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### 30/20 GHZ DEMONSTRATION SYSTEM SSUS-D/BSE

FINAL REPORT, JULY 1981 CONTRACT NO. NAS-3-22500, NASA LEWIS RESEARCH CENTER REPORT NO. CR-165454



space division

GENERAL 🍪 ELECTRIC





## 30/20 GHZ DEMONSTRATION SYSTEM SSUS-D/BSE

FINAL REPORT, JULY 1981
CONTRACT NO. NAS-3-22500, NASA LEWIS RESEARCH CENTER
REPORT NO. CR-165454

This contract was performed by the Space Systems Division of the General Electric Company, in Valley Forge, Pennsylvania. The Earth Station and Master Control Center work was performed by the Digital Communications Company, Germantown, Md, under subcontract to General Electric.



#### **CONTENTS**



#### INTRODUCTION

COMMUNICATION AND TT&C SYSTEMS

ANTENNA DESIGN CONSIDERATIONS

SPACECRAFT CONFIGURATION AND SPACECRAFT BUS COMPONENTS

EARTH STATIONS AND MASTER CONTROL CENTER

MISSION OPERATIONS SYSTEM

DEMONSTRATION SYSTEM PLAN





INTRODUCTION



#### REQUIREMENTS



#### **GENERAL**

4-YEAR SATELLITE LIFE

(SSUS/A OR SSUS/D)

PAYLOAD < 400 LB

CPS & TRUNKING NOT SIMULTANEOUS (ALSO OPTION 2)

SS-TDMA REROUTING FOR BBP FAILURE

IMPATT AND TWT'S (40 WATTS @ 40%)

MCC, SCC IN CLEVELAND (CPS, TRUNKING & T&C) - CPS OR TRUNK OPERATION
3M (DOWNLINK) ANTENNA, 51 dBi @ 3º OFFSET (FIXED BEAM), SAME UP/DOWN HPB

**CLOSED LOOP SYSTEM TIMING** 

#### CPS

2 ADJACENT SECTOR SCANS (2 X 10% CONUS COVERAGE) +3 SPOTS

INDEPENDENT UP/DOWN SCANNING

FREQUENCY REUSE VIA XPOL

TDMA FORMAT, BBP (MODEMS, CODECS, STORAGE, SWITCHING, REFORMATTING), SCALEABLE TO 480 MBPS

ADAPTIVE FEC 15/6 dB

UPLINK 4X 30 MBPS (27.5 MBPS) OR 1 X 120 MBPS

**DOWNLINK 240 MBPS** 

RESERVATION SCHEME

OPTION 1 (2 X 30 MBPS INPUT, 120 MBPS OUTPUT)

**OPTION 2 (FDMA WITH POWER DIVERSITY)** 

#### TRUNK

4 FIXED BEAMS (PLUS 2 ALTERNATIVES)

SS-TDMA @ 256 MBPS; IF SWITCHING - SCALEABLE TO 20 X 20
ANTENNA DIVERSITY, 18/8 dB, 10<sup>-6</sup>/10<sup>-4</sup> BER (AT MODEM) FOR RAIN ZONES FDE

**PREASSIGNED** 

#### DEMONSTRATION SYSTEM ELEMENTS

The satellite system described herein consists of the four elements depicted on the opposite page, e.g., the Satellite, Launch Vehicle, Mission Operation System and the Ground Network.

The satellite element includes the software to test the satellite, integrate it with the AKM and launch vehicle at ETR, and includes that software portion that adapts the launch and on-orbit software to the particular satellite design, e.g., sensor geometrics, thruster calibrations, command and telemetry formats and functions, etc.

The Launch Vehicle element includes the normal interface engineering between the STS, SSUS-D and satellite as well as integration and safety considerations.

The MOS element includes launch and on-orbit activities, including facilities, equipment, personnel, software, computing and communications costs. Four years of O&M are assumed.

The Ground network consists of an antenna diversity type trunking earth station, a TDMA CPS type earth station, an optional FDMA CPS type earth station and a master control center for the purpose of coordinating the communications network activities (it is assumed that additional trunking and CPS earth stations will be available).



## DEMONSTRATION SYSTEM ELEMENTS



#### SATELLITE

- PAYLOAD
- BUS
- AGE
- SOFTWARE
- LAUNCH SUPPORT

#### LAUNCH VEHICLE

- SSUS-D/AKM
- **ADAPTOR**
- INTEGRATION/SAFETY & INTERFACE ENGINEERING

#### MOS

- STDN (S-BAND), GSFC, LeRC
- TAC
- SATELLITE CONTROL CENTER (SCC)
  - HARDWARE
  - SOFTWARE (SATELLITE CONTROL)
  - CONSULTATIONS
- LAUNCH TEAM
- CONTRACTOR INPUTS

### GROUND NETWORK

- CPS EARTH STATIONS, (TDMA + OPTION 2)
- TRUNK EARTH STATIONS
- MASTER CONTROL CENTER (MCC)
  - HARDWARE
  - SOFTWARE (EXPERIMENTS CONTROL)
  - PROCEDURES (EXPERIMENTS OPERATIONS)
  - **M&O**
  - COMMUNICATIONS

## TRADEOFF SUMMARIES FOR DESIGN OPTIMIZATION (COMMUNICATIONS)

The satellite concept features a large (10') deployable antenna, with two scanning beams, four fixed beams plus monopulse sensing for roll, pitch and yaw, a processor for antenna control, bit regeneration, adaptive FEC, switching and reformatting and high power (40 watt) TWT and IMPATT amplifiers. This challenging technology requires a thoughtful analysis of tradeoffs, options, and risks to achieve a design optimized for the NASA experimental mission. The next three charts highlight some of the considerations leading to the proposed design.

In the communications area, summarized at the right, the antenna system offers substantial optimization challenges with regard to performance, weight and physical arrangement both during launch and on-orbit and also have risk implications with regard to beam pointing during the mission as well as successful deployment. The processor, patterned after the Motorola design provides the functions described above but also can, with ground command assistance, change the beam scanning sequence, reallocate TDMA burst times, reallocate routes and control the adaptive FEC feature. The GE design incorporates these features and functions with a minimum of on-board automony; however, many aspects of the system architecture and requirements need further clarification and optimization.

Finally, the optimized design includes the items to be built and/or specified by GE including TWT and IMPATT amplifiers.



## TRADEOFF SUMMARIES FOR DESIGN OPTIMIZATION (COMMUNICATIONS)



#### COMMUNICATIONS

**1 VS 2 ANTENNAS** 

PFF VS CASSEGRAIN

**VPD VS SWITCH** 

**OPTIMIZED MONOPULSE** 

**CELL SIZE** 

**UPLINK/DOWNLINK OPTIMIZATION** 

SINGLETS VS TRIPLETS

**MOTOROLA PROCESSOR** 

GE SS-TDMA SWITCH, LNR'S, VPD'S, HORNS, EPC

**OPTIONS IMPACT** 

HAC-CDD TWT AND IMPATT AMPLIFIER

# TRADEOFF SUMMARY FOR DESIGN OPTIMIZATION (SPACECRAFT BUS)

Spacecraft bus tradeoffs included consideration of monopulse sensor location and type to achieve the best antenna pointing at minimum complexity. A consideration also was given to appendages requiring possible deployment such as solar arrays, large reflectors and antenna feeds. Minimum complexity and risk is achieved by fixing the complex antenna feed systems to the spacecraft body and deploying both the high power solar arrays and the 10-foot antenna aperture by space proven mechanisms.

Thermal distortion effects were examined for effects on antenna gain and beam pointing. Materials, fabrication methods, pointing and sensor techniques and one versus two antenna configurations were examined to achieve the final optimal recommended design.

All of these tradeoffs were considered with the view of using the conventional (to be) well proven vertical launch SSUS-D arrangement with adequate weight and power margins and high confidence deployment.

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# TRADEOFF SUMMARY FOR DESIGN OPTIMIZATION (SPACECRAFT BUS)



- DUAL LIGHTWEIGHT MONOPULSE, ANTENNA EMBEDDED, PLUS GE 3-AXIS FOR ROLL, PITCH, YAW CONTROL
- MINIMUM COMPLEXITY FOR DEPLOYMENT MECHANISMS
  - ARRAY
  - SINGLE (LANDSAT D) POWER HINGE FOR ANTENNA
  - NO FEED DEPLOYMENT
- MINIMIZE POTENTIAL FOR THERMAL DISTORTION, MISALIGNMENTS 1 ANTENNA
- VERTICAL SSUS-D LAUNCH

## TRADEOFF SUMMARY FOR DESIGN OPTIMIZATION (MOS)

MCS tradeoffs considered various launch and on-orbit options ranging from leasing complete facilities and services from commercial entities such as a U.S. carrier or Intelsat to facilities making maximum use of available NASA facilities, equipment and services considering also the impact to satellite design and program costs. These tradeoffs considered available facilities such as tracking antennas, satellite control centers, large computers for orbit and attitude computations, T&C equipment, software programs, availability of experienced personnel; for the three functional activities:

- launch planning and contingency planning
- launch
- on-orbit O&M

Costs were a principle determinant in these considerations.



## TRADEOFF SUMMARY FOR DESIGN OPTIMIZATION (MOS)



- S-BAND TT&C AND RANGING (BSE/BS-II)
- MSOCC (GSFC) LAUNCH WITH NASCOM/STDN
- NASA LAUNCH HARDWARE, SOFTWARE
- FIXED S-BAND TAC AT CLEVELAND (LA)
- SCC/MCC CO-LOCATED IN CLEVELAND, STDN BACKUP; OR SEPARATE SCC-MCC LOCATIONS
- SCC/MCC SHARE USE OF MINI COMPUTER
- Lerc (or GSFC or Contractor) operates SCC/MCC

#### FEATURES OF GE APPROACH

The features of the GE design are summarized at the right. Considering the impact of a large Ka-band antenna on satellite design and the established DOMSAT carrier trend for the SSUS-D spacecraft the single reflector approach will be favored for operational use. This not only minimizes antenna weight and simplifies deployment but importingly, also minimizes thermal distortions and other mechanical misalignments. In the GE design, the monopulse feeds for Cheveland and LA (roll, pitch and yaw sensors) are embedded into the single antenna system such that the spacecraft 3-axis steering points the spacecraft so as to minimize antenna beam pointing errors (spacecraft is not aligned with the local vertical as is normally done). Consequently, pointing errors are only the result of relative distortions in the BFN and reflector assembly that cause one beam to move relative to others. Based on extensive GE thermal analyses these errors are well within acceptable ranges.

The penalty for a single reflector but with separate independent beam forming networks is a loss in performance, either uplink or downlink gain, or both, of the order of 1 dB. In a larger sense this loss in antenna performance may be more than compensated by the approximate weight savings of 50 pounds which could be used to generate more prime power, add transponders, etc.

Use of SSUS-D, which is expected to be the "work horse" of STS synchronous launches, is the lowest cost launch arrangement and the small SSUS-D class satellite, being a minimum weight also will be lowest in cost, with more than ample weight margins. This is believed to be the minimum cost approach since it avoids the larger SSUS-A and STS (proportional) cost, and the cost of duplicating larger satellites even if the SSUS-D approach involves spacecraft bus design costs.

The BSE-BS II 3-axis spacecraft bus makes available standard GE 3-axis components requiring a minimum of modification, such as attitude control, secondary propulsion, thermal, TT&C, power system including regulation and housekeeping batteries, and monopulse attitude sensing. The array power needs to be increased from 900 watts to 1100 watts; however, the battery system, attitude control and other subsystems are adequate for the NASA mission. Increase in the size and strength of the structure is needed; however, the same basic structural elements (ribs, cones, cylinders, etc), materials, fastenings and procedures will be used. The BSE/BS II bus uses heat pipes to conduct heat away from the TWT bodies and to distribute this heat over the radiator for space radiation. The same design will be used for the SSUS-D satellite.

The BSE/BS II bus uses S-band T&C and an S-band turnaround transponder for ranging. Consequently, the satellite is compatible with launch by NASA STDN/NASCOM facilities under GSFC Code 500. Experienced NASA personnel and NASA software, facilities and computers are also available so that a minimum out-of-pocket launch cost can be accomplished. The contractor must provide support to ETR and GSFC activities, update software to make it satellite compatible, provide T&C software and an on-orbit satellite control team. An S-band T&C tracking antenna is available at GSFC (which may have to be time shared). While TDRS plans call for some reduction in STDN it is expected that an ample, residual STDN facility will be available to support NASA geosynchronous missions including the Wideband Demonstration.

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POC technology used in the GE concept are Processor, SS-TDMA switch, TWT, IMPATT, FDMA; antenna technology is similar to that of the POC programs but will be a GE design.

Finally, DCC has proposed a CPS aggregate rate MODEM that permits demodulation and detection at the throughput rate of the earth station instead of at the burst rate. This technology can have a significant effect on CPS earth station cost.



#### FEATURES OF GE APPROACH



#### SINGLE 10' ANTENNA

- MINIMIZE WEIGHT
- SIMPLIFY DEPLOYMENT
- MINIMIZE EFFECTS OF THERMAL DISTORTION AND MISALIGNMENT

#### SSUS-D (VERTICAL) LAUNCH

- MINIMUM COST
- STANDARD HARDWARE AND PROCEDURES

#### **BSE/BS II BUS**

- 3-AXIS, MONOPULSE STEERED
- LIGHTWEIGHT, SUN TRACKING SOLAR ARRAY
- PROVEN THERMAL DESIGN TECHNIQUES

#### **NASA LAUNCH (S-BAND)**

- MSOCC
- STDN/NASCOM
- MAXIMUM USE OF NASA HARDWARE AND SOFTWARE

**MAXIMUM POC TECHNOLOGY** 

**AGGREGATE RATE MODEM** 

#### DEMONSTRATION SYSTEM CONCEPT

The Demonstration System Concept consists of a CPS TDMA system based on the use of on-board processing with two scanning beams, and an IF type trunking SS-TDMA system with four fixed beams. An option for FDMA using fixed beams is included. The two scanning beams are connected to the processor via the redundant ring switched receivers. The uplink signals are then demultiplexed into four 27.5 msps and one 110 msps carriers for each beam. Processor outputs consist of two 110 msps carriers, one for each downlink scanning beam. Each CPS TDMA carrier is amplified by one of the amplifier chains to the 40 watt level. Amplifier redundancy is provided by a reserve IMPATT.

In the trunk mode, fixed beam SS-TDMA carriers are received on the LA, Cleveland, Houston or NY and DC or Tampa beams, (4 total), pass through four receivers to the input of the SS-TDMA switch network. The DC-Tampa beam has a programmable LO to account for the frequency offset of the DC carrier. After conventional SS-TDMA switching, the four TDMA carriers are each amplified by the TWT amplifiers backed up by IMPATT amplifiers. Microwave switching at the output of the power amplifiers routes the signals to the proper antenna port.

Either CPS operation or trunk operation is provided for.

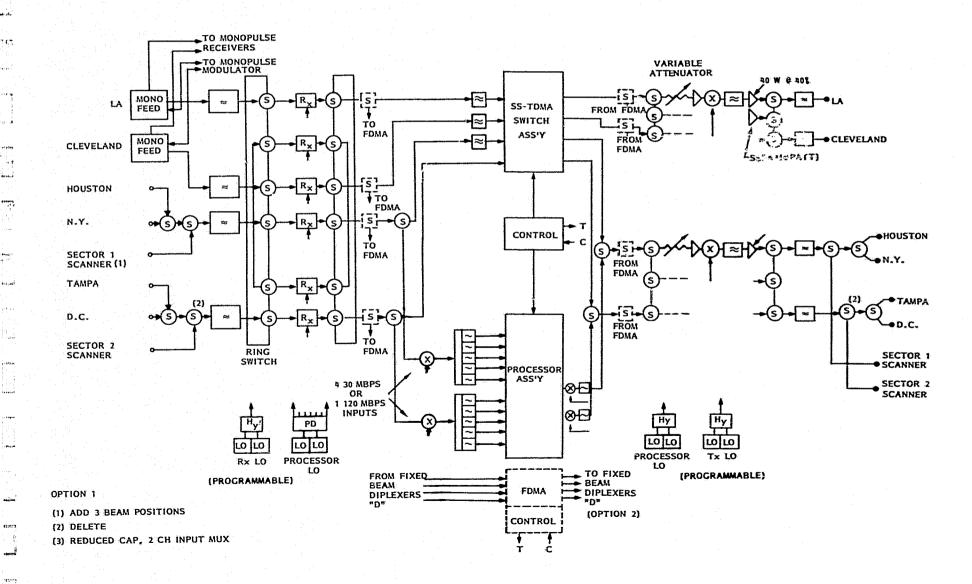
For the optional FDMA operation the FDMA routing assembly is switched to the four fixed beams, but at IF via the FDMA IF switches. The FDMA assembly provides for four 10 MHz paths from any one beam to the other four. Consequently, each TWT will be linearized by backoff in order to control intermodulation power.

Note that an option also exists for reduced CPS operation by eliminating one scanning beam, augmenting the remaining beam by the three isolated spots and by reducing the processor capability to two 27.5 msps inputs and one 110 msps output signals.



### **DEMONSTRATION SYSTEM CONCEPT**

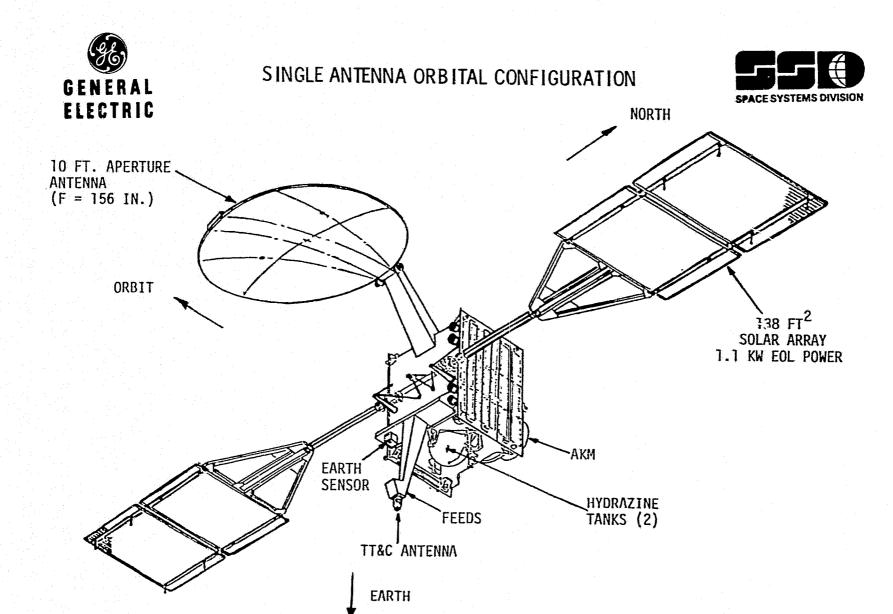




## SINGLE ANTENNA ORBITAL CONFIGURATION

The GE preferred approach consists of a 3-axis stabilized spacecraft with sun tracking solar arrays and a single 30/20 GHz 10' reflector deployed on the east spacecraft side. The feeds, including the imbedded monopulse elements, are fixed to the spacecraft body in an offset fed prime-focus-fed arrangement. An S-band T&C antenna also is mounted on the feed. Another S-band T&C, used only during the ascent spinning mode is located on the backside of the 10' reflector.

The spacecraft is balanced around the apogee motor axis during ascent. After antenna deployment, despite shifts in CG caused by antenna deployment, the spacecraft also is balanced such that the thrusters line of thrust passes through the new CG.



- 4 YEAR SATELLITE LIFE
- SSUS-D/STS
- PAYLOAD < 400 LB</li>
- SINGLE HINGED ANTENNA DEPLOYMENT
- 10' OFFSET FED, RIGID FEED STRUCTURE
- 3 AXIS, (SPINNING ASCENT)
- SUN TRACKING SOLAR ARRAY
- STAR 30B AKM (1473 LB BOL)
- TWO TT&C ANTENNAS
- TWO CONFIGURATION BALANCE

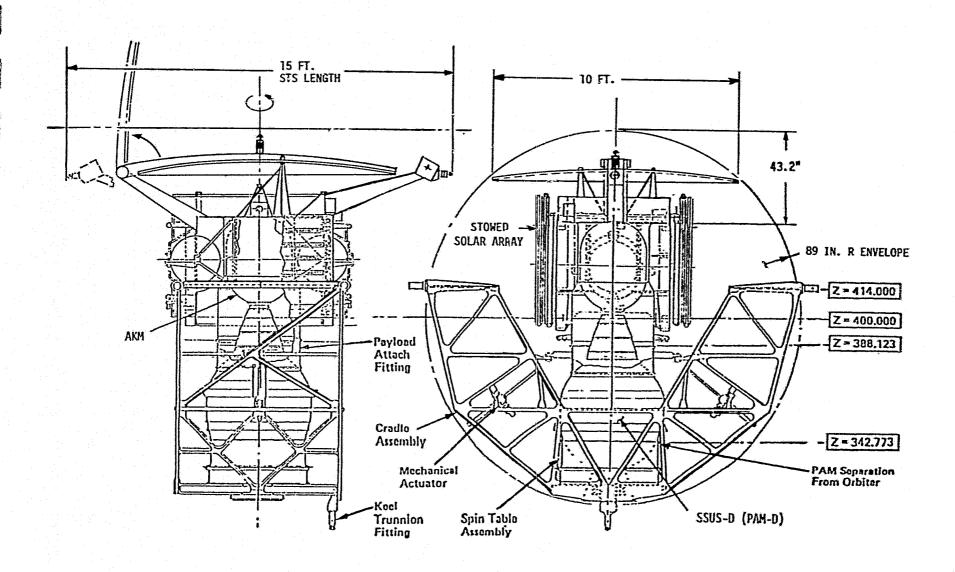
#### SINGLE ANTENNA LAUNCH CONFIGURATION

During launch the satellite is attached to the vertically oriented perigee motor of the SSUS-D, supported by the SSUS-D cradle. A spin table imparts spin momentum just prior to STS separation. The solar arrays are folded along side the spacecraft body (two panels each) and the rigid 30/20 GHz reflector, located over the top of the spacecraft, is deployed by a powered, single-axis hinge. The drawing at the right is a side view showing the projection of the fixed feed system with the T&C omni-antenna attached. Another T&C omni-antenna is located on the reflector back side. The power hinge arm assures the correct F/D ratio after deployment. Since the satellite assembly spins inside the STS, the required STS bay length of 15 feet, is determined by the feed projections.



## SINGLE ANTENNA LAUNCH CONFIGURATION





### STS/SSUS-D SPACECRAFT WEIGHT SUMMARY

SSUS-D and Star 30 apogee motor, based on four years of north-south stationkeeping, result in a satellite payload and margin of 537.3 pounds. Payload and margin include transponders, antenna reflector, BFN's and antenna system supports and deployment mechanisms. This is considerably in excess of the 400 pounds specified by the SOW. The spacecraft subsystem allocations are based on subsystems which are similar if not identical to those on BSE/BS II. Power system is sized for 1100 watts end-of-life with housekeeping battery subsystem for 150 watts during eclipse. The fuel includes an allowance for 3 sigma launch errors and miscellaneous fuel consumed during ascent.



## STS/SSUS-D SPACECRAFT -WEIGHT SUMMARY - 4 YEAR MISSION 1100 WATTS EOL POWER



SUBSYSTEM	WEIGHT (POUNDS)	
ATTITUDE CONTROL	73.3	
THERMAL CONTROL	55.0	
POWER	284.0	
SPS (DRY)	55.4	
AKM (DRY)	68.8	
TT&C	24.0	
STRUCTURE	170.0	
BALLAST & ESD	<u>15.0</u>	
TOTAL HOUSEKEEPING	745.5	
SPS FUEL (4 YEARS)	190.0	
AKM PROPELLANT	1277. 2	
PAYLOAD* & MARGIN	<u>537.3</u>	
TOTAL LAUNCH WEIGHT	2750.0	

#### \* PAYLOAD INCLUDES:

- TRANSPONDERS
- ANTENNA
- ANTENNA AND FEED SUPPORTS
- ANTENNA DEPLOYMENT MECHANISMS

### PAYLOAD WEIGHT AND POWER SUMMARY

Payload weight and power for antenna, receiver and transmitter assemblies is summarized at the right. Total weight of 346.5 pounds leaves 190.8 pounds for margin, more than ample even for an experimental mission. Implementation of Option 1 (reduction of scanning capacity to one beam, with reduced processor throughput) increases this margin to 220.4 pounds. Implementation of Option 2 (FDMA) reduces margin to 178.4 pounds. Note that a separate 30 GHz aperture adds 49.9 pounds to the payload or 396.4 pounds total (NASA 400 pound spec is not exceeded). The elimination of the 30 GHz antenna was not done primarily from a consideration of weight.

Daytime power is summed for the two operating modes, trunking or CPS assuming that IMPATT amplifiers are in operation respectively. This power added to that for housekeeping establishes the 1100 watt end-of-life requirement. Elimination of the backup IMPATT mode reduces power considerably since the IMPATT efficiency is less than 15% overall. In addition, the IMPATT amplifiers will be inefficient in the backed off mode for FDMA. GE believes a better application for IMPATTS would be a 30 GHz or 20 GHz beacon for propagation experiments.



## PAYLOAD WEIGHT AND POWER SUMMARY



BASELINE ANTENNA ASS'Y	WT LB 169. 6	DAYTIME PWR WATTS 24	NIGHTTIME PWR WATTS 0
TRANSMITTER ASS'Y	95.5	818 - 416. 9	27
TOTAL	346.5 LB **	879 - 640. 9 W *	27 W
OPTION 1	316. 9 LB	820 - 581 <b>.</b> 9 *	27 W
OPTION 2	358. 9 LB	800	27 W

NOTE: TRUNK, CPS, FDMA NOT SIMULTANEOUS

<sup>\*</sup> TRUNK - CPS MODE

<sup>\*\*</sup> ADD 49. 9 LB FOR SEPARATE RECEIVE ANTENNA ASSEMBLY

## TWO ANTENNA ORBITAL CONFIGURATION

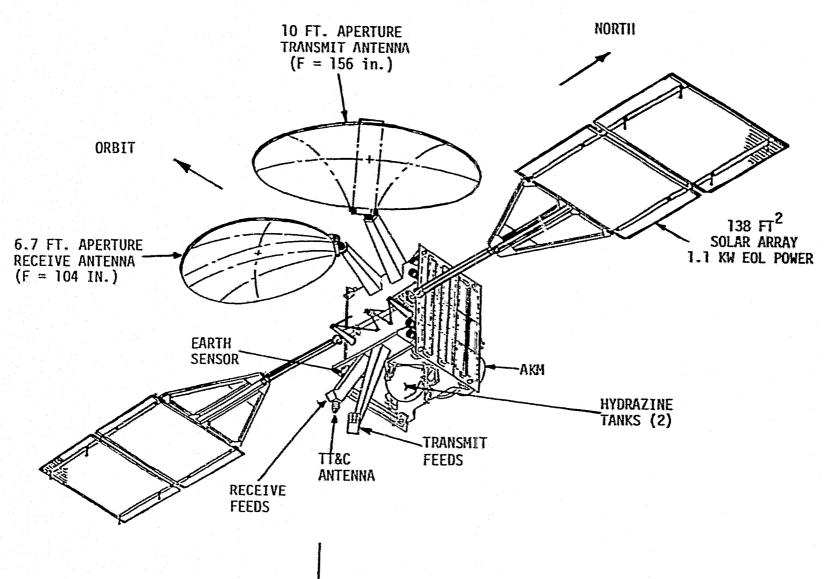
While not recommended, a two reflector (30 GHz and 20 GHz) system also was examined. Both antennas are deployed on the east side of the spacecraft with the feeds rigidly attached to the spacecraft body. The spacecraft is the same as that described previously.

A Total Horax



## TWO ANTENNA ORBITAL CONFIGURATION





EARTH

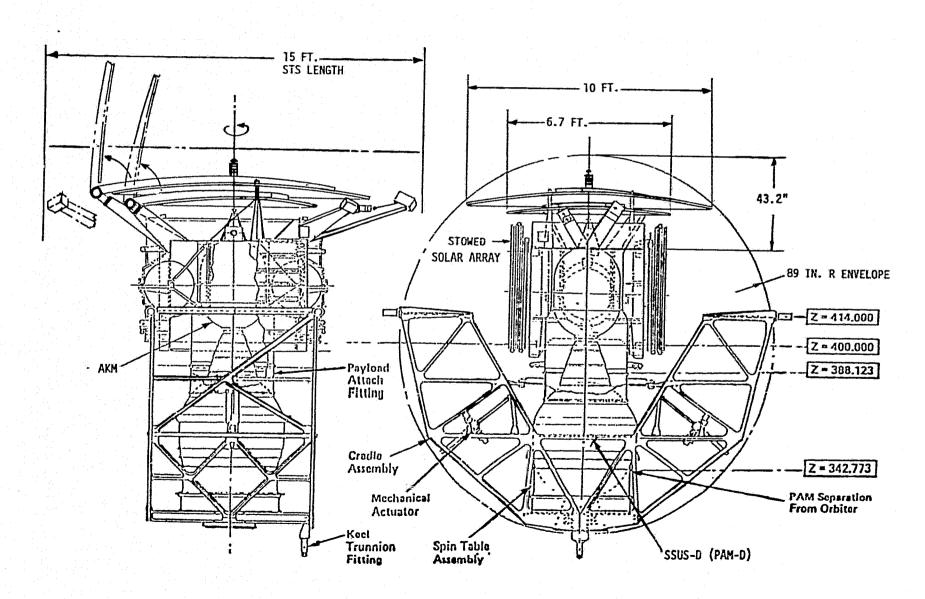
### TWO ANTENNA LAUNCH CONFIGURATION

The launch arrangement is similar to that for one antenna except now both antennas are retained on top of the spacecraft during ascent. Each is deployed by means of a power hinge; however, the reflectors must also be translated away from each other. This requires each hinge to be doubly articulated. While such hinges are feasible their added complexity and risk are acceptable only if no alternatives exist. Actually, it has been shown that weight, pointing and thermal considerations favor the single reflector approach and this is the approach proposed by GE.



## TWO ANTENNA LAUNCH CONFIGURATION





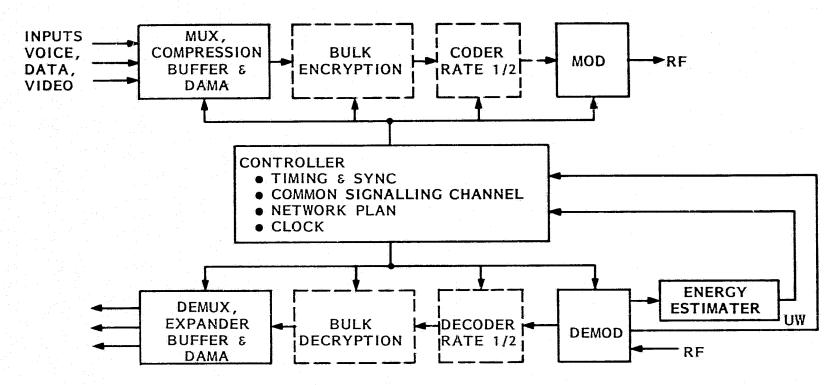
#### CPS EARTH STATION CONFIGURATION

The CPS earth station having the RF parameters listed works in conjunction with the satellite scanning beam and base-band processor. The uplink burst operates at either 27.5 or 110 msps depending on throughput requirements and receives a downlink burst at 220 msps. Adaptive FEC and rate diversity are used to combat rain fading to overcome typically 15 dB uplink fades and 6 dB downlink fades. Rain fade is measured by estimating the energy received by the demodulator and relaying this information to a central Master Control Center for action. The Master Control Center also provides network signalling and switching and control experiments procedures. Earth station timing is derived from a unique word generated by the satellite baseband processor, plus additional network information or network plan programmed into the software. Updates are provided via a common signalling channel or order wire to correct for satellite drift. It is desirable to maintain frequency lock by transmitting a reference carrier from the satellite; this carrier also can be modulated by a submultiple of the burst rate to lock the CODEC. A unique feature of this arrangement, proposed as a cost reduction item is an "aggregate" rate MODEM which performs demodulation and detection at the station throughput rate rather than at the burst rate. Interface is at 64 kbps for PCM voice and data.



#### CPS EARTH STATION CONFIGURATION





- COMPATIBLE WITH SCANNER ANTENNA
- 27.5/110 MBPS UPLINK BURST
- 220 MBPS DOWNLINK BURST
- ADAPTIVE FEC (15/6 dB FADE)
- CONVENTIONAL MODEM OR "AGGREGATE RATE DEMOD"
- COHERENT DOWNLINK, PILOT OPTION
- CENTRAL CONTROL (MASTER CONTROL CENTER)
- 64 KBPS
- OPEN LOOP SATELLITE DRIFT CORRECTION

#### RF PARAMETERS

- 20/30 WATTS HPA
- 600°K NOISE TEMP.
- 1 GHz IF, DUAL CONVERSION
- SINGLE THREAD OPTION
- 3/5 M ANTENNA

#### TRUNKING EARTH STATION

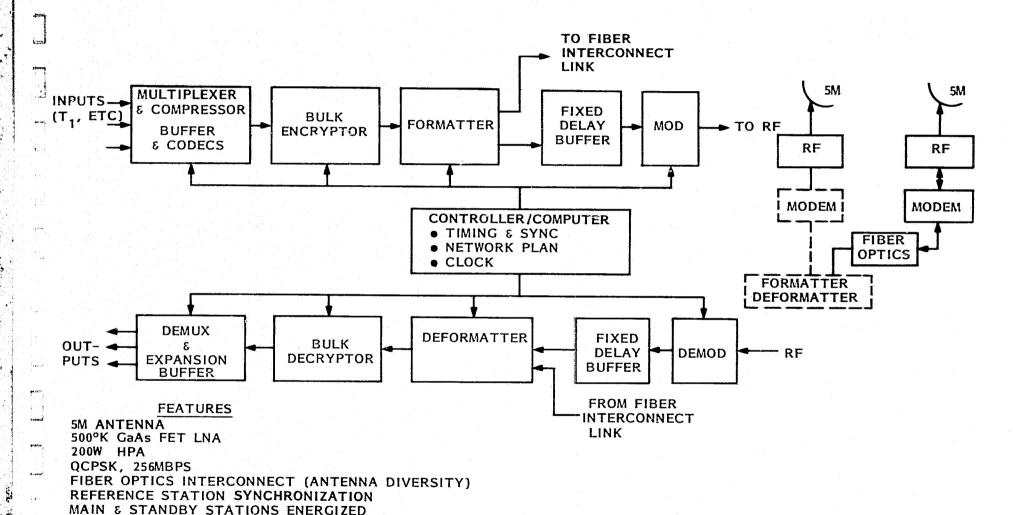
This station operates in the SS-TDMA MODE in conjunction with satellite IF switching. Inputs are at Ti levels or higher and bulk encryption and decryption is used to maintain privacy. The unique feature of this station is its use of antenna diversity via a fiber optics interconnect link. Both stations have the same RF equipment complement and are energized. In normal operation they transmit and receive on alternate frames thereby assuring full system synchronization at all times. During periods of rain fades (or equipment failures) the station having the best signal to noise ratio is selected for operation. A fixed delay is used to compensate for the different satellite range of the two antennas.



4x4 SS-TDMA IF SWITCH

### TRUNKING EARTH STATION CONFIGURATION





## ITEMS FOR CONCERN

Comparing the current and projected end-of-program status of the POC with the desirable program status at the beginning of Phase III, e.g., the start of the satellite development program, has identified two areas of major concern. Recognizing the uncertainties of TWT developments on other past programs, it is in NASA's interest to resolve as many of these as possible prior to the hardware program in order to avoid expensive program delays. This requires the development and qualification of a fully documented prototype TWT coupled with the start of life demonstrations. Such a program is least expensive during the period beford start of Phase III and sufficient time appears to be available. An even more serious deficiency exists with the processor. The current program involves only a few of the chip developments and the overall system architecture is not well defined. In addition, the projected availability of CMOS memory should be reassessed. Much more is needed to be done before the processor becomes a credible technology even for the NASA experimental satellite. However, it is doubtful that sufficient time is available to qualify a unit before the start of Phase III however desirable this may be. Alternatively, a complete working brassboard capable of full Demonstration System operation and part qualification is a minimum that ought to be accomplished before the Phase IV if the potential for expensive program delays during Phase IV is to be minimized. There are other challenges in the satellite design, namely VPD, LNR, LO, upconverter, SS-TDMA switch assembly, EPC, deployable antenna, minimization of antenna system thermal distortion, accurate satellite pointing. However, it is believed that sufficient information and experience is available (or will be available) so that potential problems can be overcome during the normal process of Phase II design and test despite the large number of innovations and design extrapolations required.



## ITEMS FOR CONCERN (POTENTIAL IMPACT ON PHASE III SCHEDULES AND COSTS)



- TWT DEVELOPMENT AND RELIABILITY DEMONSTRATION (EXTENSION OF POC)
  - HAC EDD SHOULD BUILD AND TEST A PROTOTYPE
  - HAC-EDD SHOULD INITIATE PROTOTYPE LIFE DEMONSTRATIONS
- PROCESSOR AND RELIABILITY DEMONSTRATION (EXTENSION OF POC)
  - NASA SHOULD ESTABLISH COMPLETE PROCESSOR REQUIREMENTS.
  - MOTOROLA SHOULD COMPLETE SYSTEM ARCHITECTURE
  - MOTOROLA SHOULD REASSESS "MEMORY" TECHNOLOGY
  - MOTOROLA SHOULD BUILD, TEST A COMPLETE BRASSBOARD
  - MOTOROLA SHOULD QUALIFY PARTS





COMMUNICATION AND TT&C SYSTEMS

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#### TRUNKING SERVICE CONCEPT



- SIX NODE NETWORK: NODES AT LOS ANGELES, HOUSTON, CLEVELAND, TAMPA, WASHINGTON, D.C., AND NEW YORK
- MASTER CONTROL CENTER IS AT CLEVELAND
- ANY FOUR NODES SIMULTANEOUSLY ACTIVE
- SS-TDMA SYSTEM, 256 MBPS BURST DATA RATE, NODES INTERCONNECTED BY MEANS OF AN IF SWITCH AT THE SATELLITE
- SYSTEM COMMUNICATION CAPACITY APPORTIONED AMONG EARTH TERMINALS ON A PREASSIGNED BASIS VIA THE PROGRAMMING OF THE IF SWITCH INTERCONNECT SEQUENCE
- SATELLITE SWITCH IS NETWORK BURST TIME REFERENCE
- EARTH TERMINALS MAINTAIN SYNCHRONIZATION BY A CLOSED LOOP THROUGH THE SWITCH AT THE LOOP-BACK TIME
- ORDERWIRE INCLUDED IN LINKS TO CLEVELAND

#### TRUNKING SERVICE DESCRIPTION

Trunking services are provided to four nodes at Los Angeles; Cleveland; New York or Houston and Washington, D.C. or Tampa. These nodes are serviced by six fix-pointed satellite antenna beams.

Control of the network is exercised by the Master Control Center (MCC) located in Cleveland. The MCC includes a terrestrial communications line to the Telemetry, Tracking and Command (TTAC) station located at GSFC by means of which the trunking portion of the payload is controlled. This S-band station is used to receive the spacecraft bus and payload telemetry and to transmit commands also. In addition, along with a similar station at Los Angeles, it provides the satellite tracking functions via an onboard turnaround transponder. The LA station provides telemetry and command backup.

The Cleveland and Los Angeles terminals also transmit a circularly polarized pilot signal to the satellite for monopulse sensing of the spacecraft attitude.

Earth stations within a beam share a common uplink and downlink carrier frequency through the use of time division multiple access (TDMA) of the satellite receiver, for uplink operation, and TDMA of the satellite transponder transmitter for downlink operations. Uplink and downlink carrier frequencies are 28.75 GHz and 18.95 GHz, respectively, for all nodes except that at Washington, D.C., for which the frequencies are 28.45 GHz and 18.65 GHz. The data burst rate is 256 Mbps for all transmissions.

Nodes are interconnected at the satellite by means of an IF switch which provides all required beam interconnects within a 1 msec frame time. This preassigned interconnect sequence repeats until the switch is reprogrammed by commands from the MCC. Interconnect time between beams is apportioned according to the traffic between the nodes serviced by the beams.

All earth terminals operate in synchronism with the satellite switch using the loopback time provided in each frame, during which time the uplink transmissions from a node are returned to that node, to measure and maintain synchronization.

An orderwire is provided between all earth terminals and the MCC for coordination of the network and to provide satellite ephemeris data to aid initial synchronization of terminals entering the network.

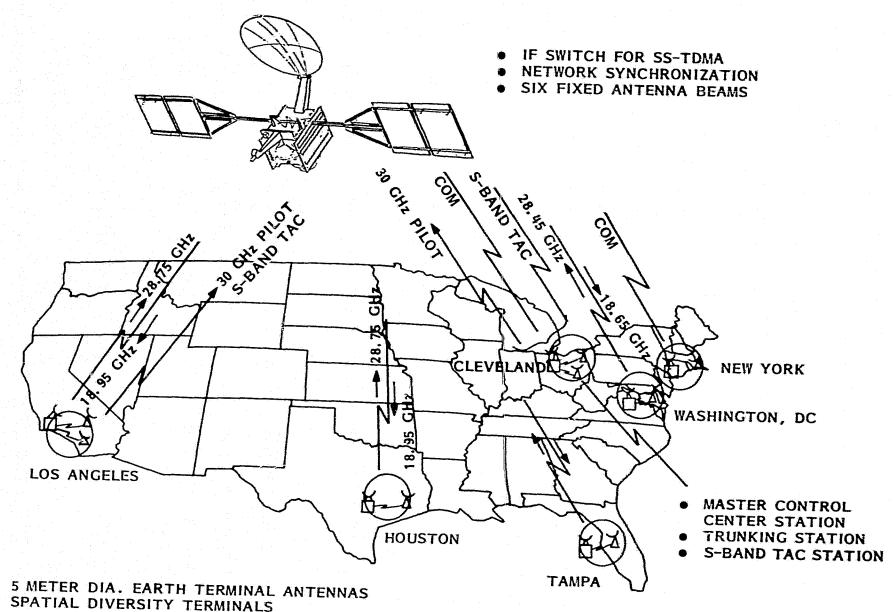
TOWNS WITH THE

Earth terminals in the trunking service use a combination of high EIRP and G/T and spatial diversity to compensate for rain induced fading of 18 dB on the uplinks and 8 dB on the downlinks.



## TRUNKING SERVICE DESCRIPTION





#### TRUNKING SERVICE DOWNLINK FRAME STRUCTURE

The trunking service frame structure is summarized by the downlink structure. A superframe consisting of 512 TDMA frames, each 1 msec long, defines the intervals at which the network can be reconfigured. It is slightly longer than the double loop time between an earth terminal and the MCC.

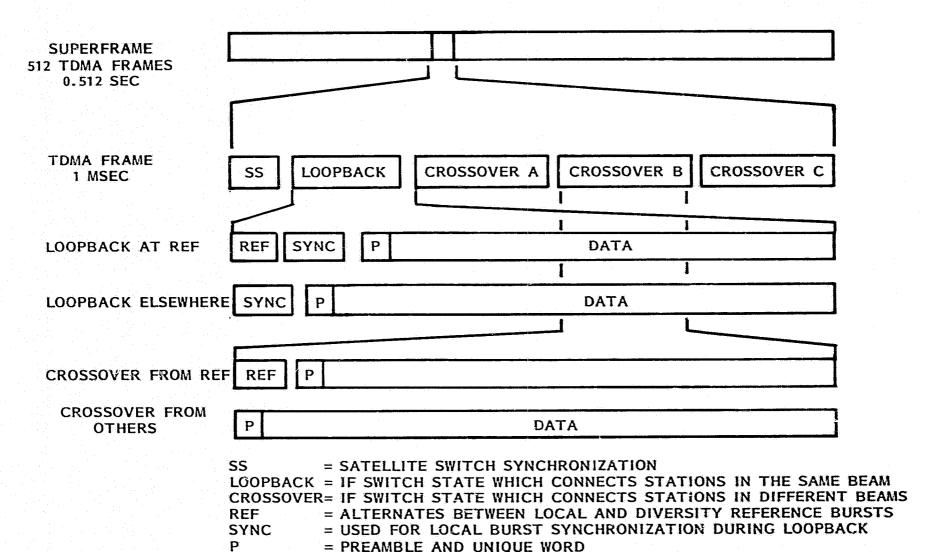
Within each TDMA frame connectivity is provided between all nodes including loop back of each node to itself. In addition, time is provided for the reference station, part of the MCC, to achieve synchronization with the satellite switch. Transmissions for this purpose take place during the intervals denoted SS. Having achieved synchronization with the satellite switch, a reference burst is transmitted from the reference station, alternately from the prime and diversity sites, within each change in state of the switch. These bursts provide the information required by the earth stations to acquire and maintain synchronism with the switch. During the loopback switch state a sync window is provided during which synchronization transmissions from the earth stations are returned to them to establish their timing or phasing, with respect to the switch cycle and to track the switch for closed loop tracking. Timing of the transmissions for initial entry of an earth terminal into the network is provided via an orderwire from the MCC which enables the terminals to rapidly align themselves with the sync window.

With each change in the destination of transmission, each earth terminal inserts a preamble into its transmission for carrier and bit timing recovery by the receiver. The preamble also contains a unique word and orderwire. In the case of transmissions to and from the reference station, station monitoring and control data, respectively, are included in the preamble.



# TRUNKING SERVICE DOWNLINK FRAME STRUCTURE





= DATA BURST - 256 MBPS

DATA

#### TRUNKING SERVICE PREAMBLE, UNIQUE WORDS AND OVERHEAD

Three types of preambles are used depending upon the source and destination. Preambles originating at the reference terminal contain data defining the network plan in addition to the synchronization symbols, unique word (UW) and orderwire (OW) information common to all preambles. Preambles destined for the reference terminal contain transmitting terminal bit error rate (BER) summary data. Transmissions not involving the reference terminal contain preambles consisting of synchronization, UW and OW data only.

Preambles are sent from both the standby and on-line stations at each terminal. That from the standby site is transmitted first so that the data from the on-line site immediately follows its preamble. Transmissions from the standby station are used to monitor the health of the station and carrier fading conditions.



# TRUNKING SERVICE PREAMBLE, UNIQUE WORDS AND OVERHEAD



	CARRIER AND BIT TIMING RECOVERY	UW	VOICE ORDER- WIRE				
FROM REFERENCE STATION	75 SYMBOLS	12 4	16	75	12	4 16	DATA
		NETWO PLAN DIVER CONT	AND SITY				
	CARRIER AND BIT TIMING RECOVERY		VOICE ORDER- WIRE				
TO REFERENCE STATION	75	12 1	16	75	12	1 16	DATA
		BER SUMMA					
	CARRIER AND BIT TIMING RECOVERY		ICE DER RE				
FROM/TO OTHER SITES	75	12 16		75	12	16	DATA

TRANSMITTED BY ON-LINE SITE

FROM STANDBY SITE



## **CUSTOMER PREMISE SERVICE**



- TWO SCANNING BEAMS EACH COVERING A SECTOR OF THE EASTERN CONUS PLUS, IN COMBINATION, SPOTS AT DENVER, SAN FRANCISCO AND SEATTLE
- MASTER CONTROL CENTER IS AT CLEVELAND
- EARTH STATION BURST TIMING IS GOVERNED BY THE BBP DEMODULATORS/UNIQUE WORD DETECTOR AND SYNCHRONIZING CORRECTIONS ARE DERIVED AT THE MASTER CONTROL CENTER (MCC) LOCATED AT CLEVELAND
- LINKS HAVE RATE DIVERSITY PLUS FORWARD ERROR CORRECTION FOR RAIN FADE COMPENSATION
- STATIONS TRANSMIT EITHER 27.5 MSPS OR 110 MSPS AND RECEIVE 220 MSPS. FOUR 27.5 MSPS UPLINK CHANNELS OR ONE 110 MSPS UPLINK CHANNEL ARE AVAILABLE IN EACH SECTOR
- INTERCONNECTION BETWEEN EARTH STATIONS IS BY MEANS OF A STORE-AND-FORWARD PROTOCAL IMPLEMENTED THROUGH THE USE OF A SATELLITE BORNE BASEBAND PROCESSOR (BBP)
- CHANNELS THROUGH THE SATELLITE ARE DEMAND ASSIGNED
- CIRCUIT SWITCHED NETWORK PROVIDED
- INITIAL EARTH TERMINAL ENTRY IS BASED ON TIMING INFORMATION TRANSITTED FROM THE MCC TO THE EARTH STATION VIA AN ORDER WIRE.

## CUSTOMER PREMISE SERVICE

Customer Premise Service (CPS) is provided to two contiguous sectors in the Eastern CONUS plus isolated regions centered at Denver, San Francisco and Seattle. For this service the satellite system includes a transmit and a receive beam, both scanned, to provide the coverage of each sector and the isolated regions associated with each. The same carrier frequencies are used in each sector and isolation between the adjacent sectors is achieved by a combination of orthogonal polarization of beams and scan control to maximize spatial isolation.

Circuit switched communications are provided between any two earth stations in the service on a demand assigned basis. The interconnection is made through a baseband processor (BBP) in the satellite in which received signals are demodulated, stored in input memory, mapped onto the output memory by means of a baseband switch, and read from the output memory for transmission at the appropriate time as defined by the transmit antenna pointing direction. The BBP also includes provisions for forward error correction decoding of the uplink data and encoding of the downlink data. The error control coding, along with up to 4:1 data rate reduction, provides approximately 10 dB of extra margin for rain fade compensation.

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The CPS incorporates two classes of stations, a 3 meter diameter antenna class which transmits bursts of 27.5 MSPS and a 5 meter class that transmits 110 Msps bursts. Both receive a time division multiplex data stream at 220 MSPS.

The CPS network is controlled from the Master Control Center (MCC) located in Cleveland. Orderwires through the satellite connect the earth stations with the MCC and supports the communications needed to command and monitor each earth station and transmit earth station requests for capacity assignment changes. Satellite ephemeris data is supplied via the orderwire from the MCC to aid earth station entry into the network.

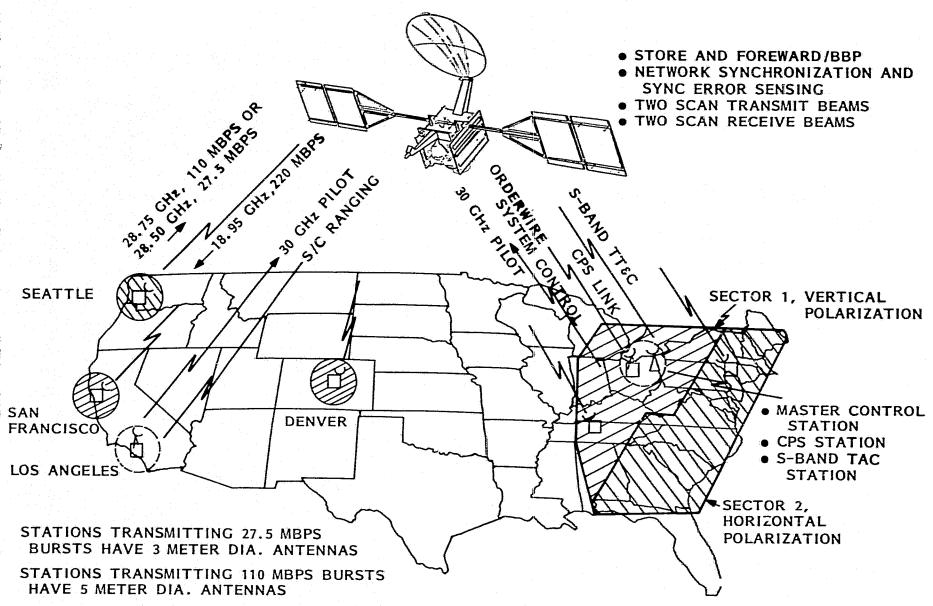
BBP reconfiguration data, required to respond to changes in earth terminal traffic requirements, is generated at the MCC and transmitted to the satellite via either a scanning beam or a fixed beam to Cleveland.

A 30 GHz pilot for use by the satellite monopulse sensor also is provided from Cleveland and LA earth stations.



#### **CUSTOMER PREMISE SERVICE**





#### CPS FRAME FORMATS

The frame time is the time allocated for scanning one sector, i.e., 1 millisecond. A superframe is made up of 512 frames. Instructions for any reconfiguration of the BBP elements or the earth terminals are executed at the beginning of a superframe.

The scanned beam of the satellite receive antenna is stepped through the assigned sector. While it dwells on a particular area all stations in that area that have been assigned the same transmit carrier frequency access the satellite via TDMA. Each station transmits a preamble, which includes guard time, carrier and clock recovery bits, a unique word for timing error measurements and phase ambiguity resolutions, and orderwire data for transmitting terminal status, health, requests for the use of error correction coding, changes in capacity requirements and so on. Following the preamble the traffic information is transmitted. Included here is the supervision and control information for call setup and takedown. This relieves the MCC of those functions except it assigns the required system resources and configures the system.

The downlink frame is similarly organized except that, since the downlink data is time division multiplexed, only one preamble is required for each area and the orderwire may be shared by the terminals in an area.

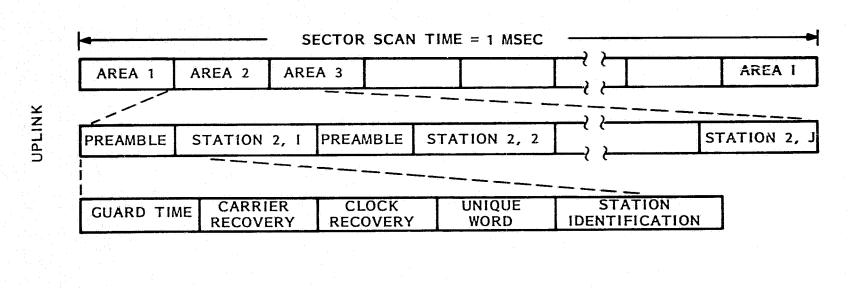


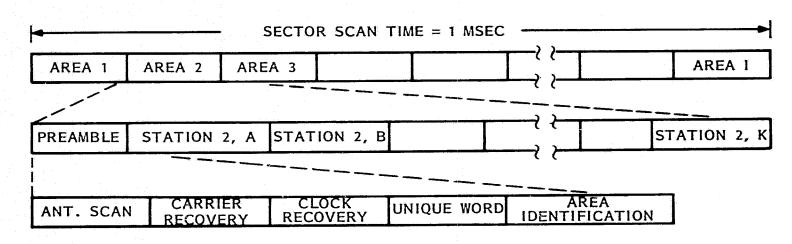
DOWNLINK

or record Albabase

#### **CPS FRAME FORMATS**







• UPLINK AND DOWNLINK DO NOT NECESSARILY COVER THE SAME AREA SIMULTANEOUSLY.

#### FREQUENCY PLAN

The frequency plan is consistent with the planned operation of the demonstration system and simplifies its implementation.

The planned operation of the system is that it will operate in either the CPS or the trunking mode, and operation in these modes is mutually exclusive. In the CPS mode earth stations simultaneously accessing the satellite through the same beam will transmit either 27.5 MSPS, on any one of four FDMA carriers, or 110 MSPS on a fifth carrier frequency. Again, operation in the FDMA, 27.5 MSPS or 110 MSPS, modes is mutually exclusive. These same frequencies may be used simultaneously in both sectors, and associated spot coverage areas, on, however, orthogonally polarized carriers. The carrier frequencies for CPS operations are such that the demultiplexing filter design is routine. The CPS downlink operates at 220 MSPS burst rate for all uplink rates.

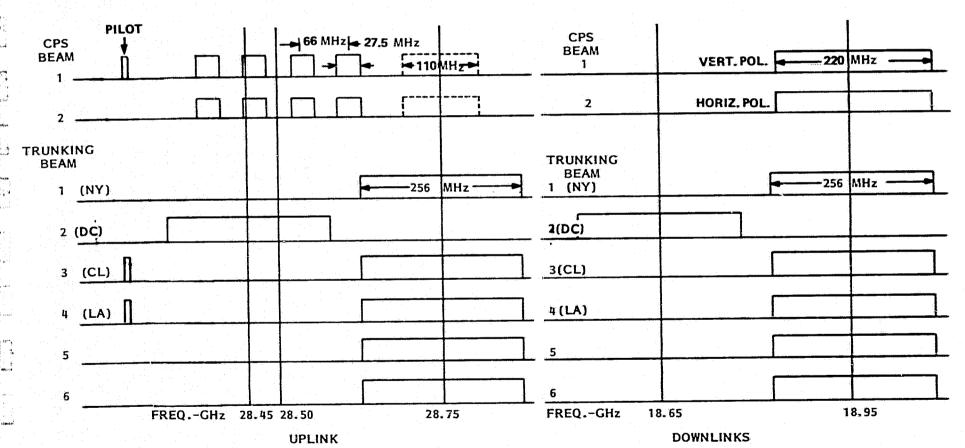
In the trunking mode both the uplink and downlink from all nodes operate at 256 MSPS burst rates and all, except those from the Washington, D.C. node, use the same uplink carrier and the same downlink carrier frequency. The carriers for the Washington, D.C. node are offset from those of the other nodes to permit supplementing the spatial isolation between it and the others through filtering at the receive terminals. There is a potential interference problem when terminals in the DC or NYC nodes transmit to themselves or to other terminals in the same node. In that case the signal received from the adjacent node by the satellite beam skirts and hence transmission back to it by the same means may not be sufficiently below the carrier so as to cause negligible influence. If that should prove to be the case additional filtering at the satellite is required.



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## FREQUENCY PLAN





• CPS AND TRUNKING BEAMS NOT SIMULTANEOUSLY ACTIVE

CPS NARROWBAND AND WIREBAND UPLINK CHANNELS NOT SIMULTANEOUSLY ACTIVE

#### BASELINE PAYLOAD BLOCK DIAGRAM

The baseline payload supports the two experiments planned, SS-TDMA for trunking and scanning beam, baseband switched TDMA for CPS.

The payload is configured for use with a single reflector antenna and, hence, common feed horns are used for both transmit and receive. The feeds are grouped into two sets corresponding to the two scan sectors plus three feeds serving the isolated trunking nodes at Houston, Tampa and Los Angeles. Feeds for the other three trunking nodes, NYC, DC and Cleveland, are shared with the CPS.

Two beam forming networks (BFN), a transmit and receive, are associated with each scanning beam. These are implemented with variable power dividers to permit combining of singlet beams, (beams from single feeds), to provide more uniform gain over the scan area than is possible with single beams alone.

RF switches provide for reconfiguration of the trunking nodes and for selection of the CPS or trunking modes. Both services use the same receivers. Four are required but six, interconnected by ring switches, are provided giving two-for-four redundancy. The four active receivers are connected to the IF switch for system operations in the trunking mode. This switch provides interconnection between receive and transmit trunking beams. For system operations in the CPS mode, two of the receivers connect the receive scanning beams to the BBP through a demultiplexer associated with each scanning beam. The demultiplexer separates the 5 possible uplink carriers for processing in the BBP. The store-and forward protocol is implemented in the processor which demodulates the data on each carrier, applies forward-error-correction as required, stores the data for routing through a baseband digital switch, assembles the switch output into a time division multiplexed (TDM) output, encodes the data if required, and modulates the data onto an IF carrier for upconversion and transmission.

A digital routing processor (DRP) is included in the BBP and in it are processed the control messages received from the MCC which are then passed onto the other elements of the BBP and to the IF switch, scanning antennas, LO's, and RF switches. Payload timing information is also generated in the DRP. In the present configuration the MCC communicates with the BBP through the TT&C subsystem when the payload is in the trunking mode, which requires only a low rate uplink, and through a CPS link when in the CPS mode which requires a high data rate for rapid BBP configuration. The TT&C link can also be used as a backup to the CPS link for uploading data.

An alternative approach to implementing the MCC-BBP links is through the use of a fixed beam to the Cleveland node. Implementing the link in that way provides continuous, relatively high speed communications that are not dependent on the scanning antenna for operation. This requires increased BBP complexity, and an additional channel through the processor.

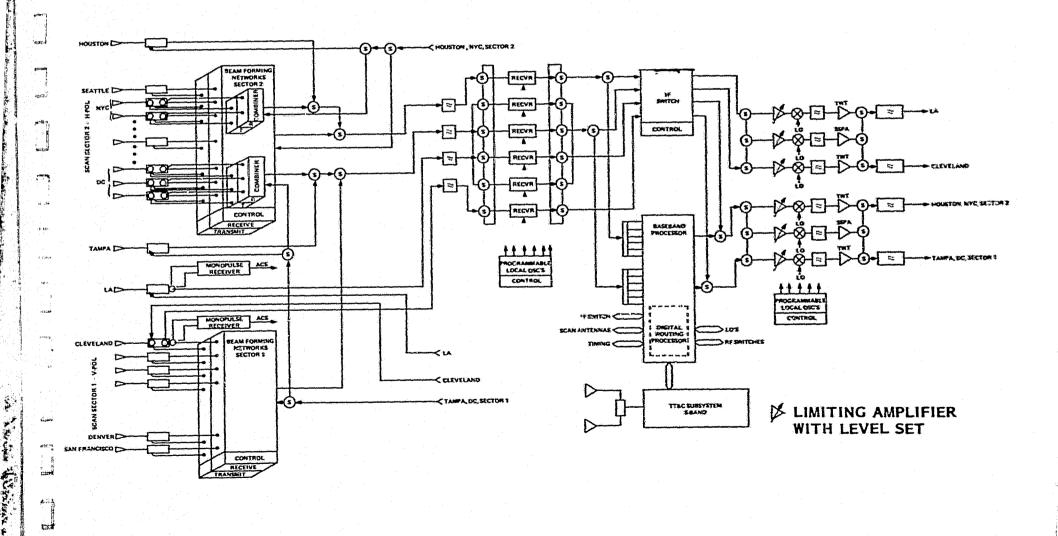
Upconversion and power amplification is accomplished by means of a cascade of a limiting IF amplifier, upconverter, TWTA and output filter. Four such cascades are arranged in pairs with each pair having an associated similar cascade for redundancy. The redundant path has an IMPATT solid state power amplifier (SSPA) instead of a TWTA. The amplitude limiting amplifier is included to assure full power output from the power amplifiers by compensating for differences in trunking station EIRP, weather conditions and component aging.

Programmable LO's drive the upconverters to provide a constant carrier frequency to earth stations in the various nodes when there are crossovers from and to the Washington, DC node which operates at carrier frequencies different from the other nodes.



# BASELINE PAYLOAD BLOCK DIAGRAM





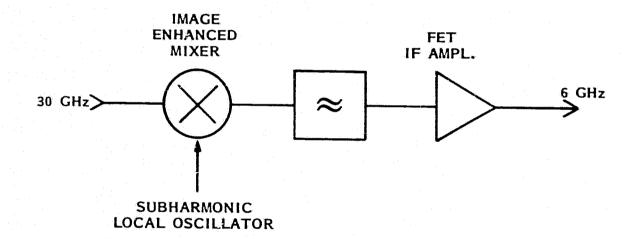
#### LOW NOISE RECEIVERS

A low noise receiver (LNP) made up of an image enhanced mixer followed by a low noise FET IF amplifier should meet the NASA goal of a receiver with a 5 dB noise figure. Experimental results obtained by General Electric, as shown in the two following figures, confirms that the goal is achievable.



## LOW NOISE RECEIVERS





• NASA 1982 DEVELOPMENT GOALS OF DOWN CONVERTER NOISE FIGURES (5 dB AT 30 GHz) SHOULD BE ATTAINABLE.

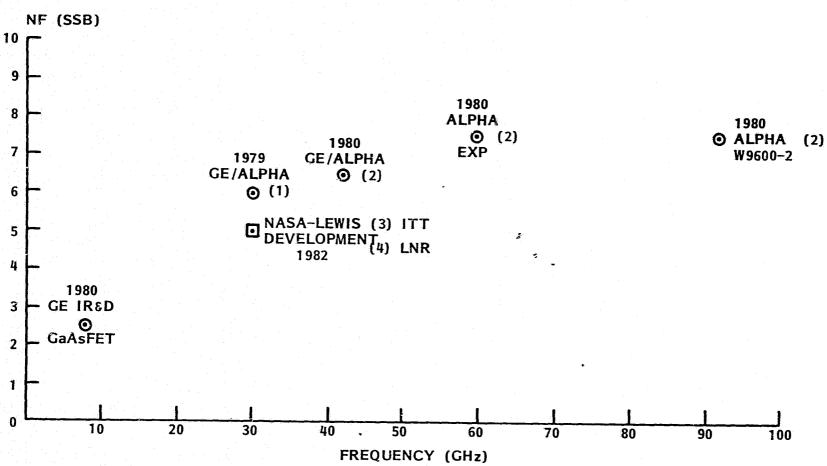
# RECEIVER NOISE FIGURES VERSUS FREQUENCY

Experimental results obtained over the past few years show the trend in noise figures as a function of frequency. The results at 30 GHz are consistent with the trend and are within 1 dB of the NASA goal.



## MILLIMETER NOISE FIGURES VS. FREQUENCY





- (1) SUB-HARMONICALLY PUMPED SUSPENDED QUARTZ STRIPLINE GaAs BEAM LEAD DIODES IMAGE ENHANCED
- (2) SAME AS (1) EXCEPT AT FUNDAMENTAL
- (3) MIXER WAVEGUIDE IMAGE ENHANCED (SINGLE DIODE)
- (4) MIXER DUAL DIODE COMMON JUNCTION BALANCED

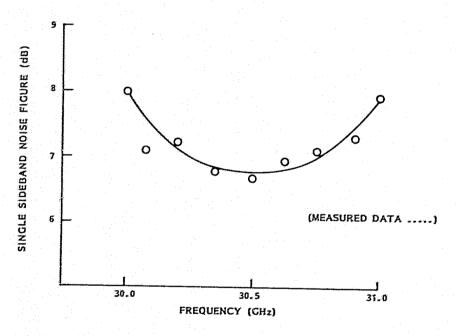
## RECEIVER SPOT NOISE FIGURE

Low noise amplifier noise figure as a function of frequency, measured with a 3.5 dB noise figure IF amplifier, show noise figures 2 to 3 dB greater than the NASA goal. Attainable improvements in mixer conversion loss and the use of a lower noise IF amplifier can reduce the receive noise figure to 5 dB.

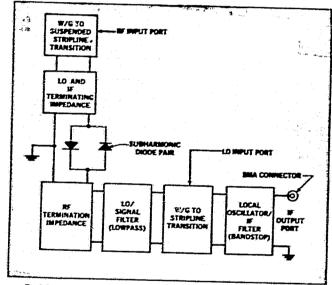


# RECEIVER SPOT NOISE FIGURE





SSB NOISE FIGURE MEASURED WITH A 3.5 dB NF & CHz IF AMPLIFIER



Subharmonic mixers built with an antiparallel diode pair offer many advantages. All the design elements can be integrated into a single stripline circuit,

BLOCK DIAGRAM OF SUBHARMONICALLY PUMPED MIXER

## LOCAL OSCILLATORS

A signal source of the design shown, suitable for use as the receiver subharmonic local oscillator, has been breadboarded by General Electric. The circuit tested produced 50 milliwatts at 11.4 GHz, which is the desired subharmonic, and exhibited satisfactory spectral purity. This result indicates the feasibility of constructing the local oscillators required.



#### LOCAL OSCILLATORS



- LOCAL OSCILLATOR DESIGN HAS BEEN BREADBOARDED BY GE
- OUTPUT FREQUENCY: 11.4 GHz L.O., DOUBLED IN SUBHARMONICALLY PUMPED MIXER
- OUTPUT POWER: 50 mW
- EFFICIENCY: 1.2%
- GOOD SPECTRAL PURITY

#### GENERAL ELECTRIC 11.4 GHz LO BLOCK DIAGRAM

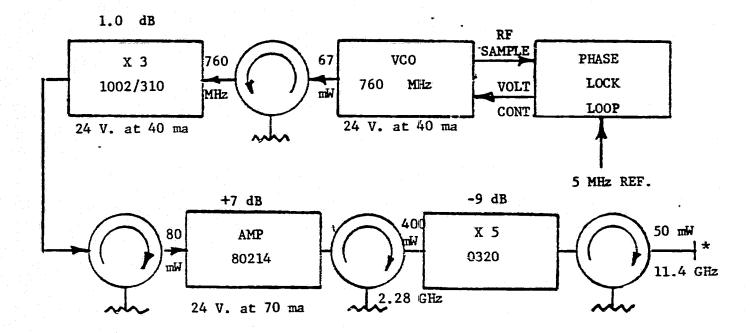
The LO chain is stabilized by a 5 MHz crystal oscillator reference and contains a VCO multiplier and two diode multipliers, suitably isolated, to obtain a stable 50 my reference at 11.4 GHz. One such unit was built and tested.



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# GE 11.4 GHz LO BLOCK DIAGRAM





\*WR75 Waveguide

## 20 GHz TRANSMITTERS

An IMPATT solid state power amplifier (SSPA) and a travelling wave tube amplifier (TWTA) are used as the transmitter RF final stage amplifiers. The IMPATT amplifier exhibits relatively low efficiency compared to the TWTA under development.

The following four figures give expected amplifier performance and comparison data. The first shows design goals for an IMPATT amplifier and, as indicated, it is expected that the desired device efficiencies will not be achieved and hence neither will that of the amplifier as a whole.



## **20 GHz TRANSMITTERS**



## • IMPATT AMPLIFIER

- LOW POWER EFFICIENCY
- HIGH NON-LINEARITY

# TRAVELLING WAVE TUBE AMPLIFIER

 POWER EFFICIENT TWT UNDER DEVELOPMENT

#### TRW IMPATT TRANSMITTER CONFIGURATION

This diagram describes one such solid state amplifier under development with relevant characteristics and design goals. Experience with similar devices, including regulators, indicates that efficiency goal in particular will likely not be achieved which will result in efficiencies considerably below that of a TWTA. Experience with IMPATTS at C-band and Ku-band have not encouraged their use as TWTA replacements because such devices have no advantage in efficiency, linearity, weight or reliability. The same may be true at 20 GHz.

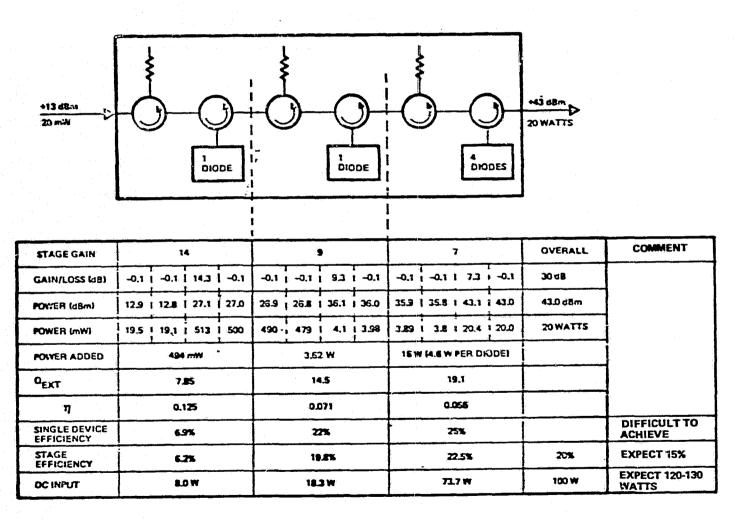


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The Witness

## TRW IMPATT TRANSMITTER CONFIGURATION





#### 20 GHz TWTA SUMMARY DATA

This chart lists TWT performance and weight characteristics for tubes operating at 20 GHz. The EDD 918H and Telefunken 20030 are the only TWT's that come close to the requirement.



