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VOLUME II

FINAL REPORT

FOR

PLANNING ASSISTANCE FOR THE 30/20 GHZ PROGRAM

by G. Al-Kinani, M. Frankfort, D. Kaushal, R. Markham, C. Siperko and M. Wall

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16. Abstract This volume, Volume II of the three volume Final Report, contains contractor reports (CR) for Tasks 4, 5 and 6 of the planning assistance program. Under Task 4, Western Union reviewed, commented and offered recommendations on Hughes and TRW's 30/20 GHz communication system baseline and multiple design concepts developed in accordance with the requirements of their Phase II contracts. In the baseline concept development the communications payload on Flight 1 was specified to consist of on-board trunking and emergency communications systems (ECS). On Flight 2 the communications payloads consisted of trunking and CPS on-board systems, the CPS capability replacing the Flight 1 ECS. No restriction was placed on the launch vehicle size.

In the multiple concepts development Hughes and TRW were free to select and recommend alternative design scenarios. Constraints placed on multiple concept development effort were that launch vehicle size for Concept 1 was restricted to SUSS-D and for Concept 2 a SUSS-A. The three types of services, i.e., trunking, CPS and ECS need not be demonstrated concurrently on the same flight, the intent being to use an existing bus with minimum modifications. An objective is to limit the launch vehicle size to SUSS-A as an upper bound.

In Task 5 the design concept development was based on satisfying the baseline requirements set forth in the SOW for a single demonstration flight system. Key constraints on contractors were cost and launch vehicle size. Western Union concluded that no significantly different or new concepts had been proposed in the two contractors' reports that were reviewed.

In Task 6, five major areas of new technology development were reviewed: (1) 30 GHz low noise receivers; (2) 20 GHz Power Amplifiers; (3) SS-TDMA switch; (4) Baseband Processor; (5) Multibeam Antennas.

Multiple contracts were awarded for the five major areas. In general, the projected performance of the sub-systems is in agreement with the NASA Statement of Work. Further study is required to evaluate the end-to-end system performance and allocation of performance parameters to various system elements when viewed on an overall system performance basis. Further effort is also required in defining and assuring the system element reliability needed to build a spacecraft with a ten year design life.

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VOLUME II

EXECUTIVE SUMMARY

1.0 INTRODUCTION

In accordance with the Statement of Work requirements of the "Planning Assistance for the 30/20 GHz Program" contract with the NASA Lewis Research Center (LeRC), Western Union was tasked to: review and critique the functional design concepts and technical designs for a 30/20 GHz demonstration flight system developed by TRW, Hughes, Ford Aerospace, GE, and RCA under the NASA LeRC 30/20 GHz Program Phase II studies; review and critique the technical design review reports submitted by NASA LeRC's technology readiness contractors. The technology being developed under multiple contracts awarded by NASA LeRC are: baseband processor, IF switch matrix, 30 GHz low noise receiver, 20 GHz GaAs FET power amplifier, 20 GHz Impatt power amplifier, 20 GHz dual mode TWTA, multi-beam antenna.

This volume, Volume II of the three volume final report contains the Tasks 4, 5 and 6 reports. The Tasks 4 and 5 reports discuss the results of Western Union's review of the 30/20 GHz demonstration flight system functional design concepts and technical designs developed by the aerospace contractors under their respective Phase II studies. Specifically, Task 4 reviewed TRW and Hughes baseline and multiple design concepts and Task 5 reviewed Hughes and RCA multiple design concepts.

The Task 6 report discusses the results of Western Union's review of the technical design review reports submitted by the technology readiness contractors.

Highlights of the three task reports are summarized in the following sections.

1.1 TASK 4 - REVIEW SUMMARY

1.1.1 Objectives

The Task 4 objectives were to review, comment and offer recommendations on Hughes and TRW 30/20 GHz communication system baseline and multiple design concepts developed in accordance with the requirements of Tasks 1, 2 and 3 in their respective Phase II study contracts.

1.1.2 Review of TRW and Hughes Baseline and Multiple Design Concepts

Under Task 4, Western Union reviewed, commented and offered recommendations on Hughes and TRW's 30/20 GHz communication system baseline and multiple design concepts developed in accordance with the requirements of their respective Phase II contracts. Three Hughes and TRW task outputs were reviewed as part of this effort. The three task outputs are:

Task 1: Baseline System Development

Task 2: Multiple Concepts Development

Task 3: Recommended Concepts for Detailed Development in their respective Task 4 efforts.

The baseline and multiple concepts development efforts were based on a two flight demonstration system. In the baseline concept development the communications payload on Flight 1 was specified to consist of trunking and emergency communications (ECS) on-board systems. On Flight 2 the communications payloads consist of trunking and CPS on-board systems, the CPS capability replacing the Flight 1 ECS. No restriction was placed on launch vehicle size.

In the multiple concepts development Hughes and TRW were free to select and recommend alternative design scenarios. Constraints placed on the multiple concept development effort were that launch vehicle size for Concept 1 was restricted to SUSS-D and for Concept 2 a SUSS-A. The three types of serivces i.e., trunking, CPS and ECS need not be demonstrated concurrently on the same flight and the intent is to use an existing bus with minimum modifications with an objective to limit the launch vehicle size to SUSS-A as an upper bound.

Both TRW and Hughes functional system design configuration, availability and BER objectives stated and the transmission data are compatible with the NASA SOW requirements.

System availability is a key performance parameter for trunking application. In the baseline design the use of diversity earth stations, adaptive rain response techniques, and normal operating margins were identified as the system design approaches to be used to achieve the required availability. The required margin to maintain the specified availability is 20 dB for uplink and 10 dB for downlink. The ability of the baseline system to meet system performance and availability requirements has not been clearly shown. Further analysis is required to establish the adequacy of the total system margin to satisfy the availability requirement as the satellite position is moved towards the orbital extremes. The question of the adequacy of system margin as a function of satellite location should be addressed. In view of the availability requirements and extensive frequency reuse, the design of the larger antenna with one steerable trunking beam for measurement of interbeam interference characteristics and cross polarization and implementation of dual orthogonal feed system to maximize frequency reuse should be a requirement for the demonstration system. The scalability of the antenna subsystem to 20 fixed beams and six scanning beams is not addressed. The size of spacecraft antenna and TWTAs vary over a considerable range and no effort is made to be consistent with the specification of the subsystems being developed under the technology contracts. The trunking ground station sizes also vary over a large range. However, Western Union recommends that the maximum antenna size be 7.5 meters.

The baseline design concept for network control should be reassessed. A static control approach does not lend itself to the level of traffic anticipated in an operational system and precludes redistribution of resources as traffic demands on a real time basis. While more complex, a dynamic network control approach is felt to be more efficient and appropriate.

1.2 TASK 5 - REVIEW SUMMARY

1.2.1 Objectives

The Task 5 objectives were to review and offer comments and recommenda tions on Hughes and RCA 30/20 GHz communication system final design conception relative to their respective SOW requirements, Western Union's perception of 30/20 GHz communication system requirements, and constraints in terms of system cost and launch vehicle size imposed by NASA.

1.2.2 General Comments

Although generally both the contractors meet the baseline NASA Statement of Work requirements for a single demonstration flight, it is Western Union's opinion that no single concept proposed by either of the two contractors convincingly demonstrates a high degree of scalability to an operational system. A detailed discussion of the system aspects and other considerations to demonstrate scalability to an operational system was presented in Task 3. The system concepts reviewed here either emulate the previous system design concepts or provide further details, and no significantly different or new concepts have been proposed.

1.2.3 Comparison of Hughes and RCA Concepts

Hughes has proposed both TDMA and FDMA transmission modes for trunking on a non-simultaneous basis. There are four primary and two secondary nodes. The nodes are Los Angeles, Cleveland, New York or Tampa and Washington, DC or Houston. The primary and secondary nodes for either transmission mode are the same. The transmission data rate per channel is 256 Mbps in either transmission mode. In the FDMA case multiplexing and demultiplexing is accomplished at RF prior to any frequency translation. Complete connectivity is provided by a 6 x 4 (6 input, 4 output) IF switch and two redundant paths are provided to bypass the failed cross-point switches. The transmitter is driven by a 40 watt TWT. The trunking earth station size is 5 meters with 500 watt TWT. The rain margin is provided by adaptive power control. An 8 watt solid state power amplifier (SSPA) provides back-up for TWT for clear weather operation only. Frequency reuse is demonstrated using spatial and polarization isolation.

Customer Premise Service (CPS) is provided by independently scanned uplink beam and downlink beams. The signals after downconversion are routed to the baseband processor where the signals are demodulated, stored and forwarded. If the uplink signal from a particular CPS station is forward error coded (FEC) due to rain, the signal is decoded by the baseband processor. Downlink signals to stations suffering severe rain attenuation are FEC encoded in the baseband processor. The data transmission rates are either four 32 Mbps or one 128 Mbps. The earth station sizes for 32 Mbps and 128 Mbps are 3 meters and 5 meters, respectively. The ground station HPA for 32 Mbps and 128 Mbps stations are 7 watts and 10 watts, respectively. Hughes has proposed the use of LEASAT bus which requires SUSS-A launch vehicle. The satellite design has a four year operational life. The satellite antenna has monopulse tracking for high antenna pointing accuracy. There is no cross-connected between the baseband processor and TDMA switch.

RCA has proposed TDMA transmission mode for trunking and non-simultaneous TDMA or FDMA transmission mode for CPS service. The spacecraft antenna subsystem is the same as proposed by TRW and Ford in the technology development contracts. There are four primary nodes and two alternate nodes. The nodes are Los Angeles, Cleveland, New York or Tampa and Washington, DC or Houston.

Connectivity among the nodes is provided by a 4 x 4 (four input, four output) TDMA IF switch matrix with internal redundancy to bypass failed cross-point switches. The trunking transmission rate is 256 Mbps. The ground station antenna size for trunking station is five meters using 400 watt TWTA. Adaptive power control is used to provide uplink rain margin. The CPS transmission rates are either four channels at 30 Mbps or one 120 Mbps. The ground station antenna sizes for 30 Mbps and 120 Mbps are three meters and five meters, respectively. The HPA size for both sizes of CPS stations are 200 watts. The routing, coding/decoding and store forward is provided by the baseband processor being developed by Motorola. RCA has a much lighter spacecraft bus with a SUSS-D launch capability. The design life of this satellite is four years. The comunication throughput of both RCA and Hughes is essentially the same. One of RCA's concepts has cross-connect between CPS and trunking. In general, RCA has made an effort to utilize the sub-subsystem being developed by others. However, the interface problems have not been addressed. Neither Hughes nor RCA has investigated instrumentation to monitor system performance parameter, nor have they addressed the impact of such instrumentation on weight, power and cost of the satellite.

1.3 TASK 6 - REVIEW SUMMARY

1.3.1 Objectives

The Task 6 objectives were to review, comment and offer recommendations on the new technology system and technical designs defined in technical design review data submitted by NASA's technology readiness contractors. Two sets of design review data from each of 12 technology readiness contractors were reviewed in the Task 6 effort.

1.3.2 Areas of New Technology and General Comments

Technology readiness contracts have been awarded in seven areas. Each contract calls for a systems study and design effort and a "proof-of-concept" (POC) model which will demonstrate the transferability of the paper design to hardware. The five areas are:

- 30 GHz Low Noise Receivers
- GaAs FET Power Amplifiers
- Impatt Power Amplifiers
- TWT Amplifiers
- Satellite Switched - Time Division Multiple Access Switches
- Baseband Processors
- Multi-Beam Antennas

The contractors' efforts have been judged based on three sets of references: the NASA Contract Statements of Work received by each, the Western Union Task II report on Functional Requirements and the output of other NASA 30/20 GHz program contracts in the systems area, as well as on more general communication system requirements.

Generally, there seems to have been insufficient attention paid to the overall system design and allocation of performance to various system elements, and to obtaining information on the range of system element performance necessary to make an optimum allocation. In addition, little attention has been paid to a defining and assuring the system element reliability needed to build a spacecraft with a ten year design life. Western Union feels that much more effort is needed in these two areas if a successful 30/20 GHz program is to be realized.

1.3.3 Low Noise Receivers

Two contractors participated in this study - LNR, Inc. and ITT. Both chose the same design, an image enhanced mixer, which represents current state of the art to obtain the 5 dB noise figure called for in the specification. However, since the potential for improvement of this concept is limited, new development programs will be required for future designs. Within these limitations both contractors are providing satisfactory hardware.

1.3.4 GaAs FET Power Amplifiers

Contracts were awarded to TI and TRW. While both contractors' designs meet the specifications given to them, the resulting designs have too little power output and are too large to be useful in a Ka-band satellite as presently conceived.

1.3.5 Impatt Power Amplifiers

Two contracts were awarded, to LNR and TRW. While the specifications will be met by the contractor's designs, the resulting units will be of questionable utility to a Ka-band satellite design, even though they have higher power output and are smaller than the GaAs FET designs. In addition, the narrow bandwidth available from the Impatt Amplifiers will make satellite design and redundancy switching more difficult than for a wideband amplifier.

1.3.6 TWT Power Amplifier

One contract was awarded to Hughes. The bandwidth and power output of this amplifier are satisfactory for a Ka-band satellite, but its size, especially the power supply, lead to some serious questions about overall satellite configuration.

1.3.7 Satellite Switched - Time Division Multiple Access Switches

Two contracts were awarded, to GE and Ford Aerospace. Both contractors selected the same approach for the basic 20X20 switch, a coupled crossbar design with GaAs FET crosspoints. Both designs appear satisfactory for the task, although many minor points need to be clarified, including the reliability/redundancy analysis. The same architecture has been extended to a 100x100 switch by GE for CPS use. This approach is more questionable.

1.3.8 Baseband Processor

One contract was awarded to Motorola. The design seems basically satisfactory, although in a number of areas, such as forward error correction coding, an investigation of alternate approaches would be useful.

1.3.9 Multiple Beam Antennas

Two contracts were awarded, to TRW and Ford Aerospace. The TRW uses a more or less standard design, requiring four reflectors or a complicated two reflector system. The Ford design uses only two reflectors for equivalent performance. On the other hand, the Ford feed design is heavily tied into a fixed frequency plan. A combination of these ideas would be desirable, if possible.

NASA REPORT NO. 1-4-W-1-T4

TASK 4 REPORT
PLANNING ASSISTANCE
FOR THE
30/20 GHZ PROGRAM
--
REVIEW OF HUGHES/TRW BASELINE AND
ALTERNATE (MULTIPLE) DESIGN CONCEPTS

NASA CONTRACT NO. NAS3-22461, TASK 4
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TASK REPORT
PLANNING ASSISTANCE FOR THE 30/20 GHZ COMMUNICATION PROGRAM
NASA CONTRACT NAS3-22461, TASK 4

1.0 INTRODUCTION

Under the requirements of NASA Contract No. NAS3-22461, Task 4, Western Union was tasked to review, comment, and offer recommendations on Hughes and TRW's 30/20 GHZ communication system baseline and multiple design concepts developed in accordance with the requirements of their respective Phase II contracts. Three Hughes and TRW task outputs were reviewed as part of Western Union's Task 4 efforts. The three task outputs are:

- Task 1: Baseline System Development
- Task 2: Multiple Concepts Development
- Task 3: Recommended Concepts for Detailed Development in their respective Task 4 efforts.

The baseline and multiple concepts development efforts were based on a two flight demonstration system. In the baseline concept development (task 1) the communications payload on Flight 1 was specified to consist of trunking and emergency communications (ECS) on-board systems. On Flight 2 the communications payloads consist of trunking and CPS on-board systems, the CPS capability replacing the Flight 1 ECS. No restriction was placed on launch vehicle size.

In the multiple concepts development (task 2) Hughes and TRW were free to select and recommend alternative design scenarios. Constraints placed on the multiple concept development effort was that the launch vehicle size for Concept 1 was restricted to SUSS-D and for Concept 2 a SUSS-A.

Western Union's review, comment, and recommendation efforts was performed through direct interface with Hughes and TRW, and through written interim reports. Western Union attended the Hughes/TRW presentations made to NASA at the LERC and offered verbal comments and recommendations during the course of the meetings. Subsequently, the written report material submitted by the two contractors were reviewed and interim task reports were submitted to

NASA with comments and recommendations. This Task Report is a consolidation of the previous verbal and interim report comments and recommendations with additional review comments incorporated relative to the Hughes/TRW Task 3 recommended concepts.

The criteria or guidelines against which the baseline and multiple design concepts was reviewed are:

- o The SOW for the Phase II studies "Requirements Determination for the Demonstration of a 30/20 GHZ Communication System," Tasks 1, 2, and 3.
- o Other direction given by the NASA Program Office.
- o Western Union's perception of the functional requirements for a demonstration system based on projections of initial operational system traffic density, routing, and performance.
- o Compliance with NASA program objectives, both technical and cost.

The review comments and recommendations on the Hughes/TRW Tasks 1, 2, and 3 outputs are given in the next three sections, respectively.

The key objectives of the 30/20 GHZ program are:

- o to develop the key technology needed for operational systems in the 30/20 GHZ band;
- o to demonstrate, through an experimental flight program, the applicability of the band and readiness of the technology for operational 30/20 GHZ systems;
- o to develop the technology to conserve valuable spectrum resources;
- o to develop system design concepts and technology that provide cost competitive services relative to other transmission media, satellite or terrestrial.

The Phase I Fixed Communications System Market Demand Assessment studies provided a forecast of telecommunication service demand for the 1990-2000 year time frame that substantially exceeds the available capacity of "C" and "Ku" band systems. Three major service categories were identified in those studies; voice, data, and video. Within the three service categories those applications that are broadcast services are excluded as candidates for Ka band systems, the remaining applications being possible Ka service candidates contingent on other technical and operational constraints imposed by the Ka band system for specific services..

If one assesses the satellite carrier community in terms of the types of services each provide, three specific types of carriers can be identified; trunking carriers, CPS carriers, and trunkng/CPS carriers. Irrespective of their classification, all carriers are likely to provide a mix of services that include voice, data, and video traffic. Development and demonstration of Ka band technology applicable to the commercial services environment must consider the requirements of the three basic types of carriers mandating that the demonstration system have both trunking and CPS capabilities.

To demonstrate the applicability of the Ka band to commercial services, the basic capabilities and performance of the trunking and CPS systems must be equivalent to that expected for an operational system. Key technical/performance characteristics such as availability, switching/routing capabilities, network control, system synchronization, throughput capacity, adaptive compensation techniques, etc. must be demonstrated. While it is recognized that the demonstration system will not be sized to provide full operational system capabilities, it is essential that the technology and system capabilities be directly scalable to operational system requirements.

2.0 DEMONSTRATION SYSTEM DESIGN REQUIREMENTS

The baseline design requirements were derived from the "Requirements Determination for the Demonstration of a 30/20 GHZ Communications System" SOW modified in accordance with the results of review meetings between NASA and the Phase 2 contractors.

The baseline system has been defined to be a two flight demonstration system designed to demonstrate the technology and system performance for three basic types of communications services:

- Trunking
- Customer Premise Services
- Emergency Communications Services

The trunking and Customer Premises Services (CPS) capabilities are considered to be primary demonstration or experiment requirements and the Emergency Communications Services (ECS) capabilities a secondary experiment requirement.

The three types of services need not be demonstrated concurrently on the same flight. Since the development of a CPS on-board baseband processor will not be developed within a time frame compatible with Flight A hardware availability requirements, current planning for a two flight program is to implement trunking and ECS capabilities on Flight "A" (1986), and Trunking and CPS capabilities on Flight "B" (1988). The ECS subsystem may provide limited CPS experimental capabilities.

The same spacecraft bus will be used for both flights. The intent is to use an existing bus with minimum modifications with an objective to limit the launch vehicle size to SUSS-A as an upper bound.

2.1 TRUNKING REQUIREMENTS

Basic requirements for the baseline trunking system, from the cited SOW, are:

- provide SS-TDMA and FDMA transmission capabilities (simultaneous operation not a requirement).
- support T3/T4 user interface rates in SS-TDMA and FDMA modes.
- capable of achieving high nodal availability (.9999) using diversity earth stations and a combination of fixed margin and adaptive compensation techniques.
- capability of SS-TDMA connectivity between seven fixed beams.

2.2 CPS REQUIREMENTS

Basic requirements for the baseline CPS system, from the cited SOW, are:

- Provide TDMA transmission capability with nominal burst rates of 32/128 MBPS on the uplink and 256 MBPS on the downlink
- Provide on-board baseband switching/routing capability
- Provide CONUS coverage using scanning beam antenna(s)
- Capable of achieving a .999 link availability with a combination of fixed margin and adaptive compensation techniques
- low cost user earth terminals
- capable of supporting user rates ranging from 64 KBPS - 6.3 MBPS.

2.3 ECS REQUIREMENTS

The basic requirements for the ECS system are:

- Uplink FDMA channel capabilities; 32 KBPS, 1.5 MBPS, and 6.3 MBPS.
- Downlink channel capabilities: 6.3 MBPS TDMA; 32 KBPS, 1.5 MBPS, 6.3 MBPS FDMA in a bypass mode.
- Three on-board processor modes:
  1. Bypass mode for redundancy

2. 6.3 MBPS emergency mode w/wo FEC
3. 6.3 MBPS CPS TDMA mode.

- Rapidly deployable earth stations.

2.4 OTHER CONSIDERATIONS

2.4.1 CAPACITY CONSIDERATIONS

Based on Western Union's perceptions of operational system requirements, additional demonstration system design considerations are addressed in the following.

In Section 1.0 it was noted that the satellite carrier community could be divided into three separately identifiable types of carriers in terms of the transmission requirements for the market segments they address. The three carrier types identified were; trunking only carriers, trunking/CPS carriers, and CPS only carriers. In a previous effort (reference 4) market share estimates were developed for each of the carrier types and based on the estimates, satellite capacity requirements for operational systems were developed. The projected capacity requirements for the three carrier types in the year 2000 time frame are:

- o trunking only carrier - 10 GBPS
- o trunking/CPS carrier - 4 GBPS Trunking
  - 4 GBPS CPS
- o CPS only carrier - 4 GBPS

Initial operational system capacity requirements in the 1990-1995 time frame will be lower than that given above, reasonable projections being 2 GBPS CPS and 4 GBPS trunking for a trunking/CPS carrier, 2 GBPS for a CPS carrier, and 6 GBPS for a trunking carrier. In the design and development of the 30/20 GHZ demonstration system the initial capacity requirements should serve as a guideline for demonstrating the scalability and system dynamics of the experimental system to an operational capabilities.

2.4.2 TRUNKING CONSIDERATIONS

Pertinent factors that need to be considered relative to operational system capabilities include: extension of the number of fixed beams; adaptive rain compensation control implementation; frequency reuse; link design and capacity constraints.

The number of fixed beams considered to be required for an operational trunking system is projected to be at least 18-20. Beam connectivity in the demonstration system is limited to four beams. To demonstrate that connectivity can be extended to an 18-20 beam system the TDMA switch implemented in the demonstration system should be a 20x20 switch capable of demonstrating the switching dynamics (switching speed, switch mode reconfigurability) required for the operational environment. Further the demonstration system antenna subsystem design and the design of other trunking and spacecraft subsystems should clearly demonstrate scalability to operational system requirements.

The three primary adaptive rain compensation techniques anticipated in the trunking system are; FEC, downlink power control, and uplink power control. The demonstration system requires development of appropriate control algorithms and network monitor/control mechanisms.

Frequency reuse is a requirement in the implementation of a high capacity (4-10 GBPS) multi-beam trunking system. Experiments are required to establish frequency reuse capabilities and constraints in the Ka band system designs. The demonstration system design must be capable of demonstrating frequency reuse via orthogonal polarizations and beam separation. The preferred approach is to design the system with at least one fixed beam in rain zone "E" to provide for cross polarization isolation experiments, and a second steerable beam capable of being moved into the above fixed beam coverage area to provide for beam isolation and interbeam interference experiments. These beams may be in addition to the seven beam capability planned for the demonstration system, but need not be.

The NASA SOW specifies uplink/downlink rain margins for the demonstration system. Rain attenuation in the Ka band is extremely severe, particularly in rain zones D_2, D_3, and E. Reference 4 gives rain attenuation in the various rain zones for a system in which the satellite is located at the 90°W longitude. For that scenario the trunking system availability criteria (.99999) could be satisfied with a combination of diversity earth stations and adaptive compensation techniques.

As the satellite location moves outward toward the orbital extremes (70°W and 140°W) the rain attenuation will increase appreciably as rain path length increases with decreasing earth station elevation angles. Rain cell size is a function of rain rate and for a constant rain rate the increased attenuation introduced by decreasing elevation angles is not reflected by a proportional increase in diversity gain. An important factor in establishing the demonstration system technical design requirements, performance, and constraints is to establish the worst case rain attenuation conditions and the attendant system margin requirements to satisfy availability criteria. Technical limitations can then be identified and alternative concepts developed that can optimize orbit utilization and on-orbit capacity.

2.4.3 CPS CONSIDERATIONS

The same basic trunking coniderations identified in the preceeding subsection apply to the CPS system. In the CPS case the number of scanning beams required for an operational system is expected to be at least six.

The CPS system design consider additional adaptive rain attenuation capabilities and does not have the benefit of diversity gain because of cost constraints. The adaptive control algorithms, monitor, and control must be extended in the CPS design to incorporate the additional adaptive capabilities.

The effects of rain attenuation as a function of rain rate, satellite location, and earth station elevation angle are substantially more severe for CPS relative to the trunking case because of the single site earth station implementations. Orbital utilization, on-orbit capacity constraints, and technical limitations must be identified in the demonstration system CPS design. Further considerations in this respect are hybrid design (FDMA/TDMA), customized uplink/downlink transmission rates, and adaptive rates.

CPS system capacity will be allocated between a large number of user networks and a demand assigned pool. User network allocation and switching/routing assignments are relatively fixed, changing only as users enter or leave the systems or amend their capacity requirements. The on-board baseband processor and the CPS network control subsystem should reflect the mix between fixed and demand assigned requirements in its real time processing capabilities. As a guideline 40% of the CPS traffic can be considered to be fixed assigned requiring only a manual control capability to change assignments/routing, and the remaining 60% can be considered to be demand assigned requiring real time processing capabilities.

2.4.4 MASTER CONTROL STATION (MCS)

For purposes of this review effort it is assumed that the Network Control Center (NCC) is co-located with the Master Control Station. Reference 4 outlines in more detail, MCS and NCC functional requirements. Some of the key functional requirements are:

- o monitor/measure satellite position data - plan and execute station keeping maneuvers to station keep the satellite within to at least $\pm .05^{\circ}$ East/West and $\pm .05^{\circ}$ North/South.
- o provide network synchronization
  - perform ranging measurements via either turnaround ranging in conjunction with 3 other trunking stations or by loop back ranging at 3 trunking stations plus the MCS using unique words.
  - compute satellite ephemerides from the ranging data.
  - transmit ephemeride data via OW channel(s) to network earth stations for computation of their own respective slant range and range rates.
- o monitor spacecraft health and control: reconfiguration of on-board systems; trunking IF switch matrix mode configuration; CPS on-board processor switching/routing control - manual control for fixed assigned channels, dynamic control (real time) for demand assigned channels.

- synchronization of TDMA burst assignments with trunking IF switch, baseband processor, and scanning beam (CPS) antenna track.
- redistribution of resources in accordance with traffic loading requirements.
- central control for adaptive rain response requirements within the networks.
- monitor/control of all network earth stations, particularly unattended stations.

3.0 REVIEW, COMMENTS, AND RECOMMENDATIONS HUGHES/TRW BASELINE DESIGN CONCEPTS

3.1 INTRODUCTION

The Hughes/TRW Baseline Design concepts were developed in accordance with the Task 1 requirements under their respective "Requirements Determination for the Demonstration of a 30/20 GHZ Communications System" contract. Hughes/TRW contract SOW requirements are for a two flight demonstration program encompassing three communications networks; trunking, CPS, and emergency. The trunking and CPS networks are primary demonstration system experiment requirements and the emergency communication network is a secondary experiment requirement.

To provide adequate development time for an on-board baseband processing unit for the CPS network, initial planning calls for the trunking and emergency systems to be flown on Flight A (1986) and, trunking and CPS systems to be flown on Flight B (1988). The emergency system on Flight A will have limited CPS capabilities.

The trunking system to be flown is required to demonstrate both SS-TDMA and FDMA transmission capabilities. The CPS system is required to demonstrate TDMA and baseband switching/routing capabilities, and the emergency system is required to demonstrate hybrid FDMA/TDMA capabilities. Section 2.0 describes the conceptual design requirements more fully.

In the development of the baseline system design concepts, the two contractors were directed to limit the design to the NASA SOW and to program office directions.

