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TRACKING AND DATA ACQUISITION SYSTEM FOR THE 1990's

VOLUME V

TDAS GROUND SEGMENT ARCHITECTURE AND OPERATIONS CONCEPT

DRAFT FINAL REPORT

Prepared by:
Robert Daly

Prepared for:
NASA/Goddard Space Flight Center
Greenbelt, MD 20771

STANFORD TELECOMMUNICATIONS INC.

6888 Elm St. • Suite 3A • McLean, VA 22101 • (703) 893-3220

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SECTION 1

INTRODUCTION

1.1 PURPOSE OF VOLUME V

Stanford Telecommunications Inc. undertook this study on behalf of NASA to develop and examine alternative TDAS architectures. The results of the study are reported in nine separate volumes. The purpose of this volume is to present the analyses and findings of the TDAS preliminary study obtained for the ground segment architecture and the operational concept. As indicated by the shaded aress in the study flow diagram, this volume addresses four principal tasks: the TDAS ground segment architecture; operational assessments; ground system technology assessments; and, in part, the overall architectural evaluation.

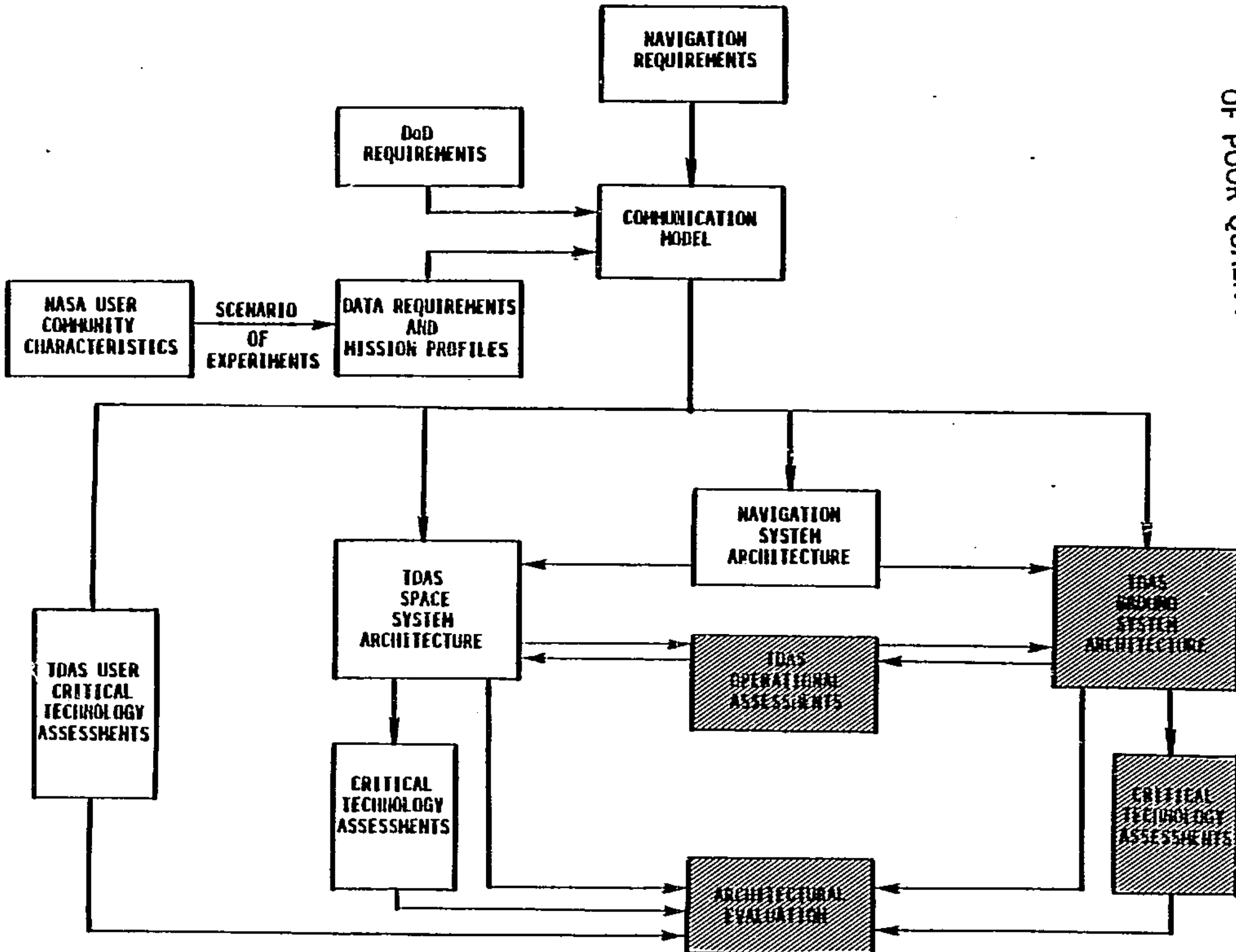
This report first develops ground segment and operational requirements. Then, after examining alternative RF terminal configurations, functional descriptions of the TDAS ground segment elements are inferred from the adopted TDAS control and operations concepts and the ground segment architectural goals. Functional descriptions of the ground segment elements lead to the definition of the TDAS network and required traffic flows. Finally the TDAS ground terminal hardware technologies are identified and assessed.

The nine TDAS reports are listed below:

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 IX	TDAS Cost Summaries

TDAS STUDY FLOW

SHADED AREAS ADDRESSED IN VOLUME V



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1.2 BACKGROUND

1.2.1 Role of the Ground Segment

The ground segment provides access to and from the TDAS space relays, connectivity among ground segment elements, and operations and control for both the space and ground systems. It consists of all of the antennas, RF equipment, baseband equipment, switching equipment, display and control equipment, computers, software, simulation units, buildings, utilities, communications, and support services required to maintain all ground segment operations.

THE ROLE OF THE GROUND SEGMENT

- PROVIDE ACCESS TO AND FROM TDAS RELAYS AND CONNECTIVITY IN THE GROUND NETWORK
- PROVIDE SPACE SYSTEM OPERATIONS AND CONTROL
- PROVIDE GROUND SYSTEM OPERATIONS AND CONTROL

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1.2.2 TDAS Ground Segment Architectural Goals

A primary goal of the ground architecture study has been to provide USAT TT&C and mission data directly to the mission control centers. Other goals include: downlink data rates equal to or exceeding 600 Mbps at each site; rain availability of 99.9%; no impacts imposed on the users of TDRSS; and emergency backup of all control functions.

GROUND SEGMENT ARCHITECTURAL GOALS

- 5 REPRESENTATIVE SITES IN CONUS THAT CAN RECEIVE MISSION DATA AND CONTROL MISSION EXPERIMENTS
- DOWNLINK DATA RATE CAPACITIES FOR RECEIVING MISSION DATA WILL MEET OR EXCEED 600 MBPS 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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1.2.3 From TDRSS to TDAS

The TDRSS ground segment consists of a single ground terminal with all of the equipment necessary to support the interfaces with the TDRSS space relays. The TDAS architectural goal of providing TT&C and mission data directly to the mission centers leads to the kind of multilink network depicted in the figure.

Thus, the TDAS ground segment is quite different than the TDRSS ground segment. The TDAS era begins in 1994, when the TDRSS service contract expires. The work reported on here begins the process of preparing for an orderly and effective transition from TDRSS to a new system that will meet NASA's tracking and data requirements for the 1990's.

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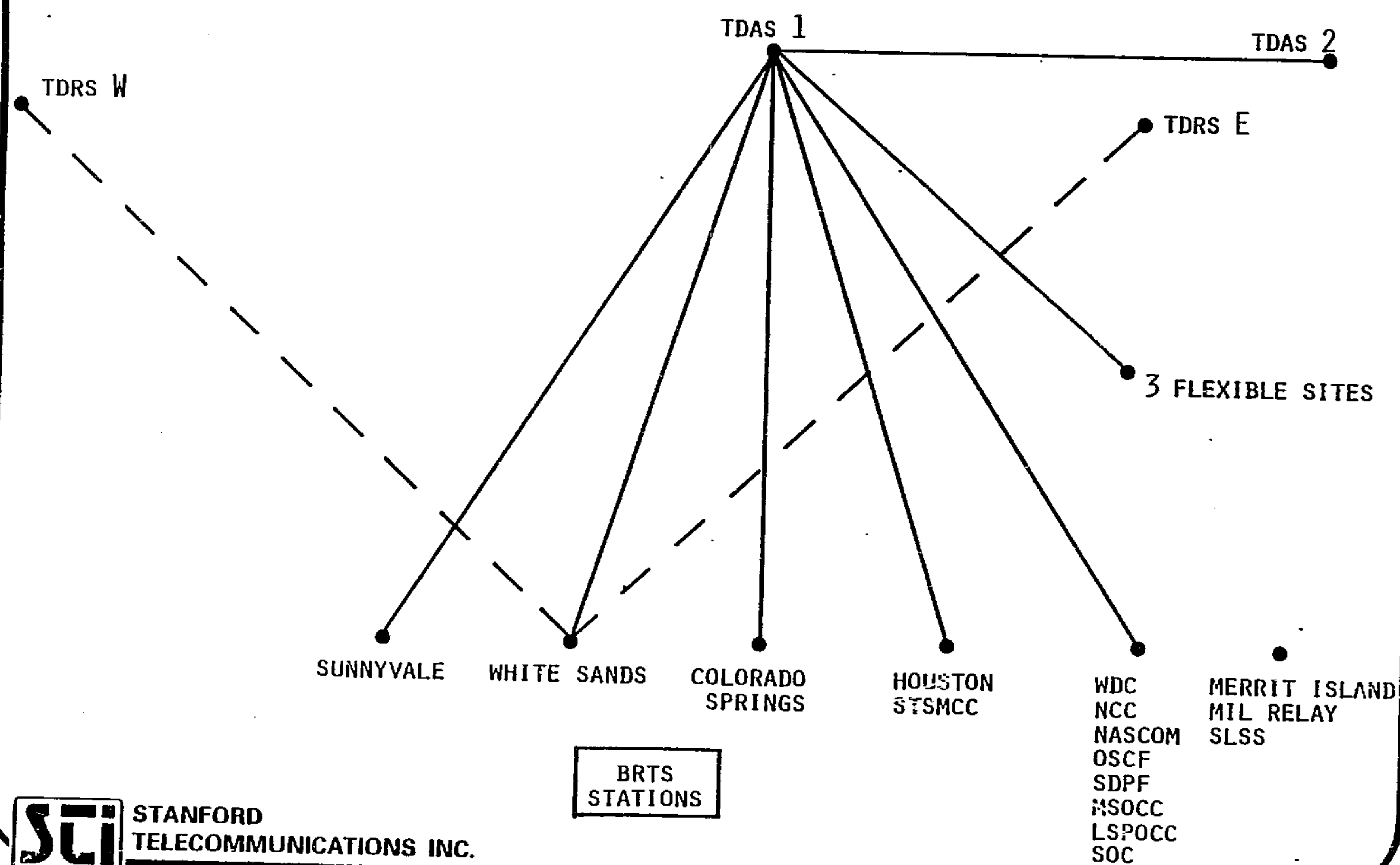
TDAS VS TDRSS ACCESS TO SPACE RELAYS



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1.2.4 Approach

After the TDAS space segment architecture was explored, the task statements of the preliminary TDAS study required the development and evaluation of alternative ground segment architectures. The accompanying figure illustrates the approach used to develop and evaluate ground segment alternative architectures.

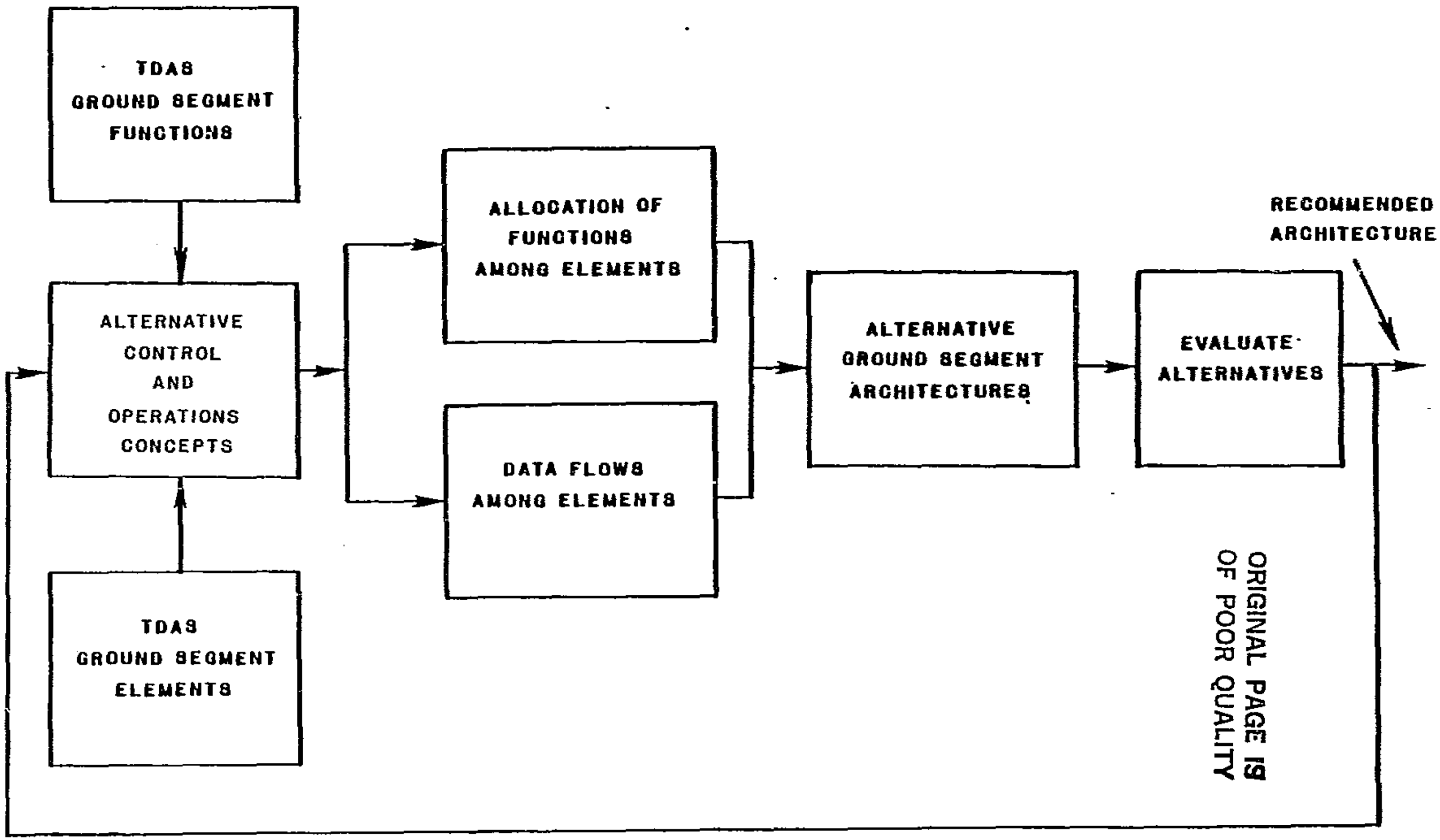
The process begins with the identification of TDAS ground segment functions and individual elements. Alternative operations and control concepts allow functions to be allocated to elements, thus defining an architecture and the flow of information between elements.

Alternatives are evaluated at both the element level, e.g. the impact of rain attenuation on RF terminal configuration, and at the systems level, e.g. the total downlink capacity of a specific architectural alternative.

The scheduling efficiencies of alternative TDAS system architectures are also evaluated here to assess channel availability and loading achieved by the TDAS services for different mission models.

TDAS GROUND SEGMENT

ARCHITECTURE DEVELOPMENT



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SECTION 2

SUMMARY

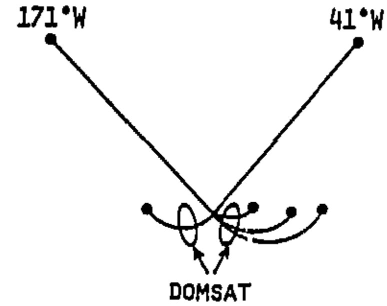
2.1 TDAS CONSTELLATION/NETWORK OPTIONS

TDAS will require a distributed ground terminal architecture to provide TT&C and mission data directly to the mission control centers (MCC's). Several TDAS constellation/network options featuring distributed ground terminal architectures are illustrated in the accompanying figure. Each option is consistent with one of three possibilities for enhancing the TDRS bus. While each option achieves the objective of providing TT&C and mission data directly to the MCC's, each will place different requirements on the TDAS ground segment architecture. For example, in option 1A Houston requires no antennas, but in option 3A it may require as many as four antennas, if diversity operation is required. Three classes of constellations have been considered for TDAS: two frontside satellites (option 1); one frontside and one backside satellite (option 2); and two frontside satellite with one backside satellite (option 3).

TDAS CONSTELLATION/NETWORK OPTIONS

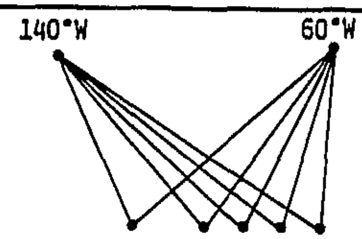
OPTION 1A:

ENHANCEMENTS
SMA
WSA



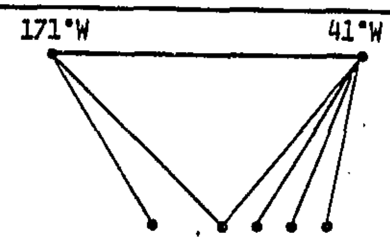
OPTION 1B:

ENHANCEMENTS
SMA
WSA
MBA
LSA



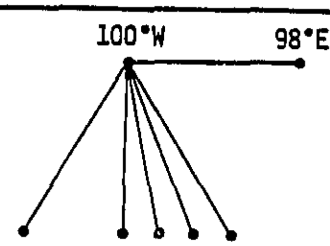
OPTION 1C:

ENHANCEMENTS
SMA
WSA
MBA
LSA
X-LINK



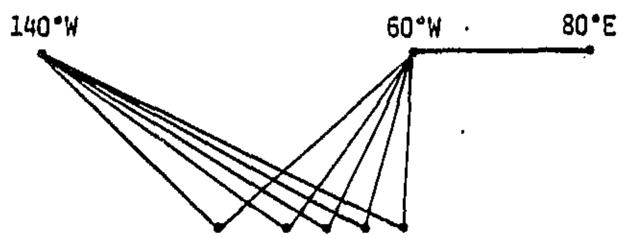
OPTION 2:

ENHANCEMENTS
SMA
WSA
MBA
LSA
X-LINK



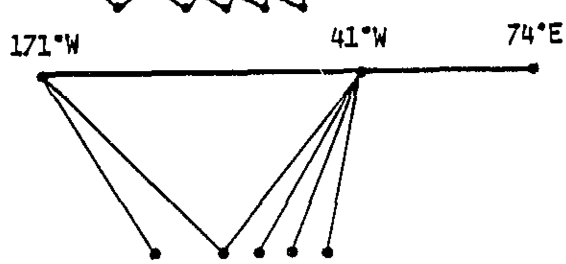
OPTION 3A:

ENHANCEMENTS
SMA
WSA
MBA
LSA
X-LINK



OPTION 3B:

ENHANCEMENTS
SMA
WSA
MBA
LSA
X-LINK



2.2 THE IMPACT OF SCHEDULING ON CHANNEL REQUIREMENTS

The table summarizes the results of simulating the scheduling processes for the NASA and DoD mission models. The simulation account for the characteristics of each mission: visibility; contact time; dump rate and the need for dedicated channels. The simulations yielded two important system performance measures, channel availability and channel loading, for various combinations of mission models and TDAS constellations. The results are referenced to a baseline TDAS spacecraft which has 2 KSA and 5 WSA channels.

Excellent channel availabilities around 99% can be achieved with all 2-spacecraft constellations for the NASA mission model with a 55% channel loading.

Adding the Dod missions causes the channel availability to deteriorate to 70% for 2 Baseline TDAS spacecraft. A three-spacecraft constellation achieves an excellent availability at 97% for the NASA + DoD Mission Model with a loading at 83%.

SUMMARY OF SA SCHEDULING PERFORMANCE FOR BASELINE TDAS DESIGN

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	83

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2.3 RAIN ATTENUATION AND DIVERSITY GAIN

Rainfall degrades the performance the space/ground link at K_u and K_a bands; severe attenuation and depolarization effects can occur and must be accounted for in the design of the ground terminal. Significant power margins or other RF techniques, such as space diversity, may be necessary to achieve acceptable system availability.

The accompanying table summarizes the single-site rain attenuation predicted by the Global model and the diversity gain predicted by the Kaul model for each of the TDAS ground locations and constellation options at three different operating frequencies for an availability of 99.9%.

Single-site rain attenuation is affected by regional rainfall rates and the elevation angle to the satellite. For large enough antenna spacings (10 km), diversity gain depends on local meterological conditions, i.e., the fraction of total local rainfall attributable to thunderstorms.

Significant rain attenuation occurs for both Washington D.C. and Houston at K_a band operation, especially for the uplink. Diversity gain displays a threshold effect. At any location, the relatively lower values of rain attenuation primarily result from stratiform rain. Since stratiform rain is constant over hundreds of kilometers, diversity improvement is not possible. Thunderstorm rain, on the other hand, contributes to the higher values of attenuation and is constant over much smaller regions measuring several kilometers. Diversity gain comes into play as the amount of thunderstorm rain increases.

Because of its larger elevation angles at each of the sites, constellation 2 achieves minimum rain attenuation among the constellation options.

RAIN ATTENUATION AND DIVERSITY GAIN*

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99.9% AVAILABILITY	15 GHz		20 GHz		30 GHz	
	RAIN ATTEN(dB)	DIV GAIN(dB)	RAIN ATTEN(dB)	DIV GAIN(dB)	RAIN ATTEN(dB)	DIV GAIN (dB)
SUNNYVALE						
IB + 3A (W)	2.1	0	4.0	0	9.0	0
IB + 3A (E)	6.1	0	11.2	1.9	25.6	2.9
IC + 3B	3.7	0	6.8	0	15.4	0
2	2.2	0	4.2	0	9.4	0
WHITE SANDS						
IB + 3A (W)	2.0	0	3.8	0	8.8	0
IB + 3A (E)	2.7	0	4.9	0	11.4	0
IC, 3B + 1A	5.7	0	10.6	0	24.6	2.2
2	1.5	0	2.8	0	6.4	0
COLORADO SPRINGS						
IB + 3A (W)	1.0	0	2.0	0	4.5	0
IB + 3A (E)	1.4	0	2.6	0	6.0	0
IC + 3B	3.3	0	6.1	0	13.9	0
2	0.8	0	1.4	0	3.2	0
HOUSTON						
IB + 3A (W)	14.5	5.5	26.1	11.8	55.0	22.2
IB + 3A (E)	12.6	4.3	22.7	9.5	47.5	17.3
IC + 3B	17.2	7.3	31.1	15.1	66.2	29.5
2	10.2	2.6	18.4	6.9	38.1	11.1
WASHINGTON, DC						
IB + 3A (W)	10.0	2.5	18.3	6.7	40.5	12.7
IB + 3A (E)	4.3	0	7.3	0	17.1	0
IC + 3B	5.2	0	9.5	0.3	21.0	0
2	4.5	0	8.1	0	17.9	0

*BASED ON 10 KM SPACING OF GROUND ANTENNAS.

2.4 TDAS DOWNLINK CONFIGURATIONS

The results of four downlink designs are summarized in the table. Both K_u and K_a band configurations are displayed for each of the constellation options 2 and 3A. Total downlink data rate, satellite power, number of satellites, and the number of ground antennas are shown for each configuration.

For either constellation option, the downlink data rate is doubled by moving from K_u to K_a band, with roughly the equivalent satellite power (1 db increase for 3A), the same number of satellites, and an additional ground antenna. The downlink data rate is also doubled for either frequency band by moving from option 2 to option 3A; however, the satellite power must be doubled, the number of ground antennas more than doubled and an additional satellite added. In terms of the comparisons given in this figure, K_a band operation of option 2 appears to be the most efficacious.

DOWNLINK CONFIGURATION COMPARISONS

	K_U BAND				K_A BAND			
OPTION / PARAMETER	TOTAL DOWNLINK DATA RATE (Mbps)	SATELLITE POWER (WATTS)	NUMBER OF SATELLITES	NUMBER OF GROUND ANTENNAS	TOTAL DOWNLINK DATA RATE (Mbps)	SATELLITE POWER (WATTS)	NUMBER OF SATELLITES	NUMBER OF GROUND ANTENNAS
CONSTELLATION OPTION 2	3000	203	2	5	6000	206	2	6
CONSTELLATION OPTION 3A	5700	398	3	12	12000	518	3	13

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2.5 UPLINK POWER REQUIREMENTS

At K_u band no more than 30 watts of power would be required to uplink 300 kbps at 99.9% availability from any site in all constellation options.

At K_a band no more than 100 watts of power would be required to uplink 300 kbps at 99.9% availability from any site, except Houston and Washington D.C., in all constellation options.

No more than 100 watts of power would be required to uplink 300 kbps at 99.5% availability from Houston and Washington, D.C. at K_a band.

Uplink power requirements for constellation 3A at Washington, D.C. and Houston at K_u and K_a bands are summarized in the figure.

UPLINK POWER SUMMARY
CONSTELLATION 3A

	K_u BAND		K_a BAND	
	RAIN ATTEN. db	UPLINK POWER W	RAIN ATTEN. dB	UPLINK POWER W
WASHINGTON D.C.	10 (99.9%)	5	40.5 (99.9%) 17.4 (99.5%)	1412 7
HOUSTON	14.5 (99.9%)	14	55 (99.9%) 25.2 (99.5%)	NA 42

ASSUMPTIONS:

- 60 ft. ANTENNA
- 14 db BACKOFF & LOSSES
- -113 dbW/m^2 AT SATELLITE

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2.6 THE TDAS GROUND TERMINAL

TDAS will require a distributed ground terminal architecture; that is, the ground segment functions related to handling of forward- and return-link user signals, performed by WSGT for TDRSS, must be distributed to the end-points of the multibeam space/ground links for TDAS.

A new network element must be defined to implement the distributed architecture. The new network element is the TDAS Ground Terminal (TGT). The TGT provides the interface for all network elements requiring access to the space relays and it is a common modular element of all ground terminals in the TDAS network.

GROUND SEGMENT/SPACE SEGMENT INTERFACE

THE DISTRIBUTED GROUND TERMINAL ARCHITECTURE REQUIRES A NEW NETWORK ELEMENT, THE TDAS GROUND TERMINAL (TGT):

THE TGT INTERFACES NETWORK ELEMENTS TO THE TDAS SPACE RELAY UNDER THE CONTROL OF THE NCC.

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2.7 TDAS CONTROL CONCEPT

Three network elements are involved in the TDAS control concept. The Network Control Center (NCC) controls the occurrence of network events by promulgating scheduling messages among the network elements. Scheduling messages are interpreted to yield required space segment configurations by the White Sands Ground Terminal (WSGT) and are interpreted to yield ground segment configurations by the TDAS Ground Terminal (TGT). The accompanying table also indicates emergency back-up control functions for each of the elements.