## 20 GHz TWT SUMMARY DATA



MFG	MODEL	POWER OUTPUT (WATTS)	GAIN (dB) (SAT)	AM/PM	EFF (왕)	WEIGHT (LBS)	STATUS
HUGHES EDD	292H	4.0	50	-	19	(1)	FLIGHT JCS
THOMSON CSF	,	15.0	50	4.5	33	1.32	PROTOTYPE CLASSIFIED
TELEFUNKEN	20030	30.0	50	****	38	1.90	PROTOTYPE
WATKINS JOHNSON	3712	25.0	52	5.0	50	TBD	UNDER DEVELOPMENT IR&D
HUGHES EDD	91 8H	75.0	47	2.0	40	8.00	UNDER DEVELOPMENT NASA LEWIS

<sup>(1)</sup> TWTA 4.75 LBS 1294H

#### TWTA POWER SUPPLY WEIGHT VERSUS TWT RF OUTPUT POWER

The chart shows there is considerable industry experience in TWT power supplies in the TWT power range of 40 watts and above albeit none are for a 20 GHz TWT. The power supply is not a technology problem.



# TWTA POWER SUPPLY WEIGHT VS. TWT RF POWER OUTPUT



MFG	MODEL	RF POWER OUTPUT	WEIGHT	EFFICIENCY	STATUS
TELEFUNKEN		20	3.74	84	FLIGHT ANIK-B
GE	BSE	100	12.0	85	FLIGHT BSE
	BS-2	100	10.0	85	IN DEVELOPMENT
GE	FOR THOMSON 150W	150	13.5	82.5	IN DEVELOPMENT
FIAR TRW		200			FLIGHT CTS
		10	6.4	85	QUAL DSCS III
WJ		40	8.8	85	QUAL DSCS III
WJ		10	5. 9	85	QUAL DSCS III
HAC		40	12.0	85	QUAL DSCS III
HAC FIAR	(DUAL COLLECTOR)	20	4.0	85	FLIGHT CTS OTS

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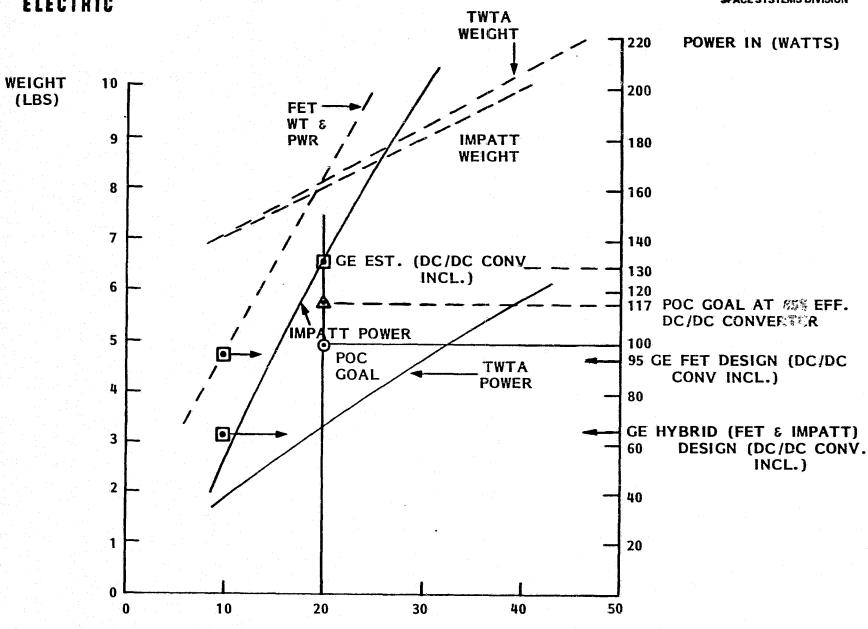
#### 20 GHz POWER AMPLIFIERS

Data from the preceeding two charts, and other data, have been combined to show weight and power drain trends of various types of power amplifiers versus RF power output. These data indicate that, above about 10 watts of RF power, TWTA's offer a significant advantage in terms of minimal spacecraft bus power requirements and have no weight penalty.



#### 20 GHz POWER AMPLIFIERS





RF POWER OUT (WATTS)

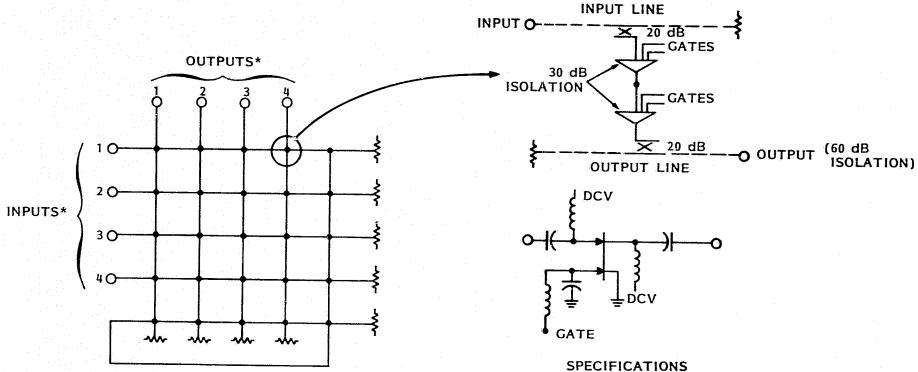
#### SS-TDMA SWITCH CONCEPTS AND CHARACTERISTICS

The RF switch design and specifications are summarized in the chart. The basic configuration is a crosspoint switch where the crosspoints are implemented by directional couplers and amplifiers. The amplifier, when active, compensates for the coupler loss and when inactive provide additional isolation between the input and output lines. As shown here and on the next figure redundancy is provided by means of extra input and output lines which provide a path through the switch that can be substituted for a failed path. Additional lines can be added for greater redundancy.



### SS-TDMA SWITCH CONCEPT & CHARACTERISTICS (POC TECHNOLOGY)





\*INPUT/OUTPUT SEQUENCE MAY BE CHANGED TO "MOVE" FAILED CROSSPOINT TO AN "UNUSED" LOCATION

DERIVATIVE OF 20x20 SWITCH, 1985 TECHNOLOGY DEMONSTRATION

FULL CONNECTIVITY, 10 YEARS RECONFIGURATION RATE 2 μS SWITCHING TIME <10 NS IF ≈6.2 GHz **BANDWIDTH** 1000 MHz, 1 dB **GAIN RIPPLE** 1 dB PHASE LINEARITY ± 5 DEGREES MAX **INSERTION LOSS** 15 dB/CONNECTION

ISOLATION 40 dB MIN SIGNAL RANGE -50 dBM TO +10 dBM NF

35 dB MAX

#### CPS BASEBAND PROCESSOR

The BBP is based on the work being done by Motorola, Inc.'s Government Electronics Division for NASA. Under that program a BBP architecture has been developed, integrated circuits needed to meet size and weight goals identified and development of some of these IC's has started.

The BBP will support one 110 MSPS or four 27.5 MSPS u; link channels in each of the two antenna scan sectors and one 220 MSPS downlink in each sector. It provides signal regeneration to minimize earth station EIRP and G/T requirements, forward error correction decoding and a 2:1 symbol rate reduction to provide additional uplink margin to compensate for rain induced carrier fading, a constant downlink symbol rate and carrier frequency to minimize earth station clock and carrier acquisition requirements, and finally, provides the data buffering required by the use of scanning antenna beams.



### CPS BASEBAND PROCESSOR



- BASED ON MOTOROLA, INC. BASEBAND PROCESSOR DEVELOPMENT
- PROVIDES CONTINUOUS CARRIER ON DOWNLINK MINIMIZES ACQUISITION REQUIREMENT
- CONSTANT SYMBOL RATE OF 220 MSPS ON DOWNLINK MINIMIZES CLOCK ACQUISITION REQUIREMENT
- PROVIDES SIGNAL REGENERATION MINIMIZES ES EIRP AND G/T REQUIREMENT
- PROVIDES BUFFERING REQUIRED BY BEAM SCANNING
- PROVIDES CAPABILITY FOR FEC DECODING AND CODING ON ALL CHANNELS
  - 25 MBPS CAPACITY FOR RAIN FADE COMPENSATION
- SUPPORTS
  - TRANSMIT AND RECEIVE BEAM IN EACH SECTOR
  - 1 OR 2 CHANNELS AT 110 MBPS
  - UP TO 8 CHANNELS AT 27.5 MBPS

#### BASEBAND PROCESSOR DEMONSTRATION MODEL CONCEPT

Two channels, each of which processes one 110 MSPS data stream or four 27.5 MSPS streams and includes a forward error correction (FEC) decoder, are included in the processor. There are two modulator channels, corresponding to the demodulator channels and the number of scanning beams, each of which has provision for FEC encoding. The baseband switch interconnects the demodulator and modulator channels by providing a mapping of the demodulator channel memories onto the modulator channel memories. The switch also routes data to the digital routing processor (DRP) and from it to the modulator channels.

After the received signals from a scanning beam are frequency demultiplexed each of 5 resulting data channels are down-converted from an approximately 6 GHz IF to a 3 GHz IF as required by the demodulators. There are 5 demodulators, one for each data channel, and each provides soft decisions (4 level) plus clock and status data. If an uplink burst is encoded the soft decision data is passed through the decoding units, otherwise the sign bit only is passed directly to the switch input memory (FEC Decoder Output Memory). The switch passes the data to the appropriate output memory from which the downlink data is time division multiplexed for transmission.

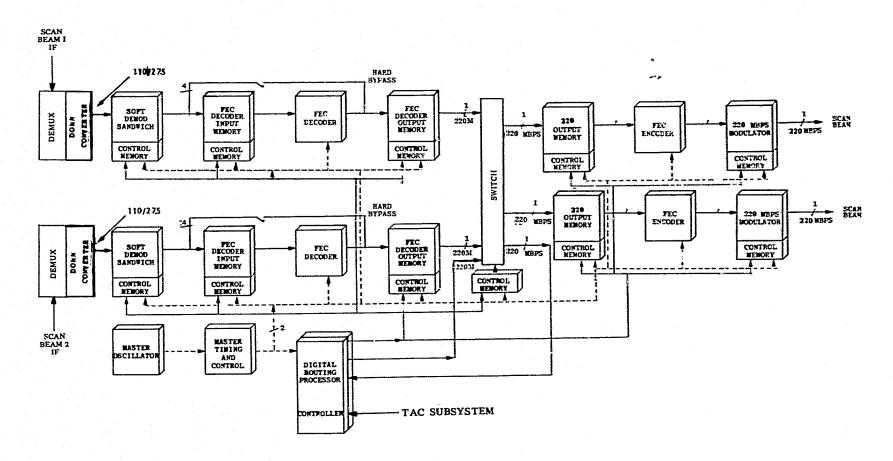
All BBP operations are controlled by the DRP which controls data to the various control memories.



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# BASEBAND PROCESSOR DEMONSTRATION MODEL CONCEPT





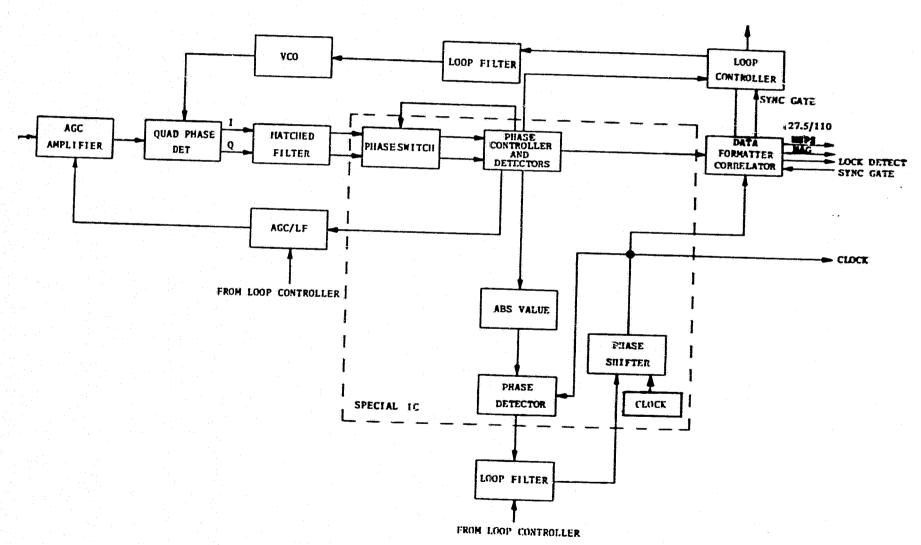
## 27.5/110 MSPS DEMODULATOR

In addition to recovering the data and clock from the SMSK modulated uplink carrier, the demodulator also generates a burst time offset signal for use in adjusting the earth station timing. The demodulator operates at normal or half symbol rate as required to gain rate diversity for rain compensation. It generates 2 bit soft decisions for each received symbol.



## 27.5/110 MSPS DEMODULATOR





## FEC INPUT ASSEMBLY

This assembly provides the data buffering required to slow the symbol rate into the convolutional decoder. It is organized to minimize memory speed requirements.



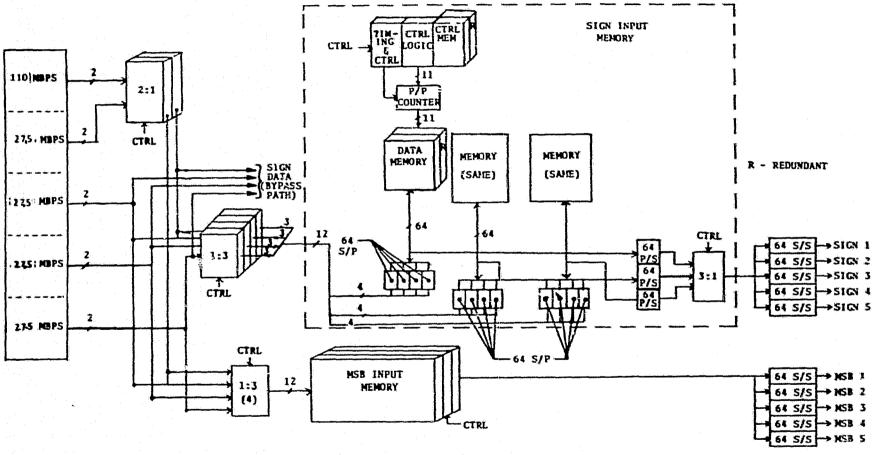
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IN THE WATER WATER

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#### FEC INPUT ASSEMBLY





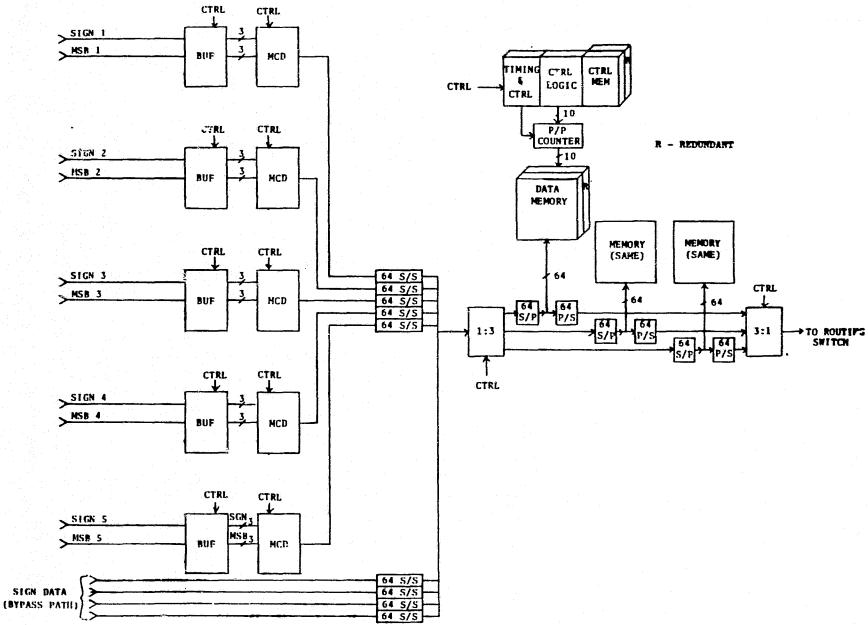
## FEC OUTPUT ASSEMBLY

The output assembly contains the maximum likelihood convolutional decoder (MCD) and the memory to buffer the data for routing through the switch.



### FEC OUTPUT ASSEMBLY





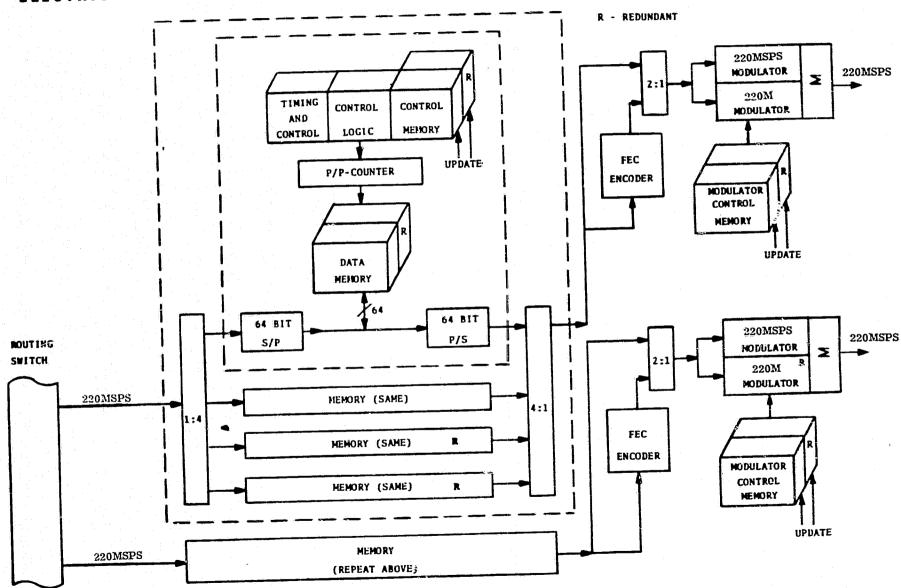
#### CUTPUT MEMORY/MODULATOR

Shown are the elements of the modulator path. Data for the routing switch are read into memory and recalled from it as required to assemble the downlink data stream. The data are either transmitted directly or are FEC encoded as required by the downlink conditions and passed to the modulators.



## **OUTPUT MEMORY/MODULATOR**





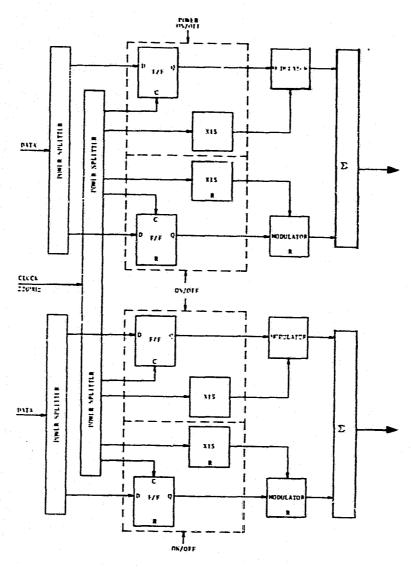
#### 220 MSPS MODULATOR SLICE

Data applied to the modulator assembly is modulated on to an IF carrier. The IF carrier is also generated here. A redundant modulator is provided for each path.



## 220 MSPS MODULATOR SLICE





R - REDUNDANT

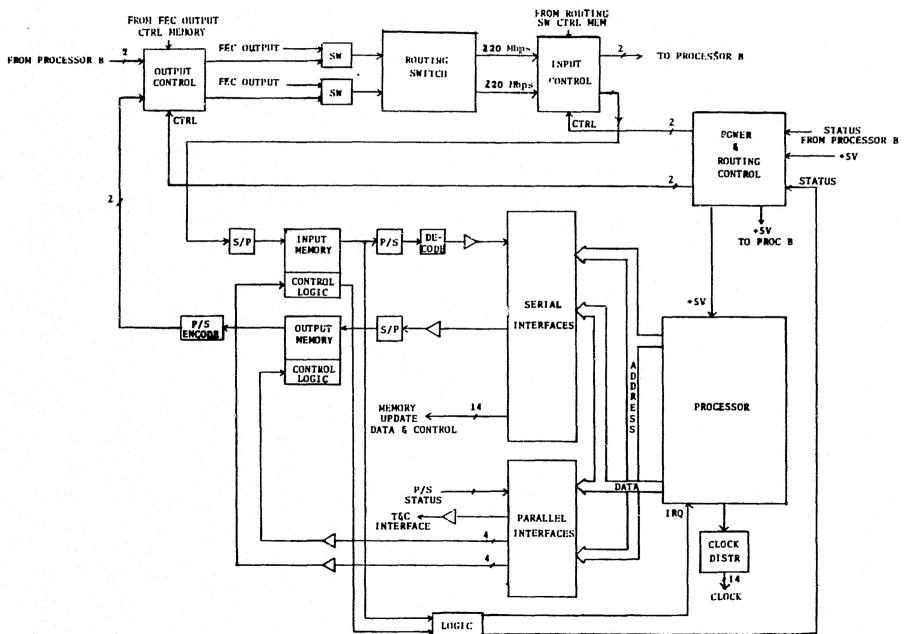
#### DRP CONTROLLER

The Digital Routing Processor (DRP) consists of a dual microprocessor system with an active main processor and a totally redundant inactive backup processor. The DRP's primary activity will be to direct routing information from the Master Control Center (MCC) to the output memories and then to initiate the reconfiguration of the system. The data is received via the orderwire into the input memory. The DRP sets up the transfer of routing data to the control memories by transferring only the address of the data block and the amount of data. The control memories will then transfer the data independent of the DRP. The DRP also has the capability of receiving data via the Telemetry and Command interfaces. If the DRP Controller fails, a backup processor is powered on and the failed processor is turned off.









## SYSTEM ENGINEERING REQUIREMENTS

The design of the Digital Routing Processor (DRP) must include a comprehensive systems engineering phase where the DRP's responsibilities with respect to the base band processor are defined. The DRP processing requirements will be defined in terms of the algorithms that are implemented, which then define the speed and memory requirements. The DRP speed requirements may be achieved by choosing an optimum combination of CPU speed and versatile interfaces. An interface which can perform many of the data transfer functions independent of the DRP can improve overall system performance. Once the general function of the baseband processor has been defined in terms of speed requirements, such as general responsiveness of the system, the appropriate hardware/software trades can be made. The approach used to achieve high speed will drive the design of all of the system components. Other requirements of the baseband processor, such as fault tolerance, also affect the overall system performance.

Finally, test modes, both for internal and external checks, test equipment and control software also need definition. A plan for on-orbit diagnostics also is needed.

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## DRP SYSTEM ENGINEERING REQUIREMENTS



## DRP/SYSTEM REQUIREMENTS NEED TO BE DEFINED IN TERMS OF:

- ALGORITHMS
  - SIZE
  - SPEED
- RELEVANT INTERFACES
  - CHOSEN TO MEET SPEED REQUIREMENTS
- GENERAL FUNCTION
  - RECONFIGURABILITY
  - CONTROL FUNCTION
- HARDWARE/SOFTWARE TRADES
  - IMPACT ON OTHER SYSTEM COMPONENTS
- FAULT TOLERANCE IMPACT
  - RAD HARDNESS
  - CONFIGURATION OF CPU WITH RESPECT TO BACKUP
- DUAL OPERATION TO ACHIEVE SPEED?
- TEST MODES (INTERNAL CHECKS)

## EDAC REQUIREMENTS:

- DATA MEMORY
- CONTROL MEMORY

#### KEY ASSUMPTIONS EFFECTING DRP SIZING

The DRP speed, memory architecture, size and overall performance of the baseband processor are effected by a number of assumptions about the system speed requirements and the functions that the DRP is expected to perform. The overall response speed of the baseband processor is probably the greatest technology driver. The Master Control Center (MCC) sends routing data to the DRP which is then loaded into the baseband processor control memories. The DRP commands the baseband processor to reconfigure either in response to the MCC or via a timer. Since the DRP is a conventional CPU that will take approximately 50 µsec to respond to an interrupt and hundreds of microseconds or milliseconds to load data, the DRP can not respond quickly (within a few microseconds) to a request to reconfigure unless an unconventional processor or I/O technique is used.

The DRP also has other functions to perform besides loading control tables. The DRP is responsible for error recovery, control of the scanner antennas as well as formatting and decoding data from the orderwire. All of the DRP functions must be considered when sizing the processor for speed.

Fault tolerance can impact speed in several ways. If the memories in the system are not "rad" hard with low error requirements, then an error detection and correction (EDAC) approach must be used with a corresponding loss in speed. The DRP is currently planned to be a dual processor for backup, with some speed penality to verify processor status. It is probable that compromise in the fault tolerance approach can be made, such as dual operation of the DRP CPUs to achieve speed. A survey of the EDAC requirements in the data memory and control memory may also indicate where the error recovery requirements may be reduced.



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## KEY ASSUMPTIONS EFFECTING DRP SIZING



**RESPONSIVENESS ISSUE:** 

- MCC SEND ROUTING INFORMATION TO DRP
- DRP LOADS CONTROL MEMORY
- DRP COMMANDS BASEBAND PROCESSOR TO RECONFIGURE
  - RECONFIGURATION IS IN RESPONSE TO MCC OR TIMER
- TYPICAL 8 BIT PROCESSOR WILL RESPOND TO AN INTERRUPT IN 50 μ SECONDS AND TAKE HUNDREDS OF MICROSECONDS (OR MILLISECONDS) TO LOAD DATA
- IF THE DRP IS EXPECTED TO RESPOND QUICKLY TO A REQUEST TO RECONFIGURE (E.G., 2 μ SEC), CONVENTIONAL PROCESSOR OR I/O TECHNIQUE WILL NOT SUFFICE

DRP FUNCTIONS:

- LOADING CONTROL TABLES
- ERROR RECOVERY
- CONTROL OF ANTENNA
- FORMATTING DATA
- DECODING DATA

ALL OF THESE FUNCTIONS EFFECT THE PROCESSOR SPEED, MEMORY ARCHITECTURE, SIZE AND OVERALL PERFORMANCE

## DRP PROCESSOR REQUIREMENTS

Detailed DRP requirements need to be addressed, however, in general processor requirements have been determined. The CPU should be either an 8 bit or 16 bit CMOS processor with word size chosen by considering the type of I/O transfers the DRP must perform. The CMOS technology of the processor was chosen due to power requirements. The processor random access memory (RAM) requirements are CMOS for low power - and sized to hold data tables, buffer of the RAM have not been addressed. The read only memory (ROM) will be sized to hold executive routines, utilities, buffer of I/O will have to be derived from an analysis of the DRP functions and hardware/software trades.



### DRP PROCESSOR REQUIREMENTS



DRP PROCESSOR: DETAILED REQUIREMENTS NEED TO BE ADDRESSED. GENERAL REQUIREMENTS ARE:

- 8 OR 16 BIT CMOS PROCESSOR
- RAM (CMOS) FOR:
  - DATA TABLES
  - BUFFER SPACE FOR ORDERWIRE MESSAGES
  - CONTROL PARAMETERS
  - COMMANDS FROM MCC
- ROM (CMOS) FOR:
  - EXECUTIVE ROUTINES
  - UTILITIES
  - INTERRUPT ROUTINES
- SERIAL AND PARALLEL INTERFACES (CMOS)

PROCESSOR SPEED AND MEMORY SIZE MAY BE DERIVED BY AN ANALYSIS OF DRP FUNCTIONS AND HARDWARE/SOFTWARE TRADES

#### PROCESSOR TECHNOLOGY

The general requirements of the DRP processor call for a space qualified, rad hard 8 or 16 bit CMOS processor. There is currently no space qualified, rad hard 8 or 16 bit CMOS processor available, however, GE has built and flown a 16 bit bipolar processor, and an 8 bit non rad hard CMOS processor (RCA 1802) has also flown before. Sandia is currently developing a CMOS version of the 8155 and 8555 ram, ROM, I/O chip combination. The DRP also requires CMOS serial interfaces, and at present, sources of the serial interface need to be identified.



#### PROCESSOR TECHNOLOGY



#### DRP PROCESSOR:

- CURRENT PROGRAMS AT SANDIA WILL DEVELOP AN 8085
   CMOS PROCESSOR
- SUPPORT CHIPS REQUIRED:
  - SANDIA PROGRAM WILL DEVELOP 8155 AND 8355 ROM, RAM AND I/O CHIPS
  - HIGH SPEED SERIAL INTERFACES ARE ALSO REQUIRED, SOURCE NEEDS TO BE IDENTIFIED

#### TECHNOLOGY CONCERNS

The current POC program is not developing the key technology in the CMOS-rad hard memory area. The program is dependent on market pressure to develop high density (16 k to 64 k) rad hard RAMS that are not subject to random errors. GE has surveyed the memory market for its military and commercial satellite programs and has concluded that the 1982 technology will be up to the  $4 \text{ k} \times 1$  CMOS rad hard RAMS with good error rates (but not 100% error free). Higher density RAMs with lesser rad tolerance and higher error rates will be available (16 k - 64 k). The survey has concluded that the 1982 memory technology will be small density, relatively error free RAMs or high density RAMs that have an EDAC requirement. The impact will be more weight, size and power or lower performance.

or two designs



#### TECHNOLOGY CONCERNS



CMOS-RAD HARD MEMORIES: OGRAM IS DEPENDENT ON MARKET PRESSURE
TO DEVELOP HIGH DENSITY, ZERO ERROR RAMS.

- SURVEY INDICATES 1982 TECHNOLOGY WILL BE 4 K X 1 CMOS RAD HARD RAMS
- HIGH DENSITY BUT WITH LESSER RAD TOLERANCE AND HIGHER ERROR RATES WILL BE AVAILABLE

CONCLUSION: MEMORY TECHNOLOGY IN 1982 WILL BE SMALLER DENSITY,

OR HIGHER DENSITY WITH EDAC REQUIRED. IMPACT WILL

BE MORE WEIGHT, SIZE, AND POWER OR LOWER PERFORMANCE

#### TECHNOLOGY ASSESSMENT

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The baseband processor has been assessed, for those components which drive the technology. Eight components have been identified. Six of the components are currently part of the Motorola POC program and will be completely developed at Motorola. The Minimum Convolution Decoder, the Serial/Parallel Converter, Translator chips, Demodulator/Bit Sync, CLOS three stage 8 x 8 routing switch and high data rate multiplexer will be developed by Motorola under their current contract. The memory technology is the highest risk item since the current trends indicate that the 1982 technology will only be up to  $4k \times 1$  CMOS rad hard RAMs and not  $2k \times 8$  as required. The CPU risk is moderate due to the schedule for development of the Sandia CMOS 8085 – due late 1982. There are alternative processor approaches which may be used (such as the GE 16 bit bipolar processor).



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## PROCESSOR TECHNOLOGY ASSESSMENT



COMPONENT RE	QUIRED TECHNOLOGY	SYSTEM	RISK	COMMENT
MCD	SIG-CMOS	FEC	MODERATE	MOTOROLA APPROACH
SERIAL/PARALLEL CONVERTERS	ECL-MOSAIC	DRP	MINOR	MOTOROLA APPROACH
TRANSLATOR (CMOS/ELL)	ECL-MOSAIC	DRP	MINOR	MOTOROLA APPROACH
DEMOD/BIT SYNC	ECL-MOSAIC	DEMOD	MODERATE	MOTOROLA APPROACH
CLOS THREE STAC (8 x 8) ROUTING SWITCH	E ECL-MOSAIC	BASEBAND SWITCH	MODERATE	MOTOROLA APPROACH
MEMORY	CMOS	ALL COMPONENTS	HIGH	CURRENT TRENDS INDICATED 1982-4K, NOT 2K x 8 AS REQUIRED
CPU (8085)	CMOS	DRP	MODERATE (TIMING)	PROCESSOR UNDER DEVELOP- MENT - SANDIA
MULTIPLEXER	ECL-MOSAIC	ALL COMPONENTS	MINOR	HIGH DATA RATE MUX REQUIRED

#### ANTENNA ASSEMBLY CHARACTERISTICS (BASELINE)

The table lists the major elements and their weight and power for the baseline single reflector antenna system, resulting in a total system weight of 169.6 pounds and system power of 24 watts.

The note refers to an alternative two reflector (receive and transmit) system also examined which results in 49.9 pounds of additional weight. This approach was not recommended, primarily from considerations of deployment and thermal distortions.

Also listed are the BFN components and their unit weights.

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## ANTENNA ASSEMBLY CHARACTERISTICS (BASELINE)



## 1 10' REFLECTOR

ITEM	QTY	UNIT WT	TOTAL WT LB	TOTAL POWER WATTS
REFLECTOR	1	54. 9	54.9	
BOOM & STRUCTURE	1	33.7	33.7	
POWER HINGE	1	8.1	8.1	
FEED SUPPORT	1	15.4	15.4	
MISC (WG, ETC)	1 SET	6.0	6.0	
SENSORFEED PLATFORM	1	10.0	10.0	
BFN (30/20 GHz)	1 SET	16.8	24.1	24
SECOND TTAC ANT. ASS'Y	1	2.0	2.0	
CONTINGENCY			<u>15.4</u>	
BFN COM	UNIT WT	169.6 LBS *	24 W **	
HORN GMT		0.08		
		0.09		
30/20 GHz	0.10			
SWITCH	0, 17			
SWITCH	0.11			
VPD ASS	'Y (20 GHz)	0, 43		
VPD ASS	'Y (30 GHz)	0, 30		

<sup>\*</sup> ADD 49.9 LB FOR SEPARATE RECEIVE ANTENNA ASSEMBLY

<sup>\*\* 12</sup> WATTS FOR OPTION 1

### RECEIVER ASSEMBLY CHARACTERISTICS

Size, weight, power and the number of the various items making up the receiver assembly are summarized. It is seen that the BBP is a significant contributor to the volume, weight and power required by the receiver subsystem. The processor data are those extrapolated from available POC data. There is considerable uncertainty regarding the assumed weight and power.

Indications are that the processor weight would be 40.8 pounds and 210 watts or higher. If a high speed dedicated channel to Cleveland is desired, size, weight and power increase to 1800 cubic inches, 51 pounds, 250 watts, respectively.



## RECEIVER ASSEMBLY CHARACTERISTICS (BASELINE)



ITEM	VOL IN <sup>3</sup>	QTY ACTIVE/STANDBY	UNIT WT LB	TOTAL WT LB	DAYTIME PWR WATTS	NIGHTTIME PWR WATTS
INPUT BPF (30 GHz)	0.07	4/0	0, 05	2.0	0	0
T SWITCHES (30 GHz, WG)	7.3	6	1.0	6.0	0	0
T SWITCHES (6 GHz, COAX)	2.0	6	0.3	1.8	0	0
LNA	0.8	N/A	N/A	N/A	N/A	N/A
MIXER/FILTERS/IFA (20 GHz)	0.8	6/4	0.3	1.8	8, 0	0
MIXER/FILTER/IFA (6 GHZ-PROC)	1,6	10/2	0.3	3.6	20.0	0
LO ASS'Y (15 GHz)	120	1/1	2.0	2.0	6.0	0
LO ASS'Y (PROCESSOR)	105	2/2	2.0	4.0	6.0	0
ROUTING SWITCHES (30 GHz)	2.0	4/0	0.5	2.0	0	0
ROUTING SWITCHES (6 GHz)	2.0	2/0	0.3	0.6	0	0
CHANNEL FILTERS (6 GHz)	12.5	5/0	1.2	6.0	0	.0
PROCESSOR ASS'Y	558	1/0	33	33, 0	142 *	0
SS-TDMA (4 x 4) ASS'Y	1320	1.0	4.2	4.2	5 +	0
NON CONTIGUOUS MUX	8	2/0	3.5	7.0	0	0
MISC	-		<del></del>	7.4	18	0
SUBTOTAL				81, 4 LBS	37-200 W*	0

<sup>\*</sup> TRUNK-CPS MODE

## TRANSMITTER ASSEMBLY CHARACTERISTICS (BASELINE;

Size, weight, power and the number of each component required is shown. The power summary includes provision for operation with the redundant IMPATT power amplifiers. Note that the trunk mode, when four power amplifiers are on (including two 40 watt IMPATTS) results in the highest power requirement.

Consideration of the potential IMPATT efficiency, linearity and weight does not favor their application in operational systems at Ka-band, Ku-band or C-band. Use of all TWT's (and application of the IMPATT as a beacon) results in significantly lower trunk mode transmitter power - 585.2 watts, including 10% margin. This is a significant consideration since an all TWT configuration permits the use of the BS 2 solar array.



# TRANSMITTER ASSEMBLY CHARACTERISTICS (BASELINE)



ITEM	VOL	QTY ACTIVE/STANDBY	UNIT WT	TOTAL WT	DAYTIME PWR WATTS	NIGHTTIME PWR WATTS
T SWITCHES, (COAXIAL, 6 GHz)	2.0	6/0	0.3	2.4	0	0
SWITCHES (20 GHz, WG)	2.0	4/0	0.5	2.0	0	0
T SWITCHES (WG, 20 GHz)	7.3	6	1.0	6.0	0	0
SWITCHES (COAXIAL, 6 GHz)	2.0	2/0	0.3	0.6	0	0
IFA, U/C, FILTERS	0.8	6/2	<b>5.3</b>	1.8	8	0
TWTA (40W)	536	4	12.0	48.0	518	24 *
IMPATT (40 W)	400	2	11.5	23.0	471	0
OUTPUT FILTER	1.2	4	0.1	0.4	0	0
VARIABLE ATTENUATOR	1.5	6	0.1	0.6	0	0
LO ASSEMBLY	120	1/1	2.0	2.0	6.0	<b>o</b>
MISC				8.7	74 - 37.9	3
				95.5 LB	818 - 416.9 **	27 W

ECLIPSE OPERATION

<sup>\*\*</sup> TRUNK-CPS MODE

#### LINK PERFORMANCE AND AVAILABILITY

Uplink and downlink budgets for the trunking stations are presented in the following charts as are link budgets for CPS operation with 27.5 MSPS and 110 MSPS stations. Link availability for both the trunking and CPS services are also estimated.

Leader Warrier



## LINK PERFORMANCE AND AVAILABILITY



TRUNKING LINK BUDGETS

CPS LINK BUDGETS

TRUNKING AND CPS LINK AVAILABILITY

#### TRUNKING LINK BUDGETS

Assuming a 200 watt earth station transmitter, a 10<sup>-4</sup> BER, and limited earth station antenna tracking capability, the uplink shows a 2.2 dB margin above the 18 dB fade margin required for the worst location, least receive antenna gain, which is Washington, DC.

The downlink shows a 6.9 dB extra margin above the 8 dB required. Under these conditions both links could fade by the required margins and link would still have about a 1 dB margin.

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# TRUNKING LINK BUDGETS



NOTES

UPLINK (28.75 GHZ)				NOTES
	(dBW)	:	23.0	200 W TRANSMITTER
ES TRANSMITTER POWER	(dB)	-	1.5	
ES TRANSMISSION LOSS	(dBi)	•	61, 0	5M ANT., 50% EFF.
ES ANTENNA GAIN ES ANTENNA POINTING LOSS	(dB)	:	●. 0	LIMITED TRACKING ANT.
	(dB)	:	213.5	
FREE SPACE LOSS	(dB)	:	0.6	
ATMOSPHERIC LOSS	(dBi)		51.4	CALCULATED, FOR DC, WORST CASE
S/C ANTENNA GAIN S/C ANTENNA POINTING LOSS	(dB)	:	2.0	CALCULATED
	(dB)	•	0.8	
S/C TRANSMISSION LOSS S/C SYSTEM NOISE TEMPERATURE	(dB°K)	:	30.1	
	(dBW/HZ°K)	:	228.6	
BOLTZMANN'S CONSTANT	(dB/HZ)	:	118.7	
RESULTANT C/NO REQUIRED FADE MARGIN	(dB)	:	18.0	
LINK FADED C/NO	(dB/HZ)	:	97.7	
LINK PADED C/NO	(42),			
DOWNLINK (18.95 GHZ)				
	(dBW)		16.0	40 WATTS
S/C TRANSMITTER POWER	(dB)		2.0	
S/C TRANSMISSION LOSS	(dBi)	•	50, 2	
S/C ANTENNA GAIN	(dB)	:	0.7	
S/C ANTENNA POINTING LOSS	(dB)	:	209.9	
FREE SPACE LOSS	(dB)	:	0.5	
ATMOSPHERIC LOSS	(dBi)	:	56.9	5M ANTENNA, 50% EFF.
ES ANTENNA GAIN	(dB)	:	0.0	LIMITED TRACKING, ANT.
ES ANTENNA POINTING LOSS	(dB°K)	:	28.4	
SYSTEM NOISE TEMPERATURE	(dB/HZ)	•	110.4	
RESULTANT C/NO	(dB)	:	8.0	
REQUIRED FADE MARGIN	(dB/HZ)	•	102.4	
LINK FADED C/NO	(db/iiz)	•		
W6 DECUMED	(dB)		8.4	10 <sup>-4</sup> BER
Eb/NO REQUIRED	(dB)		3.0	
RECEIVER DETECTION LOSS	(dBbps)	:	84.1	
DATA RATE	(dB/HZ)	•		
REQUIRED C/NO	(aprile)	-		

#### TRUNKING LINK AVAILABILITY

The values listed in the table are rain attenuations in the various zones with the indicated percentages of time. Thus, providing an 8 dB downlink fade margin means that in rain zone D3 the actual attenuation will be less than that value more than 99.5% of the time. The link then operates satisfactorily in the region to the right of the lines drawn among the attenuation values. On the scale shown the difference in availability for  $10^{-4}$  and  $10^{-6}$ BER is not distinguishable in rain zones D2, D3 and E.

Without space diversity the tandem link availability may be as low as 99% between stations in the D3 and E rain zones. With diversity sufficient to give independent fading, however, the availability approaches 99.99%.



# TRUNKING LINK AVAILABILITY



#### **DOWNLINK**

• f = 20 GHz	AVAILABILITY				
RAIN	99. 99 %	99. 95 %	99.9 %	99.5 %	99 %
ZONE					
В	13	1 6	4	1	1
C	20	8	. 5	1	1
<b>D1</b>	23	9	6	2	1
D2	28	12	18	3	1
D3	36	17	12	3	2
E	55	29	20 !	4	2
F	17	<u></u>	4	2	1

- 8 dB FADE MARGIN DASHED LINES: 10<sup>-6</sup> BER DOTTED LINES: 10<sup>-4</sup> BER

#### **UPLINK**

•	f = 30 GHz	AVAILABILITY					
	RA IN	99.99 %	99.95 %	99.9 %	99.5 %	99 %	
	ZONE	29	13	a	2	9	
	C	45	17	11	3	2	
	D1	50	21 1	14	4	2	
	D2 D3	63 80	28   39	$-\frac{18}{27}$	6 8	3 4	
	Ε	120	64	43	10	4	
	F	37	13	9	4	2	

• 18 db fade margin

#### CPS UPLINK BUDGET AT 27.5 MSPS

These link budgets compare the performance with and without FEC for a scanning antenna that steps in units of beam width (switch BFN) with those of antenna using a variable power divider BFN (VPD BFN) with which beams can be shaped to avoid low gain spots in the coverage areas.

Using a 20 watt earth station transmitter and the switch BFN, it is seen that the required rain margins can be provided only through the use of FEC which in effect means at least a 2:1 data rate reduction (another 3 dB increase in  $E_0/N_0$  is available by a further 2:1 data rate reduction for a total of 9.6 dB at one fourth the nominal data rate). The margins can be provided without FEC when the VPD BFN is used.



# CPS UPLINK BUDGET AT 27.5 MSPS



			SWITCH	BFN	VPD B	FN
			NO CODING	CODING	NO CODING	CODING
ES TRANSMITTER POWER	(dBW)	:	13.0			
ES TRANSMISSION LOSS	(dB)	:	1.5			
ES ANTENNA GAIN	(dBi)	:	56.1			
ES ANTENNA POINTING LOSS	(dB)	:	1.0			
FREE SPACE LOSS	(dB)	:	213.3			
ATMOSPHERIC LOSS	(dB)	:	0.6			
S/C ANTENNA GAIN AT BEN PORT	(dBi)		44.9*		50.0*	
S/C ANTENNA POINTING LOSS	(dB)	:	0.0*		0.0*	
S/C TRANSMISSION LOSS	(dB)	:	0.7		0.7	
S/C SYSTEM NOISE TEMPERATURE	(dB°K)	:	30.1		30.1	
BOLTZMANN'S CONSTANT	(dBW/HZ°K)	:	228.6		228.6	
RESULTANT C/NO	(dB/HZ)	:	95.4		103.0	
Eb/NO REQUIRED (10-4 BER)	(dB)	:	8.4		8.4	
RECEIVER DETECTION LOSS	(dB)	:	3.0		3.0	
CODING GAIN	(dB)	:	0.0	6. 2	0.0	6.8
DATA RATE	(dBbps)	:	74.4	****		
REQUIRED C/NO	(dB/HZ)	:	85.8	78.4	<b>.</b> 858	78.4
MARGIN	(dB)	:	9.6	17.0	17.2	24.6
REQUIRED MARGIN	(dB)	:	15.0	15.0	15.0	15.0
EXCESS MARGIN	(dB)	:	- 5.4	1.2	2.2	8,6

<sup>• 3</sup> METER ES ANTENNA

- BURST DATA RATE IS 27.5 MSPS
- CODING IS RATE 1/2, CONSTRAINT LENGTH 5, SOFT DECISION (2 BIT)
- CODING GAIN INCLUDES GAIN DUE TO 2:1 DATA RATE REDUCTION
- FREQUENCY IS 28.75 GHZ

<sup>\*</sup> WORST CASE INCLUDES POINTING LOSS

#### CPS UPLINK BUDGETS AT 110 MSPS

This case is similar to the previous one. Here a 30 watt earth station transmitter is assumed and, since the earth station uses a 5 meter antenna, limited tracking capability is assumed to eliminate earth station antenna pointing losses.



# CPS UPLINK BUDGET AT 110 MSPS



			SWITCH	H BFN	VPD BF	<u>N</u>
			NO CODING	CODING	NO CODING	CODING
ES TRANSMITTER POWER	(dBW)	:	14,,8		14.8	
ES TRANSMISSION LOSS	(dB)	<b>:</b>	1.5		1.5	
ES ANTENNA GAIN	(dBi)	•	60.5		60.5	
ES ANTENNA POINTING LOSS	(dB)		0, 0		0.0	
FREE SPACE LOSS	(dB)	:	213,3		213.3	
ATMOSPHERIC LOSS	(dB)	=	06		0.6	
S/C ANTENNA GAIN AT BEN PORT	(dBi)	:	44, 9*		50.0*	
S/C ANTENNA POINTING LOSS	(dB)	:	0 0*		0.0*	
S/C TRANSMISSION	(dB)	:	0.7		0.7	
S/C SYSTEM NOISE TEMPERATURE	(dB°K)	:	30.1		30.1	
BOLTZMANN'S CONSTANT	(dBW/HZ°K)	:	228.6		228.6	
RESULTANT C/NO	(dB/HZ)	:	102.6		107.7	
Eb/NO REQUIRED (10-4 BER)	(dB)	:	8.4		8.4	
RECEIVER DETECTION LOSS	(dB)	•	3.0		3.0	
CODING GAIN	(dB)	:	0.0	7.4	0.0	7.4
DATA RATE	(dBbps)	:	80.4		80.4	
REQUIRED C/NO	(dB/HZ)	<b>:</b>	91.8	84.4	91.8	84.4
MARGIN	(dB)	:	10.8	16.4	15.9	23.2
REQUIRED MARGIN	(dB)	2	15.0	15.0	15.0	15.0
EXCESS MARGIN	(dB)	*	- 4.2	1.4	0.9	8.8

o 5 METER ES ANTENNA

<sup>\*</sup> WORST CASE INCLUDES POINTING LOSS

BURST DATA RATE IS 110 MSPS

o CODING IS RATE 1/2, CONSTRAINT LENGTH:5, SOFT DECISION

o CODING GAIN INCLUDES GAIN DUE TO 2:1 DATA RATE REDUCTION

# CPS DOWNLINK BUDGET - 3M EARTH STATION

The 220 MSPS downlink to a 3M earth station can be supported by the spacecraft using either type of antenna (switch or VPD). The link budgets indicate that 20 watt satellite amplifiers are sufficient for both trunking and CPS provided coding is used.



# CPS DOWNLINK BUDGET 3M EARTH STATION



			SWITCH	BFN	VPD	BFN
			NO CODING	CODING	NO CODING	CODING
S/C TRANSMITTER POWER	(dBW)	:	16.0		16.0	
S/C TRANSMISSION	(dB)	:	2.0		2.0	
S/C ANTENNA GAIN AT BEN PORT	(dBi)	<b>:</b> .	46.7*		47.7*	
S/C ANTENNA POINTING LOSS	(dB)	:	0.0*		0.0*	
FREE SPACE LOSS	(dB)	:	209.7		209.7	
ATMOSPHERIC LOSS	(dB)	:	0.5		0.5	
ES ANTENNA GAIN	(dBi)	:	52.5		52.5	
ES ANTENNA POINTING LOSS	(dB)	:	0.3		0.3	
ES SYSTEM NOISE TEMPERATURE	(dB°K)	:	28.4		28.4	
BOLTZMANN'S CONSTANT	(dBW/HZ°K)		228.6		228.6	
RESULTANT C/NO	(dB/HZ)	:	102.9		103.9	
Eb/NO REQUIRED (10 <sup>-4</sup> BER)	(dB)	:	8.4			
RECEIVER DETECTION LOSS	(dB)	*	3.0			
CODING GAIN	(dB)	<b>.</b>	0.0	7. \$	0.0	7.4
DATA RATE	(dBbps)	*	83.4	<del></del>	83.4	
REQUIRED C/NO	(dB/HZ)	=	94.8	87.4	94.8	87.4
MARGIN	(dB)	. :	8.1	15.5	9.1	16.5
REQUIRED MARGIN	(dB)	<b>:</b>	6.0	6.0	6.0	6.0
EXCESS MARGIN	(dB)	:	2.1	9.5	3.1	10.5

o 3 METER ES ANTENNA

- O DATA BURST RATE IS 220 MSPS
- O CODING IS RATE 1/2, CONSTRAINT LENGTH 5, SOFT DECISION
- O CODING GAIN INCLUDES GAIN DUE TO 2:1 DATA RATE REDUCTION
- o FREQUENCY IS 18.95 GHZ

<sup>\*</sup> WORST CASE INCLUDES POINTING LOSS

# CPS DOWNLINK BUDGET 5M EARTH STATION

The 220 MSPS downlink to a 5m earth station can be supported by the spacecraft using either type of antenna (switch or VPD).



# CPS DOWNLINK BUDGET 5M EARTH STATION



			SWITCH	BFN	VPD	BFN
			NO CODING	CODING	NO CODING	CODING
S/C TRANSMITTER POWER	(dBW)	:	16.0		16.0	
S/C TRANSMISSION	(dB)	:	2.0		2.0	
S/C ANTENNA GAIN AT BFN PORT	(dBi)	:	46.7*		47.7*	
S/C ANTENNA POINTING LOSS	(dB)	<b>#</b>	0.0*		0.0*	
FREE SPACE LOSS	(dB)	:	209-7		209.7	
ATMOSPHERIC LOSS	(dB)	=	G. 5		0.5	
ES ANTENNA GAIN	(dBi)	:	56.9		56.9	
ES ANTENNA POINTING LOSS	(dB)	:	0-0		0.0	
ES SYSTEM NOISE TEMPERATURE	(dB°K)	ŧ.	28.4		28.4	
BOLTZMANN'S CONSTANT	(dBW/HZ°K)		228-6		228.6	
RESULTANT C/NO	(dB/HZ)	:	107-6		108.6	
Eb/NO REQUIRED (10-4 BER)	(dB)	:	8:. 4			
RECEIVER DETECTION LOSS	(dB)	:	3-0 -			
CODING GAIN	(dB)	•	Qi. O	7.4	0.0	7.4
DATA RATE	(dBbps)		83.4		83.₹	
REQUIRED C/NO	(dB/HZ)	:	94.8	87.4	94.8	87.4
MARGIN	(dB)	:	12.8	20.2	13.8	21.2
REQUIRED MARGIN	(dB)	:	6.0	6.0	6.0	6.0
EXCESS MARGIN	(dB)		6.8	14.2	7.8	15.2

o 5 METER ES ANTENNA WITH LIMITED TRACKING

<sup>\*</sup> WORST CASE AND INCLUDES POINTING LOSS

O DATA BURST RATE IS 220 MSPS

o CODING IS RATE 1/2, CONSTRAINT LENGTH 5, SOFT DECISION

CODING GAIN INCLUDES GAIN DUE TO 2:1 DATA RATE REDUCTION

o FREQUENCY IS 18.95 GHZ

#### CPS LINK AVAILABILITY

Assuming a 6 dB rain margin at  $10^{-6}$  BER, availabilities as shown are achieved in the downlink. Since the attenuation experienced rises rapidly with availability for the uplink, the two BER availabilities are not distinguishable on the chart.



# CPS LINKS AVAILABILITY



#### DOWNLINK

• f = 20 GHz	AVAILABILITY						
	99. 99 %	99.95 %	99.9 %	99.5 %	99 %		
ZCNE							
В	13	6	4	1	1		
C	20	1 8 -	5	1	1		
<b>D1</b>	23	1 9	6	2	1		
D2	28	12	8	3	1		
D3	36	17	12 i	3	2		
E	55	29	20	4	2		
<b>F</b>	17	6	4	2	1		

- 6 db fade margin Dashed lines 10<sup>-6</sup> ber Dotted lines: 10<sup>-4</sup> ber

#### **UPLINK**

	AVAILABILITY							
	99. 99 %	99.95 %	99.9 %	99.5 %	99 %			
ZONE								
В	29	13	9	3	2			
C	45	17	? 11	3	2			
<b>D1</b>	50	21	14	4	2			
D2	63	28	18	6	3			
D3	80	39	27	8	4			
Ε	120	64	43	10	4			
F	37	T 13		4	2			

15 db fade margin

#### CPS TANDEM LINK AVAILABILITY

Assuming uplink and downlink margins of 15 dB and 6 dB respectively, the link availabilities shown in the table result. In particular they get as low as 99.0% in rain zones D2, D3 and E. This assumes stations communicating in the same rain zone. Communication between rain zones will improve the poor availabilities and degrade the better ones. If all the margins shown previously to be available through the use of FEC and the VPD BFN is used to compensate rain fading then availabilities of about 99.5% can be obtained.



# CPS TANDEM LINK AVAILABILITY



RAIN ZONE	AVAILABILITY
В	99.9 %
C	99.9 %
D1	99.9 %
D2	<b>99.</b> 0 %
D3	<b>99.</b> 0 %
E	<b>99.</b> 0 %
F	99.9 %

- 6 db downlink fade margin
- 15 db uplink fade margin

#### OPTION 1 PAYLOAD

This optional payload provides the baseline trunking capacity but with reduced CPS capacity. Only one sector plus three isolated spots are scanned for CPS. The uplinks are two 27.5 MSPS links and only one 110 MSPS downlink is provided.

For this option the scan sector is taken to include the CONUS East Coast but is modified from the baseline to include the Cleveland area.



#### **OPTION 1 PAYLOAD**



- SINGLE SECTOR SCAN + 3 SPOTS
- TWO 27.5 MBPS UPLINKS
- SINGLE 110 MBPS DOWNLINK CHANNEL
- EXTEND SECTOR 2 COVERAGE TO INCLUDE CLEVELAND IN SCANNING BEAM

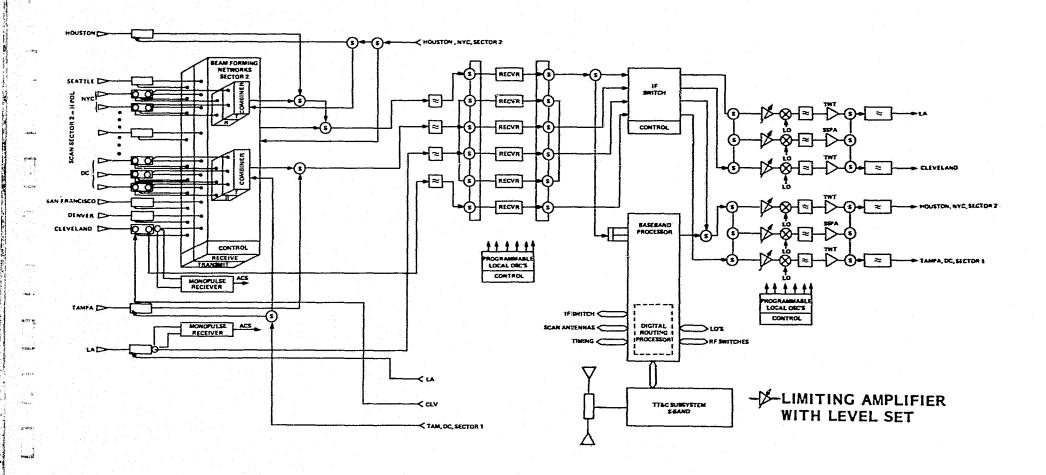
#### OPTION 1 PAYLOAD BLOCK DIAGRAM

Except for the elimination of one set of scanning beam feed horns and BFN's and miscellaneous switches the payload is similar to the baseline. However, due to the reduction in the number of FDMA channels, the BBP is considerably simplified.



# OPTION 1 PAYLOAD BLOCK DIAGRAM





## BASEBAND PROCESSOR FOR OPTION 1

Only one path through the processor is required for this option and the number of functional modules is reduced in each element if the path is reduced. For example, the soft demodulator sandwich need contain only two (rather than 5) demodulators and the other elements are similarly simplified. The baseband switch can be simplified to one element of the CLOS switch.

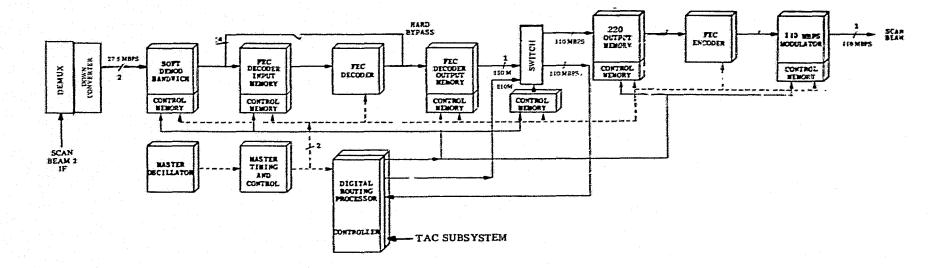
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## **BASEBAND PROCESSOR FOR OPTION 1**





#### ASSEMBLY CHANGE - OPTION 1

The estimated reduction of the payload weight and power are shown in the table. The processor changes are estimated under the assumption that the technology developments leading to an operational system are used for this option.



# ASSEMBLY CHANGE OPTION 1



ITEM	WT LB	POWER WATTS
ANTENNA (BFN + WG + FEED SUPPORT)	- 14	- 12
PROCESSOR	- 10. 9	- 47
SWITCHES (30/20 GHz, WG)	2.0	0
MIXER/LO ASS'Y	<u>-2.7</u>	
	- 29. 6 LB	- 59 WATTS

#### OPTION 2 PAYLOAD

This option adds a SS-FDMA CPS capability to the payload but leaves the baseline payload otherwise uncommended. To incorporate this addition the IF switch is extended to provide routing to the SS-FDMA assembly. This makes FDMA operation available to the trunking nodes as well as to the CPS sites, if desired.

Alternatively, separate IF switches can be used to route the fixed beam signals to the FDMA routing assembly as described in the Introduction to this Report.



## **OPTION 2 PAYLOAD**



- ADD SS-FDMA SUBSYSTEM TO BASELINE PAYLOAD
- EXTEND IF SWITCH TO 8 X 8 TO ROUTE CHANNELS TO SS-FDMA SUBSYSTEM
  - FDMA AVAILABLE TO TRUNKING AND CPS SITES

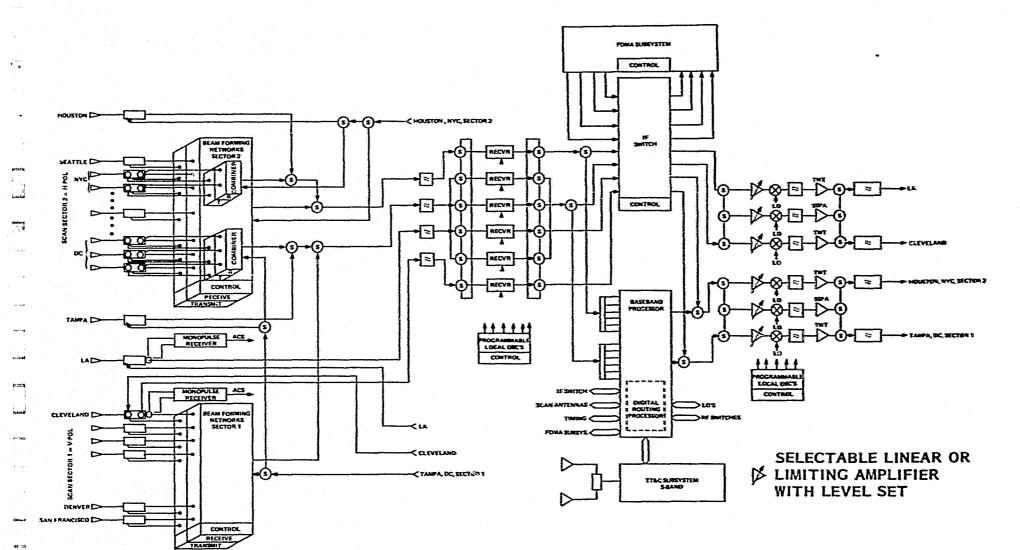
#### OPTION 2 PAYLOAD BLOCK DIAGRAM

The SS-FDMA assembly is added to the baseline payload and the IF SS-TDMA switch is extended to an 8 x 8 switch to incorporate the SS-FDMA assembly. Also, since multiple carriers will now access the transmitters, means must be provided for linearization when in the SS-FDMA mode. The TT&C capabilities must be extended to provide control of the SS-FDMA equipment. Other than these changes the payload is the same as for the baseline.



## OPTION 2 PAYLOAD BLOCK DIAGRAM





# OPTION 2 FDMA NARROWBAND CHANNELIZATION/SWITCHING ASSEMBLY (FIXED BEAM OPERATION)

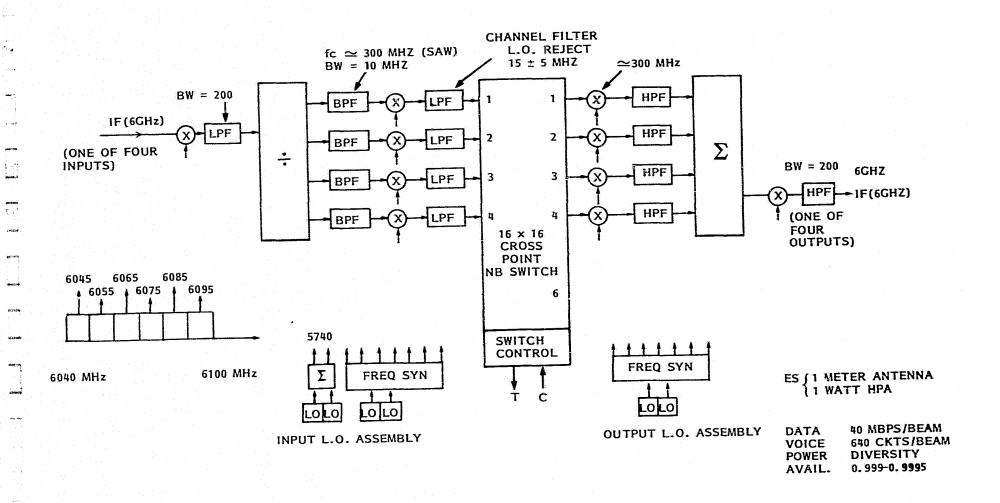
An adequate test of FDMA technology and systems can be achieved by including the proposed FDMA routing assembly for operation with the four fixed beams. Each of the four uplink beams is downconverted into the 300 MHz frequency band for 10 MHz channelization via SAW filters and full cross point switching. This permits four 10 MHz paths from each uplink to each of four downlinks with switch reconfigurability.

The fixed beam satellite G/T and EIRP are sufficient to support FDMA earth stations having antennas as small as one meter in conjunction with one watt HPA's. FDMA operation requires linearization of the TWT and/or IMPATT amplifiers to achieve acceptable intermodulation performance. This is accomplished by controlling the drive to the final amplifiers.



# FDMA NARROWBAND CHANNELIZATION/SWITCHING ASSEMBLY, OPTION 2 (FIXED BEAM OPERATION)





#### OPERATING CHARACTERISTICS SS-FDMA/CPS FIXED BEAM OPERATION

Using 32 kbps 4  $\phi$  CPSK delta modulation as a standard unit of capacity the baseline satellite performance is adequate to provide 640 such voice circuits or trunks, per beam for test and demonstration of FDMA by earth stations located within the fixed beams.

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To accomplish an attractive experiment full signalling and switching and automatic fade response via power diversity, using the MCG should be provided. Use of variable speed MODEMS in the range of 32 kbps to 128 kbps will enhance flexibility. Because power diversity operation with FDMA is effective in providing availability of 0.9995 or better the network can be designed to survive sun transmit outages.

GENERAL ELECTRIC	

## OPERATING CHARACTERISTICS SS-FDMA/CPS (FIXED BEAM OPERATION)



ELECTRIC		SPACE SYSTEMS DIVISION
FREQUENCY, GHz	20	30
POWER, dBw	+ 16	0
LOSSES, dB	- 1.5	- 2
BACK-OFF, dB	- 7. 0	0
ANTENNA GAIN, PEAK, dBi	51	<b>46.</b> 8
EDGE LOSS (AVERAGE), dB	- 1.5	- 0.5 (POINTING)
EIRP, dBw	57	44.3
MISC. LOSSES, dB	- 2.0	- 2
ANTENNA GAIN, dB	43.2 (IM)	51
RECEIVER SIGNAL, dBw	- 111.4	- 119.8
SYSTEM TEMP (CLEAR SKY), $dB > K$	28.0 (NF = 5 dB)	30
C/T dBw/ <sup>O</sup> K	- 139. 4	- 149.8
BW, $dB > 1 Hz^*$	43	
CNR, TOTAL, dB	46.2	<b>35.</b> 8
CNR <sub>TH</sub> , dB	18.5	(17.5 dB EXCESS)
NUMBER OF VOICE TRUNKS (PER BEAM)	640 (BANDWIDTH LIMITED)	

<sup>\* 40</sup> CPSK, ΔMOD, 32 KBPS

#### CNR (UP/DOWN) VERSUS FADE MARGIN

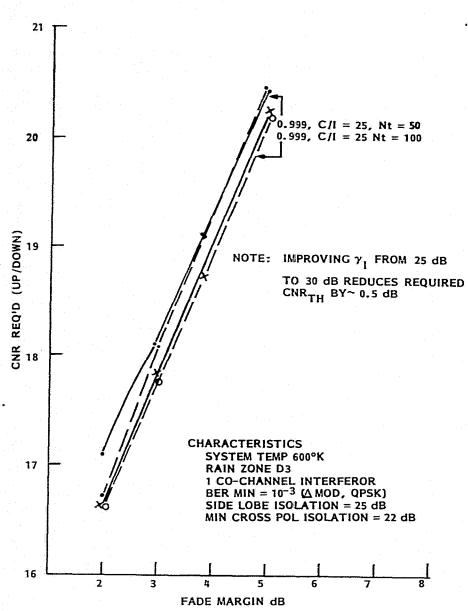
Fixed fade margin versus thermal CNR uplink or downlink is plotted to show typical power diversity operation with FDMA. In this system it is assumed that worst case cross polarization isolation and sidelobe isolation are used to minimize co-channel interference from neighboring beams.

The solid lines represent two assumptions with regard to numbers of carriers based on a total availability of 0.999 and an intermodulation ratio of 25 dB. Fixed margins of 3 - 4 dB corresponding to 18 - 19 dB carrier to noise ratios are indicated. Improving intermodulation to 30 dB (dashed lines) reduces thermal CNR requirements by only 0.5 dB, indicating that intermodulation at this value is not a particular problem. While not shown, calculations indicate that availabilities of 0.9995 are readily achievable for the assumed parameters but with somewhat higher CNR's.



# CNR (UP/DOWN) VS FADE MARGIN





#### OPTION 2 ASSEMBLY CHANGE

Addition of the FDMA system requires the addition of the channelization and switching "routing" assembly previously described, and eight coax switches to route the FDMA signals to the routing assembly. The receiver assembly weight is increased by 12.4 pounds and the power is increased by 56 watts. There are no changes required in the transmitter.

Note that if IMPATT amplifiers are to be used they must be designed to achieve the required linearity. No such requirement is presently imposed on the present IMPATT POC programs.



# ASSEMBLY CHANGE OPTION 2



VOL ITEM IN <sup>3</sup>	QTY ACTIVE/STANDBY	UNIT WT LB	TOTAL WT LB	DAYTIME PWR WATTS	NIGHTTIME PWR WATTS
FDMA ROUTING ASS'Y 105	1/0	8. 9	8.9	51	0
SWITCHES (6 GHz COAX) 2	8/0	0.3	2.4	0	0
MISC			1.1	5	
SUBTOTAL			12.4 LB	56 WATTS	

#### TELEMETRY AND COMMAND SUBSYSTEM

The proposed TT&C subsystem is based directly on the BS 2 TT&C subsystem, which evolved from the earlier BSE TT&C subsystem which has operated successfully in orbit. The subsystem proposed will use only the S-band components of the previous configurations, which provide adequate performance for the proposed mission with a smaller package. The general TT&C operation is the same as the BS 2 subsystem except operation will be continuous because the subsystem will constantly control the routing/switching of the uplink channels to the various beams, not required in the BS 2. The S-band operating parameters will be the same as BS 2:

Command: nominal 2100 MHz carrier with a 1 kbps rate with NRZ-L format; data at 200 bps; BER  $< 10^{-6}$ 

Telemetry: 240/221 times CMD frequency, 512 bps with Biphase-L format, 8-bit words; BER  $< 10^{-5}$ ;  $P_t = 850$  mW

Ranging: Tone/PM with four major tones (500 kHz to 20 kHz) and seven minor tones (100 kHz to 10 Hz)

The Command and Telemetry functions include switching for routing uplink signals on a particular beam to the correct downlink beam for the signal destination, not required for the BS 2. The switch signals are generated at the earth station, which determines the optimum trunk routing based on system channel demands. The current command rate is adequate for the initial system configuration, and may be updated for larger numbers of channel switches in the future.