3.2 TRW BASELINE SYSTEM DESIGN CONCEPTS

3.2.1 TRW Baseline Trunking Design Concepts

3.2.1.1 Summary of Trunking Design Concepts

The TRW baseline design concepts provide trunking capabilities on both demonstration flights; SS-TDMA and FDMA on Flight A and SS-TDMA on Flight B. The transmission rate in the SS-TDMA mode is 512 MBPS per transponder, providing a total system capacity of 2.0 GBPS in the four transponder system. In the FDMA mode each transponder is capable of handling two FDMA carriers, each operating at a transmission rate of 274 MBPS.

The baseline system is designed for seven trunking beams directed at: Cleveland, New York, Boston, Washington DC, Seattle, Los Angeles, and Tampa. Since there are only four transponders, connectivity is restricted to the Cleveland beam and any three of the remaining six beams. One transponder is dedicated to Cleveland, and the remaining three are shared by NYC/Tampa, Wash. DC/Seattle, and Boston/Los Angeles. An on-board TDMA IF switch provides beam connectivity in the SS-TDMA mode, and an FDMA switch provides connectivity between beam pairs in the FDMA mode.

The transponder power amplifiers are dual mode TWTA's that normally operate in the low power mode (approximately 10W) in clear weather and in the high power mode (75W) when precipitation is present at a trunking node. The TWTA power is adaptively controlled. Impatt and GaASFET solid state amplifiers, being developed under technology development contracts provide redundancy for the TWTA's on a 3:2 basis. The output power of the solid state amplifiers is limited to about 10 watts, therefore, the redundancy provided is limited to clear weather conditions, i.e., the additional margin realized by TWTA operation in the high power mode is not available. The power amplifiers are also shared with an ECS carrier on Flight A and a CPS carrier on Flight B.

Two 4.0 meter antennas are provided for CONUS coverage, one providing earth coverage in the eastern half of CONUS and the second coverage in the western half. The two antenna subsystem was selected to minimize off axis scan losses that would otherwise exist with a single antenna subsystem because of the wide FOV.

The system performance design objectives are: system availability .9999; BER = 10^{-6}; and system operating margin of 20 db on the uplink and 10 db on the downlink.

Rain response techniques employed to meet the systems availability criteria are: use of diversity earth stations; adaptive downlink power control; and adaptive FEC. These mechanisms are in addition to the normal operating margins.

The trunking frequency plan provides for frequency reuse only through beam isolation because all trunking carriers are horizontally polarized.

The on-board TDMA and FDMA IF switches are controlled from the Master Control Station. In the baseline systems a 6x6 TDMA switch matrix is planned for Flight A and a 5x5 TDMA switch matrix on Flight B. With four transponders a 4x4 switch matrix is required, the additional ports available providing redundancy.

The Network Control Center (NCC) is colocated with the Master Control Station (MCS). The primary integrated facility functions are:

- spacecraft station keeping
- range measurements/processing
- system (network) synchronization
- reallocation of system resources, TDMA switch reconfiguration, and burst slot assignments (fixed and demand)
- monitor/control of spacecraft health
- monitor/control of network earth stations status and configuration
- experiment scheduling, control, and data collection/processing.

TRW plans for use of a Fleetsatcom spacecraft bus capable of shuttle launch using a SUSS-A launch vehicle with Liquid Apogee Kick Motor (LAKM) augmentation. The LAKM is used because of its restart capability and the need for a perigee burn, as well as an apogee burn, to lift the payload into the synchronous orbit.

The spacecraft design life is two years (N/S station keeping) but it does not provide eclipse operation.

The baseline trunking ground segment is designed with 12.0 meter diversity earth stations at each node. The diversity earth stations are utilized because of the stringent availability requirement for trunking. The diversity gain realized will, in conjunction with other adaptive rain response capabilities, contribute to the margin required to meet system availability criteria.

The demonstration system trunking earth stations will be equipped with TDMA, FDMA, and diversity switching capabilities with user and diversity interfaces to T3-T4 rates.

3.2.1.2 Comments and Recommendations

Comments and recommendations on the TRW baseline trunking design have been generated from review of the TRW baseline design report relative to the requirements outlined in Section 2.0.

SYSTEM: The functional system design configuration, availability and BER objectives, and the per channel transmission rates are compatible with projected operational system requirements based on the results of earlier market demand assessment studies. From an operational system point of view, TDMA has the highest priority and a 512 MBPS burst rate is compatible with expected trunking system requirements. The demonstration system design should clearly show that the satellite trunking capacity can be scaled upward to as high as 10 GBPS throughput and that the number of beams can be increased to the 18-20 range. In this respect the TDMA switch to be implemented should be at least a 20x20 switching matrix to demonstrate the scalabilty and switching dynamics, i.e., switch mode reconfiguration, switching speed, isolation, etc.

System availability is considered a key performance parameter for trunking applications. In the baseline design the use of diversity earth stations, adaptive rain response techniques, and normal operating margin were identified as the system design approaches to be used to achieve the required availability. The primary concern in the link budget analysis given was to achieve the operating margin requirements, 20 db uplink/10 db downlink, specified rain attenuation tables are given in Reference 4 for each CONUS rain zone. The tables give margin requirements to satisfy the link availabilities specified. Comparing the Reference 4 tables with the TRW trunk link budget it is seen that the .9999 link availability is satisfied, at the satellite position chosen, with the margins provided in the analysis plus addition of FEC margin and diversity gain. Moreover, availability can be achieved with diversity gain only assuming it behaves as expected, i.e., diversity gain increases on a db for db basis with single site rain attenuation.

Further analysis is required to establish the adequacy of the total available system margin to satisfy the availability requirement as the satellite on-orbit position is moved toward the orbital extremes. For a given rain rate at a trunking node the diversity gain can be expected to be essentially constant with decreasing earth station antenna elevation angles the rain path length increases and hence rain attenuation will increase. The question of the adequacy of system margin as a function of satellite station location should be addressed. Orbital arc constraints will limit on-orbit capacity or will require additional technology to resolve.

A consideration in specifying the satellite G/T is that the low noise receiver noise figure is specified to be 5.3 db. The specified noise figure is based on the technology available in the 1986 time frame. In optimizing system performance, and in view of the system margin requirements, another look at the LNA noise figure may be beneficial in that some G/T improvement may be realized if a lower noise temperature can be achieved, with new technology, so that other system noise sources are the limiting factors.

Further attention should also be given to shared use of the trunking transponders with ECS and CPS carriers. The ECS and CPS carriers are not homogenous with the trunking carriers and intermodulation effects on the smaller carriers at the back-off level identified, 4.7 db, may be more severe than anticipated requiring additional back-off of the trunking PAs. This in turn will reduce the available margin.

In general, the ability of the baseline system to meet system performance and availability requirements has not been clearly shown.

ANTENNA SUBSYSTEM/BEAM CHARACTERISTICS: The antennas have been identified as a critical technology because of the stringent design requirements imposed on supporting structures and the attendant influence on antenna performance (i.e., surface tolerance, gain, efficiency, etc.). In view of the availability requirements the design of the larger antennas should become a demonstration system requirement.

The design of the baseline antenna subsystem should also consider:

- the need for one steerable trunking beam to provide for measurement of interbeam interference characteristics and cross polarization isolation.
- implementation of dual orthogonal feed system to maximize frequency reuse and provide for cross polarization measurements.
- the antenna subsystem scalability to increase the number of beams to 18 or more in an operational system.

TRUNKING EARTH STATIONS: The size of the trunking earth stations in the baseline design concept is 12.0 meter. An analysis of system availability was given in Reference 4, considering earth station antenna size, margin requirements in each CONUS rain zone as a function of availability, and various adaptive rain response techniques in addition to diversity earth station gain. That analysis indicated that regardless of the earth station size (5.0M, 7.0M, and 12.0M were examined) a .9999 link availability could not be attained in all rain zones without benefit of diversity gain. Assuming diversity gain behaves as expected (1.0 db additional diversity gain per each db added single site attenuation) above a single site attenuation on the order of 18.0 db, then the .9999 availability could be satisfied by all of the antenna sizes. The only advantage of the 12.0M antenna versus the 5.0M is some additional clear weather margin equal to the differences between the gain of the antennas. The disadvantage of the 12.0M antenna is that its cost, implemented, is substantially higher than a 5.0M or 7.0M antenna. With two antennas implemented in a diversity configuration at each trunking node, cost savings with use of the 5.0M and 7.0M antennas are significant. Western Union recommends that the largest antenna size be no larger than 7.0-7.5 meters.

3.2.2 TRW Baseline Emergency Communication System (ECS) Design Concepts

3.2.2.1 Summary of ECS Design Concepts

The Emergency Communication System is a secondary demonstration system experiment that would be implemented on Flight "A" only. The primary objective of the ECS is to demonstrate the applicability of the "Ka" band in establishing communications links to a disaster area using small rapidly deployable earth stations. The ECS provides limited CPS and technology experimental capabilities with implementation of low rate (6.3 MBPS) TDMA channels, variable power dividers, and phase shifters where the latter two are applicable to CPS scanning beam control.

The ECS is designed to operate with three earth station sizes; 2.0M, 3.5M, and the 12.0M trunking earth stations proposed by TRW (note Western Union previous recommendation that trunking earth station size be limited to 7.0-7.5M). The 2.0M and 3.5M earth stations are deployable within a disaster area to establish emergency communications.

Five operating modes are provided:

- Analog bypass mode with filtering and AGC
- One 1.5 MBPS and 7-32 KBPS SCPC (FDMA) channels with on-board demodulation/remodulation.
- One 1.5 MBPS and 7-32 KBPS SCPC (FDMA) channels with on-board demodulation, FEC decoding, and remodulation.
- 6.3 MBPS channel with on-board demodulation/remodulation.

- 6.3 MBPS channel with on-board demodulation, FEC decoding, and remodulation.

The basic uplink transmission capability of the 2.0M earth stations is one 32 KBPS channel using a 2 watt power amplifier. The 3.5M earth stations can transmit up to a 6.3 MBPS composite transmission rate comprised of a combination of one 1.5 MBPS channel with rate 1/2 coding (3.0 MBPS transmission rate) and multiple 32 KBPS channels. The trunking earth station uplinks operate at 6.3 MBPS in a TDMA mode. The downlinks to earth stations in the ECS beam (1.5) are 6.3 MBPS TDM channels and to the trunking spot beams 6.3 MBPS TDMA channels. The performance objective of the ECS is a BER 10^{-6}.

The uplink 1.5 MBPS and 32 KBPS SCPC channels are demultiplexed in an analog demultiplexer and demodulated. The baseband digital bit streams are multiplexed into a 6.3 MBPS bit stream in accordance with their respective addressed destinations. The multiplexed 6.3 MBPS bit streams are routed through an SS-TDMA switch to their respective downlink channels.

The ECS provides full interconnectivity between the 1.5^{o} emergency beam and the three active trunking beams. There are two 1.5^{o} emergency beams that utilize the two 4.0M satellite antennas to provide east CONUS and west CONUS coverage. East and west CONUS coverage cannot be provided simultaneously. The 1.5^{o} vertically polarized emergency beams are formed by steerable 19 horn feed clusters that are capable of forming reduced beams widths of $.9^{o}$ and $.3^{o}$, depending on how many and which feed horns are excited. The emergency beam positions in CONUS are steerable by a mechanical x-y positioner controlled from the MCS.

The nominal operating margins provided for the 2.0M system operating at 32 KBPS uplink and 6.3 MBPS downlink are 15.0 db and 6.0 db, respectively. Margins provided for the 3.5M system operating at 6.3 MBPS uplink and downlink are 17.0 db and 10.0 db, respectively. The ECS availability is not identified, but because of the lack of adaptive rain response capabilities it is expected to be somewhat less than .999.

Control of the ECS is centralized in the MCS to minimize on-board and earth station processing requirements.

3.2.2.2 Comments and Recommendations

The objective of the ECS is not oriented toward its applicability in a commercial carrier environment, but to access its potential as a rapidly deployable system to establish emergency communications capabilities within a disaster area. The ECS design concept developed by TRW has application in this respect but with important limitations.

A premise of the ECS is that rapidly deployable earth stations would be moved into a disaster area to establish a communication capability to national or state disaster control centers, as the case may be. An obvious limitation is that there are 50 states in addition to a national headquarters, and a concept providing connectivity between a disaster area and any one of the possible 51 control centers using trunking system fixed beams is impractical. A more viable approach might be implementation of multiple steerable beams or connectivity via scanning CPS beams. Restriction of ECS coverage to CONUS has political implications that would also have to be addressed.

The operating margin provided in the ECS and the absence of adaptive rain response capabilities limit the availability achievable to somewhat less than .999, restricting the systems use and capabilities under rain conditions, particularly in rain zones D_2, D_3, and E.

In the TRW design concept, the ECS would share trunking channel TWTA's with TDMA or FDMA carriers. The ECS carrier is substantially smaller than either the TDMA or FDMA carriers and can potentially suffer severe intermodulation interference effects because of the non-homogenious carrier sizes. A more detailed analysis of intermodulation interference is necessary.

3.2.3 TRW Baseline Customer Premises Services (CPS) Design Concepts

3.2.3.1 Summary of CPS Design Concepts

Implementation of CPS capabilities in the 30/20 GHZ demonstration system is planned for Flight "B" because of the need to develop the baseband processor technology to be flown. The CPS system design concept provides connectivity between users accessing the network through CPS and trunking earth stations with cross connectivity between the trunking and CPS system implemented on-board the satellite. Cross connectivity is accomplished by interfacing the on-board CPS communication subsystem to input/output ports of the on-board trunking SS-TDMA IF switch. Individual user connectivity is accomplished in the CPS baseband processor at the 64 KBPS channel level.

User interface rates to the CPS system extends from 64 KBPS to 6.3 MBPS (T-2), with the average rate nominally at 1.544 MBPS (T-1). The baseline CPS system operates in an FDM/TDMA mode on the uplink and TDMA mode on the downlink for users accessing the network through CPS earth stations. For users accessing the network through trunking earth stations operation is in a SS-TDMA mode on both the uplink and downlink. Satellite access is through the fixed spot beams for the trunking earth stations and through independent east and west scanning beams for CPS earth stations. There are voids in the CONUS coverage through the central states and South Florida. TRW asserts that coverage required in those areas could be provided by fixed spot beams.

The total transmission capacity of the baseline CPS system is 768 MBPS divided between the trunking beam(s) accesses and accesses through the east and west CPS scanning beams, i.e., 256 MBPS uplink/downlink capability via the trunking beams and each of the two CPS scanning beams.

CPS earth stations can access the satellite via five uplink channels, four of which transmit at a 32 MBPS burst rate and one at a 128 MBPS burst rate. A CPS earth station may be equipped to operate over multiple uplink channels depending on its specific traffic requirement. The downlink burst rate to all CPS earth stations is 256 MBPS.

CPS traffic originating at trunking stations is embedded within the 500 MBPS trunking TDMA channel(s). Interconnectivity to the CPS communication subsystem on-board the satellite is provided at an output port of the SS-TDMA IF switch. The aggregate uplink CPS capacity from all trunking stations is 256 MBPS. Similarly, traffic originating at CPS earth stations with trunking earth station destinations is cross connected between the two systems at an input port of the on-board SS-TDMA switch. The aggregate downlink capacity to all trunking stations is 256 MBPS.

The performance objectives of the CPS system are to achieve a system availability of .999 at a BER 10^{-6}.

CONUS coverage for the baseline CPS system is provided by two scanning beams, one of which provides coverage of the eastern half of CONUS and the second the western half of CONUS. The beams are independent of each other and cover their respective footprint areas via eight tracks that are sequentially scanned in an east-west direction. The CPS scanning antenna system uses the two 4.0M reflectors in conjunction with a feed system employing 30 pill boxes for transmit and 20 pill boxes for receive. Beam scanning is accomplished by programmed control of the relative phase and power of each array element (pill box).

Beam control and scan setting times are projected to be less than 500 nanoseconds and 1.5 microseconds, respectively. Beam dwell time at each programmed beam location is adaptable to the traffic capacity and propagation conditions that exist. Traffic smoothing between scanning tracks is also accomplished by virtue of the adaptable dwell time.

Scanning losses are a concern. Scanning losses on boresight along the beam tracks is on the order of .3 to .4 db, however, scanning losses between two tracks can range from 3.5 to 6.0 db.

Frequency reuse is provided by beam separation and orthogonal polarization. The east and west beams are independent and spatially separated. The scanning beams are vertically polarized and hence, are orthogonal to the horizontally polarized trunking beam.

The CPS baseband processor is the heart of the CPS system. The processor design is based on TRW's proposed design for the POC model. The baseline processor has three sections, each section capable of accommodating up to five FDM/TDMA carriers and providing user connectivity on an individual channel basis. Internal processing includes demultiplexing the FDM carriers, demodulation, decoding, routing, encoding, remodulation, and TDMA burst capabilities. FEC decoding and encoding is adaptively controlled and are independent.

The processor design is oriented toward implementation with LSI wherever possible. The technology drivers in the processor design are micro-electronic chips to perform high speed demodulation, decoding, and switching processes.

The power amplifier in each of the CPS downlink channels is a 75W TWTA that is continuously operated at full power, consequently, adaptive downlink power control is not provided in the conceptual CPS system design.

Adaptive rain response capabilities in the conceptual CPS system design include: independent R½ FEC on the uplink and downlink, uplink power control, and bit rate reduction. In the latter case the information rate of the 32 MBPS channels is reduced to 16 MBPS to provide for the ½R encoding. The 128 MBPS channel does not have an FEC coding capability. Earth stations with 128 MBPS channel transmit at an information rate of 16 MBPS on a separate channel. The information bit rate of the 128 MBPS channel is therefore reduced by a factor of eight.

The normal clear weather operating margins provided in the CPS conceptual design are: 4.7 db uplink in the 128 MBPS channel; 6.7 db uplink in the 32 MBPS channels; and 5.3 db in the 256 MBPS downlink channels.

The CPS earth stations are 3.5M systems with step tracked antenna subsystems. The earth stations are non-redundant and can be equipped with both 32 MBPS and 128 MBPS uplink capabilities. The upconverter and downconverter are agile to provide the capability to be switched to any of the five assigned uplink carrier frequencies depending on specific requirements. System synchronization, burst timing, and precision ephemeride data for each earth station are provided by the Master Control Station via the order wire channel.

The network control concept for the CPS network is a highly centralized architecture in which virtually all of the processing is performed at the Master Control Station (MCS). The MCS provides:

- satellite CPS scanning patterns control
- baseband processor routing control
- CPS earth station parameters monitoring and control
- ranging measurements in conjunction with other trunking earth stations
- precision ephemeride computations
- network synchronization and burst timing
- satellite orbit determination and control.

Programming and control of the CPS scanning beams is a function of traffic density at each beam dwell location, load leveling requirements between beam tracks, and propagation conditions and adaptive rain response functions initiated at specific dwell locations.

The MCS controls application of the various rain response functions based on data collected from network earth stations and the satellite. The rain response functions controlled are: uplink power, uplink FEC, downlink FEC, and information rate reduction. In the case of the 128 MBPS uplink channels, the MCS will switch the uplink channel to a 32 MBPS FEC encoded channel with an information data rate of 16 MBPS at CPS earth station where rain is present on the transmission path. Depending on prevailing rain conditions one or more of the adaptive rain response capabilities can be enabled concurrently.

Baseband processor routing control is a function of traffic activity and call set up and termination requests received from each CPS earth station. Extensive processing capacity is required because all baseband processor channels are controlled on a real time basis on demand.

TDMA synchronization and timing functions are distributed between the satellite, MCS, and CPS earth stations. The satellite master oscillator is used as the system time reference and as a frequency source for all downlink carriers and data clocks. All earth station oscillators are phase locked to the satellite MO.

Frame start is established at each terminal by a combination of carrier, data clock tracking, and a downlink timing epoch signal consisting of one bit per TDMA burst.

The MCS measures the satellite range in conjunction with 2 to 3 trunking stations and computes the satellite position and velocity (ephemerides) to a high level of precision. Range measurements are continuous and the frequency of ephemeride computations is high. The ephemeride data together with burst timing is transmitted to all CPS earth stations via the OW channel. The CPS terminals compute their own range and range rate and correct their burst timing on a continuous basis. The objective in making continuous range measurements, precision ephemeride computations, and continuous CPS burst timing corrections is to achieve a CPS burst arrival accuracy at the satellite of ± 2 nanoseconds, eliminating the need for unique word detectors and synchronization buffers on-board the satellite and optimizing TDMA frame efficiency.

The status of all network earth stations and the spacecraft are monitored at the MCS and in the event of a fault appropriate commands are initiated via the network OW channels.

In addition to the functions identified the MCS also performs satellite orbit determination and station keeping functions, monitors and control trunking network functions, and performs other operational, experiment, and mission related functions.

New technology required for implementation of the MCS includes: development of systems timing technique; baseband processor control; scanning beam control and calibration; and earth station network control.

3.2.3.2 Comments and Recommendations

Comments and recommendations on the TRW baseline CPS design concepts, reviewed relative to the NASA specified requirements and other considerations outlined in Section 2.0, are given in the following.

SYSTEM: The functional system design configuration, availability and BER objectives stated, and the transmission data rates are compatible with the NASA SOW requirements outlined in Section 2.0. From an operational system point of view TDMA has the highest priority in terms of transmission mode desirability. A basic premise of the CPS concept is that the earth stations are low cost systems, precluding consideration of diversity earth stations for availability purposes. With consideration given to the adaptive rain response capabilities in the baseline CPS design that include: independent uplink and downlink FEC; uplink power; and reduction of the information rate to 16 MBPS; the system availability requirement (.999) at a BER 10^{-6} cannot be met in all rain zones. The CPS availability problem was considered in Reference 4. Comparing the Reference 4 margin requirements for a .999 availability to the TRW link analysis, the uplink availability in rain zones D3/E and the downlink availability in rain zone E cannot be satisfied, however, an availability exceeding .995 is achieved. Further impact on achieving availability will be introduced as the satellite on-orbit station is moved toward the orbital extremes increasing the rain path length and rain attenuation. Further analysis and additional design alternatives are necessary to resolve the availability problem.

The CPS baseline design concept did not provide adaptive FEC in the 128 MBPS uplink channels. The 128 MBPS transmission rate was reduced to 16 MBPS information rate plus ½ R/FEC by switching to one of the 32 MBPS carriers with its FEC enabled. It appears that traffic originally carried on the 32 MBPS carrier and all but 16.0 MBPS of the traffic on the 128 MBPS carrier is dropped. The apparent traffic reduction is severe and an availability problem persists in rain zone "E". Alternative design concepts should be identified to achieve the CPS availability criteria with minimum reductions in information rates. These could include: customized SCPC carrier sizes and increased antenna sizes in rain zone "E"; variable rate TDMA techniques, etc.

A comparative assessment of complexity and cost between trunking CPS cross connectivity on-board the satellite and at individual trunking stations is desirable. Since there will be a limited number of trunking stations, implementation at the trunking stations may be economically a more viable approach.

<u>ANTENNA SUBSYSTEM</u>: Two CPS scanning beam antennas, previously described, are incorporated in the baseline CPS design concept; one scanning beam providing east CONUS coverage and the second providing west CONUS coverage. The

polarization of the scanning beams are orhogonal to the trunking beams to provide for a limited demonstration of frequency reuse. Considering the number of scanning beams and trunking beams necessary for an operational satellite with 4.0 Gbps trunking and 4.0 Gbps CPS capacity, a more rigorous demonstration of frequency reuse factors achievable is necessary to demonstrate scalability of the baseline concepts to operational system capabilities.

A fundamental requirement of the demonstration system is to demonstrate not only scalability but also operational system dynamics.

Scanning beam losses are also a concern, particularly at the crossover between tracks. High scanning losses compound an already difficult availability problem and must be reflected in the link analysis in considering adaptive rain response requirements under worst case design conditions.

<u>MASTER CONTROL STATION</u>: The general functional capabilities of the MCS were previously outlined. The MCS functions of primary interest relative to the CPS system are the network control and system synchronization/timing functions.

The network control capabilities in the TRW baseline design are extensive requiring very large real time processing capabilities. The network control design provides a capability to individually route up to 60,000 - 64 KBPS channels between beams on a real time demand basis. This is substantially more capability than necessary for an operational system environment. The CPS network is comprised of a large number of individual user networks and a pool of demand assigned channels. The user networks are expected to be fixed assigned or wired connections requiring assignment or reassignment only when a user enters or leaves the CPS system. This kind of channel assignment does not require a real time capability but can be accomplished manually at a control terminal. It is expected that the complexity and cost of the network control center can be reduced by considering the split between manually assigned and real time demand assigned requirements. A reasonable estimate is that 40% of the channels can be manually assigned and 60% demand assigned.

The TRW baseline design concept for system synchronization and timing was also well conceived. The objective was to minimize earth station cost, eliminate some on-board processing (UW detection/buffering) to establish uplink synchronizations, and to enhance TDMA frams efficiency. The synchronization and timing approach is certainly a desirable one in a fully matured operational CPS system with several thousands of earth stations. For the demonstration system, with a limited number of CPS earth stations, the processing requirements and accuracy can be relaxed to reduce MCS costs. Substantially larger guard times are tolerable and the frequency of ephemeride updates to the CPS terminals can be reduced. The demonstration system must, however, be scalable to a fully implemented CPS system and the ability to achieve improved synchronizations and timing accuracies should be demonstrated. From a capital investment point of view it is desirable to minimize initial investment cost and gracefully grow the system as the network matures so that further capital investments are made on an incremental basis only when needed.

3.3 HUGHES BASELINE SYSTEM DESIGN CONCEPTS

3.3.1 Hughes Baseline Trunking Design Concepts

3.3.1.1 Summary of Trunking Design Concepts

The Hughes baseline design concepts provide trunking capabilities on both demonstration flights; SS-TDMA and FDMA on Flight A and SS-TDMA on Flight B. The transmission rate in the SS-TDMA mode is 500 MBPS per transponder, providing a total system capacity of 2.0 GBPS in the four transponder system. In the FDMA mode each transponder is capable of handling two FDMA carriers, each operating at a transmission rate of 274 MBPS.

The baseline system is designed for seven trunking beams directed at: Cleveland, New York, Boston, Washington DC, Seattle, Los Angeles, and Tampa. Since there are only four transponders connectivity is restricted to the Cleveland beam and any three of the remaining six beams. One transponder is dedicated to Cleveland, and the remaining three are shared by NYC/Tampa, Washington DC/Seattle, and Boston/Los Angeles. An on-board TDMA IF switch provides beam connectivity in the SS-TDMA mode, and and FDMA switch provides connectivity between beam pairs in the FDMA mode.

The transponder power amplifiers are dual mode TWTA's that normally operate in the low power mode (15W) in clear weather and in the high power mode (75W) when precipitation is present at a trunking node. The TWTA power is adaptively controlled. Impatt and GaASFET solid state amplifiers, being developed under the technology development contracts provide redundancy for the TWTA's on a 3:2 basis. The output power of the solid state amplifiers is limited to about 10 watts, therefore, the redundancy provided is limited to clear weather conditions, i.e., the additional margin realized by TWTA operation in the high power mode is not available.

A single 4.1 meter (13.5 ft) antenna is provided for CONUS coverage. The half power beam width of each beam is 0.3^{0}. Scan loss and total antenna losses are significant, 4.0 db and 6.3 db, respectively, at 27.5 GHz.

The system performance design objectives are: system availability .9999; BER 10^{-6}; and system operating margins of 20 db on the uplink and 10 db on the downlink.

Rain response techniques employed to meet the system availability criteria are: use of diversity earth stations; adaptive downlink power control; adaptive uplink power control; and adaptive FEC. The rain response mechanisms are in addition to the normal operating margins.

The trunking frequency plan provides for demonstration of frequency reuse by beam isolation and orthogonal polarization. The New York beam is vertically polarized and the remaining six beams horizontally polarized.

The on-board TDMA and FDMA IF switches are controlled from the Master Control Station. A 6x6 TDMA IF switch is planned for both demonstration flights in the baseline concept.

The Network Control Facility is colocated with the Master Control Station (MCS). The primary integrated facility functions are:

- network control
- spacecraft control

- processor control
- TT&C
- service

The Network Control allocates channel assignments to trunking and CPS earth stations on a demand basis and as a function of traffic loading with time.

System synchronization and timing functions are shared by the MCS and the spacecraft. The local oscillator frequencies at all earth stations are phase locked to the spacecraft master oscillator (MO). The long term drift of the spacecraft master oscillator is monitored at the MCS from which commands are periodically generated to update the MO. The spacecraft also generates a preamble for frame start synchronization at all earth stations.

The MCS measures satellite range and range rate in conjunction with two other trunking stations. Using the measured data a prediction of the spacecraft ephemeris is computed. The predicted ephemeris and earth station location data are used to calculate the slant range and range rate for each earth station. Finally burst timing assignments are computed and transmitted to all earth stations via the OW channel. The trunking and CPS earth stations maintain their relative burst timing assignments by linear extrapolation of prior data between updates from the MCS.

