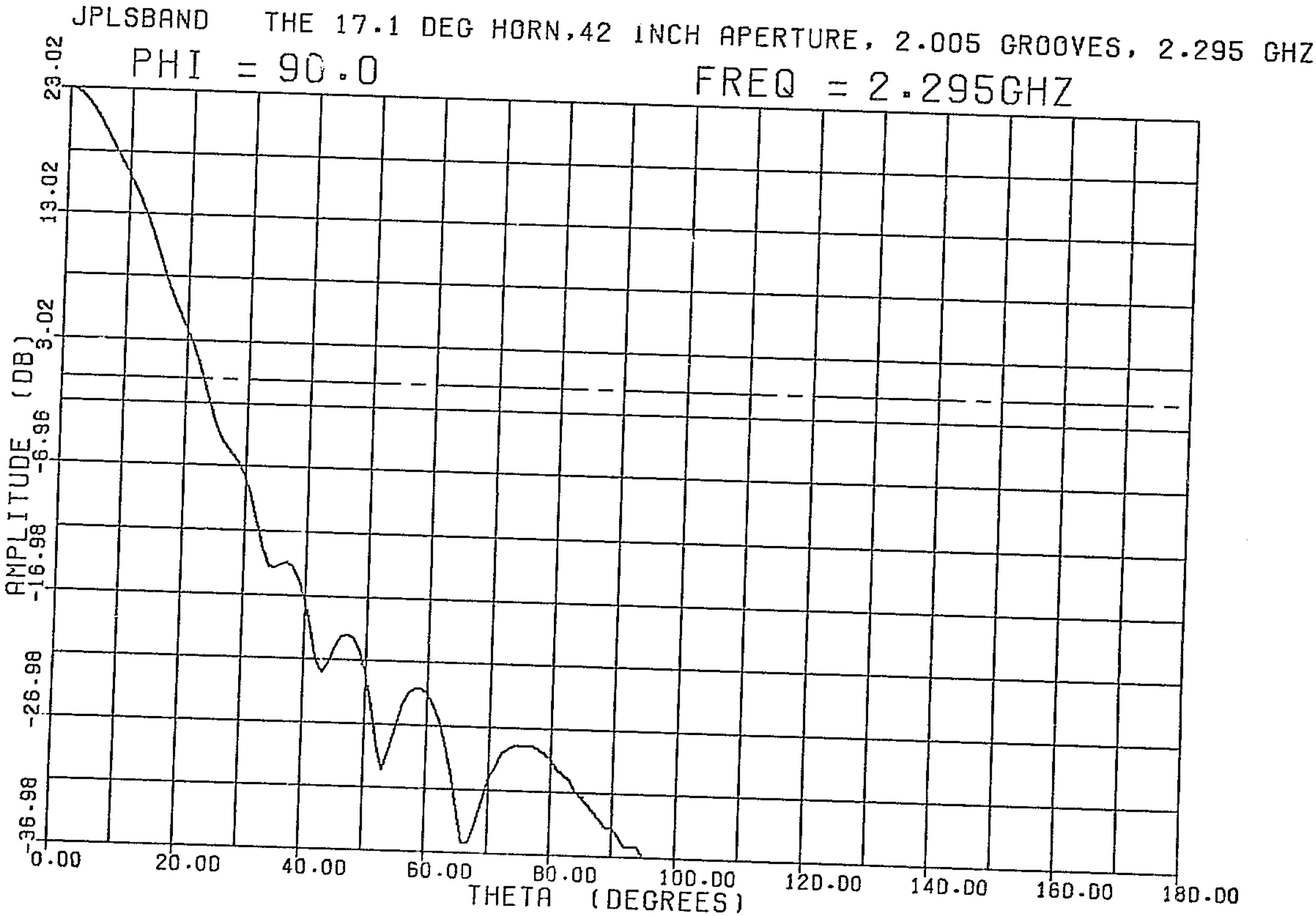


Figure A-2. S-Band Feed Pattern at 2.295 GHz (Phi = 90.0)

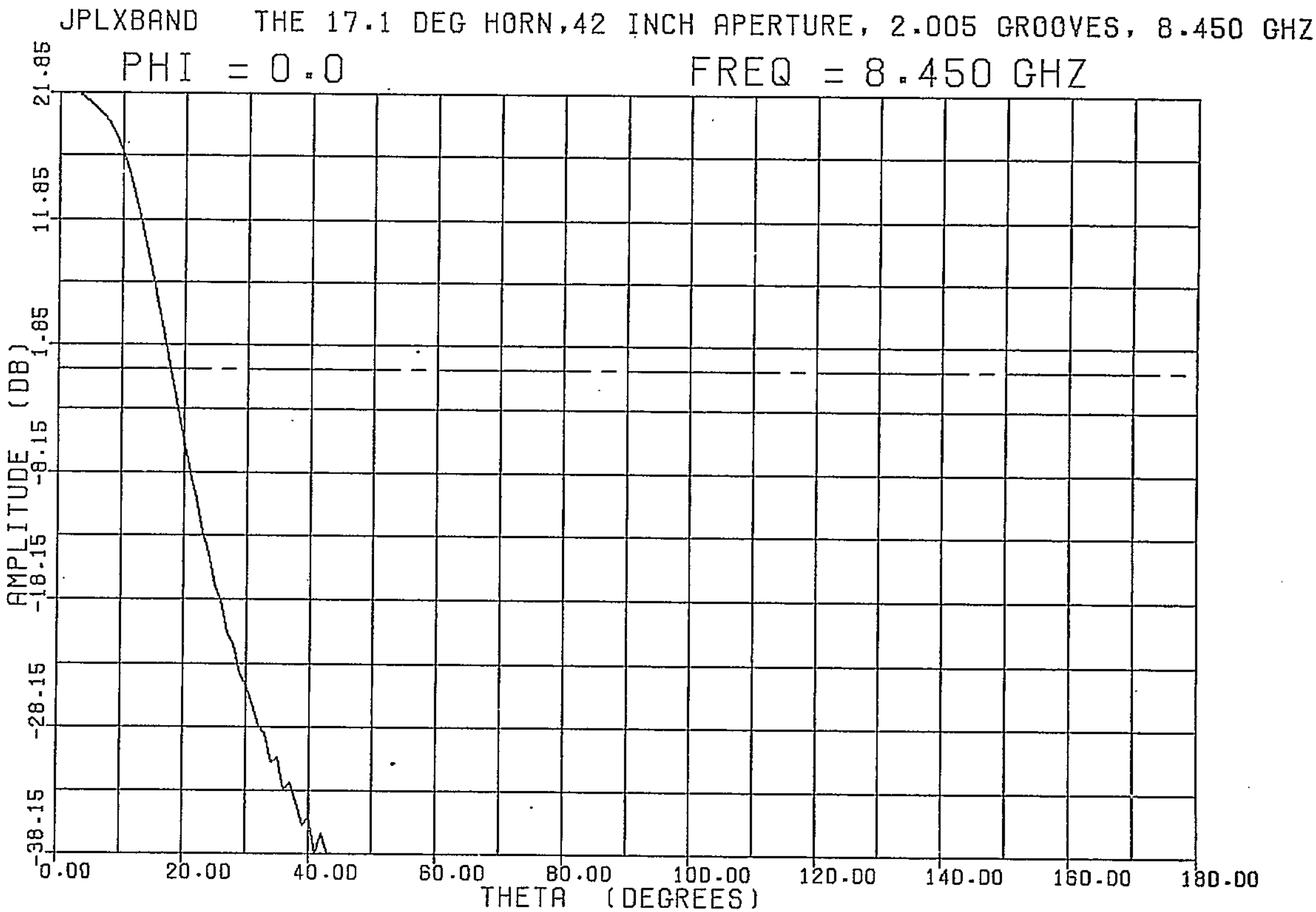


Figure A-3. X-Band Feed Pattern at 8.45 GHz (Phi = 0.0)

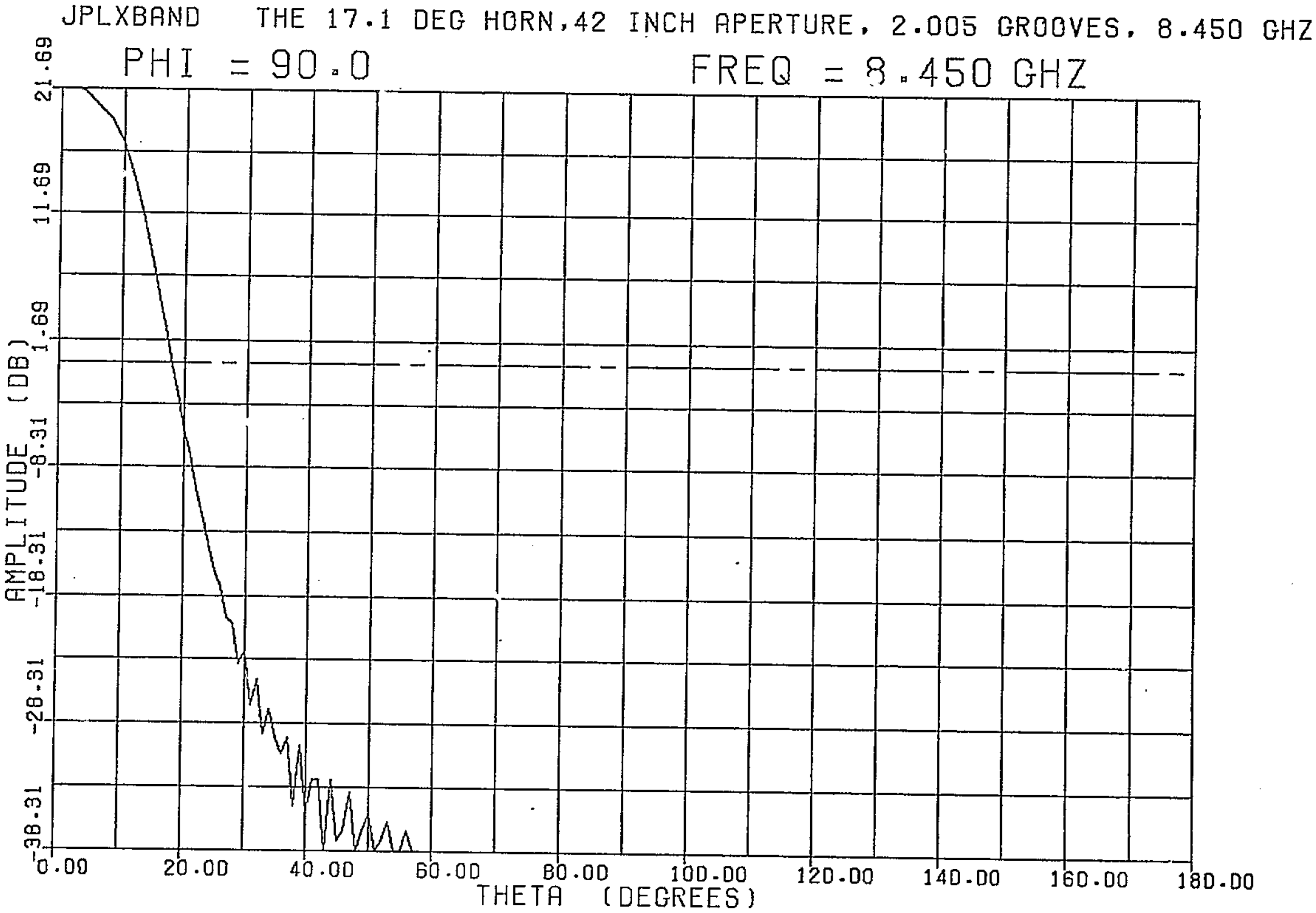


Figure A-4. X-Band Feed Pattern at 8.45 GHz (Phi = 90.0)

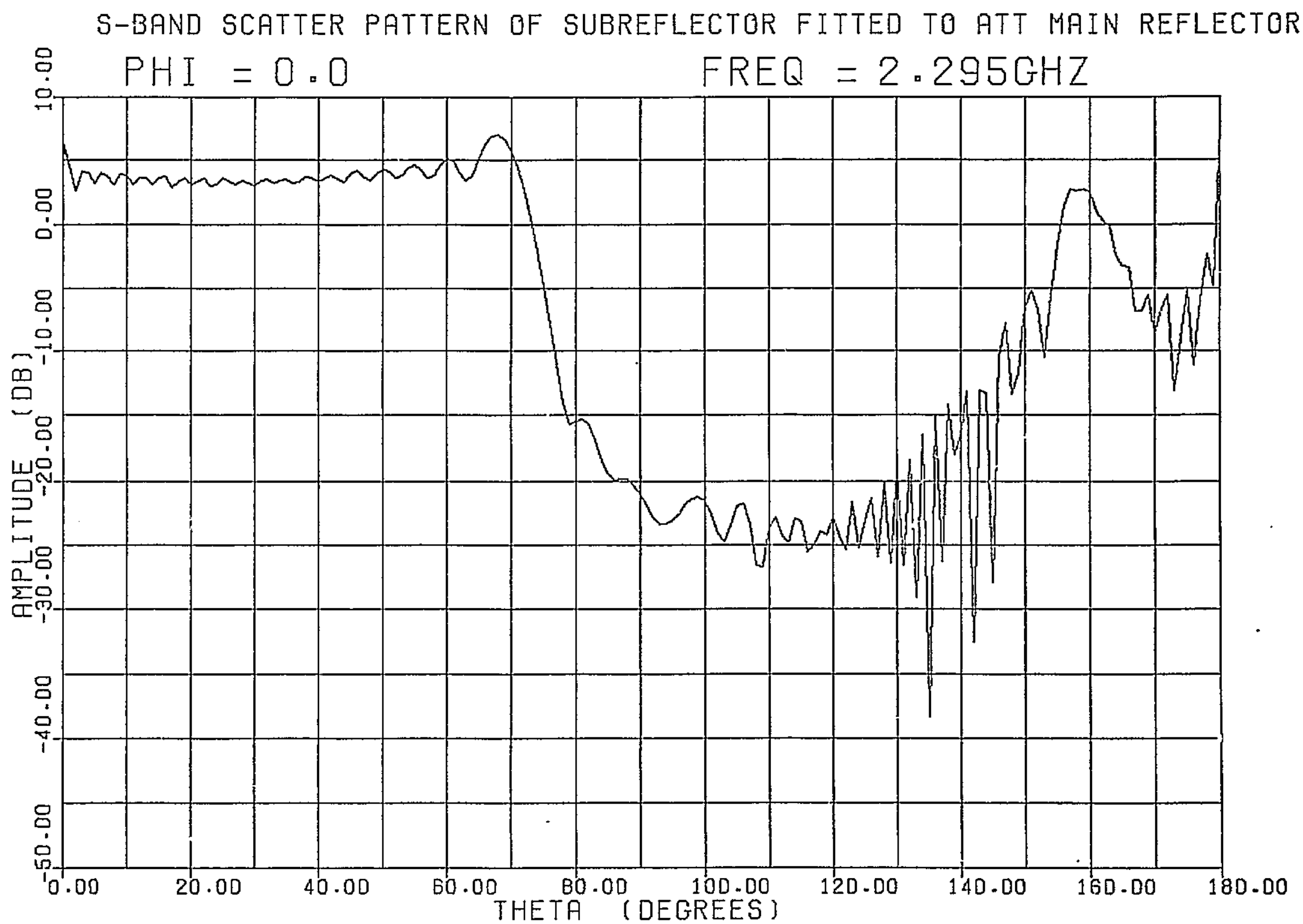


Figure A-5. S-Band Subreflector Scatter Pattern at 2.295 GHz (Phi = 0.0)

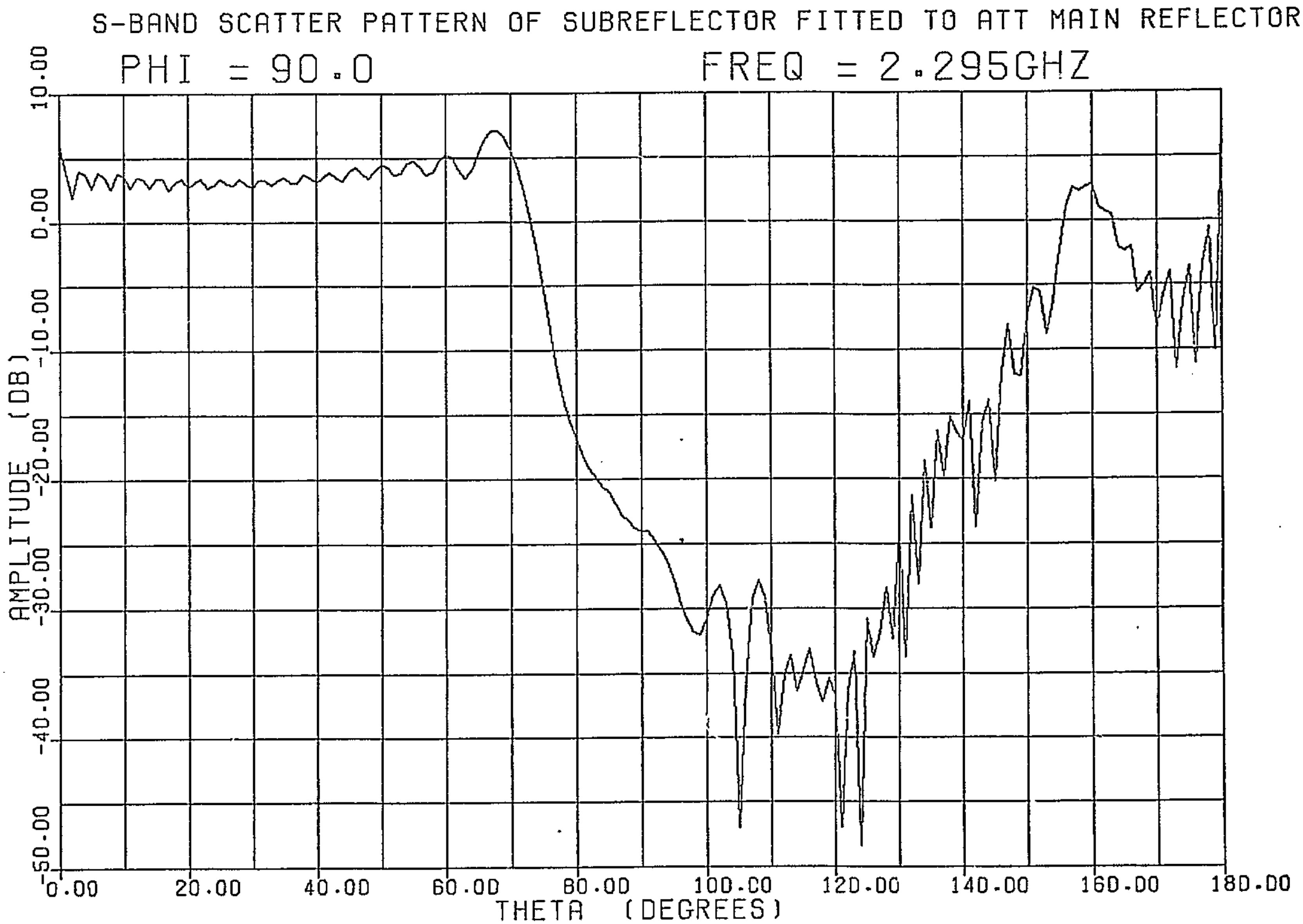


Figure A-6. S-Band Subreflector Scatter Pattern at 2.295 GHz (Phi = 90.0)