#### TELEMETRY AND COMMAND SUBSYSTEM



- BASED ON THE BS-2 DESIGN
  - USED FOR S/C TELEMETRY COMMAND AND RANGING
  - PAYLOAD TELEMETRY AND CONTROL DATA IN TRUNKING OPERATION
- EARTH STATION
  - 5 METER DIAMETER ANTENNA, FIXED POINTING
  - 2 KW TRANSMITTER

#### TELEMETRY AND COMMAND SUBSYSTEM BLOCK DIAGRAM

The TT&C Transponder is a direct BS 2 transfer except only the S-band components are used (and Ku-band are eliminated). A dual antenna system coupled by a hydrid combiner insures meeting a requirement for at least a -7 dB gain over  $\pm 100^{\circ}$  angle from the yaw axis, and a 0 dB gain within  $\pm 10^{\circ}$ , (solar array deployed). For receive, a diplexer directs the signal to a hybrid which applies the input power to the two receivers; the output of the selected receiver, demodulator, and decoder is then used to control the satellite. The uplink signal requirement at the receiver input is: carrier acquisition threshold = -107.5 dBm; command threshold = -105.0 dBm.

The ranging tone signals from the phase lock receiver demodulator are routed directly to the operating transmitter for immediate re-transmission. A switch routes the active receiver output to the active transmitter. The delay time through the transponder is specified at  $1000 \pm 40$  nsec which permits adequate ranging accuracy to control the satellite.

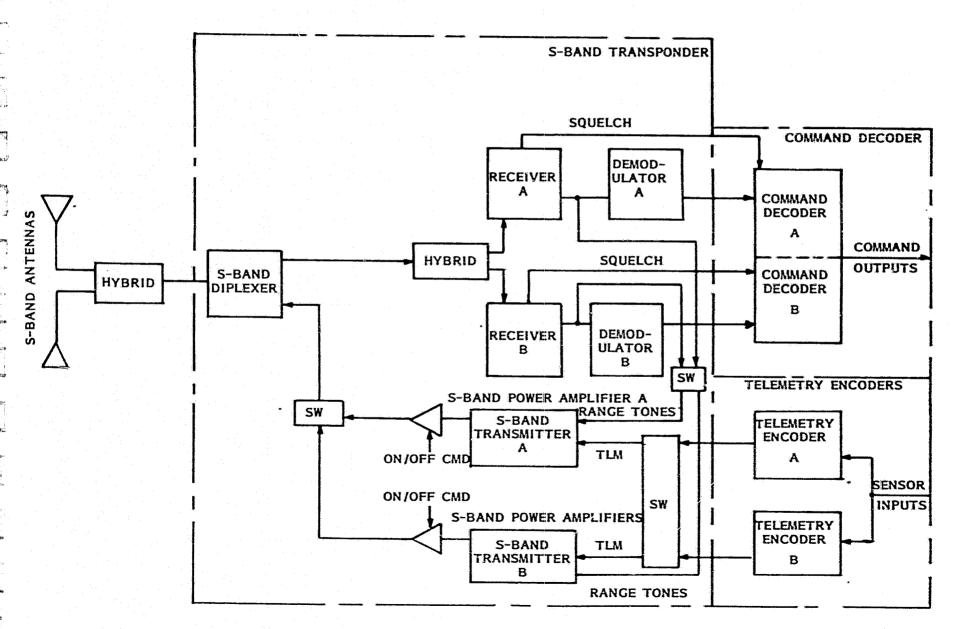
The transmitter unit, with redundancy, uses appropriate switches to select the encoder/transmitter channel. The telemetry data is PSK modulated onto a 190 kHz subcarrier which is applied, along with the ranging tones, to the transmitter phase modulator. Telemetry words are 8 bits in length, with 64 words per minor frame and 1024 words per major frame. The allocation of data for monitoring traffic routing and for monitoring satellite functions is still to be determined.

The TT&C subsystem is directly usable during launch as well as for normal operational functions in orbit.



## TELEMETRY AND COMMAND SUBSYSTEM BLOCK DIAGRAM





#### TELEMETRY AND COMMAND EARTH STATION (TAC)

The TAC provides the control signals for the satellite. For the proposed system, it will also provide user signal switching where trunk reconfiguration at the command rate is acceptable. The computer generates all commands in response to telemetry signals, user requirements, and orbit and control data from remote centers.

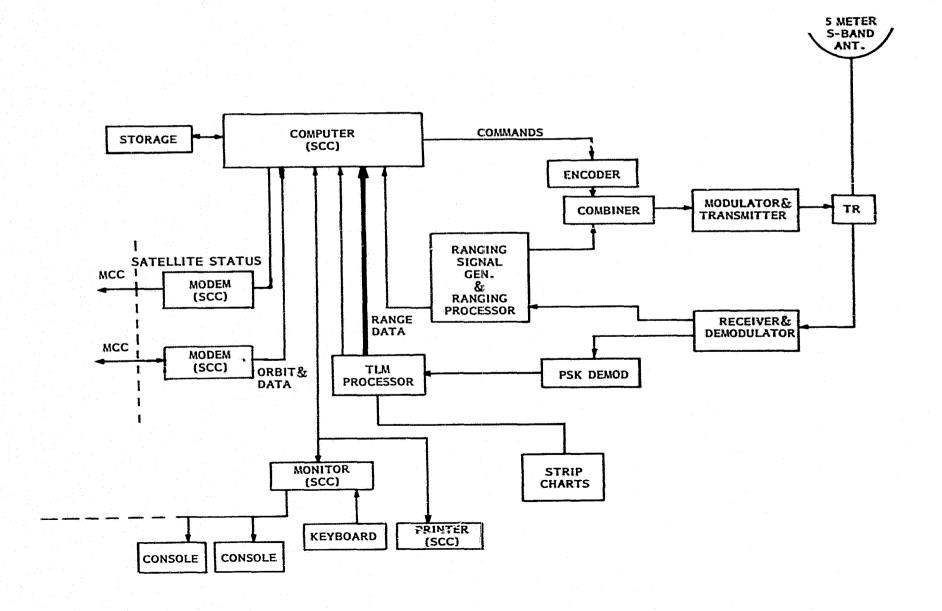
The block diagram incorporates the three major functions of the TAC: commands from the SCC computer through the encoder and transmitter; telemetry signals received and processed for use by the SCC computer and SCC operators; and ranging signals transmitted, received and processed. The SCC computer operation is monitored at several consoles within the SCC; provisions are included to insert local data and commands as well as to incorporate inputs from the two remote stations. GSFC will generate orbit data and provide the necessary information to generate satellite control commands; the SCC will provide inputs for the overall control of the satellite system. The additional function of controlling channel switching in the satellite is implicit in the Command and Telemetry operation. The very high speed switching which may be required for versatile TDMA operation should be provided by a separate subsystem not associated with the TT&C functioning.

The TAC uses a 2 kW transmitter with a five meter diameter antenna. The BER in the satellite is less than  $10^{-6}$  which is considered satisfactory for the proposed system. The telemetry receive BER is better than  $10^{-5}$ , also considered acceptable. Perhaps the significant difference in TT&C operation for this system as compared to the BS 2 is the addition of the switching commands which reduces the time available for TT&C functions; however, the data transfers are adequate for normal operations and, as emergency override, can be incorporated as required if additional TT&C data is required at any point in time.



# TELEMETRY AND COMMAND EARTH STATION









ANTENNA DESIGN CONSIDERATIONS

# ANTENNA DESIGN REQUIREMENTS

The starting design parameters of the antenna are in the antenna diameter of three meters and the needed peak gain of 51 dB, 3° off boresight. It was possible to optimize the antenna configuration to comply with this downlink requirement and use the scaled dimensions for the uplink antenna. However, it is shown in this report that the antenna can be optimized for operation at both the uplink and the downlink frequencies and, hence, save the weight of an additional uplink (one for transmit and one for receive). The transmit and receive polarization can be the same (using a diplexer to networks crowding problem is overcome by spreading the connections away behind the feeds which are located on a spherical surface.



# ANTENNA DESIGN REQUIREMENTS



- THREE METER ANTENNA FOR DOWNLINK OPERATION AT 20 GHz
- MINIMUM PEAK GAIN OF 51 dB, 30 OFF BORESIGHT
- THE UPLINK ANTENNA AT 30 GHz SHALL HAVE THE SAME HALF POWER BEAM-WIDTH AS THE DOWNLINK
- COMMON UTILIZATION OF THE TRUNKING AND CPS ELEMENTS WHERE POSSIBLE
- CLEVELAND OPERATION IN EITHER THE TRUNK OR CPS MODES WITH ADDITIONAL MONOPULSE CONTROL
- SIX NETWORK NODES WITH FOUR SIMULTANEOUSLY ACTIVE AND MONOPULSE OPERATION AT LOS ANGELES
- TWO SCANNING BEAMS EACH OCCUPYING TENTH OF CONUS
- EVALUATION OF WEIGHT AND POWER IMPACT WHEN USING ONLY ONE SECTOR AND THREE ADDITIONAL SCANNING SPOT BEAM LOCATIONS
- SCALABLE TO OPERATIONAL SYSTEM

#### KEY ANTENNA ISSUES FOR SSUS-D LAUNCHED Ka-BAND COMSAT SYSTEM

The issue of single reflector versus dual reflectors, as explained later, was narrowed down to consideration only of a single reflector using either Prime Force Fed (PFF) or a flat plate subreflector, dependent on the location of the antenna on the spacecraft. The preferable approach uses a single PFF reflector which saves the weight and complexity of the subreflector.

With regard to polarization the preferred approach uses orthogonal transmit/receive beams because orthomode couplers are easier to adjust and probably can be designed for lower insertion loss than can receive/transmit diplexing filters.

The three layer BFN design was marginal since the sector coverage beams could not be confined to eight or less feeds.

Simplifications in the feed arrangement made it possible to use VPDs without the need to have lossy variable phase shifters. The VPDs can be restricted to only 3 states which are sufficient to form singlets, doublets or triplets and hence achieve cross-over levels between the scanned beams at only -0.5 dB. Thus VPD's are the preferred approach.

The circularly polarized pilot signal needed for monopulse tracking simplifies the monopulse operation on the spacecraft. In this case the sum and difference "channels" are formed by multi modes within the horns thereby simplifying the hardware. It is planned to provide monopulse sensing of Cleveland and Los Angeles beacons thereby providing yaw information as well as pitch and roll.



# KEY ANTENNA ISSUES FOR SSUS-D LAUNCHED Ka-BAND COMSAT SYSTEM



CONFIGURATION:

ONE ANTENNA VS. TWO ANTENNAS

**OPTICS:** 

SINGLE REFLECTOR VS. DUAL REFLECTORS

POLARIZATION:

IDENTICAL TRANSMIT/RECEIVE VS. ORTHOGONAL TRANSMIT/RECEIVE

SCAN BEAM BFN:

3 LAYER VS. 4 LAYER

CONTROL ELEMENT: SWITCH VS. VPD/VPS

RF TRACKING:

CP VS. LP

## CONFIGURATION

This chart summarizes the advantages and disadvantages of single reflector versus dual reflector design approaches considering only direct ramifications to antenna performance.



#### CONFIGURATION



#### **ADVANTAGES**

#### **DISADVANTAGES**

#### **SINGLE REFLECTOR**

REQUIRES ONLY ONE OFTICAL COMPONENT

LATERAL DIMENSION OF OPTICS IS SMALLER

RESULTS IN LESS WEIGHT

AXIAL DIMENSION OF OPTICS IS LARGER

FOR THE SAME EQUIVALENT F/D

FEED LENGTH ADDS TO OVERALL AXIAL

LENGTH OF OPTICS

FEED AND MAIN REFLECTOR ARE SEPARATED

BY LARGE DISTANCE, WHICH MAY REQUIRE LONG W.G. RUN IN CERTAIN CONFIGURATIONS

#### **DUAL REFLECTOR**

AXIAL DIMENSION OF OPTICS IS SMALLER

FEED IS AT MORE CONVENIENT LOCATION

IT IS POSSIBLE TO USE SUBREFLECTOR FOR POLARIZATION COMBINATION OR DIPLEXING

RMS SURFACE INACCURACIES OF THE TWO

REFLECTORS COMBINE

LATERAL DIMENSION OF OPTICS IS LARGER WITH ACCEPTABLE SUBREFLECTOR AND FEED

HORN APERTURE DIMENSIONS

OPTICAL ALIGNMENT IS MORE DIFFICULT

SPILLOVER RADIATION (DIFFRACTION) IS IN

DIRECTION OF COVERAGE RANGE

ELECTRICAL PERFORMANCE FOR LARGE SCAN

ANGLE IS POORER

#### OPTICS

This chart summarizes the advantages and disadvantages of using one reflector versus two reflectors.



#### **OPTICS**



# **ADVANTAGES**

## DISADVANTAGES

## ONE ANTENNA

LESS VOLUME.

LESS WEIGHT.

SINGLE DEPLOYMENT.

30 GHz AVERAGE GAIN IS HIGHER.

FOR RF TRACKING IT REQUIRES ONLY 1

TRACKING CIRCUIT.

MORE CROWDED FEED CIRCUIT.

ABOUT TWICE AS MANY BFN COMPONENTS.

LOWER 30 GHz CONTOUR GAIN.

ABOUT HALF FRAME TIME PER BEAM POSITION.

LARGER 30 GHz GAIN SLOPE.

## TWO ANTENNAS

TRANSMIT AND RECEIVE FEEDS ARE PHYSICALLY SEPARATED.

CONTOUR GAIN CAN BE OPTIMIZED FOR

**BOTH BANDS.** 

NO DIPLEXER IS REQUIRED.

MORE VOLUME REQUIREMENT RESULTS IN

COMPROMISED GEOMETRY.

MORE WEIGHT.

DUAL DEPLOYMENT.

This chart summarizes the advantages and disadvantages of using a 3 layer BFN versus a 4 layer BFN.



LONGER DWELL TIME.

#### BFN



## **ADVANTAGES**

#### DISADVANTAGES

## 3 LAYERS PER SCANNING BEAM

SIMPLER MICROWAVE AND CONTROL CIRCUIT. ALLOWS MINIMUM CELL SIZE OF  $\alpha \approx 0.5^{\circ}$  ONLY.

SMALLER VOLUME WEIGHT AND COST. PEAK AND CONTOUR GAIN IS LOWER.

OPTIMUM REFLECTOR DIAMETER IS SMALLER.

# 4 LAYERS PER SCANNING BEAM

ALLOWS MINIMUM CELL SIZE OF  $\alpha \approx 0.35^{\circ}$ THUS IT HAS MORE TRAFFIC MATCHING
FLEXIBILITY.

HAS LARGER PEAK AND CONTOUR GAIN.

REQUIRES TWICE AS MANY COMPONENTS THAN 3 LAYER SYSTEM.

RESULTS IN HALF DWELL TIME RELATIVE TO 3 LAYER SYSTEM.

MORE LOSSY.

#### CONTROL ELEMENT

This chart summarizes the advantages and disadvantages of using switches for scan control versus VPD's.

Variable phase shifters (VPS) also are considered but analysis indicates these are not needed.

The Williams



#### **CONTROL ELEMENT**



## **ADVANTAGES**

## DISADVANTAGES

## SWITCH

SIMPLE.

2 STATE CONTROL

LOWEST LOSS.

SMALLEST VOLUME.

SMALLEST WEIGHT.

FASTEST RESPONSE.

CAPABLE OF SINGLET FORMATION ONLY.

LOWEST GAIN AT TRIPLE CROSSOVERS

#### VPD/VPS

ALLOWS FORMATION OF DOUBLETS, TRIPLETS VPD IS MADE UP OF 4 COMPONENTS, 2 OR LOW SIDELOBE SPOT BEAMS

FOR 2 REFLECTOR CASE IT IMPROVES MINIMUM CONTOUR GAIN BY ABOUT 1 DB

FOR 1 REFLECTOR CASE IT COULD INCREASE MINIMUM CONTOUR GAIN BY ABOUT 1 DB ON DOWNLINK AND 5 dB ON UPLINK

OF WHICH ARE VARIABLE

VPS/VPS IS ABOUT TWICE AS LOSSY AS SWITCH

FLEXIBLE USE REQUIRES VPS WHICH IN-CREASES SWITCHING TIME AND INCREASES LOSS.

LOSS INCREASE DUE TO VPS IS ABOUT 1 DB.

INCREASED WEIGHT, VOLUME AND POWER CONSUMPTION

#### POLARIZATION

This chart compares the use of identical versus orthogonal transmit/receive polarizations. The orthogonally polarized case is clearly preferred.



#### **POLARIZATION**



# IDENTICAL TRANSMIT/RECEIVE POLARIZATION

ORTHOGONAL TRANSMIT/RECEIVE POLARIZATION

REQUIRES DIPLEXERS WITH LARGE
ISOLATION AND POWER HANDLING BOTH
ON SPACECRAFT AND GROUND.

REQUIRES ORTHOGONAL COUPLER AND POSSIBLE ADDITIONAL FILTERS, BUT HAS LOWER LOSS AND SIMPLER DESIGN.

#### RF TRACKING

The single horn approach in which sum and difference "channels" are formed by multi modes within the horn considerably simplifies the satellite circuitry and is the preferred design even though a circularly polarized beacon is needed. This approach also was used for BSE and is being implemented on BS-II.



# **RFTRACKING**



CP

ALLOWS SIMPLE MONOPULSE COUPLER USING 1 HORN.

LP

NEEDS A MINIMUM OF 3 AND POSSIBLY 4 HORNS FOR MONO-PULSE TRACKING.

# BEAM TOPOLOGY PLAN FOR $\alpha = 0.5^{\circ}$

With this large cell size it was not possible to reduce the number of beams in each zone to eight, which is the maximum needed for a three level BFN.

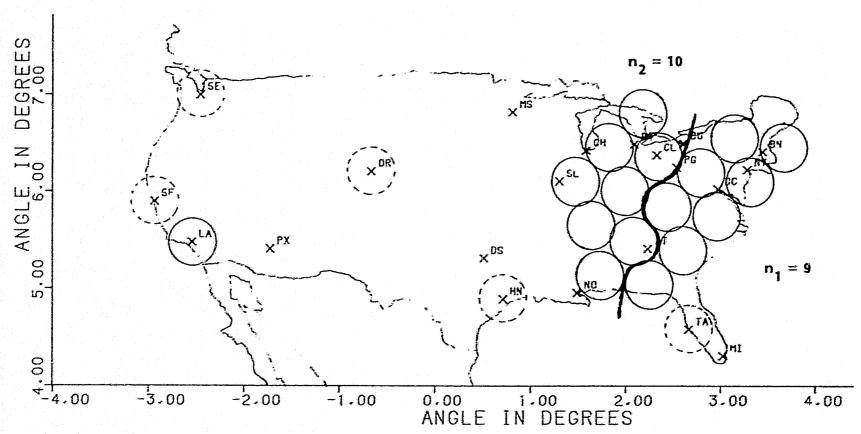


# BEAM TOPOLOGY PLAN FOR $\alpha = 0.5^{\circ}$



# 100.0 DEG WEST

0.50-0.50 CELL



# BEAM TOPOLOGY PLAN FOR $\alpha = 0.45^{\circ}$

This plan is very similar to the 0.50 plan.

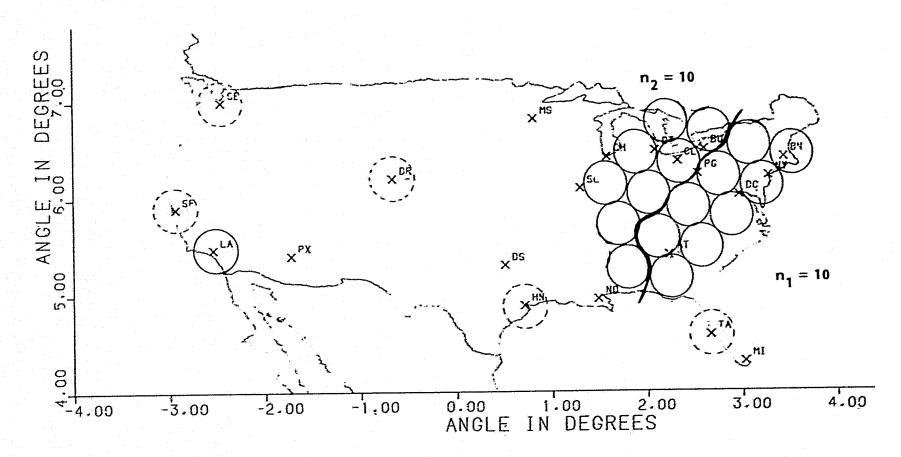


# BEAM TOPOLOGY PLAN FOR $\alpha = 0.45^{\circ}$



# 100.0 DEG WEST

0.45-0.45 CELL



# BEAM TOPOLOGY PLAN FOR $\alpha = 0.4^{\circ}$

This plan favors the optimization of the downlink, using the one reflector concept. The uplink signal level suffers only at the triplet intersection midpoint, when switching is used for scanning.

The situation is considerably improved by the use of VPD's.

A TOWN GOODS



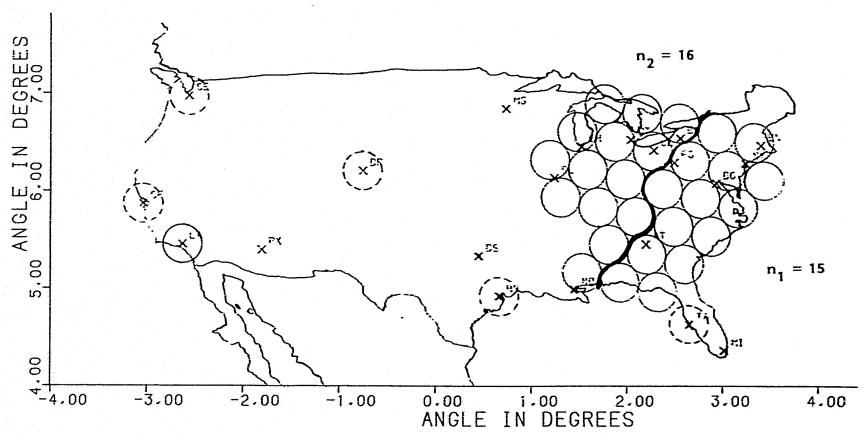
TELL ACTION

# BEAM TOPOLOGY PLAN FOR $\alpha = 0.4^{\circ}$



# 100.0 DEG WEST

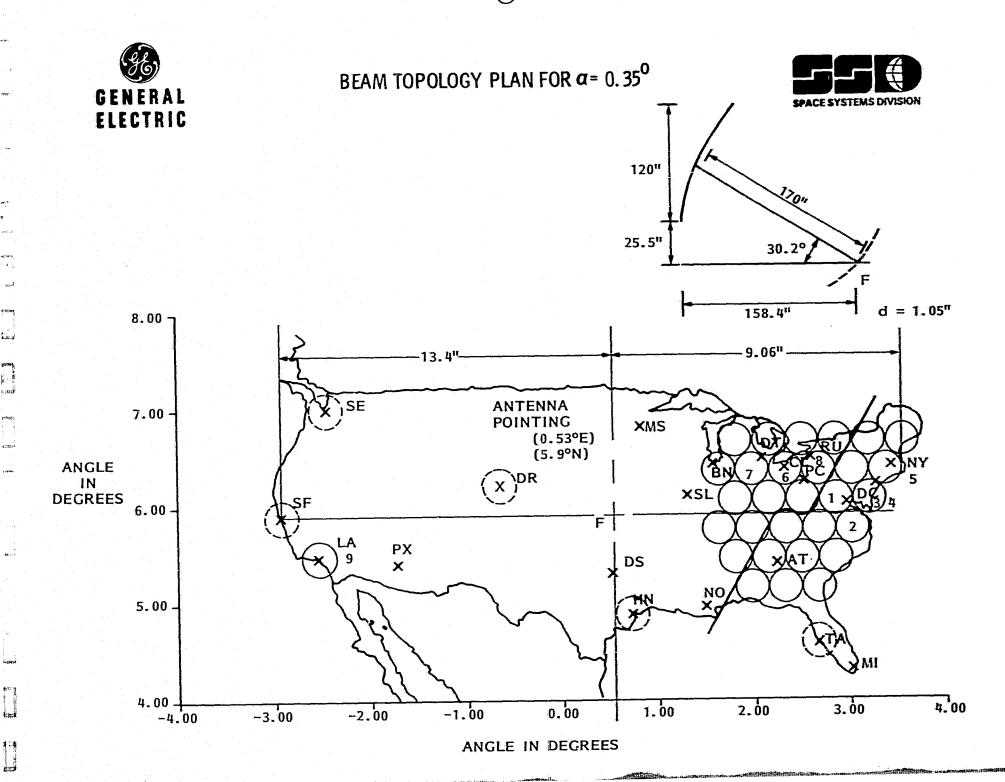
0.40-0.40 CELL



#### BEAM TOPOLOGY PLAN FOR $\alpha = 0.35^{\circ}$

This plan favors the uplink performance at the expense of approximately half a dB in the downlink.

Dimensions are given for the size of the feed horn layout and the configuration of the reflector.



# BEAM TOPOLOGY PLAN FOR $\alpha = 0.35^{\circ}$

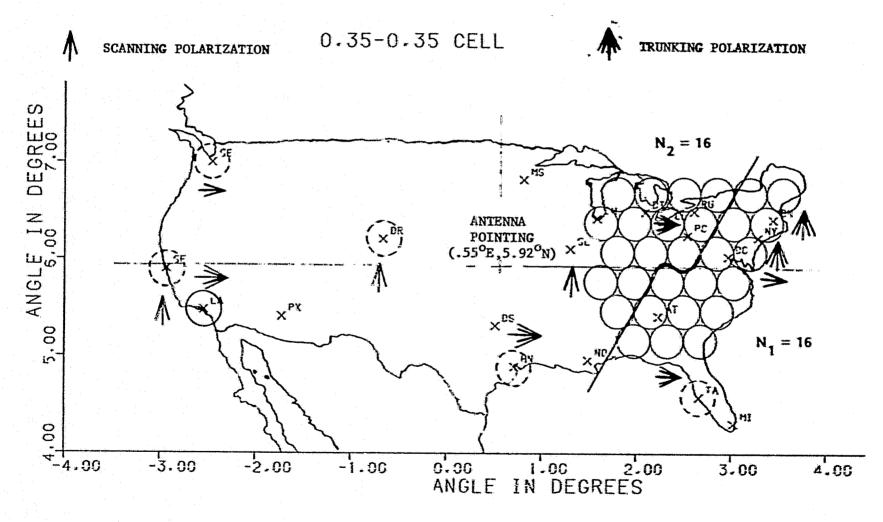
This chart shows the selected polarizations of the scan and the spot beams.



# BEAM TOPOLOGY PLAN FOR $\alpha = 0.35^{\circ}$



# 100.0 DEG WEST



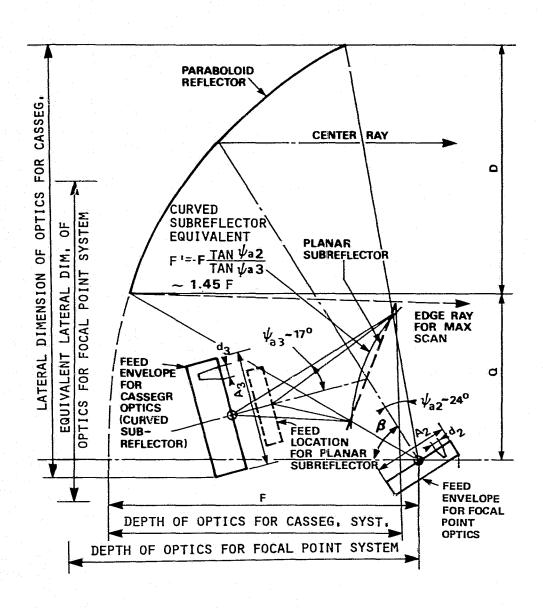
#### BASIC GEOMETRICAL CHARACTERISTICS OF SINGLE AND DUAL REFLECTOR OFFSET FED OPTICS

This geometrical presentation shows the complexity of using Cassegrainian arrangements, and the increased dimensions of the feed cluster. Note that while the front to back overall dimension is reduced over that of the PFF the reflector height is increased substantially. A flat subreflector (or nearly flat) is a preferred choice in this arrangement.



# BASIC GEOMETRICAL CHARACTERISTICS OF SINGLE AND DUAL REFLECTOR OFFSET FED OPTICS





### ANTENNA EFFICIENCY VERSUS SCAN ANGLE

This chart summarizes some typical beam and scan efficiencies of different offset antenna configurations. The parameters are the F/D ratio, Q/D (which is the vertix offset normalized to the reflector diameter),  $D_{\lambda}$  (the diameter wavelength ratio),  $\theta_{\rm m}$  (the maximum scan angle) and  $\alpha$  (cell size beam width).

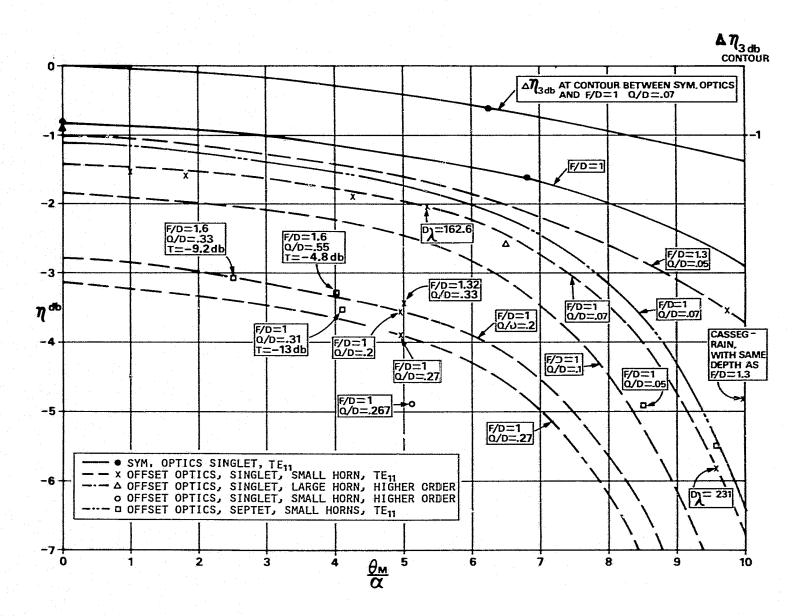
Note the range of the edge taper T which effects efficiency.



Ch. Lingue Williams

#### ANTENNA EFFICIENCY VS. SCAN ANGLE





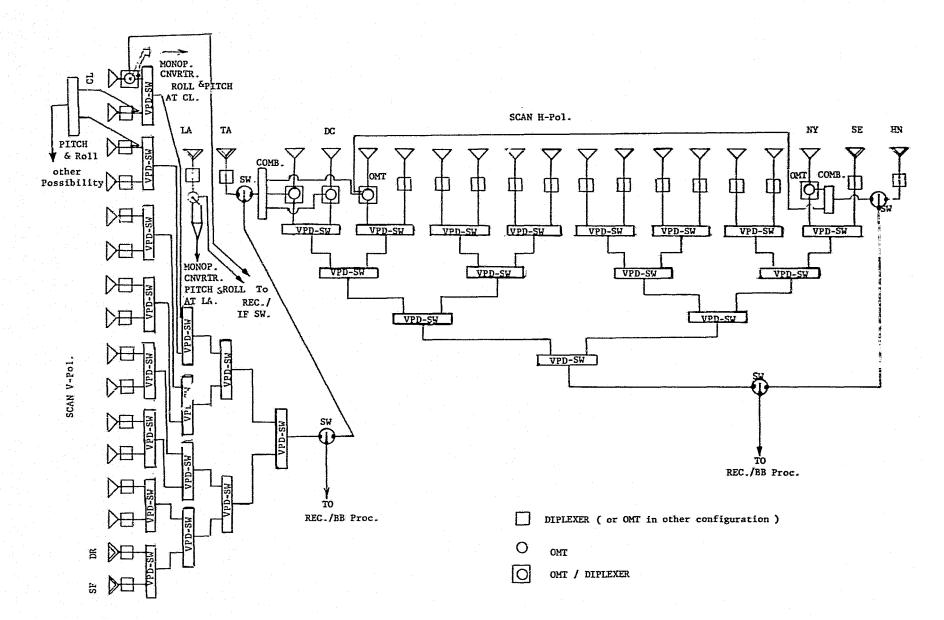
#### RECEIVE FUNCTION FEED NETWORK

This diagram describes the BFN network for forming two sector scan beams and six fixed spot beams. 16 horns are used for each sector scan plus separate horns for Houston, Los Angeles and Tampa. Note that New York, Washington and Cleveland share horns with the scanning antennas.



# RECEIVE FUNCTION FEED NETWORK (TRANSMIT NETWORK USES SAME HORNS)





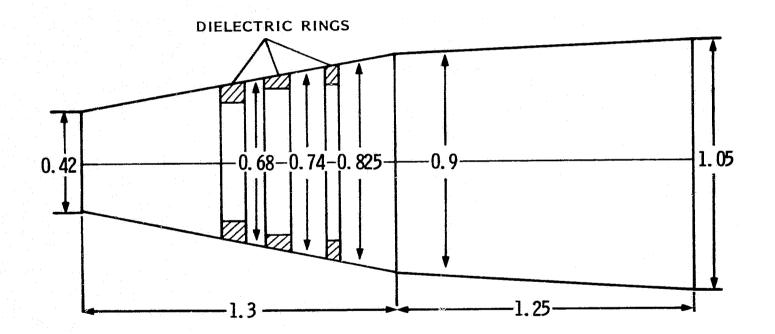
#### GEOMETRY OF MULTIMODE HORN FOR 55% BANDWIDTH

This configuration is scaled from a developed horn which is built by General Electric, Valley Forge, for INTELSAT and operates at C-band (6 GHz-band). It operates using circularly polarized signals. Such a horn, when used for this application at Ka-band, operates exactly as scaled when used in clusters of triplets. The clustering also reduces the crosspol of the offset reflector, as explained later. For singlet operation a TM01 mode or the TE21 mode is added which reduces the linearly polarized cross-pol of the offset reflector.



### GEOMETRY OF MULTIMODE HORN FOR 55% BANDWIDTH





### MEASURED PATTERNS OF WIDEBAND REDIRECTING ELEMENT FOR SINGLE REFLECTOR OPTICS

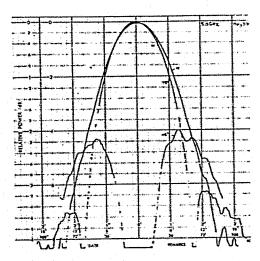
These are the patterns of the wideband horn which is scaled in the previous chart.



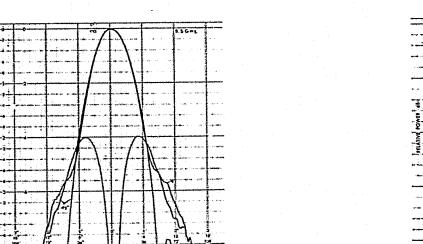
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## MEASURED PATTERNS OF WIDEBAND REDIRECTING ELEMENT FOR SINGLE REFLECTOR OPTICS

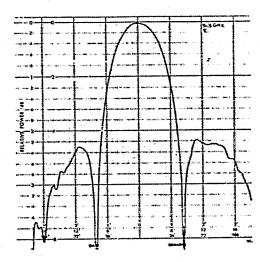




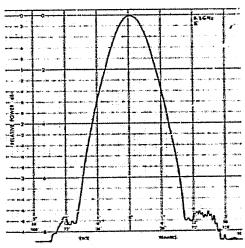
MEASURED PATTERN OF BROADBAND HORN, H AND 45° PLANE, 5.3 GHz. (SCALED 19.1 GHz.)



MEASURED PATTERN OF BROADBAND HORN, H AND 45° PLANE, 8.3 GHz. (SCALED 30 GHz.)



MEASURED PATTERN OF BROADBAND HORN, E PLANE, 5.3 GHz. (SCALED 19.1 GHz.)



MEASURED PATTERN OF BROADBAND HORN, H AND 45° PLANE, 8.3 GHz. (SCALED 30 GHz.)

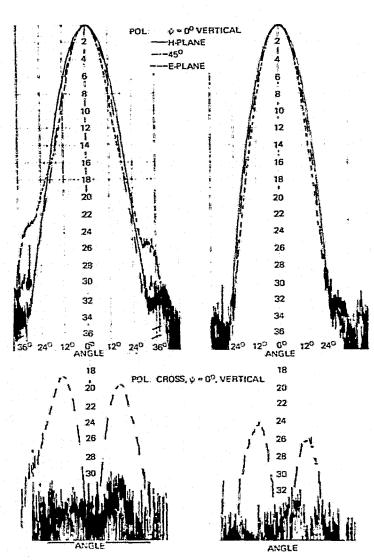
# MEASURED PATTERNS OF WIDEBAND RADIATING ELEMENT FOR DUAL REFLECTOR OPTICS

These patterns are scaled from a similar wideband multimode horn which is used in a Cassegrainian earth station antenna.

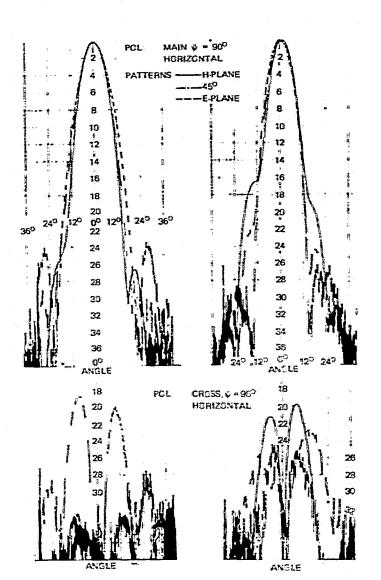


# MEASURED PATTERNS OF WIDE BAND RADIATING ELEMENT FOR DUAL REFLECTOR OPTICS





MEASURED PATTERN OF DUAL FREQUENCY BAND MULTIMODE HORN, 17.7 GHz (SCALED).



MEASURED PATTERN OF DUAL FREQUENCY BAND MULTIMODE HORN, 28.3 GHz (SCALED).

#### WIDEBAND FEED COMPONENTS

These are photographs of a wideband orthocoupler and a wideband diplexer which operate at C-band. The orthocoupler was built for INTELSAT and its two ports handle the uplink and the downlink (each on one port).

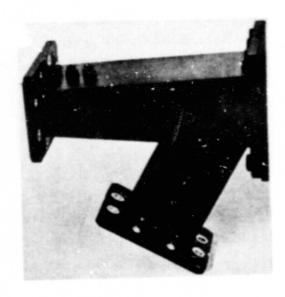


### WIDEBAND FEED COMPONENTS

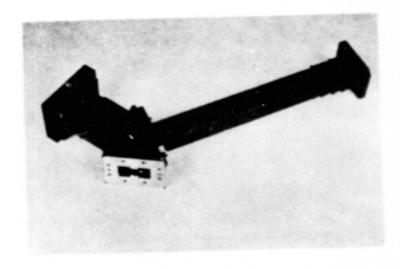


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8



ORTHOCOUPLER



DIPLEXER

#### ACHIEVABLE GAIN CHARACTERISTICS FOR SPOT BEAMS

The dB numbers are the evaluated insertion loss of the feed network based on the component losses previously tabulated. These are subject to improvements by a few tenths of a dB as switches and components improve by continuing development. The worst case gains are "boxed in." The RF gain numbers (G<sub>0</sub>) are as shown on the projected spot beam charts at the end of this section.



## ACHIEVABLE GAIN CHARACTERISTICS FOR SPOT BEAMS



## (1 ANTENNA CONFIGURATION, d = 1.05 IN, D = 120 IN)

<u>~</u>			18. 95 GHz			28.75 GHz	
	CITY	G <sub>o</sub> dB	dB	G dB	G <sub>o</sub> dB	dB	GqB
V	CL	53.00	0.65	52.35	57.00	1.00	56.00
	NY	51.70	1.55	50. 15	<b>54.</b> 10	2. 20	51.90
	DC	51. 80	1.00	50. 80	52.70	1.30	51. 40
	LA	<b>53. 1</b> 0	0.65	52. 45	55.00	1.00	54. 00
	HN	<b>53.</b> 10	1. 15	51.95	55.00	1.70	53.30
	TA	53. 10	1. 15	51.95	55. 00	1.70	53.30

# ACHIEVABLE GAIN CHARACTERISTICS WITH VARIOUS SCANNING BEAM ANTENNA ALTERNATIVES

In this chart a comparison is made between one and two reflector approaches using either scanning switches or VPD/ VPS.  $G_{po}$  is the peak RF gain of the beam,  $G_{co}$  is the minimum contour gain (or edge of cell gain) based on slightly deformed scanned beams,  $G_{p}$  is the peak gain including feed network losses,  $G_{c}$  is the minimum contour gain including feed network losses and  $\alpha_{circ}$  is the assumed feed network losses. The shown losses are conservative numbers based on available data. Also note that the minimum contour levels for the triplets does not take into consideration the overlap assumption (which improves these levels considerably).

4

Recent reports from EMS (Atlanta) indicate lower insertion losses for the ferrite components (VPDs and switches). Their reported VPD loss of 0.38 dB (maximum) at 20 GHz and 0.42 dB (maximum) at 30 GHz (with the assumption that the VPS is not necessary lowers the 3.2 dB loss (at 20 GHz) to 2 dB and the 4.0 dB loss (at 30 GHz) to 2.4 dB. Also, the switching concept loss is lowered by 0.4 dB (1 dB instead of 1.4 dB).



# ACHIEVABLE GAIN CHARACTERISTICS WITH VARIOUS SCANNING BEAM ANTENNA ALTERNATIVES



#### **ASSUMPTIONS**

 $a = 0.5^{\circ}$ , D = 2.9 m FOR 1 ANTENNA, D = 2.9 m/1.93 m FOR 2 ANTENNAS F/D = 1.3

	SWI	ТСН	VPD/VPS		
BFN LOSS (dB)	20 GHz	30 GHz	20 GHz	30 GHz	
	1.4	1.8	3.2	4.0	

ALTERNATIVES: 1/2 ANTENNA, SWITCH/VPD

MAX. BEAM SCAN

	NO. OF ANTENNAS			l				2	\$
	BFN CONFIGURATION	SWI	TCH	VPD/	VPS	SWIT	ГСН	VPD/	VPS
	FREQUENCY BAND, GHZ	20	30	20	30	20	30	20	30
FOR SINGLET BEAM	$^{\eta}$ PEAK, dB $^{\eta}$ CONT., dB	- 3.74 - 7.34	- 4.44 -10.94			- 3.74 - 7.34	- 3.74 - 7.94		
FOR TR IPLET BEAM	η PEAK, dB η CONT., dB			- 4.91 - 5.83	- 6.21 - 8.83			- 4.91 - 5.83	- 5.21 - 5.83
a <sub>CIRC</sub>	, 48	1.6	2.0	3.4	4.2	1.4	1.8	3.2	4.0
	G <sub>po</sub> , dB	51. 93	54.75	50, 76	52.98	51. 93	51, 93	50.76	50.46
	G <sub>co</sub> , dB	48. 33	48.25	49.84	50.36	48, 33	47.73	49.84	49. 84
	G <sub>p</sub> , dB	50, 33	52.75	47.36	48. 78	50,53	50.13	47.56	46.46
	G <sub>c</sub> , dB	46.73	46.25	46. 44	46.16	46. 93	45.93	50, 04	45.84

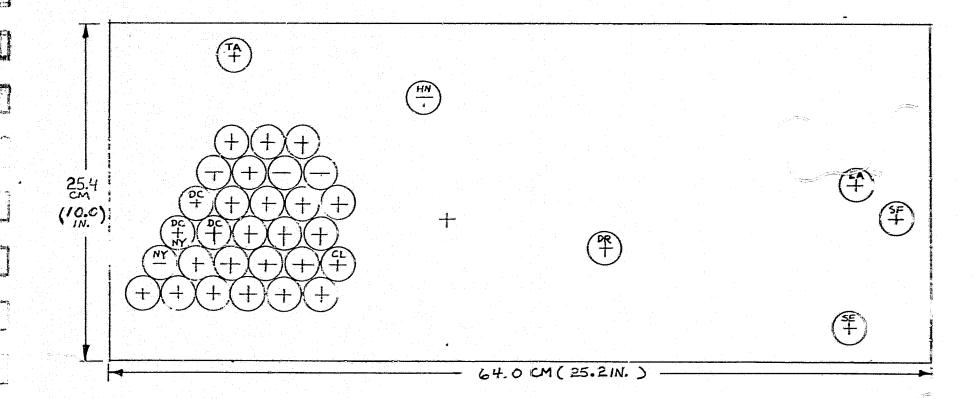
## FRONT VIEW OF FEED APERTURES ( $\alpha = 0.35^{\circ}$ , 1 ANTENNA CONFIGURATION)

This view is a mirror image of the radiation beam footprints previously shown for  $\alpha=0.35^{\circ}$ . The feed size corresponding to this cell size is 1.05". The feed apertures are located on a spherical surface, with the focal point of the reflector located on this surface nearer to the eastern coverage zone. The center of the spherical surface is on the reflector at the location coinciding with the center axis of the boresight radiating aperture. The outer dimensions of the feed carrying assembly for CONUS coverage is  $10^{\circ}$  x  $25.2^{\circ}$ .



# FRONT VIEW OF FEED APERTURES ( $a = 0.35^{\circ}$ , 1 ANTENNA CONFIGURATION)





## SIDE VIEW OF FEED CIRCUIT ( $\alpha = 0.35^{\circ}$ , 1 REFLECTOR CONFIGURATION)

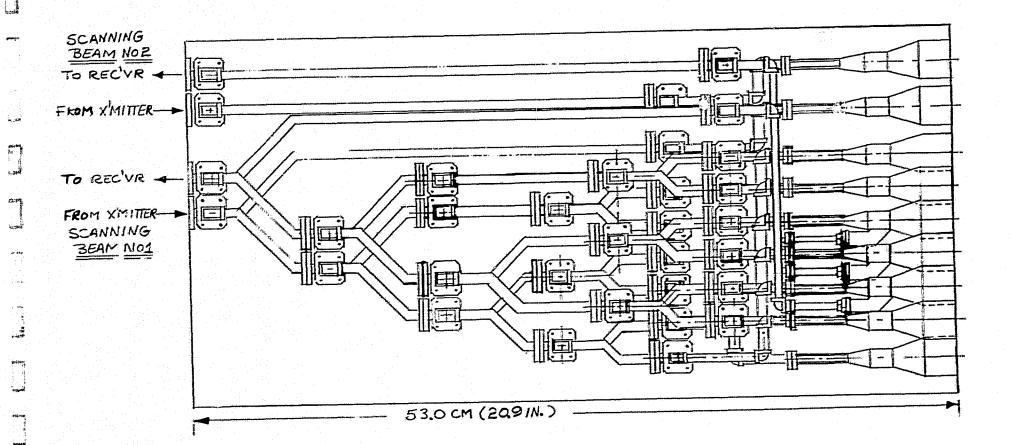
This side view shows some details of the layout of the feed horns for the 0.35° cell size, containing 35 horns, of which 32 are for scanning. The other three plus five of the scanning horns (shared for trunking) are used for spot beams directed respectively to Los Angeles, Houston, Tampa, Cleveland, New York and Washington, D.C. Only one of these horns is used for three functions, e.g., shared in the spot beams of New York and Washington, D.C. as well as for scanning. New York and Washington, D.C. ports are separated by a multiplexer on the same polarization port of this feed and the scanning beam is on the other polarization. Consequently this feed has four ports. Two ports are for one polarization at 20 GHz and 30 GHz and the other two are for the other polarization at 20 GHz and 30 GHz. Two of the ports of the vertical polarization are attached to multiplexers to generate the four ports handling T<sub>x</sub> and R<sub>x</sub> functions for D.C. and NY.

The horns are drawn here, for simplicity, with their apertures on a flat plane instead of a spherical surface. This demonstrates the capability to fit all the associated components even when the horns are on a flat surface. Eventually the scanning beam ports converge again to the four ports shown to the left of this drawing.



# SIDE VIEW OF FEED CIRCUIT (a = 0.35°, 1 REFLECTOR CONFIGURATION)





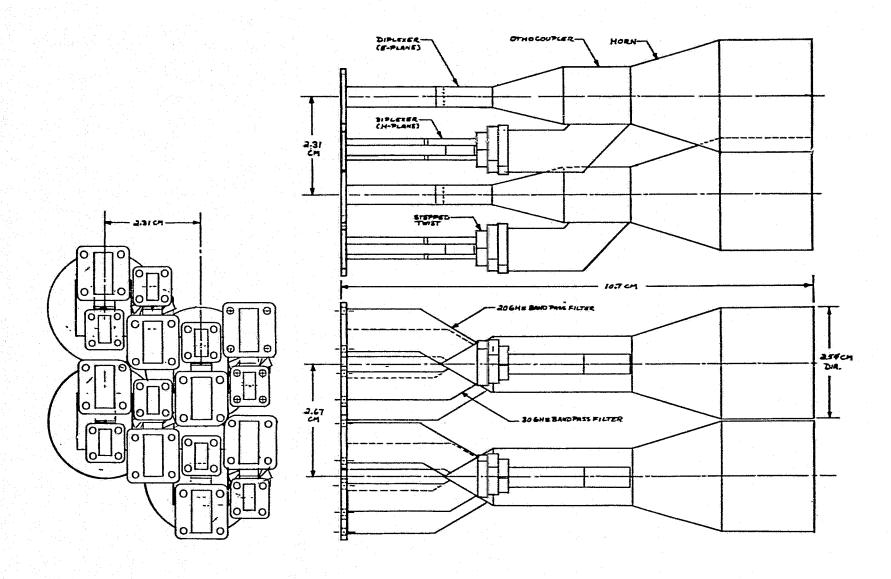
### TYPICAL PART OF THE FEED CLUSTER ASSEMBLY

This drawing shows more details of the feed connections in two planar views. In this arrangement the transmit and receive functions are orthogonally polarized.



### TYPICAL PART OF THE FEED CLUSTER ASSEMBLY





## TYPICAL LAYOUT OF FEED ASSEMBLY USING VPD/VPS FOR 1 REFLECTOR CONFIGURATION (5 LAYER IMPLEMENTATION)

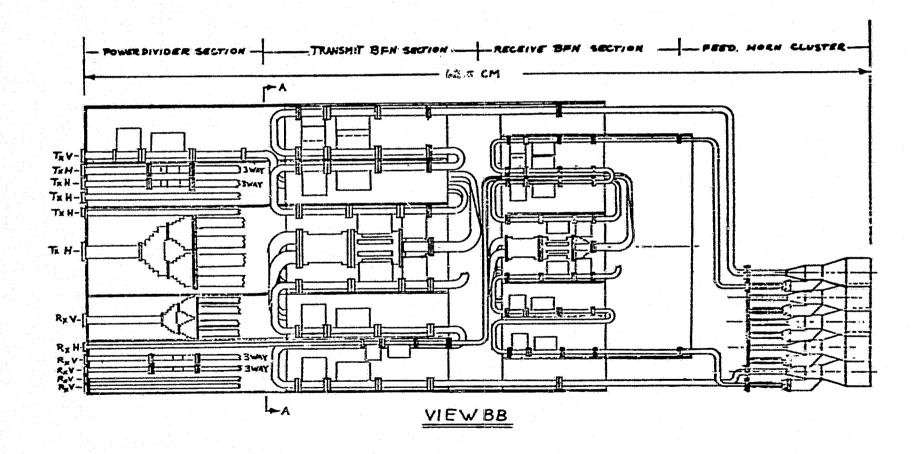
This arrangement also shows the feasibility of packaging receive and transmit BFN's together, neglecting the advantage of the spherical surface.

Note that only four VPD layers are needed for this experimental system, instead of the five layers shown for complete CONUS coverage scanning. Also note that the VPS (variable phase shifter) function may be eliminated.



# TYPICAL LAYOUT OF FEED ASSEMBLY USING VPD/VPS FOR 1 REFLECTOR CONFIGURATION (5 LAYER IMPLEMENTATION)





## ASSUMED FEED COMPONENT WEIGHTS (kg) $(\alpha = 0.4^{\circ}, D = 2.95 \text{ m})$

-

These weights are scaled from other components which were used at C-band and at X-band. The weights of the VPDs are recently reported by EMS (Electromagnetic Sciences, Inc. technical report on "Microwave Components and Techniques 20/30 GHz Multiple Beam Antenna Network" of November 5, 1980, Table 5.1) to be 0.051 kg at 20 GHz. The weight of the VPD and its associated switching electronics (without redundancy) is reported to be 0.136 kg. Therefore, the weights reported in this table are conservative.



## ASSUMED FEED COMPONENT WEIGHTS (Kg)



 $(\alpha = 0.4^{\circ}, D = 2.95 \text{ cm})$ 

COMPONENT	WEIGHT (Kg) COMMON	20 GHz	30 GHz
HORN	0.0366		
ORTHOCOUPLER	0.0411		
DIPLEXER	0.0455		
SWITCH		0.0770	0.0500
VPD		0. 1200	0.0850
VPS		0.0770	0.0500
COMPLETE RADIATING SOURCE	0. 1231		

### ASSUMED LOSS CHARACTERISTICS (dB)

Recent developments at EMS of Atlanta indicate that the switch losses are 0.15 dB instead of the 0.25 dB of this chart (at 20 GHz). Also the VPD's are reported to have a loss of 0.38 dB and 0.42 dB (maximum) respectively at 20 and 30 GHz, with 6 bits, and a switching speed of  $0.5 \,\mu sec$ .



### ASSUMED LOSS CHARACTERISTICS (dB)



FREQUENCY BAND (GHz)	20	30
WAVEGUIDE (1 m)	0.40 dB	0.60 dB
SWITCH	0. 25	0.30
VPD	0.50	0.60
VPS	0.80	1.00
HORN	0.10	0, 15
OC	0.15	0.20
DIPLEXER	0, 25	0.30
DIVIDER	0.15	0, 20

## ACHIEVABLE GAIN CHARACTERISTICS WITH VARIOUS SCANNING BEAM ANTENNA ALTERNATIVES

Recent developments by EMS (of Atlanta) lowers the VPD losses. They report Variable Power Divider (VPD) loss of 0.38 dB maximum at the 20 GHz range and 0.42 dB maximum at the 30 GHz range. Also it is possible to eliminate the variable phase shifter at each horn. These reduce the insertion losses of the VPD/VPS combination to 2 dB at 20 GHz and 2.4 dB at 30 GHz.

THE WAY WAY



#### ACHIEVABLE GAIN CHARACTERISTICS WITH VARIOUS SCANNING BEAM ANTENNA ALTERNATIVES



ASSUMPTIONS:

 $\alpha$  = 0.350, D = 3.045 m FOR SINGLE ANTENNA, D = 3.045 m/2.026 m FOR 2 ANTENNAS

Q/D = 0.212

	SW	ITCH	VPD/VPS		
	18, 95 GHz	28, 47 GHz	18.95 GHz	28, 47 GHz	
BFN LOSS	1.65	2.1	3.7	4.6	

AT f = 18.95 GHz ( $\lambda$  = 15.83 cm) D = 192.3  $\lambda$ , G<sub>0</sub> = 55.62 (1 OR 2 ANT) f = 28.47 GHz ( $\lambda$  = 1.053 cm) D = 288.97 $\lambda$ , G<sub>0</sub> = 59.16 (1 ANT) D = 192.3  $\lambda$ , G<sub>0</sub> = 55.62 (2 ANT)

ALTERNATIVES: 1 OR 2 ANTENNA, SWITCH OR VPD/VPS MAX. BEAM SCAN:  $-3^{\circ}$ 

	NO. OF ANTENNAS			1				2	
	BEN CONFIGURATION	SWITCH		VPD/VPS		SWITCH		VPD:VPS	
	FREQUENCY BAND, GHZ	18.9 GHz	28.4 GHz	18.9 GHz	28.4 GHz	18.9 GHz	28, 4 GHz	18.9 GHz	28.4 GHz
FOR SINGLET BEAM	η <sub>PEAK</sub> , dB η <sub>CONT</sub> , dB	- 2.62 <sup>a</sup> - 7.52 <sup>a</sup>	- 2,16 <sup>a</sup> -12,16 <sup>a</sup>	- 2.62 <sup>2</sup> - 7.32 <sup>a</sup>	- 2,62 <sup>a</sup> -12,16 <sup>a</sup>	- 2,62 <sup>a</sup> - 7,32 <sup>a</sup>	- 2.62 <sup>a</sup> - 7.32 <sup>a</sup>	- 2,52 <sup>3</sup> - 7,22 <sup>2</sup>	- 2,62 <sup>a</sup> - 7,32 <sup>a</sup>
FOR TRIPLET BEAM	η <sub>PEAK</sub> , dB η <sub>CONT</sub> , dB			- 3.82 <sup>b</sup> - 7.32 <sup>b</sup>	- 2.92 <sup>b</sup> - 7.92 <sup>b</sup>			- 3.82 <sup>b</sup> - 7.32 <sup>b</sup>	- 3.82 <sup>b</sup> - 7.32 <sup>b</sup>
	acirc, dB	1, 65	2.1	3.7	4.6	1,65	2.1	3.7	4.6
	G <sub>po</sub> , dB	53.00 <sup>a</sup>	57.00 <sup>a</sup>	53, 00 <sup>a</sup> 51, 80 <sup>b</sup>	57.00 <sup>a</sup> 56.24 <sup>b</sup>	53.00 <sup>a</sup>	52.55 <sup>a</sup>	53.00 <sup>a</sup> 51.80 <sup>b</sup>	52.1 <sup>a</sup> 50.9 <sup>b</sup>
	G <sub>co</sub> , dB	48, 30 <sup>3</sup>	47.00 <sup>a</sup>	48. 3 <sup>a</sup> 48. 3 <sup>b</sup> 51. 4 <sup>c</sup>	47.00 <sup>a</sup> 57.24 <sup>b</sup> 54.60 <sup>c</sup>	48.30 <sup>3</sup>	47.85 <sup>a</sup>	48, 30 <sup>2</sup> 48, 30 <sup>2</sup> 51, 40 <sup>C</sup>	47.4 <sup>a</sup> 47.4 <sup>a</sup> 50.5 <sup>c</sup>
	G <sub>p</sub> , dB	51.35	54.90	49.3 <sup>a</sup> 48.1 <sup>b</sup>	52,40 <sup>a</sup> 51,64 <sup>b</sup>	51.35 <sup>a</sup>	47.85 <sup>a</sup>	49.3 <sup>a</sup> 48.1 <sup>b</sup>	48.4 <sup>3</sup> 47.2 <sup>b</sup>
	G <sub>c</sub> , dB	46. o5	44.90	44.6 <sup>a</sup> 44.6 <sup>b</sup> 47.7 <sup>c</sup>	48, 40 <sup>a</sup> 46, 64 <sup>b</sup> 50, 0 <sup>c</sup>	46, 65 <sup>8</sup>	46, 20 <sup>a</sup>	44.6 <sup>a</sup> 44.6 <sup>b</sup> 47.7 <sup>c</sup>	43. 7 <sup>a</sup> 43. 7 <sup>b</sup> 46. 8 <sup>c</sup>

- a CLEVELAND, SINGLET
- DC, TRIPLET
- COMBINED SINGLET/TRIPLET MINIMUM

#### SSUS-D LAYOUT OF ANTENNA FEED SCHEMES

This arrangement is intended for  $0.5^{\circ}$  or  $0.45^{\circ}$  topology cells. In this situation a smaller antenna (than the 120") is needed with somewhat lower gain levels. The advantage of this system is the small number of component beams, allowing for longer dwell times. The number of beams in each zone is eight.

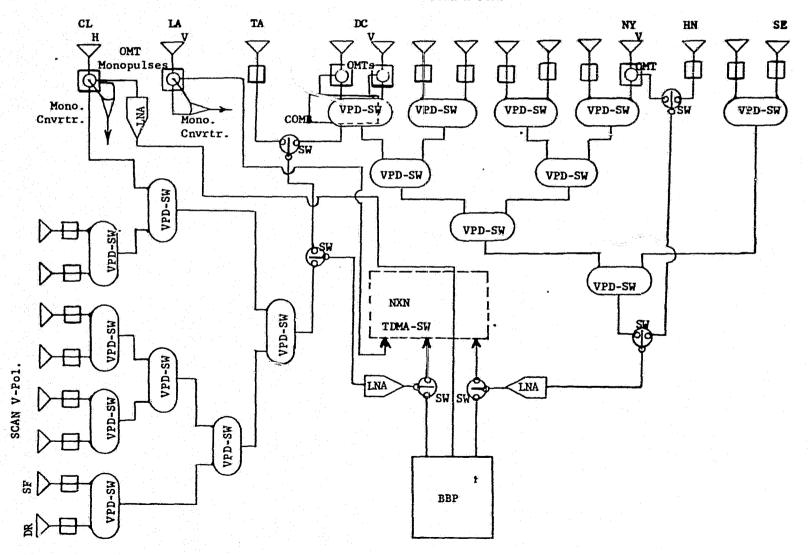


A LULIN ALBERT

### SSUS-D LAYOUT OF ANTENNA FEED SCHEMES



SCAN H-Pol.



## RECEIVE FUNCTION FEED NETWORK (TRANSMIT NETWORK USES SAME HORNS)

This shows the multifunction of the feed network for both East and Mid West Zones of the experimental system. There are 16 horns in each zone, for beam scanning, with a cell size of  $0.35^{\circ}$  or  $0.4^{\circ}$ . This results in four layers of Variable Power Dividers (VPDs) or switches (SW). The insertion loss of the ferrite switches is less than the loss of the VPDs. The VPDs, however, yield more flexibility in the scanning increments and by using doublets and triplets the cross over levels between beams can be as high as 51 dBi. Using switches reduces this level to the minimum attainable level of 47.5 dBi as shown on later charts.

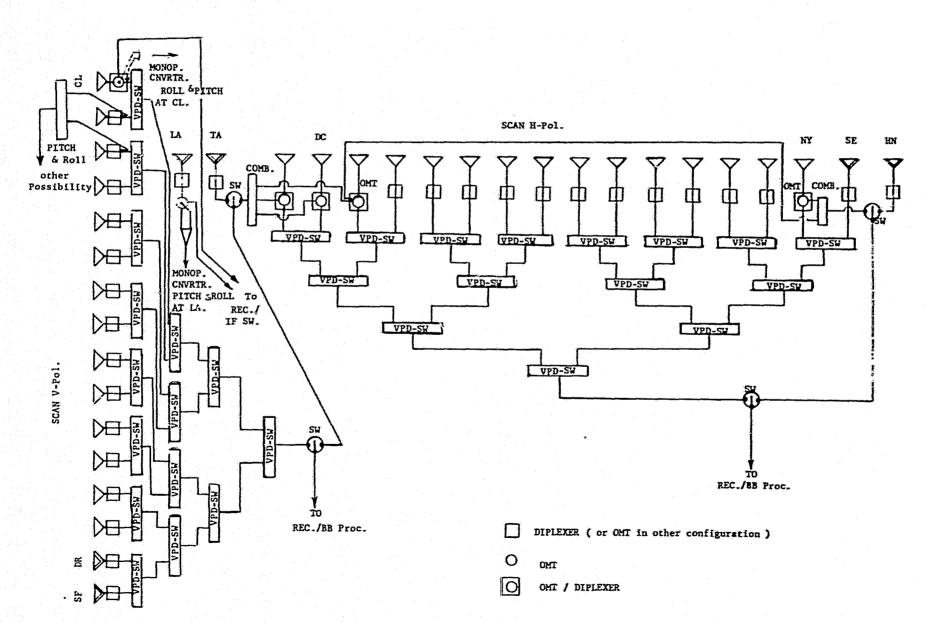
The needed components for the multifunction operation are the diplexer, the orthomode transducer (OMT) and the OMT/diplexer. Examples of such components were shown previously. These components are well developed since the early 50's for the C, X and Ku band regions of the spectrum.

The monopulse operation at Cleveland and Los Angeles is a simple addition of a rear TM01 orthogonal mode port which was developed on previous programs.



# RECEIVE FUNCTION FEED NETWORK (TRANSMIT NETWORK USES SAME HORNS)

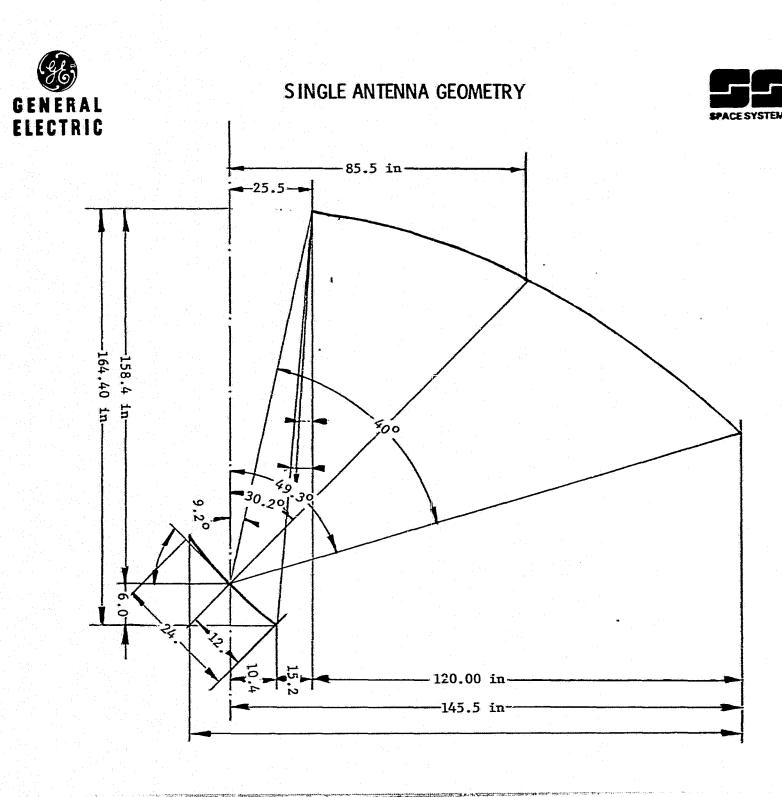




## SINGLE ANTENNA GEOMETRY

The detailed dimensions of the 10 foot antenna which is used to generate the radiation patterns of this report is shown. Note that the feed cluster is located on a spherical surface, which generate coherent beams from coherent excitation signals. This condition simplifies the design procedures and facilitates beam formations in doublets and triplets without significant beam squinting. This is also mandatory to achieve negligible beam squint across the transmit and receive frequency bands.

ACCOUNT TO THE PARTY



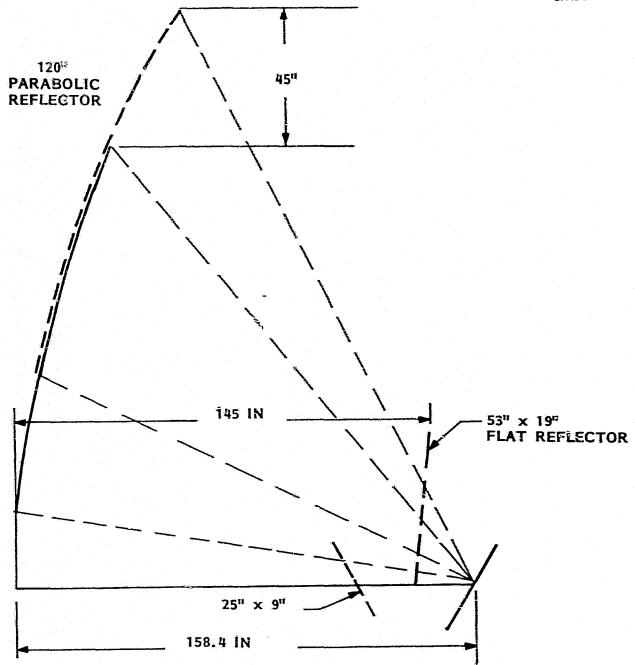
#### SINGLE REFLECTOR AND SUBREFLECTOR

A subreflector may be used to relocate the feed cluster nearer to the vertex of the main reflector. The preferable shape of this reflector is flat in order to shorten the distance between the main vertex and the feed, by approximately  $40^{tt}$ . The height of the assembly increases by  $45^{tt}$ , due to the need to increase the offset of the main reflector. Moreover the flat reflector adds weight and complexity particularly with regard to alignment. The subreflector approach is not recommended.



### SINGLE REFLECTOR AND SUBREFLECTOR





## AGGREGATE BEAMS AND FEED FORMATIONS FOR REFLECTOR AND LENS ANTENNAS

The arrangements of the aggregate beams are determined by the feed configuration.

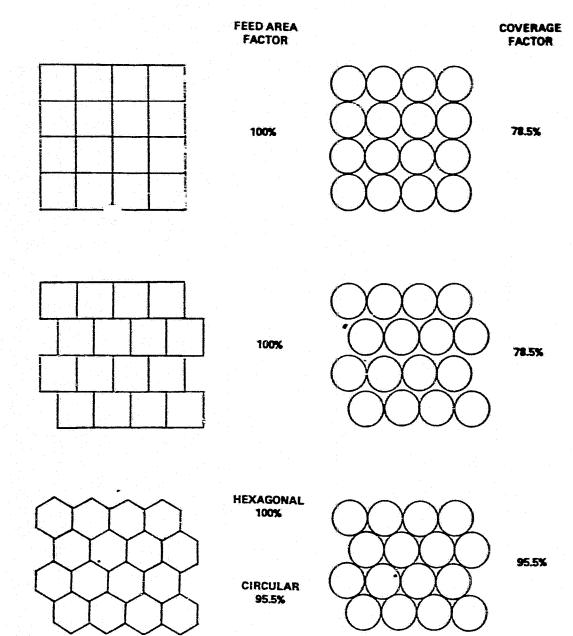
Symmetrical aggregate cells of circular beams are assumed. These are independent of symmetric feed configurations and slightly dependent (in ellipticity) on the feed excitation modes. The shape of the pattern contour lines, near the peak of the beam, is elliptic in general.

Circular feed apertures yield uniform proximity between the beams, with high coverage factor, and hence uniform scanning coverage.



# AGGREGATE BEAMS AND FEED FORMATIONS FOR REFLECTOR AND LENS ANTENNAS





### IDEAL AND OPTIMUM ANTENNA COVERAGE

The ideal gain, as determined by the size of the topology cell is approximately equal to the peak gain of an optimum sized antenna and optimum feed configuration which complies with the contiguous coverage requirements at lowest interference levels.

The feed modes of reflector antennas completely control the antenna depolarization.

