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FINAL REPORT

SPACE SHUTTLE/TDRSS COMMUNICATION AND TRACKING SYSTEMS ANALYSIS

PREPARED FOR

NASA, LYNDON B. JOHNSON SPACE CENTER
HOUSTON, TX 77058

CONTRACT NO. NAS 9-17349

TECHNICAL MONITOR: WILLIAM E. TEASDALE

APRIL 30, 1986

TR-8514-02

LinCom Corporation

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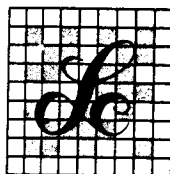TECHNICAL MONITOR: WILLIAM E. TEASDALE

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1.0 SUMMARY

1.1 Introduction

This final report presents the results of LinCom's efforts on the study of the "Space Shuttle/TDRSS Communication and Tracking Systems Analysis," performed under Contract No. NAS9-17349. It represents a portion of the work accomplished during the reporting period May 1, 1985 through April 30, 1986.

LinCom has been under contract to NASA/JSC since August 1976 to modify and extend an analytical simulation package (LinCsim) which allows the analytical verification of data transmission performance through TDRSS satellites. The scope of this effort has recently been expanded to include the effects of radio frequency interference (RFI) on the bit error rate (BER) performance of the S-band return links. On the other hand, since 1976 LinCom has been expanding this program to make it also applicable to Shuttle unique/ground station capabilities.

Now that both the TDRSS and Shuttle programs have completed the conceptual design phases and most of the design/development activities (especially the TDRSS), it is time for the NASA to focus it's attention on potential enhancements to the Shuttle and TDRSS communication system as well as the Shuttle navigation sensors that can upgrade the Shuttle communications, tracking and navigation capabilities. In order to evaluate the technical and operational problem areas and provide a recommendation, the NASA/JSC Statement of Work (SOW) provides for a study to evaluate these enhancements through simulation and analysis. These enhancement techniques must first be characterized, then modeled mathematically, and finally updated into LinCsim. The LinCsim package can then be used as an evaluation tool.

2.0 SUMMARY OF WORK ACCOMPLISHED

This final report documents the analysis, modeling, simulation and evaluation performed by LinCom under two tasks contained in the Statement of Work. What follows is a summary of tasks accomplished by LinCom during this contract period.

2.1 Characterization and Modeling of Potential Enhancements

There are three areas of potential enhancements: (1) Shuttle payload accommodations, (2) TDRSS SSA and KSA services and (3) Shuttle tracking system and navigation sensors. Our approach here is to identify the areas of potential enhancements, provide functional characterizations and then develop analytical models.

2.1.1 Shuttle Payload Communications Enhancements

The Shuttle will be used to support the Space Station effort as early as the launch and assembly phase. Communications amongst the station, EVAs and the Shuttle are required. The current capability is UHF voice between the Shuttle and EVA. Enhanced capabilities includes compressed digital TV, digital voice, heads up display and commands and telemetry.

The Orbit Maneuvering Vehicle (OMV) will likely be Shuttle based. The OMV will require digital compressed TV support for its return link which is beyond the capability of the current S-band payload interrogator.

A DoD payload kit has also been proposed. It will be in a receive only mode employing a 24 inches dish mounted on a CCTV pan and tilt unit. It will use a FET pre-amp front end with 2 db noise figure and interface with either the payload interrogator/communication interface unit or directly with the Ku-band signal processor in the bent-pipe mode.

Other non-mission specific enhancements considered include: (1) high date rate S-band via TDRS for attached payloads, (2) capability to handle encrypted data for the payload signal processor, (3) accommodation for suppressed carrier modulation for the payload interrogator (4) Ku-band signal processor/payload interrogator forward link bent pipe and (5) concatenated Reed-Solomon/Convolutional coder/decoder.

2.1.2 TDRSS Single Access (SSA & KSA) Services

Within the next 5-10 years, there will be more and more users competing for the TDRSS single access services. This situation will become more severe when the Shuttle has to support the space station and its neighboring elements such as the co-orbiting platform, polar orbiting platform, OMV, OTV and other TDRSS users. Currently only two SA users can be supported simultaneously by a TDRS. The TDRSS will be forced to look for new ways beyond the standard services to accommodate more users. This type of nonstandard services will be able to support higher data rates as well as multiple users by employing perhaps bandwidth efficient modulations, high rate codes, and frequency division multiplexing. This then opens up the possibility for the Shuttle to improve its communications system data rate and BER performance capability.

The future procurement of additional TDRS's and the eventual placement of these satellites will also affect the TDRSS SSA and KSA user traffic. LinCom has closely followed the NASA/GSFC TDRSS augmentation development and analyze their selected approaches for the purpose of modeling, simulation and subsequent evaluation.

2.1.3 Shuttle Tracking System and Navigation Sensors

2.1.3.1 Background

The Orbiter maintains current position and velocity through periodic propagation using numerical integration of acceleration based on theoretical force models. Orbital maneuvers use sensed velocity and a gravitational force model. The TDRSS provides two-way range change (Doppler) over a path from the master station on the ground, through the TDRSS, to the Orbiter transponder, and back. Nominally, two relay satellites can be seen and the use of Doppler data through both satellites over one Orbiter revolution should result in adequate state vectors. Should only a single relay satellite be available in some geometrical configuration then two passes are desired. This would require about 135 min.

The early maneuvers in a rendezvous sequence are targeted by the ground and must be planned around ground tracking coverage. The terminal phase maneuvers are determined onboard and must be planned in accordance with onboard relative observation (spacecraft to spacecraft) restrictions. The terminal rendezvous phase navigation is performed with the use of the star tracker and/or Ku-band rendezvous radar, which provide relative observations between the Orbiter and the target spacecraft.

The star tracker measures two components of the relative position at any one time, so it is a relatively weak navigation device. It poses other operational difficulties such as recognition of the proper object to track, limitations on target brightness, lighting requirements on the target, and proximity of Sun line of sight with respect to instrument field of view. The rendezvous radar is limited primarily by the short range over which it can track passive objects. There are other constraints associated with rendezvous. Time lines must be worked until proper tracking and communication

coverage are available for the early maneuvers targeted by the ground.

With the advent of the Space Station era, the NASA may consider to enhance the Shuttle capability to perform on-orbit position determination of the Orbiter and deployed payloads. Enhanced capabilities are also required for the Shuttle to maneuver around the station while performing rendezvous and docking operations.

2.1.3.2 Potential Enhancements study

Use of the GPS for navigation would remove the constraints associated with ground control, star trackers and the Ku-band radar, assuming that the satellite to be met is not maneuvering and its state can be accurately determined by the ground and propagated accurately onboard. Availability of the GPS for navigation will greatly reduce navigation restrictions on flight planning, trajectory design, and flight control.

The use of laser sensors, accelerometers and strap-down gyros can also be used to improve range, range rate and acceleration determination accuracies.

2.2 Simulation and Evaluation

The resultant models for the potential enhancements described above have been incorporated into LinCsim as modularized software packages. Depending on the type of problem, analytical techniques, Monte-Carlo techniques or a combination of the two is used. The software has been debugged and verified. Finally, LinCsim has been exercised to evaluate the performances of these enhancements.

2.3 Other Supporting Studies

In addition to the above mentioned efforts, LinCom personnel was

directed by the NASA/JSC technical monitor on various supporting studies,

analyses, model development and link simulations to ensure that elements of

the Shuttle C&T Systems meet Space Shuttle Program (SSP) requirements. These

efforts are documented in Appendix 1-13.

APPENDIX 1. SPACE STATION MULTIPLE ACCESS SYSTEM

STUDIES AND ANALYSIS

PART I: EXECUTIVE SUMMARY

1.0 INTRODUCTION

Recently, LinCom was tasked in a three-month study to come up with a Space Station (SS) multiple access (MA) system conceptual design. One purpose of that effort, which imposed the time constraint, was to support the prototype breadboard development procurement of the SS MA antenna and RF subsystems under the JSC Tracking and Communications Division's Advanced Development Program. The results of that study were presented [1] in a JSC meeting on December 14, 1984.

Because of the hasty schedule and the very nature of a conceptual design, the emphasis on the study was to provide a basic set of system requirements, constraints, desirable features, options, and tradeoff criterions from which the MA system could evolve. In addition, a strawman system is provided to motivate some concrete issues that need to be addressed.

Shortly after the completion of this brief exercise, it becomes apparent to many that there are more issues that need to be raised, critical areas that need to be examined, and trade-offs that need to be made. It is believed that an early head-start on some of these problems will help track and complement the efforts of the Phase B contractors. As a consequence, we have been tasked during the last five months to revisit certain selected aspects of the MA system - concentrating on the more critical issues and problem areas this time. During this period, we have also looked at another aspect of the SS external communications function, namely, communicating with the TDRSS. This final report documents the findings of the current effort.

The final report can be divided into two parts. The first part is

this executive summary which serves to highlight the issues and trades

considered for some more complicated problem areas, and the results and

conclusions for other relatively straightforward ones. It also

identifies some critical areas that warrant further study. The second

part of this report consists of a set of appendices which contain a more

detailed treatment of each subject matter considered.

2.0 BACKGROUND

Figure 1 is a simplified block diagram defining the external SS

links under consideration. The Space Station MA system supports

communications between the Space Station (SS) and Extra-Vehicular

Activity (EVA), the Space·Shuttle Orbiter (SSO), the Orbit Transfer

Vehicle (OTV), the Orbit Maneuvering Vehicle (OMV), Free Flyers (FF),

and a Co-Orbiting Platform (COP). Another MA user, though attached to

the SS, is the Mobile Remote Manipulator System (MRMS). There can be up

to 10 MA users during the Initial Operation Configuration (IOC) and 19

MA users during the Growth Configuration.

EVA support is for a 1 km sphere around the Space Station, see

Figure 2. OMV/OTV support is primarily around a disc of 37 km in

radius, 18 km thick. There is also a requirement to communicate within

a region defined by the 185 km rectangle. This rectangle is actually a

curvilinear prism since the horizontal lines represent sections of

orbits parallel to the SS orbit. The FF/COP support is between 185 to

2000 km. Regions leading the SS are defined similarly.

The primary link between the Space Station and ground is through

the Tracking and Data Relay Satellite System (TDRSS). The operational

TDRSS consists of two satellites, TDRS-East and TDRS-West, and a ground

station at White Sands (WSGT). Since the TDRSS is not really designed
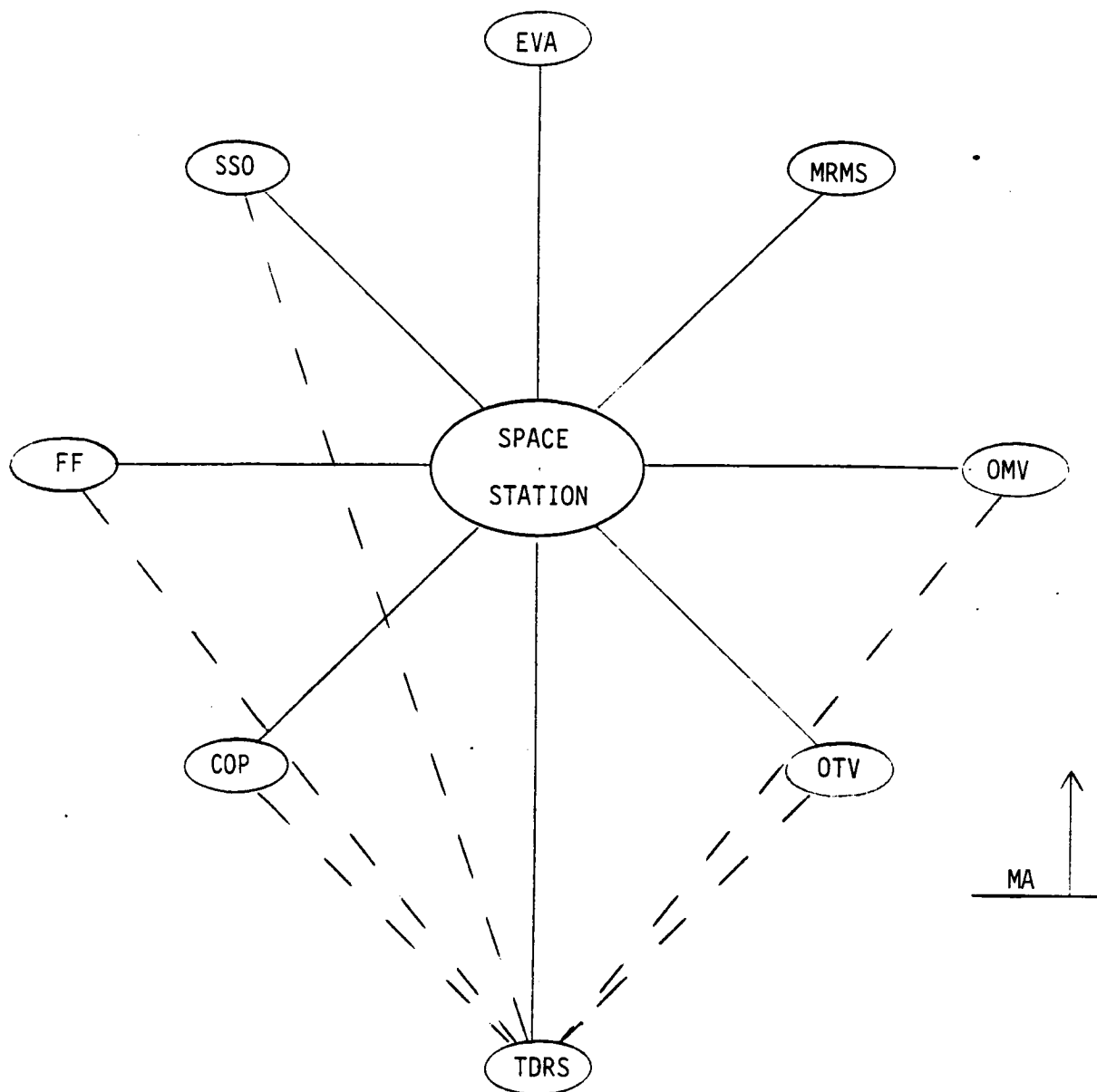
Figure 1.   SPACE STATION MULTIPLE ACCESS
SYSTEM AND INTERFACE WITH TDRSS
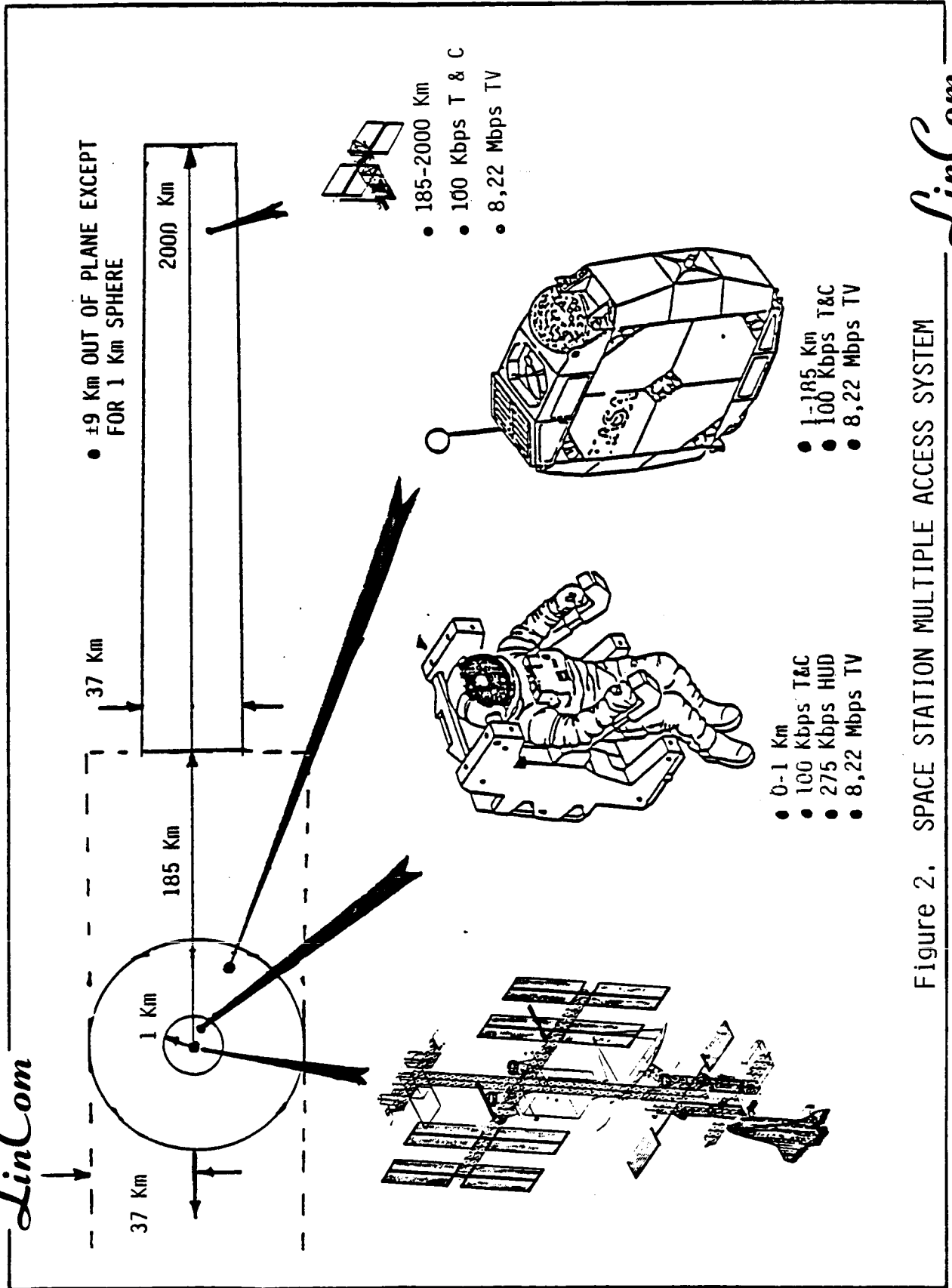
Figure 2. SPACE STATION MULTIPLE ACCESS SYSTEM

- ±9 Km OUT OF PLANE EXCEPT FOR 1 Km SPHERE

2000 Km

37 Km

185 Km

1 Km

37 Km

- 185-2000 Km
- 100 Kbps T & C
- 8,22 Mbps TV

- 1-185 Km
- 100 Kbps T&C
- 8,22 Mbps TV

- 0-1 Km
- 100 Kbps T&C
- 275 Kbps HUD
- 8,22 Mbps TV

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for the SS communications load, there is some concern as to what is the

best way for the SS to share this NASA resource. Note that some MA

users would also like to communicate with the TDRSS. The ability to

simultaneously serve the SS and these MA users in a "cluster"

configuration adds another dimension to the problem of straining the

capability of the TDRSS.

3.0 MA SYSTEM STUDIES

3.1 FDMA Issues

The earlier study [1] recommended a SS MA system baseline based on

a demand-assigned Frequency Division Multiple Access (FDMA) scheme. The

FDMA scheme offers many advantages over other systems such as TDMA, CDMA

and FHMA, in view of the SS requirements. These advantages include: low

user complexity, good bandwidth efficiency, matured technology, low EIRP

requirement compared to TDMA, and low overall system cost. However, the

FDMA scheme is not without drawbacks. In what follows, our efforts on

the issues associated with employing a FDMA system for the SS are

summarized. First, the issues associated with channel allocation are

considered. They include regulatory considerations, nonlinear and

bandlimiting effects, and oscillator stability. Implementation issues

involving the user equipment architecture and commonality as well as

multiplexing, formatting and synchronization are considered next.

3.1.1 Frequency Management

The immediate questions for a demand-assigned FDMA system are

related to frequency management: How much total bandwidth is required?

How much is available? Can the power flux density impingement limits

on Earth be satisfied? What much bandwidth should be allocated to a

channel? How should the channels be placed on the frequency plan? For the first two questions the conclusions from this study are:

- Roughly 200 MHz bandwidth for forward and 400 MHz bandwidth for return are required.

- The exact frequency allocation at K-band should be left to NTIA.

- Power Flux density is a problem when nondirectional antennas are involved. A spectrum spreading technique such as direct sequence spreading should be used for the orderwire channel (required for demand assignment) to meet the power flux density limits. TT&C channels may need relief.

Several guidelines have been established for channel allocation regarding the last two questions:

- To minimize degradation, the channel bandwidth and guard band between channels should be as wide as possible to take advantage of the available MA system bandwidth allocation.

- The strong channels and weak channels should be separated as far as possible in frequency.

- There will be other non-SS related users of the MA frequencies. To mitigate their interferences, the MA system should provide channel diversity as well as a communication time-out capability.

3.1.2 Interferences Due to Bandlimiting and Nonlinear Operation

Nonlinearities in the transmitter (RF power amplifier) and the receiver (low noise amplifier and mixer), coupled with signal bandlimiting, give rise to interchannel interference (ICI) and intermodulation (IM) products that affect FDMA system performance. ICI refers to the spilling over of the signal spectrum tail of one channel

to adjacent channels. IM product refers to cross-products of two or more signal which fall into other channels, when they pass through a common nonlinearity.

The options available for the SS MA system to mitigate these distortions are:

- Use more bandwidth per channel. The cause for ICI is nonlinear operation on a bandlimited signal. Hence, it can be mitigated by using a RF bandwidth equal to at least 3 to 4 times the symbol rate. This however affects the system bandwidth requirement. Another possibility is to use a more bandwidth efficient modulation scheme, see later discussions under modulation selections.

- Back off HPA. The more the HPA is backed off, the less nonlinear it is. Unfortunately, the transmit EIRP will be less.

- Use post-HPA filtering. Aside from cost and power attenuation loss considerations, this may be impractical for low rate channels because of the high selectivity required.

- Separate weak and strong channels. By separating the weak and strong channel in frequency, interference rejection via filtering becomes more practical.

- Use power control. The EIRP differences between strong and weak channels can be reduced by judiciary power control. To implement power control, the user equipment may require additional complexity.

All these options, with the exception of separating strong from weak channels, incur a cost. Hence careful trade-offs must be performed in finalizing a particular implementation.

Because of the complexity due to the large number of variables

(nonlinearity model, power level, signal format, filter, frequency assignment, etc.), computer simulation appears to be the only viable tool to analyze this problem. An approach to attack this problem has been outlined as a part of the study.

3.1.3 Oscillator Stability

One of the fundamental limits of how close two channels can be packed together under a FDMA scheme is the frequency stability of the two carriers. Over a typical space operational lifetime of 7 years, the frequency of an oscillator from which the carrier is derived will drift if a crystal oscillator is used. (Space operation requirements and cost considerations usually preclude the use of atomic standards.) Environmental effects such as temperature variation, vibration, g-force loading, shock, load and voltage changes can all contribute to the fluctuations in the output frequency of the crystal oscillator.

It appears that for K-band operation, commercially available oven-controlled crystal oscillators will drift no more that 5 KHz in either direction. Since the cost of this oscillator is only on the order of $1,000, stepping down to a less capable crystal oscillator is not much of a tradeoff. With the oven-controlled oscillator, the guard band to be allocated between FDMA channels to account for long term oscillator instability should be about 10 KHz. The bandwidth premium to be paid for the guard band is only significant for low data rate channels and does not really affect the utilization efficiency of the total allocated spectrum.

3.1.4 User Commonality

The central issue here is to come up with a common set of user

equipment capable of serving all MA user links in order to share development cost and to standardize equipment. The three major areas in the design of the user transceiver are the architecture of the RF/IF subsystem, the modem and the codec implementation.

The RF/IF subsystem provides frequency translations. It could also provide channel multiplexing/demultiplexing (mux/demux) filtering functions. The mux/demux functions can also be done in the modem. Since a user can have multiple links requiring multiple modems, it is more desirable to minimize channel-dependent processing at the RF/IF subsystem level so that the same IF signal can be used to feed the modems. Besides, it is less costly to filter at the modem level. Criterions for selecting the IF frequencies are also addressed in this study.

Since the modem is required to support a wide range of users and data rates, it should be a "smart" modem. It appears that a microprocessor-based digital modem will be required. To facilitate mux/demux filtering, a double heterodyne technique is proposed. Criterions for IF selection have been considered. It is also recommended that the A/D subsystem should be implemented with two different logic families: high speed ECL for the TV data rate and low power CMOS for other data rates. However, the two subsystems should be plug-compatible to maintain commonality. (The rest of the modem is not really data rate dependent.)

Commercial convolutional rate 1/2 codec chips will be available for data rates less than 5 Mbps. It appears that the SS user coding schemes should be standardized based upon these chips for all non-TV links. For high rate TV, the chips are not directly applicable. Anyway, bandwidth expansion associated with rate 1/2 codecs for TV data is a problem for

efficient spectrum utilization. If coding is needed to improve performance margin for this link, a more comprehensive study is required.

3.1.5 Multiplexing, Formatting and Synchronization

For the SS, the baseband digital processing subsystem/modem is not collocated with the RF subsystem. Depending on the signal distribution method selected, frequency multiplexing can be best done at either ends. The trade-off here is ease of implementation. There are also up to three types of antenna system covering different user ranges. The grouping of users served is a driver for arranging channels on the frequency plan.

The important issues for selecting the data format (mainly the block length) are overall data transfer efficiency and bit slippage rate. As a rule of thumb, the product of the bit slippage rate and the number of bits in a frame should be at least 10 times smaller than the bit error rate. Considerations for data encryption is not a big driver for format selection.

Carrier and clock recovery should not be too serious a problem except for low rate channels. For the purpose of frequency co-ordination, the SS should consider including a pilot in its signal transmission. This pilot can be used by the user for calibration during periods of benign Doppler and for compensating Doppler while in the high dynamics state.

3.2 Other Issues

3.2.1 Modulation Schemes

Since the channel is usually nonlinear due to the near saturation

operation of the HPA for maximum output power, modulation techniques are pretty much limited to the class of constant envelope modulation schemes. This precludes Quadrature Amplitude Modulation (QAM), Quadrature Partial Response (QPR), Amplitude Phase Shift Keying (APSK), etc., that can provide more bits/Hz. What remains is the class of modulation schemes that only uses phase variations in the signal to transmit information. One could use Continuous Phase Modulation (CPM) which can be more bandwidth efficient if the higher order forms are used. However, CPM receiver structures are often complicated, requiring Viterbi-type phase trellis decoders.

If a reasonable amount of bandwidth is available, QPSK (Staggered-QPSK) appears to be a logically compromise. Differential encoding should be used with QPSK to avoid ambiguity resolution and to combat cycle-slipping and slow fading, even though it incurs a 0.3 db performance penalty. If sufficient bandwidth is not available, then a price in terms of performance and modem complexity must be paid. The degradation will be a function of the nonlinearity, available bandwidth, and the modulation technique used. The only dependable way to predict performance is through simulation.

3.2.2 Orderwire Channel

Two general approaches to implementing the orderwire channel have been identified. In a random access approach, perhaps the simplest, the user access a common orderwire whenever he desires. A conflict may exist if two or more users access the channel at the same instant. However, this occurrence is rather remote for the SS scenario. There are also well known techniques to resolve this conflict if it indeed occurred. In a deterministic approach, e.g., with TDMA, CDMA, or FDMA,

the orderwire is uniquely allocated to a user so that no conflict is possible. Out of the three, TDMA is the most complicated. CDMA has the advantage that it is compatible with a SS-based ranging system, yet it has the disadvantage of requiring a more complex receiver.

A preliminary investigation of the amount of data required in an orderwire data packet was also completed. Most of the information bits will be allocated to the user/SS location and velocity to aid antenna pointing. The position requires roughly 18 bits per axis; the velocity requires 12. The total number of bits of the data packet is on the order of 170.

3.2.3 Alternate Approaches

Potential alternatives to the SS MA system have also been studied. An attempt has been made to identity a simple, minimal alternative using existing and/or TDRSS-compatible capabilities. A evolutionary approach is envisioned; the capabilities are added as required during buildup, IOC, and growth.

The key is to use two or three different systems for (1) the EVAs, (2) the MRMS, and (3) the rest of the users. TV support is only provided to the first two users. The Shuttle, EVA and MRMS should be interoperable during buildup. The rest of the users will be served by an S-band MA service during IOC using signal formats compatible with TDRSS S-band link services. Dedicated channels (similar to SSA) will be time-shared while low data rate support will be via a TDRSS MA-type scheme. During growth, the SS S-band MA system can be upgraded to K-band where more bandwidth will be available. The S-band signals can be used as a first IF so that most equipment can be salvaged. One potential problem with the above approach is the potential interference

with the SS/TDRSS link.

3.2.4 Mobile Remote Manipulator System (MRMS)

There is a requirement to provide a minimum of 6 video channels for the MRMS. Assuming that digital TV at 22 Mbps is used, the composite data rate is 132 Mbps. In order to conserve bandwidth and to simplify transceiver design, the six channels should be time-division multiplexed into a composite superchannel. Both RF and optical links have been examined for the MRMS link. In terms of link margins, both appear feasible. Hence the tradeoff criterions are cost and ease of frequency management. For RF links, issues concerning using 3-12 GHz and higher frequencies (20 to 60 GHz) are examined. The advantage of the lower frequencies is the commercial availability of stock bandwidth efficient (3 bits/Hz) digital radios designed for microwave links.

Both fiber and free space optical links are considered. The problems with a free space link are transmit power and blockage. The main problem with the fiber approach is the handling of the fiber as the MRMS travels.

Analog NTSC TV has also been considered. It is probably the least expensive approach in terms of bandwidth (6 MHz/channel) and hardware requirements. However, it is not easily made amenable to encryption for privacy.

4.0 TDRSS UTILIZATION

Since the SS, as well as some MA users such as the Shuttle, OMV, OTV, etc. relies on the TDRSS for communicating with the ground, it is important to assess the TDRSS capability in terms of supporting this "cluster" of users. Tnere are two kinds of services provided by the

TDRSS: (1) standard services consisting of the MA, SSA, and KSA links and (2) IF services. The current capabilities of both services have been examined here. In addition, the actual capabilities of the space and the ground segment, not necessarily associated with the services, have been assessed. Eventually, the TDRSS has to be enhanced to fully support the SS. We have looked at ways of enhancing the TDRSS with a minimal impact on the existing system.

4.1 Standard Service

In order to use the standard TDRSS service, the user has to adhere to a fixed signal format and carrier frequency assignment. The following standard TDRSS capabilities for SS cluster support have been identified:

- Only one KSA user can be supported per TDRS single access antenna because of the narrow beamwidth.
- Two KSA users can be supported per TDRS via polarization diversity.
- SSA return link bandwidth is limited by the TDRS space-ground link which is 20 MHz for forward and 10 MHz for return.
- It is feasible to provide simultaneous SSA/KSA support although the coverage zone will be determined by the KSA autotrack system. Polarization diversity can be used for KSA; either polarization or frequency diversity can be used for SSA.
- Multiple TDRSs are not efficient for providing more KSA links and does not increase MA support. However, it can double the number of users supported by SSA.

4.2 IF Service

The IF service allows a certain degree of flexibility in selecting the signal characteristics. The following raises some of the issues:

- IF service allows more efficient usage of the KSA channel by using bandwidth efficient modulation schemes. For example, it is likely that up to 500 Mbps can be supported with Octal Phase Shift Keying (8PSK) modulation. Which modulation scheme is the best?

- FDMA can be used to support multiple users with KSA. What are the effects on the TDRS autotrack system if FDMA is used? What degradations are to be expected from the FDMA composite signal through the nonlinear TWTA used for the TDRS space-ground link?

- If time-sharing is used to support the SS cluster, what operational modifications are required to minimized re-acquisition from user to user?

- What additional ground equipment is required to support IF service?

4.3 TDRSS Enhancements

We have concentrated in this effort only on enhancements that require minor changes. Consequently, we have skimmed over issues such as adding a 60 GHz crosslink between the TDRSs. Our recommendations are as follows:

- Open up the SSA channel for SS cluster users. This requires adjusting some filter bandwidths, space-ground link EIRP and frequency separation between SSA1 and SSA2.

- Reuse the defunct Advanced Westar (AW) capability. The AW K-band equipment can be used for dedicated SS support. The issues to be considered are regulatory aspects of frequency co-ordination,

antenna pointing, and G/T. The C-band equipment can be used for
space-ground link to JSC, GSFC, etc. to alleviate the TDRSS
NASCOM traffic bottleneck. To implement this, the TDRS will need
the capability to select space-ground links.

- Use the spare TDRS-Central as an operational satellite. Other
users can offload some data traffic to TDRS-C to make way for the
SS users. In addition, the SS users can use it for high rate
data dump using both KSA links when visible.

5.0 RECOMMENDATIONS

Before any of the details of the MA FDMA system can be studied in
a meaningful way, it is very important that a frequency plan be
specified and approved by the regulatory agencies. Hence, an early
frequency allocation is desirable to minimize wasted effort.

The TV link is the biggest user of the allocated bandwidth and
therefore deserves special attention. One way to reduce its impact is
to use bandwidth efficient modulation scheme. Unfortunately, there are
other constraints. The EVA is the primary user of the TV link and it is
power starved. Bandwidth efficient schemes require complex modems which
are likely to be power hungry. Another way to reduce power consumption
is to reduce the EVA transmit power by the use of coding. However,
coding involves bandwidth expansion and additional hardware. It appears
that the TV link problems as they relate to signal processing, channel
allocation, coding, modulation, modem design and implementation, etc.
will need to be studied in a more comprehensive and extensive manner.

Another issue is the impact of the recommendations of the
Consultative Committee for Space Data Systems (CCSDS) URSI standards.
Two key questions here are: What is the impact of total compliance with

CCSDS standards? If total compliance is not desirable, how should the standards be modified for the SS MA system?

Finally, it is desirable to come up with a SS-based combined communication and tracking system to serve the users as an alternative option to a multi-target radar system for mid- to far- range. This would provide some cost and frequency management advantages.

REFERENCE

[1] "Space Station Multiple Access System Conceptual Design", presented on December 19, 1984 under Contract No. NAS 9-17152.

PART II. APPENDICES A-M

APPENDIX A: COMMENTS ON LOCKHEED MA BASELINE

Here are some comments on the MA baseline. Most are just typos and points requiring clarifications. The more important ones are comments on the high power amplifiers and the TV/ops data multiplexing scheme. The headings correspond to the different sections of the Agenda.

1. Requirements and Ground Rules.

   - How does one schedule time-sharing for the two-way order-wire channel?

   - Is a 22 Mbps Viterbi decoder practical?

   - Typo on last chart in group regarding BER.

2. Frequency Planning and Allocation.

   - LinCom frequencies are selected to be the same as TDRSS to take possible advantage of their RF hardware implementation/experience.

   - On page ZT/7-b, bps should be sps.

4. Antenna/RF/IF Systems

   - Figure 2. OW TDM. How practical? Typo at the end of backup material for Figure 2 - will will. Need more description of the OW channel.

   - How can a gimballed antenna support 5 users? How does the reflector cluster type antenna look?

   - Need a coordinate system definition for Figure 5a.

   - On High gain antenna page. Look at the TRW SSDS study scenario where users are scheduled very infrequently.

