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TRACKING AND DATA ACQUISITION SYSTEM FOR THE 1990's

VOLUME I
EXECUTIVE SUMMARY

DRAFT FINAL REPORT

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SECTION 1

INTRODUCTION

- STUDY OBJECTIVES
- STUDY FLOW
- KEY FINDINGS

1.1 STUDY OBJECTIVES

Stanfordford Telecommunications Inc. undertook this study on behalf of NASA to develop and examine alternative architectures for the Tracking and Data Acquisition System (TDAS). The TDAS era begins in 1994, when the service contract for the Tracking and Data Relay Satellite System (TDRSS) expires. The objective of the study has been to define a baseline TDAS architecture that will satisfy NASA's requirements in the 1990's and maintain the TDRSS services.

The organization of the study and key findings are given in the Introduction. After summarizing requirements, the report presents the TDAS Space Segment, Ground Segment, and Navigation System Architectures. The results of the study are reported in eight separate volumes listed below.

TDAS REPORTS

Volume I	Executive Summary
Volume II	TDAS User Community
Volume III	TDAS Communications Mission Model
Volume IV	TDAS Space Segment Architecture
Volume V	TDAS Ground Segment Architecture and Operations Concept
Volume VI	TDAS Navigation System Architecture
Volume VII	TDAS Space Technology Assessment
Volume VIII	TDAS Frequency Planning

STUDY OBJECTIVE

- DEFINE A BASELINE TDAS ARCHITECTURE THAT WILL SATISFY NASA'S REQUIREMENTS IN THE 1990'S AND MAINTAIN THE TDRSS SERVICES.
  - MISSION PROFILES
  - COMMUNICATIONS AND NAVIGATION REQUIREMENTS
  - TDAS SYSTEM ARCHITECTURE
    - -- SPACE SEGMENT
    - -- GND SEGMENT
    - -- NAVIGATION
  - OPERATIONAL ASSESSMENTS

1.2 STUDY FLOW

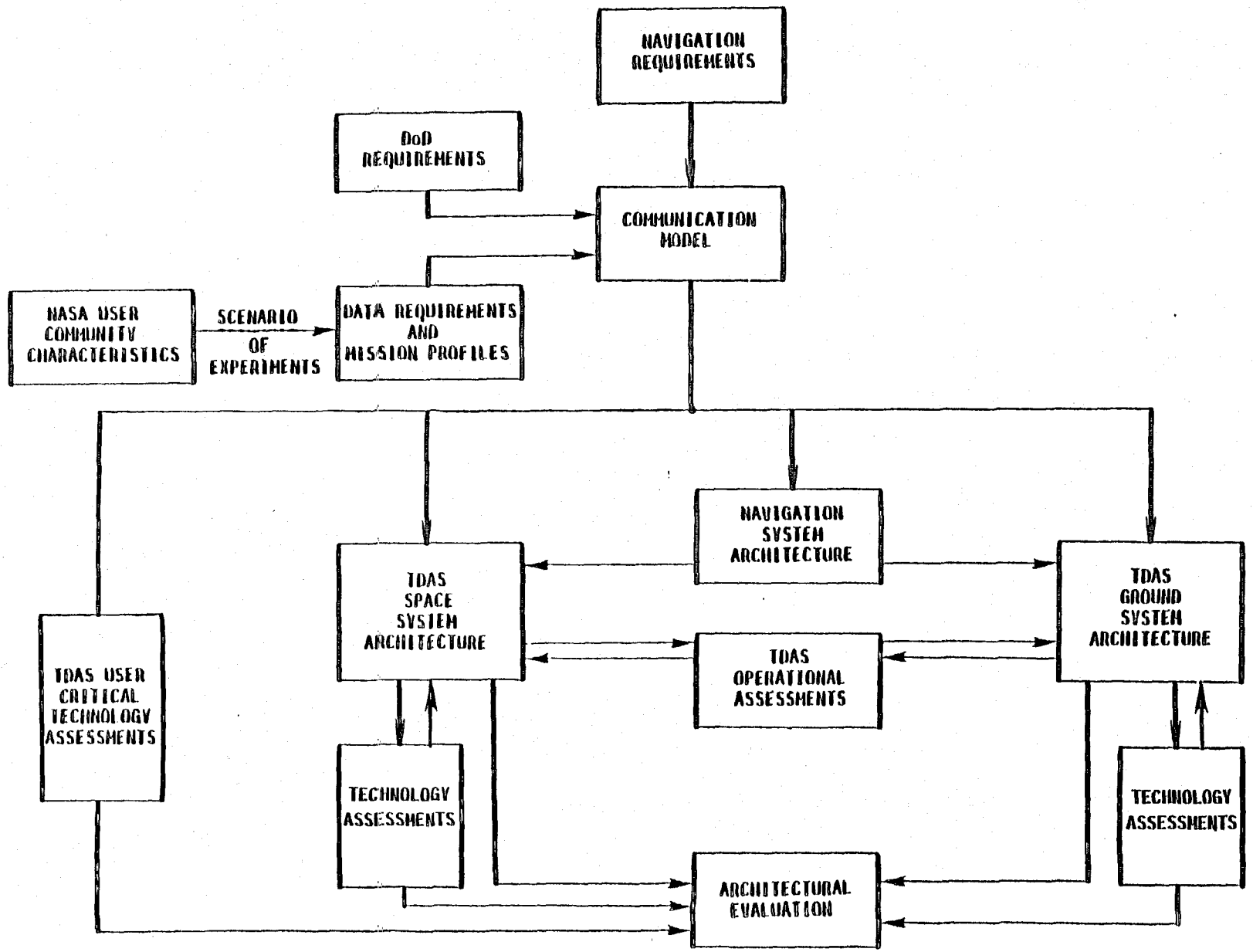
The study began with defining mission profiles for both NASA and DoD users of TDAS. Mission profiles describe the mission (experiments, orbits, timeframe) and summarize user requirements (dump rate, contact time, navigation accuracy). Communication models were then derived from the mission profiles.

With communications requirements specified, the space segment, ground segment, and navigation system architectures were developed. Critical technologies, identified in the architecture studies, for both TDAS and users were identified and assessed.

Alternative control and operations concepts were explored. The operational impacts of scheduling and acquiring the new TDAS services were assessed, as well as the use of new navigation techniques in the TDAS timeframe.

Finally, alternative architectures were evaluated for their capability to meet requirements and for their costs.

TDAS STUDY FLOW



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1.3 KEY FINDINGS

By the mid 1990's NASA requirements for single access channels will exceed TDRSS capacity by 250%. Whereas TDRSS has four single access channels, NASA will require at least ten to support its missions with a channel availability of 90% or better.

A 2-TDAS spacecraft constellation will satisfy NASA requirements. The baseline TDAS spacecraft can be developed with low-risk technology and a 5 to 10% increase in weight over the TDRSS spacecraft. TDAS will require about 1300 watts of additional power.

TDAS will allow users direct access to their spacecraft and payloads and eliminate the need for high cost DOMSAT relays.

In the TDAS timeframe, beacon one-way tracking will satisfy users in the TDAS mission model with accuracy requirements down to 10 meters. One-way tracking eliminates much of the operational complexity of coordinating forward and return links required of two-way tracking.

KEY FINDINGS

- NASA REQUIREMENTS WILL EXCEED TDRSS CAPACITY BY THE MID 1990's.

-

TDRS NASA CAPABILITIES (1985 - 1995)		TDAS NASA REQUIREMENTS* (1995 - 2005)	
SA CHANNELS	MA CHANNELS	SA CHANNELS	MA CHANNELS
4	20	10	20

* TO ACHIEVE A MINIMUM CHANNEL AVAILABILITY OF 90%

- A 2-TDAS SATELLITE CONSTELLATION, WITH SPACECRAFT WEIGHT ONLY SLIGHTLY GREATER THAN THAT OF TDRS (WITHIN 10%), CAN MEET TDAS NASA REQUIREMENTS.

- TDAS CAN BE DEVELOPED USING LOW RISK TECHNOLOGY.

- TDAS ELIMINATES THE NEED FOR DOMSAT RELAY REQUIRED BY TDRSS.

- BEACON ONE-WAY TRACKING WILL SATISFY USERS IN THE TDAS MISSION MODEL WITH ACCURACY REQUIREMENT DOWN TO 10 METERS IN ADDITION TO REDUCING THE NEED FOR COMPLEX TWO-WAY OPERATIONS.

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SECTION 2

REQUIREMENTS

- SCIENCE AND ENGINEERING DATA
- DRIVERS
- MISSION PROFILES
- NASA AND DOD REQUIREMENTS

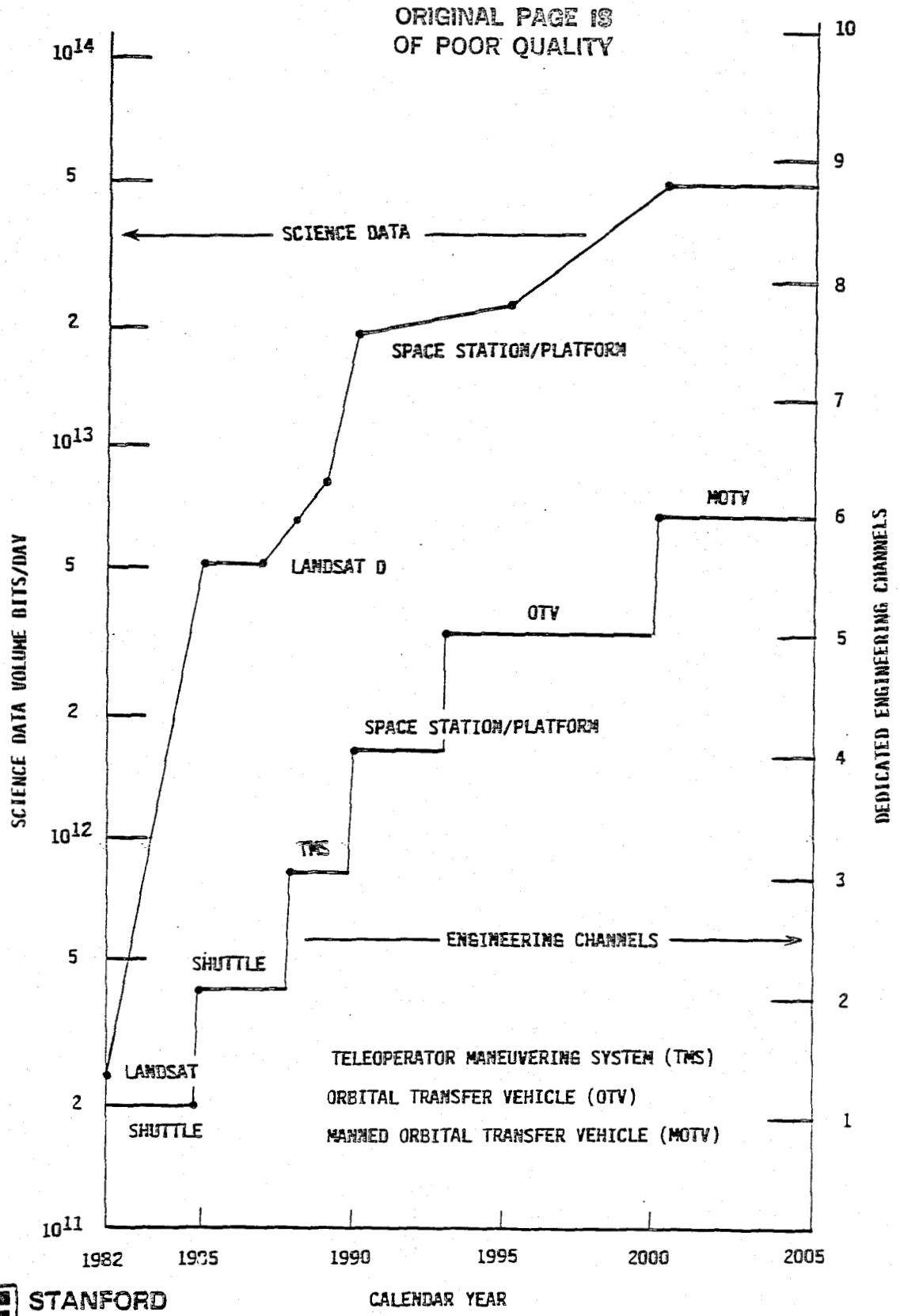
2.1 SCIENCE AND ENGINEERING DATA REQUIREMENTS

Estimates for the growth of science and engineering data over the 20 years covering both the TDRSS and TDAS timeframes are shown in the figure.

The growth in science data is principally the result of two factors: increased resolution of earth-resources observation and the implementation of the space station. On the other hand, the growth in requirements for engineering channels is attributable to increased operations in space, including the suport of man in space. Such channels are dedicated 24 hours per day to the return of engineering data on the health and welfare of the vehicle in space.

The growth of science and engineering data depicted in the figure is based on the activity projected for a busy day during any given year in the 20 year period, that is, the simultaneous operation of all available vehicles and science missions.

SCIENCE AND ENGINEERING DATA REQUIREMENTS



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2.2 PROJECTED MISSION PROFILES

Mission profiles were developed for both NASA and DoD missions. NASA planning information, analysis of past experience, and interviews with NASA program manager and the user community were used to develop the NASA mission profiles. The DoD mission profiles were derived from a prior STI study performed for the Air Force and published in Dec., 1979, "Satellite Control Satellite" (SCS).

The NASA mission profile projects user activity over the period 1995-2005 and the DoD mission profile shown projects requirements over the period 1986-2000.

While no specific NASA requirement for data rates exceeding 300 Mbps were identified, it is very likely that some NASA users will require data rates in this range in the TDAS timeframe.

PROJECTED MISSION PROFILES

- NASA MISSION PROFILES:
  - BASED ON MISSION PROFILES & COMMUNICATION REQUIREMENTS FOR 1995 - 2005 IDENTIFIED IN TDAS STUDY

S/C TYPES	# S/C	ORBIT ALTITUDE (KM)	DATA RATES			
			≤ 50 KBPS	50 KBPS < DR ≤ 50 MBPS	50 MBPS < DR ≤ 300 MBPS	> 300 MBPS
FREE FLYERS	12	300-5000	✓	✓	✓	✓*
SUPPORT VEHICLES	4	LEO-GEO		✓		
SHUTTLE	2	200-1100		✓		
SPACE STATION/ PLATFORM	1	400		✓	✓	

*✓ = NO SPECIFIC REQUIREMENT BUT HIGHLY PROBABLE.