Hughes plans for use of a Leasat spacecraft bus capable of shuttle launch using a SUSS-A launch vehicle.

The trunking earth stations in the baseline system design are 12.0M space diversity systems using either DS3 or DS4 diversity switches and interconnected by either a terrestrial microwave or fibre optic link. Diversity spacing is on the order of 16-32 KM (10-20 miles). The earth stations are equipped for TDMA and FDMA operation at 500 MBPS and 274 MBPS, respectively. At Cleveland and New York two FDMA channels are planned. The diversity earth stations are utilized because of the stringent availability requirement for trunking. The diversity gain realized will, in conjunction with other adaptive rain response capabilities, contribute to the margin required to meet system availability criteria.

3.3.1.2 Comments and Recommendations

Comments and recommendations on the Hughes baseline trunking design concepts have been generated from review of the Hughes baseline design report relative to the requirements outlined in Section 2.0. The results are essentially the same as the comments and recommendations given relative to the TRW baseline design concepts. For completeness they are repeated in the following as they apply to the Hughes baseline design concepts.

SYSTEM: The functional system design configuration, availability and BER objectives, and the per channel transmission rates are compatible with projected operational system requirements based on the results of earlier market demand assessment studies.

From an operational system point of view, TDMA has the highest priority and a 500 MBPS burst rate is compatible with expected trunking system requirements. The demonstration system design should clearly show that the satellite trunking capacity can be scaled upward to as high as 10 GBPS throughput and that the number of beams can be increased to the 18-20 range. In this respect the TDMA switch to be implemented should be at least a 20x20 switching matrix to demonstrate the scalability and switching dynamics, i.e., switch mode reconfiguration, switching speed, isolation, etc.

System availability is considered a key performance parameter for trunking applications. In the baseline design the use of diversity earth stations, adaptive rain response techniques, and normal operating margin were identified as the system design approaches to be used to achieve the required availability. In the trunk link budget, a fair amount of operating maintenance margin was built into the design E/N_0. The uplink and downlink power are both operating in the high power mode to compensate for the 20 db uplink and 10 db downlink rain attenuations identified. Rain attenuation tables are given in Reference 4 for each CONUS rain zone. The tables give margin requirements to satisfy the link availabilities specified. Comparing the Reference 4 tables with the Hughes Trunk Link Budget it is seen that the .9999 link availability is satisfied with the margins provided in the analysis plus addition of FEC margin and diversity gain. Moreover, availability can be achieved with diversity gain only assuming it behaves as expected, i.e., diversity gain increases on a db for db basis with single site attentuation above 18 db.

The Hughes conceptual design utilizes 12.0M antennas for the diversity trunking earth stations. The analysis given in Reference 4 shows that trunking availability can be satisfied with an antenna size as small as 5.0M. Western Union recommends that trunking antenna size be limited to 7-7.5 meters which will provide substantial cost savings relative to 12.0M antennas and still satisfy availability objectives.

An additional consideration with respect to availability is the orbital position of the satellite. Rain attenuation increases appreciably as the earth station elevation angle decreases. Further analysis is necessary to determine whether there are orbital position constraints imposed as a consequence of the increased attenuation levels relative to total available margin as a function of the satellite position. In this case assuming a constant rain rate the diversity gain achievable is fixed and the increased attenuation resulting from the increased rain path lengths at the lower elevation angles will tend to use up, and could exceed, the available margin.

A consideration in specifying the satellite G/T is that the low noise receiver noise figure is specified to be 5.3 db. The specified noise figure is based on the technology available in the 1986 time frame. In optimizing system performance, and in view of system margin requirements, another look at the LNA noise figure may be beneficial in that some G/T improvement may be realized if a lower noise temperature can be achieved with new technology, so that other system noise sources are the limiting factors.

Further analysis is necessary for the multi-carrier transponder operation (TDMA-FDMA - ECS/CPS). While on a power basis it may be possible to operate in a multi-carrier mode, a detailed intermodulation analysis may preclude such operation, particularly since the carriers are non-homogenous.

<u>ANTENNA SUBSYSTEM/BEAM CHARACTERISTICS</u>: The antennas have been identified as a critical technology because of the stringent design requirements imposed on supporting structures and the attendant influence on antenna perfor

mance (surface tolerance, gain, efficiency, etc.). In view of the availability requirements the design of the larger antennas should become a demonstration system requirements.

The design of the baseline antenna subsystem should also consider:

- the need for one steerable trunking beam to provide for measurement of interbeam interference characteristics and cross polarization isolation.
- antenna subsystem scalability to increase the number of beams to 18 or more in an operational system.

SYSTEM SYNCHRONIZATION AND TIMING: The Hughes' synchronization and timing approach represents a well conceived open loop system in which various functions are distributed between the spacecraft and the MCS. The MCS functions include computation of range, range rate, and burst timing for all network earth stations. No indication is given relative to consideration of tradeoffs (cost, complexity) between performing the functions locally based on MCS ephemeris estimates. To establish the minimum cost approach a trade-off analysis should be developed.

In the demonstration system synchronization and timing accuracies can be relaxed because of the limited number of earth stations. The key criteria is that the system demonstrate scalability to a fully implemented operational system and appropriate system dynamics. Potential demonstration system cost savings that can be realized by relaxing accuracies, providing the other criteria are satisfied, should be assessed.

TRUNKING EARTH STATIONS: The size of the trunking earth stations in the baseline design concept is 12.0M. An analysis of system availability was given in Reference 4, considering earth station antenna size, margin requirements in each CONUS rain zone as a function of availability, and various adaptive rain response techniques in addition to diversity earth station gain. That analysis indicated that regardless of the earth station size (5.0M, 7.0M, and 12.0M were examined) a .9999 link availability could not be attained in all rain zones without benefit of diversity gain. Assuming diversity gain behaves as expected (1.0 db additional diversity gain per db added single site attenuation) above a single site attenuation on the order of 18.0 db, then the .9999 availability could be satisfied by all of the antenna sizes. The only advantage of the 12.0M antenna versus the 5.0M is some additional clear weather margin equal to the differences between the gain of the antennas. The disadvantage of the 12.0M antenna is that its cost, implemented, is substantially higher than a 5.0M or 7.0M antenna. With two antennas implemented in a diversity configuration at each trunking node, cost savings with use of the 5.0M and 7.0M antennas are significant. Western Union recommends that the largest antenna size be no larger than 7.0-7.5 meters.

3.3.2 Hughes Baseline Emergency Communication System (ECS) Design Concept

3.3.2.1 Summary of ECS Design Concept

The Emergency Communication System is a secondary demonstration system experiment that would be implemented on Flight "A" only. The primary objective of the ECS is to demonstrate the applicability of the "Ka" band in establishing communications links to a disaster area using small rapidly deployable earth stations. The ECS provides limited CPS experimental capabilities with implementation of low rate (6.3 MBPS) TDMA channels and a steerable antenna.

The base ECS system provides for 6.3 MBPS channels, one in each of three trunking spot beams and one in the steerable 1.5° beam. Uplink transmission rates are 6.3 MBPS, or 1.5 MBPS and/or up to 7-35 KBPS channels operating in SCPC and SCPC-TDM modes. All downlinks are 6.3 MBPS TDMA.

The uplink channels are demodulated, routed to the appropriate TDMA multiplexer and remodulated for transmission downlink. Downlink transmissions are via three of the trunking spot beams and the steerable 1.5° beam that can be positioned to cover an emergency or disaster area anywhere within CONUS.

The 2.0M ECS earth stations are designed to be rapidly deployable to an emergency area. The performance objective of the ECS channels are BER 10^{-6}. The nominal operating margins provided on the uplink and downlink including adaptively controlled downlink power is inadequate to satisfy a .999 availability objective in all CONUS rain zones, however, for the demonstration system, operation is not essential during periods of heavy rains.

Control of the ECS is centralized in the MCS to minimize on-board and earth station processing requirements.

3.3.2.2 Comments and Recommendations

The objective of the ECS is not oriented toward its applicability in a commercial carrier environment, but to assess its potential as a rapidly deployable system to establish emergency communications capabilities within a disaster area. The Hughes ECS design concept has application in this respect, but with limitations. The same comments made relative to the TRW concept apply to the Hughes concept and they are repeated in the following for completeness.

A premise of the ECS is that rapidly deployable earth stations would be moved into a disaster area to establish a communication capability to national or state disaster control centers, as the case may be. An obvious limitation is that there are 50 states in addition to a national headquarters, and a concept to providing connectivity between a disaster area and any one of the possible 51 control centers using trunking system fixed beams is impractible. A more viable approach might be implementation of multiple steerable beams or connectivity via scanning CPS beams. Restriction of ECS coverage to CONUS has political implications that would also have to be addressed.

The operating margin provided in the ECS and the absence of adaptive rain response capabilities limit the availability achievable to somewhat less than .999, restricting the systems use and capabilities under rain conditions, particularly in rain zones D_2, D_3, and E.

In the Hughes design concept the ECS would share trunking channel TWTA's with TDMA and FDMA carriers. The ECS carrier is substantially smaller than either the TDMA or FDMA carriers and can potentially suffer severe intermodulation interference effects because of the non-homogenous carrier sizes. A more detailed analysis of intermod interference is necessary.

3.3.3 Hughes Baseline Customer Premises Services (CPS) Design Concepts

3.3.3.1 Summary of CPS Design Concepts

Implementation of CPS capabilities in the 30/20 GHz demonstration system is planned for Flight "B" because of the need to develop the baseband processor technology to be flown. The CPS system design concept provides connectivity between users accessing the network through CPS and trunking earth stations with cross connectivity between the trunking and CPS systems implemented on-board the satellite. Cross connectivity is accomplished by interfacing the on-board CPS communication subsystem to input/output ports of the on-board trunking SS-TDMA IF switch. Individual user connectivity is accomplished in the CPS baseband processor at the 64 KBPS channel level.

User interface rates to the CPS system extend from 64 KBPS to 6.3 MBPS. The baseline CPS system operates in an FDM/TDMA mode on the uplink and TDMA mode on the downlink for users accessing the network through CPS earth stations. Each CPS scanning beam has a transmission capacity of 250 MBPS on the uplink and downlink. The uplink capacity is divided between six TDMA carriers; five operating at 25 MBPS burst rates and the sixth at a 125 MBPS burst rate. The downlink is a single carrier operating at a 250 MBPS burst rate.

CPS users can also access the CPS system through the trunking beams via either the trunking earth stations or CPS earth stations within the trunking spot beams. The uplink and downlink channel sizes and capacity for accessing via CPS earth stations is the same as for CPS earth stations accessing through the CPS scanning beam; five 25 MBPS and one 125 MBPS TDMA channels uplink and one 250 MBPS channel downlink. CPS users accessing the network through trunking stations operate within the trunking SS-TDMA network. User data is uplinked and downlinked at a 500 MBPS burst rate. Interface to the CPS system is at the on-board TDMA switch.

The total transmission capacity of the baseline CPS system is 750 MBPS; 500 MBPS through the trunking beams and 250 MBPS through the single CPS scanning beam to be implemented.

Hughes proposes six scanning beams for an operational system with a total transmission capacity of 1.5 GBPS plus 500 MBPS for trunking beam accesses.

The performance objectives for the CPS system are to achieve a system availability of .999 at a BER 10^{-6}.

CONUS coverage for the baseline CPS system is provided by six scanning beams each of which scan a designated region within CONUS. The beams are independent of each other and individual beam scanning is accomplished by programmed control of the relative phase and power exciting the array feed horns. The beam dwell time is determined by the traffic capacity at each scan position within the respective regions. In the demonstration system a single scanning beam is planned using 32 feed horns in the feed array. The operational version with six scanning beams would have a total of 192 feed horns. Critical technology for the CPS scanning beam design are the variable power dividers and phase shifters. The CPS scanning beam-beam width is 0.3^{o}.

In the baseline CPS system frequency reuse is achieved by beam separation. The CPS beams are vertically polarized and orthogonal to the horizontally polarized trunking beams.

The Hughes baseband processor design concept is based on a static network control approach as opposed to a dynamic control approach. In the static approach channel connectivity is preassigned and the assumption is that excess capacity exists so that channel assignments can be made at the earth station without requiring on-board switching on a dynamic or demand basis. On-board routing and switching is therefore not a real time process. The static network control approach is oriented toward the Hughes objective to minimize MCS costs.

The on-board baseband processor incudes FDMA demultiplexers, demodulators, FEC decoders, the routing switch, FEC encoders, TDMA high speed multiplexer, and TDMA burst modulator.

The power amplifiers in each of the CPS downlink channels are 75 Watt TWTA's that are operating at full power continuously, therefore adaptive downlink power control is not available.

Adaptive rain response capabilities in the conceptual CPS system design consist of uplink and downlink FEC (R 1/3, K=5). The normal operating margins provided are 17.0 db uplink and 8.4 db downlink.

TDMA synchronization and timing functions are distributed between the satellite, MCS, and CPS earth stations. All earth station oscillators are phase locked to the satellite master oscillator. The satellite generates a preamble that is used to synchronize frame start at all earth stations; MCS, CPS and trunking. The MCS in conjunction with two trunking stations measures satellite range and range rate. The satellite state vectors are computed and using the predicted ephemeris data the range, range rate, and burst timing for all earth stations are computed. The timing data is transmitted to all earth stations to update their respective microprocessor timing algorithms. Between timing updates the individual earth stations revise their respective burst timing by a linear extrapolation of previous data. The CPS stations generate a preamble to provide for carrier and clock recovery at the satellite receive TDMA modems.

The CPS earth stations are 3.0M non-redundant systems equipped with a step tracked antenna. The stations are sized for one 25 MBPS and one 125 MBPS uplink. The power amplifier implemented is a 500 watt TWTA that is shared by the two uplink carriers. The nominal uplink power required for the 25 MBPS uplink is 40W and for the 125 MBPS uplink, 200W.

3.3.3.2 Comments and Recommendations

Comments and recommendations on the Hughes baseline CPS design concept, reviewed relative to the NASA specified requirements and other considerations outlined in Section 2.0 are given in the following.

SYSTEM: The functional system design configuration, availability and BER objectives stated, and the transmission rates are compatible with the NASA SOW requirements outlined in Section 2.0. From an operational point of view TDMA has the highest priority in terms of transmission mode desirability. A basic premise of the CPS concept is that the earth stations are low cost systems, precluding considerations of diversity earth stations for availability purposes. With considera tion given to the adaptive rain response capabilities in the baseline CPS design, independent uplink and downlink FEC, the system availability requirement (.999) cannot be met in all rain zones. The CPS availability problem was considered in Reference 4. Comparing the Reference 4 margin requirements for .999 availability to the Hughes link analysis, the uplink availability in rain zones D_3 and E cannot be satisfied, however an availability exceeding .995 is attained. To satisfy the availability criteria (.999), in rain zone "E", an approach given in Reference 4 was reduction of transmission rates and an increase of earth station size. Alternative design concepts need to be addressed to resolve the availability problem.

Hughes assumption in developing the network control concept was that excess capacity was available and therefore dynamic network (and baseband processor) control was not necessary. In Reference 4 the projected CPS transmission capacity for a fully matured operational system is 4.0 GBPS and for an initial operational system 2.0 GBPS. The transmission capacity in the baseline design concept is about 2.0 GBPS (operational system). If the projections are relatively accurate excess capacity is not likely to be available. Further, traffic distribution assumptions are necessary to preassign capacity or channels. With the absence of accurate traffic distribution data on an apriori basis, system resource utilization is apt to be inefficient. While more complex, it seems that a dynamic network control approach would be more appropriate. The demonstration system must show scalability (capacity and system dynamics) to an operational system.

A comparative assessment of complexity and cost between trunking - CPS cross connectivity on-board the satellite and at individual trunking stations is desirable. Since there will be a limited number of trunking stations, implementation at the trunking stations may be economically a more viable approach.

It is assumed that the trunking channel TWTA's shared by the trunking and CPS carriers carry CPS or trunking traffic and not both simultaneously (on the demonstration system). Separate TWTA's are necessary for an operational system since inadequate power is available for simultaneous shared use (see Hughes link budgets).

The link budgets did not consider CPS scan losses at beam edge. The analysis should reflect the worst case operating environment so that appropriate margin and rain response approaches can be established.

ANTENNA SUBSYSTEM: Six CPS regional scanning beams are incorporated in the baseline design concept to provide CONUS coverage, each with a 250 MBPS transmission capacity. With projections for an operational system (fully matured) on the order of 4.0 GBPS additional scanning beams will be necessary. The plan for the demonstration system is to implement a single scanning beam. This is felt to be totally inadequate. With 4.0 GBPS CPS and 4.0 GBPS trunking requirements for an operational satellite extensive frequency reuse is necessary. The demonstration system should vigorously demonstrate reuse capabilities through both spatial isolation and orthogonal polarization. Further the demonstration system should clearly demonstrate not only scalability but the systems dynamics of an operational system. The weight of the feed assemblies for a six beam scanning system is high and adding additional scanning beams will further increase the weight, and is likely to impact the potential capacity achievable in an operational system. Other alternative designs should be pursued considering the preceeding.

MASTER CONTROL STATION: The baseline design concept for network control should be reassessed. A static control approach does not lend itself to the level of traffic anticipated in an operational system and precludes redistribution of resources as traffic demands on a real time basis. While more complex, a dynamic network control approach is felt to be more efficient and appropriate.

The CPS network is comprised of a large number of individual user networks and a pool of demand assigned channels. The user networks are expected to be fixed assigned or wired connections requiring assignment or reassignment only when a user enters or leaves the CPS system. This kind of channel assignment does not require a real time capability but can be accomplished manually at a control terminal. The cost of the MCS control center can be reduced by considering the split between manually assigned and dynamically assigned requirements. A reasonable estimate is that 40% of the channels can be manually assigned and 60% demand assigned.

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EARTH STATION: The use of a single 500 watt TWTA for shared use by 25 MBPS and 125 MBPS carriers is inadequate based on the link calculations. The power required for the two carriers was 240 watts, a back-off of slightly more than 3.0 db from saturation. A 3.0 db back-off is inadequate, 6-8 db being more appropriate to minimize effects of intermodulation. Separate TWTA's may be necessary for each channel.

4.0 REVIEW, COMMENTS, AND RECOMMENDATIONS - TRW/HUGHES MULTIPLE DESIGN CONCEPTS

4.1 INTRODUCTION

Under Task 2 of their respective Phase II study contracts, TRW and Hughes were tasked to develop Multiple Design Concepts for a two flight demonstration system. Each contractor was required to develop two design concepts for which the design guidelines were basically the same as those applicable to the baseline design concept (Section 2.0) except for launch vehicle constraints imposed by NASA. The constraints were that the Design Concept 1 launch vehicle size was limited to a SUSS-D capability (1200-1400 lbs), and the Design Concept 2 launch vehicle size was limited to a SUSS-A capability (2200 lbs).

The objective of the multiple design concepts is to reduce the Phase III flight system cost. The baseline and multiple design concepts provide NASA with a range of flight system capabilities and costs. The purpose of the demonstration system is to demonstrate the technology, system performance, and capabilities required for an operational system. In addition scalability of the demonstration system to an operational system and operational system dynamics must be demonstrated. Based on the foregoing criteria for the demonstration, the lowest cost flight system meeting these objectives can be selected from the baseline and multiple design concepts.

4.2 TRW MULTIPLE DESIGN CONCEPTS

4.2.1 SUMMARY OF TRW MULTIPLE DESIGN CONCEPTS

4.2.1.1 GENERAL

TRW's Design Concept 1, SUSS-D compatible, limited the on-board communications subsystem to a Trunking only capability on Flight A and a CPS only capability on Flight B. In the Design Concept 1, neither ECS or FDMA capabilities were considered. In Design Concept 2, SUSS-A compatible, again Flight A was limited to a Trunking only capability, however adequate weight and power margin are available for some secondary experiments. Flight B provided both Trunking and CPS capabilities with on-board cross connectivity, the communication subsystem design being essentially the same as the Baseline Design concept.

4.2.1.2 DESIGN CONCEPT 1 - SUMMARY

The on-board communications and support subsystems in Design Concept 1 are designed to be compatible with a SUSS-D launch capability. Because of the size and weight constraints imposed by the SUSS-D, the on-board system on Flight A was limited to Trunking capabilities only, and the Flight B on-board system was limited to CPS capabilities only.

In Design Concept 1, the dual 4.0M antenna apertures of the baseline design concept are replaced by a single 3.0M (10ft) aperture with a $.45^{\circ}$ beamwidth. In addition, a .76M (30 inch) antenna with a 1.5° beamwidth is provided for spacecraft TT&C communication with Cleveland and spacecraft autotrack via two dispersed beams.

The Flight A trunking system design concept provides seven fixed beams of which four can be active simultaneously. The transmission rate of each trunking SS-TDMA channel is 512 MBPS, therefore with four active channels the trunking throughput capability is 2,048 MBPS. The on-board trunking communications system, aside from antenna size, is basically the same as in the baseline design concept. Two of the trunking beams, Cleveland and Los Angeles, are fixed in the Flight A design to support satellite attitude control requirements. Boston and New York share a common $.45^{\circ}$ BW beam. As in the baseline design, adaptively controlled dual mode TWTA's are incorporated in the design for rain response purposes.

The Flight B CPS design concept provides a single scanning beam with an increased pill box array to minimize scanning losses over a 6° FOV. Since trunking is not provided on Flight B, the fixed beam feeds are removed and separate transmit and receive scanning beam pill box arrays are provided to eliminate the need for a diplexer.

The capacity of the CPS system is reduced substantially from the baseline design concept capabilities, and the burst rates have been halved. The clear weather downlink burst rate is 128 MBPS and the high and low rate uplink channels are 64 MBPS and 16 MBPS. One 64 MBPS and four 16 MBPS uplink channels are provided for. Independent adaptively controlled 1/2R FEC is incorporated in the downlink and uplink for rain response purposes. As in the baseline system, the 75W TWTA is normally operated at full power.

The CPS Baseband processor on Flight B is scaled down to support a single input and output port since there is only a single 128 MBPS CPS channel and the Trunking subsystem has been deleted.

The frequency plan provides for frequency reuse on Flight A only. There are four active spot beams that share two frequencies. Frequency reuse is provided by beam separation only and provisions are not incorporated in the design to demonstrate frequency reuse via orthogonal polarizations. The limited CPS capabilities on Flight B do not provide frequency reuse capabilities through either space separation or othogonal polarization.

The MCS at Cleveland and the Los Angeles earth station provide three axis references for spacecraft attitude control. The Cleveland carrier used for on-board sensing is the 3.5 MBPS TT&C signal and Los Angeles transmits a 30GHZ beacon signal. There is about 10db of rain fade margin designed into the control links. Under deep fade conditions the spacecraft can maintain its attitude within acceptable limits for periods of greater than 24 hours.

Other MCS functions are essentially the same as in the baseline system except for scaling to match reduced system capacity.

The trunking earth stations proposed for concept 1 are 12.0 diversity systems. A space diversity implementation is necessary to achieve trunking system availability (.9999) objectives. The TDMA transmission rate from the trunking stations is 512 MBPS for each TDMA channel implemented, and the BER performance objective is 10^{-6}.

With a lower availability (.999) requirement and reduced transmission rates the CPS earth stations are 3.5M systems. CPS stations can be equipped with one 64 MBPS and/or one or more 16 MBPS TDMA uplinks. All CPS earth station's receive the 128 MBPS TDMA downlink. Again, the BER objective is 10^{-6}.

The system synchronization and timing approach is the same as described in the baseline design.

4.2.1.3 DESIGN CONCEPT 2 - SUMMARY

The on-board communications subsystem in design concept #2 are essentially the same as the baseline design concept. The communication subsystems on Flight A is limited to a trunking capability only. On Flight B both trunking and CPS capabilities are provided.

The guidelines for Design Concept 2 limit the launch vehicle to SUSS-A with a solid propellant upper stage which reduces the payload weight capability relative to the baseline launch vehicle where augmentation was incorporated with a liquid apogee kick motor (LAKM).

In Flight A, space, weight, and power margins are available for allocation to secondary experiments since the payload carries the trunking communications subsystem only. In Flight B with CPS and trunking capabilities, no allocation is available for secondary experiments.

To limit payload weight to 2200 lbs. various operational constraints are being assessed. These include: limited eclipse operation; limited N/S stationkeeping; and constraining the number of high power links.

The concept 2 antenna subsystems, beam configurations, signaling rates, and communications subsystems are the same as in the baseline concept except for the method of interconnecting the trunking and CPS systems, on-board. In the concept 2 design, CPS traffic originating in a fixed trunking beam are uplinked as CPS carriers independent of the uplink trunking carriers. Since they are in a different portion of the band, the CPS FDMA carriers can be demultiplexed and interfaced directly to the CPS Baseband Processor Unit without traversing the IF SS-TDMA switch. In the downlink the CPS traffic shares the trunking carrier on a time shared basis with trunking traffic. The CPS traffic is distributed across the trunking frame utilizing trunking dead time. After demodulation of the uplink CPS carrier, all traffic addressed to specific earth stations are accumulated and then Time Division Multiplexed with trunking traffic within the trunking frame. This approach permits the CPS downlink to share a common frequency with trunking and does not require downlink power sharing.

Other features of the Concept 2 Trunking and CPS design approaches were described in Section 3.0 in the baseline systems description.

4.2.1.4 COMMENTS AND RECOMMENDATIONS

The comments and recommendations given in Section 3 for the TRW baseline trunking design concept applies to the present Design Concept #1 Flight A trunking system. An additional comment is that the use of a 10 foot antenna will reduce clear weather margin relative to the baseline design, all other factors being equal, necessitating use of the adaptive rain response mechanisms for more shallow rain fades.

The Design Concept #1, Flight B CPS system is inadequate to effectively demonstrate operational system capabilities, performance, and dynamics. The total clear weather transmission rate is 128 MBPS with a lower throughput capacity based on TDMA frame efficiency and the demands for adaptive FEC. A single CPS scanning beam is incorporated in the Flight B design using the 10 ft. reflector. The basic design of the antenna subsystem varies considerably from the baseline design in that additional phase shifters are required to reduce scan losses, separate transmit and receive arrays are planned, the beamwidth is wider, and the number of tracks required are fewer. The design variations are sufficiently widespread that a clear demonstration of scalability to an operational system, operating performance, and system dynamics is questionable. The limitation to a single scanning beam, limited transmission capacity, reduced baseband processor capabilities, and absence of a trunking communications capability severely limit the ability of the demonstration system to adequately demonstrate the technology and performance dynamics required in an operational system environment. The consensus is that the capabilities of Design Concept #1 are inadequate and will not satisfy program objectives.

The comments and recommendations given in Section 3.0 for the trunking and CPS systems apply to Design Concept #2 and are not reiterated here. A further comment relative to trunking/CPS system interconnectivity is that trade-off analysis between the various connectivity approaches should be performed to identify the relative merits and limitations of each with respect to operational system network and internetwork traffic flow scenarios.

4.3 HUGHES MULTIPLE DESIGN CONCEPTS

4.3.1 SUMMARY OF HUGHES MULTIPLE DESIGN CONCEPTS

4.3.1.1 GENERAL

In approaching the multiple design concept development task, Hughes ascertained that the need for 30/20 GHZ satellite systems would be limited because of the potential to considerably expand "C" and "Ku" band capacity through high frequency reuse factors achievable with implementation of multiple spot beams on "C" and "Ku" band satellites. Hughes's view was that the need for 30/20 GHZ systems would have to be generated by designing and marketing the system for specific target markets. The result was that their Multiple Design Concept 1 and Design Concept 2, Flight 1 was oriented toward specific teleconferencing applications, although the capabilities exist for various analog and digital operating modes to accommodate a wide range of applications.

Design Concept #1 provides for operation on sixteen channels, two in each of eight beams. The design concept is an FDMA transmission system in which traffic routing to specific beams (and earth stations) is accomplished by frequency assignments.

Design Concept #2, Flight #1 is the same as Concept #1 except that the system is expanded to a fourteen spot beam capability. Twelve of the fourteen beams have two channels and the remaining two have expanded capacity capabilities in the form of one additional TWTA and two low power solid state amplifiers.

Design Concept #2, Flight #2 is essentially the same as the baseline system except for lower transmission data rates and the deletion of adaptive FEC decoding/coding on-board.

4.3.1.2 DESIGN CONCEPT #1 - SUMMARY

Design Concept #1 is designed to provide a video teleconferencing network for NASA. The premise is that after completion of demonstration system experiments NASA would lease back the satellite from a carrier who would buy it.

The Concept #1 system is designed for a SUSS-D launch capability and a Hughes HS376 bus is proposed. The system operates in an FDMA transmission mode in which sixteen channels are available, two in each of eight spot beams. Eight of the sixteen channels (one in each beam) are always available for point-to-point communications. The second channel in each beam can be either a broadcast channel or in the absence of a broadcast transmission, a second point-to-point channel can be switched into each beam.

