CR 137494

16

[redacted]

[redacted]

FINAL REPORT
SYSTEM DESIGN OF THE PIONEER VENUS SPACECRAFT

VOLUME 7
COMMUNICATION SUBSYSTEM STUDIES

By

D. M. NEWLANDS

ET AL.

July 1973

Prepared Under

Contract No. [redacted] NAS 2-7250

By

HUGHES AIRCRAFT COMPANY

EL SEGUNDO, CALIFORNIA

For

AMES RESEARCH CENTER

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

[redacted]

CR-137494

[redacted]

FINAL REPORT
SYSTEM DESIGN OF THE PIONEER VENUS SPACECRAFT

VOLUME 7
COMMUNICATION SUBSYSTEM STUDIES

By

D. M. NEWLANDS

ET AL.

July 1973

Prepared Under

Contract No. [redacted] NAS 2-7250

By

HUGHES AIRCRAFT COMPANY

EL SEGUNDO, CALIFORNIA

For

AMES RESEARCH CENTER

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

PREFACE

The Hughes Aircraft Company Pioneer Venus final report is based on study task reports prepared during performance of the "System Design Study of the Pioneer Spacecraft." These task reports were forwarded to Ames Research Center as they were completed during the nine months study phase. The significant results from these task reports, along with study results developed after task report publication dates, are reviewed in this final report to provide complete study documentation. Wherever appropriate, the task reports are cited by referencing a task number and Hughes report reference number. The task reports can be made available to the reader specifically interested in the details omitted in the final report for the sake of brevity.

This Pioneer Venus Study final report describes the following baseline configurations:

- "Thor/Delta Spacecraft Baseline" is the baseline presented at the midterm review on 26 February 1973.
- "Atlas/Centaur Spacecraft Baseline" is the baseline resulting from studies conducted since the midterm, but prior to receipt of the NASA execution phase RFP, and subsequent to decisions to launch both the multiprobe and orbiter missions in 1978 and use the Atlas/Centaur launch vehicle.
- "Atlas/Centaur Spacecraft Midterm Baseline" is the baseline presented at the 26 February 1973 review and is only used in the launch vehicle utilization trade study.

The use of the International System of Units (SI) followed by other units in parentheses implies that the principal measurements or calculations were made in units other than SI. The use of SI units alone implies that the principal measurements or calculations were made in SI units. All conversion factors were obtained or derived from NASA SP-7012 (1969).

The Hughes Aircraft Company final report consists of the following documents:

<u>Volume 1 - Executive Summary</u> - provides a summary of the major issues and decisions reached during the course of the study. A brief description of the Pioneer Venus Atlas/Centaur baseline spacecraft and probes is also presented.

Volume 2 - Science - reviews science requirements, documents the science-peculiar trade studies and describes the Hughes approach for science implementation.

Volume 3 - Systems Analysis - documents the mission, systems, operations, ground systems, and reliability analysis conducted on the Thor/Delta baseline design.

Volume 4 - Probe Bus and Orbiter Spacecraft Vehicle Studies - presents the configuration, structure, thermal control and cabling studies for the probe bus and orbiter. Thor/Delta and Atlas/Centaur baseline descriptions are also presented.

Volume 5 - Probe Vehicle Studies - presents configuration, aerodynamic and structure studies for the large and small probes pressure vessel modules and deceleration modules. Pressure vessel module thermal control and science integration are discussed. Deceleration module heat shield, parachute and separation/despin are presented. Thor/Delta and Atlas/Centaur baseline descriptions are provided.

Volume 6 - Power Subsystem Studies

Volume 7 - Communication Subsystem Studies

Volume 8 - Command/Data Handling Subsystems Studies

Volume 9 - Altitude Control/Mechanisms Subsystem Studies

Volume 10 - Propulsion/Orbit Insertion Subsystem Studies

Volumes 6 through 10 - discuss the respective subsystems for the probe bus, probes, and orbiter. Each volume presents the subsystem requirements, trade and design studies, Thor/Delta baseline descriptions, and Atlas/Centaur baseline descriptions.

Volume 11 - Launch Vehicle Utilization - provides the comparison between the Pioneer Venus spacecraft system for the two launch vehicles, Thor/Delta and Atlas/Centaur. Cost analysis data is presented also.

Volume 12 - International Cooperation - documents Hughes suggested alternatives to implement a cooperative effort with ESRO for the orbiter mission. Recommendations were formulated prior to the deletion of international cooperation.

Volume 13 - Preliminary Development Plans - provides the development and program management plans.

Volume 14 - Test Planning Trades - documents studies conducted to determine the desirable testing approach for the Thor/Delta spacecraft system. Final Atlas/Centaur test plans are presented in Volume 13.

Volume 15 - Hughes IR&D Documentation - provides Hughes internal documents generated on independent research and development money which relates to some aspects of the Pioneer Venus program. These documents are referenced within the final report and are provided for ready access by the reader.

Data Book - presents the latest Atlas/Centaur Baseline design in an informal tabular and sketch format. The informal approach is used to provide the customer with the most current design with the final report.

CONTENTS

PRECEDING PAGE BLANK NOT FILMED

1. SUMMARY

1.1 MAJOR ISSUES

Communications subsystem tradeoffs were undertaken to establish a low cost and low weight design consistent with the mission requirements. Because of the weight constraint of the Thor/Delta launched configuration, minimum weight was emphasized in determining the Thor/Delta design. In contrast, because of the greatly relaxed weight constraint of the Atlas/Centaur launched configuration, minimum cost and off the shelf hardware were emphasized and the attendant weight penalties accepted. Communication subsystem hardware elements identified for study included probe and bus antennas (CM-6, CM-17), power amplifiers (CM-10), and the large probe transponder and small probe stable oscillator required for doppler tracking (CM-11, CM-16). In addition, particular hardware problems associated with the probe high temperature and high-g environment were investigated (CM-7).

Various antennas were considered for the large and small probes consistent with the basic requirement of conical coverage at 45 ± 10 deg for the large probe and 60 ± 10 deg for the three small probes. Candidate antennas identified included the annular slot, turnstile, discone, archimedean spiral, equiangular spiral and loop-vee. The loop-vee was selected for the small probe and the equiangular spiral for the large probe because of their minimum size and weight.

Because of the diverse requirements of the probe and orbiter mission, different antennas were selected (Task CM-12) for the probe bus and orbiter. For the selected spin axis orientation perpendicular to the ecliptic (Task EX-12), probe bus communication during cruise required a toroidal beam. A bicone was chosen over a conical log spiral or radiator array as the minimum weight solution that would provide the required gain. Probe bus high data rate science return at entry required gain concentrated along the aft spin axis. An 18 dB medium gain horn was selected over an endfire radiator or radiator array for minimum system weight and cost. The orbiter requirement of high gain perpendicular to the spin axis resulted in a trade of a mechanically despun antenna (MDA) and an electronically despun antenna (EDA). An alternate azimuthal omnidirectional design was eliminated due to the attendant increase in required transmitter power. Because of development status, demonstrated reliability on previous Hughes spacecraft and flexibility to varying requirements (in particular the potential addition of a dual frequency occultation requirement (Task CM-19)), the MDA was selected. In addition to the high gain devices a pair of omni antennas were included (common to the probe bus and orbiter) to provide 4π sr command coverage. A conical log sprial and slotted cone radiator was selected for low weight and availability.

A comparison of solid state versus traveling wave tube amplifiers was undertaken. A solid state amplifier was chosen for minimum weight and for commonality. A basic 7W module for the Thor/Delta spacecraft and a 9 W module for the Atlas/Centaur spacecraft was used as a building block to meet the requirements of the probes, the probe bus, and the orbiter.

The science tracking requirement of two-way doppler for the large probe and one-way doppler for the small probe resulted in the study of available transponders for the large probe and stable oscillators for the small probe. A transponder was also required for the probe bus and orbiter but not as part of the science payload. For maximum commonality, the transponder selected to meet the large probe science requirements was also selected for the orbiter and probe bus. The Viking lander transponder was selected for the large probe based on hardware availability. The added cost of repackaging the unit to modify its footprint on the shelf to reduce its impact on the large probe was accepted for the Thor/Delta design.

Three available stable oscillators were identified as applicable to the small probe requirements. A Hewlett-Packard oscillator met all criteria except for a frequency shift experienced after exposure to simulated entry acceleration. An alternate Applied Physics Laboratory design was lighter, smaller, and much less sensitive to shock, but exhibited inadequate short term stability. The third design, by Frequency Electronics, Inc., demonstrated the required stability of one part in 10^9 when tested in the probe acceleration and temperature environment. It was potentially the most stable design and by far required the lowest power.

A trade of mechanical switching versus ferrite or diode switching resulted in selection of mechanical switching based on low insertion loss and high isolation. A diplexer was chosen consisting of a circulator and separate filters as opposed to an integrated design because of higher achievable isolation and easier packaging in the probes. The exciter output isolator was eliminated in the small probes for magnetic cleanliness. This resulted in a need to turn off the small probe transmitter during entry to avoid damaging reflections from the plasma sheath.

High temperature performance was considered for critical elements of the probe communication subsystem. In particular, it was shown that the transponder would have an acceptable noise figure at temperatures up to 70°C and that the filters could function up to 77°C. High-g performance was similarly considered. Point-to-point and printed circuit construction similar to those used in the power amplifier and transponder were shown to survive the high-g levels associated with entry. A permanent frequency shift was exhibited in the Hewlett-Packard oscillator requiring further study. The large probe transponder and small probe exciter demonstrated adequate performance when exposed to shock acceleration levels well above the 700 g qualification requirement.

Selection of the Atlas/Centaur launch vehicle has directly benefited the communication subsystem design, principally in the resulting use of the Viking lander transponder without modification. However, updates of the mission set and science payload that were considered for the Thor/Delta have resulted in many additional changes in the final Atlas/Centaur baseline design. In particular, the elimination of the small probe magnetometer has allowed the inclusion of an output isolator. The increased large probe communication angle and different small probe communication angles have resulted in the selection of an omnihemispherical antenna for all the probes. The omni reduces the sensitivity of the communication link to probe attitude variation during the descent and allows use of a common antenna design for large and small probes. The selection of dual frequency occultation for the nominal orbiter payload has resulted in the addition of an X-band transmitter and horn and a dual channel rotary joint to the MDA. The increased space available for the fixed probe bus bicone antenna has led to the selection of a larger bicone array to take advantage of the attendance increase in gain.

A trade studies summary is presented in Table 1-1.

1.2 BASELINE DESIGN

The communication system consists of the radio frequency subsystem and the antenna subsystem. For the Thor/Delta configuration, these subsystems were designed for the lowest possible cost within the system weight and performance constraints. In particular, the greatest possible design commonality and selection of developed hardware was emphasized wherever weight limitations would allow. The relaxed weight constraint of the Atlas/Centaur resulted in design changes to achieve greater commonality and increased use of developed hardware. Changes in the science payload and the mission requirements that were not incorporated in the Thor/Delta baseline but were incorporated in the final Atlas/Centaur baseline account for additional differences between the two configurations.

The Thor/Delta probe bus radio frequency subsystem consists of two 7 W solid state power amplifiers, redundant preamplifiers/receivers and exciters, and the associated rf switches, transmit filters, and diplexers. Three rf power operating modes are incorporated in the power amplifier, and summing hybrid design. Ten rf W output power can be delivered through the bicone, medium gain horn, or widebeam omni. Five or one W can be delivered through any antenna from either power amplifier. Redundant low noise preamplifiers and the Viking transponder are connected through the diplexer to either omni for the receive function.

The Thor/Delta orbiter rf subsystem is identical to that of the probe bus except for changes in the switching arrangement necessary to accommodate the different antenna complement. In particular, the orbiter has only three antenna instead of four. Ten, five and one rf W output power levels can be delivered to the high gain antenna or widebeam omni and, as in the probe bus, the narrowbeam (spinning) omni can transmit only the 5 and 1 W modes.

TABLE 1-1. TRADE STUDIES SUMMARY

Issue	Thor/Delta Baseline Configuration	Alternatives	Rationale For Selection
Probe antennas	Loop ve (small probe) Equiangular spiral (large probe)	Annular slot, turnstile, discone, Archimedean spiral	Gain, coverage, Minimum size and weight (hemispherical coverage, curved turnstile selected for Atlas/Centaur large and small probes)
Probe bus cruise antenna	Bicone	Conical log spiral, radiator array	Scaled from existing hardware Minimum complexity (stack of two bicones selected for Atlas/Centaur design)
Probe bus entry antenna	Medium gain horn	Endfire radiator, radiator array	Scaled from existing hardware Minimum weight and cost Minimum interference (shadowing)
Orbiter high gain antenna	Mechanically despun	Electronically despun, azimuthal omni	Flight experience Mature technology Growth potential Radio occultation accommodation
Spacecraft omni directional antennas	Conical log spiral slotted cone radiator	Planar spiral Curved turnstile	Gain, coverage, Low weight Availability of design
Power amplifier	Solid state	TWT	Suitable for probe entry environment Commonality (modular approach) Minimum weight
Transponder	Viking lander transponder	Philco Ford Motorola General Dynamics TRW AEG-Telefunken	Suitable for probe entry environment, Low cost, weight, size Commonality, Availability
Stable oscillators	Frequency Electronics Inc.	Hewlett Packard Applied Physics Lab	Best stability Least power required Least sensitive to shock
RF switching	Mechanical	Ferrite diode	Lowest insertion loss, highest isolation
Diplexer	Circulator/ Separate filters	Integrated design	Highest isolation Easier probe packaging

Atlas/Centaur only

Issue	Atlas/Centaur Baseline Configuration	Alternatives	Rationale For Selection
Dual frequency occultation experiment	Despun, separate X band horn, 3 W X band transmitter No change to S band communications	Gimbaled MDA reflector with dual frequency feed MDA with dual frequency feed Moved by precessing spacecraft	Lowest cost and weight Highest reliability Best operability

The Thor/Delta large probe rf subsystem is a nonredundant, single antenna 10 W mode only version of the bus subsystem. All hardware parts are identical to those used in the probe bus and orbiter except for deletion of the internal regulator in the power amplifier.

The Thor/Delta small probe rf subsystem is similar but simplified. Only one power amplifier is included, identical to the module used in the large probe. The receiver of the Viking transponder is deleted. The exciter is the same except for deletion of the auxiliary oscillator. Isolators are not included due to magnetic cleanliness requirements. A stable oscillator designed for one part in 10^9 stability is provided for one-way doppler.

The probe bus antenna subsystem consists of a medium gain horn for high data rate science transmission at entry, a biconic horn for cruise data transmission, and an omnidirectional conical log spiral/slotted cone combination to provide 4π sr command coverage and transmission during maneuvers or probe targeting. The orbiter antenna subsystem consists of the same omni pair, but employs a mechanically despun high gain antenna for transmission during cruise or orbital operation. The high gain antenna is a focal point fed reflector based on Intelsat IV flight hardware. The large probe antenna subsystem consists of a planar four-arm equiangular spiral to provide conical coverage peaked at 45 deg from the spin axis. The small probe antenna subsystem consists of a loop-vee radiator to provide similar coverage peaked at 60 deg.

The Atlas/Centaur probe bus rf subsystem configuration is essentially the same as the Thor/Delta configuration; the main differences are power amplifiers with higher output levels (9 instead of 7 W), and the elimination of separate rf preamplification ahead of the receiver. The diplexer is simplified to only a circulator, since filtering is provided within the Viking receiver. The power amplifier 1 W mode is eliminated.

These changes are also incorporated into the Atlas/Centaur orbiter rf subsystem. In addition, the switching arrangement of the despun portion of the subsystem is changed from the Thor/Delta configuration to provide reception as well as transmission through the high gain antenna. Additional changes reflect the inclusion of the X-band occultation experiment. These include an X-band TWTA transmitter, a dual channel (S and X-band) rotary just and an X-band horn mounted so as to be boresight coincident with the S-band communications MDA. An increase from two to four power amplifier modules results from increased losses due to longer rf lines and increased data rate requirements. RF switching is slightly different to account for the increased number of power amplifiers.

The Atlas/Centaur large probe rf subsystem is substantially revised. As in the case of the spacecraft subsystem, the power amplifier output level has been increased and the preamplifier deleted. Three power amplifiers are included instead of two. Corresponding switching and filtering changes are incorporated.

The Atlas/Centaur small probe rf subsystem differs from the Thor/Delta configuration only in the use of a larger (9 W) power amplifier.

The Atlas/Centaur probe bus antenna subsystem differs from the Thor/Delta probe bus subsystem only in the revised bicone design. In particular, a double bicone stack is employed to increase the gain. This increase in size is directly due to the relaxed weight constraint and the increased shroud volume provided in the Atlas/Centaur. This antenna does not need to be deployed after launch as in the Thor/Delta case. The Atlas/Centaur orbiter antenna subsystem differs from the Thor/Delta orbiter subsystem in the dual frequency feed and gimbal required for X-band occultation, and in provided reception, as well as transmission with the high gain transmitter. Probe antennas have been redesigned to provide essentially hemispherical coverage with >0 dBi gain over the earthward hemisphere. This allows flexibility in probe targeting and relaxes communications restraints on probe spin axis alignment with the local vertical. The curved turnstile is selected for both probes for commonality and resulting lower development costs.

An Atlas/Centaur baseline subsystem hardware summary is given in Table 1-2.

TABLE 1-2. ATLAS/CENTAUR DESIGN SUBSYSTEM HARDWARE SUMMARY

Unit	Characteristics	Selection Criteria	Hardware Source
Probe antennas	Hemispheric coverage curved turnstile 0.23 kg (0.5 lb)	Commonality, insensitive to probe spin axis allignment	New
Orbiter high gain antenna	Mechanically despun palabolic reflector 1.54 kg (3.4 lb)	Developed, allows adding separate despun X band horn	Intelsat IV
Probe bus cruise antenna	Dual bicone 3.45 kg (7.6 lb)	Minimum complexity scaled from existing hardware	*Data systems
Probe bus entry antenna	Medium gain horn 0.91 kg (2.0 lb)	Minimum weight and cost, minimum interference, scaled from existing hardware	Intelsat IV (modified frequency beamwidth)
Omni antennas	Conical log/spiral slotted cone radiator 0.18 kg (0.4 lb), 0.27 kg (0.6 lb)	Low weight, availability	*HS-350/surveyor
Rotary joint (orbiter)	Dual channel concentric coaxial line 0.78 kg (1.7 lb)	Developed technology	Telesat (derived)
Transponder	2.0 kg (4.4 lb)	Suitable for probe entry environment Commonality Avalability	Viking lander
Exciter (small probe)	0.64 kg (1.4 lb)	Suitable for probe entry environment Availability	Part of viking lander transponder
Switches	Mechanical	Lowest insertion loss Highes isolation	Pioneer, Helios
Power amplifier	Solid state 0.86 kg (1.9 lb)	Suitable for probe entry environment Commonality Availability	*HS-350
Bandpass filter	0.45 kg (1.04 lb)	Highest isolation and easiest probe packaging	ATS E (modified frequency and bandwidth)
Circulator	0.11 kg (0.25 lb)	Highest isolation and easiest probe packaging	*HS-350
Stable oscillator	0.34 kg (0.75 lb)	Best stability Least power Least sensitive to shock	Frequency Electronics, Inc New design
X band horn	25.4 cm (10 in.) 0.32 kg (0.7 lb)	Meets occultation requirement Minimum cost	Intelsat IV
X band transmitter	3 W rf 3.67 kg (8.1 lb)	Meets occultation requirement Minimum cost	

*Hughes classified programs

2. INTRODUCTION

This volume discusses the communication subsystem hardware tradeoffs and the resulting Thor/Delta baseline design. It also summarizes the final Atlas/Centaur baseline design. Information is derived from Hughes contract study tasks and from related internal reports.

The subsystem requirements derived for the Thor/Delta baseline design are described in section 3. These are divided into the mission requirements, the requirements dictated by system considerations, and those dictated by subsystem considerations.

System tradeoffs are discussed in Volume 3 of this report. The Thor/Delta design subsystem tradeoffs performed are presented in section 4. Large and small probe antenna designs are discussed in subsection 4.1 in response to Statement of Work 2.2.4-(6) as performed in Study Task CM-6. Several antenna designs are identified which meet the basic requirement of a conical antenna pattern. The equiangular spiral is selected for the large probe and the loop-vee for the small probe Thor/Delta designs.

Probe bus and orbiter antennas are discussed in subsections 4.2 and 4.3, using data from study task CM-18. For both the orbiter and the probe bus a conical log spiral and slotted cone radiator combination is selected to provide the required 4π sr command coverage. For the probe bus a bicone antenna is selected for communication during cruise and a medium gain horn selected for communication at bus entry. A mechanically despun antenna (MDA) is selected over an electronically despun antenna (EDA) to provide high gain normal to the spin axis for the orbiter.

Based on study task CM-10, a trade of solid state versus traveling wave tube amplifiers is presented in subsection 4.4. A 7 W solid state module is selected for use in the Thor/Delta design in multiple configurations to satisfy the requirements of all vehicles.

The large probe transponder and small probe stable oscillator are discussed in subsections 4.5 and 4.6. Although part of the probe science payload, they are presented here as an integral part of the communication subsystem. The Viking lander transponder is selected as the most advanced space qualified design able to meet the large probe requirements. The same transponder is then selected for the probe bus and orbiter to provide low cost commonality between the vehicles. Available stable oscillators are compared with respect to low weight, low volume, low power, and frequency stability under simulated probe entry and descent environments.

Passive elements of the design are discussed in subsection 4.7. In particular, mechanical switches are selected over ferrite or diode switches to provide low insertion losses and high isolation. Also, a flexible diplexer design is selected based on incorporating a circulator and separate receiver and transmitter filters for packaging versitility.

Results of high temperature and high-g tests from Study Task CM-7 are discussed in subsection 4.8. Adequate temperature and acceleration performance is demonstrated.

The Thor/Delta baseline resulting from the study task trades is presented in section 5. The Atlas/Centaur baseline design is presented in section 6. The principal difference due to the added weight capability and low cost emphasis is in the selection of an unmodified Viking lander transponder and a 9 W solid state module. Science payload changes and mission redefinition not included in the Thor/Delta study account for many additional changes in the baseline Atlas/Centaur design. The previous Atlas/Centaur spacecraft design derived in parallel with and using the same mission definition as the Thor/Delta spacecraft (done as part of the launch vehicle utilization study) is given in Volume 11 of this report.

3. SUBSYSTEM REQUIREMENTS

The design of the telecommunications subsystems must satisfy the mission scientific and engineering data return and interplanetary navigation objectives. Scientific data return consists of both telemetering data from the on-board scientific instruments and providing for radio science and gravitational investigations which utilize the telecommunications subsystems directly. In this section, the general mission requirements are used to generate spacecraft telecommunications system requirements which, in turn, lead to requirements for both the antenna and radio frequency subsystems.

3.1 MISSION REQUIREMENTS

Mission requirements fall into two main categories. The "physical" mission objectives determine the obvious telecommunications power requirements and the spacecraft environments. The mission requirements related to the low cost and spacecraft operability objectives influence subsystem design philosophy in requiring maximum commonality between subsystems, the use of existing hardware to the fullest extent possible, maximum compatibility with the deep space network (DSN) as configured for the 1975-1980 time period, and the use of techniques which lead to good operability. This section addresses mainly the impact of the "physical" mission objectives. In the remainder of this section the low cost and operability objectives will not be discussed explicitly; however, they are determining factors in the trade study and baseline design sections that follow.

The telecommunications coverage required for the various mission phases is summarized in Table 3-1.

3.2 SYSTEM REQUIREMENTS

This subsection documents the basic Thor/Delta design communication system requirements. Deviations to these requirements caused by changing to the Atlas/Centaur launch vehicle and the change in mission set are discussed in section 6.

A review of Table 3-1 leads to the adoption of the following ground rules for the telecommunications design:

TABLE 3-1. MISSION TELECOMMUNICATIONS COVERAGE REQUIREMENTS

Mission Phase	Coverage Requirements
Launch	Engineering telemetry through wide range of spacecraft attitudes and spacecraft/earth geometries
Near-earth	Engineering telemetry and command through wide range of spacecraft attitudes and spacecraft/earth geometries
Early (large) midcourse maneuvers	Engineering telemetry and command in any spacecraft attitude
Cruise	Science and engineering telemetry, two-way Doppler tracking and command in nominal cruise (spin axis perpendicular to eclipse) attitude
Later (small) midcourse maneuvers	Engineering telemetry and command in nominal cruise attitude
Probe checkout (prior to probe release)	Engineering telemetry, probe data, and command in nominal cruise attitude
Probe release	Engineering telemetry and command in probe release attitude
Probe operation	Probe carrier (two-way for large probe) and telemetry prior to blockout and during descent after blackout. Nominal descent communications angle (spin axis/earth line angle) of less than 60 deg. Provision must be made for targeting and probe attitude dispersions.
Probe bus entry	Bus science data and two-way Doppler tracking in bus entry attitude (earth-line and spin axis essentially coincident)
Orbit insertion	Engineering telemetry and command in orbit insertion attitude; this for attitude verification prior to and after occultation
Orbital operations	Science and engineering telemetry, two-way Doppler tracking and command in nominal cruise attitude
RF occultations	The rf occultation experiment will be enhanced if the spacecraft antenna can track the virtual earth point (in two dimensions) when entering and exiting occultations. This enhancement is more pronounced with X-band than with S-band due to beamwidth considerations

- Full mission spacecraft command capability in any attitude
- Near-earth telemetry coverage in any attitude (launch, near-earth, early TCMs)
- Full mission coverage in nominal cruise attitude
- Coverage for unique scheduled situations (probe release, probe bus entry, orbit insertion)

Additional ground rules arising from mission requirements, the low cost objective and design decisions include the following:

- Compatible with DSN configuration specified for the 1975-1980 period
- Maximum use of the 26 m net. The 64 m net used only for mission critical events.
- Utilize S-band for all telecommunications. Limit X-band to radio science applications.
- Maximum commonality between the telecommunications subsystems on each of the vehicles

Good spacecraft operability considerations include:

- Separate transmit and receive functions as much as possible
- Provide circular polarization for all links for operational simplicity
- Size beamwidths for minimum operational impact

The design philosophy arising from these ground rules is to provide spherical command capability throughout the multiprobe and orbiter missions by the use of two switched omni antennas which together give greater than -6 dBi gain over the sphere. Given the existence of the omni antennas for the receive function, they can be efficiently utilized for the transmit function during times of nonstandard spacecraft attitude such as the launch phase and TCMs. The transmit function during standard or predictable spacecraft attitudes (cruise, bus entry, and probe and orbital operations) is provided by antennas selected especially for these purposes. The selection of these antennas is discussed in the trade study section of this volume. Antenna coverage requirements are summarized in Table 3-2. Line drawings of the probe bus and orbiter showing the location of the antennas selected to meet these systems coverage requirements are shown as Figures 3-1 and 3-2.

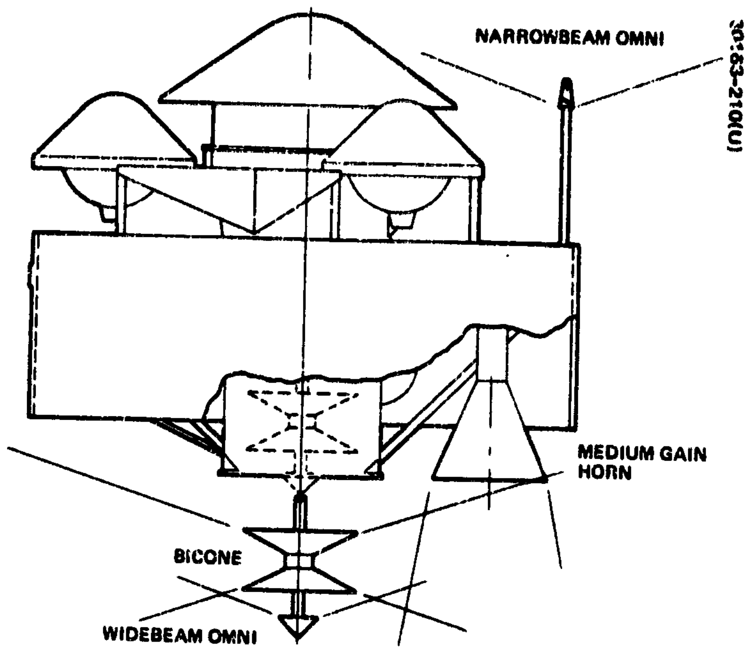


FIGURE 3-1. THOR/DELTA PROBE BUS BASELINE CONFIGURATION

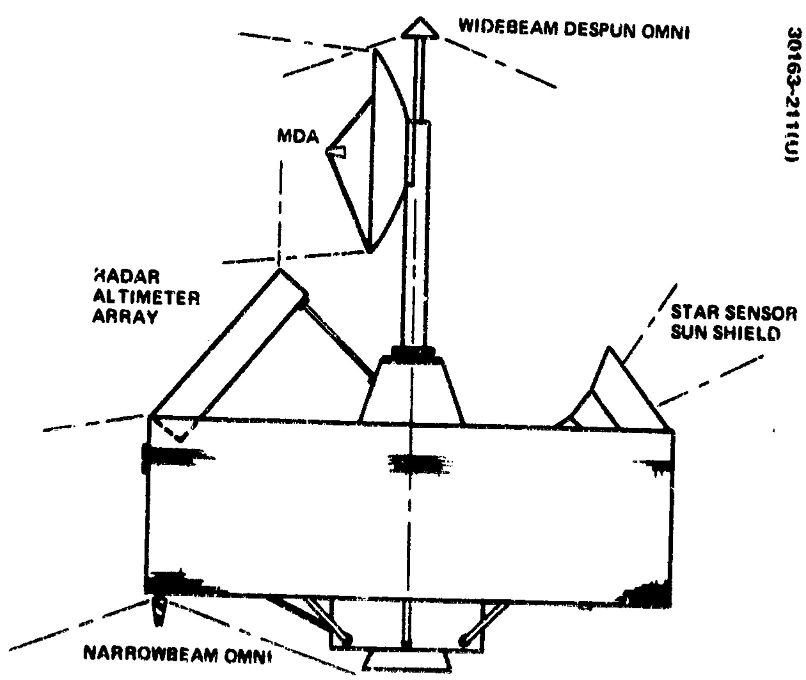


FIGURE 3-2. THOR/DELTA ORBITER BASELINE CONFIGURATION

TABLE 3-2. ANTENNA REQUIREMENTS SUMMARY

Vehicle	Antenna	Pattern	Direction	Gain	Rationale
Small probe	Loop-vee	Conical	60 deg from spin axis	Low	Small probes are targeted nominally 60 deg from sub-earth point. Earth line traces 60 deg cone about probe spin axis
Large probe	Equiangular spiral	Conical	45 deg from spin axis	Low	Large probe is targeted nominally 45 deg from sub-earth point
Probe bus	Bicone	Toroidal	Perpendicular to spin axis	Low	Spin axis is perpendicular to ecliptic plane during cruise
	Medium gain horn	Directed beam	Along aft spin axis	Medium	Aft spin axis is directed to earth at entry
Orbiter	Mechanically despun	Directed beam	Perpendicular to spin axis at variable azimuth	High	Spin axis is perpendicular to ecliptic plane during cruise and orbit. High data rate is required. Earth moves in azimuth during mission.
Orbiter and probe bus	Conical log spiral and slotted cone radiator combination	4π sr		Omni	Command coverage at any orientation. Non-nominal attitudes (i.e., orbit insertion, probe separation, and TCM) are varied.

In the launch, near-earth, and midcourse phases, the requirement was telemetry coverage at modest bit rates for spacecraft control and monitoring. During the cruise phase, emphasis was on providing telemetry coverage for science and engineering without altering the spacecraft attitude. The probe bus had special requirements relating to bus attitude during probe release and science return during bus planetary entry. The orbiter had to support high science return data rates during orbit operations. No communications requirement existed for orbit insertion since this occurs in earth occultation. However, communications had to be maintained before and after occultation for spacecraft operations.

The sizing of the telemetry links followed directly from the science complement and associated experiment data return requirements given for this systems design study. The probe data rates resulted from the descent optimization trades discussed in Volume 3 of this report wherein descent speed (and thus data rate) was varied to achieve weight and/or cost minimization. The orbiter link was sized by the requirement to telemeter science data at maximum Earth-Venus range (end of mission). In this case the raw data return requirement was further modified by the addition of spacecraft data storage so that the required data transmission could be averaged over a significant portion of the orbital period to prevent designing to a peak rate of small duration (periapsis pass). The probe bus link was sized by science data return requirements during probe bus entry and by the requirements for spacecraft status data over omnidirectional antennas during the probe release sequence when the spacecraft is not in its standard altitude.

The command links utilized the standard DSN PCM/PSK/PM modulation. The telemetry links were also PCM/PSK/PM and compatible with the DSN multimission telemetry system. Convolutional encoding was used on the downlinks to improve link performance with minimum cost and hardware impact. The link performance calculations are discussed in Volume 3 of this report. From these calculations the system design parameters were derived. For the downlinks the required effective radiated power (ERP) can be allocated between antenna gain and transmitted power considering the spacecraft prime power availability and the antenna coverage requirement discussed previously. There is a great deal of interaction between the selected implementation and the allocation of these resources as will be discussed in the following paragraph.

The design of communication links with existing spare hardware and ground station links is an iterative process. The requirements specify the performance, and then the available hardware and existing ground station capabilities are examined to see how this performance can best be met. In some cases this process results in a modification of performance if the overall requirements can be satisfied with a cheaper or more easily implemented solution. Under these circumstances, it is not possible to entirely separate the required performance from specific implementation schemes and the system requirements. This can be seen in Table 3-3, which lists the telemetry systems requirements derived from the considerations discussed in this section.