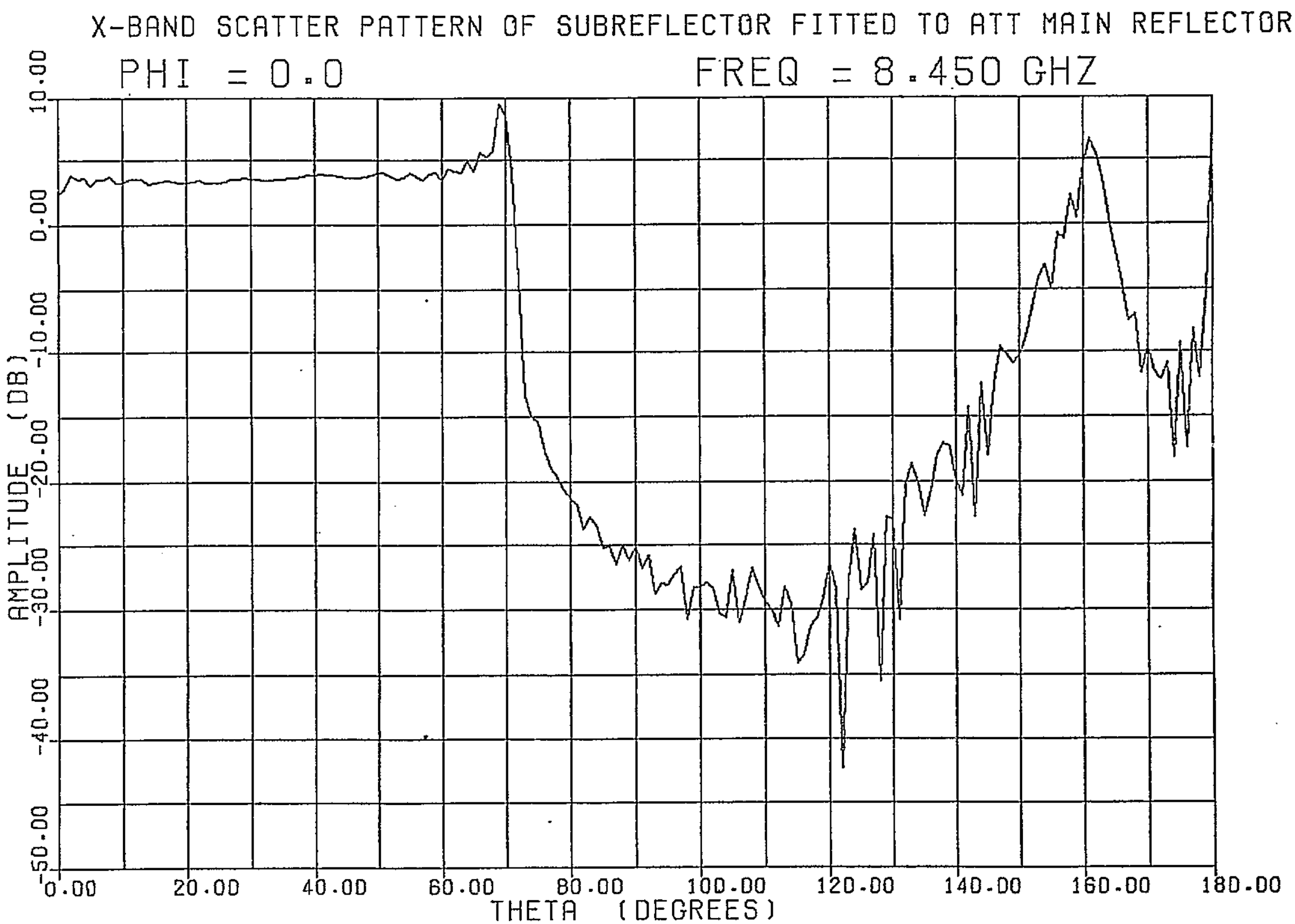


Figure A-7. X-Band Subreflector Scatter Pattern at 8.45 GHz (Phi = 0.0)

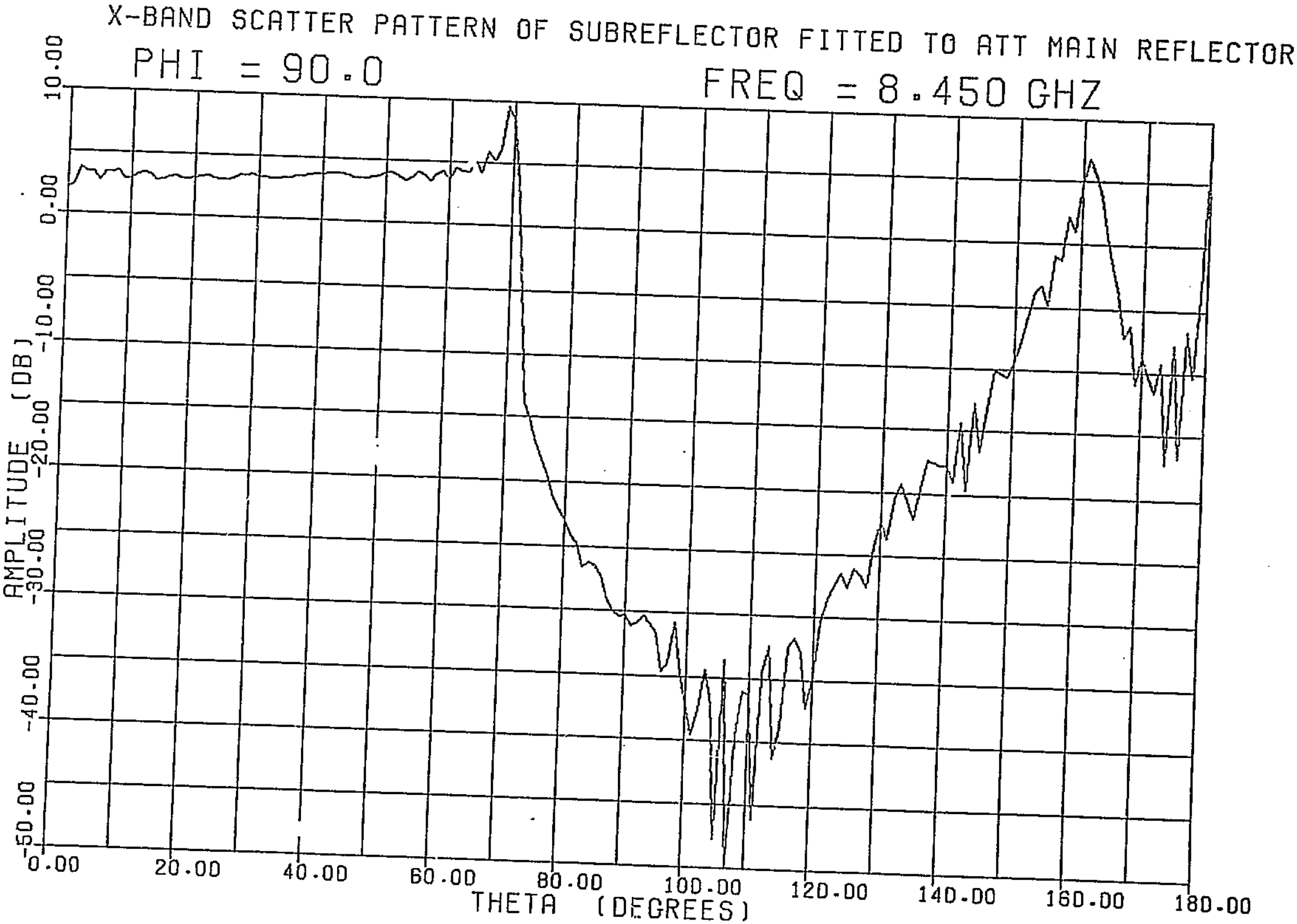


Figure A-8. X-Band Subreflector Scatter Pattern at 8 45 GHz (Phi = 90.0)

Table A-I. 30-Meter Antenna Efficiency Summary

Component	2.295 GHz	8.450 GHz
Forward Spillover	0.944	0.986
Reverse Spillover	0.983	0.991
Illumination Efficiency	0.882	0.896
Phase Efficiency	0.980	0.998
Blockage	0.918	0.918
Cross Polarization	0.999	0.999
Surface Tolerance	0.983	0.790
Overall Efficiency	0.723	0.633
Ideal Gain (dB)	57.16	68.48
-10 Log Efficiency	-1.41	1.99
Feed Loss (dB)	0.10	0.07
Net Gain (dB)	55.65	66.42

Table A-2. 34-Meter Antenna Efficiency Summary

Component	2.295 GHz	8.450 GHz
Forward Spillover	0.944	0.986
Reverse Spillover	0.983	0.991
Illumination Efficiency	0.882	0.896
Phase Efficiency	0.980	0.998
Blockage	0.937	0.937
Cross Polarization	0.999	0.999
Surface Tolerance	0.990	0.879
Overall Efficiency	0.743	0.719
Ideal Gain (dB)	58.25	69.57
-10 Log Efficiency	-1.29	-1.43
Feed Loss (dB)	0.10	0.07
Net Gain (dB)	56.86	68.07

Table A-3. Antenna Noise Temperature Summary

Noise Contributor	Noise Temperature (°K)			
	S-Band		X-Band	
	Reflector @ Zenith	Reflector @ 30° Elevation	Reflector @ 90° Zenith	Reflector @ 30° Elevation
Spillover and Diffraction	3.05	2.87	0.17	0.29
Blockage	2.06	3.23	2.18	3.43
Main Beam	4.15	6.06	4.63	6.90
Maser	2.5	2.5	3.5	3.5
Receiver Follow-Up	0.1	0.1	0.6	0.6
Waveguide	6.9	6.9	4.7	4.7
Radome	0.0	0.0	0.1	0.1
System Noise Temperature	18.76	21.66	15.88	19.52

Table A-4. 30-Meter Antenna Array G/T

Component	S-Band		X-Band	
	Reflector @ Zenith	Reflector @ 30° Elevation	Reflector @ Zenith	Reflector @ 30° Elevation
Gain for 1 Antenna (dB)	55.65	55.65	66.42	66.42
-10 Log of System Noise Temperature	-12.73	-13.36	-12.01	-12.90
G/T for 1 Antenna (dB/K)	42.92	42.29	54.41	53.52
Array Factor (13 Antennas)	11.14	11.14	11.14	11.14
Array G/T (dB/K)	54.06	53.43	65.55	64.66
Specified G/T (dB/K)	53.24	52.19	65.23	64.12
Margin (dB/K)	0.82	1.24	0.32	0.54

Table A-5. 34-Meter Antenna Array G/T

Component	S-Band		X-Band	
	Reflector @ Zenith	Reflector @ 30° Elevation	Reflector @ Zenith	Reflector @ 30° Elevation
Gain for 1 Antenna (dB)	58.86	56.86	68.07	68.07
-10 Log of System Noise Temperature	-12.73	-13.36	-12.01	-12.90
G/T for 1 Antenna (dB/K)	44.13	43.50	56.06	55.17
Array Factor (9 Antennas)	9.54	9.54	9.54	9.54
Array G/T (dB/K)	53.67	53.04	65.60	64.71
Specified G/T (dB/K)	53.24	52.19	65.23	64.12
Margin (dB/K)	0.43	0.85	0.37	0.59

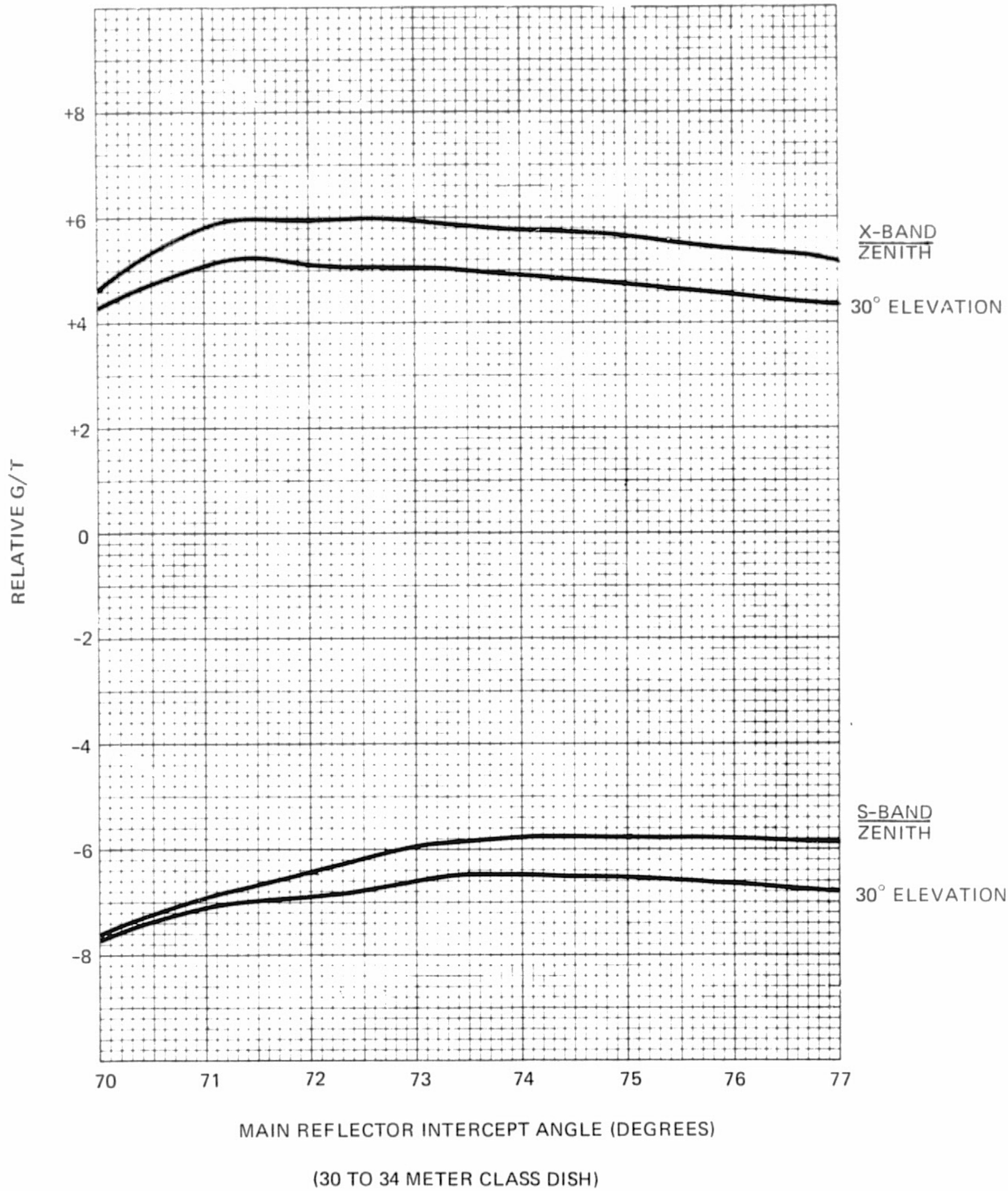


Figure A-9. G/T versus Main Reflector Intercept Angle for both S-Band and X-Band

APPENDIX B

SUBREFLECTOR SUPPORT STRUCTURE BLOCKAGE CALCULATIONS

Figures B-1 and B-2 show subreflector support structure blockage calculations for the 30 and 34-meter antennas. Spar blockage is first calculated by optical techniques. The fan shaped secondary blockage area is conservatively approximated by the trapezoid defined by the narrow blockage dimension at the primary shadowing boundary and by the extreme limits at the reflector edge. Next, both plane-wave and spherical-wave projections through the legs are made to determine the ratio of shaded to open area. The plane-wave shading factor is applied to the inner area. The spherical-wave shading factor is applied to the fan shaped shadow area. A phase efficiency is determined and used to weight the subreflector support leg open area. The total area is then compared to the open area to obtain a weighting factor which is applied to the optical blockage computations.

Optical shadowing computations consider the open truss subreflector support legs as solid objects. In actuality, the truss sections have a large percentage of open area. An estimate of the open area versus the shadow area may be made by projecting the truss into the antenna aperture and calculating the resulting open area. A plane-wave incident on the reflector will see a plane projection of the truss structure into the antenna aperture. Secondary shadowing is due to a projection of the truss into the aperture from the focal point. The plane-wave projection has a 32% optically open area. The spherical-wave projection has a 60% optically open area. Not all of the optically open area is useful in fact. For openings less than one quarter wavelength, the opening appears solid. In areas near the junction of two members where dimensions are less than one quarter wavelength, the opening appears nearly solid. A 90% weighting factor is applied to the optical open area to account for areas with small dimensions.

Plane waves propagating near a metal structure have a phase change due to an apparent artifical dielectric. The closer the wave is to the metal, the more pronounced the phase change; the change in phase was modeled and calculated. When the total phase is integrated and compared to zero phase, there is an approximate 85% efficiency (which varies with opening size). Since every ray passes through two sections of the truss, the net efficiency is 85% squared or 72%.

The primary shadow is then 0.32 x 0.9 x 0.72 or 20.7% open. The secondary shadow is 0.6 x 0.9 x 0.72 or 38.9% open. These factors are applied to the optical shadows calculated to determine the net rf shadow.

Applying these corrections to the 30-meter antenna, the following is obtained:

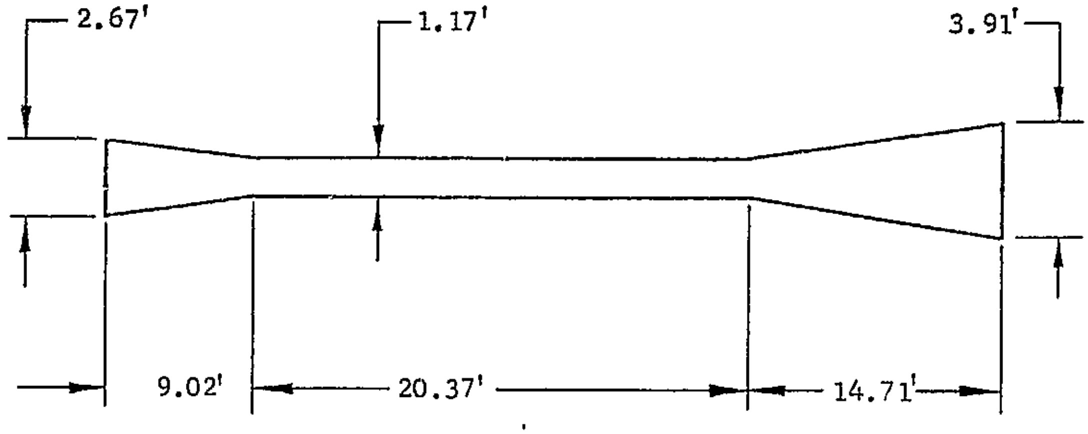
Direct Shading	0.21 x 0.793	0.017
Secondary Shading	0.020 x 0.611	0.012
Total Support Structure	Shadow	2.9%

The 34-meter antenna subreflector support truss is 9 inches wide, compared to 12 inches wide for the 30-meter antenna. Therefore, the open area for the 34-meter truss is 15% open for direct shading and 29% for the secondary shading. Using these scale estimates, the following is obtained:

Direct Shading	0.0125 x 0.85	0.011
Secondary Shading	0.0117 x 0.71	0.008
Total Support Structure	Shadow	1.9%

The total shadowing utilized in final performance calculations is as follows:

	30-Meter	34-Meter
Truss	2.9	1.9
Subreflector (estimate)	1.26	1.26
Total Blockage	4.2%	3.2%

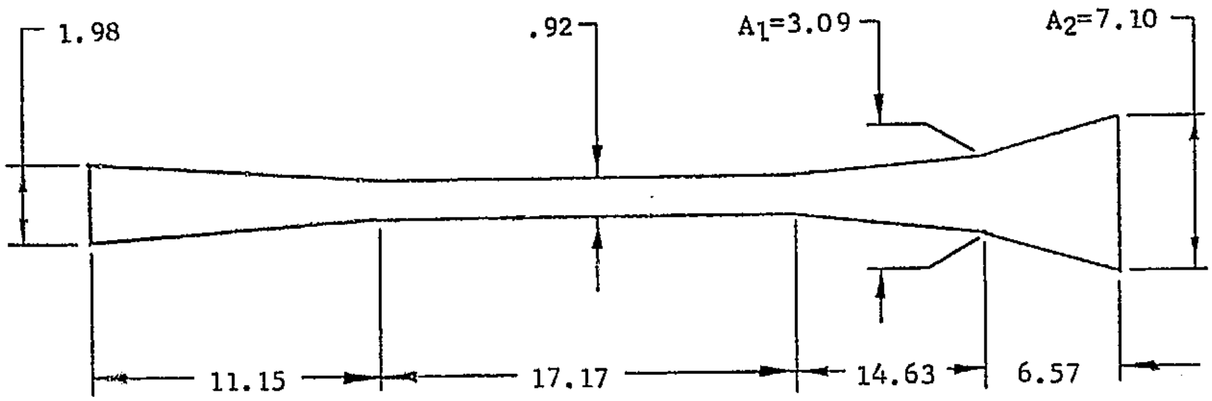


$$A = \frac{1.17 \times 49.2}{14.75} = 3.91'$$

SHADING DIAGRAM FOR ONE QUADRIPOD LEG

ITEM	CALCULATION		SQUARE FEET OF SHADOW
DIRECT SHADING	$4\left(\frac{2.67 + 1.17}{2}\right) 9.02$	=	69.27
	$4\,(1.17)\,20.37$	=	95.33
SECONDARY SHADING	$4\left(\frac{1.17 + 3.91}{2}\right) 14.7$	=	149.35
TOTAL SHADOW			313.95
TOTAL AREA	$\pi(49.20)^2$	=	7603.23
PERCENTAGE OF SHADING	$\frac{313.95 \times 100}{7603.23}$	=	4.1%

Figure B-1. 30-Meter Standard Antenna, Blockage Calculations



$$A_1 = \frac{0.92 \times 49.2}{14.63} = 3.09 \qquad A_2 = \frac{55.77 \times 1.37}{10.7} = 7.10$$

SHADING DIAGRAM FOR ONE TRIPOD LEG

ITEM	CALCULATION		SQUARE FEET OF SHADOW
DIRECT SHADING	$3\left(\frac{1.97 + 0.92}{2}\right) 11.15$	=	48.33
	$3\,(0.92)\,(17.17)$	=	47.39
SECONDARY SHADING	$3\left(\frac{0.92 + 3.09}{2}\right) 14.63$	=	88.00
	$3\left(\frac{3.09 + 7.10}{2}\right) 6.57$	=	100.42
TOTAL SHADOW			284.14
TOTAL AREA	$\pi(55.77)^2$	=	9771.27
PERCENTAGE OF SHADING	$\frac{284.14 \times 100}{9771.27}$	=	2.9%

Figure B-2. 34-Meter Modified Antenna, Blockage Calculations

APPENDIX C

STRUCTURAL/MECHANICAL ANALYSES

This appendix summarizes the structural and mechanical analyses that were performed to predict the performance of the 30-meter standard antenna and the 34-meter modified antenna. Included are discussions of loads, RF performance, and survivability of both antennas as well as a presentation of locked rotor frequencies for the 34-meter modified antenna.