- DOD MISSION PROFILES:
  - BASED ON A MODEL EXTRACTED FROM STI STUDY (1979) FOR USAF: SATELLITE CONTROL SATELLITE (SCS) STUDY

SCS MODEL	NO. S/C	ALTITUDES		DATA RATES		
		≤ 20,000 KM	≥ SYNCH	≤ 20 MBPS	> 20 MBPS	> 300 MBPS
SCS B-	68	✓		✓	✓	✓

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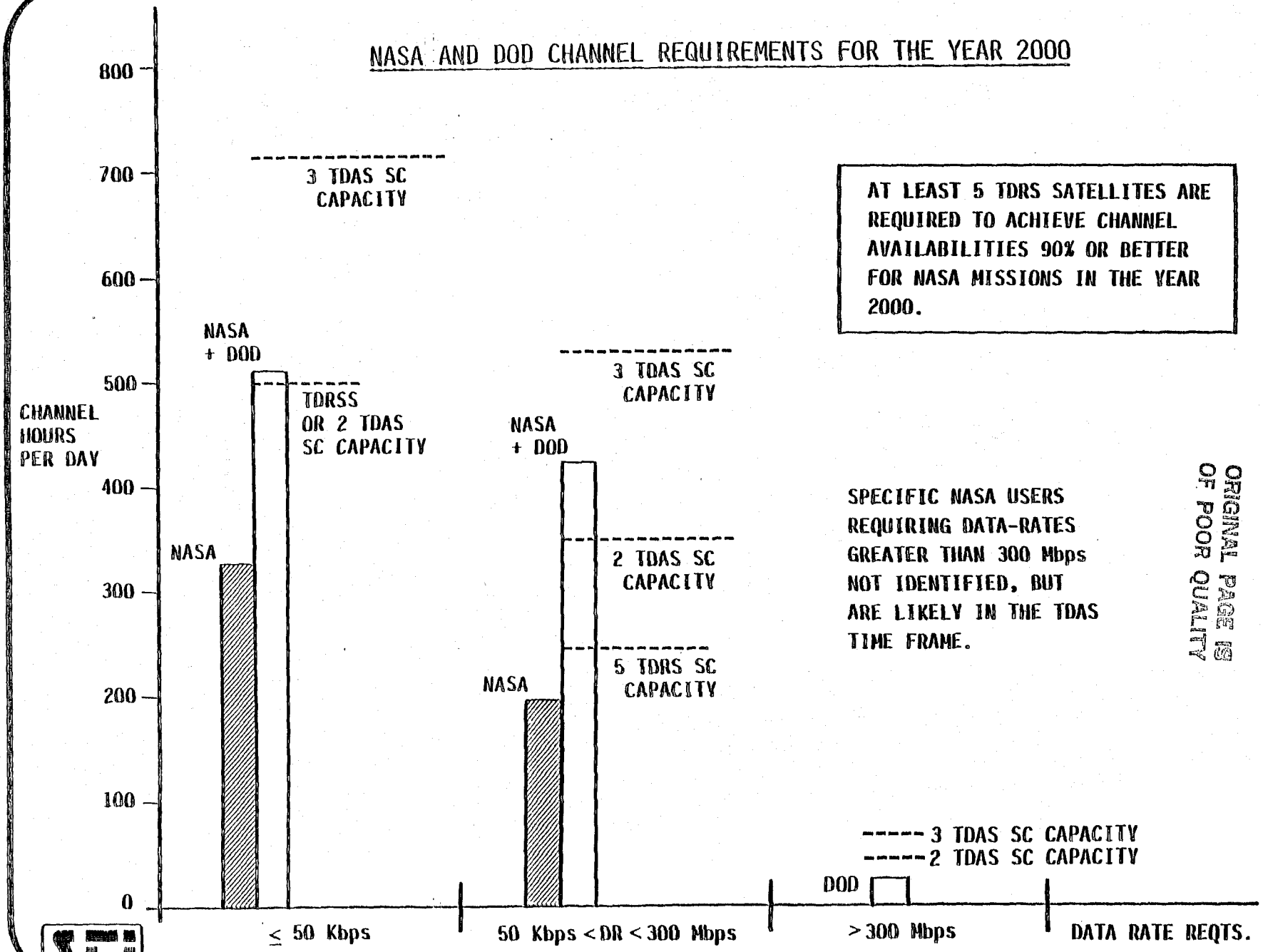
2.3 NASA AND DoD CHANNEL REQUIREMENTS

Channel requirements for the NASA and the NASA-plus-DoD mission models are shown in the figure. TDAS constellations with two baseline spacecraft satisfy the NASA mission model with ample margin, but do not meet the NASA-plus-DoD mission profile requirements, which require three baseline TDAS spacecraft to meet requirements in the 50 Kbps - 300 Mbps range. The TDAS constellations satisfy the DoD channel requirements for data rates greater than 300 Mbps.

NASA AND DOD CHANNEL REQUIREMENTS FOR THE YEAR 2000



AT LEAST 5 TDRS SATELLITES ARE REQUIRED TO ACHIEVE CHANNEL AVAILABILITIES 90% OR BETTER FOR NASA MISSIONS IN THE YEAR 2000.

SPECIFIC NASA USERS REQUIRING DATA-RATES GREATER THAN 300 Mbps NOT IDENTIFIED, BUT ARE LIKELY IN THE TDAS TIME FRAME.

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2.4 SCHEDULING THE NASA AND DOD MISSION MODELS WITH TDAS SPACECRAFT

Results of simulating the scheduling process for the NASA and DoD mission models are shown in the table. The simulation accounts for the dynamics of the scheduling process and the characteristics of each mission. Two important system performance measures, channel availability and channel loading, were obtained form the simulations.

While 2 TDAS spacecraft yield excellent scheduling performance for the NASA mission model, adding the DoD users lowers channel availability to an unacceptable level. Good scheduling performance for the NASA-plus-DoD mission model results when a third TDAS spacecraft is added.

SCHEDULING PERFORMANCE FOR NASA AND DOD MISSION MODELS WITH THE TDAS BASELINE SPACECRAFT

SINGLE ACCESS SERVICES (KSA+WSA)	NUMBER OF TDAS BASELINE SPACECRAFT	CHANNEL AVAILABILITY %	CHANNEL LOADING %
NASA ONLY	2	98.9	55
NASA & DOD	2	71.0	88
NASA & DOD	3	97.0	83

MINIMUM REQUIREMENTS: AVAILABILITY $\geq$ 90%

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2.5 SCHEDULING THE NASA MISSION MODEL WITH TDRSS SPACECRAFT

Results of simulating the scheduling process for the NASA mission model are shown in the table. Five TDRSS spacecraft are required to exceed the minimum availability requirement of 90%. The table indicates the tradeoff between channel availability and channel loading. While adding a sixth TDRSS spacecraft decreases channel loading by 9%, channel availability increases by 3%.

SCHEDULING PERFORMANCE FOR TDAS NASA MISSION MODEL WITH TDRS SPACECRAFT

NUMBER OF TDRS SPACECRAFT	NUMBER OF KSA CHANNELS	CHANNEL AVAILABILITY %	CHANNEL LOADING %
2	4	42	99
3	6	70	92
5	10	93	72
6	12	96	63

MINIMUM REQUIREMENTS: AVAILABILITY $\geq$ 90%

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SECTION 3

TDAS SPACE SEGMENT

- ARCHITECTURE GOALS
- TDAS VS TDRSS CAPABILITY SUMMARY
- TDAS TECHNOLOGY ASSESSMENT
- TDAS SPACECRAFT
- TDAS TECHNOLOGIES
  - SMA
  - 60 GHz SA
  - LSA
  - MBA
  - IF-SWITCH
  - CROSSLINK
- WEIGHT AND POWER SUMMARY
- TDAS CONSTELLATIONS

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3.1 TDAS ARCHITECTURE GOALS

The development of the TDAS architecture has been guided by achieving the following goals: an improved SMA service; the provision of user satellite TT&C data directly to the mission centers; an increased number of high-rate single access channels; the reception of mission data and the control of experiments at 5 CONUS locations; improved coverage; and the provision of ultra-high rate single accesses.

TDAS ARCHITECTURAL GOALS

IMPROVE SMA SERVICE
PROVIDE USAT TT&C DATA DIRECTLY TO MISSION CENTERS
ALLOW USERS TO RECEIVE MISSION DATA AND CONTROL EXPERIMENTS AT 5 OR MORE CONUS LOCATIONS
PROVIDE INCREASED NUMBER OF HIGH-RATE ACCESSES
PROVIDE ULTRA-HIGH RATE ACCESSES (> 300 MBPS)
PROVIDE 100% COVERAGE

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3.2 CAPABILITY SUMMARY

The table contrasts the TDAS space segment capabilities with those of TDRSS. The key features of TDAS that distinguish it from TDRSS are: onboard beam forming for the multiple access system; the W-band and laser single accesses; the multiple beam antenna space/ground link with onboard switching; and the crosslink system.

CAPABILITY SUMMARY

	TDRSS	TDAS
MULTIPLE ACCESS	• 1 FORWARD CHANNEL • 20 RETURN CHANNELS (SYSTEM MAX) • BEAMFORMING AT GROUND	• 2 FORWARD CHANNELS • 10 RETURN CHANNELS PER S/C - LINK GAIN INCREASES BY 4.5 dB • ONBOARD BEAMFORMING
SINGLE ACCESS	• 2 K-(OR S-)BAND PER S/C • DATA RATES TO 300 Mbps	• 2 K-(OR S-)BAND • 5 W-BAND • 1 LASER } PER S/C • DATA RATES TO 1 Gbps
SPACE-TO-GROUND	• SINGLE BEAM ANTENNA - 1 FIXED LINK • K_u BAND TO WHITE SANDS • DOMSAT RELAY	• MULTIPLE BEAM ANTENNA (5 FIXED HORNS, 4 STEERABLE) - 5 FIXED LINKS - 1 MOBILE LINK • ONBOARD TWO-WAY SWITCH • RETAIN K_u AT WHITE SANDS, USE K_a AT ALL OTHER SITES • NO DOMSAT RELAY
CROSSLINK	• NONE	• 1 FORWARD PER S/C (25 Mbps) • 1 RETURN PER S/C (1.8 (Gbps) • LASER OR 60 GHz

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3.3 TDAS TECHNOLOGY ASSESSMENT

To meet the projected implementation schedule, the TDAS technologies must be available by 1989. The accompanying table summarizes an assessment of the expected risk attending the availability of the TDAS technologies.

With the exception of the crosslink technologies, all developments are expected to be low risk. Development of the 2-Gbps GaAs laser crosslink by 1989 incurs moderate risk; somewhat less risk is associated with the development of the 2-Gbps 60-GHz crosslink and even less risk is incurred with the development of a 1-Gbps 60-GHz crosslink. The 1 Gbps 60-GHz crosslink permits an all low-risk TDAS technology development.

TDAS TECHNOLOGY ASSESSMENT

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TECHNOLOGY	RISK (LOW / MEDIUM / HIGH)	APPLICATION	
ON-BOARD BEAM FORMING AND STEERING		S-BAND MULTIPLE ACCESS SPACE-TO-SPACE LINKS	SMA
10 WATT 1 METER 60 GHz TERMINAL		60 GHz SINGLE ACCES SPACE-TO-SPACE LINKS	WSA
LASER GaAs OR ND:YAG DIRECT DETECTION (1 GBPS)		LASER SINGLE ACCESS SPACE-TO-SPACE LINKS	LSA
LASER GaAs .86 μM HETERODYNE DETECTION (2 GBPS)		LASER CROSS LINK TDAS SC-TO-TDAS SC	LASER X-LINK
60 GHz TERMINAL 4 METER ANTENNA 12.5 WATT (1 GBPS) 25 WATT (2 GBPS)		60 GHz CROSS LINK TDAS SC-TO-TDAS SC	60 GHz X-LINK
MULTIBEAM ANTENNA 20/30 GHz		20/30 GHz SPACE-TO-GROUND LINK	MBA
INTELLIGENT ON-BOARD SWITCH 36 x 9		INTERFACE BETWEEN SPACE-TO-SPACE AND SPACE-TO-GROUND LINKS	SWITCH

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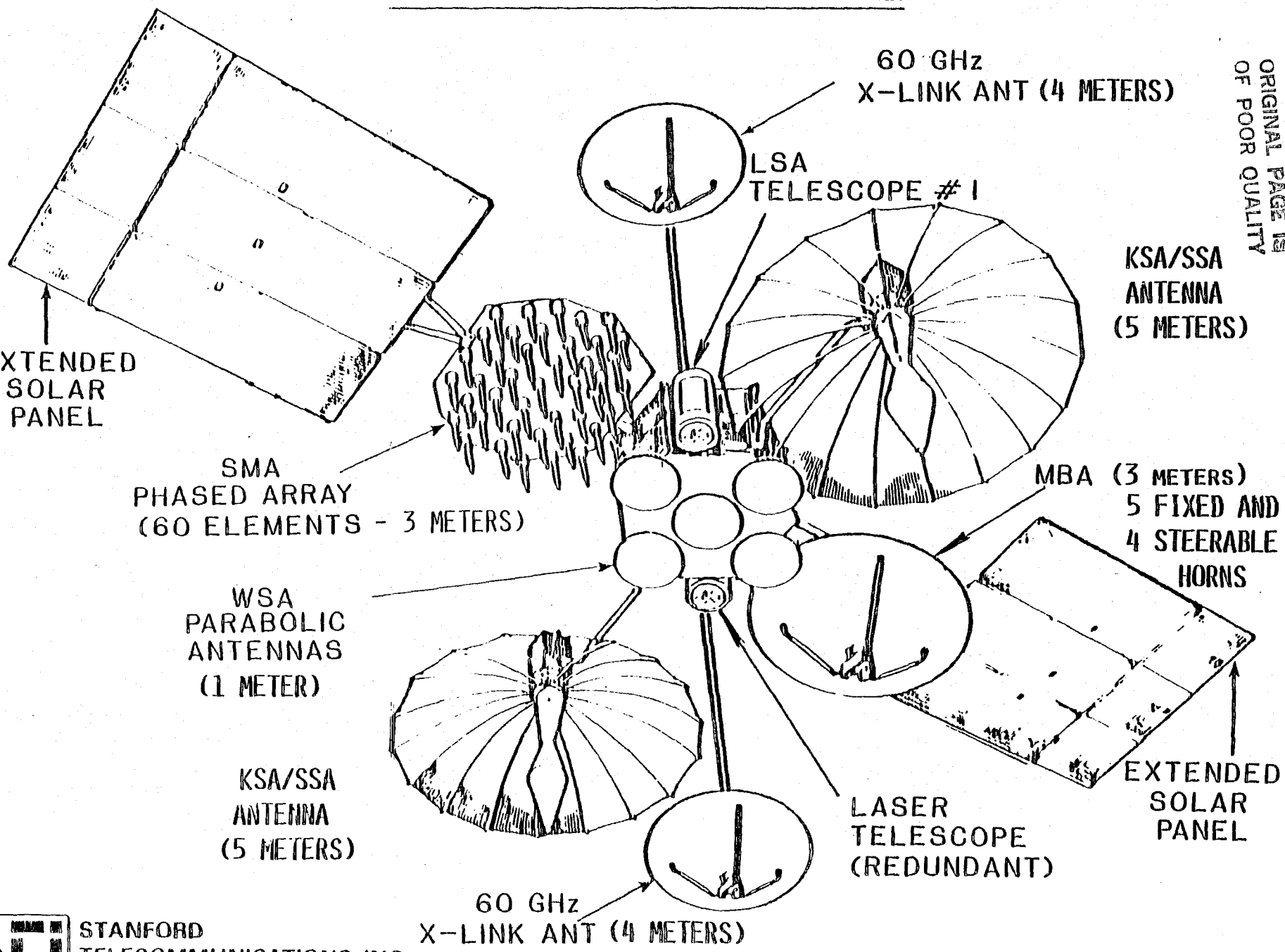
3.4 THE TDAS SPACECRAFT

The two figures that follow depict the TDAS Spacecraft; a 60-GHz crosslink system is shown in the first figure and a laser crosslink system is shown in the second figure.