TABLE 3-3. SUMMARY OF DERIVED TELEMETRY SYSTEMS REQUIREMENTS

Mission Phase	Range, 10^9 km	Transmitter Power	Data Rate	Antenna	Communications Angle, deg	Modulation Index deg
Near earth	-	1.45	16	Omni	-	36.1
Bus cruise	0 to 48.7	1.75/7/14	16	Bicone	90	36.1
Large probe checkout	44.3	14	184/16	Bicone	90	57.1/36.1
Small probe checkout	44.3	14	16/16	Bicone	90	47.5/36.1
Large and small probe release	46.5	14	16	Omni	29/46	36.1
Bus coast after probe release	48.7 to 70.3	7	64	Medium gain horn	0 to 4	36.1
Large probe release/entry	46.5/70.3	14	184	Equiangular spiral	28/28	57.1
Large probe descent	70.3	14	276/184	Equiangular spiral	45	62.5/57.1
Small probe release/entry	46.5/70.3	7	16	Loop-vee	26.0/41.7	34.7
Small probe descent	70.3	7	16	Loop-vee	60	34.7
Bus entry	70.3	14	2048	Medium gain horn	2.5 to 4	72
Orbit insertion	52.2	14	16	Omni	-	44.3
Orbiter end of mission	250	7	64	HGA	-	53.7

3.3 SUBSYSTEMS REQUIREMENTS

The telecommunications subsystems requirements resulting from the mission and systems requirements discussed above and from other systems and subsystems trades are listed on Tables 3-4 through 3-7. These requirements are the basis for the subsystems designs discussed in sections 5 and 6 of this volume.

TABLE 3-4. ORBITER COMMUNICATION SUBSYSTEMS REQUIREMENTS

Antenna Subsystem

- Two switched omnidirectional antennas

  Right hand circular polarization
  > -6 dBi gain over sphere
  Transmit 2295 MHz, receive 2115 MHz

- Mechanically despun high gain parabolic dish antenna (MDA) pointed normal to spin axis

  Right hand circular polarization
  Despin azimuth pointing control
  > 23.5 dBi peak gain
  11 deg beamwidth
  Transmit only, 2295 MHz

RF Subsystem

- DSN compatible
- PCM/PSK/PM uplinks and downlinks
- Three selected levels of power delivered to MDA: 38.9/36.0/30.0 dBm
- Three selectable levels of power delivered to despun omni: 38.7/35.8/29.5 dBm
- Two selectable levels of power delivered to spinning omni: 36.8/30.8
- Low noise preamplifier (noise figure = 3.5 dB)
- System noise temperature = 600°K
- Two 7/1.75 W dual mode solid state power amplifiers
- Phase lock receivers
- Redundant exciters
- Two-way doppler tracking, receiver/exciter combination used as transponder, 240/221 turnaround ratio
- One-way doppler tracking with no uplink (auxiliary oscillator)

TABLE 3-5. PROBE BUS COMMUNICATION SUBSYSTEM REQUIREMENTS

Antenna Subsystem

- Two switched omnidirectional antennas

  Right hand circular polarization
  > -6 dBi gain over sphere
  Transmit 2295 MHz, receive 2115 MHz

- Bicone antenna

  Right hand circular polarization
  > 3 dBi gain over spin plane
  30 deg beamwidth
  Transmit only, 2295 MHz

- Medium gain horn

  Right hand circular polarization
  > 18 dBi peak gain along aft spin axis, 20 deg beamwidth
  Transmit only, 2295 MHz

RF Subsystem

- DSN compatible
- PCM/PSK/PM uplinks and downlinks
- Three selectable levels of power delivered to bicone: 39.7/36.8/30.8 dBm
- Three selectable levels of power delivered to medium gain horn: 40.0/37.1/31.1 dBm
- Three selectable levels of power delivered to widebeam omni: 39.5/36.6/30.6 dBm
- Two selectable levels of power delivered to narrowbeam omni: 36.8/30.8 dBm
- Low noise preamplifier, (noise figure = 3.5 dB)
- System noise temperature = 600°K
- Two 7/1.75 W dual mode solid state power amplifiers
- Phase lock receivers
- Redundant exciters
- Two-way doppler tracking, receiver/exciter combination used as transponder, 240/221 turnaround ratio
- One-way doppler tracking with no uplink (auxiliary oscillator)

TABLE 3-6. LARGE PROBE COMMUNICATION SUBSYSTEMS REQUIREMENTS

Antenna Subsystem

- Equiangular spiral antenna

  Right hand circular polarization
  Conical pattern
  Peak gain 45 deg from spin axis
  > 3.9 dBi ± 10 deg from peak
  40 deg beamwidth
  Transmit 2295 MHz, receive 2115 MHz

RF Subsystem

- DSN compatible
- PCM/PSK/PM downlink; carrier only uplink
- Power delivered to antenna >40.4 dBm
- Low noise preamplifier (noise figure = 3.5 dB)
- System noise temperature = 600°K
- Two 7 W solid state power amplifiers
- Phase lock receiver
- Two-way doppler tracking, receiver/exciter combination used as a transponder, 240/221 turnaround ratio
- One-way doppler tracking with no uplink (auxiliary oscillator)

TABLE 3-7. SMALL PROBE COMMUNICATION SUBSYSTEMS REQUIREMENTS

Antenna Subsystem

- Loop-vee antenna

  Right hand circular polarization
  Conical pattern
  Peak gain 60 deg from spin axis
  >2.4 dBi $\pm$ 10 deg from peak
  40 deg beamwidth
  Transmit only, 2295 MHz

RF Subsystem

- DSN compatible
- PCM/PSK/PM downlink
- Power delivered to antenna >38.3 dBm
- One 7 W solid state power amplifier
- One-way doppler tracking (stable oscillator)

4. TRADE STUDIES

The communication subsystems have a number of special requirements imposed by the Pioneer Venus mission. The high-g (~ 500 g) and high temperature environment (~700°C at the antenna) experienced by the probes, coupled with the demands of minimum size and weight, required preliminary experimental investigations. The measured performance of a stable oscillator revealed that this was indeed a problem area requiring further investigation. These investigations also included obtaining antenna test patterns for preliminary antenna designs applicable to the large and small probes. Probe thermal design tradeoffs also required knowledge of how severely the components would degrade with increasing temperature so that limits could be set on the internal probe temperatures. Measurements were, therefore, made on the performance of an S-band power amplifier at elevated temperatures. Performance with temperature of existing DSN compatible transponders was also investigated.

Other tradeoffs included a comparison between electronically and mechanically despun high gain antennas, an industry survey of available microminiature transponders, and a tradeoff between solid state power amplifiers and TWT amplifiers.

The final selection of preferred components meeting the communications subsystems requirements has been made on the basis of several criteria, derived principally from the overall mission requirement of low cost. They are:

1) Low technical risk, known design

2) Off-the-shelf availability

3) Commonality between probe bus, orbiter, large probe, and small probe

4) Low weight and volume (particularly for the Thor/Delta design)

5) High reliability

TABLE 4-1. ANTENNA SUBSYSTEM TRADE STUDIES

Trade Study	Selected Approach	Principle Reasons / Experimental Results
Omni-directional antennas for probe bus and orbiter	Combination of conical log spiral and slotted cone radiator	Gain/coverage, weight, availability of design
Orbiter high gain antenna	Mechanically despun antenna-parabolic reflector with focal point feed	Proven space hardware design, low weight, and complexity
Probe bus medium gain antenna	Conical horn	Rugged, simple, design scaled from existing hardware, easily mountable
Probe bus azimuthal omnidirectional antenna	Bicone	Scaled from existing hardware, meets gain requirements with minimum complexity
Probe antennas	Equiangular spiral for large probe, and loop-vee for small probe	Equiangular spiral chosen for gain/coverage. Loop-vee because of its small size. Former satisfies all requirements but loop-vee had low gain because of small, curved ground plane

Tables 4-1 and 4-2 summarize the principal results of the various trade studies. Although the studies were originally performed to be directly applicable to the Thor/Delta spacecraft design with great emphasis on weight reduction, most of the results are also applicable to the Atlas/Centaur design. Section 5, the Thor/Delta baseline design, is directly based on the results of these studies. Section 6, which represents the Atlas/Centaur baseline, modifies some of the conclusions reached herein due to the relaxed weight constraint which allows increased emphasis on low cost approaches. Also, coincident with the change of launch vehicle, there was a change of mission set and baseline science complement which altered the subsystems requirements somewhat.

4.1 PROBE ANTENNAS

The gain/coverage and other electrical requirements associated with the probe antennas are listed in Table 4-3. The gain/coverage values are design goals. The dimensions are proportioned from the pressure vessel sizes and the approximate space available for the antennas.

The conical pattern for the probes can be achieved with any one of the antennas listed in Table 4-4. Size, weight, polarization and pattern constraints limit the number of candidates worthy of consideration to just a few types. For example, the pattern has to have uniform signal level in the ϕ (spin) direction, and a conical pattern with a null at $\theta = 0$ in the θ (elevation) plane. Main lobe radiation patterns of some of the more interesting candidate antennas are compared in Figure 4-1. The pattern of an axial mode helix radiator is included for comparison to show the relative difference in gain and the pattern fall-off as a function of coverage angle. The radiation patterns of these candidate antennas were obtained from the literature. These data were used as an indication of the approximate and relative performance achievable with the candidate antennas.

The equiangular spiral is selected as a model antenna because it best meets the overall design goals listed in Table 4-3. Two important advantages of the equiangular spiral antenna are that it is smaller than the annular slot antenna and it easily provides the needed beamwidth.

The loop-vee antenna is chosen as a possible antenna for the small probe, because it is small. The peak gain is not so high as some others, but it is nearly constant over a wide angle.

Experimental models of these antennas, shown in Figure 4-2, were built and tested. Construction details of the loop-vee antenna and its gain in the spin plane are shown in Figure 4-3. Similar information is given for the equiangular spiral in Figure 4-4. Figure 4-5 illustrates the symmetry of the antenna gain with spin angle. Typical antenna radiation patterns are shown in Figures 4-6 and 4-7. Further information concerning this experimental trade study can be found in Hughes Aircraft Company TIC 41-16/73/051, "Development Study of Planetary Probe Antennas" included in Volume 15 of this report.

TABLE 4-2. RADIO FREQUENCY SUBSYSTEM TRADE STUDIES

Trade Study	Selected Approach	Principle Reasons / Experimental Results
Microminiature transponder	Viking lander transponder (Philco-Ford)	Low cost, weight and size. DSN compatible
Power amplifier	7 W solid state module	Commonality between probes and probe bus and orbiter. Smaller size and weight than TWTA
Stable oscillator	Test HP 10543 oscillator. Study alternate designs by APL and FEI	HP oscillator met $1{:}10^9$ stability except for $5{:}10^7$ frequency shift after high g test. Alternate design (FEI) smaller, less weight
Communication subsystem passive components	Mechanical switches. Filters separate from diplexer	Low loss, high isolation, probe packaging
High temperature electronics	Test power amplifier	Power output degrades to 5.5 watts at 93°C
High g electronics	Test HP stable oscillator and other components with representative construction	Point to point and printed circuit construction successfully meet greater than 500 g

TABLE 4-3. PROBE ANTENNA DESIGN GOALS

Item	Large Probe	Small Probe
Frequency, GHz	2.115±0.005;2.295 ±0.005	2.295 ±0.005
Antenna pattern	Conical	Conical
Polarization	Right-hand circular	Right-hand circular
Coverage angle (elevation) deg	45 ±10	60 ±10
Beamwidth (in θ-plane), deg	40	40
Gain at center of θ-coverage range, dBi	5	4.5
Gain at edges of θ-coverage range, dBi	4.1	3.6

TABLE 4-4. CANDIDATE PROBE ANTENNAS

Antenna	Description	Advantage	Disadvantage
Annular slot	17.8 cm diameter, 5.1 cm high	Good gain	Approximately 5 percent bandwidth
Turnstile	Up to 28 cm in cross section	Performance documented	Bandwidth limited
Discone	15.3 cm diameter, 16.8 cm high	--	Poor circular polarization, large size
Archimedean spiral	15.3 cm diameter, 5.1 cm high	Broad bandwidth, good circular polarization	Lower radiation efficience
Equiangular spiral	15.3 cm diameter, 5.1 cm high	Good gain, broad bandwidth, acceptable circular polarization	Circular polarization not as good as with archimedean spiral
Loop-vee	9 cm diameter, 5.1 cm high	Small, lightweight, symmetrical patterns	Low gain

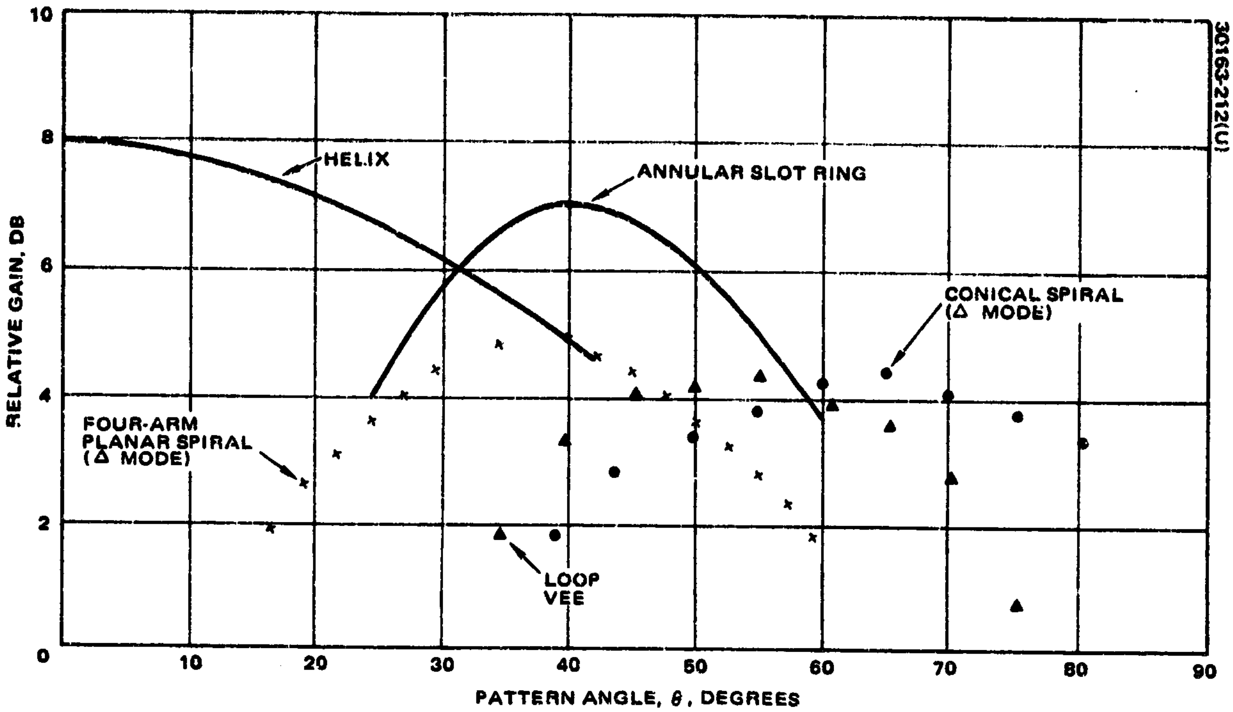


FIGURE 4-1. PROBE ANTENNA COVERAGE PATTERN

FIGURE 4-2. EQUIANGULAR SPIRAL AND LOOP-VEE ANTENNAS (PHOTO 4R29622)

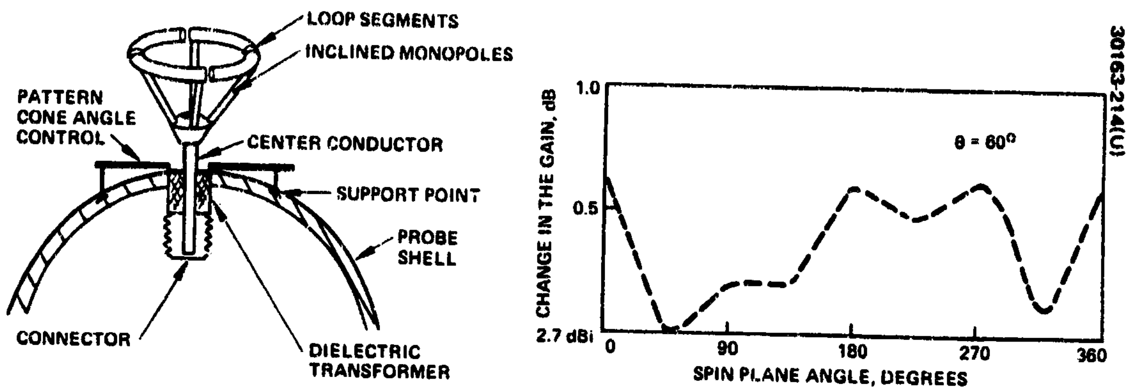


FIGURE 4-3. LOOP-VEE ANTENNA EXPERIMENTAL RESULTS

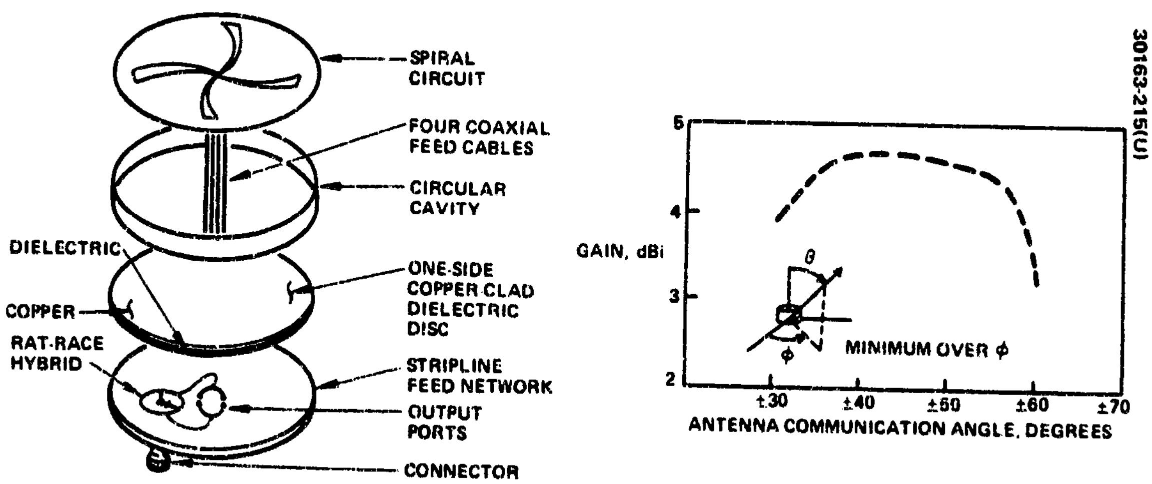


FIGURE 4-4. EQUIANGULAR SPIRAL ANTENNA EXPERIMENTAL RESULTS

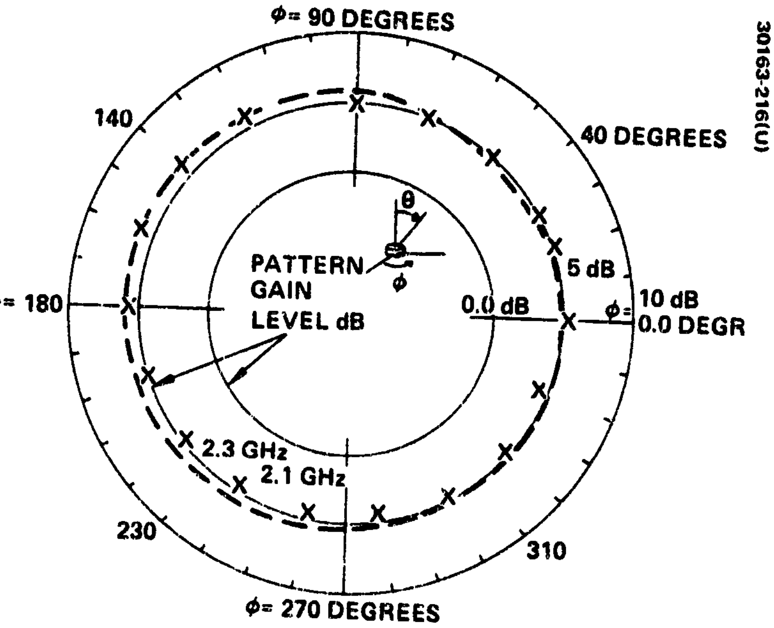
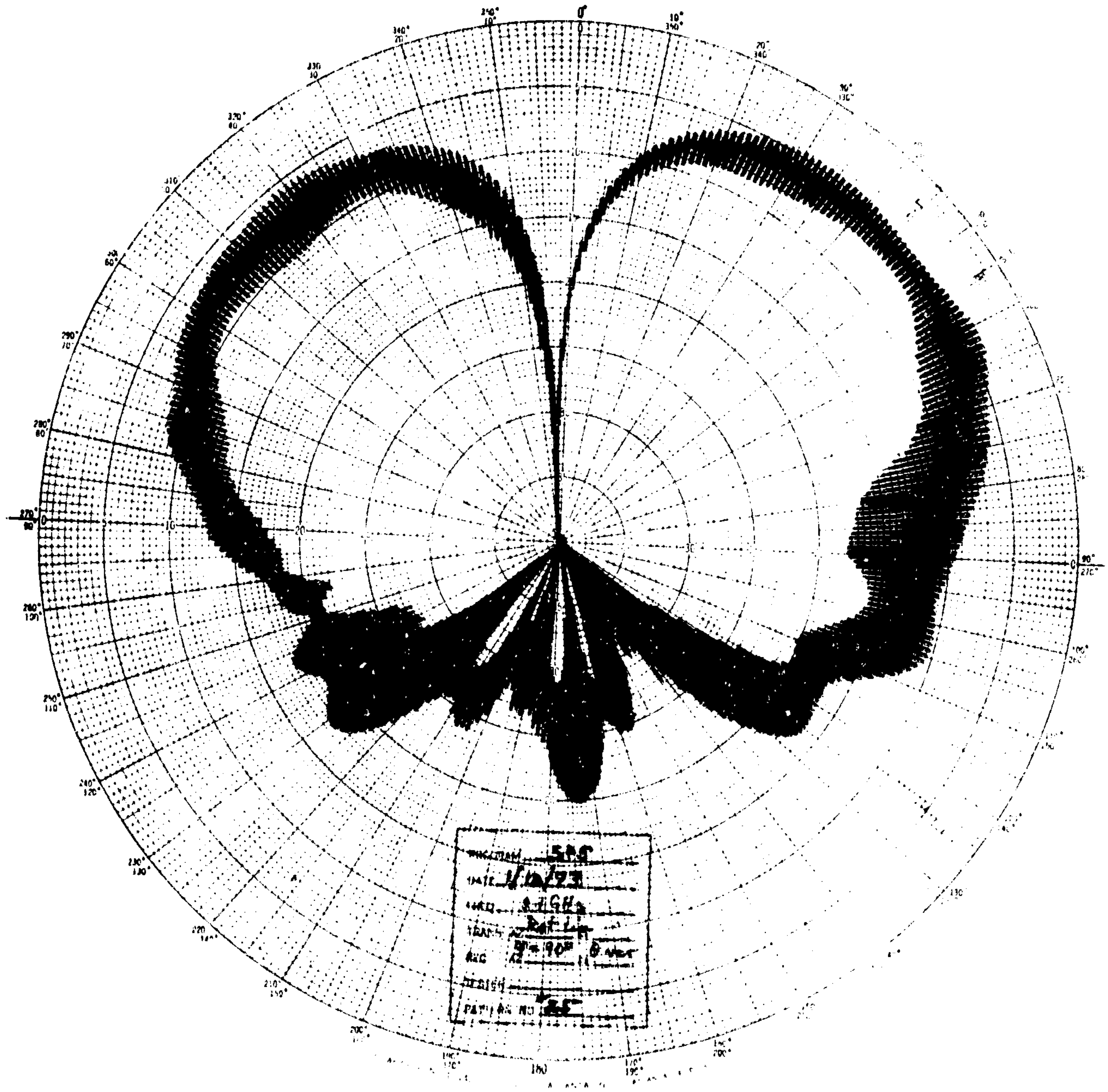


FIGURE 4-5. SPIRAL ANTENNA GAIN VERSUS AZIMUTH ANGLE, θ = 45 DEGREES



30163-217(U)

FIGURE 4-6. EQUIANGULAR SPIRAL ANTENNA RADIATION PATTERN, 2.1GHz, ϕ = 90 DEG, θ VARIABLE

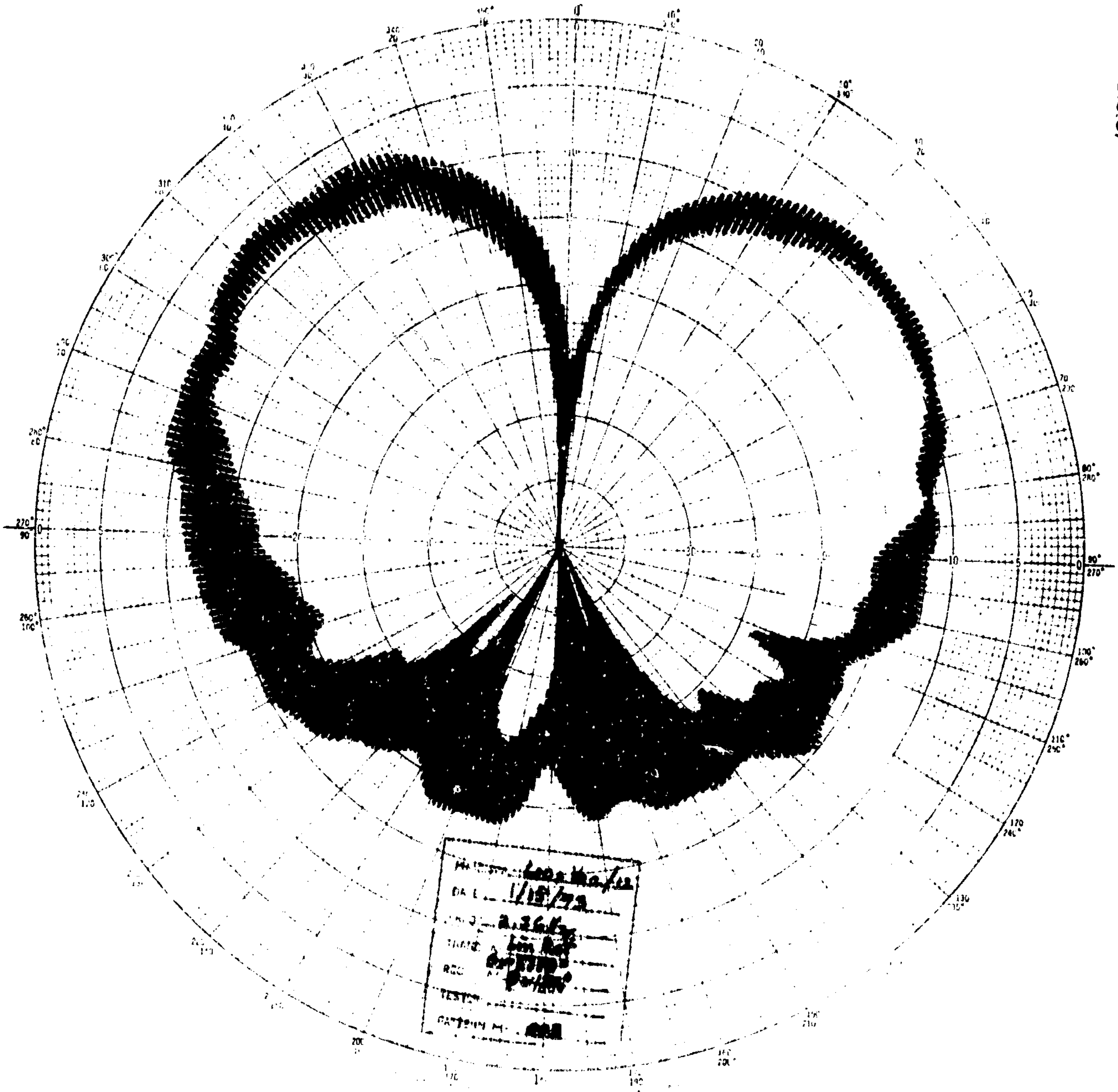


FIGURE 4-7. LOOP-VEE RADIATOR RADIATION PATTERN, 2.3 GHz,
ϕ = 180 DEG, θ VARIABLE

30163-218(U)

REPRODUCIBILITY OF THE ORIGINAL PAGE IS POOR.

4.2 PROBE BUS ANTENNAS

The subsystem must fulfill three different antenna coverage requirements on the probe bus. A medium gain antenna with gain directed along the aft spin axis is required during bus entry, an antenna with a toroidal beam about the spin axis is required during cruise, and essentially omnidirectional coverage is required for command reception and telemetry while the bus is in nonstandard attitudes.

Medium Gain Antenna Selection

Prime candidates for the medium gain antenna are end-fire radiators and horns. The end-fire radiators such as the helix, yagi, and disc on rod antennas must be mounted away from the spacecraft structure to avoid interference. These antennas also have to be at least five wavelengths long and thus are structurally undesirable. An array of end-fire radiators would be more suitable, but the array still has the problem of mounting so as to avoid interference from the spacecraft structure. Since only the aperture of a horn must be unobstructed, this antenna can be located within the spacecraft structure with no interference. The horn antenna is also much simpler than the end-fire radiator, and the design parameters can be scaled from existing hardware.

Table 4-5 summarizes the candidate medium-gain antennas. A single conical horn is selected as the most advantageous when all factors are considered.

TABLE 4-5. CANDIDATE MEDIUM GAIN ANTENNAS

Antenna Type	Advantages	Disadvantages
End-fire radiator	Design available	Mounting to avoid interference with structure is difficult. Length of antenna is structural problem.
Array of radiators	Shorter than single end-fire radiator	Complex, new design, mounting to avoid structural interference is difficult.
Conical horn	No structural interference problem. Can be scaled from existing hardware	—

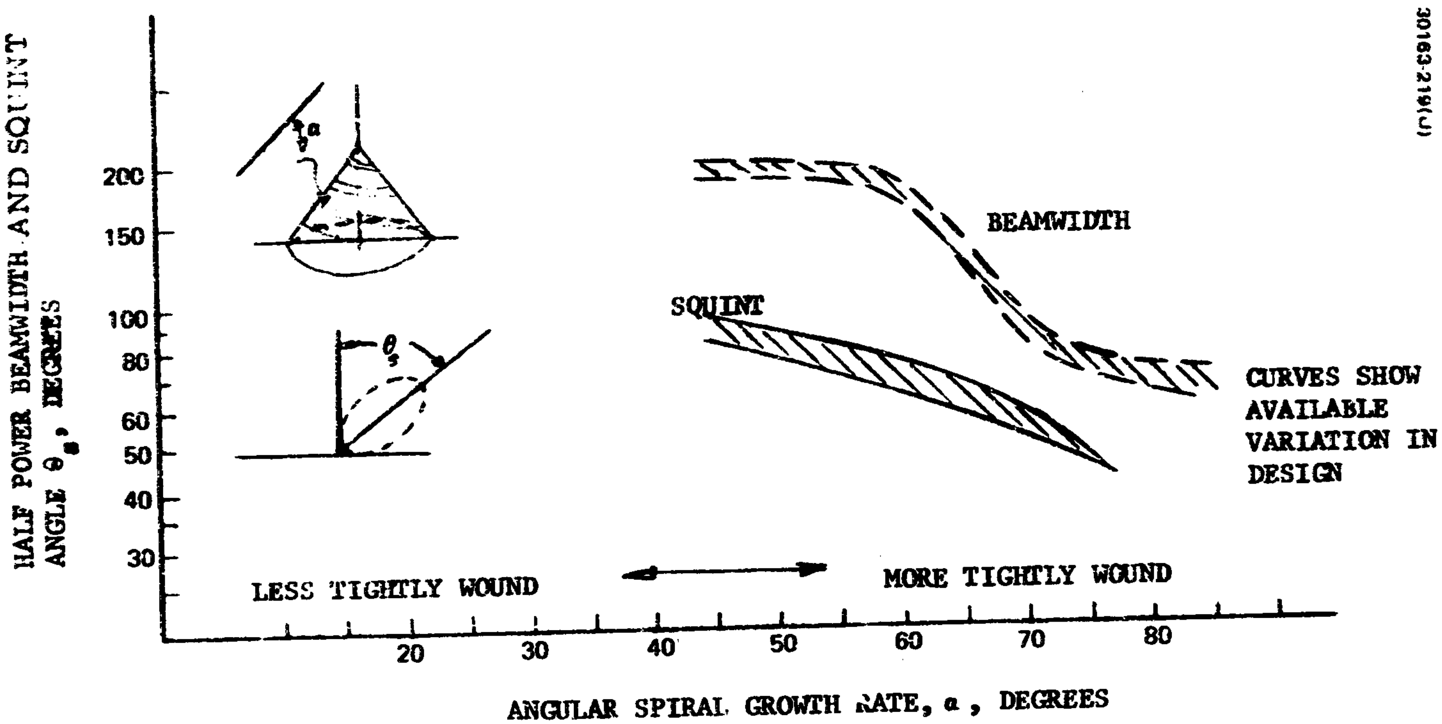


FIGURE 4-8. CONICAL LOG SPIRAL DESIGN DATA

Toroidal Beam Antenna Selection

Candidate antennas to provide omnidirectional coverage in the spin plane during probe bus transit are a bicone, conical log spiral, and an array of radiators. The third candidate is the most complex and expensive. It is related to the electronically despun antenna in design concept. The pattern in the spin plane will have a gain ripple. The bicone and conical log spiral are simpler antennas and can be scaled from existing hardware.