1.0 LOAD DETERMINATION

The loads on the antenna structure are induced mainly by gravity and wind forces; seismic loads are also included. Consideration for thermal loads is neglected because the combination of gravity and wind loads governs over the combination of gravity and thermal loads.

The basic wind loads on the antenna reflector structure are derived from JPL wind tunnel test reports. Based on data from JPL Report JPL-CP-4, pressure distributions for various reflector orientations are developed (refer to Figure C-1). Similarly, calculations of resultant moments, drag, and lateral loads on the antenna reflector are based on data from JPL Report JPL-CP-3. Refer to Figure C-2 for typical antenna wind loads for the 30-meter standard antenna. Loads generated by wind forces acting on the other parts of the antenna structure are calculated using AISC and EIA Standards.

Gravity and other dead loads are calculated as follows. Weight of the panels is calcuated based on an average weight of 2.5 lb/ft^2 for standard panel designs. Weight of the reflector backup structure, including subreflector support structure and elevation wheel, is determined directly from the computer program with a 10% increase to account for joint details. Weight of the alidade structure is determined from the design and detail drawings taking into account all piece parts and the joints and corner weldments. Mechanical component weights are taken from vendors' drawings. Refer to Figure C-3 for the summary of weights and inertias of the 30-meter standard antenna.

From the superposition of gravity and wind loads, the resultant loads and moments at the elevation bearing, the azimuth track and the pintle bearing are determined. These moments and forces are summarized on Figure C-4.

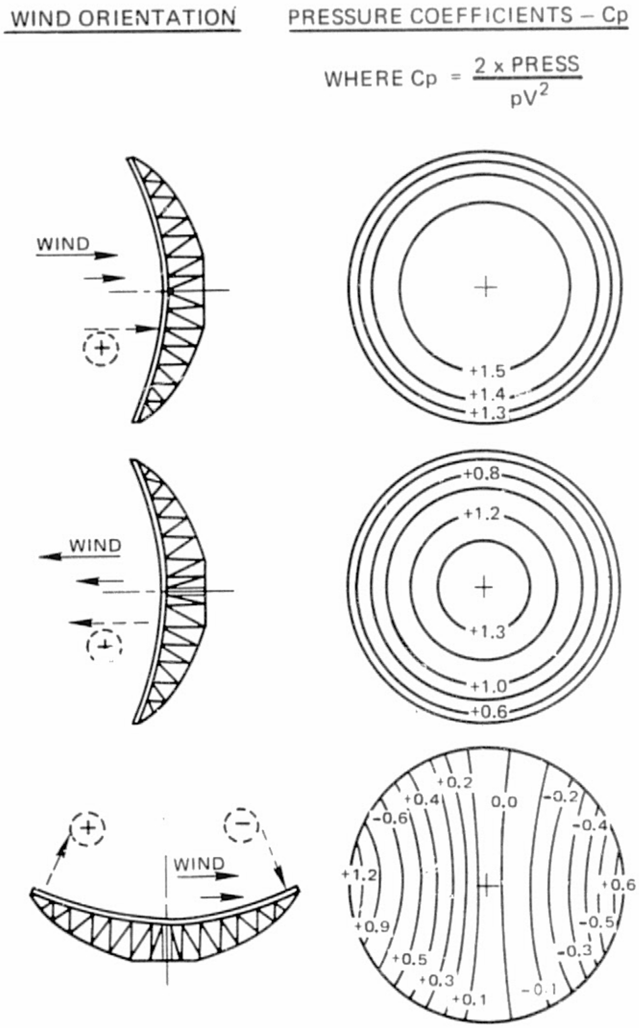


Figure C-1. Wind Pressure Distribution Across Reflector

Seismic loads are computed based on ground acceleration of 0.25g which is specified for Zone IV in the Uniform Building Code (UBC). Shear loads are calculated and distributed at various antenna components using the method specified in the UBC. Overturning moments are based on this shear distribution appropriately transferred to the antenna foundation. These loads are shown in Figure C-5 for the 30-meter standard antenna.

2.0 RF PERFORMANCE

Antenna rf performance (gain) is affected by blockage losses, optical losses, and pointing losses. Blockage loss is determined from the shading of the aperture by the subreflector and subreflector support structure. This is discussed in Appendix B. Optical losses, which are calculated in terms of phase errors, are caused by misalignment and distortion of the primary and secondary reflectors and include:

- Panel manufacturing and alignment errors
- Panel and backup structure distortions due to gravity and wind
- Subreflector and feed defocusing and miscollimation due to gravity and wind loads

Pointing loss is caused by the rf beam shift due to wind gusts. When the antenna is controlled by an autotrack system, all pointing errors having slow time variations are corrected. The only significant pointing error factors remaining are the effects of wind gusts on the antenna structure and servo.

2.1 Optical Losses

The fixed portion of the optical losses consists of: (a) panel manufacturing errors, (b) panel alignment errors, and (c) subreflector manufacturing error. The estimate of these errors is based on history of similar hardware. Manufacturing error of 30-meter antenna panels built by WDL is 0.020 inch rms (weighted average measured normal to the panel surface) based on actual factory measurements. These panels are installed and aligned in the field within 0.015 inch rms (measured normal to theoretical curve). This error includes tooling and instrumentation inaccuracies.

Reflector panel distortion errors are based on deflection calculations of panels under uniform 20 mi/h wind loads and gravity loads. Panel gravity distortion error for the zenith position is zero since the panel manufacturing error includes panel gravity error (ie, the panels are measured in the zenith look position to determine manufacturing errors).

The manufacturing error of the machined, solid surface subreflector is estimated to be less than 0.012 inch rms based on standard machining tolerances of such elements on a precision tracer mill. Subreflector distortions due to gravity and wind loads are estimated based on those obtained for similar subreflectors.

The main source of variable optical losses is the reflector distortions due to gravity and wind loads. The WDL RMS computer program (which is a modified version of the original JPL RMS program) is used to calculate reflector phase errors due to reflector distortions in terms of the half path length error. The same program also calculates the rf pointing error for the given prime focus geometry. In addition, this program calculates rf losses due to defocusing and miscollimation of the cassegrain optics.

Since the antenna operates between 15° and 90°, the panel alignment is done at an optimum elevation angle to minimize the peak gravity distortions over the normal travel range. Thus, the worst case distortions occur near the 15° elevation and zenith positions. The optimum elevation angles are 46° and 57° for 30-meter standard and 34-meter modified antennas respectively.

Reflector distortions due to wind loads are calculated for a 20 mi/h steady wind. These wind distortions, for a number of antenna orientations, are combined with gravity distortions to determine the total rms reflector distortions.

The total resulting phase error is calcualted by taking the rss of the aforementioned individual phase errors presented in terms of half path length errors. Refer to Attachment 1 of this appendix for the phase error summaries for different antenna orientations for both the WDL 30-meter standard antenna and the WDL 34-meter modified antenna.

Gain degradation due to optical losses is calculated using the following equation.

$$L_o = K \left(\frac{\sigma_p}{\lambda}\right)^2 \text{ dB}$$

where

K = constant

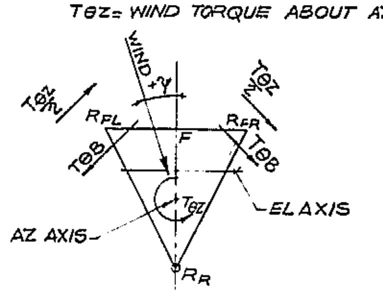
σ_p = rms half path length errors including surface distortions and defocusing

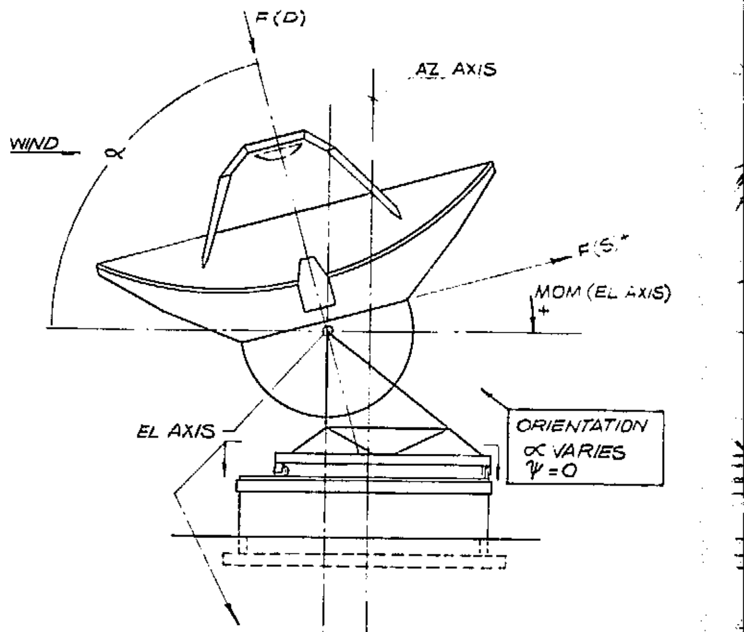
λ = wavelength

Gain losses due to optical path length errors are summarized in Table C-1 for various combinations of wind and gravity at different antenna orientations.

NOTATIONS:

R_P = REACTION AT PINTLE POST
α = ELEVATION ANGLE OR PITCH ANGLE
ψ = YAW ANGLE OR AZIMUTH ANGLE
R_{FL} = REACTION AT FRONT LEFT WHEEL
R_{FR} = REACTION AT FRONT RIGHT WHEEL
R_R = REACTION AT REAR WHEEL
F(D) = AXIAL FORCE PARALLEL TO REFLECTOR AXIS
F(S) = SIDE FORCE NORMAL TO REFLECTOR AXIS
$T_{\theta z}$ = WIND TORQUE ABOUT AZ-AXIS





EFF WIND TORQUE ON FRONT WHEEL — AVAILABLE TORQUE

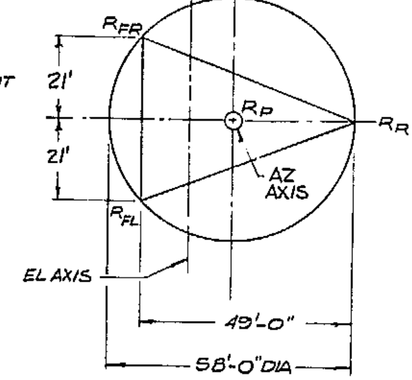
$$T_{FL} = \frac{T_{\theta z}}{2} + T_{\theta B} \leq (9.57)\,(R_{FL})$$

$T_{\theta B}$ = BIAS TORQUE ON FRONT WHEEL

$$T_{FR} = \frac{T_{\theta z}}{2} - T_{\theta B} \leq (9.57)\,(R_{FR})$$

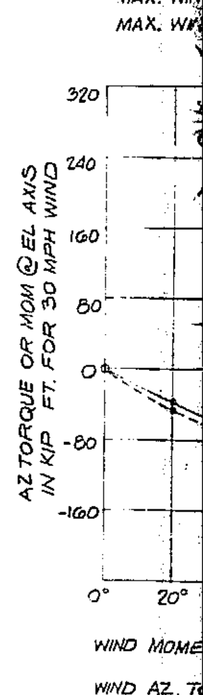
AVAILABLE TORQUE
$= R \times 29.0 \times 0.33 = 9.57 \times R$
WHERE 0.33 = COEF. OF FRICTION (TRACTION)
29.0 = RADIUS OF TRACK IN FT
R = REACTION ON WHEEL (D.L + WIND)

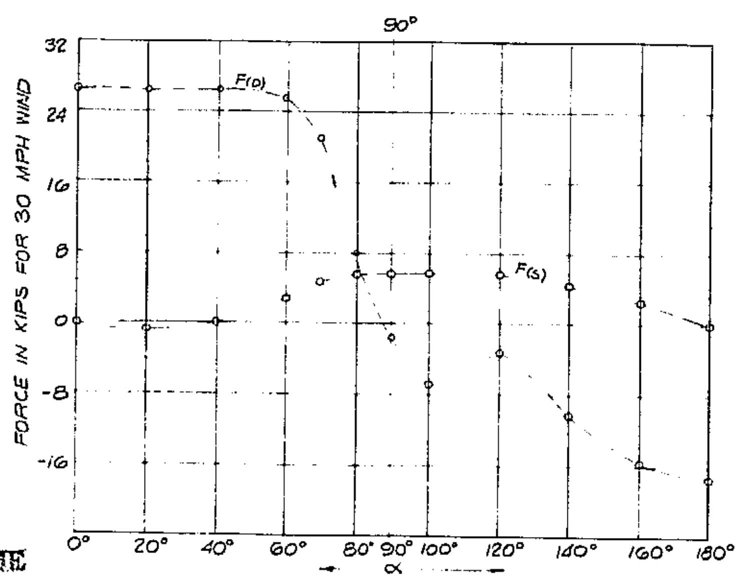
WIND TORQUE CRITERIA



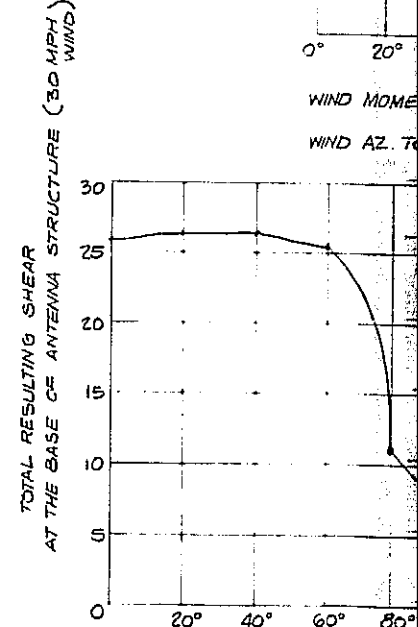
CHANGE IN VALUES W/R TO WIND VELOCITY FOR 30MPH	
VELOCITY (MPH)	FACTOR
30	1.00
45	2.25
70	5.45
80	7.11
'V' MPH	$(0.0011)(V)^2$

NOTE: MAX. VALUE OF 'V' = 80 MPH



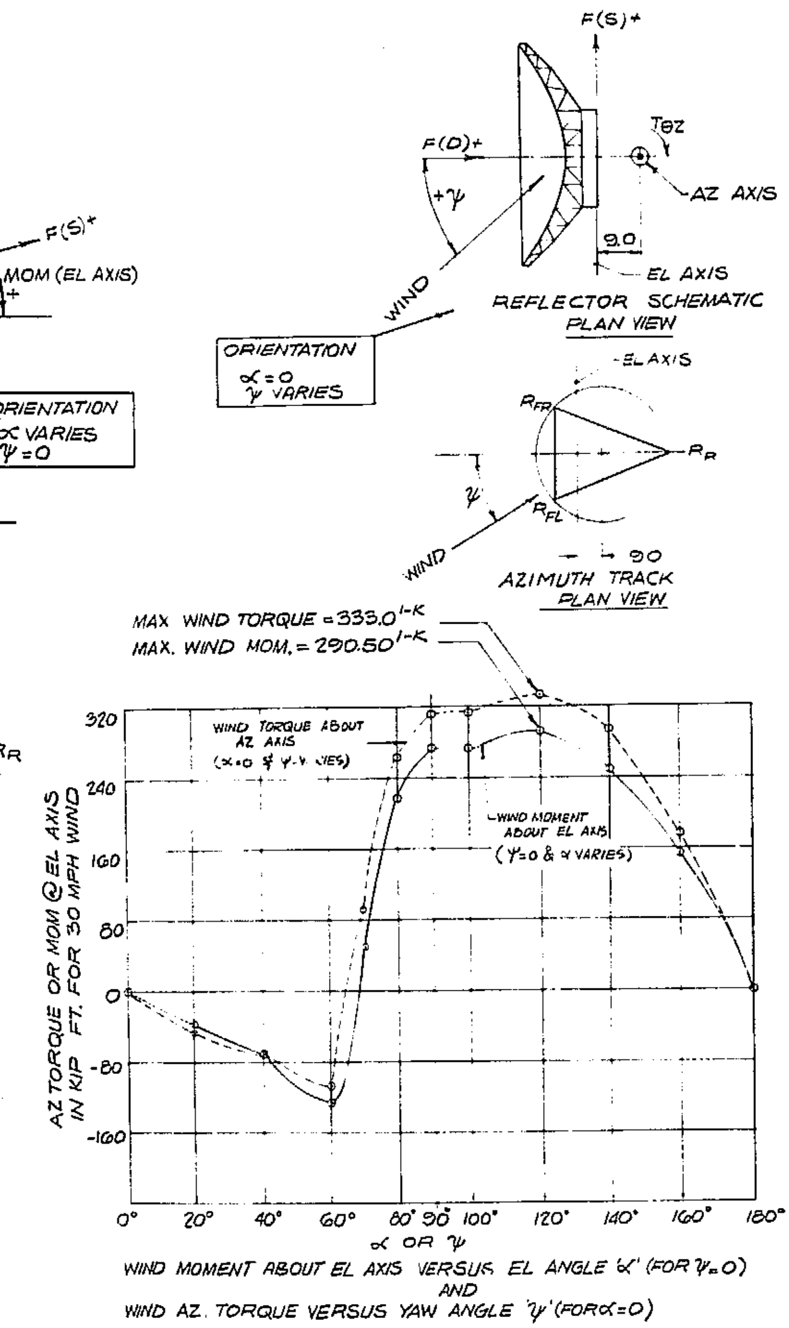


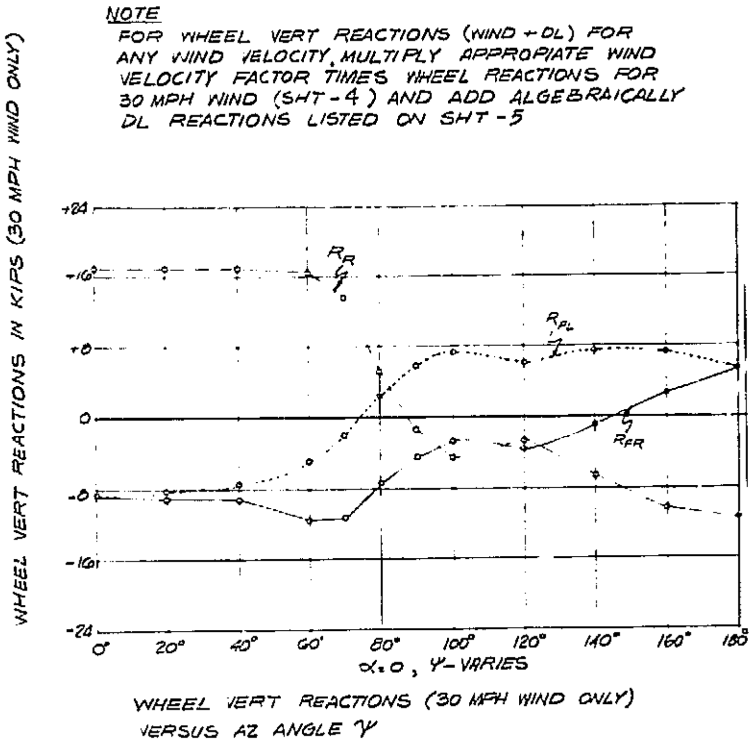
F(D) VERSUS α (FOR ψ=0) AND
F(S) VERSUS α (FOR ψ=0)