The TDRSS heritage is evident in the TDAS bus architecture. Features required to maintain the TDRSS services have been retained, while elements have been added to support the new TDAS services and capabilities.

TDAS SPACECRAFT WITH 60 GHz CROSSLINK



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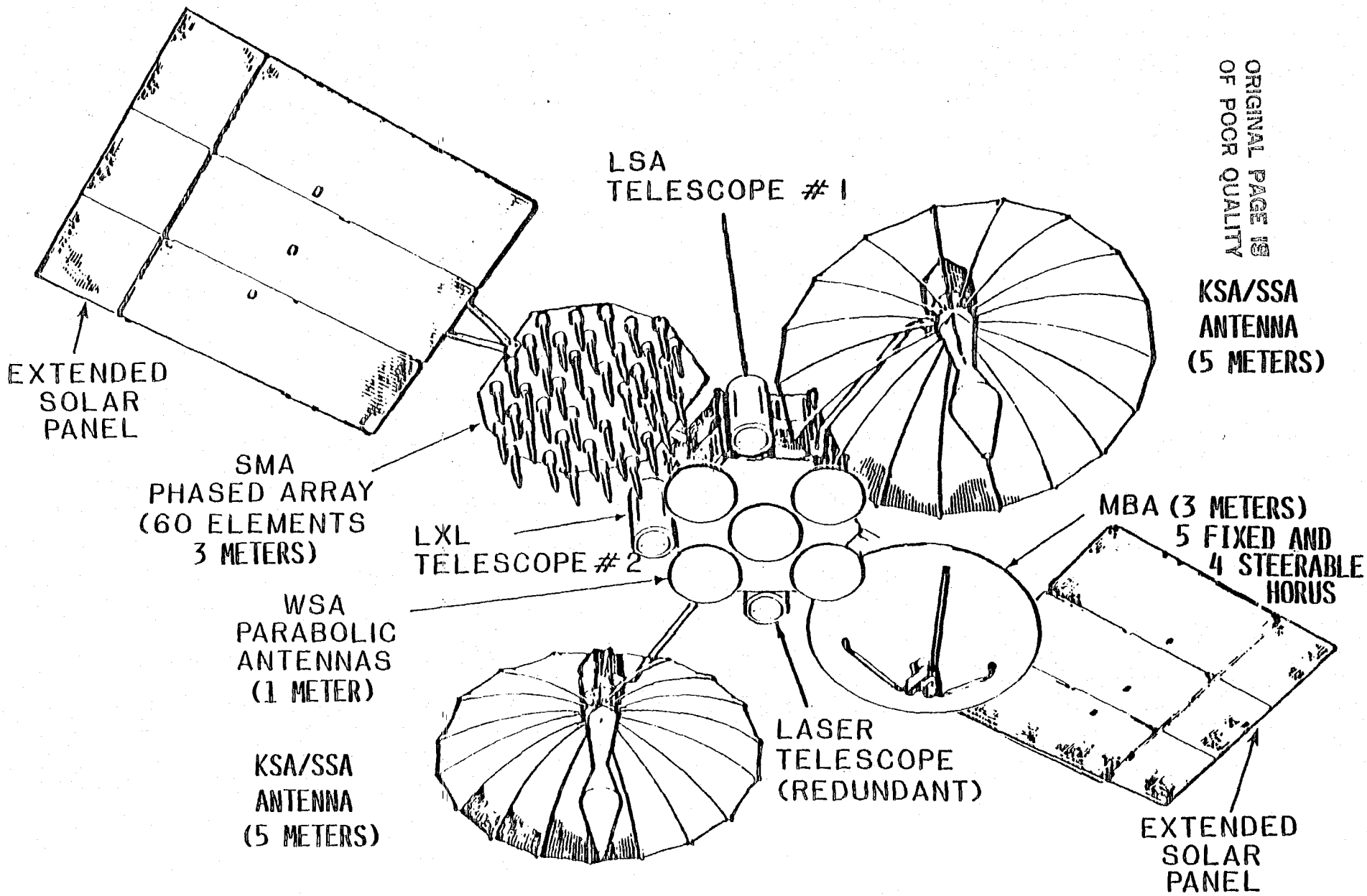
TDAS SPACECRAFT WITH LASER CROSSLINK



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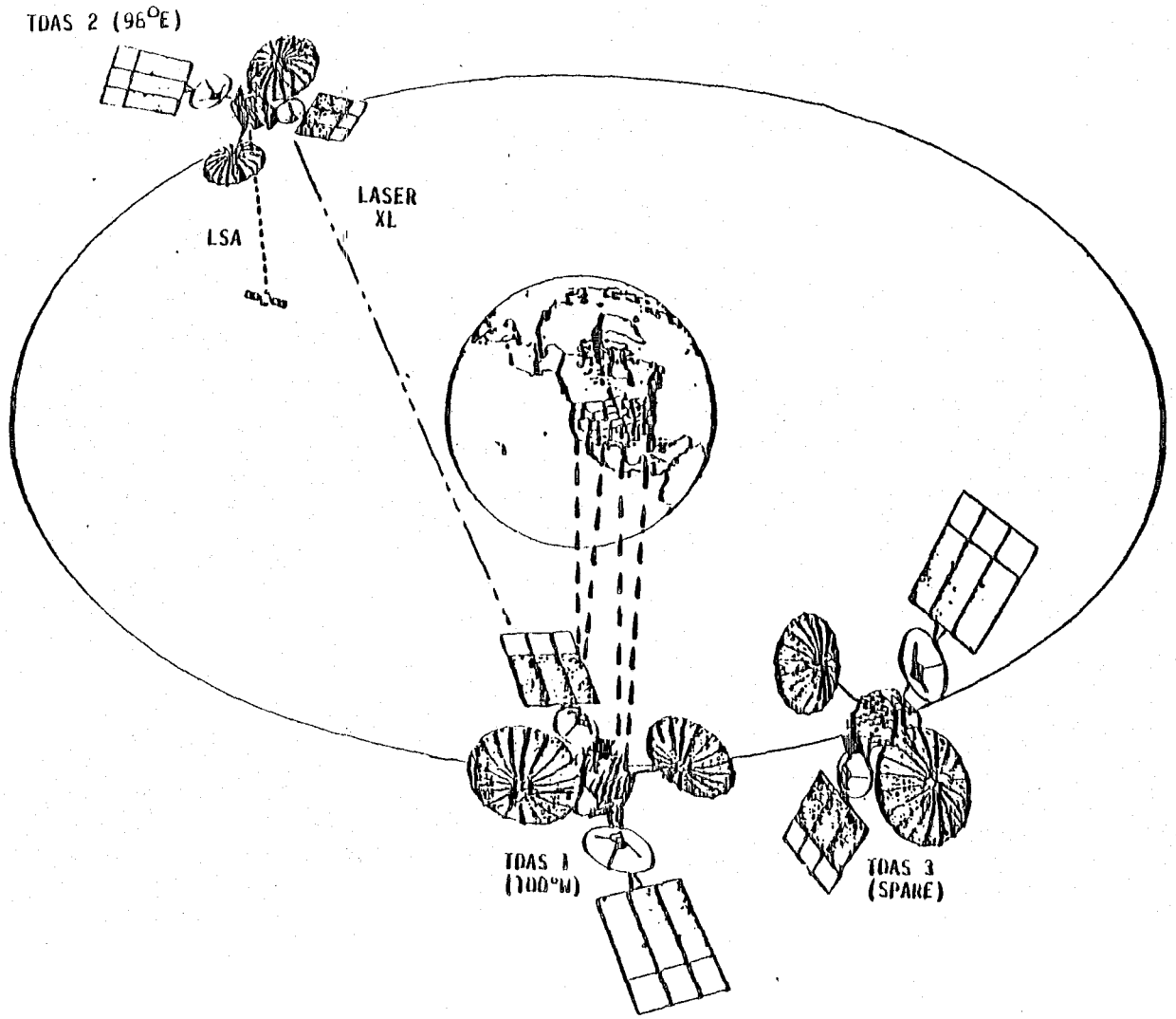
3.5 TDAS CONSTELLATIONS

The two-satellite constellation meets NASA requirements in the TDAS timeframe. Additionally, the constellation mitigates the impacts of rain attenuation by achieving favorable elevation angles for all CONUS locations. The advantages of this constellation operating at K_a band are considerable: high space/ground link availabilities and high capacities can be achieved with minimal use of diversity operation. Additionally, a coverage of at least 98% is achieved for all users with altitudes greater than 200 km.

The three-satellite constellation meets the NASA-plus-DoD mission requirements in the TDAS timeframe. Since each ground station views two spacecraft, the space/ground link capability is doubled compared to the two-satellite constellation. Because of smaller elevation angles, sites like Houston and Washington require diversity operation. A coverage of 100% is achieved for all users with altitudes greater than 200 km.

TWO SATELLITE CONSTELLATION

MEETS NASA REQUIREMENTS



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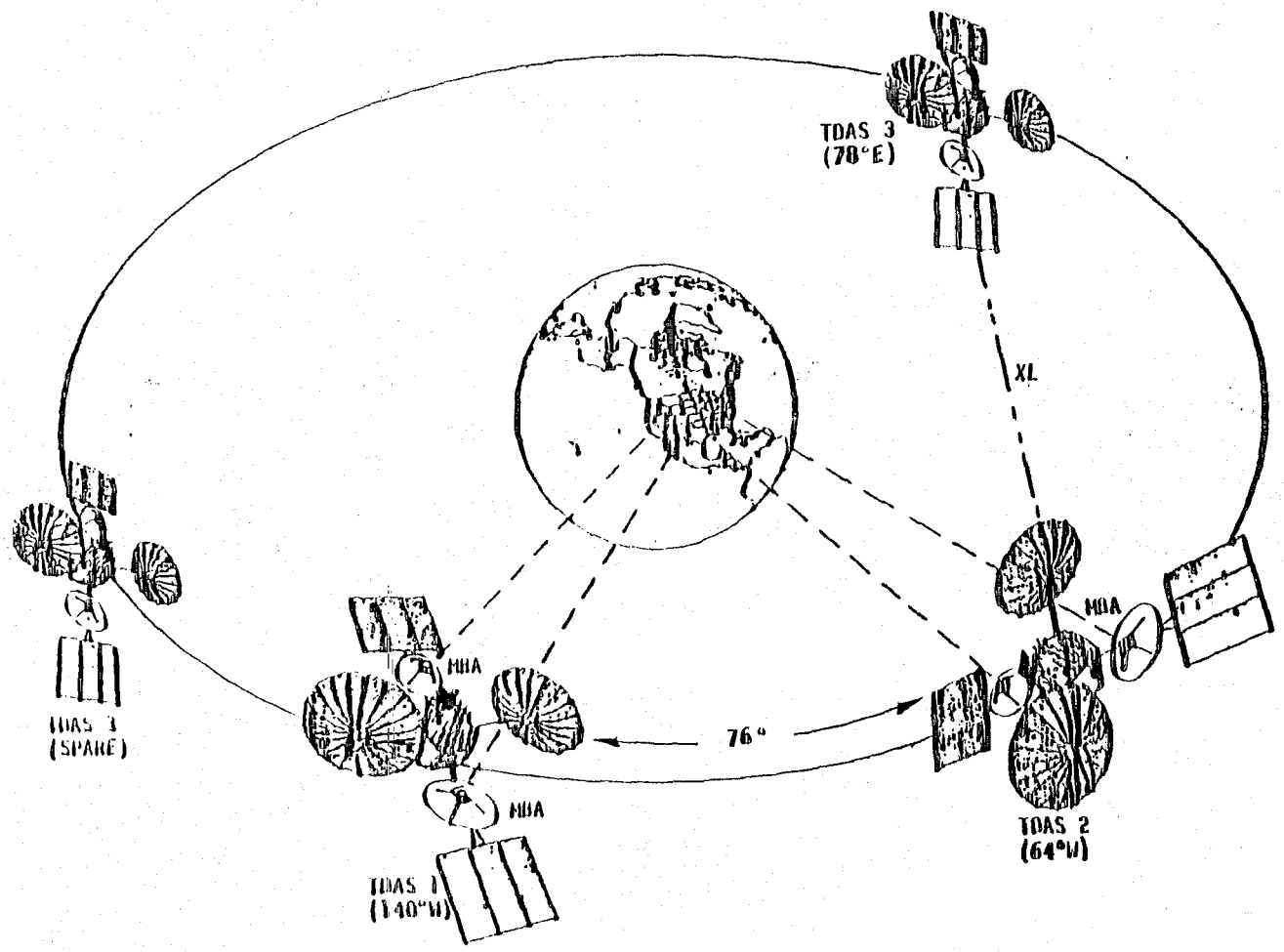
THREE SATELLITE CONSTELLATION

MEETS NASA + DOD REQUIREMENTS



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3.6 TDAS TECHNOLOGIES

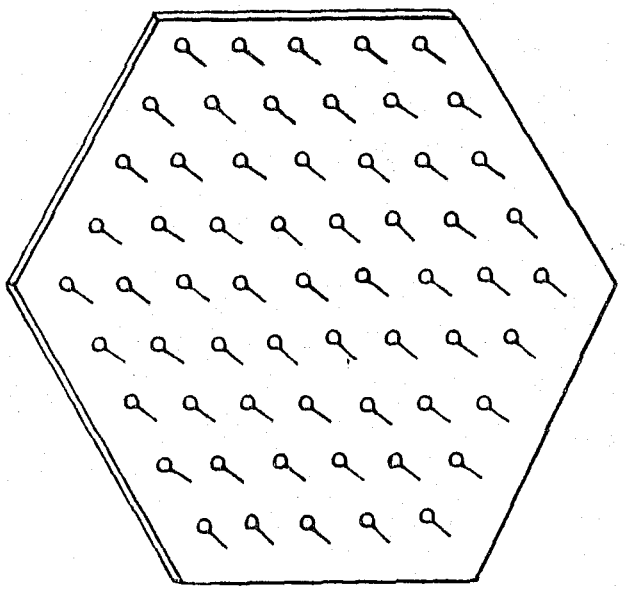
3.6.1 Improved S-Band Multiple Access

The key development of the TDAS S-Band multiple access subsystem is onboard beamforming. Onboard beamforming allows direct links to be established between the user spacecraft and the user ground facilities through the TDAS relay.