Extremely broad frequency bandwidths are attainable at optimum coverage and cell edge gain. This is discussed in the following charts.



### IDEAL AND OPTIMUM ANTENNA COVERAGE



• IDEAL POWER GAIN OF PROJECTED COVERAGE ANGLE "A" (IN SQUARE DEGREES)

41,253 A

#### ASSUMES ZERO INTERFERENCE BEYOND THE COVERAGE AREA

- PRACTICAL ANTENNA CONFIGURATIONS LIMIT THE ATTAINABLE
  GAIN AT THE COVERAGE AREA AND INTERFERENCE LEVELS
  BEYOND ITS BOUNDARIES
- THIS WORK HANDLES ANTENNA DESIGN CONSIDERATIONS WHICH DETERMINE
  - OPTIMUM ANTENNA SIZES
  - OPTIMUM FEED ARRANGEMENTS
  - OPTIMUM FREQUENCY BANDWIDTH LIMITATIONS
  - FEED-ANTENNA REQUIREMENTS WHICH MINIMIZE INTERFERENCE AND DEPOLARIZATION

#### CROSS OVER AND PEAK GAIN

The ideal gain and cross over gain levels are shown for antenna diameters between 40" and 55", a cell size of 1° and in a frequency range of 17 to 30 GHz. This chart is applicable to any other cell size by addition of the ideal gain differential (in dBs) between the 1° cell and the other cell size. Also the antenna diameter "D" shown must be multiplied by 1° divided by the other cell size. The feed diameter "D" is independent on the cell size for the same F/D shown (1.32).

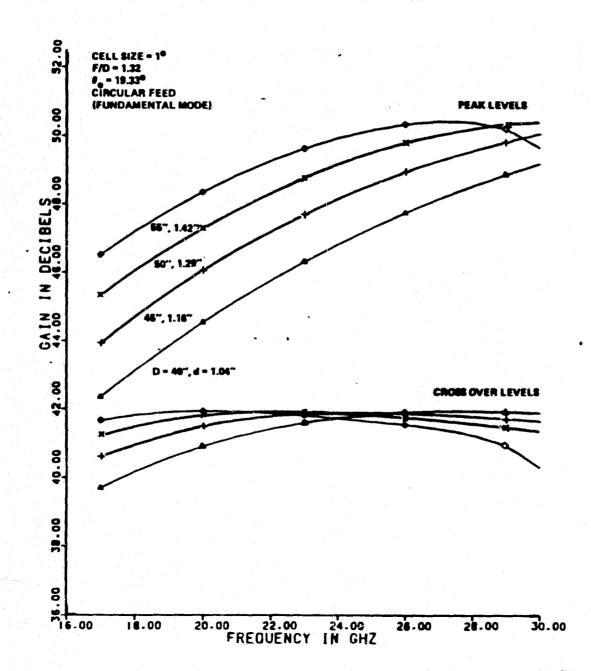
For an antenna diameter of 120" and an optimum edge cell gain (cross over level between beams) which is optimally flat within 0.25 dB in the range of 18-30 GHz (x-x marked curve) the optimum cell size  $\alpha = 50/120 = 0.42^{\circ}$ . Since the slope of the antenna pattern is higher at high frequencies it is desirable to favor the edge gain at high frequencies and hence a smaller cell size of 0.35° is selected. The feed diameter is 1.05".



•

### CROSS OVER AND PEAK GAIN





## EAST-WEST SCANNING PERFORMANCE 18.95 GHz OFFSET REFLECTOR SINGLETS

The calculated patterns at 18.95 GHz are shown for a 120" reflector at the extreme of east-west scanning and in the plane of symmetry of the offset reflector, with F/D = 1.32. The primary feed is sized for  $0.35^{\circ}$  component cells. Horns use the fundamental TE11 mode.

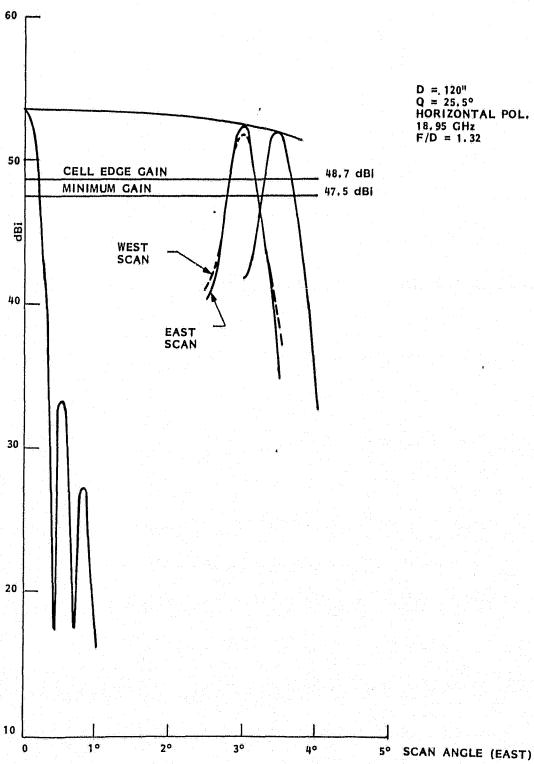
The cross-over levels between the beams are higher than 48.7 dBi in the whole scan range (and beyond  $\pm 3^{\circ}$ ). The triple cross-over point in the middle location of three beams is always above 47.5 dBi, also in the whole scan range.

It can be recognized that for this antenna configuration, with the cluster of feeds located on a spherical surface (including the focal point of the reflector), the west and east scanned beams cross-over levels are above the minimum gain levels shown, even though the peaks of the west scanned beam is lower than the peak of the east scanned beam.



### EAST-WEST SCANNING PERFORMANCE OFFSET REFLECTOR SINGLETS





D = 120" Q = 25.5° HORIZONTAL POL. 18.95 GHz F/D = 1.32

#### EAST-WEST SCANNING PERFORMANCE 28.75 GHz OFFSET REFLECTOR SINGLETS

The calculated patterns at 28.75 GHz are shown for the same 120" reflector at the extreme locations of the east-west scanning in the plane of symmetry of the reflector (F/D = 1.32). The same horn of the previous figure is used, using the fundamental TE11 mode.

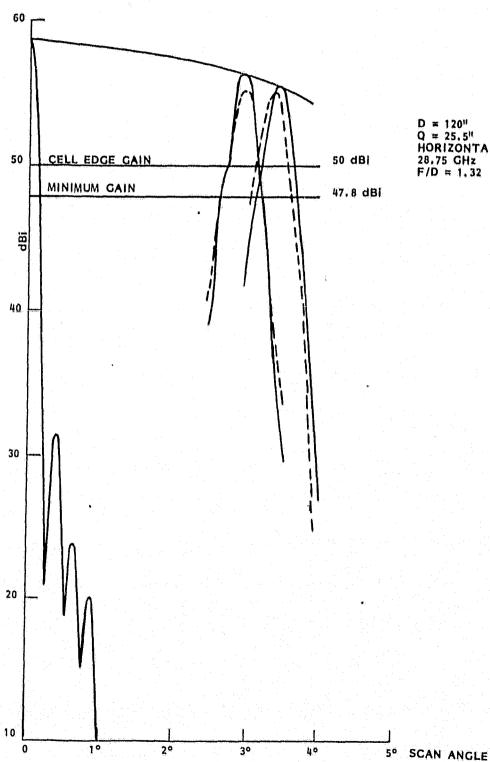
The cross-over level between the beams (which is the cell edge gain) is above 50 dBi, in the whole scan range (and beyond  $\pm 3^{\circ}$ ). This level is 1.3 dB higher than the level at 18.95 GHz because the high frequency performance is favored. The triple cross-over point between three beams is always above 47.8 dBi, which is almost the same as for 18.95 GHz (47.5 dBi), also in the whole scan range.

These levels confirm the equality of the minimum levels of coverage for both frequencies using the same antenna and feed configurations. Edge cell gains and peak levels, however, favor the high frequencies.



### **EAST-WEST SCANNING PERFORMANCE** OFFSET REFLECTOR SINGLETS





D = 120" Q = 25.5" HORIZONTAL POL, 28.75 GHz F/D = 1.32

## EAST-WEST SCANNING PERFORMANCE OFFSET REFLECTOR TRIPLETS

Use of one reflector for both uplink and downlink results in different 3 dB beam widths. The configuration of the system, however, yields a minimum attainable level which is almost equal for both. The cross-over level of the beams is 48.7 dBi at 18.95 GHz (as previously shown), which is 2.3 dB below the 51 dBi specified as the peak gain. Similarly at 28.75 GHz the cross-over level is 50 dB which is 1 dB below the specified 51 dBi.

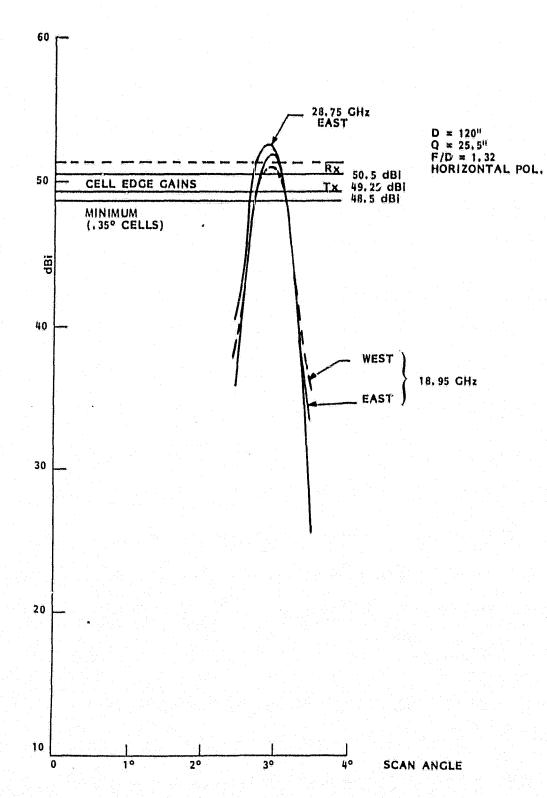
In order to further improve the cross-over levels and achieve equal beam shapes for the transmit and receive links it is possible to use triplet radiators; i.e. each beam will be formed of three adjacent beams. In this situation (as shown in this figure) the beam shapes are very similar at 18.95 and 28.75 GHz, and the minimum attainable levels between farther triplets improved to 48.5 dBi. Adjacent triplets, however, have cross-over levels approximately -.5 dB from the peak level.



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# EAST-WEST SCANNING PERFORMANCE OFFSET REFLECTOR TRIPLETS





#### OPTIMUM ANTENNA

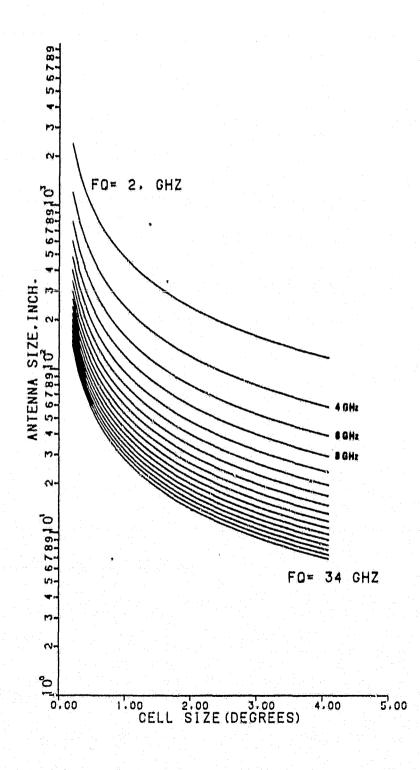
In this chart the optimum antenna size is parametrically plotted as a function of frequency vs the cell size in degrees.

The optimum antenna size is the one which yields maximum cell edge gain (as defined in the "Cross-Over and Peak Gain Charts".)

I L. I L. I

## OPTIMUM ANTENNA





#### SCANNED TRIPLET DESIGN AT 18.95 GHz

This figure shows an example of a maximum scanned triplet pattern at 18.95 GHz. The fundamental mode of the feed horns yields cross-polarization levels of -34 dB maximum.

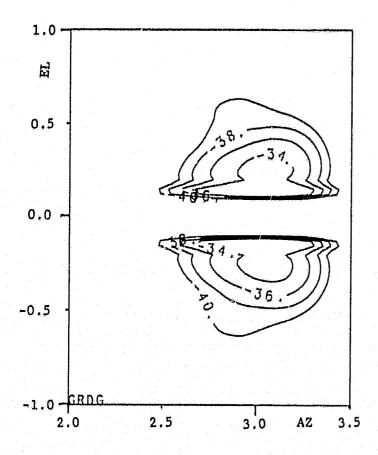
This level is lower than the level of a single horn using the fundamental mode by approximately 4 dB. The triplet has the advantage of lower and faster decaying sidelobes.

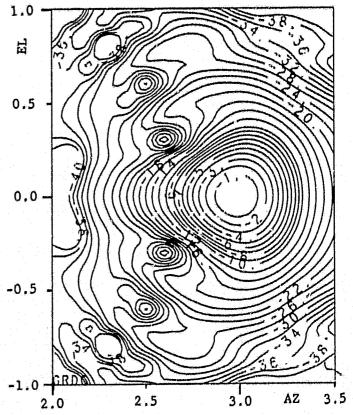


### SCANNED TRIPLET DESIGN AT 18. 95 GHz



Configuration		TE11	F.P. OFFSET
Geometry	_	<u>, in </u>	120
	F	/D	1.32
	Q	, in	25.5
	d	, in	1.05
	α	, deg	.35
	n		3
Beam			SCANNED 3° E
Polarization			HORIZONTAL
Longitude,	d	eg.	100 W
Antenna Axis	E	W	.55 E
Pointing,	N	S	5.92 N
Deg.	E	W Bias	0.0
Frequency,	G	Hz	18.95
Max. Gain,	ď	<b>b</b>	51.7





#### SCANNED TRIPLET PATTERN AT 28.75 GHz

This figure shows an example of a maximum scanned triplet pattern at 28.75 GHz. The fundamental mode of the feed horns yields cross-polarization levels of -30 dB maximum. This is also 4 dB better than the levels of a single from using the fundamental mode.

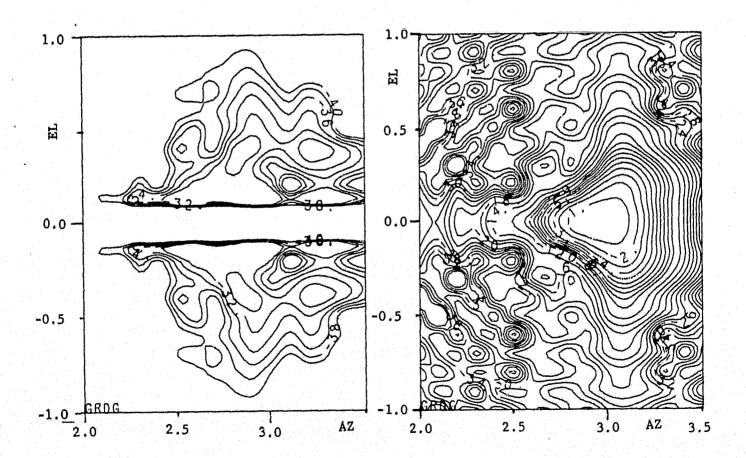


### SCANNED TRIPLET PATTERN AT 28. 75 GHz



a street to be seen a

Configuration	TE11	F.P. OFFSET
Geometry	D, in	120
	F/D	1.32
:	Q, in	25.5
	d, in	1.05
	a, deg	.35
	13	3
Beam		SCANNED 30 E
Polarization		HORIZONTAL
Longitude,	deg.	100 W
Antenna Axis	EW	.55 E
Pointing,	NS	5.92 N
Deg.	EW Bias	0.0
Frequency,	GHz	28.75
Max. Gain,	ďb	52.3



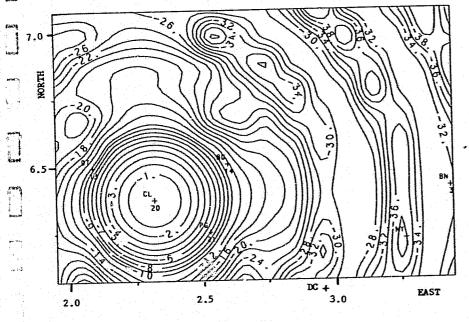
The pattern at 18.95 GHz is horizontally polarized.

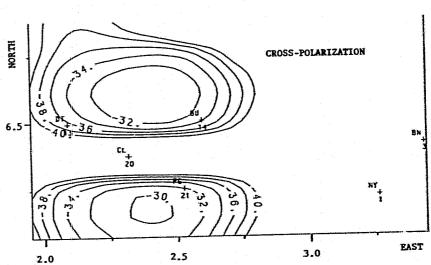
Note that the interference in Boston, New York and Washington, D.C. is better than -30 dB. (D = feed diameter = 1.05".)





	and the second second	
Configuration	TE11	F.P. OFFSET
Geometry	D, in	120
	F/D	1.32
•	0, in	25.5
	d. in	1.05
	a, deg	.35
	В	1
Beam		CLEVELAND, OH
Polarization		HORIZONTAL
Longitude,	deg.	100 W
Antenna Axis	EW	.55 E
Pointing,	NS	5.92 N
Deg.	EW Bias	0.0
Frequency,	GHz	18.95
Max. Gain.	ďb	53.00
******		





The pattern at 18.95 GHz is vertically polarized,

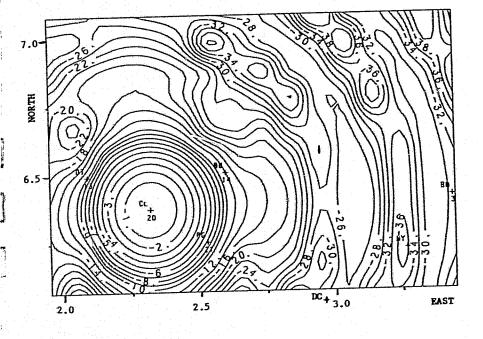
A COLET ACTIONS

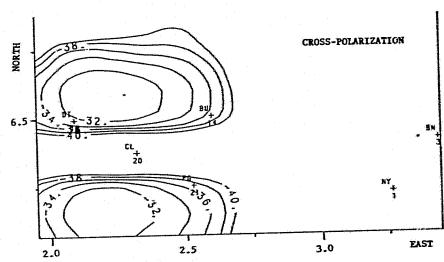
This beam achieves isolation better than  $-30~\mathrm{dB}$  at New York, Boston and Washington, D.C. Fundamental TE11 feed mode is used with D = 1.05".





Configuration	TE11	F.P. OFFSET
Geometry	D, in	120
	F/D	1.32
•	Q, in	25.5
•	d. in	1.05
	a, deg	.35
•	n	1
Beam		CLEVELAND, C
Polarization		VERTICAL
Longitude,	deg.	100 W
Antenna Aris	EW	.55
Pointing,	RS	5.92
Deg.	EW Bias	0.0
Frequency,	GHz	18.95
Max. Gain.	<u>ap</u>	53.00





The pattern at 28.75 GHz is horizontally polarized.

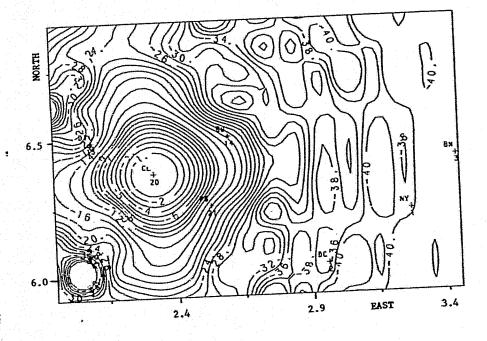
Note the high peak gain of 57 dBi, using a 1.05" feed with the fundamental TE11 mode.

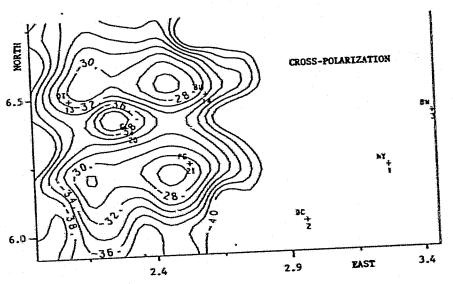






Configuration	TEIL	F.P. OFFSET
	D. 12	120
Geometry .	E/D	1.32
	0. in	25.5
•	d. in	1.05
	a, des	.35
	7.0	1
	_8	CLEVELAND OH
Beam		
Polarization		HORTZONTAL
Longitude,	deg.	100 W
		.55 E
Antenna Aris	NS	5.92 N
Pointing,	EW Bia	0.0
Deg.		28.75
Frequency,	GHz	57.00
Max. Gain,	ďδ	57.00





# CALCULATED GAIN CONTOURS (DIFFERENCE MODE PATTERNS AT CLEVELAND, 28.3 GHz)

The proposed circularly polarized beacon at Cleveland generates pitch and roll signals by phasing the difference pattern relative to the sum pattern in conjunction with the linearly polarized TM01 mode of the single port feed. This main beam peak gain is approximately 5.4 volts/volt/degree.

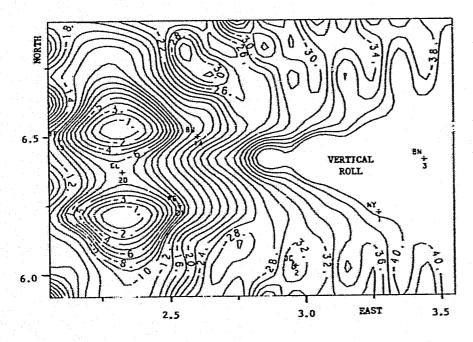
A similar method is used to measure roll and pitch from a pilot located in Los Angeles. The combined patterns are used to generate yaw errors.

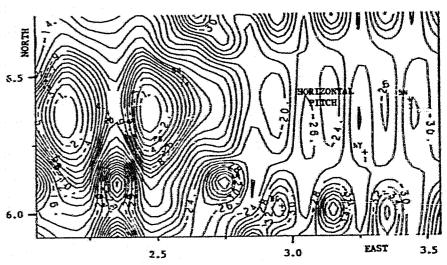


# CALCULATED GAIN CONTOURS (DIFFERENCE MODE PATTERNS AT CLEVELAND, 28.3 GHz)



Configuration	TMOY	F.P. OFFSET
	D. in	120
Geometry	F/D	1.32
	Q, 12	25.5
	d, in	1.05
•	a, deg	.35
	12	1
Beam MONOP	ilse	CLEVELAND, OH
Polarization		CIRCULAR
Longitude,	deg.	100 W
Antema Aris	EW	.55 E
Rointing.	NS	5.92 N
De.	EW Bias	0.0
Frequency.	GHz	28,30
Max. Gain.	ďb	49.50





# CALCULATED GAIN CONTOURS (WASHINGTON, D.C.)

The pattern, at 18.95 GHz is a horizontally polarized triplet.

Note that the isolation at Cleveland is better than 30 dB. Also the cross-polarization isolation using the fundamental mode is better than 30 dB.

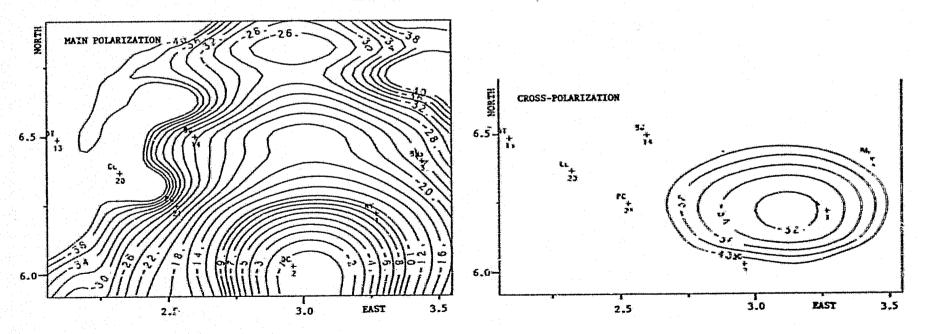
The location of Washington, D.C. is between three beams, consequently, a triplet was necessary for this spot beam. The downlink level at D.C. is 51.3 dBi.



# CALCULATED GAIN CONTOURS (WASHINGTON D.C.)



Configuration	TEIL	F.P. OFFSET
Geometry	D, 12	120
	F/D	1.32
•	0, in	25.5
•	d, ia	1.05
	c, deg	.35
	2	3
Bezu		WASHINGTON
Polarization		HORIZONTAL
Longitude,	deg.	100 W
Antema Aris	EW	.55 ₺
Pointing,	rs	5.92 N
Deg.	EN Bias	0.0
Frequency,	CEz	18.95
Max. Gain,	<b>Č</b> b	51.8



## CALCULATED GAIN CONTOURS (WASHINGTON, D.C.)

This pattern is horizontally polarized at 28.47 GHz.

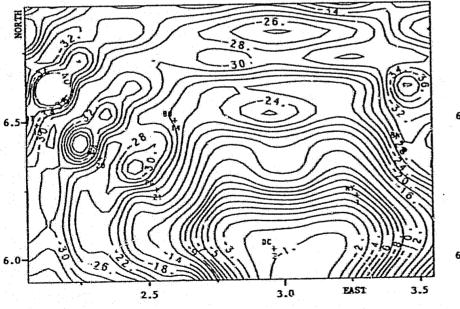
Note that the uplink level at D.C. is 51.4 dBi. This pattern is similar to the downlink pattern, with cross-polarization levels peaking at -30 dB from the peak, using the fundamental TE11 mode in circular 1.05" horns.

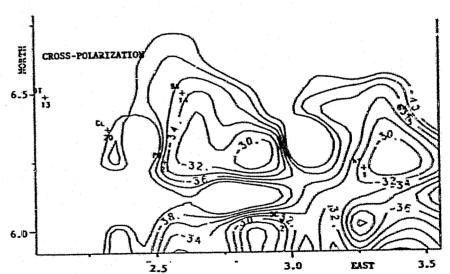






Configuration	TEIL	F.P. OFFSET
Geometry	D, in	120
	F/D	1.32
	Q, in	25.5
•	d, in	1.05
•	a, det	.35
	12	3
Bezz		MASHINGTON, DO
Polarization		HORIZONTAL
Longitude,	deg.	100 W
Antenna Aris	EW	.55 E
Pointing.	HS	5.92 19
Deg.	EW Bias	
Frequency.	GHz	28.47
Max. Gain.	ďδ	52,70





## CALCULATED GAIN CONTOURS (NEW YORK, N.Y.)

This pattern is horizontally polarized at 18.95 GHz.

Peak gain is 51.7 dBi.

The beam is formed by a doublet, which locates the composite beam at New York using a component size of .35°.

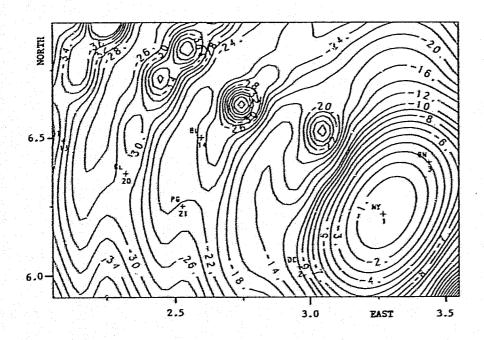
The doublet pattern results in higher side-lobe levels than for a triplet. The isolation to Cleveland, however, is still of the order of 30 dB.

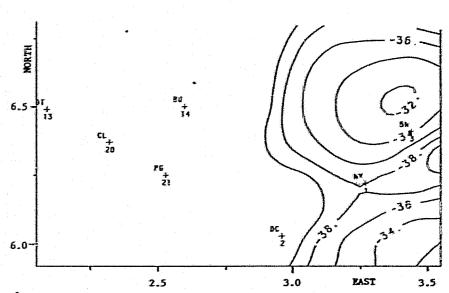


# CALCULATED GAIN CONTOURS (NEW YORK, N.Y.)



Configuration	TEIL	F.P. OFFSET
Geometry	D, 12	120
•	F/D	1.32
	Q, in	25.5
	d, 1n	1.05
,	a, deg	.35
	13	2
Beam		new York, ny.
Polarization		HORIZONTAL
Longitude,	deg.	100 W
Antema Aris	EW	.55 🗷
Pointing,	RS	5.92 N
Deg.	EW Bias	0.0
Frequency,	GEz	18.95
Max. Gain,	Č5	51.70





# CALCULATED GAIN CONTOURS (NEW YORK, N.Y.)

This pattern is horizontally polarized at 28.47 GHz.

Peak gain is 54.1 dBi.

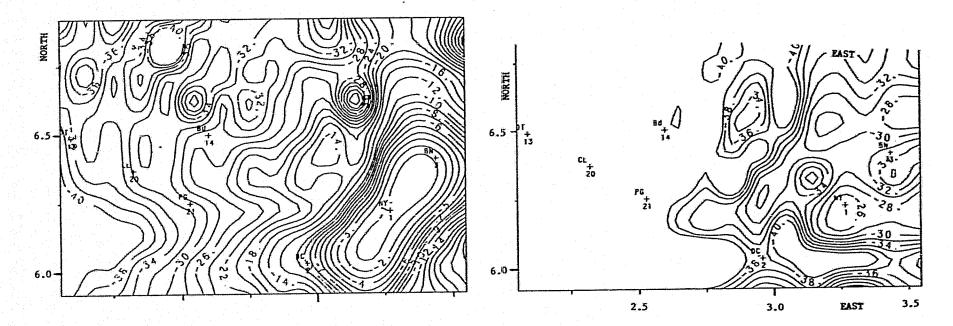
Note the frequency dependence of the peak gain of the doublet compared to the frequency independence of the triplet.



# CALCULATED GAIN CONTOURS (NEW YORK, N.Y.)



		· <u> </u>
Configuration	TE11	P.P. OFFSET
Geometry	D, in	120
	F/D	1.32
1	Q. in	25.5
	d, in	1.05
!	a, deg	.35
	10	2
Bean		NEW YORK, NY
Polarization		HORIZONTAL
Longitude,	deg.	100 W
Antenna Aris	EW	.55 €
Pointing.	KS	5.92 N
Deg.	EW Bias	0.0
Frequency,	GHz	28,47
Max. Gain,	ďъ	54.1



# CALCULATED GAIN CONTOURS (LOS ANGELES)

This pattern is vertically polarized at 18.95 GHz.

This beam is the western most scanned trunking beam. Peak gain of the beam, using a 1.05" feed horn is 51.5 dBi. This gain, however, can be increased to 53.1 dBi by using a larger horn of 1.45". A large horn reduces the spill-over radiation. It cannot be used in a fully implemented system because of its large size.



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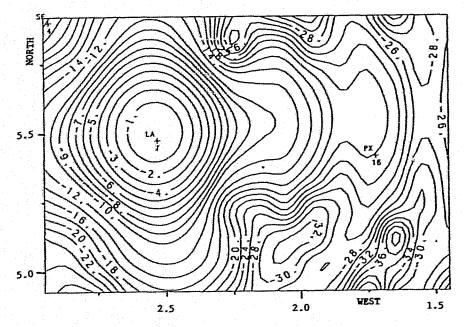


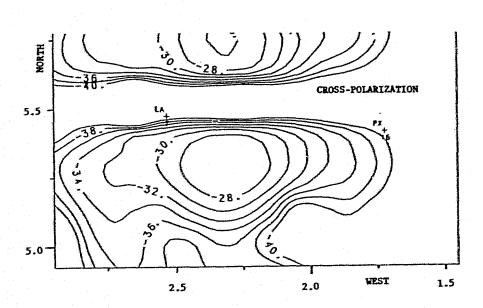


Configuration	TEL:	F.P. OFFSET
Geometry	D, in	120
	F/D	1.32
	0. in	25.5
•	d, in	1.45
	a, deg	.35
	2	1
Bezz		LOS ANCELES
Polarization		VERTICAL
Longitude,	deg.	100 W
Antema Aris	EW	.55 E
Pointing.	RS	5.92 N
Deg.	EW Bias	0.0
Frequency,	CHz	18.95
Max. Gain.	ďъ	53.1

51.5

1.05





# CALCULATED GAIN CONTOUR (LOS ANGELES)

This pattern is vertically polarized at 28.75 GHz.

There is little difference in the peak gain with either of the two horn sizes (1.05" and 1.45"0, due to the already low spill-over at the higher frequency. Peak gain is approximately 55 dBi.

Note the high cross-polarization (only -22 dB below the peak) which is caused by the large curvature of the TE11 mode which does not fit the offset configuration of the reflector. Use of multimodes; i.e., combination of TE11, TM11 and TE21 or TM01 modes (dependent on the polarization) can reduce the cross-polarization component.



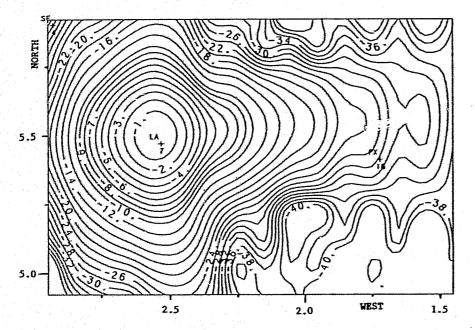
# CALCULATED GAIN CONTOURS (LOS ANGELES)

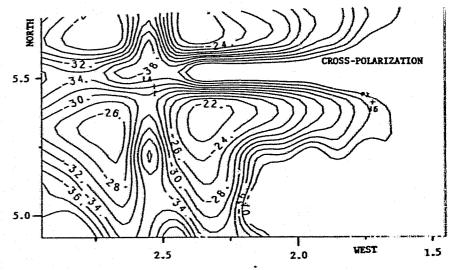


Configuration	TE11	F.P. OFFSET
Geometry	D, in	120
	F/D	1.32
· · · · · · · · · · · · · · · · · · ·	Q, in	25.5
	d, in	1.45
	a, deg	.35
	D.	1
Beam		LOS ANGELES
Polarization		VERTICAL
Longitude,	deg.	100 W
Antenna Aris	EW	.55 g
Pointing,	KZ	5.92 N
Deg.	EW Bias	0.0
Frequency,	GEz	28.75
Max. Gain,	ďЪ	55.4

55.0

1.05





#### FOCUSED TRIPLET BEAM

This focused triplet beam at the high frequency represents the worst case deformed beam in the system. The scanned triplet beam has slightly higher gain with a less deformed pattern.

Note that the central portion of this beam has good coverage for a 0.4° cell size even with triplet deformation, and extends the coverage beyond the cell size in three symmetric directions.

Also note that when combined triplet and singlet beams are scanned a well overlapped pattern arises near the focused beam area.

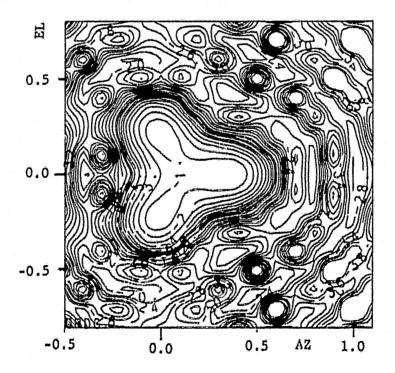
er warron glensprach



### FOCUSED TRIPLET BEAM



	the property of the second of	
Configuration	TB11	F.P. OFFSET
Geometry	D, in	102.6
	F/D	1.32
	Q, in	22.0
	d, in	1.05
	a, deg	0 a 4 hours
	מ	3
Beam		FOCUSED
Polarization		HORIZONTAL
Longitude,	deg.	100 W
Antenna Axis	EW	.55 E
Pointing,	NS	5.92 N
Deg.	EW Bias	0.0
Frequency,	GHz	28.95
Max. Gain,	ďЪ	51.3



#### CALCULATED GAIN CONTOURS

This is a difference pattern using two horns on both sides of the Cleveland horn.

Such a pattern is not adequate for tracking purposes because of the lack of continuity with a similar pattern which is located orthogonally. This method therefore is not recommended.

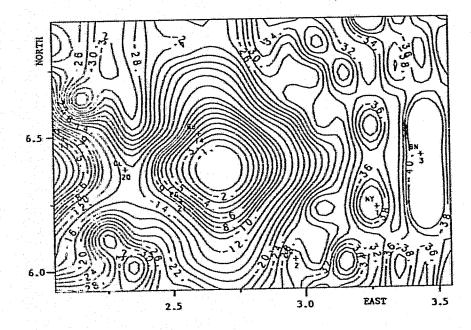


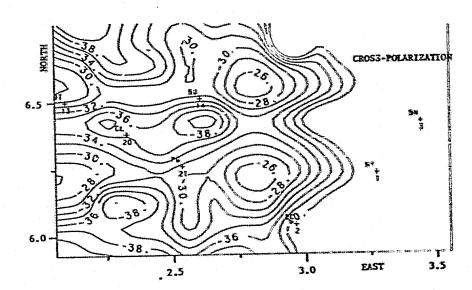
## CALCULATED GAIN CONTOURS



Configuration	TEll	F.P. OFFSET
Geometry	D, in	120
	F/D	1.32
•	0, in	25.5
•	d, in	1.05
•	a, det	.35
	n.	2
Beam		CLEVELAND, OH
Polarization		HORIZONTAL
Longitude,	deg.	100 W
Antenna Aris	EW	.55 E
Pointing.	NS	5.92 พ
Deg.	EW Bias	
Frequency.	CHz	28.47
Max. Gain,	ďъ	53.5

OUT OF PHASE HORNS ON BOTH SIDES OF CLEVELAND









# SPACECRAFT CONFIGURATION

AND

SPACECRAFT BUS COMPONENTS

#### CONFIGURATION CHARACTERISTICS

The spacecraft is designed for launch by the STS/SSUS-D (PAM-D), which stows the spacecraft in a vertical position in the STS cargo bay. SSUS-D definition and performance with the STS has been taken from McDonnell-Douglas document G6626C, "PAM-D User's Requirements Document," dated 28 January 1981.

A specific requirement for Shuttle safety necessitates ejecting the spacecraft/SSUS-D from the cargo bay and delaying SSUS-D rocket motor firing until sufficient distance from the STS is achieved. This "loiter" requirement is about one-half an orbit of 45 minutes to one hour.

Epacecraft characteristics are for a three-axis stabilized satellite with active nutation control (ANC) provided during the spin phases (loiter, SSUS/D/spacecraft firing, and AKM firing modes). The spacecraft has a two-wing symmetrical solar array to reduce on-orbit torque for the geosynchronous operating orbit. Large North and South oriented panels mount all payload and subsystem heat dissipating components for optimum heat radiation to space. The Apogee Kick Motor (AKM) which places the satellite in its final orbit is housed in a central cylinder and is attached to a ring supported by the 37 1/2 inch diameter satellite thrust cone. Hydrazine fuel for the 4 year mission is contained in two bladder tanks having a total capacity sufficient for eight years life. The spacecraft is balanced for launch with the lateral centers of gravity on the SSUS-D and AKM thrust axis, and the inertia ratios are limited as shown to insure stability in the spin phases.

A modular design, as used on the BSE and DSCS-III satellites, has been adapted to permit parallel fabrication, assembly and testing of subsystems and assemblies.

Spacecraft subsystem components used on previous programs are utilized in all possible cases, and new designs will use fully developed matrials and construction.



### CONFIGURATION CHARACTERISTICS



### LAUNCH BY STS/SSUS-D

- VERTICAL INSTALLATION IN STS
- INTERFACES, LOADS, CRITERIA AND ENVIRONMENTS FROM MDAC DOCUMENT MDC G6626C, 28 JANUARY 1981, "PAM-D USER'S REQUIREMENTS DOCUMENT"
- UP TO ONE HOUR LOITER TIME AFTER EJECTION FROM STS

## SPACECRAFT CHARACTER ISTICS

- 3 AX IS STABILIZATION ON ORBIT (ACTIVE NUTATION CONTROL DURING SPIN PHASE)
- 2 WING SYMMETRICAL SOLAR ARRAY
- NORTH AND SOUTH OR IENTED EQUIPMENT PANELS
- CENTRAL SOLID ROCKET AKM
- HYDRAZ INE FUEL FOR 4 YEAR MISSION LIFE
- SPACECRAFT C. G. COINCIDENT WITH AKM AND SSUS-D THRUST AXES DURING SPIN PHASE
- SPIN PHASE INERTIA RATIOS (0.90  $\gg \frac{^{1}\text{SPIN}}{^{1}\text{LATERAL}} \gg 1.10$
- MODULAR DESIGN FOR PARALLEL ASSEMBLY
- MINIMUM DEPLOYMENTS (FIXED FEED)
- MAX IMUM USE OF EXISTING COMPONENTS AND DESIGNS

## STS/SSUS-D (PAM-D) LAUNCH VEHICLE

The SSUS-D (PAM-D) is an STS (Shuttle) attached upper stage designed and developed by McDonnell-Douglas. The upper stage consists of a Thiokol Star-48 solid rocket motor with a 12 inch long, 37 1/2 inch diameter spacecraft attach fitting (3712 attach fitting). A vee-band clamp, as used on the standard Delta launch vehicles is used for spacecraft attachment and release. The PAM-D can be used with the Delta (3920), or with the STS (SSUS-D). A SSUS-D system. The SSUS-D has the capability for placing a 2750 pound spacecraft into the 160 X19, 323 N. M. Douglas, which have shown a progressive increase in performance during their long operational life. A summary of represents optimized performance for the particular AKM tabulated.

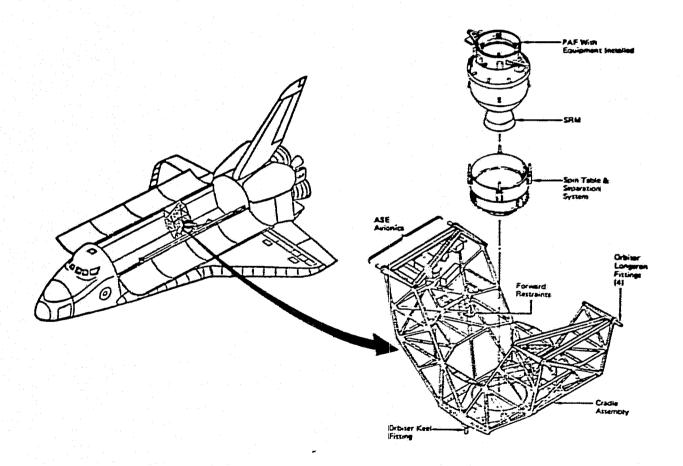
#### Delta Launch Vehicle Performance to Geosynchronous Orbit

Year	Delta L/V	AKM	S/C Launch Weight (Lbs.)	S/C Orbital Weight (Lbs.)
1973	2914	Star 27		Weight (Los.)
1975	<b>3914</b>		1490	780
	3314	Star 30	2100	
1977	3910/PAM-D	Star 30B		1100
1980	3920/PAM-D		2300	1220
1981		Mod. Star 30B	2787	1490
T20T	STS/SSUS-D	Mod. Star 30B	0.770	1430
		2750	1473	



## STS/SSUS-D (PAM-D) LAUNCH VEHICLE





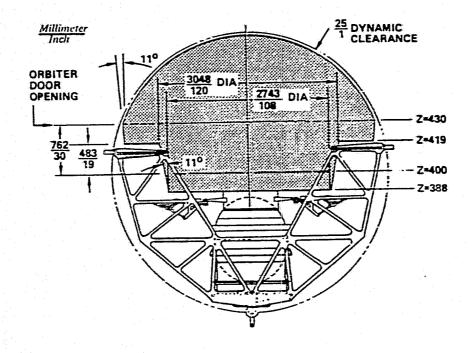
#### STS/SSUS-D INSTALLATION ENVELOPE

The STS/SSUS-D envelope shown is defined in the MDAC PAM-D User's Guide. The stowed spacecraft is oriented vertically in the STS cargo bay, with an allowable spacecraft height of 101 inches above the vee-band attach interface. The lower spacecraft diameter is limited to 108 inches by the cradle geometry, with larger dimensions permissible in the upper envelope area. The nominal length of the installation is approximately 9 feet; however, since the spacecraft/SSUS-D is spun-up to 60 RPM prior to ejection from STS, the total swept radius of the spacecraft must clear any other STS cargo.



### STS/SSUS-D INSTALLATION ENVELOPE





#### STS/SSUS-D LAUNCH WEIGHT

Weights for the SSUS-D assemblies shown are from the PAM-D User's Guide using the maximum capability Star 48 propellant load necessary to inject a 2750 pound spacecraft into transfer orbit. A 5% (516 pound) launch weight contingency has also been included. Total STS cargo weight is 10,829 pounds corresponding to a paid cargo bay length of ten feet, calculated as follows:

Paid Length = 
$$\frac{\text{SSUS-D Launch Weight}}{\text{Total STS Cargo Weight}}$$
 X 60 =  $\frac{10,829}{65,000}$  X 60 = 10 Ft

On this basis the SSUS-D launch cost is based on total cargo cost  $\times \frac{10}{60} \times \frac{4}{3}$  where the 4/3 factor is specified by NASA for shared payloads. For longer installed lengths than 10 feet, the launch cost is proportional to length  $\times 4/3$ .



# STS/SSUS-D LAUNCH WEIGHT



ITEM	WEIGHT (POUNDS)
SPACECRAFT	2,750
SSUS-D (PAM-D) @ BURN-OUT	<u>416</u>
TOTAL BURN-OUT WEIGHT	3,166
SSUS-D EXPENDABLES	4,397
TOTAL IGNITION WEIGHT	7,563
SSUS-D CRADLE	2,505
STS FITTINGS	245
NOMINAL STS PAYLOAD	10,313
5% LAUNCH CONTINGENCY	<u>516</u>
TOTAL STS PAYLOAD	10,829 POUNDS

#### STS/SSUS-D OPTIMIZATION WITH MODIFIED STAR 30B AKM

The Thiokol Star 30B solid rocket Apogee Kick Motor (AKM) has been developed and flown on the Delta/PAM-D launched SBS satellite. This motor can be modified to provide optimized STS/SSUS-D performance, by lengthening the propellant case four inches to accommodate added propellant. This type modification has been used successfully by Thiokol on the Star 37 series motors (Delta 3rd stage), and represents a proven low-risk technique to increase rocket motor total impulse.

A preliminary orbit optimization analysis results in an AKM propellant load of 1277. 2 pounds, giving a spacecraft on-orbit weight (including precession fuel) of 1472. 8 pounds.



# STS/SSUS-D OPTIMIZATION WITH MODIFIED STAR-30B AKM



SPACECRAFT LAUNCH WEIGHT	2750 POUNDS
TRANSFER ORBIT INCLINATION	27º (1. 7º REMOVED BY SSUS-D)
REQUIRED AKM DELTA V	5896. 47 FPS
AKM EFFECTIVE ISP	293.5 SECONDS
AKM EXPENDABLES	1277.2 POUNDS
SPACECRAFT INJECTED WEIGHT INCLUDING PRECESSION FUEL	1472. 8 POUNDS

# SINGLE ANTENNA LAUNCH CONFIGURATION

The STS/SSUS-D spacecraft and SSUS-D are stowed in the STS vertically, with the spacecraft housed AKM positioned directly above the Star 48 solid rocket motor. Since only 43.2 inches of headroom is available above the AKM, it is necessary to fold the antenna reflector as shown for launch. The feed is fixed however, resulting in only one rotational deployment of the passive reflector once the spacecraft is on-orbit. The only other spacecraft deployment required is to release and extend the folded solar arrays.

Total cargo bay length is dictated by the large aperture, long focal length payload antenna requiring a total cargo bay length of 15 feet for the spinning spacecraft/SSUS-D assembly. A cradle attached retractable sun shield assembly is used to protect the spacecraft and SSUS-D during STS operations prior to ejection while the cargo bay doors are open. The antenna installation as shown could be utilized to replace the movable sun-shield segments with smaller fixed shield sections attached to the cradle to complete the sun shield for this configuration.

The launch configuration shown has an inertial ratio (I Spin | less than 0.9 for the spacecraft attached to the SSUS-D, and greater than 1.10 for the spacecraft alone, meeting the inertia requirements for all spin phases of operation.

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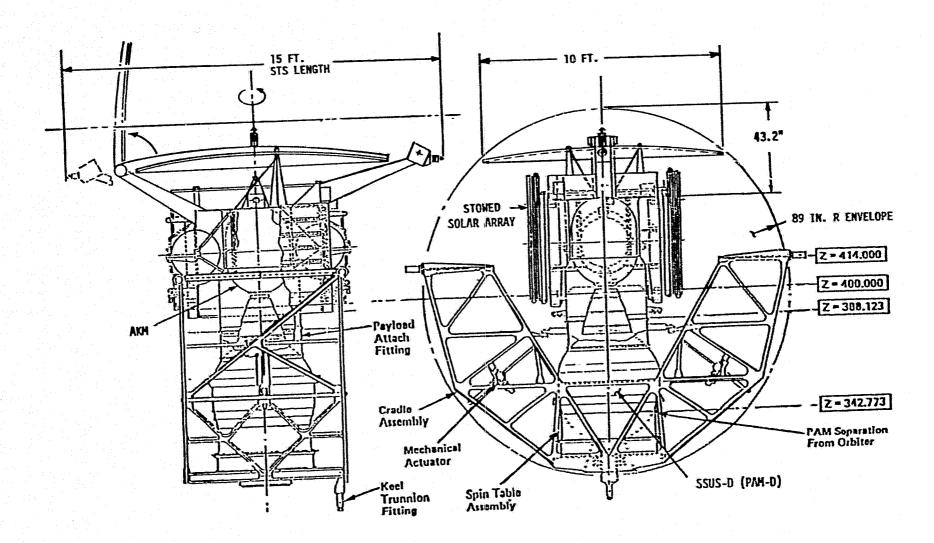


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# SINGLE ANTENNA LAUNCH CONFIGURATION





# SINGLE ANTENNA ORBITAL CONFIGURATION

The single antenna orbital configuration is shown with the solar array wings and antenna reflector fully deployed. The orbital arrangement provides a full field-of-view for the 10 foot aperture transmit/receive antenna with only one approximately 90° deployment of the passive reflector. The earth sensor and orbital TT&C antenna are mounted to the feed support structure, and the equipment panels are oriented North and South for optimum heat rejection to space. Hydrazine thrusters are mounted on the East and West facing bulkheads and around the SPS tanks to provide torque capability about pitch, roll and yaw axes, and for E-W and N-S station keeping.

Note that two TT&C antennas are provided, one on the stowed reflector for transfer orbit, and one on the feed support

A single axis solar array drive rotates the solar array one revolution per day (24 hour orbit), to maintain the array

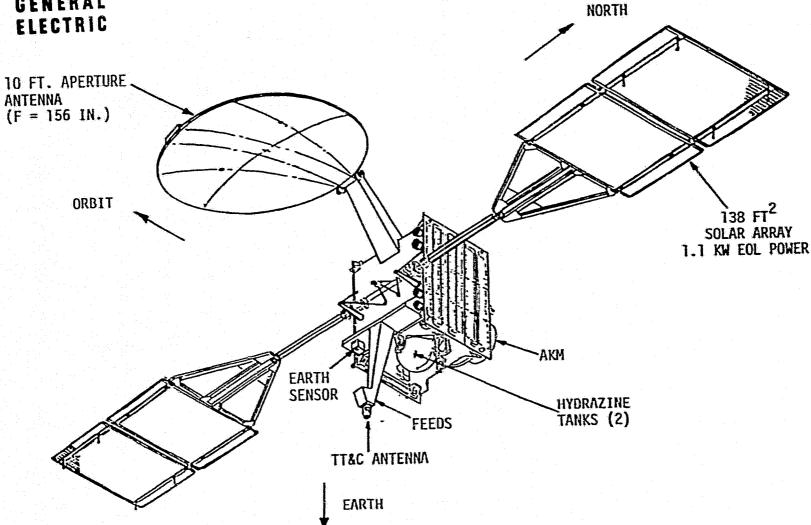
To compensate for center-of-gravity shifts due to antenna deployment, the SPS hydrazine tanks are loaded differentially for launch, and equalized on-orbit. The resultant shift in propellant mass can thus be used to balance the C. G. affect due to reflector deployment.

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# SINGLE ANTENNA ORBITAL CONFIGURATION





- 4 YEAR SATELLITE LIFE
- SSUS-D/STS
- PAYLOAD < 400 LB
- SINGLE HINGED ANTENNA DEPLOYMENT
- 10' OFFSET FED, RIGID FEED STRUCTURE
- 3 AXIS, (SPINNING ASCENT)
- SUN TRACKING SOLAR ARRAY
- STAR 30B AKM (1473 LB BOL)
- TWO TT&C ANTENNAS
- TWO CONFIGURATION BALANCE

#### TWO ANTENNA LAUNCH CONFIGURATION

The launch configuration for the two antenna configuration is similar to the single antenna design, with the smaller receive antenna reflector positioned below the transmit reflector. Two fixed feeds are located opposite the reflector pivots.

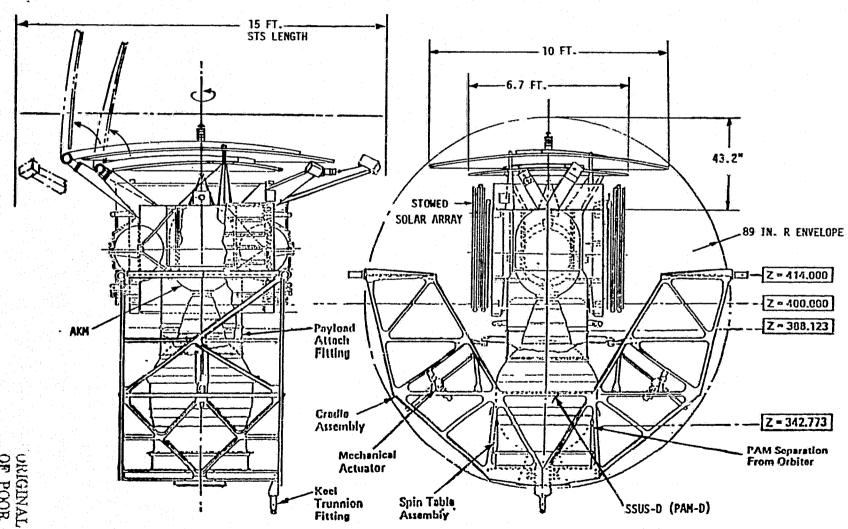
The two antenna design is heavier and more complex than the single antenna configuration since two rotating joints are required to deploy each reflector. Rotation about two axes are required in order to rotate the reflectors up and to a side by side position. Overall stowed length is 15 feet, identical to the single antenna configuration.

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### TWO ANTENNA LAUNCH CONFIGURATION





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# TWO ANTENNA ORBITAL CONFIGURATION

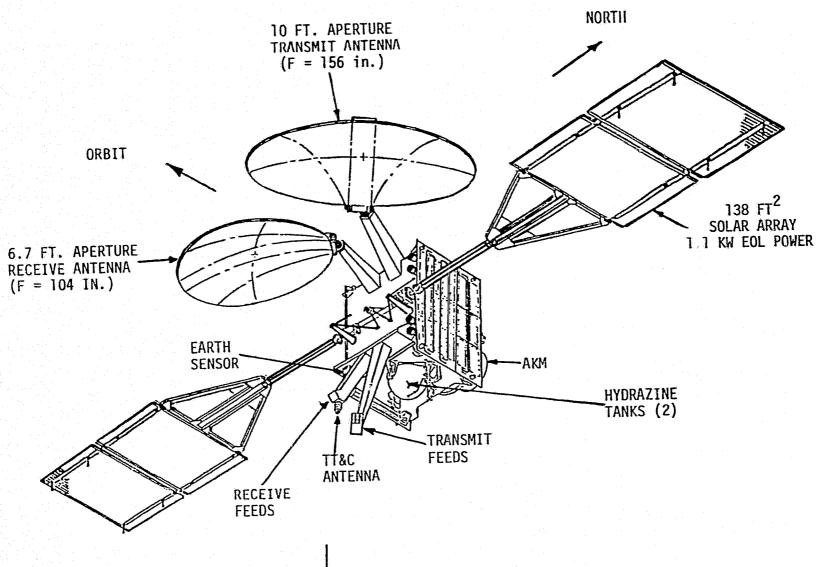
The two antenna orbital configuration shows the spacecraft with the antennas deployed side-by-side, and the solar array fully extended. With the exception of the antennas, all other installations and characteristics are identical to the single antenna design. The two antenna configuration is not recommended because:

- The double rotation deployment is more complex
- The arrangement is heavier
- Complexity is added in order to point both apertures to the same boresight despite differential thermal expansion.



### TWO ANTENNA ORBITAL CONFIGURATION





**EARTH** 

### STS/SSUS-D LAUNCH TO ORBIT SEQUENCE

Launch sequence from the STS 160 N. M. parking orbit is initiated approximately one-half orbit (45 minutes) prior to an equatorial crossing. The 45 minutes is a safety provision to allow sufficient time for the STS to move from the wicinity of the spacecraft prior to SSUS-D ignition.

The spacecraft/SSUS-D assembly is spun-up to 60 RPM by the cradle attached spin table, the cradle vee-band released and the assembly is spring ejected vertically from the STS cargo bay. The listed events 2 through 5 constitute the spinning phases of the orbit injection sequence. During spin phases the spacecraft attitude control subsystem uses body mounted horizon crossing and digital sun sensors to determine spacecraft attitude, and controls the spacecraft with the hydrazine thrusters for active nutation control and precession maneuvers.

After SSUS-D burn out the spacecraft is properly oriented and injected into final orbit by the on-board Star 30B AKM. Note that during the transfer orbit phases, spacecraft power is provided by the batteries and exposed outboard solar array panels.

On-orbit, the spacecraft is de-spun, the antennas and solar array deployed, and the spacecraft oriented and positioned for normal three-axis operation in its assigned orbital slot.



# STS/SSUS-D LAUNCH TO ORBIT SEQUENCE



- 1. THE SATELLITE ATTACHED TO THE SSUS-D, IS CARRIED INTO LOW EARTH ORBIT BY THE STS.
- 2. THE SSUS-D AND SPACECRAFT, AFTER CHECKOUT, IS SPUN-UP AND SPRING EJECTED VERTICALLY FROM THE STS NEAR THE EQUATORIAL CROSSING.
- 3. AFTER ACHIEVING THE REQUIRED SEPARATION DISTANCE FROM THE STS, THE SSUS-D SOLID ROCKET MOTOR IS IGNITED, PLACING THE SATELLITE IN THE 160 BY 19,323 N.M. TRANSFER ORBIT.
- 4. AFTER SSUS-D BURN-OUT, THE SSUS-D IS SEPARATED, AND THE SPINNING SPACE-CRAFT IS PRECESSED SO THE INTEGRAL SOLID ROCKET APOGEE MOTOR IS PROPERLY OR IENTED FOR SYNCHRONOUS ORBIT INJECTION
- 5. AT A PRESELECTED FUTURE APOGEE, THE APOGEE MOTOR IS IGNITED PLACING THE SPACECRAFT IN THE GEOSYNCHRONOUS OPERATING ORBIT
- 6. THE SATELLITE IS DESPUN AFTER INJECTION, THE SOLAR ARRAYS ARE DEPLOYED, AND THE NORMAL THREE-AXIS ORIENTATION IS ACQUIRED
- 7. AFTER PERFORMING ANY VELOCITY ADJUST MANEUVERS REQUIRED TO POSITION THE SATELLITE AT ITS ASSIGNED ORBITAL SLOT, THE MISSION PHASE IS INITIATED

#### BSE SPACECRAFT

The BSE (Broadcast Satellite Experimental) is a geosynchronous comsat designed and built by General Electric for Japan. BSE was launched by a 2914 Delta in 1978.

Launch weight of BSE was 1490 pounds and orbital weight at the beginning of mission was 780 pounds. The overall arrangement is similar to the SSUS-D spacecraft with the exception of the smaller fixed antenna installation and orbital attitude requirements. BSE is designed for a three year orbital life, and end-of-life power is 800 watts.

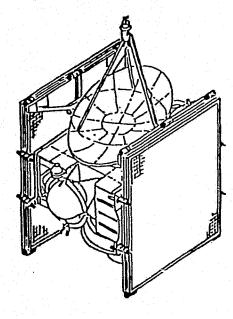
A second generation Japanese comsat, BS-2, is currently in design and fabrication at General Electric.

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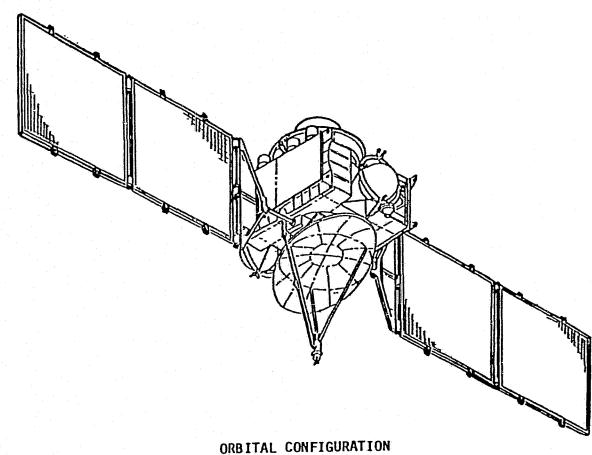


## **BSE SPACECRAFT**







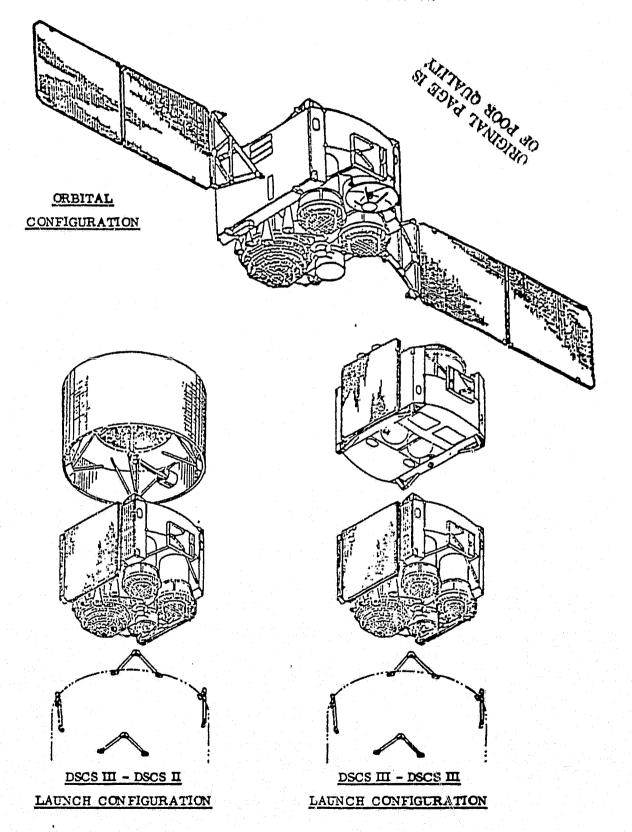


#### DSCS III MILITARY COMSAT

DSCS III is a large geosynchronous communications satellite designed and developed by General Electric for the Air Force. DSCS III is designed for dual launch with a DSCS-II on Titan-IIIC, or dual DSCS-III launch by STS/IUS. The satellite is designed for a 10 year mission life and total weight is 2200 pounds including 600 pounds of on-orbit hydrazine fuel. The solar array produces 1100 watts BOL and 837 watts EOL (10 years) power.

BSE and DSCS-III components and designs have been selected for the STS/SSUS-D spacecraft for all possible applications.

# DSCS-III MILITARY COMSAT (TITAN-IIIC OR STS/IUS LAUNCH)



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#### LANDSAT-D FLIGHT SEGMENT

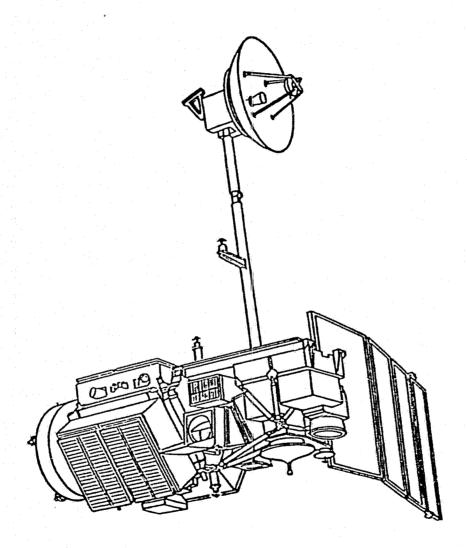
Landsat-D is a new generation earth observation satellite currently being qualified by General Electric for NASA, Goddard. Landsat-D is scheduled for launch in 1982 by a two-stage Delta 3920 to an operating orbit of 380 N. M. Total spacecraft weight including the Multi-Mission Spacecraft bus is 4700 pounds. The four panel single wing array is 150 square feet in area and provides an end-of-life power of 1200 watts at 3 years.

Landsat-D is designed for retrieval by STS and the deployable TDRSS antenna and solar array use redundant drive powered hinges for deployment and retraction. These powered hinges and retention mechanisms from Landsat-D will be used for antenna deployment and retention on the STS/SSUS-D spacecraft.



## LANDSAT-D FLIGHT SEGMENT





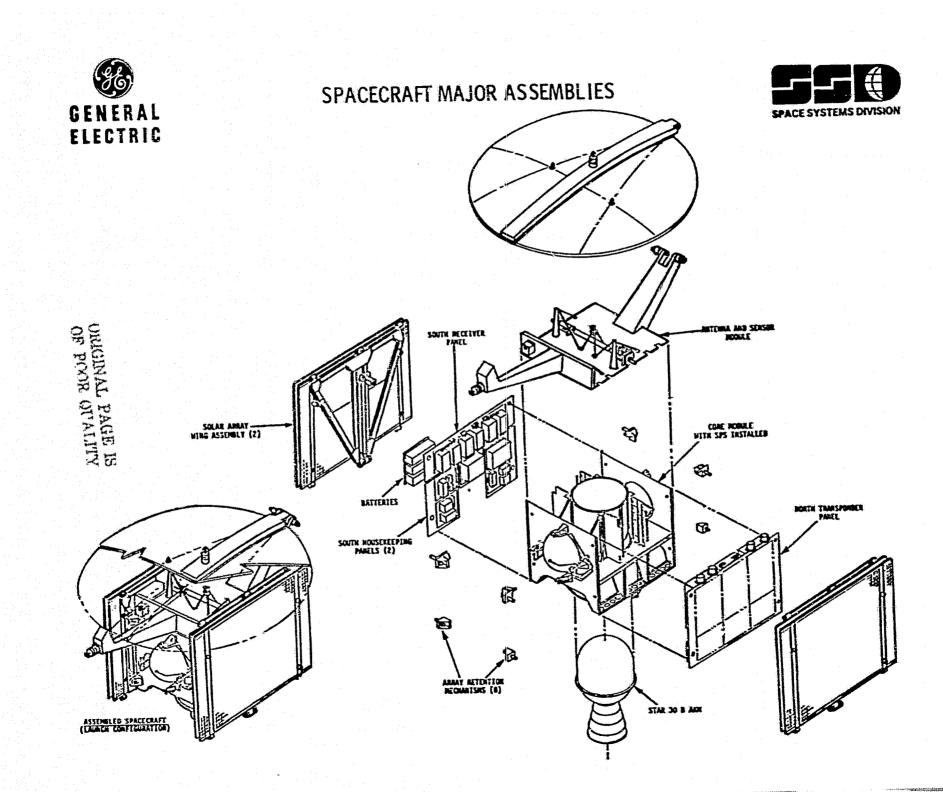
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## SPACECRAFT MAJOR ASSEMBLIES

The major spacecraft sub-assemblies are shown in the exploded view. This modular arrangement was used on both BSE and DSCS-III and permits maximum fabrication flexibility in allowing parallel build-up and testing of subsystems and subassemblies. The core structure is assembled and the all-welded hydrazine Secondary Propulsion Subsystem (SPS) is installed as a single assembly and tested. Simultaneously, the North and South payload and South equipment mounting/radiator panels are assembled and bench tested for electrical and RF performance. Antennas, sensors and the solar array drive are mounted to the removable upper bulkhead and tested for functional performance and during final assembly.

These separate modular sub-assemblies are integrated in the spacecraft launch configuration by first attaching the upper bulkhead antenna/sensor module to the core structure/SPS assembly. Interconnecting electrical harness segments, the internally mounted momentum wheels, internal insulation and solar array retention fittings are installed next. The pre-tested North and South equipment panels are then installed using matchtooled frame interface attachments. Final assembly at the factory is completed by installing external insulation over all non-heat rejecting surfaces and attachment of the solar array wing assemblies, antenna reflector, and batteries. The loaded AKM is shipped separately and is installed in the central well at the launch site to complete the spacecraft assembly.

The completely assembled spacecraft is attached at the 37 1/2 inch vee-band separation clamp to the SSUS-D and the separable interface electrical connectors mated to complete the launch installation. The SPS hydrazine fuel is loaded, and pyrotechnic devices are installed at the launch site during the STS integration cycle in accordance with STS safety requirements.



#### NORTH TRANSPONDER PANEL

The entire North equipment panel is devoted to mounting the Ka band transmitter assembly consisting of four 40 watt TWT's with power supplies, two Impatt amplifiers and associated drivers and switching components. The variable power dividers will be mounted to two inboard shelves over the TWTA and Impatt areas. Overall panel size is 66.5 inches wide and 50.6 inches long giving an effective radiator area of 23 square feet and component mounting area of 17 square feet.

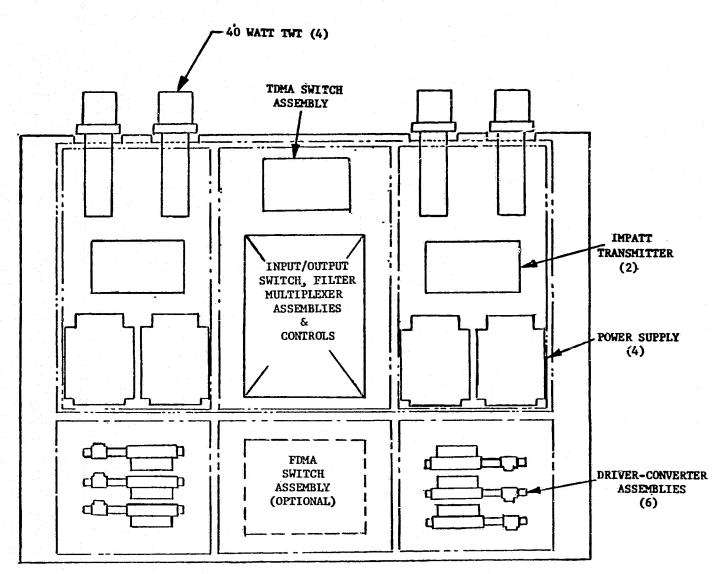
The panel utilizes a high thermal conductivity magnesium-thorium plate and heat pipes for thermal control and has a total heat radiation capacity of over 600 watts not including heat dissipated directly by the external TWT radiation coolers. Optical Solar Reflectors (OSR) are bonded to the panel radiating surfaces to provide a stable thermal radiator with minimum end-of-life degradation.