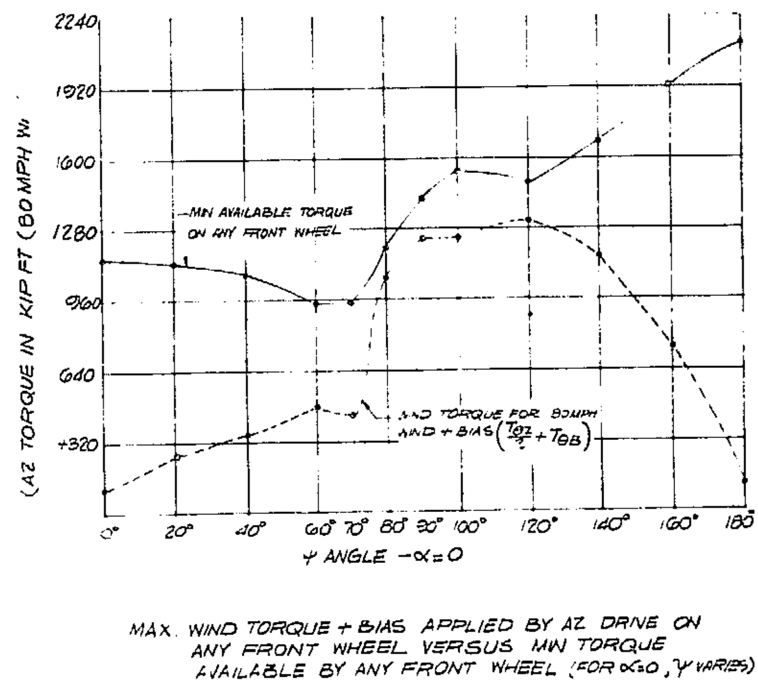


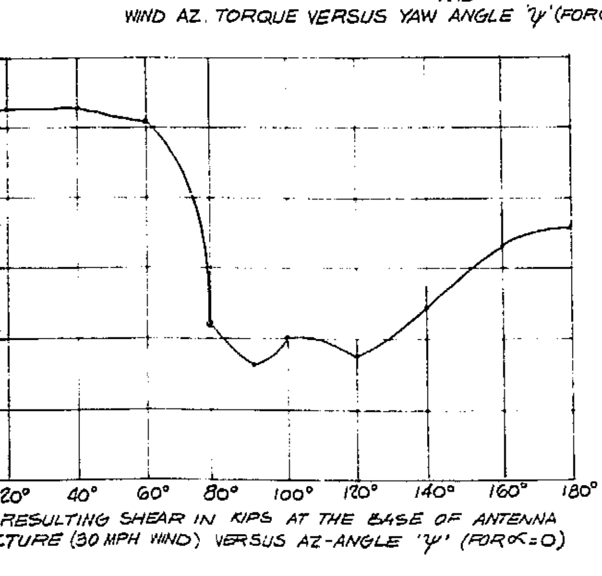
TOTAL RESULTING SHEAR IN
STRUCTURE (30 MPH WIND) VE

FOLDOUT FRAME





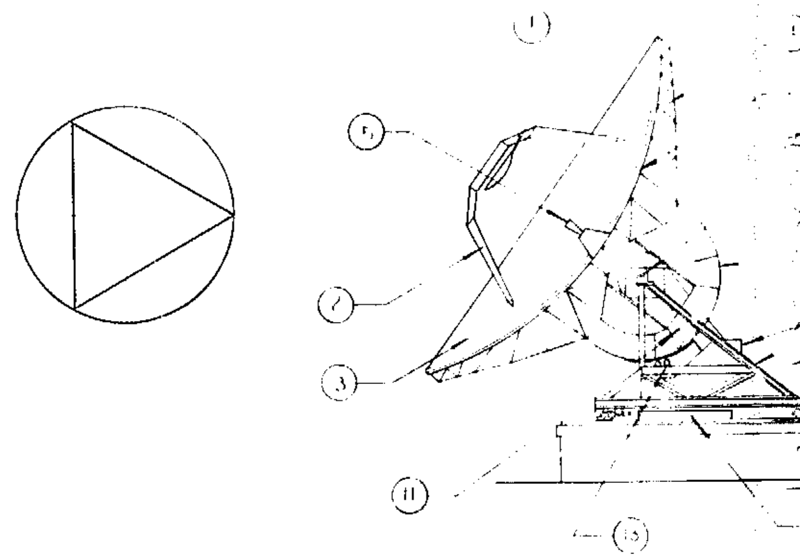




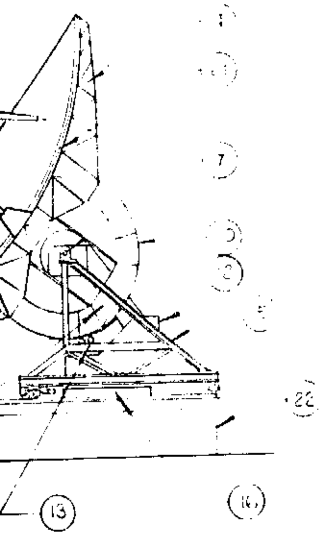
*TθB = BIAS TORQUE ON EACH FRONT WHEEL = 110 K.FT

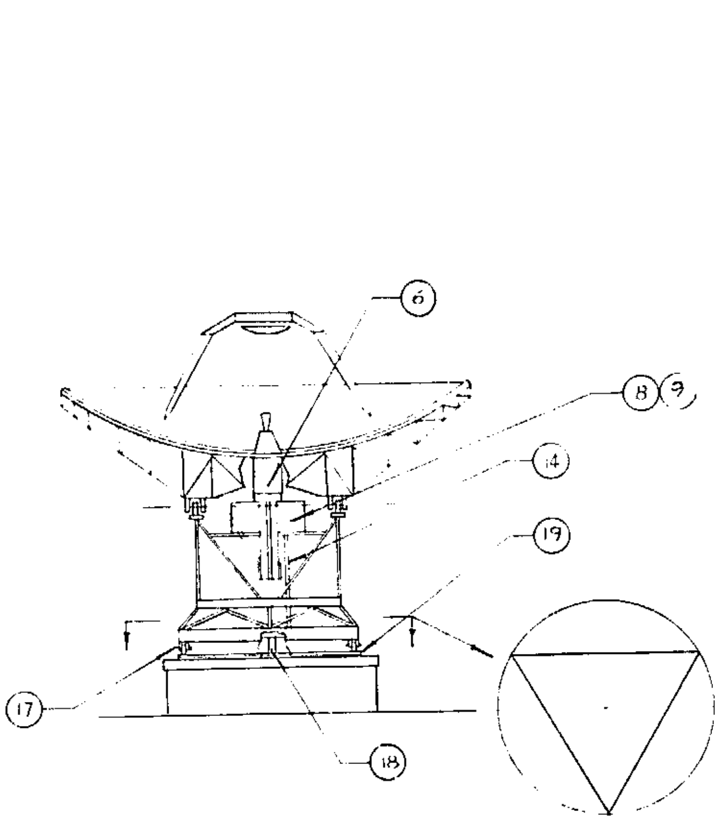
Figure C-2. Wind Loads on 30-Meter Standard Antenna

FOLDOUT FRAME



ITEM NO	DESCRIPTION	TOTAL WT LBS	$\bar{X}$ (FT) CG FROM EL AXIS	$(W)(\bar{X})$ (FT LBS) AT EL AXIS	I EL AXIS LB-FT SEC²	I AZ AXIS REFL AT 90° LB-FT SEC²	I AZ AXIS REF AT 0° LB-FT SEC²	WT ROTATING ABT EL AXIS (LBS)	WT AB[illegible]
MASS MOMENT OF INERTIA FOR ANTENNA COMPONENTS									
1	SUB REFLECTOR	300	45.0	13,500	0.019 x 10⁶	0.001 x 10⁶	0.027 x 10⁶	300	[illegible]
2	SUB-REF SUPPORT	6,000	39.4	236,400	0.34 x 10⁶	0.098 x 10⁶	0.482 x 10⁶	6 000	[illegible]
3	REFLECTOR PANEL	22,000	21.2	466 400	0.726 x 10⁶	0.891 x 10⁶	1.043 x 10⁶	22,000	[illegible]
4	REFL BACK UP STRUCT	105,000	10.62	1,115,100	1.564 x 10⁶	2.435 x 10⁶	2.460 x 10⁶	105 000	[illegible]
5	FEED CONE	3,000	9.0	27,000	0.009 x 10⁶	0.023 x 10⁶	0.030 x 10⁶	3 000	[illegible]
6	FEED ENCLOSURE	5,000	7.5	37,500	0.009 x 10⁶	0.013 x 10⁶	[illegible]	5 000	[illegible]
7	ELEVATION BEARINGS	4,000				0.042 x 10⁶	[illegible]		[illegible]
8	ELE. EQUIP RMS	10,000				0.042 x 10⁶	0.042 x 10⁶		[illegible]
9	ELECTRONIC EQUIP	5,000				0.021 x 10⁶	0.021 x 10⁶		[illegible]
10	ELEVATION WHEEL	25000	-10.0	-250,000	0.228 x 10⁶	0.193 x 10⁶	[illegible]	25 000	[illegible]
11	COUNTERWEIGHTS	106,400	-15.75	-1,675,800	0.862 x 10⁶	0.314 x 10⁶	0.165 x 10⁶	106 400	[illegible]
12	ELEVATION GEAR	2,000	-16.6	-33 200	0.023 x 10⁶	0.010 x 10⁶	0.004 x 10⁶	2 000	[illegible]
13	ELEVATION DRIVES	10,000				0.013 x 10⁶	0.013 x 10⁶		[illegible]
14	FURNISHINGS	10,000				0.070 x 10⁶	0.070 x 10⁶		[illegible]
15	AZIMUTH MOUNT	130,000				1.370 x 10⁶	1.370 x 10⁶		[illegible]
16	AZ-ENCLOSURE	8,000				0.090 x 10⁶	0.090 x 10⁶		[illegible]
17	AZ DRIVES & WHEELS	21,000				0.550 x 10⁶	0.550 x 10⁶		[illegible]
18	PINTLE BRG & POST	5,000				0.003 x 10⁶	0.003 x 10⁶		[illegible]
19	AZ TRACK	30,000							
20	LADDERS & PLATFORMS	22,000				0.066 x 10⁶	0.066 x 10⁶		[illegible]
21	DE-ICING EQUIPS	3,000	21.0	63,000	0.098 x 10⁶	0.122 x 10⁶	0.122 x 10⁶	3 000	[illegible]
22	CONC PEDESTAL AND FOUNDATION								
23									
24									
25									
TOTALS	TOTAL WT ITEM 1 THRU 21	532,700			3.877 x 10⁶	6.4[illegible] x 10⁶	6.627 x 10⁶	277700	[illegible]





MPONENTS		
L AXIS AT 0° S-FT²	WT ROTATING ABT EL AXIS (LBS)	WT ROTATING ABT AZ AXIS (LBS)
027×10^6	300	300
82×10^6	6,000	6 000
043×10^6	22,000	22 000
60×10^6	105 000	105,000
030×10^6	3,000	3 000
042×10^6	5,000	5 000
042×10^6		4,000
042×10^6		10,000
021×10^6		5,000
027×10^6	25 000	25,000
65×10^6	106 400	106,400
004×10^6	2,000	2,000
013×10^6		10,000
070×10^6		3,000
370×10^6		130 000
090×10^6		8,000
550×10^6		21,000
003×10^6		4,000
066×10^6		22,000
122×10^6	3,000	3,000
627×10^6	277,700	50[illegible] 700

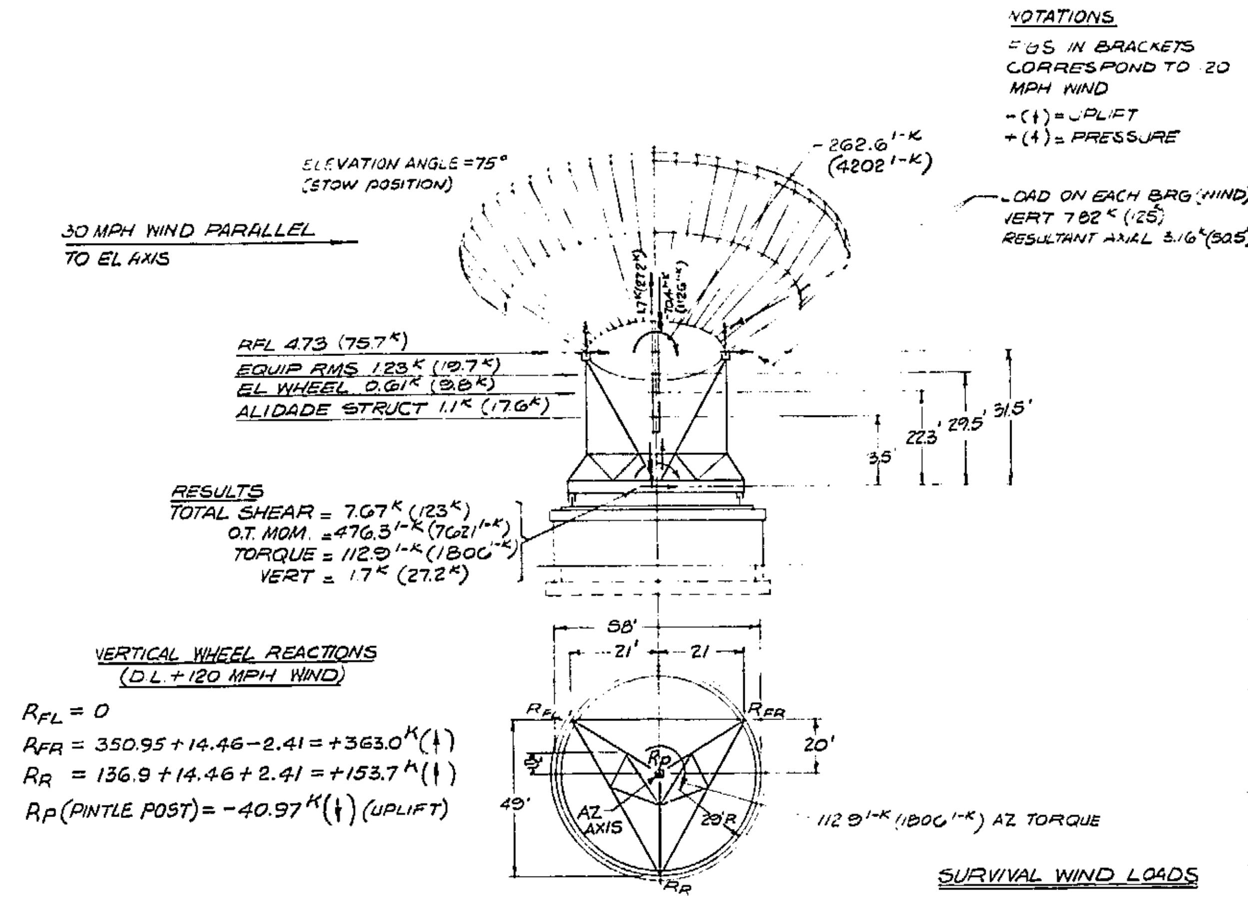
WEIGHT FOR 1 INCH RADIAL ICE ON ANTENNA COMPONENTS		
ITEM NO	DESCRIPTION	TOTAL WT LBS
1	SUB-REFLECTOR	800
2	SUB-REF SUPPORT	7000
3	REFLECTOR PANEL	90 000
4	REFL BACK UP STRUCT	124,000
5	FEED CONE	
6	FEED ENCLOSURE	
7	ELEVATION BEARING	
8	ELEC EQUIP RMS	3000
9	ELECTRONIC EQUIP	
10	ELEVATION WHEEL	6 600
	COUNTER WEIGHTS	
12	ELEVATION GEAR	
13	ELEVATION DRIVES	
14	FURNISHINGS	
15	AZIMUTH MOUNT	50000
16	AZ-ENCLOSURE	
17	AZ DRIVES & WHEELS	
18	PINTLE BRG & POST	
19	AZ TRACK	
20	LADDERS & PLATFORMS	4000
21	DE-ICING EQUIPS	
22	CONC PEDESTAL & FOUNDATION	
23		
24		
25		
TOTAL	TOT WT ITEM 1 THRU 20	285,400

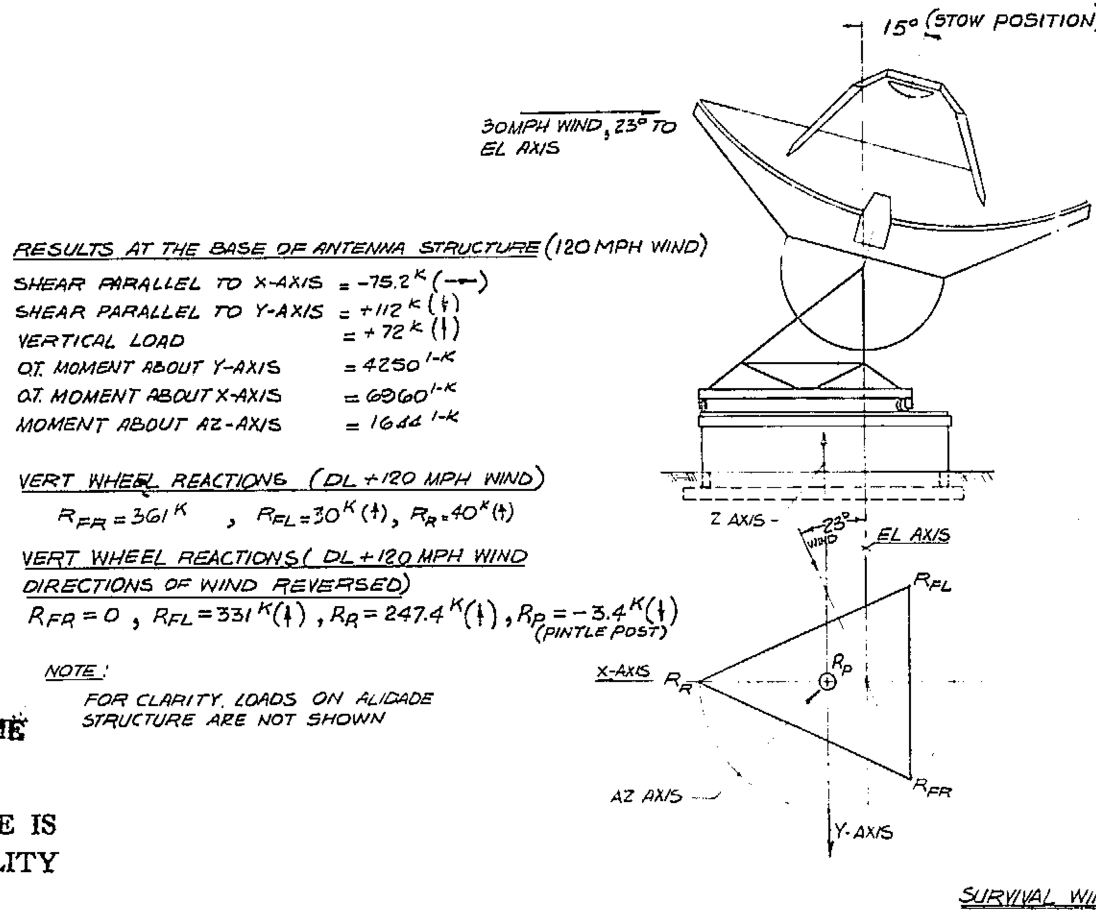
Figure C-3. Weight and Inertia of the 30-Meter Standard Antenna