The TDAS SMA offers two forward links as compared to one for TDRSS and achieves a 4.5db link gain over TDRSS.

IMPROVED S-BAND MULTIPLE ACCESS SUBSYSTEM

- 61 ELEMENT ARRAY
- 10 RETURN BEAMS
  2 FORWARD BEAMS
- 1 ELEMENT FOR NAVIGATION BEACON
- 650 LBS, 420 W
- 26° CONICAL FOV



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TECHNOLOGY DEVELOPMENT

- ONBOARD BEAMFORMING PROCESSING:
  - DECREASED SGL BANDWIDTH
  - REDUCED BEAMFORMING LOSS
  - ELIMINATION OF CALIBRATION
  - DIRECT DATA DISTRIBUTION
- ELEMENT GAIN INCREASED BY 1.5 dB
- LINK GAIN INCREASED BY 4.5 dB

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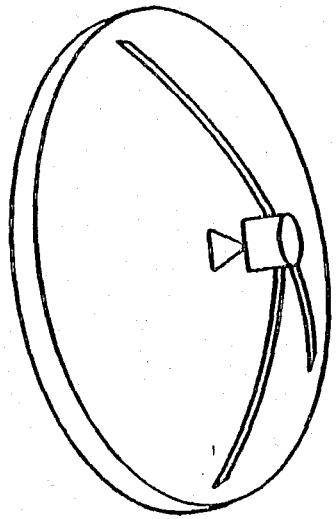
3.6.2 60-GHz Single Access

The 60-GHz single access service offers data rates up to 50 Mbps. The one meter dish chosen for the service minimizes the system pointing losses for user acquisition and tracking. The dishes are mounted on the main body of the spacecraft for attitude stability.

The key technology developement is power generation; the 60-GHz service requires a 10-watt transmitter. Since the user 60-GHz terminal also requires a 10-watt transmitter, TDAS 60-GHz terminal development will also satisfy a principal user terminal development requirement.

60 GHz SINGLE ACCESS SUBSYSTEM

- DATA RATES TO 50 MBPS (RETURN LINK)
- 1 M DISH OPTIMUM FOR USER ACQ/TRK
- DEDICATED ANTENNA POINTING AND CONTROL SYSTEM
- MECHANICALLY STEERABLE PARABOLIC DISH
- BODY MOUNTED FOR BETTER S/C ATTITUDE CONTROL
- 500 LBS, 210 W



TECHNOLOGY DEVELOPMENT

- 10 W TRANSMITTER - TWT OR IMPATT
- 450° K RECEIVER-AMP
- LOW INERTIA, SMOOTH REFLECTOR
- 60 GHz LOW LOSS FEED
- ANTENNA POINTING AND AUTOTRACK CONTROL SYSTEM

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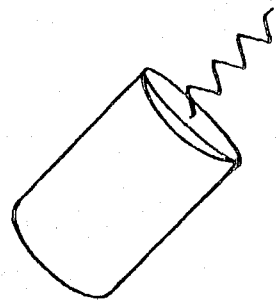
3.6.3 Laser Single Access

The laser single access service offers data rates up to one Gbps. GaAs or ND: YAG lasers using direct detection are the candidate technologies.

Power generation is the key technology development; a few hundred milliwatts of output power is required. As in the case for 60-GHz, TDAS terminal development of the laser crosslink equipment will also satisfy user terminal development requirements.

LASER SINGLE ACCESS SUBSYSTEM

- DATA RATES
  300 MBPS - 1 GBPS
- GaAs (OR ND: YAG) LASER
- DIRECT DETECTION
- 25 CM TELESCOPE
- 170 LBS, 135 W*
- BEACON LASER FOR ACQ/TRK
- POTENTIAL DEEP SPACE RELAY CAPABILITY
  - DATA RATES COMPARABLE TO VOYAGER (100 KBPS)



TECHNOLOGY DEVELOPMENT

- FEW HUNDRED MW POWER OUTPUT
  - COHERENT OR NONCOHERENT
- IMPROVED FREQUENCY STABILITY OF TRANSMIT LASER
  - FOR FSK MODULATION
- LOW NOISE PHOTODETECTORS
  - 3 TO 5 DB REDUCTION IN AVALANCH MULTI-PLICATION NOISE

* SIZING BASED ON ND: YAG LASER

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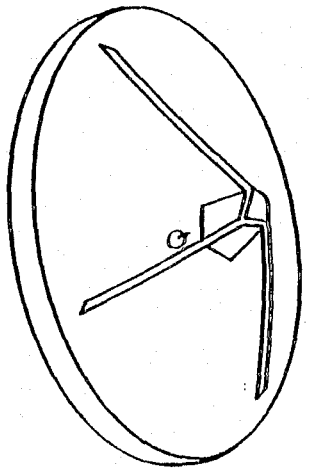
3.6.4 30/20 GHz MULTIBEAM ANTENNA

The multibeam antenna has 5 fixed and 4 movable feeds. One of the fixed and one of the movable feeds will operate at K_u band and will provide the space/ground link with backup for the White Sands Ground Terminal.

Dual frequency operation and dual polarization operation at both K_u and K_a bands are the key technology developments.

30/20 GHz MULTIBEAM ANTENNA SUBSYSTEM

- 3 METER DISH
- 5 FIXED FEEDS, 4 MOVABLE
- SINGLE REFLECTOR STRUCTURE FOR LIGHT WEIGHT, LOW STOWAGE VOLUME
- SQUARE FEED ARRAY FOR BETTER POLARIZATION AND EFFICIENCY
- 30/20 GHz FREQUENCY
  - BANDWIDTH SUPPORTS HIGH RATE DOWNLINK
  - ONE KU-BAND FEED FOR WSGT
- 205 LBS, 450 W



TECHNOLOGY DEVELOPMENT

- LIGHT WT/RIGID/SMOOTH REFLECTOR
- LOW LOSS/LIGHT WT FEEDS AND WAVEGUIDES
- MECHANICALLY SCANNABLE LONG LIFE FEEDS
- DUAL FREQUENCY/DUAL POLARIZATION FEEDS

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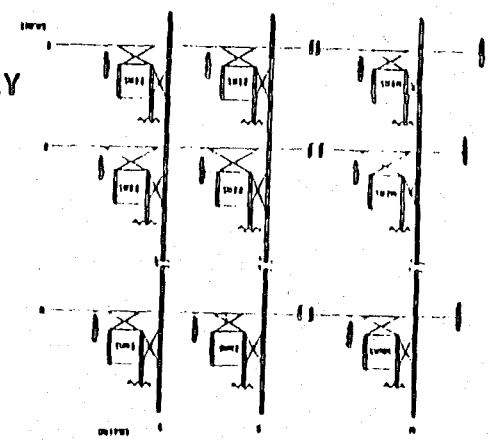
3.6.5 IF Switch

The TDAS onboard IF switch user a 9 x 36 crossbar coupler architecture. The use of dual gate GaAs MESFET switching devices achieves a low power, light weight switch.

The development of broadband switching elements is the key technology issue. Since there is no requirement for fast switching, switching speed is not a technical issue.

IF SWITCH SUBSYSTEM

- 36 x 9 SWITCH
  - ONE-WAY OR TWO-WAY OPERATION
- CROSSBAR COUPLER ARCHITECTURE
- NO FAST SWITCHING REQUIREMENT
- DUAL GATE GaAs MESFET CROSSPOINT SWITCH
- 15 LBS, 10 W



TECHNOLOGY DEVELOPMENT

- BROADBAND SWITCHING ELEMENTS (2.5 GHz)
- BROADBAND DIRECTIONAL COUPLERS
- LOW LOSS, LOW VSWR

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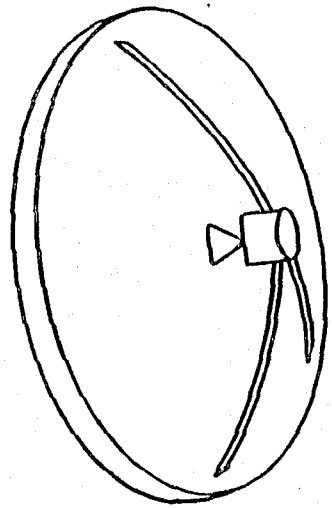
3.6.6 60-GHz Crosslink

The 60-GHz crosslink subsystem user frequency division multiplex and maintains the coherence of the crosslink signals. The crosslink signals are heterodyned through the repeater; there is no need to demodulate them.

A 25 watt transmitter and a 4 meter dish are required to support a 1.8 Gbps crosslink. Both power generation and reflector smoothness are key technology developments.

60 GHz CROSSLINK SUBSYSTEM

- 4 METER DISH
- 25 W TRANSMITTER
- 1000° K RECEIVER
- NO DEMODULATION OF USAT SIGNALS
- 1.8 GBPS RETURN LINK CAPABILITY
- FREQUENCY DIVISION MULTIPLEX
- ACCOMMODATES NAVIGATION DATA (DOPPLER, PN)
- SIMPLE POINTING AND TRACKING SUBSYSTEM
- 460 LBS, 200 W



TECHNOLOGY DEVELOPMENT

- REFLECTOR SURFACE SMOOTHNESS
- LOW LOSS FEED
  - BEAM WAVE GUIDE
- RF POWER GENERATION
  - TWT (CAVITY COUPLED OR RING-PLANE)
  - IMPATT
    - -- POWER COMBINING
    - -- IMPROVED CONTROL OF DOPING DENSITY PROFILE

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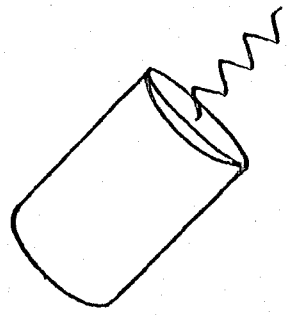
3.6.7 Laser Crosslink

The laser crosslink uses a GaAs laser with phase or frequency modulation and heterodyne detection. There is no need to demodulate the user spacecraft signals at the repeater.

Power generation is the key technology issue. Promising techniques to achieve one watt of transmitter power include both coherent and noncoherent power combining and multidiode arrays with inverse spectroscopic combining.

LASER CROSSLINK SUBSYSTEM

- GaAs DIODE LASER
- CURRENT INJECTION MODULATOR
- PHASE OR FREQUENCY MODULATION
- HETERODYNE DETECTION RECEIVER
- 1.8 GBPS RETURN CAPACITY
- ACCOMMODATES NAVIGATION DATA (DOPPLER, PN)
- BEACON LASER FOR ACQ/TRK
- 240 LBS, 250 W



TECHNOLOGY DEVELOPMENT

- 1 W TRANSMITTER
  - COHERENT OR NONCOHERENT POWER COMBINING
  - MULTIDIODE ARRAY WITH INVERSE SPECTROSCOPIC COMBINING
- LOW NOISE PHOTODETECTOR
  - 3 TO 5 DB IMPROVEMENT IN AVALANCH MULTIPLICATION NOISE
- IMPROVED FREQUENCY STABILITY OF TRANSMIT LASER
  - LINE WIDTHS < 1 MHZ
- PHASE LOCKED RECEIVER
  - LOW INTENSITY NOISE LO
  - GOOD SPATIAL MODE MATCHING (< ½ DB LOSS)
  - WIDEBAND DETECTOR (2-4 GHZ)

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3.7 SPACECRAFT WEIGHT AND POWER SUMMARY

The table presents a comparison of the TDAS spacecraft weight and power estimates with the weight and power requirements of the TDRSS spacecraft.

The weights of the two spacecraft are comparable. The TDRSS weight includes 1700 pounds for the Advanced WESTAR package which is primarily fuel. The TDAS spacecraft will have over 2000 pounds of enhancements instead of the Advanced WESTAR package.

The TDAS spacecraft will require more power than the TDRSS spacecraft, 3000 W versus 1700 W.

SPACECRAFT WEIGHT/POWER ESTIMATE SUMMARY

	TDRS	TDAS	
		LASER X-LINK	60 GHZ X-LINK
WEIGHT:	5000 LBS	5230 LBS	5450 LBS
POWER:	1700 W	3050 W	3000 W

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SECTION 4

TDAS GROUND SEGMENT

- ARCHITECTURE GOALS
- TDAS NETWORK
- TDAS GROUND TERMINAL
- SPACE SEGMENT CONTROL
- GROUND TERMINAL OPERATIONS PHILOSOPHY
- GROUND SEGMENT ARCHITECTURAL IMPACT

4.1 GROUND SEGMENT ARCHITECTURE GOALS

The ground segment architecture goals stem from the overall TDAS architecture goals. A primary ground segment architecture goal has been to provide USAT TT&C and mission data directly to the mission control centers.

Other goals of the ground segment architecture have been: downlink data rates of 600 Mbps or greater at each site; 99.9% rain availability; no impacts on the users of TDRSS; and emergency backup of all control functions.

GROUND SEGMENT ARCHITECTURAL GOALS

- 5 SITES IN CONUS THAT CAN RECEIVE MISSION DATA AND CONTROL MISSION EXPERIMENTS.
- DOWNLINK DATA RATE CAPACITIES 600 MBPS TO 1 GBPS AT EACH SITE.
- OUTAGE CAUSED BY RAIN ATTENUATION WILL NOT EXCEED 0.1%
- NO IMPACTS ON THE USERS OF TDRSS.
- EMERGENCY BACKUP OF CONTROL FUNCTIONS.