Each channel is capable of operating at a transmission rate of up to 50 MBPS providing a total transmission capacity of 800 MBPS. The on-board communcation subsystem is a transparent repeater therefore analog transmissions can also be accommodated. The on-board system can therefore handle compressed digital video transmissions that range from 56 KBPS to 50 MBPS, and analog video transmissions. Multichannel operation within each transponder is possible with appropriate TWTA back-off considerations. The bandwidth of fourteen of the wideband channels is 100 MHZ and two channels are 300 MHZ to provide for additional SCPC carriers in each wideband channel.

The Hughes analysis indicates that each channel is capable of accommodating up to 14-T-1 carrers, or 5-6.3 MBPS carriers, or 2-3 27 MHZ analog video carriers.

The link design provides for rain margin of 10 db on the uplink and 5 db on the downlink. On-board adaptive FEC and downlink power control are not provided.

In the Concept #1 plan the second flight is identical to Flight #1, serving as an on-station back-up or to provide increased capacity.

The earth stations in Concept #1 are 4.0 Meter terminals equipped to provide digital video codecs and transmission equipment in accordance with user requirements. Channel assignments are handled via an OW channel with the MCS. Diversity earth stations are not considered in this design concept.

4.3.1.3 DESIGN CONCEPT #2 - SUMMARY

Design Concept #2, Flight #1 is an expanded version of the Concept #1 design approach to fit a Leasat bus. The number of spot beams has been increased to fourteen to accommodate a customer community outside of NASA.

Beams 1-7 share the spectrum with beams 8-14, the frequency reuse capability made possible by beam separation.

Twelve of the fourteen beams have two wideband channels and two have increased channel capabilities provided by three additional power amplifiers feeding each beam.

The transmission capabilities, analog and digital, are the same as Concept #1. In the present case channel assignments and the broadcast capability are segregated to each of the two seven beam groups.

Design Concept #2, Flight #2 is similar to the baseline design concept with lower data transmission rates and no on-board adaptive FEC capabilities. The Flight #2 system is also designed to fit a Leasat bus.

The trunking communications system uses an SS-TDMA/FDM transmission mode in a six beam configuration.

The beams are grouped in three pairs; i.e., New York-Cleveland, Los Angeles-Washington DC, and Chicago-San Francisco. Each group has two 125 MBPS TDMA channels one of which can be fixed assigned to a high density traffic location and the second time shared between the two cities in the group. With six TDMA channels the transmission capacity of the trunking system is 750 MBPS.

The CPS communication system provides connectivity between trunking nodes and CPS nodes through 2-125 MBPS and 2-25 MBPS TDMA channels that share the trunking power amplifiers. Connectivity between CPS and Trunking is provided via the on-board SS-TDMA switch.

The CPS scanning beam provides sequential TDMA coverage of up to fifteen spot locations. Beam scanning control is originated at the MCS in accordance with channel and connectivity demands.

An on-board processor is provided for CPS operation. Uplink transmissions from the trunking and CPS beams are demodulated and routed at baseband to addressed downlink beams, remodulated and burst out downlink via the addressed beam channel.

The earth stations in Concept #2, Flight #1, are the same as in Concept #1 except that the power amplifier size has been reduced (to 100 watts) because of increased satellite antenna gain.

The earth stations in Concept #2, Flight #2 are 4.0M terminals for both trunking and CPS, that operate in a TDMA transmission mode.

Synchronization and timing for the TDMA systems is as described in Section 3.0. The transmission link design provides for 10 db of rain margin on the uplink and 5 db on the downlink.

4.3.1.4 COMMENTS AND RECOMMENDATIONS

The 30/20 GHZ market scenario on which Hughes based their multiple design concept is not compatible with previous detailed 30/20 GHZ Communication System Demand Assessment Studies performed by Western Union and ITT. The results of those studies indicated that there will be a substantial demand for Ka band satellite communication services in the 1990 to 2000 year time frame for not only video, but for voice and data services. The Western Union and ITT demand assessment forecasts were based on an extensive literature research effort as well as surveys of a broad range of corporate, institutional, and Government user groups. While the absolute magnitudes of the capturable Ka band market may be questioned, the forecasts represent the most credible information available at this time and, consequently, should be the basis on which the various 30/20 GHZ design concepts are developed.

Multiple design concepts #1 and #2-Flight #1 have limited usefulness in terms of developing the appropriate technology and demonstrating the performance and dynamics applicable to an operational system designed to meet the voice, video, and data markets forecasted in the WU and ITT studies.

The conceptual designs, oriented toward forcing a video teleconferencing market, assumed that outages are acceptable for this type of service and provisions were not incorporated to achieve the availability requirements identified for trunking and CPS systems. Adaptive rain response techniques (FEC, power, variable rate) and diversity earth stations were not considered. The available system margin is limited to the 10db uplink and 5db downlink rain margins provided for in the link analysis plus a small amount of excess margin.

It is, of course, possible to operate the system in FDMA and TDMA operating modes, but the design proposed by Hughes does not provide the necessary electronics in the network or MCS earth stations for the latter. In either case system availability and operational constraints are not appropriate for an operational system designed to satisfy the service needs for the markets forecasted.

The Concept #2 - Flight #2 design is conceptually similar to the baseline design but again its operational capabilities relative to identified trunking and CPS requirements, the forecasted markets, and the baseline design itself, are constrained.

The transmission rates of the Concept #2 - Flight #2 system are reduced relative to the baseline and it is a low availability design that does not have benefit of adaptive rain response mechanisms or diversity earth station gain.

In addition to reduced transmission rates and low availability, multichannel operation of the lower power TWTA's (relative to the baseline system) requires a detailed intermodulation analysis to establish that trunking performance, even in clear weather, can be achieved.

In the CPS system the CPS beam is steerable to fifteen locations. CPS traffic can originate and terminate anywhere within CONUS and, therefore, the CPS scanning beam must be capable of providing CONUS coverage rather than coverage of specific CONUS nodes. Further, sequentially positioning of the beam to provide connectivity reduces TDMA efficiency.

Scalability to fully matured operational system capacities and demonstration of operational system dynamics was not addressed for either the trunking or CPS systems.

In general the recommendation is that Hughes multiple design concepts be redeveloped in accordance with the requirements and considerations outlined in Section 2.0.

5.0 REVIEW, COMMENTS, AND RECOMMENDATIONS - TRW/HUGHES CONCEPT RECOMMENDATION

5.1 INTRODUCTION

TRW and Hughes Task #3 effort, under their respective Phase II study contracts, is to assess the capabilities of the baseline and multiple design concepts developed relative to the objectives of the demonstration system and identify the concepts each recommends for further study in the subsequent Phase II study tasks.

5.2 TRW CONCEPT RECOMMENDATION

TRW has assessed the capabilities of four design concepts that include the baseline concept, concept #1, concept #2, and a high capacity satellite concept. The high capacity satellite concept is oriented to provide substantial on-station capacity and an 8-10 year design life for operational use following the experimental period.

The baseline concept, concept #1, and concept #2, satellite systems were described in Sections 3.0 and 4.0 and provide no post experiment operational life.

TRW's cost comparison indicates that program cost is relatively insensitive to satellite size.

The order of the TRW recommendations for further development is the high capacity satellite, baseline concept, and finally the concept #2 system.

5.2.1 COMMENTS AND RECOMMENDATIONS

TRW's concept recommendations all provide high rate SS-TDMA trunking and scanning beam CPS system capability with a baseband processor operating in a TDMA transmission mode. The recommended concepts are compatible with operational system functional requirements identified by Western Union in Reference 4.

The primary candidate recommended for further study, the high capacity satellite, is intended to provide high capacity post experiment operational capabilities. At this juncture Western Union recommends that operational use of the demonstration system satellites not be a consideration. The satellite size can therefore be reduced, the key objectives of the demonstration system being to demonstrate:

- applicability of 30/20 GHZ band to operational system applications
- performance capabilities relative to operational system requirements
- scalability to an operational system
- operational system dynamics.

TRW has restrained the design concepts developed to date to the same basic trunking and CPS TDMA design approaches with variations in capacity as a function of launch vehicle design. While the recommended concepts are compatible with the Reference 4 functional requirements, the study efforts need to be expanded. For example, in all of the design concepts: no effort was made to verify system availability; tradeoffs between system synchronization/timing and network control approaches were not considered; TDMA efficiency in the CPS system was not evaluated as a function of scanning beam dwell requirements; tradeoffs between use of fixed spot beams (in addition to trunking spot beams) in conjunction with the scanning beams in the CPS system to optimize TDMA efficiency; traffic density and routing scenarios were not developed for use in concept development and design optimization. For the concepts developed projections of technologies that can produce significant reduction of earth station (CPS) costs, not necessarily in the demonstration system time frame, but in time for initial operational system are necessary. CPS earth station costs are of paramount importance in the development of an economically competitive CPS system. The implication of the above comments is that the scope of the design effort should be expanded before a demonstration flight system design concept can be selected, beyond that the requirements in Section 2.0 and comments/recommendations in Section 3.0.

5.3 HUGHES CONCEPT RECOMMENDATIONS

Hughes, in their Task #3 effort, provided a cursory assessment of: transparent repeater FDMA versus satellite switched (IF switch & Baseband Processor switched) TDMA transmission approaches; antenna design and earth coverage alternatives for multi-spot beam and scanning beam systems; and other technologies that are oriented toward FDMA transmission techniques that presumably will result in the lowest cost ground segment, particularly in the CPS case. In the CPS system the ground segment is the major component in user service costs and, consequently, it requires considerable attention in the design of Ka band systems to control user service costs so that they are economically competitive with service costs using other media over relatively short (several hundred miles) transmission distances.

Hughes assessment of antenna size and realizable antenna gain considering scan loss incurred because of the wide FOV required to provide CONUS coverage, was directed toward a satellite with a single antenna capability. A two antenna system providing east and west earth coverage can resolve the scan loss problem producing improvement in realizable antenna gain as the antenna size is increased.

A comparison of uplink/downlink interconnectivity via fixed spot and scanning beams revealed that: scanning beam interconnectivity requires a baseband processor for efficient TDMA operation and it is not a viable FDMA technique; fixed beams permit operation in a TDMA or FDMA mode at their respective maximum per channel transmission rates in a multi-channel transponder, however, multi-channel FDMA operation results in loss of satellite capacity because of channel PA back-off requirements to reduce intermodulation interference; multi-channel FDMA operation produce problems in combining uplink carriers; the scanning beam is more flexible in that capacity can be transferred from link-to-link to match traffic levels by varying beam dwell times; the complexity and cost of the scanning beam is higher than for fixed beams.

The use of transparent repeaters eliminates the need for on-board switching and minimizes the number of active elements in the satellite repeater. It is, however, less spectrum efficient than the SS-TDMA approach.

Hughes briefly identified design approaches, applicable to an FDMA concept, that tend to reduce earth station costs. Those identified are: FDMA operation in a multi-carrier configuration permits use of lower burst rates that simplify TDMA synchronization and timing requirements that tend to lower earth station cost; amplifier (PA) efficiency in a multi-channel system can be enhanced by use of predistortion techniques that provide pseudo-linear power amplifier operation; that excess spectrum can be traded to reduce intermodulation interference effects; on-board regeneration will reduce uplink power requirements; and that systems availability can be maintained by adaptive uplink power control and trading off available capacity for margin.

Hughes recommended two concepts for further development, a refined Concept #1 and a refined Concept #2 Flight #1, both transparent repeaters applicable to FDMA operation. The Concepts recommended will provide analog, TDM and TDMA transmission capabilities with the constraints previously identified. Demonstration capabilities include (but are not limited to): use of many fixed beams for earth coverage; on-board regeneration; shared use of TWTA's between antenna feeds; low speed switching of carriers between beams to redistribute capacity; adaptive rain compensation; etc.

5.3.1 COMMENTS AND RECOMMENDATIONS

Hughes' recommended concepts are spot beam FDMA concepts oriented toward reducing earth station costs, and eliminating the need for on-board switching/routing, and scanning beams. The multi-channel transparent repeater FDMA concepts permits system operation in analog, TDM and TDMA transmission modes using carrier sizes and burst rates up to the maximum channel throughput capability. The basic assumption in the recommended concepts is that available Ka band spectrum is unlimited, because of the 2.5 GHZ bandwidth and, therefore, some inefficiency in spectrum use is permissable. This assumption is contrary to one of the primary objectives of the 30/20 GHZ communications system program; i.e., efficient utilization of the Ka band spectrum.

The primary motivation in recommending the FDMA concepts is to lower earth station costs which is essential if Ka band satellite systems are to be a viable competitor with other transmission media. At the present time it is well known that analog FDMA and low burst rate TDMA transmission systems, particularly earth stations, are substantially less costly than high burst rate SS-TDMA systems. To conclude that FDMA system will hold a cost advantage over higher rate SS-TDMA systems at the time initial Ka band systems are expected to be implemented, based on the present relative costs, may be presumptuous and inaccurate. The use of LSI techniques even in the present time frame, can substantially reduce the cost of high rate TDMA terminals. The current problem is that the demand for high speed terminals has not yet developed and until a reasonable market does develop, suppliers will not make the capital investment necessary to translate discrete component terminal designs into LSI components. Digital processing and semiconductor technology is also changing rapidly and it is likely that new technology developed during the next decade will result in substantial cost reductions for TDMA systems relative to current costs. An excellent example of the impact that a viable market has on hardware and systems cost is the CATV market. The cost of video receivers in 1976 was on the order of 10K and today a 24 channel remotely tunable video receiver can be purchased for 3.5K.

It is felt that the concept development study effort should be expanded to include a more thorough assessment of the technology that is expected to be available in the 1990 time frame and the impact of the projected technology on system cost, considering both FDMA (analog, TDM, TDMA) and SS-TDMA system designs.

Reference 4.0 discussed the capacity requirements for operational Ka band trunking and CPS systems for the three basic types of carriers, i.e., trunking only, trunking/CPS, and CPS only carriers. The objectives of the demonstration system are to demonstrate:

- the applicability of the 30/20 GHZ band to operational system applications
- performance capabilities relative to operational systems requirements
- scalability to an operational system
- operational system dynamics.

Based on the cited objectives the demonstration system design should not be constrained and, indeed, should be a reduced capacity replica of an operational satellite. For example, the satellite antenna subsystem should not be limited to a single antenna with its consequent reduction in gain due to scan loss, when a dual antenna system will permit use of larger antennas, lower scan losses, and higher realizable gain. Similarly, the CPS system, by definition, must be capable of providing CONUS coverage, therefore, scanning beams and fixed spot beams are required to satisfy the earth coverage requirements.

In general, the study effort and concept development needs to be expanded to appropriately address design and cost tradeoffs between FDMA and SS-TDMA systems and to select a design concept that is as near to fully satisfying projected operational system requirements as possible, considering the technology expected to be available in the 1990 time frame. The expanded effort should include development of traffic density and routing scenarios to provide a basis for comparison of the relative capabilities and efficiency of system alternatives and for design optimization. More detailed analysis is required to clearly show that the systems design satisfies performance requirements, i.e., BER, availability, etc.

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TASK 5 REPORT
PLANNING ASSISTANCE FOR THE 30/20 GHZ PROGRAM
REVIEW AND CRITIQUE OF THE PHASE II DETAILED DESIGNS

NASA Contract No. NAS3-22461 Task 5
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SECTION I
TASK REPORT 5
INTRODUCTION

1.0 OBJECTIVES

Under the requirements of NASA Contract No. NAS3-22461, Western Union was tasked to review, comment and offer recommendations on Hughes and RCA Phase II Final Concept Design for 30/20 GHz trunking and CPS communication systems. As a part of Western Union's Task 3 efforts, the multiple concepts developed by the two contracts were reviewed relative to the NASA SOW and Western Union's perception of 30/20 GHz communication system requirements based on the results of earlier Western Union market demand assessment studies and the functional design described in the Task II report on the present Planning Assistance Program.

The design concept development was based on satisfying the baseline requirements set forth in the SOW for a single demonstration flight system. Key constraints on contractors were cost constraints, and the launch vehicle size for a single demonstration flight. The outputs of this task are:

- review of two (2) design concepts,
- comparison of experiment capabilities.

1.1 GENERAL COMMENTS

Although generally both the contractors meet the baseline NASA Statement of Work requirements for a single demonstration flight, it is Western Union's opinion that no single concept proposed by either of the two contractors convincingly demonstrates a high degree of scalability to an operational system. A detailed discussion of the system aspects and other considerations to demonstrate scalability to an operational system is presented in Task 3. Various aspects which need further study and pointed out in Task 3, also apply to this Task 5 effort. In general, the system concepts proposed in Task 5 either emulate the previous system design concepts or provide further details. In general, Western Union concluded that, no significantly different or new concepts have been proposed in the two contractor's reports that were reviewed.

SECTION II
DEMONSTRATION SYSTEM DESIGN REQUIREMENTS

2.0 INTRODUCTION

The objective of this section is to review, discuss and evaluate the various system design concepts proposed by Hughes and RCA consistent with the requirements set forth for space, ground and control segments for a 30/20 GHz operational system for three classes of carriers, 1) trunking, 2) CPS and 3) CPS/trunking.

Under the NASA Task 3, Phase II technical design requirements for the three carrier classes considered the design efforts of the contractors were to be addressed to the entire space, ground and control segment subsystem for the demonstration of 30/20 GHz network concepts such that a practical cost target could be established. The objective of the demonstration satellite is to establish the feasibility of a fully operational satellite communication network to be operated by various classes of carriers, i.e., trunk only, Customer Premise Service only and trunk/CPS. Although the Task 5 effort is directed toward the demonstration satellite, under cost and payload constraints, the system design must be scalable to a fully operational commercial communication satellite network.

This Task Report is a comprehensive review of the design concept reports submitted to NASA under Task 3 by the following two contractors:

1. Hughes, "Phase II Flight Experiment System Preliminary Design Report, April 28, 1981" Document Code 1-4-H-2-T4.
2. RCA Astro, "30/20 GHz Demonstration Systems, May 12, 1981 Suplement to Presentation of April 23, 1981."

The baseline design requirements are derived from "Requirements Determination for the Demonstration of 30/20 GHz Communication System" Statement of Work. A baseline system has been defined to demonstrate the technology and system performance for two basic types of communication services: Trunking and Customer Premise Services.

Present planning is directed toward a single demonstration flight system using an existing spacecraft bus with minimum modifications, with an objective to limit the launch vehicle to SUSS-A as an upper bound.

2.1 TRUNKING REQUIREMENTS

The basic requirements for the baseline trunking system, from the SOW, are:

- Provide SS-TDMA and optionally, FDMA transmission capabilities (simultaneous operation not required).
- Support T3/T4 user interface in SS-TDMA and FDMA mode.
- Capable of achieving high nodal availability (0.9999) using diversity earth stations and combinations of fixed margin and adaptive compensation techniques.
- Capability of SS-TDMA between four primary nodes and two alternate nodes, although only four beams may be operated at one time.

2.2 CPS REQUIREMENTS

Basic requirements for the baseline CPS system, from the cited SOW are:

- Provide TDMA transmission capability with nominal burst rates of 30/120 MBPS on the uplink and 240 MBPS on the downlink.
- Provide on-board baseband switching/routing capability.
- Provide maximum coverage using two scanning beams.
- Capable of achieving a 0.999 link availability with a combination of fixed margin and adaptive compensation techniques.
- Low cost user terminals.
- Capable of supporting user rates from 64 KBPS - 6.3 MBPS.

2.3 GENERAL CONTEXT AND COMMENTS ON BASIC SYSTEM ISSUES

The concepts provided by the two contractors satisfy the minimum requirements set forth in the Statement of Work. Although the concepts are well conceived, there are no significant variations between the concepts proposed, or significant departures from the SOW, by Hughes and RCA insofar as system configuration and throughput capacity are concerned. In comparison to previous design concepts presented by Hughes, the current concepts are more in line with the Statement of Work. RCA has furnished somewhat more detail and analysis of various aspects of their previous system design.

The space segment configuration and its capabilities proposed by the contractors are chosen to be compatible with the launch vehicle required to deliver the payload into orbit. The significant issues to be addressed in the demonstration flight are:

- Antenna subsystem and beam characteristics,
- Network synchronization and timing,
- Baseband processor,
- Master Control Station,
- Technology experiment,
- Earth station interface.

In view of the fact that the present effort is toward an evolutionary flight system with cost and launch vehicle constraints, it is essential that the concepts proposed by contractors be demonstrated to a high confidence level which verifies a smooth transition from a demonstration system to a fully operational system. Based on Western Union's perception of operational system requirements, the following demonstration system considerations are not addressed adequately and require further investigation:

- Frequency reuse,
- Antenna subsystem and beam topology,
- Link availability,
- Synchronization and timing,
- Terrestrial interface,

- o Consideration of existing and projected traffic requirements and its impact on space segment design.

In Western Union's Task 3 report to NASA, various aspects of system consideration have been discussed in detail in Section V, "System Considerations." It is Western Union's belief that in order to verify the transition from a demonstration satellite system to an operational system, the topical studies and analysis discussed in Section V of Task 3 also apply to the system designs proposed under Task 5.

A brief description of the significant features is given below.

- o Hughes has proposed both TDMA and FDMA transmission modes for trunking on a non-simultaneous basis. The primary and secondary nodes for either transmission are the same. The transmission data rate is 256 MBPS in both transmission modes. The FDMA transmission multiplexing and demultiplexing is done at RF. The CPS is provided via the baseband processor. There is no cross-connect between the baseband processor and the TDMA switch. The transponder can be configured to operate either in a CPS or trunking mode non-simultaneously. The trunking and CPS operational concepts suggested by RCA are similar to the Hughes' concept. RCA has provision for FDM/FDMA operation using ground adaptive power control utilizing the available trunking and CPS hardware on the spacecraft. RCA's FDMA operation is for CPS whereas Hughes' is for trunking operation.

- o The availability summary by RCA for a BER of 10^{-6} indicates that an availability of 0.9999 for trunking is not satisfied in rain zone E. For CPS an availability of 0.999 is met only in rain zone F with a 9.6 db FEC gain. Details of availability and link analysis are given in the RCA report dated April 23, 1981.

- The RCA communication payload has essentially the same capabilities as Hughes insofar as the throughput for trunking and CPS operation is concerned. Hughes has an FDMA capability for trunking at 256 MBPS where RCA has FDM/FDMA capability for CPS operation at 32 MBPS. By a suitable reconfiguration of the IF switch it is conceivable to have a limited FDMA operation in the RCA design. Furthermore, with essentially the same capability, RCA has a much lighter bus with a SUSS-D launch capability, compared to the LEASAT bus proposed by Hughes which requires a SUSS-A launch vehicle. Both the RCA and Hughes satellite designs have a four year operational design life.

- Hughes met the specified 18.0 db and 8.0 db uplink and downlink margins respectively for trunking. The 18.0 db uplink margin is provided by a 500 Watt TWT at the ground station. Since a large clear weather margin is not essential, adaptive power control should be considered. This will result in increased reliability of the earth station TWT amplifiers. RCA has used two 200 Watt TWTA in parallel to provide the specified rain margin. An adaptive power control implementation at the ground station will permit operation of the TWTA in a backed-off mode thereby enhancing its reliability.

- RCA has not investigated in detail the synchronization aspects of the system.

- Both Hughes and RCA have not investigated instrumentation to monitor various parameters and the impact of such instrumentation on the weight, power and cost of the satellite.

- RCA has made reference to the hardware being developed by other contractors and makes use of the "best case" specified parameters under consideration, and it is there fore, an optimistic design. Furthermore, interface problems with the equipment of various vendors are not addressed. However, it must be noted that only RCA has made an effort to co-ordinate and utilize the hardware being developed by other major aerospace contractors.

SECTION III
REVIEW OF HUGHES AND RCA DESIGN CONCEPTS

A brief review of the two contractors design report is summarized in this section.

3.1 HUGHES

Under this task Hughes has proposed the following two concepts.

3.1.1 Option 1

This concept uses a 3.0 meter antenna for both receive and transmit beams. For trunking operation the antenna generates six beams pointed toward Los Angeles, Cleveland, New York or Washington and Washington D.C. or Tampa. Only four of the six beams are active at any one time. The peak gain of the antenna is 56.1 db and 53.1 db for receive and transmit respectively. With edge losses of 5.1 db and 5.6 db, the net gains for receive and transmit beams are 51.0 db and 47.5 db, respectively. Since the receive beam width is about two-thirds of the transmit beamwidth, more than twice the number of receive beams with respect to transmit beams are required to provide the same coverage. The New York and Washington D.C. beams are frequency isolated. The Los Angeles and Cleveland beams are isolated from each other and others by polarization and/or spatial isolation. The Option 2 frequency plan utilizes the available spectrum more efficiently using frequency reuse by virtue of spatial and polarization isolation.

The TDMA transmission rate for trunking operation is 256 MBPS per beam. Complete interconnectivity is provided by 6x4 (six input - four output) IF switch. Two redundant paths are provided to by-pass failed cross-point switches. The transmitter is driven by a 40 Watt TWT. An 8 Watt Solid State Power Amplifier (SSPA) provides back-up for the TWT for clear weather operation only. The microwave subsystem consists of two sets of identical units. One set is used for trunking service. The other set can be used for either scanning beam or trunk service by activating switches directly preceding and following the IF switch matrix. Three for two redundancy is used for all units containing active devices except for the IF switch matrix which is internally redundant. The antenna has monopulse tracking for high antenna pointing accuracy.

The ground station antenna size for trunking is five meter with spatial diversity and the transmitter size is 500 watts. The uplink and downlink margins exceed the required 18 db and 8 db respectively.

CPS operation is provided by single independently scanned uplink beam and downlink beams. In the CPS mode, the New York, Washington D.C. and Cleveland beams are also covered with the CPS scanning beams. The signals after down conversion are routed to the baseband processor where the signals are demodulated, stored and forwarded. If the uplink signal from a particular CPS station is forward error coded (FEC) due to rain, the signal is decoded by the BBP decoder. Downlink signals to stations suffering severe rain attenuation are FEC encoded in the baseband processor. The 128 MBPS multiplexed data stream is modulated on an IF carrier, upconverted, amplified in a 40 watt TWT and transmitted downlink. Since simultaneous operation of trunking and CPS service is not required, the same frequency plan is used for both.

The ground station antenna size is three meters and the HPA size is 7 watts. The required 15 db rain margin is provided by 7.6 db of power control at the ground station and a 7.4 db FEC improvement.

The changes incorporated in the antenna subsystem as compared to the baseline, result in a significant reduction of antenna weight. These changes are as follows:

1. Scanning beams and the beam forming network are reduced from two to one for both transmit and receive.
2. Receive low-speed configuration switches are reduced from six to five.
3. Transmit low-speed reconfiguration switches are reduced from seven to six.
4. CPS receive feed horns are cut from 29 to 16.
5. CPS transmit feed horns are reduced from 15 to 10.
6. BFN pre-amplifiers are reduced from 32 to 19.

7. High speed switches for the receive CPS beam scanning reduced from 26 to 14.

8. High speed switches for the transmit CPS beam scanning cut from 12 to 8.

3.1.2 Option 2

Compared to Option 1, this configuration includes the capability for a four by four beam FDMA routing and two scanning beams for receive; and two scanning beams for transmit, each with independent scanning capability. The nodes for FDMA transmission are the same as those for TDMA transmission. Multiplexing and demultiplexing is done at RF and full connectivity is provided by channelization filters. The outputs of the multiplexers are routed directly to the TWTA or SSPA for downlink transmission. Since the receive beam width is about two-thirds of the transmit beam, more than twice the number of receive beams as compared to transmit beams are required to provide the same coverage. Each scanning beam provides coverage for one sector. Each sector covers approximately 10% of the CONUS. Sector 1 scanning beam coverage includes spots at Seattle, New York and Washington D.C. Sector 2 scanning beam coverage includes spots at Cleveland, Denver and San Francisco. The scanning beams are orthogonally polarized.

Two types of ground stations are used in this configuration; five meter antennas for trunking and large CPS (128 MBPS) stations, and three meter antenna for small (32 MBPS) CPS station. The ground station HPA for the trunking station is 500 watts, 10 watts for large CPS station and 7 watt for small CPS station. The uplink rain margin of 15 db is provided by a 7.6 db power boost at the ground station and a 7.4 db FEC improvement. With a 40 watt spacecraft transmitter, the margin for five and three meter CPS stations is 12.9 db and 8.4 db, respectively.

3.2 RCA

Under this task RCA has proposed the following two concepts.

3.2.1 Option 1

The antenna subsystem used by RCA in this conceptual design is the same as that proposed by TRW and Ford. Both antenna subsystems are in agreement with the baseline requirements. There are four primary nodes and two alterate nodes. The nodes are Los Angeles, Cleveland, New York or Tampa and Washington D.C. or Houston. Connectivity among the nodes is provided by a 4x4 TDMA IF switch matrix. CPS coverage is provided by a single scan sector beam with contiguous coverage (10% CONUS) plus three other spot beam locations. The routing, coding/decoding and store/forward is provided by the baseband processor being developed by Motorola.