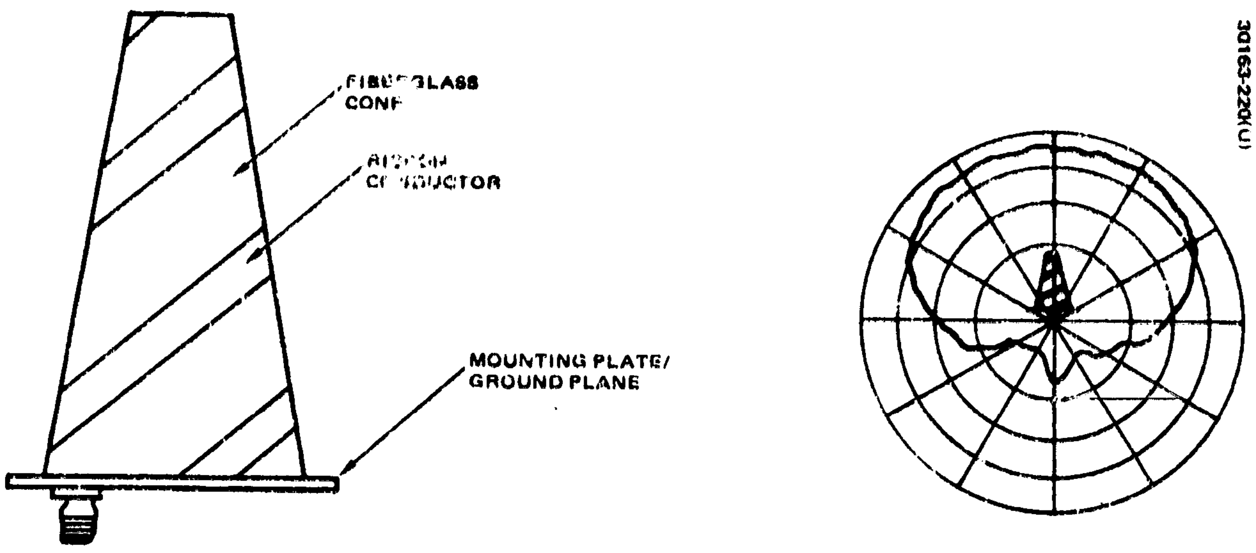
The bicone consists of a circular array of slots on a circular feed waveguide radiating into a circularly symmetric flared region. Circular polarization can be achieved either by using crossed slots or single slots at 45 deg inclination.

The conical spiral is smaller in diameter than the bicone antenna, but longer. For a base diameter of 10.6 cm, the height of the conical spiral is 40 cm. To provide an azimuthal omni pattern, a four arm spiral has to be excited in the first order difference mode and designed with a fast spiral growth rate as shown in Figure 4-8. The cone angle is controlled by the spiral growth rate. If the spiral antenna had more gain when operated in the difference mode, it could be used as two antennas in one, by exciting the spiral in the sum and difference mode and using it in place of the bicone and the back-omni.

Table 4-6 summarizes the advantages and disadvantages of the various antennas which give rise to toroidal beam patterns. The antenna gain requirement in the probe bus is best met with the bicone antenna since it is relatively low cost and its design can be scaled from existing space hardware.

TABLE 4-6. CANDIDATE TOROIDAL BEAM ANTENNAS

Type of Antenna	Advantages and Disadvantages
Bicone	Scaled from existing hardware
Conical log spiral	Low gain, long, slender, small base diameter, scaled from existing hardware
Multiple radiators	Complex, heavy, costly design, ripple in spin plane



CONICAL LOG SPIRAL RADIATOR

TYPICAL Θ-PLANE RADIATION PATTERN

FIGURE 4-9. CONICAL LOG SPIRAL ANTENNA

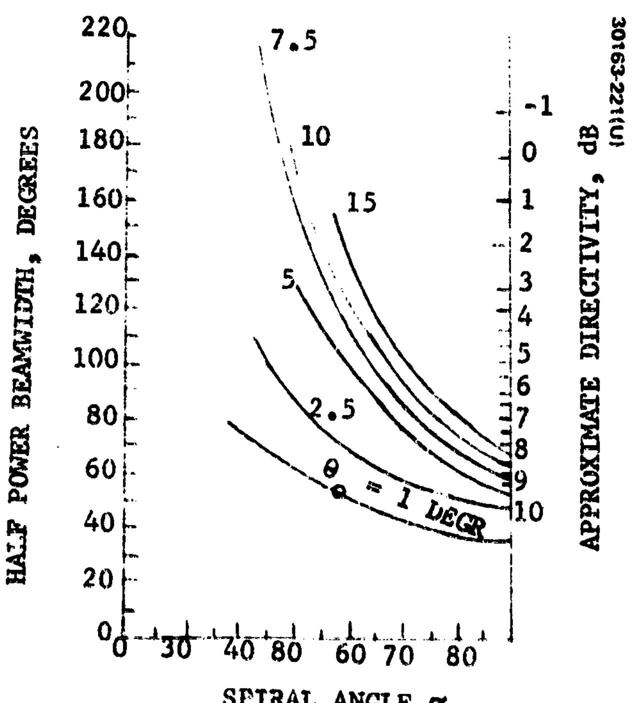


FIGURE 4-10. CONICAL LOG SPIRAL HALF POWER BEAMWIDTH AND APPROXIMATE DIRECTIVITY

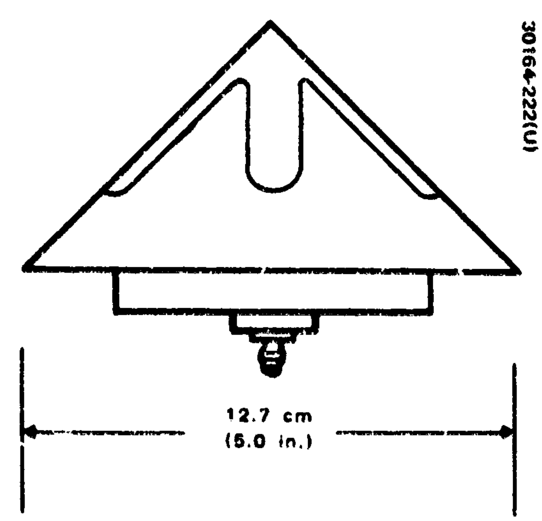


FIGURE 4-11. SLOTTED CONE RADIATOR (SURVEYOR TYPE)

Spherical Coverage Antenna Selection

To provide spherical coverage about the spacecraft, at least two radiators, each giving approximately hemispherical coverage, are needed. Several antennas are applicable including the conical log spiral, slotted cone, planar spiral and curved turnstile. The first two can provide better than hemispherical coverage whereas the latter two provide coverage over only one-half to three-fourths of a hemisphere.

The conical log spiral (Figure 4-9) is a broadband radiator that can be designed for wide angle coverage. Much design information has been generated over the years and design costs can be reduced by using these available data. Figure 4-10 shows the wide range of gain/coverage achievable. The spiral angle, α, is related to the spiral wrap factor. A large spiral angle means a tightly wound spiral. The angle θ_o is the spiral half-angle. As θ_o approaches zero, the conical log spiral becomes a log helix.

The slotted cone radiator, Figure 4-11, consists of a crossed-dipole element radiating through a slotted cone. The feed of the crossed-dipole is a simple split-tube balun. Circular polarization is achieved by exciting the orthogonal elements of the dipole in phase quadrature and with equal amplitude. The latter is accomplished by keeping the length-versus-diameter ratios of the two dipole arms equal. The proper phasing is achieved by adjusting the length of the two dipole arms to be unequal until a 90-deg phase difference exists between the impedances of the arms. Measured patterns (Figures 4-12 and 4-13) show the wide angle coverage achievable.

The planar spiral is the special case of the conical spiral with $\theta_o = 90$ deg. The spiral growth can be defined either as geometric change $r = e^{C\phi}$ or as an arithmetic change, $r = C\phi$. The dimension r is the radius vector from the center of the spiral to a point on the spiral ϕ deg from $\phi=0$. The other variable, C, relates to the spiral growth rate. The geometrically growing spiral is known as the equiangular spiral. The arithmetic spiral is also called the Archimedean spiral. Typically, coverage is over not more than 120 deg with either type of planar spiral. The more tightly wound Archimedean spiral is preferred when clean, circularly symmetric patterns with good axial ratio are important as they are here. However, the gain coverage is on the order of one to two dB lower.

The curved turnstile radiator has its dipole arms bent down towards the ground plane so that the beam broadens. To obtain acceptable circular polarization, a two-line feed is energized through a 90-deg quadrature hybrid. The dipole arms can be flat leaves curved down. The modified turnstile radiator has gain/coverage characteristics very similar to the planar spiral antenna.

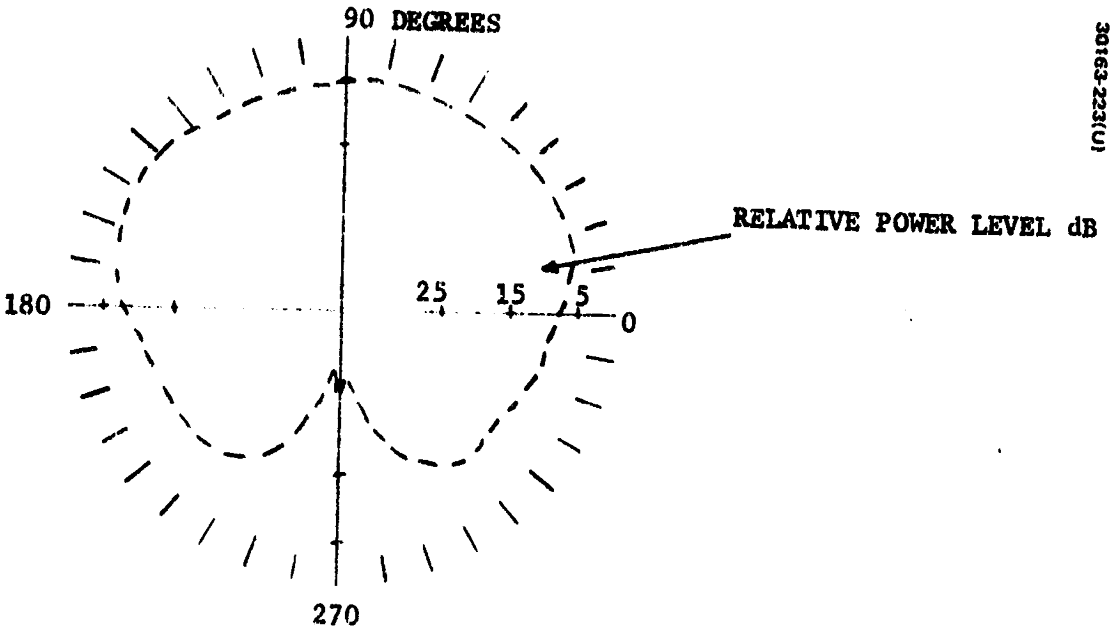


FIGURE 4-12. ELEVATION (θ PLANE) PATTERN, SLOTTED CONE ANTENNA, 2.295 GHz

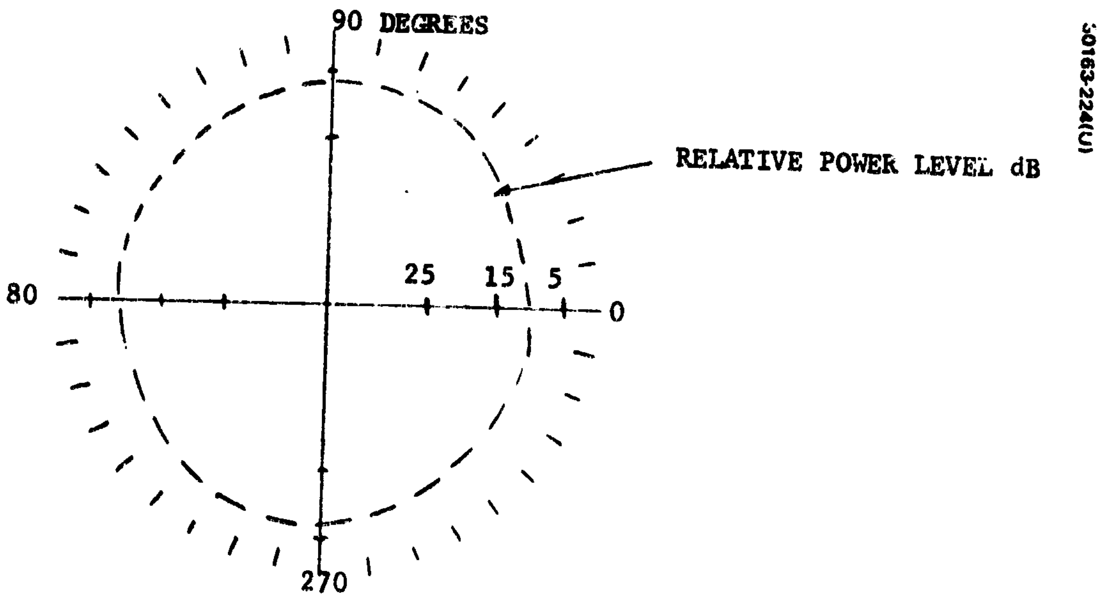


FIGURE 4-13. AZIMUTH (Φ OR SPIN PLANE) PATTERN, SLOTTED CONE ANTENNA, 2.295 GHz

Table 4-7 summarizes the characteristics of the candidate omni-coverage radiators. Considering size, weight, design availability, and gain/coverage performance, an antenna subassembly consisting of a slotted cone radiator and a conical log spiral is preferred. The slotted cone radiator provides coverage over 220 deg, and the conical log spiral fills in the remainder of the sphere. This antenna combination is applicable to the orbiter as well as the probe bus.

4.3 ORBITER ANTENNAS

The orbiter requires a high-gain antenna to support science telemetry during the orbital phase of the mission and spherical antenna coverage for command reception and for telemetry transmission while the orbiter is in nonstandard altitudes. The spherical coverage antenna requirement trade is identical to that presented in subsection 4.2 for the probe bus. The antennas (slotted cone and conical log spiral) selected to provide omnidirectional coverage are the same for both bus and orbiter.

The choice and design of the high-gain antenna for the orbiter spacecraft is influenced by the spacecraft and communication system design selections. For the spin axis normal to the plane of the ecliptic, a despun antenna assembly or an azimuthal omnidirectional (toroidal) antenna pattern are required. The latter approach is very unfavorable because of the much lower antenna gain and the concomitant requirement of much higher transmitter power to support the orbiter data rates. Therefore, this section focuses on the following three candidate despun antenna systems: 1) electronically despun antennas, 2) mechanically despun antennas, and 3) mechanically despun reflectors.

TABLE 4-7. OMNIDIRECTIONAL/SPHERICAL COVERAGE ANTENNAS

Conical log spiral	Design-variable coverage, 50 to 220 deg half-power beamwidth. Broad frequency band of operation. Hardware can be scaled from existing hardware.
Slotted cone radiator	Lightweight, greater than hemispherical coverage, hardware available.
Planar spiral	Less than hemispherical coverage, low profile, hardware can be scaled from existing hardware.
Curved turnstile	Less than hemispherical coverage, new design

Electronically Despun Antenna (EDA)

The electronically despun antenna system has as its functional units the transmit assembly, the antenna proper, and the beam steering/interface assembly. The transmit assembly may be a central signal source feeding into a power distribution and control network or it may be a network of distributed signal amplifiers. The antenna proper consists of the radiators, groundplane, and associated structures. The beam steering interface assembly includes such items as cabling and the power dividing and switching networks.

For an EDA to be applicable and competitive with an MDA, the EDA should have low ripple, continuous signal transmission capability, the required gain at the specified coverage angle, low antenna system losses, and low prime power requirement. The critical assembly of an EDA is the electronic and control circuitry to despin the antenna beam. Much of the weight and loss can be due to the method and implementation of the despin assembly.

The various EDA approaches differ in the following ways:

1) Type of array element

2) Type of rf power source

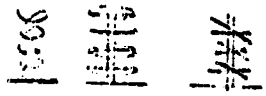
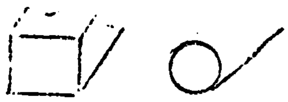
3) Type of electronic beam despinning

The radiating element for a circularly polarized EDA is chosen on the basis of radiation efficiency, gain, axial ratio over the half-power beamwidth angle, weight, and size. Table 4-8 lists several candidate radiators for an EDA. The preferred radiators are those that can easily be fed by coax and have a low form factor. The crossed dipole is a prime candidate. The two cavity backed slot radiators are also suitable elements, especially when the EDA is to be integrated with the solar array. A helix is applicable when the space is available between the EDA ground plane cylinder and the inside wall of the shroud.

The beam despin network may be one of several designs. One approach uses phase controlled hybrid networks to feed the rf to a sector on the cylindrical array. A second approach uses rf switches to feed the signal to only a fraction of the total number of elements at a given time. In a third approach, final distributed rf amplifiers at the element level in the array are dc controlled to vary the rf output at each radiator.

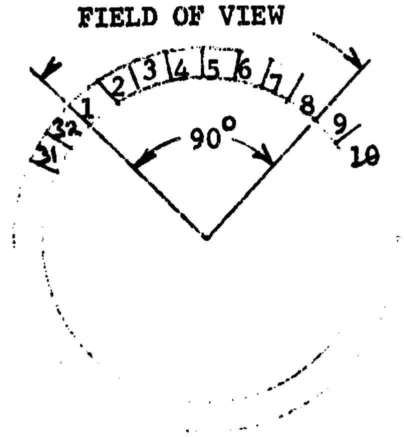
In a practical application of the phase controlled hybrid concept the phase variation is digitally controlled, the ramp portion of the current waveforms being approximated in a number of steps. A tradeoff exists between control complexity and rf ripple. The rf switch control technique is considered least desirable, since it requires the use of a highly reliable,

TABLE 4-8. RADIATION ELEMENTS FOR AN EDA IN ORDER OF PREFERENCE

Type	Design	Remarks
Crossed dipole		Can be integrated with solar array, but some shadowing on the solar array. Design can be based on Surveyor slotted cone dipoles
Slots — dipole-fed		Can be integrated with a solar array. Design can be derived from other radiators.
Helix or other end-fire radiator		Long, does not fit flush with groundplane, does require only part of area available.
Square or circular waveguide		Best with a waveguide feed network, mounts flush, requires full available area
Cavity-backed spiral		Heavy, requires full available area, low gain
Orthogonal slots loop excited		Can be integrated with a solar array, mounts flush, designed hardware available

lightweight switch which is not readily available. Using distributed rf amplifiers in the EDA allows amplitude control at each radiator to despin the radiated beam. Recent advances in technology make this approach feasible. The important advantage is the minimization of rf losses in the power distribution and phasing networks. A phase shifter is required at each final amplifier to vary the phase to the appropriate value as a function of the relative position of the radiating array sector.

A particular EDA design based on an existing design of an L/S-band EDA which had been developed on company funds for Metsat/SMS was used as a representative EDA. Alternatives were also considered during the



ELECTRONICALLY DESPUN ANTENNA – LAYOUT OF THE 32 STACKS OF RADIATORS, EIGHT STACKS RADIATING AT ONE TIME

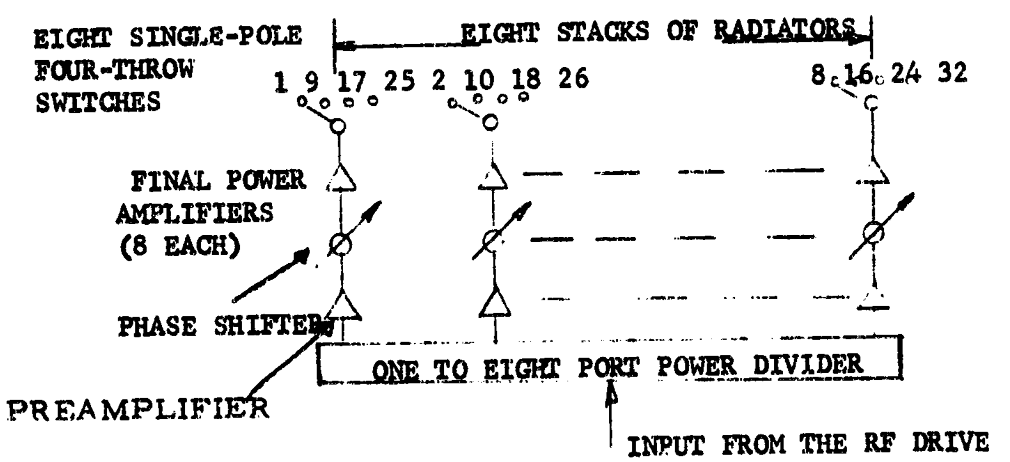


FIGURE 4-14. ELECTRONICALLY DESPUN ANTENNA SWITCH/PHASE NETWORK

systems study. In particular, a distributed rf amplifier scheme based on a Texas Instruments study performed for Ames Research Center* was examined during a systems trade study of high-gain antenna candidates. The results of this trade study are given in Volumes 3 and 4 of this report.

The candidate company funded design is illustrated in Figures 4-14 through 4-17. The aperture is a ring of 32 stacks of 5 radiators each. Each radiator consists of four slots backed by a loop-excited cavity as shown in the cutaway view of Figure 4-15. The crossed loops are excited through 90-deg, 3 dB hybrids in order to obtain two equal field components in phase quadrature. As seen from Figure 4-17, the slot radiators are interlaced with the solar array.

The diameter of the EDA is sized for a 10-deg beamwidth in the plane of spin. The height of the cylindrical antenna determines the elevation beamwidth (along the spin axis). Of the 32 stacks of radiators, 8 are energized at any given time resulting in a net gain of 22.5 dB.

A switching/phasing network (Figure 4-14) provides for synchronous rotation of a well defined directional antenna beam. There are eight single-pole, four throw switches. Eight phase shifters are required to control the phase of each energized stack of cavity backed slots. Since the phase shifters add several dB of loss, it is desirable to include transistor amplifiers in the network to reduce the primary rf source power level and establish a better dc to rf conversion ratio.

Table 4-9 summarizes characteristics of this EDA. The weight assumes special construction techniques such as foam structure with 0.015 cm (0.006 in) aluminum foil facing.

Mechanically Despun Antenna (MDA) Array

To obtain an 11-deg beamwidth and a net gain (after antenna losses) of 23.5 dB, the mechanically despun array dimensions must be on the order of six wavelengths. Figure 4-18 plots the planar array performance as a function of its size. A mechanically despun array may be slightly smaller than a reflector because greater control over the aperture illumination exists, and therefore more efficient use of the aperture can be made. However, this is obtained at the expense of greater complexity.

A mechanically despun array may consist of an array of radiators such as helices or dipoles or the array may be a flat plate slot array. The design of the array of radiators requires the selection of the type of radiating element and the feed network. Table 4-10 lists radiating elements.

---

* R. D. Meeks, "An Electronically Phased Modular Array Antenna for Pioneer Venus Communications", NASA/Ames Report U1-991840-F, 22 November 1972.

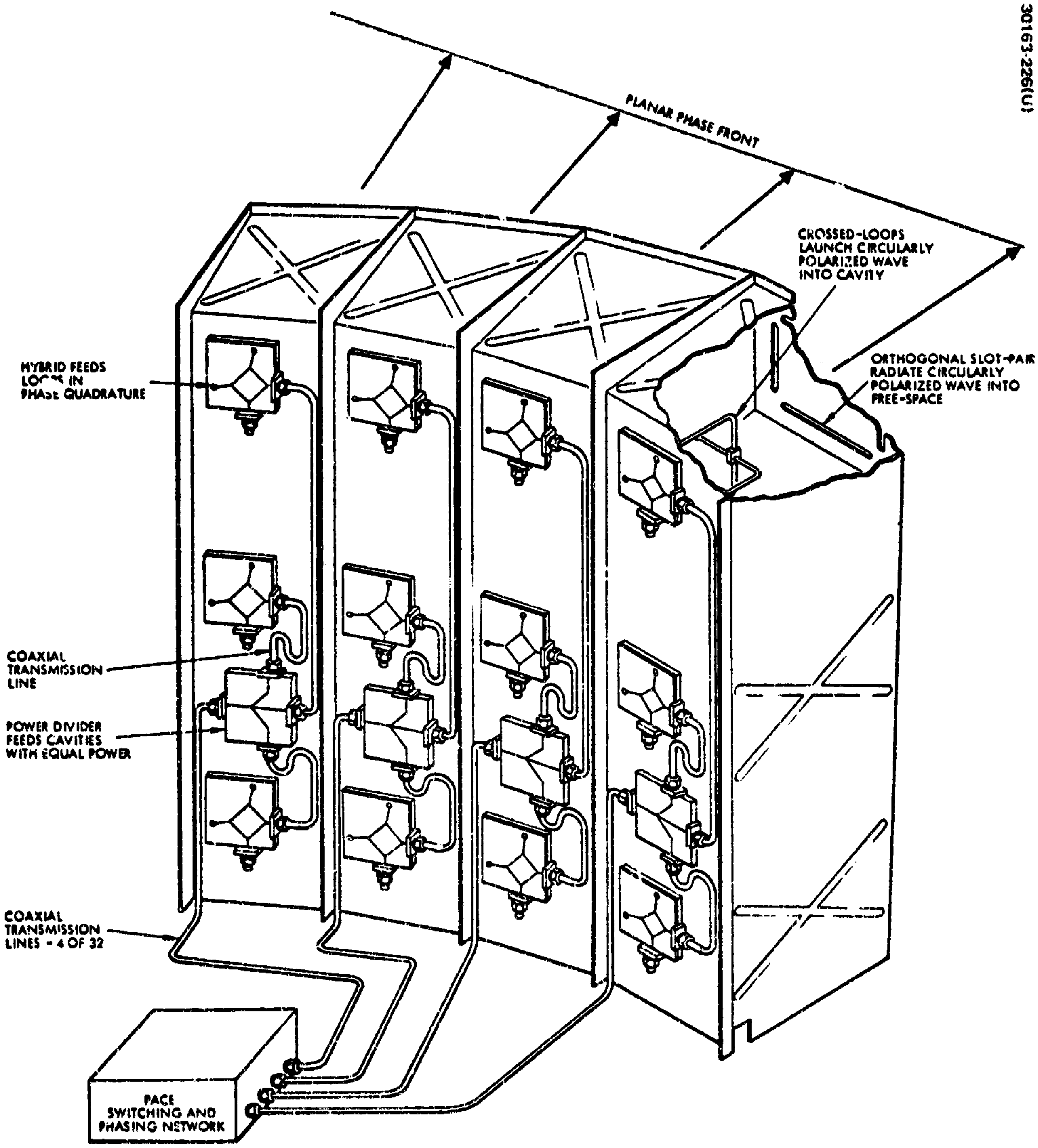
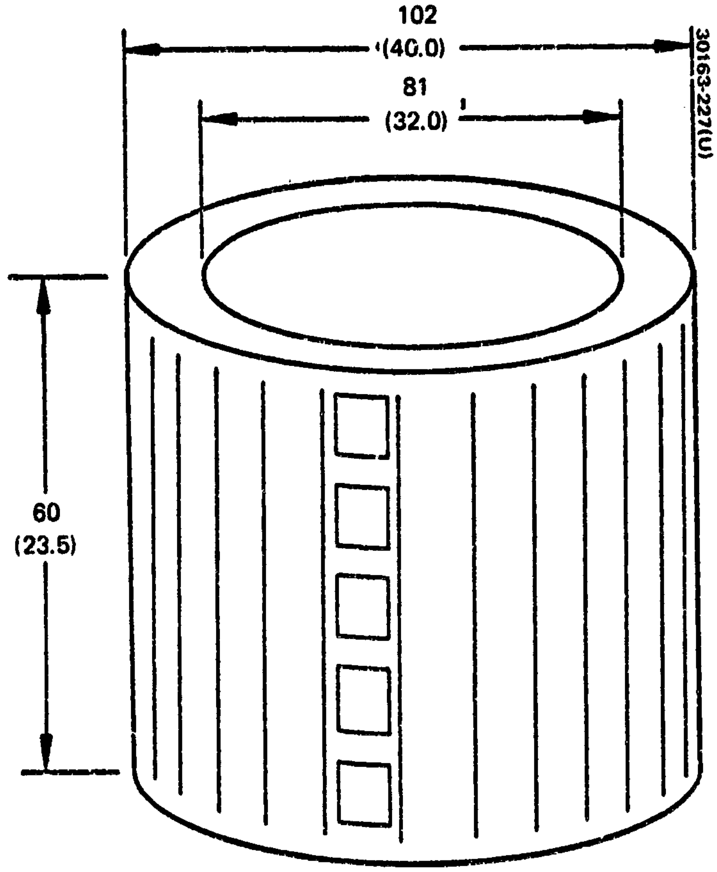


FIGURE 4-15. S-BAND ELECTRONICALLY DESPUN ANTENNA CUTAWAY VIEW



DIMENSIONS IN
CENTIMETERS AND (INCHES)

FIGURE 4-16. ELECTRONICALLY DESPUN ANTENNA OUTLINE – 32 STACKS OF FIVE ELEMENTS EACH

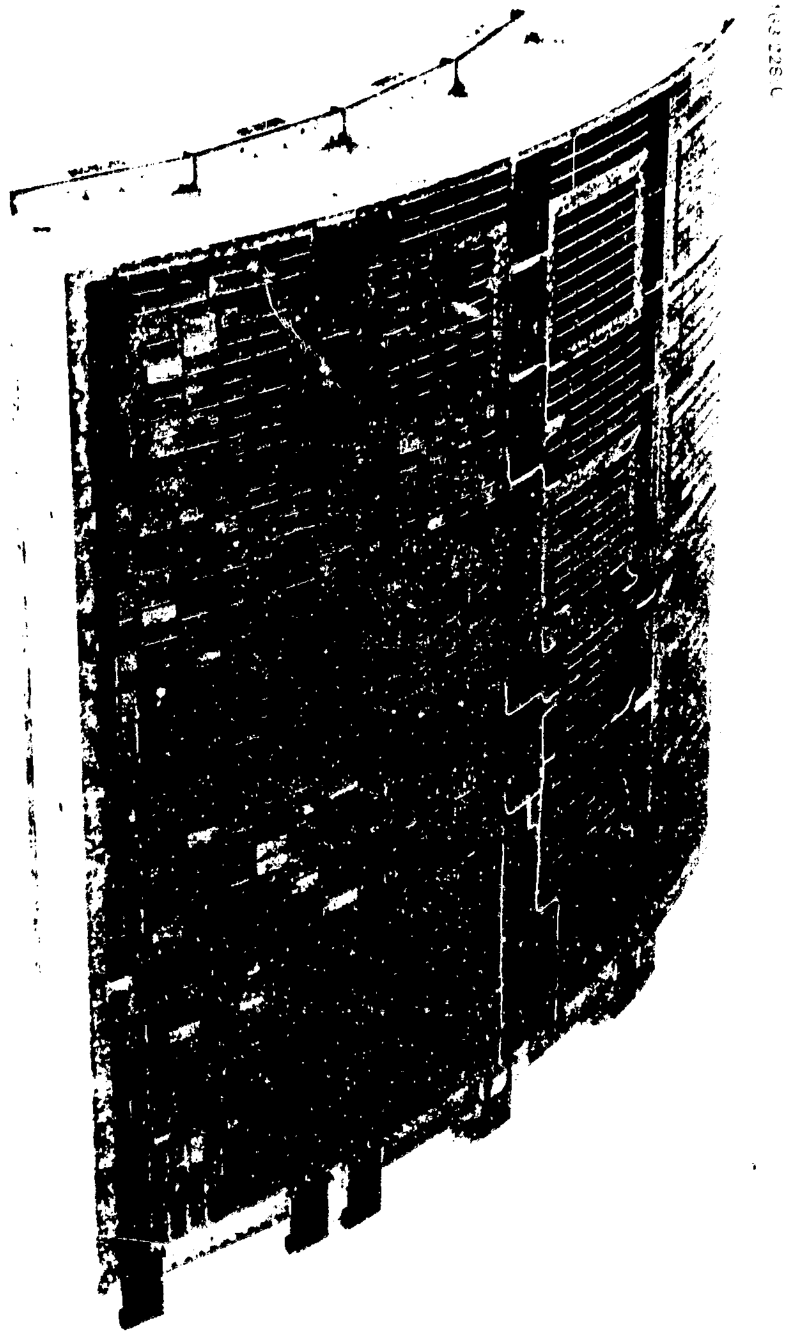


FIGURE 4-17. ELECTRONICALLY DESPUN ANTENNA FRONT VIEW SHOWING SOLAR CELLS AND RADIATING SLOTS (PHOTO 30163-228)

TABLE 4-9. HIGH GAIN ELECTRONICALLY DESPUN ANTENNA (EDA) PERFORMANCE PARAMETERS

Size (cylinder)	1.04 m (40 in.) diameter, 60 cm (23 in.) high	
Polarization	Circular; axial ratio, 3 dB	
Peak gain		25.5 dBi
Circuit losses (hybrids/cable)	-1.0 dB	
Switch loss	-0.5 dB	
Aperture efficiency loss (70 percent)	-1.5 dB	
Total losses		-3.0 dB
Net gain		22.5 dBi
Beamwidth (spin/plane/normal to spin plane)	10 by 12 deg	
Mass		
EDA assembly		
Structure (includes slot radiators)	6.1 kg (13.5 lb)	
Feed network	1.8 kg (4.0 lb)	
Switches	0.68 kg (1.5 lb)	
Total weight	8.6 kg (19.0 lb)	

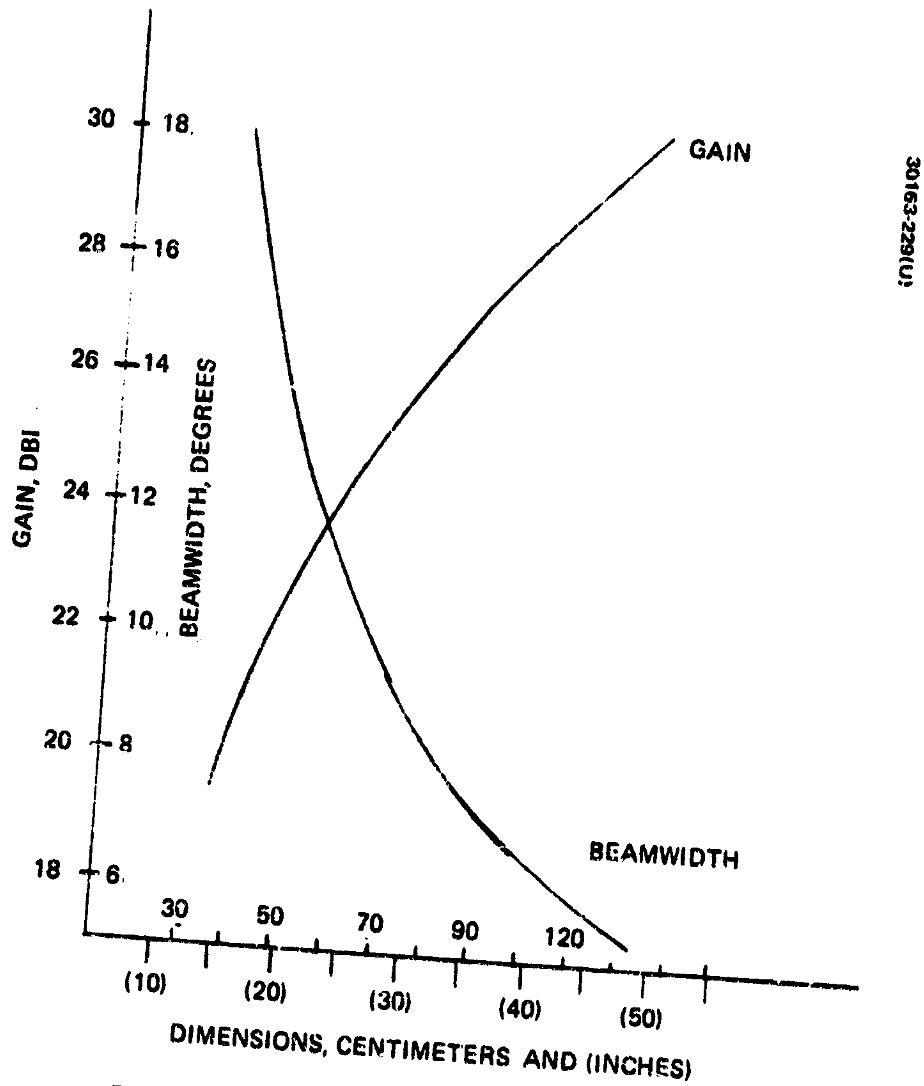


FIGURE 4-18. PLANAR ARRAY PERFORMANCE

TABLE 4-10. CANDIDATE RADIATING ELEMENTS FOR CIRCULARLY POLARIZED PLANAR AND LINEAR ARRAYS ON SPACECRAFT

Type of Radiator	Characteristics
Crossed dipole	Low profile ~0.3 λ, < λ element spacing, 10 percent bandwidth
End-fire	1 to 5 λ long, applicable in widely spaced element arrays, lightweight, up to 30 percent bandwidth
Backfire	0.6 λ high, > λ element spacing, up to 30 percent bandwidth, medium weight
Planar spiral	~0.3 λ high, > λ element spacing, greater than 4 to 1 bandwidth, medium to heavy weight
Conical spiral	0.8 to more than 2 λ high, > λ element spacing, greater than 4 to 1 bandwidth, light to heavy as a function of bandwidth, etc.
Open-ended waveguides and horns	Can be flush with ground plane, $\lesseqgtr$ λ spacing, 10 to 15 percent bandwidth, normal design heavy, but with foil/foam, lightweight
Crossed or inclined slots	Can be flush with ground plane, < λ spacing, 10 percent bandwidth, normal design heavy, but with foil/foam design, lightweight

Table 4-11 lists the candidate feed networks. Open ended waveguide radiators are applicable when the feed network is also in waveguide. A helix, disc on rod, or yagi are very similar; they are end-fire radiators extending above the ground plane by a minimum of 1 1/2 wavelengths. The crossed dipole extends only 0.3 wavelength above the ground plane. It can be easily fed end-on from a stripline feed. The backfire radiator is an extension of the dipole radiator by the addition of a second reflector. It too can be connected easily to a coaxial connector.