TDAS CONTROL CONCEPT

	PRIMARY	EMERGENCY BACK-UP
● NETWORK CONTROL	NCC	WHITE SANDS
● SPACE SEGMENT CONFIGURATION	WSGT	GODDARD
● GROUND SEGMENT CONFIGURATION	TGT	TGT MANUAL

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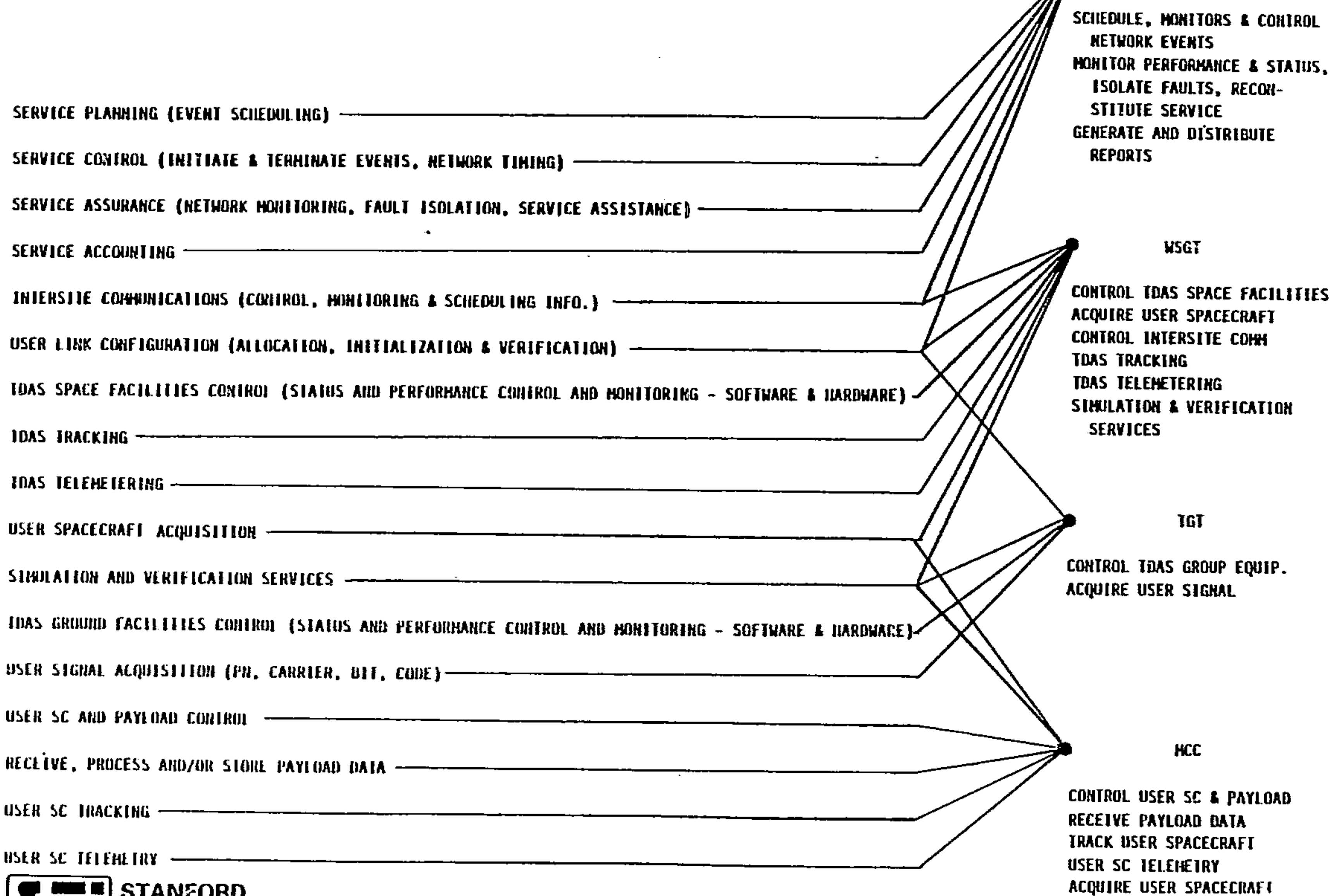
2.8 TDAS GROUND SEGMENT FUNCTIONAL ALLOCATION

Operations and control concepts and the ground segment architectural goals provide the rationale to allocate basic functions to the ground segment elements. The allocation results in a functional description of each ground segment element which is summarized in the figure. The functional descriptions of the ground segment elements define the baseline ground segment architecture.

TDAS GROUND SEGMENT
FUNCTIONAL ALLOCATION



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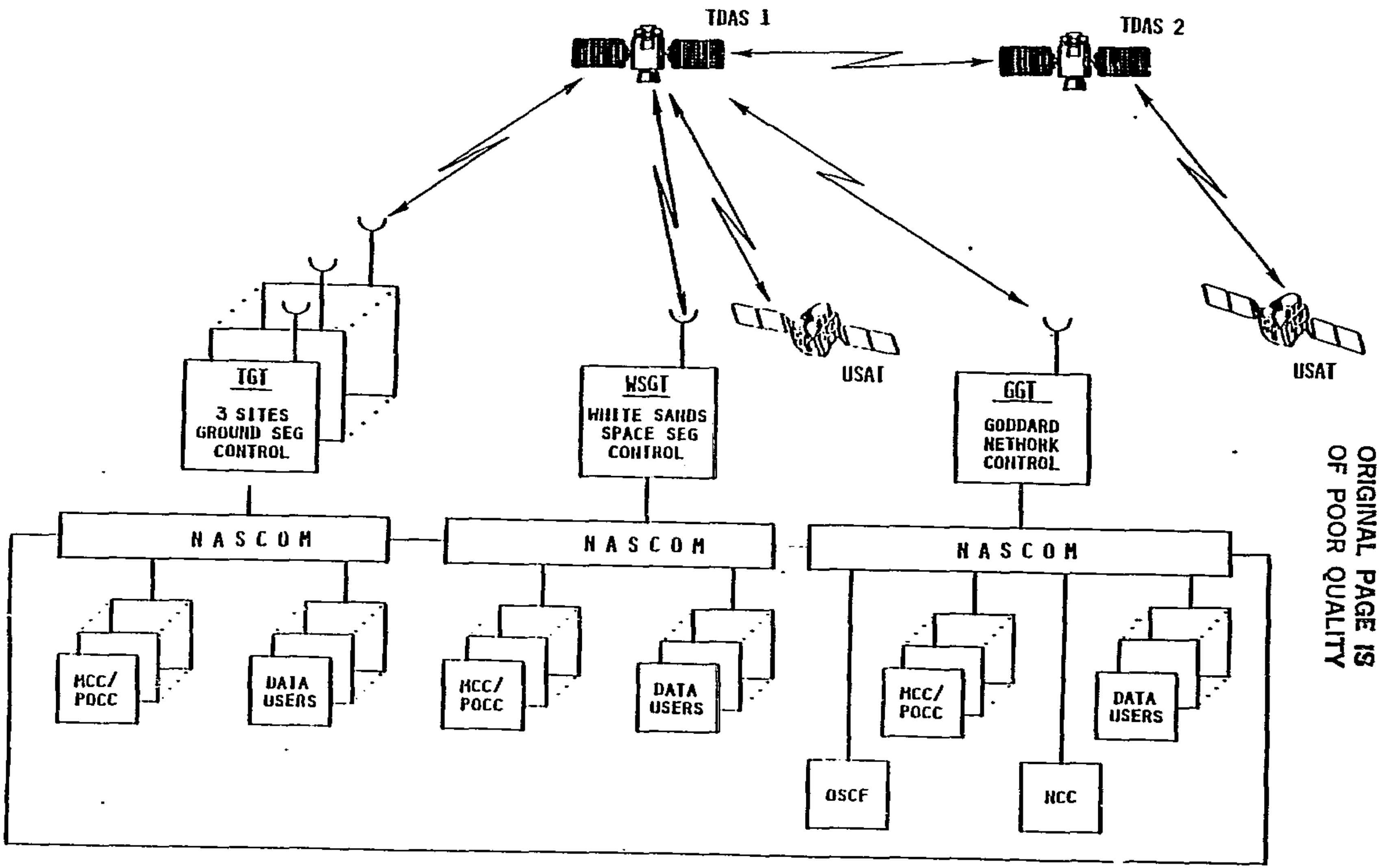
2.9 TDAS NETWORK ELEMENTS

The TDAS network elements are displayed in the figure. Each TDAS ground element possesses a TGT to link it to the space relays. The TDAS MBA and on-board switch perform the TDRSS NASCOM/NGT/DOMSAT data distribution function. NASCOM assumes a local distribution function for TDAS, interfacing such elements as the NCC, the OSCF and the MCC/POCC's to the ground terminals. The connectivity of the TDAS elements resembles a star network as opposed to the serial nature of the TDRSS connectivity.

TDAS NETWORK ELEMENTS



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2.10 TDAS GROUND SEGMENT TRAFFIC

The figure summarizes the exchange of messages and data between ground segment elements. The NCC distributes scheduling and reconfiguration messages and receives service, system and equipment status information, as well as, performance monitoring data and requests for service. Also included are the exchange of TDAS and user spacecraft acquisition status, in addition to user orbit and tracking data for tracking and non-tracking MCC/POCC's, respectively. The exchange of tracking and orbit data is based on the use of a return link tracking technique.

TDAS GROUND SEGMENT TRAFFIC

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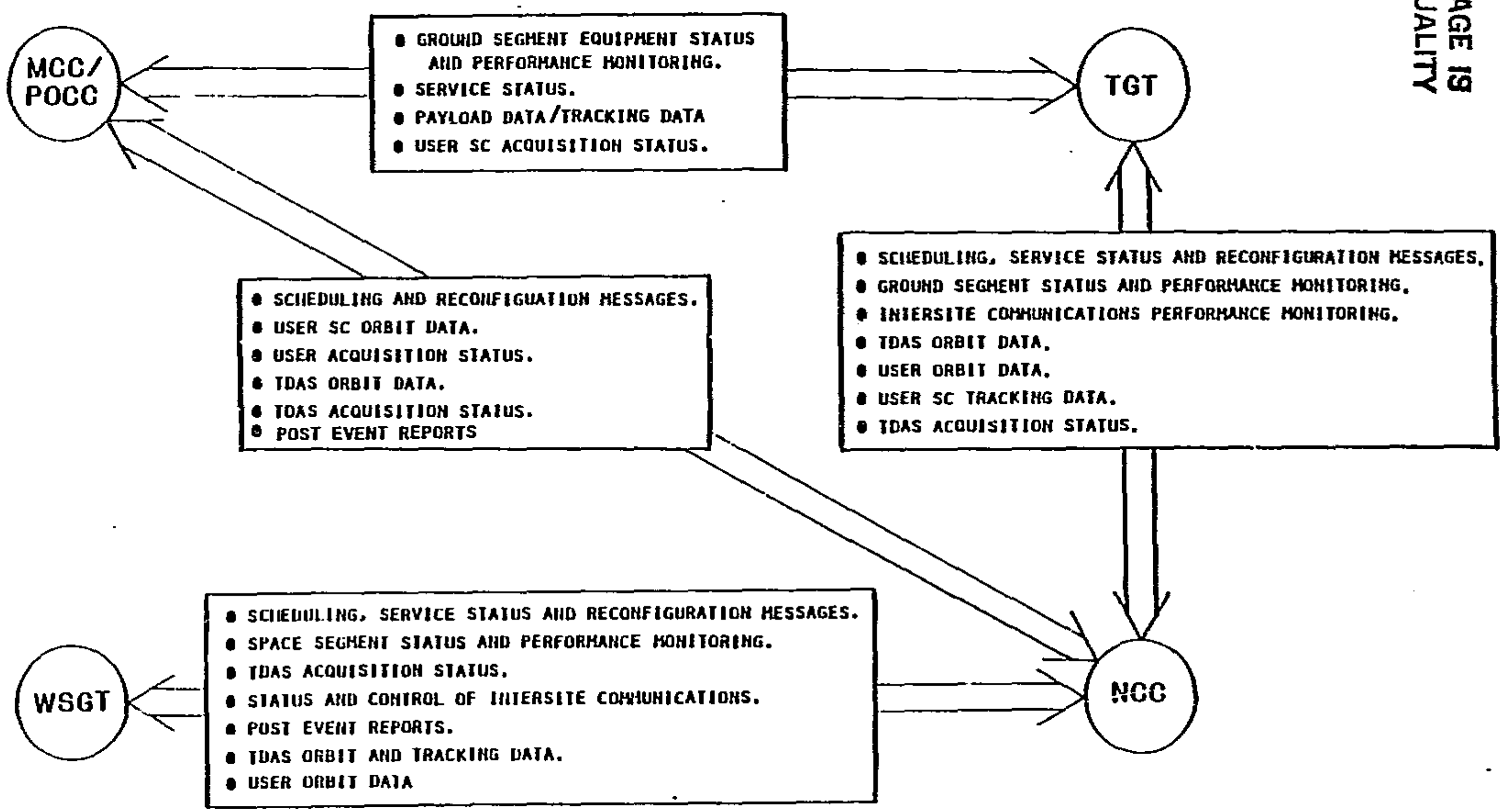

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2.11 TGT HARDWARE CONFIGURATION

The generic TGT has appropriate hardware to receive 2 KSA, 2 SSA, 5 WSA, 1 laser SA and 10 SMA channels and to transmit 2 forward link signals each on the KSA, SSA, WSA and SMA channels. The TDAS satellite control function shown is applicable only to the TGT's associated with the WSGT and the GGT.

The TGT hardware configuration includes automatic equipment status/fault monitoring and a frequency reuse feed subsystem for crosspolarized signals.

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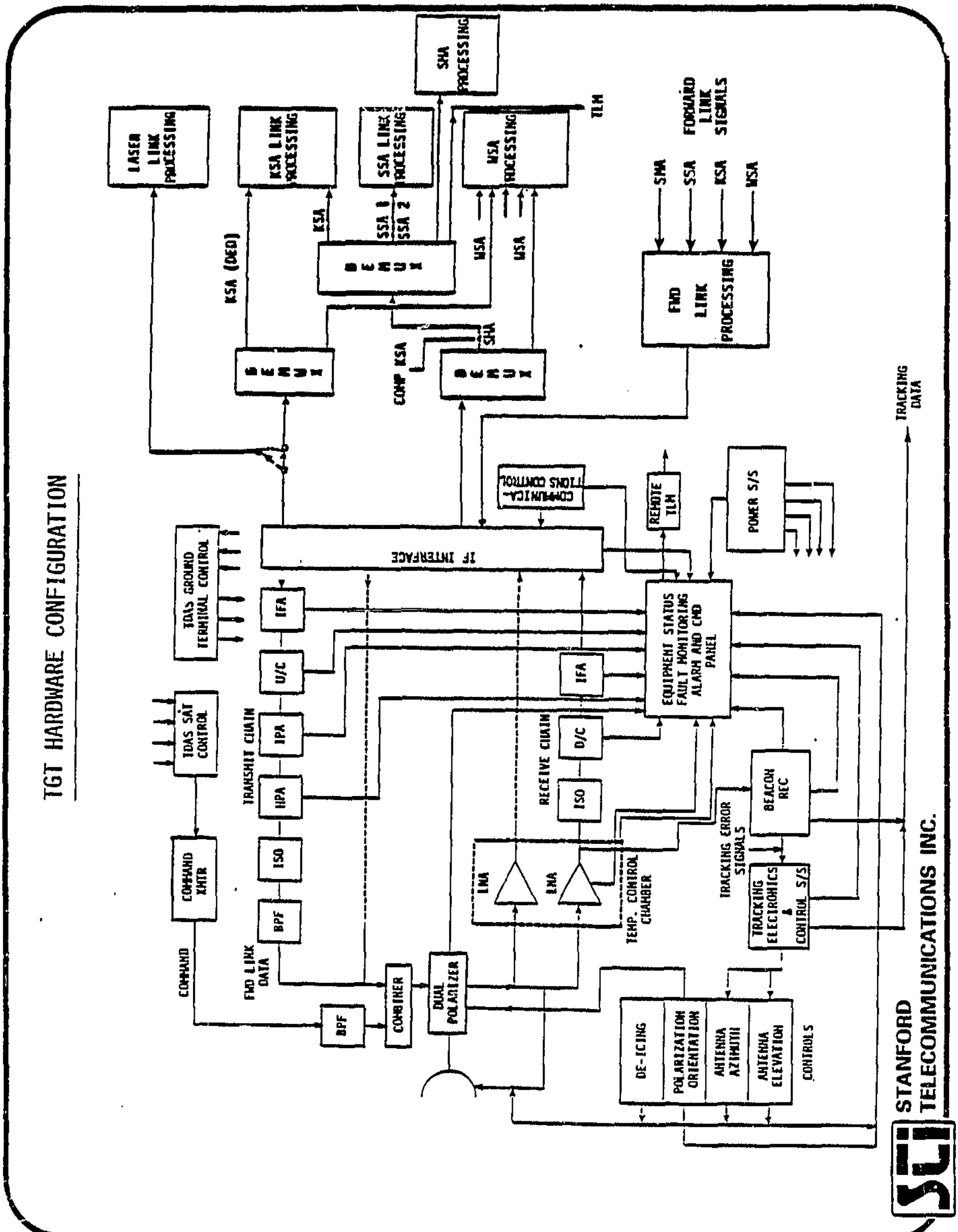

2.12 TGT TECHNOLOGY ISSUES

The key issues identified in the TGT technology assessment are listed in the figure. Issues were identified for the antenna, the LNA, the HPA, the baseband equipment and the diversity terminal. The issues relate to the readiness of the technology for application in the TDAS timeframe rather than to questions of basic technology development.

KEY GROUND TERMINAL TECHNOLOGY ISSUES

TECHNOLOGY AREA	ISSUES
ANTENNA	DESIGNS AND TECHNIQUES TO YIELD HIGH EFF.
	ADEQUATE SURFACE TOLERANCE TO MINIMIZE GAIN LOSS
	FEED MATERIAL AND FABRICATION TECHNOLOGY TO REDUCE RF LOSSES
	HIGH X-POL ISOLATION IN FREQUENCY REUSE FEED DESIGN
LOW NOISE AMP.	DEVELOPMENT OF LOW NOISE FIGURE LNA'S
HPA	ENHANCEMENT IN OUTPUT POWER CAPABILITIES
	LOW LOSS POWER COMBINING METHODS TO ACHIEVE ADEQUATE POWER LEVELS
	IMPROVEMENT IN POWER GEN. EFF.
BASEBAND EQUIP.	HIGH DATA RATE MODEMS ($\geq$ 1 GBPS)
	CARRIER/CLOCK ACQUISITION AT HIGH DATA RATES
DIVERSITY TERMINAL	DIVERSITY SWITCHES THAT CAN HANDLE HIGH DATA RATES ($\geq$ 1 GBPS)

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SECTION 3

TDAS GROUND SEGMENT AND OPERATIONAL REQUIREMENTS

3.1 DISTRIBUTED GROUND TERMINAL ARCHITECTURE

To satisfy the goal of providing USAT TT&C and mission data directly to mission control centers, the TDAS space segment architecture makes use of multibeam space/ground links switchable through the TDAS relay to the USAT. In the TDAS era, the space segment performs the data distribution function provided by DOMSAT and landline common carriers for the TDRSS.

To accomodate the multibeam space architecture, the ground segment must, of course, provide access to the space segment at several appropriate ground locations. Furthermore, to achieve the goal of meeting NASA mission requirements in the year 2000 with no impact on the users of TDRSS, requires that the ground segment functions related to handling of forward- and return-link user signals, performed by WSGT for TDRSS, must be distributed to the endpoints of the multibeam space/ground links for TDAS. TDAS will, therefore, require a distributed ground terminal architecture to interface the mission control centers (MCC) or project operations control centers (POCC) to the TDAS network. No user impact occurs when the ground terminals interfacing the MCC/POCC's to the space relay are part of the TDAS network.

TDAS GROUND SEGMENT ARCHITECTURE DRIVER

PRIMARY TDAS ARCHITECTURAL GOAL HAS BEEN TO:

- MEET NASA MISSION REQUIREMENTS IN THE YEAR 2000 WITH NO IMPACT ON THE USERS OF THE TDRSS

IMPLICATIONS FOR TDAS GROUND SEGMENT ARCHITECTURE:

- THE TDRSS GROUND SEGMENT FUNCTIONS RELATED TO HANDLING OF FORWARD-AND RETURN-LINK USER SIGNALS, PERFORMED BY WSGT, MUST BE DISTRIBUTED TO THE ENDPOINTS OF THE MULTIBEAM TDAS SPACE/GROUND LINKS.
- LEADS TO A DISTRIBUTED GROUND TERMINAL ARCHITECTURE

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3.2 TDAS CONSTELLATION/NETWORK OPTIONS

The TDAS spacecraft architectural task identified five specific technology enhancements to increase the capability of the TDRS bus:

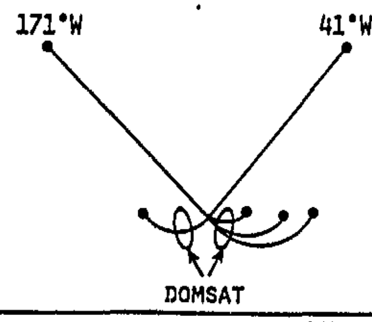
- W-band single access (WSA);
- 60 element S-band multiple access array with on-board beam forming (SMA);
- multiple beam antenna with on-board switch (MBA);
- crosslinks between relays (X-Links);
- laser single access (LSA)

The accompanying table depicts several TDAS constellation/network options for including five fixed ground terminals in the TDAS network. Each option is consistent with a particular enhanced TDRS bus. The table illustrates how the MBA and X-Link enhancements increase the complexity and diversity of the TDAS constellation/network options. Each option places different requirements on the TDAS ground segment architecture. Antenna, RF, data and tracking ground subsystems will vary for different options, as well as the control system to schedule, allocate and monitor the TDAS network resources. The Option 1 constellations use two front side satellites, while the Option 2 constellation uses one front side and one back side satellite. The constellations of Option 3 use two front side satellites and one back side satellite.

TDAS CONSTELLATION/NETWORK OPTIONS

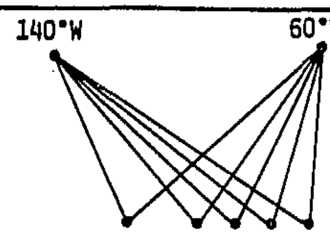
OPTION 1A:

ENHANCEMENTS
SMA
WSA



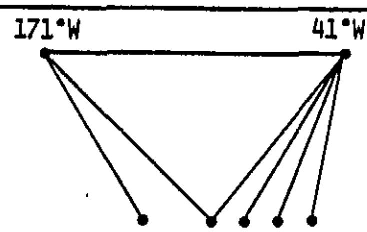
OPTION 1B:

ENHANCEMENTS
SMA
WSA
MBA
LSA



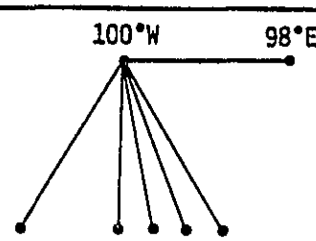
OPTION 1C:

ENHANCEMENTS
SMA
WSA
MBA
LSA
X-LINK



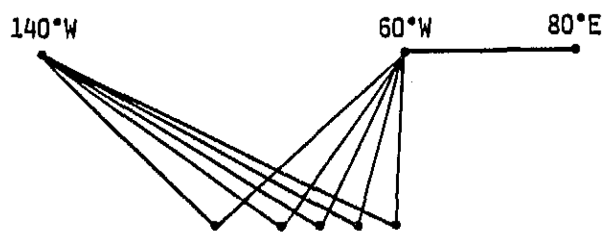
OPTION 2:

ENHANCEMENTS
SMA
WSA
MBA
LSA
X-LINK



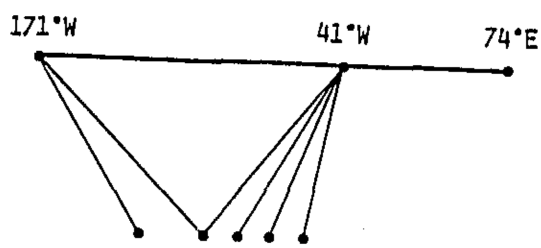
OPTION 3A:

ENHANCEMENTS
SMA
WSA
MBA
LSA
X-LINK



OPTION 3B:

ENHANCEMENTS
SMA
WSA
MBA
LSA
X-LINK



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3.3 MISSION SUPPORT REQUIREMENTS

3.3.1 Projected Mission Profiles

Since TDAS is a common user system, the missions expected to be supported in the TDAS time frame determine the required TDAS capabilities. In particular, the TDAS ground segment must accomodate the types and volumes of forward- and return-link traffic, as well as schedule, monitor and control TDAS resources to meet the needs of the user community. Volume II of this study, "TDAS User Community Characteristics", identifies and describes the missions and experiments, while Volume III, "TDAS Communications Mission Model", derives the communications requirements.

Mission profiles were developed for both NASA and DoD missions. NASA planning information, analysis of part experience, and interviews with the NASA program managers and the user community formed the basis of 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. Two SCS mission profiles were examined, SCSA and SCSB. The SCSA mission profile projects TT&C and medium to medium-high rate data requirements over the 1986-1990 period, while the SCSB mission profile adds high to ultra-high rate data requirements for the 1986-2000 period. The DoD mission profiles include geosynchronous satellites*; mission profiles with the geosynchronous satellites deleted are designated $SCSA^-$ and $SCSB^-$.

* TDAS is not required to support geosynchronous satellites.

PROJECTED MISSION PROFILES

- NASA MISSION PROFILES:
  - BASED ON MISSION PROFILES & COMMUNICATION REQUIREMENTS FOR 1990 - 2005 IDENTIFIED IN TDAS STUDY

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

- DOD MISSION PROFILES:
  - BASED ON 2 MODELS EXTRACTED FROM STI STUDY (1979) FOR USAF: SATELLITE CONTROL SATELLITE (SCS) STUDY

SCS MODEL	NO. S/C	ALTITUDES		DATA RATES		
		$\le$ 20,000 KM	> SYNCH	$\le$ 20 MBPS	> 20 MBPS	> 300 MBPS
SCS A	56	✓	✓	✓		
A-	40	✓		✓		
SCS B	92	✓	✓	✓	✓	✓
B-	68	✓		✓	✓	✓

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3.3.2 TDAS Communications Channel Requirements

The mission profiles lead to communication mission models. Communication mission models specify the total number of channel hours required per day to support users in a given data-rate range. The assumptions listed in the figure were used to construct the communications mission model from the mission profiles.

Communication requirements are based on supporting mission activities on a "busy day" in the year 2000 as defined in the figure. All of the vehicles listed as active during the busy day require dedicated high-rate single access channels 24 hours per day to return engineering data, in addition to channel requirements to return science data. Thus, the communications mission model includes a total of six KSA and WSA channels dedicated to engineering data. The return of science data, on the other hand, can be scheduled for shorter varying durations and channels assigned when they are needed.