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### NORTH TRANSPONDER PANEL





### DSCS III AND BSE TRANSPONDER PANELS

The SSUS-D transponder panel uses designs and hardware developed on the DSCS-III and BSE panels. DSCS-III has a 36 square foot panel area mounting four forty watt and six ten watt conductively cooled TWTA'S. The DSCS-III design does not use heat pipes and is designed to meet survivability requirements for a ten year mission life. Total maximum panel heat dissipation is approximately 500 watts.

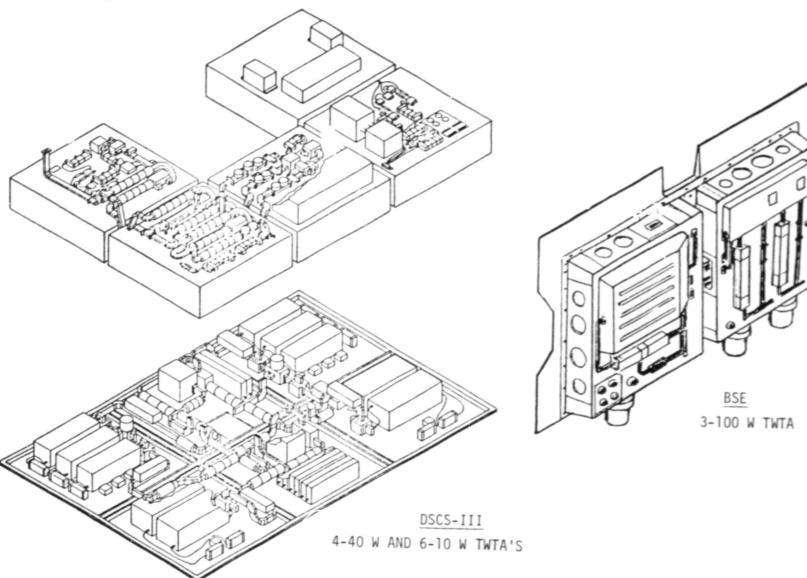
The BSE North transponder panel has a total radiator area of 10.4 square feed and supports three (2 operating) 100 watt direct radiation cooled TWTA's. Lateral and vertical heat pipes are used to increase panel radiator efficiency giving a maximum three year end-of-life dissipation capability of over 300 watts exclusive of the TWT heat radiated by the collector radiators.

Both DSCS-III and BSE panels are of integrally machined magnesium-thorium construction, and both support low-heat dissipation components on inboard shelfs over the panel mounted TWT's and power supplies.



# DSCS-III AND BSE TRANSPONDER PANELS





#### SOUTH EQUIPMENT PANELS

The south equipment panels consist of an upper "T" shaped panel for the payload receivers and processor and two side panels supporting attitude control (ACS), power (EPS) and TT&C subsystems components. The nickle-cadmium battery assemblies are supported in a lower well between the housekeeping panels, and are thermally isolated from the panel and spacecraft.

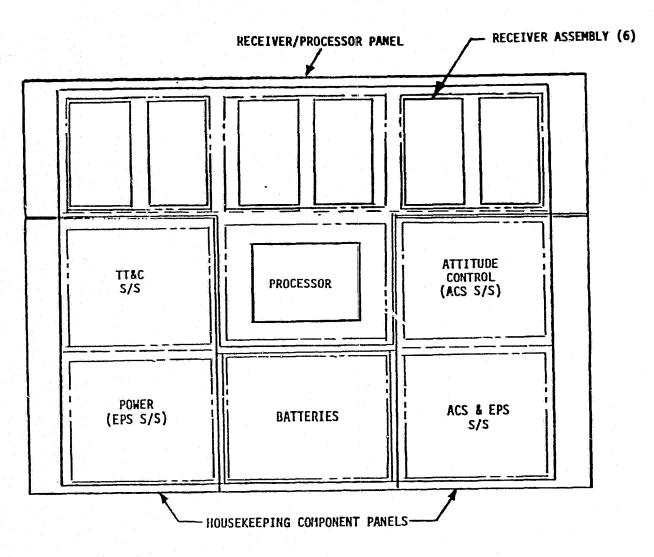
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The South panels, having significantly lower total heat dissipation components than the North panel will most likely not require heat pipes. Required radiator areas will be covered with OSR, and all non-radiating areas will be insulated.



### SOUTH EQUIPMENT PANELS





#### BSE AND SSUS-D STRUCTURES

Key drivers for the structure are a lightweight producible design using state-of-the-art materials and construction, accommodating mounting requirements for all spacecraft payload and subsystem equipment. The structure has been designed to meet the launch loads and environments imposed by the STS/SSUS-D launch vehicle.

The STS/SSUS-D structure is a derivative of the smaller BSE communication satellite structure previously designed and flown by General Electric on the Delta 2914 launch vehicle. BSE and STS/SSUS-D structures illustrated to the same scale, have identical load paths and structural arrangements.

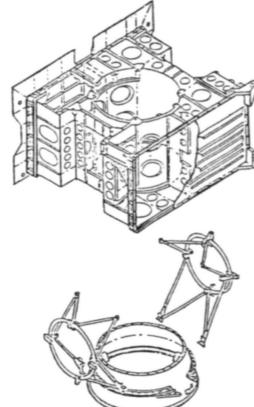
BSE used minimum gauge stiffened magnesium construction and was designed to support a spacecraft Launch Gross Weight (LGW) of 1490 pounds. The larger SSUS-D spacecraft structure designed for an LGW of 2750 pounds, will use stiffened magnesium internal structure and aluminum honeycomb sandwich side panels and bulkheads based on the DSCS-III panel designs. Both structures use machined magnesium-thorium north and south equipment mounting/radiator panels. The SSUS-D structure will utilize high stiffness to weight graphite-epoxy composite construction for the primary thrust cone and internal struts.



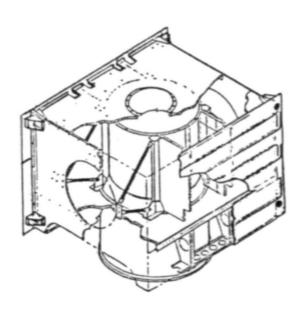
## BSE AND SSUS-D STRUCTURES







STS-SSUS-D



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## DSCS III AND BSE PRIMARY STRUCTURES

Materials and construction for the SSUS-D spacecraft structure have almost all been developed and used on the DSCS-III and BSE structures illustrated. DSCS-III is a large structure designed for dual spacecraft launch by the Titan III C or STS/IUS. Body panels are of highly efficient non-buckling aluminum honeycomb sandwich construction having aluminum panel faces chem-etched to 0.005 inch thickness. DSCS-III uses GE developed graphite-epoxy struts in both primary ar. secondary structural applications. Total weight of the DSCS-III structure is 300 pounds, 13.6% of the spacecraft on-orbit weight of 2200 pounds.

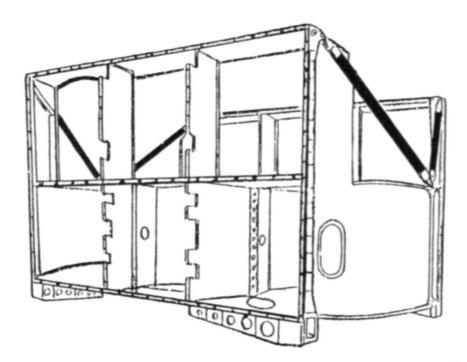
The smaller semi-monocoque stiffened magnesium BSE structure has a total weight of 105 pounds, 13.4% of the on-orbit weight of 783 pounds.

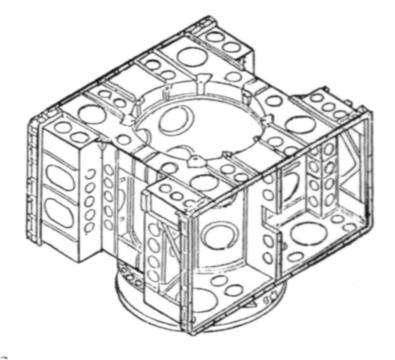
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## DSCS-III AND BSE PRIMARY STRUCTURES







DSCS-III

ALUMINUM HONEYCOMB SANDWICH CONSTRUCTION OF POOR QUALITY

BSE

SEMI-MONOCOQUE MAGNESIUM/ALUMINUM CONSTRUCTION

#### SSUS-D SPACECRAFT PRIMARY STRUCTURE

The primary structure consists of a thrust cone attached to a central stiffened cylinder with rectangular upper and lower bulkheads. Removable North and South oriented communications and housekeeping panels support virtually all internally mounted components, and the separable upper bulkhead mounts the external antennas, sensors and the solar array drive. SPS tanks and thrusters are supported by the East and West panels and internal "vee truss" strut assemblies, and the four momentum wheels are mounted below the lower bulkhead. The bulkheads, North and South panels and keels, and East and West panels and trusses distribute all equipment loads to the central cylinder and thrust cone while the AKM, representing 50% of the spacecraft launch weight, is supported by an aluminum ring at the thrust cone/lower bulkhead juncture. This structural arrangement efficiently redistributes the spacecraft loads to the launch vehicle interface with the central cylinder and thrust cone forming the backbone of the structure.

The thrust cone is the most highly loaded structure transferring all spacecraft shear, axial and bending loads to the launch vehicle interface. The thrust cone is a monocoque graphite-epoxy shell with a lower machined aluminum ring provided for mating to the SSUS-D 3712 attach fitting via the separation vee-band. The central cylinder is an aluminum stiffened magnesium shell similar in construction to the BSE design. The cylinder and thrust cone are joined at the lower bulkhead by an aluminum splice/AKM adapter ring. This fixed cone-cylinder-bulkhead joint results in an efficient structural load path to the L/V separation interface with minimum discontinuities.

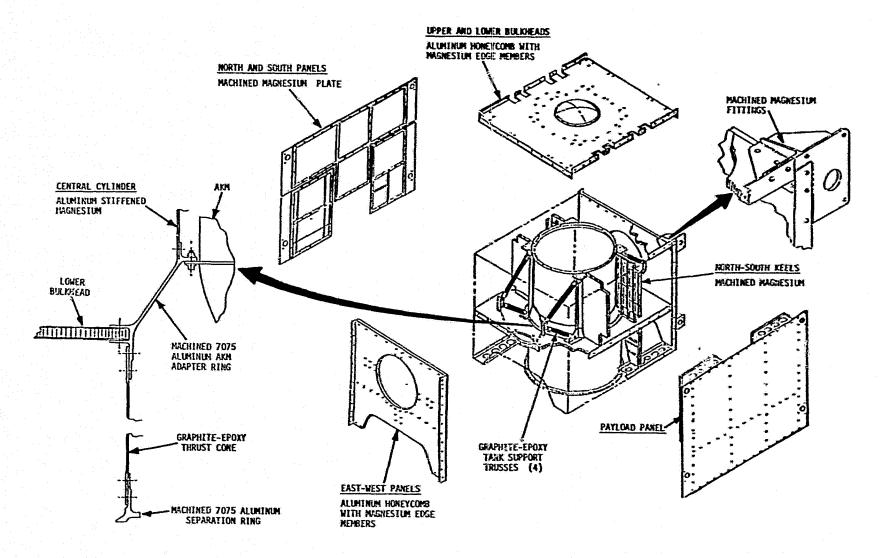
Conventional aluminum honeycomb sandwich is used for the East and West panels and bulkheads providing lightweight, non-buckling panels with simple mating and attachment interfaces. The North-South keels are integrally machined magnesium plates, similar to the BSE keel designs. Separation and AKM/Splice rings are machined aluminum forgings.

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## SSUS-D SPACECRAFT PRIMARY STRUCTURE





## DSCS III COMPOSITE STRUCTURES

The East-West vee truss assemblies, supporting the SPS propellant tanks, are graphite-epoxy tubes, and the thrust cone is a monocoque graphite-epoxy shell. Use of graphite-epoxy composite materials for these elements results in lower weight with increased stiffness over conventional aluminum or magnesium designs.

Composite construction has been developed and used at General Electric on the BSE Kevlar-epoxy Ku Band antenna and on DSCS III for the Gimbal Dish Antenna. Graphite-epoxy struts were developed for DSCS III resulting in a total weight saving of 25 pounds. Struts used vary in diameter from 5/8 inch up to 2 1/2 inches and are used in both primary and secondary structural applications.

The SSUS-D composite elements will use the basic composite technology developed for DSCS-III to achieve predictable weight savings at low risks.



DSCS III COMPOSITE STRUCTURES



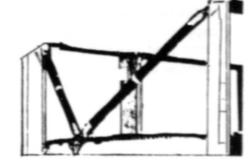


GIMBAL DISH ANTENNA

- 33" DIA. BUILT-UP KEVLAR REFLECTOR
- GRAPHITE EPOXY SUPPORT STRUTS
- LOW THERMAL DISTORTION



- . 8 GRAPHITE-EPOXY STRUTS
- . 8 POUND WEIGHT SAVING



TANK, PANEL AND ANTENNA SUPPORT STRUCTURE

- 62 GRAPHITE—EPOXY STRUTS
- 17 POUND WEIGHT SAVING

### ANTENNA AND SENSOR SUPPORT STRUCTURES

Low distortion and high stiffness to weight graphite-epoxy composite construction will be used for the antenna and sensor support structural elements. The 10 foot diameter aperture offset-fed antenna reflector will utilize graphite-epoxy faced aluminum honeycomb core construction for the basic reflector, and built-up graphite epoxy box-rib structures will be used for the reflector and feed supports and reflector spine. The sensor and feed support platform will be a graphite-epoxy faced aluminum honeycomb core sandwich plate with graphite-epoxy struts.

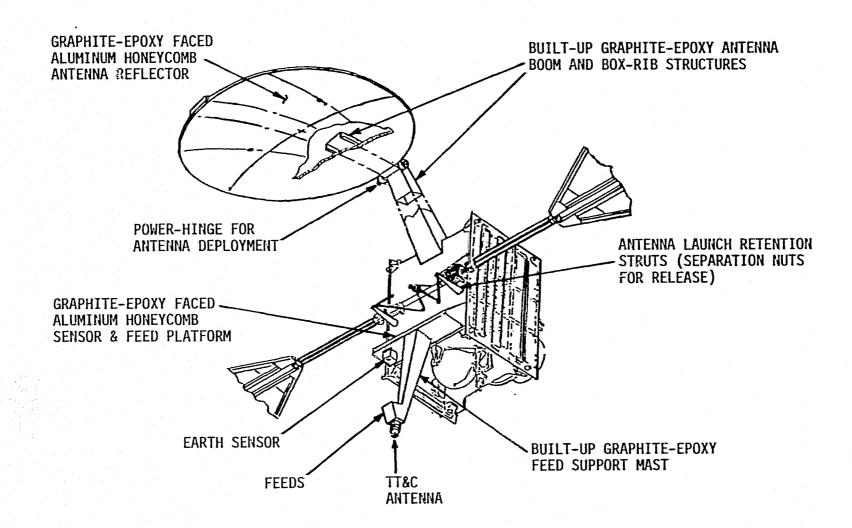
The stowed antenna reflector will be supported for launch on graphite-epoxy struts and released by dual pyro activated separation nuts. The reflector will be deployed approximately 90 degrees by a redundant drive train powered hinge. These retentions and hinge mechanisms have been developed and qualified for the Landsat-D satellite currently under development by General Electric for NASA, GSFC.

The antenna configuration selected for the SSUS-D application meets the launch envelope and deployed antenna aperture and field of view requirements with only one release and deployment of the passive reflector required. The reflector structure using graphite-epoxy sandwich construction will have the structural integrity necessary for launch support at three points formed by the pivot hinge and two retention posts. Use of low-distortion composites for the fixed feed and reflector support structure will insure that minimum thermal distortion effects are experienced by the antenna system.



### ANTENNA AND SENSOR SUPPORT STRUCTURES





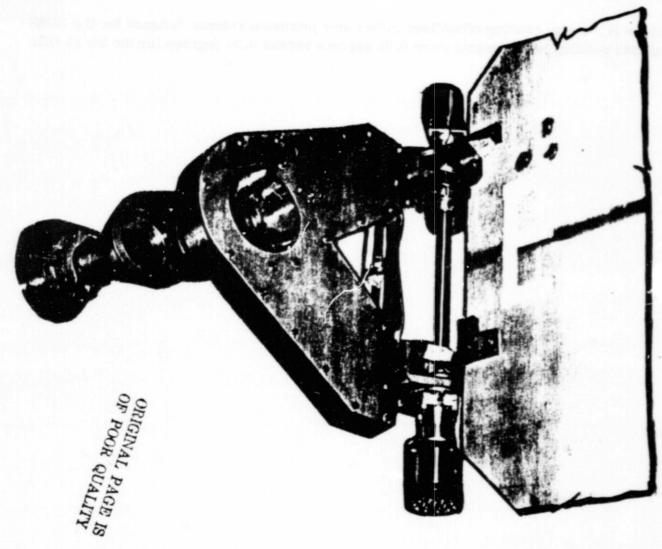
#### LANDSAT-D POWER HINGE

Power hinges have been developed and qualified on the Landsat-D program for deployment of the solar array and TDRSS antenna boom. The hinge shown is at the Landsat-D solar array yoke pivot and serves to extend the array panels through a closed loop cable/pulley system. The drive consists of two separate stepper motor drive systems with redundant bearings such that either a motor drive or bearing failure does not prevent hinge operation. This mechanism will be used for antenna reflector deployment on the SSUS-D spacecraft, to drive the reflector open against precision stops or latches.



# LANDSAT-D POWER HINGE





#### NASA LAMMR DESIGN STUDY

The conceptual design of the 20/30 GHz antenna has been based on the LAMMR antenna preliminary design developed by General Electric for NASA, GSFC.

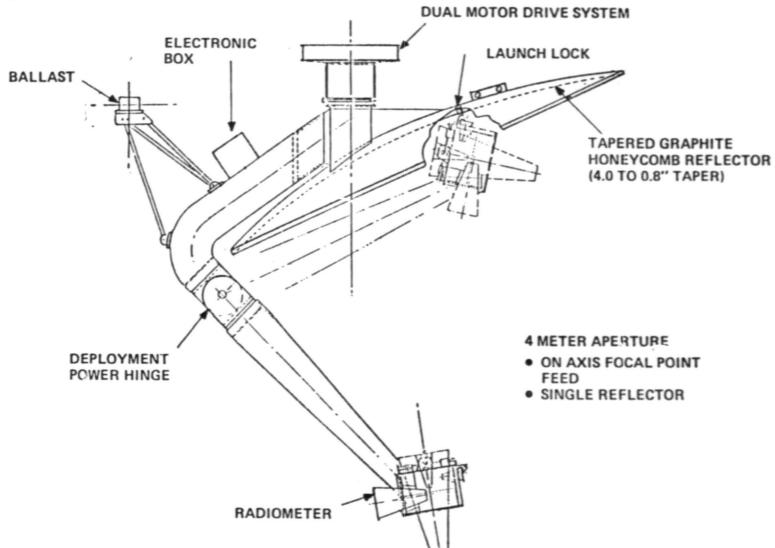
LAMMR is a large aperture (4 meters) rotating offset feed radiometer precision antenna designed for the NOSS spacecraft. LAMMR antenna pointing requirements were 0.02 degrees versus 0.05 degrees for the 20/30 GHz antenna.

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### NASA LAMMR DESIGN STUDY \*





\* NOSS RADIOMETER DESIGN STUDY CONDUCTED BY GE FOR NASA-GSFC, CONTRACT NAS 5-25582, MARCH 1980

### LAMMR ORBITAL CONFIGURATION

The LAMMR antenna orbital configuration consists of the 4 meter aperture reflector, deployed feed and control rotating mechanism. The system was balanced and rotated about the vertical axis at 60 RPM to scan along the ground path of the satellite. LAMMR operating attitude was 700 km (380 nm). Low distortion graphite-epoxy construction was selected, as shown, for all alignment critical antenna elements. In addition to low thermal distortion, the high modulus to weight of these composites permitted meeting the high 15 Hz orbital stiffness requirement at the lowest weight. This high stiffness requirement was required to limit any orbital jitter problem and also to limit 1g ground testing where small deflections would create large boresight (hence pointing) errors.

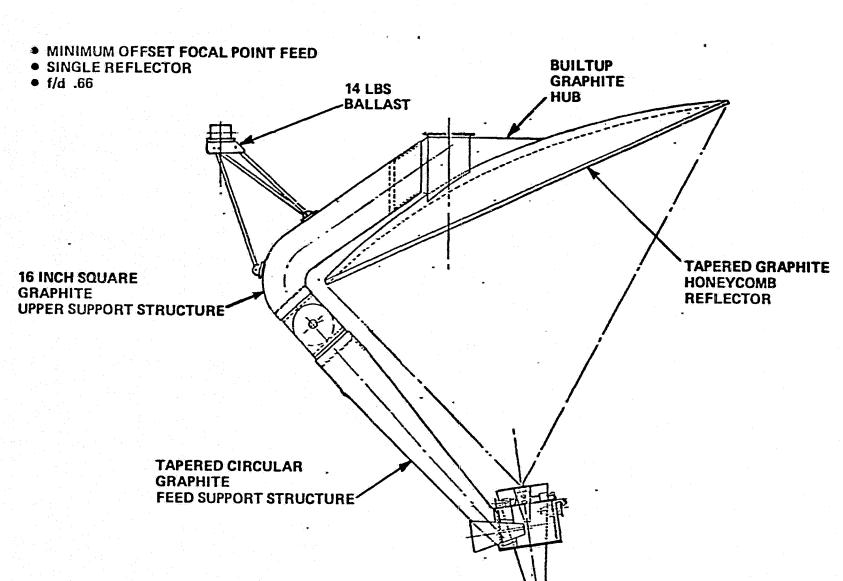
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## LAMMR ORBITAL CONFIGURATION





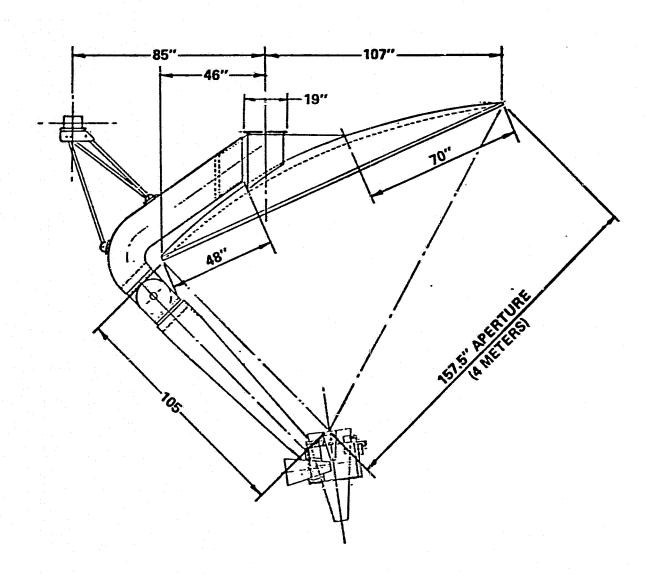
### LAMMR ANTENNA DIMENSIONS

Dimensions and geometry are shown for the 4 meter (157.5 inch) aperture, F/D = 0.66 (F=105 inches) LAMMR antenna. The 20/30 GHz antenna has a 10 foot (120 inch) aperture and F/D of 1.32 (F=158.4 inches). The overall dimensions of these two offset feed designs are comparable permitting generalized comparison of overall pointing performance.



## LAMMR ANTENNA DIMENSIONS





### LAMMR REFLECTOR ALTERNATES

The various materials and configurations tabulated were analyzed for the LAMMR reflector, calculating thermal gradients and associated thermal distortions. For LAMMR, the last entry was the selected configuration consisting of a 0.4 inch to 4.0 inch tapered aluminum honeycomb core with 0.008 inch to 0.040 inch tapered graphite-epoxy faces. Since the LAMMR antenna rotates, insulating the back reflector surface did not significantly reduce thermal distortions and presented a problem in preserving dynamics balance for the rotating antenna assembly. For these reasons insulation of the back surface was not adopted for LAMMR. The fixed 20/30 GHz reflector however revolving only once a day with respect to the sun, benefits from back surface insulation which reduces both gross temperature fluctuations and gradients over the longer geosynchronous orbit period.



## LAMMR REFLECTOR ALTERNATES



DISH BACK	CONSTRUCTION		FRONT SURFACE		BACK SURFACE			ANALYTICAL MODELING	REF. FIG. #
	FACE SHEETS	CORE	αs	€N	ας	€Н	INSUL.		
	.030" ALUMINUM	2"2.3#/FT <sup>3</sup> ALUM.	.25	.05	.06	.66	YES	1 DIMENSIONAL	1
INSULATED	.020" GRAPHITE EPOXY	2" - 2.3#/FT <sup>3</sup> ALUM.	.9	.9	.06	.65	YES	1 DIMENSIONAL	2
INSOLATED	.015" GRAPHITE EPOXY	1.7" — 2.3#/FŢ <sup>3</sup> ALUNI.	.5	.4	.06	.66	YES	1 DIMENSIONAL	3
	.030" GRAPHITE EPOXY	3.54-2.3#/FT <sup>3</sup> ALUNI.	.5	.4	.06	.66	YES	1 DIMENSIONAL	4
	000// 00 45/ 177 500/4								
	.020" GRAPHITE EPOXY	2.0" - 2.3#/FT <sup>3</sup> ALUM.	.9	.9	.9	.9	NO	1 DIMENSIONAL	5
UNINSULATED	.015" GRAPHITE EPOXY	1.7" - 2.3#/FT <sup>3</sup> ALUM.	.5	.4	.14	.05	NO	1 DIMENSIONAL	6
	.030" GRAPHITE EPOXY	3.5生2.3#/FT <sup>3</sup> ALU耐。	.5	.4	.14	.05	NO	1 DIMENSIONAL	7
		:							1
INSULATED SHEET-	.015" GRAPHITE EPOXY	1.0" - 2.3#/FT <sup>3</sup> ALUM.	.5	.4	.06	.66	YES	2 DIMENSIONAL	8
SHEET GRADIENTS	.030" GRAPHITE EPOXY	4.0" — 2.3#/FT <sup>3</sup> ALUM.	.5	.4	.06	.66	YES	2 DIMENSIONAL	9
SHEET GRADIENTS	.015"→.030" GRAPHITE EPOXY	1.0"→4.0"—2.3#/FT <sup>3</sup> ALUM.	.5	.4	.06	.66	YES	2 DIMENSIONAL	10
UNINSULATED SHEET SHEET	.008" GRAPHITE EPOXY	0.8" — 2.3#/FT <sup>3</sup> ALUM.	.5	.4	.14	.05	NO	2 DIMENSIONAL	11
GRADIENTS	.040" GRAPHITE EPOXY	4.0" - 2.3#/FT <sup>3</sup> ALUM.	.5	.4	.14	.05	NO	2 DIMENSIONAL	12
SHEET GRADIENTS	.008"→.040" GRAPHITE EPOXY	0.8"→4.0"—2.3#/FT <sup>3</sup> ALUM.	<b>.</b> 5	.4	.14	.05	NO	2 DIMENSIONAL	13

#### LAMMR POINTING ERROR ANALYSIS

The pointing error analysis for the selected composite LAMMR design shows a calculated total pointing error of 0.022 degrees versus a 0.020 degree requirement. The analysis used the General Electric GERMS computer program and was a preliminary evaluation of the worst-case thermal gradients and tolerances. Subsequent refinement of both the design and the analysis would likely have resulted in LAMMR pointing performance below the 0.020 degree requirement.

The proposed 20/30 GHz ten foot aperture reflector design uses approximately 0.02 inch graphite-epoxy faces on a 1/2 inch thick aluminum honeycomb core, and reflector and feed supports are built up boxes of 0.050 inch thick graphite-epoxy. The lack surface of the reflector and outer surfaces of the support boom are covered with multi-layer super insulation to reduce thermal fluctuations and gradients.

Estimated total pointing error for the 20/30 GHz antenna based on LAMMR results are 0.03 degrees minimum to 0.04 degrees maximum. The increased error from the calculated value of 0.022 degrees for LAMMR results primarily from predicted higher thermal distortions for the 20/30 GHz antenna having a significantly longer orbital period. These errors should be regarded as static pointing errors which will largely be compensated for by the action of the monopulse sensors.



# LAMMR POINTING ERROR ANALYSIS



	BUDGET (DEGREES)	CALCULATED ERRORS (DEGREES) (TIME 32)	CALCULATED ERRORS (GEGREES) (TIME 68)
BEARING RUNOUT	0.005 <sup>0</sup>	0.005 <sup>0</sup>	0.005 <sup>0</sup> .
FEED POSITION	0.0015 <sup>0</sup>	0.0015 <sup>0</sup>	0.0015 <sup>0</sup>
JITTER	0.0015 <sup>0</sup>	0.000°	0.000
1G FEED	0.005 <sup>0</sup>	0.004 <sup>0</sup>	. 0.0040
HOISTURE FEED	0.0020	0.002 <sup>0</sup>	0.0020
RSS	0.007 <sup>0</sup>	0.006 <sup>0</sup>	0.0050
1G ANTENNA	0.001	(1)+0.003 <sup>0</sup>	(1)+.003 <sup>0</sup>
SPIN FEED	0.003	+0.005°	+.005 <sup>0</sup>
SPIN ANTENNA	. 0.004	(1)+0.010 <sup>0</sup>	(1)+.010 <sup>0</sup>
THERMAL FEED	0.002	-0.0004 <sup>0</sup>	006 <sup>0</sup>
THERMAL ANTENNA	0.003	(1)-0.00140	(1)+.004 <sup>0</sup>
TOTAL	0.020	0.022 <sup>0</sup>	0.0220
SPEC	0.020	0.020 <sup>G</sup>	0.020 <sup>0</sup>

(1) FROM GERMS

#### THERMAL CONTROL SUBSYSTEM

The low risk thermal control design selected for the spacecraft meets all thermal requirements using components which have proven life performance. The Thermal Control Subsystem (TCS) design utilizes thermal coatings, multi-layer insulation, insulation spacers, heat pipes, and electrical heaters activated by thermostats with command override. The TCS design imposes no operational restrictions, and has no single peint failures.

Thermal balance tests and orbital performance of the Broadcast Satellite Experimental (BSE) have verified its design for both the transfer orbit and orbital missions. The STS/SSUS-D TCS design is very similar thermally to the BSE design. A TCS overview is shown with the spacecraft in the orbital configuration.

The satellite is primarily insulated with multi-layer insulation blankets, with heat radiation areas on the north and south panels. To minimize the effects of concentrated heat dissipation under the transponder TWT's and power supplies, redundant heat pipes are located on the north panel. The north and south panels exchange heat primarily by internal radiation. This same approach was used successfully on BSE to effectively provide a large 'sothermal radiator panel. Both north and south panel radiating areas are covered with Optical Solar Reflectors (OSR). OSR was selected as the primary heat radiation coating because it is the most stable coating available with extensive synchronous altitude satellite heritage. The Electrostatic Discharge (ESD) approach is to ground all components including each layer of the multi-layer blankets and the thermal coatings.

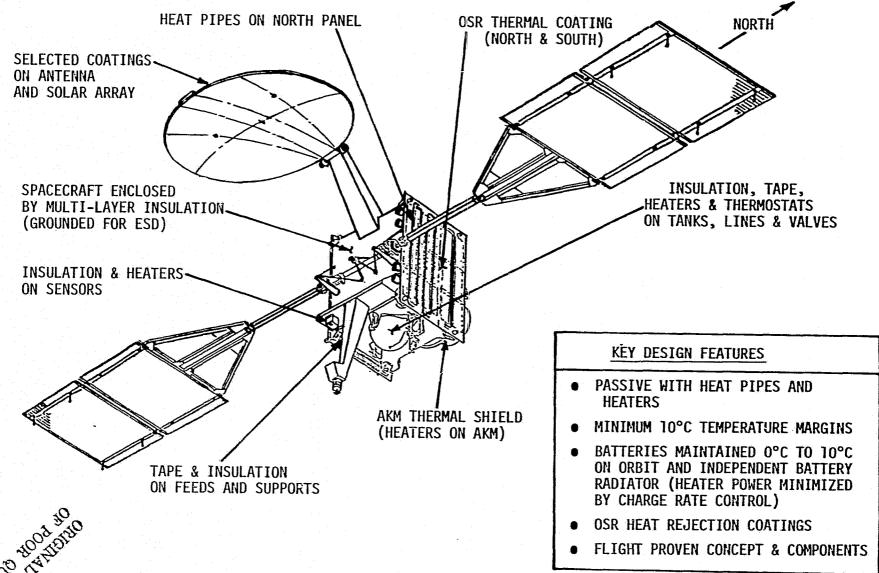
Heater/thermostat assemblies supplement the design on: the batteries, which must be maintained above 0°C; the Secondary Propulsion Subsystem, to maintain hydrazine above 1.7°C; and the AKM to maintain its temperature prior to firing. Compensation heaters, not normally on, will be located on the north panel to provide power during periods of initialization and during reduced payload operation to maintain minimum temperature levels. All thermostats are redundant and all heater assemblies have either redundant commandable assemblies or redundant elements. All thermostat circuits can be overridden by ground command and separate commands are provided for the prime and redundant heater circuits in each assembly.

General Electric thermal control experience on the BSE, Nimbus and Landsat and DSCS III provides a solid basis for the thermal control approach selected. The overall design concept is also very similar to those used, in whole or in part, on: The Application Technology Satellite (ATS-6); the Communications Technology Satellite (CTS), LES 8 and 9; RCA-Satcom; and the Fleetsatcom satellites. It is also being used on other spacecraft including the European OTS, Intelsat V, and BSE. These satellites are similar in that they are three-axis stabilized, synchronous satellites with communications payloads. All utilize thermal control techniques including heaters, multi-layer insulation, OSR or silver teflon coatings, and some have heat pipes.



## THERMAL CONTROL SUBSYSTEM





#### ATTITUDE CONTROL SUBSYSTEM

With limited ground intervention, the Attitude Control Subsystem (ACS) provides satellite control during the Transfer Orbit, Drift Orbit, and Synchronous Orbit phases and performs the listed functions.

A nominal 60 rpm spin velocity is imparted to the satellite and SSUS-D at separation retaining its spin momentum until completion of apogee motor firing. During this phase, the ACS provides three major functions: 1) nutation damping, 2) telemetered sun and earth direction data for use with ephemeris information to allow ground computation of the satellite inertial attitude, and 3) through uplink commands, reorients the satellite to the attitude required for apogee motor firing. Precession is accomplished by means of on-board controlled operation of the precession/nutation damping thrusters. Following apogee motor burn, the satellite remains spin stabilized while nutation is damped and further spin speed data is processed for final spin momentum removal. Earth acquisition is completed immediately following the final despin maneuver. Release of the solar arrays at this time allows arraymounted Sun sensors to acquire the Sun completing the acquisition process. Subsequently, the four skewed reaction wheels are activated to supply control torques. On-orbit, three-axis control is maintained during all mission phases by a zero momentum stabilization system. Redundant passive earth sensors, redundant RF sensors and redundant array mounted sun sensors are used to derive roll, pitch, and yaw error signals. On-board processing of the sensor signals allows any two of the three attitude sensors to provide sufficient information for three-axis control. Reaction to disturbance torques are provided by four (4) reaction wheels. The reaction wheels are configured to allow a failure of any unit or its drive electronics without causing service interruption or degradation of performance. The hydrazine thrusters can be used in a backup mode with some degradation in pointing accuracy. The low thrust engines are controlled by the ACS and are used for stationkeeping and to unload accumulated momentum stored by the reaction wheels.

ACS performance in each phase is tabulated with the 0.05 degree operational mode beam pointing capability being most signifigant for system performance. This accuracy is achieved by integrating the monopulse RF sensor with the 20/30GHz antenna to minimize alignment and distortion effects between the ACS sensors and antenna system.

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### ATTITUDE CONTROL SUBSYSTEM (ACS)



#### ACS FUNCTIONS

- ACTIVE NUTATION DAMPING DURING SPIN PHASE
- PROVIDES SPIN AXIS ATTITUDE DATA
- CONTROLS GROUND COMMANDED PRECESSION
- CONTROLS DESPIN
- MAINTAINS THREE-AXIS ATTITUDE CONTROL THROUGHOUT THE MISSION USING SEVERAL COMBINATIONS OF SENSORS
- MAINTAINS THE SOLAR ARRAY PERPENDICULAR TO THE SUN LINE
- CONTROLS EAST/WEST AND NORTH/SOUTH STATIONKEEPING MANEUVERS

### ACS PERFORMANCE

Spin Phase		Wheel Capture	
Attitude det accuracy     Precession accuracy	0.30°, 3σ 0.1°, 3σ	Time to achieve normal pointing	30 mins, after earth acquisition
Nutation damping	= 60 min, before AKM burn = 90 min, after AKM burn	Operational Mode	
• Spin rate	60 RPM ± 15 RPM	Beam pointing accuracy     Stability margins	0.05 deg. 3X (wrt control loop gains)
Despin	teach and the second	E. W. N. S. Stationkeeping	
Despin time     Final rate	20 min. ±0.3°/sec/axis	Pointing accuracy     Stability margins	0.1 deg. 3X wrt control loop gains
Earth Acquisition		Solar Array Control	
Initial conditions     Accuracy     Acquisition time	1°/SEC/AXIS ± 2°, PITCH, ROLL± 5°, YAW 6 HOURS AFTER AKM BURN	Accuracy	± 1.0 deg.

### ACS BLOCK DIAGRAM

The simplified ACS block diagram shows the ACS components and interfaces with the solar array drive and hydrazine Secondary Propulsion Subsystem (SPS). The items shown cross-hatched are the sensors and control logic used during the transfer orbit spin phase, and are no longer required once the spacecraft is de-spun and stabilized on orbit. Note, however, that the thrusters used for nutation control and precession during the spin phase are used as part of the three-axis control system during orbital operation.

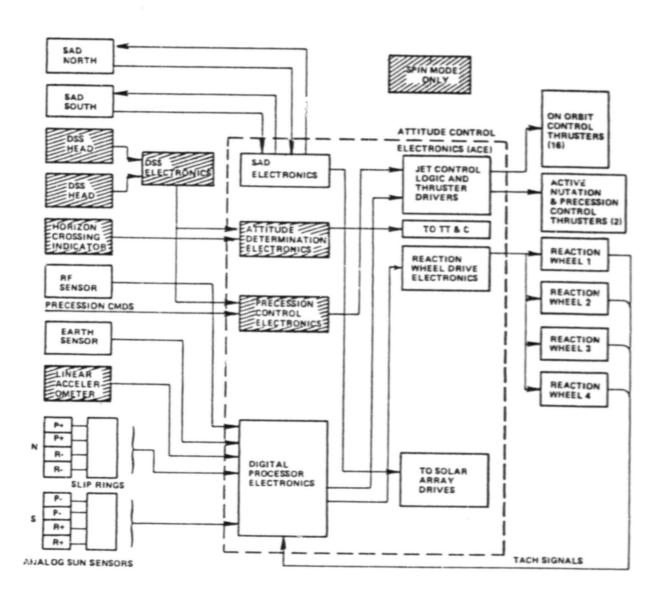
The central component of the ACS subsystem is the Attitude Control Electronics (ACE) package which contains the circuitry to process sensor signals and send control signals to the SPS thrusters and reaction wheels.



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## ACS BLOCK DIAGRAM





#### ACS DESIGN CHARACTERISTICS

Component characteristics are summarized for the ACS sensors and reaction wheels. The earth sensor is the DSCS-IIIQuantic sensor which has been selected for BS-2, the second generation BSE. This sensor is a single unit which provides two functionally redundant operating channels. The RF Sensor (Monopulse) elements are integrated with the antenna feed, and use the BS-2 electronics. Linear accelerometers are existing components previously flown on the Block-5 spacecraft. All other sensors and the reaction wheels are BSE components.

The attitude control electronics (ACE) is a modified BSE design incorporating provisions for the Active Nutation Control (ANC) functions and for the added fourth reaction wheel.

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DESIGN CHARACTERISTICS
PASSIVE, RADIATION BALANCE, ANALOG
• NULL ACCURACY • 0.05 DEGREE
• LINEAR RANGE - ±5.0 DEGREES
AUTOMATIC SUN REJECTION
OPERATES DURING TRANSFER ORBIT ONLY
• EACH SENSOR HEAD HAS A ±64 DEGREE FIELD OF VIEW.
ACCURACY±10 DEGREE (±40°)
DIGITAL OUTPUT OF SUN ASPECT ANGLE
PASSIVE SCANNING
OPERATES DURING TRANSFER ORBIT ONLY
• 10 MS AT 60 RPM ACCURACY - EARTH PULSE
SUN PROTECTED
PASSIVE SCANNING
. MOUNTED ON OPPOSITE EDGES OF NORTH AND SOUTH SOLAR ARRAY PANELS
. LINEAR RANGE - ±30 DEGREES. PASSIVE
ACCURACY = 0.2 DEGREE
TWO ROLL AND TWO PITCH SENSORS ON EACH PANEL
ES DEGREE HALF-CONE ANGLE FIELD OF VIEW
• FOUR PER SPACECRAFT
- SPEED = 2350 RPM
OUTPUT TORQUE (STALL) = 6.2 OZ. IN.
MOTOR TYPE - AC INDUCTION
ANGULAR MOMENTUM = 0.6 FT-LB-SEC
. SENSITIVITY =-114 DEW PER SQUARE METER
ACCURACY - 0.0410
PAM-D FIRING PHASE ONLY
NUTATION CONTROL

#### BSE ATTITUDE CONTROL SUBSYSTEM

The BSE Attitude Control Subsystem shows the ACS and SPS hardware planned for use on the SSUS-D spacecraft. The BSE was launched by the Delta 2914, and used a passive nutation damper for spin phase nutation control. The passive damper has been removed and Active Nutation Control (ANC) added to accommodate the 45 minute loiter time required after ejection of the spinning SSUS-D/spacecraft assembly from the STS cargo bay.

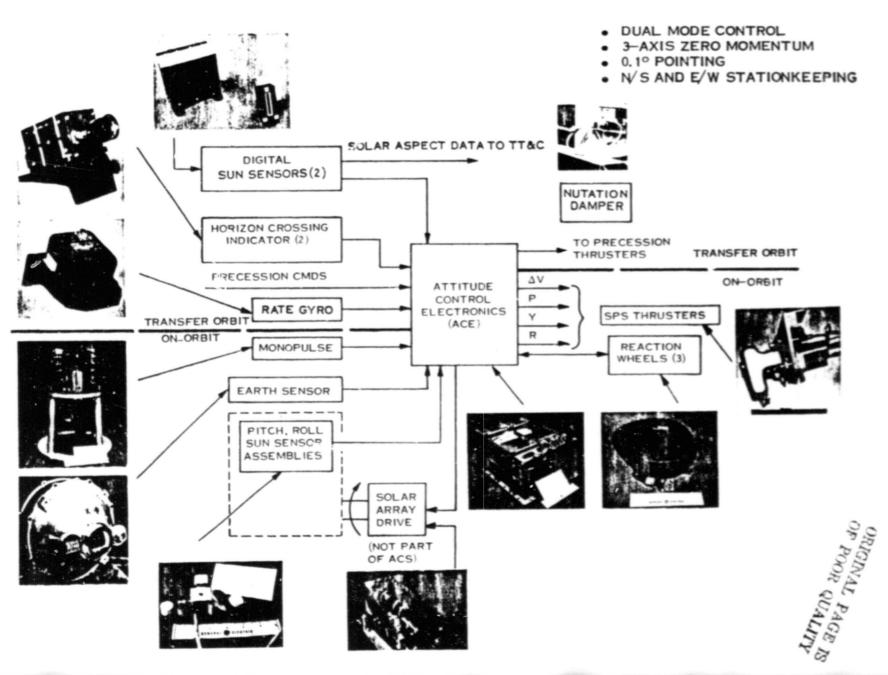
The reaction wheels, digital and analog sun sensor horizon crossing indicators, and rate gyro are BSE/BS-2 components, and the ACE electronics package are modified BSE designs. The BSE earth sensor has been replaced on BS-2 and the SSUS-D spacecraft with the redundant channel DSCS-III earth sensor.

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#### **BSE ATTITUDE CONTROL SUBSYSTEM**





#### ELECTRICAL POWER SUBSYSTEM

The Electric Power Subsystem performs the following functions to provide electrical power for all modes of satellite operation during launch, parking and transfer orbits, and mission operation in synchronous orbit:

- 1. Converts solar energy to electrical power.
- Regulates and distributes power to the satellite subsystems.
- 3. Stores energy in batteries for use during eclipse periods or short duration peak demand periods.

Highly efficient solar cells covering the faces of the array panels are constantly oriented to the Sun to convert the incident solar energy to electrical power. The solar array output is connected directly to the user loads through relays and fuses with no in-line power limiting devices. The bus voltage is regulated at 28 volts dc + or - 2 per cent at the user load terminals. Battery energy is provided for satellite loads during launch, ascent and transfer orbit injection until the folded array assemblies can be illuminated. During transfer orbit and eclipse periods the battery also shares the load. Three 4-ampere-hour sealed nickel-cadmium 16-cell batteries are utilized to satisfy the total energy storage requirement. Each battery has its own dedicated charge regulator and reconditioning circuitry. The reconditioning cycle is initiated and terminated by ground commands. Battery discharge is accomplished at the regulated bus voltage through the use of a voltage boost converter. The EPS provides centralized power control and distributes and turns all power on and off by ground command. The EPS also provides all safing, arming, and actuation functions associated with all electro-explosive device (EED) initiators. EED's are used to fire the Apogee Kick Motor (AKM), and to release the stowed solar array wing assemblies and antenna reflector.

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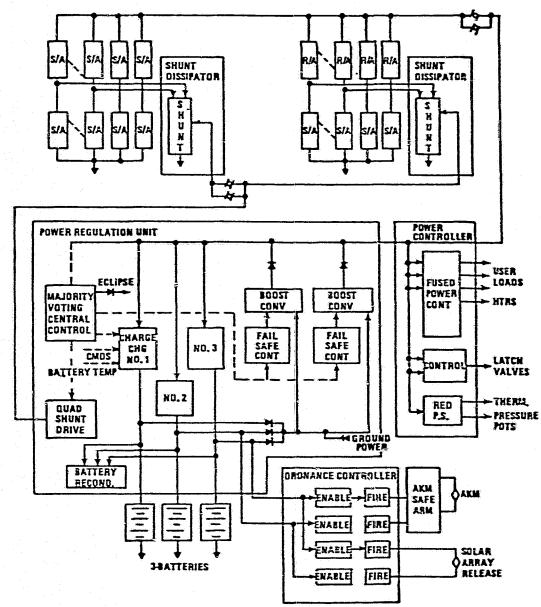
Successful operation of the EPS system over the total mission is assured by the maximum use of redundancy and elimination of all potential single-point failure modes. This is exemplified in the solar array where loss of one circuit or the loss of one battery has no mission effect since mission requirements are still provided. Majority voting with redundancy is used in the PRU central control logic, series and parallel redundancy in the ordance controller, and active or standby redundancy on such items as the Boost Regulator.



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## **ELECTRICAL POWER SUBSYSTEM (EPS)**





#### **EPS PERFORMANCE SUMMARY**

The Electrical Power Subsystem summarized is designed to provide power to the four year 20/30 Ghz spacecraft mission meeting the following payload and subsystem power budget:

Subsystem	Power Bu	dget
	Day (watts)	Night (watts)
Payload	800	27
Attitude Control	23	23
Thermal Control	50	22
TT&C	15	15
Power Subsystem	80	20
Total Load	968	107
10% Margin	97	11
Total Power Required D	1065 watts	118 watts

The payload day power requirement of 800 watts does not include the 10% margin previously shown. Total margin, including the payload is applied to the total load.



#### **EPS PERFORMANCE SUMMARY**



SOLAR ARRAY AREA

138 FT<sup>2</sup>

MINIMUM ARRAY POWER - 4 YEARS

1100 WATTS

MAX IMUM USER LOAD - 4 YEARS

968 WATTS

**REGULATION AT EPS TERMINALS** 

28 VOLTS + 1 %

MAXIMUM DEPTH OF DISCHARGE (2 OF 3 BATTER IES CONDITION)

60 %

**ECLIPSE USER LOAD** 

**107 WATTS** 

BATTERY CAPACITY

12 AH

#### **EPS DESIGN CHARACTERISTICS**

Component and sub-assembly characteristics are described for the EPS subsystem, exclusive of the solar array structure and mechanisms.

The solar array consists of four equal size panels using the high efficiency solar cells currently specified for the BS-2 spacecraft. Cell arrangement and installation is identical to that used on BSE and DSCS-III.

Shunt dissipators, located on the solar array yoke, use the BSE/DSCS-III design scaled-up to accommodate the higher SSUS-D spacecraft power level.

The Power Regulation Unit and Power Controller are BSE/DSCS-III designs, and the Ordnance Controller is the larger DSCS-III component.

The three Ni - Cad batteries are the BSE/BS-2 16 cell 4AH assemblies. The BSE batteries meet the total night load requirement at a maximum depth of discharge of 60% considering only two battery assemblies operating.

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## EPS DESIGN CHARACTERISTICS



Hardware Item	Design Characteristics
Solar Array	<ul> <li>Four 6.5 ft x 5.3 ft Panels - 138 ft<sup>2</sup>     gross area</li> <li>High Efficiency Solar Cells</li> <li>Diode Isolation Between Circuits</li> </ul>
Shunt Dissipators	<ul> <li>Located on the Solar Array Yoke</li> <li>Regulates Array Output Voltage by Sequentially Loading Down Portions of the Array</li> <li>Drive Signals Provided by the Power Regulation Unit</li> </ul>
Power Regulation Unit	Battery Charge Control, Battery Reconditioning Control, Battery Isolation     Drive Control for Shunts     Priority Control of Array Power to     -Load -Shunting     -Batteries -Battery Discharge     Protection     Independent Power Buses to Some User Loads
• Batteries	<ul> <li>Three - 4 AH Each, Sealed 16-Cell Nickel Cadmium Batteries</li> <li>Full Power Provided with Two of Three Batteries Operating</li> </ul>
Power Controller	<ul> <li>Provides the Following Functions         <ul> <li>Command Controlled On/Off Power and</li> <li>Heater Switching</li> <li>On/Off Status of Selected Power Switches</li> <li>Load Overcurrent Protection (Fuses)</li> </ul> </li> </ul>
Ordnance Controller	<ul> <li>Provides the Following Functions</li> <li>Command Controlled Power To</li> <li>Apogee Kick Motor</li> <li>Solar Array Release</li> <li>Antenna Deployment Release</li> </ul>

#### SOLAR ARRAY ASSEMBLY

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The solar array consists of two symmetrical wing assemblies leaving a total panel area of 138 square feet and total span of 47 feet. Each wing has a boom and yoke to position the array panels outboard to clear the shadow line from the deployed antenna reflector. All panels are of rigid sandwich construction having graphite-epoxy faces bonded to aluminum honeycomb core. Mechanisms are provided to secure and release the stowed array, to deploy and latch the panels, and a drive that continuously orients the deployed array toward the Sun. The drive contains slip-ring assemblies to transmit power and signals across the rotating interface. Deployment is controlled by imboard panel synchronization cables and rate control dampers at the panel hinge lines.

The retention system secures the folded panels for launch at four points for each wing, and is released by commands firing the dual-pyro activated retention nuts. This retention system is currently used on the DSCS III and Landsat-D spacecraft. Deployment mechanisms use the DSCS-III design, the DSCS III locking hinges, and the ETS-III rate control dampers. The solar array drive assembly consists of the DSCS III drive and slip-ring modules joined by a rigid drive shaft.

High stiffness to weight graphite-epoxy composite materials are used for array panel construction. The composite sandwich design uses 0.005 inch graphite-epoxy faces bonded to a 0.75 inch thick aluminum honeycomb core. The density of the core used in this design is 2.0 lb/ft<sup>3</sup>. The increased panel stiffness of the graphite-epoxy panels over an all aluminum design will reduce deflections during launch and increase the deployed array stiffness. The composite array panels are similar to those developed and flown on the OTS Satellite in 1978, and Solar Max in 1979.

Boom and yoke frame construction utilizes built-up graphite-epoxy segments attached to root pivot and hinge fittings similar to the BSE and DSCS-III designs.

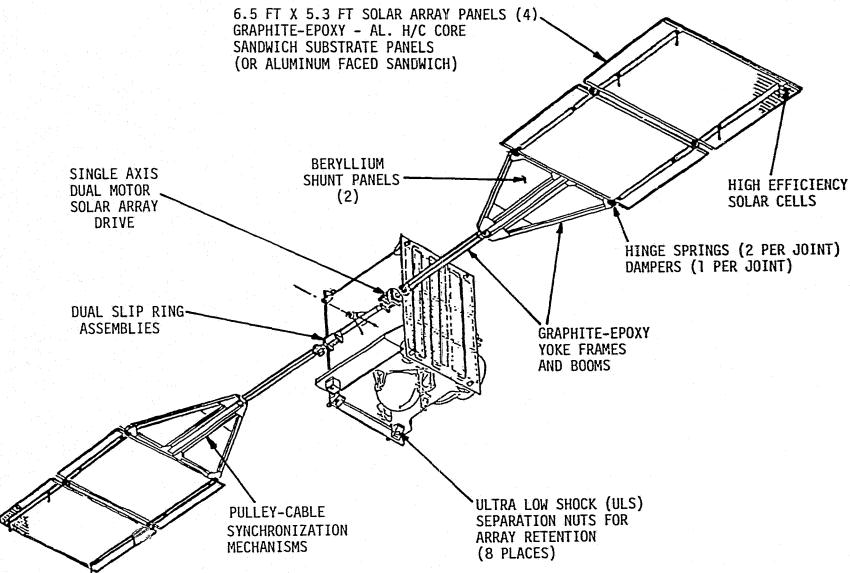
Alternate lower cost array structures using conventional aluminum face honeycomb sandwich panels and aluminum frame members, such as used for the array structures on DSCS III and Landsat-D, can be used at an increase in weight of 15 to 20 pounds.



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#### SOLAR ARRAY ASSEMBLY





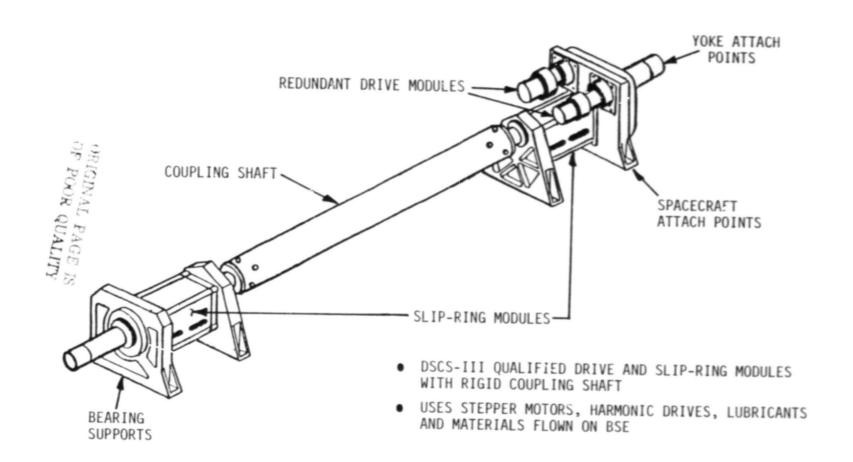
#### SOLAR ARRAY DRIVE

The Solar Array Drive and Power Transfer Assembly (SADAPTA) uses the existing qualified DSCS III drive and slip ring modules joined by a rigid coupling shaft sized to properly position the two modules for attachment to the upper bulkhead.



## SOLAR ARRAY DRIVE





## DSCS-III SOLAR ARRAY DRIVE AND SLIP-RING MODULES

The drive module contains redundant drive trains coupled to a single main gear to rotate the drive shaft one revolution per day (orbit period) to maintain position of the array panel perpendicular to the sun. Control of the drive is provided by the ACS attitude control electronics. Two slip-ring assemblies are provided to transfer power and signals across the rotating interface.

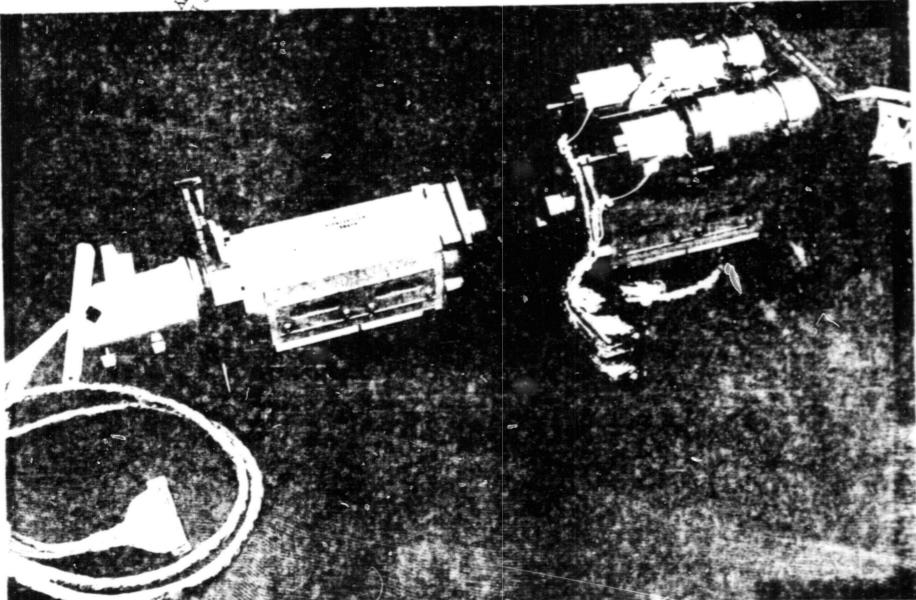
Each drive train contains a stepper motor, harmonic drive, slip-clutch and pinion gear. This basic drive train was qualified and flown on BSE and all basic components, gear designs, bearings and lubricants have been retained on the DSCS-III drive module. These components have been developed from General Electric's long-life solar array drive program and have accumulated life testing far in excess of the four year 20/30 GHz spacecraft requirements. Drive torque for the solar array drive is 20 foot-pounds for one motor and 40 foot-pounds if both motors are energized.

The DSCS-III slip-ring modules use the materials and lubricants identifical to those successfully flown on BSE and also adopted for Landsat-D, ETS-III and BS-2. The slip-ring arrangement separates the positive and negative power rings by the signal rings and spare rings to preclude a total bus short in the module.



## DSCS-III SOLAR ARRAY DRIVE AND SLIP-RING MODULES





#### SOLAR ARRAY RETENTION

Each folded solar array wing assembly is secured to the spacecraft body by four dual-pyro activated retention nuts. Each attach point has preload capability up to 4000 pounds to insure the array is rigidly supported throughout the dynamic launch environmental sequence. The array is released by redundant signals from the EPS ordnance controller activating the dual pyro initiators in each nut. This type retention/release system is used for DSCS-III spacecraft separation, DSCS-III and Landsat-D solar array retention, and Landsat-D TDRSS boom retention. The "Ultra Low Shock" separation nuts qualified for Landsat-D will be used, and the pyros or "Electro - Explosive Devices" (EED's), have been qualified on earlier programs.

This same retention system will also be used for retention and release of the antenna reflector.

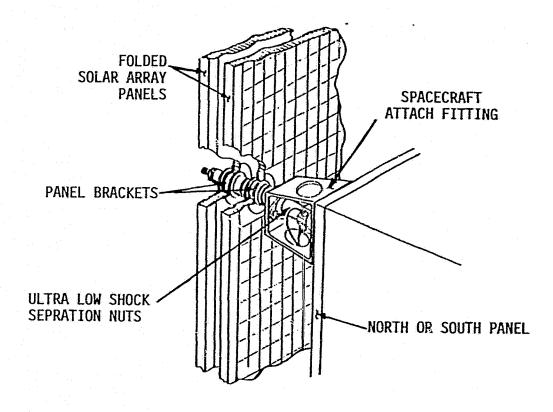
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## SOLAR ARRAY RETENTION





- FOUR ULTRA LOW SHOCK (ULS) SEPARATION NUTS PER WING
- RELEASE BY DUAL PYRO INITIATORS ON EACH NUT ACTIVATED BY REDUNDANT SIGNALS
- 4000 POUNDS JOINT PRELOAD
- QUALIFIED FOR DSCS-III AND LANDSAT-D

#### BSE SOLAR ARRAY ASSEMBLY

A BSE solar array wing assembly including all retention and deployment mechanisms is shown mounted to the shaker for vibration; testing. After completing tests as an assembled wing, this unit was attached to the full scale Structural Development Model spacecraft for final qualification to the launch loads and environments.

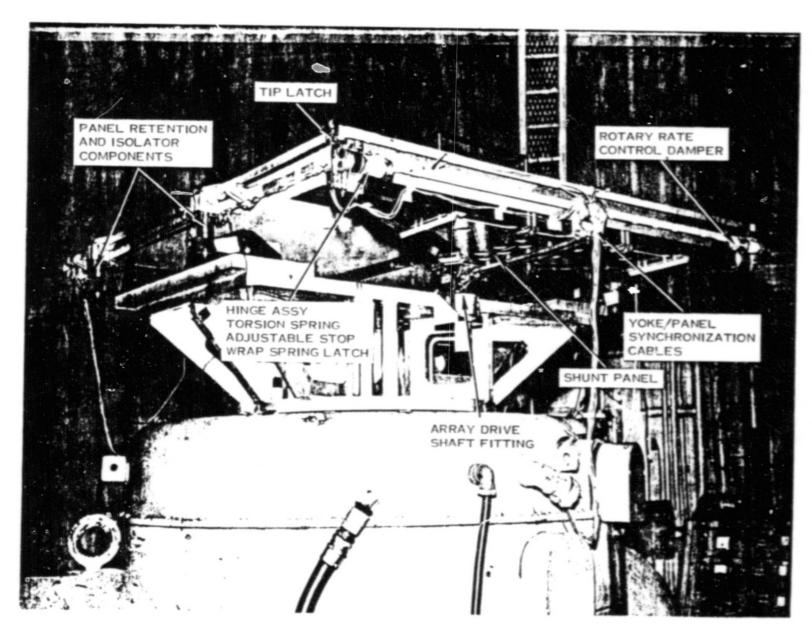
A similar verification and test program will be performed for the 20/30 GHz spacecraft solar array.

TOTAL HOSPINS



## BSE SOLAR ARRAY ASSEMBLY





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#### SECONDARY PROPULSION SUBSYSTEM

The Secondary Propulsion Subsystem (SPS) is a mass expulsion, monopropellant, catalytically decomposed, hydrazine system with helium pressurant operating in a simple blow-down (non-regulated) mode. Two thruster groups each capable of performing all mission functions, are maintained as separate entities by normally closed latching isolation valves. The following functions are provided:

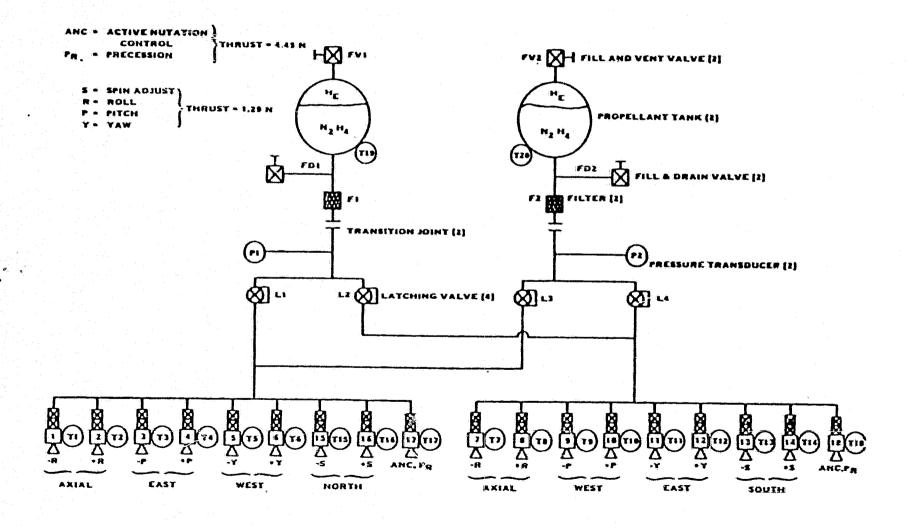
- Nutation Control during SSUS-D firing.
- Spin Functions
  - Spin Rate Adjust
  - Precession
  - Despin
- Orbit Adjust Functions
  - Removal of orbit injection errors
  - Drift correction
  - East/West and North/South stationkeeping
- Attitude Control Functions
  - Attitude Acquisition
  - Reaction Wheel Unloading
  - Reaction Wheel Backup

In operation, control of thruster firing is maintained by the Attitude Control Subsystem. Each thruster is controlled with a pair of normally closed series redundant solenoid operated valves. The thrusters have redundant thrust chamber heaters to pre-heat the chamber. The propellant is catalytically decomposed in the thrust chamber. Eight of the thrusters in each group operate at a maximum initial thrust level of 0.29 lbf and provide East/West, North/South adjustments and reaction wheel reset on-orbit. One thruster in each group operates at an initial thrust level of 1.0 lbf for active nutation control and precession maneuvers.



## SECONDARY PROPULSION SUBSYSTEM





#### SPS PROPELLANT BUDGET

A total SPS hydrazine propellant and helium pressurant load of approximately 190 pounds is required for the 4 year 20/30 Ghz spacecraft life. The propellant allocations include the initial spin phases, de-spin and orbital acquisition functions and allowances for residual trapped fuel and loading tolerances. The major propellant load, required to maintain the spacecraft attitude and position on orbit, is 140 pounds, or almost 75% of the total fuel load.

The SPS tanks have a total fuel capacity of 303 pounds. The tanks will be initially loaded differentially for launch. After the spacecraft is on orbit and the antenna reflector deployed, the tanks will be equalized with the fuel transfer used to compensate for center of gravity shift due to reflector deployment.

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## SPS PROPELLANT BUDGET



MANUEVER/FUNCTION	PROPELLANT WEIGHTS, POUNDS
SPIN RATE ADJUST	0.22
PRECESSION AND NUTATION	7.90
DESPIN	1.96
ATTITUDE ACQUISITION	0.36
STATION ACQUISITION	34. 20
N/S STATIONKEEPING	127.40
E/W STATIONKEEPING	6.25
REACTION WHEET RESET	1.50
TORQUE CONTROL	4. 90
RESIDUAL AND TOLERANCE	4.13
PRESSURANT	1.00
TOTAL	189. 82

## SPS HARDWARE CHARACTERISTICS

SPS key components and their design characteristics and functions are listed. The propellant and pressurant are stored in two 22.25 inch diameter spherical bladder tanks, having a total fuel capacity of 303 pounds of hydrazine. The tanks are as specified for DSCS III and are currently being verified for STS compatibility by fracture mechanics analysis. Additional weight for local strengthening shown to be required in the attach lug areas has been included in the total tank weight. Thrusters, valves and filters are used on both the BSE and DSCS III Programs.



## SPS HARDWARE CHARACTERISTICS



HARDWARE ITEM	DESIGN CHARACTERISTICS
PROPELLANT TANKS	<ul> <li>SPHERICAL TANKS NOMINALLY 22. 25 INCHES IN DIAMETER</li> <li>QUALIFIED TO HOLD 303 LBM OF PROPELLANT</li> </ul>
HIGH THRUST ENGINES (HTE)	<ul> <li>TWO HTE'S FOR PRECESSION/NUTATION CONTROL</li> <li>1.0 LBf</li> </ul>
LOW THRUST ENGINES (LTE)	<ul> <li>16 LTE'S</li> <li>INITIAL RATING = 0.29 LBf</li> <li>DUAL SEATED VALVES</li> </ul>
LATCHING ISOLATION VALVES	FOUR VALVES PROVIDE ISOLATION BETWEEN THE PROPELLANT TANKS AND THRUSTER GROUPS
• FILTERS	PARTICLE RETENTION CAPABILITY OF 10 MICRONS
FILL AND DRAIN/VALVES	PERMIT FILLING, DRAINING AND VENTING OF PRESSURANT AND HYDRAZ INE
PRESSURE TRANSDUCERS	PROVIDE PROPELLANT TANKS PRESSURE DATA
TEMPERATURE SENSORS	MON ITOR TEMPERATURE OF PROPELLANT TANKS AND THRUST CHAMBERS

#### BSE SECONDARY PROPULSION SUBSYSTEM

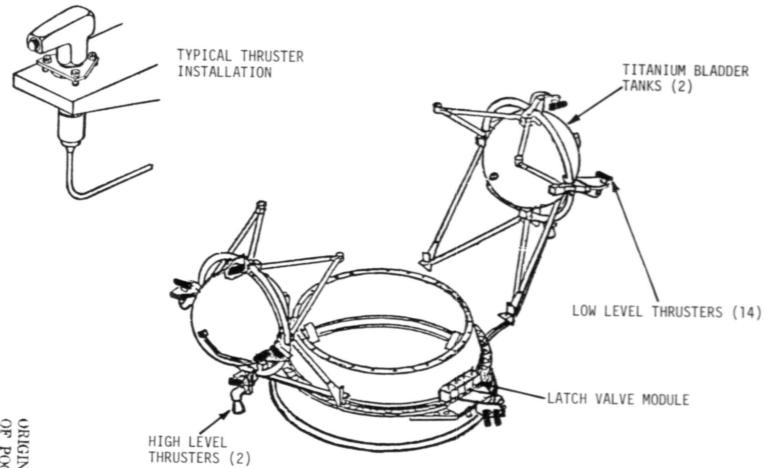
The BSE SPS uses two 16-1/2 inch propellant tanks having a total capacity of 125 pounds. The system utilizes 14 low level thrusters for normal attitude control functions and two high level thrusters for precession maneuvers during the spin phase. The entire all welded SPS is assembled to the thrust cone and truss supports and tested prior to installation on the spacecraft furing the final assembly cycle.

The thrusters, valves, filters and other subsystem hardware flown on BSE have been subsequently used on DSCS-III and have been selected for the SSUS-D spacecraft SPS.



## BSE SECONDARY PROPULSION SUBSYSTEM





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## MODIFIED STAR 30B AKM

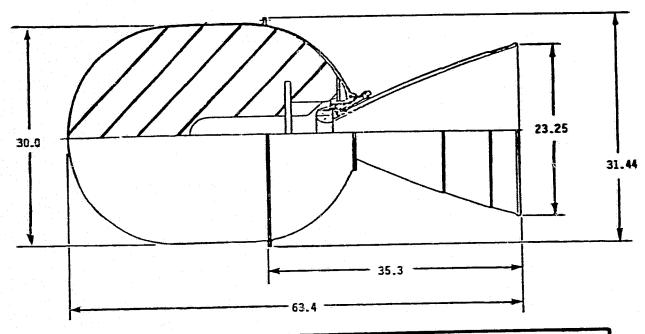
The apogee kick motor is a solid propellant "stretched" Thiokol Star-30B rocket motor ignited at the apogee of the elliptical transfer orbit to inject the satellite into a circular equatorial synchronous orbit. To make full use of the increased capability of the STS/SSUS-D launch vehicle, a higher AKM propellant load is needed, requiring the 30 weight increase is four pounds (one pound per inch). The stretching modification for solid rocket motors to increase propellant capacity has been successfully employed by Thiokol on previous designs, notably on the 37-inch diameter summarized. Major components of the modified STAR 30B AKM is shown and performance characterics are nozzle assembly and ignition system. When launched on the STS, the Safe and Arm Initiation Device is placed in the Two commands are necessary to cause a firing current to be sent via the Ordnance Controllers to the two redundant detonators contained within the body of the Safe and Arm Initiator device.