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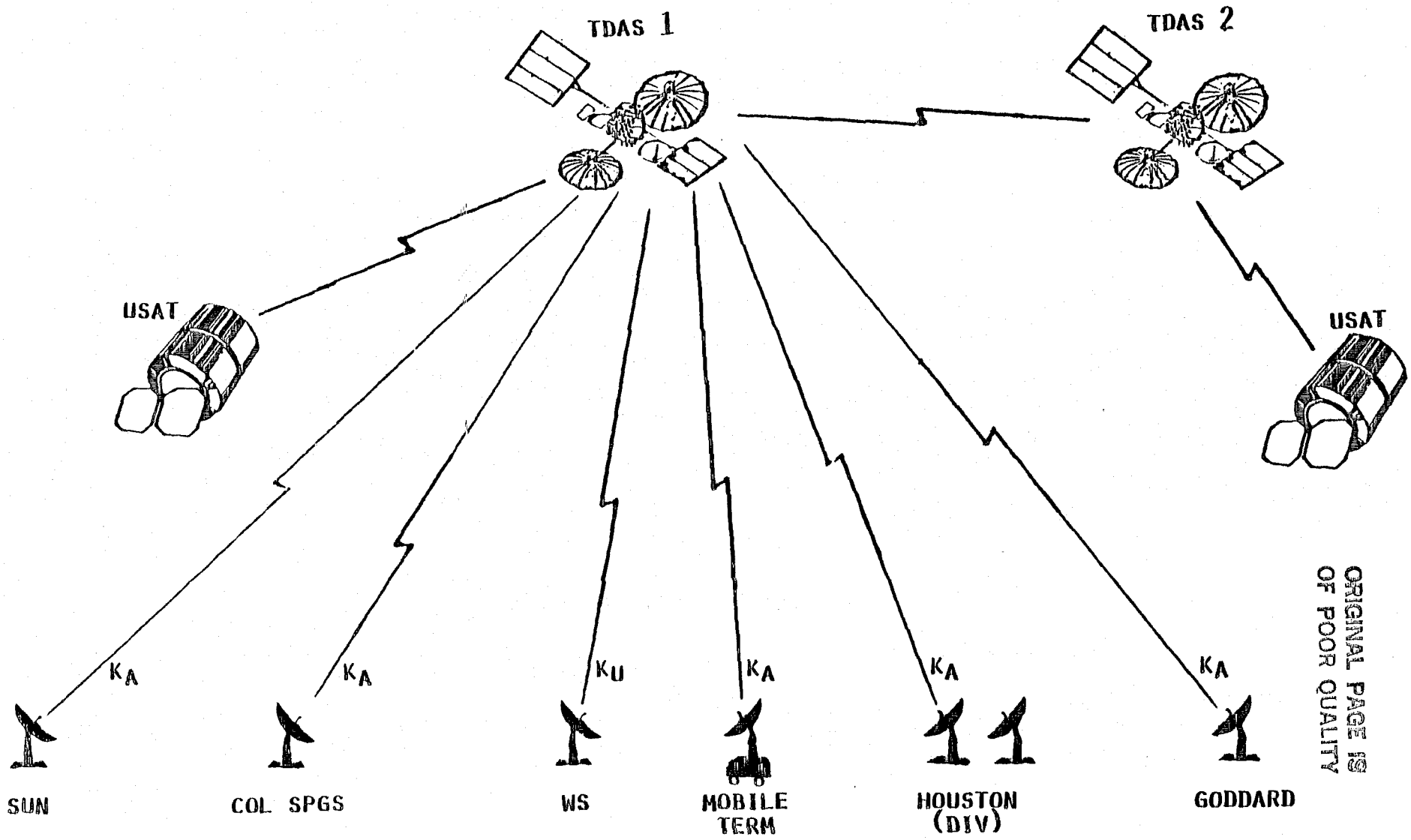
4.2 TDAS GROUND SEGMENT ARCHITECTURE

The figure displays the TDAS ground segment architecture for the 2-satellite constellation. The use of the K_u-band space/ground link is retained at White Sands to maintain continuity of the TDRSS services and K_a-band space/ground links are used at the other TDAS sites including mobile terminals. Diversity operation is required to achieve 99.9% availability on the Houston downlink at K_a-band.

TDAS GROUND SEGMENT ARCHITECTURE



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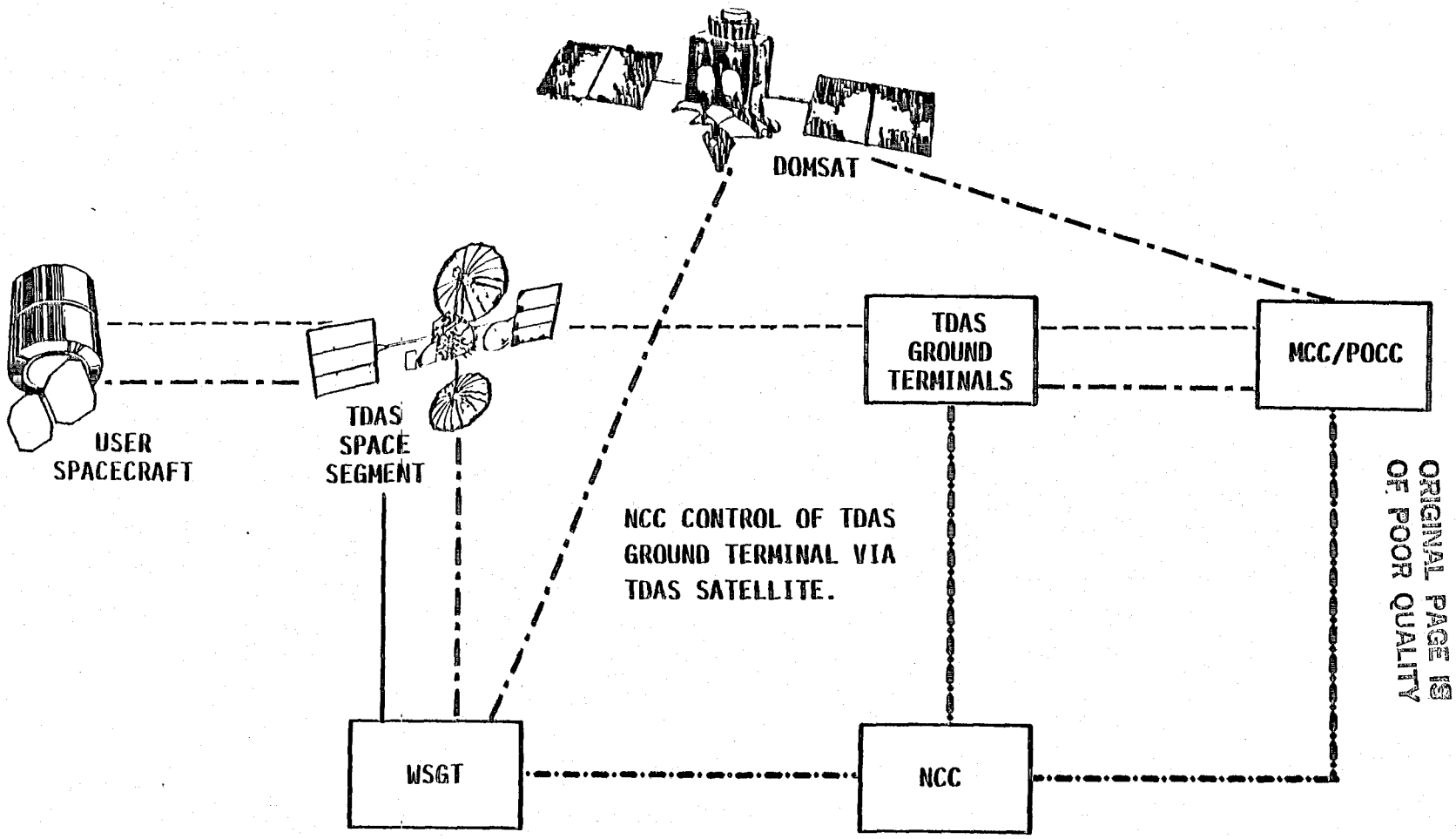
4.3 THE TDAS NETWORK VS THE TDRSS NETWORK

In TDRSS all user data is first sent to the White Sands ground terminal. High rate user data is then relayed via DOMSAT to the users' mission control centers. TDAS eliminates the need for the DOMSAT relay by distributing data directly to the ground terminals serving the users' mission control centers. The users also have more direct access to the TDAS space relay and their spacecraft through this ground terminal.

TDAS NETWORK/TDRSS NETWORK



TDAS USER DATA AND TT&C

TDRSS USER HIGH RATE DATA AND TT&C

SCHEDULING, MONITORING OPERATIONS

SPACE SEGMENT CONTROL

TDAS ELIMINATES THE NEED FOR THE DOMSAT RELAY.

USERS HAVE MORE DIRECT CONTROL OF THEIR SPACE-CRAFT AND EXPERIMENTS.

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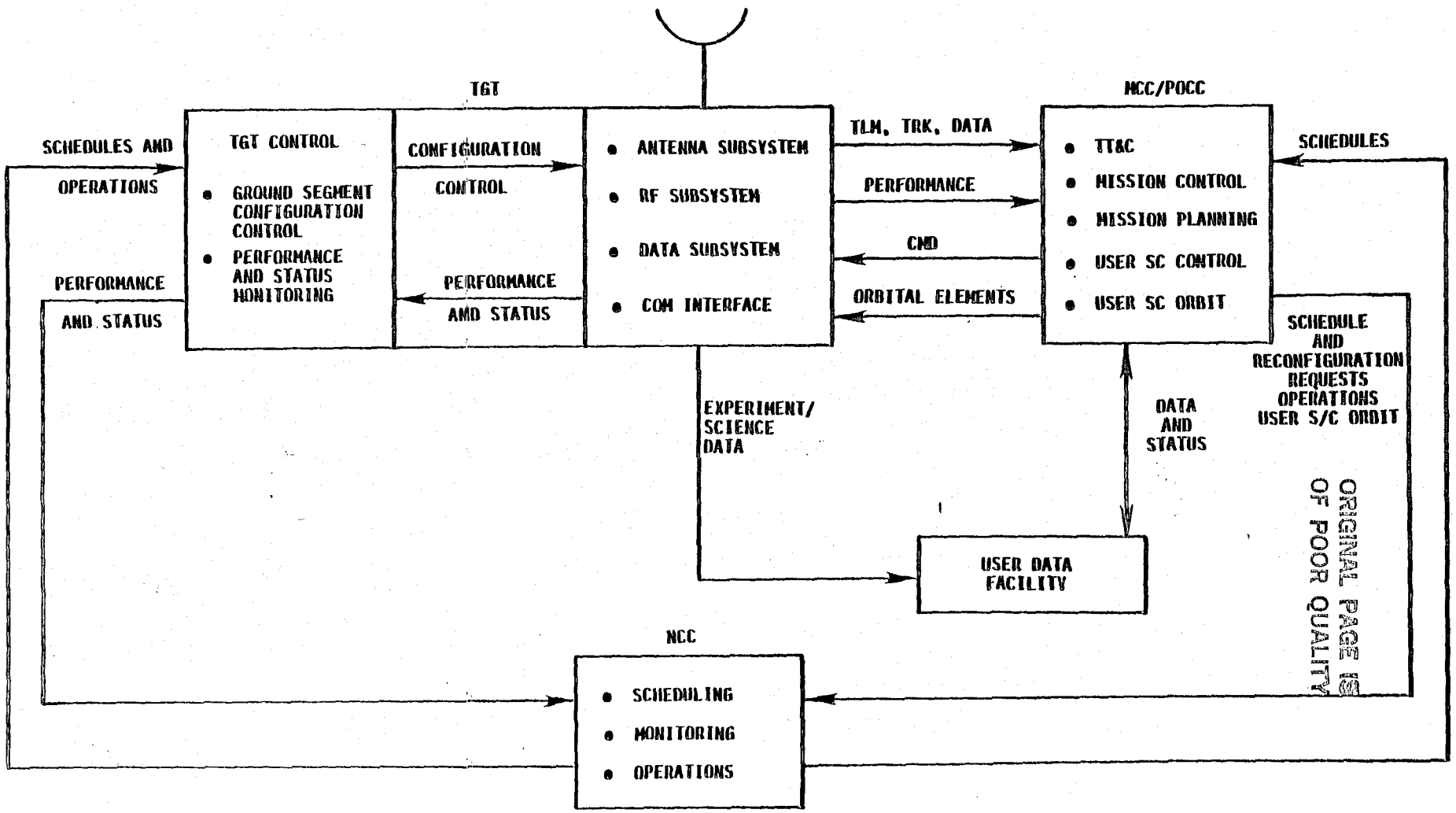
4.4 TDAS GROUND TERMINAL

TDAS requires a distributed ground terminal architecture to accomodate the multibeam space/ground links. A new network element must be defined to implement the distributed architecture. The new element is the TDAS Ground Terminal (TGT) which provides the interface for all network elments requiring access to the space relays. Thus, the TGT will be a modular element common to all ground terminals in the TDAS network.

The figure displays a functional block diagram of the TGT and the interfaces to other network elements. The TGT includes a monitoring and control element which controls the configuration of the TGT subsystems and monitors their performance and status. The TGT control element communicates with the NCC, deriving configuration messages from NCC scheduling messages and sending performance and status data to the NCC.