In satisfying the science-data contact time, it was assumed that a 75% scheduling efficiency was achieved, i.e., on the average 75% of the channels that can be scheduled for science data are carrying traffic. This later assumption leads to a static communication mission model in which scheduling inefficiencies decrease a channel's utilization from 24 hours to 18 hours per day. The 25% reduction in channel loading attempts to account for the scheduling loss incurred by the random and conflicting load placed on the system by the science-data contact time requirements. Daily contact time requirements for science data can vary from a few hours to a full day depending on the mission. Contact time epoch depends on the mission as well.

COMMUNICATIONS REQUIREMENTS - ASSUMPTIONS

- CONSTANT ACTIVITY - NUMBER OF FLIGHTS PER YEAR CONSTANT FROM 1980's THROUGH 1990's.
- SPACE STATION/PLATFORM OPERATIONAL IN MID-1990
- ENGINEERING DATA RETURNED IN REAL TIME
- NASA WILL SUPPORT DOD SHUTTLE FLIGHTS
- BUSY DAY DEFINED BY SIMULTANEOUS OPERATION OF:
    - TWO SHUTTLES
    - ONE ORBITAL TRANSFER VEHICLE
    - ONE HEAVY LIFT LAUNCH VEHICLE
    - ONE MANNED ORBITAL TRANSFER VEHICLE
    - ONE SPACE STATION/PLATFORM
    - ONE TELEOPERATOR MANEUVERING SYSTEM
    - ALL SCIENCE MISSIONS
- MINIMUM ACTIVITY DEFINED BY SIMULTANEOUS OPERATION OF:
    - ONE SHUTTLE
    - ONE SPACE STATION/PLATFORM
    - ONE TELEOPERATOR MANEUVERING SYSTEM
    - ALL SCIENCE MISSIONS
- SCHEDULING ASSUMED TO BE 75% EFFICIENT (100% ON DEDICATED CHANNELS)

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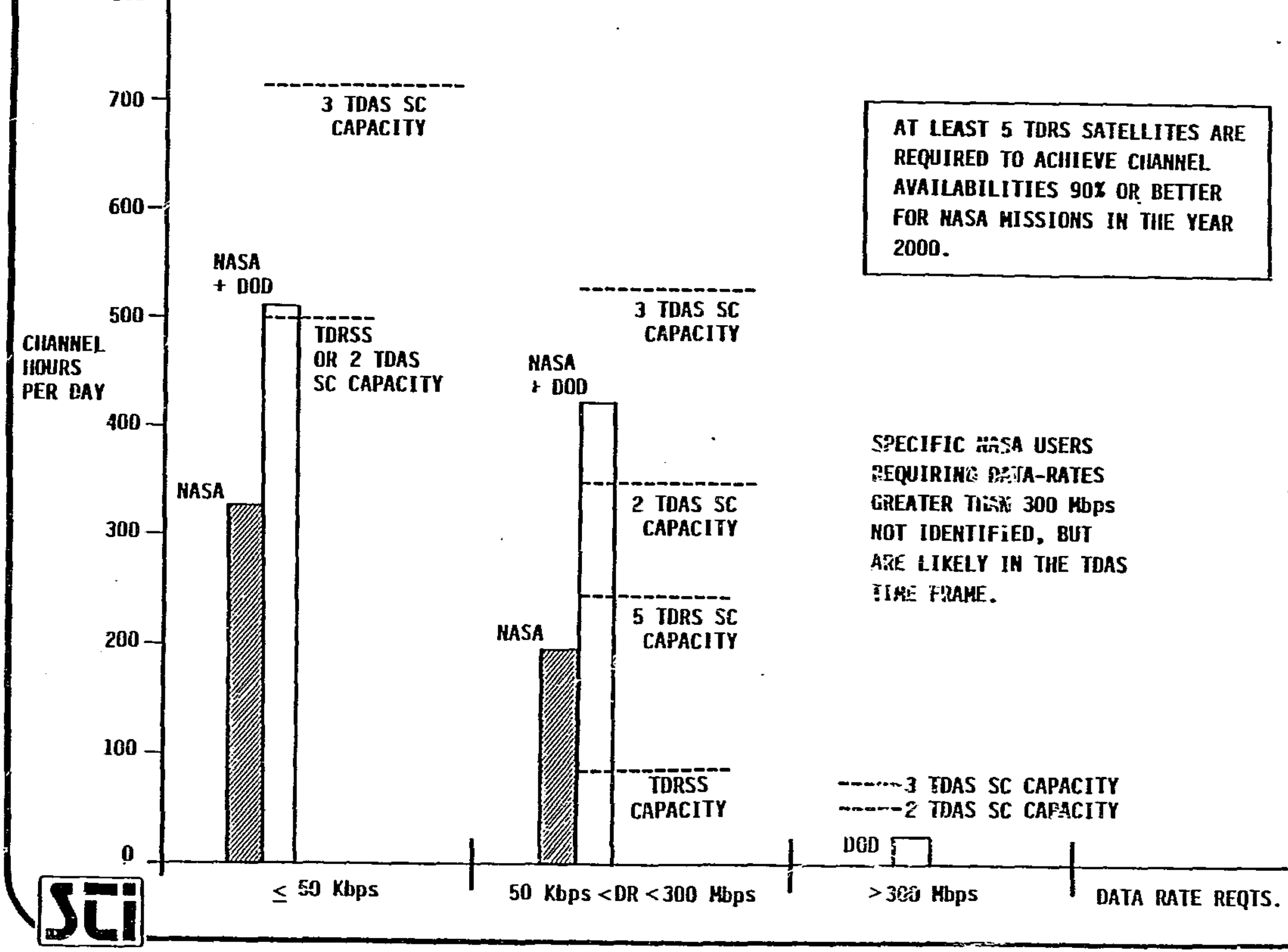
3.3.2 TDAS Communications Channel Requirements (Continued)

The figure compares the NASA and the NASA-plus-DoD communications mission models with the channel capacities achieved by both two and three TDAS-spacecraft constellations. TDAS constellations with two baseline spacecraft satisfy the NASA mission model requirements with adequate margin, but do not meet the requirements of the DoD mission models for the WSA service. At least four active TDAS spacecraft are required to exceed the WSA channel requirements of the static DoD mission models.

The return channel requirements shown in this figure estimate the total traffic, by service type, that the ground segment must schedule and distribute to the appropriate user.

NASA AND DOD STATIC CHANNEL REQUIREMENTS FOR THE YEAR 2000



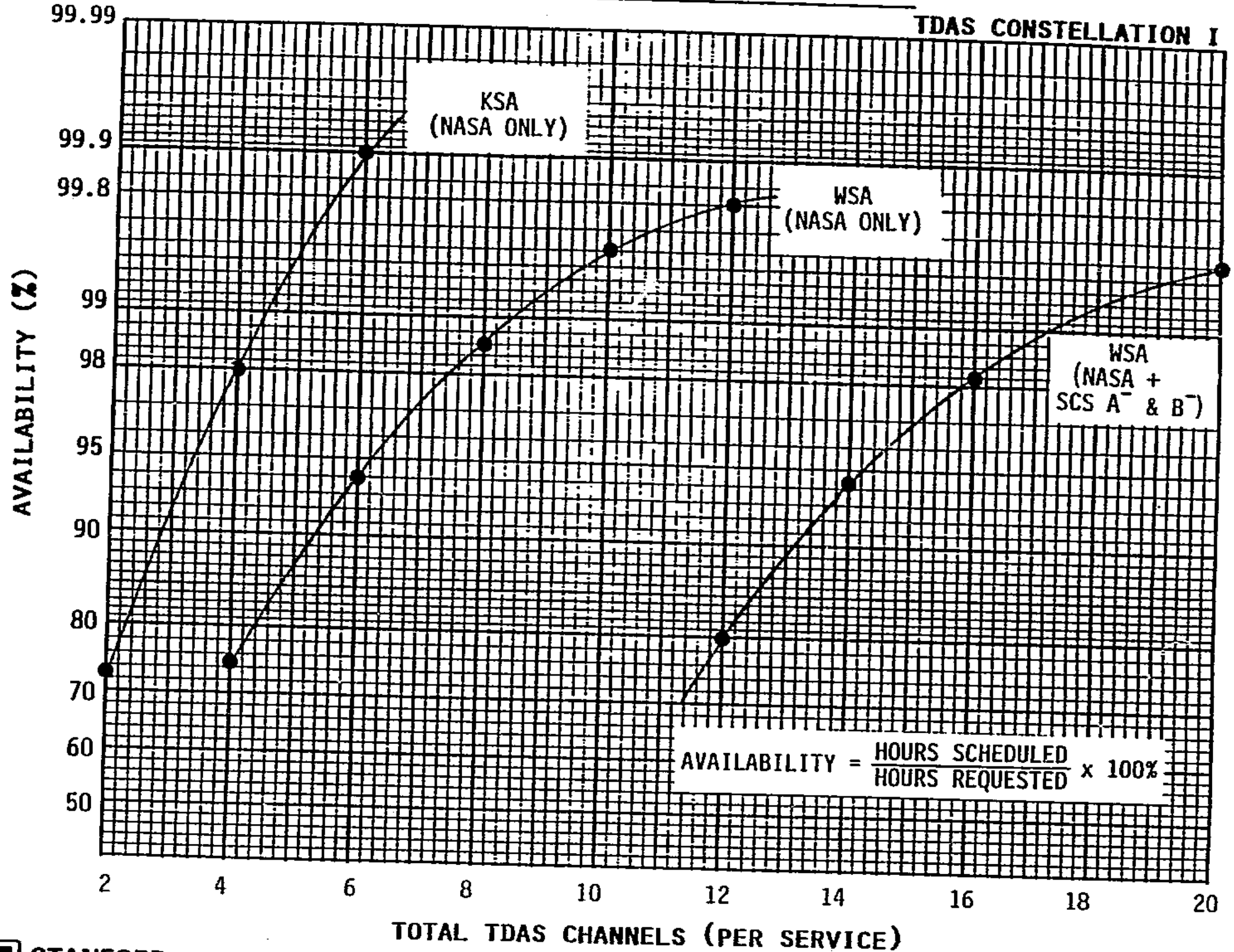
3.4 THE IMPACT OF SCHEDULING ON CHANNEL REQUIREMENTS

While the static communications models are useful in estimating overall channel requirements, they do not shed light on how the system would perform in a complex operational environment that includes the dynamics of scheduling and visibility for a group of heterogeneous users. To obtain performance measures that account for such dynamics, the scheduling process was simulated for the users in the various mission models. The simulation accounted for the characteristics of each mission: visibility; contact time; dump rate and the need for dedicated channels. Two important system performance measures, channel availability and channel loading, were obtained from the simulations for various combinations of mission models and TDAS constellations.

Channel availability is the ratio of hours scheduled to hours demanded, expressed as a percentage. It is the percent of time that a channel is free when a user requests service or the probability that a user will not experience a scheduling conflict when requesting service. Channel loading is the ratio of hours scheduled to the total number of hours available for scheduling. There is a tradeoff between channel loading and channel availability. Higher channel availability is achieved at the expense of lower channel loading.

The results of simulating the scheduling processes for the NASA and DoD mission models with constellation 1A are plotted in the accompanying figure. For the NASA mission model, two baseline satellites (2 KSA and 5 WSA channels each) achieve high single access service availabilities 98% for the KSA service and 99.6% for the WSA service. On the other hand, for the NASA + DoD mission models, an availability of approximately 67% is achieved for the WSA service. If the number of WSA channels is increased to 15, the equivalent of 3 baseline TDAS spacecraft, then the availability for the WSA service would be 97% for the NASA + DoD mission models.

CHANNEL AVAILABILITY VS. NO. OF CHANNELS



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3.4 THE IMPACT OF SCHEDULING ON CHANNEL REQUIREMENTS (Continued)

Simulation results obtained for channel loading as a function of the number of channels per service are shown in the figure. For the NASA mission model and two baseline TDAS spacecraft, channel loadings of 57% and 51% are achieved for the KSA and WSA services, respectively, while the WSA service would be fully loaded for the NASA + DoD mission models. The WSA service would be 97% loaded for the equivalent of three TDAS baseline spacecraft while 75% WSA service loading is achieved for four baseline spacecraft.

Because visibility changes, channel loading is sensitive to varying the TDAS spacecraft constellation, especially the 2-spacecraft constellations. Coverage differences among the 2-spacecraft constellations can cause the total contact time of the dedicated users to vary as much as 15 hours per day which, in turn, causes variations in channel loading as large as 10%.

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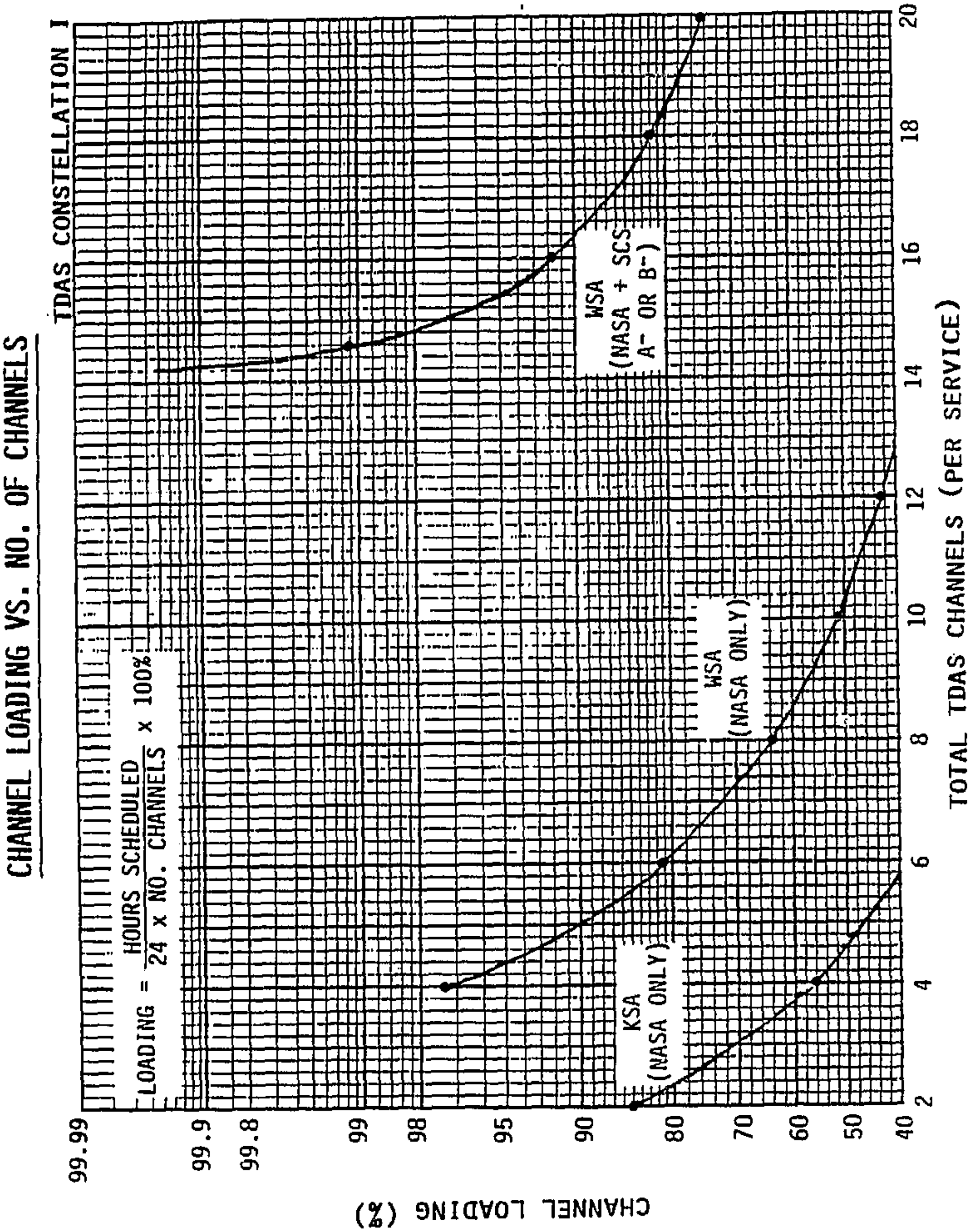

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3.4 THE IMPACT OF SCHEDULING ON CHANNEL REQUIREMENTS (continued)

The tradeoff between availability and loading is evident in the figure, which was obtained from simulation of the scheduling process for the NASA single access users. As previously mentioned, high availability is achieved at the expense of low channel loading; for example, to achieve an availability of 98% or higher requires a channel loading less than 60% for the NASA SA users.

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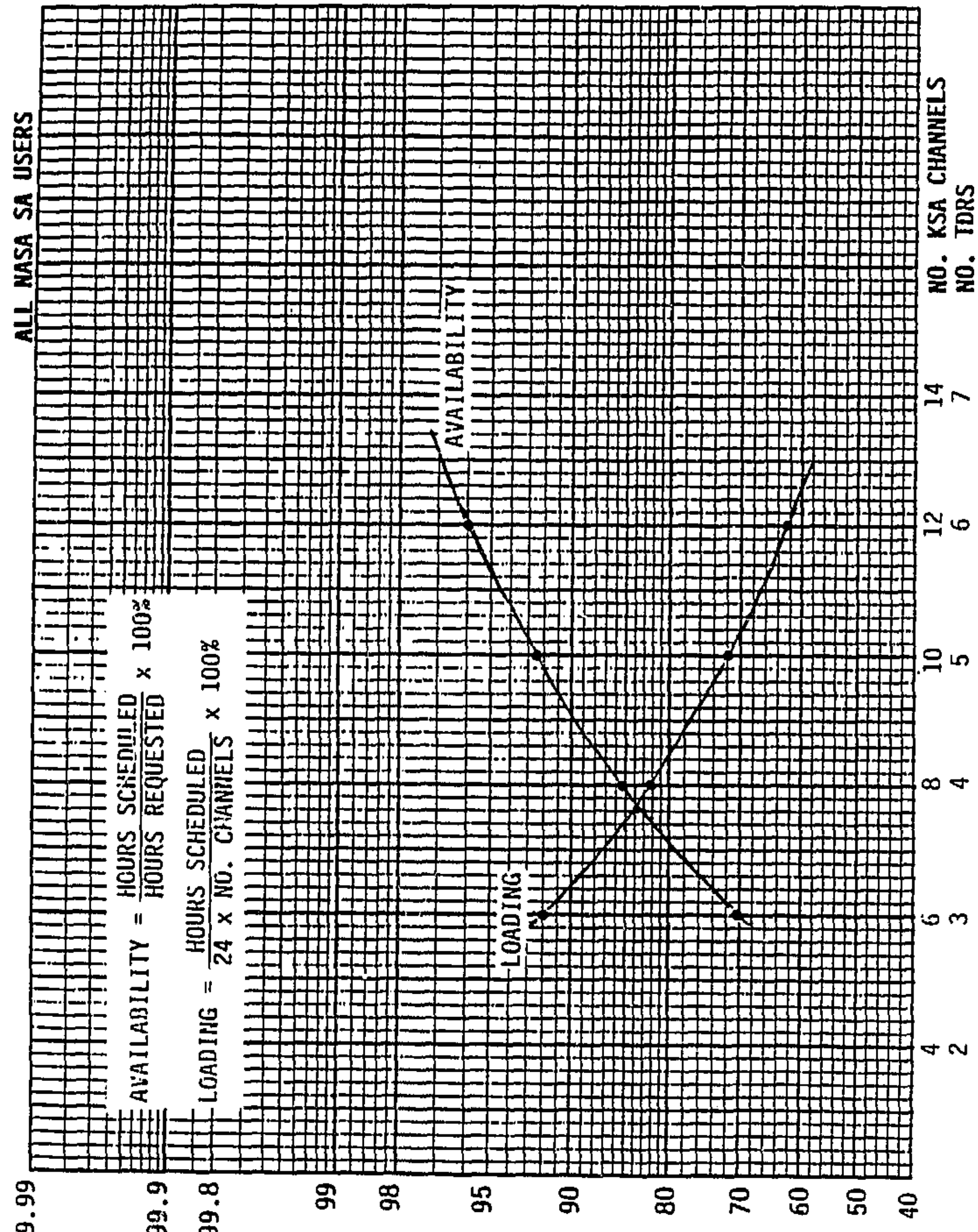
CHANNEL LOADING AND AVAILABILITY VS. NO. OF TDRS



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3.4 THE IMPACT OF SCHEDULING ON CHANNEL REQUIREMENTS (Continued)

The table summarizes scheduling performance for the baseline spacecraft in various constellation options. Simulations of the NASA and DoD mission models determined the performance measures, channel availability and channel loading, for each constellation listed in the table.

The results demonstrate that excellent channel availabilities in the vicinity of 99% can be achieved with 2-spacecraft constellations for the NASA mission model with a channel loading of 55%.

When the Dod missions are added the scheduling performance of the 2-spacecraft constellations deteriorates. Adding DoD missions causes the availability to be reduced to 71%. A 3-spacecraft constellation achieves excellent availability: 97% for the combined NASA and DoD Single Access users with an 83% loading.

SUMMARY OF SA SCHEDULING PERFORMANCE FOR BASELINE TDAS DESIGN

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	83

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3.5 FUNCTIONAL REQUIREMENTS

The ground segment must perform several basic functions to schedule, monitor, and control both space and ground facilities to provide the users proper end-to-end links between their ground locations and their spacecraft. The table lists all of the basic functions of the ground segment, including those of the TDAS network ground elements and the user ground elements.

The functions are organized into three decending levels of organizational generality: the provision of network services; the control of network resources; and the control of user resources. A particular allocation of these functions to a set of ground segment elements leads to a ground segment architecture.

GROUND SEGMENT BASIC FUNCTIONS

FUNCTIONS RELATED TO PROVIDING NETWORK SERVICES

SERVICE PLANNING (EVENT SCHEDULING)

SERVICE CONTROL (INITIATE & TERMINATE EVENTS, NETWORK TIMING)

SERVICE ASSURANCE (NETWORK MONITORING, FAULT ISOLATION, SERVICE ASSISTANCE)

SERVICE ACCOUNTING

FUNCTIONS RELATED TO CONTROLLING NETWORK RESOURCES

INTERSITE COMMUNICATIONS (CONTROL, MONITORING & SCHEDULING INFO.)

USER LINK CONFIGURATION (ALLOCATION, INITIALIZATION & VERIFICATION)

TDAS SPACE FACILITIES CONTROL (STATUS AND PERFORMANCE CONTROL AND MONITORING - SOFTWARE & HARDWARE)

TDAS TRACKING

TDAS TELEMETERING

USER SPACECRAFT ACQUISITION

SIMULATION AND VERIFICATION SERVICES

TDAS GROUND FACILITIES CONTROL (STATUS AND PERFORMANCE CONTROL AND MONITORING - SOFTWARE & HARDWARE)

USER SIGNAL ACQUISITION (PN, CARRIER, BIT, CODE)

FUNCTIONS RELATED TO CONTROLLING USER RESOURCES

USER SC AND PAYLOAD CONTROL

RECEIVE, PROCESS AND/OR STORE PAYLOAD DATA

USER SC TRACKING

USER SC TELEMETRY

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3.6 SECURITY REQUIREMENTS

Besides supporting the DoD shuttle missions, TDAS will have additional capacity to accomodate a variety of other national-security related missions. To support classified missions, TDAS must provide adequate security arrangements. Classified missions and the need to protect TDAS resources place the following general security requirements on the ground segment:

- Secure communications between space segment control at WSGT and the TDAS spacecraft for command and telemetry messages;
- Secure communications for transfering classified information in both digital and analog form among the nodes of the ground segment. Such information includes event scheduling and planning data, acquisition data, control data, and status messages related to classified missions.
- Secure processors for determining orbital parameters for classified spacecraft;
- Secure processors for TDAS TT&C;
- Secure files for storing operations data related to classified missions;
- Software and hardware processes to segment classified and unclassified information;
- Controlled access to classified information with automatic audit trails;
- End-to-end secure links between a user and his spacecraft.

SECTION 4

TDAS RF TERMINAL CONFIGURATIONS

4.1 SPACE/GROUND LINK FREQUENCIES

The downlink capacity required to satisfy the NASA mission model dictates the choice of either K_u or K_a band for the TDAS space/ground links. K_a band can support downlink data rates in excess of 300 Mbps, whereas 300 Mbps is about the maximum practical data rate for QPSK at K_u band.

Rainfall degrades the performance of satellite systems at these frequencies. Adverse effects, such as attenuation and depolarization of the space/ground link signals can be very severe and must be taken into account in the design of the ground terminal. Significant power margins or other RF techniques, such as space diversity may be necessary to achieve acceptable system availability. Since these techniques are quite costly and usually involve achieving large margins, it is critical to accurately access both the effects of the degradation and the remedies to cure them.

TDAS SPACE/GROUND LINK FREQUENCIES

FREQUENCY BAND / FACTOR	K_U BAND	K_A BAND
CONTIGUOUS ALLOCATED BANDWIDTH		+
ANTENNA GAIN		+
SPACE LOSS	+	
RAIN ATTENUATION	+	
DEPOLARIZATION EFFECTS	+	
RISK/COST	+	
COMPETITION FOR SPECTRUM		+

+ ≡ RELATIVE ADVANTAGE

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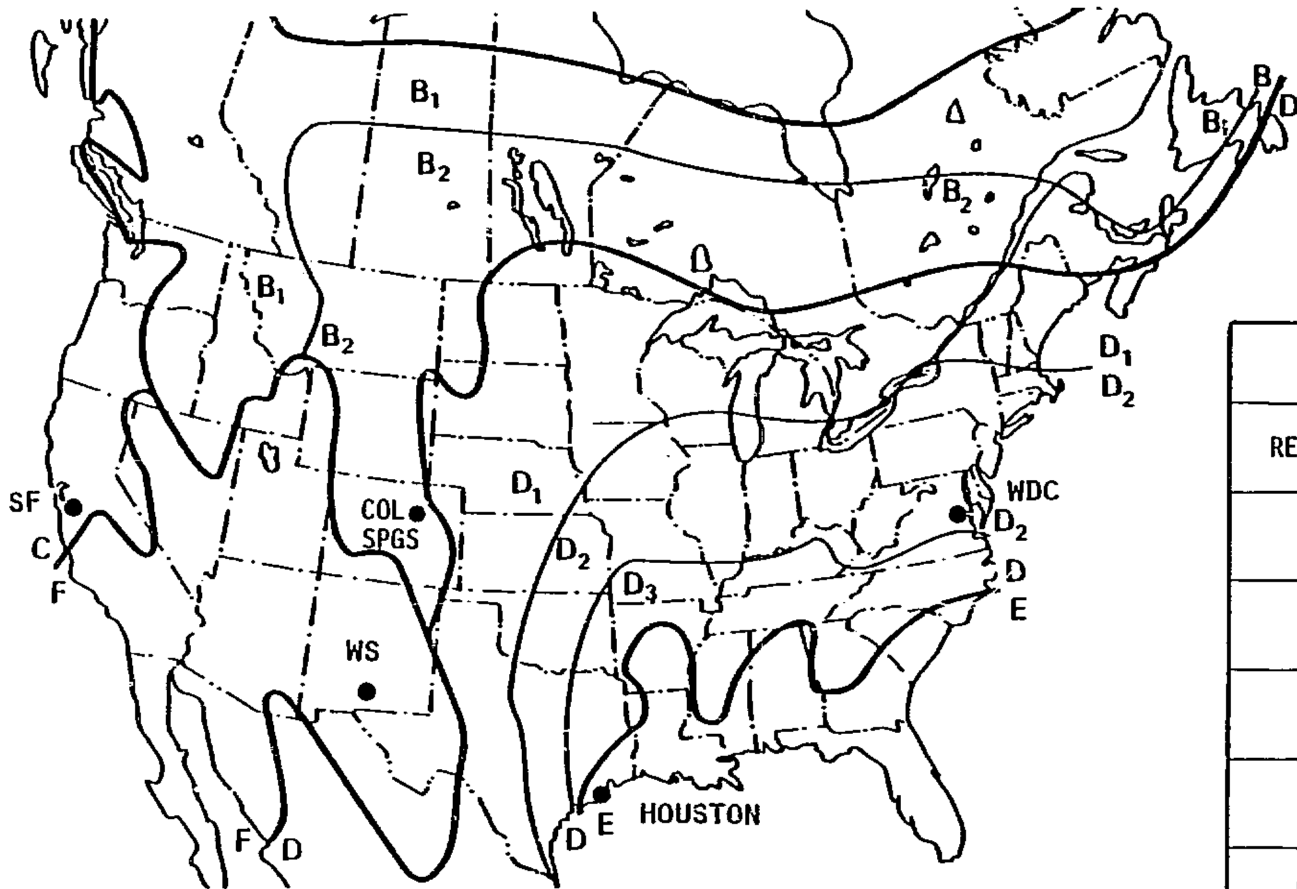
4.2 REPRESENTATIVE GROUND STATION LOCATIONS

The location of a ground terminal determines the severity of the rainfall experienced by that terminal. There are eight rain climate regions in the continental U.S. Each is characterized by a different measured cumulative distribution function for rain rate, which records the percent of time during a year that the rain rate exceeds a given level. For example, the rain rate in Washington D.C. exceeds 14.5 mm/hr, 8.77 hrs. during a year or .1% of the time.