- Proposed antenna system for SS and User. Major problem here about the 10 W linear PAs. Since the users are on FDMA, there is no need for a 10 W PA. Combining a number of dedicated low power PAs at the antenna feed is a better solution since there is really no coherency requirement. This avoids the low efficiency, expensive high power PAs. The same comment applies to the 45 W design example.

6. Modulation Considerations

- Recommendations. Why is differentially coherent detection complex?

6. Video Considerations

- Multiplexing ops data with TV is OK when both are present. The situation is a bit sticky when TV is no longer present. Why would one want to transmit and receive at high power mode (high TV data rate) while the need does not exist? Doesn't one want to conserve power on the EMU? Also, do we transmit at pulse mode, i.e., only on the slots where there are ops data, or do we transmit dummy TV data? Isn't it nice to have a backup link (if the ops data link is separate)? What if EVA ventures beyond the TV coverage range and still wants ops data coverage?

APPENDIX B: REVIEW OF HUGHES MA ANTENNA BREADBOARD PROPOSAL

General Comments

One of the advantages of the active lens antenna concept is that the final RF high power amplification stage can be performed by a number of solid state power amplifiers (SSPA). This avoids the need to develop a 50 watt linear TWTA. However, a phase control problem has to be traded off.

The disadvantage is that we are talking about roughly 40 beams. With the beam control system added (which most likely requires a computer), the active lens concept appears to be riskier, more complicated and more expensive than using fixed beams. This is primarily due to the R&D nature of the project.

Miscellaneous Comments.

p.3. It will be interesting to have a copy of their preliminary tradeoff study to find out the rationale behind choosing an active lens antenna over the conventional MBA, or the multiple fixed beam concept. It would appear that they may "just want to gain the experience".

p.4. Note that Hughes' experience does not include active lens antenna designs. This is an R&D type of program for them.

p.5. The 40 dB to 47 dB gain requirement appears to be high.

p.9. Both power divider breadboards look pretty bulky (see Figs. 9 & 10). How many are needed? A 40 db gain beam has a HPBW of approximately 1.5 degree. To cover Figure 2b, it would appear that one needs about 40 "feeds". Does one need 40 power dividers?

Comments on Detailed Design and Trade Studies

The technique for phase delay variation compensation required for signal coherency through the lens elements has been left out. This will be a major problem area (LinCom has considerable experience with the various approaches, tradeoff, etc.) This is an important issue since the accuracy of phase compensation can affect the performance of the antenna e.g., beamwidth, beamsquint, sidelobes, nulls, and usable RF bandwidth. Apparently, the demonstration model is to be adjusted manually so the problem may not show up. The question is: Are periodic adjustments and recalibration required while in operation? What will be the size of the phase control system? The same comment applies to the BFN.

Not all beams are required to have the same HPBW/gain. Can this help in simplifying the design?

What about packaging; size, weight and power; and beam control?

What about calibration?

What about a test plan?

What is to be verified in the way of performance?

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APPENDIX C: MORE COMMENTS ON LEMSCO MA BASELINE

1. FREQUENCY SELECTION

The frequency band between 13.8 and 14.0 GHz is used by the Shuttle radar. Hence, it is not desirable for use by the MA forward link as proposed earlier. A more appropriate band will be the proposed alternate band from 13.4 to 13.7 GHz, if one wants to conform to the TDRSS frequencies.

The Shuttle radar example carries a deeper message. The band from 13.4 to 14.0 GHz are allocated primarily to radiolocation, hence one expects to find other radar users at this band. Equivalently, there will be other primary users for any other band. The interferences from these users must be accommodated. The point is to design the MA system so that it can cope with these interferences (not necessarily overcome them).

The final frequency plan must be approved by the NTIA. Hence, the best approach is to have them find the frequency bands at K-band between 12 to 18 GHz.

2. TV/OPS DATA MULTIPLEXING

If a user switches often from TV + OPS data to OPS data only and vice versa, then one has to worry about the signal dropout time penalty associated with the transition from one data rate to another. This time includes the time to alert both parties (SS and user), effect the actual transition by switching the transmitter, detect loss of lock by the other party, switch to another receiver, and finally acquire.

The hardware penalty of the multiplexing scheme is not an important issue since the digital TV format requires multiplexing anyway.

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APPENDIX D: ALTERNATE APPROACH FOR MA

1.0 INTRODUCTION

This memo is an exercise in examining potential alternatives for the Space Station MA system. The approach adopted here is to identify the simplest alternatives, not necessarily the best. The primary motivation is to use existing and/or TDRSS-compatible capabilities where possible. There are basically four groups of users: the Shuttle, the EVAs, the MRMS, and the rest of the mid- to far-range users. The MA capabilities envisioned are evolutionary; they are added as required during buildup, IOC and growth.

2.0 OPERATIONAL SCENARIO

During buildup, the MA users will consist of the Shuttle and the MRMS. The MRMS will need to be controlled by the Shuttle. (An alternative is to be controlled by the ground through the SS/TDRSS link).

During IOC, the MA users will consist of the Shuttle, the MRMS, EVAs, one OMV, one platform and a few free-flyers. The free-flyer/OMV traffic will probably be light so that the MA system does not have to serve too many users at the same time.

At the growth stage, the MA system has to double or triple its IOC capability in term of the number of users to be served.

3.0 MA ALTERNATIVES

The key here is to use two or three separate systems for (1) the EVAs, (2) the MRMS, and (3) the rest of the users. Both the EVA and the MRMS may require real-time, continuous (up to hours) TV coverage and are

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close range users. The requirement on the antenna system is 360 degrees coverage with low gain. Assuming 6 full TV channels at 22 Mbps, the MRMS requires 132 Mbps. Assuming 4 full TV channels at 22 Mbps, the EVA support requires 88 Mbps for supporting 4 EVAs during growth. These data rate and antenna requirements for the EVA and the MRMS are quite distinct from the rest of the users. For this reason, the MRMS and EVA should be supported as one (or two) independent service.

The rest of the users do not really need to be in contact with the SS continuously or in a particular time slot. Normally, they will be controlled by the ground through the TDRSS. They only need to communicate with the SS in the rendezvous zone where they will be controlled by the SS. Full rate TV is something that is nice to have but probably not really essential. Hence, this group of users is characterized by relatively low data rates, and moderate to high SS antenna gain because of the distance to be covered.

3.1 MRMS and EVA Services

The MRMS and EVA services should be designed to share the RF/IF equipment to be cost effective. For example the gap fillers for the EVA antenna system should be shared by the MRMS. However, 100 percent sharing may not be desirable or cost effective because of the slightly different operational requirements.

The MRMS should use a multiplexed composite channel for the 6 TV channels at a 132 Mbps data rate. This eliminates the guard bands to separate the 6 channels for a FDMA scheme. If we assume a fairly efficient modulation scheme, the MRMS service requires roughly between 150 to 200 MHz of bandwidth.

The EVA channels should be FDM, same as the baseline system

requiring about 200 MHz of bandwidth.

Because of the proximity operation and the high data rate advantage, both the MRMS and the EVA services are neither likely to interfere with other frequency allocations nor be interfered. This gives the two services flexibility in frequency allocation. We shall tentatively assume that they will operate in a 500 MHz band somewhere between 14 to 18 GHz that does not interfere with other communications functions of the SS.

During buildup when the MRMS is to be controlled by the Shuttle, the MRMS comm system can be a payload on board the Shuttle. This payload package will become a spare after buildup.

3.2 S-Band MA Services for IOC

The rest of the users are served by an S-band MA service during IOC. The signal format will be compatible with the TDRSS SSA, S-band Shuttle transponder, and MA services of the TDRSS. Most users will use the TDRSS/MA format for continuous telemetry coverage (up to 50 Kbps) and will only use the TDRSS/SSA format for periodic (perhaps 10 minutes) high data rate coverage (up to 6 Mbps), same as the current practice for TDRSS users. Because of the 100 MHz bandwidth available, it appears 2 or 3 SSA-type channels can be accommodated, in addition to the SS/TDRSS SSA channel.

This capability should be adequate for IOC. The advantage of this particular approach is that the users do not need to procure additional hardware to communicate with the SS. The selection of S-band is pragmatic. Unless there is a need for imaging data, most spacecrafts will only use the S-band capability of the TDRSS. This is true, for example, for the currently planned Shuttle-based OMV where the plan is

to use the S-band service and transmit slow-scan TV.

The IOC antenna system for the S-Band service should consist of a TDRS type MA antenna and two or three single access antenna. The single access antennas should be designed to handle both S- and K-band signals by employing dual S- and K-band feeds.

3.3 Upgrading the S-band MA service for Growth

During growth, the S-band MA can be upgraded to K-band where more bandwidths are available for more (high data rate) users. The S-band signals can be used as the first IF so that most of the equipment can be salvaged during the change over.

4.0 POTENTIAL PROBLEMS

One potential problem with this approach is that the S-band system may interfere with the TDRSS operation. Also, if one is to upgrade the system to K-band during growth, the frequency bands must be selected and built into the antenna/RF system during IOC.

APPENDIX E: PRELIMINARY MULTI-CHANNEL MRMS ANALYSIS

SUMMARY

RF and optical links are examined in light of the MRMS requirements. In terms of link margins, both implementations appear feasible. The remaining questions are cost and frequency management. For RF links, issues concerning using 3-12 GHz and higher frequencies (20/30 or 60 GHz) are examined. The advantage of 3-12 GHz is the commercial availability of stock bandwidth efficient (3 bits/Hz) digital radios designed for microwave links. Both free space and optical fiber transmission are considered for optical links. Analog TV is also considered. It is probably the least expensive approach although digital encryption techniques cannot be used to ensure privacy. A ground-based eavesdropper, however, may not have the needed sensitivity to pick up the TV signal.

1.0 MRMS DATA TRANSMISSION REQUIREMENTS

There is a requirement to provide a minimum of 6 video channels for the MRMS. Assuming that digital TV at 22 Mbps is used, the composite data rate is 132 Mbps. In order to conserve bandwidth and to simplify transceiver design, the six channels should be time-division multiplexed to form a composite superchannel. (Multiplexing/demultiplexing at 132 Mbps should not be a technology issue).

Two transmission options are available for handling the composite video channels: RF or optical. Before examining the options, it is worthwhile to look at the physical aspects of the MRMS configuration and the issues involving placement of the (RF) antenna or (optical) telescope on the SS structure.

2.0 MRMS STRUCTURAL ASPECTS

The MRMS could move on either the front or back side of the upper and lower keels, the keel extension and the transverse boom as shown in Figure 1. Figure 2 is a detailed diagram of the proposed deployable single fold beam for the keel and boom struss structure. A large cross-section (9 X 9 feet) is proposed to provide a wide track for the MRMS and the payloads it must carry, and also to provide a large open area inside the packaged beam for incorporation of utility lines. The proposed MRMS is shown in Figure 3. It consists of three layers and is only 1 bay (9 X 9 feet) square. It can access all four surfaces of the beam structure by moving 1 bay at a time. The Shuttle RMS and the foot restraint positioning arms can move longitudinally along the platform edge they are on.

2.1 MRMS Transmit Antenna Placement Options

The transmit antenna (antenna here also applies to the optical telescope) can be placed either (1) on the platform, (2) on a tower on the platform, or (3) under the platform. The first two options may potentially interfere with the operation of the foot restraints and the RMS. If the antenna is mounted on the platform then some positions of the foot restraints and the RMS may block the line-of-sight of the antenna. In that case, an alternate receive antenna must be visible. If the antenna is mounted on a small tower then the tower structure may interfere with the operation of the MRMS. The third option can potentially alleviate the interference problem. However, the antenna in this case must be retractable so as not to interfere with the movement of the MRMS platform. Also the (partial) blockage within the beam

ORIGINAL PAGE IS
OF POOR QUALITY

Side view

Power
conditioning
radiators

Array mast

Array wing

Transverse
boom

Lower radiators

Upper boom

Upper keel

Lower keel

Keel extensions

Lower boom

9'

Front view

A

B

C

396'
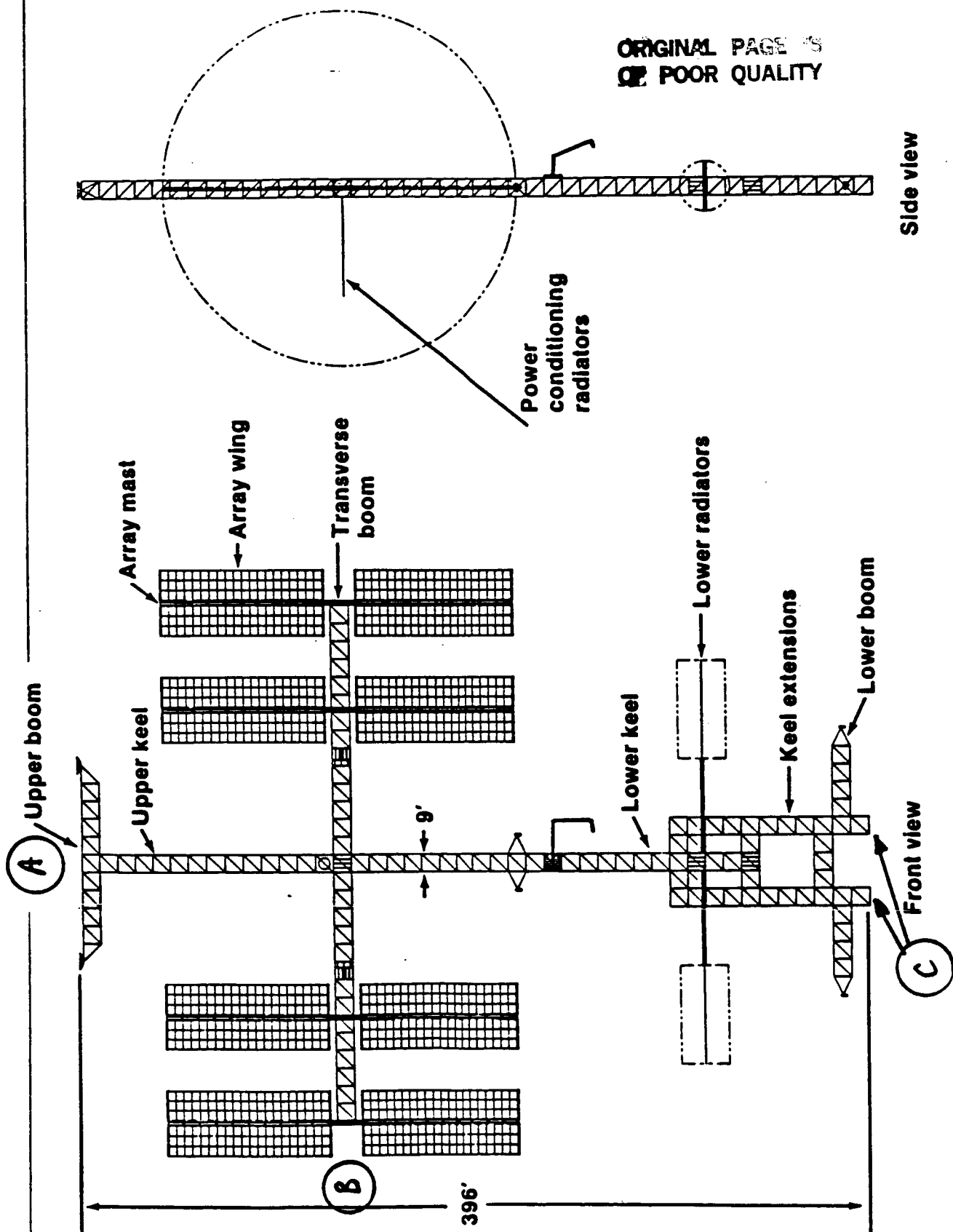
Figure 1. - OVERALL SPACE STATION DIMENSIONS AND NOMENCLATURE
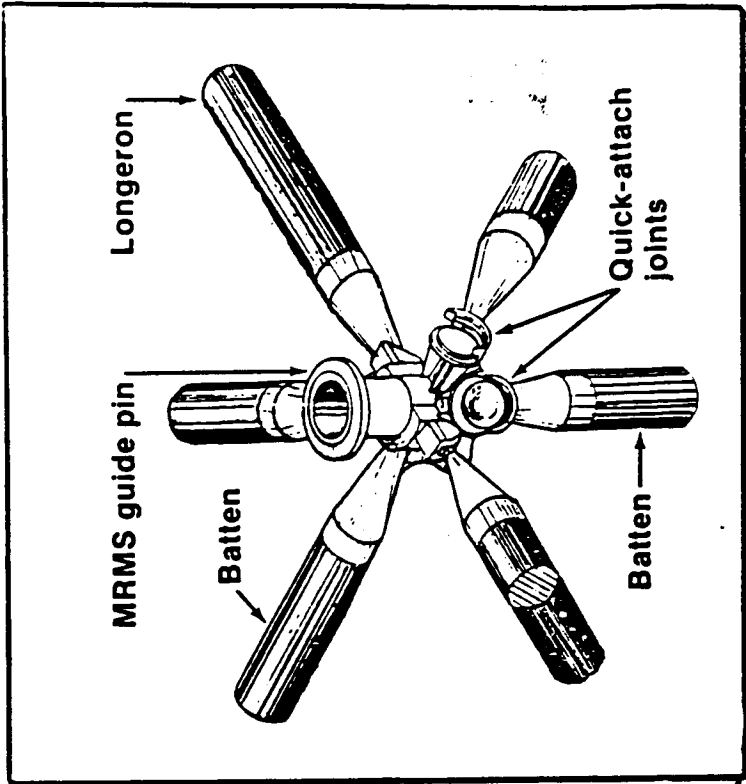
Deployable joint detail

Longeron

Quick-attach joints

MRMS guide pin

Batten

Batten

Folding longeron

Telescoping diagonals

Side view

9'

End view

Longerons

Diagonals

Battens
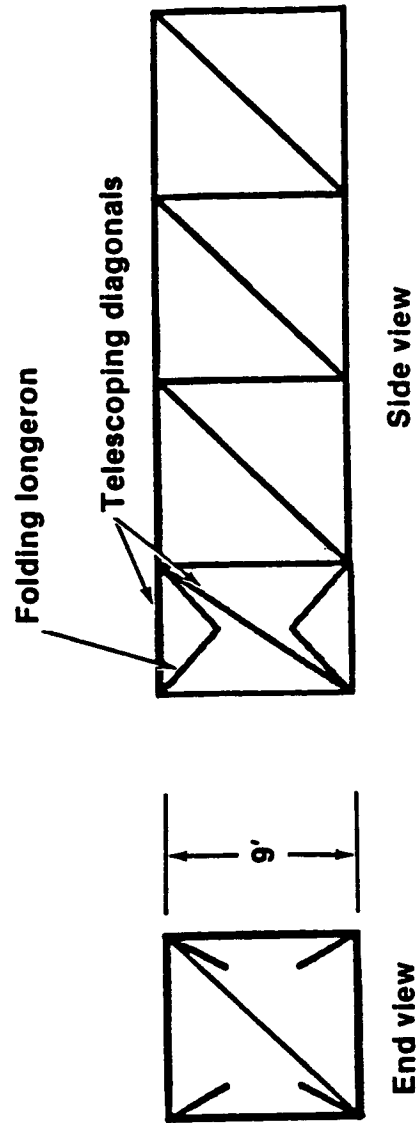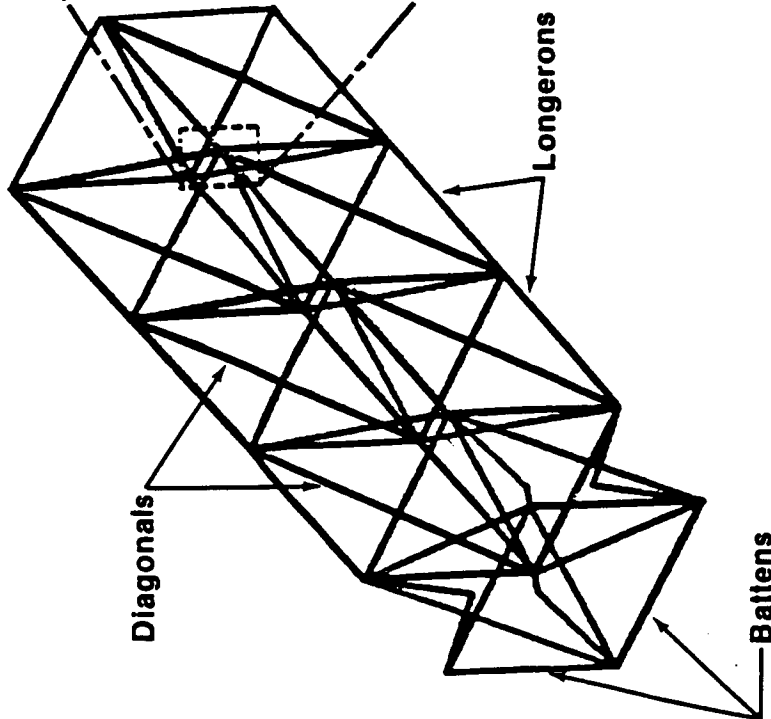
Figure 2. - SCHEMATIC OF DEPLOYABLE BEAM SHOWING ONE BAY BEING DEPLOYED AND DETAIL OF JOINT

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SHUTTLE RMS

ROTATING LOGISTICS PLATFORM

PUSH/PULL DRAWBAR

FOOT RESTRAINT POSITIONING ARMS

ROTATIONAL DRIVE

TRACK LAYER

7

GUIDE PINS

CORNER SWITCH (4)
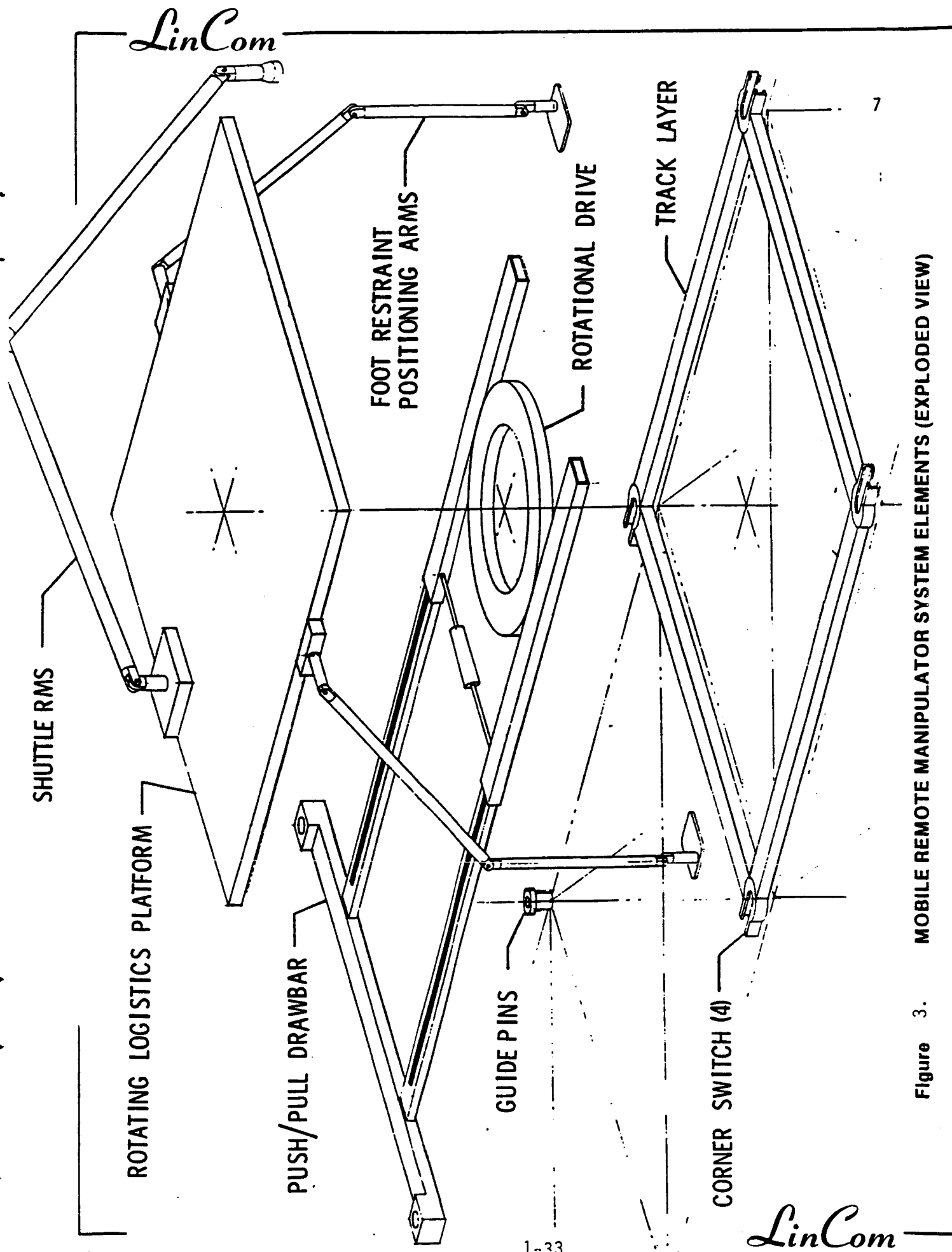
Figure 3.   MOBILE REMOTE MANIPULATOR SYSTEM ELEMENTS (EXPLODED VIEW)

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enclosure "tunnel" due to the utility lines or flexing of the beam must be taken into consideration.

2.2   MRMS Receive Antenna Placement Options

To provide receiving coverage for the MRMS, multiple antennas must be used. The minimum number of antennas is two - one each on tall extension structures on the front and back side of the keel overlooking the SS from both sides. If such a concept is used, then both the transmit antenna on the MRMS platform and the receive antenna on the SS must be capable of pointing and tracking, unless the antennas are omnidirectional. It appears that, at least one of the antennas - most likely the one on the MRMS platform - can use some directional gain.

If the antenna on the MRMS is only required to point along the keel and the boom, then the antenna is only required to either point straight ahead or back (180 degrees). With this technique, one requires two antenna sites at one end of the transverse boom and at one end of the keel (see locations marked A and B in Figure 1). If the MRMS antenna is above the platform, then a set of two antenna are required at each site - one on each side of the beam structure. If the antenna is below the platform, then only one antenna is required per site. To cover the keel extensions, passive reflectors can be used. Or, one can put two more antenna sites at the two ends of the keel extensions (see locations C in Figure 1).

3.0   RF SYSTEM OPTIONS

The main driver in picking the RF frequency is to avoid interference to other SS RF links (at S and K band), or terrestrial users. The most straightforward solution is to pick the 20/30 GHz band

or the 60 GHz band to avoid interference. On the other hand, the lower frequencies i.e., between 3 to 12 GHz may prove to be attractive since stock digital radios (see next section) with 1 to 10 watts of transmit power are available. However, the use of these frequencies will be predicated on approval by regulatory agencies. Because of the distance advantage (150 m operating range vs 400 Km orbit), the associated space loss would minimize interference to and from terrestrial users.

Figures 4 shows a link budget for a hypothetical C-band link at 6 GHz. All parameters are conservative, and even then the link has an 18 db margin with a small size antenna (7 cm diameter). Figure 5 shows a link budget for an alternate hypothetical 60 GHz link. In order to compensate for the increased space loss, the antenna gain has to be increased to 20 db, resulting in a 2 cm dish. It appears that both systems have plenty of margin. Hence, cost and frequency management will be the main considerations.

3.1 Stock Microwave Digital Radios

The widespread use of PCM equipment for Telco toll and trunk circuits has supported the market for commercially available high bandwidth efficiency (3 bits/Hz) digital radios. The technique and hardware necessary to carry two DS3 streams (1344 voice channels, or 90.258 Mb/s with auxiliary 12 - 32 Kbps channels) in a 30 to 40 MHZ RF bandwidth has been well established since the late 70's. The modem employs 8PSK or 16/64 QAM and uses direct RF modulation.

Figure 6 shows a Rockwell/Collins flyer for their 8PSK digital radios while Figure 7 shows their QAM digital radios. Note that they cover the 3 - 12 GHz range. For example, the MDR-2306 at 6 GHz can handle 3 DS3 streams at 135 Mbps.

LINK BUDGET

TRANSMITTING SATELLITE DESCRIPTION
   TRANSMIT POWER,   W   1.00
                    DBW   0.00
   TRANSMIT LOSS, DB   -1.00
   TRANSMIT ANTENNA GAIN, DB   10.00
   ESTIMATED DISH DIAMETER, CM   6.89
   EIRP, DBW   9.00
   ANTENNA POINTING LOSS, DB   -1.00

SYSTEM & TRANSMISSION LOSSES
   SYSTEM AGING EFFECTS, DB   0.00
   SPACE LOSS, DB   -91.53
             RANGE, KM   0.15
         FREQUENCY, GHZ   6.00

RECEIVING SATELLITE DESCRIPTION
RECEIVE CARRIER POWER
   RECEIVE ANTENNA GAIN, DB   0.00
   POLARIZATION LOSS, DB   0.00
   POINTING LOSS, DB   -3.00
   RF LOSS, DB   -1.00
   RECEIVE CARRIER POWER, DBW   -87.53
NOISE POWER
   BACKGROUND NOISE DENSITY, DBW/HZ   -201.61
     BACKGROUND TEMPERATURE, K   500.00
   FROND END NOISE DENSITY   -200.98
     RECEIVER NOISE FIGURE, DB   3.00
   RECEIVER NOISE DENSITY, DBW/HZ   -198.27

   RECEIVED C/NO, DB-HZ   110.74
   DATA RATE, MBPS   132.00
        , DB (HZ)   81.21

   AVAILABLE EB/NO, DB   29.54
   REQUIRED EB/NO, DB (BER = 1.0E-5) 9.60
   CODING GAIN, DB   0.00
   IMPLEMENTATION LOSS, DB   -2.00

   SYSTEM MARGIN, DB   17.94

Figure 4. C-Band Link Budget.

LINK BUDGET

TRANSMITTING SATELLITE DESCRIPTION
    TRANSMIT POWER,   W   1.00
                    DBW   0.00
      TRANSMIT LOSS, DB   -1.00
      TRANSMIT ANTENNA GAIN, DB   20.00
      ESTIMATED DISH DIAMETER, CM   2.18
      EIRP, DBW   19.00
      ANTENNA POINTING LOSS, DB   -1.00

SYSTEM & TRANSMISSION LOSSES
  SYSTEM AGING EFFECTS, DB   0.00
  SPACE LOSS, DB   -111.53
      RANGE, KM   0.15
      FREQUENCY, GHZ   60.00

RECEIVING SATELLITE DESCRIPTION
RECEIVE CARRIER POWER
  RECEIVE ANTENNA GAIN, DB   0.00
  POLARIZATION LOSS, DB   0.00
  POINTING LOSS, DB   -3.00
  RF LOSS, DB   -1.00
  RECEIVE CARRIER POWER, DBW   -97.53
NOISE POWER
  BACKGROUND NOISE DENSITY, DBW/HZ   -201.61
    BACKGROUND TEMPERATURE, K 500.00
  FROND END NOISE DENSITY   -196.98
    RECEIVER NOISE FIGURE, DB 7.00
  RECEIVER NOISE DENSITY, DBW/HZ   -195.69

  RECEIVED C/NO, DB-HZ   98.17
  DATA RATE, MBPS 132.00
    , DB (HZ)   81.21

AVAILABLE EB/NO, DB   16.96
  REQUIRED EB/NO, DB (BER = 1.0E-5) 9.60
  CODING GAIN, DB   0.00
  IMPLEMENTATION LOSS, DB   -2.00

  SYSTEM MARGIN, DB   5.36

Figure 5. 60 GHz Link Budget.
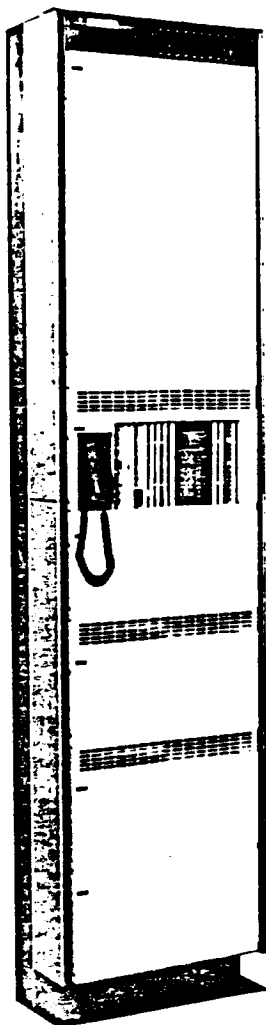
MDR-( ) Digital Radio

The MDR-11-5 Microwave Digital Radio operates in the 10.7- to 11.7-GHz band, and uses 8-level phase-shift keying (8-PSK) modulation with 5-watt twt power amplifiers. The MDR-11-5 is capable of transmitting two DS3 signals (1344 PCM voice channels) at 90 Mb/s in a 40-MHz RF channel over a single radio polarization. The MDR-11-5N narrowband version accommodates a single DS3 signal (672 PCM voice channels) at 45 Mb/s in a 20-MHz RF channel on a single polarization. The MDR-6 Microwave Digital Radio operates in the 5.9- to 6.4-GHz band and transmits two DS3 signals in a 30-MHz bandwidth. The systems meet or are better than all requirements of the Federal Communications Commission for Part 21, Domestic Public Radio Service, and FCC Report and Order 19311 for digital radio.

The MDR-12-5 has a capacity equivalent to 672 voice channels and serves the business user under Part 94 of the FCC Rules. The MDR-8-5N and MDR-8 Microwave Digital Radio have capacities equivalent to 672 and 1344 voice channels, respectively. These 8-GHz products operate in the 7.1- to 8.5-GHz band and serve, via microwave, the government user of digital communications.

The design features up to twelve 32-kb/s digital service channels for orderwire, fault alarm, switching, and auxiliary data. Protection options include hot-standby, frequency-diversity, and multiline configurations. The MDS-10 1:N digital switch provides DS3 radio protection switching on a hitless basis. Digital signals are regenerated at each repeater station and transmission performance is virtually independent of system length.

Propagation variations can produce signal distortions that may severely degrade the quality of transmission. To reduce the effects of this distortion, an adaptive equalizer is used in all MDR radios. The adaptive equalizer tracks both the amplitude linear slope and null components and dynamically adjusts compensation circuits.

Output power listings are based upon minimum power at the output of the branching network. The typical system gain is based on nominal power output and receiver threshold for an output of 10^{-6} bit error rate (BER), and is shown below.

TYPE	FREQUENCY BAND (GHz)	EQUIVALENT CHANNEL CAPACITY	OUTPUT POWER (W*)	SYSTEM GAIN AT 10^{-6} BER (dB)
MDR-6	5.9 - 6.4	1344	5	103
MDR-8	7.125 - 8.5	1344	5	105
MDR-8-5N	7.125 - 8.5	672	5	109
MDR-11-5	10.7 - 11.7	1344	5	108
MDR-11-5N	10.7 - 11.7	672	5	109
MDR-12-5	12.2 - 12.7	672	5	109

*Adjustable down to 1 watt

Figure 6. 8PSK Modem.