The stripline feed with hybrid power dividers is a very common device. The loss per power divider is on the order of 0.3 dB, including line length loss between hybrids. The loss of the feed network can be very significant in an array of even medium gain. The circuit loss can be minimized by using rf amplifiers at each radiating element. However, this adds to the weight, complexity, and cost of the antenna system.

Another type of feed network is a stepped radial line power divider. It is a parallel plate structure with a central feed point. The parallel plate region is stepped in order to control the coupling to the pickup probes which form the interconnect to the radiating elements. The radial power divider provides a tapered aperture amplitude distribution so that the aperture efficiency is 80 percent or less. With a loss of 0.3 dB in the power divider, the total antenna loss (including aperture mismatch and aperture efficiency) is on the order of 2.0 dB.

The flat plate slot array consists of lengths of waveguide with slots cut into the broadwall. The array of waveguides can be fed from another linear slot array or from a feed network as discussed above. The linear slot array is usually preferred, because it is compact and ideal for feeding a linear array. The array of linear arrays of slotted waveguides is most efficient when the aperture dimensions are greater than 10 wavelengths. The power lost in the terminations of the linear slot arrays increases rapidly as the length of the arrays is reduced.

The flat plate annular slot array is a combination of the concepts or radial line power divider and a slot array. It is constructed as a parallel plate line, but radiating slots are used in place of the pickup probes. The aperture size is limited to a diameter not much more than 10 wavelengths providing an aperture efficiency of 60 percent. Circular polarization is not easily achieved with slot arrays. Design and manufacturing costs are high for planar and annular slot arrays.

MDA Reflector Antennas

Several designs of mechanically despun reflector antennas can be considered. The cassegrain reflector is not included because it is inefficient when the reflector diameter is less than 30 wavelengths. Dual reflector antennas, with the primary reflector smaller than 30 wavelengths generally have low radiation efficiency because of large aperture blockage by the secondary reflector.

TABLE 4-11. CANDIDATE ARRAY FEED NETWORKS

Type of Feed Networks	Advantages and Disadvantages
Stripline hybrid power dividing network	Lossy, area proportional to number of radiators, custom design required; for linear, planar, or circular arrays
Radial line power divider	Low loss, custom designed for system; most applicable to planar and circular arrays
Slotted wave-guide line — source feed	Medium loss dependent on the length and number of slots; suitable for feeding line sources
Quasioptical feed	Large volume; suitable for feeding linear, planar and circular arrays

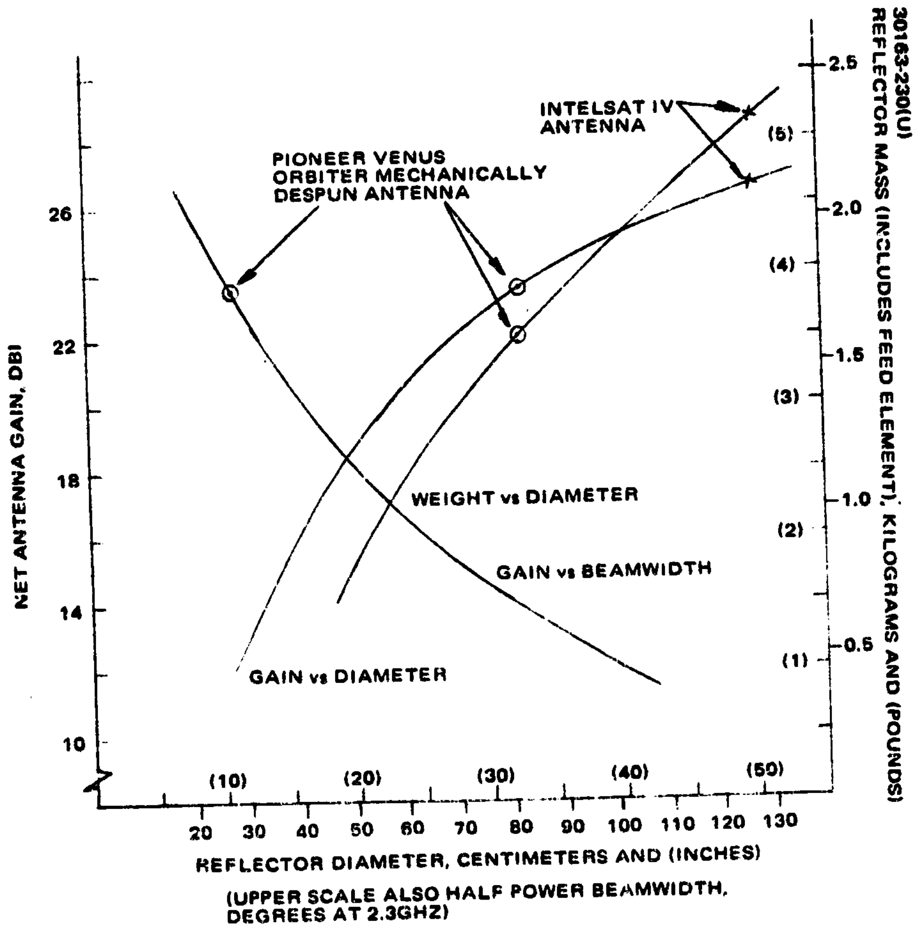


FIGURE 4-19. PARABOLIC REFLECTOR PERFORMANCE - GAIN, BEAMWIDTH, AND MASS VERSUS PRIMARY

The most common reflector design suitable for the high gain antenna is the parabolic reflector with focal point feed. Figure 4-19 shows the interrelationships between gain, beamwidth, diameter, and weight for this type of antenna. In the case of Pioneer Venus, the required antenna diameter is 76 cm. The Intelsat IV communication antenna used this type of design. Figure 4-20 is a photograph of the reflector used on that spacecraft.

The reflector is constructed of 0.95 cm (3/8 in) expanded aluminum honeycomb core sandwiched between two layers of 0.025 cm (0.01 in) epoxy fiberglass cloth face sheets. Aluminum foil 0.0025 cm (1 mil) thick is bonded to the front surface of the reflector to provide a continuous highly reflective surface. The dish is fastened in the back to a mounting flange.

The feed may be a cavity-backed turnstile, a helix, a conical horn, or other small radiator, which gives circular polarization. A conical horn is preferred because it has high radiation efficiency and good pattern characteristics.

Other designs include the offset feed type, cylindrical reflector, and the hog-horn. The latter can be ruled out because of size. The offset-feed reflector gives less feed blockage and therefore finds application in multiple beam reflector systems where the multiple element feed is large and bulky. As a high-gain MDA, it is not considered useful. The design cannot be derived from existing hardware and the high development cost cannot be justified since there is no specific advantage.

The cylindrical reflector requires a line source feed. It finds application where simple beam-steering in one plane is required. However, in a fixed beam mechanically steerind antenna system, the cylindrical reflector provides no advantage over the focal point parabolic reflector.

A subcategory of MDA antennas is one in which only the reflector needs to be mechanically despun. The feed is spacecraft-body fixed. No rotary joint is needed. A design approach uses a cylindrical reflector with a sleeve dipole feed. The reflector illumination is inefficient because spillover and back radiation are high. Table 4-12 compares the losses in this type of antenna (used on Helios) with the more standard MDA design. It is seen that the focal-point fed reflector has higher efficiency. In case of failure such as bearing freeze-up, either design is inoperative, but the despun reflector can be jettisoned and the feed system can be used for a backup mode at a greatly reduced capability.

MDA-EDA Tradeoff

Table 4-13 summarizes the advantages and disadvantages of the various high-gain antennas considered for the Pioneer Venus orbiter spacecraft. The configuration selected on the basis of the foregoing discussion and extensive HAC experience utilizes an MDA with parabolic reflector and a focal point feed.

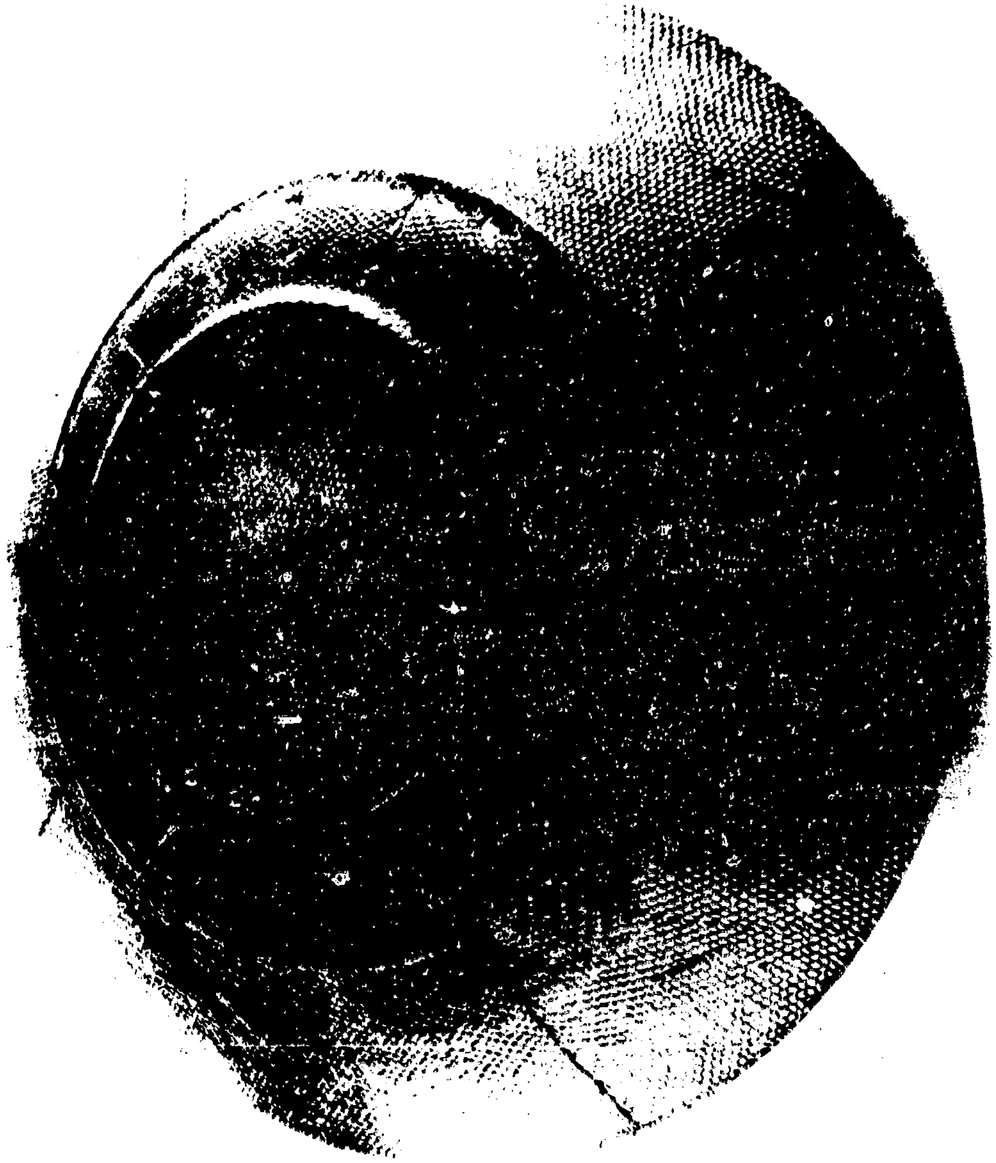


FIGURE 4.20. HONEYCOMB SANDWICH REFLECTOR FOR INTELSAT IV SPACECRAFT (PHOTO 30163 231)

TABLE 4-12. ANTENNA SYSTEM LOSSES

Loss Factors	Focal Point Feed Parabolic Reflector, dB	Helios Type Antenna, dB
Feed blockage	0. 20	0.4
Subreflector blockage	–	See feed blockage
Illumination taper	1. 0 (10 dB taper)	1. 1
Polarization loss	0. 15	(0. 15)*
Feed loss	0. 1	1. 0
Reflector surface errors	0. 2	0. 2
Feed phase error and defocusing	0. 25	(0. 25)*
Aperture mismatch	0. 25	(0. 25)*
Spillover (2. 4 dB)	0. 45	1. 7
Rotary joint	0. 2	–
Feed line	0. 1	Feed loss
Strut blockage	0. 2	
	3. 0	4. 4 (5. 05)*

*A more conservative approach to the losses should also include these parenthetical numbers.

TABLE 4-13. HIGH GAIN ANTENNA TRADEOFFS

Types of Antennas and Systems	Advantages and Disadvantages
Electronically despun antennas	No mechanically moving parts, greater complexity, less space proven
RF switch	Low reliability, simple design
DC switch	Higher reliability, more complex
Phase switch	Complexity, weight, medium reliability
Mechanically despun antennas	Moving parts, extensive use in space, hardware developed
Slot arrays	Complex, high design and manufacturing cost, circular polarization not easily obtained
End-fire radiator arrays	Feed losses, design cost, higher technical risk
Parabolic reflector with focal point feed	Design well known, hardware may be derived from existing designs, light-weight, low technical risk
Cylindrical reflector	Lower gain per unit area, new design
Offset feed	Not applicable, lower gain per unit area, new design
Mechanically despun reflector	Eliminates rf rotary joint
Cylindrical reflector	Lower gain per unit area, high level back radiation and spillover. Dual reflector increases blockage. Custom design, not extension of existing designs.

4.4 POWER AMPLIFIER SELECTION

The objective of this study was to investigate the use of a solid state power amplifier module that could be used as a building block to form any of the required power amplifiers in the probes, probe bus, and orbiter. A second objective was to perform a performance/cost tradeoff with a TWT.

The design choice for the Thor/Delta is a 7 W solid state power amplifier module, similar to that employed in a military space application. The design, which utilizes the MSC 3005 transistor in its output, wil be space qualified this year. The module can be used alone as on the small probe, or used in a parallel configuration which permits summing for higher power in an external hybrid combiner as in the large probe, probe bus, and the orbiter. This commonality of design aids greatly in reducing subsystem nonrecurring costs. The power amplifier module can also be operated in a low power mode to conserve the spacecraft primary power. The Atlas/Centaur design was a 9 W module (see Section 6).

S-band solid state power amplifiers in the 7 W output range have only recently been developed for space applications. However, these applications are increasing in number, and space qualified components as well as actual flight experience will be available within the next year.

Traveling-wave tubes (TWT) have had a more extensive application history in space. Power outputs have ranged from 4.5 to 24 W with a dual output power mode being a common feature of the higher power amplifiers. Much higher power tubes (100 W) are also space qualified.

A tradeoff between a possible 7 W, solid state power amplifier module and the TWT amplifier (TWTA)used on Pioneer 10 shows that the former is much lighter weight and smaller in size (see Tables 4-14 and 4-15). Efficiency is roughly comparable. The cost of the solid state power amplifier should be roughly half of the TWTA. At this power level, only one factor favors the TWTA; namely, that it is "off the shelf" and has proven reliability in space application. However, if the TWTA were chosen for the orbiter mission, or for the probe bus, commonality of design with the large and small probes would be sacrificed and costs would therefore be much higher.

The power level is certainly a key factor. If the required output power were greatly increased, a TWTA would presently be the only available choice.

Obviously, performance of the solid state power amplifier is related to cost whenever the state of the art is approached. For that reason, if less stringent limits were imposed on weight and power consumption, the cost would be less. A 20 percent cost reduction is estimated if the weight were to increase to 0.7 kg (1.5 lb) and the dc power requirement were 33.6 W.

Solid State Amplifier Versus TWTA Tradeoff

Table 4-14 summarizes the performance of various solid state devices that are of interest to this study. In the top grouping are integrated power

TABLE 4-14. SUMMARY OF TRANSISTOR AMPLIFIERS

Type	RF Power, W	DC Power, W	Gain, dB	Mass kg (lb)	Dimensions cm	(in.)	Status
Integrated Power Amplifiers							
Philco 272-1	20	105	15	1.5 (3.25)	5.1 x 12.7 x 22.9	(2 x 5 x 9)	Prototype
Philco 272-2	10	48	10	0.9 (2.0)	5.1 x 12.7 x 17.8	(2 x 5 x 7)	Prototype
Philco 272-3	5	21	7	0.5 (1.0)	5.1 x 12.7 x 7.6	(2 x 5 x 3)	Prototype
Hughes	2[1]	35	NA	1.9 (4.2)	9.5 x 13.3 x 27.9	(3.75 x 5.25 x 11)	Telesat
Hughes	9	24	7	0.5 (1.1)	4.3 x 6.4 x 17.0	(1.7 x 25 x 6.7)	Qualification model being developed for military space program
Exciter							
Philco SGLS	1	11	NA	0.5 (1.01b)	393 cm³	(24 in.³)	Space qualified (Skynet)
Hughes	1	11.5	NA	1.5 (3.3)	7.4 x 16.1 x 25.9	(2.9 x 6.35 x 10.2)	Prototype being built for space qualification by [illegible]/73 for OSO
Power Amplifier without regulator							
NASA Goddard	1/2	27/7	8	0.0 (0.1)	16.4 cm³	(1 in.³)	Nimbus – tracking and data experiment
MSC 41842	10	33	30		7.6 x 6.4 x 1.3	(3 x 2.5 x 0.5)	Being space qualified
MSC 41832	[illegible]	22	21	0.1 (0.3)	49.2 cm³	(3 in.³)	Commercial
Radiation Inc.	[illegible]	21	17	0.1 (0.33)	9.7 x 5.3 x 2.5	(3.8 x 2.1 x 1.0)	Commercial
Hughes	10	24	7	0.1 (0.12)	49.2 cm³	(3 in.³)	Development
Hughes	2	12	23	0.2 (0.42)	123 cm³	(7.5 in.³)	Development
Hughes	2.5	8.1	21.5	0.1 (0.33)	10.2 x 4.2 x 3.3	(4 x 1.65 x 1.3)	Qualification model being discharged for military space program

[1] Output at 4.2 GHz; [illegible] W available at 1.4 GHz.

TABLE 4-15. SUMMARY OF TWA AND TWT

Type	RF Power, W	DC Power, W	Line Voltage	Gain, dB	Mass kg (lb)	Dimensions cm	Dimensions in.	ROM Cost, K$	Space Qualified	Space Applications
TWA										
WJ-12-6	35	135	28 ±4V	30	7.3 (16)[1]	11.7 x 17.8 x 35.6	(4.6 x 7 x 14)		Yes	–
WJ-1171-4	24	72	28 ±4V	31	2.3 (5)	7.6 x 10.2 x 30.5	(3 x 5.4 x 12)		Yes	–
WJ-1094-1	24/12	80/52	25 -50V	33/30	4.0 (8.9)	7.6 x 17.8 x 26.7	(3 x 7 x 10.5)		Yes	–
WJ-1171-2	24	70	28 ±3%	31	1.9 (4.2)	7.6 x 11.2 x 30.5	(3 x 4.4 x 12)		Yes	–
WJ-1171-3	24/12	73/42	28 ±3%	31/28	2.1 (4.55)	7.6 x 11.2 x 30.5	(3 x 4.4 x 12)		Yes	Helios
WJ-1171-1	6	24	28 ±3%	33	1.7 (3.8)	7.6 x 11.2 x 30.5	(3 x 4.4 x 12)	50	Yes	Pioneer 10
1398H	12	60	27 ±5V	30	3.9 (8.5)	10.7 x 15.2 x 27.9	(4.2 x 6 x 11)	55	Yes	Classified
TWT										
242-HA	2	57/32	HVPS	27/24	0.7 (1.5)	3.8 x 5.3 x 23.6	(1.5 x 2.1 x 9.3)	16.6	Yes	Mariner 71
WJ-395-3	100	222	HVPS	33	1.4 (3.1)	4.1 x 7.1 x 34.3	(1.6 x 2.8 x 13.5)		Yes	–
WJ-338-1[2]	20	80	HVPS	35	1.6 (3.5)	4.6 x 6.4 x 27.9	(1.8 x 2.5 x 11)		Yes	–
(3)	50/25	92/50	HVPS	40/?	1.1 (2.5)	7.1 x 7.1 x 38.1	(2.8 x 2.8 x 15)	26[4]	No	–
239H	4.5	16	HVPS	27	0.5 (1.0)	4.1 x 5.1 x 21.6	(1.6 x 2 x 8.5)	16.6	Yes	TACSAT
214H	5.0	23	HVPS	27	0.5 (1.0)	2.8 x 7.6 x 21.0	(1.1 x 3 x 8.25)	16.6	Yes	Pioneer 6, 7, 8
HVPS										
WJ-1084	–			–	Similar to WJ1084-1				Yes	Mariner 71
(3)	20/10/5	67/40/25	$28\ ^{+4}_{-2}V$		2.7 (6)	6.4 x 11.4 x 27.9	(2.5 x 4.5 x 11)[7]	35[6]	No	
388020-100	(8)	20	25-31	–	0.7 (1.5)	3.8 x 16.3 x 17.8	(1.5 x 6.4 x 7)	12	Yes	TACSAT

Notes:
1) Includes weight of pressurized enclosure
2) Tested to 9500 g shock level
3) Hughes internal development for community broadcast satellites. Proposed for ATS-G. Highest efficiency tube.
4) Estimated. Plus $100K for high g redevelopment.
5) Hughes proposed assuming use of 242-HA TWT.
6) Includes integration and test with tube but not the $16.6K tube cost. Also add estimated $150K development.
7) Integrated TWA package dimensions.
8) Used with 239H TWT.

TABLE 4-16. COMPARISON OF TRANSPONDERS

	Philco-Ford	Motorola		General Dynamics	TRW(3)	AEG-Telefunken(1)
Receiver N. F. (dB)	6.5	8.5	6.0		6.0	3.5
Exciter output (dBm)	21	18	33	33	17	NA
Mass, kg (lb)	2.0 (4.4)	8.8 (19.3)	3.2 (7)	6.2 (13.0)	2.9 (6.4)	2.3 (5)
Size, cm^3 ($in.^3$)	2212 (135)	5243 (320)	1807 (110)	4588 (280)	3162 (193)	2458 (150)
DC power, W	7	22	15	38	3	8
ROM cost, (K$)(5)	165	220	200	No bid	No bid	167(2)
Program	Viking	MVM '73 development		Military(4)	Pioneer F&G	Helios

Notes:
1) Receiver only
2) Assume 1$ = 2.85 DM
3) Exclusive of dc-dc converter
4) SGLS compatible rather than DSN compatible
5) Recurring per unit, ROM, not including Hughes G&A and fee.

amplifiers which include an output isolator and a regulating power supply. The second grouping consists of exciter drivers which have been or are about to be used in space applications although at a somewhat lower power level. The performance parameters are for the entire exciter. The last of the three groupings describes just the power amplifier itself. Note that weights and sizes for these devices are very small.

Table 4-15 summarizes information for traveling-wave amplifiers (TWA), TWT, and TWT high voltage power supplies. In addition to those listed there are previous generations of tubes which have flown on space missions. For instance, the forerunner of the 242-HA is the 242-H which has flown on Mariner 69. It, in turn, was a selected version of a 394-H, which has been flown on Apollo. Older generation Hughes S-band TWTs have also flown on Mariner 4 and 5, Lunar Orbiter, and Surveyor. The most recent space applications are the Hughes 242-HA TWT mated with the WJ1084 power supply, and the WJ1171-1 TWA.

Additional information on both solid state amplifiers and TWT amplifiers is contained in a company sponsored IR&D report 4116.02/100 entitled "Solid State Versus TWT Transmitter Trade Study," which is included in Volume 15 of this report. Note that all dollar values given in this report are rough order of magnitude (ROM) and are exclusve of Hughes G&A and fee.

4.5 MICROMINIATURE TRANSPONDER SELECTION

A study was made to select a baseline design for a phase lock loop receiver that is readily adaptable to the large probe, probe bus, and orbiter bus. Emphasis was placed on presently available space hardware or hardware which is already in an advanced stage of development. Since this hardware in some cases included the modulator/driver as part of an integrated transponder package, this survey was enlarged to include the entire transponder.

It has been shown on a company-funded program that the transponder designed for the Viking Lander represents the most advanced design in presently space qualified hardware. For the Thor/Delta application, the present Viking transponder would be repackaged to reduce weight and ease layout constraints in the large probe. This is possible because "footprint" constraints, peculiar to the Viking spacecraft, forced the transponder to a non-optimum integrated receiver-exciter package design. However, since the Atlas/Centaur application is addressed to cost saving, even at some weight expense, the Viking transponder would be used in its present configuration with a minimum of modification.

Various companies were contacted for information regarding their communications transponder capabilities. Table 4-16 summarizes the data which was obtained. Note that all costs are ROM and do not include Hughes G&A and fee.

TABLE 4-17. STABLE OSCILLATOR SUMMARY

Type	Frequency (MHz)	Mass, kg (lb)	Pwr Requirements, W	Size cm^3 (in^3)	Stability	Comments
APL	19	0.3(0.75)	0.25 +2.0 for 0.5 h	131(8)	$7{:}10^9$ thru 300 g $5{:}10^9$ for 2 min	Test data with ±0.2°C over control. ± 2°C with Phase change material is calculated. Redesign to improve short term stability. Add temperature compensation.
HP 10543A	5	0.6(1.25)	3.5 +8 for 0.5 h	475(29)	$5{:}10^7$ thru 700 g $1{:}10^9$ 4.5° -49°C $1{:}10^9$ after 30 min from 4.5°C $5{:}10^{10}$/day	Best commercial oscillator on market. Acceleration test result is not entirely conclusive.
FEI Pioneer F&G	38.2	0.05(0.1)	0.08	19.7(1.2)	$1{:}10^6$ long term	Oven not included
FEI CSO	2 1/2 + 1 derived from 5	0.7(1.6)	1.5 at 0°C 0.25 at 50°C	606.(37)	$1{:}10^8$ after 15 min $1{:}10^9$ after 3 h (starting at 0°C)	Trade of mass and size for power, i.e. 0.34 kg (0.75 lb) 245 cm ($15\ in^3$) at twice the power is possible
FEI French balloon experiment		0.4(0.9)	0.08	328(20)	1 min after turn on $1{:}10^9$ for 0.5 h with 30°C temperature change	13 hr time constant
FEI Pioneer Venus	38.2	0.3(0.6)	0.6 maximum 0.3 at 4.5°C 0.1 at 43.3°C	128(7.84)	$1{:}10^9$ thru 200 g $1{:}10^9$ 4.5° - 49°C	Lowest total power, best stability

At the present time the Philco microminiature DSN compatible Viking transponder is clearly the lowest weight and lowest cost unit. The transponder is based on a modular design concept in which the transmitter and receiver are assembled from modules into integrated units. All modules are of microelectric hybrid design using either thin or thick film technology. The modules are stacked one behind the other and mounted to a machined aluminum interconnect chassis.

The transponder has a built-in provision for cross strapping and the exciter has an auxiliary oscillator which can be substituted for the coherent frequency input from the receiver. The Viking transponder design closely fits the requirements of the Pioneer Venus mission and it will be possible to use this transponder with a minimum of modification.

An alternate possibility is a microminiature transponder which is being developed by Motorola. Ultimately this transponder, which uses beam lead monolithic integrated circuits, is expected to be smaller and lighter weight than the Philco-Ford Viking unit. However, its design is not yet completed and therefore it has not been selected for the baseline design. The two Motorola units which are represented on Table 4-16 are much further advanced in terms of availability, but as can be seen from the table, they are clearly less desirable than the Viking transponder.

Additional information on the Motorola transponders, as well as the remaining DSN compatible units listed in Table 4-16 may be found in the IDC, "Deep Space Communications Transponder Survey," included in Volume 15 of this report.

4.6 STABLE OSCILLATOR

Experimental work performed at Hughes on a company-sponsored program to evaluate oscillators for possible space applications is applicable to the selection of the stable oscillator for the Pioneer Venus small probes. Part of this work, "Evaluation of the Hewlett-Packard 10543A Oscillator," is included in Volume 15 of this report. It is of interest to consider this H-P oscillator for the Pioneer Venus application, since the unit is fairly compact and has outstanding frequency stability specifications. However, as shown in Table 4-17, there was a frequency shift of 5 parts in 10^7 induced by a 700 g acceleration. If this proves to be a general characteristic of this type of oscillator, rather than a chance flaw in the unit which underwent the test, it would seem to rule out this type of oscillator for Pioneer Venus. In any case, the frequency will have to be non-standard for the Pioneer Venus application and this factor may negate any cost savings which may otherwise accrue from selecting an off-the-shelf item.

Under Contract NAS 2-7250 from NASA/ARL, the Applied Physics Laboratory of Johns Hopkins University is investigating a stable oscillator design for the Pioneer Venus small probe. Using a crystal supplied by Bliley, the APL oscillator has been run through a preliminary series of tests which indicate that it is much less sensitive to acceleration g forces than the HP oscillator which was tested at Hughes. The number reported, 7 parts in 10^9 for 300 g, is still a larger frequency shift than desired but because the short term drift in frequency was 5 parts in 10^9 for 2 min, the true stability may have been masked. The short term stability of this oscillator would have to be improved before this type of design could be applied to Pioneer Venus. The APL oscillator development is of particular interest because calculations, based on the use of phase change material for temperature control, indicate that the oscillator would be very small and lightweight. It would also require much less power than the HP oscillator.

In addition to HP and Bliley, a third manufacturer of high quality crystal oscillators is Frequency Electronics Inc. (FEI). FEI also has the benefit of experience in space applications. As indicated in Table 4-17, FEI has supplied the 38.2 MHz crystal oscillator for the Pioneer F&G program. FEI uses a patented crystal cut which allows 1 part in 10^6 stability over a temperature range of 20° to 80°C without any additional temperature compensation.