RAIN RATES	
REGION	R_p (mm/hr) .1%
B_1	4.2
B_2	6.1
C	7.2
D_1	9.8
D_2	14.5
D_3	22
E	35
F	5.2

U.S. RAIN CLIMATE REGIONS

(NASA REFERENCE PUBLICATION 1082)

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4.2 REPRESENTATIVE GROUND STATION LOCATIONS (Continued)

The accompanying table lists 5 candidate locations for TDAS ground stations. The locations are fairly representative, in so far as satisfying operational requirements, geographic diversity and climate variation for a multibeam TDAS system.

The table indicates wide variation in rain rate at a given exceedance level among the locations. As will be shown, large differences in rain rate portend correspondingly large differences in required rain margin, especially at K_a band.

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REPRESENTATIVE GROUND STATION LOCATIONS

CLIMATE AND LOCATION

POINT RAIN RATES (mm/hr)

	0.01% 0.88 HR/YR	0.1% 8.77 HR/YR	0.5% 43.8 HR/YR	1.0% 87.7 HR/YR
SUNNYVALE 37.5N 122W TEMPERATE-MARITIME	28	7.2	2.7	1.8
WHITE SANDS 32.N 106W SUB-TROPICAL-ARID	23	5.2	1.4	0.7
COLORADO SPRINGS 40N 105W POLAR-MODERATE	23.5	6.1	2.3	1.5
HOUSTON 30N 95W SUB-TROPICAL-WET	98	35	10.6	6
WASHINGTON DC 39N 77W TEMPERATE-CONTINENTAL	49	14.5	5.2	3

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4.3 RAIN ATTENUATION PREDICTION MODEL

RF ground system design requires an accurate statistical characterization of the attenuation caused by rainfall. Five commonly used models are available to the system designer to estimate the cumulative attenuation statistics for the space/ground paths: Rice - Holmberg; Dutton - Daugherty; Global; Lin; and Piecewise Uniform Rain Rate. Because of its proven accuracy and ease of use, the Global Model of Crane and Blood was chosen for this study.

The Global Model transforms cumulative statistics of point rainfall rate into cumulative statistics of rain attenuation. Exceedance level, location and constellation determine the inputs to the model which are: rainfall rate; height of the 0° isotherm; height of the ground station; and elevation angle. Elevation angle is a function of location and constellation. The model then computes the output: the rain attenuation value for the input exceedance level.

RAIN ATTENUATION PREDICTION MODEL
GLOBAL MODEL DUE TO CRANE & BLOOD

CDF OF POINT RAINFALL RATE → GEOPHYSICAL DATA / THEORETICALLY DERIVED RELATIONSHIPS → CDF OF RAIN ATTENUATION

- EXCEEDANCE LEVEL
- LOCATION

↓

- RAINFALL RATE
- HEIGHT OF 0° ISOTHERM
- HEIGHT OF GROUND STATION
- ELEVATION ANGLE

↓

- ATTENUATION VALUE FOR THE EXCEEDANCE LEVEL

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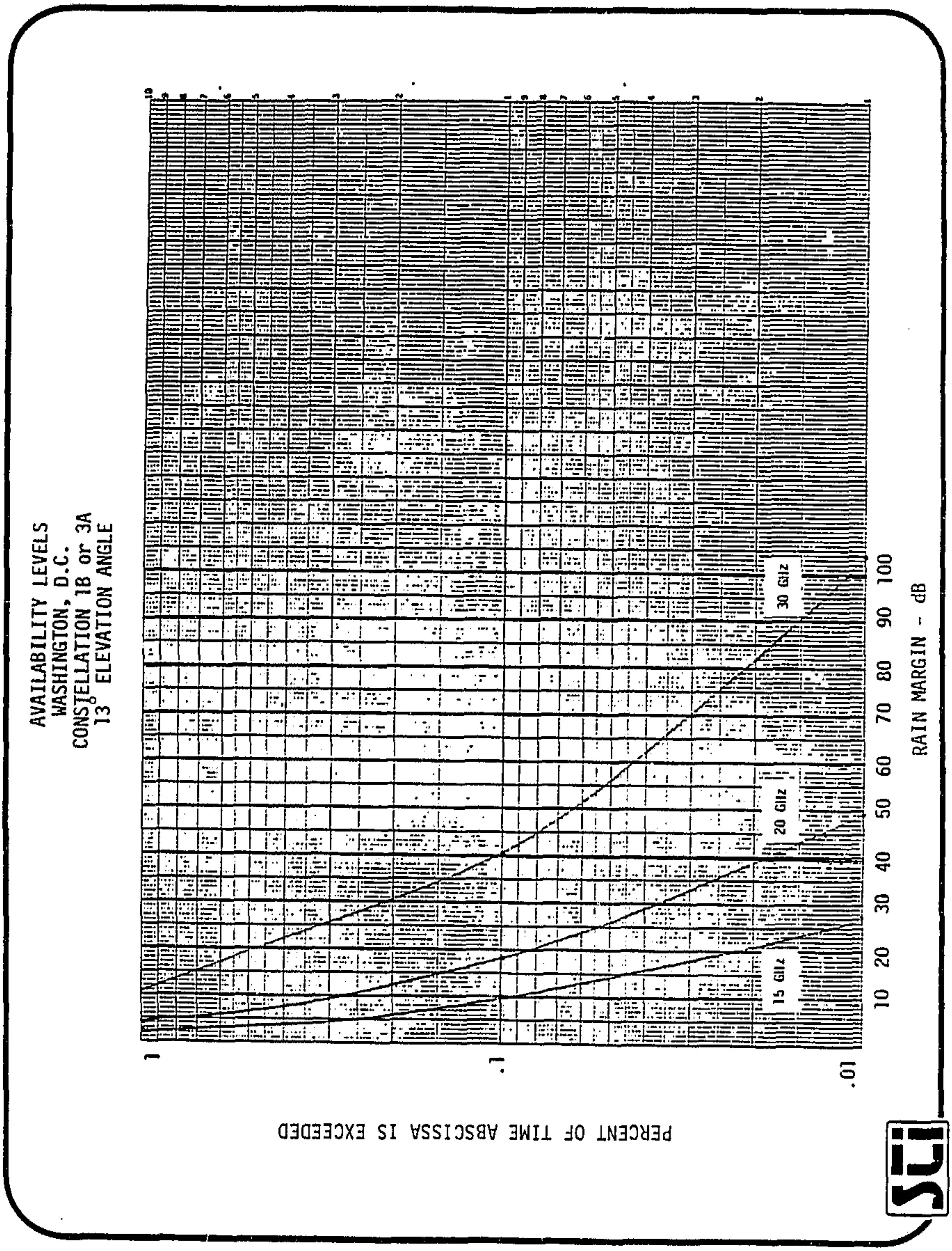
4.4. LINK AVAILABILITY

When a system is designed with a margin for rain, link availability is the probability that rain attenuation will not exceed the margin or the percent of time that rain attenuation is below the margin. Link availability as a function of margin is simply the cumulative distribution function for rain attenuation.

The figures that follow plot availability (actually one minus availability) as a function of margin for each of the five locations. Results for both K_u band (15 GHz) and K_a band (20/30 GHz) depict the worse case attenuation, i.e., the constellation yielding the smallest elevation angle for the location. For example, constellation 1B or 3A requires 40 db of rain margin at 30 GHz at Washington D.C. to achieve an availability of 99.9%. The curves illustrate the price that must be paid in terms of increased margin to obtain availabilities above 99.9%.

The availability levels and margins shown in these figures are for the constellations with 2 front-side satellites located at longitudes off the east and west coast of the U.S. While these constellations possess desirable coverage properties, they obviously will present difficulties in achieving rain margins required for high operational avialability at all of the ground locations. This is especially true at K_a band. As will be shown shortly, constellation 2 with a front-side satellite directly over the U.S. mitigates most of the extreme effects of rain attenuation by achieving larger elevation angles for the more troublesome sites.


AVAILABILITY LEVELS
WASHINGTON, D.C.
CONSTELLATION 1B or 3A
13° ELEVATION ANGLE
30 GHz
20 GHz
15 GHz
10 20 30 40 50 60 70 80 90 100
RAIN MARGIN - dB
1
.1
.01
PERCENT OF TIME ABSCISSA IS EXCEEDED

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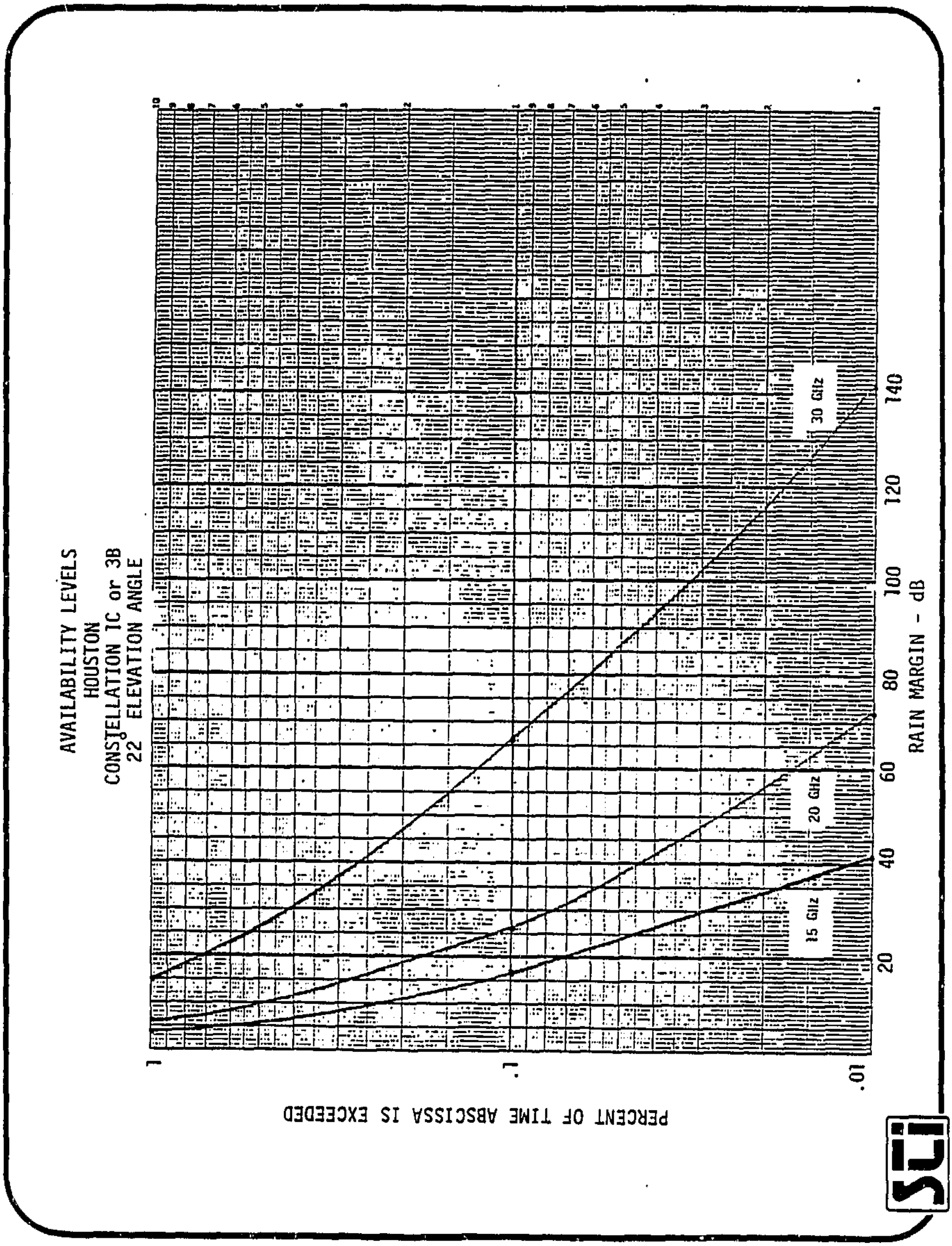

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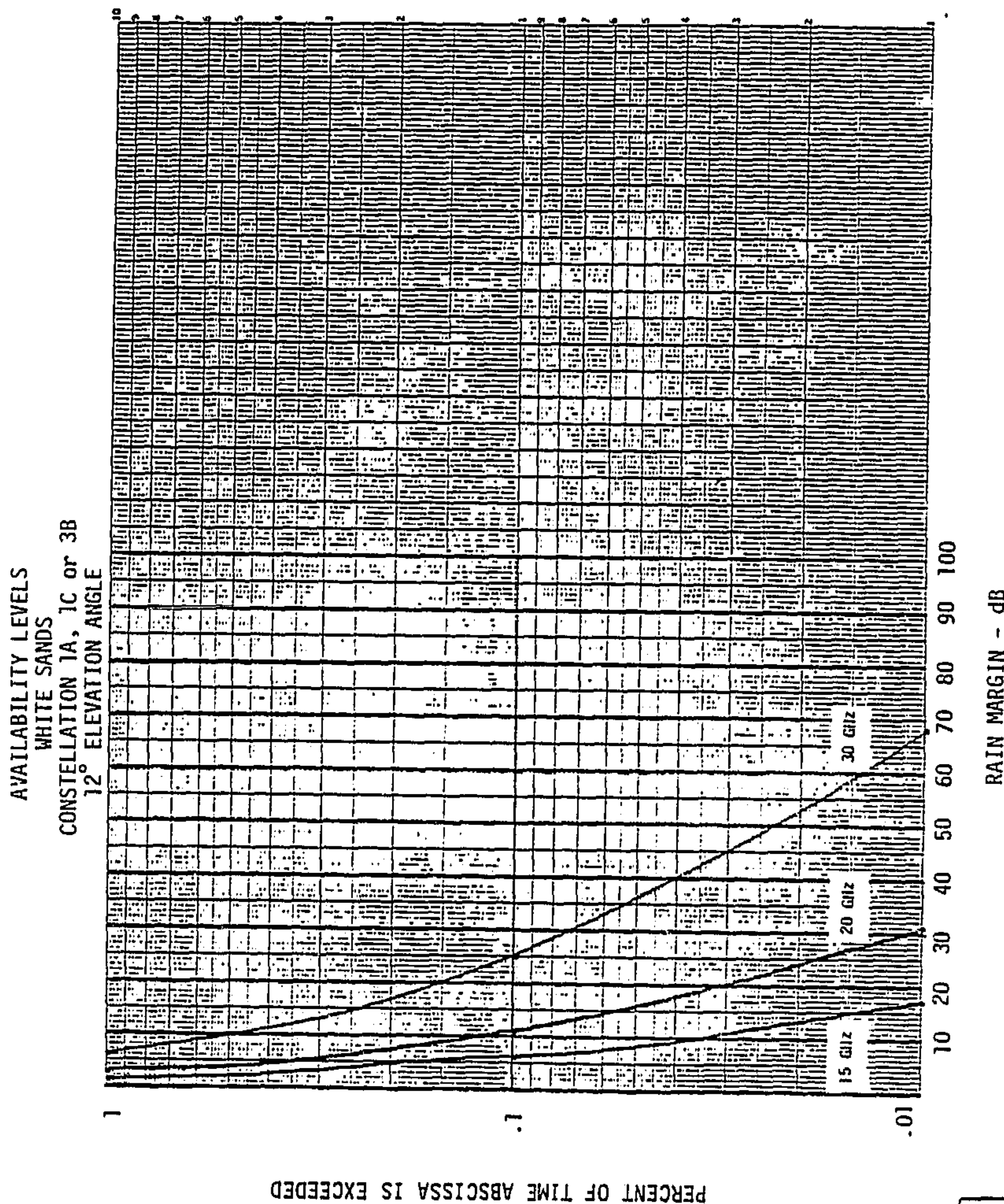

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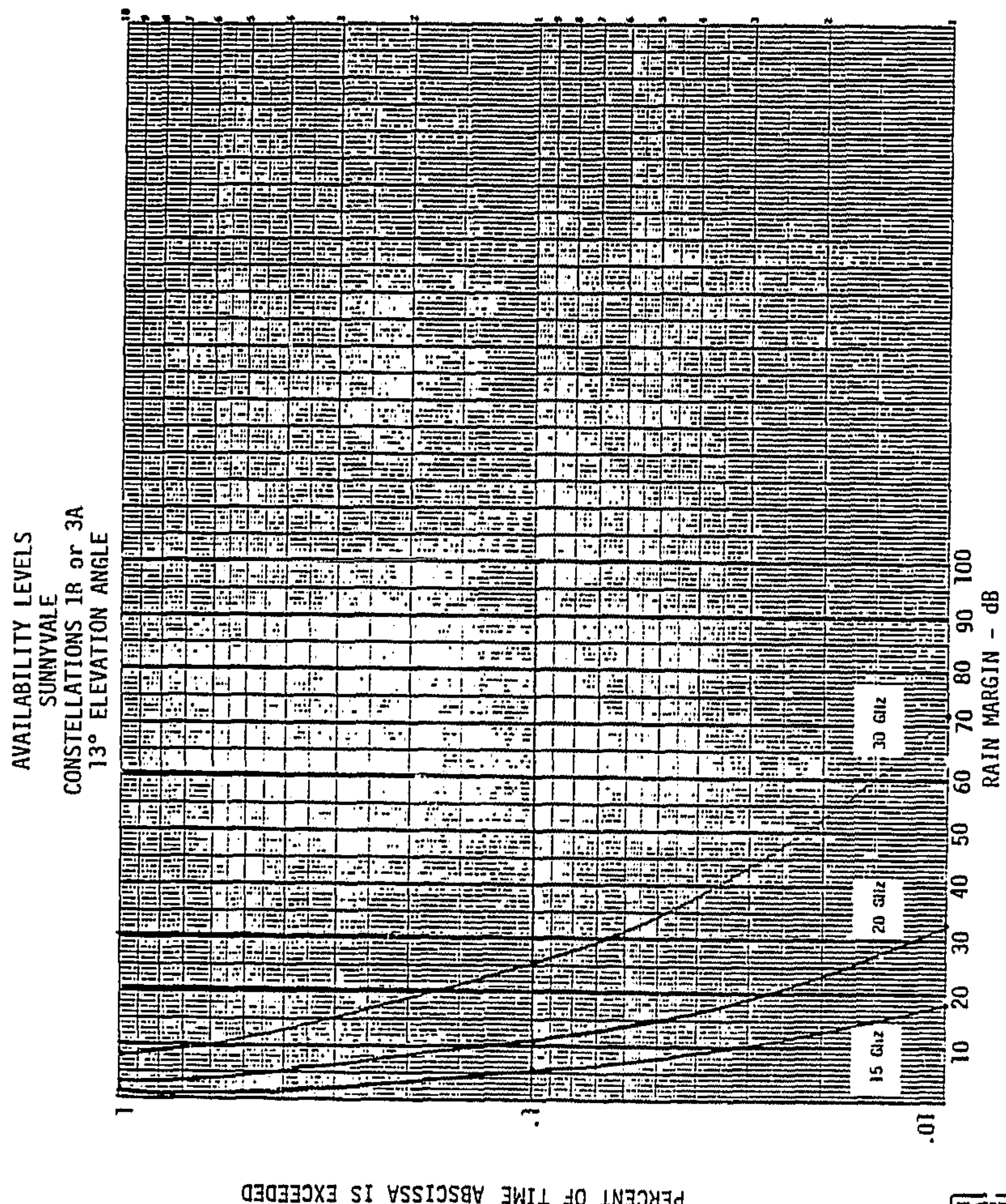
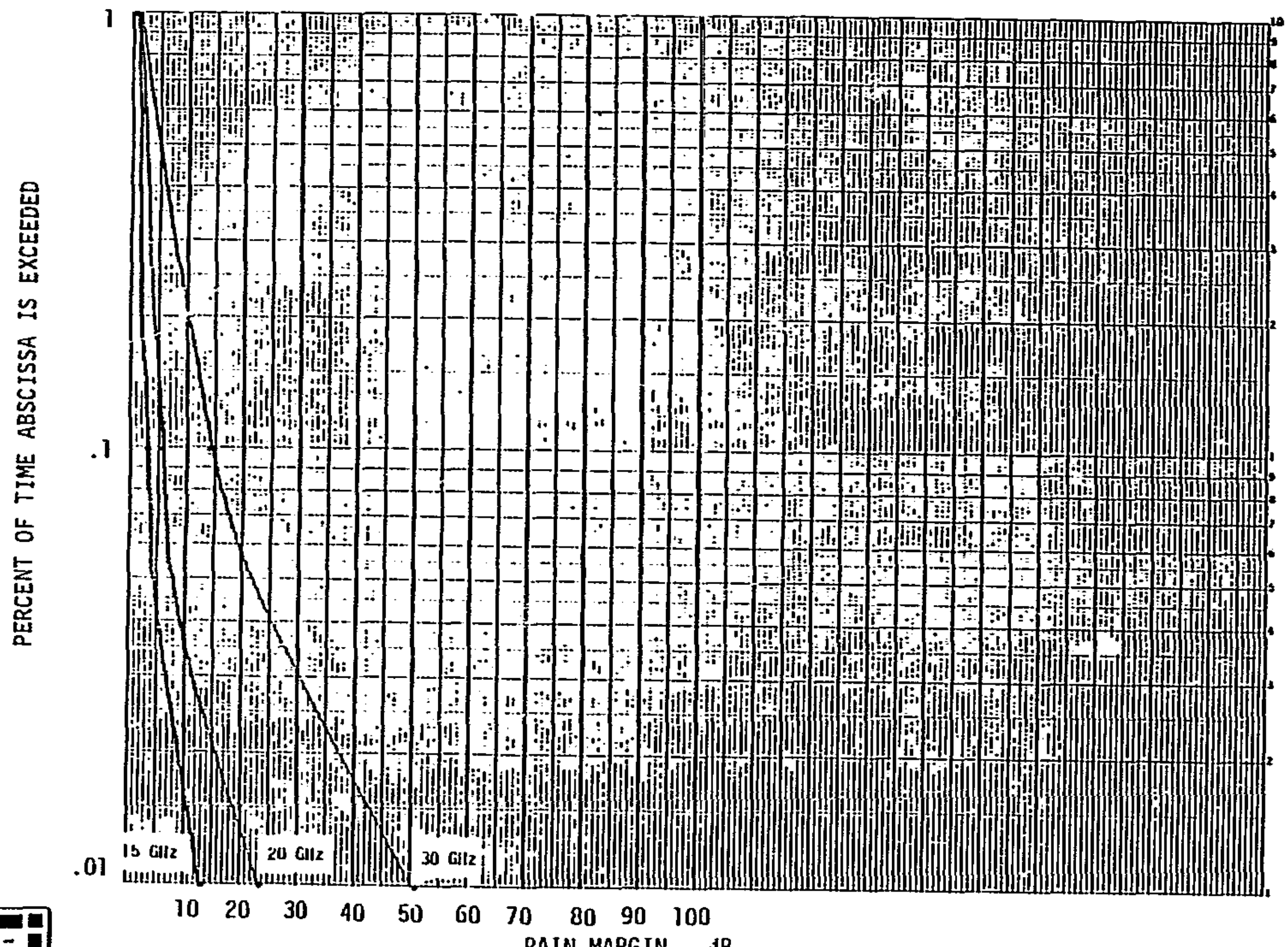


AVAILABILITY LEVELS
COLORADO SPRINGS
CONSTELLATION 1C or 3B
11° ELEVATION ANGLE



4.5 DIVERSITY IMPROVEMENT

4.5.1 The Kaul Model

While space diversity is a common technique used to combat the deleterious effects of RF fading on point-to-point ground links, its application on space/ground links at the frequencies of interest here is not well understood. Investigators are only beginning to include local meterological effects in their diversity modeling efforts. The often-applied diversity-gain computations, which predict large gains for increasing antenna separations independent of local climate conditions, are of marginal value in assessing the performance of space diversity systems. The difficulty here is that rain rate can be constant over quite extensive areas in some parts of the country, causing fading patterns that are correlated at large distances. The predicted diversity gain (based on data gathered in a different region) then fails to materialize because of correlated fading.

In 1980 Kaul began to explore a two component rain model that could account for local variability in diversity gain. Kaul suggested a method of extending the well-known Hodge emperical model for diversity gain; the Hodge model depends only on single-site attenuation and antenna separation. Notwithstanding its sparce development, the Kaul model will be adapted to our needs.