TDAS GROUND TERMINAL
CONTROL AND INTERFACES



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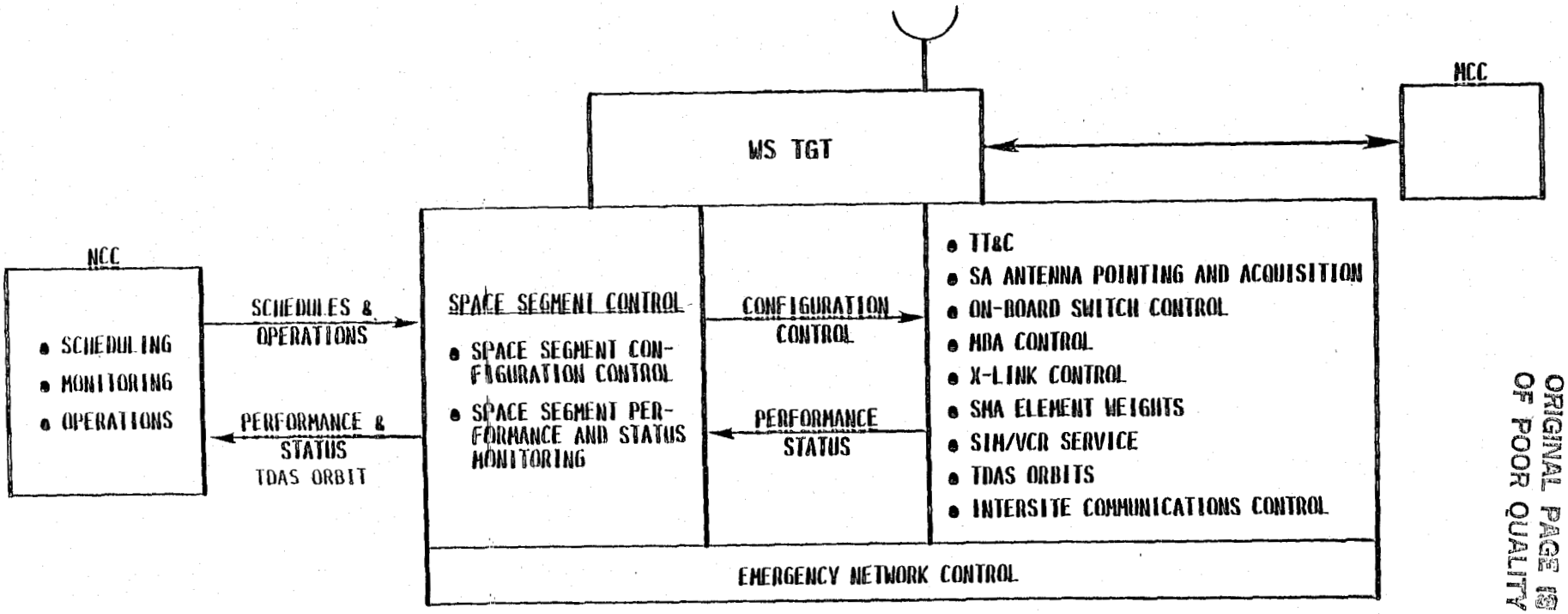
4.5 THE WHITE SANDS GROUND TERMINAL

The White Sands Ground Terminal (WSGT) controls the space segment configuration; it communicates with the NCC, deriving configuration control for the space segment from NCC scheduling messages, and returns performance and monitoring data back to the NCC. A space segment control element is shown (TOCC, TDAS Operations Control Center), as well as the functions and processes that determine the configuration of the space segment. The WSGT includes a TGT to interface it to the TDAS space relay. The backup emergency network control function is also shown to reside at White Sands.

In the TDAS timeframe, WSGT must be augmented to accomodate the new services and technologies, such as the WSA, the MBA, the onboard switch, and the crosslink. On the otherhand, SMA beamforming and autotrack functions performed at WSGT for TDRSS will be moved to the space segment.

TDAS SPACE SEGMENT CONTROL VIA WSGT WHITE SANDS TGT

- WSGT AUGMENTED TO ACCOMODATE NEW SERVICES AND TECHNOLOGIES



FUNCTIONS MOVED TO SPACE SEGMENT:

- BEAMFORMING
- AUTOTRACK

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4.6 TGT CONFIGURATION CONTROL

Each TDAS ground segment network element has a TGT to interface it with the space segment. TDAS ground segment control is distributed to each TGT; that is, each TGT controls its own configuration on the basis of NCC scheduling and operations messages.

The TGT subsystems are capable of autonomous operations and recovery. Each possesses distributed monitoring and control intelligence and fully redundant equipment strings.

The TGT has an executive monitoring and control computer and microprocessor interfaces with each subsystem.

TDAS GROUND TERMINAL OPERATIONS PHILOSOPHY

- AUTOMATIC CONTROL AND MONITORING
- AUTONOMOUS OPERATIONS AT SUBSYSTEM LEVEL
- MANUAL OVERRIDE AT SUBSYSTEM LEVEL
- FAIL-SOFT AT SUBSYSTEM LEVEL
- REDUNDANCY

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TDAS GROUND TERMINAL CONFIGURATION CONTROL ARCHITECTURE

- DISTRIBUTED MONITORING AND CONTROL SYSTEM
- MICROPROCESSOR INTERFACE WITH EACH STRING OF COMMUNICATIONS HARDWARE AND CENTRAL/EXECUTIVE CONTROL COMPUTER
- FULL REDUNDANCY FOR EACH STRING OF COMMUNICATION HARDWARE
- MICROPROCESSOR:
  - AUTOMATICALLY CORRECTS STRING EQUIPMENT FAULTS BY SWITCHING IN REDUNDANT UNIT;
  - AUTONOMOUSLY ADJUSTS STRING EQUIPMENT TO CORRECT FOR SIGNAL ANOMALIES TO OPTIMIZE PERFORMANCE AND DATA OPERATIONS
- AUTOMATIC CONFIGURATION/RECONFIGURATION OF EACH COMMUNICATION STRING VIA DEDICATED MICROPROCESSOR ON INSTRUCTION FROM EXECUTIVE CONTROL COMPUTER
- MANUAL CONTROL OF COMMUNICATION STRING VIA MICROPROCESSOR KEYBOARD
- EXECUTIVE CONTROL COMPUTER INTERFACES WITH NCC.

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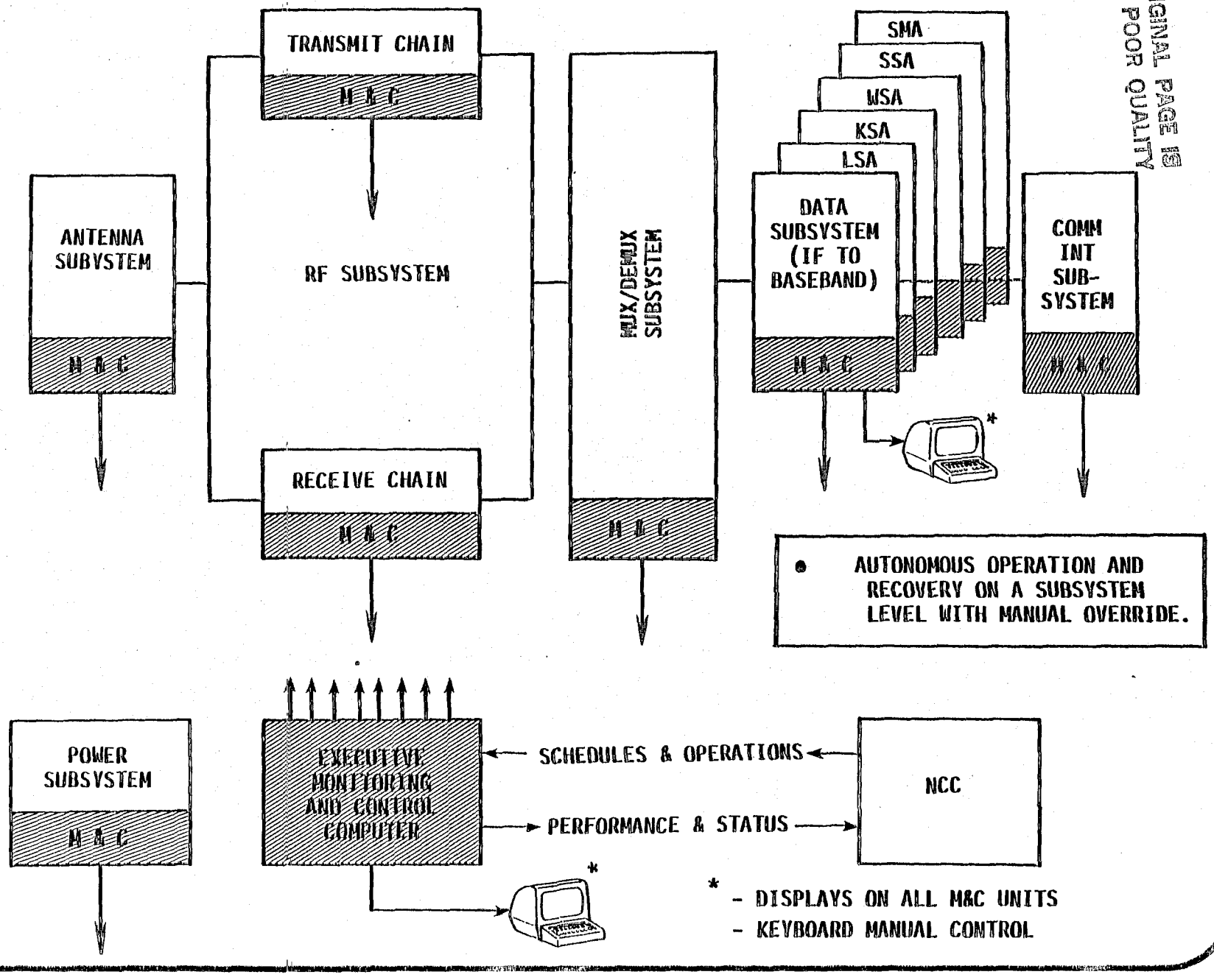
4.7 TGT MONITORING AND CONTROL ARCHITECTURE

The TGT monitoring and control architecture is depicted in the figure. The executive monitoring and control computer communicates with each of the subsystem microprocessors, sending each: set-up data; configuration control messages; real-time operations data; and test commands. The subsystem microprocessor reports performance and status back to the executive computer. The executive computer responds to NCC scheduling and operations messages. The subsystems operate autonomously, automatically switch in redundant equipment strings to recover from faults, and respond to manual override.

TGT MONITORING AND CONTROL ARCHITECTURE



- AUTONOMOUS OPERATION AND RECOVERY ON A SUBSYSTEM LEVEL WITH MANUAL OVERRIDE.

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4.8 GROUND SEGMENT IMPACTS ON TDAS ARCHITECTURE

A two satellite constellation, one frontside and one backside operating at K_a band, is the preferred choice to meet NASA requirements in the TDAS timeframe. Continued K_u-band operation for the White Sands space/ground link allows TDRS compatibility in the transition from TDRSS to TDAS.

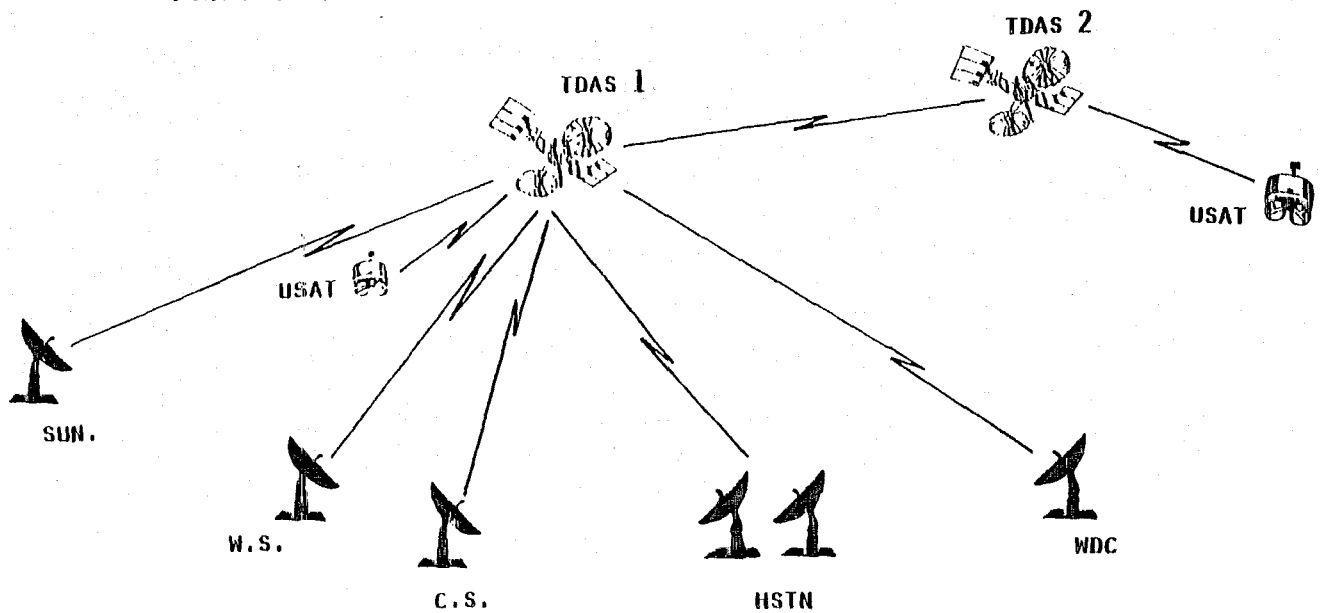
GROUND SEGMENT IMPACTS ON TDAS ARCHITECTURE

DRIVERS:

- DISTRIBUTE DATA DIRECTLY TO SEVERAL GEOGRAPHICALLY DISPERSED USERS.
- SUPPORT USERS WITH DATA RATES GREATER THAN 300 MBPS.

FINDINGS:

- K_U-BAND SPACE/GROUND LINK TO WHITE SANDS IS REQUIRED TO MAINTAIN TDRSS COMPATIBILITY
- K_A-BAND SPACE/GROUND LINKS TO ALL OTHER SITES IS PREFERABLE TO K_U-BAND.
- A TWO-SATELLITE CONSTELLATION, 1 FRONTSIDE AND 1 BACKSIDE, MINIMIZES THE IMPACT OF RAIN ATTENUATION AT ALL CONUS SITES. DIVERSITY OPERATION ONLY REQUIRED AT HOUSTON.