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MDR-2000 Series Digital Radio Family

The MDR-2000 series is a new family of second generation, high-capacity digital radios. The family of products operates in the 4-, 6-, and 11-GHz common-carrier bands. Depending upon frequency band, the radios can carry two, three, or four DS3 signals (1344, 2016, or 2688 voice channels), using 16- or 64-QAM techniques. In addition to the radios, the MDR-2000 series includes a DST-2000 terminal rack in which the DS3 digital processing and protection-switching functions are performed. The terminal and transmission functions are split between the two types of racks so as to optimize the use of space. At a repeater location this arrangement allows two transmitter-receivers with space diversity and regenerators to be contained in one 19-in. rack.

Design features include 12 RF channels in the 11-GHz band, up to 1:11 multiline hitless protection switching, and 1:1 hot-standby/space-diversity or frequency-diversity protection. Optionally, ANC-2000 service channels are available that provide two express and two local orderwire facilities, express and local monitor-control channels and express and local RS232C data channels.

Improved equalization techniques are used to ensure satisfactory operation of the high-capacity radios. In addition to slope and notch correction as used in the present MDR-( ) radio IF adaptive equalizers, the notch correction tracks with frequency as distortions move through the radio passband. A new equalization technique is also used in the radio baseband; a transversal equalizer will improve the quality of the signal by reducing intersymbol (bit-to-bit) interference.

TYPE	FREQUENCY BAND (GHz)	EQUIVALENT CHANNEL CAPACITY	OUTPUT POWER (dBm)	SYSTEM GAIN AT 10^{-3} BER (dB)
MDR-2204	3.7 - 4.2	1344	33	102
MDR-2306	5.9 - 6.4	2016	33	101
MDR-2311	10.7 - 11.7	2016	36	107
MDR-2411	10.7 - 11.7	2688	33	101
DST-2X00	—	1344/2016/2688	—	—
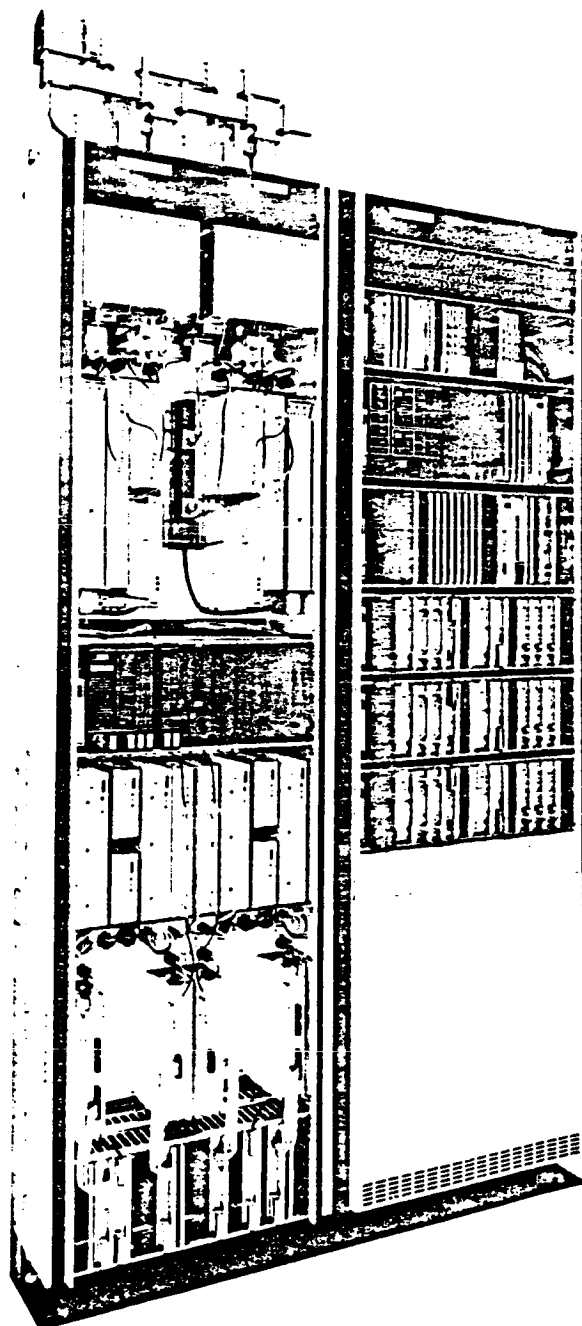
Figure 7.   QAM Modem.

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4.0 OPTICAL SYSTEM OPTIONS

The main advantage of using an optical system for the MRMS is that it will not interfere with other RF links. There are two ways to use lightwave for communications: via free space or via fiber optics. Both systems are capable of supporting the MRMS requirement. Each however suffers from drawbacks that need to be overcome.

4.1 Free Space Link

The ideal optical system for the MRMS is one that employs fixed line-of-sight (LOS) antennas to eliminate the acquisition and tracking subsystem. With the "tunnel" concept discussed above where the antenna only points along the beam structure, the system may be marginally practical. To see this, let us examine the link budget in Figure 8 which is based on an optical system proposed earlier by TRW and subsequently critiqued by LinCom. (A more complete optical link analysis can be performed with CATSS, the software package developed by LinCom residing in the JSC/VAX 750.) The system uses a laser transmitter at an IR wavelength of 0.825 micron. All parameter values are typical except for the transmit power of 3 mW which is a little on the high side if one wants to stay away from array laser diodes.

With this system, the transmit antenna is designed to point with an accuracy of 0.3 m at a distance of 150 m (2 milliradians pointing error). Since the SS keel distortion can be as much as +/-1.5 m, acquisition and tracking are required.

To cover the distortion without relying on a tracking system, the beam divergence of the transmitter can be broadened to 20 milliradian. However, since the transmit gain is inversely proportional to the square

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Figure 8. TRW Optical Link Budget Example.

SPACE STATION MRMS LINK

LINK PARAMETERS
================

LASER TYPE	GAALAS	INPUT
WAVELENGTH, MICRON	0.825	INPUT
LINK TYPE	COMM	INPUT
SYMBOL ERROR RATE	1.00E-07	INPUT
DATA RATE, BPS	1.32E+08	INPUT
MODULATION FORMAT	MANCHESTER	INPUT
EXTINCTION RATIO	10.00	INPUT

TRANSMITTER PARAMETERS
======================

	FACTOR	DB	
PEAK POWER, W	1.00E-03	-30.00	INPUT
AVERAGE POWER,W	5.50E-04		
PULSE WIDTH, SEC	3.79E-09		
PULSE RATE, PPS	1.32E+08		
TRANSMISSION EFFICIENCY	0.21	-6.87	
OPTICS EFFICIENCY	0.50		INPUT
RMS WAVEFRONT ERROR LOSS	0.41		INPUT
CIRCULARIZATION LOSS	1.00		INPUT
POINTING LOSS	0.92	-0.35	
POINTING ERROR, RAD	2.00E-03		INPUT
POINTING JITTER, RAD RMS	0.00		INPUT
TOTAL POINTING ERROR, RAD	2.00E-03		
TRANSMITTER GAIN	8.01E+04	49.04	
APERTURE DIAMETER, M	1.00E-02		INPUT
OBSCURATION DIAMETER, M	0.00E+00		INPUT
BEAM DIVERGENCE, RAD	2.00E-02		INPUT

CHANNEL PARAMETERS
==================

FREE SPACE LOSS	1.92E-19	-187.18	
RANGE SEPERATION, M	150.00		INPUT
BACKGROUND RADIANCE, W/M^2/SR/ANG	0.00E+00		INPUT
BACKGROUND IRRADIANCE, W/M^2/ANG	0.00E+00		INPUT
ATMOSPHERIC LOSS	1.00E+00	0.00	INPUT

RECEIVER PARAMETERS
===================

RECEIVER ANTENNA GAIN	1.45E+11	111.61	
APERTURE DIAMETER, M	1.00E-01		INPUT
OBSCURATION DIAMETER, M	0.00E+00		INPUT
TRANSMISSION EFFICIENCY	0.52	-2.85	
OPTICS EFFICIENCY	0.52		INPUT
OPTICAL FILTER TRANSMISSION	0.90	-0.46	INPUT
OPTICAL FILTER BW, ANGSTROMS	100.00		INPUT
RECEIVER DIAMETRICAL FOV, RAD	1.00E-02		INPUT
AC COUPLING LOSS	1.00	0.00	INPUT

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Figure 8. (Continued).

```
DETECTOR PARAMETERS
====================
DETECTOR TYPE                              APD              INPUT
   DETECTOR NOISE FACTOR                  3.31
   AVALANCHE GAIN                       190.00              INPUT
   IONIZATION COEFFICIENT              7.00E-03             INPUT
   UNITY RESPONSITIVITY, A/W              0.55
DETECTOR QUANTUM EFFICIENCY               0.83              INPUT
DETECTOR NOISE EQUIVALENT POWER, W/HZ^.5  1.42E-13
PREAMP NOISE CURRENT DENSITY, A/HZ^.5     6.00E-12
   EFFECTIVE REC. TEMP., DEG K          300.00             INPUT
   EFFECTIVE RECEIVER RESISTOR, OHMS    460.20             INPUT
NOISE EQUIVALENT BANDWIDTH, HZ          1.32E+08
PROCESSING LOSS                          0.5623   -2.50 INPUT
RECEIVED BACKGROUND POWER, WATT        0.00E+00     ERR


RECEIVED SIGNAL AND NOISE PARAMETERS
=====================================
RECEIVED SIGNAL, WATTS PEAK            1.97E-07   -67.06
SYSTEM MARGIN                            10.30    10.13 INPUT
RECEIVED OPTICAL POWER, WATTS AVG      1.05E-08   -79.78
SIGNAL CURRENT, A^2                    8.17E-13
SHOT NOISE CURRENT, A^2               2.936E-14
BKG NOISE CURRENT, A^2                       0
AMP NOISE CURRENT, A^2                4.750E-15
DETECTOR OUTPUT SNR                      23.96    13.80


REQUIRED SIGNAL PARAMETERS
===========================
REQUIRED SNR AFTER PROCESSING LOSS     2.40E+01    13.80
```

of the divergence, the transmit signal will be reduced by 10.5 db. We now investigate this possibility.

The link considered above is basically limited by background noise induced by the sun in the FOV requirement. A sun block can be placed behind the transmitter to eliminate this effect. Only the off-axis sun scatter will be of concern which is typically 20 db down from the on-axis condition. Figure 9 is an exercise to evaluate the link margin if the background noise can be eliminated. A few parameters are also modified from the Figure 8 example:

Transmit power	1 mW (1/3 X)
Transmit FOV	20 milliRadians (3.3 X)
Receive Aperture	4 inches (4 X)

This system now has a 10 db margin even with a less expensive lower power transmitter. Also, the increased receive aperture can tolerate more obstructions along the LOS.

4.2 Fiber Optics Link

If the transmitter and the receiver are connected by an optical fiber, then both the space loss and the background noise will be eliminated. The transmission loss of the signal is close to 46 db for the TRW example. For a 150m cable, the attenuation is negligible. There may be a little loss due to dispersion. However, the overall link should have plenty of margin. Hence, LED transmitters can be used in place of the more expensive laser diodes.

The main problem is mechanical. The cable must be on a spool and must be wound or unwound as the MRMS travels. The cable may get tangled. Reliability may also be a problem. Also, some operational constraints must be place on the movement of the MRMS to ensure that the

Figure 9. Modified Optical Link Budget.

SPACE STATION MRMS LINK (TRW EXAMPLE)

LINK PARAMETERS
================
LASER TYPE	GAALAS	INPUT
WAVELENGTH, MICRON	0.825	INPUT
LINK TYPE	COMM	INPUT
SYMBOL ERROR RATE	1.00E-07	INPUT
DATA RATE, BPS	1.32E+08	INPUT
MODULATION FORMAT	MANCHESTER	INPUT
EXTINCTION RATIO	10.00	INPUT

TRANSMITTER PARAMETERS
======================

	FACTOR	DB	
PEAK POWER, W	2.93E-03	-25.33	INPUT
AVERAGE POWER,W	1.61E-03		
PULSE WIDTH, SEC	3.79E-09		
PULSE RATE, PPS	1.32E+08		
TRANSMISSION EFFICIENCY	0.21	-6.87	
OPTICS EFFICIENCY	0.50		INPUT
RMS WAVEFRONT ERROR LOSS	0.41		INPUT
CIRCULARIZATION LOSS	1.00		INPUT
POINTING LOSS	0.42	-3.73	
POINTING ERROR, RAD	2.00E-03		INPUT
POINTING JITTER, RAD RMS	0.00		INPUT
TOTAL POINTING ERROR, RAD	2.00E-03		
TRANSMITTER GAIN	8.59E+05	59.34	
APERTURE DIAMETER, M	1.00E-02		INPUT
OBSCURATION DIAMETER, M	0.00E+00		INPUT
BEAM DIVERGENCE, RAD	6.11E-03		INPUT

CHANNEL PARAMETERS
==================

FREE SPACE LOSS	1.92E-19	-187.18	
RANGE SEPERATION, M	150.00		INPUT
BACKGROUND RADIANCE, W/M^2/SR/ANG	1.71E+01		INPUT
BACKGROUND IRRADIANCE, W/M^2/ANG	0.00E+00		INPUT
ATMOSPHERIC LOSS	1.00E+00	0.00	INPUT

RECEIVER PARAMETERS
===================

RECEIVER ANTENNA GAIN	9.36E+09	99.71	
APERTURE DIAMETER, M	2.54E-02		INPUT
OBSCURATION DIAMETER, M	0.00E+00		INPUT
TRANSMISSION EFFICIENCY	0.52	-2.85	
OPTICS EFFICIENCY	0.52		INPUT
OPTICAL FILTER TRANSMISSION	0.90	-0.46	INPUT
OPTICAL FILTER BW, ANGSTROMS	100.00		INPUT
RECEIVER DIAMETRICAL FOV, RAD	1.00E-03		INPUT
AC COUPLING LOSS	1.00	0.00	INPUT

Figure 9.   (Continued)

```
DETECTOR PARAMETERS
====================
DETECTOR TYPE                                  APD                INPUT
   DETECTOR NOISE FACTOR                          2.33
    AVALANCHE GAIN                               52.00        INPUT
    IONIZATION COEFFICIENT                     7.00E-03       INPUT
    UNITY RESPONSITIVITY, A/W                     0.55
DETECTOR QUANTUM EFFICIENCY                       0.83        INPUT
DETECTOR NOISE EQUIVALENT POWER, W/HZ^.5      2.61E-13
PREAMP NOISE CURRENT DENSITY, A/HZ^.5         6.00E-12
    EFFECTIVE REC. TEMP., DEG K                300.00        INPUT
    EFFECTIVE RECEIVER RESISTOR, OHMS          460.20        INPUT
NOISE EQUIVALENT BANDWIDTH, HZ                1.32E+08
PROCESSING LOSS                                0.5623    -2.50 INPUT
RECEIVED BACKGROUND POWER, WATT              3.18E-07   -64.98


RECEIVED SIGNAL AND NOISE PARAMETERS
=====================================
RECEIVED SIGNAL, WATTS PEAK                  1.83E-07   -67.37
SYSTEM MARGIN                                  2.00     3.00 INPUT
RECEIVED OPTICAL POWER, WATTS AVG            5.05E-08   -72.96
SIGNAL CURRENT, A^2                          1.42E-12
SHOT NOISE CURRENT, A^2                      7.446E-15
BKG NOISE CURRENT, A^2                       4.677E-14
AMP NOISE CURRENT, A^2                       4.750E-15
DETECTOR OUTPUT SNR                            24.01    13.80


REQUIRED SIGNAL PARAMETERS
===========================
REQUIRED SNR AFTER PROCESSING LOSS           2.40E+01   13.80
```

cable does not get tangled with the beam structure. For example, if the spool is mounted on the platform, then the MRMS cannot travel in a corkscrew manner when it travels along the keel.

5.0 ANALOG TV

All six video channels can be on FDM requiring a total of 36 MHz bandwidth using conventional NTSC analog modulation and 6-MHz channel spacing. The integrated MRMS and MA TV channels (at least for the high quality EVA TV) can probably be supported with about 80 MHz. If one can get away with using VHF or UHF, it may be the least expensive solution. If not one can probably use C-band.

6.0 MISCELLANY

One advantage of using RF is that the "gap filler" antennas for the MA system can be shared. One disadvantage of an RF system is that interferences can arise from third-order intermod products, a fact that is sometimes overlooked.

The signal distribution from the antenna sites to the HAB and LAB modules should be integrated with the MA system.

APPENDIX F: TRADE-OFF ANALYSIS FOR MA MODULATION TECHNIQUE

SUMMARY

This memo is a preliminary investigation of the factors to be considered for selecting the modulation technique for the SS MA system. If the bandwidth is available (BT greater than or equal to 1), QPSK (or Staggered-QPSK) appears to be the logically choice since it has been used widely and it performs well compared with other modulation schemes. (The exceptions are some combined modulation/coding schemes that require complicated Viterbi-type decoders which may not be matured in time for high data rates, at the 20 Mbps range). If QPSK is used, then differential encoding should be used since it only introduces a 0.3 db loss at a BER of 10^{-5}. For this loss, the system can be made more tolerant to cycle-slipping and slow fading. It also eliminates the need for phase ambiguity resolution.

If the bandwidth is not available, then a price must be paid in terms of performance degradation and modem complexity. The degradation will be a function of the severity of the nonlinearity and channel bandlimiting. Depending on the exact nature of the channel, different modulation techniques will rank differently. Unfortunately, there is no known analysis to predict their overall performance. The only dependable way is through simulation. Analysis is only useful for weeding out modulation schemes that are clearly undesirable.

1.0 MA CHANNEL CONSIDERATIONS

The MA channel is characterized by a mix of low TT&C and high digital TV data rates. The data throughput for the MA system as a whole is on the order of a couple hundred Mbps. Depending on the

eventual frequency allocation, bandlimiting may or may not be an issue in the selection of the MA modulation format. However, in order to derive the maximum output power, the transmitter HPA should be driven near saturation. For this reason, the MA channel is usually nonlinear, especially for the TV data users.

1.1 Implications for Modulation Selection

Since the channel is most likely nonlinear, modulation techniques are pretty much limited to the class of constant envelope modulation schemes. This precludes, for example, the highly bandwidth efficient schemes that transmit information using amplitude (and phase) information such as Quadrature Amplitude Modulation (QAM), Quadrature Partial Response (QPR), or Amplitude Phase Shift Keying (APSK).

What remains is the class of modulation schemes that only use phase variations in the signal to transmit information. Two distinct representatives within this class are M-ary PSK (MPSK) and Continuous Phase Modulation (CPM). In MPSK, the signal is contained in the discrete phase states. In CPM, the signal is contained in the phase trajectory. A simple example for MPSK is the classical BPSK. A simple example for CPM is Minimal Shift Keying (MSK).

2.0 TRADEOFF CONSIDERATIONS

If bandwidth is not a major concern, then the selection of the modulation schemes will be dictated by their classical infinite bandwidth AWGN performance as shown in the following examples:

Modulation Format	Required E_b/N_0 for 10^{-7} BER
QPSK/BPSK	11.3 db

MSK(CPM/2)	11.3
CPM/4	13.3
8PSK	14.6

In the table CPM/n denotes CPM with a modulation index of 1/n. When bandlimiting is not a problem, QPSK (or BPSK) and MSK are clearly the winners. However, QPSK should always be the first choice instead of BPSK since it is twice as bandwidth efficient.

2.1 Degradation Due To Bandlimiting

When bandlimiting becomes a factor the performance of these modulations will deviate from the table given above. This is because their spectral shapes are different. The degree of bandlimiting can be characterized by a BT product where B is the one-sided RF bandwidth and T is the desired bit time. Generally speaking, when BT is greater than 1.5 or 2 the degradation (mostly from intersymbol interference, or ISI) due to bandlimiting will be less than a few tens of a db. For BT between 0.4 to 1.5, bandlimiting can introduce significant losses to the tune of a few dbs. For BT smaller than 0.4, bandlimiting becomes the dominant loss factor for a communication link and usually determines the irreducible error.

2.2 Combined Effect of Nonlinearity and Bandlimiting

Nonlinearity will introduce additional degradations since the transmit signal is distorted by the nonlinearity through AM/AM and AM/PM conversion effects. On top of this, the nonlinearity also aggravates the interchannel interference problem. If the HPA were linear, then a signal can be first filtered to its allocated channel spacing before the final amplification. However, a nonlinearity tends to destroy the

effect of prefiltering by restoring the output signal spectrum to its original shape before filtering. Any desired filtering must be done after the nonlinearity. Post-HPA filtering is costly both in terms of dollar cost of the filter and the power loss through the filter. The amount of broadening of the bandlimited signal depends on the modulation selected. Typically, CPM schemes are more tolerant to the nonlinearity. In this sense, they are superior.

2.3 Implementation Issues

Modems designed to operate for a nonlinear, bandlimited channel are quite different from classical modems designed for linear, wide-band channel:

- In general, equalization must be employed at the receiver to recover some of the losses due to the nonlinearity and bandlimiting.

- Surprisingly, the classical I&D detector is no longer optimal. A simple sample-after-filtering detector usually gives better performance.

- Depending on the degree of nonlinearity and bandlimiting, other receiver subsystems such as the carrier tracking loops and bit synchronizers will deviate from their predicted performance obtained through classical analysis.

3.0 MPSK SYSTEM

There are three variations of a MPSK modulation system. The basic MPSK system requires an M-fold phase ambiguity resolution. When the data is first differentially encoded then the receiver can bypass the ambiguity resolution stage. This is because any phase offset will

be canceled during the data detection process as the data information is contained in the phase transition. The modified system is termed MDPSK. The MDPSK signal can be detected using a coherent phase-locked loop receiver as in the MPSK case - termed <u>coherent detection</u> of MDPSK. Or it can be detected without the explicit knowledge of the phase, requiring only a frequency-locked loop for its implementation. The latter is termed <u>differentially coherent detection</u> of MDPSK.

The performance of the 3 systems are different. For very high SNR they can be approximated by their asymptotic approximations:

Modem	BER Approximation
MPSK	$\mathrm{Erfc}(\sqrt{R_s} \sin \pi/M)/L$
CMDPSK	$2\,\mathrm{Erfc}(\sqrt{R_s} \sin \pi/M)/L$
DCMDPSK	$\sqrt{\dfrac{1+\cos \pi/M}{2\cos \pi/M}}\ \mathrm{Erfc}\sqrt{R_s(1-\cos \pi/M)}/L$

where $L=\log_2 M$ and $R_s = \log_2 M\, E_b/N_0$. As a result, the performance of CMDPSK is nearly identical to MPSK at high SNR. At a BER of 10^{-5}, the difference is approximately 0.3 db. The performance of DCMDPSK is approximately 2.3 and 2.8 db degraded from MPSK for M=4 and 8 respectively. Figure 1 shows a plot of the BER curves for M=4 and 8.
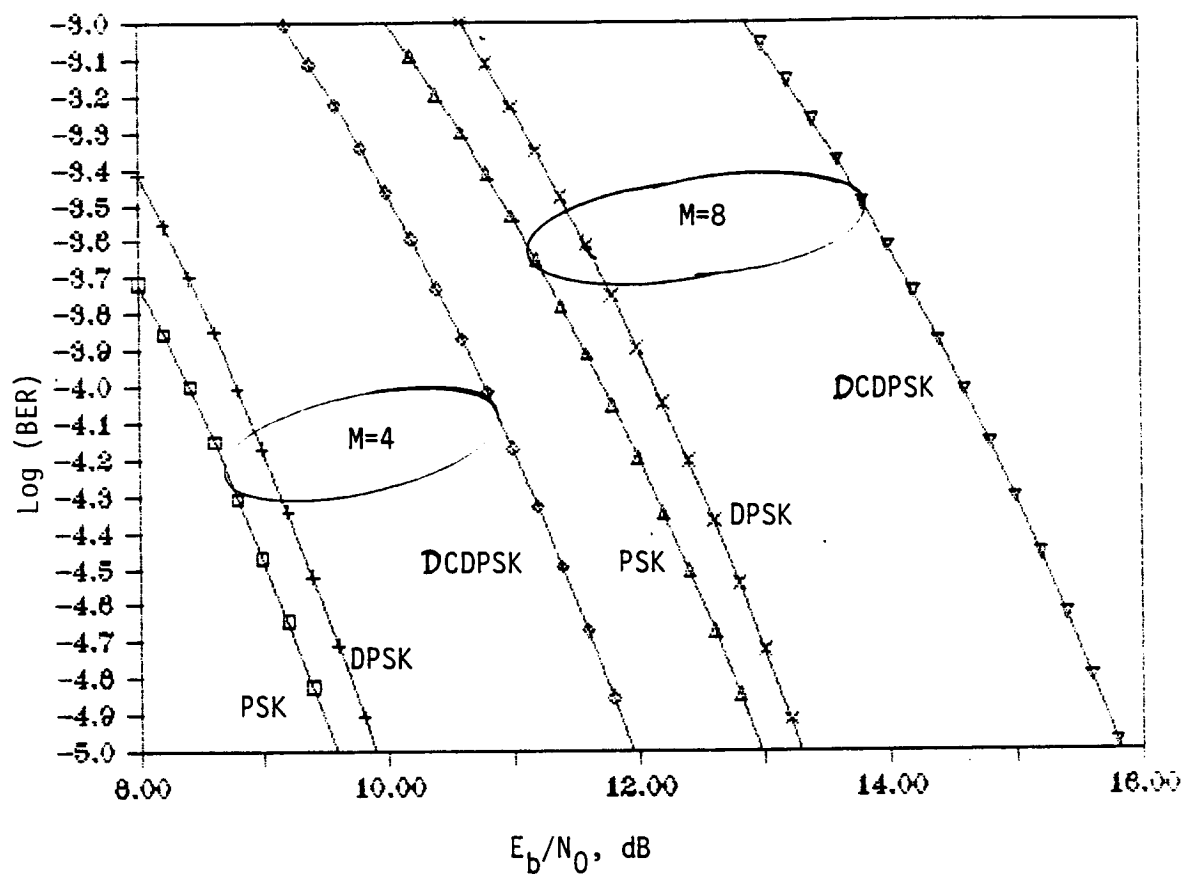
Figure 1. BER Performance Curves for PSK, DPSK, DCDPSK for M=4
and 8 (BER Range is Between 10^{-3} to 10^{-5})

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APPENDIX G: ORDERWIRE DATA BASE ANALYSIS

SUMMARY

This memo considers two approaches to implementing the orderwire channel for the SS MA system. It appears that a random access technique is the least expensive one. This memo also provides a preliminary look at the information needed in an orderwire data packet (frame) to initiate the MA link.

1.0 ORDERWIRE

The orderwire channel is for the SS to manage the MA links between itself and the users. To establish a return link (user to SS), the user normally initiate a request through the orderwire. The SS in turn acknowledges the request and allocates a channel (consisting of frequency and hardware resource) to the user. The user can then start the communication process. Alternatively, the SS can also prompt the user to initiate the process. The user then goes through the above sequence after being prompted.

To establish a forward link (SS to user), either the user or the SS can initiate the process. The other party then acknowledges the initiation so transmission can begin.

2.0 ORDERWIRE ACCESS SCHEMES

Two access systems can be considered for the SS MA orderwire: random or deterministic. In a random access system, the user accesses a common orderwire channel whenever he wants to transmit. A conflict may exist if two or more users want to access the channel at the same instance. In a deterministic system, the orderwire is pre-allocated to

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a user so that no conflict is possible e.g., TDMA, CDMA or FDMA.

2.1 Random Access Orderwire

A random access orderwire may be the least expensive approach for the SS MA system. Because the number of simultaneous users are relatively small and that the number of users initiating service is even smaller at any given time, the chance for conflict is remote. With a simple contention resolution scheme such as waiting for a random elapsed time before retransmission, this conflict can be resolved. (The user can find out if there is a conflict by checking the received orderwire data from the SS).

To implement the random access orderwire, a user ID identifying the orderwire packet is required.

2.2 Pre-assigned Orderwire

Of the three MA schemes, TDMA is probably the least desirable. Even for a low rate (a few hundred bps) user channel, the resulting total TDMA system rate will require an EIRP too high for the omni-antenna system to handle. Also maintaining system sync is quite complicated.

FDMA is practical. However, due to the frequency instability of the user oscillators, a minimum channel separation of up to 50 KHz is required regardless of the data rate. Hence, the RF bandwidth to be allocated to the orderwire will be on the order of a couple MHz. This is not a real constraint. However, the user receiver must be capable of handling the set of frequencies so that a frequency synthesizer is required.

The amount of RF bandwidth required for CDMA will also be on the

order of a few MHz. However, a CDMA receiver is more complicated than a FDMA receiver. If the CDMA receiver is already available on board the user, for example because of the TDRSS link, then CDMA is viable. Also, the SS may use the PN signal for ranging.

Pre-assigned orderwire channels do not require user ID.

3.0 ORDERWIRE RETURN LINK (USER TO SS)

The following information is needed to determine the user characteristics and link requirements:

o User ID (6 bits)

o Forward/Return (1)

o Service Type (2)

o Data Rate (3)

o Data Format (2)

o User Location (90)

The following information is needed for modem operation and/or future expansion capability:

o Sync Pattern (28)

o Status (1)

o Parity Check (8)

o Spare (40)

A maximum of 167 bits is needed. Depending on the access scheme used some of the data items are not required. The data information can be contained in one frame or can be spread over a few frames.

3.1 User ID

The SS will need to keep a user data base. This data base includes individual maximum transmit EIRP, dynamics, and service requirements.

The user ID identifies this user data base. Assuming potentially 64 users, it requires 6 bits. If a CDMA scheme is used for the orderwire, then the unique PN code sequence defines the user and a user ID is not required.

3.2 Forward/Return

One bit is used to denote forward or return link.

3.3 Service Type

The service type defines whether a TV, TT&C, or HUD+TV (EVA) channel is requested. It requires 2 bits.

3.4 Data Rate

For digital TV, the data rate may vary from 2 to 22 Mbps. 3 bits will be enough to represent up to 8 distinct data rates within this range. For HUD, the data rate is fixed. For TT&C, it appears that 8 levels should be enough to specify data rates in the form of $1/2n * 100$ Kbps where n ranges from 0 to 7. This covers the range from 781 bps to 100 Kbps. Hence 3 bits will be required and the value of the data rate will be determined by the type of service requested.

3.5 Data Format

This is required only if the link is allowed to select bi-phase or NRZ, or coded or uncoded data. 2 bits will be required.

3.6 User Location

User location will be required for the SS to direct its antenna beam. From the user location the SS can also determine the range

between itself and the user. This range information can be used to instruct the user to adjust its EIRP if power control is to be implemented for the MA system.

It appears that if the user location can be determined to 1 Km accuracy, both functions can be satisfied. First of all, the accuracy is acceptable for the very coarse power control requirement. Secondly 1 Km at the far range, where accurate pointing is required, represents a small angular error. At the mid-range where the angular error is large, the SS uses wide beamwidth antenna coverage. At the near range, the SS is required to control the users for the purpose of rendezvous so more accurate locations must be derived from other means.

Some users will be tracked by the ground so their locations can be accurately determined with ephemeris data. This information can be relayed to the SS via the regular TDRSS link. Some users will have a GPS receiver on board. For this class of users, they can probably get very accurate position fixes. There may be another class of users that operates strictly from the SS and depends on the SS for tracking with some other means such as radar.

Hence the user location information only applies to the user who can determine its own location. To estimate the number of bits required we assume that:

Parameter	Maximum	Accuracy	Bits
Position	+/-13,000 Km	0.1 Km	18
Velocity	+/-20 Km/s	0.01 Km/s	12

There are three components (x,y,z) to position and velocity so that the total number of bits required is 90. The user probably do not need to transmit time, since the SS can time-tagged the location message. The

accuracy achievable should be good enough to determine the location of the user to a Km.

3.7 Sync Pattern

If the orderwire link is not continuously operational between the user and the SS, then a time slot must be provided for the SS to acquire the user transmitted signal. This may required perhaps 10-20 bits for the SS to acquire carrier and bit sync. If the link is continuously established, then the whole frame can be used for initial acquisition. A frame sync pattern is also required to define the data frame. 8 bits should be enough.

3.8 Status

One bit should be reserved to indicate user activity. This bit is normally set to zero when service is not required. It is set to 1 to initiate return link request or to indicate ready for forward link.

3.9 Parity Check

8 bits should be used for parity check.

3.10 Spare

40 spare bits should be allocated for future capability expansion.

4.0 ORDERWIRE FORWARD LINK (SS TO USER)

A maximum of up to 171 bits is required. The following information is needed for service assignment:

o User ID (6)

o Forward/Return (1)

o Service Type (2)

o Data Rate (3)

o Data Format (2)

o SS Location (90)

o Channel (Frequency) Assignment (4)

The first 5 data items (user ID, forward/return, service type, data rate and data format) serve to acknowledge and verify the link request. They are identical as the ones for the orderwire return link. The format for the SS location bits is the same as that of the user location for the return link. It is intended to help a user to direct its narrowbeam antenna. The number of bits required for channel assignment is determined by the maximum number of channels in any service type. 4 bits should be enough.

The following information is needed for receiver operation and/or future expansion capability:

o Sync pattern (28)

o Status (1)

o Parity Check (8)

o Spare (40)

Here the data items are functionally identical to the orderwire return link except for the interpretation of the status bit. This bit is normally set to zero when no service is required. This bit is set to 1 to initiate link request or to indicate link readiness.

APPENDIX H: MA USER COMMONALITY STUDY

SUMMARY

This memo provides a preliminary look at a transceiver conceptual design that serves to address the issues associated with designing a common set of user equipment that can satisfy the MA user link requirements. Specifically, we focus on the architecture of the RF/IF subsystem, the modem and the codec implementation. It appears that a "smart" microprocessor-based digital modem can be used for the core of the user equipment. To facilitate channel multiplexing/demultiplexing (bandpass filtering) a double heterodyne technique is proposed.

1.0 INTRODUCTION

There are up to 30 potential users of the SS MA system. If a common set of equipment can be designed to satisfy all the user needs, the development cost of the user equipment can be shared and will become less prohibitive. Figure 1 shows a conceptual block diagram of the functional requirements of a general-purpose user transceiver equipment. In what follows we examine the concept of commonality as they apply to, in light of the various link requirements, the three main components of the user equipment: RF/IF subsystem (frequency converters), modem, and codec (within the data subsystem shown).

The 6-channel high rate TV for the MRMS is ignored here for commonality consideration. The MRMS is really not a "user" but rather a part of the SS. Also, the 6-channel TV is best served by a single high data rate (132 Mbps) multiplexed channel, something that is unique in the MA system requirement.