The trunking transmission rate is 256 MBPS. The CPS transmission rate for TDMA is either four channels at 30 MBPS or one 120 MBPS. The downlink transmission rate is 240 MBPS. For CPS transmission the system provides two 30 MBPS FDM/TDMA channels on uplink and one 120 MBPS channel on downlink.

The diversity ground station antenna for trunking service is five meters using a 400 watt TWTA. The ground station antenna size for CPS terminals is five meters for 120 MBPS stations and three meters for 30 MBPS stations. The HPA size for both types of terminals is 200 watts.

3.2.2 Option 2

The antenna subsystem for this option is also the same as developed by TRW. This option also includes 4 x 4 beam FDMA routing and channelization assembly for trunking. The transponder can be configured either in FDMA or TDMA mode at any one time. The transmission data rates remain same as in option 1.

SECTION IV
EXPERIMENT PLANS

4.1 CAPABILITIES

Hughes and RCA have each proposed two design concepts. Each design concept can provide transmission system capabilities to conduct most of the important service, technology and combined service/technology experiments identified in Sections 4.2, 4.3 and 4.4.

4.2 TECHNOLOGY EXPERIMENTS

The following set of experiments are necessary to demonstrate the critical technology of the 30/20 GHz communications subsystems.

PT-1 (Transponder Performance Evaluation)

The objective of the experiment is to determine transponder performance as a function of time in space environment and obtain fundamental data for further advancement of transponder components.

The satellite transponder and associated antennas form the primary portion of the communications subsystem on a communication satellite. Critical parameters to be measured include gain, phase noise introduced by frequency translation, delay, filter distortion effects caused by channelization filters, and interference for all transponder path configurations.

PT-2 (20 GHz TWT Transmitter Experiments)

The objective of the experiment is to demonstrate an efficient, multilevel 20 GHz TWT transmitter and evaluate its performance on-orbit. In the analysis of baseband distortion, it is important to understand the nonlinearity characteristics of the TWTA which is the primary contributor to transponder nonlinearity. These characteristics may be affected by switching from one mode to another or TWT input backoff in steps of 1 db by ground command.

PT-3 (Multiple Spot and Scanning Beam Antenna Evaluation) and
PT-15 (30/20 GHz Multiple Scanning Spot Beam Antenna)

These two experiments should be conducted as one experiment. The objective is to determine and evaluate beam pattern, gain stability and coupling and to develop antenna technology so that high gain and high capacity scanning beams can be fabricated.

This experiment is critical for the assessment of antenna design. Concern with scanning beam systems include capacity limitation, scanning losses, synchronization complexity, gain contour, and slope effects. Concerns with spot beam antennas include switching hardware complexity, to confirm the choice of the frequency/polarization plans, the isolation between fixed and scanning spots (when the scanning are steered through or near the fixed beams antennas) should be measured. Specific parameters to be measured include antenna gain, antenna pattern, polarization isolation, beam pointing, etc.

PT-4A (Impatt Solid State Transmitter)
PT-4B (GaAsFET Solid State Transmitter)

The objective is to determine communications performance, life and stability under space environment. Obtain fundamental data to guide future use of Impatt and GaAsFET microwave power devices.

Solid state microwave power devices, used in suitable power combining circuits are promising candidates for future efficient, reliable spaceborne transmitter applications.

PT-7 (IF Switch Matrix Performance Test)

The objective of this experiment is to evaluate the performance of the IF switch matrix in the operational environment.

The IF switch is one of the new technologies being developed by NASA. The critical design parameters, which must be tested with the switch at maximum reconfiguration rate, include connectivity, random switching, switching speed, beam isolation, etc. Reliability of the IF switch is a major concern. A self-test feature checking any in/out connection by ground command would be useful.

PT-9 (Baseband Processor (BBP) Evaluation)

The objective of this experiment is to establish the on-orbit characteristics of the BBP subsystem such as connectivity capabilities, FEC performance and its susceptibility to electrical, mechanical and radiational damage.

The Baseband Processor has been designed using several advanced technology developments. This necessitates the assessment of its characteristic, and its numerous functions on-orbit. The advanced technology developments include modulation technique, high speed baseband routing switch, modular distributed processing techniques, memory configuration and the special LSI design. Extensive tests should be conducted on the BBP functions within the satellite system architecture such as store-and-forward capacity and routing capability, isolation, redundancy capability (if used), FEC decoding (both hard and soft decision) and encoding, including bit rate reduction (if used), under varied conditions of SNR, BER, satellite positional stability, antenna pointing stability/accuracy and sync word lengths. A provision to bypass the BBP (or parts thereof) should be incorporated should an on-orbit failure require troubleshooting.

PT-16 (Synchronization)

The objective of this experiment is to demonstrate the feasibility of synchronizing satellite beam steering with earth station burst timing. This experiment is essential to evaluate the synchronization technique selected for the ground station network. Key areas of concern include the synchronization of burst assignments with the scanning beams, hardware and software function complexities, stability of synchronization subsystem, etc. If applicable both open-loop and closed-loop techniques should be evaluated.

PT-20 (Antenna Pointing Accuracy)

The objective of this experiment is to demonstrate the antenna pointing accuracy requirements of the spacecraft and the earth terminal. Monopulse feeds pointing toward one or more earth stations is required. It is important for maintaining synchronization and the communications link's performance that the antenna pointing accuracy should be compatible with the beam width. The effects of spacecraft pointing error on ground antenna tracking or pointing during normal operations and station-keeping maneuvers should be evaluated.

PT-21 (Interference Assessment)

The objective of this experiment is to determine the level of interference versus beam separation assuming frequency reuse. The levels of cochannel interference and cross-polarization isolation will directly affect the link's performance. The measurement of these two parameters when the number of beams is increased to about 20 beams will give an adequate assessment of the antenna sidelobe level and beam separation assuming frequency reuse. This experiment should be conducted during uniform and non-uniform loading of the beam.

4.3 OPERATING EXPERIMENTS

The following experiments are necessary to demonstrate commercial service applicability.

PS-1 (30/20 GHz Propagation Measurements) and PS-29 (Propagation Experiment)

The object is to measure the radio wave propagation effects and evaluate system performance on operating earth-space paths.

At 30/20 GHz, the troposphere has a significant effect on the carrier-to-noise ratio of a propagation wave. The reduction in carrier to noise ratio reduces the allowable data rate for a given bit error rate and the quality of transmission.

In the most severe cases, transmission outages will occur. Propagation measurements and studies are necessary to allow the prediction of outages with a high degree of certainty so that the means to reduce the frequency and durations of these outages can be developed. A 20 GHz beacon instead of 30 GHz beacon should be utilized for this experiment to avoid interference problems.

PS-10 (Bit Stability During Switching)

The objective of this experiment is to measure directly the effect of diversity switching relative to bit integrity.

Power efficient digital receivers generally require the existence of a digital clock synchronized to the received bit stream to control the integrate-and-dump or matched filter's sampling instants, or to control otherwise the timing of the output bit streams.

The received bit-transition time clock has some time jitter and frequency drift corresponding to the oscillator phase noise and path change velocity. The effect of diversity switching on bit integrity can be so severe that it causes multiplexers or switches in the data link to produce a totally corrupted bit pattern. These effects should be fully investigated.

PS-14 (System Synchronization Evaluation)
PS-24 (Synchronization Parameterization)

These two experiments should be conducted as one experiment. The objective is to evaluate the stability of the network synchronization as a function of time and SNR and to measure the time required for resynchronization after drop-out.

Synchronization tracking loop depends on several parameters, including the phase noise in the carrier induced by various oscillator short term stability, carrier tracking-loop dynamic, transient response and acquisition, performance requirements, and signal to noise ratio in the tracking loop.

Each synchronization tracking loop requires the use of some form of phased locked oscillator tracking loop. In addition to tracking the oscillator phase noise, the loop must also acquire the carrier in a reasonable acquisition time and operate over the required range of oscillator-frequency drifts. The implications of these effects on the performance of PSK or APSK modems should be considered since the detection is only partially coherent because of the imperfect carrier tracking caused by various loop noise effects.

Results of this experiment will determine the future synchronization schemes to be considered such as length of unique words, error threshold, and modulation techniques.

PS-25 (Diversity Operation)

The objective of this experiment is to determine the increased availability afforded through the use of diversity techniques within a limited region of coverage and to determine the optimum spacing required for best diversity improvement.

The significant path loss variations at 30/20 GHz due to rainfall necessitates the deployment of diversity arrangements. Space diversity is one arrangement that needs to be thoroughly evaluated in terms of switching and control techniques of traffic from one site to another without interruptions and the effects on synchronization, the relationship between separation distance, fade depth and diversity gain. This experiment is essential, since empirical data to substantiate the belief that there is nearly a db for db diversity gain improvement for cases where single site attenuation exceeds the 15-18 db range is not available.

PS-27 (Propagation Availability)

The objective of this experiment is to determine the service availability and individual and joint fade statistics.

The severity of rain attenuation in the 30/20 GHz band, particularly where high system availability is required, mandates that the system designer consider multiple techniques for improving system availability. These would include adaptive power control, adaptive FEC, space diversity earth station complexes, and location of the satellite within the domestic orbital arc. Experimental explorations of these and other techniques such as adaptive reduction of the transmission data rate and the reduction of the number of quantization bits for digital voice channel, are necessary for system design trade-off considerations.

PS-30 (User Acceptance)

The objective is to evaluate user acceptance of low cost communication versus moderate service availability.

Duration and time of occurrence of outage are important factors in determining the acceptability of low cost service. Requirements for minimum EIRP, minimum antenna size and narrowband communications (voice, facsimile, etc.) should be determined.

4.4 COMBINED OPERATION/TECHNOLOGY

The following experiments are necessary to demonstrate commercial service applicability and special technical capabilities that enhance system performance/availability.

PSAT-4 (Cophasing Parameterization)
PSAT-5 (Cophasing Stability Measurements)

The objective of the experiment is to determine the performance of cophasing as a function of the measurement time, the measurement format, and the signal-to-noise ratio of the system. To determine the stability of the phased array as a function of time.

The cophasing operation is the process of taking a set of array phase measurements and computing the deviations of the uplink and downlink beam from the intended directions and correcting for these deviations by updating the steering vectors associated with the phased array.

The required SNR's of the cophasing schemes are not known, nor are the measurement times and measurement format (e.g., one single measurement, or summed sequential measurement). These factors are interrelated. To obtain the data necessary for accurate design, a study of these relationships and array instabilities is required.

PSAT-6 (Low Bit Rate FDMA/TDMA)

The objective of this experiment is to evaluate network performance for low bit-rate (6.3 MBPS) FDMA/TDMA via the emergency service channels, link performance, adaptive FEC, service quality for voice, FAX, TTY and freeze-frame TV.

Low bit-rate FDMA/TDMA service could become a very important application of 30/20 GHz communications to low cost CPS type services. Spacecraft equipment complexity, network performance and link performance need to be evaluated and demonstrated.

PSAT-7 (Variable Bit-Rate SS-TDMA)

The objective of this experiment is to test network synchronization for wideband communication with adaptive bit-rate.

Improved availability can be obtained by adaptive reduction of the transmission data rate, providing an increased level of energy per bit for given available transmitter power conditions. This approach should be evaluated as part of system design trade-off consideration.

PSAT-8 (Trunking and CPS Experiments)

The objective is to develop quantitative end-to-end system performance data for trunking and CPS under various propagation conditions with and without the aid of adaptive compensation and to develop network operational control procedures.

It is necessary to evaluate the system performance in terms of system parameters such as TDMA acquisition/reacquisition time, carrier and bit timing, BER versus E/N_o performance, BER improvement with adaptive fade compensation, effects on system BER and synchronization due to station keeping, dynamic burst assignments, satellite switch reconfiguration, loss of primary reference bursts, and BER as function of load variations, intermodulation characteristics, BER as a function of TWT back-off and number of carriers and demonstrate the performance of a DAMA control system.

PSAT-11 (Adaptive Polarization)

The objective of this experiment is to develop statistical data on measured depolarization effects at 30/20 GHz as a function of rainfall statistics. To develop an adaptive polarization tracking subsystem and to evaluate its performance, particularly in heavy rain zones.

Rain depolarization is an important system and earth station design consideration, particularly in linearly polarized frequency reuse systems. Parameters to be measured include polarization shift relative to measured rain rates, BER with and without adaptive tracking, cross-polarization isolation and interference with and without adaptive tracking.

4.5 SUMMARY AND RECOMMENDATIONS

4.5.1 Hughes

The description of the experiments is very brief and methodology of performing the experiments is not given. It is mentioned, however, that most of the experiments will be conducted except the experiments which cannot be accommodated in the system, namely:

PS-4 (Above 40 GHz Propagation)
PS-23 (C-Band and Ku-Band Experiments)
PSAT-4, 5 (Cophasing Experiments)
PT-15 (30/20 GHz Multiple Scanning Spot Beam Antenna)
PT-6, 14, 17, 22 (Intersatellite Link)
PSAT-3 (Multilevel TWT Control)

For the reasons mentioned in the previous section, it is important to conduct several of these experiments such as PSAT-4, PSAT-5 and PSAT-15.

C-2

PS-4, PS-23, PT-6, PT-14, PT-17 and PT-22 cannot be accommodated in one flight system.

PSAT-3 experiment is not considered to be important since a control approach can be simulated during ground testing. It is expected, however, that the control method will be demonstrated as part of PT-2 experiment.

4.5.2 RCA Astro

A substantial number of experiments will not be accommodated in the RCA system. Several other experiments will be partially conducted. Evaluation techniques, methods and the means to be used in performing the experiments are not given, consequently, the meaning of "partially conducted" can neither be deduced from the RCA report, nor is it given.

For the reasons mentioned in Sections 4.2, 4.3 and 4.4, it is important to accommodate, PSAT-4, 5, 6 and to fully conduct PS-27, 29, 30, PSAT-11 and PT-15.

The rest of the experiment which will not be conducted are categorized as follows:

- PS-9 (FDMA/TDMA Operational Comparison)
  No simultaneous FDMA/TDMA trunking mode incorporated in NASA design concept.

- PS-4 (Above 40 GHz Propagation)
  Above 40 GHz bandwidth is not expected to be used beyond the year 2000, also the placement of beacons on the spacecraft may jeopardize the performance of other important experiments.

- PS-23 (C-Band Ku-Band Beacon Experiments)
  This experiment is not an objective of the NASA experimental system.

- PS-31 (30/20 GHz Propagation Phenomena)

- PS-33 (30/20 GHz Propagation Experiment)
  The objective of these experiments will be achieved by conducting PS-1, PS-29.

- PSAT-1 (A/G Communications)
  A separate frequency band should be allocated for A/G communication.

- PSAT-2 (Spread Spectrum Feasibility)
  Spread spectrum communications use a much wider bandwidth than that of the data information for transmission.

- PT-13 (Small Earth Terminal Dual Feed Experiment)
  Ku band is not part of this experimental system.

o	PT-6	(Intersatellite Experiments)
o	PT-14	These experiments require more than one
o	PT-17	spacecraft.
o	PT-20	

4.6 EXPERIMENTS PLANS MATRIX

The matrix on the following pages identifies the experiments presented by each contractor which can or cannot be supported by each communication subsystem as well as the identification of the important experiments.

The experiments are in three categories:

- Service Experiments
- Service and Technology Experiments
- Technology Experiments

For the service experiments the following types of experiments are shown in the matrix:

- o Marketable Services, Performance, Demand, User Acceptance
- o System Control Synchronization
- o Customer Premise Service Earth Stations
- o Propagation Experiments
- o Traffic Modeling Simulation
- o Enhancement of Link Availability.

The following types of experiments are shown in the matrix for the Service and Technology Experiments category:

- o Communications Service Experience
- o Enhancement of Link Availability

The following types of experiments are shown in the matrix for the Technology Experiments category:

- o Space Segment Experiments
- o Ground Segment Experiments
- o Transmission Impairments
- o System Performance and Monitoring
- o Acquisition Tracking and Synchronization
- o Intersatellite Link.

SERVICE EXPERIMENTS

EXPERIMENT TYPE	NO.	OBJECTIVE	RCA ASTRO		HUGHES	
			YES	NO	YES	NO
MARKETABLE SERVICES, PERFORMANCE, DEMAND, USER ACCEPTANCE						
GOAL:						
DEMONSTRATE APPLICABILITY TO A RANGE OF COMMERCIAL SERVICES.	PS-8	DEMONSTRATION OF VOICE, VIDEO AND DATA SERVICES	PARTIALLY		X	
EVALUATE COMPATIBILITY OF 30/20 GHz SYSTEM WITH EXISTING FACILITIES	PS-9	FDMA/TDMA OPERATIONAL CAMPARISON		X	X	
	PS-15	HEAVY ROUTE TRUNKING	X		X	
	PS-16	LONG HAUL S/C COMPATIBILITY	X		X	
	PS-18	SERVICE DEMAND - NON-DIVERSITY	PARTIALLY		X	
	PS-19	SERVICE DEMAND - DIVERSITY	PARTIALLY		X	
	PS-28	MARKET DEVELOPMENT	X		X	
	PS-30*	USER ACCEPTANCE		X	X	
	PS-34	TEST MARKET	PARTIALLY		X	

*IMPORTANT EXPERIMENTS

SERVICE EXPERIMENTS

EXPERIMENT TYPE	NO.	OBJECTIVE	RCA ASTRO		HUGHES	
			YES	NO	YES	NO
<u>SYSTEM CONTROL SYNCHRONIZATION</u>						
<u>GOAL</u>:						
EVALUATE PERFORMANCE AND EFFICIENCY OF CPS DAMA SYSTEM. EVALUATE NETWORK SYNCHRONIZATION CHARACTERISTICS AS FUNCTION OF SIGNAL QUALITY AND TIME.	PS-12	DEMAND ASSIGNMENT CONTROL FOR CPS	X		X	
	PS-14*	SYSTEM SYNCHRONIZATION EVALUATION	X		X	
	PS-24*	SYNCHRONIZATION PARAMETERIZATION	X		X	
<u>CUSTOMER PREMISE SERVICES (CPS) EARTH STATIONS</u>						
<u>GOAL</u>:						
RELIABILITY/PERFORMANCE LOW COST UNATTENDED CPS.	PS-11	CUSTOMER PREMISE STATION	X		X	
	PS-13	NARROW BAND FDMA SYSTEM	X		X	

*IMPORTANT EXPERIMENTS

SERVICE EXPERIMENTS

EXPERIMENT TYPE	NO.	OBJECTIVE	RCA ASTRO		HUGHES	
			YES	NO	YES	NO
<u>PROPAGATION EXPERIMENTS</u>						
<u>GOAL:</u>						
DEVELOP PRECIPITATION ATTENUATION STATISTICS AND MATHEMATICAL MODELS FOR ALL CONUS RAIN ZONES APPLICABLE TO THE DESIGN OF 30/20 GHz AND HIGHER FREQUENCY TRANSMISSION SYSTEMS.	PS-1*	30/20 GHz PROPAGATION MEASUREMENTS	X		X	
	PS-2	PROPAGATION CONSTRAINTS ON DIGITAL SYSTEMS	X		X	
QUANTITATIVELY EVALUATE THE IMPACT OF PRECIPITATION LOSSES AND EFFECTS ON SYSTEM AND SUBSYSTEM PERFORMANCE.	PS-3	PROPAGATION CONSTRAINTS ON SCANNING MBA SYSTEMS	X		X	
	PS-4	ABOVE 40 GHz PROPAGATION		X		X
	PS-23	C-BAND Ku-BAND BEACON		X		X
	PS-27*	PROPAGATION AVAILABILITY	PARTIALLY		X	
	PS-29*	PROPAGATION EXPERIMENT	PARTIALLY		X	
	PS-31	30/20 GHz PROPAGATION PHENOMENA		X	X	
	PS-32	SYSTEM IMPACT OF 30/20 GHz	PARTIALLY		X	
	PS-33	30/20 GHz PROPAGATION EXPERIMENT		X	X	

*IMPORTANT EXPERIMENTS

SERVICE EXPERIMENTS

EXPERIMENT TYPE	NO.	OBJECTIVE	RCA ASTRO		HUGHES	
			YES	NO	YES	NO
<u>TRAFFIC MODELLING SIMULATION</u>						
<u>GOAL</u>:						
DETERMINE TRAFFIC FLOW IN NETWORK MODELS. DYNAMICALLY ALLOCATE RESOURCES ACCORDING TO DEMANDS.	PS-20	DYNAMIC TRAFFIC MODEL-TRUNKING	PARTIALLY		X	
	PS-21	DYNAMIC TRAFFIC MODEL-CPS	PARTIALLY		X	
	PS-22	DYNAMIC TRAFFIC MODEL-COMBINED	PARTIALLY		X	
<u>ENHANCEMENT OF LINK AVAILABILITY</u>						
<u>GOAL</u>:						
EVALUATE 30/20 GHz AVAILABILITY AND PERFORMANCE IMPROVEMENTS ACHIEVABLE WITH SPACE DIVERSITY EARTH STATIONS AND ADAPTIVE LINK POWER CONTROL TECHNIQUES.	PS-10*	BIT STABILITY DURING SWITCHING	X		X	
	PS-17	LONG HAUL SPACE DIVERSITY	X		X	
	PS-25*	DIVERSITY OPERATION	X		X	
	PS-26	LINK POWER CONTROL	X		X	

*IMPORTANT EXPERIMENTS

SERVICE AND TECHNOLOGY EXPERIMENTS

EXPERIMENT TYPE	NO.	OBJECTIVE	RCA ASTRO		HUGHES	
			YES	NO	YES	NO
COMMUNICATIONS SERVICE EXPERIMENTS						
GOAL:						
QUANTITATIVE SYSTEM PERFORMANCE DATE FOR SERVICE APPLICATIONS, NEW TECHNOLOGIES AND DESIGN FEATURES.	PSAT-1	AIR TO GROUND COMMUNICATIONS		X	X	
	PSAT-2	SPREAD SPECTRUM FEASIBILITY		X	X	
	PSAT-4*	COPHASING PARAMETERIZATION		X		X
	PSAT-5*	COPHASING STABILITY MEASUREMENTS		X		X
	PSAT-6*	LOW BIT RATE FDMA/TDMA		X	X	
	PSAT-8*	TRUNKING AND CPS EXPERIMENTS	X		X	
ENHANCEMENT OF LINK AVAILABILITY						
GOAL:						
EVALUATE ADAPTIVE RAIN COMPENSATION TECHNIQUES TO ENHANCE LINK AVAILABILITY FOR THE TRUNKING AND CPS SYSTEMS	PSAT-3	MULTILEVEL TWT CONTROL	IF SELECTED			X
	PSAT-7*	VARIABLE BIT RATE SS-TDMA	X		X	
	PSAT-9	SPACE DIVERSITY EXPERIMENT	X		X	
	PSAT-10	ADAPTIVE FADE COMPENSATION	X		X	
	PSAT-11*	ADAPTIVE POLARIZATION	PARTIALLY		X	

*IMPORTANT EXPERIMENTS

TECHNOLOGY EXPERIMENTS

EXPERIMENT TYPE	NO.	OBJECTIVE	RCA ASTRO		HUGHES	
			YES	NO	YES	NO
SPACE SEGMENT EXPERIMENTS						
GOAL:						
EVALUATE PERFORMANCE AND RELIABILITY OF SPECIFIC TECHNOLOGIES	PT-1*	TRANSPONDER PERFORMANCE EVALUATION	X		X	
	PT-2*	20 GHz TWT TRANSMITTER EXPERIMENTS	X		X	
	PT-3*	MULTIPLE SPOT AND SCANNING BEAM ANTENNA EVALUATION	X		X	
	PT-4A*	IMPATT SOLID STATE TRANSMITTER		X		
	PT-4B*	GaASFET SOLID STATE TRANSMITTER	PARTIALLY		X	
	PT-7*	IF SWITCH MATRIX PERFORMANCE TEST	X		X	
	PT-9*	BASEBAND PROCESSOR EVALUATION	X		X	
	PT-15*	30/20 GHz MULTIPLE SCANNING SPOT BEAM ANTENNA	PARTIALLY		X	
GROUND SEGMENT EXPERIMENTS						
GOAL:						
EVALUATE PERFORMANCE TO OPTIMIZE GROUND SEGMENT PERFORMANCE AND FLEXIBILITY	PT-13	SMALL EARTH STATION DUAL FEED EXPERIMENT		X	X	
	PT-19	GROUND TERMINAL TECHNOLOGY	X		X	

*IMPORTANT EXPERIMENTS

TECHNOLOGY EXPERIMENT

EXPERIMENT TYPE	NO.	OBJECTIVE	RCA ASTRO		HUGHES	
			YES	NO	YES	NO
TRANSMISSION IMPAIRMENTS						
GOAL:						
EVALUATE INTERFERENCE THAT ARISES AS A FUNCTION OF BEAM SEPARATION AND MULTI-CHANNEL (FDMA) LOADING OF TRANSPONDER CHANNEL.	PT-11	CHANNEL INTERFERENCE EXPERIMENT	X		X	
	PT-21*	INTERFERENCE ASSESSMENT	X		X	
	PT-24	MULTIPLE CARRIERS PER AMPLIFIER	X		X	
SYSTEM PERFORMANCE AND MONITORING						
GOAL:						
EVALUATE PERFORMANCE OF THE DEMONSTRATION SYSTEM, DESIGN APPROACHES AND CONSTRAINTS. MONITORING AND NETWORK CONTROL OF ADAPTIVE RAIN COMPENSATION SUBSYSTEMS.	PT-12	BASEBAND PROCESSOR ERROR DETECTION AND CORRECTION	X		X	
	PT-18	FADE CONTROL TECHNIQUES	X		X	
	PT-23	NETWORK LINK SYSTEM MONITORING	X		X	
	PT-26	PRELAUNCH SIMULATION AND TESTS	X		X	
	PT-27	FUNDAMENTAL FLIGHT SYSTEMS TESTS	X		X	
	PT-28	TECHNOLOGY EXPERIMENTS	X		X	

*IMPORTANT EXPERIMENTS

TECHNOLOGY EXPERIMENTS

EXPERIMENT TYPE	NO.	OBJECTIVE	RCA ASTRO		HUGHES	
			YES	NO	YES	NO
ACQUISITION TRACKING AND SYNCHRONIZATION						
GOAL:						
EVALUATE BEAM ACQUISITION TRACKING AND TDMA SYNCHRONIZATION CONSIDERING SATELLITE STATION KEEPING ACCURACY WITH RESPECT TO CPS SCANNING BEAM.	PT-16*	SYNCHRONIZATION	X		X	
	PT-20*	ANTENNA POINTING ACCURACY	X		X	
	PT-25	BEAM ACQUISITION AND TRACKING	X		X	
INTERSATELLITE LINK						
GOAL:						
INTERSATELLITE LINKS CARRYING HIGH DATA RATE TRAFFIC	PT-6	INTERSATELLITE RELAY		X		X
	PT-14	INTERSATELLITE LINK		X		X
	PT-17	INTERSATELLITE LINK CAPABILITY		X		X
	PT-22	INTERSATELLITE LINK		X		X

*IMPORTANT EXPERIMENTS

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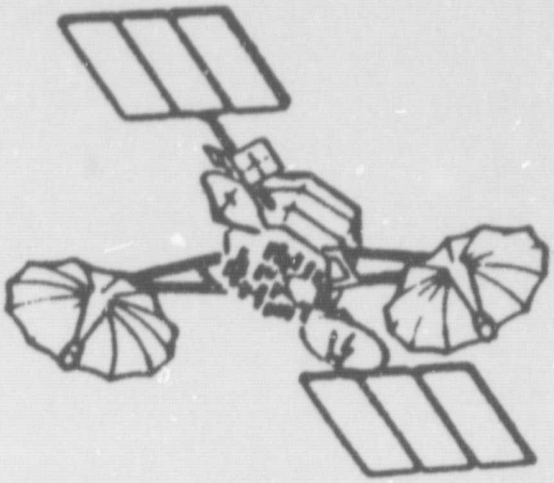

TASK 6
FINAL REPORT
PLANNING ASSISTANCE FOR THE 30/20 GHZ PROGRAM

REVIEW AND CRITIQUE OF THE TECHNOLOGY READINESS CONTRACTORS' EFFORT

NASA CONTRACT NO. NAS3-22461, TASK 6
LEWIS RESEARCH CENTER
21000 BROOKPARK ROAD
CLEVELAND, OHIO 44135

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THE WESTERN UNION TELEGRAPH COMPANY
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7916 WESTPARK DRIVE
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DATE: MAY 8, 1[illegible]
REVISED AUGUST 3, 1981

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TASK 6 FINAL REPORT
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TASK 6 FINAL REPORT

PLANNING ASSISTANCE FOR THE 30/20 GHZ PROGRAM

TECHNOLOGY CONTRACTORS DESIGN REPORTS

REVIEW - COMMENTS

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TASK REPORT

PLANNING ASSISTANCE FOR 30/20 GHZ COMMUNICATION PROGRAM

NASA CONTRACT NA3-22461, TASK 6

1.0 INTRODUCTION

Under the requirements of NASA Contract No. NAS3-22461, Task 6, Western Union was tasked to review and critique specific technology developments requirements and development approaches used by the technology contractors, as well as the development progress. The inputs to this task were the initial set of reports and presentations submitted to NASA in November of 1980 and additional reports and presentations submitted up to May 7, 1981.