2/

FOLDOUT FRAME

Ford Aerospace & Communications Corporation





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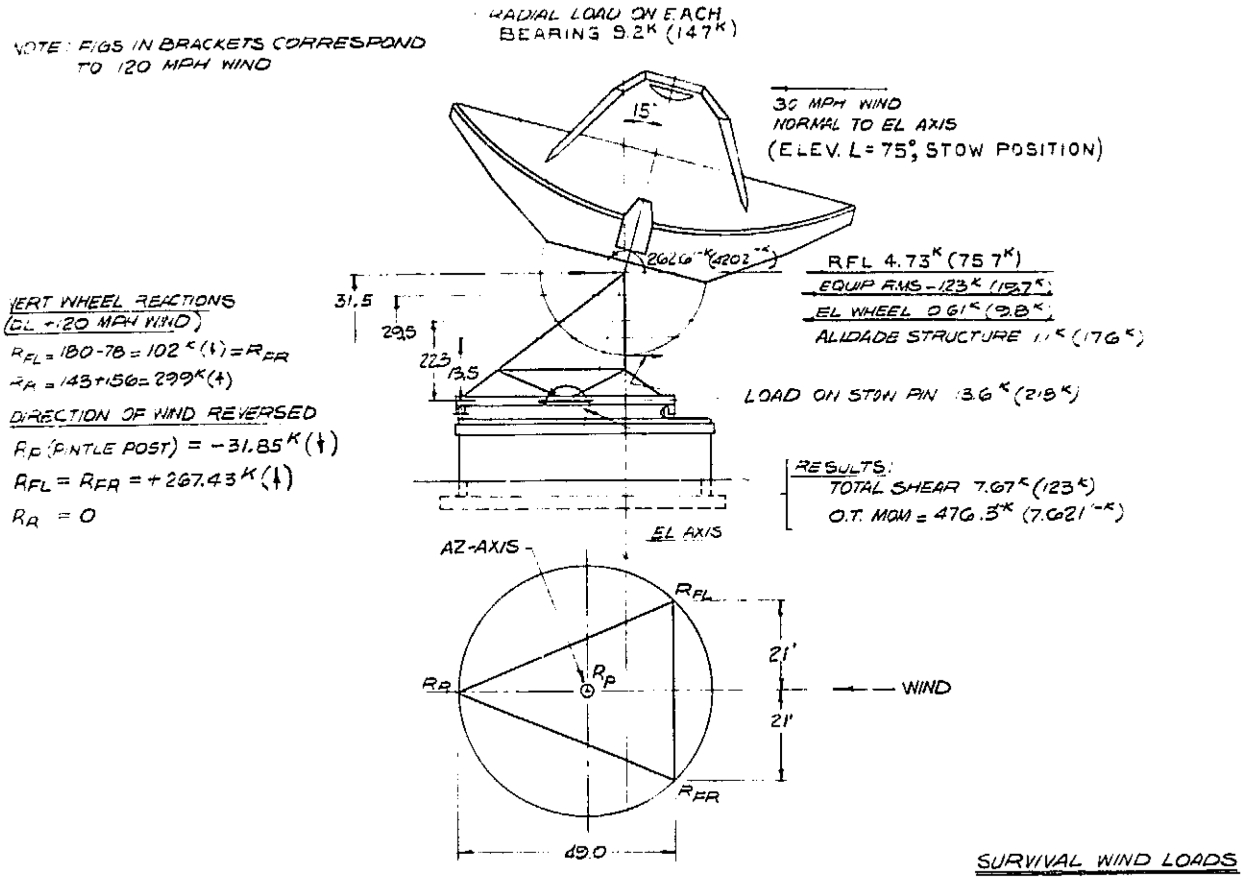
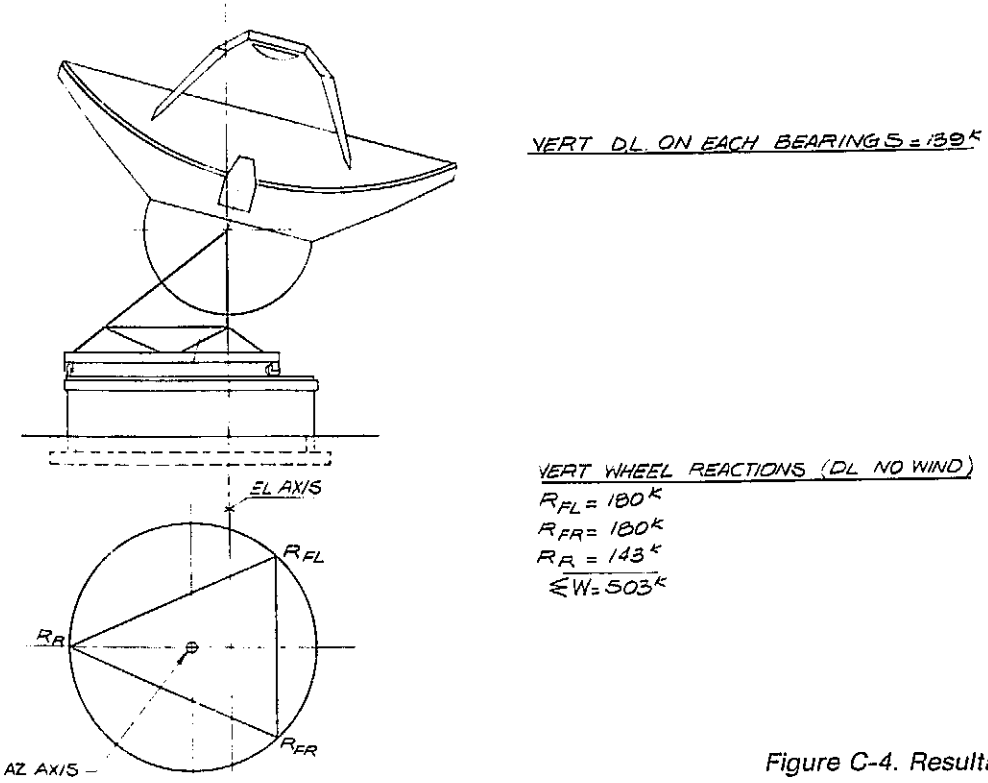
ORIGINAL PAGE IS OF POOR QUALITY

S
BRACKETS
POND TO 20
D
LIFT
ESSURE
EACH BRG (WIND)
K (125)
AXIAL 3.16K (50.5K)

D LOADS





D LOADS

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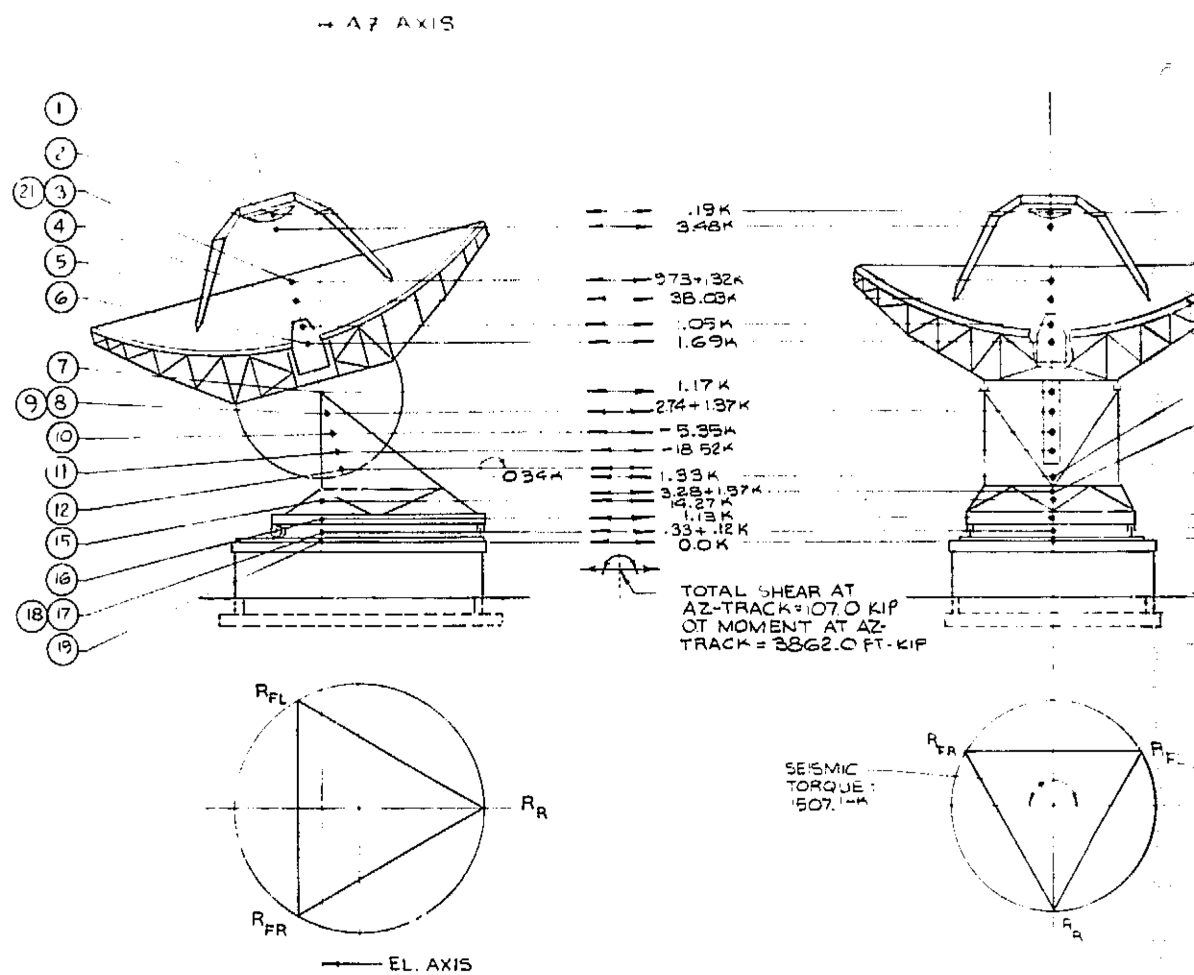
Figure C-4. Resultant Loads and Moments of the Standard Antenna Structure



SEISMIC + DL. REACTIONS	DIRECTION OF SEISMIC LOADS REVERSED
$R_R = 143K + 74K = 217K$ (↓)	$R_R = 143K - 74K = 69K$ (↓)
$R_{FL} = 180K - 37K = 143K$ (↓)	$R_{FL} = 180K + 37K = 217K$ (↓)
$R_{FR} = 180K - 37K = 143K$ (↓)	$R_{FR} = 180K + 37K = 217K$ (↓)

SEISMIC LOADS NORMAL TO ELEV AXIS

SEISMIC ANALYSIS

GROUND ACC^n (HORIZ) = 0.20^G

REF: U.B.C.

BASE SHEAR, $V = (.20)(W_{DL}) = (.20)(533^K) = 106.6^K$

SHEAR AT ANY LEVEL, $X = V_X = V\left(\frac{W_X h_X}{\Sigma W_X h_X}\right)$.

WHERE, W_X = MASS DESIGNATED AT LEVEL, X.

h_X = HEIGHT ABOVE THE BASE TO THE LEVEL DESIGNATED AS, X.

M_{OT} = BASE MOMENT AT THE TOP OF CONCRETE LEVEL
$= J\Sigma V_X h_X$, WHERE J = NUMERICAL COEFFICIENT FOR THE BASE MOMENT, (CONSERVATIVELY ASSUMED TO BE 1.0)

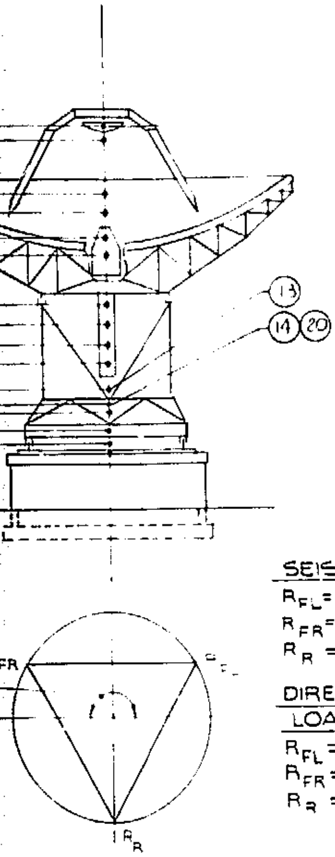
M_X = OVERTURNING MOMENT AT LEVEL, X.

$M_X = M_{O.T.}\left(\frac{H - h_X}{H}\right)$, WHERE H = HEIGHT ABOVE THE BASE FOR THE TOP-MOST MASS.

FOLDOUT FRAME

TE LEVEL
ENT FOR
(ASSUMED TO BE 1.0)

OVE THE BASE
OP-MOST MASS.



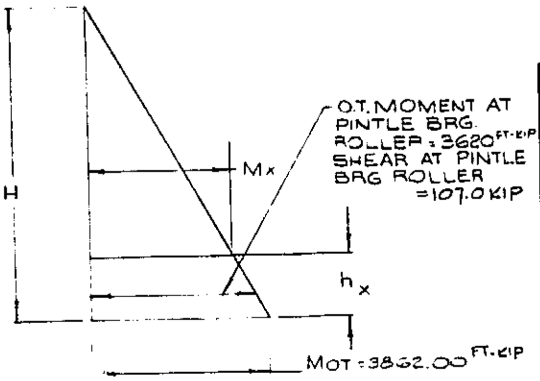


DIAGRAM SHOWING O.T. MOMENT AT ANY LEVEL, h_x

SEISMIC+DL. REACTIONS:

R_{FL} = 180 K + 86 K = 266 K (↓)
R_{FR} = 180 K − 86 K = 94 K (↓)
R_R = 143 K + 0 = 143 K (↓)

DIRECTION OF SEISMIC LOADS REVERSED:

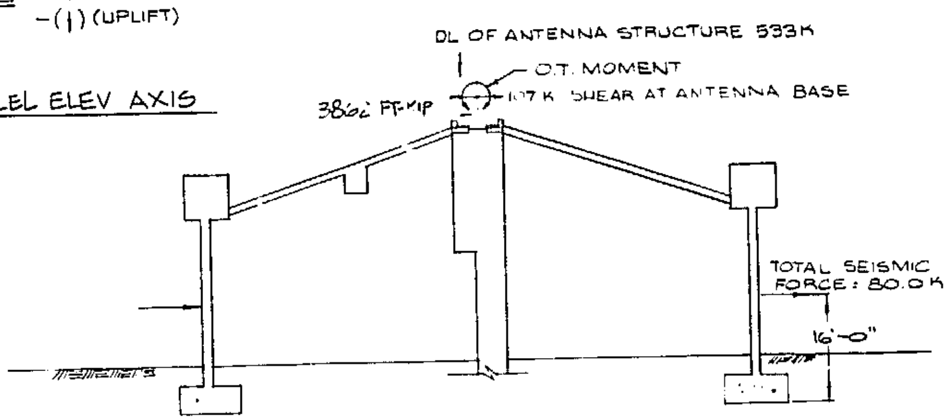
R_{FL} = 180 K − 86 K = 94 K (↓)
R_{FR} = 180 K + 86 K = 266 K (↓)
R_R = 143 K + 0 = 143 K (↓)

NOTE: +(↓) (PRESS)
−(↑) (UPLIFT)

SEISMIC LOADS PARALLEL ELEV AXIS

TABLE FOR SEISMIC ANALYSIS:
(REFLECTOR AT ELEV ANGLE = 75°)

LUMP MASS, FOR REF.	WEIGHT IN KIPS (W_x)	C.G FROM TOP of CONC (h_x) (FT)	C.G FROM AZ-AXIS (R_x) (FT)
1	.30	79.4	30.3
2	6.00	74.0	28.8
3	22.00	56.4	24.1
4	105.00	46.2	21.4
5	3.00	44.6	21.0
6	5.00	43.2	20.6
7	4.00	37.2	9.0
8	10.00	35.0	9.0
9	5.00	35.0	9.0
10	25.00	27.3	6.5
11	106.4	22.2	5.3
12	2.00	21.3	4.0
13	10.00	17.0	9.0
14	10.00	20.0	8.0
15	130.00	14.0	2.2
16	8.00	18.00	0
17	21.00	2.0	0
18	5.00	3.0	0
19	30.00	0.0	0
20	22.00	19.0	8.0
21	3.00	56.2	24.0
TOTAL	ΣW_x = 532.7 K		



SEISMIC LOADS ON CONCRETE

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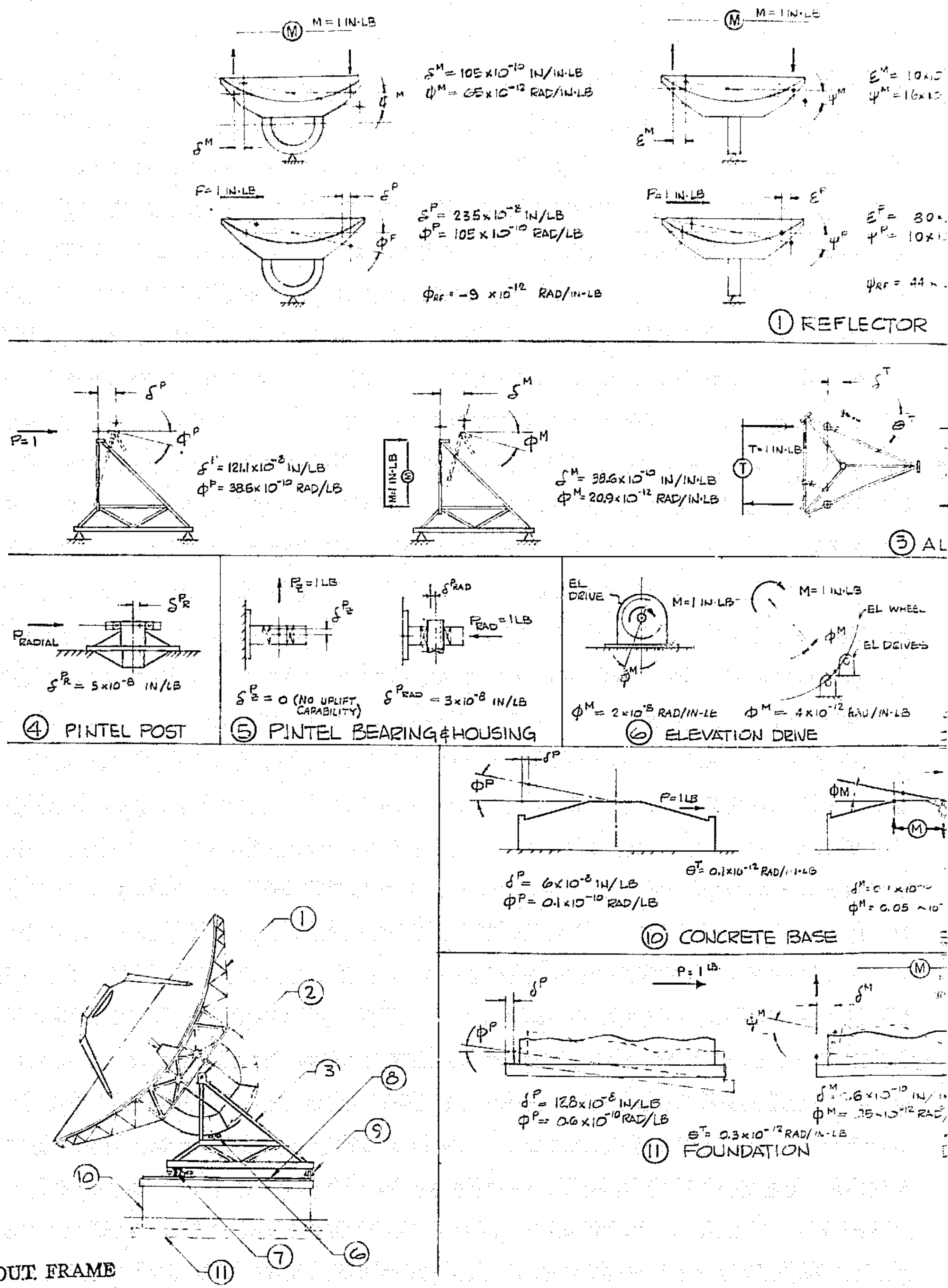
Figure C-5. Resultant Seismic Loads and Reactions