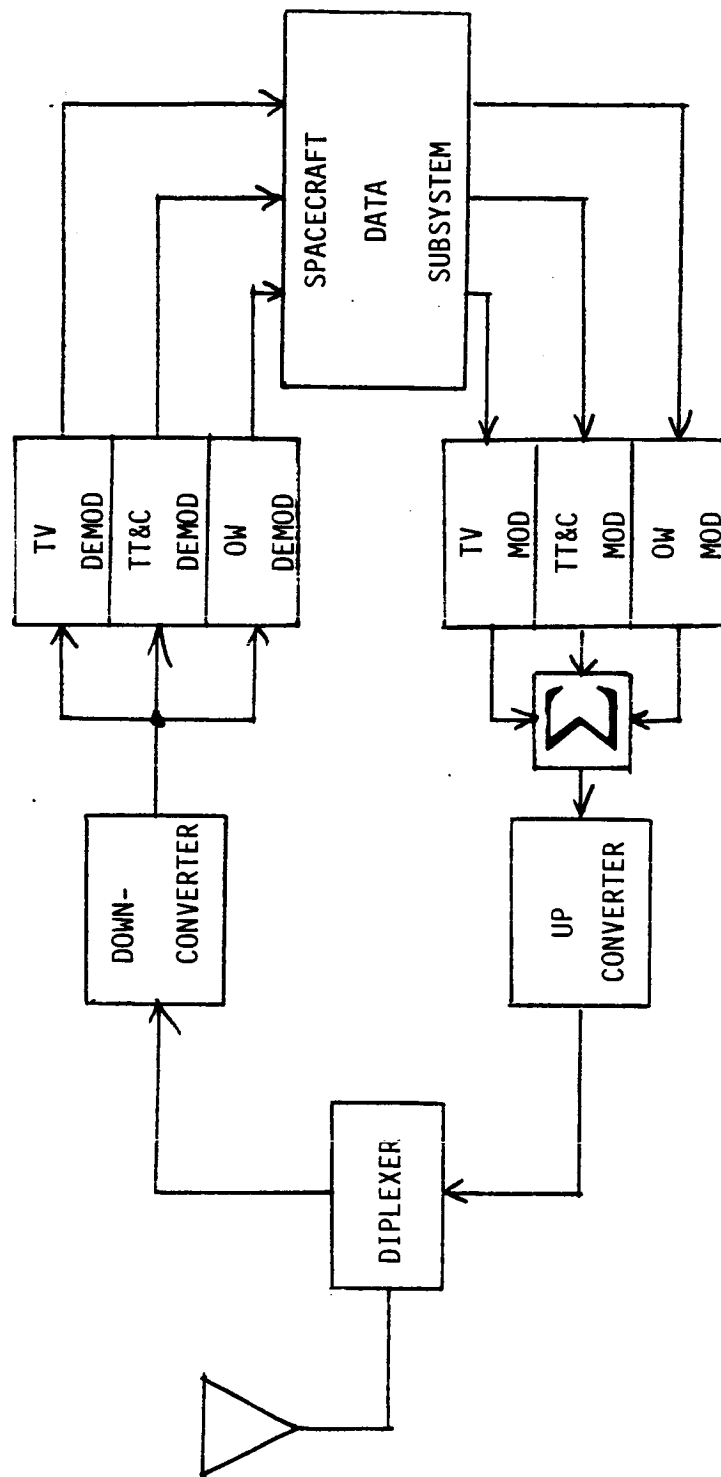There is yet another level of commonality associated with other

Figure 1. Functional Diagram of User Transceiver Equipment.

communications equipment onboard the user that may include, for example, GPS receivers and NASA standard transponders. However, they will be the subject of a future memo.

2.0 RF/IF SUBSYSTEM

The SS MA system is primarily a FDMA system. To minimize interference from other users, the user transceiver must provide the required filtering.

2.1 Frequency Downconversion

The downconversion subsystem provides the frequency conversion of the received RF signal from K-band to a convenient common IF. There are two approaches to filtering that can be taken. In the first approach, the signal is only bandlimited to the entire MA forward band (approximately 100 MHz) provided primarily by the diplexer. Additional channel selection for the user links will be performed at the demodulators. This approach is very close to the block diagram laid out in Figure 1 where a single downconverter is shown feeding three different receivers. In the other approach, channel selection will be performed within the downconversion subsystem. The disadvantage of this is that multiple downconverters are required if the user wants to use, for example, the TV and OW links simultaneously.

The first approach is recommended for maximum commonality. Figure 2 is a more detailed block diagram for the downconversion subsystem. A 370 MHz IF is chosen for illustrative purpose only. The only requirement is its ability to handle the 100+ MHz MA forward frequency band. Earlier SS MA studies have concluded that signal dynamic range variations among different users are relatively mild. Thus processing
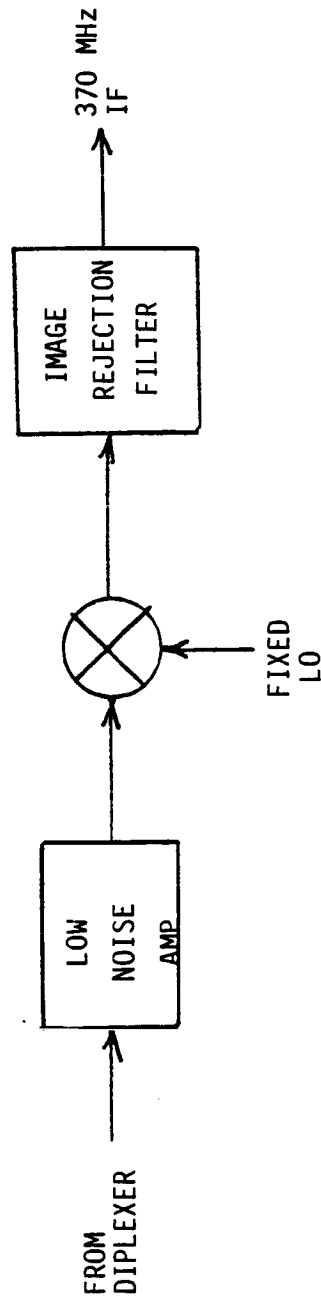
Figure 2. Downconverter Conceptual Diagram.

of the filtered composite MA RF signal would not present a serious intermod problem as a result of having to overdrive the LNA and the mixer beyond their linear operating range in order to provide an acceptable noise floor for the low power channels.

2.2 Frequency Upconversion

It is assumed that appropriate channel filtering has been performed by the individual modulators depicted in Figure 1, so that additional pre-filtering at the input to the final high power amplifying stage is not required. Post-filtering at the output of the HPA is costly and is not very practical if the signal bandwidth is narrow (for example the 100 Kbps TT&C channel) thus requiring a low loss, high Q K-band bandpass filter. Hence it is important to be able to operate the HPA with sufficient backoff (operate in the linear region).

3.0 MODEM

3.1 Demodulator

There are three functionally distinct demodulator types as indicated in Figure 1. The question is: Can a single demodulator assume all these identities? The companion question is: How practical is this?

Figure 3 shows a high level block diagram of a universal demodulator using digital technology. The BPF bank is used to provide interference rejection among MA users. It has selectable bandwidths to accommodate the channel spacing allocated for the link type. For example, it may consist of 30 and 15 MHz for high and low rate digital TV, 800 KHz for HUD, 300 KHz for TT&C, and 50 KHz for orderwire if a random access scheme is used. (If a CDMA scheme is used for the
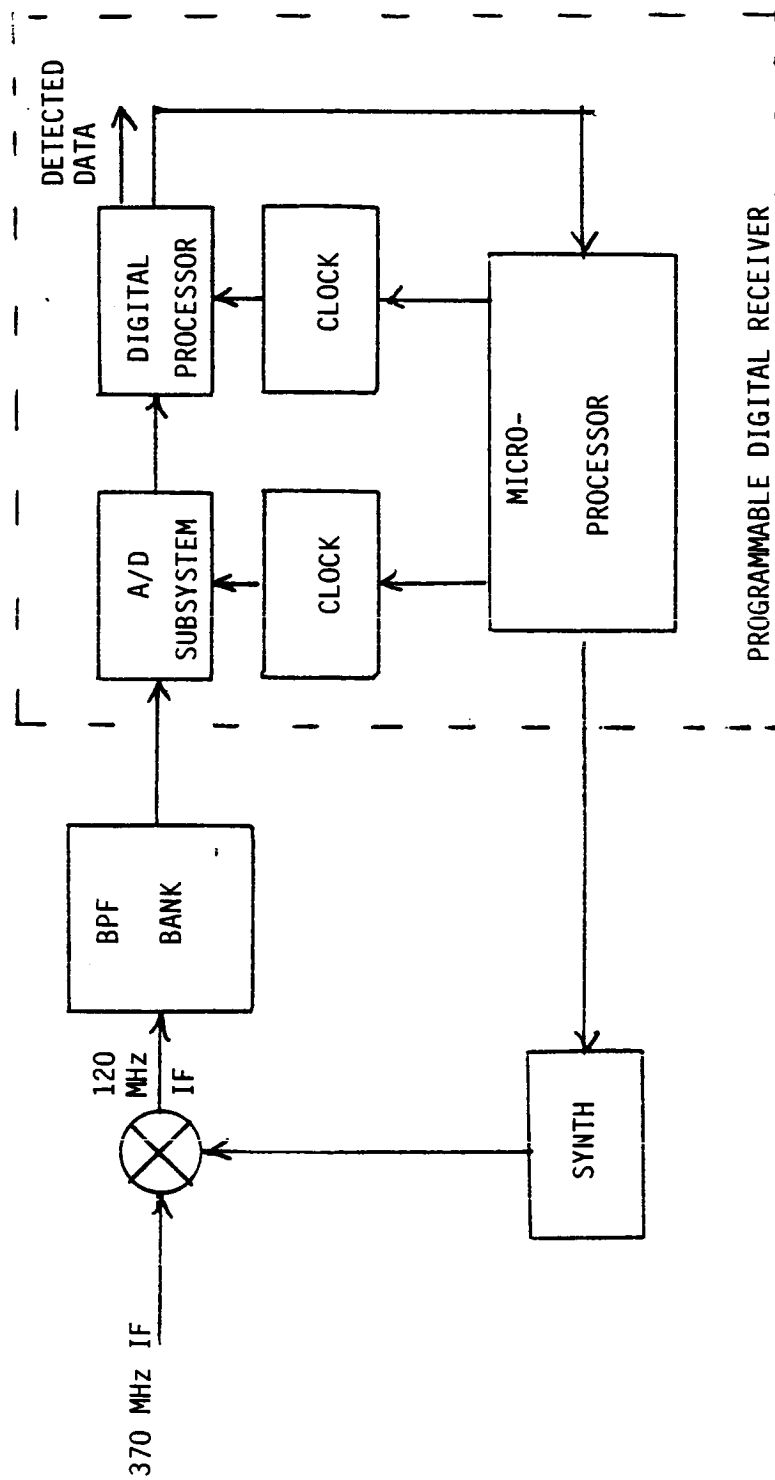
Figure 3. Demodulator Conceptual Diagram.

orderwire, then a PN demodulator and approximately 5 MHz of bandwidth are required. This situation is unique and the commonality requirement does not really apply.)

A 120 MHz second IF is shown here as an example. The only requirement for this frequency selection is that it is low enough for practical bandpass filters yet high enough to accommodate the 100 MHz signal bandwidth to permit mixing operation to center the desired channel at the input to the BPF, without introducing folding of the entire MA forward signal spectrum.

A microprocessor-controlled digital implementation provides operational flexibility, ease of maintenance, and minimization of calibration, set-to-set variations, parameter sensitivity, adjustment and select-in-test procedures during production. It also facilitates the implementation of built-in-test techniques.

Analog-to-digital converters up to 100 mega-samples/sec are available commercially. Assuming a QPSK format, the technique of I-Q sampling can be used for the high data rate TV link so that 8 samples per bit can be taken. The loss due to sampling is thus minimal. The digital processor, consisting of mainly accumulators, is used to perform the data detection, generate phase and timing error for the carrier tracking loop and bit sync. The digital processor is the only high-speed digital board(s) for the digital receiver. The loop errors are passed to the microprocessor at a slow rate (a few KHz) commensurate with the loop bandwidths.

To perform the high rate TV link demodulation the A/D and digital processing subsystems must be implemented with high-speed ECL circuits. For the TT&C and OW links, they can be implemented with CMOS using direct IF sampling and hence the power requirement can be reduced.

Therefore, one option is to make the A/D and digital processor subsystems on plug-compatible boards using both technologies, one for high and one for low data rates.

The algorithms for the microprocessor which performs the function of carrier and clock tracking are the same for all data rates. They include processing of the phase and timing error from the digital processor board and, based on these input, providing the control for the clocks (synthesizers) for A/D sampling, bit sync and carrier recovery. The development cost for the algorithm software and synthesizer/clock hardware can be shared.

3.2 Modulator

The modulator design is rather straightforward and it appears that a single QPSK modulator design can be used for all data rates. To facilitate filtering for channel multiplexing, two IF frequencies are used as shown in Figure 4. The QPSK modulator operates at a fixed 70 MHz IF. The BPF bank is used to limit the signal to the allocated channel. The signal is then upconverted and placed into the appropriate frequency slot relative to the center IF at 200 MHz. Again, all frequencies are selected for illustrative purposes only. Note that the modulator and demodulator IF frequencies are different in order to minimize potential interference.

4.0 CODEC

Commercial convolutional codec chips (rate 1/2 with Viterbi decoding) will be available for data rates less than 5 Mbps. It appears that the SS user coding schemes should be standardized to take advantage of these chips for all non-TV links. For high rate TV links,
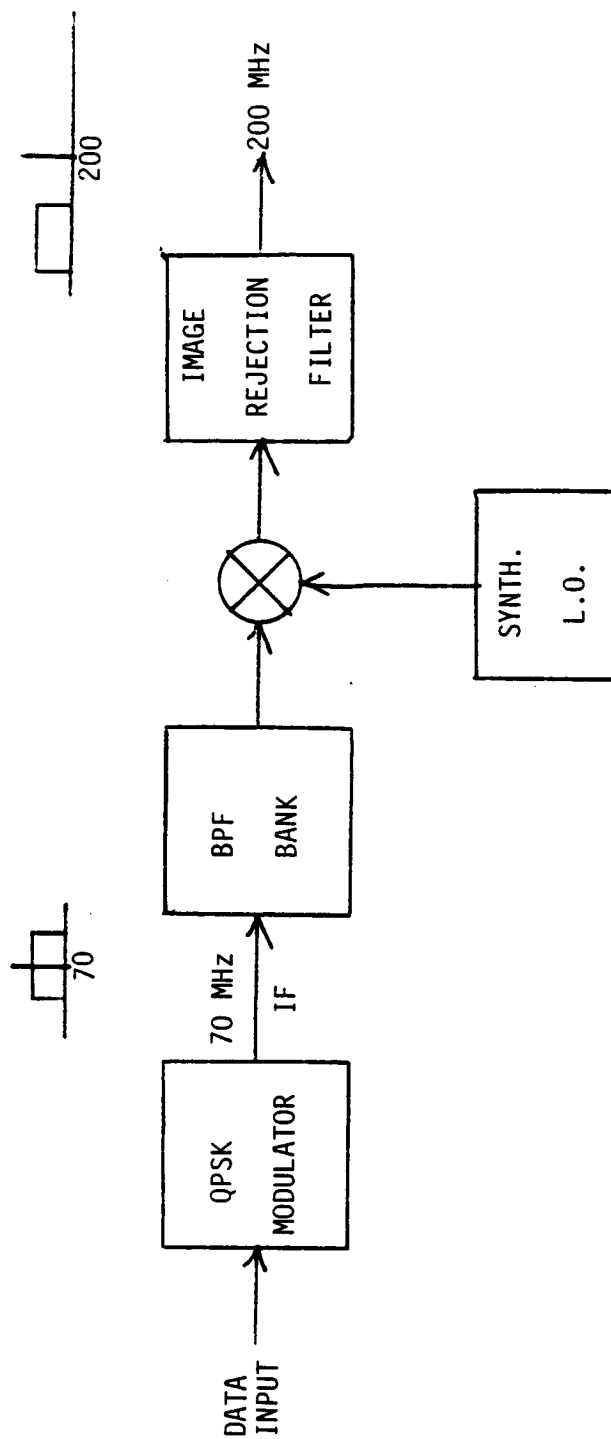
Figure 4. Modulator Conceptual Diagram.

these chips will not be directly applicable. In addition, bandwidth expansion is a problem. It appears that coding should not be employed in this case if the link margin is sufficient. If coding is a must, then a separate, more detailed study is required. In any case, this is not really a commonality issue.

APPENDIX I: FDMA INTERCHANNEL INTERFERENCE AND INTERMODULATION ANALYSIS

SUMMARY

Nonlinearities in the transmitter and the receiver, coupled with signal bandlimiting to optimize bandwidth utilization give rise to interchannel interference and intermodulation (IM) products that affect FDMA communications system performance. Interchannel interference refers to the spilling over of the spectrum of a signal to other frequency channels. Intermodulation refers to cross products of individual channels when they pass through a common nonlinearity.

The options available for the SS to mitigate these effects are: transmit power control, post-HPA filtering, HPA backoff or linearization, and separation of strong interferers from weak power channels in the frequency plan.

Because of the complexity due to the large number of variables (nonlinearity model, power level, signal format, filter, frequency assignment, etc.), computer simulation is the only viable approach to analyze this problem. This approach is outlined here.

1.0 INTRODUCTION

The baseline SS MA system is basically a demand-assigned FDMA system where the channel assignment is accomplished via the common orderwire link. In this respect, it is similar to the SPADE FDMA used by the INTELSAT IV transponders. However, the interchannel interference and intermodulation considerations are quite different: whereas the nonlinearity (transponder) is shared by many (800 channels) in SPADE, the nonlinearities involved with SS MA system operation are only shared by a few.

In this memo, we address the issues of interchannel interference and IM products associated with the SS MA system and options available for their mitigation, and comment on the avenues of analyzing their effects.

2.0 INTERCHANNEL INTERFERENCE

To obtain the maximum channel capacity in a bandwidth-limited system, channels are packed as closely together as possible. However, a QPSK signal spectrum exhibit sidelobes that interfere with adjacent channels because of the spectrum overlap. Hence, the signal must be filtered at the transmitter to minimize this interference.

2.1 Intersymbol Interference Loss Due to Filtering

Filtering in general introduces intersymbol interference (ISI) which degrades the BER performance. For a QPSK signal through a linear channel, the BER degradation as a result of limiting the signal with a 0.1 db ripple Chebychev transmission filter, is exemplified in Figure 1. The horizontal axis is a measure of the 3 db bandwidth of the filter relative to the symbol rate (which is half the bit rate for QPSK signal). The performance degradation is a function of the sharpness of the filter (indicated by the number of poles) and the method of detection. Notice that the performance of integrate-and-dump detection (solid line) is slightly worse than filter-sampler (dashed line) when the 3 db bandwidth of the filter is less than or equal to the data rate ($1/WT > 0.5$). When the bandwidth is greater than the data rate, a considerable amount of degradation is caused by the energy truncation action of the filter indicated by the lower bound curve.

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OF POOR QUALITY
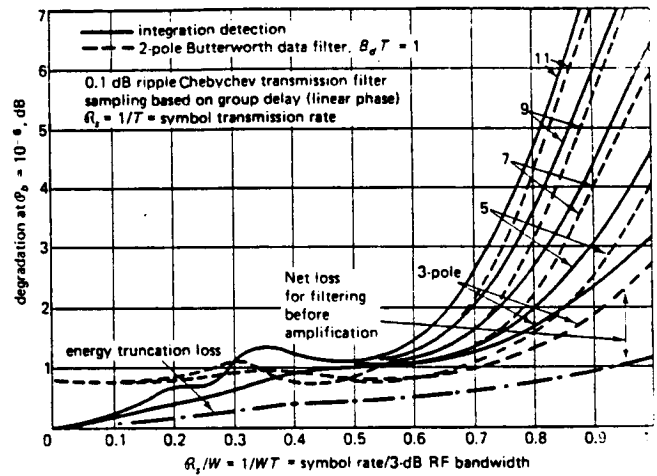
Figure 1.   Degradation Due to Signal Bandlimiting.
For QPSK, Bit Rate is Twice the Symbol Rate.

Notice that the degradation is on the order of 1 db or less if the filter bandwidth is greater than the data rate. This can be used as a rule-of-thumb starting point to iterate the design for the channel spacing for the MA system.

2.2 Nyquist Filtering

When the channel is linear, the degradation due to bandlimiting can be minimized by pulse-shaping the transmit symbol waveform. If the Nyquist criterion is satisfied, i.e., if the channel bandwidth is higher than the symbol rate, the degradation can be eliminated completely if the combined response (pulse shaping, channel, receiver front end, detector, etc.) of the received symbol in front of a sampler detector can be made to resemble a "Nyquist filter". A practical "Nyquist filter" called raised-cosine filter frequently used in satellite transmission is shown in Figure 2.

2.3 Nonlinearity

The situation is more complicated if a nonlinearity enters into the picture. Because of the pulse-shaping filter (which also serves to limit the signal bandwidth) the QPSK signal, ideally constant envelope, now exhibits considerable envelope fluctuation. This leads to spectrum spreading due to the AM/AM and AM/PM nonlinear effects of the transmit HPA. These nonlinearities tend to restore the spectral sidelobes that have been previously removed.

As a precaution against this spectral spreading, the transmit HPA may have to operated below saturation in an approximately linear zone with the associated power penalty. Post-HPA filtering to control spectrum spreading may become impractical because of the extremely high
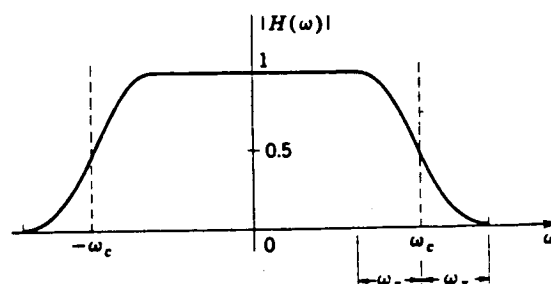
$$|H(\omega)| = \begin{cases} 1 & |\omega| < \omega_C - \omega_X \\ 0 & |\omega| > \omega_C + \omega_X \\ \frac{1}{2}(1 - \sin \frac{\pi}{2} \frac{\omega \overset{+}{-} \omega_C}{\omega_X}) & |\omega \overset{+}{-} \omega_C| < \omega_X \end{cases}$$

$$\omega_C = \frac{\pi}{T}$$

Figure 2. Raised-Cosine Filter Characteristic. Symbol
Rate is T. The ratio $\alpha = \omega_X/\omega_C$ is the Roll-off
Factor. For $\alpha = 0$, $|H(\omega)|$ is an Ideal Low Pass
Filter with Cut Off Radian Frequency ω_C.

selectivity (high Q) requirement for low data rates (100 Kbps at K-band).

The nonlinearity also distorts the signal in such a way that the ISI becomes "frozen" so that the signal can no longer be made to satisfy the Nyquist filter criterion with receive filtering. Thus, one has to accept a certain ISI loss with a nonlinear channel. Fortunately, part of this ISI loss can be recovered by using an equalizer.

3.0 INTERMODULATION

Nonlinearity also introduces intermodulation. For two input carriers at frequencies f_1 and f_2 there are output IM products generated at frequencies $mf_1 + nf_2$ where $|m + n| = 1$ (m and n can be either positive or negative.) The magnitude of these IM products is a function of the nonlinearity model, the relative magnitude of the two carriers, and the drive level (operation point). In general, the most significant IM products arise from $|m|+|n| = 3$, so-called third order IM products.

For multiple carriers with frequencies $f_1,\ldots,f_k$, there are IM products generated at frequencies $m_1 f_1+\ldots+m_k f_k$ where $|m_1 + \ldots + m_k| = 1$. In that case, the most significant IM products are defined by the third order IM products arising from $|m_1| + \ldots + |m_k| = 3$. For example, the third order IM products for the case of three carriers can be represented by the 3-tuples (2,-1,0), (-1,2,0), (-1,1,1), (1,-1,1), and (1,1,-1) where each 3-tuple represents a particular combination of m_1, m_2, and m_3.

4.0 SS MA SYSTEM SCENARIO

For the purpose of the present discussion, the MRMS is not considered.

4.1 Forward Link

The SS has to communicate with approximately 18 potential users providing 4 types (Orderwire, T&C, TV, and HUD) of link. Each link is further broken down into a number of channels. Each channel is assigned a unique frequency slot.

We assume that since a FDMA scheme is used and more than one antenna type (and site) is envisioned, the SS can and will use multiple low power RF Solid State Amplifier (SSA) devices instead of a single high power amplifier (HPA) to serve multiple users. Hence, only one signal (channel) will go through a nonlinearity. If this assumption holds, then intermodulation is not a problem; however, interchannel interference must be considered.

4.2 Return Link

Each user communicates only with the SS, using up to 3 different types of link (OW, T&C, and TV) simultaneously. Some of these users may prefer to use a single RF power amplifier to support all three channels. In this case, both intermodulation and interchannel interference effects must be considered.

5.0 CONTROL OF INTERCHANNEL INTERFERENCE AND INTERMODULATION FOR SS

As far as the SS MA system requirement is concerned, the equivalent nonlinearity "noise" power of the interference and IM products should be kept to be approximately 20 db below the desired signal, measured within the allocated channel bandwidth at the receiver front end. This assumes that the signal-to-thermal noise power ratio required is about 10 db and

the nonlinear "noise" power is required to be 10 db below the thermal noise power.

5.1 Options for Control

The above requirement has different ramifications for different users and link types. First, let us examine the options that one can use to control this nonlinear noise. These options include transmit power control, post HPA filtering, HPA backoff, and near/far channel separation. Recently, there has been reports of experimental TWTA linearizers that correct for a large part of the AM/PM and extend the linear operating range of the TWTA (for example, see Satoh and Mizuno, IEEE Journal on Selected Areas in Communications, Jan. 1983, pp 39-45.) This may be something worth exploring.

The range between users and SS varies from 0.3 to 2000 Km, representing a signal strength dynamic range of 76 db. Hence a signal intended for a user at 2000 Km has a 76 db "advantage" in interfering with a user at 0.3 Km. Power control can be used to offset this "advantage".

When the signal has a wide bandwidth, post-HPA filtering is feasible. This can be used for the TV channels. However, for each additional channel assignment, a different filter is required. In addition, a switching mechanism must be provided. Note that the multi-filter requirement is only a problem with a user. The SS can use dedicated RF paths since it has to provide support for all TV channels.

The nonlinear "noise" is a strong function of the HPA backoff. Hence, if link margin is available, the transmitter can operate at sufficient backoff to mitigate intermodulation and interchannel interference problems.

The last technique that one can use is to arrange the channels in such a way that the near-far advantage is minimized.

5.2 Forward Links

Figure 3 (Figures 3-6 are taken from an earlier LinCom MA report) shows the range of SS transmit EIRP. Under the assumption mentioned previously that each channel has a dedicated RF amplifying element, intermodulation products will be absent. What remains is interchannel interference due to spectrum broadening. The strongest interference will be from the free flyers (FF) on the orderwire channel because of the transmit EIRP difference. Figure 4 is an illustrative channel assignment for the MA forward service. To minimize the effects of interference among the different links, the following can be done:

- Provide post-HPA filtering for each link i.e., separate filters for FF, EVA, and OMV/OTV links.
- Position FF link away from OW link as far as possible as in Figure 4.
- Backoff FF link drive level when they are closer to the SS.

For the channels of a particular link type, especially TT&C, post-HPA filtering becomes impractical because of the high Q required. In that case, the options are:

- Backoff HPA if margin is available.
- Increase separation between channels.

5.3 Return Links

Figure 5 shows the range of received power flux density at the SS for different users. Some users may want to transmit signals from two or more links and use a single HPA. For these users, IM products are a

FF

OMV/OTV

EVA

```
  -20      -10        0        10        20        30        40
```

TRANSMIT EIRP, dBW
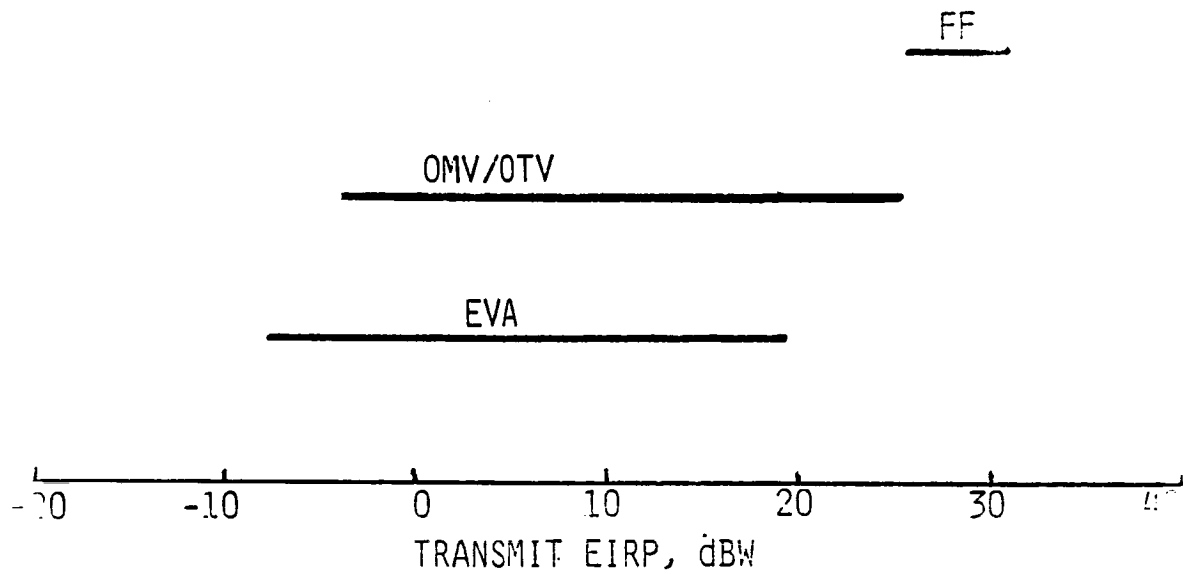
Figure 3. Forward Link Signal Strength Variation.

- TOTAL BW ~100 MHz
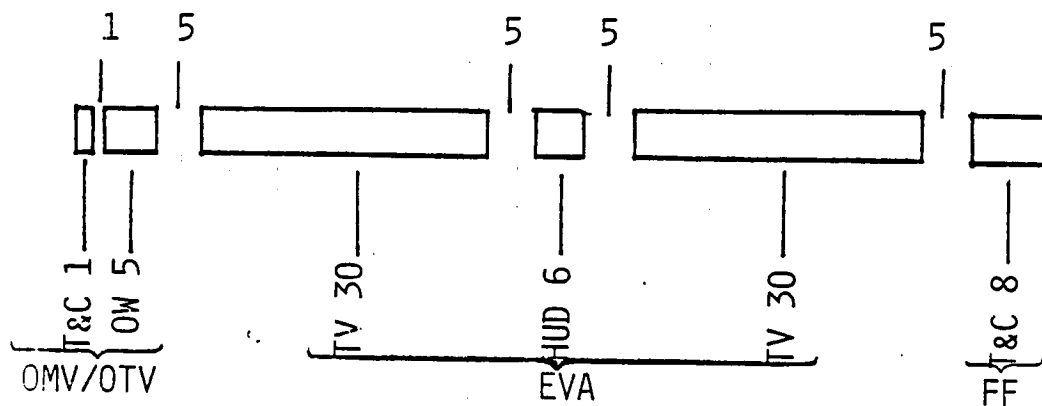
Figure 4.   Forward Link Channel Assignment Example.
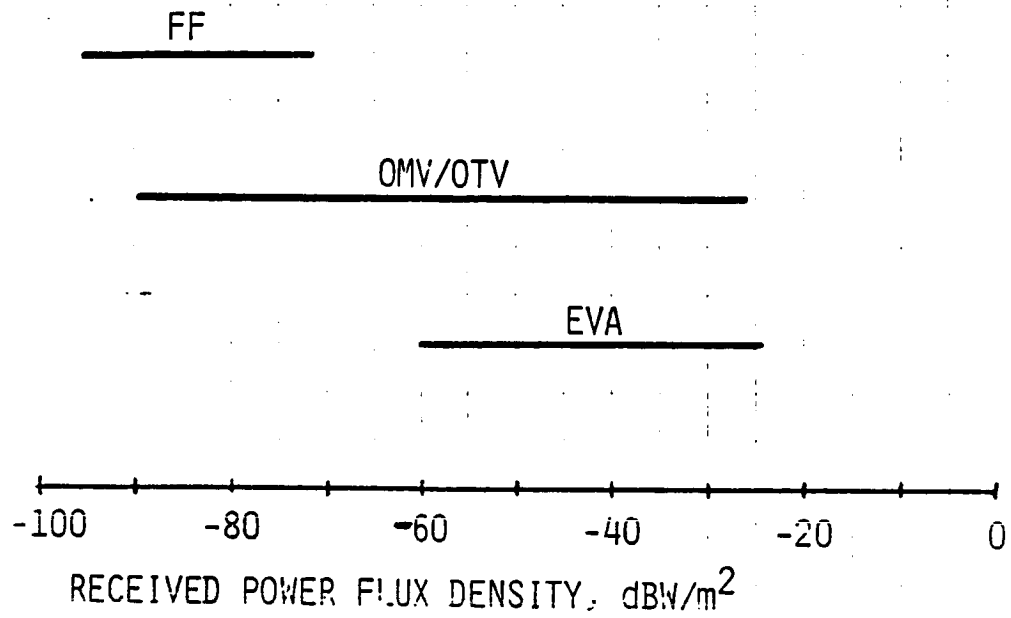
Figure 5.   Return Link Signal Strength Variation.

• TOTAL BW ~ 200 MHz
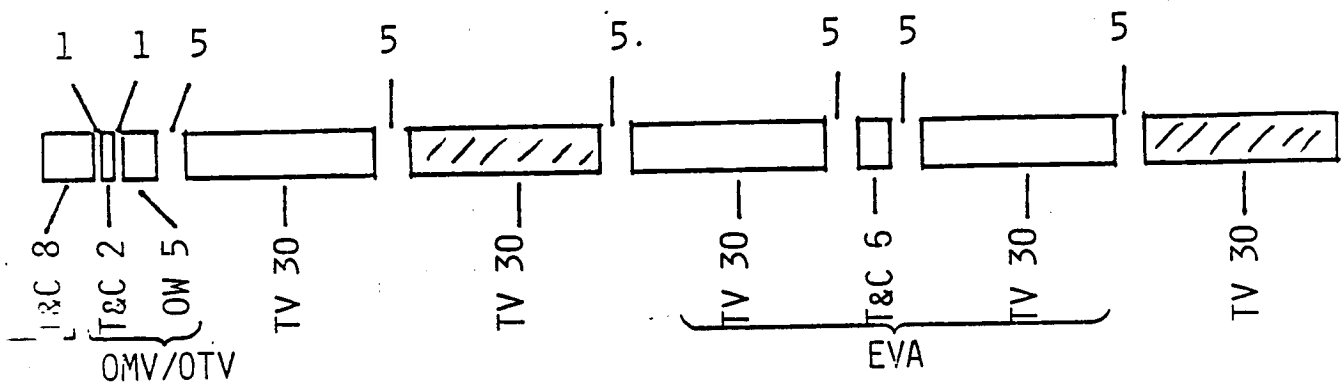
Figure 6. Return Link Channel Assignment Example.

problem, in addition to interchannel interference. Figure 6 is an illustrative channel assignment for the MA return service. To minimize the effects of nonlinear interference, the following options are available:

- Power control is an option that is not very effective for the forward service to mitigate the near-far problem. However, for the return links, if the user transmitter uses power control, then the received signal power density (received power/Hz) from different users can be made to be nearly equal. In that case, the interferences will not be aggravated by the distance disadvantage.
- Separate TV and TT&C links as far as possible on the frequency plan.
- Provide sufficient backoff.
- Use dedicated HPA for TV link and provide post-HPA filtering.