DIVERSITY IMPROVEMENT

- KAUL EXTENSION (1980) OF THE HODGE EMPIRICAL MODEL (1976)
- BASED ON A TWO COMPONENT RAIN MODEL FOR DIVERSITY IMPROVEMENT
- FREQUENCY DEPENDENT THRESHOLD
- MODEL DEVELOPMENT LIMITED

(NASA REFERENCE PUBLICATION 1082)

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4.5.2 Two Component Rain Model

The accompanying figure displays the form of the distribution function of point rainfall rates predicted by the Rice-Holmberg model. The model decomposes rainfall into 2 distinct modes:

- convective or thunderstorm rain (mode 1) which usually extends over several kilometers; and

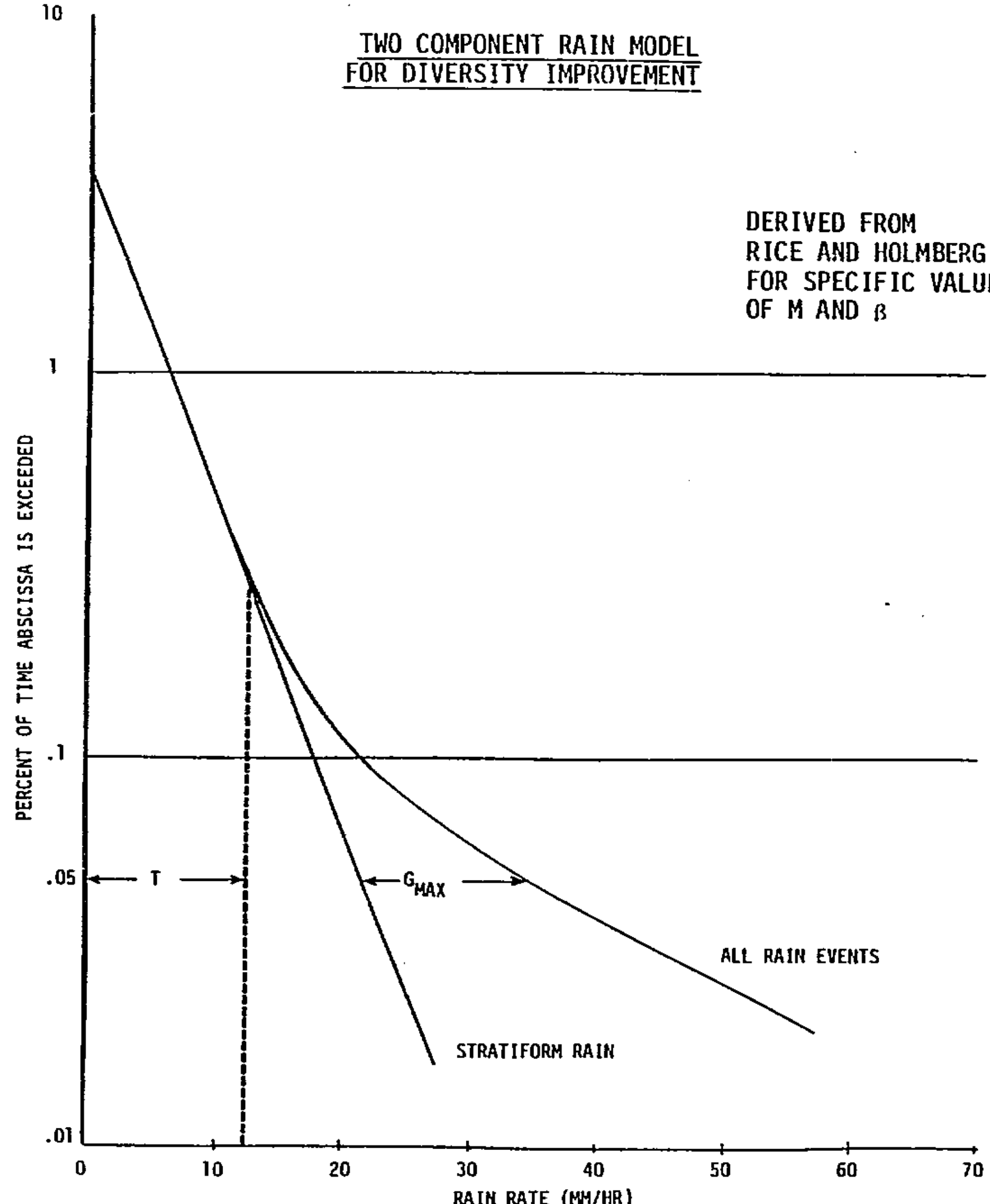
- stratiform rain (mode 2) which is constant over hundreds of kilometers.

When two antennas are separated by several kilometers, it is unlikely that both will be simultaneously affected by the same thunderstorm rain cell. The antennas will experience different fading patterns and a diversity gain for the path will be achieved for the mode 1 rainfall. On the other hand, since the rainfall rate is constant over very large distances for the stratiform or mode 2 rainfall, space diversity gain is not possible. Thus, space diversity gain is determined by the amount of thunderstorm activity along the path. Local meterological conditions are then critical in determining the performance of a space diversity system.

The two component model displays a threshold effect. Diversity improvement is available only when the rain rate exceeds a given level. Also, for a specific availability, there will be a maximum achievable diversity gain, which depends on the amount of mode 1 rain contributing to the total rainfall.

TWO COMPONENT RAIN MODEL
FOR DIVERSITY IMPROVEMENT

DERIVED FROM
RICE AND HOLMBERG MODEL
FOR SPECIFIC VALUES
OF M AND β



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4.5.3 Diversity Gain

Modifying the Hodge model according to Kaul's suggestions leads to the approximations displayed in the figure for diversity gain when the antennas are separated by 10 km. Empirical relations for the maximum gain and the threshold were derived from data found in NASA Reference Publication 1082. The data were computed for the values of average annual rainfall depth (M), ratio of thunderstorm annual depth to total annual rainfall depth (β) and elevation angle (E) shown in the figure.

DIVERSITY GAIN APPROXIMATION FOR 10 km SEPARATION

$$G = G_{MAX}\left[1 - \exp(-10\ V)\right]$$

$$G_{MAX} = 0.66\ (A - T)$$

$$V = 0.46\left[1 - \exp\left\{-0.26\ (A - T)\right\}\right]$$

$A \equiv$ SINGLE SITE RAIN ATTENUATION

$G = 0$ FOR $A \leq T$

F GHz	T dB
15	6
20	8
30	21

FOR M = 1150 MM/YR
$\beta = .3$
E = 40°

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4.5.3 Diversity Gain (Continued)

The product βM measures the thunderstorm or mode 1 rainfall depth and thus is a measure of the effectiveness of space diveristy. That is, the effectiveness of space diversity increases with the amount of mode 1 rainfall. The mode 1 ratio β and the total average rainfall depth M vary according to local meterological conditions.

The table compares the actual βM products for each candidate TDAS site with the value of βM assumed for the diversity gain model. The model's assumptions are very optimistic in estimating the diversity gain at Sunnyvale, White Sands and Colorado Springs; however, rain attenuation is mild at these locations and not likely to require the application of space diversity. Slightly conservative results will be obtained for Houston, while the results for Washington D.C. will be somewhat optimistic.

RAINFALL DEPTH AND MODE 1 RATIO

	M	β	βM	COMPUTED DIV GAIN
SUNNYVALE	525	0.06	32	VERY OPTIMISTIC
WHITE SANDS	197	0.19	37	VERY OPTIMISTIC
COLORADO SPRINGS	457	0.20	91	VERY OPTIMISTIC
HOUSTON	762	0.50	381	SLIGHTLY CONSERVATIVE
WASHINGTON D.C.	988	0.19	188	SOMEWHAT OPTIMISTIC

$M \equiv$ MEAN ANNUAL SURFACE POINT RAINFALL DEPTH (mm)

$\beta \equiv$ RATIO OF MODE 1 (THUNDERSTORM) ANNUAL DEPTH TO TOTAL DEPTH.

KAUL DIVERSITY IMPROVEMENT MODEL USED APPLIES FOR:

$M = 1150$

$\beta = 0.3$

$\beta M = 345$

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4.5.4 Rain Attenuation and Diversity Gain

The accompanying table summarizes the single-site rain attenuation predicted by the Global model and the diversity gain predicted by the Kaul model for each of the TDAS ground locations and constellation options at three different operating frequencies for an availability of 99.9%. Large variations in rain attenuation and diversity gain occur among locations and among constellations. The threshold effect of diversity gain is evident. That is, diversity gain is zero unless the single-site attenuation exceeds a threshold.

Constellation option 2 achieves minimum rain attenuation at all sites, because of its favorable elevation angle.

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RAIN ATTENUATION AND DIVERSITY GAIN*

99.9% AVAILABILITY	15 GHz		20 GHz		30 GHz	
	RAIN ATTEN(dB)	DIV GAIN(dB)	RAIN ATTEN(dB)	DIV GAIN(dB)	RAIN ATTEN(dB)	DIV GAIN (dB)
SUNNYVALE						
IB + 3A (W)	2.1	0	4.0	0	9.0	0
IB + 3A (E)	6.1	0	11.2	1.9	25.6	2.9
IC + 3B	3.7	0	6.8	0	15.4	0
2	2.2	0	4.2	0	9.4	0
WHITE SANDS						
IB + 3A (W)	2.0	0	3.8	0	8.8	0
IB + 3A (E)	2.7	0	4.9	0	11.4	0
IC, 3B + 1A	5.7	0	10.6	0	24.6	2.2
2	1.5	0	2.8	0	6.4	0
COLORADO SPRINGS						
IB + 3A (W)	1.0	0	2.0	0	4.5	0
IB + 3A (E)	1.4	0	2.6	0	6.0	0
IC + 3B	3.3	0	6.1	0	13.9	0
2	0.8	0	1.4	0	3.2	0
HOUSTON						
IB + 3A (W)	14.5	5.5	26.1	11.8	55.0	22.2
IB + 3A (E)	12.6	4.3	22.7	9.6	47.5	17.3
IC + 3B	17.2	7.3	31.1	15.1	66.2	29.5
2	10.2	2.6	18.4	6.8	38.1	11.1
WASHINGTON, DC						
IB + 3A (W)	10.0	2.5	18.3	6.7	40.5	12.7
IB + 3A (E)	4.3	0	7.8	0	17.1	0
IC + 3B	5.2	0	9.5	0.8	21.0	0
2	4.5	0	8.1	0	17.9	0

*BASED ON 10 KM SPACING OF GROUND ANTENNAS.

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4.5.5 Cross Polarization Discrimination

Frequency reuse by transmitting cross-polarized signals doubles the capacity of the downlink channels. Rain attenuation, however, can alter the polarization of a signal and destroy the orthogonality between the cross-polarized channels. The table summarizes the cross-polarization discrimination ratio (XPD) at the 99.9% level. XPD is the ratio of the recieved copolarized signal power to the received cross-polarized signal power when only the copolarized signal was transmitted. It is a measure of the isolation between the received cross-polarized channels and depends on the polarization transmitted, the elevation angle and the rain attenuation.

Depending on the requirement placed on the ground terminal design, it may be necessary to enhance the isolation between the cross-polarized channels at the ground terminal receiver. Constellation Option 2 yields an XPD in excess of 33 db at all TDAS locations, which should be adequate for all TDAS applications.

CROSS-POLARIZATION DISCRIMINATION
(CCIR XPD APPROXIMATION)

HORIZONTAL POLARIZATION 99.9% LEVEL	XPD (dB) 13 GHz DOWNLINK	XPD (dB) 20 GHz DOWNLINK
SUNNYVALE		
IB + 3A (W)	44.3	43.2
IB + 3A (E)	30.0	26.1
IC + 3B	35.7	34.5
2	43.4	42.2
WHITE SANDS		
IB + 3A (W)	43.3	42.1
IB + 3A (E)	39.2	38.0
IC, 3B + IA	30.4	29.2
2	50.5	49.3
COLORADO SPRINGS		
IB + 3A (W)	35.5	34.4
IB + 3A (E)	37.3	36.2
IC + 3B	31.6	30.5
2	42.7	41.6
HOUSTON		
IB + 3A (W)	23.4	23.0
IB + 3A (E)	26.7	25.8
IC + 3B	21.2	20.3
2	34.1	33.2
WASHINGTON, D.C.		
IB + 3A (W)	25.1	24.0
IB + 3A (E)	36.9	35.8
IC + 3B	33.1	32.1
2	36.1	35.0

4.6 REFERENCE DOWNLINK BUDGET

The table presents the reference downlink budgets for both K_u and K_a band TDAS operation; the downlink budget for TDRSS K_u band operation is included for comparison. The budgets were computed for 300 Mbps uncoded quadraphase and the TDRSS constellation.

The downlink reference budgets summarize our assumptions regarding TDAS; for example, we assume a 3 meter multibeam antenna on the spacecraft and a ground G/T of 41.5 db at K_u band and 43 db at K_a band for TDAS. The assumptions for the TDAS downlink budgets are consistent with the TDRSS downlink budget and achieve identical system margins. The 8 db serial combining loss insures that the spacecraft-to-ground link will not place an additional burden on the user spacecraft signal energy to noise intensity ratio.

The figure also displays our assumptions regrading the HPA backoff as a function of the number of carriers on the downlink. When there are six carriers, we assume them to be spaced so that the effects of intermodulation products are minimized, for example the use of Babcock spacing.

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REFERENCE DOWNLINK BUDGET

White Sands 171°W - 41°W Constellation
300 Mbps - Uncoded Quadraphase

LINK BUDGET ELEMENTS \ LINK BUDGET ALLOCATION - dB	K_u TDRSS	K_u TDAS	K_a TDAS
HPA RATING	14.25	12.50	16.00
LOSSES	-4.00	-4.00	-4.00
TDRS ANTENNA GAIN (2m)	42.75		
TDAS MBA GAIN (3m)		44.50	47.00
EIRP	53 dB	53 dB	59 dB
PATH LOSS + ATMOS LOSS	-209	-209	-211.5
GROUND G/T	41.5	41.5	43
BOLTZMAN CONSTANT	228.6	228.6	228.6
RAIN ATTENUATION	- 6	- 6	-11
SERIAL COMBINING LOSS	- 8	- 8	- 8
DATA RATE	-85	-85	-85
AVAILABLE E/N_o	15.1dB	15.1dB	15.1dB
EQUIPMENT LOSSES	- 4	- 4	- 4
REQUIRED E/N_o	- 9.6	- 9.6	- 9.6
SYSTEM MARGIN WITH RAIN	1.5dB	1.5dB	1.5dB

HPA BACKOFF ASSUMPTIONS

NUMBER OF CARRIERS	BACKOFF (dB)
1	0
2	1
6	6
MANY	10

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4.7 TDAS DOWNLINK CONFIGURATIONS

4.7.1 Downlink Designs

The following tables summarize 4 different designs for the TDAS downlink configuration. Both K_u and K_a band designs are presented for each of the constellation options 2 and 3A. Required satellite power was computed for the rain attenuation, data rate and ground antenna size (60 ft. for each case) shown in the tables, using the reference downlink budget. The need for space diversity operation is also indicated in the tables where required and rate 1/2 coding was assumed where indicated.

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CONSTELLATION 2

K_u DOWNLINK SIZING (13/15 GHz)

99.9% AVAILABILITY (RAIN)

LOCATION	NUMBER OF CARRIER	DOWNLINK DATA RATE (Mbps)	SATELLITE POWER - HPA (WATTS)	ANTENNA DIAMETER (FT)	RAIN ATTENUATION (dB)
SUNNYVALE	P_1 2 P_2 MANY	300 300	3 23	60	2.2
WHITE SANDS	P_1 MANY P_2 MANY	6 6	1 1	60	1.5
COLORADO SPRINGS	P_1 2 P_2 MANY	600 (UNCODED) 300	14 16	60	.8
HOUSTON	P_1 2 P_2 6*	300 300	18 57	60	10.2
WASHINGTON D.C.	P_1 2 P_2 MANY	600 (UNCODED) 300	32 38	60	4.5

TOTAL 203 W

P_1 EQUALS POLARIZATION OF SIGNAL i (i = 1, 2).

* USING BABCOCK OR SIMILAR SPACING OF CARRIERS.

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CONSTELLATION 3A

K_u DOWNLINK SIZING (13/15 GHz)

99.9% AVAILABILITY (RAIN)

LOCATION		NUMBER OF CARRIERS		DOWNLINK DATA RATE (Mbps)		SATELLITE POWER HPA (WATTS)		ANTENNA DIAMETER (FT)		RAIN ATTENUATION (dB)	
		WEST	EAST	WEST	EAST	WEST	EAST	WEST	EAST	WEST	EAST
SUNNYVALE	P_1	2	2	600 UNCODED	300	18	7	60	60	2	6
	P_2	MANY	MANY	300	300	22	54				
WHITE SANDS	P_1	MANY	MANY	6	6	1	2	60	60	1.5	2.7
	P_2	MANY	MANY	6	6	1	2				
COLORADO SPRINGS	P_1	2	2	300	600 (UNCODED)	2	16	60	60	1.0	1.4
	P_2	MANY	MANY	300	300	17	19				
HOUSTON	P_1	2	2	300	300	17	12	60 (DIV)	60 (DIV)	10 (DIV)	8.3 (DIV)
	P_2	6*	6*	300	300	54	37				
WASHINGTON D.C.	P_1	2	2	300	600 (UNCODED)	17	31	60	60	10	4.3
	P_2	6*	6*	300	300	54	15				
					TOTAL	203 W	195 W				

P_i EQUALS POLARIZATION OF SIGNAL i (i = 1, 2).

*USING BABCOCK OR SIMILAR SPACING OF CARRIERS.

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CONSTELLATION 2

K_a DOWNLINK SIZING (20/30 GHz)

99.9% AVAILABILITY (RAIN)

LOCATION	NUMBER OF CARRIERS	DOWNLINK DATA RATE (Mbps)	SATELLITE POWER - HPA (WATTS)	ANTENNA DIAMETER (FT)	RAIN ATTENUATION (dB)
SUNNYVALE	P_1 1* P_2 MANY	1200 (UNCODED) 300	5 25	60	4.2
WHITE SANDS	P_1 MANY P_2 MANY	6 6	1 1	60	3
COLORADO SPRINGS	P_1 1* P_2 MANY	1200 (UNCODED) 300	3 14	60	1.4
HOUSTON	P_1 1* P_2 6**	1200 (UNCODED) 300	32 61	60 (DIV)	12 (DIV)
WASHINGTON D.C.	P_1 1* P_2 MANY	1200 (UNCODED) 300	13 61	60	8

TOTAL 206 W

P_i EQUALS POLARIZATION OF SIGNAL i (i = 1, 2).

* DERIVED FROM DEMODULATED LASER LINKS

** USING BABCOCK OR SIMILAR SPACING OF CARRIERS.

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CONSTELLATION 3A

K_a DOWNLINK SIZING (20/30 GHz)

99.9% AVAILABILITY (RAIN)

LOCATION	NUMBER OF CARRIERS		DOWNLINK DATA RATE (Mbps)		SATELLITE POWER HPA (WATTS)		ANTENNA DIAMETER (FT)		RAIN ATTENUATION (dB)	
	WEST	EAST	WEST	EAST	WEST	EAST	WEST	EAST	WEST	EAST
SUNNYVALE	P_1 1* P_2 MANY	1* 6*	1200 (UNCODED) 300	1200 (UNCODED) 300	5 24	25 48	60	60	4	11
WHITE SANDS	P_1 MANY P_2 MANY	MANY MANY	6 6	6 6	2 2	2 2	60	60	4	5
COLORADO SPRINGS	P_1 1* P_2 MANY	1* MANY	1200 (UNCODED) 300	1200 (UNCODED) 300	3 15	4 17	60	60	2	2.6
HOUSTON	P_1 1* P_2 6**	1* 6**	1200 (UNCODED) 300	1200 (UNCODED) 300	51 96	40 53	60 (DIV)	60 (DIV)	14 (DIV)	13 (DIV)
WASHINGTON D.C.	1* 6**	1* 6**	1200 (UNCODED) 300	1200 (UNCODED) 300	32 60	13 24	60 (DIV)	60	12 (DIV)	8
				TOTAL	290 W	228 W				

P_i EQUALS POLARIZATION OF SIGNAL i (i = 1, 2).

* DERIVED FROM DEMODULATED LASER LINKS

** USING BABCOCK OR SIMILAR SPACING OF CARRIERS.

4.7.2 Downlink Configuration Comparisons

The 4 TDAS downlink configurations are compared in the table in terms of total downlink data rate, satellite power, number of satellites and number of ground antennas.

It is interesting to observe that for either constellation option, the data rate is doubled by moving from K_u to K_a band, with roughly the equivalent satellite power (1 db increase for 3A), the same number of satellites, and an additional ground antenna. Similarly, the data rate is doubled for either frequency band by moving from option 2 to option 3A; however, the satellite power must be doubled, the number of ground antennas more than doubled and an additional satellite added. In terms of the comparisons quantified in this table, K_a band operation of option 2 would appear to be the most efficacious configuration.

DOWNLINK CONFIGURATION COMPARISONS

OPTION / PARAMETER	K_U BAND				K_A BAND			
	TOTAL DOWNLINK DATA RATE (Mbps)	SATELLITE POWER (WATTS)	NUMBER OF SATELLITES	NUMBER OF GROUND ANTENNAS	TOTAL DOWNLINK DATA RATE (Mbps)	SATELLITE POWER (WATTS)	NUMBER OF SATELLITES	NUMBER OF GROUND ANTENNAS 5 SITES
CONSTELLATION OPTION 2	3000	203	2	5	6000	206	2	6
CONSTELLATION OPTION 3A	5700	398	3	12	12000	518	3	13

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4.8 UPLINK POWER REQUIREMENTS

Assuming a maximum uplink data rate of 300 kbps, no more that 30 watts of uplink power would be required to achieve an availability of 99.9% at K_u band for any of 5 TDAS sites and all constellations.

Again assuming a maximum uplink data rate of 300 kbps, no more than 100 watts of uplink power would be required to achieve an availability of 99.9% at K_a band for all TDAS sites, except Houston and Washington D.C., and for all constellations.

No more than 100 watts of uplink power would be required at Houston and Washington, D.C. to achieve an availability of 99.5% at K_a band for all constellations.

The figure summarizes uplink power requirements for the constellation 3A for Washington, D.C. and Houston at both K_u and K_a bands.

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UPLINK POWER SUMMARY

CONSTELLATION 3A

	K_u BAND		K_a BAND	
	RAIN ATTEN. db	UPLINK POWER W	RAIN ATTEN. dB	UPLINK POWER W
WASHINGTON D.C.	10 (99.9%)	5	40.5 (99.9%) 17.4 (99.5%)	1412 7
HOUSTON	14.5 (99.9%)	14	55 (99.9%) 25.2 (99.5%)	NA 42

ASSUMPTIONS:

- 60 ft. ANTENNA
- 14 db BACKOFF & LOSSES
- -113 dbW/m^2 AT SATELLITE

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SECTION 5

TDAS GROUND SEGMENT ELEMENTS

5.1 GROUND SEGMENT/SPACE SEGMENT INTERFACE

As pointed out in Section 3, TDAS requires a distributed ground terminal architecture. 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 elements requiring access to the space relays.

GROUND SEGMENT/SPACE SEGMENT INTERFACE

THE DISTRIBUTED GROUND TERMINAL ARCHITECTURE REQUIRES A NEW NETWORK ELEMENT, THE TDAS GROUND TERMINAL (TGT):

THE TGT INTERFACES NETWORK ELEMENTS TO THE TDAS SPACE RELAY UNDER THE CONTROL OF THE NCC.

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5.2 TDAS CONTROL CONCEPT

The control concept adopted for TDAS is summarized in the accompanying table. The Network Control Center (NCC) controls the occurrence of network events by promulgating scheduling messages among the network elements. Scheduling messages are interpreted to yield required space segment configurations by the White Sands Ground Terminal (WSGT) and are interpreted to yield required ground segment configurations by the TDAS Ground Terminal (TGT). Network events are under the control of the NCC, space segment configuration under the control of the WSGT, and ground segment configuration under the control of the TGT. The control concept also embraces emergency back-up capabilities for the three control functions resident at alternate locations.

TDAS CONTROL CONCEPT

	PRIMARY	EMERGENCY BACK-UP
• NETWORK CONTROL	NCC	WHITE SANDS
• SPACE SEGMENT CONFIGURATION	WSGT	GODDARD
• GROUND SEGMENT CONFIGURATION	TGT	TGT MANUAL

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5.3 TDAS GROUND SEGMENT FUNCTIONAL ALLOCATION

In Section 3 we identified the basic ground segment function and organized them into three categories: the provision of network services; the control of network resources; and the control of user resources. It was stated there that a particular allocation of these functions to the ground segment elements leads to a ground segment architecture. The control concept provides the operational rationale to allocate the basic functions to the ground segment elements. The control concept described in the previous section results in the allocation depicted in the figure, which associates each basic function with one or more of the four ground segment elements, the NCC, the WSGT, the TGT, and the MCC. Observe that the allocation implies a functional description of each ground segment element which is summarized in the figure. The functional description of the ground segment elements is the foundation for the baseline ground segment architecture.

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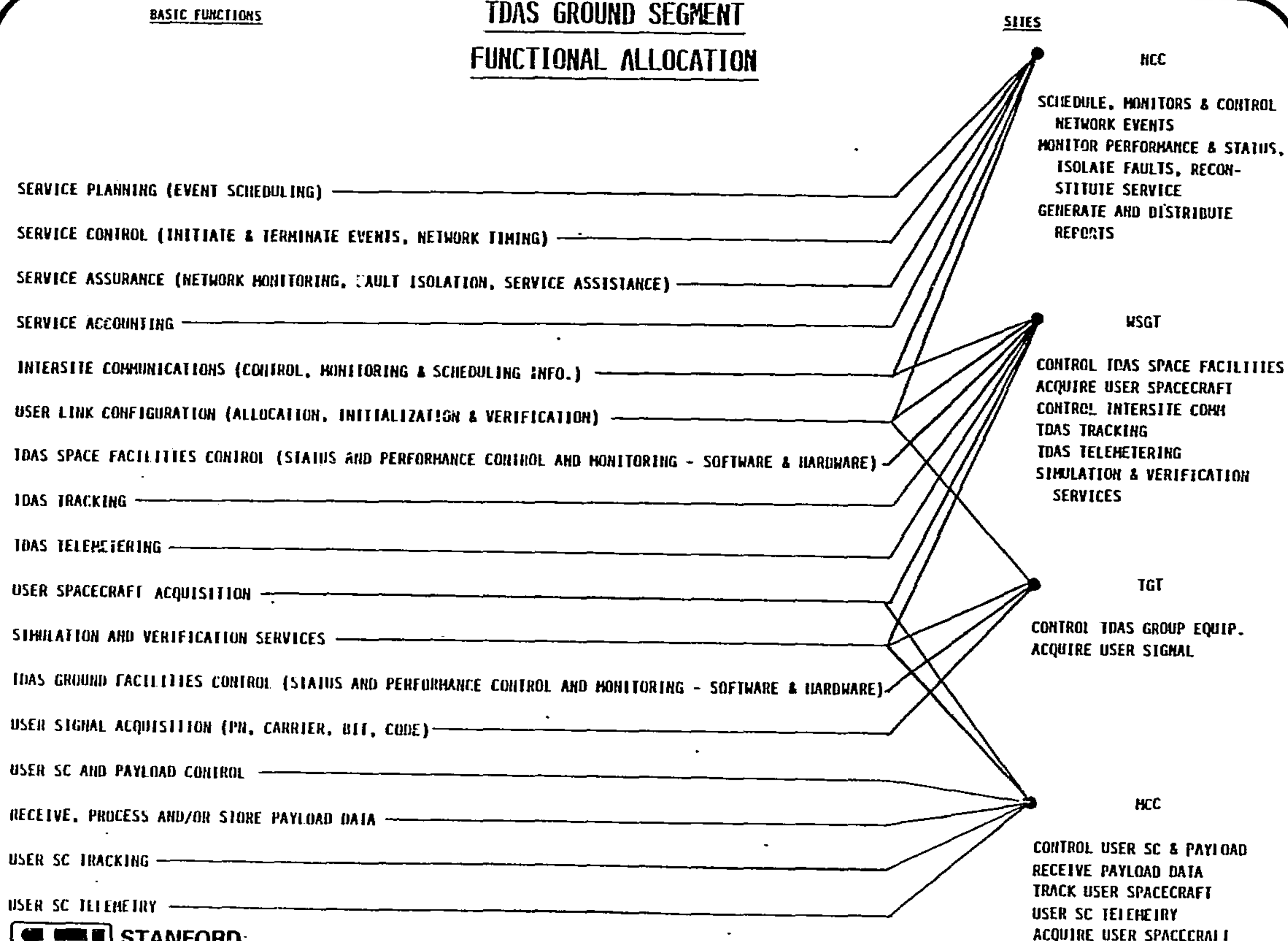
TDAS GROUND SEGMENT
FUNCTIONAL ALLOCATION



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5.4 THE TDAS GROUND TERMINAL

A functional block diagram of the TGT is displayed in the figure. In addition to specifying functions, the diagram depicts message flows over interfaces to other network elements, such as the NCC and the MCC.