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WDL-TR7835

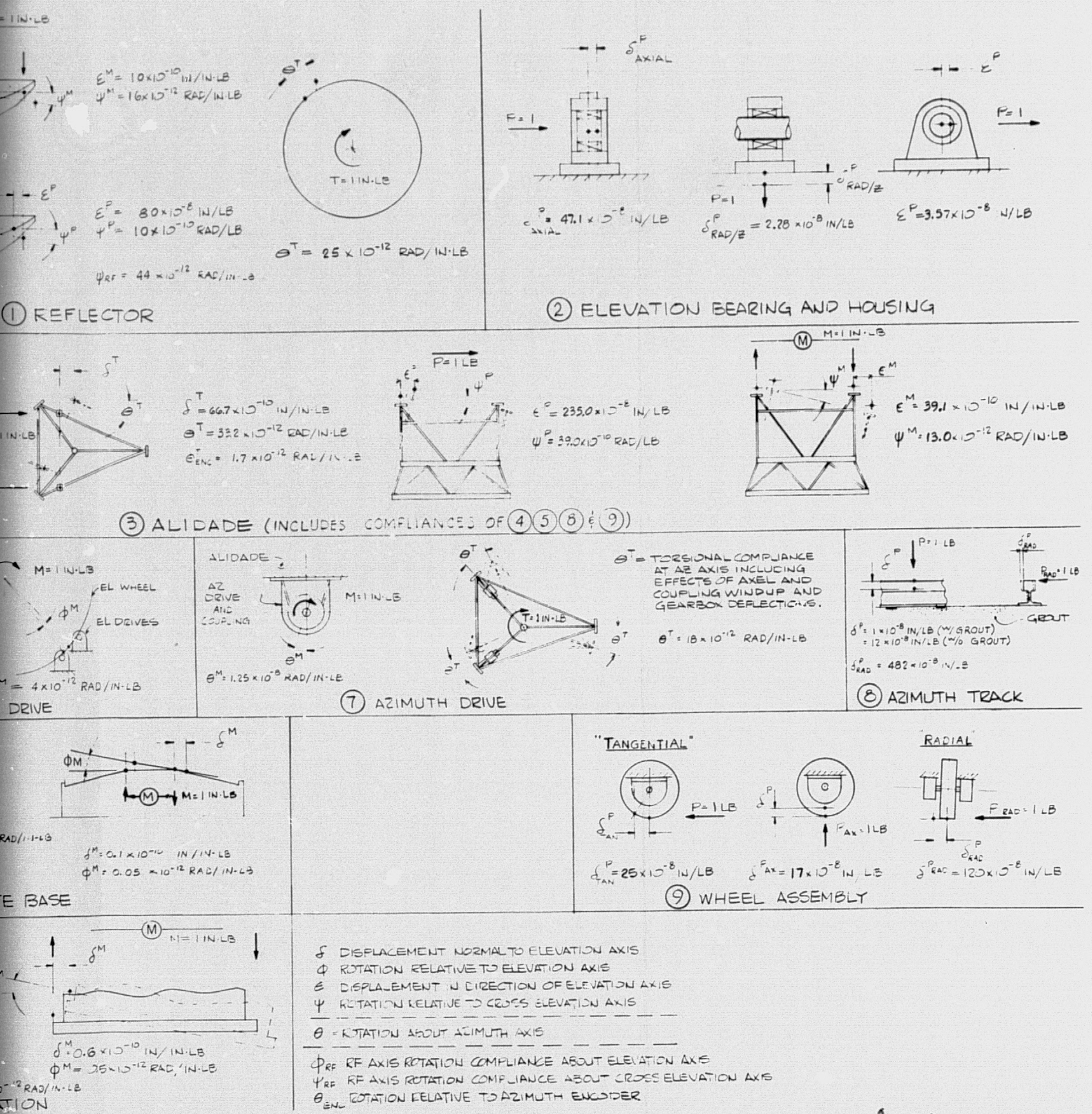

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Figure C-7. 30-Meter Antenna Structural Compliance

2.2 Pointing Losses

It has been empirically determined that gusting wind can be characterized as a random gusting velocity component superimposed on a constant (mean) speed. The time variation of structural deflections will be similar to that of the windspeed variations since structural response frequencies are considerably higher than any significant gust spectral components. If there were no gusts, an autotrack system would track out any errors due to steady wind-induced deflections. Thus, it is assumed that the average deflection caused by the mean wind speed is tracked out and the variations about the mean remain as pointing error.

The method of evaluating the magnitude of the wind gust deflections is well established when the mean and standard deviations of the windspeed spectrum are known. For this application is is assumed that mean windspeed is 20 mi/h gusting to 30 mi/h. This results in a windspeed standard deviation of 3.33 mi/h. Since the gust pointing errors are random in time, their magnitudes will be characterized by the rms value (standard deviation). For the assumed wind statistics, the rms random pointing error is approximately one third of the constant error in a steady 20 mi/h mean wind.

The relationship between the wind gust and steady mean wind errors is described as follows:

$$\sigma_v = \text{windspeed standard deviation} = k\mu_v$$

where

$$\mu_v = \text{mean windspeed}$$

Then:

$$V_p = \mu_v + 3\sigma_v = \text{peak windspeed (assuming peak is } 3\sigma \text{ value)}$$

Solving these equations,

$$k = \frac{\frac{V_p}{\mu_v} - 1}{3} = 1/6, \text{ for } \mu_v = 20 \text{ mi/h}, \; V_p = 30 \text{ mi/h}$$

If the wind velocity distribution is normal as assumed, the mean and standard deviations of the wind torque are given by

$$\mu_T = \text{mean wind torque} = K(\mu_v^2 + \sigma_v^2) = (1 + k^2)K\mu_v^2$$

$$\sigma_T = \text{wind torque standard deviation} = 2k(1 + \frac{k^2}{2})K\mu_v^2$$

$$\frac{\sigma_T}{\mu_T} = \frac{2k(1 + k^2/2)^{1/2}}{(1 + k)^2} = 0.33$$

For $\mu_v = 20$ mi/h, $\sigma_v = 3.34$ mi/h

Pointing losses are caused by pointing error of the antenna structure due to wind gust of approximately 4 mi/h which is equivalent to one third of the constant pointing error at 20 mi/h steady wind.

Gain loss due to wind gust pointing error is calculated using the standard equation:

$$L_p = 12 \frac{e_p^2}{\Theta_{HP}} \cdot$$

where

$$e_p = \text{pointing error value}$$

$$\Theta_{HP} = \text{half power beamwidth} = 1.0 \frac{\lambda}{D}$$

Structural wind gust pointing error includes the errors caused by the deformation of both reflector and pedestal structures. Reflector pointing error of a prime focus system due to steady wind is directly obtained from the WDL half path length RMS program. Correction for the cassegrain system is made by determining the relative displacement [δ (F)] of the feed phase center with respect to the displaced axis of the subreflector as shown in Figure C-6. Subreflector axis displacement takes into acount the rotation as well as the linear displacement of the subreflector.

The rf beam shift error caused by the feed displacement is calculated using the basic optics equation:

$$\Delta\Theta = \frac{\delta(F)}{MF}$$

where

M = magnification factor

F = focal distance

The resultant reflector pointing error including the correction for cassegrain optics system is calculated by adding the pointing error due to reflector deformation and rf beam shift due to feed offset.

$$\Theta_{RF} = \Theta_R + \Delta\Theta$$

The resultant reflector wind pointing error is then referenced to the elevation encoding system by removing the rotation measured by the encoder from the calculated value of the pointing error.

$$\overline{\Theta_{RF}} = \Theta_{RF} - \Theta_{ENC}$$

By dividing the reflector pointing error by the corresponding wind torque produced about the reflector vertex the reflector wind influence coefficient is calculated as

$$\Theta \frac{M}{R} = \frac{\overline{\Theta_{RF}}}{M_v}$$

Similarly, the influence coefficient about cross-elevation axis is obtained by dividing reflector wind cross-elevation pointing error by the wind torque value.

$$\psi \frac{M}{R} = \frac{\psi_{RF}}{M_v}$$

Wind influence coefficients of the pedestal are calculated by using an independent computer program taking into consideration the compliances of individual components of the pedestal including alidade structure, azimuth wheel and track, pintle post and bearing, elevation pillow blocks and drives, and foundation. The compliance values for the WDL 30-meter standard antenna are given in Figure C-7. A timeshare computer program is used to calculate the antenna structure pointing errors for various antenna and wind orientations using the combined reflector and pedestal influence coefficients and wind loads at the elevation axis as inputs.

These wind pointing errors are summarized in Attachment 2 to this appendix. Reflector and pedestal pointing errors are added algebraically prior to vector summing of elevation and cross-elevation errors to obtain the resultant pointing error of the antenna structure. The wind gust pointing errors are calculated by multiplying the structural pointing error for 20 mi/h steady wind by the 1/3 gust factor.

Additional wind gust pointing errors are caused by inability of the servo/drive system to respond to the disturbances resulting from the wind gusts. Most of the conventional servo/drive systems are capable of eliminating the effect of steady wind. Therefore, only the pointing error caused by wind gust is considered in computing servo/drive pointing error. The values of antenna structure and servo wind gust pointing errors are summarized in Table C-2 for different orientations of the antenna structure for both the 30-meter standard and 34-meter modified antennas.

2.3 Antenna Gain/Loss Summary

The error components and totals in Tables C-3 and C-4 represent the worst situations when pointing errors are combined with optical losses. Blockage losses are not included in these summaries. Overall gain improvement in the 34-meter modified antenna is due to the outboard counterweighted reflector concept.

3.0 SURVIVABILITY

This section addresses the survivability of the structural and mechanical components of the 30 and 34-meter antennas.

The WDL 30-meter standard antenna is designed to survive winds up to 120 mi/h without permanent deformation when in the stow position. The increase in reflector diameter from 30 to 34 meters has no impact since the 34-meter antenna survival requirement (100 mi/h wind) is reduced by about the same ratio.

$$\left(\frac{D_{34}}{D_{30}}\right)^3 \times \left(\frac{W_{100}}{W_{120}}\right)^2 \cong 1.00$$

3.1 Structural Components

Analysis of the structural components is divided into two distinct assemblies: the reflector assembly and the pedestal assembly (alidade structure). The reflector assembly, which consists of reflector backup structure, subreflector support structure, and ele-

Table C-1. Optical Losses Summary

Reflector Elevation Angle, Wind Direction	Losses due to Gravity/Gravity and Wind/Load Conditions			
	30-Meter Standard Antenna		34-Meter Modified Antenna	
	σp Phase Error (Inches)	Lo Gain Loss (dB)	σp Phase Error (Inches)	Lo Gain Loss (dB)
GRAVITY LOAD CONDITIONS				
Reflector @ 15°	0.056	1.10	0.041	0.59
Reflector @ 90°	0.058	1.18	0.042	0.62
Reflector @ 46°	0.025	0.22	–	–
Reflector @ 57°	–	–	0.026	0.24
GRAVITY AND WIND LOAD CONDITIONS				
Reflector @ 15°, wind from rear	0.058	1.18	0.045	0.71
Reflector @ 15°, wind 60° off rear	0.056	1.10	0.042	0.62
Reflector @ 57°, wind from rear	0.027	0.26	0.027	0.26

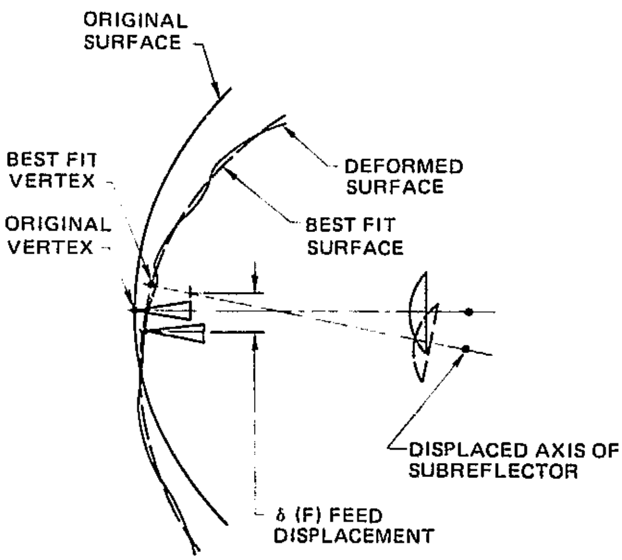

Figure C-6. Relative Displacement of Feed Phase Center with Respect to Displaced Axis of Subreflector

vation wheel, is analyzed by a three-dimensional space frame computer program. Because of the symmetry only one quadrant of the reflector assembly is analyzed. Several loading combinations are employed to define the maximum tensile and compressive stresses. Individual loading cases are combined using the WDL FORCESUM program to perform the proper combination for each quadrant to determine maximum and minimum axial stresses within the same member group. Bending stresses due to wind acting on the members are calculated using proper shielding factors per the EIA Standards. Bending stresses due to dead weight are neglected.

Bending and axial stresses are combined using the AISC interaction equation to determine the margin of safety for each group of members.

$$\frac{f_a}{F_a} + \frac{C_{mx}\, f_{bx}}{F_{bx}\left(1 - \frac{f_a}{F'_a}\right)} + \frac{C_{my}\, f_{by}}{F_{by}\left(1 - \frac{f_a}{F'_a}\right)} \leqslant 1.0$$

Most of the members in the reflector assembly of both the 30-meter standard and 34-meter modified antennas have factors of safety against material yield or buckling of 1.25 or greater.

The antenna pedestal alidade structure is analyzed using a space frame computer program. Azimuth wheels and pintle bearing are simulated by structural members with equivalent compliances in the analytical model. The AISC interaction equation is used to combine the bending and axial stresses, and most of the members have a margin of safety against buckling or material yield greater than 1.25.

3.2 Mechanical Components

All mechanical components are thoroughly analyzed to ensure adequate survival load capabilities. The 30-meter standard antenna components are designed for 80 mi/h winds in any antenna orientation and 120 mi/h winds in the stowed position. For the 34-meter modified antenna, the safety factors for these mechanical components are calculated for 50 mi/h winds in any antenna orientation and 100 mi/h winds in the stowed position.

To check the survivability of azimuth wheels and track, octahedral shear stresses are calculated for maximum wheel load and compared to the allowable stress for the material and hardness of azimuth wheels and track. Maximum wheel load occurs in 120 mi/h winds for the 30-meter standard antenna and in 100 mi/h winds for the 34-meter modified antenna.

To check the survivability of azimuth and elevation speed reducers, maximum output torque is compared to the survival capacity of the selected speed reducers. Maximum output torque is required to drive the 34-meter modified antenna to stow in 50 mi/h winds.

To check the survivability of elevation gear teeth, maximum tooth load is calculated based on survival output torque of the speed reducer. Using American Gear Manufacturers Association (AGMA) standard equations, maximum bending stress is then calculated and compared to AGMA allowables for the gear teeth based on the hardness of the teeth.

The elevation drive system for the 34-meter modified antenna is somemwhat different than for the 30-meter standard antenna. Due to the pedestal geometry, it is more efficient and less expensive to use a tangential-link adaptive drive assembly (a proven design modified to be compatible with the 34-meter antenna). The adaptive drive allows for a more closely aligned gear mesh throughout the limits of antenna travel. Although the method of analysis is similar, the survival factor of safety is increased.

Table C-5 summarizes loads and factors of safety for wheels, track, drives and elevation gear for 30-meter standard and 34-meter modified antennas.

4.0 LOCKED ROTOR FREQUENCIES OF 34-METER MODIFIED ANTENNA

The 34-meter modified antenna LRF calculations are made using Rayleigh's method and are based on the following assumptions:

a. Assume one lump mass.
b. Consider the reflector as the lump mass and the pedestal as the spring.
c. Assume the compliance of the 34-meter antenna pedestal is the same as the 30-meter antenna pedestal. This is a conservative assumption because the alidade of the 34-meter antenna is designed for the same pointing error as that of the 30-meter antenna.
d. Relationship between frequencies for the 30-meter and 34-meter antennas is:

$$\frac{(f_{34})^2}{(f_{30})^2} = \frac{(I \cdot \dot{\Theta})_{30}}{(I \cdot \Theta)_{34}}$$

where

I = reflector inertia about azimuth axis

Θ = rotational compliance of pedestal assembly

where

I = reflector inertia about azimuth axis
= rotational compliance of pedestal assembly

The 34-meter modified antenna LRF's in the three major modes are:

f_{EL} = 1.8 Hz
f_{AZ} = 1.6 Hz (reflector at zenith)
f_{AZ} = 1.7 Hz (reflector at horizon)

Table C-2. Wind Gust Pointing Error Summaries

Wind Load Direction	Reflector Elevation Angle	Structural Pointing Error (degrees)			
		Mean Speed 20 mi/h	1 σ Gust	Servo/Drive 1 σ Gust	Total Pointing Error
34-METER MODIFIED ANTENNA					
Wind from rear	15°	0.0042	0.0014	0.0006	0.0020
Wind 60° off rear	15°	0.0086	0.0029	0.0005	0.0034
Wind from rear at Look Angle	57°	0.0039	0.0013	0.0015	0.0028
30-METER STANDARD ANTENNA					
Wind from rear	15°	0.003	0.001	0.0004	0.0014
Wind 60° off rear	15°	0.0068	0.0023	0.0004	0.0027
Wind from rear at Look Angle	46°	0.0026	0.0009	0.0006	0.0015

Table C-3. Total Loss (dB) Summary of 30-Meter Standard Antenna

Reflector Elevation Angle, Wind Direction	Losses due to Gravity/Gravity and Wind Load Conditions				
	Reflector System		Pointing		
	σp (Inch)	Loss (dB)	1σ Gust	Loss (dB)	Total Loss (dB)
GRAVITY LOAD CONDITIONS					
Reflector @ 15°	0.056	1.10	0	0	1.10
Reflector @ 90°	0.058	1.18	0	0	1.18
Reflector @ 46°	0.025	0.22	0	0	0.22
GRAVITY AND WIND LOAD CONDITIONS					
Reflector @ 15°, wind from rear	0.058	1.18	0.0014	0.005	1.19
Reflector @ 15°, wind 60° off rear	0.056	1.10	0.0027	0.019	1.12
Reflector @ 46°, wind from rear	0.027	0.26	0.0015	0.006	0.27

Table C-4. Total Loss (dB) Summary of 34-Meter Modified Antenna

Reflector Elevation Angle, Wind Direction	Losses due to Gravity/Gravity and Wind Load Conditions				
	Reflector System		Pointing		Total Loss (dB)
	σp (Inch)	Loss (dB)	1σ Gust	Loss (dB)	
GRAVITY LOAD CONDITIONS					
Reflector @ 15°	0.041	0.59	0	0	0.59
Reflector @ 90°	0.042	0.62	0	0	0.62
Reflector @ 57°	0.026	0.24	0	0	0.24
GRAVITY AND WIND LOAD CONDITIONS					
Reflector @ 15°, wind from rear	0.045	0.71	0.002	0.013	0.73
Reflector @ 15°, wind 60° off rear	0.042	0.62	0.0034	0.039	0.66
Reflector @ 57°, wind from rear	0.027	0.26	0.0028	0.026	0.29

able C-5. Mechanical Components Survival Analysis

Parameter	Characteristics	
	30-Meter Standard Antenna	34-Meter Modified Antenna
Azimuth Wheel & Track		
Survival Load	363,000 lb	406,000 lb
Calculated Octahedral Shear Stress	46,260 lb/in^2	48,920 lb/in^2
Allowable Octahedral Shear Stress	61,280 lb/in^2	61,280 lb/in^2
Safety Factor	1.32	1.25
Azimuth Drive		
Survival Torque	690,000 in-lb	392,000 in-lb
Allowable Torque	980,000 in-lb	980,000 in-lb
Safety Factor	1.42	2.5
Elevation Drive		
Survival Torque	220,000 in-lb	125,000 in-lb
Allowable Torque	295,000 in-lb	295,000 in-lb
Safety Factor	1.34	2.35
Elevation Gear & Pinion		
Survival Tooth Load	49,000 lb	27,900 lb
Calculated Bending Stress	43,700 lb/in^2	24,800 lb/in^2
Allowable Bending Stress	90,800 lb/in^2	90,800 lb/in^2
Safety Factor	2.07	3.66

APPENDIX C, ATTACHMENT 1

REFLECTOR SYSTEM ERRORS

30-METER

REFLECTOR SYSTEM ERROR* (PHASE ERROR)

REFLECTOR ORIENTATION : EL ANGLE = 15°
WIND VELOCITY : 0 mi/h
WIND DIRECTION : ψ = — °
ANTENNA LOADS : GRAVITY ONLY

ERROR SOURCE	HALF PATH LENGTH ERROR – σ_p (in)
A. MAIN REFLECTOR	
1.0 PANEL MANUFACTURING	.015
2.0 PANEL ALIGNMENT	.014
3.0 PANEL DISTORTIONS	.006
4.0 BACKUP STRUCTURE DISTORTIONS	.046
SUBTOTAL RSS FOR 'A'	.052
B. SUBREFLECTOR	
1.0 MANUFACTURING	.009
2.0 SUBREFLECTOR DISTORTIONS	.004
SUBTOTAL RSS FOR 'B'	.010
C. SUBREFLECTOR DEFOCUSING	
1.0 AXIAL DEFOCUSING	.015
2.0 RADIAL DEFOCUSING	.009
SUBTOTAL RSS FOR 'C'	.018
TOTAL RSS PHASE ERROR	.056