Tecnnology readiness contracts have been awarded in five major areas, all elements of the spacecraft design. Each contract calls for a systems study and design effort and a "proof-of-concept" (POC) model which will demonstrate the transferability of the paper design to hardware. The five areas are:

- 30 GHz Low Noise Receivers
- 20 GHz Power Amplifiers
- Satellite Switched - Time Division Multiple Access Switches

- Baseband Processors
- Multi-Beam Antennas

Three sets of contracts were awarded in the 20 GHZ Power Amplifier area:

- GaAs FET Amplifiers
- Impatt Amplifiers
- TWT Amplifiers

In addition to the review of the contractors efforts, we have added general discussions of two factors we consider to be of great importance to overall systems design and to the tasks given the NASA subcontractors, namely system availability and signal impairments.

The contractors efforts have been judged based on three sets of references:

- The NASA Contract Statements of Work received by each.
- The Western Union Task II report on Functional Requirements.
- The output of other NASA 30/20 GHZ program contracts in the systems area.

as well as on more general communication system requirements.

Detailed reviews and critiques are given in the individual sections, but a few general comments can be made. Firstly, there seems to have been insufficient attention paid to the overall system design and allocation of performance to various system elements, and to obtaining information on the range of system element performance necessary to make an optimum allocation. Secondly, little attention has been paid to defining and assuring the system element reliability needed to build a spacecraft with a ten year design life. WU feels that much more effort is needed in these two areas if a successful 30/20 GHz program is to be realized.

2.0 LOW NOISE RECEIVERS

2.1 REQUIREMENTS

The performance of a receiving system is measured by its G/T, the ratio of antenna gain to system noise temperature. Since antenna gain (or size) is limited by the requirement for off-axis scan capability and physical problems in launching and deployment, the sole option available to improve the satellite G/T is to reduce the system noise temperature (assuming the antenna size constraint has been reached). With a reasonably high gain, low noise receiver (LNR), the major contributors to system noise are the LNR and the antenna. For a spacecraft antenna pointing at the earth, the antenna noise temperature is 290K, independent of antenna design, so that the only variable is the LNR noise figure. The general expression for G/T can be written as:

$$G/(T_A + T_R)$$

where T_A = antenna system noise temperature (= 290 K)

T_R = receiver noise temprature

and second order terms due to elements behind the receiver have been neglected. This can be rewritten as:

$$G/T_A(1 + \frac{T_R}{T_A})$$

or in dB:

$$G - T_A - (1 + \frac{T_R}{T_A})$$

With T_A = 290 K, the third term becomes the formula for noise figure (N.F.) of the receiver, so that the expression becomes (in dB):

$$G - T_A - N.F.$$

Thus improvements in receiver noise figure improve G/T dB for dB, and correspondingly improve system performance. Figure 2.1 is a plot of G/T vs T_R and N.F., showing the linear relationship for the latter. Antenna gain has been assumed to be 56 dB. The curves cover the N.F. range from 8 dB (present state of the art) to 0 dB, which represents an ideal noiseless receiver.

The spacecraft G/T determines the ground station EIRP needed to achieve acceptable performance and thus the ground antenna size and power amplifier output level. Since there is only one spacecraft and many ground stations (especially for CPS service) it is normally advantageous to maximize G/T as a step toward minimizing over all system cost.

One of the major objectives of the NASA 30/20 GHz program is to develop technology applicable to an operational system in the 1990-2000 time frame. In order to develop specifications for such a system, the system designers must, among many other tasks, make tradeoffs

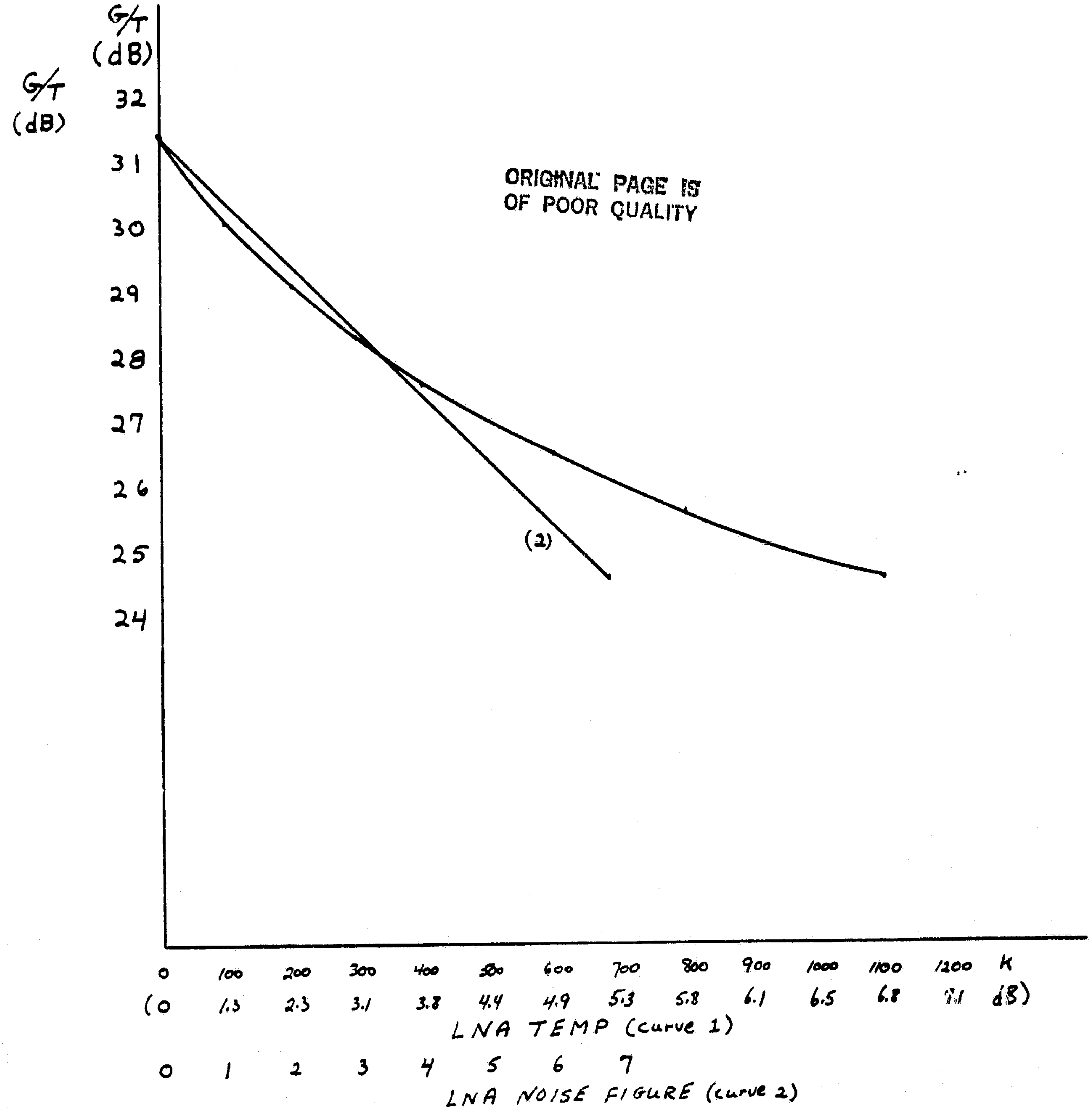

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Figure 2.1
G/T vs LNA NOISE TEMP & NOISE FIGURE

between spacecraft performance and ground station performance to arrive at an optimum sytem. In the particular case of the LNR, the designer will need a set of hardware designs covering a range of noise temperatures from 1000 K to perhaps 100 K, with cost, size, power, weight, reliability, etc. figures for each, from which the appropriate design can be selected. An important objective that should be incorporated in the NASA technology readiness program is to develop the design trade-off alternatives.

2.2 TECHNOLOGY CONTRACTS

2.2.1 General

The NASA specification for a 30 GHz Low Noise Receiver (PR188666) calls for three designs, one based on 1982 technology, aimed at a 1986 demonstration flight and resulting in a Proof-of-Concept (POC) Model, and two based on 1987 technology.

The same set of design and performance specifications apply to all three LNR designs. Thus it is unlikely that a range of design alternatives will be available to carry out system design trade-offs between the ground and space segments.

2.2.2 Electrical and RF Performance Requirements

The electrical and RF performance requirements from the Statement of Work are presented in the following list:

Input RF Band: The input RF band shall be from 27.5 to 30.0 GHz

Output Intermediate Frequency (IF): Shall be in the range of 3.0 to 6.0 GHz.

Noise Figure: The noise figure of the receiver shall be 5dB or less over the 27.5 to 30.0 GHz.

RF to IF Gain: The RF to IF gain shall be a minimum of 20 dB over the 2.5 GHz bandwidth.

In-Band Overdrive: Up to -10dBm at input with no permanent degradation in performance.

Gain Variation: Shall be ±1.0dB maximum over the bandwidth.

Gain Slope: Shall be ±0.5dB maximum per 10 MHz.

VSWR (input): 1.25 max

VSWR (output): 1.8 max

Group Delay per 100 MHz: Parabolic - ± 0.1 ns/MHz^2 max., Ripple 5 ns P-P max.

Image Rejection: Image rejection shall be a minimum of 15dB at the IF output port.

AM-PM Conversion: 1.0°/dB for input carriers up to -70 dBm

DC Power: The total operational DC power required by the POC receiver shall be a minimum consistent with achieving the performance requirements. The POC receiver input voltage levels and regulation requirements shall be ±28 vdc, ±10%.

2.2.3 Other Requirements

NASA has called for a POC design which

1. can be implemented with components available within the 1981-1983 time period, and

2. possesses the potential for future significant improvements in performance, etc.

It is not clear if these requirements are compatible or which should take precedence.

2.3 CONTRACTOR RESPONSES

2.3.1 General

Two contracts were awarded:

1. LNR Communications

2. ITT Defense Communications

At this time only the Task I (Paragraph 2.1.2) reports are available from both vendors - these cover the design for the POC model. Task II (1987 Technology) has been reported upon by LNR. Both contractors have elected to use an image enhanced mixer/intermediate frequency amplifier (IEM/IFA) design to meet the requirements quoted above. Both designs will use GaAs Schottky Barrier mixer diodes and a GaAs FET IF amplifier. There are differences in the local oscillator design approaches.

2.3.2 Performance Summary

The projected performance of the two designs is shown in Table 2.1. The ITT design shows equal or better performance than the LNR design in all categories except gain.

PARAMETER	SPECIFICATION	Inc. POC MODEL 30 GHz RECEIVER DESIGN	ITT POC MODEL 30 GHz RECEIVER DESIGN
Input RF Band	27.5-30 GHz	27.5-30 GHz	27.5-30 GHz
Output IF	2.5 GHz Bandwidth In range 3.0-8.0 GHz	3.7-6.2 GHz	2.3-4.8 GHz
Noise Figure	5dB Max	4.8 dB	<5.0 dB
RF to IF Gain	20 dB Min	25 dB	20.0 dB
In-Band Overdrive	-10 dBm Input	-10 dB	0 dBm
Gain Variation	±1.0 dB Max.	±1.0 dB Max.	±0.75 dB
Gain Slope	±0.5 dB Max/10 MHz	±0.2 dB Max/10 MHz	±0.2 dB/10 MHz
VSWR Input	1.25 Max.	1.25:1	1.2:1
VSWR Output	1.80 Max.	1.6:1	1.5:1
Group Delay	±0.1 ns/MHz^2 Max. 5 ns. p.p Max. Rip.	±0.1 ns/MHz^2 Max. 5 ns. p.p. Max. Rip.	±0.03 ns/MHz^2 2 ns. p.p. Max. Rip.
Image Rejection	15 dB Min.	20 dB	30 dB
AM-PM Conversion	1.0°/dB for Input to -70 dBm	1.0°/dB for Input to -70 dBm	0.12°/dB
DC Power	±28 VDC ±10%	28VDC ±10% 10 Watts	28VDC 2 Watts + Conversion losses
Weight	Not Specified	3.2 lbs.	Not Given
Size	Not Specified	6x6.5x2.5 in. 97.5 in.^{3}	7.1x5.15x.75 in. <27.5 in^3(+PPU)
MTBF	Not Specified	Not Given	1.27x10^6 Hrs.

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TABLE 2.1
LOW NOISE RECEIVER COMPARISON

2.3.3 LNR Design

The LNR design uses a waveguide/TEM line mixer with dual GaAs Schottky diodes pumped directly at 23.8 GHz. The local oscillator consists of a 5.95 GHz VCO locked to a 500 MHz reference. A X4 multiplier is used to obtain the required 23.8 GHz output at 13.5 dBm. The IF amplifier will be designed by LNR using available GaAs FET's. The local oscillator must be locked to the spacecraft master oscillator to avoid frequency drift problems. Since low phase noise is required in the local oscillator to maintain low error rates in the demodulator, it is important that the basic local oscillator and the frequency locking circuits contribute as little noise as possible to the (presumably clean) output of the master oscillator. The LNR design assumes a 500 MHz reference and then uses both phase locked loop (PLL) and frequency multiplier techniques to obtain the required frequency. It is not stated whether the 500 MHz is obtainable directly from the master oscillator or whether preliminary multiplication is required. The relative merits of a PLL versus direct multiplication are not discussed nor are any specifications given for the local oscillator output. In view of the high power comsumption of the PLL, this is a serious oversight.

2.3.4 ITT Design

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The ITT design uses a waveguide mixer with a single GaAs Schottky Barrier diode. A X15 Multiplier chain is used to obtain the 25.2 GHz local oscillator from a 1.68 GHz input. The IF amplifier will be designed by ITT using specially designed GaAs FET's.

The design is compact and is projected to have good performance. As in the LNR report, the analysis of the local oscillator circuits is slighted. No specifications are given for local oscillator purity, and no justification is given for the choice of a direct multiplication scheme. The source of the 1.68 GHz reference is not stated, and no allowance is made for circuitry to tie this back to the spacecraft master oscillator.

Power conversion and performance monitoring are not discussed. Reliability is given as a .93348 probability of survival for 10 years. The use of this number is discussed further in Appendix A, but it should be noted that, even ignoring the reliability of any sensing/switchover circuits, the probability of a 10 year survival for a 1:1 redundant system is only .9956, and for 2:1 redundancy only .9997. ITT mentions a 30 GHz FET being designed for preamp use, although they did not mention plans for its use.

2.3.5 Discussion

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The image enhanced mixer configuration does not satisfy item (2) quoted in section II C above. Figure 2.2, extracted from the LNR report, shows the capabilities of the various front-end technologies. The IEM can be seen to barely achieve the 5 dB noise figure required by the specification, although both vendors claim to be able to improve on this figure. LNR's report concerning 1987 technology identifies a radiation cooled mixer design with a 3.2 dB NF, but the weight and volume of the radiation cooler would make this approach impractical. Even the GaAs FET amplifier mentioned as an alternate by both vendors does not seem to be capable of much better than 4 dB NF. It is recommended therefore that NASA support technology contracts to develop:

1. GaAs FET front-ends with 3.5 dB NF or better.
2. Paramps with 1.5 dB NF or better

to determine if such equipment will be practical in the 1990-2000 time frame. Further improvements beyond 1.5 dB NF will require cryogenic techniques which are not practical for spacecraft use.

With regard to other LNR parameters, neither contractor envisions problems in meeting or bettering the required

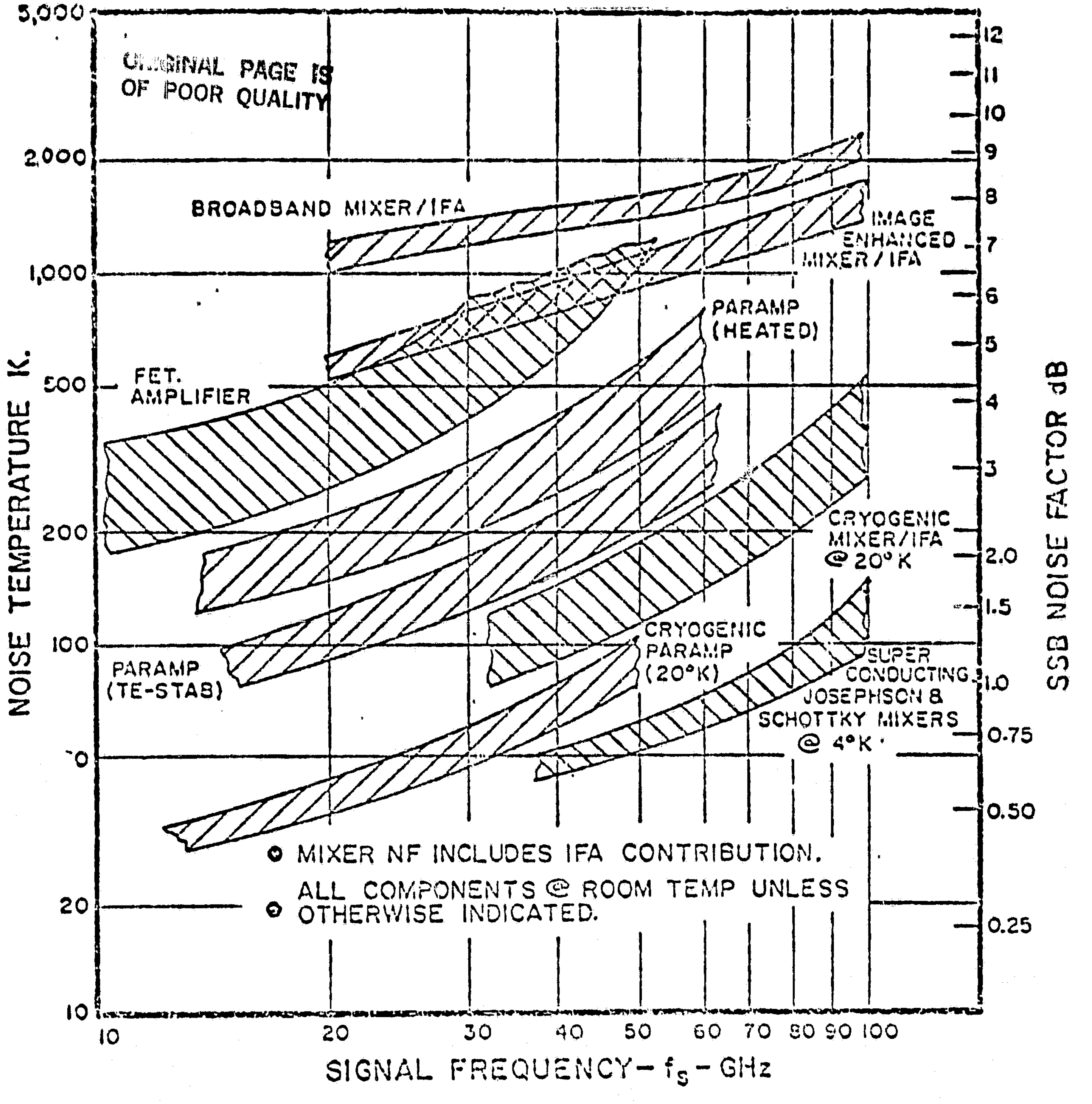

Fig. 2.2

CURRENT AND PROJECTED STATE OF THE ART NOISE TEMPERATURE COMPARISON OF VARIOUS MILLIMETER WAVE "FRONT-ENDS" performance. This subject is discussed at length in Appendix B, arriving at the conclusion that it is important to know the cost of achieving, falling short of, or improving any particular subsystem characteristic to allow an optimum allocation of impairments to each subsystem to minimize overall system cost. This information will not result from the contracts as presently defined. It is recommended that they be expanded to obtain such information.

It is difficult to judge the acceptability of the power and weight of the designs in the absence of a design for the operational satellite. However, the GE study of an SS-FDMA operational system assumed a LNR power of 60 mw. and a weight of 0.1 lbs. The differences between these numbers and the designs are startling.

3.0 POWER AMPLIFIERS

3.1 Requirements

There are three different kinds of spacecraft power amplifiers are under development for the NASA 30/20 GHz program, but they all serve the same functions in the overall system. It is therefore more convenient to combine the examinations of the three sets of designs and avoid much repetition.

The performance of a transmission system is measured by the Effective Isotropic Radiated Power (EIRP) which is determined primarily by the antenna gain and the power amplifier output. (In fact, it is simply the product of the two factors, if secondary losses are ignored). On the spacecraft, the maximum antenna size (and therefore gain) is limited by scan loss problems and deployment considerations. The required EIRP is determined by a link budget analysis considering minimum required received power, reasonable values for ground station G/T, propagation losses, etc. In addition, a higher EIRP may be needed during rain conditions, if that is the method selected to compensate for the effects of rain.

The WU Task II report showed link analyses based on a 4.1 meter spacecraft antenna and 5 meter or 3.5 meter ground station antennas for 512 Mbps trunking and 256 Mbps (downlink) CPS systems, respectively. After making suitable allowance for off-axis scan losses and variation in illumination over a given beam pattern, the Task II report shows a requirement for a downlink power of 10 Watts normal/75 watts in rain and 75 watts full time, respectively. High power is needed for CPS to allow the use of smaller antennas and non-diversity operation. Extra margin for rain operation is obtained in the CPS case by the use of forward error correction (FEC) coding. The W.U. Task II analysis was based on the Task I Systems studies and may be somewhat pessimistic as regards link degradation below theoretical. Nevertheless, it provides a fixed point of departure for analyzing subsystem performance. Since the required powers are derived from required energy per bit calculations, they scale directly with bit rate. This means that if more downlink beams are provided for the same total throughput, lower power amplifiers could be used for each beam. This would probably result in a weight and size penalty, as well as an increase in system complexity.

Scaling the WU Task II, CPS-TDMA analysis to CPS-FDMA, the required downlink power ranges from 3 watts for 10

Mbps terminals to 20 milliwatts for 64 kbps terminals. About 9 dB FEC processing gain will be required to operate during rain. (Rain Zone E is a special case - see WU Task II report).

Besides the basic characteristic of power output, many other parameters of a power amplifier are specified in the SOW (Par. 3.2.2). Each of these parameters is important to overall systems performance and parameter values are a function of the transmission mode and operating performance requirements. Without a detailed design analysis for say, a 512 Mbps TDMA System it is not clear that the parameter values specified are appropriate. However, the actual level of performance required can only be determined after a tradeoff analysis in which the generalized "cost" of meeting a particular specification is weighed against the "cost" of compensating for failure to meet it in another portion of the system (discussed in detail in appendix B). Typical examples of such tradeoffs are power output from the upconverter vs. power amplifier gain, gain deviation from flatness or group delay variations in the power amplifier vs. those in other subsystems, efficiency vs. cost of prime power and heat removal, reliability of a single amplifier vs. system reliability through redundancy, suppression of harmonics vs. output filtering or an increased system link budget allowance for spurious tones, etc.

3.2 TECHNOLOGY CONTRACTS

3.2.1 General

NASA has developed three specifications for 20 GHz power amplifiers.

1. 20 GHz GaAs FET Transmitter (PR 188664)

2. 20 GHz Impatt Transmitter (PR 188665)

3. 20 GHz TWT

    a. Auxiliary program to provide a power processing unit.

These contracts call for design and construction of a model amplifier using 1982 technology which can result in a flight qualified unit by 1986. There is no requirement for information as to projected performance in the 1990-2000 (operational) time frame, nor is there any requirement for the long range development efforts which will be required to have available operational satellite hardware designs.

3.2.2 SOW Specifications

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Table 3.1 shows a comparison of the SOW requirements of the three types of amplifiers.

3.3 CONTRACTOR RESPONSE

3.3.1 General

Two contracts each were awarded for GaAs FET and Impatt amplifiers, one was awarded for a TWT plus a support contract for a power unit suitable for the demonstration flight. At this time only the Task I (and a few Task II) reports (Transmitter Design) are available - actual construction efforts cannot yet be judged. Contracts were awarded as follows:

GaAs FET:	1)	Texas Instruments
	2)	TRW Defense and Space Syst.
Impatt:	1)	LNR Communications
	2)	TRW Defense and Space Syst.
TWT:		Hughes Electron Dynamics
TWT PPU:		TRW

3.3.2 Performance Summary

The projected performance of the contractor's designs is given in Tables 3.2, 3.3, and 3.4 for GaAs FET,

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TABLE 3.1

ELECTRICAL AND RF PERFORMANCE REQUIREMENTS

Parameter	GaAs FET	Impatt	TWT
RF Band (GHz)	17.7-20.2	19.7-20.2	17.7-21.2
Saturated Output Power (VSWR≤1.3) (watts)	6-7.5	≥20	Hi ≥25 (75 sat.) Lo ≥2.5 (7.5 sat.) (VSWR ≤1.5)
Noise Figure (dB)	≤25	≤25	≤30
RF Gain (at saturation)(dB)	30+1,-0	30±1	Hi: Not Given Lo: 20
In band over-drive (dB) (over normal drive)	≥5	≥5	Not Given
Gain Variation(dB)	≤0.5/500 MHz	≤ ±1	Not Given
Gain Slope (dB/MHz)	≤.15	≤.15	≤.15
Inp. and Outp. VSWR	≤1.4	≤1.3	≤1.5 (cold) ≤2.5 (hot)
Inp. and Outp. Imped. (ohms)	50 nom.	50 nom.	Not Given
Group Delay Variation (nsec p-p)	<0.5/500 MHz	≤0.5/50 MHz	≤0.5/1 GHz

TABLE 3.1 (Cont'd)

Parameter	GaAs FET	Impatt	TWT
Third Order Intermod. (dBc)			≤ -13 (Po + 5dB)
(at sat.)	≤ -20	≤ -15	≤ -19 (Po)
(3dB below sat.)	≤ -30	≤ -25	≤ -26 (Po -4dB)
AM/PM Conversion (°/dB)	≤ 2 (Po), ≤ 3 (Po + 3dB)	$\leq 5 \pm 1$	≤ 2 (Po), ≤ 4 (Po + 5dB)
Phase Linearity (°p-p)	≤ 5/500 MHz	≤ 10	≤ 5/1GHz
Harmonic Resp. at Sat. (dBc)	≤ -30	≤ -50	≤ -20
Spurious Resp. at Sat. (dBc)	≤ -60	≤ -60	≤ -80 29-33 GHz ≤ -50 15-29 GHz
Combined RF Effic. (%)	≤ 20	≤ 20	Not Available
DC Input (VDC)	$28 \pm 10\%$	$28 \pm 10\%$	Not Available
Baseplate Oper. Temp. (°C)	0-75	0-75	Not Available
Reliability	Not Given	Not Given	Not Available
Size	-------------------Not Given-----------------		
Weight	-------------------Not Given-----------------		

TABLE 3.2 - GaAs FET Amplifiers

Parameter	Specification	TI	TRW
Sat. Pwr. Outp. (Watts)	6-7.5	<8 (14)	7.5
N.F. (dB)	≤25	Not Given	<15
RF Gain (Sat.) (dB)	30 + 1,-0	≤33	31
Combined RF Effic. (%)	≥20	≤11 (15)	>15
Reliability	Not Given	Not Stated	Not Stated
Size (in)	"	8.75x8.25x6.96	4.5x6.3x9.8
		502 in.^{3}	278 in.^{3}
Weight (lbs)	"	Not Given	<11

Table 3.4 - TWT Amplifier (Tube + PPU)

Parameter	Specification	Hughes (Tube)	TRW (PPu)
RF Band	17.7 - 21.2	17.7 - 21.2	N/A
Sat. Pwr. Hi	75	≥77	N/A
(watts) Lo	7.5	≥7.2	N/A
RF Gain Hi (sat.)	Not Given	≥47	N/A
(dB) Lo (sat.)	20	≥16	N/A
Effic. (%) Hi	Not Available	40.3 (sat)	Not Given
Lo	Not Available	23.1 (sat)	Not Given
Reliability	Not Given	Not Given	Not Given
Size (in.)	Not Given	4x5x16	28x21x12
		320 in.^{3}	7056 in.^{3}
Weight (lbs.)	Not Given	8	Not Given

TABLE 3.3 - Impatt Amplifiers

Parameter	Specification	LNR	TRW
RF Band (GHz)	19.7-20.2	19.7-20.3	Not Given
Sat. Pwr. Outp. (Watts)	$\geq$20	22.5	20
Mode	Not Specified	Stable Amp.	I.L.O.
RF Gain (dB)	30 $\pm$ 1	39	30
AM/PM Conv. (°/dB)	$\leq$5 $\pm$ 1	$\leq$5.9	Not Given
Gain Compression (dB/dB)	Not Given	0.016	Not Given
N.F.	$\leq$25	$\leq$23	Not Given
Inp. and Outp. VSWR	<1.3	$\leq$1.25	Not Given
Gain Variation (dB)	<$\pm$1	1(p-p)	Not Given
Phase Linearity (°p-p)	<10	<10	Not Given
Gain Slope (dB/MHz)	<.15	<.1	Not Given
Group Delay Variation (nsec. p-p)	<0.5/MHz	<0.5/50MHz	Not Given
Spurious Resp. at Sat. (dBc)	<-60	<-50(harmonic) <-60(non-harm.)	Not Given
Comb. RF Effic. (%)	$\geq$20	$\geq$20.4*	20
Reliability	Not Given	Not Given	Not Given
Size (in)	Not Given	6.75x5.75x2.5 97 in.^{3}	8 x 4 x 3 96 in.^{3}
Weight (lbs)	Not Given	3.7	7
Power Input (Watts)	Not Given	120	Not Given
Baseplate Temp. Range(°C)	0-75	0.75	Not Given

*w/o Pwr. Conv. & Mon.