A control and monitoring element is shown for the TGT which controls the configuration of the TGT subsystems and monitors their performance and status. The control element communicates with the NCC, deriving configuration control messages from the NCC scheduling messages and sending performance and monitoring data to the NCC. The TGT includes an antenna subsystem, an RF subsystem, a data subsystem, and an intersite communications interface.

While the configuration shown in the figure interfaces a MCC to the network, the TGT will be a modular common element of all ground terminals in the TDAS network.

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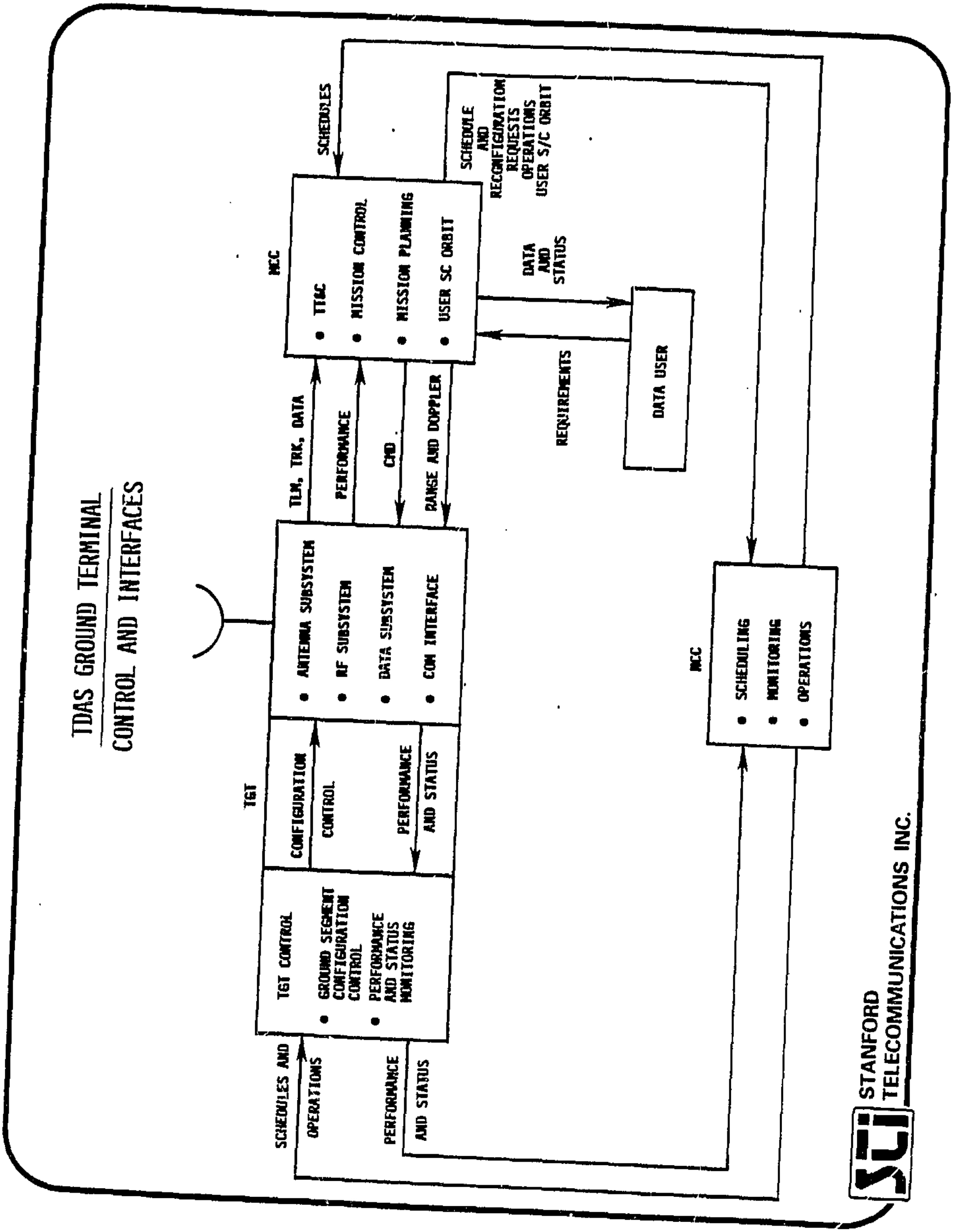

5.5 THE WHITE SANDS GROUND TERMINAL

The functional block diagram of the WSGT is displayed in the accompanying figure. The 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, 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 back-up emergency network control function is also shown to reside at White Sands.

TDAS WSGT

SPACE SEGMENT CONTROL

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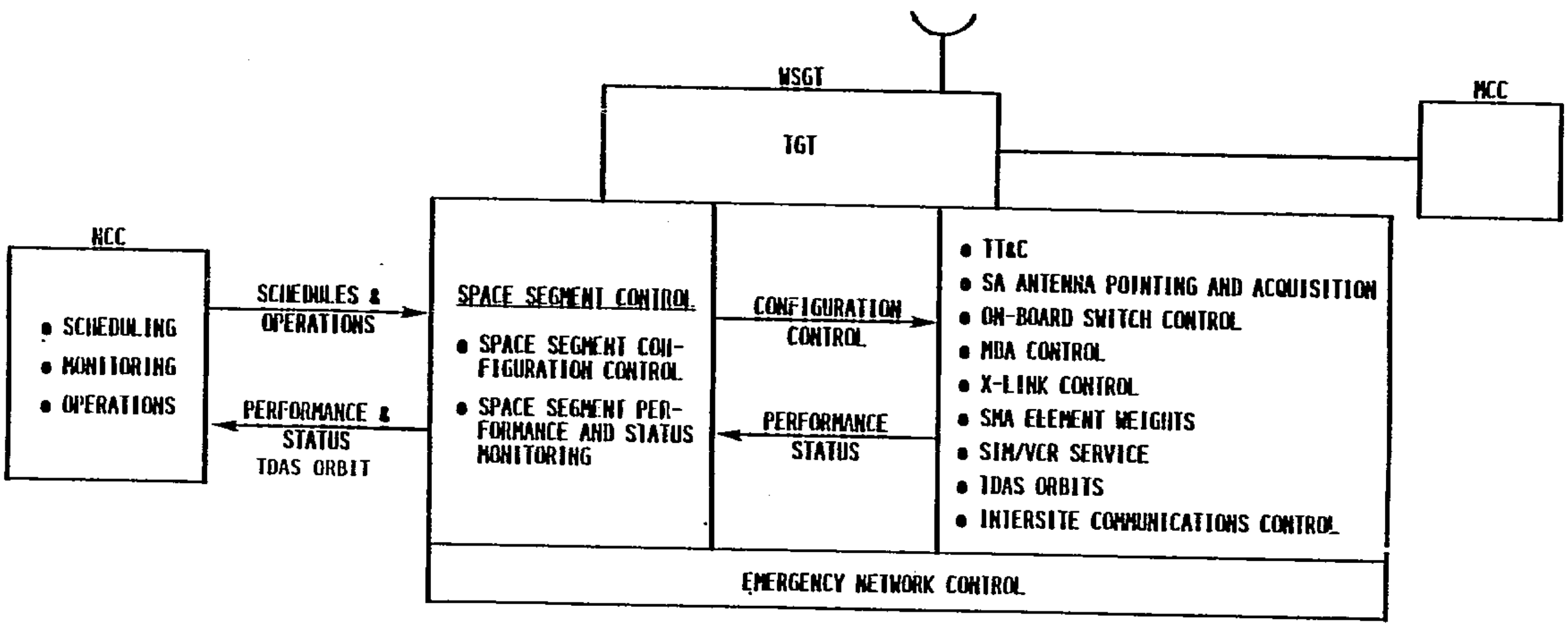

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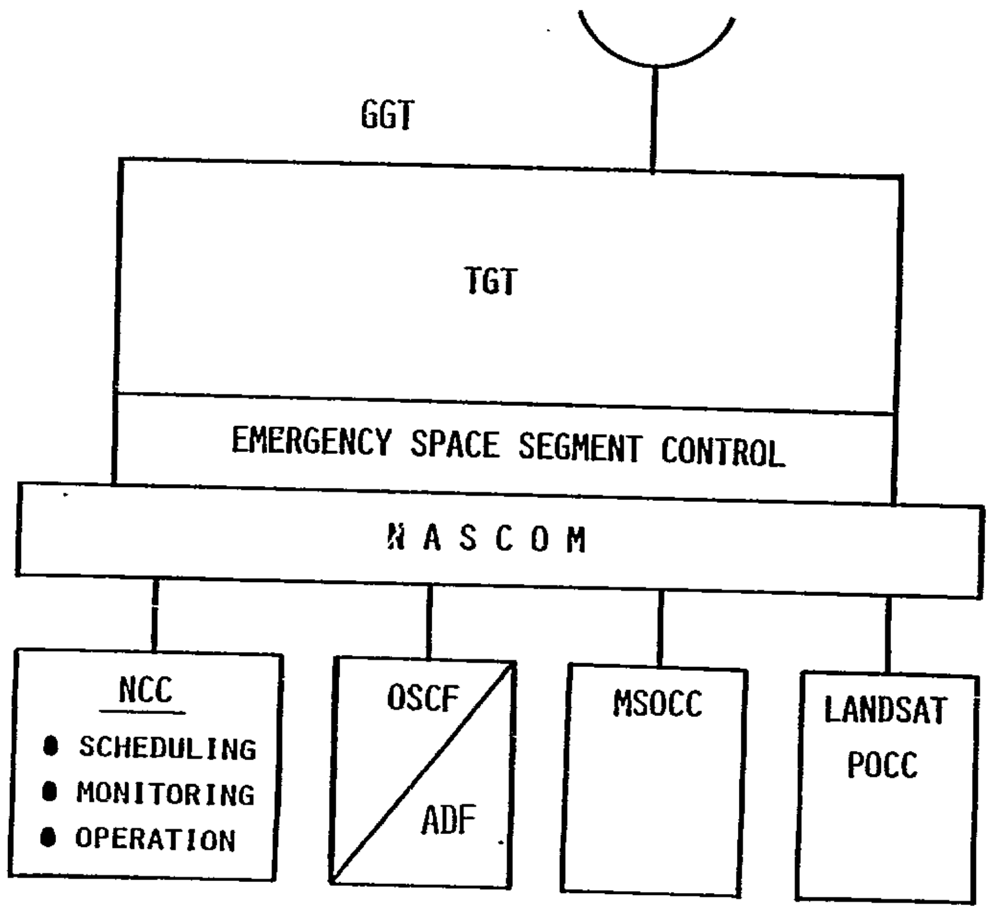
5.6 THE GODDARD GROUND TERMINAL

The Goddard Ground Terminal (GGT) interfaces the TDAS elements at NASA, Goddard to the TDAS space relay; it consists of a TGT, interfaces to the NCC and other network elements at Goddard through a local NASCOM net, and an emergency space segment control function. Although not shown, part of the emergency space segment control function would most likely reside at a Goddard facility other than the GGT.

TDAS GODDARD GROUND TERMINAL



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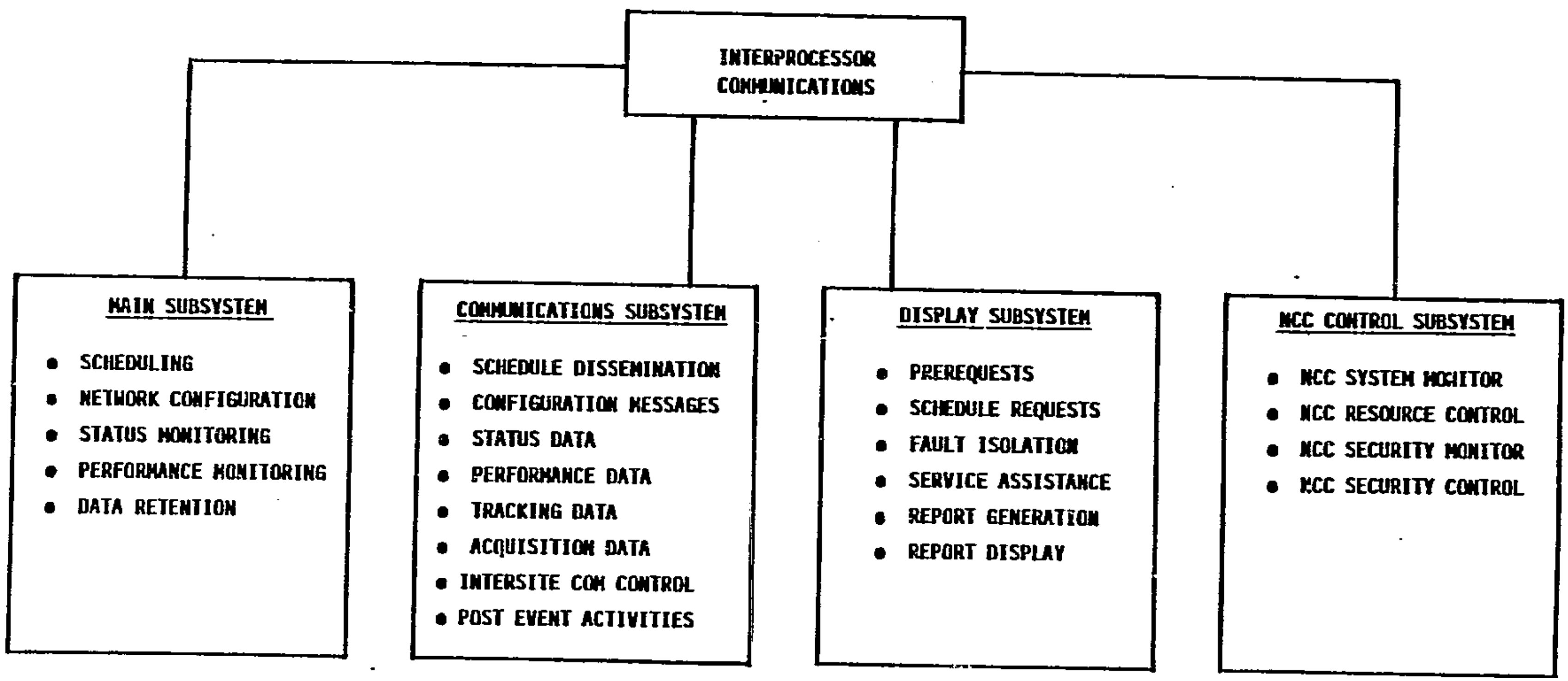
5.7 THE TDAS NETWORK CONTROL CENTER

The accompanying figure displays the TDAS NCC subsystem and the allocation of functions among the subsystems. The communication and display subsystems support the main subsystem in scheduling and monitoring network events, while the NCC control subsystem is responsible for the allocation and status of the NCC resources.

In addition to scheduling the new single access services, the NCC must control the use and monitor the performance of the new TDAS facilities, such as the MBA, the on-board switch, the crosslink, and the TGT.

TDAS NETWORK CONTROL-NCC SUBSYSTEMS



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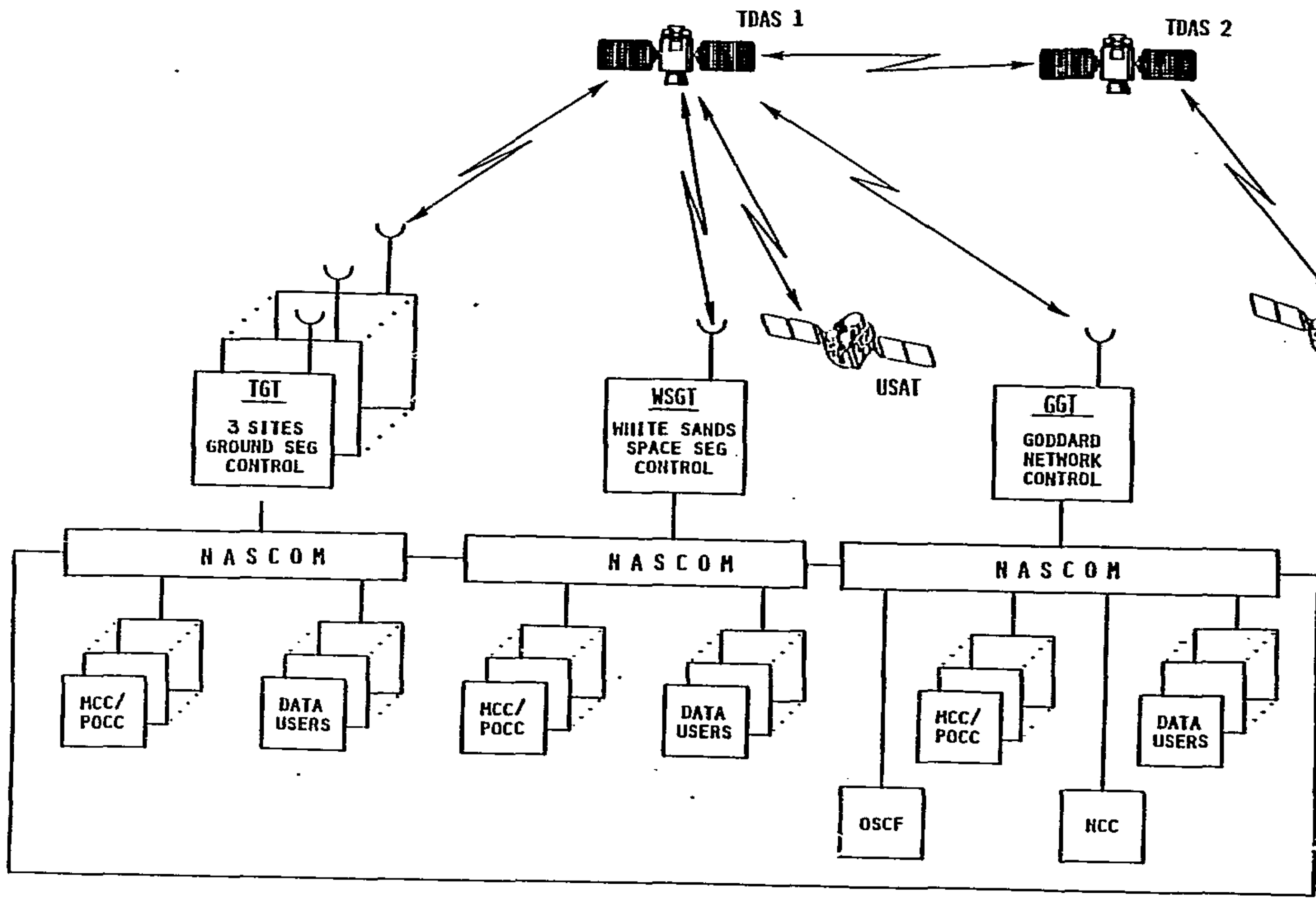
SECTION 6

THE TDAS NETWORK

6.1 TDAS NETWORK ELEMENTS

The elements of the TDAS network include the space relays, the WSGT, the GGT and several TGT's. Local networks (provided by NASCOM) will interface such elements as the NCC, the OSCF and the MCC/POCC's to the ground terminals. While the NCC and the OSCF are network elements, the MCC/POCC's and the data user sites need not be part of the TDAS network.

TDAS NETWORK ELEMENTS



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6.1 TDAS NETWORK ELEMENTS (Continued)

The connectivity of the TDAS element resembles a star network as opposed to the serial nature of the TDRSS element connectivity. The data distribution functions performed by WSGT, NGT and NASCOM for TDRSS are performed by the on-board switch, the MBA and the TGT's for TDAS. Observe that NASCOM performs local area communications for TDAS, as opposed to its intersite communications function for TDRSS.

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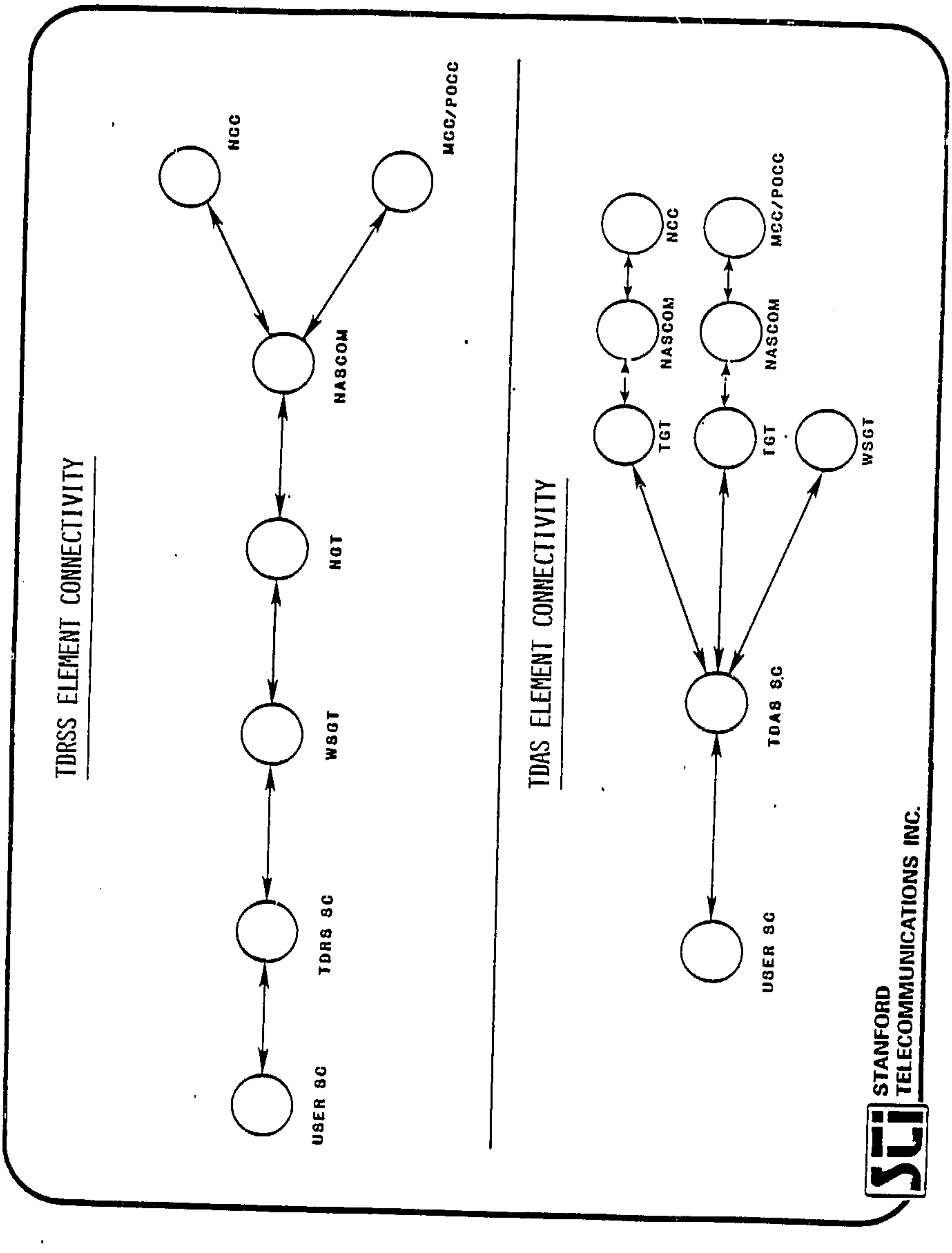
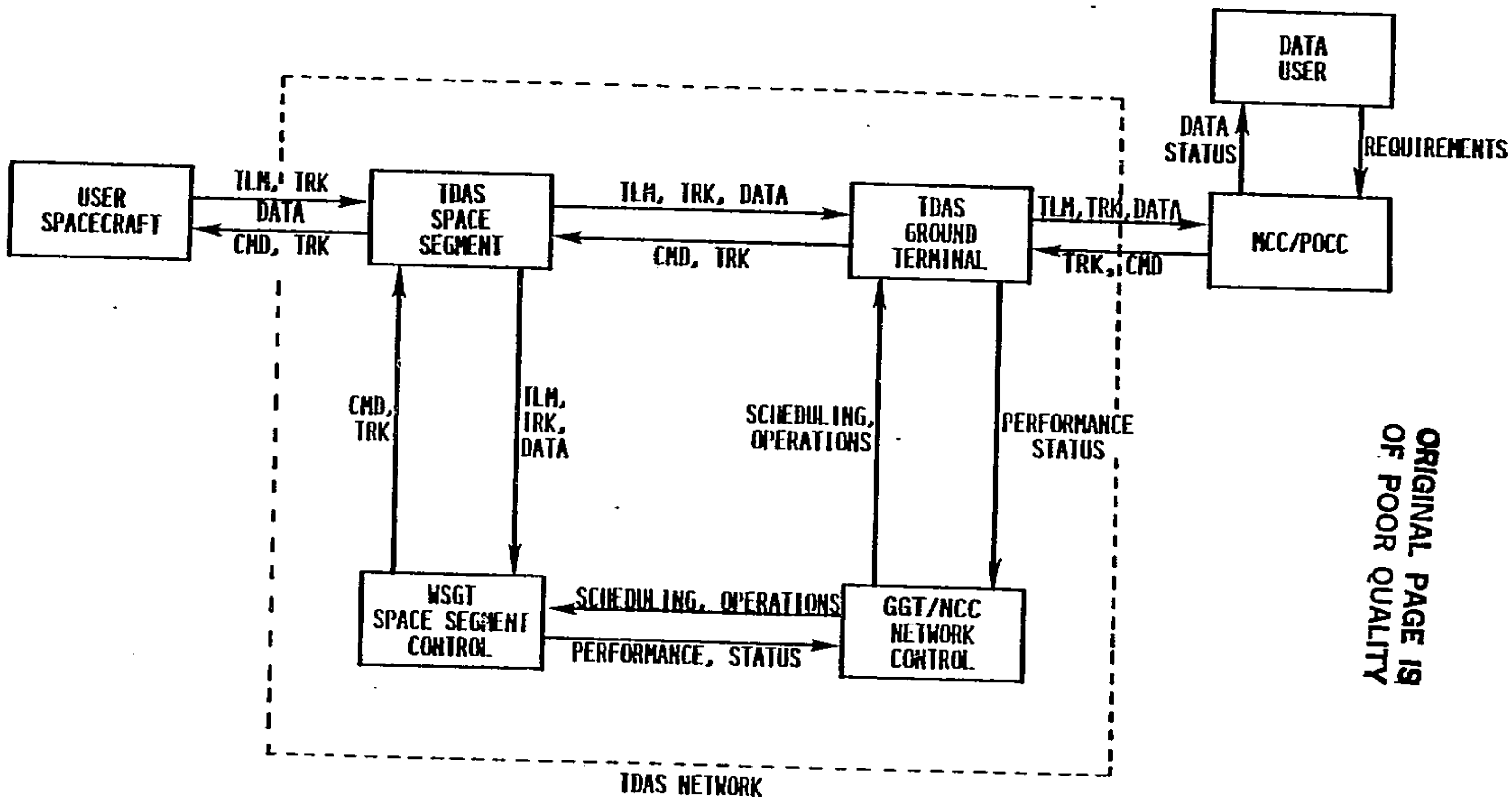


6.2 TDAS NETWORK DEFINITION

The accompanying figure depicts the TDAS network as those elements inside the dashed box. Elements of the TDAS network are under the control of the NCC, whereas the user spacecraft and the MCC/POCC resources are under control of the MCC/POCC.