* PANELS ALIGNED AT EL ANGLE = 46°

30-METER
REFLECTOR SYSTEM ERROR * (PHASE ERROR)

REFLECTOR ORIENTATION: EL ANGLE = 46°
WIND VELOCITY: 0 mi/h
WIND DIRECTION: ψ = — °
ANTENNA LOADS: GRAVITY ONLY

ERROR SOURCE	HALF PATH LENGTH ERROR - σ_p (in)
A. MAIN REFLECTOR	
1.0 PANEL MANUFACTURING	.018
2.0 PANEL ALIGNMENT	.014
3.0 PANEL DISTORTIONS	.004
4.0 BACKUP STRUCTURE DISTORTIONS	0
SUBTOTAL RSS FOR 'A'	.023
B. SUBREFLECTOR	
1.0 MANUFACTURING	.009
2.0 SUBREFLECTOR DISTORTIONS	.003
SUBTOTAL RSS FOR 'B'	.010
C. SUBREFLECTOR DEFOCUSING	
1.0 AXIAL DEFOCUSING	0
2.0 RADIAL DEFOCUSING	0
SUBTOTAL RSS FOR 'C'	0
TOTAL RSS PHASE ERROR	.025

* PANELS ALIGNED AT EL ANGLE = 46°

30-METER

REFLECTOR SYSTEM ERROR* (PHASE ERROR)

REFLECTOR ORIENTATION : EL ANGLE = 90 °
WIND VELOCITY : 0 mi/h
WIND DIRECTION : ψ = — °
ANTENNA LOADS : GRAVITY ONLY

ERROR SOURCE	HALF PATH LENGTH ERROR – σ_p (in)
A. MAIN REFLECTOR	
1.0 PANEL MANUFACTURING	.018
2.0 PANEL ALIGNMENT	.014
3.0 PANEL DISTORTIONS	0
4.0 BACKUP STRUCTURE DISTORTIONS	.046
SUBTOTAL RSS FOR 'A'	.051
B. SUBREFLECTOR	
1.0 MANUFACTURING	.009
2.0 SUBREFLECTOR DISTORTIONS	0
SUBTOTAL RSS FOR 'B'	.009
C. SUBREFLECTOR DEFOCUSING	
1.0 AXIAL DEFOCUSING	.009
2.0 RADIAL DEFOCUSING	.024
SUBTOTAL RSS FOR 'C'	.026
TOTAL RSS PHASE ERROR	.058

* PANELS ALIGNED AT EL ANGLE = 46 °

30-METER
REFLECTOR SYSTEM ERROR* (PHASE ERROR)

REFLECTOR ORIENTATION: EL ANGLE = 15°
WIND VELOCITY: 20 mi/h
WIND DIRECTION: ψ = 180°
ANTENNA LOADS: GRAVITY + BACK WIND

ERROR SOURCE	HALF PATH LENGTH ERROR – σ_p (in)
A. MAIN REFLECTOR	
1.0 PANEL MANUFACTURING	.018
2.0 PANEL ALIGNMENT	.014
3.0 PANEL DISTORTIONS	.010
4.0 BACKUP STRUCTURE DISTORTIONS	.047
SUBTOTAL RSS FOR 'A'	.053
B. SUBREFLECTOR	
1.0 MANUFACTURING	.009
2.0 SUBREFLECTOR DISTORTIONS	.004
SUBTOTAL RSS FOR 'B'	.010
C. SUBREFLECTOR DEFOCUSING	
1.0 AXIAL DEFOCUSING	.019
2.0 RADIAL DEFOCUSING	.009
SUBTOTAL RSS FOR 'C'	.021
TOTAL RSS PHASE ERROR	.058

* PANELS ALIGNED AT EL ANGLE = 46°

30-METER

REFLECTOR SYSTEM ERROR* (PHASE ERROR)

REFLECTOR ORIENTATION : EL ANGLE = 46 °

WIND VELOCITY : 20 mi/h

WIND DIRECTION : ψ = 180 °

ANTENNA LOADS : GRAVITY + BACK WIND

ERROR SOURCE	HALF PATH LENGTH ERROR - σ_p (in)
A. MAIN REFLECTOR	
1.0 PANEL MANUFACTURING	.018
2.0 PANEL ALIGNMENT	.014
3.0 PANEL DISTORTIONS	.006
4.0 BACKUP STRUCTURE DISTORTIONS	.003
SUBTOTAL RSS FOR 'A'	.024
B. SUBREFLECTOR	
1.0 MANUFACTURING	.009
2.0 SUBREFLECTOR DISTORTIONS	.003
SUBTOTAL RSS FOR 'B'	.010
C. SUBREFLECTOR DEFOCUSING	
1.0 AXIAL DEFOCUSING	.003
2.0 RADIAL DEFOCUSING	.004
SUBTOTAL RSS FOR 'C'	.005
TOTAL RSS PHASE ERROR	.027

* PANELS ALIGNED AT EL ANGLE = 46 °

30-METER

REFLECTOR SYSTEM ERROR* (PHASE ERROR)

REFLECTOR ORIENTATION : EL ANGLE = 15 °
WIND VELOCITY : 20 mi/h
WIND DIRECTION : ψ = 120 °
ANTENNA LOADS : GRAVITY + EDGE WIND

ERROR SOURCE	HALF PATH LENGTH ERROR - σ_p (in)
A. MAIN REFLECTOR	
1.0 PANEL MANUFACTURING	.018
2.0 PANEL ALIGNMENT	.014
3.0 PANEL DISTORTIONS	.007
4.0 BACKUP STRUCTURE DISTORTIONS	.046
SUBTOTAL RSS FOR 'A'	.052
B. SUBREFLECTOR	
1.0 MANUFACTURING	.009
2.0 SUBREFLECTOR DISTORTIONS	.006
SUBTOTAL RSS FOR 'B'	.011
C. SUBREFLECTOR DEFOCUSING	
1.0 AXIAL DEFOCUSING	.015
2.0 RADIAL DEFOCUSING	.010
SUBTOTAL RSS FOR 'C'	.018
TOTAL RSS PHASE ERROR	.056

* PANELS ALIGNED AT EL ANGLE = 46 °

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34-METER

REFLECTOR SYSTEM ERROR* (PHASE ERROR)

REFLECTOR ORIENTATION: EL ANGLE = 15°
WIND VELOCITY: 0 mi/h
WIND DIRECTION: ψ = — °
ANTENNA LOADS: GRAVITY ONLY

ERROR SOURCE	HALF PATH LENGTH ERROR – σ_p (in)
A. MAIN REFLECTOR	
1.0 PANEL MANUFACTURING	.018
2.0 PANEL ALIGNMENT	.014
3.0 PANEL DISTORTIONS	.006
4.0 BACKUP STRUCTURE DISTORTIONS	.017
SUBTOTAL RSS FOR 'A'	.029
B. SUBREFLECTOR	
1.0 MANUFACTURING	.011
2.0 SUBREFLECTOR DISTORTIONS	.004
SUBTOTAL RSS FOR 'B'	.012
C. SUBREFLECTOR DEFOCUSING	
1.0 AXIAL DEFOCUSING	.017
2.0 RADIAL DEFOCUSING	.020
SUBTOTAL RSS FOR 'C'	.026
TOTAL RSS PHASE ERROR	.041

* PANELS ALIGNED AT EL ANGLE = 57°

34-METER

REFLECTOR SYSTEM ERROR* (PHASE ERROR)

REFLECTOR ORIENTATION : EL ANGLE = 57°
WIND VELOCITY : 0 mi/h
WIND DIRECTION : ψ = — °
ANTENNA LOADS : GRAVITY ONLY

ERROR SOURCE	HALF PATH LENGTH ERROR - σ_p (in)
A. MAIN REFLECTOR	
1.0 PANEL MANUFACTURING	.018
2.0 PANEL ALIGNMENT	.014
3.0 PANEL DISTORTIONS	.003
4.0 BACKUP STRUCTURE DISTORTIONS	0
SUBTOTAL RSS FOR 'A'	.023
B. SUBREFLECTOR	
1.0 MANUFACTURING	.011
2.0 SUBREFLECTOR DISTORTIONS	.002
SUBTOTAL RSS FOR 'B'	.011
C. SUBREFLECTOR DEFOCUSING	
1.0 AXIAL DEFOCUSING	0
2.0 RADIAL DEFOCUSING	0
SUBTOTAL RSS FOR 'C'	0
TOTAL RSS PHASE ERROR	.026

* PANELS ALIGNED AT EL ANGLE = 57°

34-METER

REFLECTOR SYSTEM ERROR* (PHASE ERROR)

REFLECTOR ORIENTATION : EL ANGLE = 90°
WIND VELOCITY : 0 mi/h
WIND DIRECTION : ψ = — °
ANTENNA LOADS : GRAVITY ONLY

ERROR SOURCE	HALF PATH LENGTH ERROR – σ_p (in)
A. MAIN REFLECTOR	
1.0 PANEL MANUFACTURING	.018
2.0 PANEL ALIGNMENT	.014
3.0 PANEL DISTORTIONS	0
4.0 BACKUP STRUCTURE DISTORTIONS	.020
SUBTOTAL RSS FOR 'A'	.030
B. SUBREFLECTOR	
1.0 MANUFACTURING	.011
2.0 SUBREFLECTOR DISTORTIONS	0
SUBTOTAL RSS FOR 'B'	.011
C. SUBREFLECTOR DEFOCUSING	
1.0 AXIAL DEFOCUSING	.005
2.0 RADIAL DEFOCUSING	.026
SUBTOTAL RSS FOR 'C'	.027
TOTAL RSS PHASE ERROR	.042

* PANELS ALIGNED AT EL ANGLE = 57°

34-METER

REFLECTOR SYSTEM ERROR* (PHASE ERROR)

REFLECTOR ORIENTATION : EL ANGLE = 15 °
WIND VELOCITY : 20 mi/h
WIND DIRECTION : ψ = 180 °
ANTENNA LOADS : GRAVITY + BACK WIND

ERROR SOURCE	HALF PATH LENGTH ERROR – σ_p (in)
A. MAIN REFLECTOR	
1.0 PANEL MANUFACTURING	.018
2.0 PANEL ALIGNMENT	.014
3.0 PANEL DISTORTIONS	.010
4.0 BACKUP STRUCTURE DISTORTIONS	.019
SUBTOTAL RSS FOR 'A'	.031
B. SUBREFLECTOR	
1.0 MANUFACTURING	.011
2.0 SUBREFLECTOR DISTORTIONS	.004
SUBTOTAL RSS FOR 'B'	.012
C. SUBREFLECTOR DEFOCUSING	
1.0 AXIAL DEFOCUSING	.023
2.0 RADIAL DEFOCUSING	.020
SUBTOTAL RSS FOR 'C'	.030
TOTAL RSS PHASE ERROR	.045

* PANELS ALIGNED AT EL ANGLE = 57 °

34-METER

REFLECTOR SYSTEM ERROR* (PHASE ERROR)

REFLECTOR ORIENTATION : EL ANGLE = 57°
WIND VELOCITY : 20 mi/h
WIND DIRECTION : ψ = 180°
ANTENNA LOADS : GRAVITY + BACK WIND

ERROR SOURCE	HALF PATH LENGTH ERROR – σ_p (in)
A. MAIN REFLECTOR	
1.0 PANEL MANUFACTURING	.018
2.0 PANEL ALIGNMENT	.014
3.0 PANEL DISTORTIONS	.005
4.0 BACKUP STRUCTURE DISTORTIONS	.005
SUBTOTAL RSS FOR 'A'	.024
B. SUBREFLECTOR	
1.0 MANUFACTURING	.011
2.0 SUBREFLECTOR DISTORTIONS	.002
SUBTOTAL RSS FOR 'B'	.011
C. SUBREFLECTOR DEFOCUSING	
1.0 AXIAL DEFOCUSING	.001
2.0 RADIAL DEFOCUSING	.007
SUBTOTAL RSS FOR 'C'	.007
TOTAL RSS PHASE ERROR	.027

* PANELS ALIGNED AT EL ANGLE = 57°

34-METER

REFLECTOR SYSTEM ERROR * (PHASE ERROR)

REFLECTOR ORIENTATION : EL ANGLE = 15 °
WIND VELOCITY : 20 mi/h
WIND DIRECTION : ψ = 120 °
ANTENNA LOADS : GRAVITY + EDGE WIND

ERROR SOURCE	HALF PATH LENGTH ERROR – σ_p (in)
A. MAIN REFLECTOR	
1.0 PANEL MANUFACTURING	.018
2.0 PANEL ALIGNMENT	.014
3.0 PANEL DISTORTIONS	.007
4.0 BACKUP STRUCTURE DISTORTIONS	.017 **
SUBTOTAL RSS FOR 'A'	.029
B. SUBREFLECTOR	
1.0 MANUFACTURING	.011
2.0 SUBREFLECTOR DISTORTIONS	.006
SUBTOTAL RSS FOR 'B'	.013
C. SUBREFLECTOR DEFOCUSING	
1.0 AXIAL DEFOCUSING	.017
2.0 RADIAL DEFOCUSING	.022
SUBTOTAL RSS FOR 'C'	.028
TOTAL RSS PHASE ERROR	.042

* PANELS ALIGNED AT EL ANGLE = 57 °

** $\sigma_s^2 = \sigma_{GRAV}^2 + \sigma_W^2 = (.017)^2 + (.003)^2 = (.0173)^2$

APPENDIX C, ATTACHMENT 2

ANTENNA STRUCTURE WIND POINTING ERRORS

30-METER

ANTENNA STRUCTURE WIND POINTING ERROR

STEADY WIND VELOCITY : 20 mi/h

ANTENNA ORIENTATION : EL ANGLE = 15 °

WIND DIRECTION : ψ = 180 °

ERROR SOURCE	POINTING ERROR (deg)	
	EL AXIS	CROSS EL AXIS
1.0 REFLECTOR ASSEMBLY	.00024	0
2.0 PEDESTAL ASSEMBLY INCLUDING FOUNDATION	-.0031	0
SINGLE AXIS TOTALS	-.0029	0
TWO AXIS TOTAL	.0029	

30-METER
ANTENNA STRUCTURE WIND POINTING ERROR

STEADY WIND VELOCITY: 20 mi/h

ANTENNA ORIENTATION: EL ANGLE = 15°

WIND DIRECTION: ψ = 120°

ERROR SOURCE	POINTING ERROR (deg) EL AXIS	CROSS EL AXIS
1.0 REFLECTOR ASSEMBLY	.00009	.0031
2.0 PEDESTAL ASSEMBLY INCLUDING FOUNDATION	.00083	.0036
SINGLE AXIS TOTALS	.00092	.0067
TWO AXIS TOTAL	.0068	

30-METER

ANTENNA STRUCTURE WIND POINTING ERROR

STEADY WIND VELOCITY : 20 mi/h

ANTENNA ORIENTATION : EL ANGLE = 46 °

WIND DIRECTION : ψ = 180 °

ERROR SOURCE	POINTING ERROR (deg) EL AXIS	CROSS EL AXIS
1.0 REFLECTOR ASSEMBLY	.00053	0
2.0 PEDESTAL ASSEMBLY INCLUDING FOUNDATION	-.0031	0
SINGLE AXIS TOTALS	-.0026	0
TWO AXIS TOTAL	.0026	

34-METER
ANTENNA STRUCTURE WIND POINTING ERROR

STEADY WIND VELOCITY: 20 mi/h

ANTENNA ORIENTATION: EL ANGLE = 15 °

WIND DIRECTION: ψ = 180 °

ERROR SOURCE	POINTING ERROR (deg)	
	EL AXIS	CROSS EL AXIS
1.0 REFLECTOR ASSEMBLY	.00023	0
2.0 PEDESTAL ASSEMBLY INCLUDING FOUNDATION	.0040	0
SINGLE AXIS TOTALS	.0042	0
TWO AXIS TOTAL	.0042	

34-METER
ANTENNA STRUCTURE WIND POINTING ERROR

STEADY WIND VELOCITY : 20 mi/h

ANTENNA ORIENTATION : EL ANGLE = 15 °

WIND DIRECTION : ψ = 120 °

ERROR SOURCE	POINTING ERROR (deg)	
	EL AXIS	CROSS EL AXIS
1.0 REFLECTOR ASSEMBLY	-.00008	.0047
2.0 PEDESTAL ASSEMBLY INCLUDING FOUNDATION	.00072	.0039
SINGLE AXIS TOTALS	.00064	.0086
TWO AXIS TOTAL	.0086	

34-METER

ANTENNA STRUCTURE WIND POINTING ERROR

STEADY WIND VELOCITY: 20 mi/h

ANTENNA ORIENTATION: EL ANGLE = 57°

WIND DIRECTION: ψ = 180°

ERROR SOURCE	POINTING ERROR (deg) EL AXIS	CROSS EL AXIS
1.0 REFLECTOR ASSEMBLY	-.00056	0
2.0 PEDESTAL ASSEMBLY INCLUDING FOUNDATION	-.0033	0
SINGLE AXIS TOTALS	-.0039	0
TWO AXIS TOTAL	.0039	

APPENDIX D

PREDICTED ANTENNA PREVENTIVE AND CORRECTIVE MAINTENANCE DATA

FIGURE 1. LAAS ARRAY STUDY DATA SHEET

☒ STANDARD ANTENNA

☒ MODIFIED STANDARD ANTENNA

(Check applicable box)

A. ANTENNA COMPONENT Structure

B. MTBF 2,000,000 HRS: MTRS 8 HRS:

C. SPARES REQUIREMENTS: None

D. SPECIAL TOOLS AND EQUIPMENT: None

E. PREVENTIVE AND CORRECTIVE MAINTENANCE REQUIREMENTS

	TASK	ANTENNA MODE	FREQUENCY	MANPOWER	TASK DURATION (HRS)	MAN HOURS PER TASK
1.	Lubrication					
2.	Painting	D	0.2	3	120	72
3.	Removal					
4.	Replacement	D	0.004	4	8*	0.13
5.	Alignment					
6.	Leveling					
7.	Refinishing					
8.	Regrouting					
9.	Cleaning					
10.	Measurement					
11.	Adjustment					
12.	Inspection	D	12	1	4	48
13.	Repair					
14.	Lub Sampling					
15.						

*Assume one structural member fails at a time

NOTE: USE SEPARATE SHEET IF REQUIRED FOR ADDITIONAL TASKS.

FIGURE 1. LAAS ARRAY STUDY DATA SHEET

☒ STANDARD ANTENNA

☒ MODIFIED STANDARD ANTENNA

(Check applicable box)

A. ANTENNA COMPONENT Track Segment

B. MTBF 1,000,000 HRS: MTRS 20.0 HRS:

C. SPARES REQUIREMENTS: One each.

D. SPECIAL TOOLS AND EQUIPMENT: Jackhammer, Tilting level.

E. PREVENTIVE AND CORRECTIVE MAINTENANCE REQUIREMENTS

	TASK	ANTENNA MODE	FREQUENCY	MANPOWER	TASK DURATION (HRS)	MAN HOURS PER TASK
1.	Lubrication					
2.	Painting					
3.	Removal	D	0.01	2	12	0.24
4.	Replacement	D	0.01	2	8	0.16
5.	Alignment					
6.	Leveling					
7.	Refinishing					
8.	Regrouting					
9.	Cleaning					
10.	Measurement					
11.	Adjustment					
12.	Inspection (Maintenance)					
13.	Repair					
14.	Lub Sampling					
15.						

NOTE: USE SEPARATE SHEET IF REQUIRED FOR ADDITIONAL TASKS.

FIGURE 1. LAAS ARRAY STUDY DATA SHEET

[X] STANDARD ANTENNA

[X] MODIFIED STANDARD ANTENNA

(Check applicable box)

A. ANTENNA COMPONENT Wheel Assemblies (3)

B. MTBF 1,000,000 HRS: MTRS 32* HRS:

C. SPARES REQUIREMENTS: One each

D. SPECIAL TOOLS AND EQUIPMENT: None

E. PREVENTIVE AND CORRECTIVE MAINTENANCE REQUIREMENTS

	TASK	ANTENNA MODE	FREQUENCY	MANPOWER	TASK DURATION (HRS)	MAN HOURS PER TASK
1.	Lubrication	D	2	1	3	6
2.	Painting					
3.	Removal	D	0.01	3	10*	0.3
4.	Replacement	D	0.01	3	10*	0.3
5.	Alignment	D	0.01	3	12	0.4
6.	Leveling					
7.	Refinishing	None				
8.	Regrouting					
9.	Cleaning	I	12	1	1	12
10.	Measurement	None				
11.	Adjustment					
12.	Inspection					
13.	Repair					
14.	Lub Sampling					
15.						