One can also select the frequency plan such that the third-order IM products fall outside the frequency plan. For a simple 2-signal case with center frequencies f_1 (lower) and f_2 (higher), the third-order IM products are at $f_1 - F$ and $f_2 + F$ where $F = f_2 - f_1$. Using Figure 6 as an example, it can be seen that the third IM products from combining the OMV/OTV link with the TV link fall either outside the left edge of the frequency plan or interfere with the EVA or TV channel. Notice that the third-order IM products from the EVA using TT&C and TV can only interfere with adjacent TV channels.

For interference between channels for a given link type, we can either backoff the HPA or provide wider channel separation. Notice that a wider channel separation does not eliminate the IM problem.

6.0 HOW TO ANALYZE

Because of the complexity of the problem due to the large number of variables (nonlinearity model, power level, signal format, filter, frequency assignment, etc.), simulation is the only viable approach to yield any meaningful answers. As a first step, one should probably perform a signal-only simulation to determine the signal spreading due to the nonlinearity. This is performed for a single signal first and later for multiple signals to assess the intermodulation effect. This information can then be used to add an additional "nonlinear" interference noise term to link budget calculations. If the results indicated that the interference is at a range that is "critical", then a more detailed simulation will be required.

APPENDIX J: FREQUENCY MANAGEMENT

SUMMARY

Power Flux Density (PFD) compliance and channel allocation considerations are the subjects treated in this memo. To comply with PFD limits, it is recommended that a spectrum spreading technique such as direct sequence spreading be used for the orderwire (OW) channel. For TT&C, it is perhaps easier to provide workaround procedures and to ask for relieve from regulatory agencies.

Two issues concerning channel allocation (intermodulation and interchannel interference) have been considered in an earlier memo (Appendix H). In this memo, we consider guidelines for allocating the channels to minimize performance degradation, interferences, and equipment complexity.

1.0 POWER FLUX DENSITY COMPLIANCE

An earlier LinCom study showed that certain SS MA links will have trouble meeting the PFD limit impinging on Earth. This has been confirmed by recent computer simulations (see LEMSCO memo "Space Station frequency division multiple access communication system excess power flux density analysis" June 1985 by D. Cravey) performed on the JSC Systems Analysis Office's VAX 11/750 computer. As expected, the power flux density level depends heavily on the antenna pattern for a given EIRP. The broader the beamwidth, the higher is the chance of violating the flux density limit. Figure 1 is a summary of findings taken from that report. The problematic links are the orderwire and the TT&C links.

FIGURE 1. MAXIMUM EXCESS PFD SUMMARY FOR WORST CASE PATH POINTS

Link dir.	Data type	User zone	User position point (as defined in fig. 6)	Max. excess PFD, dB	% of earth with excess PFD
Fwd	OW	Far	A	-6.9	0.0
		Mid	B	16.7	2.9
		Near	D	20.2	2.9
	C&T	Far	A	-13.8	0.0
		Mid	B	-4.2	0.0
			C	32.9	0.004
		Near	D	6.3	0.388
	TV	Near	D	-17.1	0.0
Rtn	OW	Far	H	12.1	3.05
		Mid	G	12.2	3.19
			F	14.6	3.19
		Near	E	15.4	2.91
	C&T	Far	H	11.8	0.168
		Mid	G	-1.7	0.0
			F	0.7	0.022
		Near	E	1.5	0.056
	TV	Far	H	-28.0	0.0
		Mid	G	-6.7	0.0
			F	-1.5	0.0
		Near	E	-21.9	0.0

1.1 Orderwire Link

The orderwire is a problem except for the forward link at the far zone. Since the orderwire is a low data rate link, spectrum spreading technique can be used to "dilute" the power over any 4 KHz bandwidth. For example, if the orderwire signal at 400 bps is spread with a 3 MHz direct sequence, the resultant power over any 4 KHz will be reduced by a factor roughly equal to the processing gain - 7,500 or 39 db. This is enough to cover the maximum 20.2 db over-PFD-limit shown in the figure. From this point of view it appears that CDMA should be used for the orderwire. The CDMA orderwire format already has the advantage that it is compatible with a SS-based ranging system.

One problem with using CDMA is the near-far problem presented by the distance covered - from 0.3 to 2000 Km. This results in a dynamic range variation of 76 db. If the OW is only used for mid to far ranges (37 to 2000 Km) where directional antennas are required, the dynamic range can be reduced to 35 db. Now the near-far problem can be handled easily. A simple solution is to used two separate power levels for mid and far zone operation. In that case the dynamic range is only 14 db for the mid zone and 21 db for the near zone. The CDMA processing gain of 39 db should be able to handle this interference provided that only a few users are on the OW link simultaneously.

If power control is not desirable, then a FDM scheme can be put on top of the CDMA system. For example, the mid zone users can use a different frequency than the far zone user. Of course, more frequencies can be employed to divide the range into finer regions.

1.2 TT&C Link

It is not a practical matter to spread the TT&C link. Even with a

10 MHz chip rate on a 100 Kbps signal, the processing gain is only 20 db. This does not solve the PFD problem. It would result in a big waste of bandwidth since CDMA would not be practical, unless a very fine power control scheme is implemented to solve the near-far problem. Hence, one can perhaps employ a low-rate code (e.g. rate 1/4) to spread the spectrum somewhat and ask for relief from regulatory agencies. The other approach is to adopt an operational workaround procedure and transmit only when there is little chance of interfering with terrestrial communications.

1.3 TV Links

The TV links currently do not show any PFD violation. If a later analysis proves otherwise, it is perhaps best to ask for relief from regulatory agencies.

2.0 OPTIMUM CHANNEL ALLOCATION CONSIDERATIONS

The main issues are:

- How to minimize performance degradation?
- How to minimize interference (internal) among channels?
- How to minimize interference (external) from other users of the frequency spectrum?
- How to minimize equipment complexity?

In what follows, a few guidelines for optimizing the channel allocation to handle these problems are discussed.

2.1 Performance Degradation

Performance degradation arises as a result of bandlimiting the channels. To avoid degradation, the channel bandwidth and guard-band

between the channels should be as wide as possible to take advantage of the total available bandwidth allocated for the SS MA system.

2.2 Interference Among Users

In order to minimize interference among users, it is desirable to separate as much as possible, in frequency, the high power channels from the low power channels. The worst interference problem is from the strong channel to the weak channel. Since the interference power decreases as a function of the offset frequency from the center of the strong channel, frequency separation can minimize the intensity of the interference. It also makes filtering requirements less stringent since the skirt of the filter do not have to be as steep.

For the forward link, the distant user is the strong channel since the SS transmit EIRP must compensate for the distance. For the return link, the distant user is the weak channel if the near user does not use power control.

2.3 Interference From Other Users of the Spectrum

The K-band frequencies for the SS MA system will not be a primary allocation, hence there will be other users of the spectrum interfering with the MA system. To provide some capability to mitigate this interference, it is desirable to have the ability to switch to a different channel while severe interference is encountered. Since the TV channel consumes a large bandwidth, adding spare channels for the purpose of providing frequency agility is expensive. However, the low rate data channels do not consume very much bandwidth overall. Hence, there should be more channels assigned than required for low rate users to provide this agility.

C-2

2.4 Equipment Complexity

A user should be able to use a simple RF front-end for its links. For this to be feasible, the different links (TT&C, TV, HUD, etc.) should be grouped in such a way as to facilitate RF filtering. For example, the TV and HUD links should be adjacent in frequency so that the front-end of the EVA receiver can process both TV and HUD links.

APPENDIX K: FDMA OSCILLATOR STABILITY ANALYSIS

SUMMARY

It appears that commercially available Oven-Controlled Crystal Oscillators (OCXO) will drift no more than 5 KHz in either direction at the end of seven years. Hence the guard-band to be allocated between FDMA channels to account for long term oscillator instability should be about 10 KHz. The bandwidth premium to be paid for the guard-band is only significant for low data rate channels.

Short term oscillator instability affects BER performance. This is not treated here.

1.0 CRYSTAL OSCILLATOR MODEL

The deterministic component of instantaneous frequency f(t) at any time t can be modeled as

$$f(t) = f_0 + a\, f_r t$$

where f_0 is the nominal initial frequency, f_r is the reference frequency, and a is the aging rate (rate of frequency shift). In the above equation, "a" describes the average rate of change of the oscillator's output frequency, assuming that environmental parameters are constant. The oscillator also has a random frequency component which is the main contributor of the noise-like behavior of an oscillator measured over a short duration (from 1 to 100 secs). This is called the short term stability. For the purpose of channel allocation, we are more interested in the aging rates.

Environmental effects such as temperature variations, vibration, g-force loading, shock, load change and voltage changes can all contribute to the fluctuations in the crystal oscillator's output

frequency. Usually these perturbations are modeled as independent, normally distributed random variables. Therefore the combined rms perturbation is the square root of the sum of the variances of the individual perturbation. The effects of the environmental factors tend to degrade the frequency stability according to the root sum square law. A typical set of oscillator environmental effects is summarized in Table I.

2.0 TYPICAL CRYSTAL OSCILLATOR PERFORMANCE

Figure 1 shows typical performance of three types of crystal oscillators (circa 1984-1985). The main difference between the crystal oscillators is the packaging, which controls the environmental parameters. The aging rate determines the frequency drift at the end of one year from its pre-set frequency. They range from +/- 0.45 to 30 KHz. Figure 2 shows a more detailed characterization of the oven-controlled crystal oscillator (OCXO, circa 1982) used by the Space Telescope. The long term stability, when translated to K-band is 1.5 KHz for the planned mission life of 5 years.

3.0 SS FDMA CHANNEL ALLOCATION

Since the price for an OCXO is not prohibitive, its usage will be expected from MA users. Using a three sigma rule, the frequency drift will not exceed +/- 3.15 KHz at the end of a 7-year mission. The worst case is when two adjacent channel drift as in Figure 3 since the aging rate can go either way. Therefore a guard-band of 6.3 KHz will be required to safeguard this drift.

There is another cause for frequency drifting due to the relative motion between the SS and the user. At K-band, a relative velocity of

PARAMETER	STABILITY
Temperature Fluctuations	1×10^{-9}
Vibration	2×10^{-9}/G
Shock	2×10^{-9}/G
G-Force Loading	1×10^{-9}/G
Voltage Change	1×10^{-9}
Load Change	1×10^{-9}

Table I. Environmental Effects Which Degrade
Oscillator Performance.

Short Term Stability

    1.0 msec integration   2 parts per (pp) 10^9 (1 sigma)

    0.1 sec integration   3 pp 10^{11} (1 sigma)

Daily Stability ± 1 pp 10^9/24 hrs, maximum

Long Term Stability ± 1 pp 10^7/5 yrs, maximum

Temperature Stability ± 9 pp 10^{10}/25°C from -18° to +45° C

Input Power   15.2 to 16.8 Vdc, nominally

Operating Power   3.0 watts, maximum

Start Up Power   4.0 watts maximum for 3 hours

Weight   2.8 lb

Figure 1. Characteristics of the Oven-Controlled Crystal Oscillator Used by the Space Telescope.

CLOCK TYPE	APPROXIMATE COST	SHORT TERM STABILITY (1 to 10 sec.)	AGING RATE (per year)
Crystal Oscillator (XO)	75	1×10^{-8}	$\pm 2 \times 10^{-6} \sim 30$ KHz*
Temperature-Compensated Crystal Oscillator (TCXO)	300	1×10^{-9}	$\pm 5 \times 10^{-7} \sim 7.5$ KHz*
High Quality Ovenized Crystal Oscillator (OCXO)	1,000	5×10^{-12}	$\pm 3 \times 10^{-8} \sim 450$ Hz*

*@ 15 GHz

Figure 2. Typical Performance of Crystal Clocks.
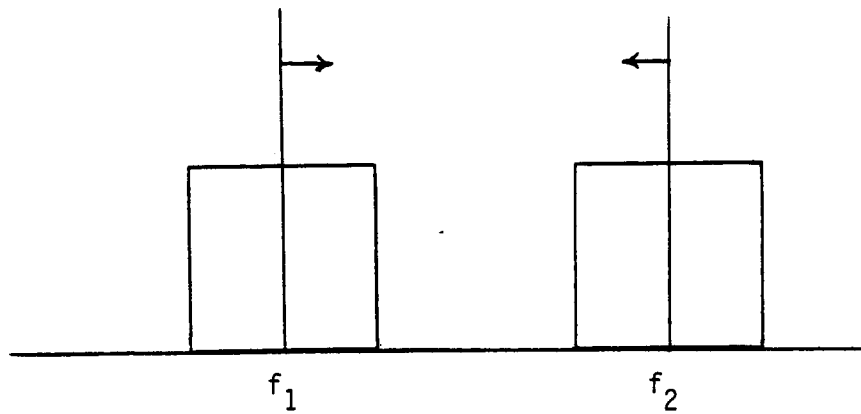
Figure 3.   FDMA Guard Band for Oscillator Instability.

1 m/s will induce a Doppler offset of 50 Hz. If the Doppler can be kept to be less than a few KHz, then it may be acceptable to accommodate it with the guard-band. Otherwise, the SS MA signal structure should allow the user to correct for this Doppler, for example, by employing a pilot frequency.

APPENDIX L: FDMA MULTIPLEXING, FORMATTING AND SYNCHRONIZATION

SUMMARY

The issues involving multiplexing, formatting and synchronization of the SS FDMA system are considered in this memo. Frequency multiplexing of the SS FDMA channels can be performed either at the modem end within the habitat modules or the antenna sites depending on the final RF amplification stage. To select the block length of the data (formatting), the important issues are overall data transfer efficiency and bit slippage rate. It is recommended that a pilot be used for aligning (synchronizing) the channels for high dynamics users.

1.0 MULTIPLEXING

Frequency division multiplexing is the process of dividing a portion of the frequency spectrum into non-overlapping channels to accommodate multiple users. For the Space Station, the pertinent questions are:

- What structure should be used in allocating the channels?

- Where is the multiplexing and demultiplexing to be accomplished?
Another indirectly related question is: How to multiplex (route and buffer) the data between the data source and the modem assigned to the frequency channel? The answer to this question is rather complicated and is dependent on the implementation of the data system. In what follows, we shall consider only the first two questions.

1.1 Multiplexing Structure

Before considering the SS, it is instructive to look at the frequency assignment for a typical FDMA system such as the INTELSAT

where a mix of services are supported. The INTELSAT IV segments the available 500 MHz into 12 transponders each with a 36-MHz bandwidth. Each transponder can be used to carry one or two TV channels (full transponder or half transponder TV). If a SPADE system is used for digitized voice, then the full bandwidth of a transponder is segmented into 800 channels with a signal bandwidth of 38 KHz and a channel spacing of 45 KHz. Quaternary PSK at 64 Kbps is used for each SPADE channel. Also a pilot is used at the band center of the transponder. A common IF frequency of 70 MHz is used by the Earth terminal.

Under the SS scenario, the earth terminal is similar to a group of modems on board the SS. The transponder can be the SS RF equipment that includes the frequency converters, HPAs, and antennas.

The basic strategy used by INTELSAT is to allocate the available RF bandwidth first into groups of frequencies so that it can be conveniently handled by the system. In this case the groups are 36-MHz in bandwidth, and the system constraint is the bandwidth that can be supported by the output power of the transponder. Each group is broken down into channels. The bandwidth allocated to a channel of a type of service is conveniently related to that of another service. For example, two half transponder TV channels can nicely fit into a full transponder TV channel. This way the system can accommodate many different users with a wide variety of service combinations while using a standardized set of earth stations, modems and IF frequencies. Let us see how this strategy can be applied to the SS, if desired.

The obvious parallel approach is to divide the spectrum into groups that can handle the 22 Mbps TV. For illustrative purposes, let us use a 30 MHz spacing. The group can be used to support the full rate TV or it can be divided to support two half-rate TV channels or 4 quarter-rate TV

channels etc., or any valid combinations therein. The remaining TT&C and OW links can then share a portion (e.g. half) of the group bandwidth.

Another approach, perhaps better, is to realize that the SS constraint is the nature and capability of the RF (converters, LNA, PA, and antenna) terminals. A good modulation plan is one such that each RF terminal (RFT) only has to handle two frequency bands, i.e., forward and return. (It is actually more desirable to separate the forward and return link in frequency. It is less taxing on the diplexer to handle the big difference between transmit and receive power). The following assignment is desirable:

TT&C group	High gain antenna
TT&C and TV group	Medium gain antenna
TV and OW group	Low gain antenna

1.2 Where To Multiplex

A signal has to be bandpass filtered and placed into the proper frequency slot. The bandpass filtering will be performed by the modem. What remains is the proper translation of the IF frequency to a proper location in one of the RF groups. The implementation of the HPA will determine where the individual signals are best assembled.

An RFT will be fed by multiple modems (each modem serves one user). Since the modems and the RFT are not collocated on the SS, some means must be provided to interconnect them. A frequency multiplexer can be used to assemble the output from the modems by translating to another IF frequency before feeding the RFT. The proper arrangement of the channels can be done at this time so that only a single group frequency translation to RF is required at the RFT, see Figure 1. For this to
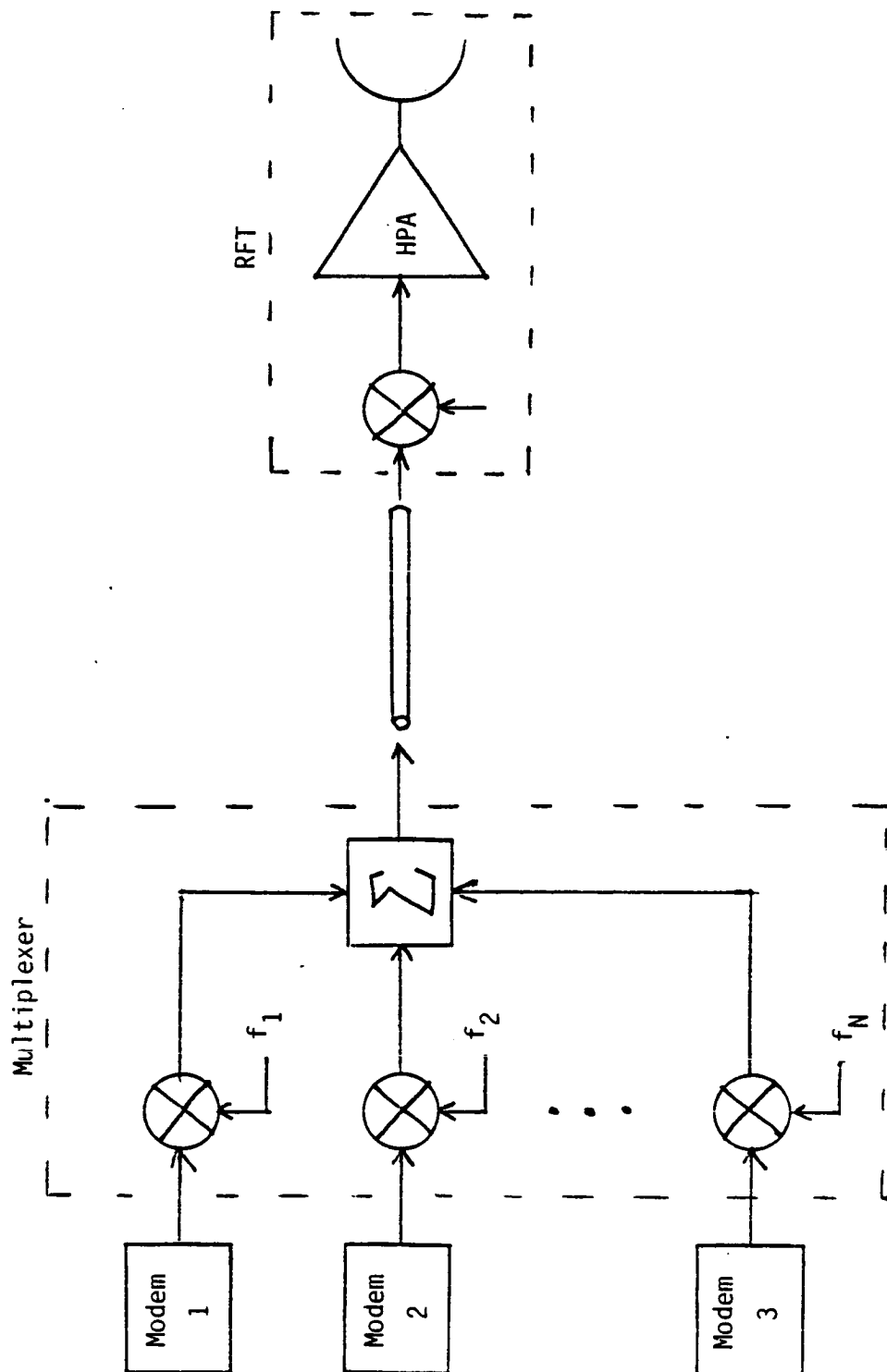
Figure 1. Multiplexing Scheme for Group RF Amplification.

work, the "cable" connecting the modems and the RFT should be able to support the second IF. Also, the multiplexing is only useful if the whole group will be amplified by a single HPA.

If the "HPA" is a bank of medium power amplifiers each of which can only handle a single channel, then the multiplexing at the modem end does not help. The channels must be demultiplexed again before feeding the amplifiers. In that case, it is probably easier to just multiplex the modem signals in a way that is easy to demultiplex at the RFT. The frequency translation will be performed individually for each channel, see Figure 2.

2.0 FORMATTING

There are a few issues to be considered to format data into data blocks. (For this discussion, we will ignore the orderwire which has its own data structure.) They are:

- Overhead
- Bit Error Rate
- Bit Slippage rate
- Encryption

These issues often have conflicting requirements.

Part of a data block is used for bookkeeping and error control. The longer the block, the less is this overhead. However, the block cannot be too long because of the bit slippage rate.

At some point in time, the modem will insert or delete a bit in a block. If this happens, all the data after this insertion or deletion will be lost. Hence, the block length must be much less than the inverse of the bit slippage rate (BSR). As a rule of thumb, the product of the BSR and the block length should be less than BER/10. For
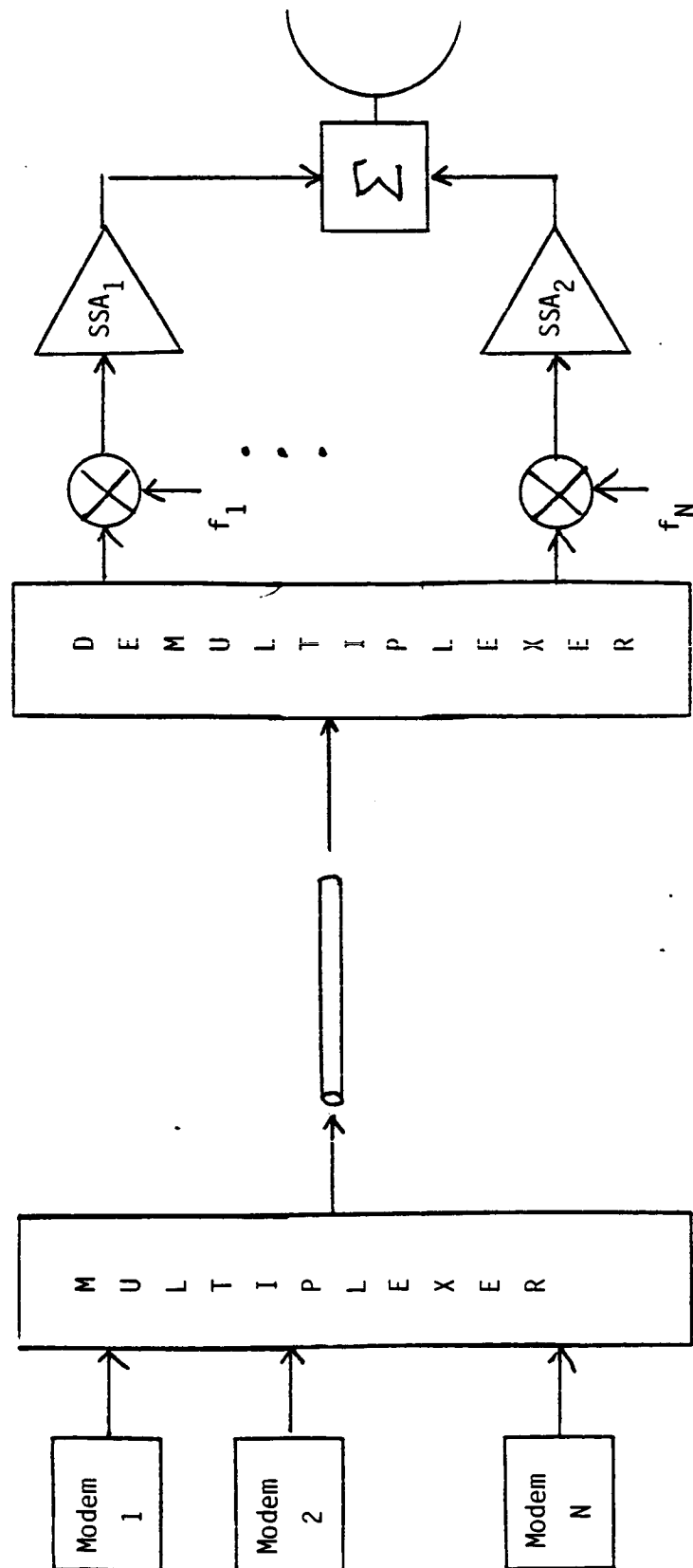
Figure 2. Multiplexing Scheme for Individual RF Amplification.

instance, if the BSR is 10^{-9} and the desired BER is 10^{-5} then the block length should be less than 1,000 bits.

The use of encryption to ensure data privacy adds another dimension to the consideration. If the Data Encryption Standard (DES) is used, the cipher operates on 64-bit blocks. When a bit error occurs, the whole data block will be deciphered incorrectly if the electronic code book (ECB) mode is used. If the cipher block chaining (CBC) mode is used, part of the next block will also be lost. This, although interesting, does not really put any real constraint on the block length. However, it may be worthwhile to format the block so that the data portion of the block is an integer multiple of 64 bits (or the block length of the particular encryption scheme).

3.0 SYNCHRONIZATION

It is probably a good idea for the SS to transmit a pilot so that a high dynamics user can use it to determine and correct for its Doppler shift to ensure proper channel occupancy. This can be accomplished by comparing the frequency difference between a local pilot generated by the user oscillator (whose drift is should be much smaller than the Doppler by design) and the received pilot which is tracked by a frequency-locked loop. The user can also use this pilot to calibrate its own oscillator drift during periods of benign Doppler e.g. during docking.

It is not anticipated that carrier and clock recovery will be a major problem for the SS MA system if QPSK modulation is used. However, the design for the low rate orderwire channel synchronization may not be trivial because of the low input CNR.

APPENDIX M: TDRSS UTILIZATION

TDRSS UTILIZATION

- EXISTING CAPABILITY

- TDRSS ENHANCEMENT

EXISTING CAPABILITY

- TDRSS CAPABILITY

  - USERS' GUIDE
  - GROUND
  - SPACE

- STANDARD SERVICES

  - 1 TDRS
  - 2 TDRSs

- IF SERVICES

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TDRSS ADVERTISED SYSTEM CAPABILITY

- North/South TDRSS Only

- FORWARD LINK
  - 2 MA
  - 4 SSA
  - 4 KSA

- RETURN LINK
  - KSA
    - 4 Services $\leq$=20 Mbps Uncoded, $\leq$=10 Mbps Coded

    or

    - 2 Services $\leq$=300 Mbps Uncoded, $\leq$=150 Mbps Coded
  - SSA
    - 4 Services $\leq$=3.15 Mbps
  - MA
    - 20 Services

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TDRSS SPACECRAFT CAPABILITY

- SA
  - 2 Antennas per TDRS

- MA
  - 1 MA (30 element phased-array) Antenna per TDRS

- WESTAR
  - 1 C-Band System (Transponder/Antenna)
  - 1 Additional K-Band System (Transponder/Antenna)

TDRSS GROUND CAPABILITY - FORWARD

- MA
  - 3 Services (1 Equipment Chain Shared by N,C&S)

- SSA
  - 6 Services (2 Chains Each for N,C&S)

- KSA
  - 6 Services (2 Chains Each for N,C&S)

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TDRSS GROUND CAPABILITY - RETURN

- 3 Receive Chains (N,S&C)

- KSA

  - Each Chain has 2 Sets of Demod/Bit Sync up to 50 Msps per Quadrature Channel

  - Each Chain shares 1 set of Demod/Bit Sync for 50 Msps to 150 Msps per Quadrature Channel

  - Each Chain shares (16) 10 Mbps Decoder Stack

- SSA

  - Each Chain has 2 Sets of Demod/Bit Sync

  - All 3 Chains share 12 De-interleaver/Decoders up to 6 Mbps (Rate 1/2) or 2 Mbps (Rate 1/3)

CONTINUE

- MA

    - Each Chain has a 30-Channel FDM Demultiplexer

    - All Chains share a MA Signal Processor that can accommodate up to 20 Users

    - All Chains share 20 Sets of Demod/Bit Sync/Decoders

STANDARD SERVICES UTILIZATION OF TDRSS

● 1 TDRS

SIMPLIFIED SA COVERAGE SCENARIO

WORST CASE COVERAGE ($\theta = 0$)

- SSA
  - $\pm$ 620 KM SS Orbit
- KSA
  - $\pm$ 86 KM SS Orbit

TDRSS

SS Cluster

θ
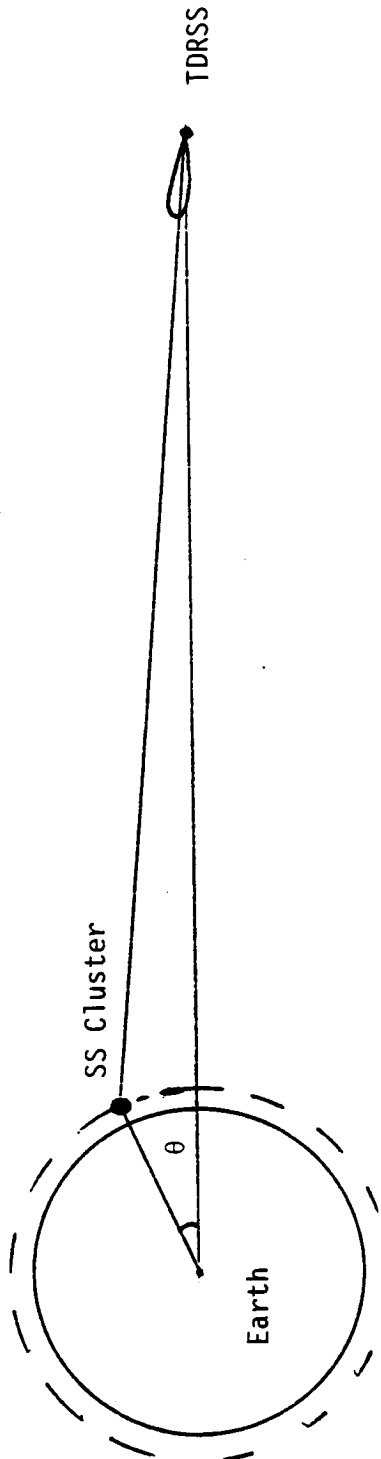
Earth

ASSUMPTIONS:

Radius of Earth = 6,370 KM

SS Orbit = 500 KM

TDRSS/Earth Center = 42,230 KM

SSA Beamwidth = 2 degrees

KSA Beamwidth = 0.28 degrees

KSA Autotrack with SS

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SIMULTANEOUS SUPPORT OF 2 KSA USERS BY A SINGLE TDRS

- The TDRSS antenna beamwidth can cover approximately +/- 90 Km of the SS orbit. Its usage as a multiple-user antenna is rather limited.

- The KSA forward and return frequencies are fixed. Hence only one user can be served by an SA antenna at a time.

- The TDRS SA antenna polarization is command selectable. Hence both SA antennas on a single TDRSS can be used to serve any two users in the SS cluster via polarization diversity.

- The axial ratio of the TDRS KSA antenna is 1 db. The isolation between RHCP and LHCP is therefore approximately 24.8 db. In order to minimize interference between the two users, the signal power both transmitted or received, when normalized by the symbol rate, should not differ by more than 6 db.

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SIMULTANEOUS SUPPORT OF 2 OR MORE SSA USERS

BY A SINGLE TDRS ANTENNA

- The TDRSS antenna beamwidth can cover approximately +/- 600 Km of the SS orbit.

- The SSA forward 20-MHz channel bandwidth is set by the demultiplexing filters in the forward processor only; the SSA return 10-MHz return channel bandwidth is set by the bandpass filter in the return processor. All other elements have approximately 100 MHz bandwidths.

- One limiting factor is the bandwidth allocation (20 MHz forward and 10 MHz return) for the SSA space-ground link.

- Hence it is not possible to fully utilize the available 100 MHz bandwidth as configured.

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CONTINUE

- To support 2 or more users, they must all operate within the 20/10 MHz allocation. As a rule of thumb, the total data rate supportable by the SSA channel will be reduced by a factor of two. Note that the ground equipment is not capable of support more than one user per receive chain with standard service.

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SIMULTANEOUS SSA & KSA SUPPORT

- TDRSS currently supports simultaneous SSA and KSA service for a single user. Hence the TDRSS should be able to provide both SSA and KSA coverage per SA antenna to a mixture of users within the beamwidth of its SA antenna - perhaps with an operational workaround in its standard service software procedure in the worst case. The TDRS KSA autotrack determines the direction of the antenna pointing.

- 1 SA antenna can support up to 2 users within the SS cluster.

- 2 SA antenna can support up to 4 users within the SS cluster by using polarization diversity for KSA. For SSA, there is the option to use either polarization and/or frequency diversity.

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STANDARD SERVICES UTILIZATION OF TDRSS

● 2 or More TDRS's

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MULTIPLE TDRS'S SUPPORT

- KSA: 2 or more TDRS's would not help if the users are close together because of the problem of interference. Only two KSA services can be supported at the same time with polarization diversity. If the users are sufficiently apart (the sidelobes of the KSA antenna pattern will be 25 db down at 1 degree from boresight - at least 600 Km apart in the best case geometry), then more TDRS's can help.

- SSA: Since the frequency of the SSA is selectable over a 100 MHz bandwidth, approximately 5 forward links (20 MHz) and 10 return links (10 MHz) can be accommodated with frequency diversity. With polarization diversity, this number could be doubled, although the MA frequency using LHP should be avoided.

- MA: The number of users remains at 20 for the return link, limited by the ground base forming capability.

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CONSIDERATIONS FOR IF SERVICE

● IMPROVED CHANNEL CAPACITY: IF Service allows the TDRSS to be
used as a transponder. With efficient modulation/coding
schemes, the data throughput rate of the SA services can be
improved - limited only by the bandwith of the channel.