Impatt, and TWT amplifiers respectively. These tables are limited to only a few of the parameters specified in section 3.2.2 because the reports project performance for few, if any parameters except for power output.

As can be seen from Tables 3.2 and 3.3 efficiency is a serious problem with solid state power amplifiers. Only one of the four contracts is likely to result in a unit meeting its specification. Size varies considerably among the units, but in the absence of an operational spacecraft design, it is difficult to determine if this will pose a serious problem. None of the vendors has made any attempt to quantify reliability. This information is necessary to set redundancy requirements which can have significant impact on the spacecraft RF section design.

3.4 Discussion

Taking the WU Task II system link budget analysis as a basis (see sec. 3.1) none of the solid state power amplifiers would be suitable for either trunking (in rain) or CPS-TDMA use, even if they met their specifications. They might be useful for a CPS-FDMA system, if the number of amplifiers needed per beam is compatible with a reasonable RF design. The impatt amplifier suffers additionally from the problem of limited bandwidth (500 MHz). This would complicate the reconfigurability and redundancy switching capabilities of the spacecraft. The TWT on the other hand is capable of supplying the power needed for trunking (in rain) or CPS-TDMA use if it is run at saturation with one signal per TWT. For CPS-FDMA operation, the back-off needed to obtain adequate linearity for multicarrier operation would reduce available power output considerably. There is very little information available about the power processing unit, which is not being designed specifically for the 30/20 GHz program, but it appears to be very large compared to other power amplifier elements. Again it is difficult to determine if this will be a real problem.

Based on the above, it does not appear that the solid state amplifier programs would result in system components useful in an operational environment even if they were successful in meeting their specifications. It would seem appropriate therefore to redirect the contractors programs toward the development of devices and amplifiers with higher output power and extend the time frames of the programs involved. The TWT program on the other hand appears capable of resulting in a useful device, and should be continued. For all programs the required efforts should be expanded to obtain the type of tradeoff information required for the analysis described in Appendix B.

4.0 IF-SWITCH MATRIX

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4.1 REQUIREMENTS

Two parallel development efforts are under way to design and build a POC model for a 20x20 IF-Switch using 1982 technology, capable of expansion, in concept at least, to a 100x100 switch for operational systems in the 1990's. The 20x20 switch could accommodate a baseline TDMA Trunking traffic network, serving 10 to 18 of the largest nodes via fixed beams with 2 or more input/output ports reserved for Trunking to CPS cross-connect at the satellite. A minimum of 500 MHz bandwidth is required to accomodate the baseline network utilizing 500 Mbps up and downlink TDMA bursts. The SOW calls for 1000 MHz required (2500 MHz desired), and allows flexibility for CPS users co-located in the fixed beams or for assigning more than one 500 MHz channel to the largest capacity Trunking stations.

4.2 TECHNOLOGY CONTRACTS

Two contractors, General Electric and Ford (FACC) have been selected to design an IF Switch Matrix and to build a POC model. The primary specifications are:

Switch Size & Connectivity	20x20
Reconfiguration Rate	2 Microseconds
Switching Time	10 Nanoseconds
Bandwidth	1 GHz (2.5 GHz Design Goal)
Isolation between Output Ports	40 dB
Insertion Loss	15 dB Max.

In addition, the Statement-of-Work calls for preliminary design of both a 100x100 IF switch and a 100x100 baseband analog switch.

Both contractors have selected the coupled-crossbar technology approach to the IF switch implementation, which appears to provide good reliability and flexibility and eases design problems, such as impedance matching and dynamic range variations for all paths. Both have also selected GaAs FET transistors as the cross-point switching element to provide the required amplification, which are considered state-of-the-art devices, and both have recommended, for reliability, the use of one-for-one switching element redundancy (two GaAs FET's per crosspoint) plus wrap-around redundancy, i.e. (20 x N) x (20 x N), configurations where the N extra in/out ports can be reconfigured to replace a failed row or column. FACC has selected N=2, i.e. a 22x22 switch, to achieve a 10 year full 20x20 reliability of .9177. GE has selected N=5, i.e., a 25X25 switch to achieve a 10 year full 20X20 reliability of .97992.

These two numbers are based on different assumptions although the assumed crosspoint (and driver) reliabilities are similar. The higher number is more desirable, if the additional weight and power can be accommodated. The question of reliability is discussed in more detail in Appendix A.

4.3 DISCUSSIONS

4.3.1 Switching Speed

The SOW switching speed specification of 10 nanoseconds can be readily met. However, as FACC points out (p. 14 of their Interim Task 1 report), the total power required to provide standby current to the switch amplifiers which are in the off-state is 23.1W (78% of the total power required), but by increasing the allowable switching time to about 12 nanosec. (from 6 nanosec.) standby power can be reduced to zero. Thus it appears that relaxation of switching speed should be considered. The major system effect of switching time is to increase slightly the guard time required between the last station burst of one switch mode and the first burst of the following mode to prevent burst overlaps. For example, with 100 switch modes per frame the additional guard time would be 100x6 nanosec. = 0.6 usec., which is a small penalty in TDMA throughput efficiency.

Total guard time is essentially composed of network burst synchronization errors (due to uncertainty in instantaneous slant range) and burst preamble length for carrier and clock recovery, plus of course, switching time. At 250 Msps, preambles of at least 40 symbols will contribute some 160 nanoseconds. Thus even for an 18x18 trunking network, with only one earth station per frame, an allowance of, say, 20 nanoseconds for switch time will not appreciably degrade throughput efficiency; this appears to be a good trade-off for reducing prime power requirements.

4.3.2 Reconfiguration Time

The SOW requirement is 2 u-seconds between switching events, and can be met with a parallel control logic implementation. Thus, defining a "mode" as a unique switch configuration (all inputs defined to all outputs), the minimum mode length is 2 usec., and the maximum number of modes in a 1 milli-second frame is 500. The "Greedy Algorithm" states that (M^2-M) is the maximum number of modes required to program a frame to handle a 100% traffic demand. For M=20, this maximum is 400-20 = 380 modes per frame. In actual practice, however, good efficiency can be achieved with considerably fewer modes per frame. The minimum number, for full trunking network connectivity is 20 modes-per-frame. At any rate, the 2 u-second minimum mode length should not be relaxed, since it is required to maintain throughput efficiency for low rate (thin) trunking station interconnect, and also for "loop-back" modes so that stations may acquire burst synchronization.

It is recommended that the expected throughput efficiency, as a function of the number of modes per frame, be evaluated for several trunking network traffic demand matrices. The traffic model in the appendix of the Motorola Baseband Processor contains a typical network with a total of about 6 Gbps trunking demand. To this must be added the Trunking-to-CPS interconnect. Also, the "Greedy Algorithm", which is based upon all switch interconnects changing whenever a mode changes, should be modified slightly to account for the capability of the present designs to change only subsets of interconnects. More balanced traffic demands, where several low capacity beams are combined at the input and output ports of the IF switch should also be analyzed.

4.3.3 CPS Networks Using a TDMA IF Switch

A 20x20 IF-Switch concept could also be used for a limited type of medium-to-high capacity CPS TDMA network without a Baseband Processor. Presumably this network could operate independently of the trunking network. The bandwidth and burst rates would be reduced, tailored to the CPS stations' traffic, and it would use a separate frequency band to allow for CPS stations in the fixed-beam trunking areas and/or CPS-Trunking interconnect implemented at the trunking stations. Scanning beams, synchronized to the TDMA IF-Switch modes and/or fixed beams could be used. However, as the number of CPS terminals increases, the throughput efficiency could decrease rapidly due to the guard time required for multiple bursts per mode.

4.4 100X100 SWITCH

4.4.1 System Application

The Task II report from GE decribes tne design of a 100X100 (actually 96X96) IF switch and a similar baseband switch. These switches are similar in performance to the P.O.C. 20X20 IF switch. They would be used for CPS service, and to judge their utility the traffic model used in the Motorola Baseband Processor (BP) study has been employed. This model proposes a total BP throughput of about 4 Gbps and thus the 100X100 switch, which is assumed to replace BP in a TDMA system, will need to handle this much traffic. Assuming for simplicity an even distribution of traffic, each input would carry 40 Mbps of data in a serial TDMA stream. Actually the traffic model shows an 8:1 range of capacity among its beams (less than 100). Carrying this through to the present case will result in a bit rate of about 100 Mbps per beam. This must of course be increased to 150-200 Mbps to allow for guard bands, synchonization, etc., (for 50-75% efficiency) putting a strain on circuit design for small CPS stations. Alternately, multiple downlinks could be used in heavy traffic spots, but this increases both matrix size and the complexity of the switch control algorithm, as well as the number of transmitters and receivers needed in the spacecraft, and is thus of questionable practicality. A second constraint on terminal design will be set by the switch configuration rate of 2 u-sec. Since the CPS system must accommodate a single channel from one user to another and therefore from one beam to another, the burst length for a single channel should ideally also be 2 u-sec. At the cost of some inefficiency the burst length can be a submultiple of 2 u-sec., assuming that normally more than one burst is sent through any switch configuration.

A "standard" frame length is 1 millisec. or 64 bits from a standard 64 kbps voice channel. At 100 Mbps of data this results in a burst length of .64 u-sec., or about 3 bursts per switch state. This number can be changed by shortening the reconfiguration time, which will increase the cost and inefficiency (due to switching time) of the matrix, or by lengthening the frame, increasing the delay time and data storage costs in the ground terminals. A study is required to determine an optimum set of parameters. A second factor arguing in favor of a longer frame or a shorter reconfiguration time is the total number of switch states needed. With a 1 milisec. frame and a 2 u-sec. reconfiguration time, only 500 states are theoretically possible and in practice only 200-300 can be accommodated. It is not clear that this provides sufficient connectivity, and this, too, requires further study.

4.4.2 Switch Architecture

The GE report proposes an extension of the 20X20 switch architecture to the 100X100 case. While a 20X20 switch is small enough to make a single stage network optimum, this cannot be said for a 100X100 configuration. A basic 100X100 single stage network requires 10,000 crosspoints, the loss of any of which permanently isolates one input from one output. Thus survivability requires redundancy. A three stage 100X100 non-blocking network (such as a Clos network) requires less than 6000 crosspoints. More importantly, an inoperative crosspoint results only in a loss of the non-blocking feature of the switch, leaving many alternate paths between any input and output. In most potential configurations of the switch this will not be noticed. When blocking occurs, it will be possible to select the particular beam pair(s) denied service to insure minimum inpact on total throughput. While the control algorithms to accomplish this are more complicated than for a single stage matrix, they will be similar to those used in stored program control telephone switches. In addition, since they will be applied at the MCS, this will not impact spacecraft cost or complexity.

Thus, with little redundancy in the spacecraft matrix system performance almost equal to that of a single stage matrix having 2-3 times the number of crosspoints can be obtained. This concept deserves further study if a 100X100 switch finds use in a system design.

Another argument used in favor of single stage networks over three stage networks is less signal distortion, but this is true only when the single stage switch is in its normal mode. Since any wrap-around path will involve 2 additional crosspoints, an amplifier (to equalize the loss vs. a normal path), and associated cabling and connectors, the design of single stage and three stage matrix elements will be much more alike than might appear at first notice.

4.4.3 <u>IF VS. Baseband Switching</u>

The size, weight, and power calculations presented in the GE report indicate a strong preference for an IF switch. Only if the cost or reliability advantages of a baseband (plus modem) design can be shown to be very large would a baseband switch be an appropriate choice.

5.0 BASEBAND PROCESSOR

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5.1 Introduction

A Technology development effort was undertaken by a single contractor, Motorola, to (1) define an operational system concept for the 1990's that would acommodate trunking, CPS and trunking-CPS interconnection utilizing a Baseband Processor (BP) for all CPS traffic, (2) select a design approach and a subset of the operational system for a 1986 demonstration flight (which would verify the approach) using 1982 technology, and (3) to build a Proof-of-Concept (POC) model of the BP to ensure that the demonstration flight's technology is adequate.

The primary requirements are listed below:

a. Traffic Demand-CPS	>2.0 Gbps (Appendix A of SOW)
b. Beamwidth	0.3°
c. Trunking/CPS Interconnect	>1.0 Gbps (Appendix A)
d. Forward Error Correction (FEC)	Adaptive, for fades up to 10 dB
e. Lifetime/Reliability	10 years/redundancy features
f. Burst Rates	Trunking-500 Mbps, CPS-TBD

g. Weight & Power 350 lbs.,1000 Watts

Design Goals

The selection of beams, CPS burst rates, FEC codes, etc., was left to the contractor to do in an intitial system study.

An operational traffic model was assumed, using TDMA, which has a total trunking demand of about 5.2 Gbps among 18 fixed beams, and a CPS demand of 3.8 Gbps among 40 (18 fixed and 22 scanned) beams; in addition, a trunking-to-CPS interconnection with a 1.6 Gbps demand was assumed.

5.2 DESIGN APPROACH

The trunking network, not a specific part of this study except to indicate frequency allocation and interconnect compatibility, consists of three up/down channels at different carrier frequencies, each of which carries a 550 Mbps Serial Minimum Shift Keying (SMSK) signal, and a 23x23 TDMA IF Switch (5 of the 18 trunking sites require two 550 Mbps channels). It uses polarization diversity (along with the 3 frequencies) and occupies 1.5 GHz of the available spectrum.

The CPS frequency allocation allows for two 440 Mbps frequency channels each occupying about 0.8 (downlink) or 1.0 (uplink) GHz, using staggered polarization diversity. Actually, each CPS uplink beam consists of 4-110 Mbps channels or 16-27.5 Mbps channels or any consistent FDM combination; each CPS downlink beam consists of 2-220 Mbps channels combined after the HPA's. The CPS network is served by 6 RF scanning beams each of which services either 3 or 4 of the 22 scanned spots, and 5 IF "scanning" beams (which time-share the fixed spots, using the 1 GHz CPS band). Thus the CPS frequency re-use factor is about 5. The 23x23 trunking TDMA subsystem is augmented by 3 extra in/out ports (thereby creating a 26x26 IF switch) for the interconnect traffic. Therefore the total throughput capacity of the baseband processor, with the switching limitations, is:

6 RF Scanned Beams	@ 440 Mbps = 2640 Mbps
5 IF Beams*	@ 440 Mbps = 2200 Mbps
3 Trunking Interconnects*	@ 550 Mbps = 1650 Mbps
	6490 Mbps

*serving 18 fixed spots

(Note that this IF Switch is larger than the Technology contracts called for, and with wrap-around redundancy could become 30x30 or larger. As pointed out in Section 4, the larger the matrix, the more questionable the choice of a single stage matrix (as proposed by GE and FACC) becomes.

Motorola has tailored its six scanning beam MBA requirements by assigning each beam roughly equal traffic from the model assumed (Appendix of the Motorola report). In so doing, the 3° areas scanned by each beam overlap considerably; the result is a compromise between efficient usage of each beam's capacity and off-axis scanning losses. The 5 IF switched fixed-spot beams, on the other hand, possess a degree of traffic demand flexibility. While Motorola has indicated a particular assignment whereby each of these 5 paths service 3 or 4 fixed spots to satisfy the traffic model, actually up to the full 440 Mbps could be assigned to one fixed spot, e.g. New York; in this case, the 4 remaining channels would service the 17 remaining fixed spots. Similarly, for the Trunking-CPS interconnect traffic, up to the full 550 Mbps (and even up to 1100 Mbps at the five trunking stations equipped with two trunking frequency channels) could be assigned to one fixed spot.

To the 14 BP paths described above (6 scanned, 5 fixed and 3 interconnect) are added 2 more paths for FEC decoding/encoding. The total of 16 paths are each demodulated (and decoded if necessary), written into Input Memory and then demultiplexed 1:2 to provide 32 subpaths which, on the succeeding frame after reception, are each transferred at a 275 Mbps rate via a 32x32 Baseband Switch to the proper Output Memory. On the following frame, the data is output to the 22 downlink modulators (after encoding if necessary) representing the two 220 Mbps downlinks for the 11 scanning and fixed beams, and after 2:1 multiplexing 6 paths are modulated onto the 3 fixed trunking interconnects through the 26x26 IF Switch. The four output paths representing two 220 Mbps channels of encoded data are, like the input decoding paths, selectable to replace any 2 of the 11 scanning and fixed beams.

5.3 DISCUSSION AND COMMENTS

5.3.1 FEC Decoding/Encoding

FEC soft (2 bit plus sign) decoders can be inserted into any two of the eleven CPS uplink beams simultaneously, for a "per-station burst"; that is, during the time a certain uplink beam is selected for decoding, up to 16-27.5 Mbps or 4-110 Mbps channels (or combinations that sum to 440 Mbps) can be decoded for two such beams. However, the decoded throughput is limited by the decoder speed (4-6 Mbps) to provide only a 150 Mbps throughput. For the 2,100 CPS terminals assumed in the Motorola traffic model, a$d assuming an uplink power margin of 5 dB (before FEC is used), the availability is .995, de-termining the instantaneous demand for decoding. On the average only [(1-.995)x2100]=11 terminals will experience significant uplink rain degradation.

Allowing for a peak-to-average ratio of 3, the BP should be sized to handle 33 uplink channels. Based on the number of deployed high, medium, and low CPS terminals (152, 276 and 1787 respectively) a peak rain induced decoder demand might be:

2 High Capacity Stations	@	33.48 Mbps =	67.68 Mbps
4 Medium Capacity Stations	@	5.732 Mbps =	22.93 Mbps
27 Low Capacity Stations	@	0.88 Mbps =	23.76 Mbps
			114.37 Mbps

Thus the 150 Mbps decoder throughput would suffice for the traffic model assumed. For a larger CPS network of 10,000 stations*, the decoder throughput is probably still sufficient. Also since the (up to 40) decoders can be shared among the 11 fixed and scanning CPS beams

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* For example, traffic Model B of the SS-FDMA RFP.

within a frame, the BP could handle the peak demand of 3 x .005 x 10,000 = 150 stations provided that the decoder does not require initialization between bursts. Similarly the capability to encode any or all of the 22 fixed and scanning 220 Mbps CPS downlinks provides the downlink margin required.

The Trunking-to-CPS uplinks are not decoded and the CPS-to-Trunking downlinks are not encoded, since (presumably) the trunking stations will meet their availability requirements through larger antennas and/or station pair (space) diversity.

The coding technique proposed is a combination of a Rate-1/2 convolutional code with two bit soft decision decoding and an uplink transmission rate reduction to 1/2 the clear weather rate. This achieves 3.6 dB coding gain plus 6.0 dB "rate reduction" gain for 9.6 dB additional uplink margin. This choice does not appear to be optimum in the sense of gain vs. throughput, but this is not a significant penalty, since only about one percent of BP throughput is affected. Thus, as long as the decoder memory and processing requirements are not significant weight or cost factors, such a code is probably acceptable.

A good feature is the additional ability to pass uncoded bursts through either of the 11x2 (and 2x11) FEC channels, thus providing additional redundant paths for the CPS traffic.

5.3.2 Satellite Aided Burst Synchronization

The BP possesses a feature which should help reduce the costs of the CPS terminals. By comparing each uplink channel's unique-word arrival time and comparing it with the proper arrival time as stored in the BPS control memory by MCS command, the BPS generates an early/late count and inserts it in the appropriate satellite-to-CPS downlink orderwire (at the start of each burst); the CPS terminal then retards/advances its transmit burst-time accordingly. This eliminates the requirement for CPS loop-back bursts for steady-state synchronization and most of the accompanying digital circuitry.

In fact, if this satellite-aided burst synchronization concept could be extended to include the trunking network, it would be useful there also. Since the trunking/CPS BP interface already exists, this extension should be considered.

5.3.3 Frequency Plan

The CPS portion of the 30/20 GHz occupies approximately 1.0 GHz. This provides 6 scanned plus 5 fixed equivalent 440 Mbps channels or 4.8 Gbps. Thus the CPS frequency-reuse factor is 4.8. This assumes a "baseline" utilization of 1 bit/Hz. The 1.5 GHz occupied by the trunking network, coupled with 23 x 23 IF Switch has a throughput of 23 x 550 = 12.65 Gbps. There results an effective trunking frequency reuse factor of 8.4. These are probably reasonable values, considering the constraints imposed by the BP, IF switch(es), traffic model, etc.. However, a final operational system configuration might have improved frequency re-use factors.

A "theoretical" maximum frequency re-use factor for 200 0.3° beamwidth contiguous CONUS-coverage spots using a hexagonal tesselation with 3 frequencies and orthogonal polarization would be 200÷3=67. This however can only be achieved if each beam's bandwidth is tailored to its traffic demand (a costly FDMA payload design) and subsets of the 200 beams with like demand are uniformly spaced. A practical maximum for traffic models postulated so far for frequency reuse is probably about 20. The advantage of improving frequency re-use factors, even though the satellite may be power (and weight) limited, is that tne same total (CPS and trunking) throughput could be achieved using a fraction of the 2.5 GHz allocated 30/20 GHz spectrum. This would allow co-locating (or closer spacing) of multiple satellites in the more desirable orbital locations, and it could alleviate bandwidth requirements (and cost) of critical earth station sub-systems.

5.3.4 Memory and Switching Requirements

Uplink channels are written (after multiplexing) into the BP's 32 Input Memories sequentially, i.e. in the order received from the station bursts in each of the 16 beams (paths). Each station is scanned only once per frame resulting in a low preamble overhead, at which time it transmits in one burst, successive sub-bursts for each station for which it has data to send. Each burst therefore represents a demand on the capacity of several downlink beams - including a requirement that it be placed in each downlink beam at the proper time, i.e. when the downlink scans the particular destination station which also occurs once per frame. This requirement is met in two steps; first the input memory is read (using random access) and the information routed to the input of the 32 x 32 switch which collects common destination subbursts and routes them to the appropriate Output Memory using sequential write instructions; then the Output Memory is read (using random access) to modulate the proper 220 Mbps (or 550 Mbps for Trunking-CPS interconnect) CPS downlink beam at the time it scans the destination spot. Each of the 64 Input and Output Memories contains 4,000 64-bit words.

Thus, the 32 x 32 Baseband Switch accomplishes the same function as a TDMA IF-Switch. When operating near full capacity, high throughput efficiency places a demand upon the maximum total number of switching states (modes) per frame similar to that of the "Greedy Algorithm"; this maximum is 992 modes per frame. A realistic number, while still retaining high throughput efficiency, may be in the 100 to 200 modes-per-frame range. Thus, a maximum switching time of 0.5 usec., say, would result in a frame efficiency of 95% to 90% for a 1 millisecond frame. Motorola did not indicate the maximum switching time of the Baseband Switch; it is recommended that this analysis be performed; it may also be affected by the access time of the RAM implemented.

It is not obvious that a random-access <u>write</u> memory concept has been investigated. If such an approach is feasible, it could (a) eliminate half of the memory storage requirement, (b) enable placing the modulators in front of the 32 x 32 switch, thus making it an IF Switch, and permitting a common technology with the trunking IF Switch development, and (c) possibly reduce the maximum number of switch modes per frame.

5.3.5 Weight and Power Prediction

Motorola has estimated that a "full-redundancy" BPU would weigh 340 lbs. and consume 1371 watts peak power using 1982 technology versus 217 lbs and 778 watts using 1987 technology, which meets design goals.

5.3.6 Limited CPS Coverage

Although the specified traffic model included only 40 0.3° beam areas for CPS users, and the design goals were met, there still remains a question as to how to service CPS users in the non-covered areas (about 85-90% of CONUS). It is believed that most of the concepts developed so far for the BPU are still applicable, but a system study is needed to verify this.

5.3.7 POC Design

The proposed POC design is a minimal concept containing one sample of every element proposed for the final design:

NXN Routing Switch

550 Mbps Trunking Channel Processing

27.5, 110, and 220 Mbps CPS Channel Processing

FEC Coding and Decoding

It should thus be capable of demonstrating the functions required of working Baseband Processor, although it is not clear from the description given that the full parallel processing capability of the FEC processing circuits will be implemented. However, this may not be necessary if the experiment design is properly organized.

The system test equipment to be used with the POC model has not been described. It is important that all the characteristics of real-world signals be simulated to provide a valid test of the operating circuits. These would include, inter alia:

TDMA Burst Nature of Inputs

Degraded Input Signals (errors, phase jitter, noise) Fading Characteristics

Timing Inaccuracies

6.0 MULTIPLE BEAM ANTENNA SYSTEM

6.1 GENERAL

The function of the multiple beam antenna system (MBA) is to provide permanent coverage (i.e., a fixed beam) to a number of cities or city pairs (18 has been assumed in most of the NASA studies) and scanning beam coverage for all other locations. Arguments have been made as to whether the scanning beam coverage should include all of CONUS or if a restriction to some limited number of additional locations beyond the fixed beam cities would be sufficient. It is Western Union's opinion that one of the prime attractions of a satellite system is the service it can give to locations outside major metropolitan areas. Such services to outlying areas, when any facility having capacity larger than a voice channel is required, tend to be unavailable or scarce and expensive when provided on terrestrial systems, whereas the cost of satellite service is basically independent of location, and construction of earth stations in such locations usually easier. Thus full CONUS coverage by means of scanning beams (true scanning or contiguous fixed) is deemed essential for the creation of a viable CPS satellite system.

In designing an MBA, the beams, fixed and scanning, must be shaped and directed such that with suitable combinations of frequency reuse, polarization reuse/ isolation and pattern isolation sufficient capacity is available to serve each location. Thus, in order to form judgements as to the adequacy of any particular design, it is necessary to have estimates of potential traffic for each beam. Many traffic models have been generated for the 20/30 GHz program. The one chosen as a model to judge MBA design is the latest available model from NASA - the one given in the Appendix A to the SS-FDMA Communications System for CPS Statement of Work (Traffic Model A). This model postulates about 6 Gbps of peak busy hour trunking traffic, 1.6 Gbps of peak busy hour trunking to CPS (and vice versa) traffic, and 2.2 Gbps of peak busy hour CPS traffic, broken down by city of origin. Total peak hour traffic carried on the CPS beams is thus 3 Gbps. However, allowing for unequal traffic distribution among the scanning beams as stated in the model, the total CPS beam capacity required varies up to 4.5 Gbps.

6.2 REQUIREMENTS

6.2.1 Operational System

The MBA operational concepts, based upon recent NASA TDMA studies, require up to 18 fixed spot beams for trunking service and 6 scanning beams (which together give near CONUS coverage) for CPS service; both fixed scanning beams would have a nominal beamwidth of about 0.3°. A design goal of 230 Kg (510 lbs.) and 18 m^3 was chosen for the maximum weight and volume respectively of the MBA subsystem. Within these constraints, study tradeoffs included: Single, Double (1 East - 1 West or 1 Transmit - 1 Receive) and quadruple (E/T, W/T, E/R, W/R) prime reflector configurations; sub-reflector optics; feed shape, size, and clusters; and beam forming networks using diode or ferrite switches, variable power dividers (VPD's), and/or phase shifters. Both 1982 and 1987 technology concepts were to be investigated.

Additionally, a fixed beam CPS concept covering CONUS in 100 contiguous beams, was also to be considered. By implication, the beamwidth of each fixed CPS beam would have to increase to abou$ 0.45°, corresponding to a loss of about 3 dB in uplink and downlink gain; however, this might be partially compensated (depending on the number of prime reflectors) by reduced off-axis scanning losses and VPD losses as compared to the CPS scanning beam. Such a contiguous beam configura-tion would enable FDM CPS operation. In any event, whether 100 fixed contiguous or 6 scanning beams provided the CPS coverage, the MBA concept must still support the 18 fixed trunking beams.