*For driven wheels. Idler wheel tasks are 20 hours total.

NOTE: USE SEPARATE SHEET IF REQUIRED FOR ADDITIONAL TASKS.

FIGURE 1. LAAS ARRAY STUDY DATA SHEET

☒ STANDARD ANTENNA

☒ MODIFIED STANDARD ANTENNA

(Check applicable box)

A. ANTENNA COMPONENT Drive motors 4 each

B. MTBF 100,000 HRS: MTRS 0.6 HRS:

C. SPARES REQUIREMENTS: One each

D. SPECIAL TOOLS AND EQUIPMENT: None

E. PREVENTIVE AND CORRECTIVE MAINTENANCE REQUIREMENTS

	TASK	ANTENNA MODE	FREQUENCY	MANPOWER	TASK DURATION (HRS)	MAN HOURS PER TASK
1.	Lubrication					
2.	Painting					
3.	Removal	D	0.09	2	0.3	0.05
4.	Replacement	D	0.09	2	0.3	0.05
5.	Alignment					
6.	Leveling					
7.	Refinishing					
8.	Regrouting					
9.	Cleaning					
10.	Measurement					
11.	Adjustment					
12.	Inspection					
13.	Repair					
14.	Lub Sampling					
15.						

NOTE: USE SEPARATE SHEET IF REQUIRED FOR ADDITIONAL TASKS.

FIGURE 1. LAAS ARRAY STUDY DATA SHEET

☒ STANDARD ANTENNA

☒ MODIFIED STANDARD ANTENNA

(Check applicable box)

A. ANTENNA COMPONENT Drive motor mounting

B. MTBF 100,000 HRS: MTRS 0.6 HRS:

C. SPARES REQUIREMENTS. Same as motor

D. SPECIAL TOOLS AND EQUIPMENT: None

E. PREVENTIVE AND CORRECTIVE MAINTENANCE REQUIREMENTS

	TASK	ANTENNA MODE	FREQUENCY	MANPOWER	TASK DURATION (HRS)	MAN HOURS PER TASK
1.	Lubrication					
2.	Painting					
3.	Removal	D	0.09	2	0.3	0.05
4.	Replacement	D	0.09	2	0.3	0.05
5.	Alignment					
6.	Leveling					
7.	Refinishing					
8.	Regrouting					
9.	Cleaning					
10.	Measurement					
11.	Adjustment					
12.	Inspection					
13.	Repair					
14.	Lub Sampling					
15.	Note: Mounting is integral with drive motors					

NOTE: USE SEPARATE SHEET IF REQUIRED FOR ADDITIONAL TASKS.

FIGURE 1. LAAS ARRAY STUDY DATA SHEET

☒ STANDARD ANTENNA

☒ MODIFIED STANDARD ANTENNA

(Check applicable box)

A. ANTENNA COMPONENT Brakes (4)

B. MTBF 833,000 HRS: MTRS 12 HRS:

C. SPARES REQUIREMENTS: One each

D. SPECIAL TOOLS AND EQUIPMENT: None

E. PREVENTIVE AND CORRECTIVE MAINTENANCE REQUIREMENTS

	TASK	ANTENNA MODE	FREQUENCY	MANPOWER	TASK DURATION (HRS)	MAN HOURS PER TASK
1.	Lubrication					
2.	Painting					
3.	Removal	D	0.01	2	4	0.08
4.	Replacement	D	0.01	2	8	0.16
5.	Alignment					
6.	Leveling					
7.	Refinishing					
8.	Regrouting					
9.	Cleaning					
10.	Measurement					
11.	Adjustment					
12.	Inspection					
13.	Repair					
14.	Lub Sampling					
15.	Note: Replace drive assembly.					

NOTE: USE SEPARATE SHEET IF REQUIRED FOR ADDITIONAL TASKS.

FIGURE 1. LAAS ARRAY STUDY DATA SHEET

☒ STANDARD ANTENNA

☒ MODIFIED STANDARD ANTENNA

(Check applicable box)

A. ANTENNA COMPONENT Gear drive seals & bearings

B. MTBF 4,000,000 HRS: MTRS 12 HRS:

C. SPARES REQUIREMENTS: One drive assembly each for Az & El

D. SPECIAL TOOLS AND EQUIPMENT: None

E. PREVENTIVE AND CORRECTIVE MAINTENANCE REQUIREMENTS

	TASK	ANTENNA MODE	FREQUENCY	MANPOWER	TASK DURATION (HRS)	MAN HOURS PER TASK
1.	Lubrication					
2.	Painting					
3.	Removal	D	0.002	2	4	0.02
4.	Replacement	D	0.002	2	8	0.03
5.	Alignment					
6.	Leveling					
7.	Refinishing					
8.	Regrouting					
9.	Cleaning					
10.	Measurement					
11.	Adjustment					
12.	Inspection					
13.	Repair See note					
14.	Lub Sampling None					
15.	Note: Replace drive assembly. Repair offline.					

NOTE: USE SEPARATE SHEET IF REQUIRED FOR ADDITIONAL TASKS.

FIGURE 1. LAAS ARRAY STUDY DATA SHEET

☒ STANDARD ANTENNA

☒ MODIFIED STANDARD ANTENNA

(Check applicable box)

A. ANTENNA COMPONENT Gear boxes (4 each)

B. MTBF 156,000 HRS: MTRS 12 HRS:

C. SPARES REQUIREMENTS: One drive assembly each for Az & El.

D. SPECIAL TOOLS AND EQUIPMENT: None

E. PREVENTIVE AND CORRECTIVE MAINTENANCE REQUIREMENTS

	TASK	ANTENNA MODE	FREQUENCY	MANPOWER	TASK DURATION (HRS)	MAN HOURS PER TASK
1.	Lubrication	D	*	1	0.2-1.0	38
2.	Painting					
3.	Removal	D	0.06	2	4	0.48
4.	Replacement	D	0.06	2	8	0.96
5.	Alignment					
6.	Leveling					
7.	Refinishing					
8.	Regrouting					
9.	Cleaning					
10.	Measurement					
11.	Adjustment					
12.	Inspection					
13.	Repair Remove and replace. Repair offline.					
14.	Lub Sampling None					
15.	*1 monthly action, 4 quarterly, 6 semiannually. 1 man required, 38 M/H per year.					

NOTE: USE SEPARATE SHEET IF REQUIRED FOR ADDITIONAL TASKS.

FIGURE 1. LAAS ARRAY STUDY DATA SHEET

☒ STANDARD ANTENNA

☒ MODIFIED STANDARD ANTENNA

(Check applicable box)

A. ANTENNA COMPONENT Drive motor cooling units (4 each)

B. MTBF 42,000 HRS: MTRS 1.0 HRS:

C. SPARES REQUIREMENTS: One each

D. SPECIAL TOOLS AND EQUIPMENT: None

E. PREVENTIVE AND CORRECTIVE MAINTENANCE REQUIREMENTS

	TASK	ANTENNA MODE	FREQUENCY	MANPOWER	TASK DURATION (HRS)	MAN HOURS PER TASK
1.	Lubrication					
2.	Painting					
3.	Removal	D	0.21	2	0.5	0.21
4.	Replacement	D	0.21	2	0.5	0.21
5.	Alignment					
6.	Leveling					
7.	Refinishing					
8.	Regrouting					
9.	Cleaning	D	12	1	4.0	48.0
10.	Measurement					
11.	Adjustment					
12.	Inspection					
13.	Repair					
14.	Lub Sampling					
15.						

NOTE: USE SEPARATE SHEET IF REQUIRED FOR ADDITIONAL TASKS.

FIGURE 1. LAAS ARRAY STUDY DATA SHEET

[X] STANDARD ANTENNA

[X] MODIFIED STANDARD ANTENNA

(Check applicable box)

A. ANTENNA COMPONENT Major bearings

B. MTBF 5,000,000 HRS: MTRS 40 HRS:

C. SPARES REQUIREMENTS: One each

D. SPECIAL TOOLS AND EQUIPMENT: Hydraulic pump, 20,000 PSI for elevation bearing.

E. PREVENTIVE AND CORRECTIVE MAINTENANCE REQUIREMENTS

	TASK	ANTENNA MODE	FREQUENCY	MANPOWER	TASK DURATION (HRS)	MAN HOURS PER TASK
1.	Lubrication	D	2	1	5	10
2.	Painting	Included in structure.				
3.	Removal	D	0.002	4	15	0.12
4.	Replacement	D	0.002	4	25	0.20
5.	Alignment	Included in RIR				
6.	Leveling					
7.	Refinishing					
8.	Regrouting					
9.	Cleaning					
10.	Measurement					
11.	Adjustment					
12.	Inspection					
13.	Repair	Remove and replace. Repair offline				
14.	Lub Sampling					
15.						

NOTE: USE SEPARATE SHEET IF REQUIRED FOR ADDITIONAL TASKS.

FIGURE 1. LAAS ARRAY STUDY DATA SHEET

[X] STANDARD ANTENNA

[X] MODIFIED STANDARD ANTENNA

(Check applicable box)

A. ANTENNA COMPONENT Bullgear Segments

B. MTBF 1,000,000 HRS: MTRS 12 HRS:

C. SPARES REQUIREMENTS: One each

D. SPECIAL TOOLS AND EQUIPMENT: None

E. PREVENTIVE AND CORRECTIVE MAINTENANCE REQUIREMENTS

	TASK	ANTENNA MODE	FREQUENCY	MANPOWER	TASK DURATION (HRS)	MAN HOURS PER TASK
1.	Lubrication	D	2	1	3	6
2.	Painting					
3.	Removal	D	0.01	2	4	0.08
4.	Replacement	D	0.01	2	8	0.16
5.	Alignment					
6.	Leveling					
7.	Refinishing					
8.	Regrouting					
9.	Cleaning	D	5	2	2	20
10.	Measurement					
11.	Adjustment					
12.	Inspection	T	1	1	0.5	0.5
13.	Repair					
14.	Lub Sampling					
15.						

NOTE: USE SEPARATE SHEET IF REQUIRED FOR ADDITIONAL TASKS.

FIGURE 1. LAAS ARRAY STUDY DATA SHEET

☒ STANDARD ANTENNA

☒ MODIFIED STANDARD ANTENNA

(Check applicable box)

A. ANTENNA COMPONENT Cone

B. MTBF N/A HRS: MTRS N/A HRS:

C. SPARES REQUIREMENTS: None

D. SPECIAL TOOLS AND EQUIPMENT: None

E. PREVENTIVE AND CORRECTIVE MAINTENANCE REQUIREMENTS

TASK	ANTENNA MODE	FREQUENCY	MANPOWER	TASK DURATION (HRS)	MAN HOURS PER TASK
1. Lubrication					
2. Painting					
3. Removal None					
4. Replacement None					
5. Alignment					
6. Leveling					
7. Refinishing					
8. Regrouting					
9. Cleaning					
10. Measurement					
11. Adjustment					
12. Inspection					
13. Repair					
14. Lub Sampling					
15.					

NOTE: USE SEPARATE SHEET IF REQUIRED FOR ADDITIONAL TASKS.

FIGURE 1. LAAS ARRAY STUDY DATA SHEET

☒ STANDARD ANTENNA

☒ MODIFIED STANDARD ANTENNA

(Check applicable box)

A. ANTENNA COMPONENT Reflector surfaces

B. MTBF 500,000 HRS: MTRS 4.2 HRS:

C. SPARES REQUIREMENTS: One of each type

D. SPECIAL TOOLS AND EQUIPMENT: Theodolite and targets

E. PREVENTIVE AND CORRECTIVE MAINTENANCE REQUIREMENTS

	TASK	ANTENNA MODE	FREQUENCY	MANPOWER	TASK DURATION (HRS)	MAN HOURS PER TASK
1.	Lubrication					
2.	Painting					
3.	Removal					
4.	Replacement	D	0.02	6	4	0.5
5.	Alignment					
6.	Leveling					
7.	Refinishing					
8.	Regrouting					
9.	Cleaning					
10.	Measurement *	D	0.02	2	4	0.16
11.	Adjustment **	D	0.02	2	0.2	0.01- 2.0
12.	Inspection					
13.	Repair					
14.	Lub Sampling					
15.						

* 250 support points
** per support point

NOTE: USE SEPARATE SHEET IF REQUIRED FOR ADDITIONAL TASKS.

FIGURE 1. LAAS ARRAY STUDY DATA SHEET

☒ STANDARD ANTENNA

☒ MODIFIED STANDARD ANTENNA

(Check applicable box)

A. ANTENNA COMPONENT Cable wrap

B. MTBF 166,700 HRS: MTRS 80 HRS:

C. SPARES REQUIREMENTS: One, set of all material

D. SPECIAL TOOLS AND EQUIPMENT: None

E. PREVENTIVE AND CORRECTIVE MAINTENANCE REQUIREMENTS

	TASK	ANTENNA MODE	FREQUENCY	MANPOWER	TASK DURATION (HRS)	MAN HOURS PER TASK
1.	Lubrication					
2.	Painting					
3.	Removal	D	0.05	2	40	4.2
4.	Replacement	D	0.05	2	40	4.2
5.	Alignment					
6.	Leveling					
7.	Refinishing					
8.	Regrouting					
9.	Cleaning					
10.	Measurement					
11.	Adjustment					
12.	Inspection					
13.	Repair					
14.	Lub Sampling					
15.						

NOTE: USE SEPARATE SHEET IF REQUIRED FOR ADDITIONAL TASKS.

FIGURE 1. LAAS ARRAY STUDY DATA SHEET

[X] STANDARD ANTENNA

[X] MODIFIED STANDARD ANTENNA

(Check applicable box)

A. ANTENNA COMPONENT Encoders

B. MTBF 12,670 HRS: MTRS 2.5 HRS:

C. SPARES REQUIREMENTS: One each

D. SPECIAL TOOLS AND EQUIPMENT: None

E. PREVENTIVE AND CORRECTIVE MAINTENANCE REQUIREMENTS

	TASK	ANTENNA MODE	FREQUENCY	MANPOWER	TASK DURATION (HRS)	MAN HOURS PER TASK
1.	Lubrication					
2.	Painting					
3.	Removal	D	0.7	1	1	0.7
4.	Replacement	D	0.7	1	1	0.7
5.	Alignment	D	0.7	2	0.5	0.7
6.	Leveling					
7.	Refinishing					
8.	Regrouting					
9.	Cleaning					
10.	Measurement					
11.	Adjustment	N.A. see alignment				
12.	Inspection	I	1	2	0.5	1.0
13.	Repair	Not recommended				
14.	Lub Sampling					
15.						

NOTE: USE SEPARATE SHEET IF REQUIRED FOR ADDITIONAL TASKS.

FIGURE 1. LAAS ARRAY STUDY DATA SHEET

☒ STANDARD ANTENNA

☒ MODIFIED STANDARD ANTENNA

(Check applicable box)

A. ANTENNA COMPONENT HVAC/PS

B. MTBF 11,110 HRS: MTRS 1.0 HRS:

C. SPARES REQUIREMENTS: One power supply assembly

D. SPECIAL TOOLS AND EQUIPMENT: None

E. PREVENTIVE AND CORRECTIVE MAINTENANCE REQUIREMENTS

	TASK	ANTENNA MODE	FREQUENCY	MANPOWER	TASK DURATION (HRS)	MAN HOURS PER TASK
1.	Lubrication	None				
2.	Painting	Included in structure				
3.	Removal	D		2	1.0	2.0
4.	Replacement	D		2	1.0	2.0
5.	Alignment					
6.	Leveling					
7.	Refinishing					
8.	Regrouting					
9.	Cleaning	None				
10.	Measurement					
11.	Adjustment	None				
12.	Inspection	None				
13.	Repair					
14.	Lub Sampling					
15.						

NOTE: USE SEPARATE SHEET IF REQUIRED FOR ADDITIONAL TASKS.

FIGURE 1. LAAS ARRAY STUDY DATA SHEET

[X] STANDARD ANTENNA

[X] MODIFIED STANDARD ANTENNA

(Check applicable box)

A. ANTENNA COMPONENT Servo electronics

B. MTBF 61,800 HRS: MTRS 2.4 HRS:

C. SPARES REQUIREMENTS: One set of modules and parts

D. SPECIAL TOOLS AND EQUIPMENT: None

E. PREVENTIVE AND CORRECTIVE MAINTENANCE REQUIREMENTS

	TASK	ANTENNA MODE	FREQUENCY	MANPOWER	TASK DURATION (HRS)	MAN HOURS PER TASK
1.	Lubrication					
2.	Painting					
3.	Removal	See repair				
4.	Replacement	See repair				
5.	Alignment					
6.	Leveling					
7.	Refinishing					
8.	Regrouting					
9.	Cleaning					
10.	Measurement					
11.	Adjustment	None				
12.	Inspection					
13.	Repair	D	0.14	2	2.4	0.7
14.	Lub Sampling					
15.						

NOTE: USE SEPARATE SHEET IF REQUIRED FOR ADDITIONAL TASKS.

FIGURE 1. LAAS ARRAY STUDY DATA SHEET

[X] STANDARD ANTENNA

[X] MODIFIED STANDARD ANTENNA

(Check applicable box)

A. ANTENNA COMPONENT Electric Controllers (SCR)

B. MTBF 11,940 HRS: MTRS 2.6 HRS:

C. SPARES REQUIREMENTS: One set of modules and parts

D. SPECIAL TOOLS AND EQUIPMENT: None

E. PREVENTIVE AND CORRECTIVE MAINTENANCE REQUIREMENTS

	TASK	ANTENNA MODE	FREQUENCY	MANPOWER	TASK DURATION (HRS)	MAN HOURS PER TASK
1.	Lubrication					
2.	Painting					
3.	Removal	See repair				
4.	Replacement	See repair				
5.	Alignment					
6.	Leveling					
7.	Refinishing					
8.	Regrouting					
9.	Cleaning					
10.	Measurement					
11.	Adjustment					
12.	Inspection					
13.	Repair	D	0.7	2	2.6	3.8
14.	Lub Sampling					
15.						

NOTE: USE SEPARATE SHEET IF REQUIRED FOR ADDITIONAL TASKS.

FIGURE 1. LAAS ARRAY STUDY DATA SHEET

☒ STANDARD ANTENNA

☒ MODIFIED STANDARD ANTENNA

(Check applicable box)

A. ANTENNA COMPONENT Safety interlocks

B. MTBF 250,000 HRS: MTRS 1.0 HRS:

C. SPARES REQUIREMENTS: One set of parts.

D. SPECIAL TOOLS AND EQUIPMENT: None

E. PREVENTIVE AND CORRECTIVE MAINTENANCE REQUIREMENTS

	TASK	ANTENNA MODE	FREQUENCY	MANPOWER	TASK DURATION (HRS)	MAN HOURS PER TASK
1.	Lubrication					
2.	Painting					
3.	Removal	D	0.04	2	1.0	0.07
4.	Replacement	D	0.04	2	1.0	0.07
5.	Alignment					
6.	Leveling					
7.	Refinishing					
8.	Regrouting					
9.	Cleaning					
10.	Measurement					
11.	Adjustment					
12.	Inspection					
13.	Repair					
14.	Lub Sampling					
15.						

NOTE: USE SEPARATE SHEET IF REQUIRED FOR ADDITIONAL TASKS.

FIGURE 1. LAAS ARRAY STUDY DATA SHEET

☒ STANDARD ANTENNA

☒ MODIFIED STANDARD ANTENNA

(Check applicable box)

A. ANTENNA COMPONENT Stow Pins

B. MTBF 250,000 HRS: MTRS 2.0 HRS:

C. SPARES REQUIREMENTS: One set of parts

D. SPECIAL TOOLS AND EQUIPMENT: None

E. PREVENTIVE AND CORRECTIVE MAINTENANCE REQUIREMENTS

	TASK	ANTENNA MODE	FREQUENCY	MANPOWER	TASK DURATION (HRS)	MAN HOURS PER TASK
1.	Lubrication	D	2	1	2	4
2.	Painting					
3.	Removal	D	0.04	2	2	0.14
4.	Replacement	D	0.04	2	2	0.14
5.	Alignment					
6.	Leveling					
7.	Refinishing					
8.	Regrouting					
9.	Cleaning					
10.	Measurement					
11.	Adjustment					
12.	Inspection					
13.	Repair					
14.	Lub Sampling					
15.						

NOTE: USE SEPARATE SHEET IF REQUIRED FOR ADDITIONAL TASKS.