● MULTIPLE ACCESS: IF Service allows a single SA service to be
shared by multiple users via FDMA. (The standard service must
be time-shared). One problem that needs to be looked at is the
effect of FDMA on the KSA autotrack system. If multiple users
on FDMA are within the same KSA beamwidth, will the autotrack
system end up pointing the antenna at the mean position of the
user cluster? Will the system become unstable? Is there a
simple way for the system to track a particular user such as the
SS?

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● LINEARITY: In order to accomodate FDMA, the TWTAs on the
TDRS must operate near the linear region to minimize the effects
of adjacent channel interference. Currently the TWTAs operate
at sufficient backoff. However, if higher data rates are to be
used, then one must increase the transmit power (hence reducing
the backoff). To minimize the effect of adjacent interference
on the weak channel from the strong channel, all users should
operate at comparable signal power levels.

● TIME-SHARE: (This comment applies to both Standard and IF
Service). If the SA service is provided to the SS cluster and
the users access the service in a time-shared manner, then the
operational procedure/software of the TDRSS should be enhanced
to handle a cluster-type of user access. Specifically, when
switching from one user to another within the cluster, the TDRSS

CONTINUE

system should perform a minimum amount of re-initialization. For example, if the SA beam covers both users, then the antenna acquisition process can be shortened and/or eliminated. In the case that the TDRS must repoint the beam, the old user position should be used as a starting point.

- GROUND EQUIPMENT: A set of comparable modem/codecs must be installed at White Sands in order to use the IF Service. The number of receiver units will depend on the scheme to be used. It will be of interest to develop a more versatile (e.g. digital) modem if a FDMA scheme is used and multiple units are required.

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TDRSS ENHANCEMENTS

- ALTERNATIVES WITH MINOR CHANGES

- TRW SDSS PROPOSAL

ALTERNATIVES WITH MINOR CHANGES

- OPEN UP SSA CHANNEL

- RE-USE AW CAPABILITY

- ADDITIONAL TDRS

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OPEN UP SSA CHANNEL

- SWITCHABLE SSA DEMULTIPLEXING FILTER THAT GIVES MORE BANDWIDTH
  (E.G. 50 MHZ) FOR SS CLUSTER USERS

- INCREASE SSA SGL TX POWER

- OFFSET SGL DOWNLINK SSA1&2 FREQUENCIES BY ADDITIONAL 50 MHZ;
  MAKE CORRESPONDING EQUIPMENT CHANGE AT WSGT

RE-USE ADVANCED WESTAR CAPABILITY

- K-BAND SPOT BEAM (1.1 METER)
  - 14.0 TO 14.5 GHZ RX UPLINK
  - 11.7 TO 12.2 GHZ DOWNLINK

- C-BAND AREA COVERAGE (2 METER)
  - 5925 TO 6425 MHZ UPLINK
  - 3700 TO 4700 DOWNLINK

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AW K-BAND

- USE FOR DEDICATED SS SUPPORT IN ADDITION TO REGULAR KSA

- CONSIDERATIONS

  - FREQUENCY COORDINATION WITH FIXED SATELLITE SERVICE

  - MODIFICATION TO PROVIDE POINTING. FOR EXAMPLE, USE KSA AUTOTRACK SIGNAL TO DRIVE GIMBAL

  - G/T SUPPORTS UP TO 50 MBPS

  - SS CAN USE SAME DISH FOR KSA BY ADDING ADDITIONAL FEED

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NEW C-BAND

- USE FOR SGL TO CONTROL CENTERS AT JSC, GSFC, ETC.

- CONSIDERATIONS
  - THIS IS FIXED SATELLITE SERVICE
  - SOLVES CHANNEL CAPACITY PROBLEM WITH DOMSAT AND NASCOM
  - NEED TO UPGRADE TDRS TO ALLOW K-BAND/C-BAND CROSS-STRAPPING

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TDRS CENTRAL

- PROVIDES 50 PERCENT MORE TDRSS SYSTEM COVERAGE

- BEST USE OF TDRSS GROUND CAPABILITY

- WHAT THAT MEANS TO SS

  - SS CAN ACCESS TDRS-E & W MORE OFTEN SINCE OTHER USERS CAN USE TDRS-C WHEN VISIBLE

  - SS CAN USE BOTH KSA1 AND KSA2 FOR HIGH RATE DATA DUMP (>600 MBPS) WHEN TDRS-C IS VISIBLE

TRW SDSS PROPOSAL

- NO TDRSS SPACECRAFT UPGRADE

- TDRS BLOCK CHANGE UPGRADES

- NEW SYSTEM OPTIONS
  - 2 TDRS SPACECRAFT
  - 3 TDRS SPACECRAFT
  - GROWTH CONFIGURATION

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NO TDRSS SPACECRAFT UPGRADE

● INCREASE WSGT ANTENNA SIZE

● IMPROVE OPERATIONAL PROCEDURES DURING HANDOVER

● THIRD TDRSS (DO NOT ADVOCATE)

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TDRS BLOCK CHANGE UPGRADES

- EXISTING AW ANTENNA CONVERSION

  - REPLACE AW K-BAND ANTENNA BY A 44 INCH CASSEGRAIN ANTENNA
    AT 60 GHZ; DOES NOT HAVE ENOUGH GAIN TO SUPPORT 300 MBPS IN
    THE CROSSLINK MODE

  - CONVERT AW 2-METER C-BAND DISH TO A CROSSLINK ANTENNA AT 60
    GHZ, TO A HIGHER GAIN SS/TDRS RETURN LINK ANTENNA, OR A
    STEERABLE SGL-TYPE FOR FUTURE USER SUPPORT

- MULTIHORN TRI-BAND FEED ASSEMBLY FOR SGL 2 METER DISH

  - MODIFY TO A KU/20/30 MULTIBEAM FEED FOR DOWNLINKS TO WSGT,
    JSC AND GSFC (TDRS-E) OR WSGT, CSOC, AND SUNNYVALE (TDRS-W)

- BLOCK CHANGE UPGRADES ALLOW NEW TDRS SYSTEM OPTIONS

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2 TDRS SPACECRAFTS

- ADDITIONAL 60 GHZ LINK TO SPACE STATION

- 2 ADDITIONAL TERMINALS AT WS FOR RELAY TO USER LOCATIONS. FOR EXAMPLE, USE SS/TDRS-W/WSGT/TDRS-E/JSC. USE 30/20 GHZ (UPLINK/DOWNLINK) FOR SGL

- FOR GROWTH, USE 60 GHZ CROSSLINKS FOR TDRS. FOR EXAMPLE, USE SS/TDRS-W/TDRS-E/JSC

3 TDRS SPACECRAFTS

- LINKS ARE BASICALLY SAME AS 2 TDRS CASE

- ELIMINATES ZONE OF EXCLUSION

- USES EITHER FOREIGN GROUND STATIONS OR 60 GHZ CROSSLINKS

APPENDIX 2. COMMENTS ON HARRIS'S CONTROL ZONE ANTENNA PROPOSAL

AND RCA'S MULTIPLE COMMUNICATIONS SYSTEM PROPOSAL

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SUMMARY

HARRIS PROPOSAL

Harris proposes to implement the Control Zone antenna using a phased-array antenna technique. The implementation uses Monolithic Microwave Integrated Circuit (MMIC) and microstrip technology. The risk involved with this approach is in the hardware implementation. Since Harris proposes to develop the key components and demonstrate a reduced version which consists of the actual hardware to be used for the full-scale antenna, potential problems with the technique will be uncovered during this developmental stage.

One area that needs to be clarified is whether six transmit channels at 56 dbm EIRP each can be supported simultaneously with the proposed design. Another area is the phase control calibration technique for path-delay variation compensation.

RCA PROPOSAL

The RCA proposal is less solid compared to the Harris antenna proposal. This is perhaps necessitated by the nature of the effort, which has to do with a much more complicated problem. RCA basically proposes to perform a more detailed study of their MA system baseline and to breadboard certain subsystems so that a demonstration of the MA system can be made at the end of the contract. This demonstration will be accomplished using the breadboards, some IR&D hardware, and standard test equipment.

An important area that needs further clarifications concerns the breadboards to be developed and some of their IR&D hardware to be incorporated

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in the demonstration. Specifically, a more detailed description is required so that we can judge which components can be considered as advanced development which can be used eventually for Phase C hardware.

GENERAL

To take full advantage of the Harris and RCA efforts, it would be worthwhile to perform a demonstration of an integrated MA communications system including both the Harris antenna and the RCA modem. To this end, the subsystems must be able to directly interface with each another. Currently as proposed, the IF frequencies are different, i.e.,3.125 GHz for Harris and 620-820 MHz for RCA.

In order to come up with a successful integrated system-level demonstration, NASA/JSC should take the responsibility early on to lay down the system-level requirements, define the tests, and coordinate test efforts of the two contractors.

In what follows, more specific comments of both proposals are provided.

1.0 HARRIS PROPOSAL: Specific Comments

1) p.24. The phased-array antenna configured as such cannot support polarization diversity. The polarization is determined by the layout of the microstrip.

2) p.25. It is not clear from Section 3.5.3 that all six channels can be supported simultaneously at 56 dbm EIRP/channel.

3) p.38. The coherent noise argument sounds strange since the transmit noises are derived from different transmit power amplifiers. But the conclusion to use separate transmit and receive arrays appears to be

the right decision.

4) p.48. Even with a dedicated amplifier channel to eliminate intermodulation
products, it may not be wise to operate near signal compression
since excessive interchannel interference can be introduced.

5) pp.50-54. The comparison between monolithic and hybrid technology is based
on recurring cost only. What about development cost?

6) p.56. Assumption 2 on the dynamic range may be optimistic since the data
rates can differ. For example consider a low rate user at 20
nautical miles and a high rate user at 1 nautical mile.

7) p.58. The IM consideration is based on six channels only. What about user
signals from other coverage zones?

8) p.74. The estimate of 2 db for combiner loss may be optimistic since 7
levels of combining are required. Do they have any similar device
that is operational or breadboarded? This comment also applies to
the transmit array later on p.78.

9) p.76. The baseline block diagram section describes the use of an output
power of 11 dbm per element to give an EIRP of 11 + 20log(177.8) =
56 dbm for 177.8 elements. To support 6 user channels, the output
power must be increased to 19 dbm per element. According to p. 79,
the output power (presumably maximum) of the amplifier is 20 dbm.
Hence it must operate at a 1 db output backoff. It seems intermod
would be a problem for the six channels. Is this an oversight of
the design?

10) p.83. The 3 GHz IF is different from the RCA MA breadboard.

11) p.88. How is phase calibrated for each radiating element. What is
involved if it is necessary to re-calibrate in space?

2.0 RCA PROPOSAL: Specific Comments, Technical Proposal

1) p. 2-1. The constant turn-around ratio between transmit and receive
frequencies is required for coherent Doppler measurement. Doppler
measurement is essential if the SS is to keep track of the
ephemeris of the users. It is misleading to say that this
simplifies hardware (stressed again on p. 2-3).

2) p. 2-3. The UHF wideband IF of 600 MHz is selected. This is different
from the 3 GHz IF selected by Harris.

3) p. 2-8. The "hockey puck" is said to be 20 Km in diameter. Should this be
37 Km in radius?

4) p. 2-8. It is said that the orderwire will be transmitted over zone 2
scanning fan beam antennas. This seems to be a deviation from the
original philosophy of the orderwire - using a link that would not
tie up directional antenna resource.

5) p. 2-8. The accuracy of the proposed ranging system is only required for
computing user ephemeris data, not for power control.

6) p. 2-10. The "decided advantage" of synchronizing the range message is
misleading. If the bit duration is a multiple of the PN code
period, then bit sync acquisition can be simplified but not the
frame acquisition of the range message. In any case, at 3 Mcps
chip rate and roughly 500 bps bit rate, there are 6000 chips/bit,
or equivalently 600 Km/bit. Since the range ambiguity is 2000 Km,
a four bit message period or a code period of 2400 will suffice.

7) p. 2-11. The 25.1 db circuit margin for the 1Km, 22 Mbps link is of
suspect.

8) p. 2-15. One concern with a fiber optic link is the mean life time of the
laser diodes. But is a laser diode really necessary? What if one

does not use a wideband IF but multiple fibers?

9) p. 2-16. The modulation tradeoff issue is rather tricky. In a practical
link, the 99% or 99.9 percent bandwidth for the idealized signal
is just not a good criterion for selecting a modulation scheme. A
constant envelope signal, like MSK, shows amplitude variations
after bandpass filtering, e.g. the 40 MHz filters proposed. When
this passes through a nonlinearity, the sidelobe level will be
much higher than if the input signal has not been bandlimited. In
addition, the first sidelobe (not the sidelobes way out at 99.9%,
at least 60 db down) is usually more important for FDMA
considerations since it has the most energy to interfere with the
neighboring channels. MSK is not much better than QPSK in this
respect.

10) p. 2-16. Other disadvantages of TDM are high EIRP, high power (all antenna
sites will be on and transmitting synchronously) and fast antenna
switching.

11) p. 2-25. Distributed processing/autonomy should be employed. Functions
that can be handled conveniently by a microprocessor at the
equipment level should not be handled by the MASC.

12) p. 2-39. The use of a digitally-controlled oscillator is recommended
instead of the D/A-VCXO combination to take full advantage of the
digital modem design.

13) p. 2-40. At 4 times per symbol per channel at 2x22 msps, the sampling rate
is 88 Mega samples per second. Is it practical to perform digital
filtering in this rate?

14) p. 2-41. What is the driver for selecting a 25 Khz acquisition range? What
is the anticipated Doppler and user frequency uncertainty?

15) p. 2-41. Where are the Nyquist bandpass filters located? What are

they used for?

16) p. 2-60. User terminal #2 is not a deliverable. Can it be on loan for the

combined antenna (Harris) MA system tests?

17) p. 2-63. It is not clear which of the critical items of the high rate

modem module can be used later in Phase C.

18) p. 2-64. The partial modem shown has a 70 MHz VCXO which is free running.

Does "partial modem" stand for modulator only? Do they intend to

manually adjust the timing, phase and frequency to demodulate the

received signal?

2.1 RCA PROPOSAL: Specific Comments, Technical Clarifications

1) p.9. Is it possible to obtain performance specifications for their IR&D

program products (synthesizers, radio, etc.) to be applied to the MA

program?

2) p.9. It is not clear how the transmit signals are selected/multiplexed to

route to different antennas within a given antenna location out of

the possible four.

3) p. 16. If fiber optic is used for RF distribution, the technique shown in

Figure 3-1 may not be desirable.

4) p. 18. See comment 2.

5) p. 20. What are "those functions necessary for the proof-of-demonstrations

in terms of filters and circuitry"? Also see comment 18 in the last

section.

6) p. 21. Is it possible to obtain performance specification for the "Positive

Location Techniques"?

APPENDIX 3. CURRENT ESTL CAPABILITIES

SUMMARY

This appendix documents the current and planned capabilities of the ESTL. It is based on a conversation with Linda Bromley on 10 October 1985.

1. Linda described the plans associated with the VAX 11/785 computer dedicated to ESTL. The current plan (funding shaky) is to procure an "APTEC" which can be used to house DIAs capable of handling data I/O between the VAX and other ESTL equipment subsystems for speeds up to 24 Mbps.

2. Currently, the main functions of the ESTL computer are:
    - Generate command and telemetry data sequence for testing
    - Act as a sophisticated BER (PDL, MRR) machine for Shuttle Commands

3. The following subsystem configurations are under "computer control":
    - Ku-band system via a LSI computer
    - Network Signal Processor (NSP) via the PICS
    - TDRSS ground station via the TICS
    - MFR (with upgrade)

    The following subsystems can be keyboard-configured:
    - STDN data generator
    - SCE
    - MSFTP

4. Linda provided system test block diagrams for:

    - Real-time Telemetry Configuration

    - Command Configuration

    - Ranging Configuration

    - Doppler Configuration

    The ranging configuration applies to the GSTDN link only. The Doppler

    configuration applies to S-band only.

5. Linda provided a list of tests that ESTL is capable of performing.

    However, the normally performed tests are a small subset which include:

    - Message Rejection Rate (MRR)

    - Percent Data Loss (PDL)

    - BER

    - Command Rejection Rate

    - Voice Quality

    - RF Acquisition

    These tests are performed as a function of the following parameters:

    - Doppler Profile

    - PN Spreading (on/off)

    - Encoding (on/off)

    - Signal Levels

    The calibration procedure includes calibrating AGC circuits and

    establishing a reference 0db CNR point.

6. Two capabilities are "must" for automating ESTL:

    - Provide real-time feedback to validate the test data. This can be in
      the form of a "quick plot" on the CRT along with predicted performance.

- Manual Mode/ Operator Interrupt

7. Linda provided a sequence of events involved with a typical ESTL test program. Using the ROSAT as a typical example, the time table is as follows:

    PLANNING   4-6 MONTHS

    ACTUAL TEST   1 WEEK

    DATA PACKAGE   2-4 WEEKS

    TEST REPORT   4-12 WEEKS

    If the ESTL is automated, the planning stage can be shortened by one half. The actual test time will be cut by 10 to 20 %. The data package and test report generation can be shortened to 2 to 4 weeks (probably the biggest payoff with automation in terms of test schedule).

8. The following is a list of potential areas for automation:

    - Data Handling

    - Analytical Prediction Baseline for Data Validation

    - Data Sheets

    - Plots

    - Archiving for Rapid Retrieval

    - Electronic Update of Test Procedure (instead of redlined copy)

    - Report Generation (text and graphics)

    - Expert System (to guide and recommend tests)

APPENDIX 4. ESTL AUTOMATION

ESTL AUTOMATION TASK REPORT OUTLINE

o   ESTL OVERVIEW

o   ESTL AS A SPACE STATION COMMUNICATION AND TRACKING TEST BED

o   TESTING AT ESTL - PRESENT CAPABILITY

o   TESTING AT ESTL - AUTOMATED APPROACH

o   INTEGRATING AUTOMATION WITH ESTL FACILITY

o   A TIME TABLE FOR AUTOMATION

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ESTL OVERVIEW

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o   SCOPE OF ESTL TESTS

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o   MAJOR TEST PROGRAMS FOR SHUTTLE

ESTL AS A SPACE STATION COMM AND TRACK TEST BED

o   APPROACH

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o   SOFTWARE CAPABILITY

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o AUTOMATED BLUELINE DRAWING AND TEST PROCEDURE GENERATION

o AUTOMATED TEST CONFIGURATION

o AUTOMATED SWITCHING

o AUTOMATED MEASUREMENT

o AUTOMATED DATA REDUCTION

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o AUTOMATED ARCHIVING OF TEST DATA BASE

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o ACCOMMODATE EXISTING HARDWARE AND TEST EQUIPMENT

o TAKE ADVANTAGE OF THE CAPABILITIES OF NEW GENERATION OF

   HARDWARE AND TEST EQUIPMENT

o DEVELOP A SOFTWARE-BASED MULTI-PURPOSE AUTOMATED TEST SYSTEM

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o DEGREE OF AUTOMATION: STANDARDIZED VS NON-STANDARDIZED TESTS

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o PAYOFF VS COST

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o TEST PLANNING ADVISOR EXPERT SYSTEM

o TEST CONFIGURATION ADVISOR

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RECOMMENDATIONS

APPENDIX 5.   SUPPORT OF TWO SSA USERS BY A SINGLE TDRS

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SUMMARY

This appendix addresses the limitations placed on supporting two simultaneous SSA users through a single TDR satellite. Problems and limitations due to satellite configuration and present design of key hardware elements are discussed. The two cases of key hardware elements are discussed. The two cases of support through one and two SA antennas are considered.

The simultaneous support of two SSA links by a single TDRS is subject to certain limitations. We consider two cases: 1) the users are supported by the same SA antenna, and 2) they are supported by the two separate SA antennas. We choose this order because the first case will shed light on the second.

1. Support using the same SA antenna:

We start with the return links. The signals from the two users will pass through the same hardware chain on the satellite. The high level block diagram of the SSA return service hardware is shown in Fig. 1.a and 1.b. A more detailed illustration of the return processor is given in Fig. 2.

The signals received from the two users will be added to each other. If they are not overlapping in frequency (but of course both within the pass-band of the service) and were the link to be linear, both could be separated on the ground. Unfortunately, the transponder is non-linear. This is particularly true for the SSA hardware which has special provisions to combat RFI. This can, but may not, lead to adverse effects and mutual interference. This is discussed in what follows.

The extensive limiting provided for RFI is within the return processor.

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The return processor is preceded by the S-band filter. Within the return processor there is a blanker followed by BPFs then mixing. This is followed by the RFI ALC which contains limiting, then more filtering, limiting and amplification. The blanker insures that pulses far exceeding the nominal signal levels are suppressed. The limiters are commandable and provide saturation at 2 to 8 dB above signal level.

The limiting of concern here is that which is likely to cause weak signal suppression and intermodulation interference. This is the limiting which takes place within and after the RFI ALC (see Fig. 2). The blanker most likely would not operate under usual space station scenarios where the two roughly co-located users are transmitting towards the TDRS. This is because they would neither have vastly different EIRPs or have pulsed RFI type transmissions.

The passage of two signals through the non-linear elements can be viewed as causing an effective loss in signal to noise ratio for both of them. If this loss is small when the signals pass through the limiters (probably set to clip at 8 dBs above nominal signal level), and if also the loss caused by passing through the transmitting TWT is small, then supporting two users not overlapping in frequency using one antenna is possible. Determining the extent of these losses depends on the modulation schemes and frequency separations used, as well as the detailed characteristics of the satellite hardware components.

The use of different user EIRPs in this scenario should be avoided if possible. (Except perhaps to offset the minor loss due to the slight mispointing of the antenna to one user compared to the other.) The use of opposite polarization is not permissible in this situation because of the way the hardware is set-up on board the TDRS. It would simply cause the

suppression of the signal from one of the users to be supported.

For the forward links the concern is that the signal transmitted to one user will also be received by the other. It is fair to assume that the directivity of the S-band antennas on the two roughly co-located users would not offer much isolation. Hence isolation has to be provided by other means. The most obvious and probably most effective is frequency separation (within the TDRS SSA forward service bandwidth). Using different PN codes may also offer additional isolation. The use of different polarizations however is not applicable in this case.

The signals to the two users have to share the same hardware chain through the TDRS. The block diagrams of the hardware are shown in Fig. 3.a and 3.b. In addition, a more detailed block diagram of the forward processor is shown in Fig. 4. The signals to the two users will simultaneously pass through the same ALC within the forward processor. They also have to share the same transmitting TWT. Fortunately the limiting action in the forward processor is much less than in the return because there is no RFI to contend with. As a result the mutual interference should not be severe. Nevertheless the powers of the two signals at the input to the transmitting TWT should be close to avoid suppression of the weaker signal.

2. Support using separate SA antennas:

For the return links the signals from the two users are processed in separate hardware chains on the satellite. Nevertheless, interference occurs if the two users are overlapping in frequency, have the same polarization and are, as in the space station application, in the same vicinity. In this case the relatively low directivity of the SA antenna at S-band (3 dB beamwidth of 2 degrees) does not offer much isolation between the users. What would happen

in this case is that the signal from one user will also be received by the other antenna pointed at the other user. This is depicted in Fig. 5.a. For the other user this added signal from the first user will appear as interference.

This can be reduced by using different polarization. This can offer 20 dB or more isolation. The SSA users normally use RHC polarization while MA users use LHC polarization. Thus care must be taken to avoid interference with the MA users if LHC polarization is used. The use of PN coding may also offer some relief. For the SS application maintaining physical separation between the users and utilizing antenna directivity is not really an applicable solution. If the two users have different EIRPs, interference with the link having the smaller margin can be increased.

It should be kept in mind that if in the first place the two users are not overlapping in frequency, then the front end filtering on each chain (which is prior to any limiting as seen from Figs. 1 and 2) would likely be sufficient to prevent interference. Different polarization can be used to further increase isolation.

For the forward SSA links the interference scenario is depicted in Fig. 5.b. Here the signals transmitted by the two SA antennas and intended to the different users will be received by both users. This is again because of the relatively low directivity of the S-band antennas deployed in space. As with the return links the use of different frequencies would likely be sufficient to avoid interference. This really depends on the sophistication of the front end filtering at the users but is relatively easy to achieve. The use of different polarization for the two signals is feasible here and would offer more than 20 dB of additional isolation. The use of different transmitting EIRPs from the satellite can increase the interference with the link having

the lower margin. It should be of no grave concern here because of the ability to provide isolation between the desired and interfering signal at the user. Again care has to be taken if LHC polarization is used with one of the users so as not to overlap with and possibly interfere with MA users.