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<u>Value</u>
1346.0 pounds
1277.2 pounds
68.8 pounds
293.5 seconds

## SPACECRAFT COMPONENT HERITAGE

Components selected for the STS/SSUS-D 20/30 Ghz spacecraft subsystems are listed with their associated program heritage.

Almost all subsystem components have been previously flown on BSE and/or have been qualified for the DSCS-III program.

The spacecraft primary structure is an enlarged and strengthened BSE design using fully developed BSE and DSCS-III materials, components, fasteners and fabrication procedures. The solar array structure uses graphite-epoxy construction similar to that flown on the OTS and SMM satellites, or if total weight margin for the satellite permits, the heavier aluminum honey comb sandwich panel design such as used on BSE and DSCS-III can be adopted.



## SPACECRAFT COMPONENT HER ITAGE



SUBSYSTEM/COMPONENT	HER ITAGE	SUBSYSTEM/COMPONENT	HERITAGE	SUBSYSTEM/COMPONENT	HERITAGE
ATTITUDE CONTROL		ELECTRICAL POWER		TT&C	
EARTH SENSOR DIGITAL SUN SENSOR HORIZON CROSSING INDICATOR	DSCS III BSE 835	SOLAR ARRAY CELLS  BATTERY CELLS  SHUNT DISSIPATORS	DSP, CS-2 BS-2 BSE BSE/DSCS III	TRANSPONDER DECODER ENCODER	BSE BSE BSE
SUN SENSOR ASSEMBLY	BSE	POWER REG. (INIT	BSE/DSCS III	ANTENNA	BSE
REACTION WHEELS RF SENSOR ACCELEROMETERS ATTITUDE CONTROL ELECTRONICS SECONDARY PROPULSION TANKS	BSE BLOCK 5 BSE MOD.  DSCS III	POWER CONTROLLER ORDNANCE CONTROLLER SOLAR ARRAY DRIVE SOLAR ARRAY RELEASE & DEPLOYMENT ASSY  AKM FUEL	BSE/DSCS III DSCS III/BSE LANDSAT-D/ DSCS III	THERMAL CONTROL  HEAT PIPES  COATINGS/PAINTS  HEATERS/THERMOSTATS  OPTICAL SOLAR REFLECTORS (OSR)  INSULATION	MACS/SMM BSE/DSCS III BSE/DSCS III DSCS III, DSP, CTS DSCS III, BSE
THRUSTERS  VALVES & FILTERS  PRESSURE TRANSDUCERS  TEMPERATURE SENSORS	BSE/DSCS III BSE/DSCS III BSE/DSCS III BSE/DSCS III	CASE SAFE & ARM	STAR 30B (STRETCHED) STAR 27, 30B	STRUCTURE  PRIMARY STRUCTURE  SOLAR ARRAY PANELS  COMPOSITE STRUCTURE	BSE/DSCS III OTS/SMM BSE/DSCS III LANDSAT-D, HGA, SMM

#### WEIGHT SUMMARY

Subsystem weights and expendables are tabulated for a four year mission giving a total payload and weight margin capability of 573.3 pounds for the STS/SSUS-D launch gross weight of 2750 pounds.

The Baseline payload weight, previously described, is 346.5 pounds, yielding the following margin for the Baseline 4 year mission:

#### Baseline Weight Margin

Subsystems (Dry) Baseline Fayload	745.5 lbs 346.5 lbs
Total Spacecraft (Dry)	1092.0 lbs
SPS Fuel (4 years)	190.0 lbs
AKM Propellant	1277.2 lbs
Margin	190.8lbs
S/C Launch Gross Weight	2750. lbs

The margin of 190.8 pounds in 17.5% of the spacecraft dry weight which should be approximately 15% for a new spacecraft design. Since about half of the subsystem weights are existing hardware requiring no weight contingency, the 190.8 pounds provides ample weight margin for the spacecraft.

A weight breakdown of the spacecraft subsystems is shown, and payload weight breakdowns were shown in previous tabulations.

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# WEIGHT SUMMARY STS/SSUS-D SPACECRAFT - 4 YEAR MISSION 1100 WATTS EOL POWER



SUBSYSTEM	WEIGHT (POUNDS)
ATTITUDE CONTROL	73.3
THERMAL CONTROL	55,0
POWER	284.0
SPS (DRY)	55.4
AKM (DRY)	68.8
TT&C	24.0
STRUCTURE	170.0
BALLAST & ESD	<u>15.0</u>
TOTAL HOUSEKEEPING	745.5
SPS FUEL (4 YEARS)	190.0
AKM PROPELLANT	1277.2
PAYLOAD* & MARGIN	537.3
TOTAL LAUNCH WEIGHT	2750.0

#### PAYLOAD INCLUDES:

- TRANSPONDERS
- ANTENNAS
- ANTENNA AND FEED SUPPORTS
- ANTENNA DEPLOYMENT MECHANISMS

## STS/SSUS-D Spacecraft Subsystem Weight Breakdown

The table lists detailed component weights for the various spacecraft subsystems used in this previous chart.



# STS/SSUS-D SPACECRAFT SUBSYSTEM WEIGHT BREAKDOWN

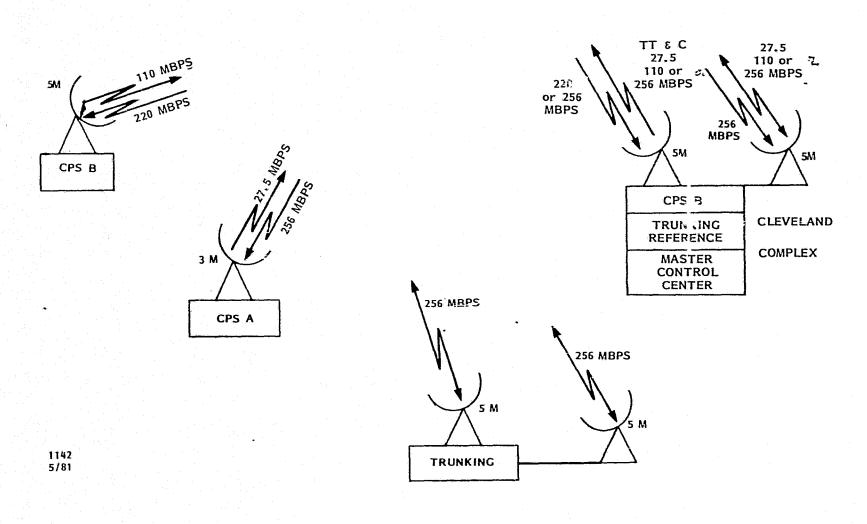


ATTITUDE CONTROL (ACS)  EARTH SENSOR  MONOPULSE  DIGITAL SUN SENSORS (2)  ANALOG SUN SENSORS (2)  RATE GYRO	(73.3)	SECONDARY PROPULSION (SPS)	(FE NIDDY CIC
EARTH SENSOR	5.7	HYDRAZINE TANKS (2) THRUSTERS (18) SUBSYSTEM HARDWARE	
MONOPULSE	18.0	THRUSTERS (18)	28.6
DIGITAL SUN SENSORS (2)	1.6	SUBSYSTEM HARDWARE	13.1
ANALOG SUN SENSORS (2)	0.7	TO STORE IN THE STORE ST	13.7
RATE GYRO	1.5	APOGEE KICK MOTOR (AKM)	(68.8)AKM @
HORIZON CROSSING INDICATOR (2)	3.0		BURN-OUT
ACS ELECTRONICS	22.0	TELEMETRY, TRACKING AND	
REACTION WHEFIS (a)	20.2	COMMAND (TT&C) S-BAND TRANSPONDER COMMAND DECODER TELEMETRY ENCODERS (2) ANTENNAS AND CABLES	175 A)
ACCELEROMETERS (2)	0.5	S-RAND TRANSPONDED	(24.0)
THERMAL CONTROL (TCC)		COMMAND DECORED	10.2
ACCELEROMETERS (2) THERMAL CONTROL (TCS) INSULATION BLANKETS	(55.0)	TELEMETRY ENCORERS (2)	5.4
SUPPORTS		ANTENNAS AND CARLES	6.8
SUPPORTS COATINGS	5.5	ANTICITIAS AND CADLES	1.6
HEATERS AND MISCELL ANEQUE	10.0	STRUCTURE	(170.0)
HEATERS AND MISCELLANEOUS HEAT PIPES POWER SUBSYSTEM (EPS)	4.0	CYLINDER ASSEMBLY	13.5
TIE/(LATILO	11.0	THRUST CONE ASSEMBLY	20.0
POWER SUBSYSTEM (EPS)  SOLAR ARRAY PANELS SHUNT DISSIPATORS (2) POWER REGULATION UNIT POWER CONTROLLER BATTERIES (3) ORDNANCE CONTROLLER HARNESS ARRAY RETENTION MECHANISMS ARRAY DEPLOYMENT MECHANISMS SOLAR ARRAY DRIVE ASSEMBLY	(284.0)	AKM ADAPTER RING	12.5
SOLAR ARRAY PANELS	80.0	EAST-WEST PANELS (2)	16.0
SHUNT DISSIPATORS (2)	12.0	EAST-WEST VEE TRUSS (4)	5.0
POWER REGULATION UNIT	31.5	NORTH-SOUTH KEELS (科)	9.0
POWER CONTROLLER	10.0	UPPER BULKHEAD	11.0
BATTERIES (3)	27.5	LOWER BULKHEAD	9.0
ORDNANCE CONTROLLER	2.5	N-TRANSPONDER PANEL	38.0
HARNESS	60.0	S-RECEIVER PANEL	11.0
ARRAY RETENTION MECHANISMS	16.0	S-HOUSEKEEPING PANELS (2)	11.0
ARRAY DEPLOYMENT MECHANISMS	9.0	SUPPORTS AND MISCELLANEOUS	14.0
SOLAR ARRAY DRIVE ASSEMBLY	17.5	BALLAST AND ESD  BALLAST ESD PROTECTION	(15 0)
YOKE AND PIVOT ASSEMBLY (2) BOOM AND PIVOT ASSEMBLY (2)	8.0	BALLAST	(15.0)
BUUM AND PIVOT ASSEMBLY (2)	10.0	ESD PROTECTION	19.0
			5.0
		TOTAL SUBSYSTEMS (DRY)	745.5 LBS

# EARTH STATIONS AND MASTER CONTROL CENTER

(This work performed by Digital Communications Company of Germantown, Maryland under subcontract to General Electric.)

# **EARTH STATION TYPES**



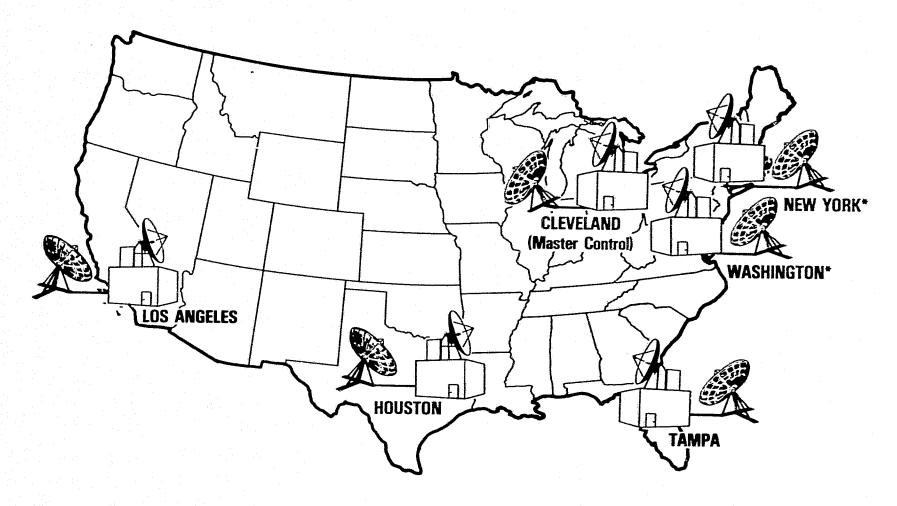
# SS-TDMA TRUNKING STATION LOCATIONS

Six possible areas can be illuminated by the satellite antennas, 4 simultaneously. One or more trunking earth stations can be located within each beam to share the available bandwidth and time. Selection of earth stations for operation and allocation of time for communications is controlled by the MCC. Preassigned routes and channels are assumed, which can be manually reassigned by the MCC, (to reduce MCC complexity and cost). Each trunking earth station consists of dual 5-meter antennas in a spatial arrangement to compensate for deep rain fades. Error rate estimates from each antenna system are relayed to the MCC for action.

# SS-TDMA trunking design objectives are as follows:

- Develop accurate and reliable fade estimation techniques
- Demonstrate antenna diversity operation with high availability
- Provide satellite switch synchronization
- Push state-of-the-art in high rate MODEMS.

# SS TDMA TRUNKING STATION LOCATIONS



\*ACTIVE NETWORK HAS FOUR NODES. WASHINGTON & NEW YORK MAY BE SUBSTITUTED FOR HOUSTON & TAMPA

#### TRUNKING SYSTEM REQUIREMENTS

Switches in the spacecraft are used to select either Houston or New York for Beam 1 and either Tampa or Washington, D.C. for Beam 2. The on-board IF switch cycles through four connectivities during each frame. Each trunking station coordinates its 256 Mbps transmissions with this switching.

The required  $18\ dB$  uplink and  $8\ dB$  downlink margins are achieved by a combination of fixed power margin and antenna diversity.

TO THE WORLD

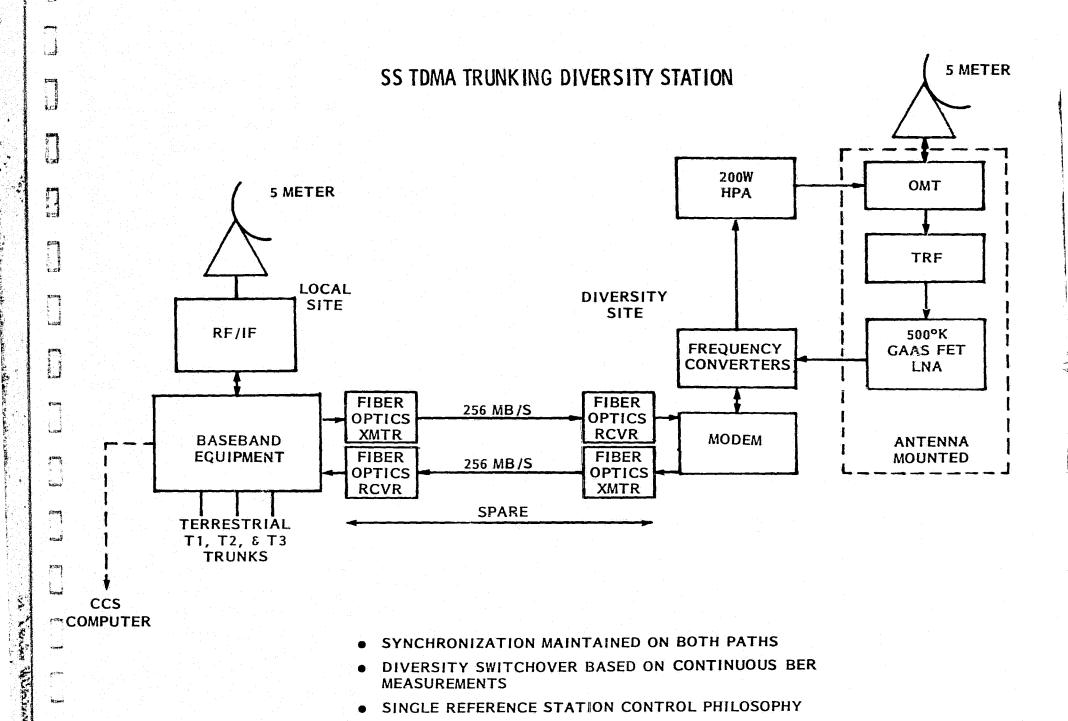
### TRUNKING SYSTEM REQUIREMENTS

- NETWORK OF 6 NODES
  - 4 SIMULTANEOUSLY ACTIVE
  - 4 FIXED BEAMS
- SATELLITE IF SWITCHING FOR BEAM INTERCONNECT
- SS-TDMA ACCESS
- NOMINAL 256 MBPS BURST RATE PER BEAM
- 5M DIAMETER ANTENNA PER STATION
- SPATIAL DIVERSITY
- RAIN FADE MARGIN
  - 18 dB UPLINK
  - 8 dB DOWNLINK

### SS-TDMA TRUNKING DIVERSITY STATUS

A single non-redundant trunking earth station is co-located with the MCC in Cleveland; this station also is the reference station for the trunking network. A 500°K GaAs FET LNA, 200 watt HPA and 5 meter antenna have sufficient performance to achieve availabilities greater than 0.9999, with antenna diversity provided by a fiber optics interconnect. Modulation is Q psk.

A CPS terminal is also co-located; while not described, the functions of trunking and CPS may be more economically provided by using common RF and interface equipment.



#### SS-TDMA TRUNKING STATUS BASEBAND EQUIPMENT

The arrangement depicted at the right is a standard SS-TDMA trunking configuration with  $T_1$ ,  $T_2$  and  $T_3$  interfaces and encryption-decryption for network privacy. The equipment contains a processor for establishing a network plan and for updating this plan via instructions from the MCC. A 16 bit wide data bus is used to pass data from input unit to the encrypter and then to the formatter. From the formatter data goes either to the fiber optic interconnect or the delay compensating buffer. The fiber or buffer output is sent to the modulator at the diversity or local site respectively.

The receive side is similar. Demodulated data is passed through the fiber or compensation buffer to the deformatter which performs the unique word recognition and data distribution. Data from the on-line path is decrypted and then output.

The site control computer accepts data from the reference station, totalizes BER data and controls the station.

The SS-TDMA trunking network is defined to have the following limitations:

- 1. CPS and trunking systems are not operated simultaneously
- 2. BER =  $10^{-4}$  at threshold; FEC will not be used
- 3. Digital speech interpolation will not be used

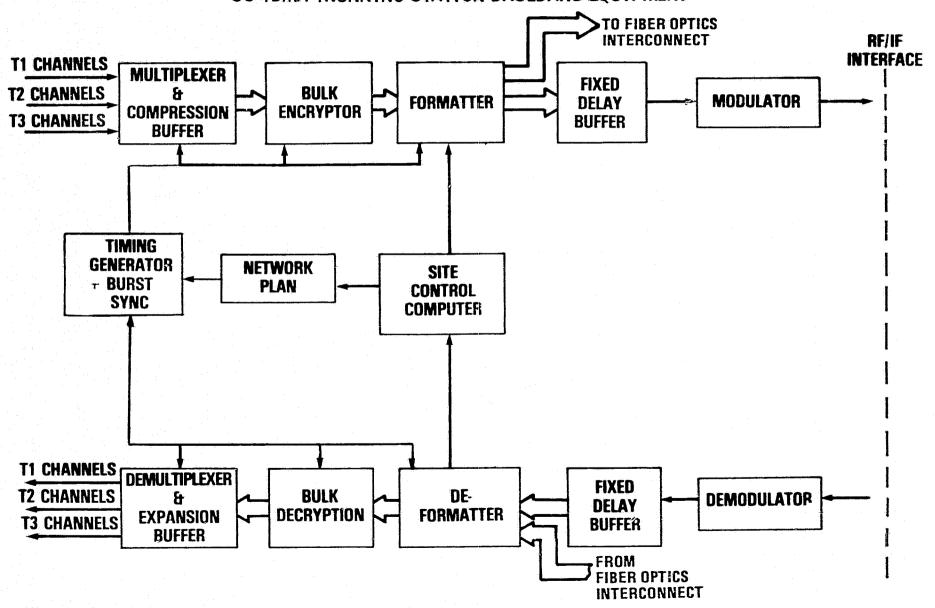
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- 4. "Manual" control of routing and burst times, no automatic signalling and switching
- 5. One manned reference station (in Cleveland) with centralized control (this may not be the best choice for a large operational network)

System Operations requires the following functions to be performed:

- 1. Begin synchronization procedure by using all digital satellite switch synchronization on both paths
- 2. Transmit alternating primary and secondary reference burst in every frame
- 3. Other trunk sites sequentially gain access to system using 20 microsecond sync window (ranging system can be verified during this step)
- 4. Bit error measurements are made on all received unique words by all trunk stations
- 5. Each sync burst consists of 100 symbols for 0.4  $\mu$ sec duration

### SS TDMA TRUNKING STATION BASEBAND EQUIPMENT



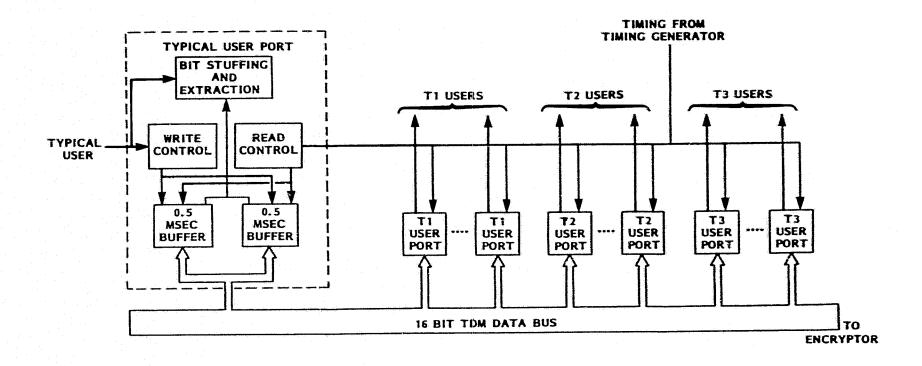
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#### MULTIPLEXER AND COMPRESSION BUFFER

The trunking station accepts T1, T2 and T3 data channels. A special purpose user pert will be developed for each. Functionally, each port accepts the data and performs the appropriate bit stuffing and extracting functions to match line and station clock rates. A double buffer technique is used to hold the data for one TDMA frame time. Station timing controls buffer readout onto the station TDM data bus. This is a 16 bit wide 16 megaword per second TDM bus used for data transport.

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### MULTIPLEXER AND COMPRESSION BUFFER

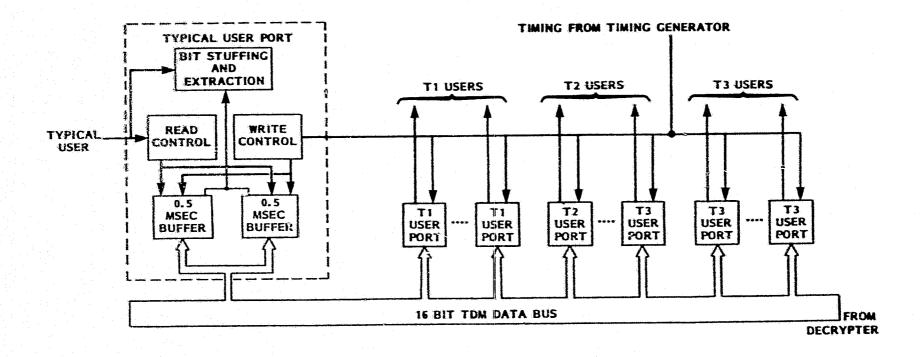


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# DEMULTIPLEXER AND EXPANSION BUFFER

Decrypted data is delivered to the demultiplexer on the TDM data bus. The half frame buffers provide sufficient storage to enable readout at the T1, T2, or T3 line rate. Adjustment for variations in input or output clock rate are made by the bit stuffing and extraction logic.

### DEMULTIPLEXER AND EXPANSION BUFFER



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#### DOWNLINK FRAME STRUCTURE

The superframe is used to coordinate network plan changes and scrambler synchronization as with conventional TDMA.

Each TDMA frame is synchronized to the satellite IF switch and starts with a loopback connectivity for closed loop synchronization. The reference station provides a reference burst in each connectivity which facilitates synchronization of the other system.

In an operational system with more than one trunking station per beam additional features would be added to the frame structure to control station acquisition.

# DOWNLINK FRAME STRUCTURE

SUPERFRAME 510 TDMA FRAMES .512 SEC	
TDMA FRAME 1 MS	SS LOOPBACK CROSSOVER A CROSSOVER B CROSSOVER C
LOOPBACK AT REF	REF SYNC ACQ P DATA
LOOPBACK ELSEWHERE	SYNC ACQ P DATA
CROSSOVER FROM REF	REF P
CROSSOVER FROM OTHERS	P DATA
1143 5/81	SS = SATELLITE SWITCH SYNCHRONIZATION LOOPBACK = IF SWITCH STATE WHICH CONNECTS STATIONS IN THE SAME BEAM CROSSOVER = IF SWITCH STATE WHICH CONNECTS STATIONS IN DIFFERENT BEAMS REF = ALTERNATES BETWEEN LOCAL AND DIVERSITY REFERENCE BURSTS SYNC = USED FOR LOCAL BURST SYNCHRONIZATION DURING LOOPBACK ACQ = USED FOR INITIAL ACQUISITION P = PREAMBLE AND UNIQUE WORD DATA = DATA BURST - 256 MBPS

#### PREAMBLE, UNIQUE WORDS, AND OVERHEAD

Each station transmits preambles from both the on-line and standby site. These are used by the system for estimating phase. Only the on-line site transmits the data.

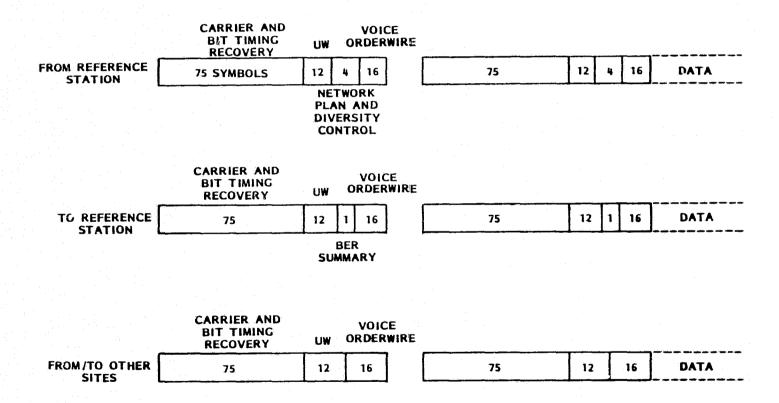
The reference station transmits the network plan once per superframe. This is more often than necessary but it is convenient. The network plan is transmitted with a rate 7/8 FEC to improve delivery probability and a 32 bit CRC to detect errors. Ten kbps are transmitted in each beam. Diversity switchover control is transferred at 100 bps with considerable redundancy protection.

Bit error rate summary information is transmitted to the reference station at 2000 bps because it is the lowest rate conveniently available. This is the total number of UW bits in error of each burst received by the station over the previous second.

The voice orderwire forms a party line among the sites. The audio is summed in analog form at each station.

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# PREAMBLE, UNIQUE WORDS AND OVERHEAD



FIRST BURST IS ALWAYS
FROM STANDBY SITE

SECOND BURST INCLUDES DATA AND IS TRANSMITTED BY ON-LINE SITE

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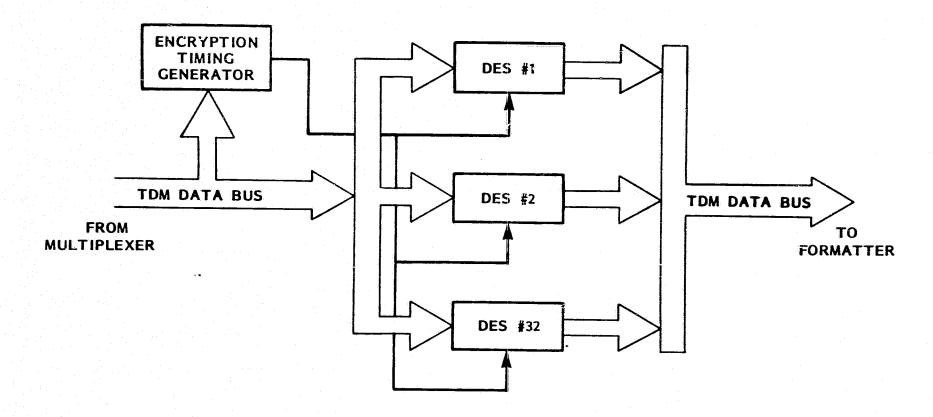
#### BULK ENCRYPTION

An option for bulk encryption of all trunking channels is provided to protect against threats to the entire network. All stations share the same key and key passing may be done using a public key system.

Encryption is performed by DES engines which run at up to 10 Mbps. The organization shown above operates 32 devices in parallel so each individual device runs at 8 Mbps. Encrypted data is placed on the TDM bus.

N.

# **BULK ENCRYPTION**

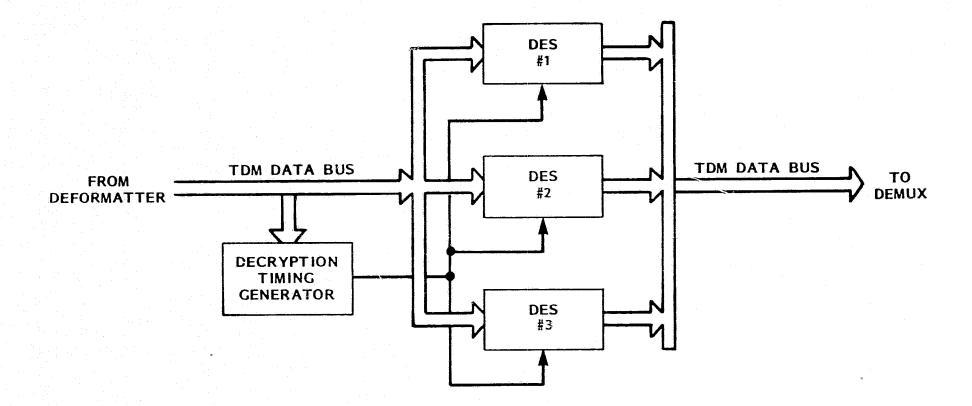


EACH DES RUNS AT 256 MBPS + 32 = 8 MBPS

#### BULK DECRYPTION

The inverse operation to the encryption operation is performed on the downlink side by the bulk decrypter. The same chip set is utilized in the same configuration as for the uplink encrypter.

# **BULK DECRYPTION**



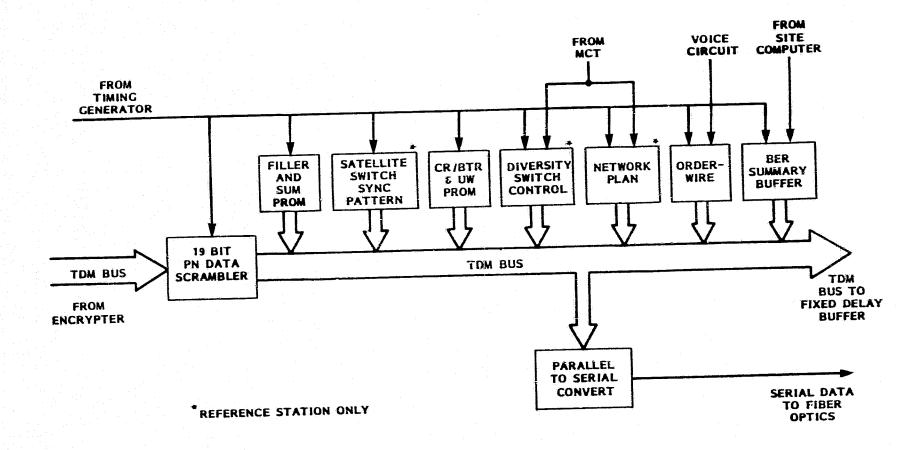
#### FORMATTER

The formatter is bus organized with station timing controlling access to the bus. Data from the encrypter is scrambled by a 19 bit PN sequence and placed on the bus after the on-line station preamble. The standby preamble is the only data passed to the standby modulator.

The reference station provides digital satellite switch synchronization patterns as needed as well as diversity control and network plan information.

Filler and start of message (SOM) is inserted in the data to permit the modulator to properly modulate data coming out of the fiber or fixed delay buffer.

#### **FORMATTER**



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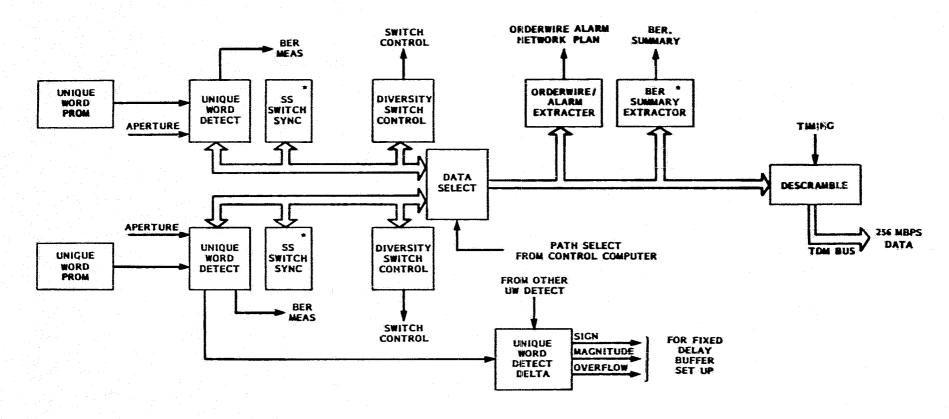
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#### DEFORMATTER

Data streams from both the on-line and standby sites are input to the deformatter. After differential decoding the unique word is detected in each stream and the bit errors are passed to the control computer. The difference in UW detection times is used at station installation to adjust the length of the fixed delay buffer. Independent burst synchronization exists for both paths.

The on-line data stream is used for orderwire, alarm and network plan extraction. At the reference station the BER summary data is extracted only from the on-line path. Data is descrambled and output from the deformatter on a TDM bus.

#### **DEFORMATTER**



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\* REFERENCE STATION ONLY

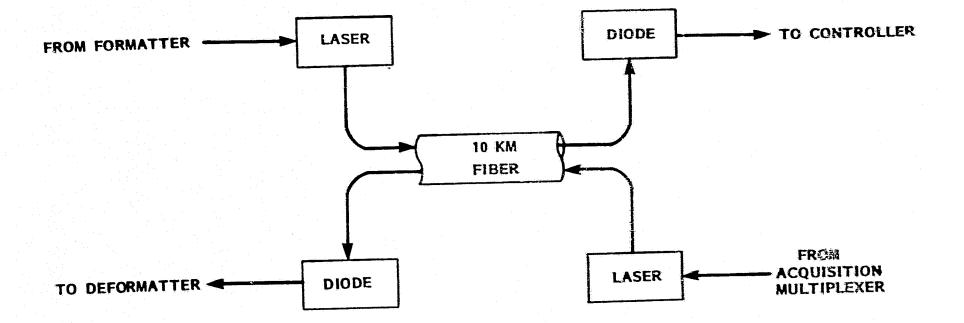
#### FIBER OPTICS

Present technology is capable of gigabit data rates in the fiber. A 256 Mbps link without repeaters over a 10 km distance is well within today's capabilities if graded index fibers are used.

Biphase (Manchester) encoding will be used to permit easy clock recovery. Fill data will be used during dead time.

TO THE WINDS

# FIBER OPTICS

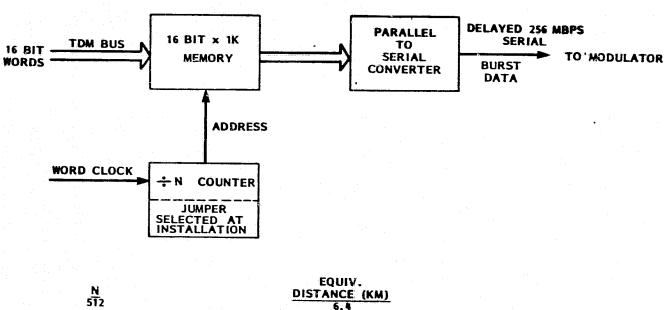


#### FIXED DELAY LINE

The fixed delay line is a 16 k bit ECL RAM organized as a shift register. During each cycle of the memory a word is read from a location and another word is written into that same location. A module N counter cycles through addresses so that there are N cycles between writing and reading a particular word. N is set at system installation. Assuming propagation at two-thirds the speed of light there are 80 buffer words needed to compensate for 1 km of fiber.

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### FIXED DELAY LINE



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EQUIV. DISTANCE (KM) 6.4 12.8

#### TIMING GENERATOR AND BURST SYNCHRONIZER

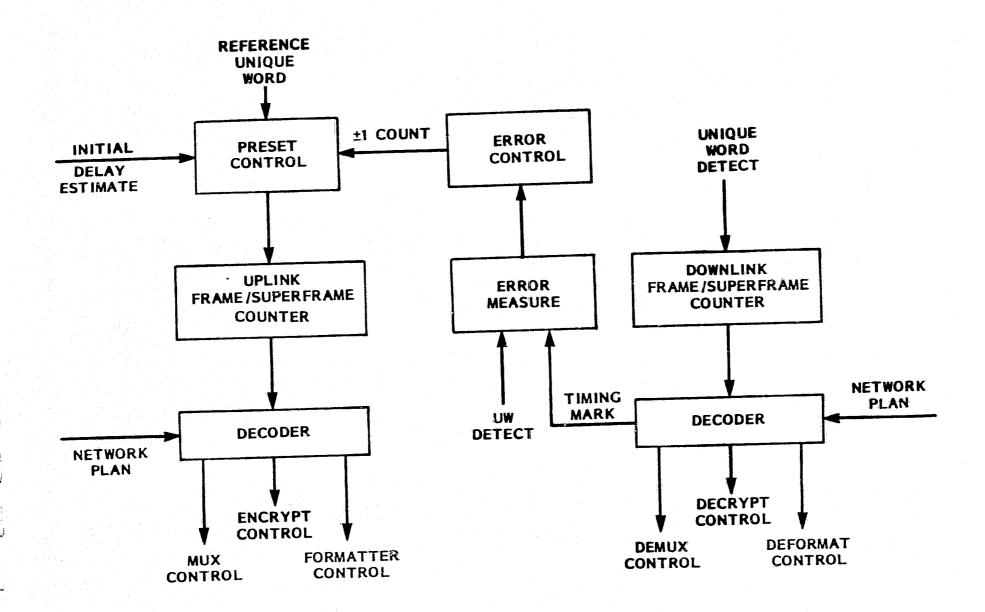
This equipment is duplicated for the remote site data path to compensate for variations in the delay. At start-up the initial delay is used to place a full power preamble in the TDMA uplink synchronization slot. Unique work detections are used to correct timing errors.

Outputs from the properly synchronized frame counters are decoded to control the terrestrial interface units, encryption/decryption, and formatter/deformatter functional units and all access to and from the TDM bus.

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# TIMING GENERATOR AND BURST SYNCHRONIZER

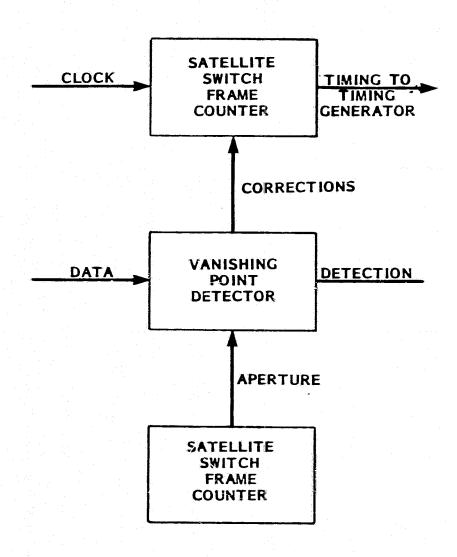
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#### SATELLITE SWITCH SYNCHRONIZATION

- 1. Employed by reference station to acquire SS synchronization
- 2. Reference station transmits straddling vector (digital bit pattern) at full power
- 3. This pattern is seen in downlink until S/C leaves loopback mode
- 4. Over several iterations the switching time may be determined to within one symbol period
- 5. This all digital technique is preferred in this digital system.

### SATELLITE SWITCH SYNCHRONIZATION



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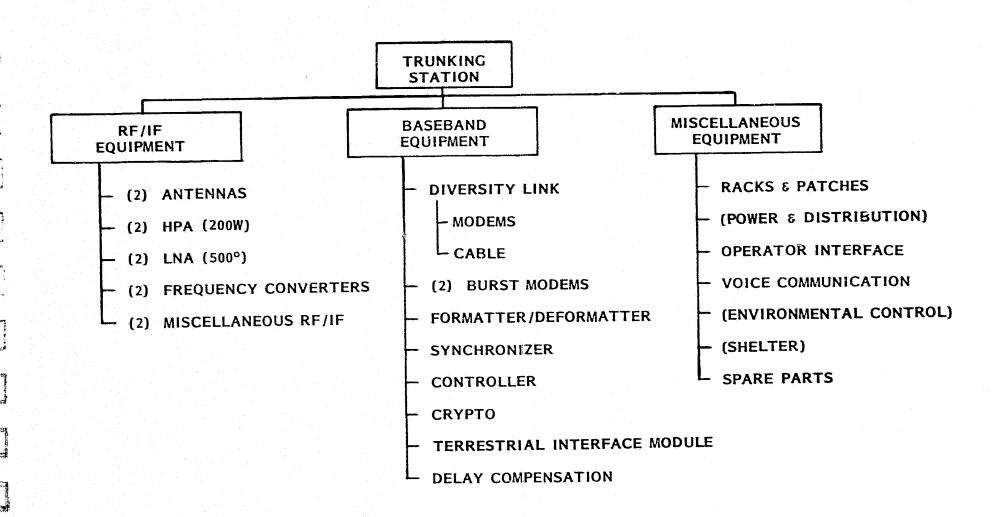
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#### TRUNKING STATION EQUIPMENT LIST

The list identifies the major components or elements of the station. Note - it is assumed that NASA will provide a shelter with environmental control and power distribution.

## TRUNKING STATION EQUIPMENT LIST

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## CPS SYSTEM DESIGN APPROACH

The CPS station must operate with the scanning beam antenna by providing 27.5 or 110 Mbps data rates on uplink and 220 Mbps on the downlink. The design goals are to achieve 15 dB uplink and 6 dB downlink margin by using fixed power margins and FEC diversity. The 27.5 Mbps station will use a 3 meter antenna and the 110 Mbps station will use a 5 meter antenna. The low rate and high rate CPS stations are designed in a modular fashion to increase commonality and minimize cost. The aggregate rate mode uses the downlink coherence to provide excellent performance. Resources are managed in a heirarchical fashion to minimize overhead.

The primary goal of the CPS demonstration is to prove that the scanning beam can be used effectively in a CPS environment. Sizing the control system for the CPS subsystem poses a problem since a completely flexible control system may be cost prohibitive and a simple system may not effectively prove the concept. Much work must also be done in lowering the cost of the modem and IF/RF components.

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## CPS SYSTEM DESIGN APPROACH

# FUNCTIONAL REQUIREMENTS

- OPERATE WITH SCANNING BEAM
- 27.5 OR 110 MB/S UPLINKS
- 220 MB/S DOWNLINK
- 15 dB UPLINK, 6 dB DOWNLINK FADE MARGIN
- DYNAMIC RESOURCE MANAGEMENT
- LOW COST

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# FEATURES AND CHARACTERISTICS

- USE BBP SYNCHRONIZATION ERROR MEASUREMENTS
- 3 OR 5 METER ANTENNAS (27.5 OR 110 MBPS)
- AGGREGATE RATE DEMODULATOR (TO MINIMIZE HIGH SPEED LOGIC REQUIREMENTS)
- SENSITIVE FADE SENSING AND ADAPTIVE FEC
- DOWNLINK COHERENCE SIMPLIFIES DESIGN (OPTION FOR PILOT)
- HEIRARCHICAL CONTROL STRUCTURE
- MODULAR DESIGN, MINIMUM CONTROL
   COMPLEXITY FOR EITHER 27.5 OR 110 MBPS
   OPERATION
- OPTIONAL CRYPTO
- 64KBPS PCM VOICE
- TWO LEVEL RESOURCE MANAGEMENT; MCC FOR FRAME ALLOCATION AND ADAPTIVE FEC AND STATION TO STATION FOR CALL SET UP

#### CPS BASEBAND DIAGRAM

The baseband equipment is similar to standard TDMA configurations except for adaptive encryption/decryption and FEC and the use of aggregate rate MODEMS to reduce cost. Interface uses multiples to standard T1 (24 x 64 kbps). Rain margin is provided by a combination of fixed power margin and adaptive FEC (rate 1/2 convolutional coding). The following parameters summarize performance:

	<u>Uplink</u>	Downlink		
Data Burst Rates	27.5 mbps (small) 110 mbps (medium)	220 mbps		
Clear Sky Margin	7 dB @ 28.75 GHz	4 dB @ 18.95 GHz 12 dB		
Fade Limits	15 dB			
(with rate 1/2 coding) Synchronization	Loop closure through BBP	Lock to reference markers		
Aggregate Throughput	T1 (small 4 T1 (mediu	uro.		
Basic Traffic Unit	64 kbps	ps		
Frame Duration	1 milliseco	1 millisecond Within MCC allocations DES		
Voice Call Management	Within MCC			
Crypto Provisions	DES			

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The essential functions in the CPS station involve transfer and buffering of incoming data, optional encryption for privacy, coding for forward error correction on an as required basis to overcome rain fading, and conversion of the digital stream to a modulated intermediate frequency. Similar processing functions are required in reverse order on the downlink. Control of all these functions is itself a CPS station function which is carried out by the station controller and synchronizer.

Essential aspects of the controller's tasks include monitoring network control information originating from the MCC to determine the lines of transmission and reception for the station. This control information is processed to define a timing for the station which is implemented by the synchronizer to provide timing pulses throughout the station. The station conformation which is implemented by the synchronizer to provide timing pulses throughout the station. The station conformation when coding should be troller also monitors the downlink quality (from raw data extracted by the demodulator) to determine when coding should be initiated or discontinued.

The entire station is designed to function at the maximum aggregate throughput rate specified for its class. This aggregate rate is well below the uplink burst rate and well below the downlink burst rate so that only modest processing speeds are required throughout the station. The aggregate rate demodulator takes samples from the downlink at the burst rate but limits further processing to the traffic which is destined to the station.

## CPS BASEBAND DIAGRAM

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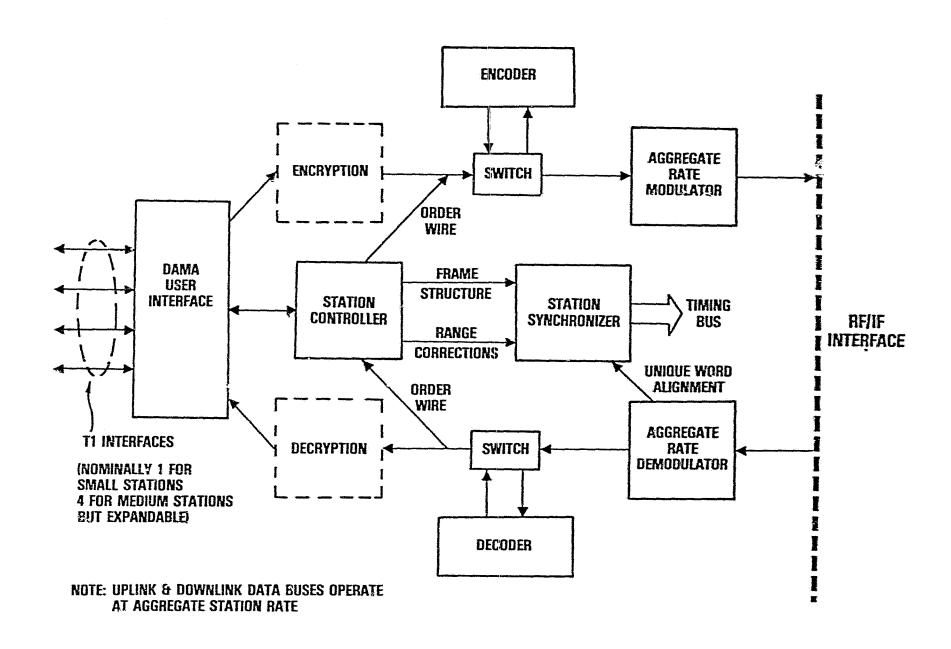
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## CPS OPERATION - NET ENTRY

Initial acquisition of synchronization by a TDMA station requires that the time equivalent range to the satellite from the joining station be known with sufficient precision to permit initial transmission without the risk of collision with ongoing traffic. In conventional TDMA systems, this initial range estimate is refined by means of an initial acquisition burst which is observed in loopback by entering station to provide it with a very precise measure of the current round trip time.

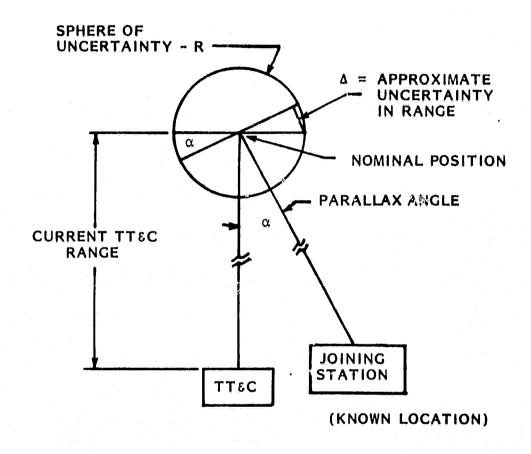
The facing slide illustrates how the current time equivalent range may be estimated based on the known current range from a single station (TT&C presumed) and ephemeris data of sufficient accuracy to guarantee that the tangential position uncertainty is not greater than 25 km. The remaining range uncertainty for an entering station is, roughly, proportional to the station's parallax angle with respect to the TT&C station. For any two stations in CONUS the parallax angle is reasonably upper bounded by 7° and for 0.03° stationkeeping the maximum tangential uncertainty is about 25 km. One concludes from this that entry range may be estimated to within ±10 microseconds, as shown.

Thus an entry slot of about 20 microsecond deviation will provide adequate guard space for initial entry bursts. If this initial burst must be very precisely located to fall within a narrow operation at the BBP, then general entry bursts with slightly different times must be sent in a trial and error fashion until alignment occurs.

# **CPS OPERATION - NET ENTRY**

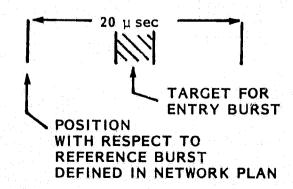
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• NET ENTRY BASED ON TT&C RANGE AND GENERAL POSITION KNOWLEDGE



 $\Delta \approx R \sin \alpha < 25 \sin 7^{\circ} \approx 3 \text{km} \longrightarrow 10 \mu \text{ sec}$  for conus stations and containment sphere of 25 km radius

### **ENTRY SLOT**



## CPS OPERATION - SYNCHRONIZATION

An overview of the activity required to obtain synchronization is shown in flow chart form on the facing page. The use of a terrestrial connection to obtain entry permission and rough range from the MCC has been postulated. (A terrestrial interconnect appears to be desireable for other purposes as well as initial entry.)

Prior to initiating an entry burst, the CPS station must acquire downlink synchronization by identifying the reference bursts. Once the station has locked to the downlink and is in possession of the rough range from itself to the satellite it can begin the uplink synchronization process as described for the preceeding slide. Once locked to the uplink, the station can communicate with the MCC via the satellite to obtain bandwidth allocation for normal transmission.

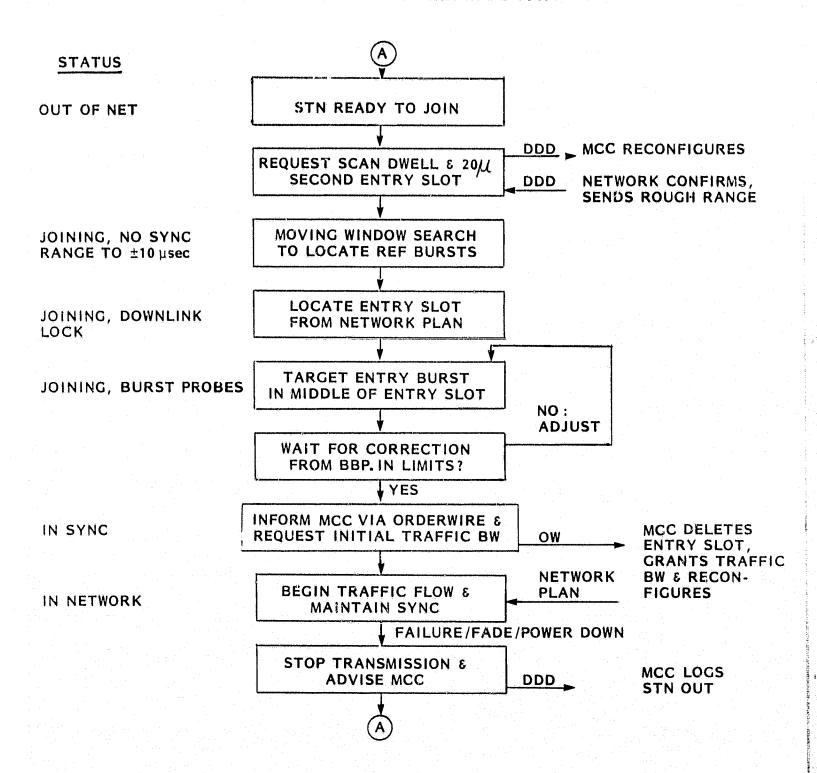
Routine maintenance of synchronization requires that the station continue to monitor the downlink to maintain lock with the reference burst and, periodically, that it receives timing error information from the BBP so that it can correct its uplink timing for satellite motion.

In the event that synchronization appears to be lost for any reason, the station is required to cease transmission and to advise the MCC that it is no longer in the network.

# CPS OPERATION - SYNCHRONIZATION

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#### CPS OPERATION - FADE REACTION

An important aspect of the CPS station control is the recognition of fading conditions and the introduction of coding when required to overcome moderate fading.

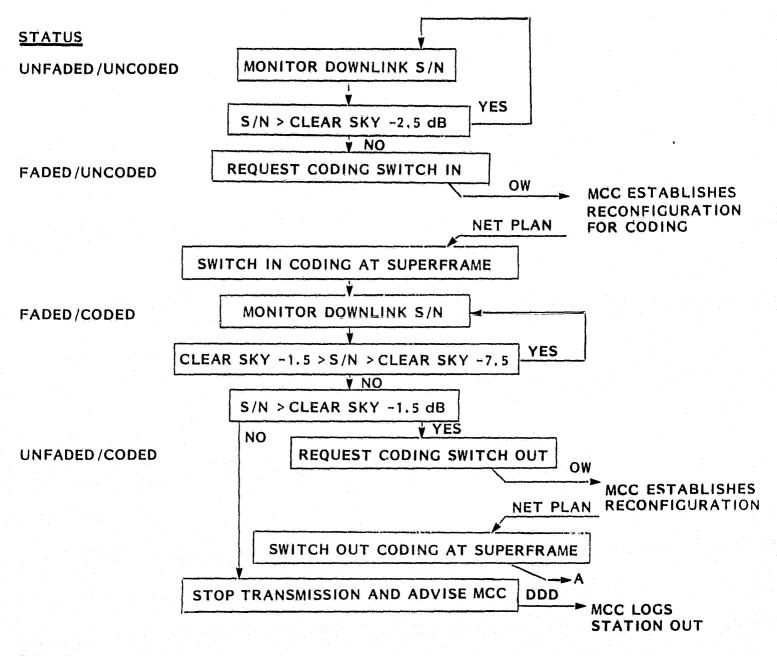
The basis of the control system is the apparent signal to noise ratio on the downlink. When this ratio drops more than 2.5 dB below clear sky conditions, a request for coding is made to the MCC. The equivalent uplink fade which occurs simultaneously is about 5.0 dB. Both fade levels are within the intrinsic margins of the station design so that satisfactory performance is still maintained with these moderate fades.

Upon receipt of permission to introduce coding from the MCC, the station switches to coded operation and continues to monitor downlink quality. When fading conditions improve to the point where the downlink signal to noise ratio is within 1.5 dB of clear sky, the station informs the MCC that coding is no longer required and, after receipt of confirmation from the MCC, returns to uncoded operation.

The difference between the switch in and switch out thresholds is intended to provide some hysteresis in the process to reduce the frequency of coding changes.

In the event that fading increases to the point where the downlink signal to noise ratio drops more than 7.5 dB from clear sky conditions, (equivalent uplink fading would be about 15 dB) the station should withdraw from the network until the rain fade is finished.

## CPS OPERATION - FADE REACTION



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# CPS OPERATION - FADE THRESHOLD

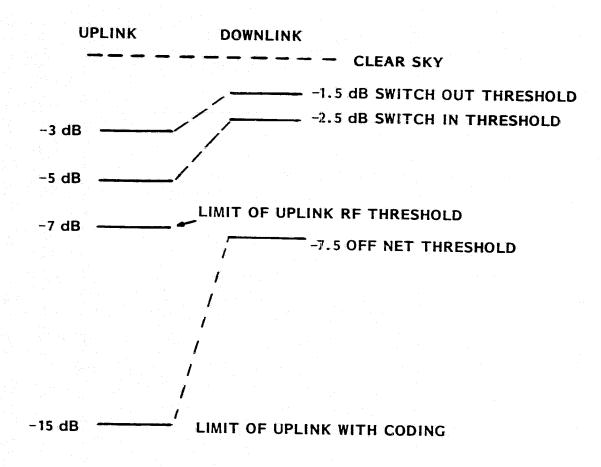
The facing illustration is intended to clarify the fade reaction strategy discussed in the preceding page. It is assumed that some measure of downlink channel quality is derived in the demodulator so that the station controller has a performance criterion on which to base coding switch in switch out decisions. A suitable and simply implementable performance index is the relative frequency of occurrence of the soft decision bits.

An important point to note is that the quality of the uplink is known only by inference from the measurable quality of the downlink. Since the depth of fade on the 30 GHz uplink is generally greater than on the downlink, special attention to a sensitive downlink performance measure is warranted. For the sake of simplicity a simple 2 to 1 fading ratio has been assumed in the diagram.

The fade reaction strategy set out in this and the preceding figure should be regarded as a preliminary general approach only. Detailed experimentation with the demonstration system to refine fade reaction strategy is recommended.

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# **CPS OPERATION - FADE THRESHOLDS**



- S/N DETERMINED BY FREQUENCY OF SOFT DECISION BITS FROM DEMODULATOR
- o 2 TO 1 FADING RATIO ASSUMED AT 30/20 GHz, RESPECTIVELY

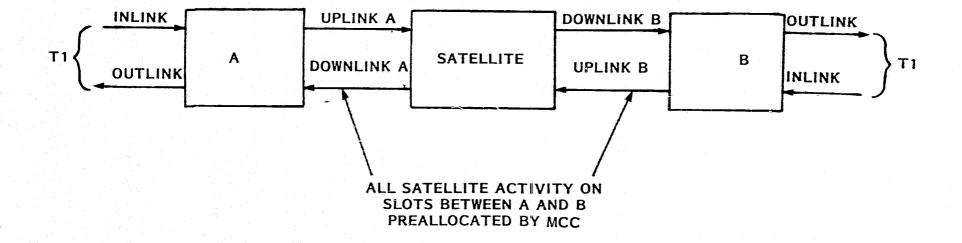
#### CPS OPERATION - RESOURCE ALLOCATION

Control of the switching of traffic in the CPS network represents a challenge. In this and the following figure a preliminary approach to the problem is exhibited. The facing figure is intended primarily to clarify the terms used. The essence of the activity is to be able to connect an originating call on the user interface "inlink" to the intended recipient at some other CPS station's "outlink". The connection is made through the satellite, with time slot switching performed by the BBP to cross connect uplink and downlink. A similar cross connect function between inlink and uplink (or downlink and outlink) is performed by the DAMA processor in the CPS station. All connections have been treated as full duplex.

To avoid excessive intermediation by the MCC, it is recommended that capacity between user pairs be preallocated by the MCC.

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# **CPS OPERATION - RESOURCE ALLOCATION**



## CPS OPERATION - VOICE CHANNEL MANAGEMENT

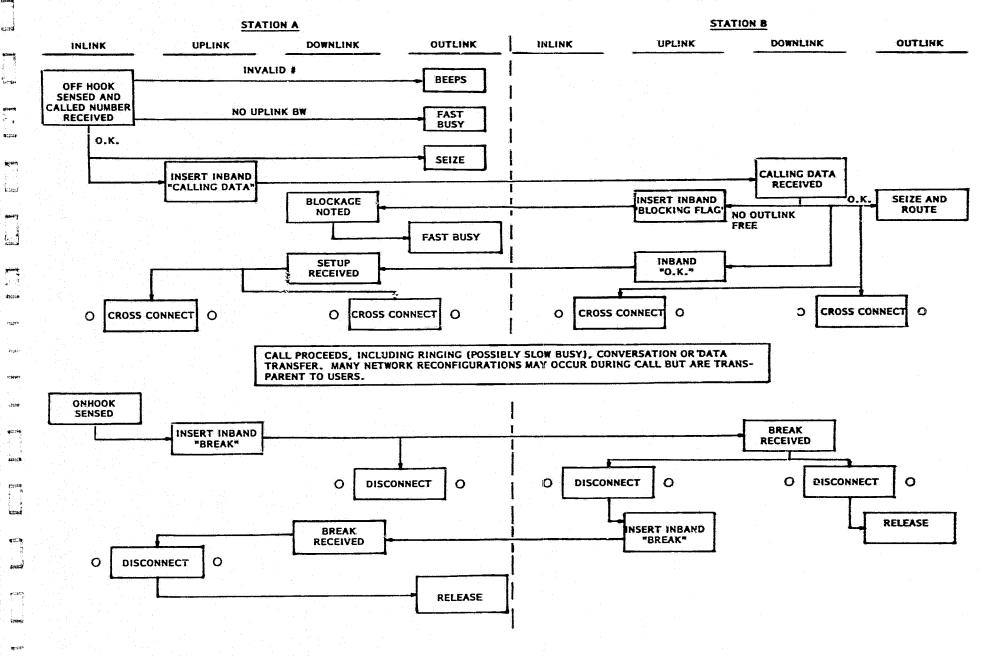
The activity flow in the facing diagram is keyed to topology of the previous block diagram and illustrates some of the major steps which occur in the setup of a voice bandwidth connection between two users who interface CPS stations.

While a voice channel (64 kbps) is the basic switching unit, the actual traffic transferred could be data as well as voice conversation.

Some switching capability at the customer's premises has been assumed in this approach (e.g., from a company PBX) so that the interfacing T1's may be regarded as a shared resource among the terrestrial users who may access a given CPS station. Not all such users need be colocated with the station since the T1 interconnect provides a convenient medium for short range backhaul.

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## CPS OPERATION - VOICE CHANNEL MANAGEMENT



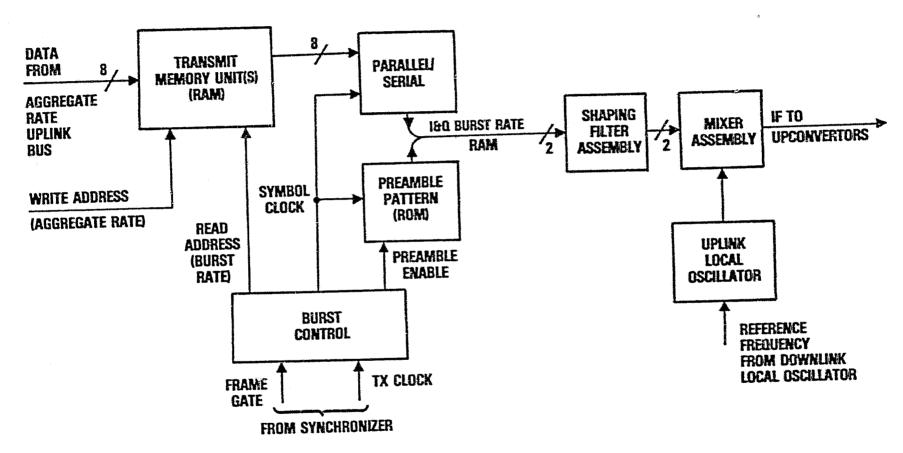
## CPS MODULATION/DEMODULATION

Significant cost savings can be achieved in CPS station hardware by the aggregate rate approach. Data encryption and encoding as well as terrestrial interfacing work at the aggregate rather than burst rate.

- 27.5 Mbps (13.75 Msps) or 110 Mbps (55 Msps) burst modulators
- 220 Mbps burst demodulators
- Demodulators function at aggregate station rate (modularized to units of 1536 kbps aggregate thruput)
- Provision for operating with stable station clock (10 ppb) or recovered pilot
- Modulator includes burst rate memory and preamble insertion
- Demodulator includes burst rate front end (including memory). Other processing, including unique word alignment, proceed at lower aggregate rate
- Filtered non-constant envelope QPSK recommended
- IF frequency 1.0 GHz

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# MODULATION/DEMODULATION CPS (AGGREGATE RATE MODULATOR BLOCK DIAGRAM)



#### NOTES:

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> TRANSMIT MEMORY UNIT IS 4096 BITS (PROVIDES FOR AGGREGATE UNIT 1536 BITS, CODED AT RATE 1/2) ACCESS SPEED <50 NS.

OTHER LOGIC DESIGNED FOR MEDIUM SPEED STATIONS (64 MHz CLOCK).

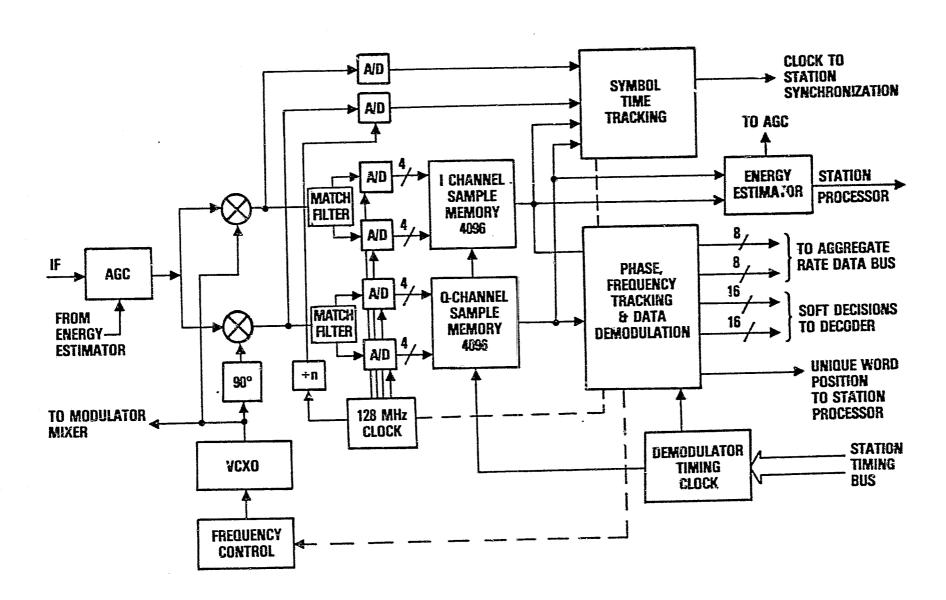
FILTER ASSEMBLY (PLUG IN) DIFFERS FOR 32 MBPS & 128 MBPS STATIONS.

TRANSMIT MEMORY UNITS ADDED (4 TOTAL) FOR MEDIUM SPEED STATIONS. MEMORY UNITS MAY BE ADDED AT ANY STATION TO INCREASE MAXIMUM AGGREGATE RATE.

# CPS MODULATION/DEMODULATION (AGGREGATE RATE DEMODULATOR)

Initial symbol timing is obtained by varying the phase of the symbol clock until minimum energy appears in the quantizer samples. A phase change of 180° puts the matched filter sampling near the correct point. Downlink preamble is then acquired by a moving window search. The station synchronizer then provides frame gates to enable capture of the correct samples in I&Q memory for subsequent processing.

# CPS MODULATION/DEMODULATION (AGGREGATE RATE DEMODULATOR BLOCK DIAGRAM) (STABLE CLOCK OPTION)



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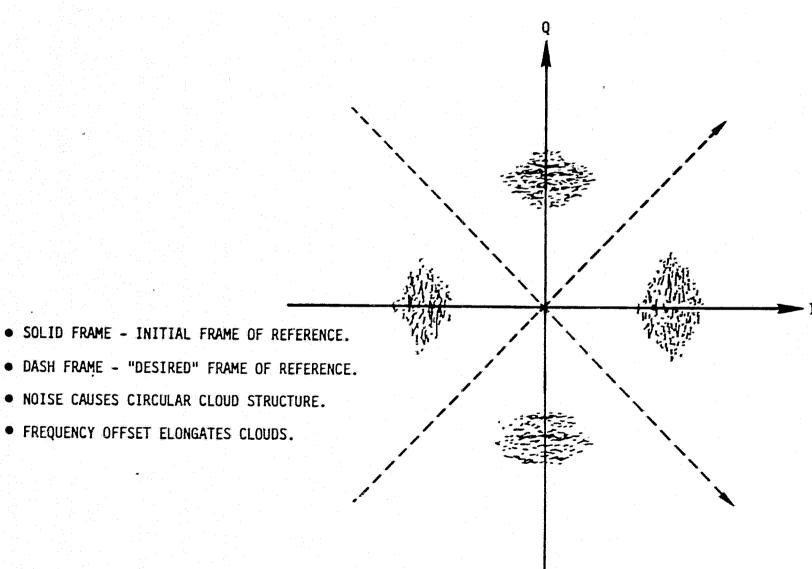
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# CPS MODULATOR/DEMODULATOR (AGGREGATE RATE DEMODULATOR PHASE ESTIMATION)

After the samples have been stored in I&Q memory, processing at the aggregate rate determines the "cloud" positions in the initial frame of reference. From this determination and comparison against the unique word the proper frame of reference is determined. Corrections are made for both initial phase error and frequency offset. Also an energy estimate is made in the processor to control AGC and tell the MCC of possible fades.

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# CPS MODULATION/DEMODULATION (AGGREGATE RATE DEMODULATOR PHASE ESTIMATION)



QUANTIZER SAMPLES FROM I & Q ARE PLOTTED AS PAIRS.