FEI also supplies the master clock for the OSO-I program. The power requirements shown in Table 4-17 are lower than the actual OSO requirements. Rather the table reflects the power which would be required if the Pioneer F&G crystal oscillator were mated with the OSO-I oven. Note also the tradeoff between weight and size on the one hand, and dc power on the other. Except for the rather long warmup time required for the stability to reach 1 part in 10^9, this approach may satisfy the Pioneer Venus mission requirements. It remains to be seen, however, how the FEI FC cut crystal reacts to the high deceleration.

Another approach that FEI has taken is to provide a crystal with a very long thermal time constant enclosure. Because there is no oven, the circuit requires very little power and stabilizes almost immediately. With a triple dewar arrangement the oscillator, used in a balloon experiment by the French equivalent of NASA (CNES) had a stability of 1 part in 10^9 for 0.5 h and over an ambient temperature range of 30°C. The Pioneer Venus probe mission is about three times longer in duration and the ambient temperature change could be as much as twice as large.

Under the company-sponsored study mentioned above, FEI was able to perform an analytical and experimental study to develop and test an oscillator meeting the specifications of Table 4-18.

A model 38.2 MHz oscillator was built and tested to demonstrate the performance of Table 4-18. A single oven type with a dewar flask package was subjected to 700 g of acceleration. There was no apparent frequency change immediately after the deceleration. Acceleration was applied in all six directions. No significant difference was observed.

The test oscillator crystal was an AT cut in a TO-8 package. A proposed flight oscillator would use an FC cut crystal for better thermal performance and a "C" type holder for more rigid mounting. This proposed

TABLE 4-18. TEST OSCILLATOR TECHNICAL SPECIFICATIONS

Frequency:	38.2 MHz
Output power:	3 mW min into 50 ohm
Frequency accuracy:	1PP10^{-6} at any steady state temperature 5^{o} to 43^{o}C, and after "warmup" following extended periods of off time
Frequency stability:	1PP10^{-9} from time (to -2.5) to (to +1.27) hours, with oscillator mounting surface temperature profiles shown on Figure 4-21.
Frequency stability:	Immediately after deceleration pulse shown in Figure 4-22 should be less than 1PP10^{-9}
Input power:	1.5 W-h, including warmup (to -2.5) to (to +1.27) hours shown in Figure 4-23
Input voltage:	+28 V±2 percent
Weight:	Less than 0.3 kg
Size:	Less than 130 cm^3

ovenized FEI flight oscillator has been designed to achieve a frequency stability of better than 1 part in 10^9 from 5 to 43^{o}C ambient temperature. The entire oscillator is housed within an oven inside an insultaing dewar flask and encapsulated for rigidity. The temperature senstive crystal and circuit components are kept at a stable temperature. The 38.2 MHz oscillator circuit uses the FC cut crystal. A 2-8 pf variable capacitor sets the fine frequency of the oscillator. A choke in series with the crystal is selected to provide 38.2 MHz. A voltage regulator provides +24 VDC from the +28 VDC input. An oven controller circuit senses oven temperature and adjusts heater voltage to maintain constant temperature. A variable resistor provides initial temperature setting.

Based on this FEI data, it is not expected that providing a stable oscillator with the technical specifications given in Table 4-18 will present a problem. Thus, these specifications have been selected as representative of the baseline stable oscillator design and are so presented in Sections 5 and 6 of this volume.

4.7 COMMUNICATION SUBSYSTEM PASSIVE COMPONENTS

Table 4-19 summarizes the performance parameters of the passive components of the communications subsystem. This listing is partly the

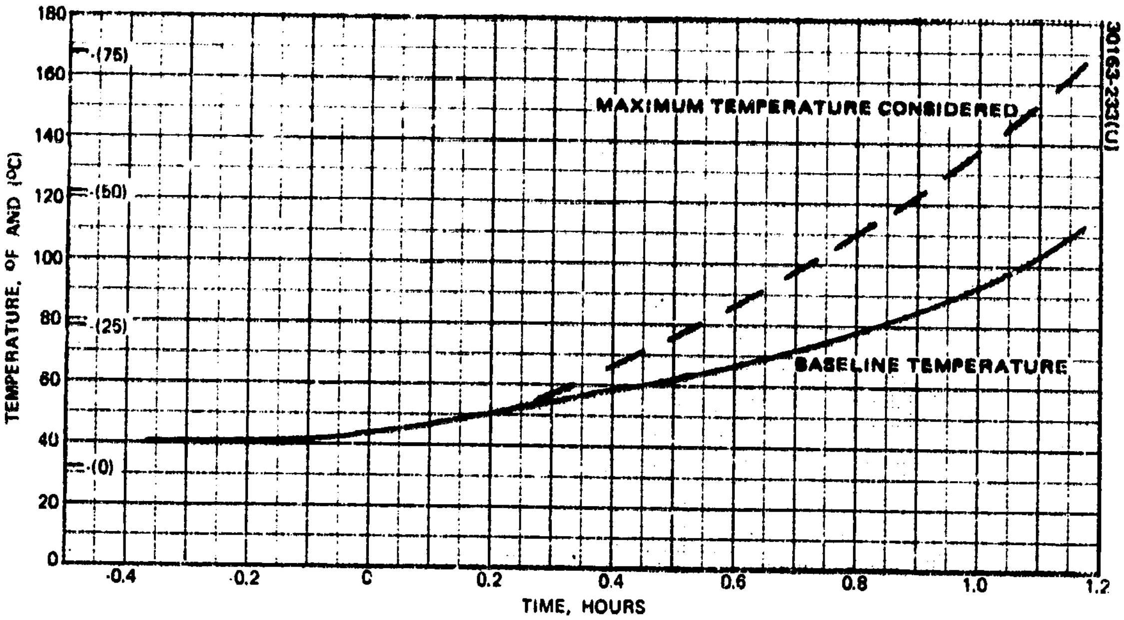


FIGURE 4-21. ASSUMED OSCILLATOR MOUNTING SURFACE TEMPERATURE PROFILES

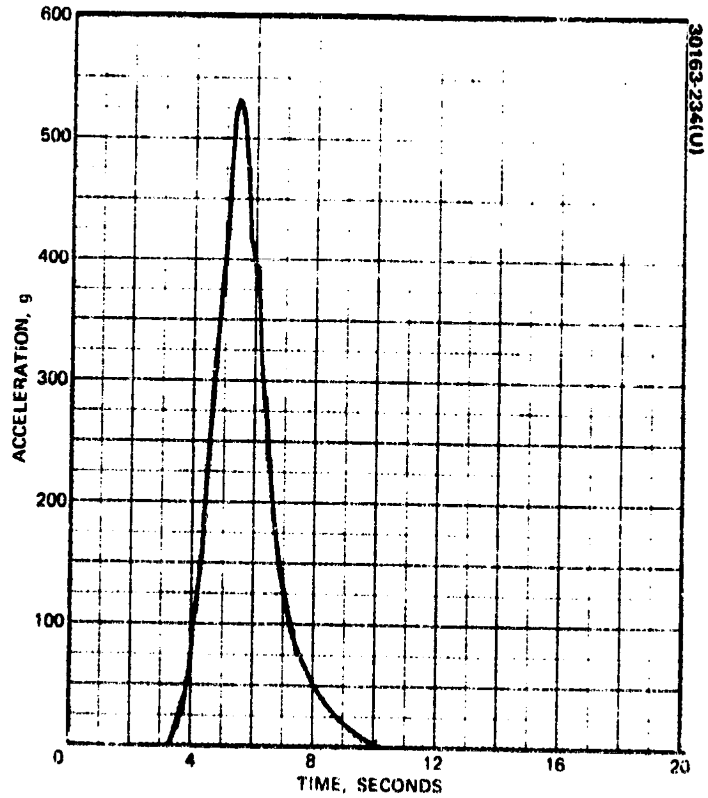


FIGURE 4-22. SMALL PROBE DECELERATION

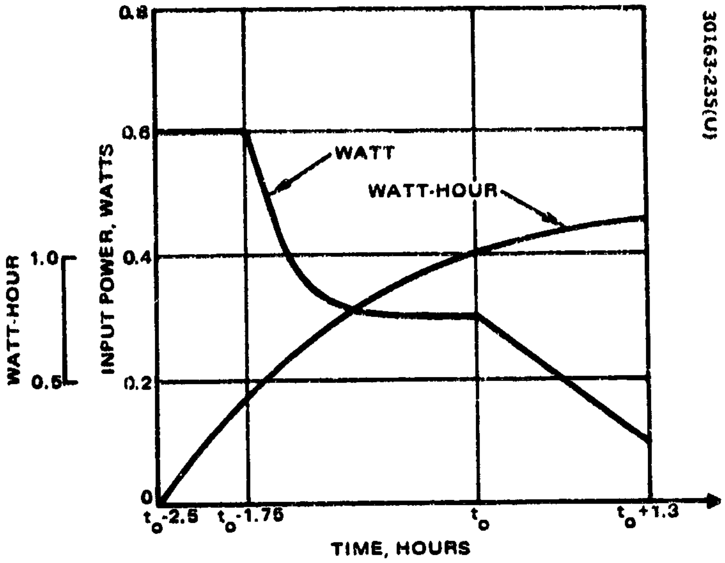


FIGURE 4-23. POWER CONSUMPTION VERSUS TIME

TABLE 4-19. RF SUBSYSTEM PASSIVE COMPONENT CHARACTERISTICS SUMMARY

	Insertion Loss, dB	Isolation, dB	VSWR
Circulator-isolator	0.2	25	1.15
Filter, receiver bandpass	0.3	50 at f_T	1.25
Filter, transmitter bandpass	0.3	35 at f_R	1.25
Filter, harmonic	0.1	30 at $2f_T$, $3f_T$	1.15
Hybrid	0.3	23	1.20
Switch, SPDT	0.15	80	1.15
Switch, transfer	0.2	60	1.20
Cable, 0.96 cm (3/8 in.) OD 0.36 cm (0.141) OD	0.20/m (0.06/ft) 0.52/m (0.16/ft)		1.10 1.10
Filter, notch	0.2	40 at f_R	1.20
Rotary joint	0.1		1.15

result of an interaction with the rf subsystem functional design. Thus for instance, the isolation of the various filters is dictated by the subsystem design considerations. In addition to compiling the expected performance characteristics of the communication subsystem elements several tradeoffs were performed to obtain optimum design performance. Mechanical switches are preferred to ferrite or diode switches when the number of switching events is relatively low because of the low insertion loss and high isolation. The choice of a diplexer design based on incorporating a circulator at the junction of the receiver and transmitter transmission lines is based on system as well as component considerations.

Switches

RF switches are required to fulfill the functional requirements of the probe bus and orbiter communication subsystems. Three types of switches were considered: mechanical, ferrite, and diode. Diode switches are very small and fast acting but suffer from relatively high insertion loss. Moreover they require a holding current in one of the switch positions. As an example, one 2 GHz coax switch has 0.45 dB insertion loss and provides 40 dB isolation with 1.2 ma of current. The isolation increases to 55 dB with 11.9 ma of current. Although the currents are not large, the insertion loss is prohibitive and therefore diode switches are least attractive for the present application.

Circulator switches have been used in space programs. For instance Wavecom makes a switch for the Viking program which has the following specifications:

Frequency	2.2 - 2.3 GHz
Isolation	20 dB
VSWR	1.2
Insertion loss	-17.8° to -106.7°C (0 to 160°F) 0.3 dB -34.4° to -17.8°C (-30° to 0°F) 0.5 dB
Power required	70 ma at 28 Vdc
Switching time	100 ms
Size	5.1x5.1x6.1 cm (2x2x2.4 in)

One disadvantage of the circulator switch is the magnetic flux leakage. This is also true of an ordinary circulator but as long as the magnetic field is not switched, the leakage field may be compensated. However, a circulator switch appears to be incompatible with the use of a magnetometer on board the spacecraft. In any case, the insertion loss is still quite high and the isolation is insufficient when used to switch rf energy between two antennas whose antenna gains differ by a number approaching the isolation provided by the switch.

Mechanical switches provide the lowest insertion loss and the highest isolation. Both Transco and Teledyne have made many rf switches for space applications but Teledyne has also developed switches that are magnetically clean. These use mechanical latching drives rather than the more common magnetic latching drives. If magnetic cleanliness is not required the magnetic latching switches would be preferred because of their improved reliability and lower cost.

Teledyne's CS-27T60-3 is a transfer switch which was used on the Pioneer spacecraft. The switch weighs 0.28 kg (10 oz) and meets the following magnetic requirements at a distance of 30.5 cm (12 in) from its center:

> 20 gamma residual field after being subjected to 25 g field along all three axes
>
> 10 gamma residual field after demagnetization with ac field along all three axes
>
> 12 gamma residual field after application of drive pulse

Teledyne's CS33S6S-3 SPDT coaxial latching switch is being supplied to Thomson CSF for use on the Helios program. Magnetic requirements for this switch are modeled after those imposed in the Pioneer program. Unlike the transfer switch, which is vented, the SPDT switch is hermetically sealed. Both switches could handle rf power up to 20 W.

<u>Filters</u>

A filter must be provided at the output of the transmitter to prevent transmitter generated excess noise at the receiver frequency from degrading the receiver performance. The noise can either be generated in the exciter and amplified by the power amplifier, or it could be due to the noise figure of the power amplifier itself. In an experiment conducted at Philco-Ford, the Viking exciter output was coupled into the Viking receiver input by means of a 30 dB coupler. No degradation in receiver performance was observed. Based on this measurement, the noise power at the output of a 20 dB gain power amplifier would have to be isolated from the receiver by at most 50 dB.

The specification of the Viking receiver states that the receiver must operate without degradation in the presence of a +20 dBm transmitter frequency signal at its input. It more than meets this requirement with a five pole filter at its input which provides approximately 65 dB isolation. Thus the isolation provided by a simple circulator would be adequate if the Viking receiver is used without an external low noise preamplifier. If however, a low noise (3.5 dB) preamplifier is required, the total isolation requirement between transmitter and receiver would be determined by the preamplifier saturation characteristics. With -25 dBm at the preamplifier input it should be entirely unaffected. If then the transmitter output is +40 dBm, a total of 65 dB isolation would be required.

There are a number of ways of configuring the rf communications subsystems for Pioneer Venus spacecraft which lead to variations in filter design requirements. The original concept pictured a diplexer as a single block which included the filtering required to prevent transmitter power from leaking into the receiver; i.e., signal at the transmit frequency f_T, and noise at receiver frequency, f_r. Such a diplexer has been flown on the Pioneer F&G programs. This diplexer, developed by Wavecom, has the following characteristics:

Frequency:	transmit	2295 MHz
	receive	2115 MHz
Passband		10 MHz minimum
Passband loss:	transmit	0.6 dB
	receive	0.76 dB
Passband VSWR		1.25:1
Interchannel isolation		85 dB
Weight		0.9 kg (1.95 lb)
Size		20.6x13.7x7.1 cm(8.1x5.4x2.8 in)

This is an integral unit and therefore it would not satisfy all the filter requirements for the probe bus baseline design with its four separate antennas. Moreover the interchannel isolation requirement need not be as high as 85 dB. In a diplexer with lower isolation and the same volume, the insertion loss should also be lower. Finally, the diplexer is quite large in terms of packaging into the large probe. If it can be split into smaller pieces it would allow greater flexibility in packaging.

This flexibility is possible if the diplexer consists of a circulator and separate filters to provide additional isolation as required. Assuming the circulator provides 15 dB isolation (limited by antenna mismatch) and that at least this much isolation is provided between the various antennas, the most stringent filter requirement would occur in the case when a separate preamp precedes the Viking receiver. In that case the receiver filter isolation requirement is 50 dB. By careful design and fabrication techniques it should be possible to limit the insertion loss to 0.3 dB in a filter with a volume 557 cm^3 (34 in^3). This represents a four section stripline type filter. For the filter in the transmit arm assembly 35 dB of isolation is required so that a similar design would very easily limit the insertion loss of 0.3 dB. This distributed approach to the diplexer design was selected principally because it made probe packaging easier.

One can also consider the use of much smaller filters which have the attendant penalty of higher insertion loss. For instance the receiver filter described in the Texas Instrument report for the electronically despun antenna system* provides approximately 45 dB isolation and has an insertion loss of 0.9 dB. On the other hand the filter is extremely small, occupying less than 16.4 cm^3 (1 in^3) of volume. This reduction in volume is not sufficient to justify the additional loss with the current subsystem design.

Rotary Joint

The rotary joint that is employed in the communication subsystem of the orbiter spacecraft is a simplified version of the multichannel rotary joint that has been developed for the Telesat program. The single channel rotary joint for the Thor/Delta design consists of the central portion of the Telesat rotary joint. This portion is a noncontacting, coaxial line design with rf propagation in the TEM mode. The input/output connections to the rotary joint are consistent with the transmission line connections employed between the rotary joint, the high gain antenna assembly and the rf subsystem. The noncontacting rf chokes at the rotational interfaces assure long life of the unit. The only contacting parts are the ball bearings used to maintain a separation between the stationary and rotating portions of the rotary joint.

Circulator-Isolator

Figure 4-24 is a picture of a 2.1-2.4 GHz isolator which is being space qualified under a military program and will be used for Pioneer Venus. This isolator has a minimum isolation of 25 dB and insertion loss of 0.2 dB from 4.4°C (40°F) to 71.1°C (160°F). It can also be operated at lower temperatures, down to -23.3°C (-10°F) but the insertion loss increases to 0.25 dB. The isolator becomes a three port circulator simply by replacing the load, which is close to the scale in the photograph, with a coaxial connector. The circulator-isolator dimensions are 5.1x5.1x1.9 cm (2x2x 3.4 in) excluding connectors. This may be contrasted with a lumped element type of isolator, such as the Trak Model 1420-1310, which has a 20 dB isolation, 0.4 dB insertion loss, but measures only 1.9x1.9x1.3 cm (3.4x 3.4x1.2 in). Again, as with the filters, the reduction in volume is not sufficient to justify the additional insertion loss with the current system design.

Coaxial Cables

Semirigid coaxial cables, to which the small OSM type of connector attaches, are available with various diameters. At low rf power levels the cable with an outer diameter of 0.36 cm (0.141 in) will be used. However, at higher power levels it is better to use the 0.95 cm (3/8 in) diameter coax. This can be seen from the following consideration. The 0.36 cm coax weighs 48 gms/meter and has an insertion loss of 0.52 dB/meter. The larger 0.95 cm cable has a mass of 136 gms/meter and its loss is 0.20 dB/ meter. Thus the "cost" of 0.32 dB is 88 gms. The rf loss must be compensated

*R. D. Meeks, "An Electronically Phased Modular Array for Pioneer Venus Communications," NASA/Ames Report U1-991840-F, 22 November 1972

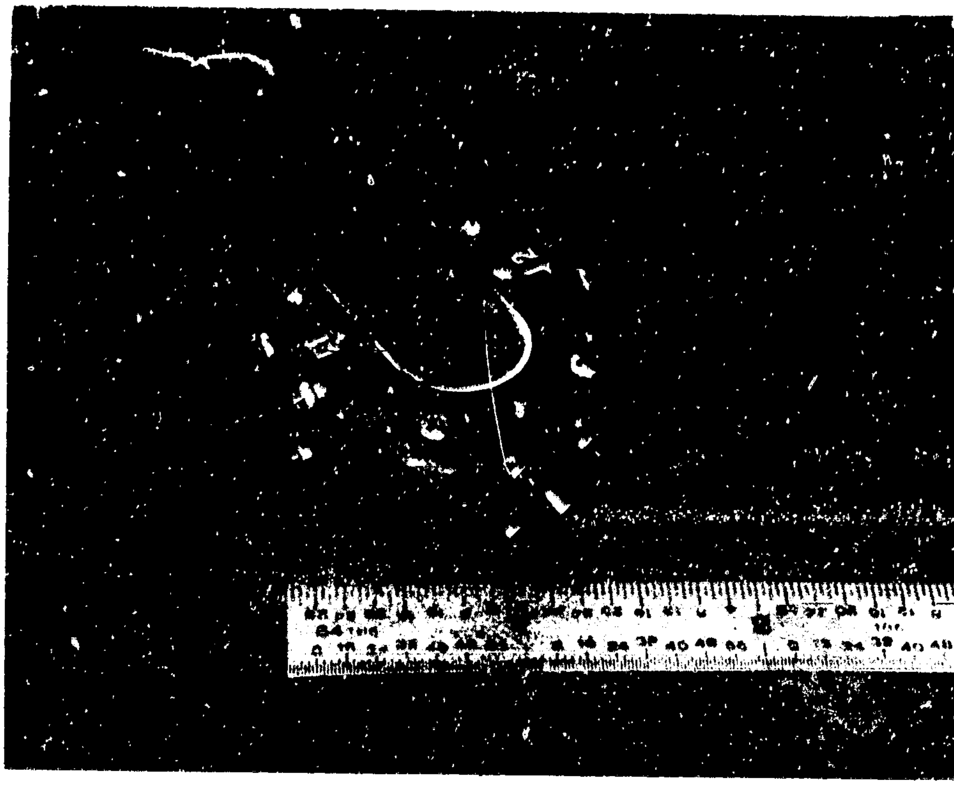


FIGURE 4-24. GHz ISOLATOR (PHOTO A29967)

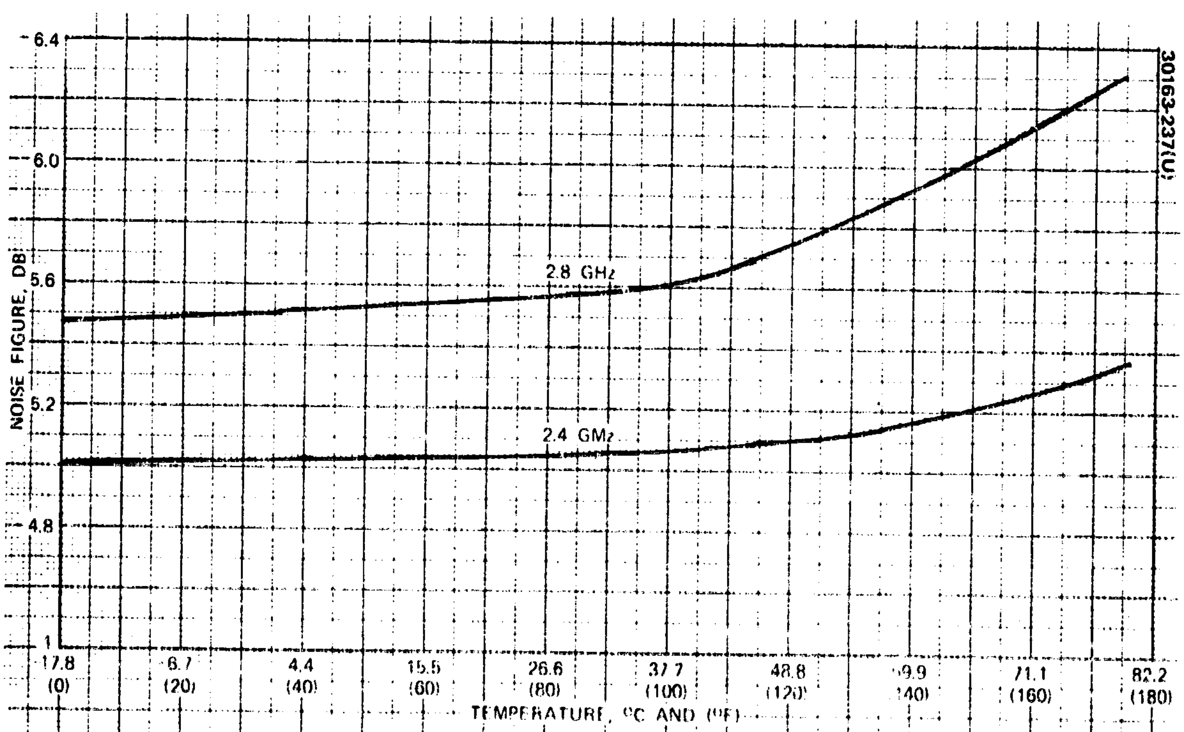


FIGURE 4-25. NOISE FIGURE VERSUS TEMPERATURE OF S-BAND PREAMPLIFIER

by additional output from the power amplifier which in turn requires additonal dc output power. Assuming the power amplifier efficiency to be independent of power output, the estimated power drain increase, with an initial 7 W rf power output, is 1.8 W. This translates to approximately 135 gms of solar panel mass so that the trade is clearly in favor of the larger coax without even considering other factors such as possible increase in the power amplifier mass or the mass of the thermal control system. Thus, the larger coax will be used following the power amplifiers. Even larger coax may be advantageously used on long cable runs butone must then take into account losses in the adapter between the OSM connector and the connector which would be needed to fit the larger cable. OSM connectors are used on the rf system components such as the circulator since the connector size determines the height of the component. The use of even larger coax for long runs will be decided based on the particular situations.

4.8 PROBE ENVIRONMENTAL CONSIDERATIONS

The severe temperature and deceleration environments seen by the probes made studies of the impact of these environments on candidate probe units mandatory.

High Temperature Electronics

To evaluate the performance of some critical elements in the probe at the end of the mission, their high temperature performance was considered. The acceptance temperature specification range of the present Viking Lander transponder is -12° to +43°C. Its qualification temperature range is -26° to +57°C. Philco has also informally tested the transponder at temperatures up to 70°C. At this high temperature there is some inevitable degradation in the performance of the transponder. For instance the noise temperature of the receiver preamplifier will increase about a half dB from its room temperature value. However, the noise figure at 21°C is typically about 5.2 dB, well under the 6.5 dB specification, so that even at 70°C the Viking receiver would meet 6.5 dB. Figure 4-25 shows the variation of noise figure with temperature in a similar Hughes-built preamplifier.

The power output of the Viking exciter drops by approximately 1.5 dB when the temperature is raised to 70°C. Over the acceptance test environments the present Viking specification calls for +21 dBm $^{+0.8\text{ dB}}_{-0\text{ dB}}$ output. This is relaxed to +21 dBm $^{+1.3\text{ dB}}_{-0\text{ dB}}$ over the qualification environmental levels. These changes in power outnut can also be expected in the power amplifier. Figure 4-26 shows data obtained on a MSC 3005 transistor amplifier circuit. Power and efficiency both drop with increasing temperature. In this experimental amplifier the 7 W power output was obtained only at temperatures below 43°C. One could obtain a more constant output power by designing the regulator voltage to decrease at lower temperature but in this case at least,one could not further raise the voltage at high temperature since the power dissipation requirement on the transistor would become excessive.

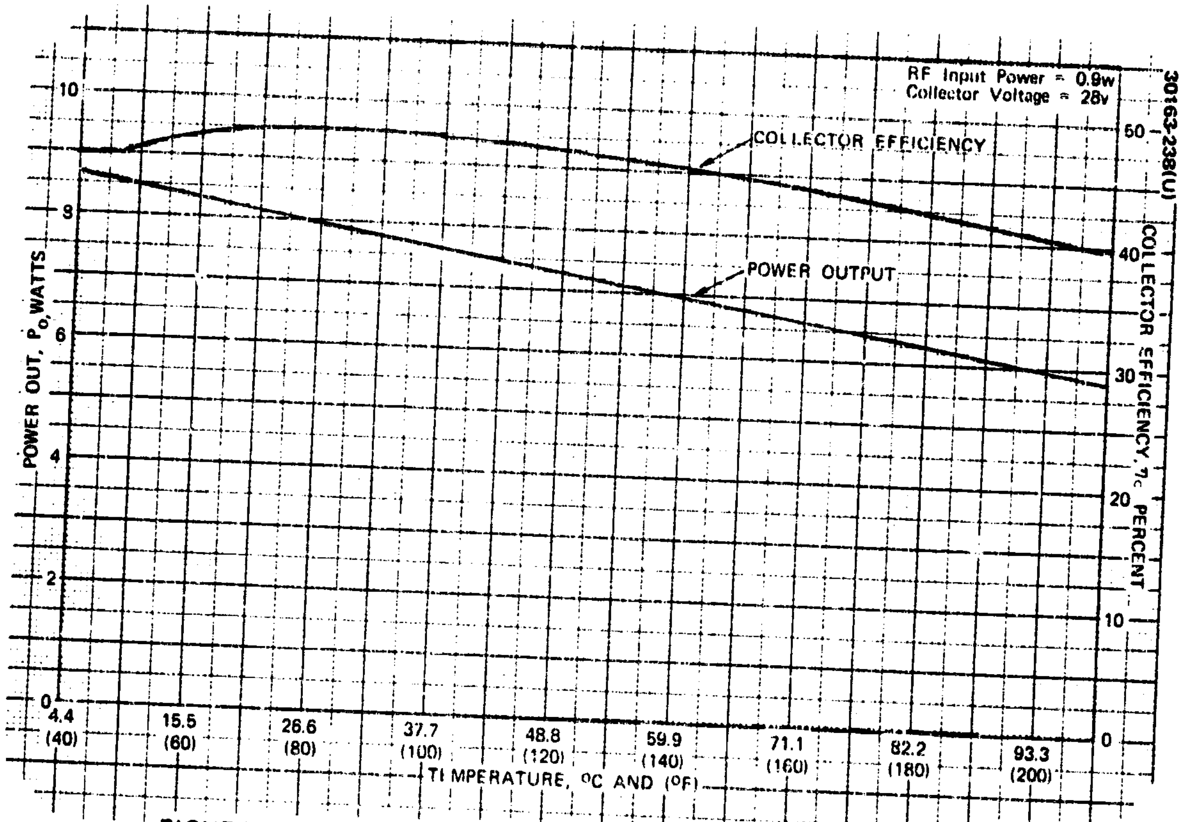


FIGURE 4-26. MSC 3005 TRANSISTOR POWER OUT AND EFFICIENCY VERSUS TEMPERATURE

A third deterioration in the present Viking transponder performance is due to frequency drift with temperature of the crystal oscillators. The exciter auxiliary oscillator uses an AT cut uncompensated series resonant third overtone crystal. The frequency uncertainty specification is ±1.3 parts in 10^5 during acceptance test environments and ±2.0 parts in 10^5 during qualification test environments. Identical frequency uncertainty requirements apply to the receiver best lock frequency. The frequency uncertainty will increase yet further at higher temperatures.

The filters used in the Viking transponder, as well as elsewhere in the large probe communication system, are relatively broadband so that their performance will not be greatly influenced at temperatures up to 77°C (170°F). The coaxial cable leading to the antenna terminal from the rf subsystem will not only convey the microwave signals but also any heat which may be present at the antenna terminal. Hughes Aircraft Company TIC 4116/73/051, "Probe Antenna Development, "included in Volume 15 of this report, points out that the antenna materials are selected to withstand high external temperature environment of 765°K. The antenna itself will provide some thermal impedance between this outside temperature and the rf subsystem. If further analysis indicates it is required, the coaxial cable will be designed to further isolate the rf subsystem from this high temperature. This is done by using silver plated thin wall stainless steel coaxial cable. A preliminary calculation shows that this approach could reduce the coaxial heat leak into the probe by a factor of 100 as compared with standard 3.5 mm diameter coaxial line.

High-G Electronics

The communication system components on both the large and small probes will be subjected to a high g environment during entry into the atmosphere of Venus. A possible deceleration profile for the small probe is shown in Figure 4-22. The communication system must be designed to survive this pulse. Due to ionization of the atmosphere, the communication system will in any event be "blacked out" during the deceleration itself. Thus the components need not be tested for normal ope. tion during the high g period. They will however have to survive the high g and be fully operative immediately afterwards.

As described in the Hughes Aircraft Co. TIC, "Electronic Component High-G Evaluation Tests," included in Volume 15 of this report, component assemblies of various constructions were subjected to high g test levels. Point-to-point and printed circuit constructions are used in the communication system power amplifier and receiver/exciter. The test showed that the circuits did survive the high g environment. However, as described in Subsection 4.6, permanent frequency shift of $5{:}10^7$ was experienced with the Hewlett Packard high stability quartz oscillator. A temporary frequency shift during the high g period is unavoidable. It is the permanent change which must be avoided. The oscillator in the cross-strap converter did not change frequency after being subjected to the high g but the accuracy of the measurement was limited to $1{:}10^8$. The stable oscillator which is being developed by the Applied Physics Laboratory of Johns Hopkins University under NASA/ARL Contract NAS 2-7250 has been subjected to 300 g level and its frequency changed less than 7:10^9 - again the limit of measurement accuracy. Further tests conducted under a company-funded program demonstrated that an oscillator with the requisite 1:10^9 stability will maintain that characteristic in the face of the high g environment.

The major component in the baseline large probe communication system is the Viking transponder and in the small probe it is the exciter portion of that transponder. This transponder has been tested to 1500 g shock level. The anticipated 700 g deceleration requirement is expected to be less severe than the shock requirement and therefore it is expected that the Viking transponder can be used "as is" from this point of view.

5. THOR/DELTA BASELINE

The criteria for selecting the communication system components for the Thor/Delta baseline were based on achieving the lowest possible cost within the weight and performance constraints of the subsystem requirements as they were formulated at the midterm design review in February 1973. To achieve low cost the greatest possible design commonality between the orbiter, probe bus, large probe, and small probe was implemented with component hardware which to the greatest extent possible was directly derived from other space programs. Table 5-1 illustrates this philosophy. Note that the only completely "new" hardware items are the stable oscillator and the probe antennas.

The communications system is divided into the radio frequency subsystem and the antenna subsystem. Details on the design of these subsystems is given in sections 5.1 and 5.2, below.