If the forward signals to the two users overlap in frequency then the use of different polarizations becomes necessary. Also the use of PN coding may be advisable to provide additional isolation.
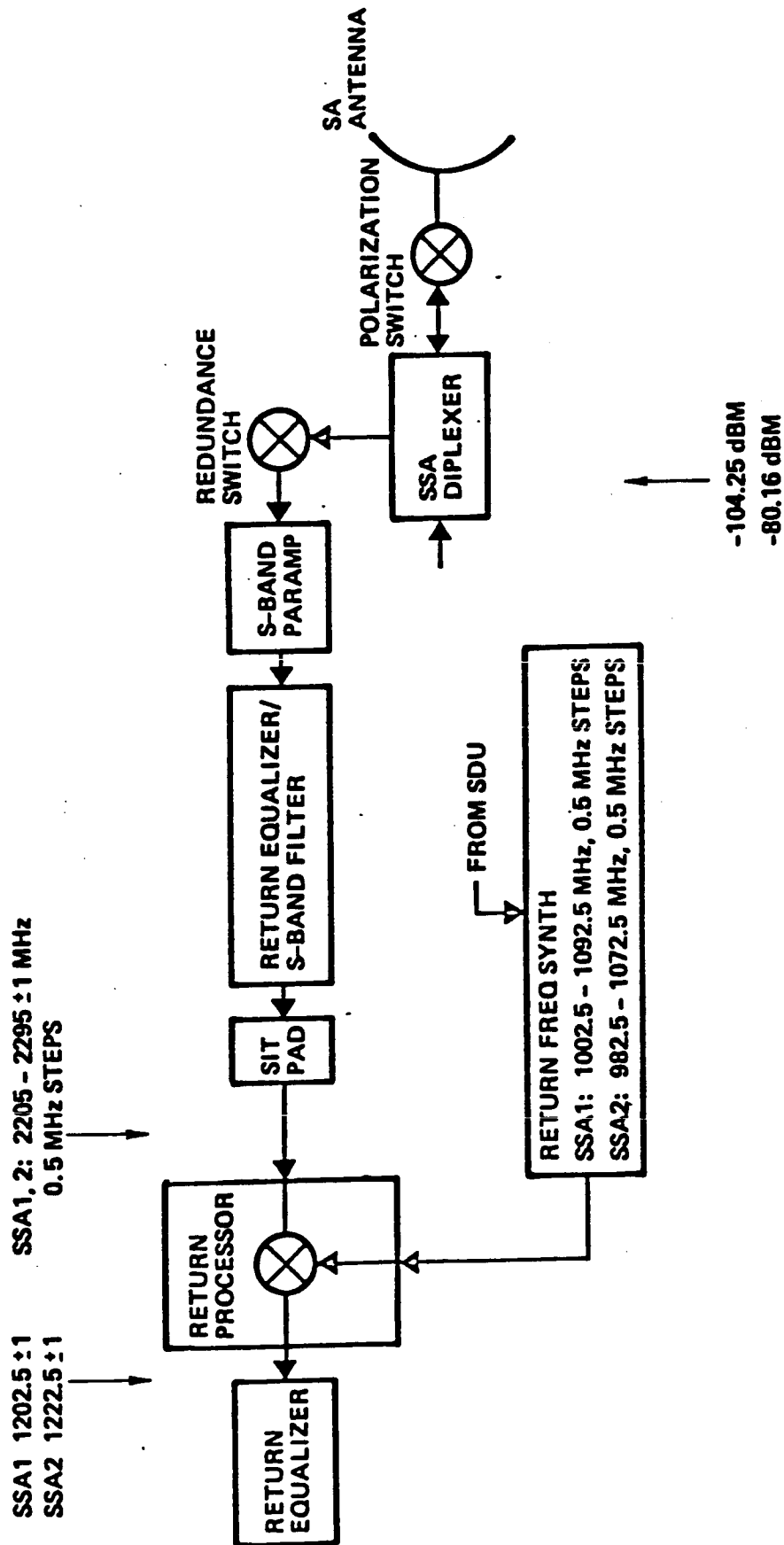
Figure 1a. Block Diagram for Part of S-band Return Link Hardware.
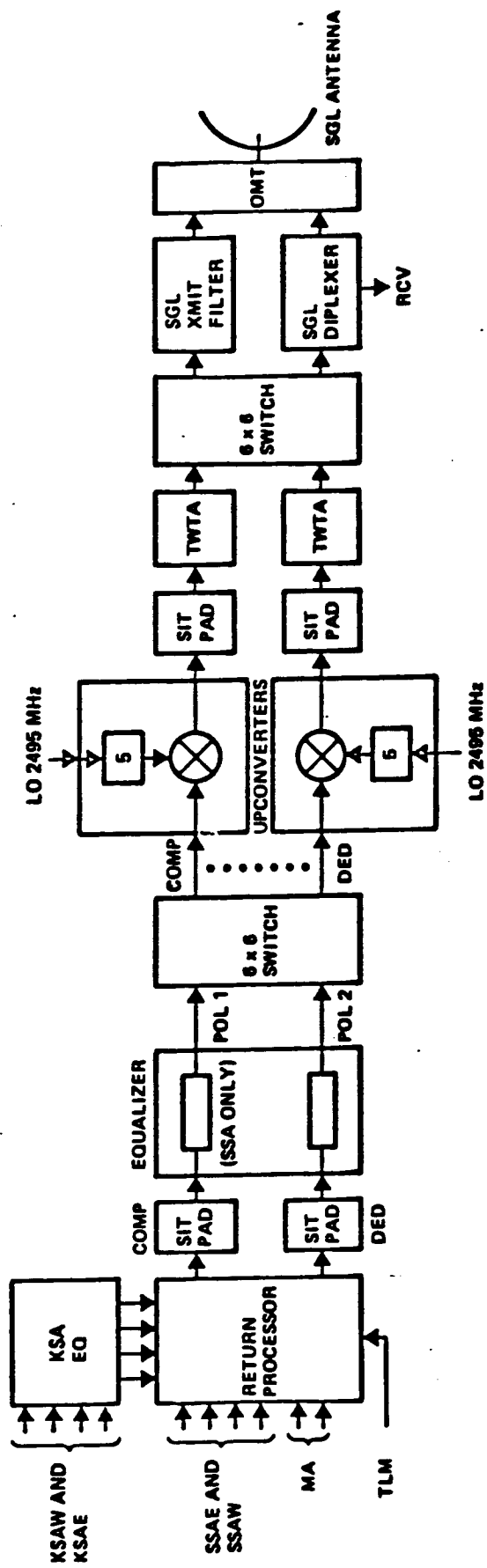
Figure 1b.   Block Diagram for Remainder of S-band Return Link Hardware.
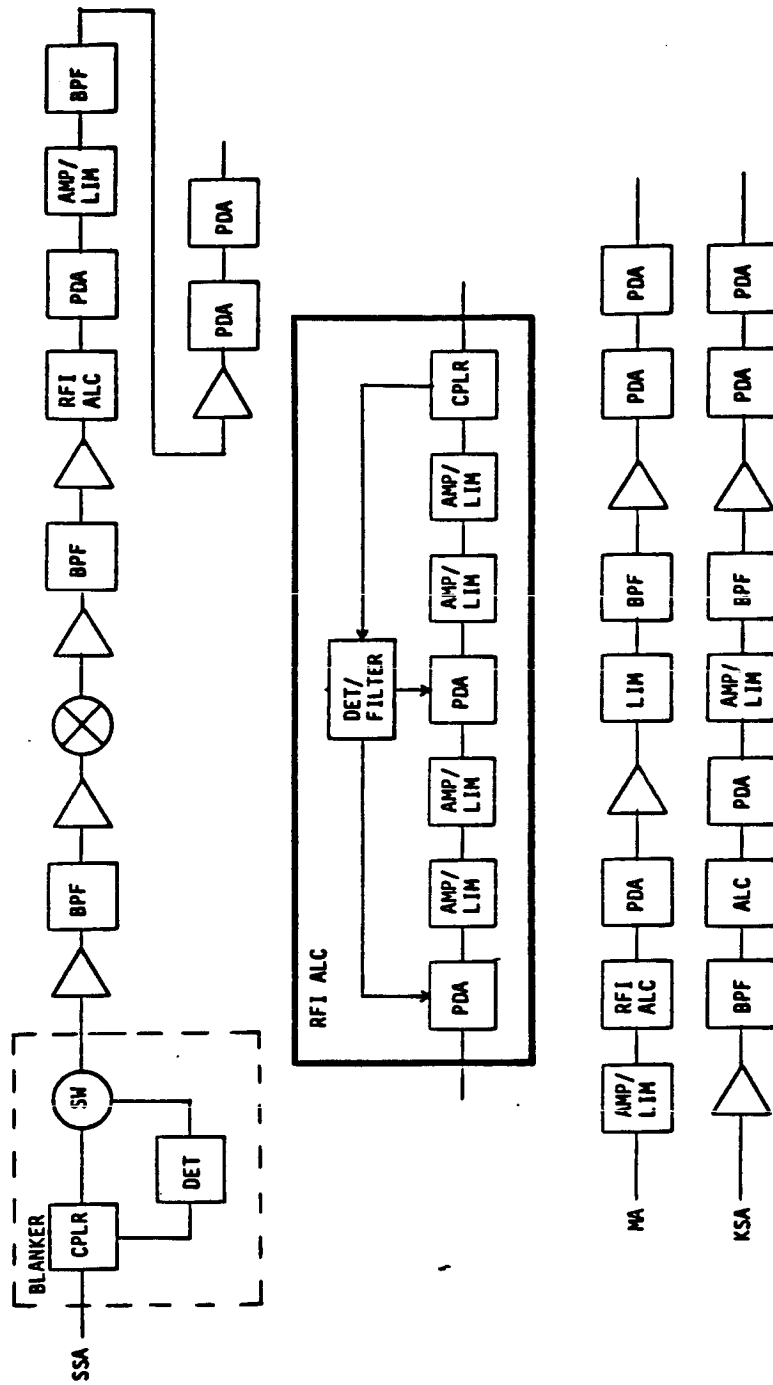
Figure 2. Block Diagram for Return Processor Components.
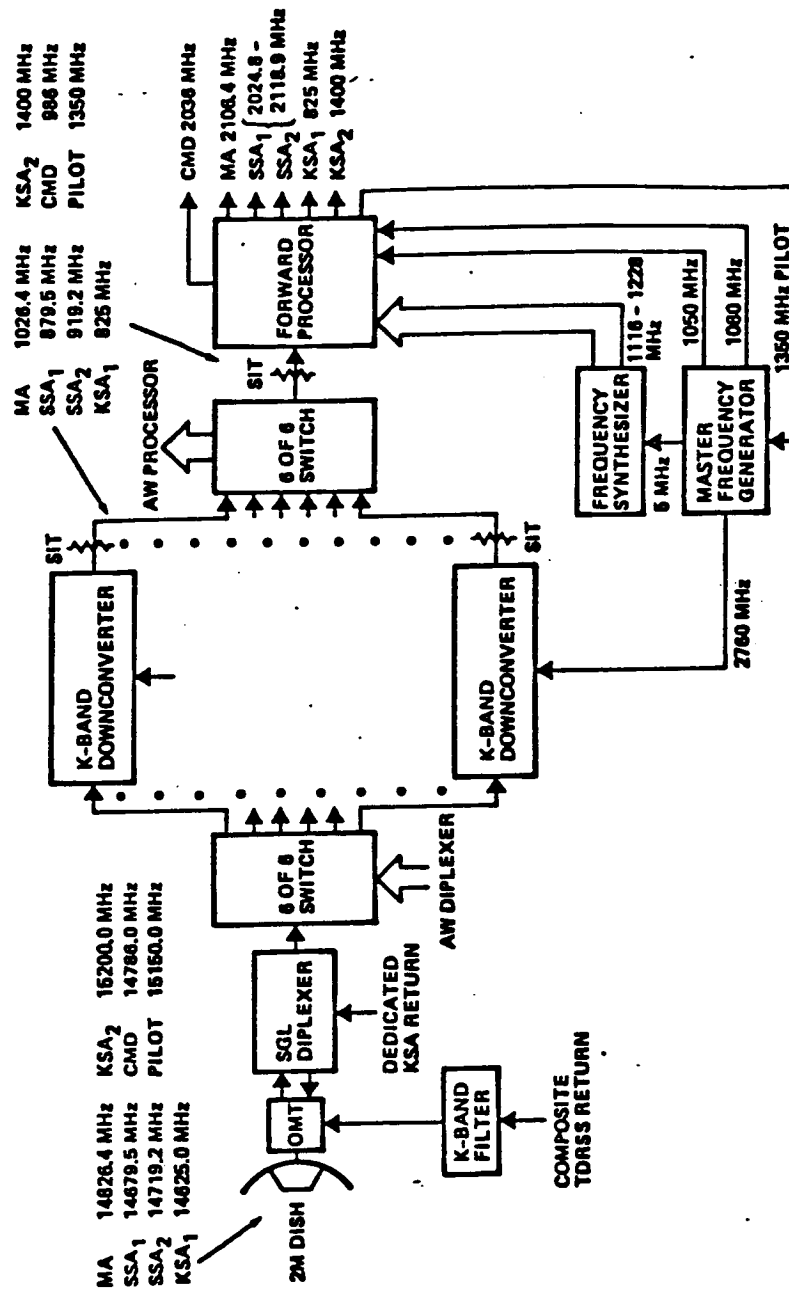
Figure 3a. Block Diagram for Part of S-band Forward Link Hardware.
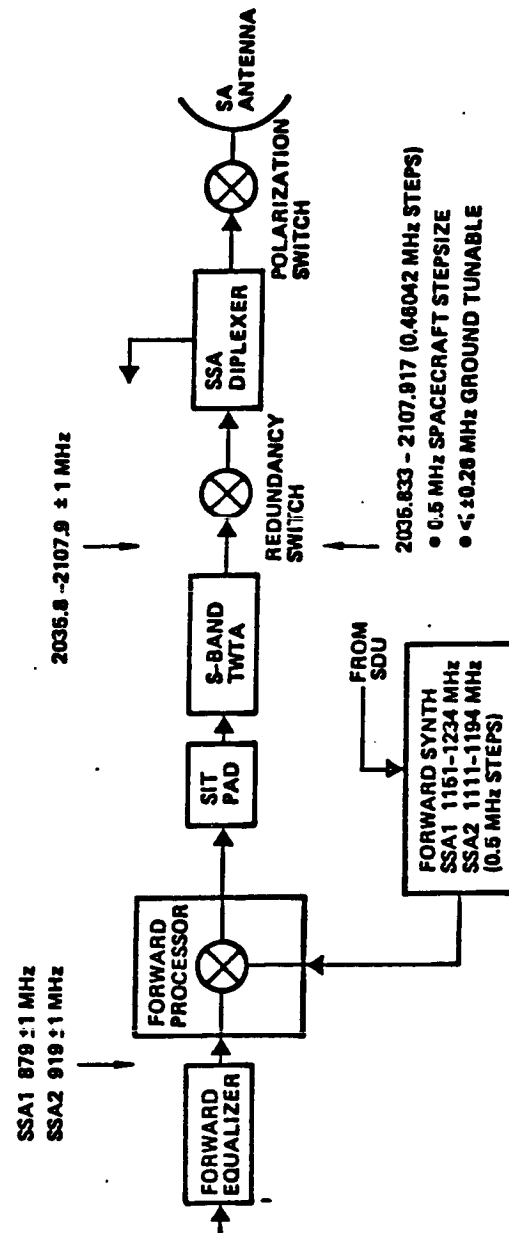
Figure 3b. Block Diagram for Remainder of S-band Forward Link Hardware.
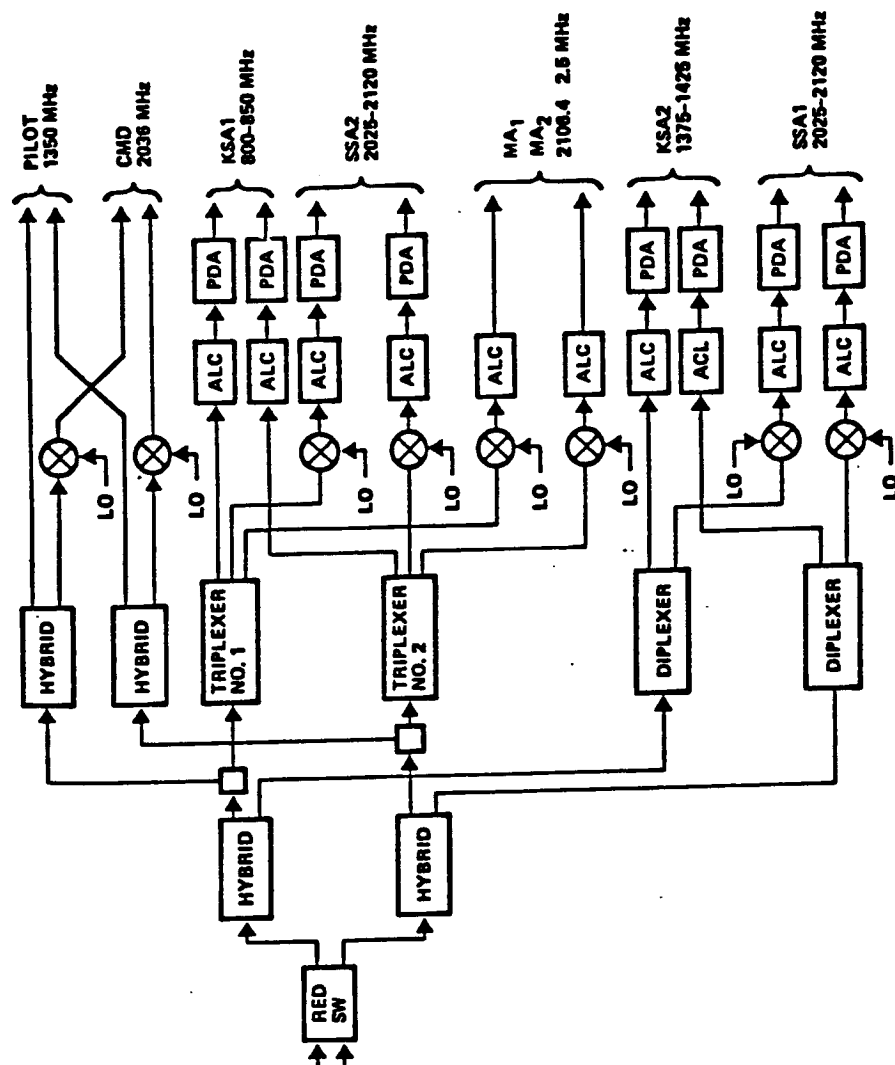
Figure 4. Block Diagram for Forward Processor Components.
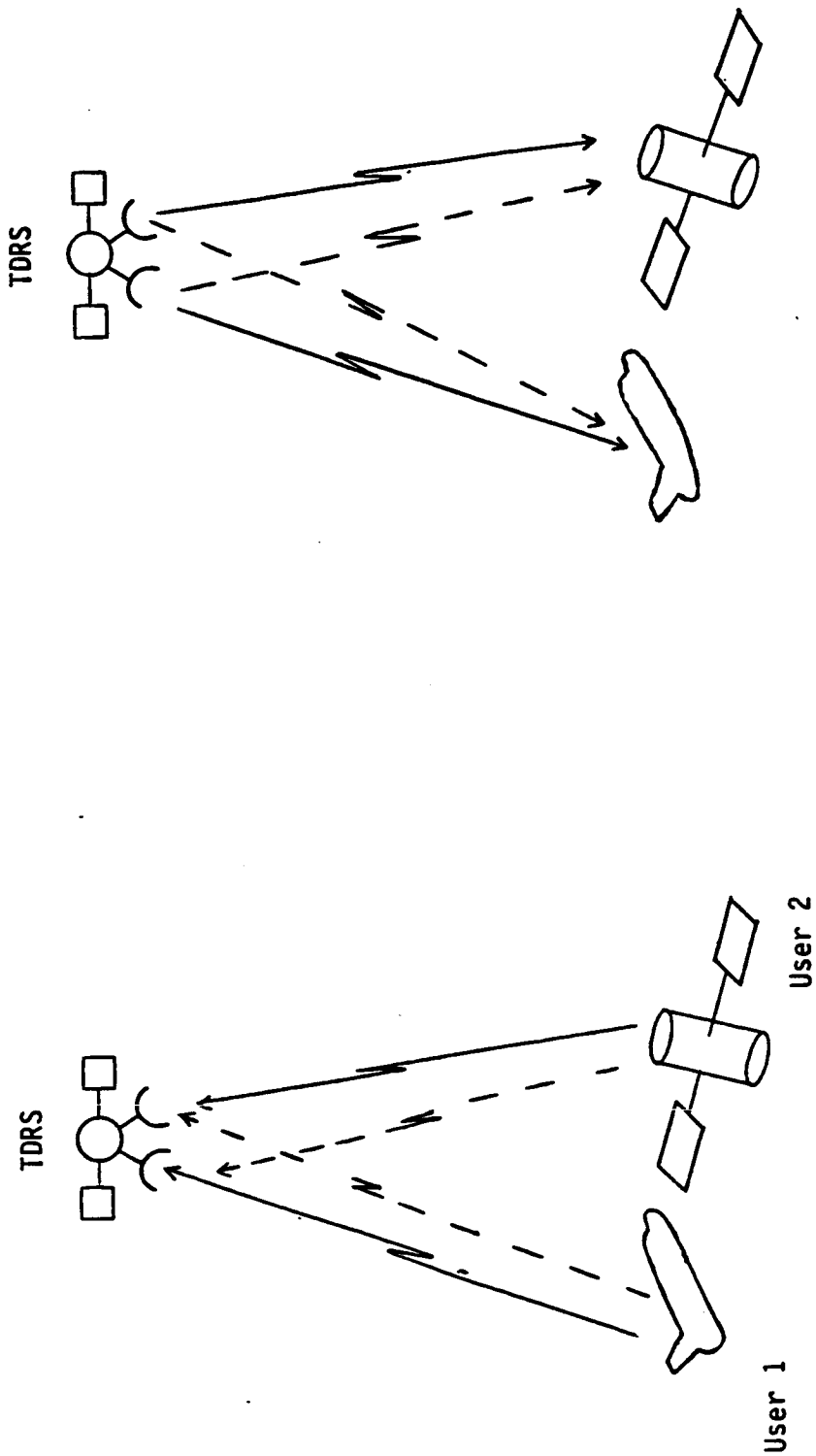
Figure 5. Interference Scenarios for Support of Two Users by Two SA Antennas of Same TDRS.

a. Return Links

b. Forward Links

APPENDIX 6.   REVIEW OF CCSDS "GREEN BOOK"

1. Review of CCSDS "Green Book".

Our preliminary impressions with the CCSDS standards are somewhat favorable. The underlying philosophy appears to be: let the data system control the transmission quality including coding/ARQ/and encryption. Since these operations are done at the virtual channel level, the data rate can be made low enough so that relatively simple, low speed processors can be used. However, there are some areas that need to be examined:

- Complexity of the deconcentrator who does the routing. What happens if a bit slip occurs?

- Why not have a different format for digital TV to save the overhead?

- How does one handle packetized audio exactly? Even though the green book says the contractors have studied the delay and found it OK, we still think that it is a strange way to handle audio.

- Some coding may be required to make the 10^{-5} BER, so concatenated coding may be required.

- (Others to be supplied later)

2. EE2 Multiplexing scheme.

My biggest problem is: what happens when TV is absent such as the forward links. The telemetry portion is right now only 4.4 % of the link capacity. This represents an increase in channel bandwidth of 22.75 times as well as a corresponding 13.6 increase in peak power. It appears that perhaps one can set the line code bits to an abnormal value to denote the absence of TV and use all the luminance and chrominance slots to transmit telemetry.

3. Shu Lin concatenated coding technique.

It appears that the concatenated coding technique will give around 3 to 4

db coding gain as opposed to 5 db of the rate 1/2 K=7 convolutional code.   A

detailed review can be fond in Appendix 7.

APPENDIX 7.   REEVIEW OF SHU LIN'S CASCADED CODING SCHEME

FOR POSSIBLE SPACE STATION APPLICATIONS

SUMMARY

The main thrust of Shu Lin's work is to find a coding scheme (inner code) to mate with a CCSDS Telemetry Transfer Frame that are already encoded by the standard RS (255,223) code. Recall that (a) this particular RS codeword has $2^8-1 = 255$ 8-bit symbols, or 2040 bits, (b) 223 information symbols, or 1784 information bits, and (c) 255-223 = 32 check symbols, or 256 check bits. Five codewords are used in one frame.

In the two inner code examples given, Lin groups the 2040 bits into 51 chunks of 40-bits. He then encodes each 40-bit chunk using a (n,40) block code where n is 59 (referred to as CC_1 in this memo) or 53 (CC_2). He constructs the block code by modifying appropriate BCH codes, namely, shortened BCH codes - zeroing some information bits. Then the cascaded codeword becomes 51x59 = 3009 and 51x53 = 2703 bits long, respectively. Since the number of information bits remains unchanged at 1784, the code rates are 0.593 and 0.66, respectively.

In this memo, the performance of the 2 cascaded codes are compared with a standard K=7, rate 1/2 convolutional code using Viterbi decoding. In order to make the comparisions, the decoded BER was estimated from the report, in which performance is given in terms of

block erasure probability and block error probability. Roughly speaking, the decoded BER is upper bounded by the sum of the block erasure probability and the block error probability. Figure 4 compares the performance of the three codes. Notice that the cascaded code has a very sharp knee. This sharp asymptotic behavior is typical of concatenated or cascaded codes. The first code outperforms the convolutional code for decoded BER less than 10^{-9}. There is not enough data given in the report for the second code; however, the cross-over point appears to be approximately 10^{-7} if the second code has the same slope as the first one. Because of this sharp knee, the cascaded codes are excellent for very low decoded BER; however, they are less tolerant to degraded channel conditions, e.g. when the channel E_b/N_0 drops below .6.5 db for the first code.

The decoding of the inner shortened BCH code consists of two steps. The first step is to compute the syndrome of the received noise-corrupted codeword. This can be done simply by using an n-stage (n=53 and 59 in our example) feed-back shift-register circuit similar to a convolutional encoder (basically doing module-2 polynomial division). The syndrome is used next to determine the error pattern. For the second inner code example, the error pattern determination can be implemented with the table look-up method. This table consists of $2^{(53-40)} = 8,192$ entries. Each entry is a "coset leader" which is basically an error pattern of 40 bits. These entries are indexed by the corresponding 8,192 possible syndromes. Hence, the decoding table can fit into a ROM of 40x8192 = 327,680 bits, or 40 Kbytes. Each time the table is invoked, 40 bits can be decoded. If one assumes a memory access time of 1000 ns (pessimistic), then the table look-up method can

potentially decode data at the rate of 40 Mbps.

Introduction

     In this memo we will compare the performance of two different cascaded coding schemes with the performance of rate 1/2 constraint length 7 convolutional code used in the Tracking and Data Relay Satellite System (TDRSS).

     The cascaded coding scheme is a generalization of the concatenated coding scheme [1]. The encoding is performed in two steps as shown in Figure 1. The (n_1,k_1) inner code C_1 and the (n_2,k_2) outer code C_2 are both linear block codes. The incoming information bits are divided into k_2 bytes of ℓ information bits each. The outer code encoder forms an n_2-byte ($n_2\ell$ bits) codeword in C_2 corresponding to the incoming k_2 bytes. The n_2-byte codeword at the output of the outer code encoder is then divided into m_2 segments of m_1 bytes each, i.e., $n_2=m_1m_2$ (see Figure 2). The inner code encoder maps then every m_1 byte segment (or $m_1\ell$ bits) into a n_1-bit codeword in C_1, i.e., $k_1=m_1\ell$. Hence, the cascade of the outer and inner code encoder maps $k_2 l$ bits at the input of the outer code encoder into m_2n_1 bits at the output of the inner code encoder. The total code rate of the cascaded coding scheme R is then

$$R = \frac{k_2\ell}{m_2 n_1} = \frac{k_2 m_1 \ell}{m_1 m_2 n_1} = \frac{k_1}{n_1} \cdot \frac{k_2}{n_2} \tag{1}$$

the product of the individual code rates of the inner and outer codes. The above described cascaded code is a binary $(m_2 n_1, k_2\ell)$ linear block code. If $m_1=1$, i.e., every byte (ℓ bits) at the input of the inner code encoder is mapped into an n_1-bit codeword at the output of the inner

code encoder, the cascaded code becomes a concatenated code.

The decoding of the cascaded code is also done in two stages. In the first stage the inner code is decoded. The inner code decoder performs the two operations of error correction and detection. If the distance between the received n_1-bit word and any codeword in C_1 is less than or equal to t_1, the error correction capability of the inner code, the decoder performs error correction. If the number of transmission errors in the received word is too high the decoded segment may contain undetected errors as the result of the error correction operation. If an uncorrectable error pattern is detected in a received word, the inner code decoder either erases the whole segment or stores the erroneous segment in a buffer with a mark. The two cascaded codes investigated in this report perform erasure-only decoding, i.e., the inner code decoder performs only the error-correction and erasure operations. The outer code decoder is designed to correct the combinations of byte erasures and byte errors. If the number of byte erasures and byte errors is too high the decoded block of $k_2\ell$ bits may contain undetected errors as the result of the error correction operation. If the number of byte erasures and byte errors is beyond the error correction capability of the outer code C_2, the outer code decoder outputs an erased block of $k_2\ell$ bits.

Both of the cascaded codes investigated here have as the outer code the (255,223) Reed-Solomon code with symbols from $GF(2^8)$, i.e., $n_2=255$, $k_2=223$, $\ell=8$. This outer code is capable of correcting any combination of e_2 byte erasures and t_2 byte errors where $e_2 + 2t_2 < 33$ has to be satisfied. The inner code of the first cascaded code CC_1 is a triple-error-correcting and quadruple-error-detecting shortened BCH code with

$n_1=59$ and $k_1=40$. This inner code is majority-logic decodable in two steps. Hence the inner code decoder can be easily emplemented. The inner code of the second cascaded code CC_2 is a double-error-correcting and triple-error-detecting shortened BCH code with $n_1=53$ and $k_1=40$. Since it has only 13 parity-check bits (there are 2^{13} possible syndromes), it can be decoded with a table-look-up decoding.

Performance Analysis

The analysis of cascaded codes was recently done [2]. Table 1 gives for the two cascaded codes CC_1, and CC_2 upper bounds for block error probability P_{er} and block erasure probability P_{es} at different channel bit error rates ε [2]. At this low probabilities the upper bounds are usually very close to the true value. The quantity we are interested in is the bit error probability $P_b(E)$. There are two factors which contribute to the bit error probability: block erasure and incorrectly decoded block. Hence

$$P_b(E) = P_{b,es}(E) + P_{b,er}(E) \tag{2}$$

where $P_{b,es}(E)$ is the bit error probability due to block erasure and $P_{b,er}(E)$ is the bit error probability due to incorrectly decoded block. If we set all the $k_2\ell$ bits in an erased block equal to 0 (or 1), usually half of those $k_2\ell$ bits are correct since 0 and 1 occur with equal probability. Hence

$$P_{b,er}(E) \cong \frac{1}{2} P_{es} \tag{3}$$

the bit error probability due to block erasure is approximately half of

the block erasure probability P_{es}. For the bit error probability due to incorrectly decoded block we can write

$$\frac{P_{er}}{k_2} \leq P_{b,er}(E) \leq P_{er} \qquad (4)$$

The worst case of $P_{b,er}(E) = P_{er}$ corresponds to the case where every $k_2\ell$ bit of an incorrectly decoded block is in error. The best case of $P_{b,er}(E) = P_{er}/k_2\ell$ corresponds to the case where only one bit of an incorrectly decoded block is in error. For both of the cascaded codes investigated here the block size is $k_2\ell = 223 \times 8 = 1784$ bits. Using the equations (2), (3) and (4) we obtain

$$0.56 \times 10^{-3} P_{er} + 0.5 P_{es} \leq P_b(E) \leq P_{er} + 0.5 P_{es} \qquad (5)$$

Because of this we can choose the more conservative value of $P_{er} + P_{es}$ as a good upper bound on the bit error probability $P_b(E)$ for the cascaded code CC_1. From Table 1 it is clear that it is much more likely that a block is incorrectly decoded than a block is erased for the first code CC_1. Assuming that this holds for the cascaded code CC_2 we can use P_{er} as an approximate value for $P_b(E)$. Figure 3 shows the decoded bit error rate $P_b(E)$ versus the channel bit error rate ε. For CC_1 the curve is drawn using linear interpolation between the two values at $\varepsilon=10^{-2}$ and $\varepsilon=10^{-3}$. For CC_2 we have only one value available. The curve for TDRSS is obtained by conversion of the $P_b(E)$ versus E_b/N_0 curve given in [3]. The conversion is done assuming that BPSK modulation is used on an AWGN channel with optimum coherent detection and binary output quantization. Under this assumption the one-to-one

relationship between channel bit error rate ε and the channel symbol energy-to-noise ratio E_s/N_0 is simply given by [4]

$$\varepsilon = Q\left(\sqrt{\frac{2E_s}{N_0}}\right) \tag{6}$$

where

$$Q(x) = \frac{1}{\sqrt{2\pi}} \int_x^\infty e^{-t^2/2} dt \tag{7}$$

The relationship between the channel symbol energy E_s and E_b is given by [5]

$$E_s = RE_b \tag{8}$$

The relationship between the bit error rate ε and E_b/N_0 can be obtained by substituting (8) into (6)

$$\varepsilon = Q\left(\sqrt{2R\frac{E_b}{N_0}}\right) \tag{9}$$

A comparison of different codes based solely on decoded bit error rate $P_b(E)$ versus channel bit error rate ε is only fair, if all the codes have the same rate. The code rates can be calculated using equation (1)

$$
\begin{array}{lll}
R = 0.5 & \text{for TDRSS} & \\
R = 0.593 & \text{for } CC_1 & \\
R = 0.660 & \text{for } CC_2 & (10)
\end{array}
$$

As we see all the three codes have different code rates. In this case it is better to plot the decoded bit error rate versus E_b/N_0 which is

shown in Figure 3. Figure 3 is obtained from Figure 2 using the conversion (9). Similar to the case of convolutional code concatenated with a Reed-Solomon outer code the bit error probability $P_b(E)$ versus E_b/N_0 curve corresponding to CC_1 is very steep [6]. At bit error probabilities lower than 10^{-7} the cascaded codes CC_1 and CC_2 perform better than the rate 1/2 convolutional code of TDRSS. Since the cascaded codes CC_1 and CC_2 have a higher code rate, they also provide bandwidth saving. For bit error probabilities higher than 10^{-7} the rate 1/2 convolutional code seems to outperform the cascaded codes CC_1 and CC_2.

The coding gains of all three codes at a decoded bit error rate of 2×10^{-12} can be obtained from Figure 4 whereby the reference is the PSK curve without coding. These are illustrated in Figure 5. The % bandwidth expansion is defined as

$$\% \text{ bandwidth expansion} = \left(\frac{1}{R} - 1\right) \times 100\% \qquad (11)$$

At the decoded bit error rate 2×10^{-12} the rate 1/2 constraint length 7 convolutional code used in TDRSS provides 5.95 dB coding gain at the expense of 100% bandwidth expansion, whereas CC_1 and CC_2 provide 6.85 dB and 7.75 dB coding gain at the expense of only 68.6% and 51.5% bandwidth expansion. From this the clear advantage of using the cascaded codes CC_1 and CC_2, whenever a decoded bit error rate lower than 10^{-7} is desired, is obvious.

The cascaded code CC_2 outperforms CC_1 since it achieves 0.9 dB higher coding gain at 17.1% less bandwidth expansion. This shows the importance of searching for good inner codes to improve the performance

of a cascaded coding scheme. As we see from this example a lower rate
inner code with higher redundancy doesn't necessarily improve the
performance of a cascaded coding scheme.

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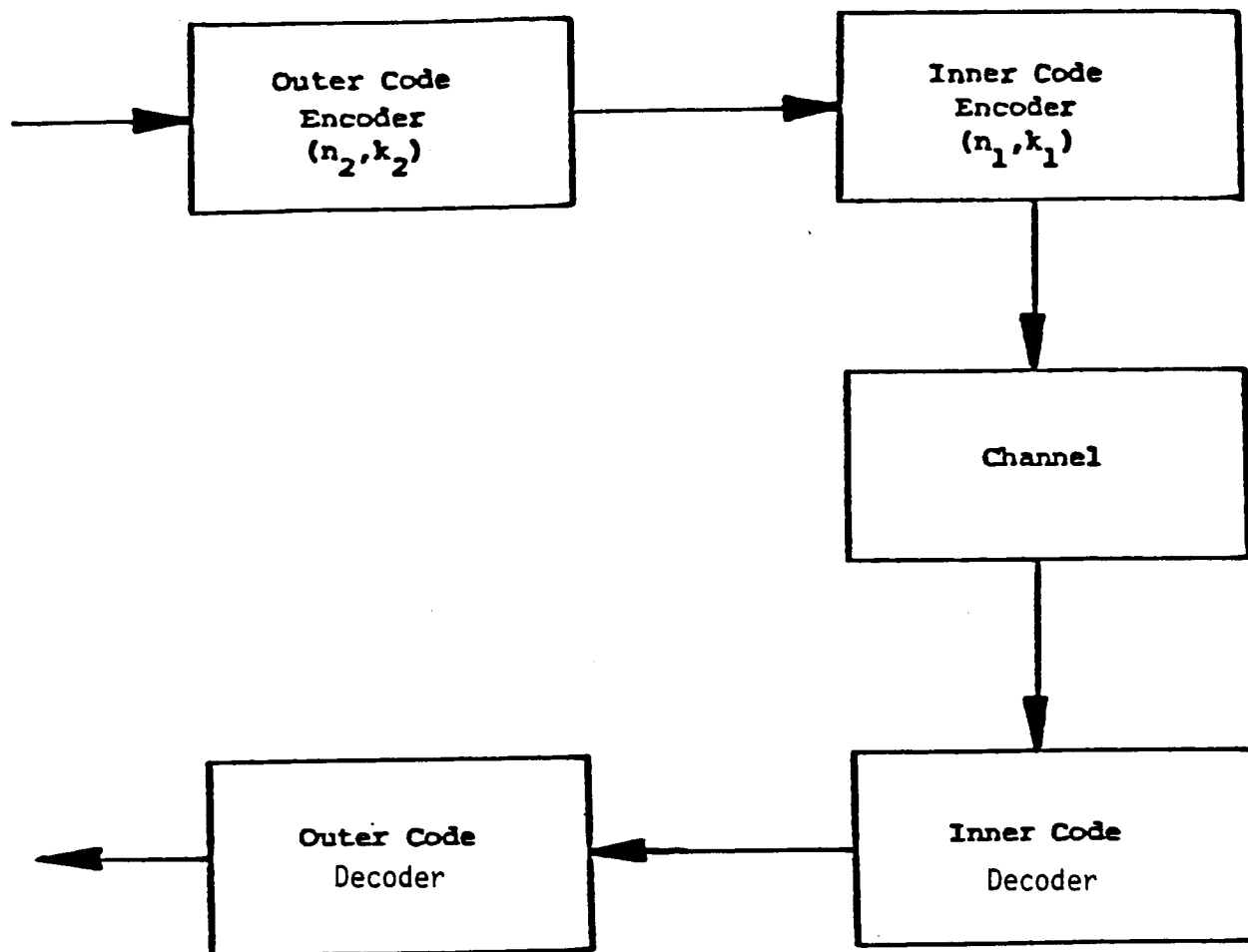
Figure 1. A Cascaded Coding System.
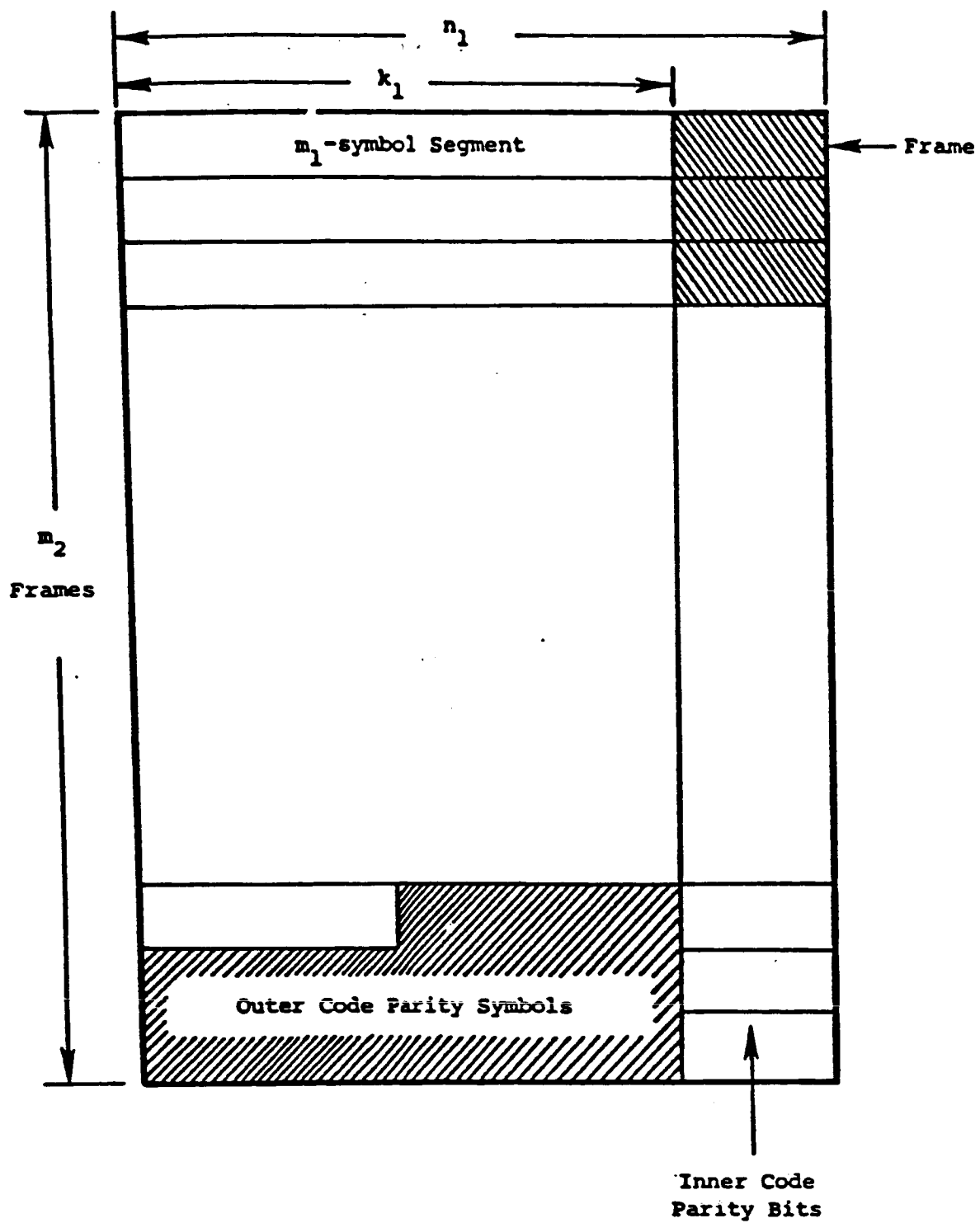
Figure 2. Block Format.
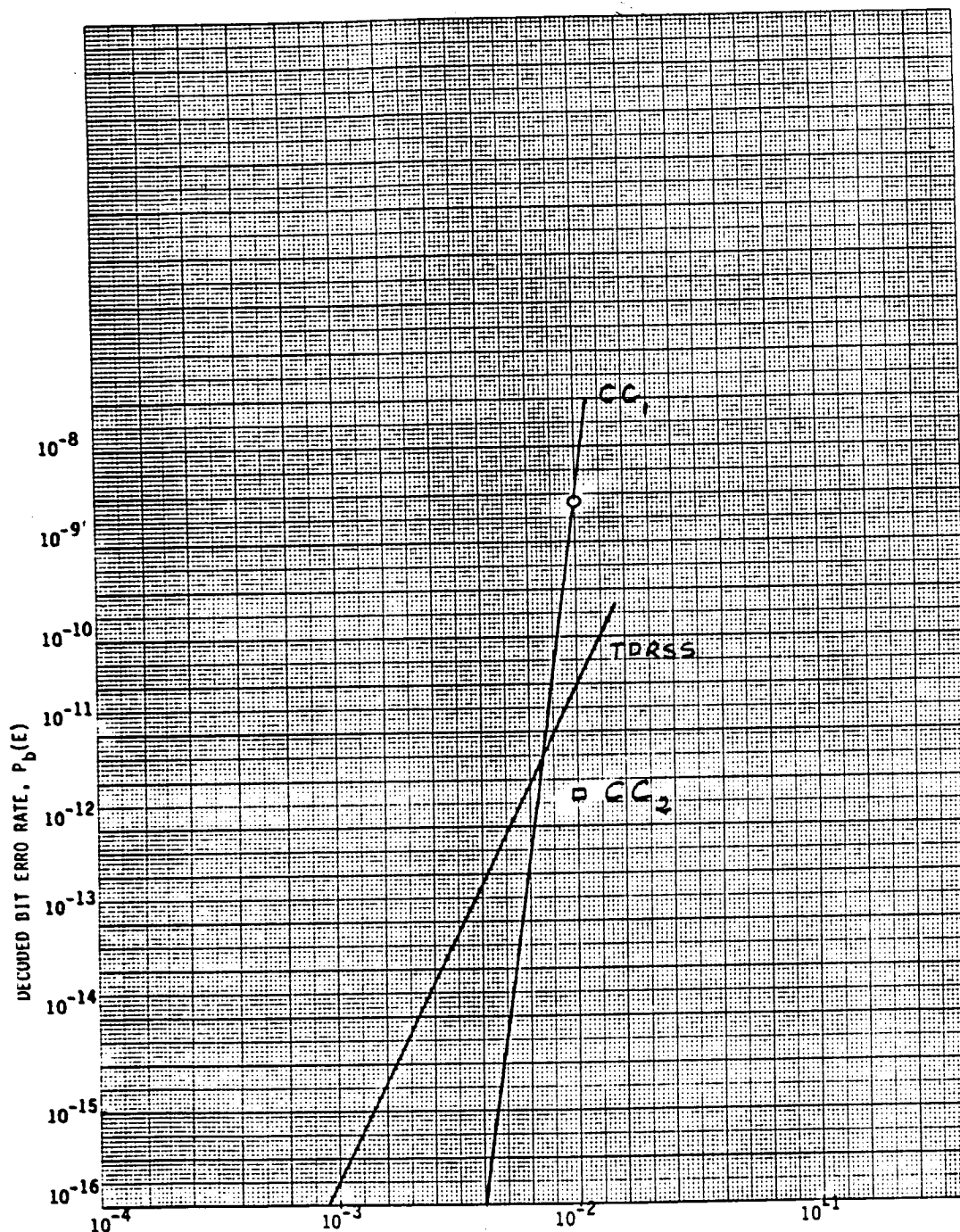
Figure 3.   Channel Bit Error Rate, ε.
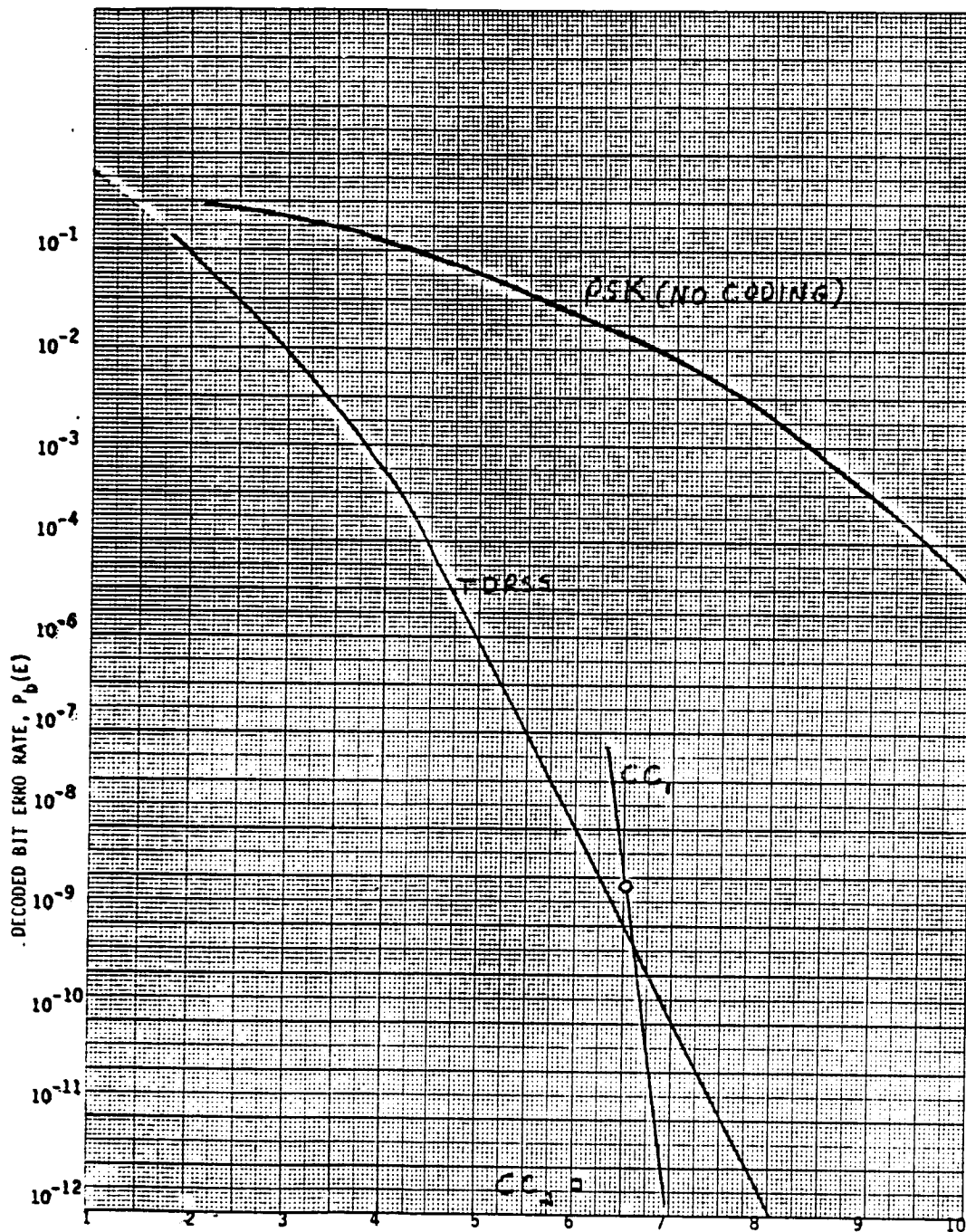
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Figure 4. E_b/N_0 (dB).