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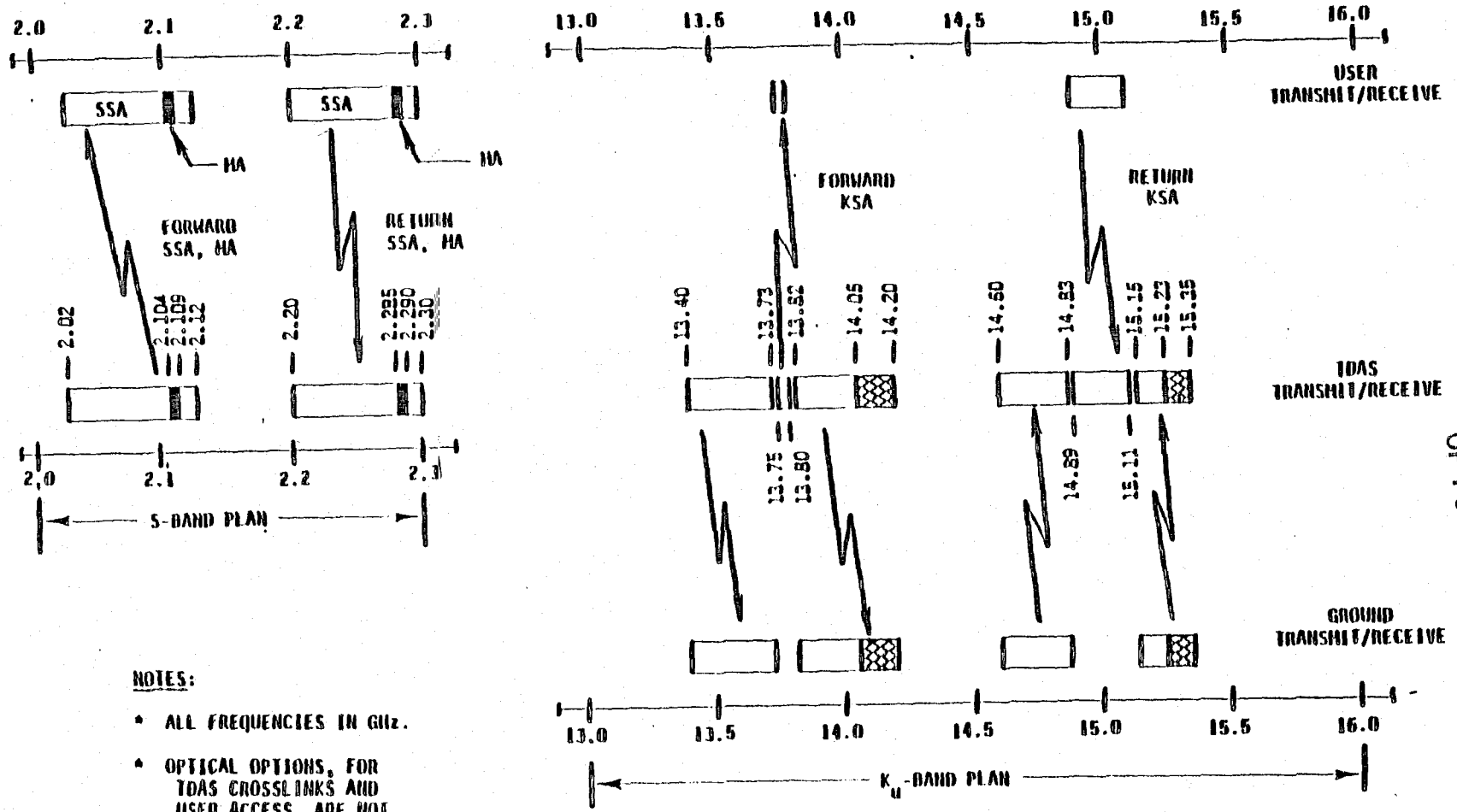
4.9 TDAS FREQUENCY PLANNING

The following two figures present frequency plans for TDAS. With the exception of adding spectrum to the K_u-band space/ground link, the S and K_u plans are identical to the TDRSS frequency plans. Frequency plans are shown for the TDAS K_a-band space/ground link and the TDAS W-band single access service.

S-BAND AND K_U-BAND FREQUENCY PLANNING

OPTIONS FOR TDAS



NOTES:

- ALL FREQUENCIES IN GHz.
- OPTICAL OPTIONS, FOR TDAS CROSSLINKS AND USER ACCESS, ARE NOT SHOWN.

FREQUENCY BANDS NOT INCLUDED IN TDRSS PLAN.

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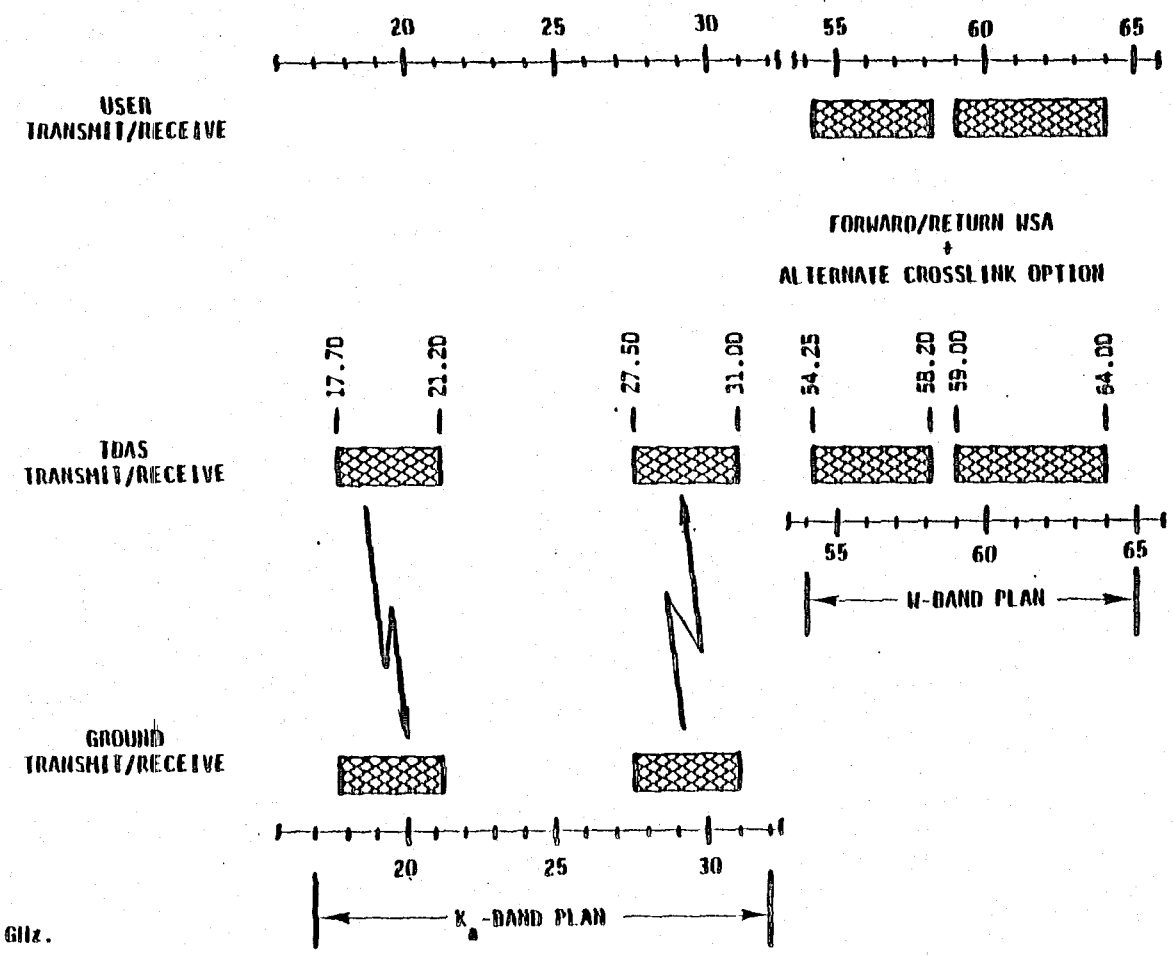
K_A-BAND AND W-BAND FREQUENCY PLANNING

OPTIONS FOR TDAS



NOTES:

- ALL FREQUENCIES IN GHz.
- OPTICAL OPTIONS, FOR TDAS CROSSLINKS AND USER ACCESS, ARE NOT SHOWN.

FREQUENCY BANDS NOT INCLUDED IN TDRSS PLAN.

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SECTION 5

TDAS NAVIGATION

- ARCHITECTURE GOALS
- ONE-WAY USER NAVIGATION ALTERNATIVES
- NAVIGATION ERROR SOURCES
- NAVIGATION PERFORMANCE SUMMARY
- SUMMARY OF USER NAVIGATION SUPPORT
- CONCLUSIONS

5.1 TDAS NAVIGATION ARCHITECTURE GOALS

The goals of the TDAS navigation architecture have been to reduce the requirements for complex two-way operations, support user onboard orbit and time determination, and satisfy users in the TDAS mission model with accuracy requirements down to 10 meters.

TDAS NAVIGATION ARCHITECTURE GOALS

- REDUCE GROUND REQUIREMENTS FOR ROUTINE TWO-WAY TRACKING SUPPORT.
- SUPPPORT ON-BOARD ORBIT AND TIME DETERMINATION.
- SATISFY USERS IN THE TDAS MISSION MODEL WITH ACCURACY REQUIREMENTS DOWN TO 10 METERS.

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5.2 USER ONE-WAY NAVIGATION ALTERNATIVES

Three one-way navigation techniques were evaluated: forward link beacon tracking (FLBT); forward link scheduled tracking (FLST); and return link scheduled tracking (RLST).

With FLBT, tracking signals are available continuously and the USAT performs the R and $\dot{R}$ measurements and orbit/time computation. In the scheduled tracking techniques, tracking signals are only available when scheduled. The R and $\dot{R}$ measurements and orbit/time computation are made by the USAT in FLST and by the ground segment in RLST. The ground segment periodically updates the USAT's navigation data in RLST.

USER ONE-WAY NAVIGATION ALTERNATIVES

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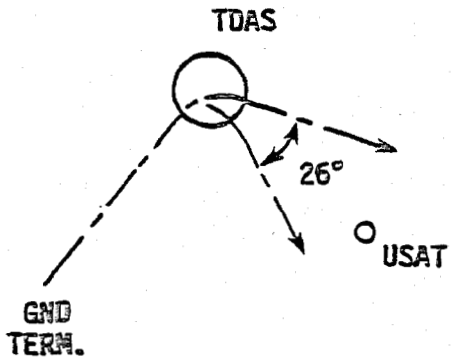
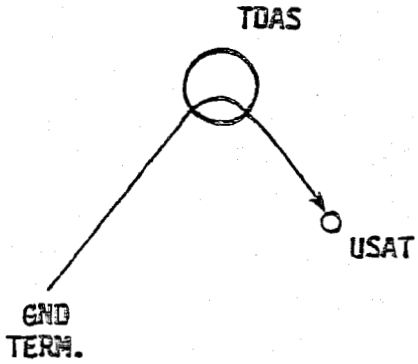
FORWARD LINK BEACON TRACKING (FLBT)



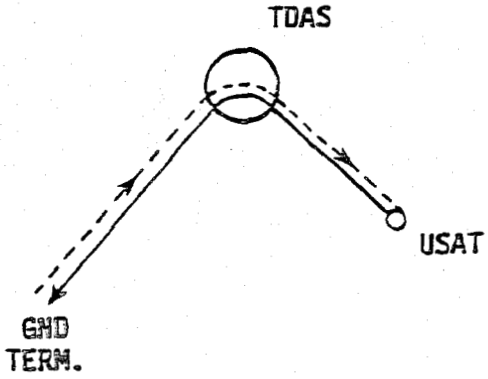
- NEAR CONTINUOUS DATA RATE
- ON-BOARD R,$\dot{R}$ MEASUREMENT & ORBIT/TIME COMPUTATION

FORWARD LINK SCHEDULED TRACKING (FLST)



- ON-BOARD R,$\dot{R}$ MEASUREMENT & ORBIT/TIME COMPUTATION

RETURN LINK SCHEDULED TRACKING (RLST)



- GROUND-BASED R,$\dot{R}$ MEASUREMENT & ORBIT/TIME COMPUTATION
- PERIODIC NAV. DATA UPLOAD FOR USER PROPAGATION

5.3 ERROR SOURCES FOR BEACON TRACKING

The accompanying table lists the source and magnitude of various errors for both current and projected capabilities. The principal error for beacon tracking stems from the model used to account for the effects of gravity. Model improvements, however, are expected to reduce this error by at least a factor of 5 by the early 1990's.

For beacon tracking drag has only secondary effects on accuracy for users with orbits above 200 km.

TDAS orbit and velosity determination is projected to be improved by 100%; however, a minimal BRTS configuration (2 BRTS per spacecraft) will not satisfy this projection, whereas VLBI techniques will meet the projected accuracy.

User oscillator drift has negligible impact on beacon accuracy.

ERROR CONTRIBUTOR SUMMARY FOR BEACON TRACKING
(SEQUENTIAL DATA PROCESSING)

ERROR CONTRIBUTOR	MODELING ASSUMPTIONS FOR ANALYSIS	ORBIT DETERMINATION IMPACT FOR 40 m ACCURACY	PROJECTED REQTS. FOR 10 m ACCY.* 30 m ACCY.**	COMMENTS
GRAVITATIONAL HARMONICS MODEL	100% GEM-9 ERROR	MAJOR	20% GEM-9 ERROR	$\geq$ 10:1 IMPROVEMENT ANTICIPATED BY EARLY 1990'S
DRAG COEFFICIENT (C_D) (<600 Km ORBITS)	2.5% OF NOMINIAL C_D (RESIDUAL ERROR)	SECONDARY	SAME AS MODEL	OPTIMIZE PROCESSOR TUNING PARAMETERS
TDAS ORBIT ERROR	50 m POS. 5 mm/s VEL.	SECONDARY	25 m POS. 2.5 mm/s VEL.	- MINIMAL BRTS CONFIG. CANNOT MEET PROJECTED REQT. - VLBI TRACKING MEETS PROJECTED REQT.
USER OSC. DRIFT	10^{-10}/DAY	NEGLIGIBLE	SAME AS MODEL	CURRENTLY AVAILABLE CAPABILITY

*98°, 600 KM ORBIT
**98°, 200 KM ORBIT

+ GEM-9 = GODDARD EARTH MODEL 9 (1979)

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5.4 BEACON TRACKING PERFORMANCE SUMMARY

Current and projected position errors are shown in the figure for three user orbit classes and three TDAS constellations. The figure demonstrates that beacon tracking satisfies users in the TDAS mission model with accuracy requirements down to 10 meters.