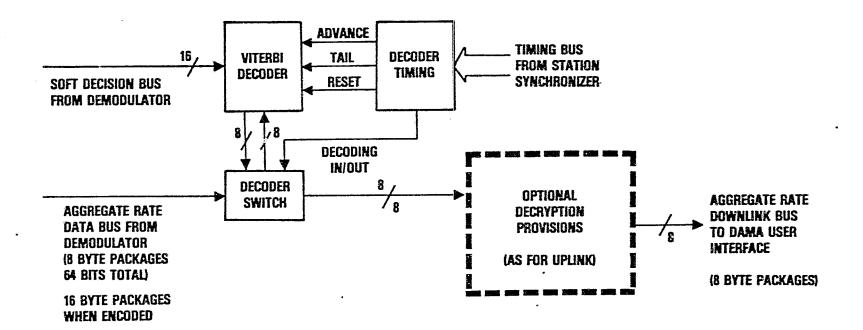
# CPS CODING FEATURES (DOWNLINK)

# CPS coding features include:

- Downlink channel quality sensed by demodulator and passed to station control.
- Request for coding setup/cleardown made via orderwire to MCC.
- When coding request granted by MCC, coding initiated by station controller (at superframe boundaries).
- Convolutional code rate 1/2, constraint length TBD.
- Viterbi decoder runs at aggregate rate (2 Mbps for small stations, 10 Mbps for medium stations).
- 3-bit soft decision output from aggregate rate demodulator.
- Each burst is tailed off.

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## CPS CODING FEATURES (DOWNLINK BLOCK DIAGRAM)



NOTE: 3 BYTE DELAY IN DECODER WHEN ACTIVE

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# CPS CODING FEATURES (UPLINK)

# CPS coding features include:

- Crypto provisions (keyed by user community)
- Crypto synchronized on a frame basis and runs at rate suitable for user community's composite traffic
- DES encryption current technology to 10 Mbps higher community rates may require parallel crypto engines
- Crypto initial values disseminated by MCC on network-wide basis.

# CPS CODING FEATURES (UPLINK BLOCK DIAGRAM)

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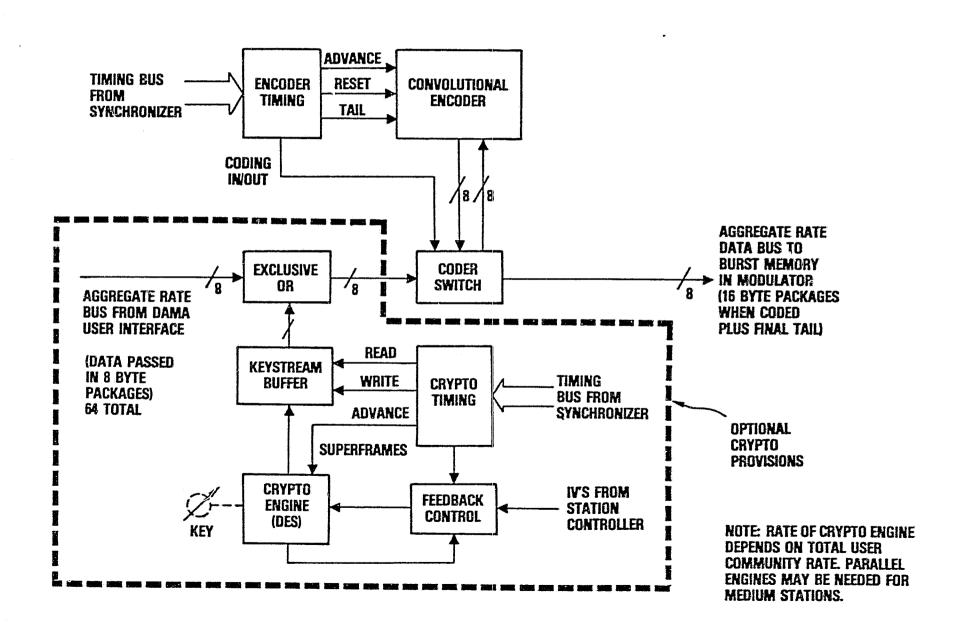
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## CPS USER INTERFACES/DAMA

## CPS user interface/DAMA features include:

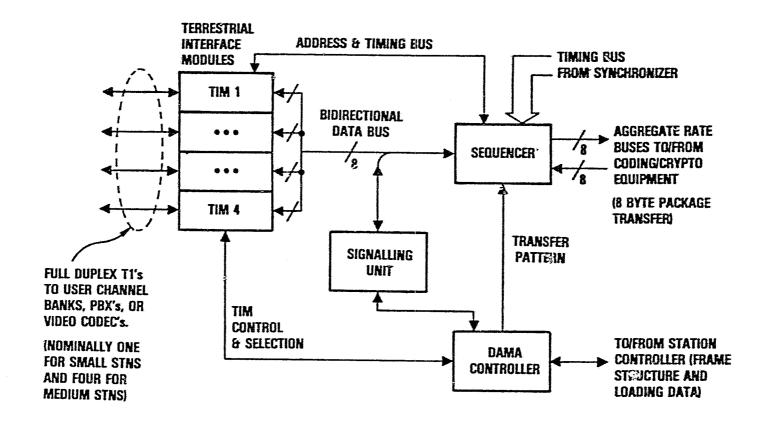
- Provides for voice call setup/teardown to destination within user community without MCC intervention
- Requests frame allocation changes from MCC (via station controller) as voice call loading varies
- Requests frame allocation changes from MCC for video conferencing setup and cleardown
- Acts as digital switch between TDMA frame and terrestrial T1
- Interface is T1 (channel bank with buffers may be needed by customer)
- Minimum traffic unit is 64 kbps
- CPS users form closed community.

# CPS USER INTERFACES/DAMA (OVERVIEW DIAGRAM)

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## CPS SYSTEM ISSUES

Many system issues are involved in the consideration of a fallback mode in the event of BBP failure. Some of these are set out in the facing page which links the system issues on the left and the corresponding impact on the right.

The conclusion appears to be that no meaningful CPS experimentation can be performed in the absence of the BBP since the CPS station architecture is so strongly influenced by the regenerating/switching satellite concept.

By providing backup 27.5 Mbps equipment, operation of the CPS stations through the 4x4 satellite switch is feasible. Such experiments would be essentially scaled down trunking experiments, however.

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## CPS SYSTEM ISSUES - FALLBACK MODE FOR BBP FAILURE

UPLINK	3	DOWNL	INK R	ATES	DIFFER

- DEMODULATION RATES MUST BE CHANGED:
   27.5 MB/S ONLY
- FREQUENCY MULTIPLEXING IN UPLINKS
- DOWNLINK L.O.s MUST BE CHANGED

BBP CLOSES SYNCHRONIZATION LOOP

 PROVISION FOR SENSING LOOPBACK OF RANGING BURSTS NEEDED

BBP PROVIDES REFERENCE BURSTS

REFERENCE BURST GENERATION BY MCC
 INTO EACH SCAN DWELL IN EACH BEAM

TDM DOWNLINK BECOMES TDMA

 DEMODULATOR CAN NO LONGER EXPLOIT DOWNLINK COHERENCE. FADE REACTION STRATEGY MUST BE REVISED.

 ORDERWIRE AND NETWORK PLAN DISTRIBUTION  MCC MUST BE CROSS-CONNECTED TO EACH SCAN DWELL IN EACH BEAM.

COMPOSITE PATH

LOSS OF REGENERATION AT SATELLITE
 RESULTS IN POORER END-TO-END PERFORMANCE.

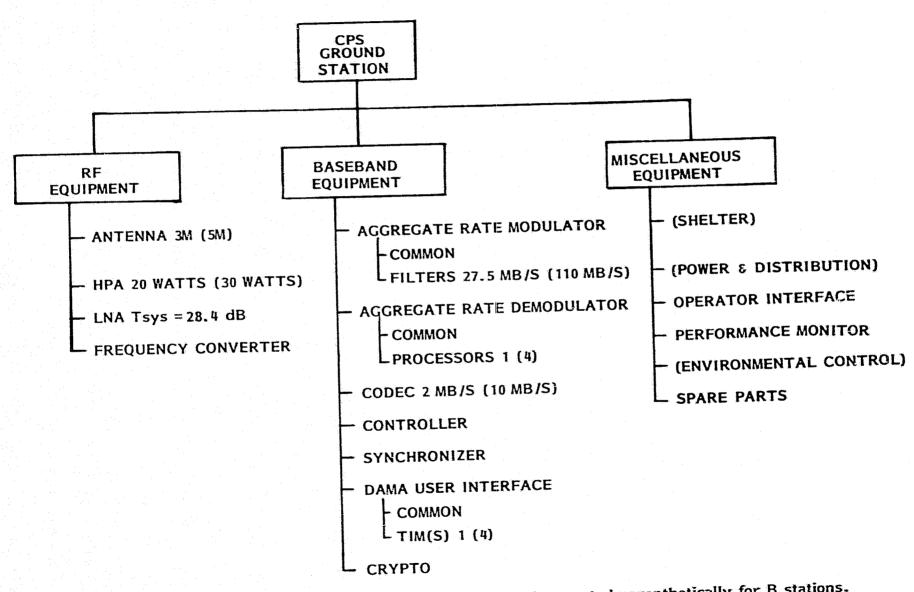
RECOMMENDATION: BACKUP BASEBAND EQUIPMENT FOR 27.5 MBPS SS TDMA

## CPS STATION EQUIPMENT LIST

The equipment list identifies major subsystems and elements. Note that the shelter, power and distribution and environmental control are provided by NASA, at Cleveland. The CPS and trunk stations can be combined, if desired to share common equipment such as antennas, HPA's, LNA's, converters.

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## CPS STATION EQUIPMENT LIST



NOTE: Category A & B stations have same equipment lists except where noted parenthetically for B stations.

#### MASTER CONTROL CENTER

The central control station (CCS) computer will run either the trunking program or the CPS trunking as selected at load time.

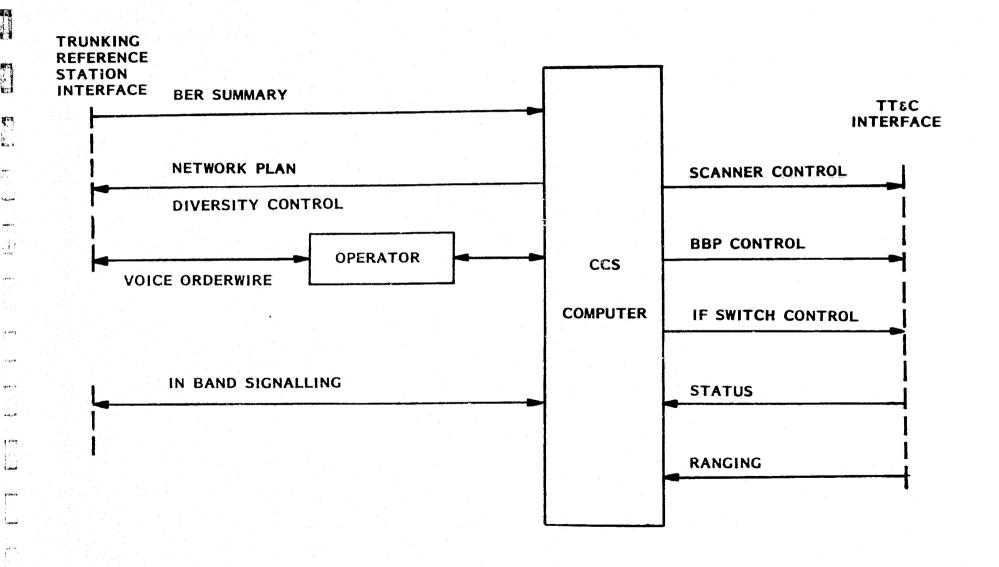
The CCS receives BER summary data from the trunking station deformatter and sends network plan and diversity control to the formatter. The trunking voice orderwire is used to request changes in resource allocations. The MCC operator manually keys these entries into the CCS computer.

CPS control will be more automated. In-band signaling is provided to control resource allocation. The CPS requirement will determine the size of the computer needed.

The CCS also interfaces with the TT&C channel to the spacecraft. BBP, scanner and IF switching are controlled via this interface. Also spacecraft switch and safety are monitored here. Ranging data may be acquired from TT&C or an alternate source may be needed.

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## MASTER CONTROL CENTER



# MASTER CONTROL CENTER REQUIREMENTS AND FEATURES

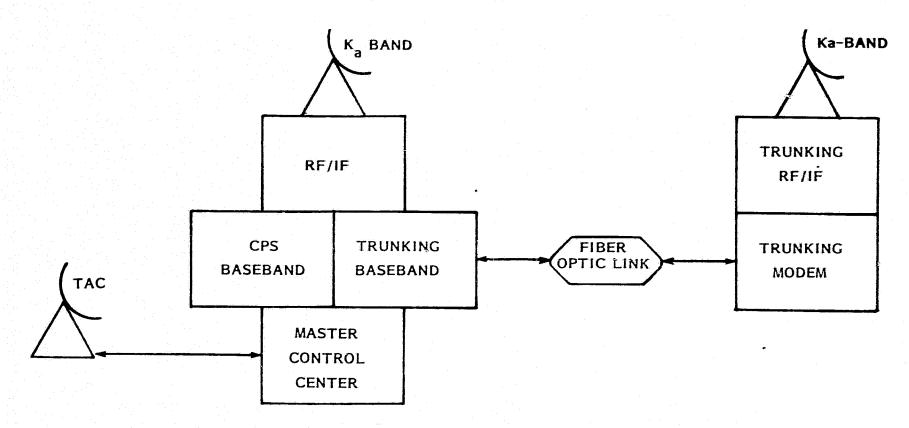
For reasons of convenience and cost savings, the MCC will be colocated with the Cleveland reference trunking station and CPS station. It interfaces with the reference trunking station at baseband to provide network plan and diversity control information to the trunking network, and also controls the baseband processor IF switching and beam scanning via a TT&C link.

The CPS station will have a high rate capability since the control orderwire is in the CPS transmission.

In order to minimize costs the trunking system control will be essentially manual. Trunking stations will request resources via voice orderwire and they will be entered into the network plan by the MCC operator (the MCC and reference station share a voice orderwire)

Control of the CPS experiment which permits full operational flexibility may be cost prohibitive. A compromise system is recommended which limits signalling and switching functions to a minimum, however, automatic call connection and fade response is included.

## MASTER CONTROL CENTER REQUIREMENTS & FEATURES



- REFERENCE TRUNKING SITE WITH DIVERSITY (CLEVELAND)
- CPS OPERATION AND FEATURES LIMITED TO EXPERIMENTAL NEEDS IN ORDER TO MINIMIZE MCC COST
- 110 MB/S CPS STATION
- MASTER CONTROL CENTER IS NON REDUNDANT
- SCC NOT SHOWN

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- CPS AND TRUNKING SERVICE NOT SIMULTANEOUS
- TRUNKING RESPONSE ALLOCATION VIA OPERATOR ENTRY (e.g. MANUAL)

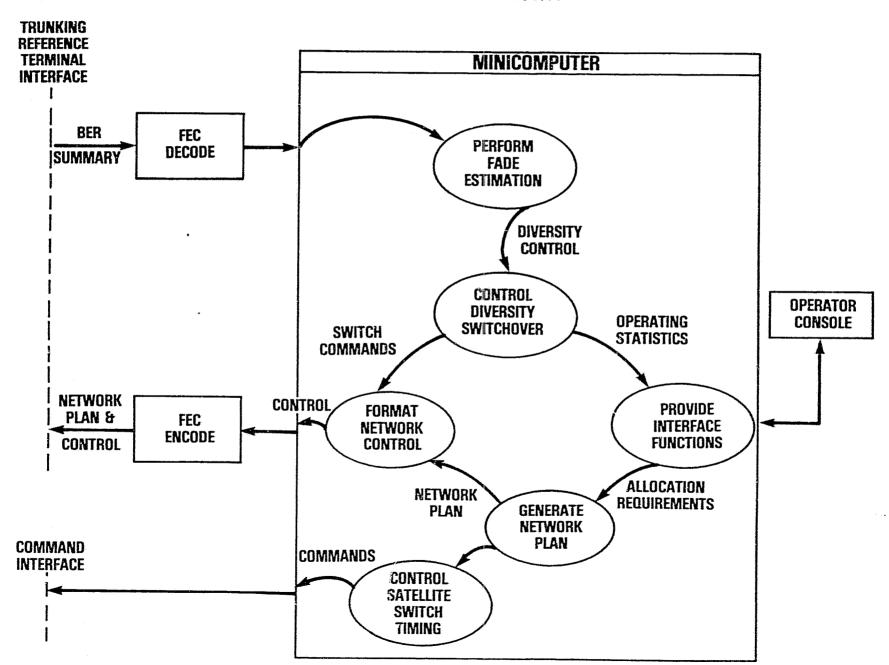
### MCC TRUNKING FUNCTIONS

Critical control information such as the BER summary network plan, and diversity control will be protected by FEC. A fade estimation algorithm operates on the incoming BER summaries to determine which stations are experiencing fades. These conclusions are used to control the generation of diversity switching commands. Statistics on error performance and diversity switching will be made available to the operator.

Requests for network resource configuration are entered manually by the operator. These are converted to allocation requirements and a new network plan will be generated. This plan is combined with the diversity switching control, FEC encoded and transmitted to the trunking stations. It is also used to alter the IF switching frame times in the S/C.

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# MCC TRUNKING FUNCTIONS



#### MCC CPS FUNCTIONS

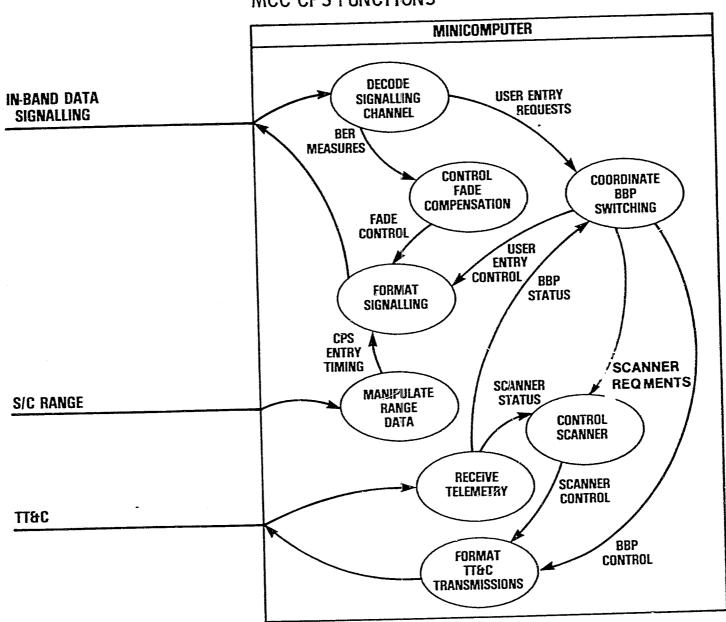
In-band signaling will be delivered to the CCS computer from the CPS baseband equipment. The decoded user entry requests are evaluated by the BBP switching coordination process. When a new CPS plan is formulated the users are permitted entry according to the new plan. This activity is coordinated with the scanner movement control. This processing is the bulk of the load on the CPS processor.

Other facilities include converting externally derived range data into station-by-station range data to control system timing, processing received TT&C telemetry, and general formatting and presentation functions.

An additional function which will be included in the final demonstration configuration is control of the BBP and scanner via the Cleveland trunking beam. (The spacecraft block diagram only permits this control in the Cleveland beam.) When the control functions are better defined these features will be incorporated.

The Authority

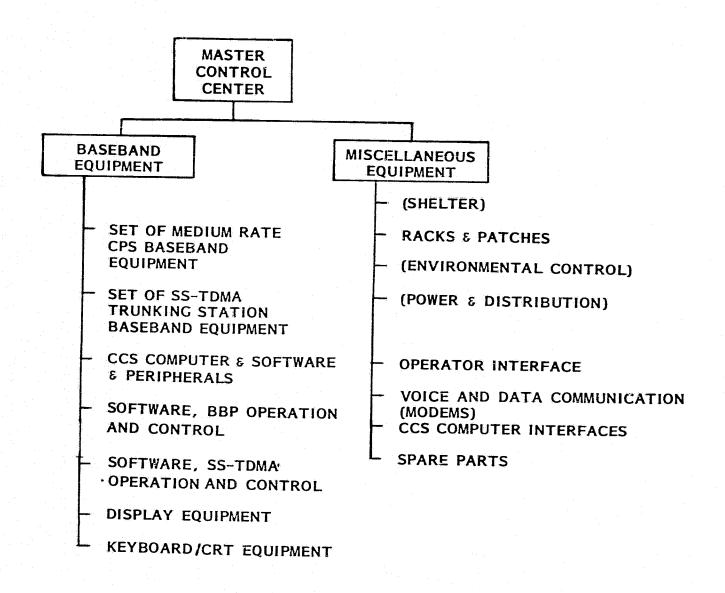
# MCC CPS FUNCTIONS



### MASTER CONTROL CENTER EQUIPMENT LIST

The equipment list at the right assumes a NASA-provided building with environmental control and power. Communications also is provided to the SCC at GSFC. A substantial portion of the MCC complexity is due to the software for the BBP which includes not only operational control and reconfiguration capability but also BBP diagnostics. Note that fail BBP reconfiguration will require a special link from the MCC to the satellite using either the trunking or CPS earth station. Slow reconfiguration and basic control is also provided at the SCC via T&C.

# MASTER CONTROL CENTER EQUIPMENT LIST



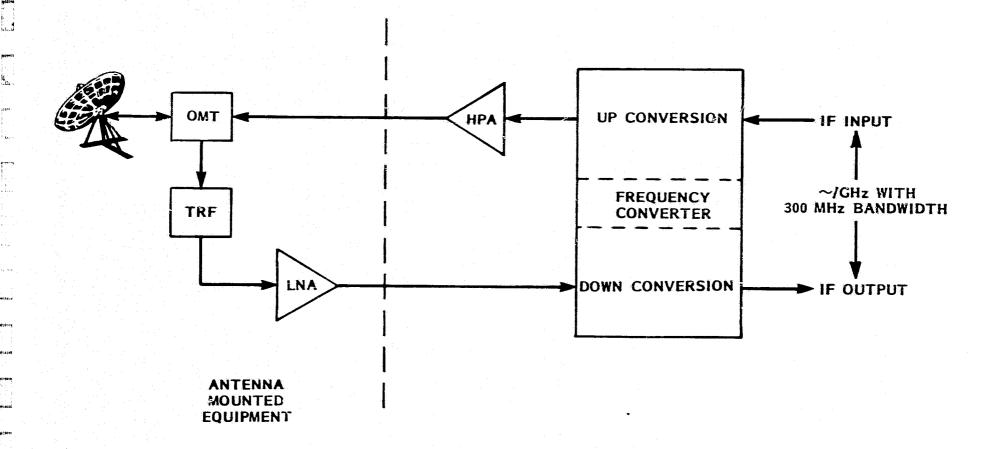
Lynna Wilson

### IF/RF EQUIPMENT

The following section describes approaches to the design of minimum cost IF/RF equipment for CPS and trunking applications, IF/RF equipment costs represent a substantial portion of total earth station cost.

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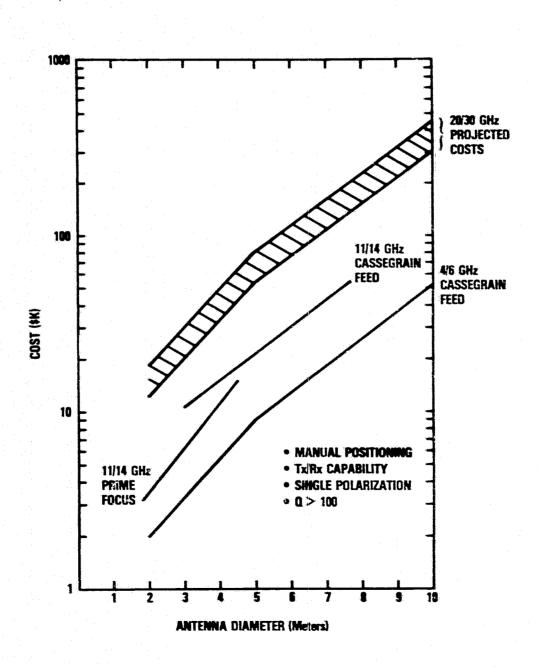
# IF/RF EQUIPMENT (BLOCK DIAGRAM)



# ANTENNA COSTS

Based on actual figures for 4/6 and 11/14 GHz antenna systems a projection was made for 20/30 GHz antennas. These are TX/RX systems and manual positioning is assumed. Steptrack or autotrack capability will greatly increase the cost of the larger antenna systems. All costs are in 1981 dollars based on quantities of 100 or more. At these frequencies the antenna surface tolerance becomes an important factor. The manufacturing techniques being considered are stretch formed panels. plastic mold and lathe turning for the smaller antennas. Also the support structure must be cost, rapid installation.

# **ANTENNA COSTS**

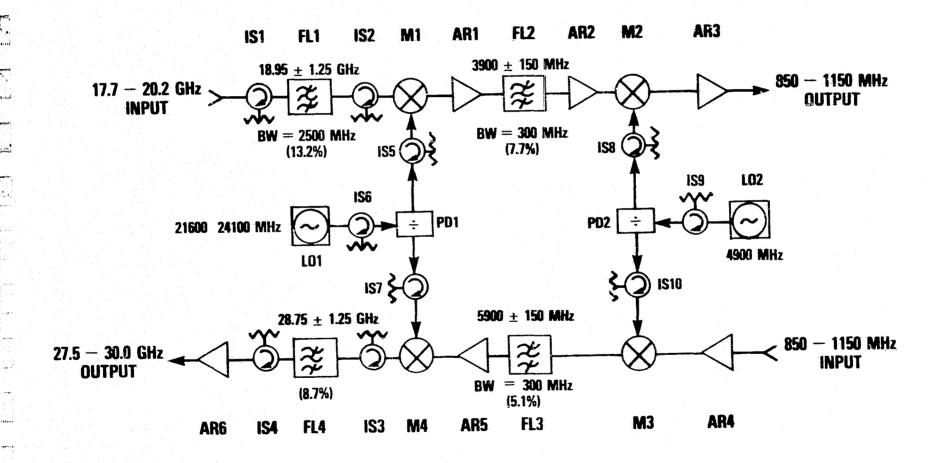


#### FREQUENCY CONVERTER

The block diagram represents a typical frequency converter design. A thorough intermodulation product analysis was performed to demonstrate feasibility. The 1.0 GHz IF selection was arbitrary and may not be the best choice for the final system design. A single design for all stations is desirable for reducing system costs. This requires an adjustable or selectable upconverter L.O. for the CPS A&B type stations. Intermod analysis shows that a single integrated unit is feasible for the converter. Design concepts are:

- Dual conversion
- Sharing of common LO's for both up and down conversion
  - 4900 MHz fixed frequency LO
  - 21600 to 24100 MHz adjustable LO
- Use of stripline technology
- Downconverter
  - 17.7 to 20.2 GHz input operating range
  - Nominal 1 GHz IF frequency
  - 300 MHz useable bandwidth
- Upconverter
  - Nominal 1 GHz IF frequency
  - 27.5 to 30.0 GHz output frequency range
  - 300 MHz useable bandwidth
- Stability 10 kHz/month
- Low cost stripline technology (extension of state of the art)

# FREQUENCY CONVERTER (FUNCTIONAL BLOCK DIAGRAM)



# PERFORMANCE OF RECEIVER (GaAs FET LNA DESIGN OBJECTIVES)

The desired noise temperature of 300°K is not achievable with current devices unless cooling to -77°C is used. Today's GaAs FET technology will produce 440°K LNAs. In order to minimize the effects of converter noise the LNA should provide at least 40 dB gain. Operating bandwidth is 2500 MHz. Low cost is again a major design criteria.

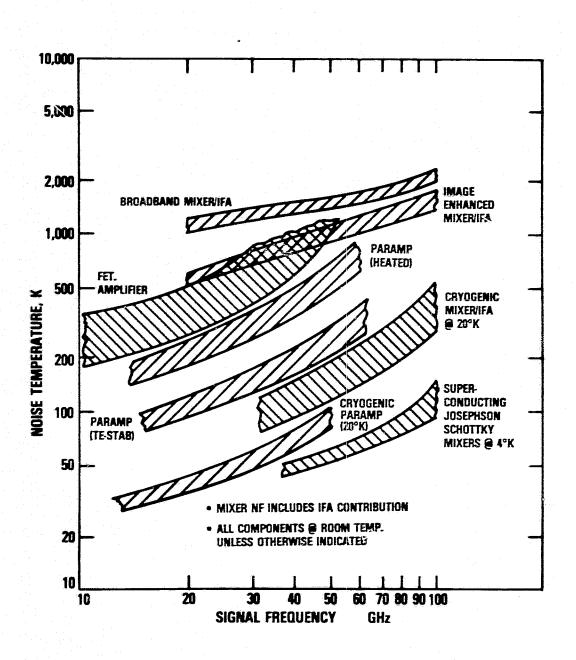
The table below and the performance chart at right show that image enhanced mixers and FET amplifiers are the best all around technology for low cost LNA's.

### Comparison of Receiver Front-End Approaches

	<u>Type</u>	Predicted (1984) Receiver Noise Temperature	Predicted (1990) Unit Cost	Predicted Development Cost (84–86)	MTBF
1.	Broadband Mixer Plus Low-Noise IF Amp	1000K	\$ 1.5K	0	High
2.	Image enhanced Mixer Plus Low- Noise IF Amp	550K	2.5K	0	High
3.	Cryogenically Cooled Image-enhanced Mixer Plus Low-Noise IF Amp	70K	12. K	\$100K	Low
4.	Uncooled Paramp	190K	9. K	50K	Moderate
5.	Thermoelectrically Cooled Paramp	85K	12. K	75K	Moderate
6.	Cryogenically Cooled Paramp	35K	18. K	100K	Low
7.	FET Amplifier	300K	1.5K	<b>50K</b>	High
8.	Cryogenically Cooled FET	77K	7.5K	50K	Low

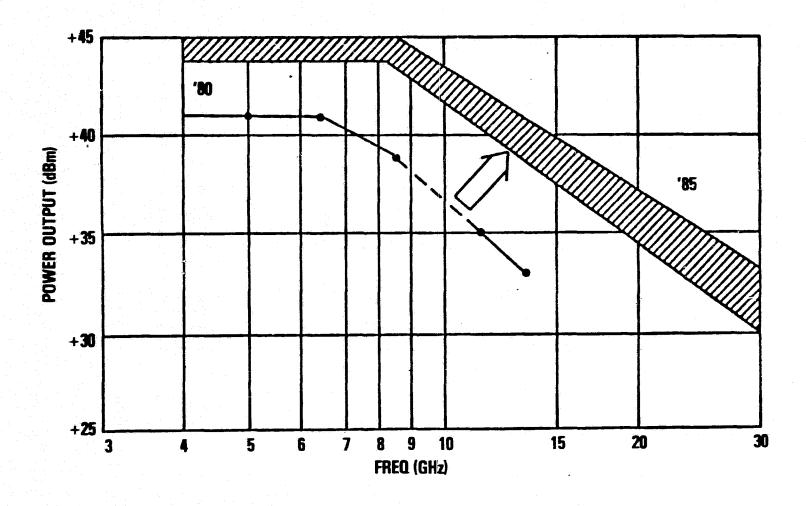
# PERFORMANCE OF RECEIVERS

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### Gaas FET HPA

Technology predictions indicate that the GaAs FET amplifier will not provide the necessary power output at 30 GHz in the 1985 time frame. Other devices must be used.



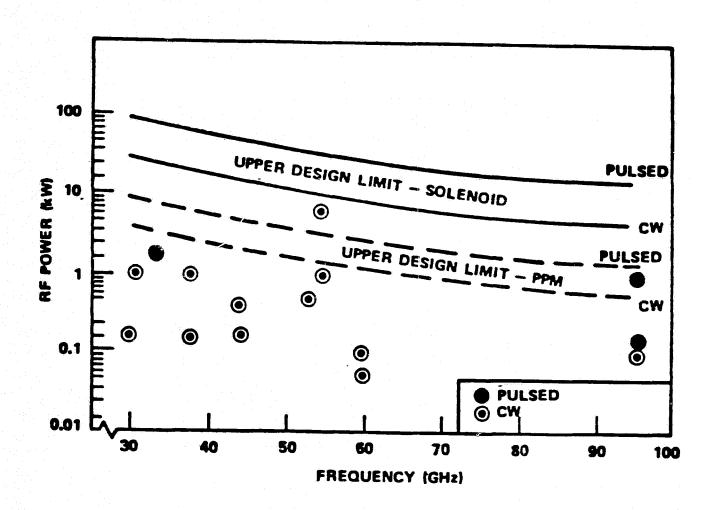
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#### HPA-TWT CURRENT STATE OF THE ART

Helix development efforts above 30 GHz were initiated less than 5 years ago. A helix TWT can only support tens of watts of RF power due to inefficient heat removal from the helix structure; however, higher power levels could be achieved with more development effort.

Coupled cavity TWT's predominantly used at frequencies in 30 to 100 GHz range. These tubes provide hundreds of watts of RF power due to efficient heat removal. Fabrication of high precision parts is a significant cost driver for both types.

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Coupled cavity TWT output power - demonstrated and projected.

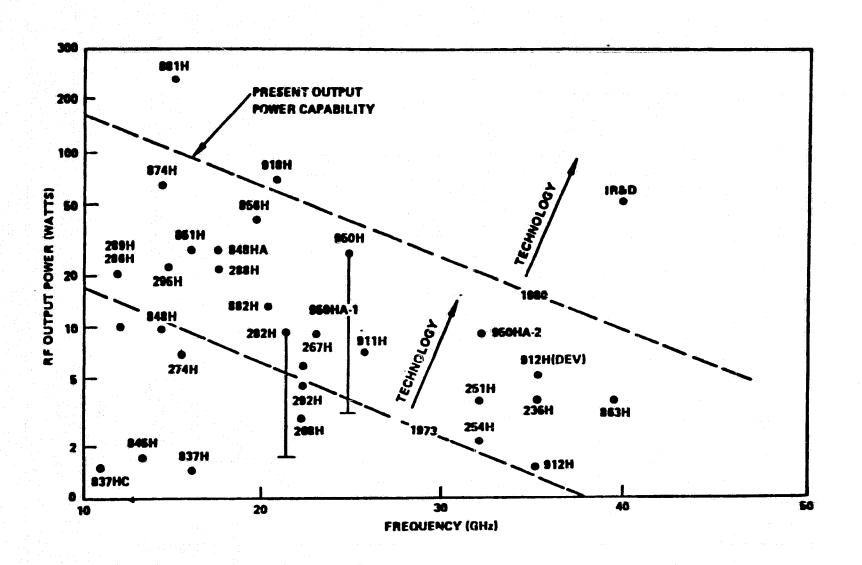
### HELIX TWTA

The present state-of-the-art at 30 GHz is approximately 20 watts. There are plans in Europe to develop a TWTA in the several hundred watt region.

# HELIX TWT (DEMONSTRATED AND PROJECTED OUTPUT POWER)

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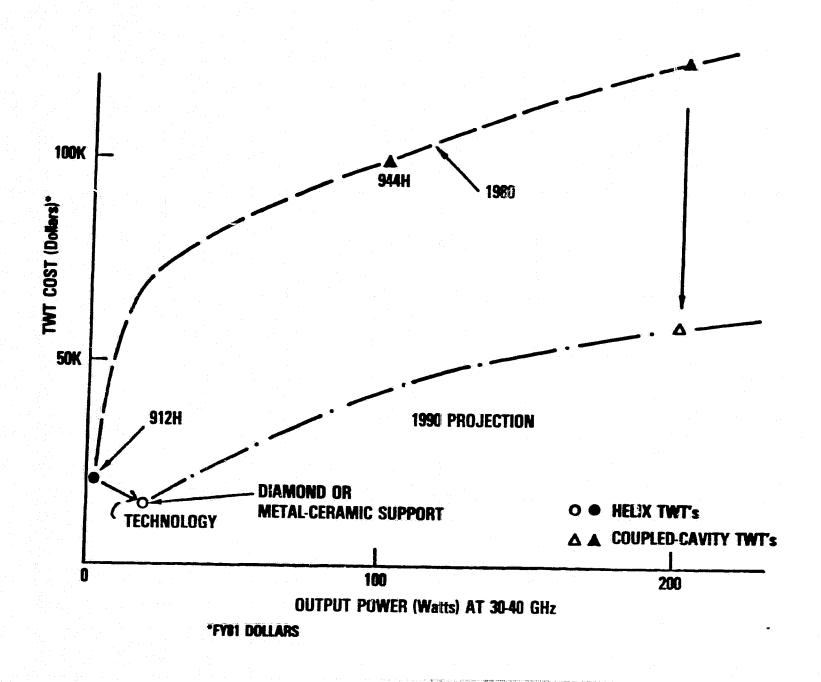


### TWTA COSTS

Although there is a dramatic cost decrease anticipated for TWTAs these devices will still cost tens of thousands of dollars in the 1990 time frame.

TATANDE NATA





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# TECHNOLOGY ASSESSMENT - RF/IF

### RF/IF

- Low cost antenna manufacturing techniques must be developed to meet tolerance, stiffness and cost requirements
- Development of a 200W helix TWTA is required
- Stripline 24 GHz L.O. for frequency converter requires one year development effort

### CPS Baseband

- Substantial portions of design are based on currently available technology (e.g., codecs, cryptos, controller)
- Aggregate Rate Demodulator
  - Operates at speeds for which no domestic technology exists. Development cycle of 18 to 24 months estimated
- DAMA User Interface
  - Hardware similar to existing digital switches. Firmware development.

### Trunk Baseband

- Substantial portions of design are based on currently available technology
- 256 Mbps burst modem
  - To date one article produced by TRW
  - NEC has also built one article
  - Significant development needed

#### Miscellaneous

The chart at the right lists other components with comments on the state of technology.

# TECHNOLOGY ASSESSMENT (Miscellaneous Items)

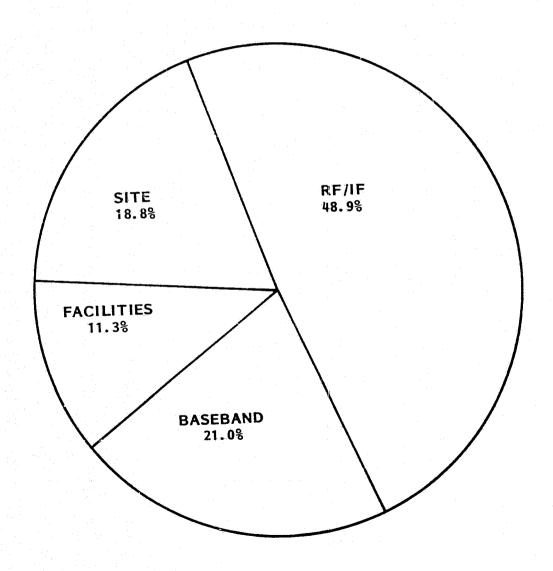
		DESIGN-	TECHNOLOGY		Υ	the state of the s
DESCRIPT	ION	ATOR	MATURE	CURRENT	CRITICAL	COMMENTS
ISOLATOR, 18.9	95 GHz	IS1 IS2	Х			FERRODISC, STANDARD PRODUCT LINE
BANDPASS FIL 18.95 ± 1.25 (		FL1		X		CAN ALLOW LARGER BANDWIDTH AND USE PRINTABLE TECHNIQUE; SHORTED STUB, DIRECT COUPLED, 3 SECTION FILTER; USED TO SUPPRESS NOISE IN IMAGE BAND; DEVELOPMENT REQUIRED
MIXER, Ka BAN	ID	M1 M4		X		HAVE DEVELOPED SIMILAR MIXER FOR AIR FORCE APPLICATIONS
AMPLIFIER, C-I	BAND	AR1 AR2 AR5		X		DESIGN EXISTS AT MAEC; GaAs FET FIRST STAGE TO KEEP NOISE FIGURE DOWN
MIXER, C-BANG	כ	M2 M3		X		SMALL DEVELOPMENT EFFORT REQUIRED
FILTER, C-BAN	<b>ID</b>	FL2 FL3	X			MUST BE MACHINED TO HOLD TOLER- ANCE DUE TO RELATIVELY NARROW PASSBAND; INTERDIGITAL, 3 SECTION; NEED TO HAVE HIGH REJECTION AT IMAGE BAND
AMPLIFIER, IF		AR3 AR4 IS3	X X		·	EXISTING TECHNOLOGY, VALID DESIGN TO BE USEFUL OVER DESIRED PASSBAND FERRODISC, STANDARD PRODUCT LINE
		IS4	^			
FILTER, 28.75	GHz	FL4		×		WAVEGUIDE SECTION; ELECTRO-FORMED; IRIS COUPLED; REQUIRES DEVELOPMENT; SIZE WOULD BE SMALL ENOUGH TO USE WITH STRIPLINE
AMPLIFIER, 28	75 GHz	ARG			×	GaAs FET REQUIRES DEVELOPMENT; NEEDS +10 dBm 1 dB COMPRESSION POINT; STATE-OF-ART TECHNOLOGY
POWER DIVIDE	R	PD1 PD2	X X			STANDARD PRODUCT LINE
ISOLATOR		IS5, IS6, IS7, IS8, IS9, IS10,	X			FERRODISC, STANDARD PRODUCT LINE
LOCAL OSCILL C-BAND	ATOR.	L02	X			STANDARD PRODUCT LINE
LOCAL OSCILL Ka-BAND	ATOR,	L01			<b>X</b>	DEVELOPMENT EFFORT REQUIRED IN ORDER TO ACHIEVE LO FREQUENCY STABILITY AND PHASE NOISE

# BREAKDOWN OF RECURRING COSTS — CPS EARTH STATION

The chart at the right shows a typical CPS earth station cost allocation. The RF/IF system dominates; this coupled with the baseband equipment represents 70% of station costs.

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# BREAKDOWN OF RECURRING COSTS - CPS EARTH STATION



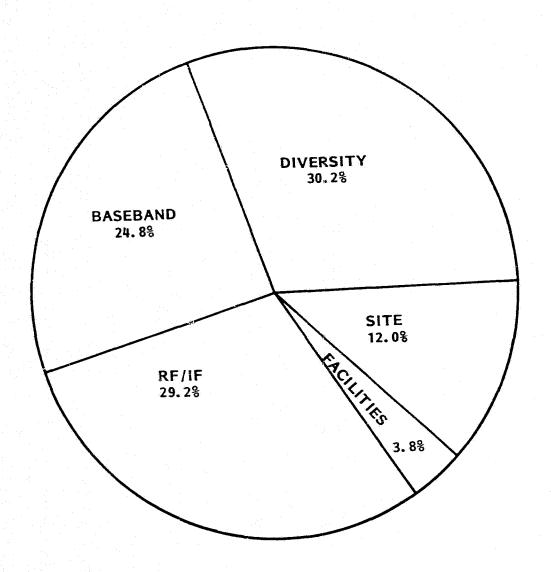
## BREAKDOWN OF RECURRING COST TRUNK EARTH STATION COMPLEX

Principle cost factors are distributed almost equally among the RF/IF, baseband and diversity links. Total cost while important is not as critical as for CPS because of the large station capacity.

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# BREAKDOWN OF RECURRING COST TRUNK EARTH STATION COMPLEX

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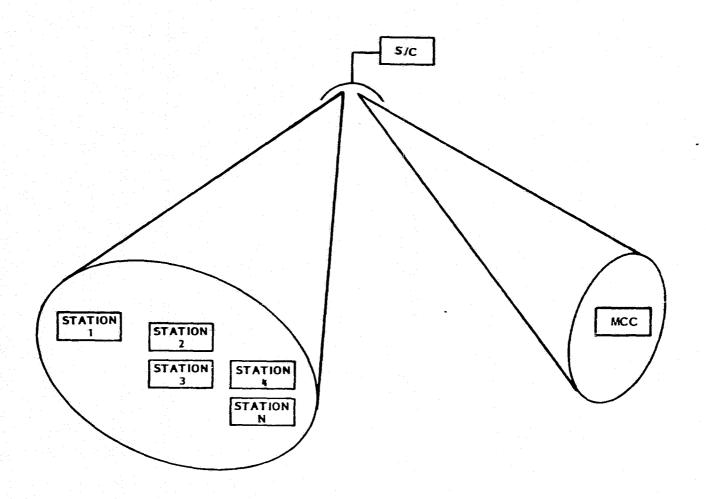


#### FDMA OPTION

In this option one or several FDMA earth stations can be located in one or more of the 6 fixed beam areas (4 simultaneously operate). These stations communicate with each other but also have a common signalling channel to the MCC. It is planned to allocate channels manually; however, automatic system response to rain fades, via the common signalling channel and the MCC computer is believed to be important to demonstrate. The satellite FDMA routing system is described in the satellite communications section.

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# FDMA OPTION (OVERVIEW)



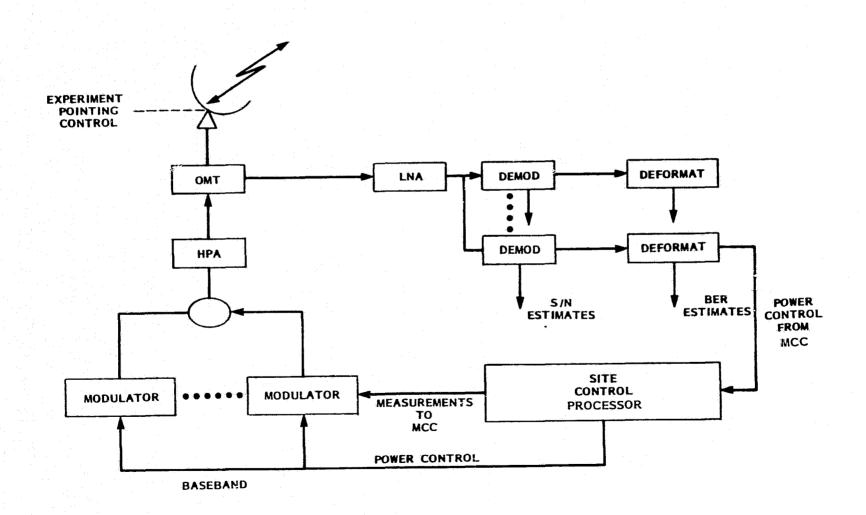
#### FDMA EXPERIMENT - IF SWITCH VERSION STATION DIAGRAM

When the experimenters mispoint the antenna the S/N and BER estimate at this site should indicate the loss of performance. Also the MCC should detect a loss in the signal received from this station. The estimates of power loss are sent to the MCC which returns a corrective action directive to boost power. It will also boost the power of its amplifiers which are communicating with this station. The effectiveness of the algorithm can be evaluated by comparing the corrective measures taken against the actual pointing losses as a function of response time.

The larger the number of modulators and demodulators at each site the more closely FDMA operation can be simulated (especially intermodulation effects).

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# FDMA EXPERIMENT - IF SWITCH VERSION STATION DIAGRAM







MISSION OPERATIONS SYSTEM



# MISSION OPERATIONS SYSTEM



- MCC IN CLEVELAND
- S-BAND T&C (GSFC)
- MSOCC LAUNCH (GSFC)
- STDN/NASCOM

### MISSION OPERATIONS SYSTEMS AND FUNCTIONS

The MOS is divided into three principle activities; Prelaunch Planning, Launch Operations and Past Launch Operations. The object of Prelaunch Planning is to develop a launch plan for both the satellite-launch vehicle and for the tracking network considering the items listed and including alternative or contingency plans. Launch operations include all the steps necessary to launch the satellite and place it in a synchronous drift orbit considering the items listed. Launch operations involves the coordination of activities at GSFC, ETR, JFC, and STDN/NASCOM. Once the satellite is in synchronous drift orbit within view of GSFC the Post Launch Operations begin, considering the items listed, including the maintenance of the correct satellite orbit, attitude and health and coordination with the MCC on satellite status. A Test Plan also is included to determine the initial satellite performance to provide a norm for subsequent comparisons.

A diagram of the principle facilities is given at the right. Prelaunch, Launch and Post Launch satellite activities are basically conducted by NASA at GSFC (MSOCC) supported by the NASA LeRC team and the contractor team in a manner similar to other synchronous orbit NASA launches. This NASA capability is expected to exist indefinitely. STDN is used to track the satellite and provide ranging and T&C functions during launch and also serves as a backup to the T&C station used in Post Launch Operations. This S-band T&C station is available at GSFC. Also available at GSFC is a large computer and software for the purposes of predicting and determining both orbit and attitude. The satellite is launched at ETR using STS under the jurisdiction of JFC. It is proposed to augment MSOCC during the Post Launch period by a contractor team to maintain 24 hour-a-day satellite surveillance.

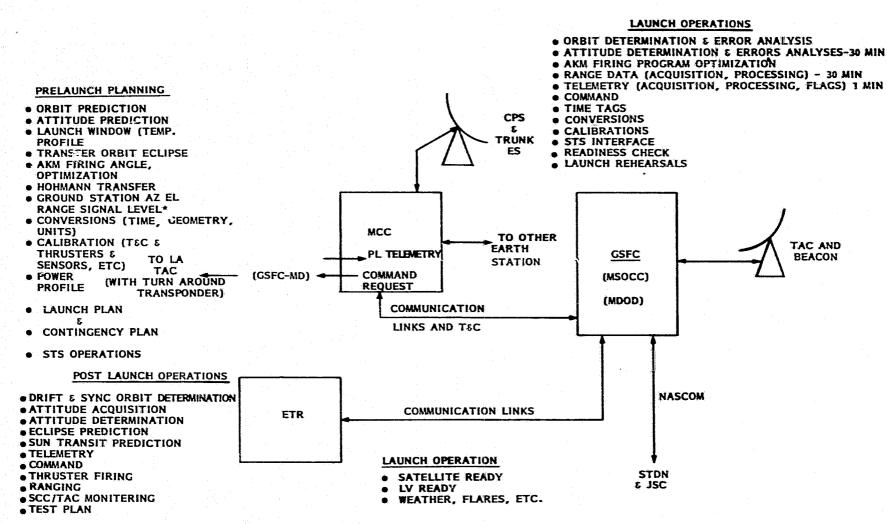
The MCC, in Cleveland, is operated by a joint LeRC/Contractor team on a forty hour a week basis to control and conduct communications experiments and tests. T&C information and voice is communicated between the MCC and MSOCC over terrestral communications links. The MCC minicomputer will be programmed to receive, process and store satellite telemetry and will display satellite status. During launch the spacecraft contractor will supply technical consultants to assist MSOCC and will integrate and test the satellite at ETR.

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#### MISSION OPERATIONS SYSTEMS AND FUNCTIONS





<sup>\*</sup> INCLUDING PROGRAM TRACK & SEARCH MODES

#### MOS SCC AT GSFC

The Satellite Control Center (SCC) located at GSFC (MSOCC) is manned in the Post Launch period by contractor personnel supported by key GSFC and LeRc personnel. A minicomputer with peripherals, multiple key boards and CRT's are used to monitor spacecraft telemetry, spacecraft status and SCC status. A T&C station, at GSFC is used for T&C links to the satellite. This station is currently available and is expected to be available in the late 1980's although it may have to be determination. Voice lines connect this SCC to the MCC for consultation, coordination of experiments and diagnosis of satellite health and status.

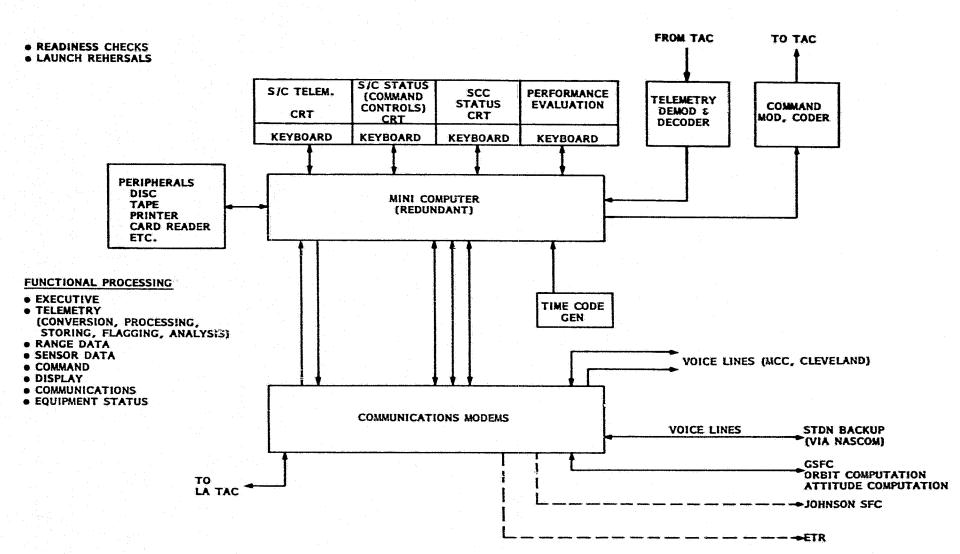
The principle facilities (minicomputer and peripherals, keyboards, CRT's etc.) are generally available at GSFC. This experiment augmented by communications with JFC, ETR, etc. also is similar to that required for satellite launch.

Ranging requires a second S-band T&C earth station located preferably near the west coast for occasional ranging measurements.



#### MOS SCC AT GSFC





#### TELEMETRY AND COMMAND (TAC) STATION

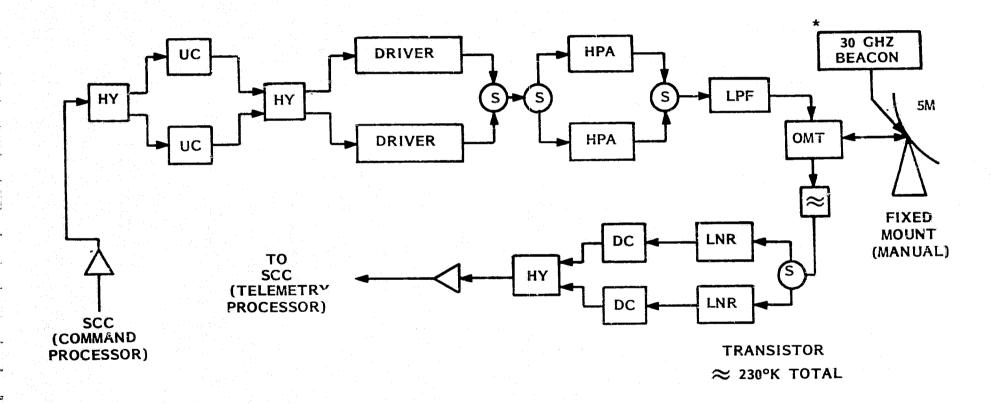
This is a tracking earth station with a 10 meter antenna, 2 kW HPA's and transistor receivers for communicating at S-band with the satellite during Post Launch Operations. It is assumed that a 30 GHz circularly polarized beacon can be added to this facility to provide a signal to the satellite monopulse system. Circular polarization significantly simplifies satellite monopulse tracking equipment. Alternatively, the beacon can be located at Cleveland in either the trunk or CPS earth station.



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## TELEMETRY AND COMMAND (TAC) STATION (GREENBELT MD)





\* ALTERNATIVELY, BEACON CAN BE PUT ON TRUNKING OR CPS EARTH STATION

#### LAUNCH AND POST LAUNCH SOFTWARE DESCRIPTION

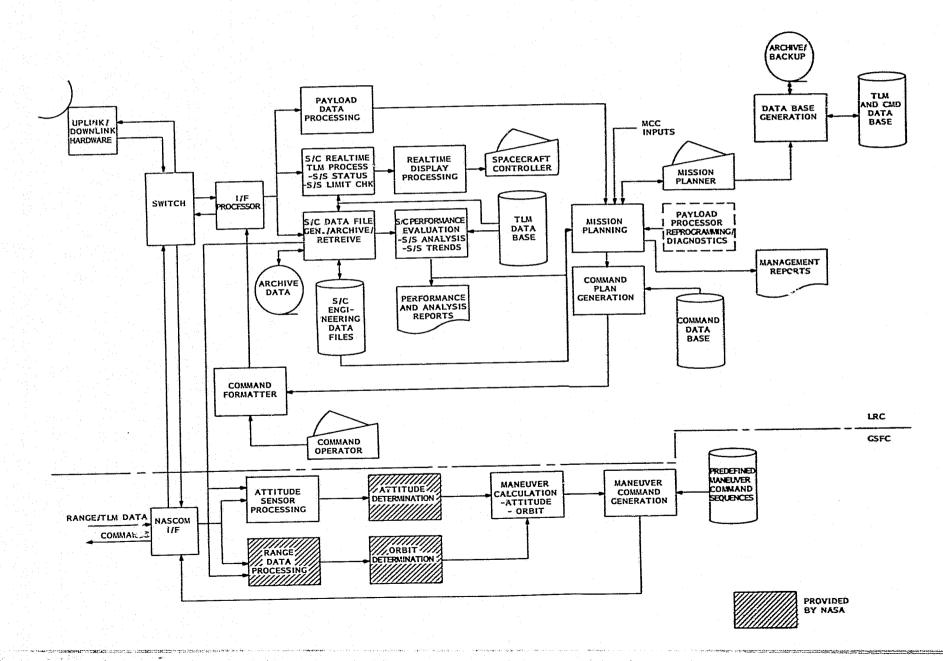
Two principle activities are described. Range and satellite telemetry (at the bottom right) are used to process range and attitude sensor data to determine satellite orbit and attitude and calculate maneuvers necessary to achieve nominal parameters. In addition, telemetry is displayed in real time for fast reaction, and also processed, flagged and stored by the computer for later analysis of spacecraft health and command status.



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#### LAUNCH & ON ORBIT SOFTWARE DESCRIPTION





## LAUNCH ORGANIZATION

The launch organization depicted at the right is assumed to be conducted under the authority of a LeRC Mission Director. The Launch Director actually directs the details of the launch operation assisted by a spacecraft coordinator, Satellite Conductor and Mission Conductor and also coordinates activities at ETR, STDN, JFC and the MCC at LeRC. The Launch Director and his staff are assumed to be GSFC (Code 500) personnel augmented by LeRC and Contractor staff. A definition of responsibilities is listed below:

*	Mission Director	Responsible for all aspects of the mission
	Satellite Conductor	Executes launch plan
•	Mission Conductor	Responsible for planning 24 hour, 7 day and 30 day mission plans  Responsible for monitoring and validating S/C commands. Verifies payload
	Command Operator	processor reprogramming
* *	Spacecraft Manager	Responsible for real time S/C performance evaluation
*	Performance Evaluator	Analyze S/C health and performance in off line environment

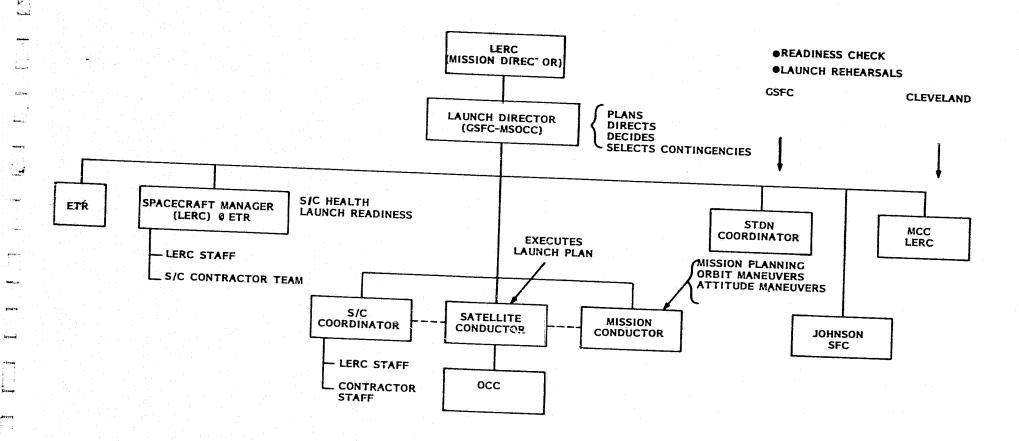
<sup>\*</sup> Required at GSFC for orbit insertion activities

in house Windows



## LAUNCH ORGANIZATION





## ON-ORBIT SOFTWARE DESCRIPTION

The following pages describe the software needed for Launch and Post Launch operations.



## ON ORBIT SOFTWARE DESCRIPTION



SOFTWARE FUNCTION	SOURCE	PURPOSE
I/F PROCESS	GE	<ul> <li>DEBLOCK AND DECOMMUTATE TLM DATA</li> <li>I/F CONTROL WITH EXTERNAL HARDWARE</li> <li>PROCESS DATA EITHER FROM S/C OR NASCOM</li> </ul>
PAYLOAD PROCESS	GE	<ul><li>ANALYZE PAYLOAD PERFORMANCE</li><li>DIAGNOSE PAYLOAD PROCESSOR PROBLEMS</li></ul>
S/C REALTIME TLM PROCESS	GE	<ul> <li>EVALUATE TLM TO DETERMINE MODES OF S/C SUBSYSTEMS</li> <li>CORRELATE MODE CHANGES TO COMMAND ACTIVITY</li> <li>PERFORM LIMIT CHECKING OF ANALOG TLM BASED UPON THE LIMITS FOR SPECIFIC SUBSYSTEM MODES</li> <li>VERIFY PAYLOAD PROCESSOR MEMORY LOADS</li> </ul>
S/C DATA FILE GEN/ ARCHIVE/RETRIEVE	GE	<ul> <li>CONVERT RAW TLM INTO ENG. UNITS AND COMPRESS S/C ENGINEERING DATA</li> <li>PROVIDE REQUIRED DATA FOR PERFORMANCE EVALUATION</li> <li>ARCHIVE/RETRIEVE DATA FROM TAPE</li> </ul>
REAL TIME DISPLAY	GE	<ul> <li>FORMAT AND DISPLAY DATA AS REQUESTED</li> <li>HANDLE ALERT, WARNING AND ERROR MESSAGE DISPLAYS</li> <li>VERIFY CMD EXECUTION</li> </ul>



## ON ORBIT SOFTWARE DESCRIPTION (CONT)



SOFTWARE FUNCTION	SOURCE	PURPOSE
S/C PERFORMANCE EVALUATION	GE	<ul> <li>PERFORM STATISTICAL PROCESSING ON SELECTED DATA</li> <li>INCLUDES MAX, MIN, AVG, STD DEV AND TRENDS</li> <li>PROVIDE SUMMARY REPORTS ON SUBSYSTEM PERFORMANCE</li> </ul>
MISSION PLANNING PROCESS	GE	<ul> <li>PLAN/SCHEDULE S/C ACTIVITIES</li> <li>CORRELATE PAYLOAD EXPERIMENT PLANS</li> <li>RESOLVE ANY ACTIVITY CONFLICTS</li> <li>CORRELATE ORBIT ADJUST ACTIVITY</li> </ul>
COMMAND PLAN GENERATION	GE	<ul> <li>GENERATE DAILY, WEEKLY PLANS BASED ON PREDICTED         ACTIVITY</li> <li>PROCESS PLAN UPDATES AND/OR REVISIONS</li> <li>IDENTIFY CONFLICTS AND PREREQUISITES</li> </ul>
COMMAND FORMATTER	GE	<ul> <li>INTERACT WITH COMMAND OPERATOR</li> <li>FORMAT COMMANDS FOR TRANSMISSION</li> <li>MAINTAIN COMMAND HISTORY</li> <li>PROCESS SINGLE CMD AND CMD SEQUENCES</li> </ul>
DATA BASE GENERATION	GE.	<ul> <li>GENERATE AND EDIT STATIC DATA BASE FILES</li> <li>COMPILE UNIQUE SUBSETS OF FILE CONTENTS</li> <li>MAINTAIN DATA BASE VERSIONS</li> </ul>



## ON ORBIT SOFTWARE DESCRIPTION (CONT)



SOFTWARE FUNCTION	SOURCE	PURPOSE
NASCOM I/F	NASA	<ul> <li>RECEIVE AND TRANSFER NASCOM DATA BLOCKS</li> <li>SYNC TLM DATA TO FRAME BOUNDARIES</li> <li>RECONSTRUCT DATA FROM ERROR ENCODING</li> </ul>
ATTITUDE SENSOR PROCESSING	GE	<ul> <li>EXTRACT SELECTED ATTITUDE SENSOR AND PROPULSION DATA</li> <li>CALCULATE SPIN RATES, CONE ANGLES AND DIHEDRAL ANGLES</li> <li>GENERATE SUMMARY REPORTS</li> </ul>
ATTITUDE DETERMIN- ATION	NASA	<ul><li>DETERMINE SPIN AXIS ATTITUDE</li><li>DEFINE PRECESSION SEGMENTS</li></ul>
MANEUVER CALCULATION	GE	<ul> <li>COMPUTE THRUSTER FIRINGS FOR PRECESSION AND ORBIT MANEUVER</li> <li>CORRELATE TO S/C OPERATIONAL CONSTRAINTS AND MANEUVER TIMES</li> <li>FORMAT FOR NASCOM I/F</li> </ul>
RANGE DATA PROCESS-	NASA	<ul> <li>PROCESS RANGE AND RANGE RATE DATA</li> <li>SMOOTH DATA FOR ORBIT DETERMINATION</li> </ul>
ORBIT DETERMINATION	NASA	- DETERMINE ORBIT FROM LAUNCH THROUGH FINAL STATIONKEEPING





DEMONSTRATION SYSTEM PLAN





# TECHNOLOGY AND SERVICE EXPERIMENTS OPERATIONS CONCEPT

#### TECHNOLOGY AND SERVICE EXPERIMENTS OPERATION CONCEPT

To facilitate planning and operations the experiments are divided between "Technology Plans" (e.g., items of engineering interest, and "Service Demonstration Plans" (e.g., items of interest to users or their representatives).

Technology experiments consist of the three categories identified. Additional propagation measurements are proposed that will add to the present store of knowledge particularly for antenna diversity and orientation of diversity stations (with regard to local weather fronts). Propagation information also is needed to correlate with the Service Demonstrations for fade compensation. Measurements of polarization effects also are important because polarization isolation is useful for providing additional interbeam isolation in multiple beam systems.

Technology assessment involves the reception, flagging, processing and retrieval of satellite telemetry which is particularly important for spacecraft evaluation and for the establishment of performance, performance trends, and failures. This information is augmented by ground tests (satellite ground test data, subsystem testing etc.) and by life test demonstrations. Finally, in orbit evaluation also is necessary, initially to establish key performance parameters and later in life to establish performance trends and failures.

The in-orbit testing of the proposed satellite is expected to require extensive planning and complex ground test equipment and procedures because of the complications in testing caused by the high burst rates, high switching speeds, multiple beams and complex onboard processing.

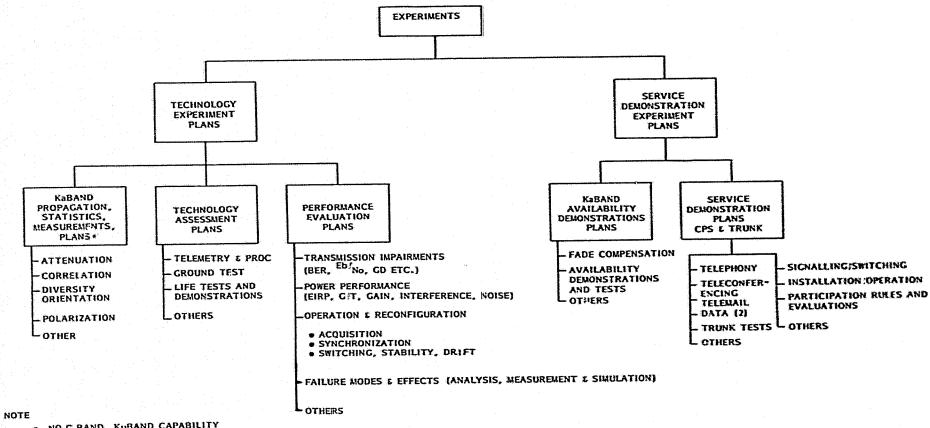
Service Demonstrations are divided between demonstrations of automatic system response to actual or simulated fades in order to demonstrate potential for high availability and actual demonstration of services such as data transmission, teleconferencing etc.

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## TECHNOLOGY AND SERVICE EXPERIMENTS OPERATIONS CONCEPT





- . NO C BAND, KUBAND CAPABILITY
- . NO INTERSATELLITE LINK

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\*REQUIRES BEACON WHICH IS NOT PART OF PRESENT CONCEPT

#### SERVICE EXPERIMENTS

The following pages list the NASA documented Service Experiments, Technology Experiments and Service-Technology Experiments by heading and experiment number, accompanied by a cursory analysis of whether a particular experiment can be performed on the subject system. Some liberality was taken in interpreting the basic intent of each experiment and whether this experiment's objective could in fact be more or less satisfied. In addition modifications to the satellite needed to perform certain experiments also is provided. Note that many propagation experiments are proposed. While the present configuration does not contain a propagation experiment, it is assumed that the ultimate design will, at least in the form of a beacon transmitter and CONUS coverage antenna.