5.1 RADIO FREQUENCY SUBSYSTEM

Probe Bus

Figure 5-1 is a block diagram of the rf subsystem proposed for the Thor/Delta probe bus. The diagram also shows the connections and rf powers delivered to the various antennas. Note that there are three rf power operating modes which are referred to as 10, 5, and 1 W modes, even though these are only approximations to the exact powers delivered to the antennas. In the 10 W mode, both power amplifiers are turned on and their outputs are added in the summing hybrid. In the 5 W mode only one power amplifier is turned on so that full redundancy is available. In the 1 W mode the power amplifier is operated with reduced voltage applied to the transistor so that power is conserved. This low power mode is required by the type II orbiter trajectory when the spacecraft is greater than one AU from the sun. All three power modes are available to the horn, bicone and wide beam omni antennas by suitable selection of switch commands. The narrow beam omni is used for transmit only in the 5 and 1 W modes.

Either of the omni antennas can be connected through a diplexer and the transfer switch to either one of the preamplifier receivers. The

TABLE 5-1. COMMUNICATIONS HARDWARE DERIVATION

Unit	Probe Bus	Orbiter	Large Probe	Small Probe
Antennas:				
High gain	NA	*Intelsat IV modify frequency, beamwidth, feed, and mechanical interface	NA	NA
Bicone	*Data systems modify frequency, beamwidth, and mechanical interface	NA	NA	NA
Wide angle omni-directional (conical crossed slots)	**Surveyor	Same as probe bus	NA	NA
Narrow beam omni-directional (conical spiral)	*HS-350 modify frequency and beamwidth	Same as probe bus	NA	NA
Medium beam horn	*Intelsat IV modify frequency and beamwidth	NA	NA	NA
Equiangular spiral	NA	NA	New (in development)	NA
Loop-vee	NA	NA	NA	New (in development
Rotary joint	NA	*Telesat modify frequency and simplify to single channel	NA	NA
Receiver/exciter	Viking, repackage to reduce weight	Viking, repackage to reduce weight	Viking, repackage to reduce weight	NA
Exciter	NA	NA	NA	Viking, with skynet packaging
Switches	Pioneer, Helios	Same as probe bus	NA	NA
Power amplifier	*Military program Increase gain, efficience, decrease power, weight	Same as probe bus	Same as probe bus	Same as probe bus
Preamplifier	*Brazilian Trade intermod for noise figure	Same as probe bus	Same as probe bus	NA
Filters:				
Bandpass	ATS-F Modify frequency bandwidth	Same as probe bus	Same as probe bus	NA
Low pass	*Telesat Modify frequency			
Notch	NA	*Telesat Modify frequency	NA	NA
Circulator	*OSO	Same as probe bus	Same as probe bus	NA
Stable oscillator	NA	NA	NA	New

* Existing HAC programs
** Previous HAC program

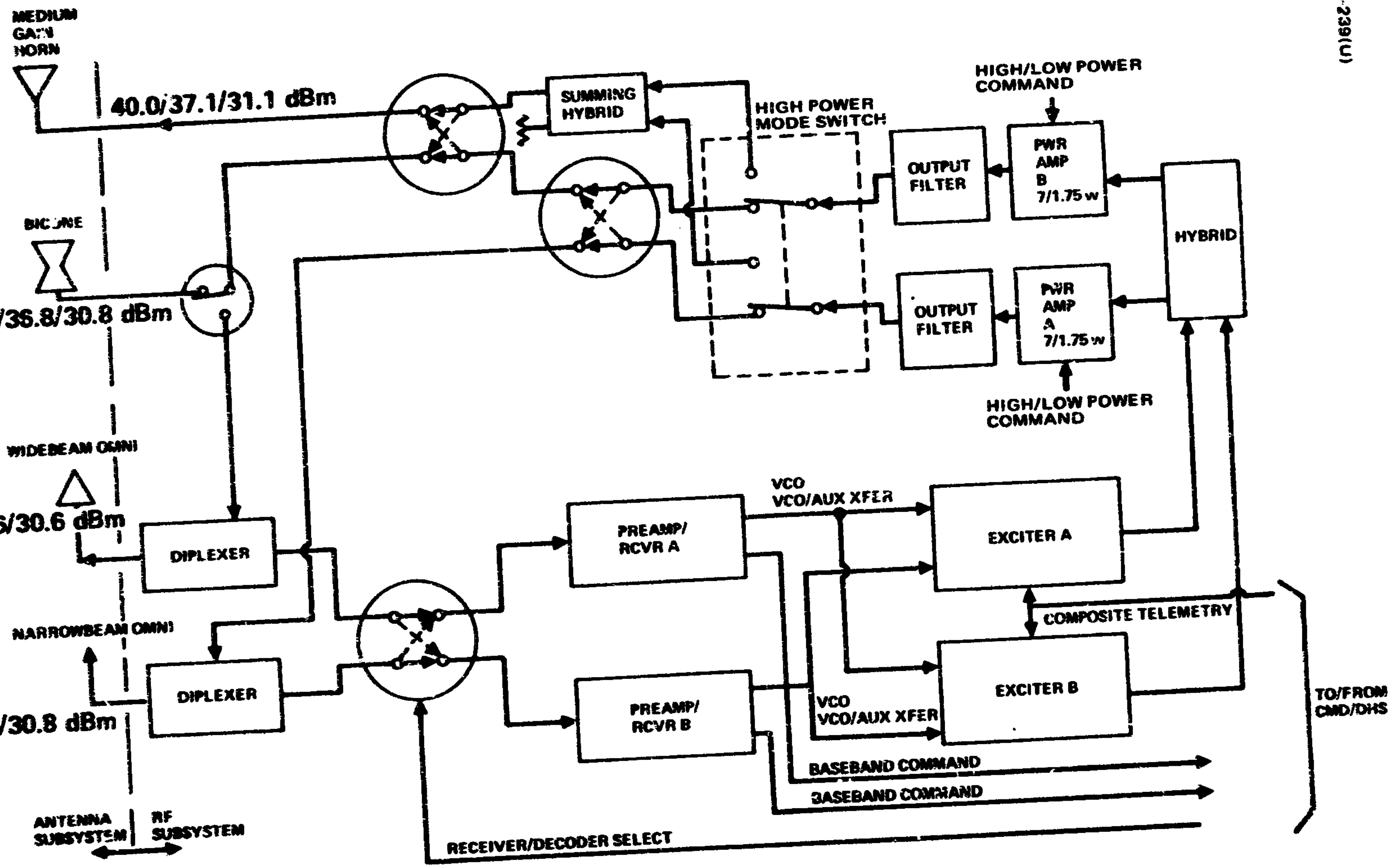


FIGURE 5-1. PROBE BUS COMMUNICATION SUBSYSTEM

TABLE 5-2. PHILCO-FORD VIKING TRANSPONDER

Key Parameters	
Input frequency	2115 MHz, nominal
Noise figure	6.5 dB, maximum
Threshold	-154 dBm
Loop noise bandwidth	20 Hz
AGC range	90 dB
Ranging bandwidth (1 dB)	1.2 MHz
Modulation stability	± 10%
F_T/F_R ratio	240/221
Output power	+21 dBm
Power drain (unregulated)	7 W $\left\{\begin{array}{l}3 \text{ receiver}\\ 4 \text{ exciter}\end{array}\right.$
Weight	1.8 Kg (4 lb)
Size	2210 cm^3 (135 $in.^3$)

"diplexer" contains a circulator and a receiver bandpass filter, the combination providing 65 dB isolation to the transmitter frequency. The 3.5 dB noise figure preamplifier is a separate unit which improves the overall receiver sensitivity. The remainder of the receiver is actually part of the Viking transponder whose principle characteristics are summarized in Table 5-2. The transponder has built in provision for cross strapping. Since both receivers are turned on at all times the exciter output is determined by either receiver VCO, or if neither receiver is phaselocked, by its own auxiliary oscillator. Only one exciter is turned on at a given time.

The power amplifier is a solid state module capable of providing either 7 or 1.75 W of rf power. In the higher power mode the amplifier has 20.7 dB of gain. Switching between these modes is accomplished by an internal regulator which switches on command to a lower dc voltage for operation in the 1 W mode. The power amplifier includes an isolator at its output to provide protection from high VSWR during switching between antennas and to the 10 W mode.

The output filter includes a low pass filter to suppress higher harmonics of the transmit frequency, and a transmitter bandpass filter to suppress noise power at the receive frequency.

The output powers are based on the insertion losses indicated by Table 4-19 in subsection 4.7 of the tradeoff studies and by estimated cable lengths between the rf subsystem components and the antennas. Similarly, the system noise temperature is calculated to be 570°K.

Table 5-3 summarizes the power, mass, and size of the rf subsystem.

Orbiter

Figure 5-2 is a block diagram of the communication subsystem for the Thor/Delta orbiter spacecraft. The similarity between this and the probe bus is very obvious. Moreover, this is true not only in the block diagram but also in the physical sense. Even cable lengths and component layout would, to the greatest extent possible, be identical on these two spacecraft.

The principal difference between the orbiter and probe bus communication subsystems is that the former has only three antennas. The high gain and widebeam (despun) omni antennas can transmit in any of the three power modes. As with the probe bus, the narrow beam (spinning) omni can transmit only the 5 and 1 W modes. In order to transmit on the despun omni the rf switch following the circulator is connected to a short circuit and thereby reflects the power back into the circulator and out of the omni. For receive, the signal from the despun omni passes through the circulator directly to the rotary joint (RJ). The purpose of the notch filter (NF) is to prevent interferometry effects in the received

TABLE 5-3. PROBE BUS RF SUBSYSTEM

	Unit Description						Totals				
	Power W	Mass, kg	(lb)	Dimensions, cm	in.	Quanity	Power W	Mass, kg	(lb)	Size, cm^3	($in.^3$)
Exciter	4.0	1.8	(4.0)	27.3 x 12.7 x 6.4	(10.75 x 5 x 2.5)	2	4	3.6	(8.0)	4425	(270.0)
Receiver	3.0						6				
Hybrid	--	0.05	(0.05)	3.8 x 2.5x 1.3	(1.5 x 1.0 x 0.5)	2	--	0.1	(0.1)	24	(1.5)
Filter, transmitter, BP	--	0.35	(0.8)	17.3 x 5.1 x 3.2	(6.8 x 2 x 1.25)	2	--	0.7	(1.6)	557	(34.0)
Filter, harmonic	--	0.1	(0.1)	10.2 x 1.3 x 1.3	(4 x 0.5 x 0.5)	2	--	0.1	(0.2)	33	(2.0)
Filter, receiver, BP	--	0.35	(0.8)	17.3 x 5.1 x 3.2	(6.8 x 2 x 1.25)	2	--	0.7	(1.6)	557	(34.0)
Circulator-isolator	--	0.12	(0.25)	5.1 x 5.1 x 1.9	(2 x 2 x 0.75)	4	--	0.5	(1.0)	197	(12.0)
SPDT switch	0.1	0.12	(0.25)	4.6 x 4.6 x 3.8	(1.8 x 1.8 x 1.5)	3	0.3	0.3	(0.75)	246	(15.0)
Transfer switch	0.1	0.33	(0.7)	10.7 x 5.1 x 5.1	(4.2 x 2 x 2)	3	0.3	1.0	(2.1)	826	(50.4)
Preamplifier	0.5	0.1	(0.25)	7.9 x 4.1 x 2.5	(3.1 x 1.6 x 1.0)	2	1.0	0.2	(0.5)	164	(10.0)
Coax cables	--			1.0 o.d.	(3.8 o.d.)		--	0.7	(1.6)		
Power amplifier											
Low power (1.75 W)	7.0	0.45	(1.0)	20.3 x 7.6 x 3.2	(8 x 3 x 1.25)	2		0.9	(2.0)	983	(60.0)
High power (7 W)	25.2										
					1 W mode		18.6	8.8	(19.45)	8013	(489.0)
					5 W mode		30.8				
					10 W mode		62.0				

30163-240(U)

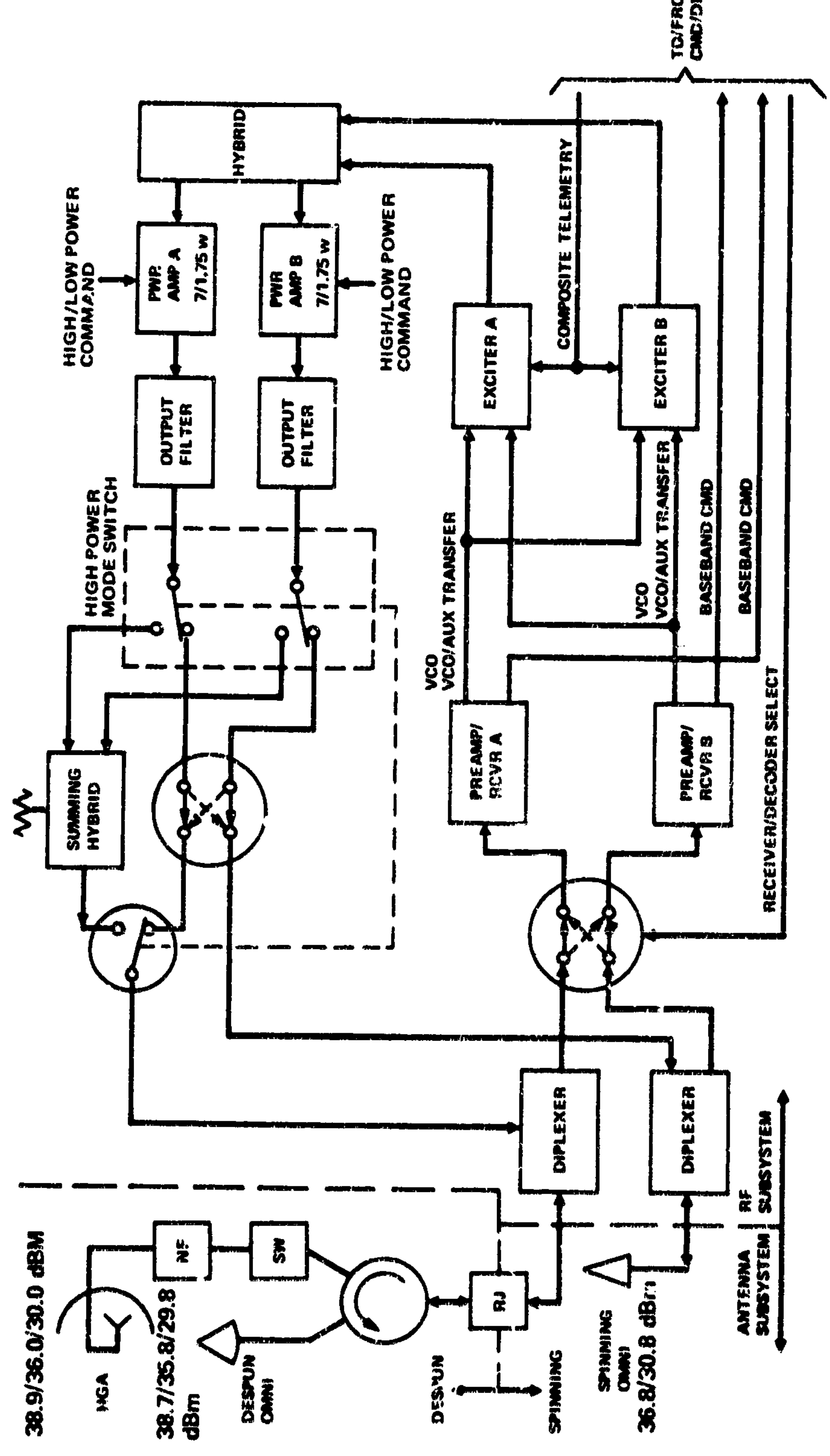


FIGURE 5-2. ORBITER COMMUNICATION SUBSYSTEM

TABLE 5-4. ORBITER RF SUBSYSTEM

	Unit Description						Totals					
	Power, W	Mass, kg	Mass, (lb)	Dimensions cm.	Dimensions (in.)	Quantity	Power, W	Mass, kg	Mass, (lb)	Size cm^3	Size in.^{3}
Exciter	4.0	1.8	(4.0)	27.3 x 12.7 x 6.4	(10.75 x 5 x 2.5)	2	4.0	3.6	(8.0)	4425	(270.0)
Receiver	3.0						6.0				
Hybrid	--	0.025	(0.05)	3.8 x 2.5 x 1.3	(1.5 x 1.0 x 0 x 0.5)	2	--	0.05	(0.1)	24	(24.5)
Filter, transmitter, BP	--	0.35	(0.8)	17.3 x 5.1 x 3.2	(6.8 x 2 x 1.25)	2	--	0.7	(1.6)	557	(34.0)
Filter, Harmonic	--	0.05	(0.1)	10.2 x 1.3 x 1.3	(4 x 0.5 x 0.5)	2	--	0.1	(0.2)	33	(2.0)
Filter, receiver, BP	--	0.35	(0.8)	17.3 x 5.1 x 3.2	(6.8 x 2 x 1.25)	2	--	0.7	(1.6)	557	(34.0)
Circulator-isolator	--	0.12	(0.25)	5.1 x 5.1 x 1.9	(2 x 2 x 0.75)	4	--	0.5	(1.0)	197	(12.0)
SPDT switch	0.1	0.12	(0.25)	4.6 x 4.6 x 3.8	(1.8 x 1.8 x 1.5)	3	0.3	0.3	(0.75)	246	(15.0)
Transfer switch	0.1	0.32	(0.7)	10.7 x 5.1 x 5.1	(4.2 x 2 x 2)	2	0.2	0.6	(1.4)	[illegible]	[illegible]
Preamplifier	0.5	0.12	(0.25)	7.9 x 4.1 x 2.5	(3.1 x 1.6 x 1.0)	2	1.0	0.3	(0.5)	164	[illegible]
Coax cables				1.0 o.d.	(3/8 o.d.)	2		0.7	[illegible]		
Power amplifier											
Low power (1.75 W)	7.0										
High power (7 W)	25.2	0.45	(1.0)	20.3 x 7.6 x 3.2	(8 x 3 x 1.25)		7.0	0.9	(2.0)	983	(60.0)
					1 W mode		18.5	8.5	(18.75)	7735	(472.0)
					5 W mode		36.7				
					10 W mode		61.9				

beam pattern of the high gain and despun omni antennas. This is necessary because the high gain antenna gain exceeds the despun omni antenna gain by a number comparable to the isolation provided by the circulator. However, with the addition of the notch filter which rejects the received frequency, this destructive interference cannot take place.

Table 5-4 summarizes the power, mass, and size of the rf subsystem for the orbiter spacecraft.

Large Probe

Figure 5-3 shows a block diagram of the rf subsystem for the large probe. In essence it is a non-redundant, single antenna, 10 W mode only, version of the two previous subsystems. The filter at the transmitter output is now shown in its component parts, as is the diplexer and the preamplifier receiver. The component parts are identical to those used in the probe bus and orbiter except for the power amplifier which is lightened by deletion of the internal regulator. This deletion is possible because the dual power operation of the power amplifier is not required and the large probe power system provides a regulated +28 V, exactly what the power amplifier requires for 7 W output power. The rf power amplifier circuit is, however, identical to that used in the probe bus and orbiter.

In this case isolators were not provided at the power amplifier output in order to keep weight at a minimum. This means the system, as shown, is susceptible to high antenna VSWR, because the reflected transmitter power will simply circulate through the circulator, reflect off the receive bandpass filter and thence back into the power amplifier. This situation must be avoided, either by turning off the transmitter whenever the antenna is mismatched to its load (as during the start of entry into the Venus atmosphere), or by providing an isolator somewhere in the line. This could most conveniently be done with a four port circulator-isolator in place of the three port circulator shown. However, for the midterm baseline design shown in Figure 5-3, the large probe would have to operate in just the same way as the small probe where isolators are banned because of the magnetometer experiment, i.e. the power amplifier must be turned off during communications "blackout" at the start of entry into the Venus atmosphere.

Table 5-5 summarizes the rf subsystem components on the large probe.

Small Probe

Figure 5-4 shows the rf subsystem block diagram of the Thor/Delta small probe. The 7 W power amplifier module is identical to the module used in the large probe. The exciter is the exciter portion of the Viking transponder except that the auxiliary oscillator was deleted

TABLE 5-5. LARGE PROBE RF SUBSYSTEM

	Unit Description					Totals					
	Power, W	Mass, kg	(lb)	Dimensions cm.	(in.)	Quantity	Power, W	Mass, kg	(lb)	Size cm^3	($in.^3$)
Exciter	4.0										
Receiver	3.0	1.8	(4.0)	27.3 x 12.7 x 6.4	(10.75 x 5 x 2.5)	1	7	1.8	(4.0)	2212	(135.0)
Hybrid	--	0.025	(0.05)	3.8 x 2.5 x 1.3	(1.5 x 1.0 x 0.5)	2	--	0.50	(0.1)	24	(1.5)
Filter, transmitter, BP	--	0.36	(0.8)	17.3 x 5.1 x 3.2	(6.8 x 2 x 1.25)	1	--	0.36	(0.8)	279	(17.0)
Filter, Harmonic	--	0.05	(0.1)	10.2 x 1.3 x 1.3	(4 x 0.5 x 0.5)	1	--	0.05	(0.1)	16	(1.0)
Filter, receiver, BP	--	0.36	(0.8)	17.3 x 5.1 x 3.2	(6.8 x 2 x 1.25)	1	--	0.36	(0.8)	279	(17.0)
Circulator	--	0.12	(0.25)	5.1 x 5.1 x 1.9	(2 x 2 x 0.75)	1	--	0.12	(0.25)	49	(3.0)
Preamplifier	0.5	0.12	(0.25)	7.9 x 4.1 x 2.5	(2 x 2 x 0.75)	1	0.5	0.12	(0.25)	82	(5.0)
Coax cables								0.3	(0.7)		
Power amplifier	22.7	0.25	(0.5)	20.3 x 7.6 x 3.2	(8 x 3 x 1.25)	2	45.4	0.5	(1.0)	983	(60.0)
							52.9	3.6	(8.0)	3933	(240.0)

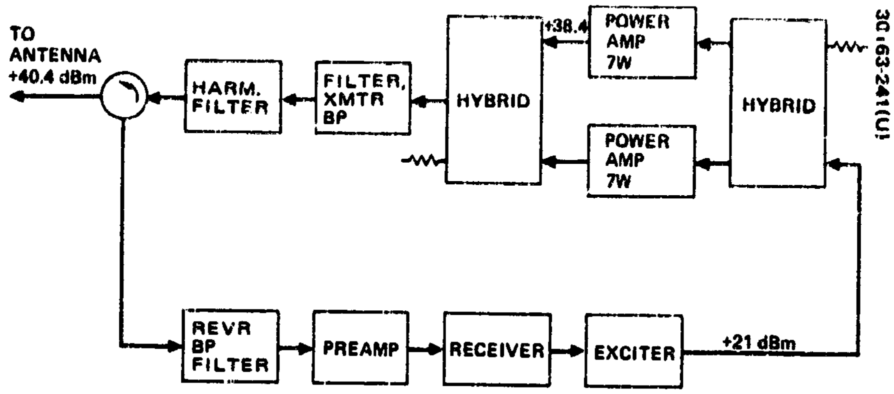


FIGURE 5-3. LARGE PROBE RF SUBSYSTEM

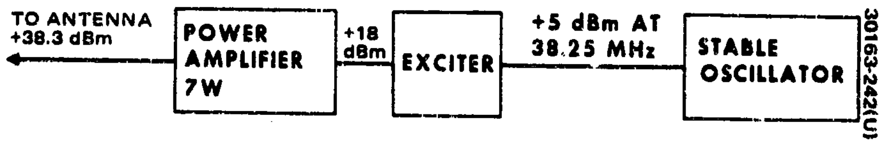


FIGURE 5-4. SMALL PROBE RF SUBSYSTEM

TABLE 5-6. SMALL PROBE RF SUBSYSTEM

	Unit Description					Totals					
	Power, W	Mass, kg	Mass, (lb)	Dimensions, cm.	Dimensions, (in.)	Quantity	Power W	Mass, kg	Mass, (lb)	Size (cm³)	Size (in.³)
Exciter	4.0	0.5	(1.0)	11.9 x 8.6 x 3.8	(4.7 x 3.4 x 1.5)	1	4.0	0.5	(1.0)	393	(24)
Stable oscillator	0.25*	0.3	(0.75)	5.1 x 5.1 x 5.1	(2 x 2 x 2)	1	0.25*	0.3	(0.75)	131	(8)
Coax cables	--						--	0.1	(0.2)		
Power amplifier	22.7	0.2	(0.5)	20.3 x 7.6 x 3.3	(8 x 3 x 1.25)	1	22.7	0.2	(0.5)	492	(30)
							26.95*	1.1	(2.45)	1016	(62)

*Average over descent and warm-up

and a 3 dB pad is substituted for the output isolator. The pad simply renormalizes the exciter output power to the value required by the power amplifier module. At the same time it provides some isolation between the exciter output and power amplifier input. The exciter output isolator cannot be left in the circuit since in this version the magnetometer experiment is carried on the small probe. Finally, the exciter is repackaged to a minimum 3.8 cm height dimension so as to obtain minimum size and weight for the small probe.

The stable oscillator is included here as part of the rf subsystem although it might very well be considered as part of the experiments payload. The oscillator is designed for 1 part in 10^9 stability during descent into the Venus atmosphere.

Table 5-6 summarizes the component parameters for the small probe.

5.2 ANTENNA SUBSYSTEM

Orbiter

The orbiter spacecraft uses a mechanically despun parabolic reflector antenna for high gain and two broad-beam antennas to provide essentially spherical coverage. Table 5-7 summarizes the performance of these antennas.

The parabolic reflector has been selected because of its low weight, design/implementation simplicity, low technical risk and low-level development required. An electronically despun array would have been heavier, more complex and had higher technical risk. A mechanically despun array is costly due to complexity. The high gain antenna is a focal point fed reflector based on a flight-proved communication antenna of the Intelsat IV program. The antenna circuit losses consist of the loss in the rotary joint, the feed line from the rotary joint to the feed, and the ohmic loss of the feed. The aperture efficiency loss is due to the effects of the aperture taper, reflector surface tolerance, aperture blockage, spill-over and feed location tolerance.

The reflector is constructed of 0.95 cm (3/8 in.) expanded aluminum honeycomb core sandwiched between two layers of 0.25 cm (0.01 in.) epoxy fiberglass cloth facesheets. Aluminum foil 0.0025 cm (1 mil) thick is bonded to the front surface of the reflector to provide a continuous highly reflective surface. The dish is fastened in the back to a mounting flange. The feed is a conical horn, probe-excited to produce right-hand circular polarization. The conical horn is selected over other candidate feeds, because these antennas provide good axial ratio of the secondary pattern, have high efficiency and low backlobe radiation.

A conical log spiral and a slotted cone antenna were used in combination to provide spherical coverage. These antennas have been selected

TABLE 5-7. ORBITER ANTENNA PERFORMANCE SUMMARY

Antenna	Pattern Shape, or Type	Peak-Gain, dB	Beamwidth, deg.	Dimensions, cm (in.)	Mass, Kg (lb)
High gain antenna parabolic reflector	Pencil beam	23.5	11.0	Diameter: 82.6 (32.5) Depth: 45.6 (18.0	1.4 (3.1)
Conical log spiral omnidirectional	Near hemispherical	Not less than -6 dBi over 97 percent of sphere	140 (-6 dBi)	Diameter: 5.1 (2.0); Height: 9.1 (3.6)	0.18 (0.4)
Slotted cone (Surveyor type) omnidirectional	Near hemispherical		220 (-6 dBi)	Diameter: 12.7 (5.0); Height: 5.1 (2.0)	0.27 (0.6)

on the basis of coverage/spacecraft interference, availability and low weight. The slotted cone is the same antenna design used on the Surveyor spacecraft. It provides better than hemi-spherical coverage and therefore is located above the reflector antenna to give it a wide unobstructed view angle. The conical log spiral is designed to fill in the partial hemisphere not covered by the Surveyor-omni pattern. The conical log spiral consists of a conducting ribbon wound on an apoxy fiberglass cone. Table 5-8 summarizes the orbiter antenna subsystem parameters.

As seen from the spacecraft configuration, Figure 3-2, the log conical spiral omni is spinning with the spacecraft. The slotted cone omni mounted above the high gain antenna is despun. It is more convenient to mount it in that manner, than on a separate spacecraft body fixed mast. On the probe bus spacecraft, the location of the two wide angle coverage antennas is reversed from that on the orbiter to minimize obstruction/ shadowing by the spacecraft body/structure.

Probe Bus

The probe bus antenna assembly includes the deployable bicone, medium gain conical horn and the omnidirectional antennas. Table 5-9 is a listing of the performance characteristics of the probe bus antenna assembly.

The bicone antenna gives an omindirectional coverage in the spin plane with a half power beamwidth of 30 deg. along the spin axis. The net gain is not less than 3 dB. A similar antenna has been built and tested at a higher frequency verifying the characteristics of the bicone antenna. The circular flared region is excited by a ring of crossed dumbbell slots located on the circumference of the circular waveguide feedline.

The bicone antenna is retracted during launch and is deployed after separation. The deployment mechanism is electromechanical. No rf moveable joint is required. A length of flexible coaxial cable provides the extendable rf connection.

The medium gain antenna is a circularly polarized conical horn with a polarizer and a transition from rectangular to circular waveguide. Endfire radiators were considered but rejected, because such an antenna would have to be mounted away from the vehicle to avoid shadowing on the radiator. A flat array is complex and becomes inefficient in this range of gain. The horn is a frequency scaled version of the earth coverage horn used on Intelsat IV.

The omnidirectional antennas are the same design as used on the orbiter spacecraft.

TABLE 5-8. ORBITER SPACECRAFT ANTENNA ASSEMBLY — DETAIL OF PERFORMANCE PARAMETERS

High Gain Antenna		
Size	82.6 cm (32.5 in.) diameter	
Polarization	Circular, axial ratio 3 dB	
Peak aperture gain	26.4 dB	
	-0.5 dB	
Circuit losses (feed, feed line and rotary joint)	-2.4 dB	
Aperture efficiency loss	-2.4 dB	
Total losses		-2.9 dB
		23.5 dB
Net peak gain		
Beamwidth	11.0	
Weight		
High gain antenna assembly (reflector)	0.77 kg (1.7 lb)	
Feed	0.18 kg (0.4 lb)	
Feed support	0.18 kg (0.4 lb)	
Feed line	0.27 kg (0.6 lb)	
Subtotal		1.4 kg (3.1 lb)
Wide-angle omnidirectional antenna assembly (slotted cone)		
Antenna	0.18 kg (0.4 lb)	
Feed line	0.09 kg (0.2 lb)	
Subtotal		0.27 kg (0.6 lb)
Rotary joint (carried under despin bearing weight)	0.36 kg (0.8 lb)	
Narrow-angle omnidirectional antenna assembly (conical log spiral		
Antenna	0.045 kg (0.1 lb)	
Feed line	0.09 kg (0.2 lb)	
Support	0.045 kg (0.1 lg)	
Subtotal		0.18 kg (0.4 lb)
Miscellaneous Components*		
Notch filter	0.45 kg (1.0 lb)	
Circulator	0.11 kg (0.3 lb)	
Switch, SPDT	0.09 kg (0.2 kg)	
Subtotal		0.08 kg (1.5 lb)
Total		1.85 kg (5.6 lb)

TABLE 5-9. PROBE BUS ANTENNA PERFORMANCE SUMMARY

Antenna	Pattern Shape, or Type	Peak-Gain dBi	Beamwidth, deg.	Dimensions, cm (in)	Mass, kg
Bicone	Equatorial - plane omni	3	30 in elevation	Diameter: 45.6 (18); height: 25.4 (10)	1.725 (3.8)
Horn	Pencil beam	18	20	Diameter: 45.6 (18); length: 66.0 (26)	0.91 (2.0)
Conical log spiral omni-directional	Near hemi-spherical	Not less than -6 dB over 97 percent of sphere	140 (-6 dBi)	Diameter: 5.1 (2.0); height: 9.1 (3.6)	0.18 (0.4)
Slotted cone (Surveyor type) omnidirectional	Near hemi-spherical		220 (-6 dBi)	Diameter: 12.7 (5.0); height: 5.1 (2.0)	0.27 (0.6)

TAB:E 5-10. LARGE AND SMALL PROBE ANTENNA PERFORMANCE SUMMARY

Antenna	Pattern Shape, or Type	Peak-Gain, dBi	Nominal 1 dB Beamwidth, deg	Dimensions, cm (in.)	Mass, kb (lb)
Large probe planar equi-angular spiral	Conical	4.8 at 45 deg	30	Diameter: 15.24 (6.0); Height: 5.1 (2.0)	0.68 (1.5)
Small probe loop-vee	Conical	2.7 at 60 deg	30	Diameter: 8.26 (3.25); Height: 4.32 (1.7)	0.23 (0.5)

Large Probe

The antenna on the large probe is a planar four-arm equiangular spiral, similar in design principle to the conical log spiral used to provide near hemispherical coverage. By feeding the four spiral arms in phase, a near hemispherical pattern results. When a 180 deg. phase change is created between adjacent arms, a conical pattern results with the pattern peak occuring at 50 $\pm$ 15 deg. The angle of maximum gain is a function of the ground plane and spiral growth rate. The characteristics of the spiral antenna designed for the large probe are given in Table 5-10. The antenna consists of a circular cavity closed off at one end by the spiral circuit and at the other end by the one-to-four port hybrid feed network. The cavity is filled with high-temperature foam to give support to the spiral circuit against high pressure loading.

Small Probe

The antenna for the small probe is a loop-vee radiator chosen because of its small size, low weight and good pattern performance. Its characteristics are given in Table 5-10. The antenna consists of four inclined monopoles each feeding to a quadrant of a horizontal loop. The antenna is very simple in construction and suitable for operation in adverse environments since only a conductor material is used in the construction of the radiator.

6. ATLAS/CENTAUR BASELINE

The criteria for selecting the communication system components for the Atlas/Centaur baseline were based on achieving the lowest possible cost, since unlike the Thor/Delta design, weight was not as serious a constraint. Also, the Atlas/Centaur baseline reflects changes in the subsystem requirements up to the present writing. The greatest possible design commonality between the orbiter, probe bus, large probe, and small probe was implemented. In addition, most of the component hardware was directly derived from other space programs as shown in Table 6-1. Note that the only completely "new" hardware items are the stable oscillator and the probe antennas.