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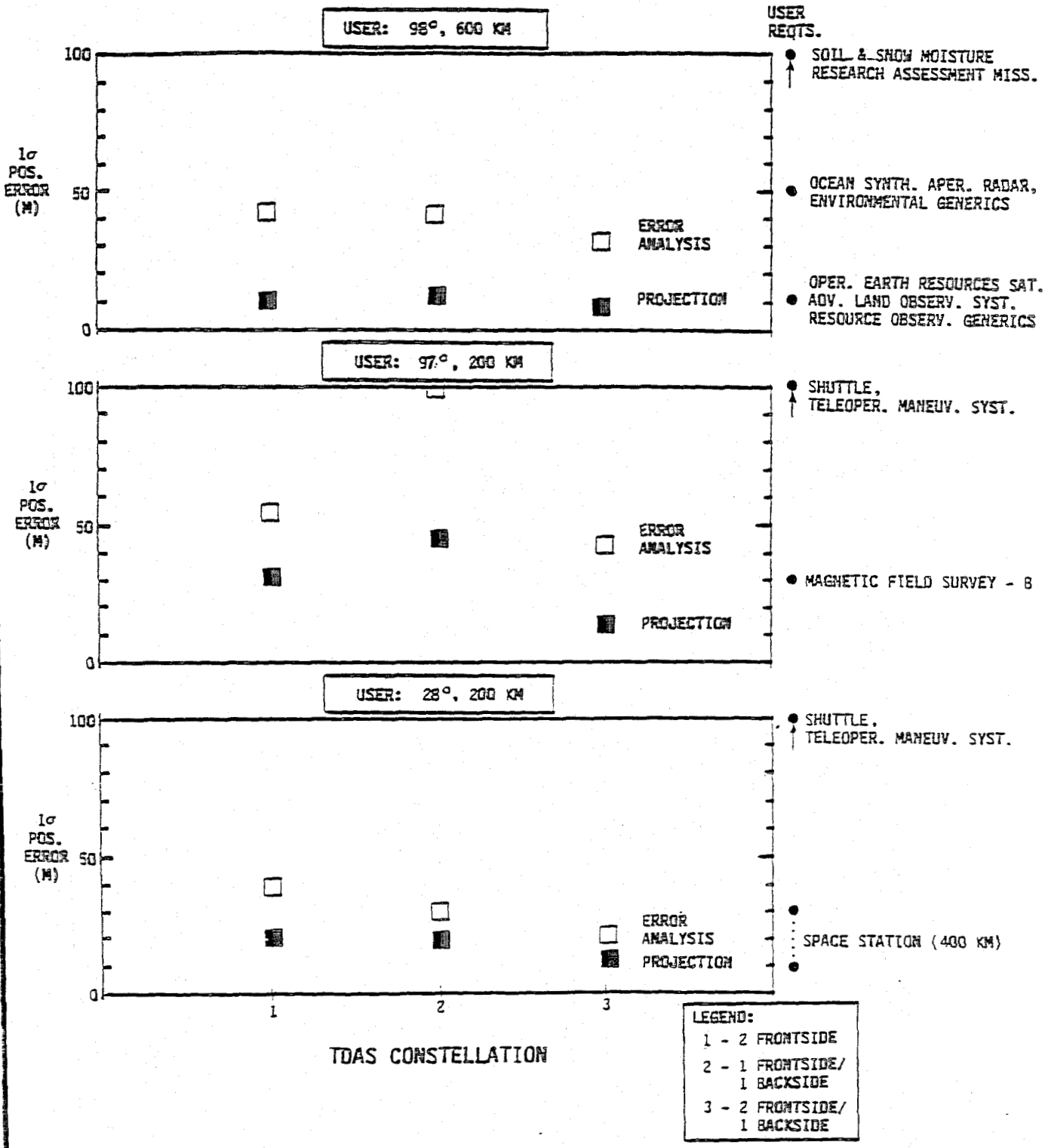
USER NAVIGATION PERFORMANCE SUMMARY - BEACON TRACKING



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5.5 FORWARD LINK SCHEDULED TRACKING PERFORMANCE SUMMARY

FLST satisfies users in the TDAS mission model with orbits greater than 600 km and accuracy requirements down to 10 meters. Projections of position error are not made for lower-altitude users since drag is the primary source of error at these altitudes and is highly mission dependent. Modeling current capabilities leads to position errors in the 50 to 100 meter range for low altitude users.

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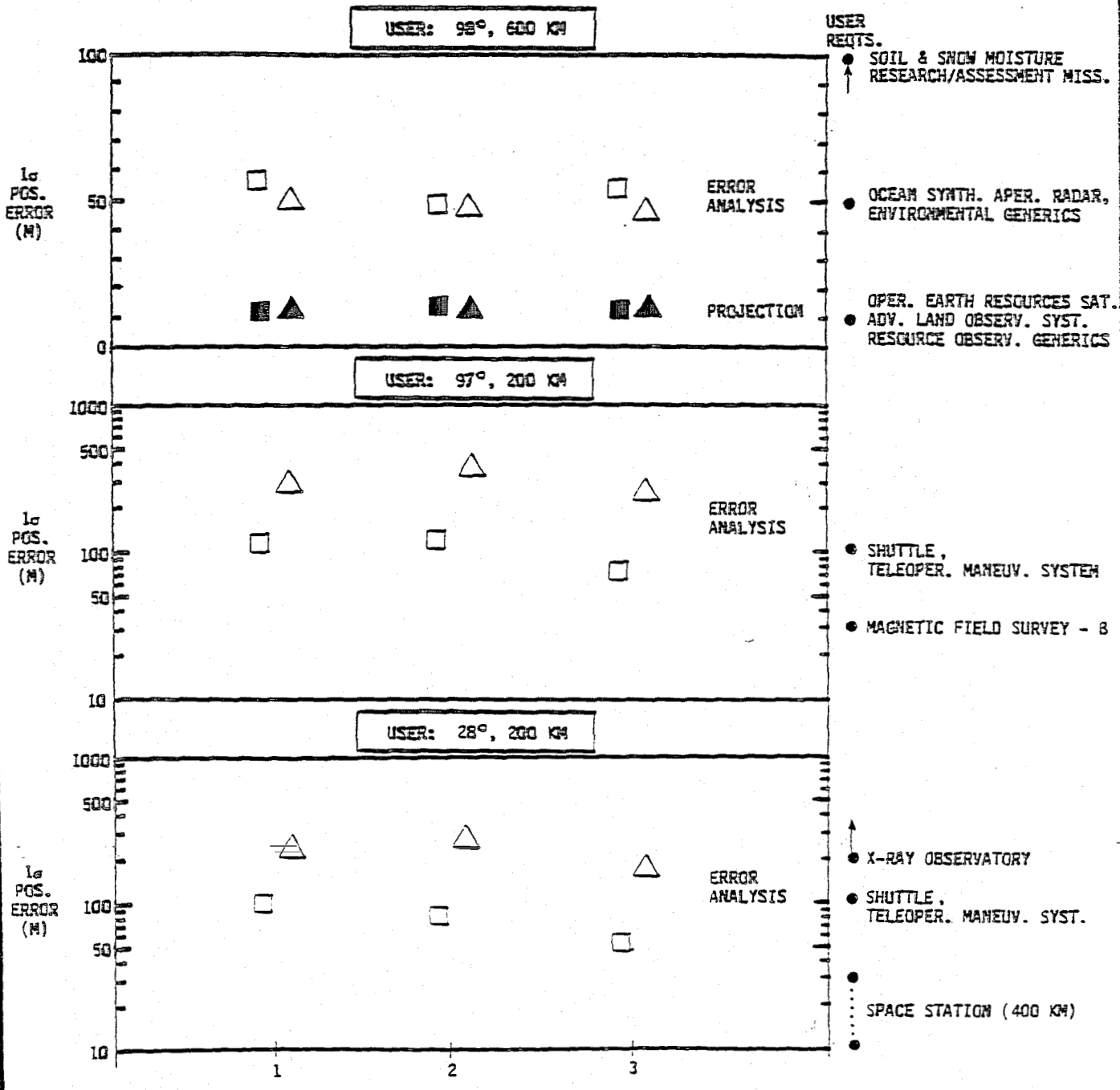
USER NAVIGATION PERFORMANCE SUMMARY - FORWARD LINK SCHEDULED TRACKING



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5.6 RETURN LINK SCHEDULED TRACKING PERFORMANCE SUMMARY

RLST satisfies users in the TDAS mission model with orbits greater than 600 km and accuracy requirements down to 10 meters. Projections of position error are not made for lower-altitude users, since drag is the primary source of error at these altitudes and is highly mission dependent. Modeling current capabilities leads to position errors in the 200 to 300 meter range for low altitude users.

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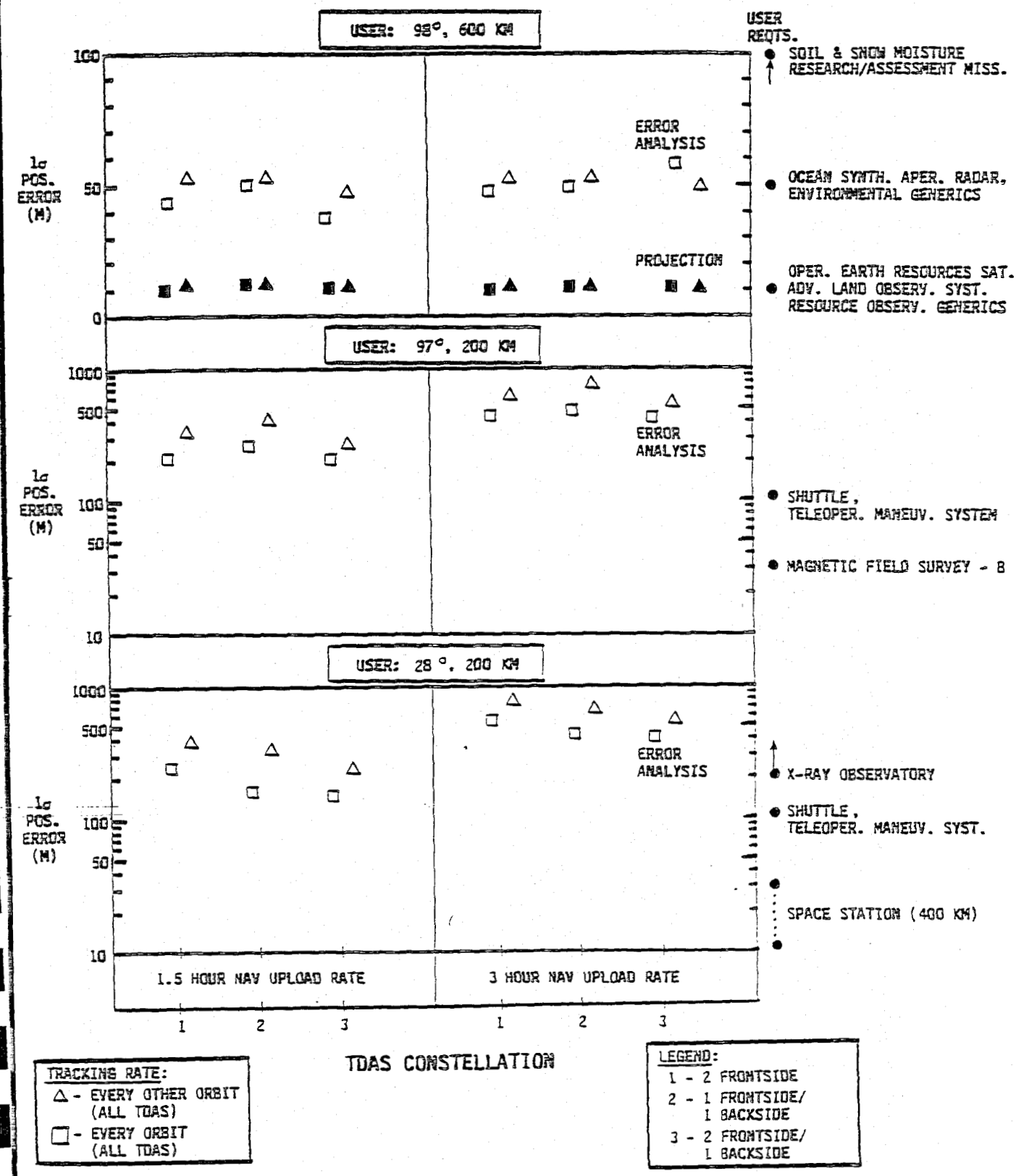
OF POOR QUALITY

USER NAVIGATION PERFORMANCE SUMMARY - RETURN LINK SCHEDULED TRACKING



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5.7 NAVIGATION STUDY CONCLUSIONS

The navigation study has demonstrated that beacon tracking can satisfy users in the TDAS mission model with accuracy requirements down to 10 meters. Both forward and return link scheduled tracking also meet accuracy requirements down to 10 meters for user with altitudes greater than 600 km. At lower altitudes scheduled tracking techniques are sensitive primarily to drag. Finally, projected TDAS tracking accuracy requirements can not be met with minimal BRTS configurations, (2 BRTS per spacecraft), but are satisfied with VLBI tracking.

NAVIGATION STUDY CONCLUSIONS

- TDAS BEACON TRACKING (FLBT) WILL MEET ALL POSITION ACCURACY REQUIREMENTS ($\geq$ 10 M) IN THE TDAS MISSION MODEL WITHOUT USING HIGH RISK TECHNOLOGY.

- SCHEDULED TRACKING ALTERNATIVES (FLST, RLST) CAN ALSO MEET THE ACCURACY REQUIREMENTS EXCEPT AT LOW ALTITUDES WHERE PERFORMANCE IS SENSITIVE TO:
  - DRAG UNCERTAINTY
  - FREQUENCY OF TRACKING PASSES AND/OR
  - FREQUENCY OF NAVIGATION DATA UPLOADS (RLST/ONLY).

- PROJECTED TDAS TRACKING ACCURACY REQUIREMENTS (25 M-POS. & 2.5 MM/SEC-VEL.) CAN BE MET WITH VLBI TRACKING BUT NOT WITH A MINIMAL* BRTS CONFIGURATION.

* 2 BRTS SITES PER TDAS S/C

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5.8 SUMMARY OF PROPOSED TDAS NAVIGATION FUNCTION

The TDAS architecture will accomodate all three one-way techniques in addition to two-way tracking. The table suggests a role for each technique. For example, beacon tracking is suggested for routine requirements, while forward and return link scheduled tracking are suggested for initial acquisition and TDAS antenna pointing, respectively. Two-way tracking is suggested for verification, while all techniques can be used for backup.

SUMMARY OF PROPOSED TDAS NAVIGATION FUNCTIONS

- TDAS ARCHITECTURE WILL ACCOMODATE ALL ONE-WAY AND TWO-WAY TRACKING TECHNIQUES.

USER SUPPORT FUNCTION		PROPOSED TECHNIQUE	RATIONALE
NAVIGATION	ROUTINE	BEACON TRACKING	- MAX. AVAILABILITY - MEETS REQUIREMENTS
	INITIAL ACQUISITION	SCHEDULED TRACKING (FORWARD LINK)	DOPPLER COMPENSATION AVAILABLE
	BACKUP	SCHEDULED TRACKING FWD. LINK / RTN. LINK / OR 2-WAY	PROVIDE REDUNDANCY VIA COMM. CHANNELS
	VERIFICATION	SCHEDULED TRACKING (2-WAY)	- GROUND-BASED OPNS. - QUALITY CONTROL
COMM./NAV.	TDAS ANTENNA POINTING	SCHEDULED TRACKING (RETURN LINK) OR BEACON TRACKING	- GROUND-BASED OPNS. - ACCURACY SUFFICIENT - DIRECT DOWNLINK TO NCC

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