CTRIC		DO ADIE ON	•
EXPERIMENT NO.		DO-ABLE ON GE SSUS-D	S/C NEED
PS-1	30/20 GHz PROP. MEAS.	ИО	NEED BEACONS, MOD CONSS ANT
PS-2 PS-3	PROP. CONSTRAINTS ON DIGITAL SYST. PROP. CONSTRAINTS ON SCANNING	ИО	SIMILAR TO ABOVE
	MBS SYSTEM	YES	
PS-4	ABOVE 40 GHz PROP.	ОИ	NEED BEACON, ANTENNA, XMITTER
PS-5			
PS-6			
PS-7			
PS-8	DEMON. OF VOICE, VIDEO, DATA SERVICES	YES	
PS-9	FDMA/TDMA OPERATIONAL COMPARISON	YES	
PS-10	BIT STABILITY DURING SWITCHING	YES	
PS-11	CUSTOMER PREMISE STATION	YES	
PS-12	DEMAND ASSIGNMENT CONTROL FOR CPS	YES	
PS-13	NARROWBAND FDMA SYSTEM	YES	
PS-14	SYSTEM SYNCHRONIZATION EVALUATION	YES	
PS-15	HEAVY ROUTE TRUNKING APPLICATIONS	YES (NO	SCANNING)
PS-16	LONG HAUL S/C COMPATIBILITY EXP.	YES `	•
PS-17	LONG HAUL SPACE DIVERSITY EXP.	YES	(REQUIRES PORTABLE SITES)
PS-18	SERVICE DEMAND EXP'S-NON DIVERSITY	YES	
PS-19	SERVICE DEMAND EXP'S-DIVERSITY	YES	(DIFFERENT DIVERSITY SEPARATIONS)
PS-20	DYNAMIC TRAFFIC MODEL-TRUNKING	YES	•
PS-21	DYNAMIC TRAFFIC MODEL-CPS	YES	
PS-22	DYNAMIC TRAFFIC MODEL-COMBINED	YES	
PS-23	C-BAND & Ku BAND EXPERIMENTS	МО	NEEDS C, Ku BAND BEACONS
PS-24	SYNCHRONIZATION PARAMATERIZATION	YES	
PS-25	DIVERSITY OPERATION	YES	
PS-26	LINK POWER CONTROL	YES	REQUIRES BER MEAS. IN SATELLITE
PS-27	PROPAGATION AVAILABILITY	YES	ADD BEACON, CONUS ANT
PS-28	MARKET DEVELOPMENT EXPERIMENT	YES	•
PS-29	PROPAGATION EXPERIMENT	YES	ADD BEACON, CONUS ANT
PS-30	USER ACCEPTANCE (EMERGENCY SERVICE)	YES	•
PS-31	30/20 GHz PROPAGATION PHENOMENA	NO	NEEDS C, Ku BAND BEACONS
PS-32	SYSTEMS IMPACT OF 30/20 GHz PROPAGATION	N YES	
PS-33	30/20 GHz PROPAGATION EXPERIMENT	NO	ADD BEACGN, CONUS ANT
PS-34	TEST MARKET EXPERIMENT (TELE CONFEREN		



## TECHNOLOGY EXPERIMENTS



EXPER IMENT NO.	EX PER IMENT	DO-ABLE ON GE SSUS-D	S/C NEED
PT-1	TRANSPONDER PERFORMANCE EVALUATION	YES	
PT-2	20 GHz TWT TRANSMITTER EXPERIMENTS	YES	
PT-3	MULTI SPOT/SCANNING BEAM ANT. EVAL.	YES	
PT-4A	IMPATT SOLID STATE TRANSMITTER	YES	ALTERNATIVE TO TWT
PT-4B	Gaasfet Solid State Transmitter	NO	ALTERNATIVE TO TWT, IMPATT
PT-5			
PT-6	INTER SATELLITE RELAY	NO	2 SATELLITE, ETC. NEEDED
PT-7	IF SWITCH MATRIX PERFORMANCE TEST	YES	
PT-8		:	
PT-9	BASEBAND PROCESSOR EVALUATION	YES	
PT-10			
PT-11	CHANNEL INTERFERENCE EXPERIMENT	YES	
PT-12	BASEBAND PROCESSOR ERROR DETECTION	YES	
	AND CORRECTION	***	DECLUDES V. DAND
PT-13	SMALL EARTH STATION DUAL FEED EXPERIMENT	МО	REQUIRES Ku-BAND
PT-14	INTER SATELL ITE LINK	NO	REQUIRES 2 SATS
PT-15	30/20 GHz MULTIPLE SCANNING SPOT BEAM	NO	(60° ANTENNA)
	ANTENNA	\#C	
PT-16	SYNCHRONIZATION	YES	2 CATC
PT-17	INTERSATELLITE LINK CAPABILITY	NO	2 SATS
PT-18	FADE CONTROL TECHNIQUES	YES	
PT-19	GROUND TERMINAL TECHNOLOGY	YES	
PT-20	ANTENNA POINTING ACCURACY	YES	
PT-21	INTERFERENCE ASSESSMENT	YES	
PT-22	INTERSATELLITE LINK	NO	INFER UPLINK FADE FROM
PT-23	NETWORK LINK SYSTEM MONITORING	YES	DOWNLINK FADE
	WELLER CARRIED FOR AMOUNTED	YES	REQUIRES LINEAR IZATION
PT-24	MULTIPLE CARRIERS PER AMPLIFIER	163	(STOP SWITCH)
n= 05	DEAM ACQUICITION AND TDACKING	YES	USE Ka-BAND BEACON
PT-25	BEAM ACQUISITION AND TRACKING	YES	OUL NO DAND DENOCH
PT-26	PRELAUNCH SIMULATION AND TESTS	YES	
PT-27	FUNDAMENTAL FLIGHT SYSTEMS TESTS	YES	
PT-28	TECHNOLOGY EXPERIMENTS	163	



## SERVICE-TECHNOLOGY EXPERIMENTS



EXPERIMENT NO.	EXPERIMENT	DO-ABLE GE SSUS-	
PSAT-1	AIR TO GROUND COMMUNICATIONS (MOBILE)	YES	
PSAT-2	SPREAD SPECTRUM FEASIBILITY	YES	
PSAT-3	MULTILEVEL TWT CONTROL	YES	
PSAT-4	CO-PHASING PARAMETERIZATION	YES	
PSAT-5	CO-PHASING STABILITY MEASUREMENTS	YES	
PSAT-6	LOW BIT-RATE FDMA/TDM	YES (	MODIFIED EXPERIMENT)
PSAT-7	VARIABLE BIT-RATE SS-TDMA	YES (	DIFFERENT RATES)
PSAT-8	TRUNKING & CPS EXPERIMENTS	YES	
PSAT-9	SPACE DIVERSITY EXPERIMENT	YES (	FLA, GULF ES)
PSAT-10	ADAPTIVE FADE COMPENSATION	NOT	AVAILABLE IN BOOK
PSAT-11	ADAPTIVE POLARIZATION	YES	

#### EXPERIMENTS OPERATIONS SUMMARY

A summary of configuration compliance with the NASA Experiments Plans Document is given at the right. Non compliant experiments are those requiring C-band or Ku-band equipment, an intersatellite link or a CW beacon for propagation measurements, which are not part of the prevent configuration, although it is possible to include the CW beacon at a later time. An examination of payload margin indicates that the proposed configuration has weight capability for additional experiments, such as Option 2. Finally it should be observed that the proposed experiments in the NASA document were inspired by satellite configurations which are now antiquated. A final version of this NASA document might reveal additional important experiments.

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Also listed on the right are GE suggestions for inclusion in the Experiments Plans. The simulation of fades to provide on the spot demonstrations of adaptive system response are believed to be important in convincing potential users that adequate availabilities can be achieved at Ka-band. This implies careful planning of experiments and equipment, particularly the inclusion of automatic fade reaction capability into the MCC computer/software system. While automatic signalling and switching is not now being considered for trunking the MCC computer is available to accomplish automatic fade compensation for the trunking antenna diversity arrangements.

The addition of a CW beacon and CONUS antenna to facilitate propagation experiments will enhance the value of the program.

Sun transit experiments for CPS systems also are believed to be important at Ka-band. Sun transit is bothersome to telephone and data users in particular and in unavoidable at C-band and Ku-band unless a reserve satellite and automatic satellite "handover" capabilities are available. At Ka-band fixed and adaptive power margins are relatively large and CPS networks are expected to be widely dispersed so that Ka-band CPS systems can be designed to provide service through sun transits. If this can be demonstrated a unique important advantage of Ka-band over the lower bands can be established and demonstrated.

Telemetry analysis, part of the Technology Experiment Plans can be a particular problem if not well planned and instrumented because of the large volume of data accumulated and the need to examine and reexamine the data for trends, "glitches" etc. as the satellite ages. A specific plan should be developed to provide guidelines for the operation, flagging, processing, archiving, retrieval and display of telemetry data.

In orbit initial satellite checkout (and subsequent checkouts) is not listed in the Experiments Plans. These checkouts provide valuable data and insight into satellite performance, performance trends and failures. A specific plan is needed to detail the tests and identify the needed test equipment and earth station facilities. In particular a detailed

Plan is required for the processor to evaluate its performance and functional capability despite its complexity. In particular, since the processor performs many functions in tandem (demonstration decoding, storage, switching etc.) it is important to measure each of these functions in order to appraise the processor's performance and condition and to assess failures.

Finally, no specific tests are included in the Plan to provide user to user evaluations of performance for voice, data or video. Such evaluations can be quite complex procedurally and involve considerable amounts of interface and miscellaneous equipment, however such tests and demonstrations are the only real means for demonstrating the flexibility, capacity and availability afforded by Ka-band Systems.



#### EXPERIMENTS OPERATIONS SUMMARY



#### DESIGN LIMITATIONS

NO C-BAND, Ku-BAND EQUIPMENT

NO INTERSATELLITE LINK

NO CW BEACON

#### RECOMMENDATIONS (EXPERIMENTS PLANNING DOCUMENT)

ADD FADE SIMULATION TEST, CPS AND TRUNK

ADD CW BEACON AND CONUS ANTENNA

ADD SUN TRANSIT EXPERIMENT FOR CPS

ADD TELEMETRY ANALYSIS

ADD IN-ORBIT SPACECRAFT CHECKOUT AND CALIBRATION

ADD PROCESSOR DIAGNOSTICS

ADD SPECIFIC USER - USER TESTS AND DEMONSTRATIONS (VOICE

DATA, VIDEO)

#### TECHNOLOGY EXPERMENT OPERATIONS

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Technology Experiments Operations involving three basic activities, propagation measurements, satellite telemetry analysis and performance measurements on the satellite (including analysis of failures, functional tests and reconfiguration capability) requires several facilities. In this plan it is assumed that the telemetry and command (TAC) earth station is colocated with the satellite control center at GSFC. Satellite commands are issued from the SCC to the satellite via the TAC and quick look telemetry is received and analyzed at the SCC. In addition, the satellite telemetry is relayed via land lines to the MCC in Cleveland where the data is culled, flagged, processed, stored and analyzed by the MCC minicomputer. The MCC in Cleveland is colocated with a trunking earth station which has the G/T and EIRP to conduct various satellite performance measurements. The MCC minicomputer also is used to support CPS signaling and switching and to control fade reactions but also will be used to control the SS-TDMA switch and processor functions and network configuration and operation. The MCC will also contain test equipment, displays and controls (working via the SCC command link) to accomplish these tasks.

Beacon receiving equipment and propagation data processing also will be required at the MCC. At least one other CPS and trunking terminal will be needed to accomplish communications tests.

The multibeam arrangement in particular will make it difficult to measure or even observe communications activities in other beams. This suggests more extensive use of telemetry than for single beam satellites and consideration of provisions for more loopbacks, e.g., the ability on command to loop any beam's traffic to the one containing the MCC. This permits monitoring of any beam's traffic and any earth station's timing with respect to satellite time.

Acres Williams



## TECHNOLOGY EXPERIMENT OPERATIONS



#### **FEATURES**

- SATELLITE INITIAL CHECKOUT AND CALIBRATION
- SATELLITE TELEMETRY CALIBRATION, STORAGE, PROCESSING, ANALYSIS -2 YEARS PLUS
- OPERATION AND RECONFIGURATION
- TRANSMISSION IMPAIRMENTS AND POWER PERFORMANCE
- FAILURE MODES AND EFFECTS (ANALYSIS AND SIMULATIONS 2 YEARS)
- (Ka-BAND PROPAGATION MEASUREMENTS AND ANALYSIS 2 YEARS PLUS)

## FACILITIES AND EQUIPMENT

SATELLITE CONTROL CENTER, ON ORBIT TAC

- CO-LOCATED
- MASTER CONTROL CENTER, TRUNK TERMINAL, CPS TERMINAL
- MINICOMPUTER AND PERIPHERALS (COULD BE SAME AS THOSE USED FOR SIGNALLING AND SWITCHING)
- TEST EQUIPMENT (POWER, NOISE, TRANSMISSION IMPAIRMENTS)
- AT LEAST ONE OTHER TRUNK, CPS TERMINAL
- (BEACON STATIONS FOR PROPAGATION MEASUREMENTS, ALSO DATA PROCESSING CAPABILITY)

#### TECHNOLOGY EXPERIMENTS OPERATIONS

Depicted at the right are the broad range of Technology Experiements, typical tests to be performed and required software. Software includes test procedures reports, standards as well as computer software. Each test or experiment to be performed requires a defined procedure, identified and specified configuration and parameters, recording of data, analysis of results, and a report. Thus substantial commitments in facilities and software will be required to accomplish the Technology Experiments Operations.

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## TECHNOLOGY EXPERIMENT OPERATIONS



FUNCTION	TESTS	SOFTWARE
SATELLITE CHECKOUT AND CALIBRATION	SIC AND PAYLOAD FUNCTIONS (INCLUDING ANTENNA PERFORMANCE)	TEST PROCEDURES AND REPORTS
	SIC-ES COMPATIBILITY TESTS (PROCESSOR AND SATELLITE SWITCH SIMULATORS)	
SATELLITE TELEMETRY	ALL PERTINENT PAYLOAD AND S/C BUS FUNCTIONS AND PROCESSOR DIAGNOSTIC TELEMETRY (ANALOGUE AND DIGITAL)	SOFTWARE FOR CALIBRATION, PROCESSING, STORAGE AND REPORTS
TRANSMISSION IMPAIRMENTS AND POWER PERFORMANCE	SIGNAL LEVELS, ANTENNA ISOLATION, NOISE DENSITY, SPURIOUS, AM/PM, ETC.	TEST PROCEDURES AND REPORTS
FAILURE MODES AND EFFECTS	T&C EVALUATION  RECONFIGURATION, START UP  ALTERNATE MODES, FAILURE SIMULATION	DIAGNOSTIC REPORTS
PROPAGATION  MEASUREMENTS  RECORDING  TIME MARKING  DATA COLLECTION  DATA PROCESSING	FADES STATISTICS  COHERENCE  X POL DEGRADATION  DIVERSITY OR IENTATION AFFECTS	TEST PROCEDURES AND CALIBRATION STANDARDS, MEASUREMENT REPORTS DATA PROCESSING ALGORTHM REPORTS

#### SYSTEM EXPERIMENTS OPERATIONS

System Experiments Operations involve experiments in two areas, demonstration of system availability despite rain fades and equipment or system failures and service demonstrations involving voice, data or video. The same basic facilities are needed as for Technology Experiments, including the MCC, its computer, its network coordination facilities (order wire). In addition, interface equipment is required at each participating earth station to connect in the user (telephone interface equipment may include amplifiers, impedance transformers, echo cancellors etc., teleconferencing equipment may include studio, video cameras, monitors, audio equipment and various queuing aides etc.). Interface equipment can be costly and well planned experiments are therefore necessary. It may be desirable to relocate an earth station and its equipment from time to time in order to accommodate different users.



#### SERVICE EXPERIMENTS OPERATIONS



#### **FEATURES**

- SIMULATED AND ACTUAL FADES
- LONG TERM AVAILABILITY (EQUIPMENT, SYSTEM, FADING)
- SERVICE DEMONSTRATIONS, END-TO-END

VOICE

**DATA** 

VIDEO

#### FACILITIES AND EQUIPMENT

SATELLITE CONTROL CENTER, ON-ORBIT TAC

CO LOCATE)

- MASTER CONTROL CENTER, TRUNK TERMINAL, CPS TERMINAL
- AT LEAST ONE OTHER TRUNK, CPS TERMINAL
- MINICOMPUTER AND PERIPHERALS
- USER SIMULATION (END-TO-END)

TELEPHONES AND INTERFACE EQUIPMENT

DATA SOURCES, SIMULATION, INTERFACE EQUIPMENT

VIDEO CAMERAS, TAPE, PROCESSORS

CONFERENCING FACILITY

## SERVICE EXPERIMENTS OPERATIONS

There is also a need for procedures, test plans, and logs in order to conduct various service operations. These can be complex because of the long term nature of the tests and the subjective nature of quality (for example quality of a teleconference) and therefore also require careful planning.

Fade compensation of actual or simulated fades requires automatic system response using the MCC computer. Long term tests of device, subsystem and system operation require procedures, test plans and extensive logs which are more manual.



## SERVICE EXPERIMENTS OPERATIONS



ELECTRIC		
FUNCTION	TESTS	SOFTWARE
FADE COMPENSATION	ACTUAL, SIMULATED FADES AND SYSTEM RESPONSES, CPS AND TRUNK	TEST PROCEDURES
AVAILABILITY	LONG TERM TESTS OF DEVICE, SYSTEM OPERATION (RECON- FIGURATION, START UP) AND RAIN FADE AFFECTS, CPS AND TRUNK	TEST PROCEDURES, TEST PLANS, OPERATING LOGS
SERVICE DEMONSTRATIONS (END-TO-END)  VOICE DATA VIDEO	SIGNALLING AND SWITCHING (CPS ONLY)  RECONFIGURATION  DAMA  SUBJECTIVE PERFORMANCE  DURING FADING	SPECIFIC TEST PROCEDURES, TEST PLANS, OPERATING LOGS AND USER TEST EVALUATION
	<ul> <li>DURING SWITCHING</li> </ul>	

**OVERALL** 





TECHNOLOGY ASSESSMENT &

#### TECHNOLOGY ASSESSMENT

Major items of concern are the TWT and processor because both of these items require major extension of the state-of-the-art. Considering potential program schedule and cost impacts if one or the other of these components experiences problems along the way it is recommended that specific transitional programs be implemented by NASA to bridge the gap between the existing "POC" programs and the space qualified devices required in the satellite program. Since qualification is needed in any event it makes sense to perform the qualifications (to the extent possible) during the transitional phase when delays are not costly. Specifically it is recommended that:

TWT Complete TWT design

Build fully documented prototypes (not engineering models) and qualify

Initiate life demonstrations

Processor Complete system architecture and specify

Develop all required IC chips

Complete demonstration system brassboard and test

Specify ground test and control equipment and software

Other items, which are less critical (any item that delays the spacecraft contractor can be very costly) are: SS-TMDA GaAs FET switches, 30/20 GHz mixer diodes, Ka-band switches and 30/20 GHz multiplier diodes which can be qualified by satellite contractor. VPD's, CMOS switches, IMPATT diodes are expected to be demonstrated sufficiently during the procetive POC programs. While it is early to estimate actual earth station technologies because the System Studies and various earth station POC developments are not started, the "aggregate rate" MODEM is certainly one candidate for brassboard development, however, objectives to lower CPS costs will certainly identify other critical technologies. The high speed terrestrial interface module (TIM) also may require development because of the high speed.



#### TECHNOLOGY ASSESSMENT



**POC STATUS** 

**INDUSTRY STATUS** 

**STATUS** 

ITEM

**PROPAGATION** 

4

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PERFORMANCE DEMO WT. POWER CONFIRMATION BREAD BOARDI **BRASS BOARD** 

/PERFORMANCE DEMO\ WT. POWER CONFIRMATION

LIFE & RELIABILITY DEMOS, PRIMARILY **DEVICES** 

ADDITIONAL OR EXTENDED POCS ETC. PRIOR TO COMMITMENT TO DEMO SYSTEM

OK (GE, HAC, TRW, FAC) NEW DESIGN (APERTURE, BPN NONE OK (TRW, FAC) **MBA/BFN/OMT** (Ka) AND SWITCH OR VPD) SPACE QUALIFICATION (DIODES) **DEVICES NOT SPACE** OK (GE) OK (TRW, LNR) LNR/DC (Ka) QUALIFIED NONE **NEW DESIGN** NONE TRANSCO (Ka) WG SWITCH NONE N/A OK (GE, IR&D) NIA (Ka) MUX/FILTERS NONE DEVICES NOT SPACE OK (GE) CK (TRW, LNR) L01S (Ka) QUALIFIED **BRASSBOARD PIECE** PROCESSOR/CONTROL MOTOROLA PARTS LAGER DEVELOPMENT TEST BRASS BOARD, BUILD PROTOTYPE, QUALIFY ASSY DOUBLE GATE FET NOT SPACE SPACE QUAL FET DEVICE **GEIFACIHACITRW GEIFAC** SS-TDMA/CONTROL ASSY **OUALIFIED** SAW OK, CMOS NOT PROVEN SPACE QUALIFY SWITCH DEVICE NONE NOT YET UNDER DEVEL SS-FDMA/CONTROL ASSY SALTERNATIVES ARE POSSIBLE) DIODE NOT SPACE QUALIFIED NONE OK (GE) SIMILAR TO LNR (Ka) UC BRASS BOARD (DEVICE NOT SPACE QUAL PROTOTYPE, LIFE DEMONSTRATION GE (16 GHz) LNR, TRW 40W SSPA (IMPATT)(Ka) SPACE QUALIFIED) SPACE QUAL PROTOTYPE, LIFE DEMONSTRATION **BRASS BOARD** FDD/CSF ALTERNATIVES HAC/EDD 40W TWT (Ka) NONE **NEW DESIGN** GE, TRW N/A **EPC** DEVELOP BREADBOARD **NEW TECHNOLOGY (MODEM)** N/A N/A CPS TDMA TERMINAL (MODEM) LOWER COST VERSION DESIRABLE **AVAILABLE** N/A FDMA TERMINAL DEVELOP BREADBOARD **NEW TECHNOLOGY (MODEM)** NIA TRUNK TERMINAL (MODEM) NONE OK **AVAILABLE** NETWORK CONTROL NONE NIA INFO AVAILABLE (Ka)

#### TECHNOLOGY ASSESSMENT CONCLUSIONS

The conclusions from the Technology Assessment are presented at the right. In addition to the comments previously made it should be noted that the MCC software development and test can be time consuming and elusive with respect to completion and an early start is recommended.

## TECHNOLOGY ASSESSMENT CONCLUSIONS

MAJOR CONCERNS	ACTIONS	COMMENTS
PROCESSOR	COMPLETE BRASSBOARD DEVELOPMENT	PROTOTYPE SCHEDULE NOT TIMELY FOR PHASE III
	BUILD, QUALIFY PARTS AND PROTOTYPE DEVELOP TEST EQUIPMENT & SO	FTWARE
TWTA	COMPLETE BRASS BOARD DEVELOPMENT	PROTOTYPE SCHEDULE NOT TIMELY FOR PHASE III
	BUILD, QUALIFY PROTOTYPE	
MINOR CONCERNS		
30/20 GHz DEVICES	SPACE QUALIFY	
IMPATT	SPACE QUALIFY DEVICES	LOWER POWER, LOWER EFFICIENCY, MORE NON-LINEARITY THAN DESIRED
ES MODEM	BUILD, TEST BREADBOARD	
MCC SOFTWARE	START EARLY	
TIM	BUILD, TEST BREADBOARD	

#### SCHEDULE

The Demonstration System Schedule for the satellite recognizes the high technology subsystems of the satellite which require extensive design engineering and development. In addition, many of the parts, in particular Ka-band devices and IC chips for the processor, developed especially for this application but with only miniscule production requirements, are expected to be procurement problems. In fact, the long term procurement cycle for integrated circuits and similar devices such as GaAs FET, and TWT's and certain materials has been a schedule driver in many recent spacecraft rpograms such as DSCS-III and is the single most important reason for increased spacecraft production times.

While it is not possible at this point in the Demonstration System Design to evaluate the schedule impact caused by piece part deliveries (due to lack of design information and specifications) a schedule can be constructed which has a minimum uncertainty by basing it on the DSCS-III and BSE/BS-2 experience. The program, including a protoflight spacecraft plus an un-integrated flight spacecraft will require 4.5 years to launch with an uncertainty at this point in time of plus and minus three months.

This schedule requires an active NASA transition for the period between the present TWT and processor POC programs and the start of the spacecraft production contract. In this time interval NASA should initiate a program to qualify the 40 watt TWT (e.g., a fully documented TWT) and begin life demonstrations so that the spacecraft contractor can continue this program expeditiously by ordering flight TWT's at contract start. The alternative is to qualify the TWT during the spacecraft contract; this is believed to be too hazardous to schedule and can have substantial impact to cost should TWT delays occur. With regard to the processor a minimum transition program involves complete definition (specification of hardware and complete functional description of operation and performance), development and space qualifications of all IC chips and test of fully assembled brassboard. Another key consideration is the ground equipment and software (for both the satellite contractor and for the MCC) necessary to operate the processor, diagnose its faults and dynamically evaluate its performance. The present POC program is not sufficient to accomplish the transition and consequently the processor presents a substantial risk in terms of spacecraft schedule and cost. Considering the present processor and TWT POC programs and the Demonstration System schedule proposed there appears to be adequate time available for a transition program. It should be noted that the transition program represents work that needs to be accomplished in any event; however, the accomplishment during the transition period will not seriously impact spacecraft schedules and costs.

Other items key to a successful and timely Demonstration System development are the space qualification of IMPATT diodes, should IMPATTS be included in the Demonstration System and the development of working breadboards of the 256Mbps trunking MODEM and aggregate rate CPS demodulator.

With these assumptions with regard to the transition the development of the MOS can begin 18 months after spacecraft start, allowing four months for launch rehearsals and the development of the ground system can begin 27 months after spacecraft start.



#### **SCHEDULE**



- PROTOFLIGHT PLUS UNASSEMBLED FLIGHT
- 54 MONTHS TO LAUNCH, NOMINAL ±3
   PDR IN 6 MONTHS
   CDR IN 18 MONTHS
- SCHEDULE ASSUMES ACTIVE NASA TRANSITION
- TWT QUALIFIED IN MID 1984 (DELIVERIES BEGIN IN 1985)
- PROCESSOR DELIVERIES IN MID 1985
- MOS BEGINS AT T + 18, 4 MONTHS FOR REHEARSALS
- GROUND SYSTEM BEGINS T + 27
- EXPERIMENTS, OPERATIONS PROCEDURES BEGIN T + 42
- SCHEDULE ASSUMPTIONS
  - PROCESSOR\* BRASSBOARD COMPLETED AND TESTED
  - PROCESSOR PARTS SPACE QUALIFIED
  - 40 WATT TWT/IMPATT BRASSBOARDS COMPLETED AND TESTED
  - IMPATT PARTS SPACE QUALIFIED
  - TWT PROTOTYPE SPACE QUALIFIED
  - TWT LIFE DEMONSTRATIONS BEGUN
  - ES 256 MBPS MODEM AND CPS DEMODULATOR BREADBOARD TESTED
- \* 1982 TECHNOLOGY, 1982 SYSTEM DESIGN

### DEMONSTRATION SYSTEM SCHEDULE (PROTOFLIGHT-FLIGHT SATELLITE)

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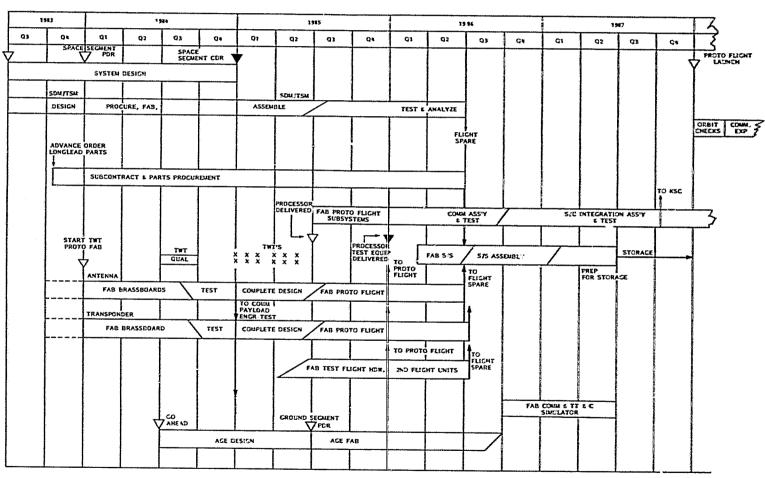
PDR in 6 months and CDR in 18 months are somewhat later than DSCS-III and BS-2 but earlier than Landsat "D". The principle inhibitor to an earlier launch is the inability to procure parts on a timely basis to support the protoflight subsystem fabrication and assembly beginning in mid 1985. Note this is also the latest date for the delivery of a flight processor. Integration, assembly and test of the spacecraft follows normal schedules leading to launch at the end of 1987. The large deployable high frequency antenna coupled with a completely new payload arrangement and north-south panel packaging design is believed to justify extensive structural and thermal testing prior to completion of protoflight design. Such testing also is needed to confirm the redesign of the enlarged and strengthened structure. Launch vehicle, PAM-adaptor and AKM can be ordered 18 months after start.



### DEMONSTRATION SYSTEM SCHEDULE (PROTOFLIGHT-FLIGHT SATELLITE) (SSUS-D) FLIGHT SYSTEM



FROCRAM START



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LV ORCER

PAN ADAPTER

ORDER

AKM

ORDER

REY
100 STRUCTURAL DEVEL MODEL
TOW THERMAL DEVEL MODEL
0 0 = ENASSEDARD

# DEMONSTRATION SYSTEM SCHEDULE, MOS

Eighteen months is allowed for software development plus 3 months for testing. This allows ample time for integration of software into the SCC for the conduct of readiness tests. Rehearsals begin after the readiness tests are completed. The T&C (TAC) S-band tracking station exists at GSFC and is expected to be available. However, modifications will be necessary for correct operating frequency and to provide the correct T&C interface (MODEMS, etc.). The SCC, as a general facility is available under colour, (MSOCC), however some additional equipment such as displays, controls and equipment pertaining to T&C will be required. Adequate time is allowed for the procurement, installation and acceptance test of this facility. Readiness tests and launch rehearsals follow in the ensuing six months, in preparation for launch.



# DEMONSTRATION SYSTEM SCHEDULE, MOS



#### PROURAM START 1982 1587 1984 1985 1926 Q2 Q3 Qs Q2 QI Q3 Q2 433 Qİ Qz Q3 Q4 SATELLITE DIAGNOSTIC ON GRBIT TACISCC EXECUTIVE TEST SOFTWARE DEVELOPMENT LAUNCH PROCEDURE LAUNCH PROCEDURE TSC SIMULATOR E SOFTWARE E DIAGNOSTIC SOFTWARE MODIFICATION ORBITAL SOFTWARE READINESS TEST SATELLITE CONTROL CENTER ACCEPT TEST FARRICATION & ASS'Y MOD. DESIGNIORDER REHEARSALS SATELLITE CONTRACTOR SUFFORT PROTOFLIGHT LAUNCH CHECKSUT

# DEMONSTRATION SYSTEM SCHEDULE, GROUND SYSTEM AND EXPERIMENTS OPERATIONS SYSTEM

This schedule supports an end-of-1987 launch. It includes definition and procurement of test equipment for in orbit evaluation of the satellite communications system via the trunking terminal, preparation of procedures for conducting communications experiments, design procurement assembly and test of propagation equipment (expected to be part of the Demonstration System) and includes provisioning of a spares depot. Major elements include development, installation and test of the trunking, CPS and FDMA (Option 2) terminals in Cleveland, adjacent to the MCC; this schedule assumes prior development of the 256Mbps trunk TDMA burst MODEM and the 220Mbps aggregate rate CPS demodulator. Three months allowance for trunk site work assumes prior establishment of the interconnect link right-of-way. Ample time is allowed in the schedules to permit the installation and test of up to six each CPS (TDMA), trunk and FDMA terminals.

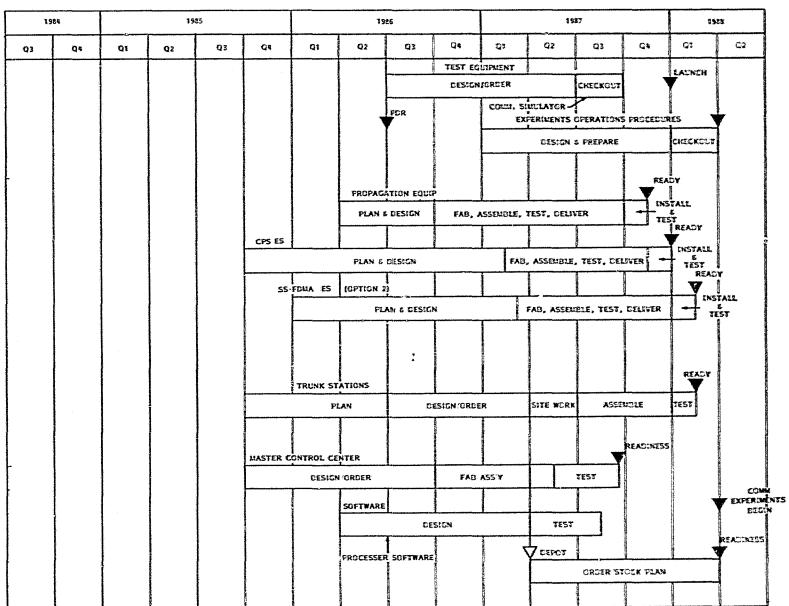
An early start also is required for the MCC in order to allow for software development and hardware procurement. In this case software development relates to the limited but automatic CPS signalling and switching capability, automatic response to trunk and CPS rain fades and to control of the processor. Integration of processor software into the total software system is a special problem.

Communications experiments can begin three months after launch (communications evaluation of the satellite using special test equipment will have begun earlier).



# DEMONSTRATION SYSTEM SCHEDULE GROUND SYSTEM AND EXPERIMENTS OPERATIONS SYSTEM





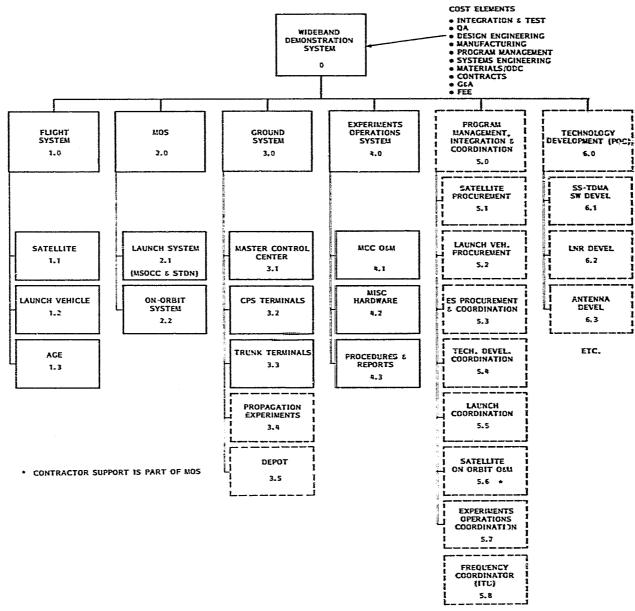
#### WORK BREAKDOWN STRUCTURE

The Work Breakdown Structure (WBS) explains the Demonstration System elements and is used to develop the ROM cost. The WBS at the right explains the total Program tasks and elements including those not currently the responsibility of the spacecraft contractor which are shown by dotted lines. These items are overall program management, integration and coordination, (for example not all the earth stations are provided by NASA and the non-NASA stations still must be coordinated) direction of the POC program, the Propagation Experiments Program (including hardware and data reduction), and establishment of a spares depot, (important if more than a few earth stations are used). The Flight System is divided into satellite, launch vehicle and AGE, MOS into launch and onorbit and Ground System into MCC, CPS terminals and trunk terminal elements. Further breakdown of WBS elements to the levels required by NASA are explained in subsequent pages. The Experiments Operations System, (WBS 4.0) provides for O&M personnel and supporting materials for the MCC which coordinates the communications experiments program. Miscellaneous Hardware (4.2) is an allowance for information displays, and controls that are not included in the basic MCC equipment. Procedures and Reports (4.3) is a first attempt to develop experiments procedures to analyze and report results. WBS 4.0 y<sup>-1</sup> not be described subsequently.



#### WORK BREAKDOWN STRUCTURE





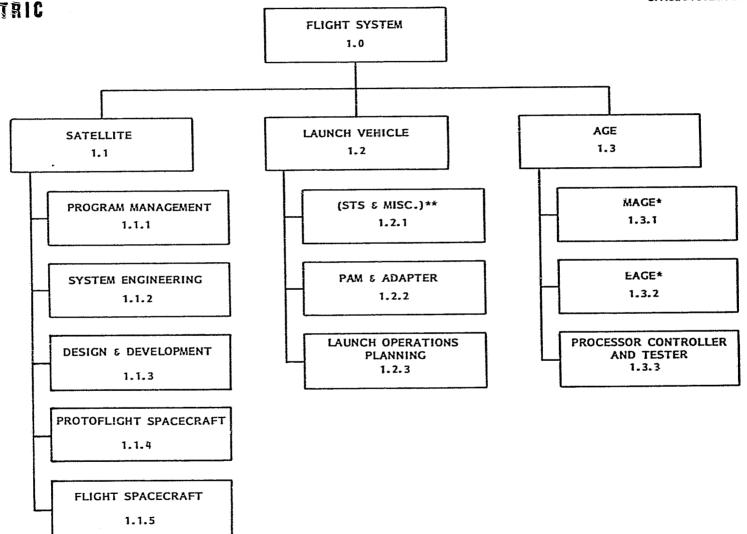
#### WORK BREAKDOWN STRUCTURE, FLIGHT SYSTEM

The Flight System WBS is depicted at the right. The satellite is broken into the defined elements in order to develop the costing (ROM) elements desired by NASA. Note that no attempt will be made to prorate program management and systems engineering costs between Design and Development (NRC) and Protoflight and Flight (RC) costs. Items shown in parenthesis, for example STS and related items, are shown in parenthesis to indicate that these costs are not included in the prime contractor's cost. Integration of the satellite into the SSUS-D and its integration into the STS, plus related interface and range and STS safety documentation are part of the prime contractor's responsibility and cost.



# WORK BREAKDOWN STRUCTURE FLIGHT SYSTEM





\*INCLUDE LAUNCH SITE TEST EQUIPMENT AND FIXTURE

\*\*STS CHARGE NOT INCLUDED

#### PROGRAM MANAGEMENT (WBS 1.1.1)

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Program Management is responsible for performance, cost and schedule. Specifically the Program Management organizes and schedules the work to be performed and monitors to assure compliance to performance, cost and schedule goals. The Program Office also is the prime customer interface in accepting new directives and in reporting problems and progress.

In this program the program office is estimated to contain the quantities of personnel listed below — assuming a protoflight program and an unassembled flight model. These personnel are under the direct control of the program manager.

	Year 1	Year 2	Year 3	Year 4
Management/Technical Personnel	15	17	12	8
Manufacturing Personnel	7	7	5	1
Product Assurance Personnel	1	2	3	3

A typical organization by function is shown at the right. Listed below is a more complete description of these activities.

#### PROGRAM MANAGEMENT ACTIVITIES (WBS 1.1.1)

#### 1.1.1.1 Project Management

- Direction and Management of all Program Activities
- Preparation and Maintenance of Implementation Plan
- Fiscal Planning, Cost Control
- Program Master Schedule, Schedule Control
- Management and Integrating of Deliverable Documentation

#### PROGRAM MANAGEMENT ACTIVITIES (WBS 1.1.1) (Continued)

- Contract Administration and Financial Support
- Reports
- 1.1.1.2 Manufacturing Management
  - Preparation of Manufacturing Plan
  - Make/Buy Decision, Implement Purchasing and Production Controls
  - Coordination, Integration, Management of Manufacturing Activities
- 1.1.1.3 Product Assurance Managements
  - Implements Quality Control Program
  - Coordination, Integration, Management of PA Activities
  - Prepares, Enforces Configuration Control Plan
  - Chairs MRB
  - Parts, Assembly Traceability Procedures
- 1.1.1.4 Project Engineering
  - Prepares Work Packages for all Design Activities
  - Prepares, Issues Design Documentation
  - Provides for Traceability of all Requirements
  - Rearranges for Design Reviews (PDR, CDR)

#### PROGRAM MANAGEMENT ACTIVITIES (WBS 1.1.1) (Continued)

- Prepares Test Plans (components, subsystems, spacecraft)
- Coordination, Integration, Management of Engineering Activities

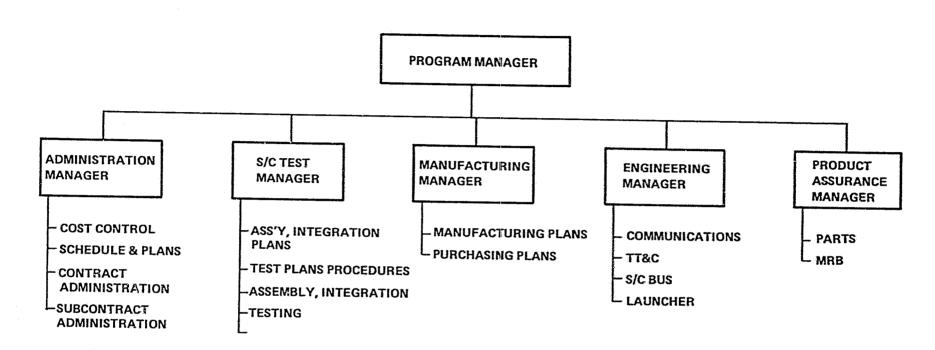
#### 1.1.1.5 Subcontracts Management

- Prepares Procurement Packages, SOW, specs
- Selects, Negotiates with Vendors
- Monitor Vendor Performance including Delivery
- Provides Engineering, PA Support as needed

#### 1.1.1.6 Spacecraft Test Management

- Develops Assembly, Integration and Test Plans
- Coordinates, Directs Spacecraft Assembly, Integration and Test
- Enforce PA Provisions

### PROGRAM MANAGEMENT (WBS 1. 1. 1)



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#### SYSTEM ENGINEERING (WES 1.1.2)

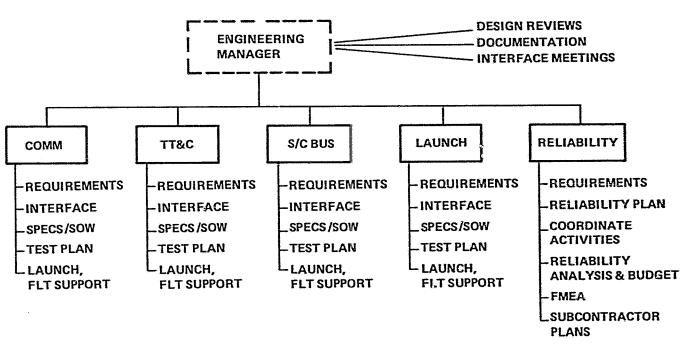
System Engineering for the program is controlled by an Engineering Manager reporting directly to the Program Manager. This organization translates the program objectives, specifications and SOW into a mutually consistant set of work packages to be disseminated to the engineering organization for action. Systems Engineering then monitors engineering progress (performance, cost, schedule) and coordinates these activities with Manufacturing, Quality Assurance, Product Assurance and Program Management. An example of such activities suitable for the subject program is shown at the right.

51

#### SYSTEM ENGINEERING (WBS 1. 1. 2)

	YEAR 1	YEAR 2	YEAR 3	YEAR 4
ENGINEERS	8	11	5	3

1.



- 1.1.2.1 SYSTEM REQUIREMENTS & ANALYSIS
- 1.1.2.2 INTERFACE CONTROL (LAUNCHER, TRACKING FACILITIES, INTERSATELLITE)
- 1.1.2.3 PREPARE SPECS, STATEMENTS OF WORK, PLANS FOR ALL ENG. ACTIVITIES
- 1.1.2.4 DEVELOPTEST PLANS
- 1.1.2.5 SUPPORT LAUNCH & FLIGHT OPERATIONS
- 1.1.2.6 DEVELOP RELIABILITY PLAN PREDICT RELIABILITY, PREPARE FMEA
- 1.1.2.7 MONITOR SUBCONTRACTOR ACTIVITIES

#### DESIGN AND DEVELOPMENT (WBS 1.1.3)

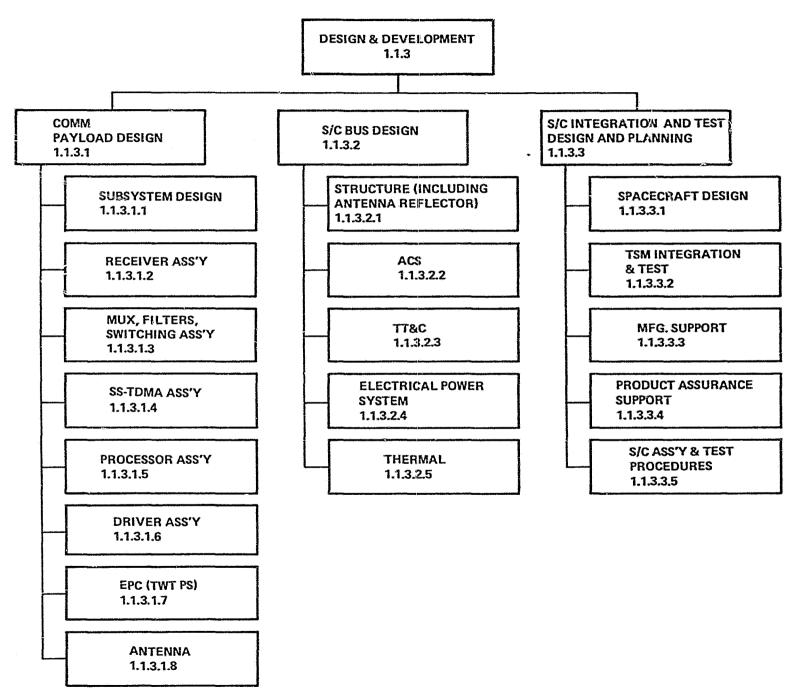
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Design activities are described by the three activity elements at the right, namely Communications Payload Design, Spacecraft Bus Design and Spacecraft Integration and Test Design and Planning. Communications Payload Design is broken into seven elements including the overall subsystem design. Each element includes materials, other direct costs (ODC) such as computer charges and subcontract costs. The Spacecraft Bus Design is broken into the five identified elements, and includes design of the thermal and structural model.

It should be noted that the TSM has been included in the WBS to achieve a conservative cost estimate reflecting principally the impact of the large deployable antenna and the complete redesign required of the north and south equipment panels. The actual need for a TSM must be reevaluated at a later time in the light of additional space-craft programs that may be acquired by GE.

Spacecraft Integration and Test Design and Planning includes principally the packaging design of the north and south panels, the integration and test of the Thermal Structural Model (TSM) and the development of spacecraft assembly and test procedures and plans. There are also ongoing manufacturing and QA activities principally related to the design process which are also listed under WBS 1.1.3.3.

#### DESIGN & DEVELOPMENT (WBS 1.1.3)



#### COMMUNICATIONS PAYLOAD (WBS 1.1.3.1)

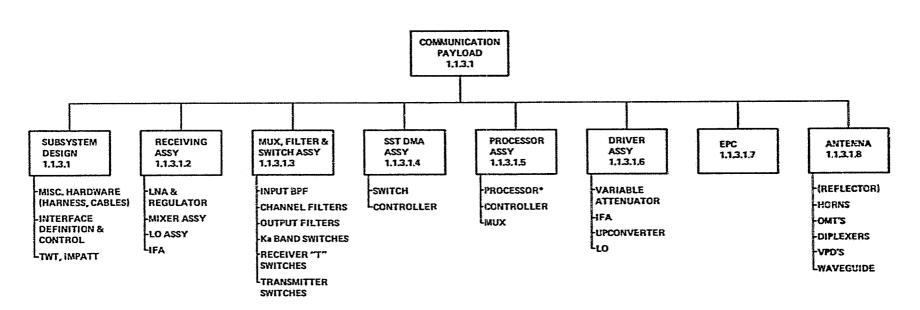
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The seven communications payload elements previously designed are broken further into their contituent parts as required by NASA and to permit detailed costing of the payload. The breakdown identifies subcontracts, a major portion of payload costs. The antenna reflector is in parenthesis because its design cost is included under the space-craft bus.

The processor includes the FDMA MUX, which is not part of the present POC; there is also a frequency converter to interface the satellite 6 GHz IF to the processor.

#### COMMUNICATIONS PAYLOAD (WBS 1.1.3.1)



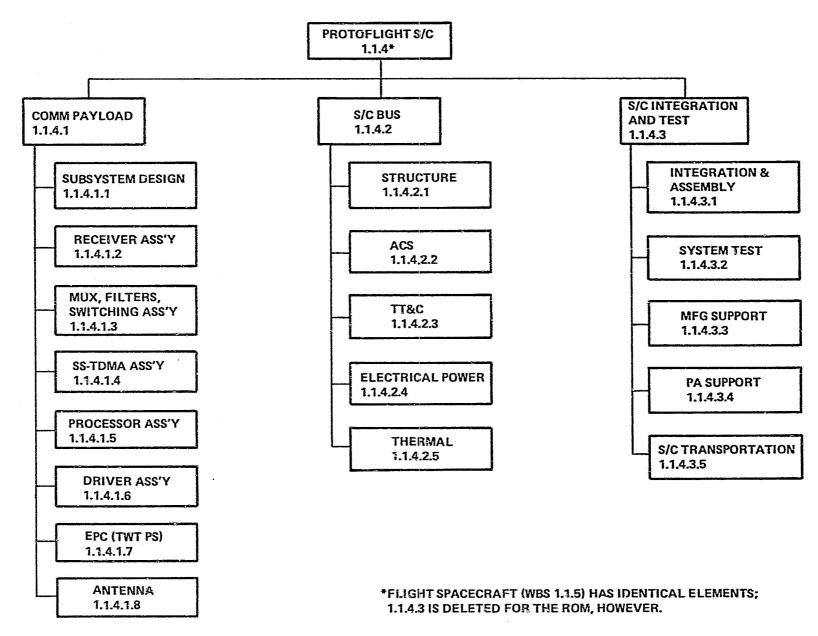
<sup>\*</sup>MARDWARE AND SOFTWARE AND TEST EQUIPMENT DEVELOPMENT

# PROTOFLIGHT SPACECRAFT (WBS 1.1.4)

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The Photoflight Spacecraft WBS elements are identical to those of Design and Development (WBS 1.1.3) except that a new category Spacecraft Integration and Test (WBS 1.1.4.3) is added, which includes general manufacturing and PA support as previously, and spacecraft transportation (packing, shipping, unpacking plus insurance). Note that Flight Spacecraft (WBS 1.1.5) is identical to the Protoflight in WBS elements, however for the ROM, costs related to WBS 1.1.4.3 are omitted.

# PROTOFLIGHT SPACECRAFT (WBS 1.1.4)



#### MISSION OPERATIONS SYSTEM (MOS), (WBS 2.0)

The MOS is divided into launch and on orbit elements. A NASA S-band launch is assumed, making maximum use of NASA facilities personnel and software. Items which are part of MOS but are not charged to the Program (to either the contractor or to LeRC directly) are indicated in parentheses. Hence, under Launch System (WBS 2.1) Launch Computer Services including basic launch software for orbit, attitude control and motor firing and associated personnel are available. STDN services for sync orbit NASA missions in the 1987 time frame are expected to be available at no charge. The Launch Team provided by Code 500 GSFC must be augmented by contractor personnel and is not charged. Contractor launch support to Code 500 (principally various spacecraft consultants) is provided by WBS 2.1.5. Launch Software Set (WBS 2.1.6) provides satellite sensor calibration and geometry, and T&C processing and calibration. Launch Procedures (WBS 2.1.7) involves the development of a launch plan, including contingency plans. Planned trajectories, launch windows, tracking earth station visibility times, elevation and acceleration etc. are typical portions of the launch plan. Most of the work is performed by Code 500 but is chargeable to the Program. The cost (ROM) for developing the Launch Plan is based however on assumption of a contractor-only team.

The On Orbit (WBS 2.2) elements, Fixed TAC, SCC and Orbital Software are available at GSFC, however personnel to operate these facilities are provided for by Item 2.2.5 which assumes 24 hour a day satellite surveillance. Another satellite software package for on-orbit operations is provided for by element 2.2.4.

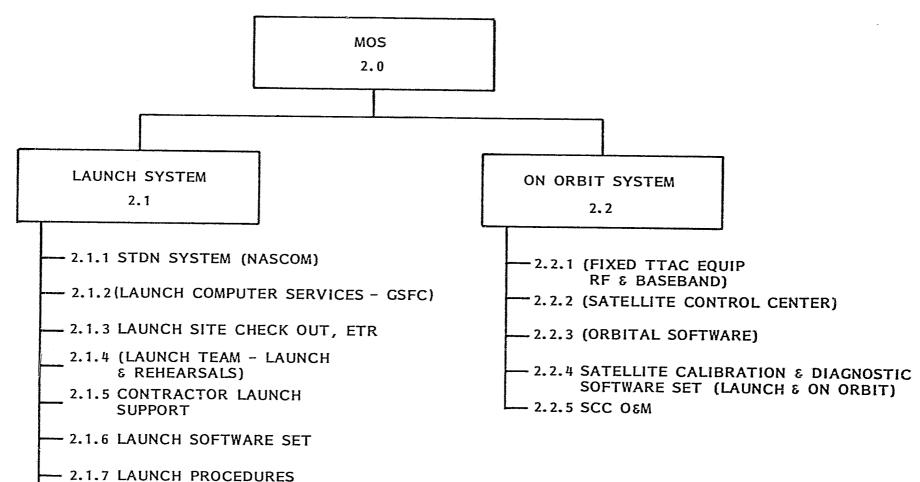


- 2.1.8 (SATELLITE CONTROL FACILITY)

(GSFC)

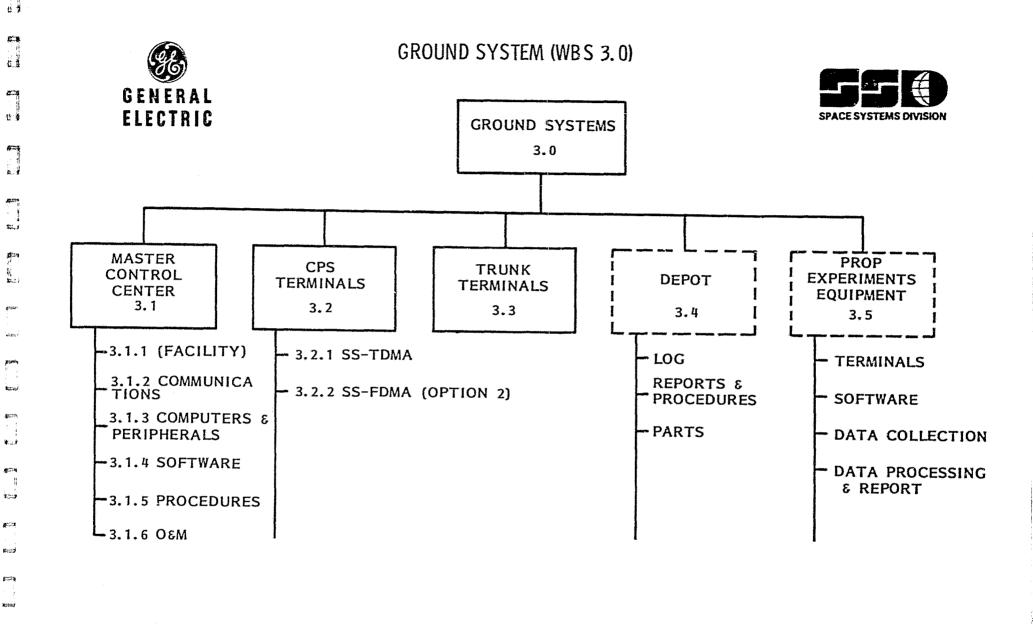
# MISSION OPERATIONS SYSTEM (WBS 2.0)





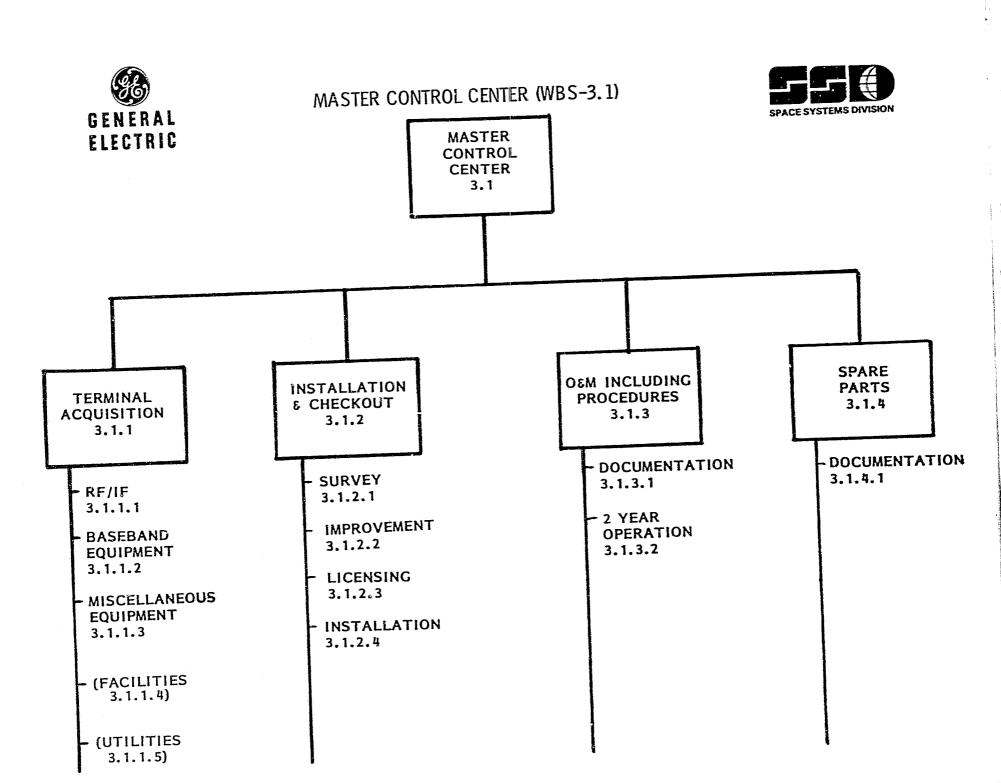
#### GROUND SYSTEMS (WBS 3.0)

Ground Systems identifies a Depot and Propagation Experiment which are not part of this procurement. The MCC and earth stations located in Cleveland make use of available NASA buildings and utilities. The MCC includes a minicomputer and software necessary to provide CPS signalling and switching, automatic response to trunk and CPS system fades and SS-TDMA and processor control reconfiguration, and monitoring and diagnostics. Procedures relate to standard configurations of the spacecraft and to the performance of satellite in orbit communications testing using test equipment and the trunking terminal. Costs include equipment costs, installation and checkout, O&M for two years and spare parts for two years. These items are further identified in subsequent pages.



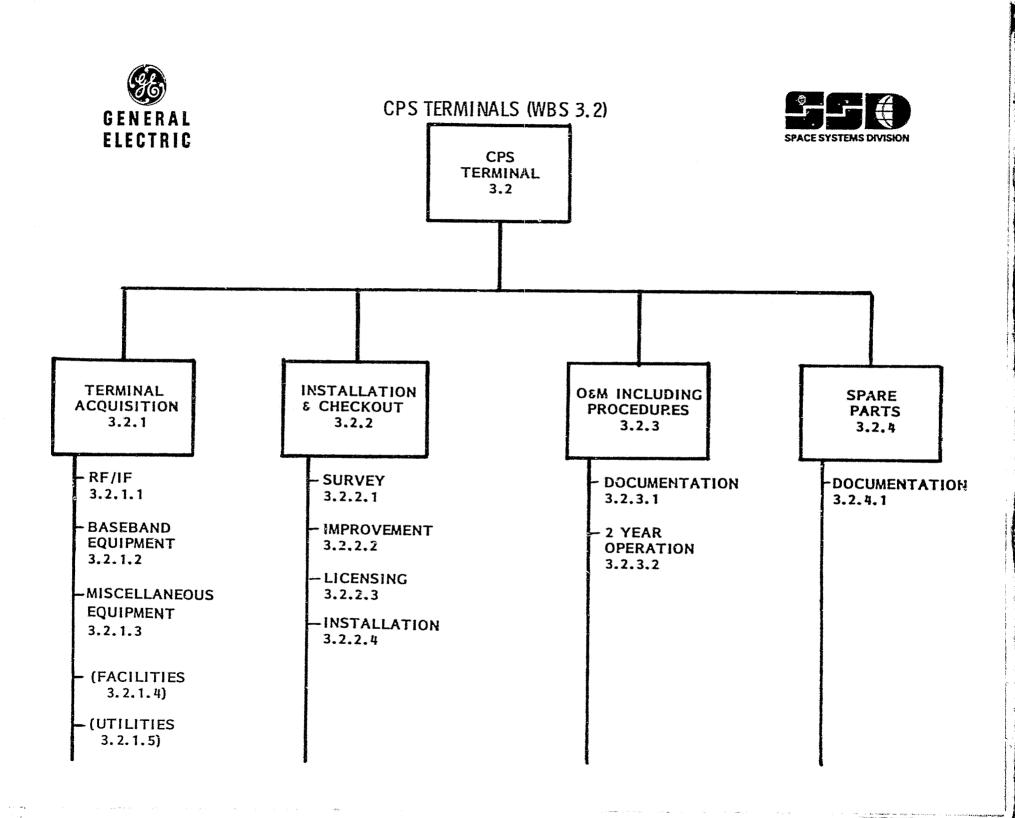
# MASTER CONTROL CENTER (WBS-3.1)

The MCC is composed of the elements listed including survey, site improvements, licensing (e.g., local permits) and spare parts for two years operation. Note that no facilities or utilities are listed since these are assumed to be provided by NASA. Documentation includes an O&M manual, spare parts, wiring diagrams and equipment layouts.



#### CPS TERMINALS (WBS 3.2)

The CPS terminal WBS is identical to that of the MCC and applies either to the TDM CPS terminal (to operate with the scanner-processor), or to the Option 2 FDMA terminal.



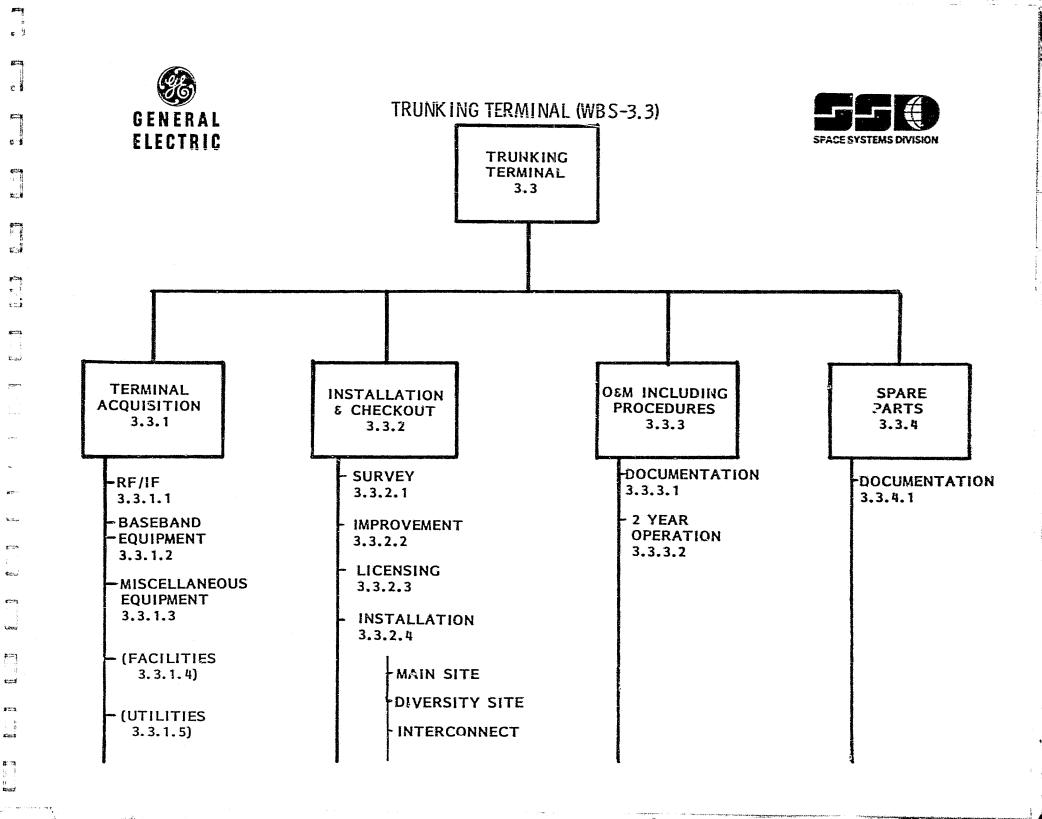
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#### TRUNKING TERMINAL (WBS 3.3)

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The Trunking Terminal WBS is identical to that of the MCC except for the requirement for Installation and Checkout (WBS 3.3.2) for the main site, diversity site and the fiber optic interconnect.



#### RISK ASSESSMENT

273

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Risk Assessment involves an appraisal of the possibilities for failure to achieve required on orbit performance and longevity or to delays causing cost overruns or both. Ground testing, including timely qualifications of new parts, implementation of adequate redundancy and adequacy of workaround plans can reasonably assure the duplication of ground test results in orbit so that the mission objective — demonstration of new Ka-band technology and related system — can be accomplished, even for a high technology satellite such as the one presently considered. Schedule delays caused by late part deliveries or equipment problems have proven particularly difficult to overcome on high technology programs. When it is realized that a spacecraft program can achieve spending rates exceeding a million dollars a week, delays, for any reason can be both frustrating and expensive. Frequently, the prime contractor's resources in personnel, facilities, equipment and money are to no avail because the problems are in subcontractor plants or piece part supplier plants.

The quantities of material involved also are often small compared to the vendor's total business so that the contractor has minimal leverage. Design differences however simple also can be expensive if a chip modification or new part is required. Procurement problems of these types account for increased costs and increased schedules of recent space programs particularly those involving new or advanced technology.

Areas of concern can be divided between "key" areas and "other" areas. "Key" areas based on GE recent experience are:

- TWT's
- Processor hardware, software and test equipment

Risk is greatly diminished by the "transition" program recommended herein which extends the present TWT POC program to include qualification of documented prototype TWT's and initiation of life tests. The spacecraft contractor will be able to order flight model TWT's according to part number and specification and adequate schedule margin is presently available to tolerate delays in qualification. Risk is also greatly diminished by the processor transition program. As a minimum NASA should extend the present FOC program to qualify all new chips and parts, build and test a complete brassboard, develop detailed performance and (functional) operating specifications and related test equipment and software. Test equipment and software to measure the internal performance of the processor, its operating functions and modes and to perform diagnostics on malfunctions is a vital part of the processor program. The additional complication of multiple beam operation and failure modes and effects analysis and related "work arounds" is yet to be assessed. Consequently implementation of the recommended processor transition program will still require the contractor to execute detailed planning coordination and surveillance of these contracts.

#### RISK ASSESSMENT (Continued)

"Other" areas of concern are the following:

1

- Ka-band; mixer diodes, multiplier diodes, ring switches and functional switches, VPD's, ferrite
- GaAs FET switch (SS-TDMA) and IF amplifiers
- IC chips for processor and SS-TDMA control and miscellaneous control

A complete, detailed design and early long lead procurement are mutually inconsistent and some program compromises are obviously needed. Since any one single item can cause schedule havoc and expensive workaround reactions and delays it is prudent to resort again to careful planning, coordination and surveillance of the design and procurement processes and not to assume uniform success in each subsystem. Schedules and costs for the Demonstration System are therefore based primarily on GE's DSCS-III experience, suitably modified to account for different technologies (where appropriate) and different procurement methods. The present POC program involving LNR, IMPATT and multibeam antenna, (including VPD's) development is probably sufficient if piece parts are available early for space qualification.

#### COST DRIVERS, SPACE SEGMENT (1981 DOLLARS)

Cost drivers are assessed using the detailed cost estimates prepared for the June 1981 ROM, computed by an analogous method from on going programs and taking into account improved performance, parts quantities, complexity and design uncertainties. Cost drivers for this payload and for the space craft bus can be evaluated separately.

Viewed this way the space craft bus cost drivers do not appear to be significant or unusual, partly because the space craft bus was defined by NASA to be a minimum effort, e.g., maximum use was made of an available space craft bus and parts, but mostly because the space craft bus requirements were truly minimal. In this case the proposed SSUS-D arrangement requires the deployment of a 10 foot aperture, generation of 1100 watts of primary power, substantial diurnal changes in dissipated power (including use of heat pipes) and pointing accuracy of .05°. These are not substantially different from current space craft requirements, for example, the BS2/DSCS III missions. Of the total space craft bus non-recurring costs of \$32,261K, 48% is devoted to redesigning and repackaging the north-south equipment panels and planning revised integration and test procedures. 15.4%, and 15.1% respectively of the total space craft bus cost (neglecting program management and systems engineering costs) are required to design for the 1100 watts and enlarge and strengthen the structure and design the 10 foot reflector and power hinge. With regard to recurring costs of the spacecraft bus 31% of the total cost is required for attitude control and propulsion, 23% for thermal and 19.0% for power and regulation. Consequently when cost drivers are considered with regard to the specified payload configuration neither non-recurring or recurring space craft bus are significantly affected, e.g., there are no cost drivers in the space craft bus relatable to the payload configuration.

The payload is a different situation because of the high non-recurring and recurring costs of the processor and antenna subsystems. 52% of the payload design cost of \$37,057K involves the processor of which approximately \$15,060K is a subcontract cost for engineering and qual model processors, spare parts, test equipment and software. 16.8% of the payload design cost of \$37,057K involves the antenna of which over \$3,000K is a subcontract cost for VPD design, qual models, and spares.

Recurring payload costs of \$19,806K show less dramatic effects, even so, 33% of the total recurring cost involves the processor, including a \$5,000K subcontract cost, and 21.4% involves the antenna, including a \$1,900K subcontract cost for VPD's. At this point in time there is considerable uncertainty with regard to the processor costs because of the early stage in its development and the lack of specifications and statements of work necessary to define it. It is interesting to note that except for the antenna cost, the cost of the SS-TDMA trunking subsystem is fairly modest, being only 5.5% of the payload non recurring cost and 2% of the recurring payload cost. The cost for TDMA is not in the satellite.

#### COST DRIVERS, SPACE SEGMENT (1981 DOLLARS) (Continued)

Viewing total costs, payload costs are 40% of the estimated satellite recurring cost of \$50M (including a pro rated share of program management and systems engineering) and 35% of the satellite non recurring cost of \$107M (including a pro rated share of program management, system engineering and AGE). These costs are a reflection of added design and management requirements for Ka-band systems (which of course are new), and for the processor and scanning antenna, (large reflector and VPD costs). Both non recurring and recurring costs (in constant dollars) will diminish for operational systems as industry gains experience with the new technology. The processor is likely to remain a costly item (cost driver) in a satellite because of its inherent complexities, difficulty in providing true functional redundancy and the parts procurement problem described previously. The scanning antennas also will be a cost driver because of the cost of VPD's and the cost of the large deployable reflector.

# COST DRIVERS, GROUND SEGMENT (1981 DOLLARS)

Cost drivers can be assessed for the three principal items, trunking terminal, CPS terminal and MCC. Trunking terminal nonrecurring cost of \$3680K allocates 51.3% to the 5M antenna development and 23.1% to the 256 Mops burst MODEM development. Reduction in the burst rate to 150 Mbps will substantially reduce MODEM development costs. However, the 5 meter antenna is likely to be the minimum size required for trunking applications. Of the \$3.507M for first unit cost 27% is required for facilities (including buried cable interconnect), 32% for program is not operational no multiplex or interface equipment, which normally represents a substantial portion of the total trunking station equipment cost, is included. Recurring costs also are higher because of the newness of the technology and because of the method of procurement. It is interesting to note that the relative cost of TDMA in a trunking earth station is not significant.

CPS terminal nonrecurring cost of \$1527K allocates 75% to TDMA equipment development (principally the aggregate rate MODEM). Of the \$885K cost of the first unit, 30% is allocated to program management and systems engineering, 24.0% to RF including antenna, and 15% to TDMA, control and display equipment. The implications of the high burst rate operation (27.5 Mbps to 220 Mbps) imply substantial costs for antenna, HPA and TDMA equipment. Recurring costs are higher because of the newness of the technology and because of the method of procurement. However, even with application of "learning factors" it appears unlikely that such an earth station could cost less than \$500K (1981 dollars).

The Master Control Center cost is \$6201K of which 14% is management and systems engineering 2.7% is computer and peripherals and 25% is for software development. The MCC controls the network signalling, switching, fade compensation and processor/scanner configuration for CPS and controls fade compensation for trunking. The network signalling and switching, while automatic is not a "full up" system, many functions (network diagnostics, billing, operator assist, etc.) normally required in operational systems are omitted to reduce costs. Software is the cost driver for the MCC and this is roughly divided between network signalling and switching and processor/scanner control.