Changes between the Thor/Delta baseline described in Section 5 and the Atlas/Centaur baseline described in this section are due to four factors. The first is, of course, the change in launch vehicle from Thor/Delta to Atlas/Centaur. The second factor is the change of mission set. This change impacted the design of the communications subsystems for the multiprobe mission since the communications ranges at the mission critical events were changed. A third factor is the new nominal science payload associated with the new mission set. Changes in scientific data return requirements directly affect communications subsystems sizing. The addition of an X-band capability to the orbiter for the dual frequency occultation experiment had a significant effect upon several orbiter subsystems, especially antenna, rf, attitude control, and spacecraft configuration. The final factor is normal design evolution. The Atlas/Centaur spacecraft design reflected in this section is a later design than the Thor/Delta design discussed in section 5. Thus, design improvements that were not included in section 5 are discussed in this section. The Atlas/Centaur design which is the same time-wise as the Thor/Delta design of section 5, is given in the Launch Vehicle Utilization Study, Volume 11 of this report. Table 6-2 lists the differences between the designs of sections 5 and 6, and ascribes each difference to one or more of the four factors discussed above.

A major trade study unique to the latest science package was the implementation of the dual frequency occultation experiment which is discussed in section 6.1. The communications system is divided into the radio frequency subsystem and the antenna subsystem. Details on the design of these subsystems is given in sections 6.2 and 6.3.

TABLE 6-1. ATLAS/CENTAUR BASELINE COMMUNICATIONS HARDWARE DERIVATION

Units	Probe Bus	Orbiter	Large Probe	Small Probe
Antennas				
High gain	NA	Intelsat IV reflector with conical horn feed	NA	NA
Dual bicone	Data Systems* Modify frequency, beam width and mechanical interface	NA	NA	NA
Wide angle omni (conical crossed slots)	Surveyor	Surveyor	NA	NA
Narrow angle omni (conical spiral)	HS-350* Modify frequency and beamwidth	HS-350* Modify frequency and beamwidth	NA	NA
Medium gain (horn)	Intelsat IV Modify frequency and beamwidth	NA	NA	NA
Curved turnstile	NA	NA	New (in development)	New (in development)
X-band horn	NA	Intelsat IV Modify frequency and beamwidth	NA	NA
Rotary joint	NA	Telesat Modify frequency	NA	NA
Receiver/exciter	Viking	Viking	Viking	NA
Exciter	NA	NA	NA	Exciter portion of Viking transponder
Switches	Pioneer, Helios	Pioneer, Helios	NA	NA
Power amplifier	HS-350*	HS-350*	HS-350*	HS-350*
Filters				
Bandpass	ATS E Modify frequency and beamwidth	ATS E Modify frequency and beamwidth	ATS E Modify frequency and bandwidth	NA
Low pass	Telesat Modify frequency	Telesat Modify frequency	Telesat Modify frequency	NA
Circulator	OSO-I, HS-350*	OSO-I, HS-350*	OSO-I, HS-350*	NA
Stable oscillator	NA	NA	NA	New

*Classified Hughes Programs

TABLE 6-2. FACTORS DETERMINING DESIGN CHANGES BETWEEN THOR/DELTA AND ATLAS/CENTAUR BASELINE DESIGNS

Difference	Factors Determining Difference
Higher level RF power amplifier units and changes to incorporate these and combine to required power levels.	Launch vehicle change. Science requirement change. Design evolution (use of existing equipment)
Elimination of low power (lw) mode in power amplifier units.	Design evolution (cost savings)
Elimination of separate preamplifier. Simplification of diplexer.	Design evolution (cost savings)
Change from single to dual bicone array on probe bus. Change from deployed to fixed antenna.	Launch vehicle change
Orbiter high gain antenna changed from transmit only to transmit/receive. Resulting changes in switching and filtering.	Follows from elimination of separate preamplifier
Addition of X band horn dual channel rotating joint and X band transmitter to orbiter.	Science requirement change
Orbiter normal RF power changed from 5 to 10 W mode resulting in additional (2 to 4) power amplifier units for redundancy. Associated switching changes.	Science requirement change. Design evolution (ERP versus data shortage considerations)
Probe antennas changed to provide hemispheric coverage with common antenna.	Mission set change. Design evolution (commonality, reliable coverage)

6.1 DUAL FREQUENCY OCCULTATION IMPLEMENTATION TRADE

The principal trade in determining the Atlas/Centaur communications configuration for the orbiter was the selection of the implementation for adding the X-band capability for the dual frequency occultation experiment. Configuration aspects of this trade are discussed in Volume 4 and attitude control considerations are covered in Volume 9 of this report. This discussion will focus on the systems aspects of the selection. Subsystem design factors will be discussed in sections 6.2 and 6.3.

The orbiter must have the capability to perform a dual-frequency radio occultation experiment during the initial Earth occultation season after arrival at Venus. The frequencies are S-band (the spacecraft telemetry downlink) and X-band (an rf system to be added specifically and only for the occultation experiment). Requirements for this experiment are:

1) The S- and X-band links must be capable of simultaneous operation.
2) The two links must be compatible with DSN capabilities.
3) Each link must be receivable for atmospheric refractions of up to 10 deg, but a capability up to 20 deg is desired.
4) The period of occultation measurements will normally be limited to the first 40 days in orbit but coverage for the entire season (72 days) is desired (3 dB more ERP). However, later in the season, things are complicated by the eclipses that occur during the occultations.
5) The frequency relationship of the S- and X-band downlinks must be the precise ratio of 3/11 for both coherent and noncoherent S-band communication modes.
6) The signal level at the DSN receiver shall be -178 dBm or greater for both links.
7) The 64 m DSS antennas will be used for all occultation measurements.

The spacecraft ERP requirements to satisfy the above requirements are summarized in Table 6-3.

It can be seen from Table 6-3 that the S-band communications system which has an on-boresight ERP of 63.5 dBm can meet the most stringent requirement, 20 deg refractive angle, at the end of the occultation season (72 days). But, it must be steered in two dimensions to track the virtual earth, since the first null occurs at about 15 deg. However, it can be used without steering at 10 deg off-boresight where the gain is down by only 10 dB to meet the nominal requirement of a 10 deg refractive angle to 40 days into the occultation season.

TABLE 6-3. ERP REQUIREMENTS

Days on Orbit	Link Loss, dB Including DSN Antenna Gain		ERP (dB) for 10 deg Refractive Angle 28 dB Refractive Defocusing Loss		ERP (dB) for 20 deg Refractive Angle 40 dB Refractive Defocusing Loss	
	2295 MHz	8415 MHz	2295 MHz	8415 MHz	2295 MHz	8415 MHz
0	192	194	42	44	54	56
40	197	199	47	49	59	61
72	200	202	50	52	62	64

For the X-band signal, three possible implementations were considered. The first used a separate despun X-band horn with a beamwidth of 20 deg, which is boresighted with the S-band HGA. The virtual earth can be tracked with sufficient ERP out to 10 deg from boresight. The second scheme used a dual frequency feed on the orbiter high gain antenna (HGA) and steered the antenna in elevation (elevation gimbal on reflector) and azimuth (despin bias) to track the virtual earth up to refractive angles of 20 deg as the spacecraft enters and exits from occultation. The third approach was to provide a dual frequency feed on a nongimballed orbiter HFA and precess the spacecraft to track the virtual earth. This requires the X-band beam be spoiled because the resulting uncertainty in spacecraft attitude is of the same order as the unspoiled 3 deg HGA beamwidth at X-band. Another approach not considered in the trade would be to provide a toroidal pattern at X-band in the spin plane. This was judged to be inefficient use of power and was not pursued further.

A summary of the three configurations traded is given as Table 6-4. The mass and cost impact on these schemes is given in Table 6-5. The costs (both dollars and weight) in this table are the increases over the orbiter without X-band capability.

The scheme with the gimballed reflector provides the best science coverage by far. It can be used for refractive angles up to 20 deg provided the X-band transmitter power (1 W to 40 days, 2 W to 72 days) is available. The 200 mW transmitter included in Table 6-4 provides coverage throughout the occultation season to refractive angles of 10 deg. It takes full advantage of the despun nature of the orbiter HGA and allows tracking the virtual earth with the antenna boresight. This scheme is the most expensive in both dollars and mass. A failsafe scheme to return the elevation scan to its rest position in case of failure must be included. Details of the gimbal design considered are given in Volume 9.

TABLE 6-4. DUAL FREQUENCY OCCULTATION TRADES

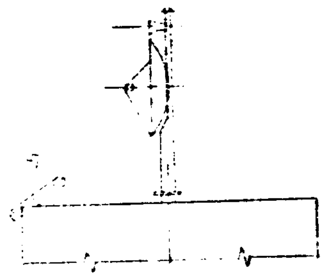
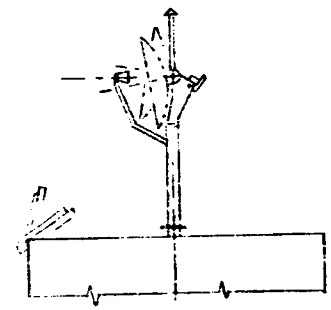
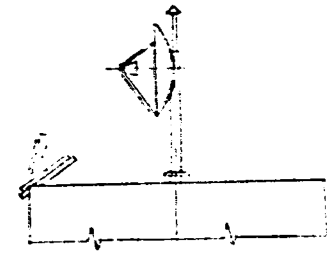
Configuration (All Antenna Assemblies are Despun in Azimuth)		 A	 B	 C
Design approach		Fixed S band HGA, Separate X band horn 3 W X band transmitter	Moving HGA reflector Fixed S/X feed 0.2 W X band transmitter	Moving spacecraft Fixed antenna with S/X feed 3 W X band transmitter
Increases to add occultation experiment	Cost K$	750	1020	770
	Mass, kg (lb)	5.26 (11.6)	8.40 (18.5)	7.67 (16.9) for 40 days
Reliability		Best	Must accommodate elevation drive failure	Additional thruster pulses required
Science		Adequate (to ±10 deg), pointing accuracy <1 deg. Best interface (separate X band)	Best boresight to earth, ±20 deg; pointing accuracy <1 deg	Worst attitude uncertainty, pointing accuracy <2.5 deg. Impacts radar altimeter usage
Mission operations		Best	Some additional operations	Worst — requires daily attitude control. Uses 1.9 kg (4.2 lb) propellant in 40 days at ±10 deg

TABLE 6-5. MASS AND COST INCREASES FOR A DUAL FREQUENCY OCCULTATION EXPERIMENT

Item Required	Design Approach					
	A		B		C	
	Mass, kg (lb)	Cost, $K	Mass, kg (lb)	Cost, $K	Mass, kg (lb)	Cost, $K
Add X-band horn	0. 23 (0. 5)	160	—		—	
Add X-band coax	0. 27 (0. 6)		0. 27 (0. 6)		0. 27 (0. 6)	130
Modify HGA for dual feed	—		0. 54 (1. 2)	130	0. 32 (0. 7)	
Add S band coax	—		0. 14 (0. 3)		—	
Add rotary joint	0. 41 (0. 9)	85	0. 41 (0. 9)	85	0. 41 (0. 9)	85
Modify HGA mast and support	—	—	1. 23 (2. 7)	30	—	—
Add elevation positioner for HGA reflector (mechanism and electronics)	—	—	3. 22 (7. 1)	400	—	—
Add X band solid state driver or transmitter	1. 40 (3. 1)	375	1. 50 (3. 3)	375	1. 40 (3. 1)	375
Add X band TWTA(3 W)	2. 27 (5. 0)	130	—	—	2. 27 (5. 0)	130
Precess spacecraft (propellant for 40 days) (electronics)	—		—		2. 00 (4. 4) (1. 90)(4. 2) (0. 10)(0. 2)	50
Experiment contingency (15 percent)	0. 68 (1. 5)	—	1. 09 (2. 4)	—	1. 00 (2. 2)	—
Totals	5. 26 (11. 6)	750	8. 40 (18. 5)	1020	7. 67 (16. 9)	770

A separate despun X band horn provides coverage to refractive angles of 10 deg. However, the beam boresight is not pointed toward the virtual earth but rather this scheme relies on the antenna gain at beam edge. Because of the nature of the S band beam this scheme cannot be extended to greater refractive angles. In fact, because 10° corresponds to a point far down on the gain slope (-10 dB) of the S band antenna, the high rate of change of gain with angle will make data reduction extremely difficult. 2.8 W of X band power is required. Table 6-4 refers to an existing 3.3 W TWTA. The cost in both mass and dollars is least of the three schemes and since the spacecraft or anything on the spacecraft does not move during the occultation, it is the most reliable scheme.

Precession of the spacecraft to keep the antenna virtual earth oriented can be implemented. A discussion of this is given in Volume 9 of this report. This scheme can operate to refractive angles of 20 deg. provided enough fuel is provided. Again, Table 6-4 refers to an existing TWTA which satisfies the ERP requirements. The costs are intermediate between the other schemes considered, but this scheme presents problems to other science because of the attitude uncertainties it introduces. It also increases the thruster pulses required and severely impacts mission operations. Precession could be used in conjunction with the separate despun X band horn discussed above to extend the refractive angle coverage of the separate horn scheme.

Based on cost, weight, reliability, and operational simplicity the separate despun X band horn is selected as the baseline implementation. However, it is recognized that the gimballed reflector implementation provides a scientifically more attractive experiment at a relatively modest increase in cost and takes maximum advantage of the features of the mechanically despun HGA. Combining the orbiter radar altimeter and the S/X band occultation experiment in a single dual frequency HGA with two-dimensional steering deserves further consideration when total costs can be evaluated by NASA.

To meet the requirements of this selected implementation, the subsystems must provide 49 dBm X band ERP at 10 deg. from the antenna boresight. This provides coverage to 10 deg. refractive angle to 40 days on orbit. The X band antenna should be separate, despun, boresighted with the orbiter HGA, and have a beamwidth of 20 deg. and a gain of 17.5 dB (on boresight). The transmitted rf power at X band should be sufficient to meet the ERP requirement stated previously.

6.2 RADIO FREQUENCY SUBSYSTEM

Probe Bus

The block diagram of the probe bus rf subsystem and its interconnection with the antenna subsystem is shown in Figure 6-1. The basic topology is essentially the same as that in the Thor/Delta with a pair of redundant transponders, two power amplifiers, transmit filtering, and rf switching and summing to connect a power amplifier output or the summed output of both amplifier to the four antennas. The main differences are power amplifier units with higher output levels and the elimination of separate rf preamplification ahead of the transponder receiver. There is no change in the rf switching arrangement.

Adequate margin in the command link was available with the available sensitivity of the Philco Ford Viking transponder that had been selected for the baseline so that the preamplifier was unnecessary. The transponder includes rf filtering in its input so that separate filtering in the diplexer also is unnecessary. As a result, the diplexer is simplified to only a circulator for coupling transmitter and receiver to an omni antenna.

A power amplifier unit composed of components currently under development on another space program at Hughes, HS-350, has been incorporated in the baseline design. Each power amplifier unit includes a three stage driver module, a driver output isolator, and a hybrid coupled output stage utilizing two MSC 3005 transistors. An output isolator and dc regulator also is included in the output stage module.

The amplifier provides 9 w output with a gain of 26.5 db. Although the mass of the power amplifier unit is nearly double that of the unit proposed for the Thor/Delta baseline, the savings in development cost and the reduced development risk in achieving the required power output justifies the baseline change.

A small increase in output power is required on the probe bus as a result of slightly longer RF cables in the Atlas/Centaur spacecraft design. However, the significantly higher power level is provided to allow greater operational flexibility and to permit use of identical power amplifier units on the orbiter and large probe systems where the full increase in power is needed to meet increased data requirements. Table 6-6 lists the power, mass, and size of the various components of the probe bus rf subsystem.

Orbiter

The block diagram of the communication subsystem for the orbiter spacecraft is shown in Figure 6-2.

Except for unique functions that require different components such as an X band transmitter and a dual channel RF rotary joint, the subsystem utilizes the same basic components that are used on the probe bus. The component layouts for the orbiter and probe bus also will be made to be as close to identical as possible.

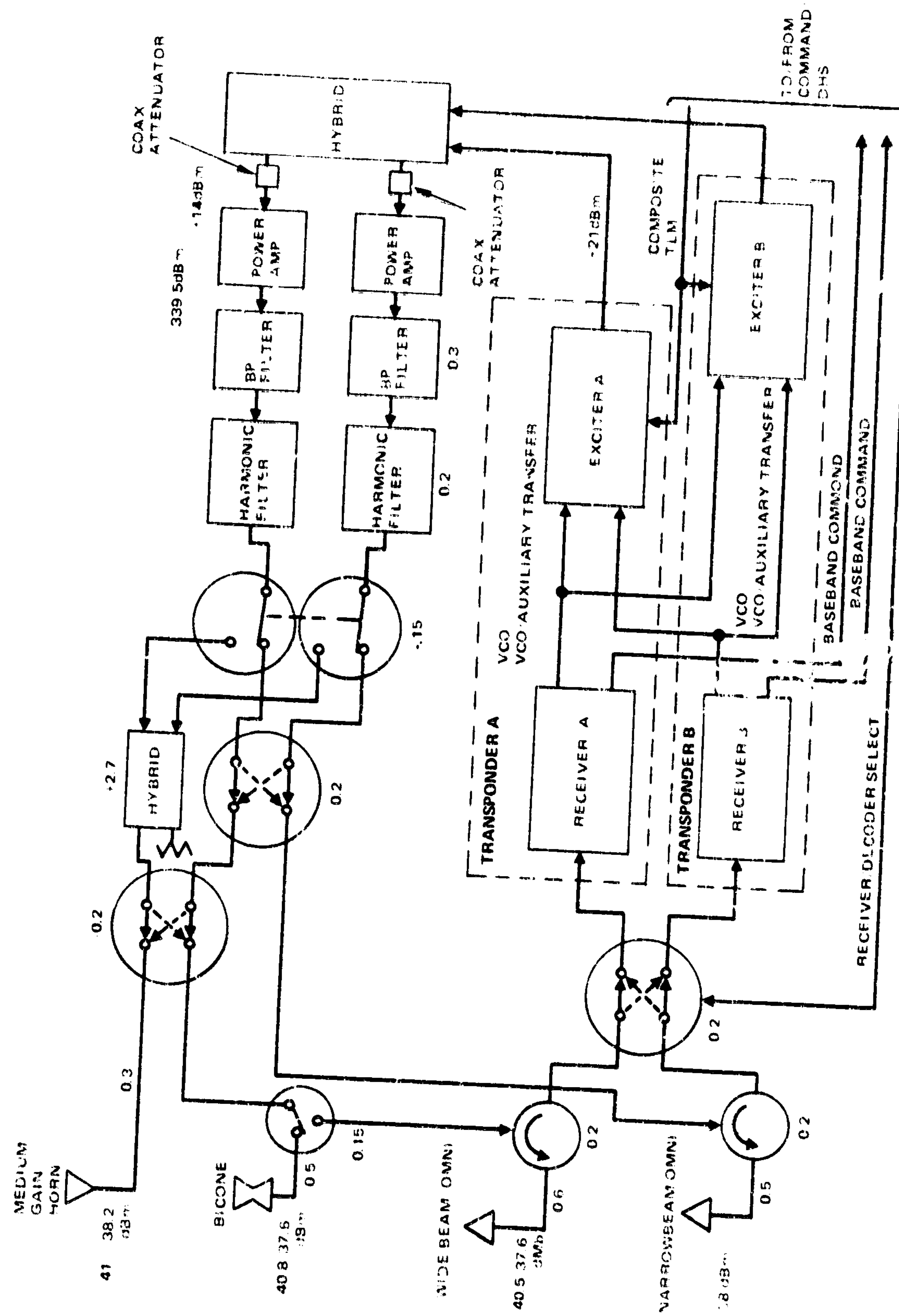


FIGURE 6-1. PROBE PUS COMMUNICATIONS SUBSYSTEM

TABLE 6-6. RF SUBSYSTEM - PROBE BUS

Unit	Power W at 24 V	Mass kg	Weight lbs	Dimensions, cm (in.)	Quantity	Power W at 24 V	Mass kg	Weight lbs	Volume cm³	Volume (in.³)
Exciter	4	2.0	4.4	27.3 x 12.7 x 6.4 (10.75 x 5.0 x 2.5)	2	4	4.0	8.8	4440	(270.0)
Receiver	3	2.0	4.4	27.3 x 12.7 x 6.4 (10.75 x 5.0 x 2.5)	2	6	4.0	8.8	4440	(270.0)
Hybrid	—	0.023	0.05	3.8 x 2.5 x 1.3 (1.5 x 1.0 x 0.5)	2	—	0.05	0.1	25	(1.5)
Filter, TXBP	—	0.45	1.0	20.3 x 5.1 x 3.7 (8.0 x 2.0 x 1.45)	2	—	0.9	2.0	766	(46.0)
Filter, harmonic	—	0.05	0.1	10.2 x 1.3 x 1.3 (4.0 x 0.5 x 0.5)	2	—	0.1	0.2	35	(2.0)
Circulator - isol	—	0.11	0.25	5.1 x 5.1 x 1.9 (2.0 x 2.0 x 0.75)	2	—	0.22	0.5	99	(6.0)
SPDT switch	0.1	0.11	0.25	4.6 x 4.6 x 3.8 (1.8 x 1.8 x 1.5)	3	0.3	0.33	0.75	241	(15.0)
Transfer switch	0.1	0.32	0.7	10.7 x 5.1 x 5.1 (4.2 x 2.0 x 2.0)	3	0.3	0.96	2.1	835	(50.4)
Coaxial cables				0.95 O.D. (3/8 O.D.)		—	1.14	2.5		
Power amplifier	32.5	0.86	1.9	17.0 x 11.4 x 4.4 (6.7 x 4.5 x 1.75)	2	32.5/65	1.72	3.8	1706	(106.0)
					6 W mode 12 W mode	43.1 75.6	9.42	20.75	8147	(497.0)

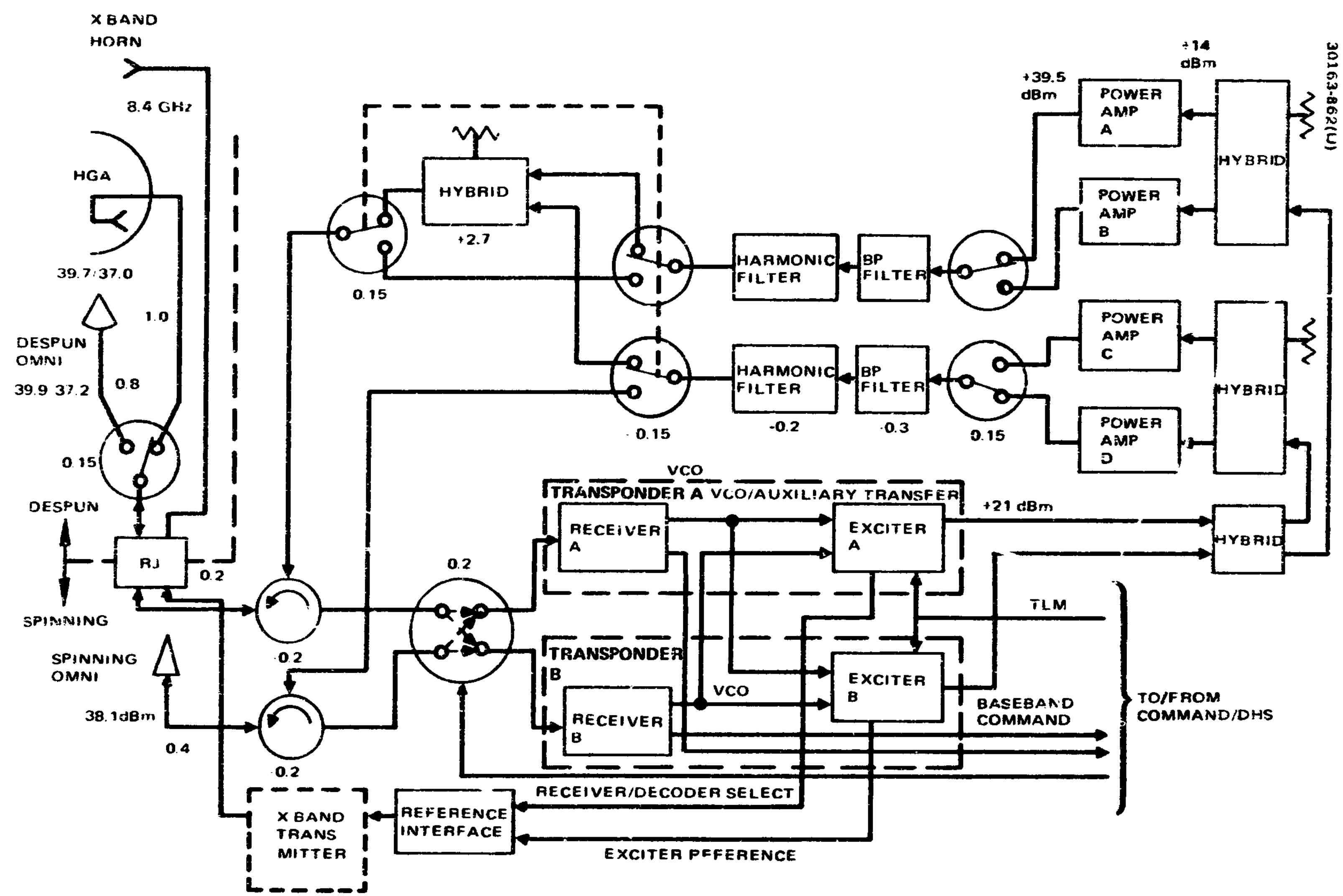


FIGURE 6-2. ORBITER COMMUNICATIONS SUBSYSTEM

The changes from the Thor/Delta baseline, described in Section 5, include the elimination of separate preamplifiers and simplification of the diplexer as in the case of the probe bus subsystem. The reduction in sensitivity and redefined orbiter mission requirements results in a need to receive as well as transmit through the high gain antenna. As a result the switching arrangement on the despun portion of the subsystem is revised with a single SPDT switch connecting the RF line to either the high gain or omni antenna. The notch filter is eliminated, since the uplink signal must pass through the switched line. Sufficient isolation is provided by the switch to prevent interference between the two antenna patterns.

The power amplifier unit output level is increased to 9 w using the same unit described for the probe bus. The high power mode, about 10 w at the antenna terminals, uses a pair of amplifier units operating in parallel. System operation has been changed such that this is now the normal mode of operation instead of the single amplifier mode. As a consequence, it is necessary to provide two additional power amplifier units to serve as redundant units to the two in operation. All four amplifiers are driven through hybrid circuits to allow independent selection of amplifier A or B for operation with either C or D. Following the redundancy selection switch, the signal paths are the same as in the Thor/Delta baseline, except for the elimination of a transfer switch between the two low power output lines. In the new configuration, there are two amplifiers available to feed each of these lines, one of which goes to the spinning omni and the other to the high gain or despun omni. Thus, each output is fully redundantly driven and the transfer switch is no longer necessary.

An X band transmitter, dual channel (S and X band) rotary joint and a separate despun X band horn antenna have been added to the orbiter subsystems for the dual frequency occultation experiment. The 3 W X band transmitter shown in Figure 6-3 consists of a solid-state driver and a space qualified TWTA. The rotary joint is a concentric coaxial line design with the X band signal being carried on the inner coaxial line. This results in the least impact on the performance of the S band link with the loss increased by only 0.1 dB.

Table 6-7 summarizes the power, mass, and size of the components in the orbiter spacecraft RF subsystem.

Large Probe

Figure 6-4 shows a block diagram of the rf subsystem for the large probe. The configuration has been extensively revised from that described for the Thor/Delta baseline. As in the case of the spacecraft subsystems, the separate receive filter and preamplifier have been eliminated since the input sensitivity of the Viking transponder provides adequate margin for the uplink.

The transmitter portion is revised to provide nearly 3 dB higher output level. This increase is due primarily to an increase in antenna coverage (decreased gain). To achieve this, three output stage modules of the identical design as the modules in the standard 9 W power amplifier unit are operated

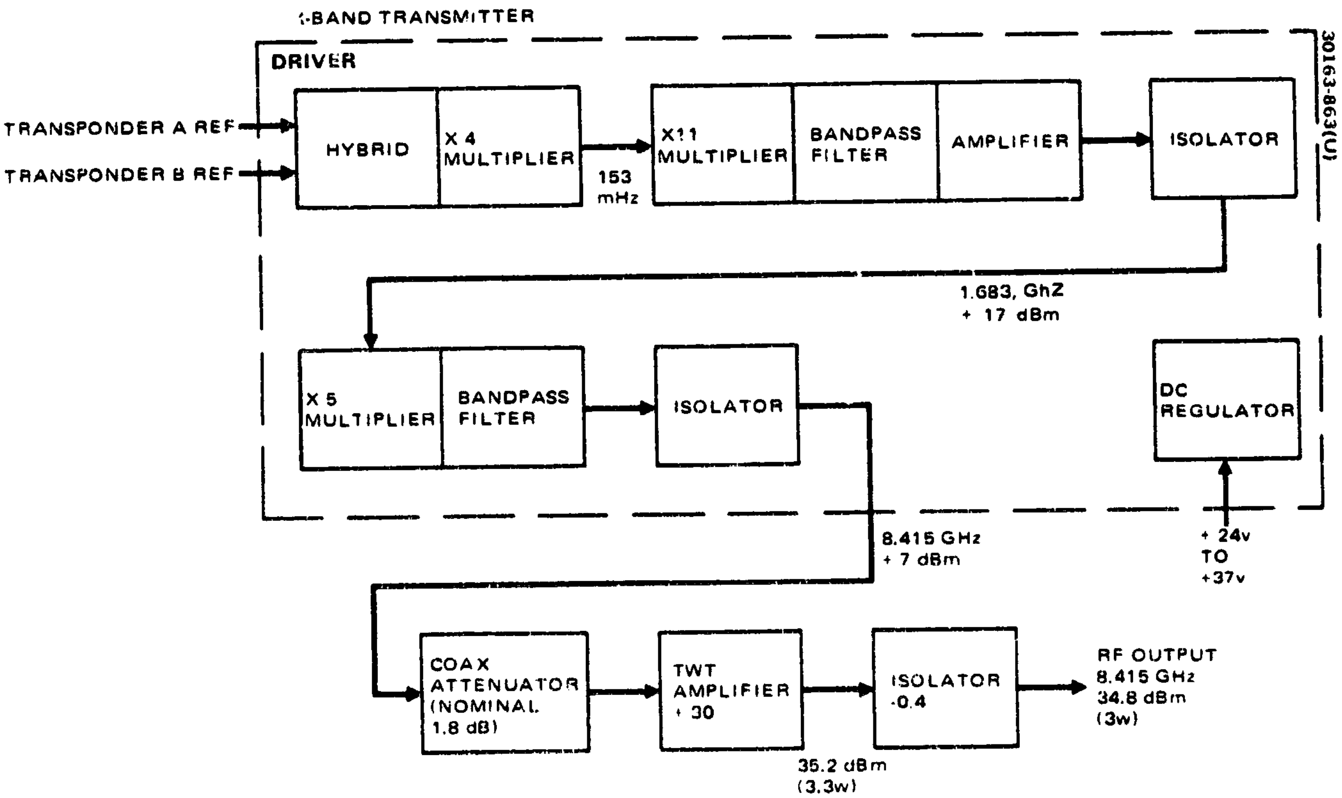


FIGURE 6-3. X BAND TRANSMITTER

TABLE 6-7. RF SUBSYSTEM - ORBITER

Unit	Power W at 24 V	Mass kg	Weight lbs	Dimensions, cm, (in.)	Quantity	Power W at 24 V	Mass kg	Weight lbs	Volume cm³	Volume (in.³)
Exciter	4	2.0	4.4	27.3 x 12.7 x 6.4 (10.75 x 5.0 x 2.5)	2	4	4.0	8.8	4440	(270.0)
Receiver	3	2.0	4.4	27.3 x 12.7 x 6.4 (10.75 x 5.0 x 2.5)	2	6	4.0	8.8	4440	(270.0)
Hybrid	–	0.023	0.05	3.8 x 2.5 x 1.3 (1.5 x 1.0 x 0.5)	1	–	0.09	0.2	50	(3.0)
Filter, transmitter	–	0.45	1.0	20.3 x 5.1 x 3.7 (8.0 x 2.0 x 1.45)	2	–	0.9	2.0	766	(46.0)
Filter, harmonic	–	0.05	0.1	10.2 x 1.3 x 1.3 (4.0 x 0.5 x 0.5)	2	–	0.1	0.2	35	(2.0)
Circulator - isol	–	0.11	0.25	5.1 x 5.1 x 1.9 (2.0 x 2.0 x 0.75)	2	–	0.22	0.5	99	(6.0)
SPDT switch	0.1	0.11	0.25	4.6 x 4.6 x 3.8 (1.8 x 1.8 x 1.5)	6	0.6	0.66	1.5	482	(30.0)
Transfer switch	0.1	0.32	0.7	10.7 x 5.1 x 5.1 (4.2 x 2.0 x 2.0)	1	0.1	0.32	0.7	278	(16.8)
Coaxial cables				0.95 O.D. (3/8 O.D.)			1.14	2.5		
Power amplifier	32.5	0.86	1.9	17.0 x 11.4 x 1.4 (6.7 x 4.5 x 1.75)	1	32.5 65	3.44	7.6	3412	(210.0)
Subsystem totals					5 W mode 10 W mode	43.2 75.6	10.9	24.0	9562	(584.0)
Occultation										
X-band driver	3.7	1.4	3.1	19.0 x 16.5 x 5.0 (7.5 x 6.5 x 2.0)	1	3.7	1.6	3.5	1567	(975.0)
X-band TWTA	15.2	2.3	5.0	25.4 x 19.0 x 9.6 (10.0 x 7.5 x 3.8	1	15.2	2.3	5.0	4643	(285.0)

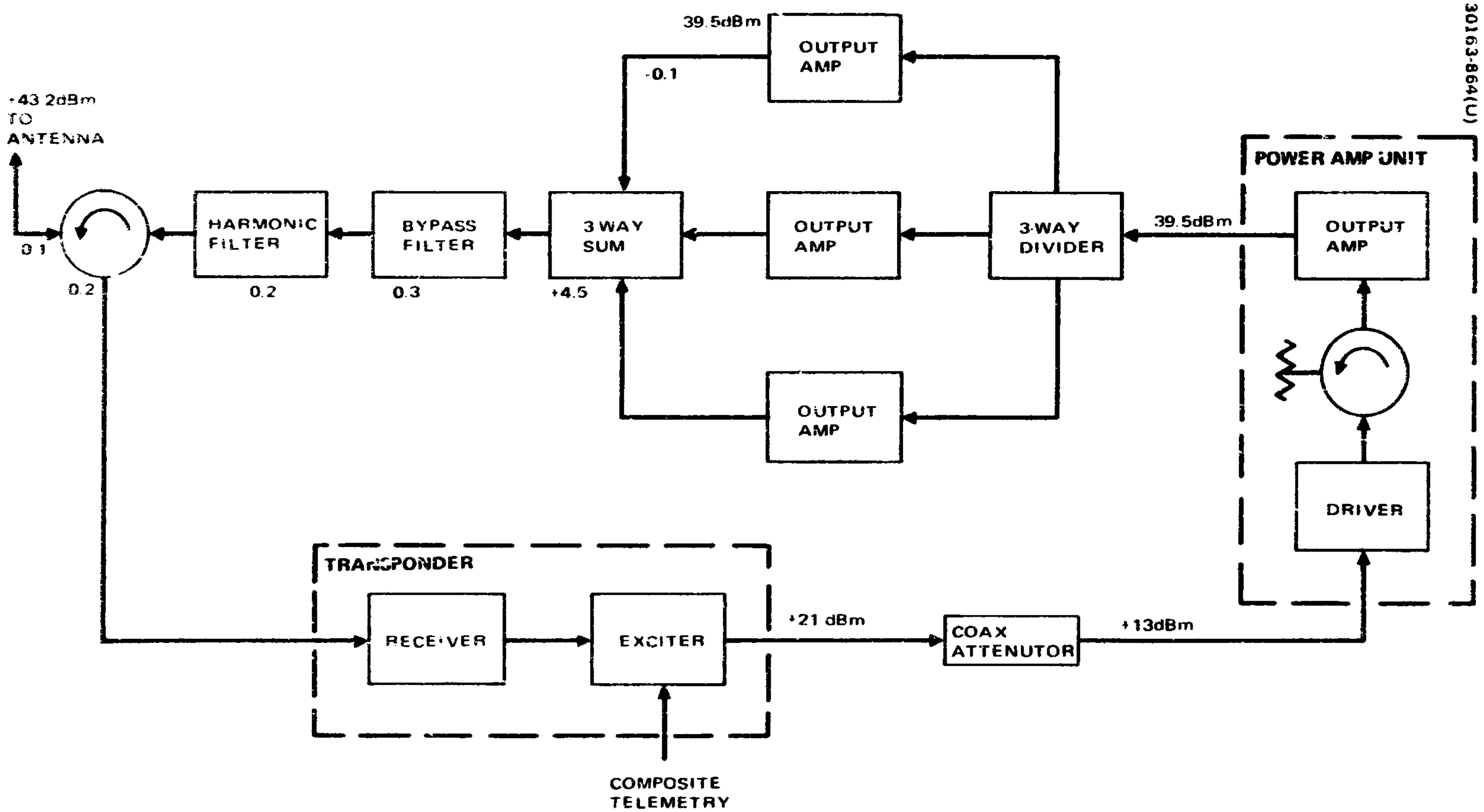


FIGURE 6-4. LARGE PROBE RF SUBSYSTEM

in parallel. The modules are completely package units, since they are separately mounted in their present application on the HS-350 satellite system. They each include regulators and output isolators to provide stable operation under possible adverse loading conditions during testing. The output amplifiers are driven through a 3 way quarter-wave transmission line divider by a complete power amplifier unit. The outputs of the amplifiers are recombined by another identical 3 way transmission line circuit operated in reverse to provide the summing function. The summer and dividers are similar to space qualified units that provide 16 and 6 way summing at UHF on the TACSAT and communications equipment (HS-318) subsystems.