The specifications for the MBA performance are listed below:

a.	Antenna Size	- Shuttle Compatible
b.	Number of Trunking beams	- 18 (Specific Cities Listed)
c.	Number of CPS beams	- 6 Scanning or 100 Fixed Contiguous
d.	Minimum Transmit Gain	- 53 dB
e.	Minimum Receive Gain	- 56 dB Trunking 53 dB CPS
f.	Bandwidth	- 500 MHz
g.	Polarization	- Dual Linear
h.	C/I Performance	- >30 dB
i.	Pointing Accuracy	- <.02° Pitch/Roll <.4° yaw
j.	Power/Beam	- 52-62 dBW Trunking, 67-75 dBW CPS

It was assumed that the loss in gain due to pointing errors was not included in items (d) and (e) above.

Thus, the pointing errors specified in item (i) should be added to the results of the MBA development efforts as reported for the final link budgets; this in turn depends upon whether or not an earth station is on an antenna pattern's slope.

6.2.2 Demonstration System

A demonstration MBA System concept (using scanning CPS beams) was also specified, suitable for a 1985-7 launch. Allthe specifications given in the preceding Section (6.1.1) for the operational system are the same, except that only 10 fixed-beams for Trunking (a listed subset of the 18 operational Trunking beams) and only 2 scanning beams for C$S are required. How-ever the 2 CPS beams are required to be selectable from 6 operational scanning beams to provide any two out of six sectors of CONUS. This requirement led to the result that the total weight of the operational and demonstration MBA configurations was about the same since all the feeds for the full six-sector CONUS coverage were required in either case for the designs selected.

6.3 DESIGN APPROACHES SUMMARY

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6.3.1 TRW

TRW has investigated MBA configurations for the combined fixed/scanning beams ranging from 1 to 4 reflectors and utilizing either Variable Power Dividers (VPD's) or phased array feed approaches. Their recommendation for the operational system with 18 fixed and scanning beams is summarized below (pp. 7-9 and 7-13 of the TRW report) assuming either 1982 or 1987 technology is used:

CHARACTERISTIC	1982 TECHNOLOGY 265 VPD's	1987 TECHNOLOGY 320 Ø SHIFTERS
No. of Reflectors	4(E/W & T/R)	2 (E/W)
Fixed Beam Trunking		
Minimum Antenna Gain	54 dB	53.5 dB
Scanning Beam CPS		
Minimum Antenna Gain	49.2 dB	48.5
C/I Trunking	>30 dB	>30 dB
C/I CPS	>30 dB	20-30 dB
Weight	590 lbs.	454 lbs.
BFN Switching Power	Not Given	Not Given

The 1987 Technology approach, which has about 0.5 dB less minimum gain (off-axis) is lighter and possesses further advantages such as graceful degradation (from phase-shifter failures) and possibility of increased G/T and EIRP using distributed LNA's or solid-state HPA's depending on future solid-state development. If the 4-reflector VPD approach were selected, using 1987 technology, the total weight would apparently decrease from 590 to 505 lbs., according to page 4-9 of the TRW report. Easy to identify measures which would ease the trunking beam problem, a reassignment of sector boundaries, if possible, would improve the scanning beam margins.

6.3.2 FACC

FACC has recommended the use of a 2 primary reflector, CONUS coverage MBA system. The transmit reflector at 20 GHz would have a 12.5 foot diameter and the receive reflector at 30 GHz would have an 8.33 foot diameter. The recommended optics is a dual-offset Swarzchild subreflector; the feeds have a square aperture and are triangulary clustered; and the beam forming network is a matrix type using a combination of switches and VPD's. The characteristics are summarized below, assuming a directivity of 55.8 dB (before BFN scanning losses):

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CHARACTERISTICS	1982 TECHNOLOGY BFN: SWITCHES & VPD's
No. of Reflectors	2(T/R)
No. of Elements	540
Fixed (Trunking) Min. Gain	53.7 dB
Scanning (CPS) Min. Gain	52.2 dB
O/I Trunking	>30*
O/I CPS	>30**
Weight	507 lbs.
BFN Switching Power	450 Watts

*Assumes -35 dB first sidelobes, -45 dB sidelobe asymptote, -40 dB cross-pol isolation.

**Assumes -40 dB sidelobe asymptote.

For the 1987 Technology FACC does not have a final design, but recommends a shaped sublens, dual-offset, MBA system using 1200 elements. FACC states that the increased weight of the sublens and extra elements may be somewhat offset by using an active BFN (transmit and receive amplifiers in each beam).

FACC has interpreted the 500 MHz bandwidth requirement for Trunking and CPS service given in the SOW as a maximum, thus limiting the capability of the MBA to a single 500 Mbps tunking beam in any spot, and limiting CPS capability comparably. This is not in accord with the traffic models developed for other parts of the 30/20 GHz program, and would present a significant limitation to spacecraft utility. It is not clear, from the information given, how difficult it would be to redesign the trunking/CPS diplexers for wider bandwidth, and to avoid significant unusable spectrum in the cross-over regions. At a minimum, a design providing, for example, 1 GHz for CPS and 1.5 GHz for trunking in two bands should be evaluated, although it must be pointed out that some of the systems studies assumed interleaved 500 MHz CPS and trunking bands to improve frequency isolation. This would further complicate diplexer design.

It would be preferable to accomplish trunking/CPS diplexing by other than frequency selective means. This would, among other advantages, remove the requirement to tailor an antenna design to a specific frequency plan and service capability, allowing easy reconfiguration of the payload before launch, if not after launch.

6.3.3 Contiguous Beams

For the 100 contiguous beam CPS MBA design, the results reported are somewhat incomplete. TWR gives two concepts without recommendation: one using four reflectors (E/W and T/R) each 10 feet in diameter weighing 548 lbs. and having a minimum gain of 47.4 dB. The other concept uses two reflectors (T/R) each 9 feet in diameter weighing 281 lbs., with a minimum gain of 45.4 dB. The 548 lb. concept, however, requires only 2 frequencies (vs. 5 frequencies for the 281 lb. concept) with a corresponding increase in frequency re-use. Also, it appears that the above weights do not include the 18 fixed trunking beams which require the 13 foot reflector(s).

FACC has developed concepts for both 55 and 119 fixed-beam contiguous CRS coverage. Taking the 119 beam concept as the closest to the 100 beam specification, it utilizes some 629 elements and produces a minimum gain of 43.1 dB. The reflector size(s) are not given but presumably are the same as the fixed/scan concept of 12.5 foot (transmit) and 8.33 foot receive. The total weight is also not given, but judging from the increased number of feed elements, diplexers and VPD's, it is probably 125 lbs. heavier than the fixed/scan concept or about 632 lbs. In this case it is clear that it includes the 18 fixed trunking beams, however, this plan also required 5 frequencies.

6.3.4 Demonstration Satellite Designs

The demonstration MBA designs from each vendor comprise two reflectors (transmit and receive) and a cut-down version of the antenna feed systems. The FACC design is scaled from a two reflector design and consequently provides baseline performance for all illuminated locations. The TRW design is modified from one-half of a four reflector design and provides somewhat degraded performance to West Coast locations. A systems analysis is needed to determine if this is acceptable. TRW also provides a design using smaller reflectors (2&3 meter). This would have less than specified performmance to all locations and is probably unacceptable unless the claimed weight and design simplicity advantages prove to be both realizable and vital to mission success.

Neither proposed demonstration satellite MBA design provides coverage of a poor propagation area (e.g., rain zone E - Gulf Coast and Florida). This is felt to be a major shortcoming as it will prevent evaluation of the actual attainable performance in this area and of the practical effects of these rain outages on service (duration, time of day, frequency, etc.,). WU recommends that the CPS coverage be extended to fully cover sectors 5 and 6. It is also recommended that the scanning beams (or at least the East Coast beam) be made variable in frequency assignment and polarization. This could be used, in conjunction with the fixed beams, to verify computed beam isolation performance.

6.3.5 POC Model Designs

The POC Model designs are reduced versions of the Demonstration Satellite concepts. This is an acceptable approach if great care is taken that the design remains directly scalable to the full antenna system, i.e., that extra space made available by omitting portions of the feed structure is not occupied by the remaining elements. To insure this, the POC designs should be derived by starting with a design for a complete MBA and only leaving out elements, not redesigning anything, even if it would make construction easier or cheaper. This should apply to the entire waveguide structure, including VPD's switches, circulators, etc., as well as the feed lines themselves.

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6.3.6 General Comments

FACC has been able to design a reflector structure with very small scan losses. This enables them to use a Transmit/Receive two antenna design which completely separates the 20 and 30 GHz feed structures. In contrast TRW requires four reflectors to accomplish this, and their 1987 two reflector design is an East/West configuration with both transmit and receive on both antennas. The feed structure chosen by FACC is much less satisfactory since it depends on frequency diplexing in the antenna structure which restricts the usable frequency range and freezes the traffic pattern into the antenna design. The TRW approach is relatively free of these problems, although it does involve frequency diplexing in some of the spot beams, which is also less than optimum. A combination of these approaches would be desirable.

The feed systems of these antennas are not only much more complicated than any designs previously flown but involve many active elements such as VPD's, switches, and phase shifters. Two important factors must be analyzed to determine if these concepts are practical in a spacecraft antenna. The first is the probability of failure of one or more of these elements (or their control circuits) over the 10 year life of the satellite. The second is the effect of each of these possible failures on antenna performance - whether one beam or many are effected, whether the pattern change is small or catastrophic - both in main beam and sidelobe performance, whether both trunking and CPS beams or only one are affected, etc. In addition, whenever a major effect on antenna performance can be caused by likely failures, a study should be made of possible remedial methods, such as redundant elements and bypass switches, to determine if they are useful, and if they can be incorporated into the design in a reasonable manner.

APPENDIX A

AVAILABILITY

1.0 INTRODUCTION

The availability required of a communication system is difficult to determine. It is based on two parameters that are difficult to quantify, especially in advance of tne actual operation of system-the value to the user of a particular level of availability, and the cost of achieving it. If only a two point system is being considered, then it is possible, at least in theory, to develop curves of revenue vs. availability based on user needs, and costs vs. availability. These curves can then be used to find the optimum availability (if the system is viable at all). As the system becomes larger and more complex such calculations become much more difficult, not only because of the number of paths involved, but because the concept of "availability" becomes less well defined. Consider for example a network interconnecting ten users. If the network degrades so that only nine of the users remain connected, the network will become less useful, and the revenues derived from it will decrease. If the network is repairable, this loss of utility consists of the denial over certain time of some real-time traffic and the

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ent beforehand how the relative costs of achieving given levels of availability for each subsystem interact to determine the cost of the overall system at the required availability. It is extremely helpful to have available for each subsystem tradeoff curves of subsystem availability vs "cost", where "cost" must include all elements impacting overall system performance, such as power consumption, weight, size, and even development time, as well as monetary factors.

For repairable systems, availability (A) is defined by:

$$A = \frac{MTBF}{(MTBF+MTTR)}$$

where MTBF = mean time to a failure event

MTTR = mean time for a failure to be corrected

(Propagation can be treated by the above formula by considering the "repair" to be the end of the anomalous propagation condition.) This equation describes a process in which the service life of the link under discussion is characterized by long periods of proper operation interrupted by short periods of improper operation. By averaging these intervals over time, the mean numbers used in the formula can be determined. (In practice the MTBF of a device is usually determined by testing many devices at the same time and averaging over the number of devices. This does not, however, affect the concept of time averaging underlying the formula.) When redundancy is used, it affects the MTBF number, since a simultaneous element failures must now occur before a system failure is noticed. Conceptually this does not change the principles involved.

When considering a non-repairable subsystem, such as a spacecraft, different concepts apply. Such a subsystem has a finite probability of operating satisfactorily for the planned service life of the system, dependent on the reliability of the individual subsystem elements and the amount of redundancy provided. This process is characterized by a long operation interval followed by a long period of system reconfiguration, spacecraft replacement, or similar events, during which system operation will be degraded or the system will be unusable. The mathematical equations that govern this type of behavior yield a result such as the following (with many simplifying assumptions):

Pr (10 year misssion life) = exp (-87600x)

where x is the reciprocal of the mean time to failure. For example, with a mean time to failure (including all redundancy of about 95 years the probability of survival of 10 years is 0.9. This means that if 10 spacecrafts were launched, nine of them would last for 10 years (on average). The problem is that if only one is launched, there is no way to determine if it was one of the nine that survived or the tenth one that failed until the 10 years are up. To increase the probability to 99% would require a mean time to failure of 995 years!

Considering the above, the problem of defining system availability for the 30/20 GHz system is not a simple one, and needs considerable study to arrive at meaningful numbers. Ignoring this problem temporarily, a typical availability "tree" for the Ka band system is shown in Table A.1. This particular tree is arbitrary, both as to the elements used in the breakdown and as to the numbers given. Much more information and analysis will be required to arrive at an optimum breakdown.

A number of assumptions have been made in deriving this table. To begin with, the propagation availability for each link has been taken as .9999, and it has been assumed that propagation should be the dominant factor in overall performance. Similarly the spacecraft is given the bulk of the unavailability allowance on the hardware side. The spacecraft has been aribitrarily broken up into four subsystems each of which ends up with an

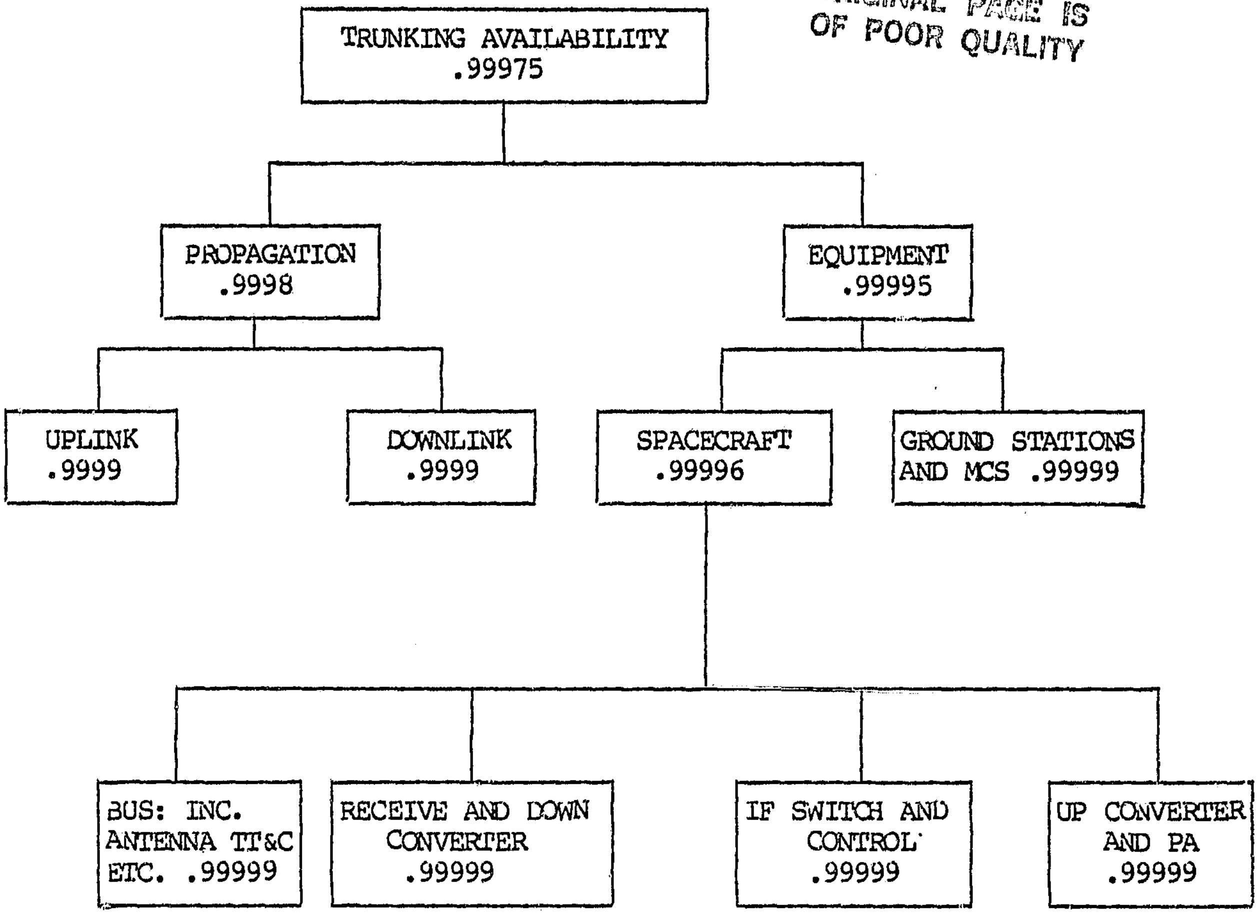

Table A.1
TYPICAL AVAILABILITY TREE

availability requirement of .99999. It does not appear that these levels of availability have been considered in the technology investigations.

It must of course be noted that the above discussion is vastly oversimplified. It ignores such questions as how to treat paths with different throughputs, whether all capacity losses are of equal importance, the differences between short term outages due to propagation, long term outages due to ground station malfunction, and permanent outages due to spacecraft failures, and more fundamentally what total system availability really means. This topic requires much more study than can be given here, and should be thoroughly treated before system design is frozen so that the proper level of availability can be designed into each subsystem.

3.0 RECOMMENDATIONS

For a carrier to offer a satellite system to its customers it must be able to assure them of a particular grade of service to suit their requirements. This is reflected in the required day-to-day availability of each service based on propagation considerations and hardware reliability. For a carrier to find a satellite system profitable, it must be able to use it for a given period of time. This is reflected in the required long-term availbility which is based on satellite hardware reliability and the degree of redundancy provided. At present there is little information on either the availabilities actually required for different services or on the capabilities of the proposed satellite system to provide them. We recommend the following steps to resolve these problems:

1) A study of proposed user services to determine the availabilities needed for each - short term and long term. This should be based on true customer needs, bearing in mind alternate communication systems available to him and the time urgency of each service, considering current industry practices.

2) A study of the percentage reduction in satellite capacity (possibly by type of reduction - partial to all users, total to some users, etc.,) tolerable to a carrier.

3) Obtaining from the technology contractors, and from others for subsystems not part of a technology contract, hardware reliability and subsystem availability numbers, parametrically as a function of size, weight, power, cost etc., to be used in system analyses.

APPENDIX B

SIGNAL IMPAIRMENTS

1.0 DISCUSSION

When a communication system is designed, the primary input specification states that a given bit stream at a prescribed rate must be sent from a source to a destination with a certain reliability (error rate). Given an additional specification of maximum bandwidth occupancy, a modulation technique can be selected. This determines the carrier-to-noise ratio (CNR) needed to achieve the given error rate, which is used to select the transmit EIRP and receive G/T of the transmission link.

In any practical system, the realized performance can only approach that derived by theoretical analysis. Each element of the transmission chain will impair the performance by some (normally small) amount which will require an increased CNR to reattain the level of performance specified initially. The objective of the system designer is to minimize the "cost" of achieving this performance, where cost is taken to include not only direct monetary components, but also other components such as size, power, weight, reliability, etc.

which cannot always be simply converted into money. Thus for example tradeoffs must be made between the cost of improving a practical demodulator and the cost of increasing transmit power to compensate for the non-ideal behavior of the device as given. This process must be generalized to consider jointly all the system elements which affect performance so that each can be allocated its "fair share" of the overall allowed impairments, and so that the latter can in fact be determined. To do this two things must be available. One is a model of the communication system using which the effects of changes in various system elements on overall performance can be determined. The second is a set of tradeoff studies showing the "cost" penalties or benefits of tightening or loosening the specifications of each system element. With this information the model can be used to determine the lowest cost system for any level of performance.

Block diagrams of typical models are shown in Figures B.1 and B.2 for a "bent-pipe" (SS-TDMA or FDMA) system and a baseband processor system respectively. Table B.1 shows the parameters of importance for each of the system elements. Both the figures and the table are to some extent arbitrary. For example, a direct RF modulator would combine the functions of modulator and up-converter, and band pass filtering has been assumed to

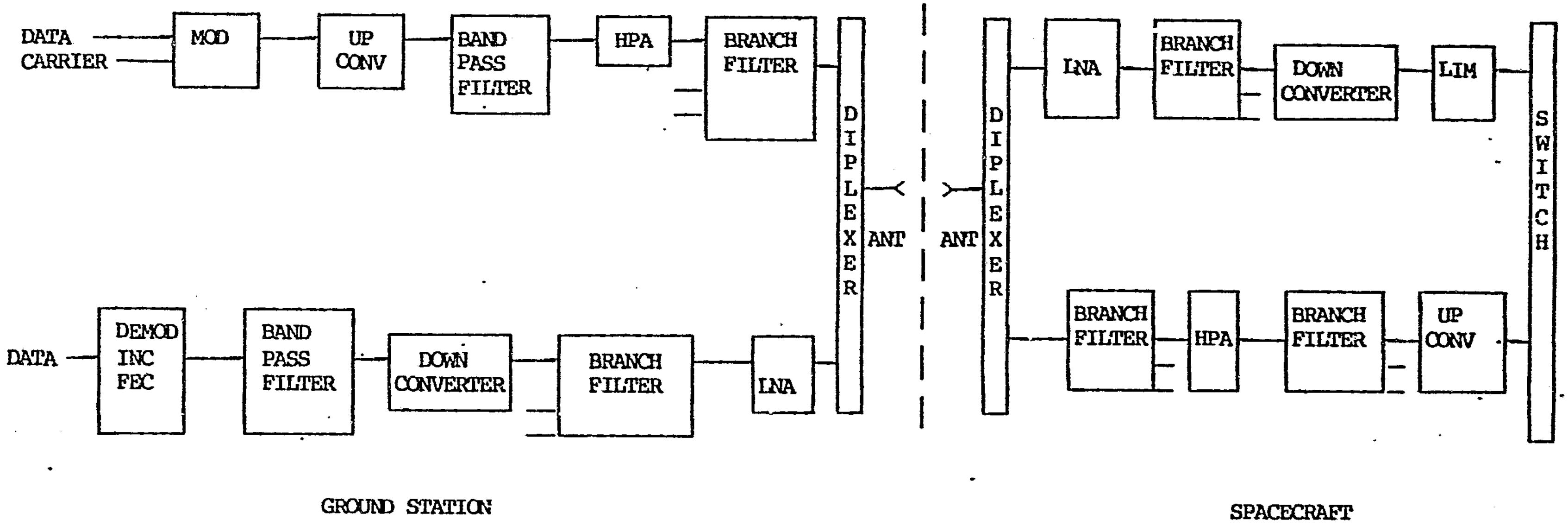

FIG. B.1
BLOCK DIAGRAM (NO DEMODULATION IN SPACECRAFT)

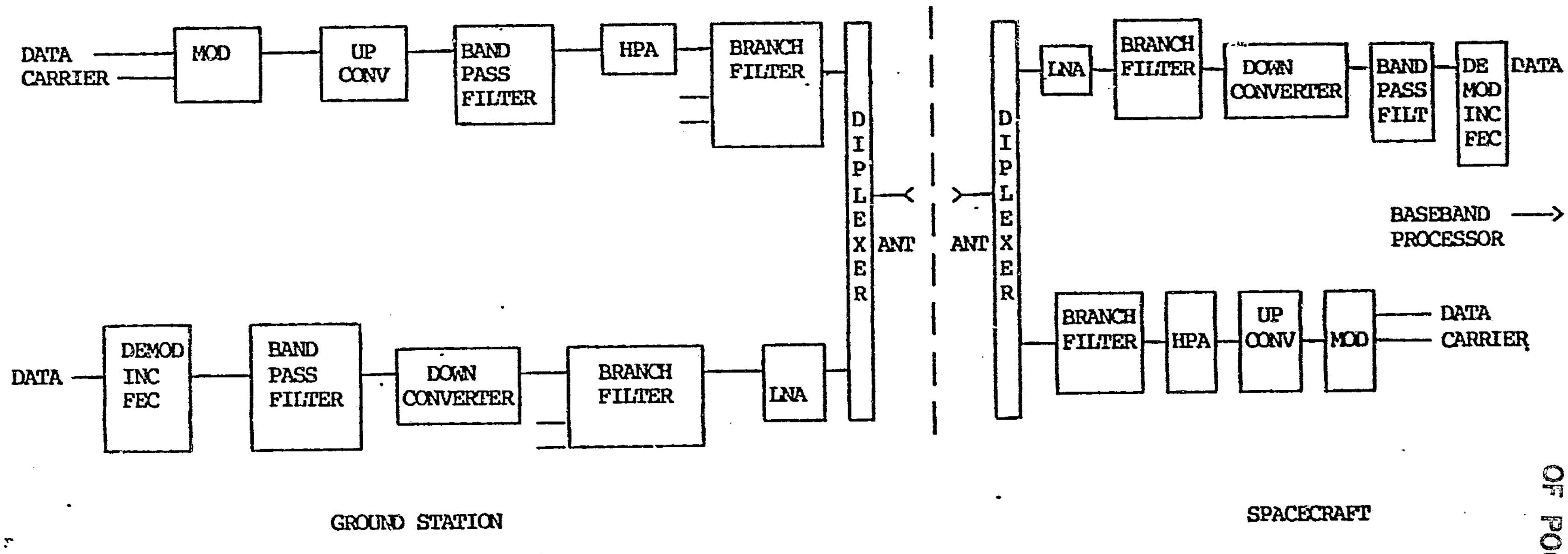

FIG. B.2
BLOCK DIAGRAM (DEMODULATION IN SPACECRAFT)

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TABLE B.1
SIGNAL IMPAIRMENT

CIRCUIT ELEMENT	AM/AM CONV	AM/PM CONV	GRP DEL	BW LIM	SPUR SIG GEN	PHASE NOISE	NOISE FIG	CARR PHASE ERR	TIM ERR	AMPL RESP	SPUR SIG REJ
MODULATOR			X	X	X	X		X	X	X	
DEMODULATOR							X	X	X		
FILTERS	X	X	X	X						X	X
UPCONVERTERS			X		X	X	X				
DOWNCONVERTERS			X		X	X	X				
HPA	X	X	X	X	X			X			
LNA							X				
AGC			[illegible]				X				
LIMITER	X	X					X				
IF/RF SWITCH	X	X	X				X			X	X
ANTENNA		X					X				X
ANT PTNG							X				X
PROPAGATION			X				X			X	

be intrinsic in some elements (e.g. HPA's) and extrinsic in others (demodulators). The impairment categories in the table are also generalized. For example "spurious signal rejection" includes feed-through in the IF switch, cross-polarization isolation and beam width in the antenna, sidelobe problems in the antenna pointing system and skirt rejection in the filters.

In a "bent-pipe" system (Fig. B.1) the signal remains in modulated form from the transmitting ground station, through the spacecraft transponder, and then to the receiving ground station. The impairments accumulate over this entire link, which must therefore be considered as a single communication channel. In contrast, when a baseband processor is used (Fig. B.2), the signal is demodulated and remodulated in the spacecraft and impairments affect the up and downlinks separately. In this case, the same overall error rate can be maintained with impairments on each link almost as large as those allowed for the whole up- and down-link in the bent-pipe case. Thus significantly larger signal impairments can be allowed at the cost of adding the extra processing in the spacecraft.

2.0 METHOLOGY

The process of arriving at an optimum set of specifications would go as follows. An overall impairment CNR penalty would be selected, based on a priori decisons about the state of the art of transmitter and receiver design, and information about the estimated costs of providing the extra EIRP or G/T to compensate for it. A typical value would be 3 dB. This must then be distributed over the various circuit elements and types of signal impairments listed in Table B.1. For example, an allocation of 1/2 dB system impairment to group delay corresponds to a distortion of about 1 nanosecond at 512 Mbps with QPSK modulation. This in turn must be allocated over the circuit elements that can contribute to this impairment: the modulator, the up- and down-coverters, the high power amplifiers, the IF/RF switching systems, and the filters and any band limiting elements. The share of the total allowance allocated to each of these elements should depend on the difficulty of achieving it, and should result from a tradeoff study of impairment vs. cost for each element in the complete transmission link. The tradeoff study should consider the allocation of the total 3 dB impairment allowance among the various categories, and, finally, the relative costs of increasing or decreasing EIRP and G/T vs. changing the system impairment allowance. An effective study of this type should use computer models of the system and automated tradeoff analyses to produce useful results with a reasonable amount of effort.

3.0 RECOMMENDATIONS

NASA is contracting for a simulation model which can perform the types of analysis needed for tradeoff studies. However, without the availability of tradeoff information for the system elements, a systematic analysis is not possible. For each element of the system, the appropriate NASA subcontractors should develop such information so that it can be determined, for example, if it is preferable to specify a higher power HPA or a lower noise figure LNA, or whether the group delay specification on some of the filters should be tightened to allow for more phase noise in an upconverter.