The scheduling, payload, tracking, telemetry, status, and performance data exchanged among the network elements and between network and user elements are shown in the figure. Appropriate communication links and interfaces will be required to support the data flows indicated.

TDAS NETWORK



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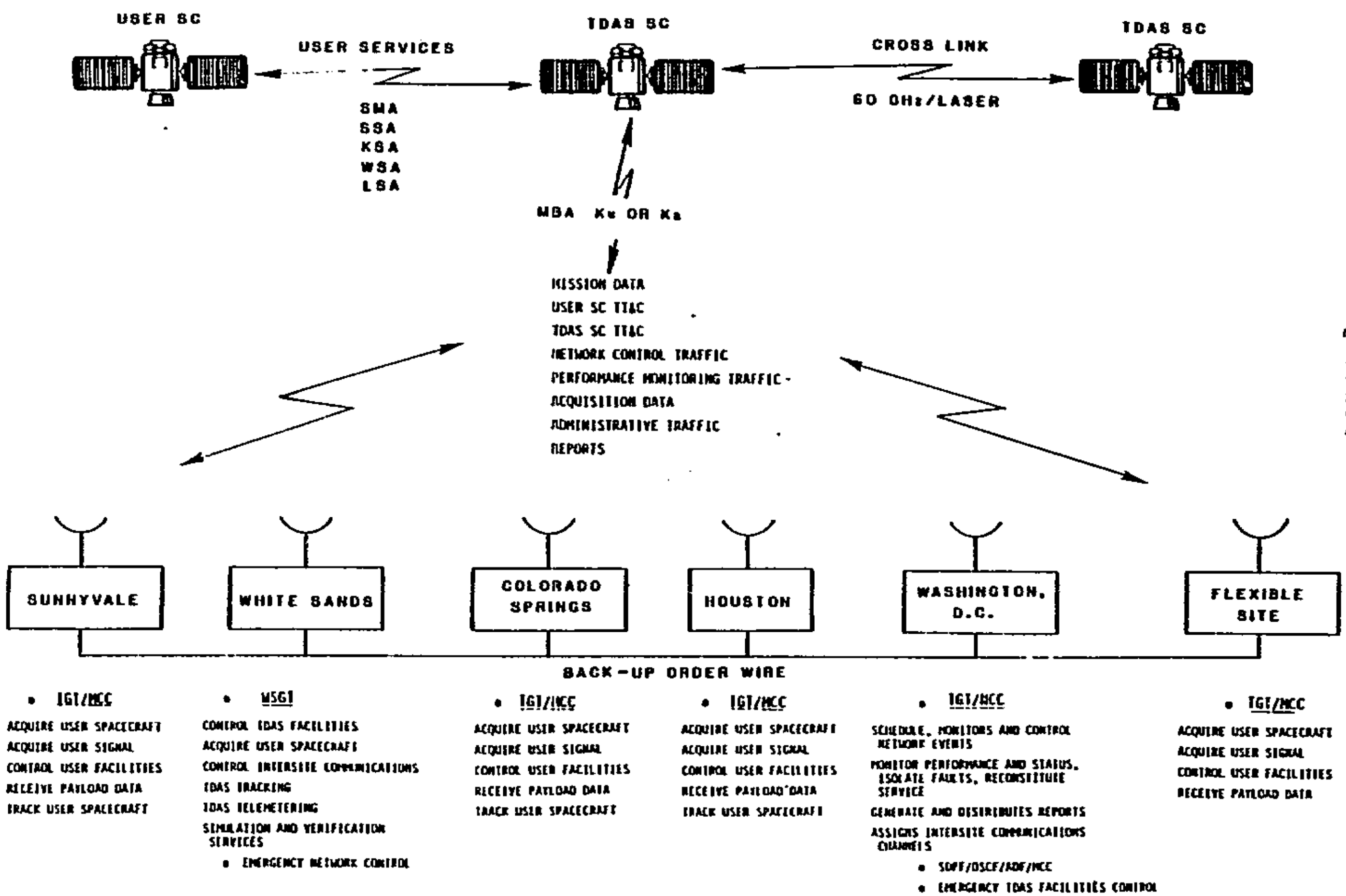
6.3 TDAS BASELINE CONCEPT

The baseline concept encompasses both the space and ground network elements, their functions and how they are interconnected to support the projected mission profiles. In the figure we show both fixed and flexible ground terminals and 2 TDAS spacecraft connected by a crosslink in a space/ground network to provide the user services indicated.

The functions associated with the network elements at the ground terminals are also shown, in addition to the kinds of traffic on the space/ground links.

TDAS BASELINE CONCEPT



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6.4 TDAS NETWORK TRAFFIC FLOWS

6.4.1 NCC Origination

The NCC sends service schedules, configuration messages and orbit data to both the WSGT and the TGT. It controls the allocation of intersite communications resources through messages to WSGT. The NCC transmits scheduling messages to the MCC/POCC, as well as ground control message (GCM) dispositions, service assistance responses, emergency routine verification service (ERVS) recommendations and post-event reports.

NCC ORIGINATION

ORIGIN \ DESTINATION	WSGT	TGT	MCC/POCC	TDAS SPACECRAFT
NCC	• SERVICE SCHEDULES (SHO) • TDAS SPACE SEGMENT RECONFIGURATION CONTROL (OPM) • INTERSITE COMMUNICATIONS CONTROL • USER ORBIT DATA (OPM) • TDAS ORBIT DATA (OPM)	• SERVICE SCHEDULES (SHO) • TDAS GROUND SEGMENT CONFIGURATION CONTROL (OPM) • OPERATIONS DATA (OPM) • USER ORBIT DATA (OPM) • TDAS ORBIT DATA (OPM) • PERFORMANCE MONITORING CONFIGURATIONS	• SCHEDULING MESSAGES • GCM DISPOSITIONS • SERVICE ASSISTANCE RESPONSES • ERVS RECOMMENDATIONS • POST EVENT REPORTS	• EMERGENCY SC COMMANDS

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6.4.2 WSGT Origination

The WSGT sends the NCC status and performance information regarding space segment equipment, in addition to TDAS tracking data, TDAS acquisition status and post-event reports. TDAS acquisition status (of the user spacecraft) is also sent to the TGT. WSGT controls the TDAS spacecraft and their payloads through SC commands.

WSGT ORIGINATION

DESTINATION / ORIGIN	NCC	TGT	MCC/POCC	TDAS SPACECRAFT
WSGT	• STATUS OF SCHEDULED SERVICE • SPACE SEGMENT PERFORMANCE MONITORING • SPACE SEGMENT EQUIPMENT STATUS • TDAS ACQUISITION STATUS • TDAS TRACKING DATA • TDAS PREV. MAIN. OR MANEUVER REQUEST • INTERSITE COM PERFORMANCE MONITORING • INTERSITE COM STATUS • POST EVENT REPORTS	• TDAS ACQUISITION STATUS	• EMERGENCY SCHEDULING MESSAGES	• TDAS SC COMMANDS

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6.4.3 TGT Origination

The TGT sends the NCC status and performance information regarding the ground segment equipment, in addition to post-event reports. Ground segment equipment status, service performance monitoring, and service status messages are sent to the MCC/POCC.

TGT ORIGINATION

DESTINATION / ORIGIN	NCC	WSGT	MCC/POCC	TDAS SPACECRAFT
TGT	• SERVICE PERFORMANCE MONITORING • GROUND SEGMENT EQUIPMENT STATUS • INTERSITE COM PERFORMANCE • POST EVENT REPORTS		• GROUND SEGMENT EQUIPMENT STATUS • SERVICE PERFORMANCE MONITORING • SERVICE STATUS	• UPLINK SIGNALS

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6.4.4 MCC/POCC Origination

In addition to sending the NCC scheduling messages and post-event reports, the MCC/POCC requests service reconfiguration, antenna or signal reacquisition, and service assistance from the NCC. It informs WSGT regarding the acquisition status of the user spacecraft, requests status and performance data from the TGT, and commands the user spacecraft and payload. It sends the NCC user spacecraft tracking or orbit data, depending on whether or not the MCC/POCC tracks the user spacecraft.

MCC/POCC ORIGINATION

DESTINATION / ORIGIN	NCC	WSGT	TGT	TDAS SPACECRAFT
MCC/POCC	• SCHEDULING MESSAGES • TDAS SERVICE RECONFIGURATION/REACQUISITION REQUESTS • USER SC TRACKING OR ORBIT DATA • SERVICE ASSISTANCE REQUESTS • POST EVENT REPORTS	• USER SC ACQUISITION STATUS • EMERGENCY SCHEDULING MESSAGES	• STATUS AND PERFORMANCE MONITORING REQUESTS	• USER SC COMMANDS • PAYLOAD COMMANDS

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6.4.5 TDAS Spacecraft Origination

The TDAS spacecraft transmits telemetry and tracking data to WSGT; emergency telemetry and tracking data are sent to GGT.

TDAS NETWORK MESSAGE FLOW

TDAS SPACECRAFT ORIGINATION

ORIGIN \ DESTINATION	GGT	WSGT
TDAS SPACECRAFT	• TDAS EMERGENCY SC TELEMETRY • TDAS EMERGENCY SC TRACKING	• TDAS SC TELEMETRY • TDAS SC TRACKING

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6.4.6 User Spacecraft Origination

The MCC/POCC receives telemetry, tracking, and payload data from the user spacecraft.

TDAS NETWORK MESSAGE FLOW

USER SPACECRAFT

DESTINATION / ORIGIN	MCC/POCC
USER SPACECRAFT	• USER SC TELEMETRY • USER SC TRACKING • PAYLOAD DATA

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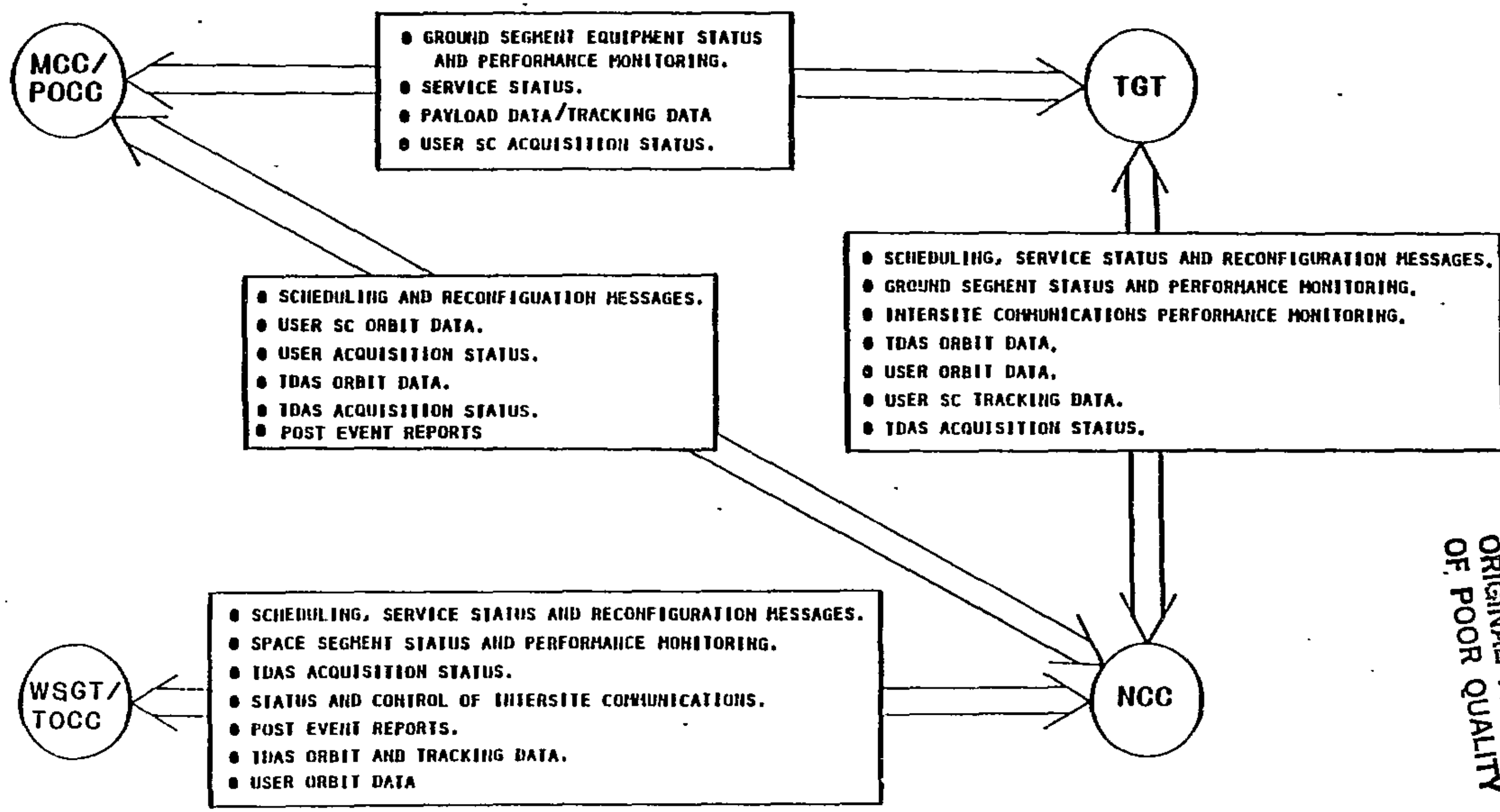
6.4.7 TDAS Ground Segment Traffic Summary

The figure summarizes the messages and data that are exchanged between pairs of ground segment elements. For example, NCC sends out scheduling and reconfiguration messages; in return it receives service, system and equipment status information, as well as, performance monitoring data. The exchange of tracking and orbit data, shown for both tracking and non-tracking MCC/POCC's, is based on the use of a return-link tracking technique.

Not Shown in this figure are possible direct communications between WSGT and TGT regarding the status of TDAS acquisition of the user spacecraft and between WSGT and the MCC/POCC regarding the status of the user spacecraft acquisition of TDAS.

TDAS GROUND SEGMENT TRAFFIC



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6.5 TDAS CONTROL MESSAGES

6.5.1 TDAS Control Message Traffic

The exchange of TDAS control messages between the NCC and other ground segment elements is summarized in the figure. As mentioned previously the NCC transmits scheduling and reconfiguration messages and receivers status and performance messages from other network elements.

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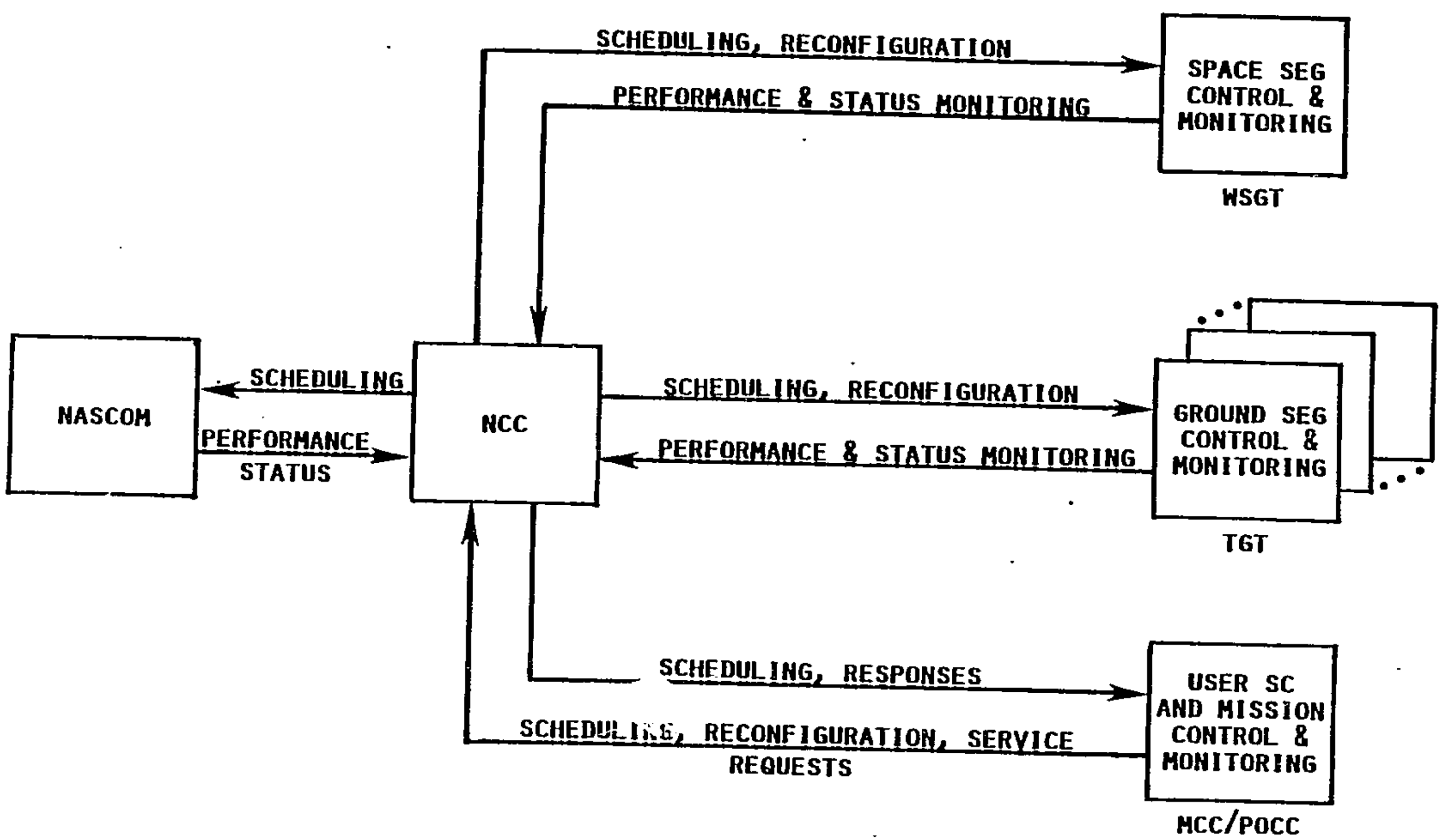
TDAS CONTROL



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6.5.2 TDAS Control Network Option

One option for implementing the TDAS control network is the use of the space/ground MBA links and the TDAS on-board switch to connect ground terminals. For example, full duplex 56 Kbps data and voice channels could be derived from a small allocation of the TDAS capacity to this function.

TDAS CONTROL NETWORK OPTION

- DERIVED FROM THE SPACE/GROUND MBA LINKS AND THE TDAS ON-BOARD SWITCH
- FULL DUPLEX 56 KBPS DATA LINKS
- FULL DUPLEX 56 KBPS VOICE LINKS

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6.5.3 Control Network Channel Requirements

Assuming that 7 TGT's are connected to both the NCC and the WSGT and that the NCC and WSGT are interconnected, then 15 full duplex voice and 15 full duplex digital channels would be required. A total of 60 50 KHz FDMA channels would satisfy this requirement. Our analysis of traffic indicated that the only information exchanged between WSGT and the TGT would be the acquisition status of the TDAS and the user spacecraft. Since acquisition status information could be relayed by the NCC between the WSGT and the TGT or exchanged by voice or low rate data lines, the capacity shown in the table is most likely a conservative estimate of the control channel requirements. Some channels would be dedicated to specific links while others could be assigned on demand. The adequacy of this estimate of channel requirements also depends on the need to send raw tracking data (rather than orbit data) from the MCC/POCC's to the NCC.

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CONTROL NETWORK CHANNEL REQUIREMENTS

ORIGIN \ DEST.	NCC	WSGT	TGT	NUMBER OF CHANNELS
NCC		1	7	8
WSGT	1		7	8
TGT	7	7		14
TOTAL CHANNELS REQUIRED				30

30	FDMA DIGITAL CHANNELS	1.5 MHZ
30	FDMA VOICE CHANNELS	1.5 MHZ
60	FDMA CHANNELS	3 MHZ

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6.6 EXAMPLES OF TDAS OPERATIONS

6.6.1 User Spacecraft Acquisition

In the transition from TDRSS to TDAS various functions performed at WSGT regarding acquisition of the user spacecraft and signal will be the responsibility of the TGT. User spacecraft acquisition is a particularly good example of TDAS operations, since it involves coordinating the activities of all four ground segment elements and both the TDAS and user spacecraft.

Events in the acquisition process are dependent and must occur in the proper sequence. The TDAS sequence illustrated for acquiring the user spacecraft differs in several significant ways with the TDRSS acquisition sequence: the forward link signal is generated and transmitted by the TGT; open loop user spacecraft antenna commands generated by the MCC are transmitted by the TGT; TDAS autotrack occurs on board the TDAS spacecraft; and TGT acquires the user signal.

USER SC/ANTENNA ACQUISITION

KSA OR 60 GHz ACQUISITION SEQUENCE (INITIATED BY TGT)

1. WSGT TRANSMITS OPEN-LOOP ANTENNA POINTING COMMANDS TO TDAS SC
   - WSGT NEEDS USER SC ORBIT DATA FROM NCC
2. WSGT TRANSMITS SWITCH COMMANDS TO TDAS SC
   - WSGT INITIALIZES SPACE TO SPACE AND SPACE TO GROUND LINKS
3. TGT TRANSMITS FORWARD LINK SIGNAL WITH DOPPLER CORRECTION FOR PN CHIP RATE AND CARRIER FREQUENCY
   - TGT NEEDS TDAS AND USER ORBIT DATA FROM NCC
4. USER SC RECEIVES FORWARD LINK SIGNAL ENERGY (ACQUISITION EIRP)
   - OPEN LOOP POINTING OF USER SC ANTENNA UNDER CONTROL OF MCC
5. USER SC ACQUIRES AND AUTOTRACKS FORWARD LINK
   - OPEN LOOP POINTING OF USER SC ANTENNA UNDER CONTROL OF MCC
6. USER SC TRANSMITS COHERENT TURNAROUND K-BAND RETURN SIGNAL
7. TDAS AUTOTRACK INITIATES SEARCH FOR RETURN SIGNAL
   - AUTOTRACK ON-BOARD TDAS SPACECRAFT
8. TGT RECEIVES RETURN LINK SIGNAL ENERGY
9. TDAS AUTOTRACK DECLARES USER SIGNAL PRESENCE TO WSGT (WSGT NOTIFIES TGT)
10. TGT ACQUIRES PN/CARRIER/BIT SYNC/DECODER/DATA
    - NEEDS TDAS AND USER ORBIT DATA FROM NCC

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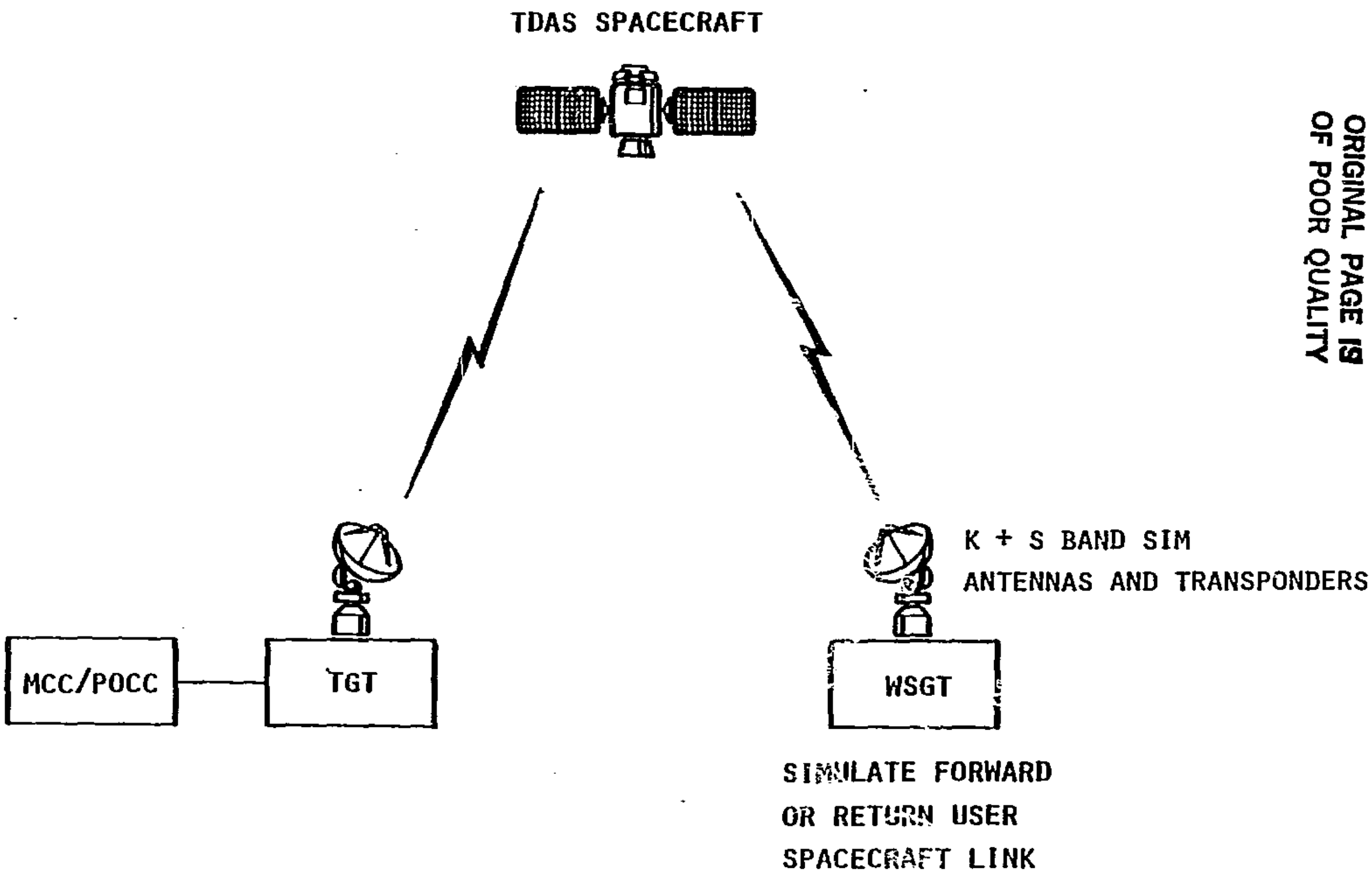
6.6.2 Simulation/Verification Service

The simulation/verification service is a particularly straightforward TDAS operation. K and S band antennas and appropriate transponders simulate the TDAS spacecraft to user spacecraft forward and return links. A W band simulation capability will have to be added to the WSGT.