Since common hardware is used, a miniature coaxial attenuator is inserted in the output line from the transponder to the input of the power amplifier unit. This compensates for the hybrid losses which are incurred on the spacecraft subsystems.

Table 6-8 lists the power, mass, and sizes of the components of the large probe rf subsystem. The three modules of the power amplifier unit (driver, isolator, output amplifier) are listed separately to allow flexibility in the layout of equipment within the unusual constraints of the probe package. However, they will be tested as a unit with the appropriate interconnecting cables.

Small Probe

Figure 6-5 shows the block diagram of the small probe rf subsystem. The configuration is the same as that for the Thor/Delta baseline, except for the change in power amplifier. In the new baseline, the standard 9 W amplifier unit is used. As in the large probe, there is flexibility in mounting the three modules that comprise the unit. The power, mass, and size of all the components are listed in Table 6-9.

6.3 ANTENNA SUBSYSTEM DESCRIPTION

The antennas on the orbiter, probe bus, and the large and small probes have been selected and designed on the basis of the gain and coverage requirements summarized in Table 6-10.

Probe Bus Antenna Subsystem

Four antennas are provided on the probe bus as shown in Figure 6-6. The interconnection of the antennas with the rf subsystem is described in section 6.1. The antennas have been chosen on the basis of commonality and off-the-shelf availability to lower the cost and meet the performance requirements. The location of the antennas on the spacecraft is governed by the radiation pattern shape and the spacecraft structure to avoid degradation of coverage in the down and up links during all phases of the mission.

A log-conical and a slotted-cone omnidirectional antenna, located on opposite ends of the spacecraft, are connected to separate receivers and

TABLE 6-8. RF SUBSYSTEM - LARGE PROBE

Unit	Power W	Mass kg	Weight lb	Dimensions, cm, (in.)	Quantity	Power W	Mass kg	Weight lb	Volume cm³	Volume (in.³)
Exciter	4	2.0	4.4	27.3 x 12.7 x 6.4 (10.75 x 5.0 x 2.5)	1	7	2.0	4.4	2220	(135.0)
Receiver	3	2.0	4.4	27.3 x 12.7 x 6.4 (10.75 x 5.0 x 2.5)	1	7	2.0	4.4	2220	(135.0)
Filter TXBP	–	0.45	1.0	20.3 x 5.1 x 3.7 (8.2 x 2.0 x 1.45)	1	–	0.45	1.0	383	(23.0)
Filter harmonic	–	0.045	0.1	10.2 x 1.3 x 1.3 (4.0 x 0.5 x 0.5)	1	–	0.45	0.1	18	(1.0)
Circulator	–	0.11	0.25	5.1 x 5.1 x 1.9 (2.0 x 2.0 x 0.75)	1	–	0.11	0.25	49	(3.0)
Coaxial cables				0.95 O.D. (3/8 O.D.)			0.32	0.7		
Transmitter	109.2									
Driver		0.20	0.45	10.2 x 4.2 x 3.3 (4.0 x 1.65 x 1.3)	1	109.2	0.20	0.45	141	(8.6)
Isolator		0.11	0.25	5.1 x 5.1 x 1.3 (2.0 x 2.0 x 0.75)	1		0.11	0.25	49	(3.0)
Output amplifier		0.545	1.2	17.0 x 6.4 x 4.4 (6.7 x 2.5 x 1.75)	4		2.18	4.8	1916	(117.2)
Three way sum div		0.09	0.2	5.1 x 5.1 x 1.3 (2.0 x 2.0 x 0.5)	2		0.18	0.4	34	(4.0)
						116.2	5.60	12.35	4810	(295.0)

TABLE 6-9. RF SUBSYSTEM – SMALL PROBE

Unit	Power, W	Mass (Weight,) kg (lb)	Dimension, (in.)	Quanity	Power, W	Mass (Weight,) kg	(lb)	Volume (in.^{3})
Exciter	4.0	0.64 (1.4)	11.9 x 8.6 x 6.4 (4.7 x 3.4 x 2.5)		4.0	0.64	(1.4)	655 (40.0)
Coaxial cables			0.95 O.D. (3/8 O.D.)			0.09	(0.2)	
Transmitter	34.2	0.86 (1.9)		1	34.2	0.86	(1.9)	
Driver		0.2 (0.45)	10.2 x 4.2 x 3.3 (4 x 1.65 x 1.3)					141 (8.6)
Isolator		0.11 (0.25)	5.1 x 5.1 x 1.9) (2 x 2 x 0.75)					49 (3.0)
Output Amplimeter		0.55 (1.2)	17 x 6.4 x 4.4) (6.7 x 2.5 x 1.75)					478 (29.3)
				RF subsystem total	38.2	1.59	(3.5)	1323 (81.0)
Stable Oscillator*	0.25**	0.34 (0.75)	5.1 x 5.1 x 5.1 (2 x 2 x 2)	1	0.25**	0.34	(0.75)	133 (8.0,

*part of science payload

**Average over descent and warmup

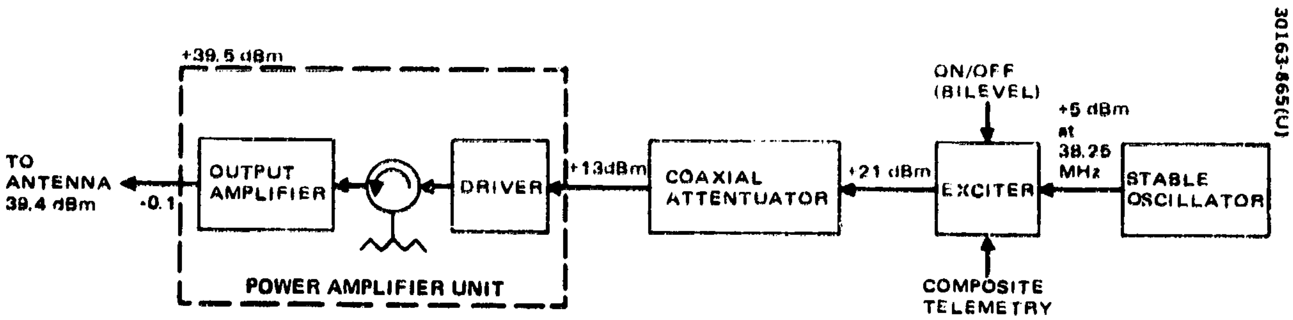


FIGURE 6-5. SMALL PROBE RF SUBSYSTEM

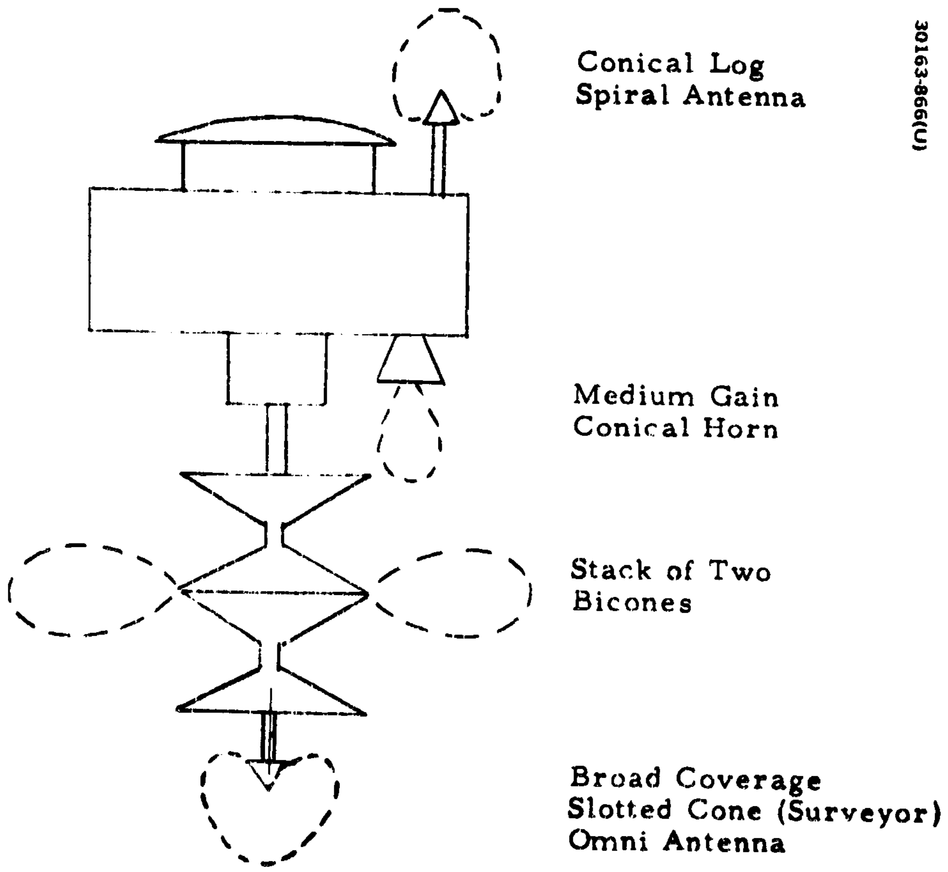


FIGURE 6-6. PROBE BUS ANTENNA SUBASSEMBLY

TABLE 6-10. ANTENNA REQUIREMENTS

Type of Coverage	Vehicle				Remarks
	Orbiter Spacecraft	Probe Bus	Large Probe	Small Probe	
Omnidirectional and spherical coverage	-6 dBi minimum over sphere	-6 dBi over sphere			Up and downlink
High gain S band Perpendicular to spin axis	23.5 dBi 11 deg beamwidth				Up and downlink
Medium gain X band Perpendicular to spin axis	17.5 dBi 20 deg beamwidth				Downlink
Medium gain Perpendicular to spin axis		18 dBi gain 20 deg beamwidth			Downlink
Low gain		6 dBi gain omnidirectional in the spin plane	0 dBi over hemisphere with maximum near 60 deg off axis	0 dBi over hemisphere with maximum near 60 deg off axis	

TABLE 6-11. PROBE BUS ANTENNA PERFORMANCE SUMMARY (ATLAS/CENTAUR CONFIGURATION)

Antenna	Pattern Shape or Type	Peak Gain, dB	Beamwidth, deg	Dimensions cm (in.)	Mass kg	Mass (lb)	Hardware Derivation
Bicone	Equatorial - plane omni	6.0	15 in. Elevation	Diameter 45.6 (18.0) High 47.0 (18.5)	3.45	(7.6)	Scaled in frequency from a classified program
Horn	Pencil beam	18.0	20	Diameter 45.6 (18.0) Long 66.0 (26.0)	0.91	(2.0)	Scaled in frequency from Intelsat IV
Conical log spiral omni-directional	Near hemi-spherical	Not less than -6 dB over 97% of sphere		Diameter 5.1 (2.0) High 9.1 (3.6)	0.18	(0.4)	Scaled in frequency from a classified program
Slotted cone (surveyor type) Omnidirectional	Near hemi-spherical	Not less than -6 dB over 97% of sphere		Diameter 12.7 (5.0) High 5.1 (2.0)	0.27	(0.6)	Surveyor program

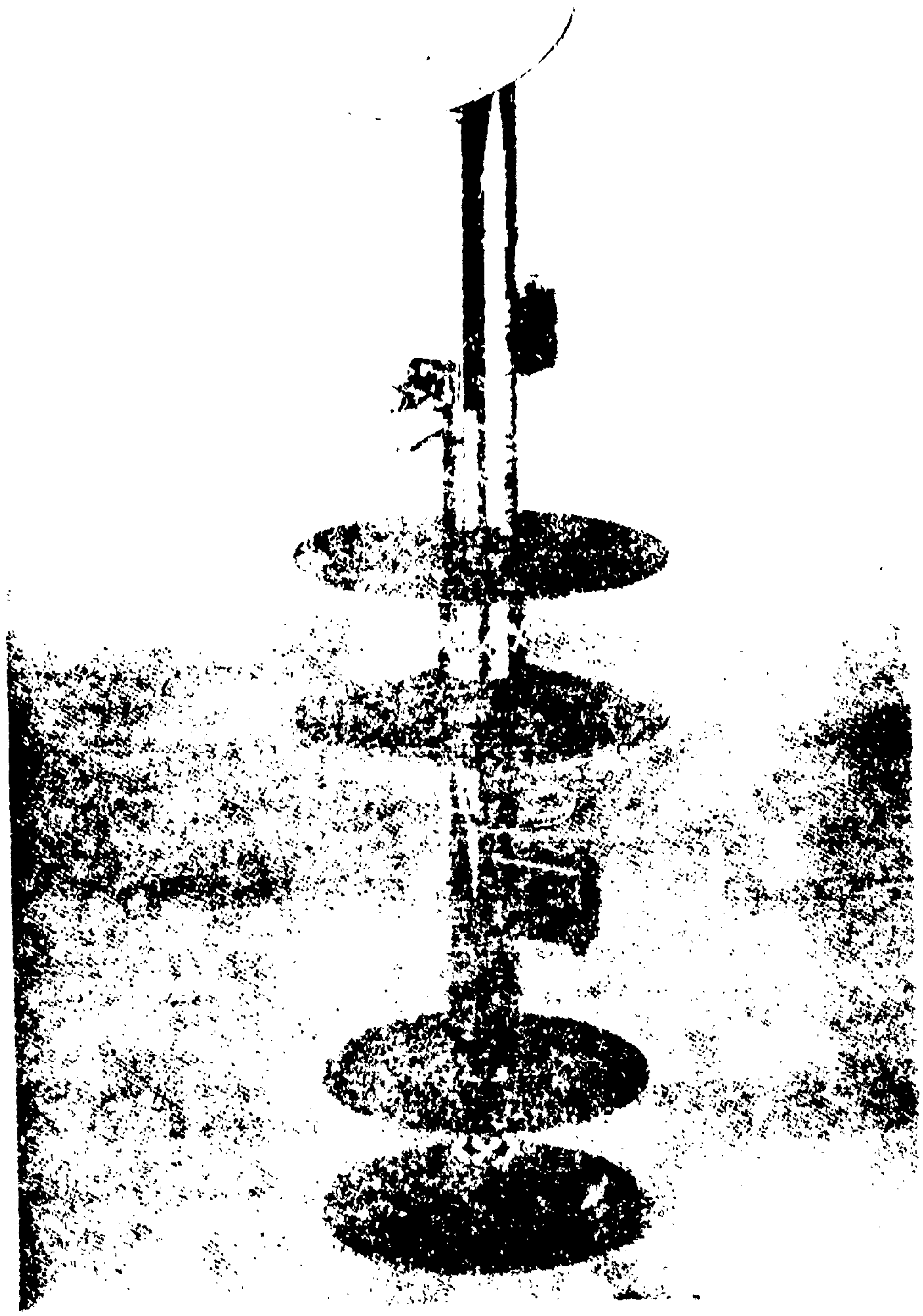
transmitters so as to provide nearly spherical coverage at all times. A bicone antenna assembly provides directional coverage in the spin plane with a gain of 6.0 dB on beam axis. The torodial pattern shape makes it unnecessary to despin the antenna. A medium gain horn radiator is used during probe bus entry when the earth line and the spacecraft spin axis are coincident. The horn radiator provides a gain of 18 dB with a 20 deg half-power beamwidth. The two omnidirectional antennas and the horn are not changed from the Thor/Delta baseline. The bicone design is revised to increase the gain by 3 dB. The characteristics of the probe bus antennas are summarized in Table 6-11.

The bicone antenna assembly is based on an existing design, shown in Figure 6-7. Two identical bicones are stacked and arrayed to achieve a peak gain of 6 dBi in the spin plane. The maximum allowable dimensions of the bicone assembly envelope based on currently available spacecraft tipoff rates and on a 4.3 cm (worst case) clearance between the antenna and the adapter during separation are given in Figure 6-8. A single bicone cannot provide the 6.0 dBi gain within the constraints of this envelope (Figure 6-9) because phase errors limit the gain of a large single bicone. Thus, two stacked bicones were selected.

Each bicone consists of a short circular waveguide feedline that ends in a coaxial to waveguide transition at one end and a cylindrical feed cavity excited in the TM_{01} mode at the other. Eight equally spaced crossed slots are machined into the outer wall of the feed cavity. The slots setup the orthogonal modes, TE_{01} and TEM in the flared radiation region. The flare angle of the bicone and the characteristics of the crossed slots are used to bring the two modal fields into time quadrature and equal amplitude to provide right-hand circular polarization.

Orbiter Antenna Assembly

The antenna assembly on the orbiter spacecraft, Figure 6-10, includes the high gain parabolic reflector, the X band horn for the science experiment, and two wide angle coverage, low gain antennas. The latter two are identical in design to those used on the probe bus and are unchanged from the Thor/Delta baseline. The high gain antenna is mechanically despun so that the main beam is pointed toward earth. The design of the high gain antenna also is not changed from the Thor/Delta design. The X band medium gain antenna also is not changed from the Thor/Delta design. The X band medium gain antenna has been added to accommodate the occultation experiment. It is a conical horn designed to operate at a frequency of 8.415 GHz. The nominal gain and 3 dB beamwidth are 17.5 dB and 20 deg, respectively. The X-band antenna assembly consists of the conical horn aperture, polarizer and waveguide transformer. All components are based on the designs used in the manufacture of the global coverage conical horns for the Intelsat IV program. Those horns were operated in the frequency bands of 4 and 6 GHz. The horn aperture dimension of 12.7 cm is governed by the gain and beamwidth requirements. The overall length of 21.6 cm is controlled by the length of the horn itself, the polarizer and the waveguide transformer. The polarizer is a simplified version of the Intelsat IV design, because of the reduced bandwidth requirement of the X-band polarizer.



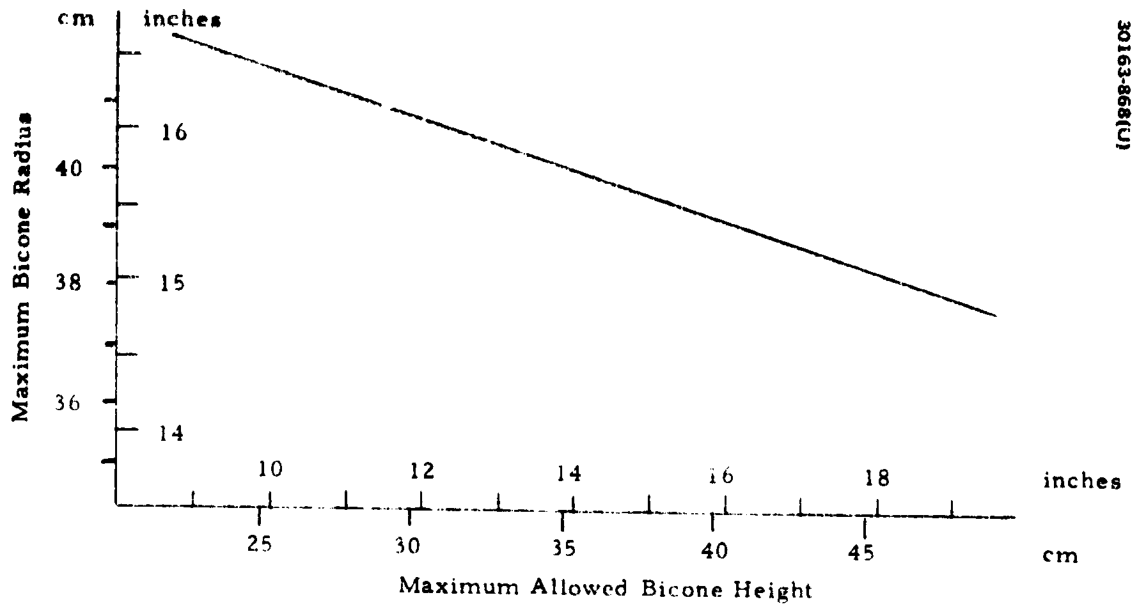


FIGURE 6-8. MAXIMUM BICONE DIMENSIONS TO AVOID SHROUD DURING SEPARATION

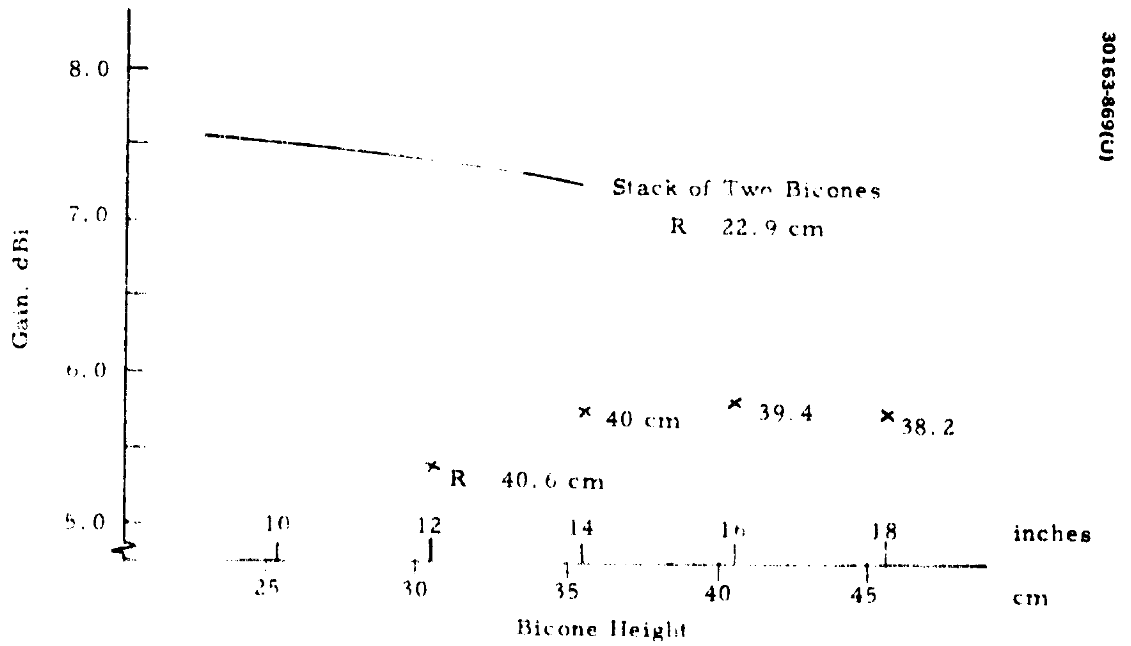


FIGURE 6-9. COMPARISON OF GAIN OF SINGLE BICONE AND STACK OF TWO BICONES

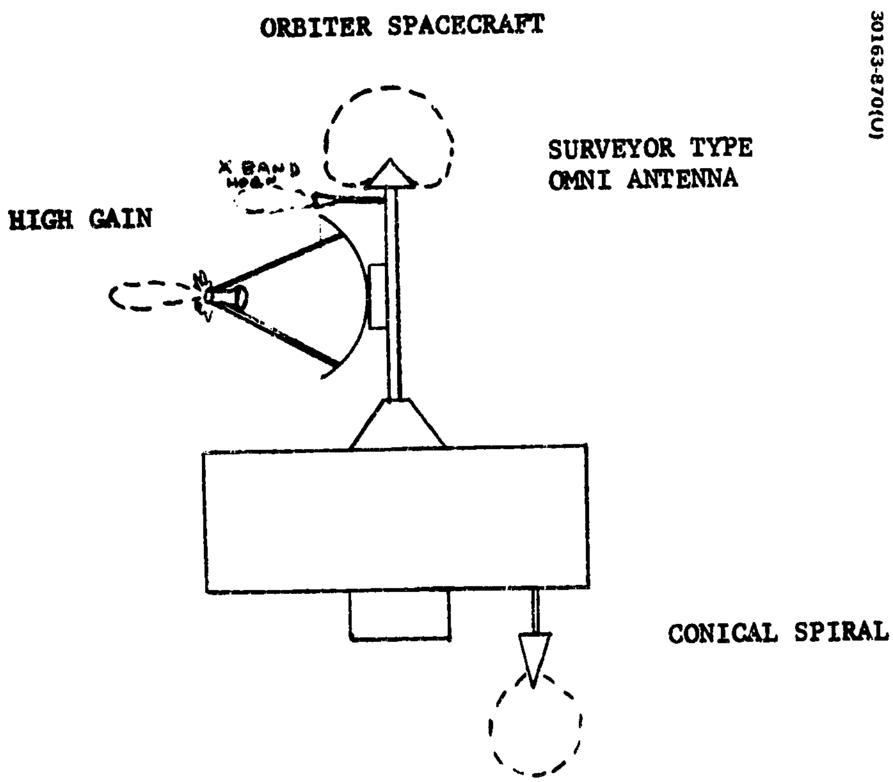


FIGURE 6-10. ORBITER SPACECRAFT ANTENNA SUBASSEMBLIES

Overall characteristics of the orbiter antennas are summarized in Table 6-12.

Probe Antennas

The antennas on the large and small probes are required to provide hemispherical coverage with a gain of 0 dBi in the horizontal probe plane and peak gain at 60 to 65 deg off axis. Several candidate antennas that have been considered for the Atlas/Centaur baseline are tabulated in Table 6-13.

A candidate is the slotted cone radiator which would be identical to the omnidirectional antenna used on the orbiter spacecraft of the probe bus. However, its gain is several dB below isotropic at 90 deg off axis. Otherwise it would be well suited for the application, since it is lightweight and small. The conical log spiral can provide coverage in the horizon plane similar to the curved turnstile radiator. However, it has to extend higher above the probe shell. Also, it is heavier by a factor of two. It is not considered the prime candidate. Even though it is the same type of antenna as used in the omnidirectional antenna assembly on the orbiter spacecraft and the probe bus, the antenna for the probe would have to be designed using different parameters such as a different spiral rate.

The selected baseline for both probes is the curved turnstile which is shown in Figure 6-11. It is similar to the slotted cone radiator in that both use a cross dipole. The design is that of a crossed dipole radiator. By proper phasing and downward bending of the orthogonal dipole arms, the normal dipole pattern can be perturbed sufficiently to provide nominally 0 dBi at 90 deg off axis and maximum gain at angles of 60 to 65 deg off axis. The circularly polarized radiation can be achieved by feeding the two crossed dipoles in equal amplitude and 90 deg out of phase by using a quadrature hybrid. Or the hybrid can be omitted and the circular polarization achieved by having the two dipoles unequal length but keeping the length-versus-diameter ratios of the two dipole arms equal. The quadrature hybrid feed is preferred, because several design iterations would be expected with the unequal length dipoles to achieve the desired result. A loss of 0.1 to 0.2 dB is expected due to the quadrature hybrid.

TABLE 6-12. ORBITER ANTENNA PERFORMANCE SUMMARY (ATLAS/CENTAUR CONFIGURATION)

Antenna	Pattern Shape or Type	Peak Gain, dB	Beamwidth, deg	Dimensions, cm (in.)	Mass		Hardware Derivation
					kg	(lb)	
High gain parabolic reflector	Pencil beam	23.6	10.3	Diameter 89.0 (35.0) Depth 49.2 (19.4)	1.41	(3.1)	Scaled in frequency and size from Intelsat IV
Conical log spiral omni-directional	Near hemi-spherical	Not less than -6 dB over 97 % of sphere		Diameter 5.1 (2.0) Height 9.1 (3.6)	0.18	(0.4)	Scaled in frequency from a classified program
Slotted cone (surveyor type) omnidirectional	Near hemi-spherical	Not less than -6 dB over 97% of sphere		Diameter 12.7 (5.0) 5.1 (2.0)	0.27	(0.6)	Surveyor program
Medium gain X band horn	Pencil beam	17.5	20.0	Diameter 12.7 (5.0) Length 21.6 (8.5)	0.23	(0.5)	Scaled in frequency from Intelsat IV

TABLE 6-13. CANDIDATE PROBE ANTENNAS

Antenna	Minimum Gain Over Hemisphere, dBi	Approximate Dimensions of Envelope, cm (in.)
Slotted cone radiator	-4.0 ± 1.0	Height 5.1 (2.0) Diameter 12.7 (5.0)
Curved turnstile	0.0 ± 0.5	Height 5.1 (2.0) Diameter 12.7 (5.0)
Conical log spiral	0.0 ± 0.5	Height 11.5 (4.5) Diameter 11.5 (4.5)

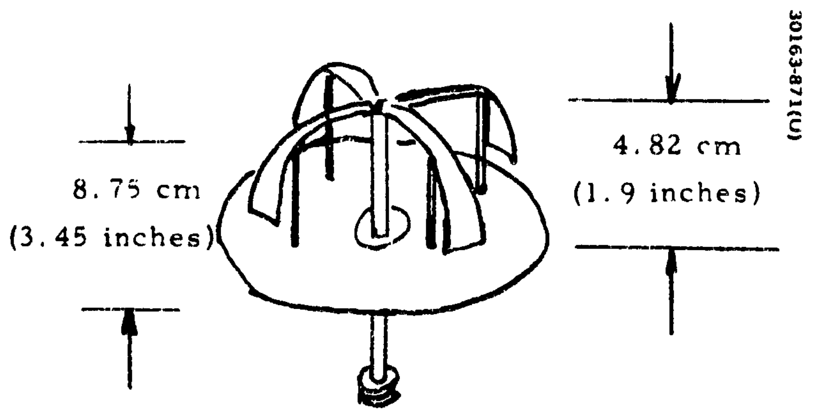


FIGURE 6-11. CURVED TURNSTILE ANTENNA MODEL