TDAS SIMULATION/VERIFICATION SERVICE



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SECTION 7

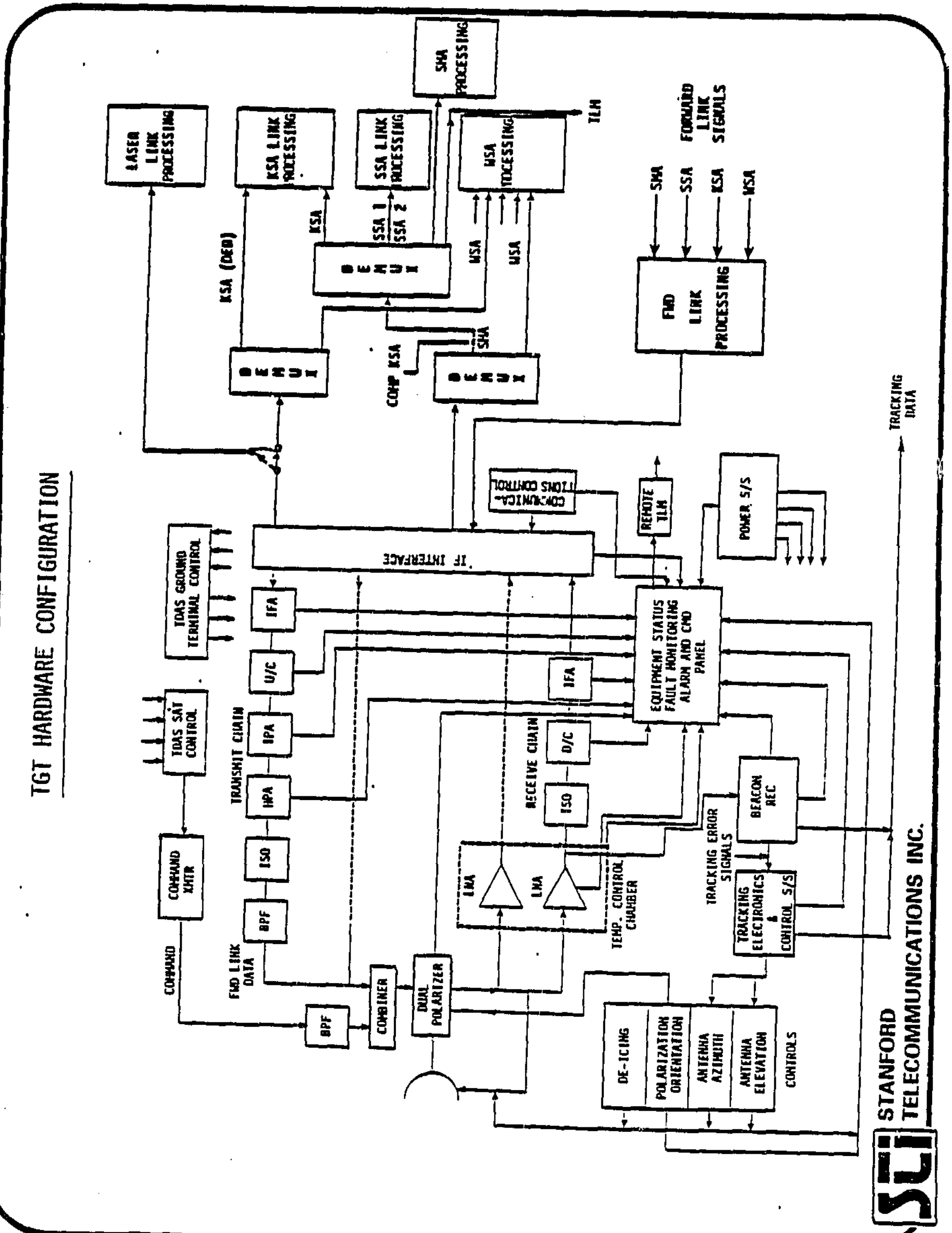
TDAS GROUND TERMINAL HARDWARE

7.1 TGT GENERIC HARDWARE CONFIGURATION

A generic hardware configuration of the TGT is given in the accompanying figure. The salient assumptions regarding the ground terminal design are listed below:

- tracking terminal;
- frequency reuse feed subsystem;
- flexibility of polarization orientation;
- cooled low noise amplifier;
- automatic equipment status/fault monitoring;
- deicing provisions;
- adequate reflector smoothness; and
- minimal gain loss due to pointing/tracking errors.

The generic TGT has appropriate hardware to receive 2 KSA, 2 SSA, 5 WSA, 1 laser SA, and the SMA channels and to transmit two forward link signals each for the KSA, SSA, WSA and SMA channels. The TDAS satellite control function included in the configuration is applicable only to the TGT's associated with the WSGT and the GGT.



TGT HARDWARE CONFIGURATION

7.2.1 TGT Monitoring and Control Concept

The TGT Monitoring and and Control concept is based on distributing intelligence to the subsystem level to allow automonous subsystem operations and and recovery (with manual over-ride). The sytem consists of an executive computer that communicates with the NCC and microprocessor interfaces with each subsystem. Each string of subsystems communications hardware is fully spared. The microprocessor automatically configures each subsystem, sets up the appropriate hardware string and automatically switches to the spare string when subsystem faults are detected.

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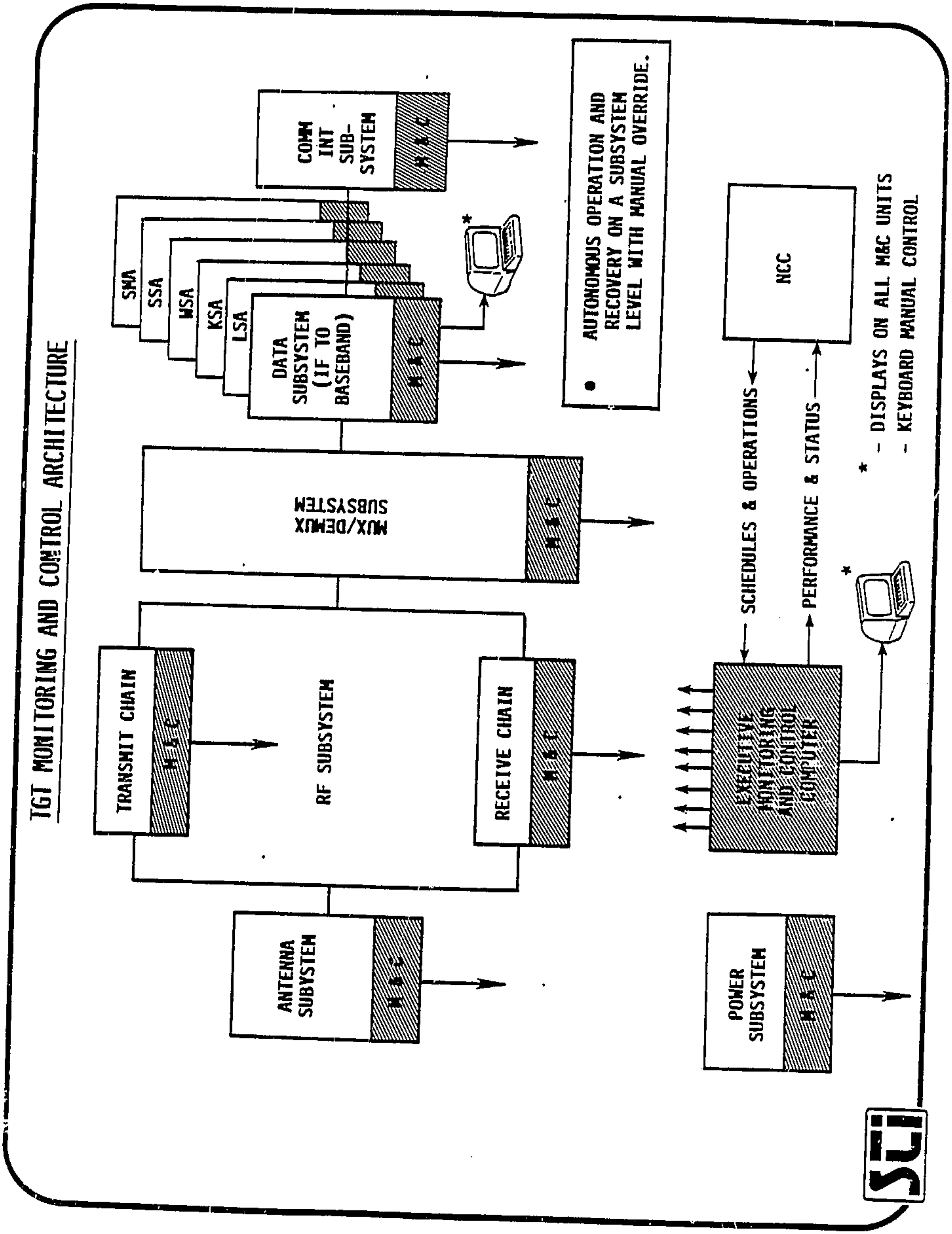
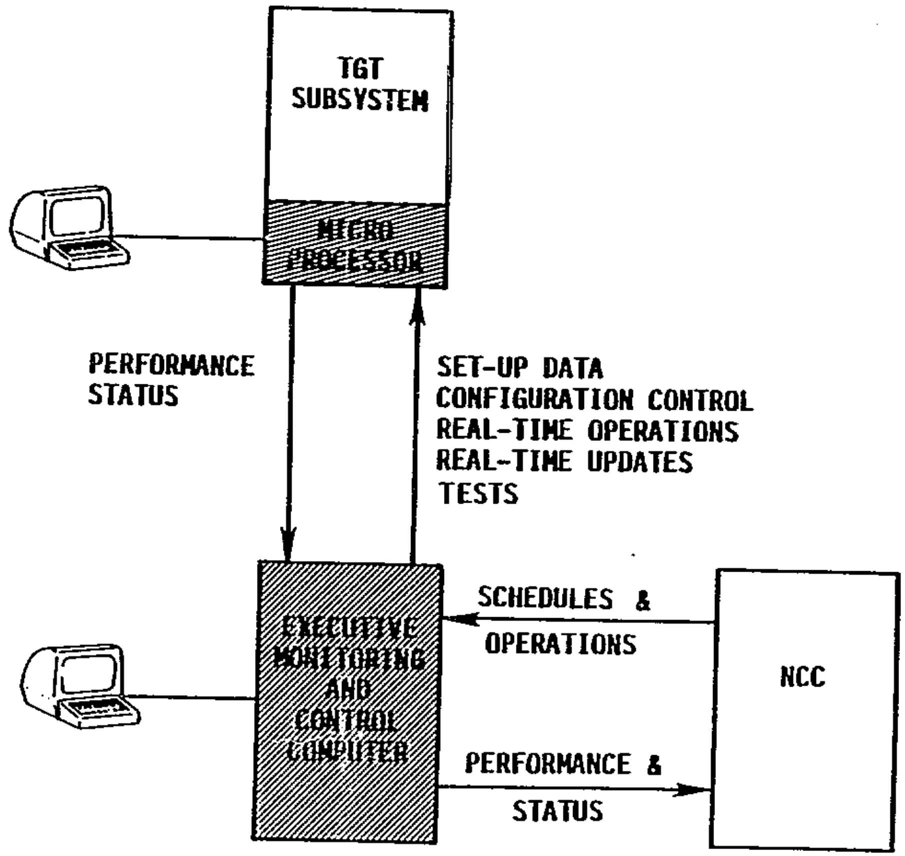


7.2.2 TGT Monitoring and Control Elemebt

The TGT monitoring and control executive computer sends the subsystem microprocessor messages that include: set-up data, configuration control messages, operations data, updates and test messages. In return it receives performance and status data from the subsystem microprocessor. The executive computer resignals to scheduling and operations messages from the NCC and sends the NCC performance and status messages.

TGT MONITORING AND CONTROL ELEMENT



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7.3 TGT EQUIPMENT COMPLEMENT

The list of key equipment for the generic TGT is given in the table. Three equipment groups are shown: RF equipment; baseband equipment; and control and interface equipment. TDAS satellite control equipment would be required only at the TGT's associated with the WSGT and the GGT.

KEY EQUIPMENT COMPLEMENT OF GROUND TERMINAL

RF EQUIPMENT

ANTENNA

MOUNT

TRACKER

BEACON RECEIVER

RF/POL: SUBSYSTEM

COMMAND TRANSMITTER

HPA

UPCONVERTER

LNA

DOWNCONVERTER

POWER SUBSYSTEM

DE-ICER

LNA TEMP. CONTROL CHAMBER

AUTO. FAULT MONITORING

CONTROL AND INTERFACES

REFLECTOR DE-ICING/POL/ANT. POINTING CONTROLS

TDAS SATELLITE CONTROL

TDAS GROUND TERMINAL CONTROL

REMOTE TELEMETRY INTERFACE

COMMUNICATION CONTROL INTERFACE

TRACKING DATA INTERFACE

BASEBAND EQUIPMENT

MUX/DEMUX; KSA, SSA, WSA, SMA, AND LASER PROCESSORS

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7.4 TGT PARAMETERS

In the following tables we list the parameters of the TGT for both K_u and K_a bands. To minimize TDAS spacecraft power and weight requirements, we have assumed 60 ft. antennas for ground terminals in either frequency band. No major technical difficulties are anticipated in realizing the TGT parameters and characteristics listed in the tables.

KEY GROUND TERMINAL PARAMETERS (13/15 GHz)

XMT: FREQ BAND	15 GHZ
REC: FREQ BAND	13 GHZ
ANTENNA DIAMETER	60 FT.
MOUNT	AZIMUTH/ELEVATION
DRIVE	DUAL MOTOR ANTI-BACKLASH
POLARIZATION	LINEAR
FEED	FREQUENCY REUSE
POLARIZATION ISOLATION	> 35 DB
POWER HANDLING CAPABILITY	5 KW @ 15 GHZ
TRACKING	PROGRAM
POINTING/TRACKING ERROR	0.01 DEG RMS
GAIN LOSS DUE TO POINTING/TRACKING ERROR	< 0.4 DB (@ 18 M DIA)
SURVIVAL WIND	125 MILES/HR
ANTENNA SURFACE TOLERANCE	0.01 INCH
UPLINK FLUX CAPABILITY	-100 DBW/M² @ TDAS ANTENNA APERTURE
REC AND XMT CHAIN IMPAIRMENTS	
GAIN FLATNESS	± 0.5 DB
AM/PM CONVERSION	< 2°/DB
GAIN STABILITY	± 0.5 DB

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KEY GROUND TERMINAL PARAMETERS (20/30 GHz)

XMT FREQ BAND	30 GHZ
REC FREQ BAND	20 GHZ
ANTENNA DIAMETER	60 FT.
MOUNT	AZIMUTH/ELEVATION
DRIVE	DUAL MOTOR ANTI-BACKLASH
POLARIZATION	LINEAR
FEED	FREQUENCY REUSE
POLARIZATION ISOLATION	> 35 DB
POWER HANDLING CAPABILITY	5 KW @ 30 GHZ
TRACKING	PROGRAM
POINTING/TRACKING ERROR	0.01 DEG RMS
GAIN LOSS DUE TO POINT/TRACKING ERROR	< 0.9 DB (@ 18 M DIA)
SURVIVAL WIND	125 MILES/HR
ANTENNA SURFACE TOLERANCE	0.01 INCH
UPLINK FLUX CAPABILITY	-113 DBW/M^2 @ TDAS ANTENNA APERTURE
REC AND XMT CHAIN IMPAIRMENTS	
GAIN FLATNESS	± 0.5 DB
AM/PM CONVERSION	< 2°/DB
GAIN STABILITY	° 0.5 DB

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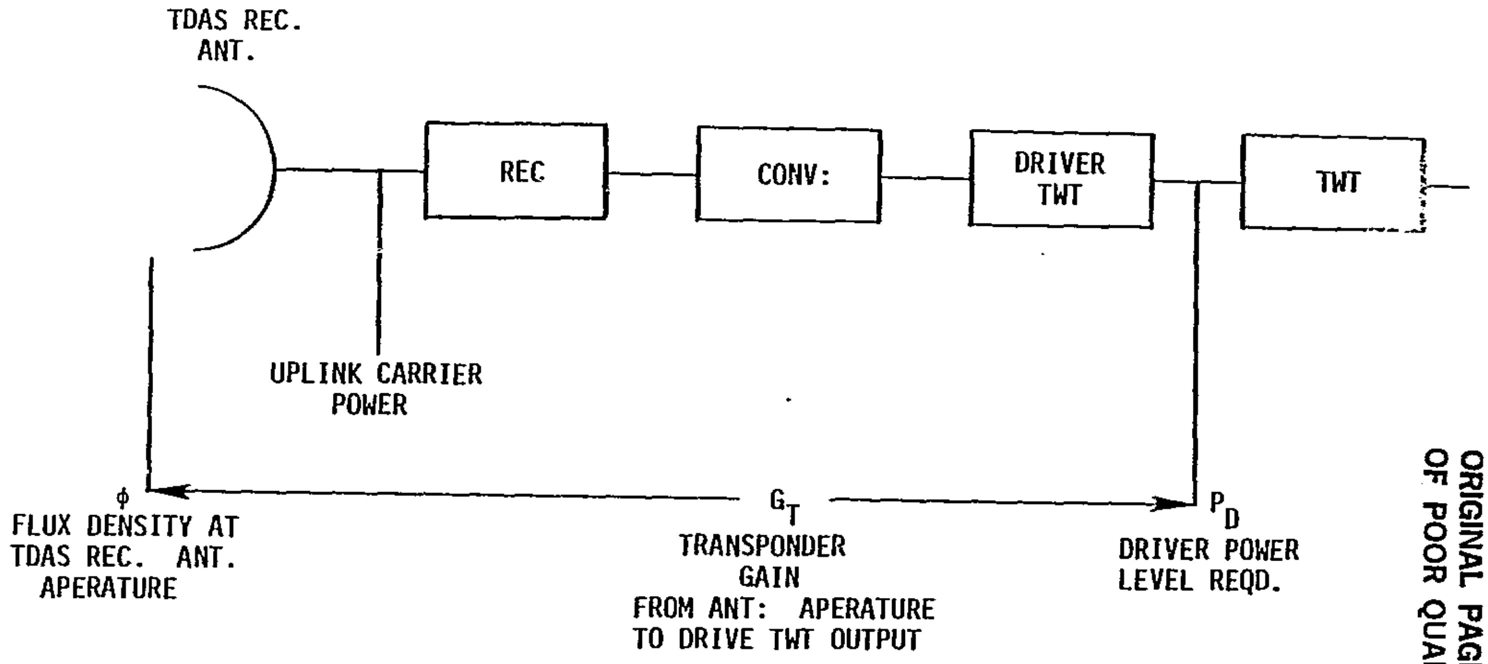
7.5 TGT HPA SIZING AT K_a BAND

7.5.1 Transponder Signal Flow

To determine the required HPA power rating we will compute the flux density at the aperature of the TDAS receive antenna required to support a 300 KBPS quadraphase uplink signal at a 10^{-5} BER. The flux density will be found by first computing the required uplink carrier power indicated in the figure.

Since rain attenuation can be quite severe at 30 GHz, it is important to determine if uplink power requirements with rain margin are reasonable.

TRANSPONDER SIGNAL FLOW



$$\phi + G_T = P_D$$

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7.5.2 Uplink Carrier Power

We assume the uplink C/N_o to be 10 db stronger than the forward link C/N_o and the uplink system temperature to be 30 db - °K. The accompanying link budget indicates a required uplink power of -123.6 dbW.

UPLINK CARRIER POWER

CONDITIONS

REFERENCE POINT:	TRANSPONDER REC. INPUT
DATA RATE:	300 KBPS
RELATIVE VALUES OF FWD LINK AND UPLINK C/N_0:	UPLINK C/N_0 10 DB GREATER THAN FWD LINK C/N_0

UPLINK CARRIER POWER REQ'D

E_B/N_0	10
DATA RATE	300 KBPS
FWD LINK C/N_0	65 DB-HZ
UPLINK C/N_0	75 DG-HZ
BOLTZMAN CONSTANT	-228.6 DB-HZ/°K
UPLINK SYSTEM NOISE TEMP	30 DB-°K
N_0	-198.6 DWB-HZ
UPLINK CARRIER POWER (C) REQ'D.	-123.6 DWB

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7.5.3 Flux Density

The required flux density at the TDAS antenna is computed in the budget presented in the table. The computations result in a required flux density of -117 dbW/m^2. With this flux density a adequate drive level is obtained for the TWT with a transponder gain of 98 db. The design value chosen for the flux density is -113 dbw/m^2.

FLUX DENSITY AND TRANSPONDER GAIN
REQ'MT FOR GROUND TERMINAL HPA SIZING

UPLINK CARRIER POWER REQ'D	-123.6 DBW
UPLINK TDAS ANT: GAIN	47 DBW
$\lambda^2/4\pi$ (@ 30 GHZ)	- 50.0 DB-M^2
LINE LOSS BETWEEN TDAS ANTENNA AND TRANSPONDER	- 2 DB
FLUX DENSITY REQ'D	-117.6 DBW/M^2
DRIVE LEVEL REQ'D	- 20 DBW
TRANSPONDER GAIN REQ'D	98 DB
DESIGN VALUE OF FLUX DENSITY	-113 DBW/M^2

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7.5.4 TGT HPA POWER REQUIREMENT

The link budget shown derives the TGT HPA power rating from the flux density required at the TDAS antenna aperature. A reasonable value of 50 watts is obtained for the assumptions given in the budget, including a 25 db rain margin. A 31 db rain margin could be achieved with a 200 watt HPA.

GROUND TERMINAL HPA SIZING

FLUX DENSITY REQUIRED AT TDAS	-113 DBW/M^2
SPREADING LOSS (@ 40,000 KM)	-163 DB-M^2
NET EIRP REQUIRED	50 DBW
RAIN MARGIN	25 DB
LINE LOSS	2 DB
SMALL SIGNAL SUPPRESSION	6 DB
OUTPUT BACKOFF	6 DB
ANTENNA GAIN (DIA: 18M, η = 48%, F = 30 GHZ)	72 DB
HPA RATING	17 DBW (50 W)

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7.6 POLARIZATION ISOLATION

Section 4.5.5 discussed the effects of rain attenuation on orthogonally polarized downlink signals. It was shown there that it is possible for the cross-polarization discrimination ratio to be as low as 20 db at the 99.9% availability level for some of the site and constellation combinations. To achieve adequate isolation in such cases, it may be necessary to employ adaptive compensation techniques to restore the orthogonality of the original signals. A technique to transform two nonorthogonal elliptically polarized signals into two orthogonal linealy polarized signals is illustrated in the figure. Such techniques require trading signal strength for increased polarization isolation.

DEPOLARIZATION COMPENSATION PROCEDURE

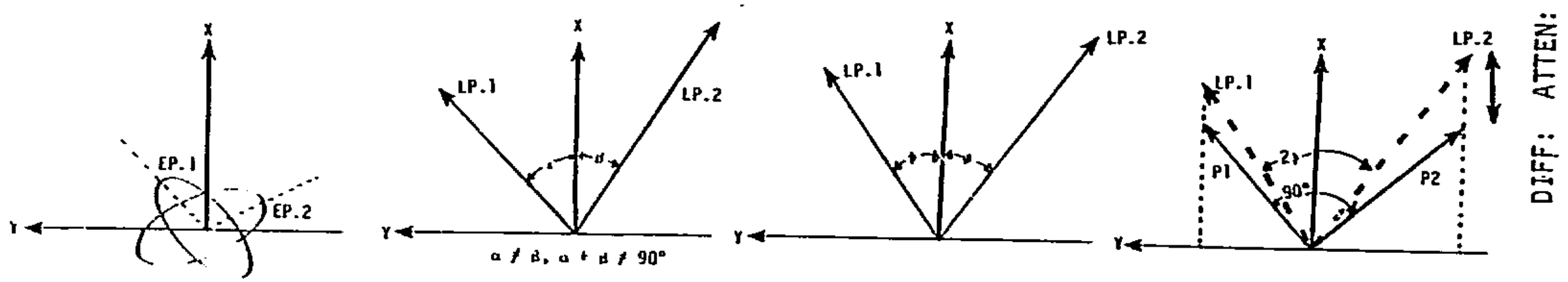
INCIDENT SIGNAL
WAVE POLARIZATIONS (NON-ORTHOGONAL ELLIPTIC)
→

STEP - I
- COORDINATE ROTATION
- DIFFERENTIAL PHASE SHIFT

→ LINEARIZED NON-ORTHOGONAL POLARIZATIONS →

STEP - II
- COORDINATE ROTATION
- DIFFERENTIAL ATTENUATION

→ INCIDENT WAVE POLARIZATIONS TRANSFORMED TO TWO LINEAR ORTHOGONAL POLARIZATIONS



EP1, EP2:
TWO RECD NON-ORTHOGONAL ELLIPTIC POLARIZATIONS

EP1 & EP2 SIMULTANEOUSLY LINEARIZED (BUT NOT ORTHOGONALIZED)

COORDINATE ADJUSTMENTS TO MAKE LINEAR POLARIZATIONS LP1, LP2 SUMMETRIC)

P1, P2:
TWO LINEARIZED ORTHOGONAL POLARIZATIONS

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7.7 TGT TECHNOLOGY ISSUES

In assessing the technologies identified to achieve the performance goals of the TGT, several key issures emerge. Issues are listed for the antennas, the LNA, the HPA, the baseband equipment and the diversity terminal. These issues relate to the readiness of the technology for applications, rather than to questions of basic technology development.

KEY GROUND TERMINAL TECHNOLOGY ISSUES

TECHNOLOGY AREA	ISSUES
ANTENNA	DESIGNS AND TECHNIQUES TO YIELD HIGH EFF.
	ADEQUATE SURFACE TOLERANCE TO MINIMIZE GAIN LOSS
	FEED MATERIAL AND FABRICATION TECHNOLOGY TO REDUCE RF LOSSES
	HIGH X-POL ISOLATION IN FREQUENCY REUSE FEED DESIGN
LOW NOISE AMP.	DEVELOPMENT OF LOW NOISE FIGURE LNA'S
HPA	ENHANCEMENT IN OUTPUT POWER CAPABILITIES
	LOW LOSS POWER COMBINING METHODS TO ACHIEVE ADEQUATE POWER LEVELS
	IMPROVEMENT IN POWER GEN. EFF.
BASEBAND EQUIP.	HIGH DATA RATE MODEMS ($\geq$ 1 GBPS)
	CARRIER/CLOCK ACQUISITION AT HIGH DATA RATES
DIVERSITY TERMINAL	DIVERSITY SWITCHES THAT CAN HANDLE HIGH DATA RATES ($\geq$ 1 GBPS)

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