CODING GAIN AT 2×10^{-12} DECODED BIT ERROR RATE
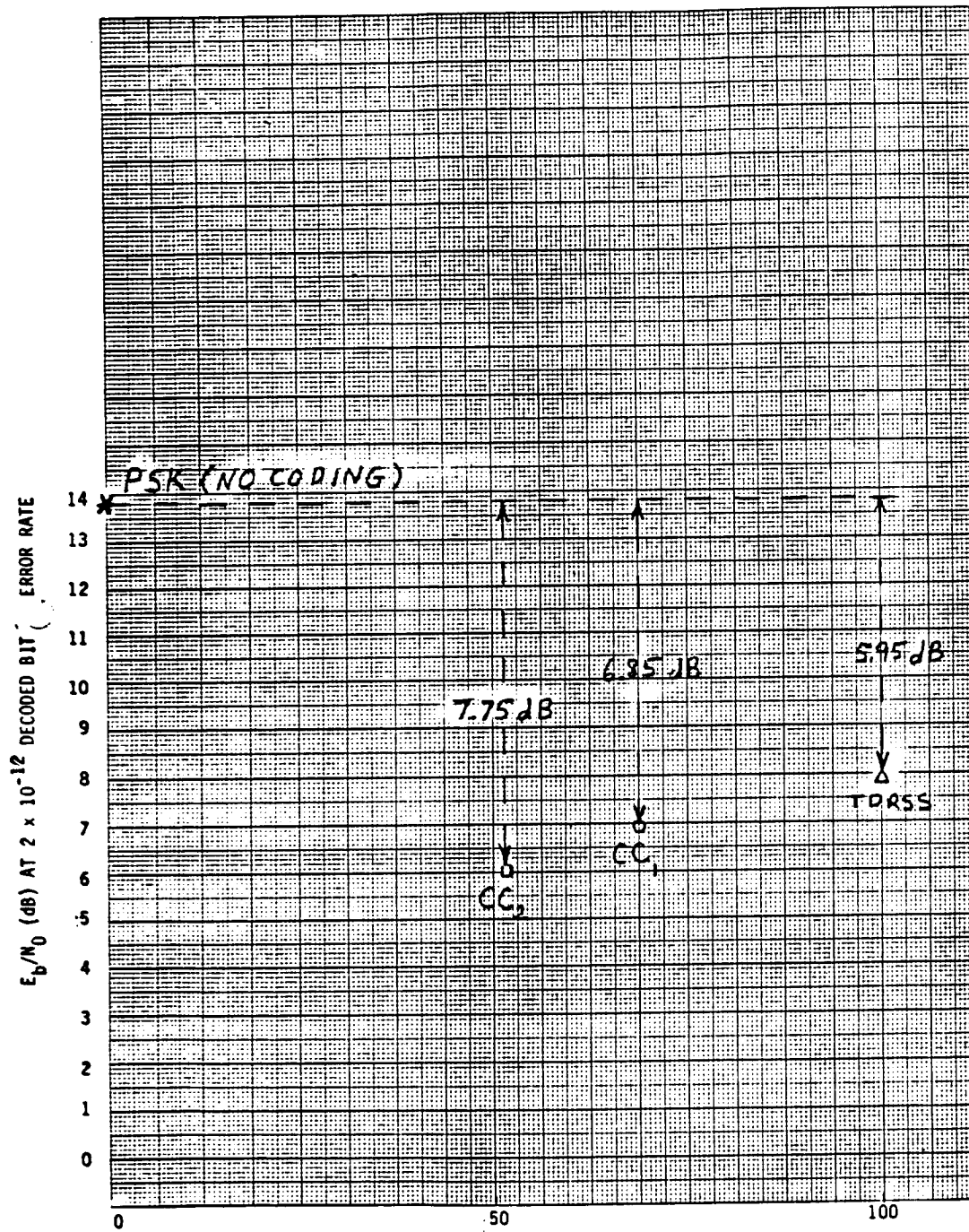
Figure 5. Percent Bandwidth Expansion.

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	CC_1		CC_2
	$P_{es} + P_{er}$	P_{er}	P_{er}
$\varepsilon = 10^{-2}$	$\leq 0.265 \times 10^{-8}$	$\leq 0.213 \times 5$	$\leq 2.13 \times 10^{-12}$
$\varepsilon = 10^{-3}$	$\leq 0.165 \times 10^{-27}$	$\leq 0.165 \times 10^{-27}$	

Table 1. Upper Bounds For Block Error Probability P_{er} and
Block Erasure Probability P_{es} at Different Channel
Bit Error Rates ε.

APPENDIX 8.   MORE COMMENTS ON CCSDS "GREEN BOOK"

SUMMARY

The purpose of this appendix is to provide additional comments on the CCSDS "Green Book" recommendations as they pertain to the Space Station (SS) MA system and the SS-TDRSS link. In general, a full-up implementation of the CCSDS recommendations requires a standardized buffer/formatter for all data sources. For telemetry transmissions, formatting data into frames is a standard operational procedure. For continuous real-time TV and audio transmission, the CCSDS recommendations represent an additional, artificial layer of data packaging that can cause some inconveniences. However, there are no obvious reasons to suspect that the CCSDS recommendations have any inherent compatibility problem with the SS communications requirements.

The CCSDS frame format requires approximately one to two percent overhead, which is not too excessive. Also, since all "data processing" functions such as coding and encryption are performed at the frame level, the processing speed can be substantially lower than the composite channel data rate. In addition, anomalies such as a sudden loss of data can be isolated to one or two frames (users).

To make the CCSDS recommendations more palatable, the following suggestions are made:

    (a)   Pay more attention to audio and video requirements in the frame design. For example, the frame length could be about the number of bits in a TV frame.

    (b)   Do not force communication link design issues such as forbidding the use of convolutional codes.

    (c)   When the communication link is not time-shared by multiple user

processes such as the case with the MA system, the CCSDS

recommendations can be bypassed.

1.0 CCSDS Description

1.1 Data Structure

1. A "Telemetry Transfer Frame" is used between major nodes involving space communication links.

2. A Telemetry/Telecommand Source Packet is used between the data source/sink and the communication link.

3. Standard Formatted Data Units are used to group source packets for delivery on the ground.

The first two structures have direct impacts on the Space Station communications link design.

1.2 Virtual Channels

The space communication link is time-division multiplexed (TDM) into a number of Virtual Channels. For example, up to 8 channels can be associated with the communication link for the Version 1 Transfer Frame Format (Ref. May 1984 "Blue Book" p. 5-5). Figure 1 illustrates the TDM scheme. Each virtual channel can either be dedicated or shared. Using the Space Station - TDRSS KSA 300 Mbps channel as an example, each virtual channel can support 37.5 Mbps minus the overhead if 8 channels are supported. If 12 channels are supported, then each virtual channel can support 25 Mbps, a number more compatible with high rate digital TV.

Each real-time continuous high rate digital TV source is logically a dedicated virtual channel. A block of virtual channels can also be dedicated to ultra high rate imagery data transmission such as for synthetic aperture

Figure 1. Virtual Channel Concept.
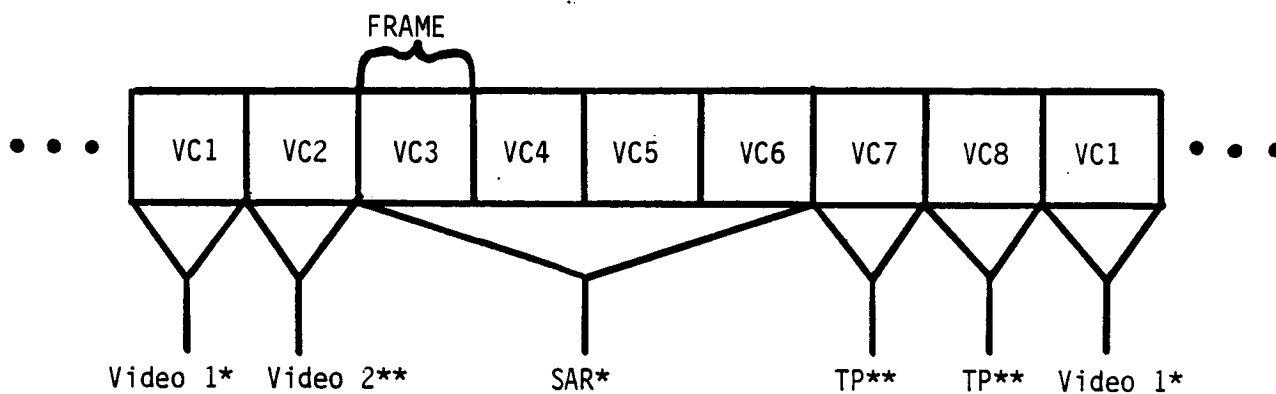
VC = Virtual Channel
TP = Telemetry Packets
 * = Dedicated
** = Shared

radar (SAR) data. Other data source packets can share the virtual channels.

Each packet can contain up to 64 Kbytes (1 byte = 8 bits) of data. However,

if the packet contains more than one frame of data (8-10 kbits), it may be

segmented by the transfer network.

1.3 Coding and Encryption

CCSDS recommends the use of RS code only for encoding at the frame level.

No other codes (such as convolutional code) are to be used for the

communications channel. Encryption is also performed at the frame level only.

This appears to be unnecessary restrictions. Additional coding and encryption

should be permissible at the communications channel level as long as they are

transparent to the data frame level.

2.0 CCSDS Telemetry Transfer Frame Format

Each frame has 10,080 bits. If the version 1 Transfer frame header

format is used (Ref. Packet Telemetry Blue Book, May 1984 p.5-5), there are 32

sync bits and 48 primary header bits. If we assume that 48 bits are also used

for the secondary header, then the overhead due to the two headers is

(48+48)/10080, or approximately one percent. This overhead including the sync

bits is (32+48+48)/10080 or approximately 1.3 percent. If the RS codeblock is

used, the overall overhead is (32+48+48+1280)/10080 or 14 percent. Therefore

it appears that overhead is not an issue here if the packet data field

consists of only one packet.

2.1 Advantages of the Telemetry Transfer Frame Format

The advantages of using the CCSDS Frame format for the Space Station are:

a) Simple implementation of the concentrator/deconcentrator for the ultra

high rate 300 Mbps SS-TDRSS link. Since a fixed frame length is used, the concentrator is a simple demultiplexer with frame sync monitoring capability.

b) Complex data processing at the Virtual Channel level only. All other processing (coding/decoding, reconstruction of data packets, etc.) can be done at the Virtual Channel level at a lower data rate.

c) Packetized data format facilitates easy routing to end users.

2.2 Disadvantages of the Telemetry Transfer Frame Format

The frame format is primarily designed for serving multiple users sharing a TDM channel communicating non-realtime bursty telemetry "data-dump". For the Space Station there are two main disadvantages for using the CCSDS Frame format. In particular, these disadvantages are more pronounced for realtime data and for non-TDM, dedicated links such as the ones for the MA system. They include:

a) Packetized audio delay. Assuming that 16 Kbps digitized voice is used, the time required to fill an uncoded frame is approximately 0.6 sec. This is the inherent delay. This delay is annoying for Space Station to Ground conversations where a delay is to be expected (the round-trip delay for a geosynchronous orbit is roughly 0.25 sec). It is probably unacceptable for EVA or crew conversations on-board the Space Station. One way to solve this problem is to use very small size packets, presumably 24 bits to reduce to a 1.5 ms delay (a typical digital telephony round-trip delay budget based on echo considerations). This is approximately 667 packets per second.

b) Video complexity. The high rate digital TV at 22 Mbps can use any help it can get to simplify the mux/demux operation, especially for

the non-TDRSS links. There are no real good reasons for packetized data when the channel is not TDM.

2.3 An Isochronous Channel Concept for Audio Transmission

There are two ways to handle audio: via data packets or via an "isochronous channel". As discussed earlier, packetized audio suffers from packet delay unless the packet consists of only a few bits. In the other approach, an isochronous channel, consisting of a few bits, is built into each virtual channel. This concept has been under consideration for audio distribution by the IEEE 802.6 Metropolitan Area Network (MAN) committee for Standardization (see attached paper in Appendix 1). For the CCSDS frames, the isochronous channel can be part of the primary or the secondary header.

If each virtual channel has a transmission rate of 25 Mbps, then a 16-Kbps audio channel can be supported by devoting $(16,000/25,000,000)*10,800 = 7$ bits to the isochronous channel per frame. However, if the virtual channel transmission rate is decreased, more bits must be allocated. Needless to say, when the number of bits is increased, the packet delay will be increased proportionately.

3.0 Integrating the EE2 Multiplexing Scheme with CCSDS

If the Space Station must operate under the CCSDS format, then each MA user link can be treated as a communication link with a single virtual channel. Since the two communicating parties are well defined, the frame headers can assume a simplified form. The frame structure does not have a big impact on the user unless the data rate is low and audio is to be supported.

If the EE2 multiplexing scheme is to be used, then the output of the multiplexer must be re-buffered and formatted into a CCSDS frame as shown in

Figure 2a. Notice that the data must be re-clocked at a different rate. If the CCSDS is not fully implemented between an MA user and the Space Station, the buffer/formatter function can be performed on the Space Station as shown in Figure 2b.

4.0 Bulk Encryption Impacts

There are two ways to derive timing for encryption. In the first technique the encryptor clock and the decryptor clock are aligned (for example to the time-of-the-day). Provided this alignment is maintained, the crypto boxes are always synchronized. In the second technique, a preamble is sent periodically so the decryptor can use it to check for synchronization. In either case, whether the data is divided into frames or not does not appear to directly interfere with the bulk encryption operation. (Except for the obvious overhead loss in data transmission efficiency.) If the data is framed, then one has the option of encrypting each frame independently. This encryption can be done at a lower rate which should be more compatible with the estimated speed of the crypto devices (20-50 Mbps). Bulk encryption at 300 Mbps may require multiplexing/demultiplexing. Encryption at the data packet level also facilitates partitioning of sensitive data among different users.

5.0 Recommendations

The CCSDS makes sense for the TDRSS link where multiple application processes must time-share a single channel. The CCSDS source packet format also makes sense for bursty telemetry/computer processing data. It is not the best approach to real-time audio and video data nor where the communication link is not time-shared.

TV Data → EE2 MUX → CCSDS Buffer/Formatter → (COMM LINK) → Space Station Information System

Telemetry →

MA User

Space Station

(a)   CCSDS Recommendation

TV Data → EE2 MUX → (COMM LINK) → CCSDS Buffer/Formatter → Space Station Information System

Telemetry →

MA User
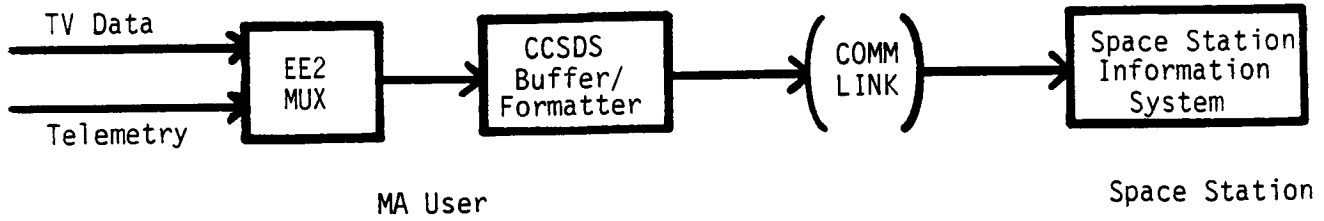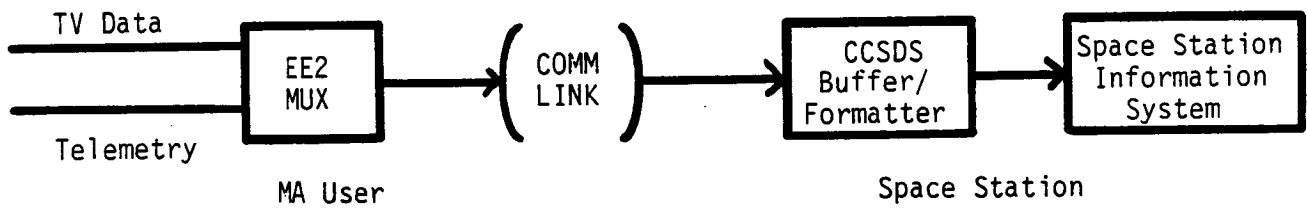
Space Station

(b)   Modified

Figure 2.   Integrating EE2 Multiplexer with CCSDS.

For the Space Station MA system channel, especially for the EVA involving high rate TV, the multiplexed scheme proposed by EE2 offers reduced complexity on the user. The advantage of the EE2 scheme is that it is "natural" for the digital video format where a frame format is used. All data clocks are derived from a 42,954,502.5 Mhz source. Accordingly, all data rates are sub-multiples of this fundamental clock frequency. To adjust for the slower frame rate TV, one simply slow down the corresponding clock rates of the multiplexer. The data can be reformatted and re-buffered to satisfy the CCSDS recommendations after it leaves the MA system on board the SS.

When the communication link involves only telemetry, even for the MA users, the CCSDS recommendations can be followed. Or, the EE2 multiplication scheme can be modified. The modification options will be considered in Appendix 8.

APPENDIX 1.

A METROPOLITAN AREA NETWORK

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A Metropolitan Area Network

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Abstract — Most high-speed multiple-access networks on the market, or those currently under design, operate in a limited geographical environment and are devoted either to data-only or voice-only transmission. However, challenges issued by the marketplace require the full integration of voice, data, and video in a real-time environment.

This paper proposes a metropolitan area network that covers a campus environment and truly integrates voice, data, and video under a single transmission medium. Furthermore, the transmission is achieved through a single media-access schema. This paper also presents marketing issues, network requirements, and technology constraints. The proposed media-access schema is also being considered by the IEEE 802.6 MAN Committee for Standardization.

I. INTRODUCTION

A metropolitan area network (MAN) serves users spread over several buildings in proximity to one another. Examples range from a true campus, in which thousands of offices, laboratories, and dormitory rooms are to be tied into one MAN; through a company occupying a few buildings scattered across an industrial park; to a firm dispersed throughout several floors in each of many high-rise buildings in an urban environment.

In each case, several different networking needs exist, encompassing voice, data, and perhaps video. Users will certainly require a comprehensive telephone system tied in to a central PABX. Data networking requirements, however, will vary. In some instances, connecting a large number of low-speed terminals and a few remote printers to a computer center will suffice. But as the technology of distributed systems evolves, there will be substantial storage and processing power spread across the network, necessitating high-speed short-delay transfers over relatively long distances. In addition, video (currently limited to security surveillance operations in most cases) is needed.

A significant portion of networking cost is in the wiring, including the cost of the cables and the cost of labor to install them. In an urban environment such as downtown Manhattan, where cable trays in skyscrapers and underground vaults are likely to be saturated, labor costs alone can approach $100 per foot. Such costs put a premium on a MAN technology that can satisfy all networking needs—voice, data, and video—using a single inexpensive and easily installed physical medium.

The concept of combining voice, data, and video on a single medium provides the potential for truly integrating these diverse information types. For example, many telephone systems convey digitized voice. If this voice stream were integrated with an intercomputer data stream, then voice messages could be stored on the digital storage devices already available. Conversely, a PABX, which is simply a special-purpose stored-program computer controlling its terminal devices using very primitive signaling protocols, could be integrated into a larger distributed computing environment and would potentially yield a much greater telephony functionality without substantially greater cost.

Integrating voice and data on the network opens opportunities for the system to store, manipulate, and transport more sophisticated information objects, including documents consisting of computer text (i.e., ASCII characters), voice annotations, and video segments, created and recreated as a multimedia presentation. A multimedia presentation such as this requires a network that not only transports all these information objects, but does so in a coordinated fashion, preserving a real-time structure in their presentation. These types of integration will be pervasive in offices of the future. From and through the terminals in their offices, users from across academic and business environments will be able to converse with each other in full view, jointly compose documents, matching and interfacing their pictorial work in real time. The benefits derived will be immeasurable.[1]

II. MARKETING CONCERNS

Network technologies are generally compared on the basis of speed, size (both area covered and capacity in number of nodes), and cost of connection per node. In these terms, the metropolitan area network market can be characterized as follows.

A. Speed

A single establishment may have thousands of telephone lines. A 2000-line network can consume more than 50 Mbits/s during peak hours. Full-motion video, uncompressed, requires 80 Mbits/s for a single one-way channel. Add to this the data transfers among hundreds of terminals

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[1] Most of the requirements stated above have been discussed at length in numerous IEEE 802.6 MAN Committee meetings. In fact, this metropolitan area network proposal has been submitted to the IEEE 802.6 MAN Committee as a proposed standard.

or personal computers and dozens of high-throughput servers, and the aggregate data rate in a MAN could easily grow to hundreds of megabits per second.

As noted earlier, the geography of a MAN requires much of this data rate to be concentrated into a few interbuilding connections, and transmitting hundreds of megabits per second on a single cable, if possible, justifies the high cost of installing these connections. Therefore, the market demand is for a very high-speed physical medium.

B. Size

A MAN must be able to interconnect several thousand nodes distributed over an area equivalent to hundreds of square city blocks (either flatly over a geographical area, or stacked in high-rise buildings). This distribution implies minimum transmission distances of tens of miles, depending on topology.

C. Cost

The cost of attaching a device to a network, relative to the cost of the device itself, is an important issue. Connection cost includes both the cost of the electronic interface and the cost of the cable and its installation. Because direct connection to a very high-speed medium will be expensive, it is appropriate only for the most powerful devices. These are the only ones that can source or sink a significant fraction of the bit rate and are themselves costly enough to justify an expensive connection.

Low-speed low-cost devices neither need, nor can they afford, a direct connection to a high-speed medium. hence, the economic imperative of at least a two-level hierarchy of networks. At the bottom level is a low-speed network (e.g., 10 Mbits/s) offering a less expensive connection cost to a relatively small number of low-speed devices (25–50). Each *low-cost network* is then connected to a high-speed *backbone network* (e.g., 100 Mbits/s).

D. Bridges

Connecting a low-cost network and a backbone network is accomplished via a *bridge*. The bridge divides the cost of a single high-speed attachment over the many devices on the low-cost network. The primary function of a bridge is to provide buffering for speed matching. The bridge's complexity, hence cost, can be kept to a minimum if it does not have to perform protocol conversions also, i.e., if the two networks have the same protocols at all levels down through media-access control (MAC).

Consideration of either distance or load balancing may also require bridges to interconnect multiple backbone networks. Local area networks are, by their nature, limited by distance. This fact is particularly true of broadcast buses, which have upper limits on end-to-end propagation time over the medium. Therefore, coverage of a greater area requires an active device that receives messages from one network and buffers them until it can retransmit them on another network. That active device is a bridge.

A bridge is also useful in isolating high-traffic subnet-

works from one another. For example, consider two sets of nodes, A and B, with the following traffic patterns. Members of A generate a total of 30 Mbits/s of messages for other members of A, and 10 Mbits/s of messages for members of B. Similarly, members of B generate 30 Mbits/s of messages for other members of B and 10 Mbits/s of messages for members of A. These can be networked in two ways. 1) Put all nodes onto a single network that must carry 80 Mbits/s, or 2) put all members of A on one 50 Mbit/s network and all members of B on another 50 Mbit/s network with a bridge between them. The cost-effectiveness of these alternatives depends on the actual data rates involved.

III. The Competing Network Technologies

Networks presently employ one of three quite different network technologies: PABX's, broad-band, and local area networks (LAN's). Each of these developed from one of the three types of information being networked: PABX's for voice, broad-band for video (television), and LAN's for data. This section examines each of these networks in terms of speed, size, cost, and the potential for integrating all three information types.

A. PABX's

A PABX-based system can easily accommodate networks of the size and area required for a MAN. It is also successful at combining voice and data, but not at integrating them. This wide coverage comes, however, at the cost of speed for data transmissions. A typical data channel is only 56 or 64 kbits/s. Each such channel, at least in a low-cost network, is a simple unshielded twisted-pair copper cable. Such a medium has an error rate that, while adequate for voice, is too high for effective data communications, necessitating multiple layers of error-control protocol that further reduce the effective data rate. In addition, these channels are generally used inefficiently.

Finally, while a PABX can handle voice and data on separate channels, a synchronized delivery of a multimedia document is very difficult. Voice and data are not guaranteed to arrive at their destination with any given real-time relationship because of the throughput limit for data.

B. Broad-band

Broad-band (CATV) technology is ideally suited to video networking. Carrier frequencies in the hundreds of megahertz provide the potential for a very high-speed backbone network. Similarly, the distances currently covered by CATV systems (through the use of repeaters) comfortably meet the requirements for a MAN.

The cost per connection of a broad-band network, however, is very high. The modems to interface to the medium cost hundreds of dollars and are, consequently. too expensive for a simple terminal or personal computer. The medium for broad-band is a half-inch to one inch diameter semirigid coaxial cable. The cost of the labor involved in

bending this cable and fitting it into cable trays is higher by far than in any other medium. Furthermore, this is a mature technology, offering little prospect for significant cost reductions in the future.

Even though broad-band is often advertised as integrating voice, video, and data, in actuality it merely combines them. Voice and video are sent, in analog form, over separate standard television channels (unless it is television audio). Computer data (as opposed to video text) are sent over a separate set of frequency channels. Thus, broad-band systems suffer the same problems of coordinating delivery of voice and text as PABX's do because of the multiple channels with different protocols.

C. Local Area Networks

The current state of the art local area networks (LAN's) are in the range of the 10 Mbit/s CSMA/CD [1] bus (i.e., Ethernet). Where higher speeds are needed between large processors, either the 50 Mbit/s Hyperchannel or Control Data Corporation's 50 Mbit/s CSMA broad-band system are used; these are expensive systems with very limited connectivity.

But, unlike the mature PABX and broad-band technologies, LAN technology is diverse and rapidly evolving. No single topology, medium, or medium-access protocol dominates. There are buses, either CSMA/CD or token-passing [2], [3], with either semirigid or flexible coaxial cable. There are rings [3] with a wide variety of copper media. Finally, there are rings with fiber optic links: the fiber distributed data interface (FDDI) [4] is a proposed standard for a 100 Mbit/s ring. Common to all the LAN's developed, however, is the design centered around computer transmission only. Furthermore, most designs are also for connection within a building only. Consequently, the LAN designs cannot easily be extended to provide MAN coverage.

IV. MAN NETWORK REQUIREMENTS

The significant advantages of a MAN are high bandwidth, low delay, and high transmission quality. In data communication applications, these are only qualitative goals; few precise rules exist. For example, no rules exist about how much delay is too much. By contrast, telephony imposes very explicit requirements on a network, specifically bandwidth, delay, and transmission quality.

A. Bandwidth

Digitized telephony is based on sampling an analog waveform 8000 times a second (once every 125 μs) and converting each sample into an eight-bit code word, hence, the 8000 byte/s bandwidth requirement. The sampling rate is determined by the Shannon sampling theorem. A waveform can be faithfully reproduced from samples taken at twice the value of the highest frequency in the waveform; voice fidelity requires less than 4 kHz. The choice of

code-word size is based on subjective requirements for acceptable dynamic range (the ratio of loudest to softest sound) and signal-to-noise ratio.

Because speech is continuous, the 8000 byte/s sample streams must be carried from each end of a conversation to the other for the duration of a telephone call (an average of 100s); no period of more or less bandwidth is demanded. By contrast, data communications are bursty; peak bandwidth demands are typically limited only by memory speeds at the source and sink, and so can range as much as many megabytes per second. This demand is not constant, however. At a continuous speed of 3 Mbytes/s, a large transmission of 80 000 bytes takes about 25 ms, but receiving the bandwidth in bursts so that the total elapsed time was 50 or 100 ms would be acceptable.

The bandwidth requirements for video are more like those of voice than those of data in character: a moderate, but constant, demand that exists for a long period of time. The major difference is in the magnitude of the bandwidth demand. Full-motion black and white video (U.S. broadcast standards) requires 80 Mbits/s. Various compression techniques are available, however, to reduce this to as little as 2 Mbits/s. These techniques can produce quality acceptable for many applications, such as teleconferencing and surveillance, and can bring the bandwidth within the range of LAN speeds. This 2 Mbits/s may have to be guaranteed, however, for hours at a time.

The bandwidth demand characteristics of these three types of traffic are summarized in Table I. The wide disparity in demand suggests that to support all of these, a single MAC protocol must have at least two different bandwidth-supply mechanisms.

B. Delay

The transition from four wires to two wires within the telephone system is made by a "hybrid" circuit. Practical nonideal hybrids introduce impedance anomalies that result in a reflection. Thus, a speaker's voice reflects off the hybrid at the listener's end and returns, after a round-trip delay, to the speaker's earpiece. If the delay is too long or the reflection is not attenuated enough, this reflection is perceived as an objectionable echo. To control this echo, many national networks enforce upper limits on the contribution to round-trip delay made by subscriber equipment at either end. These restrictions vary from administration to administration, but the most stringent requirements are apparently a 1.5 μs round-trip delay (i.e., from telephone instrument to trunk and back).

As a result of the telephony delay limit for a MAN, voice samples cannot be substantially buffered before transmission. Nevertheless, a certain amount of delay is unavoidable. Once a sample is transmitted on the medium, propagation delays occur through the medium and any repeaters needed, delays that are proportional to the total distance spanned by the network. If the MAN were to buffer and send N samples of a particular conversation at once, then the oldest sample would be delayed $(N-1)$ 125

TABLE I
BANDWIDTH DEMAND CHARACTERISTICS

	DATA	VOICE	VIDEO
PEAK BANDWIDTH	HIGH	LOW	MODERATE
DURATION	SHORT	INTERMEDIATE	LONG
CONSTANCY	BURSTY	CONTINUOUS	CONTINUOUS

μs before it even reached the medium. Because this is a significant fraction of the delay budget, the total area a MAN can cover is very sensitive to N. Therefore, samples should be sent as they are produced, one every 125 μs, leaving as much time as possible for propagation through the medium and repeaters.

C. Transmission Quality

Telephone companies have established certain quality goals for their digital transmission systems in support of the integrated services digital network (ISDN). Any MAN being used for telephony should act as an extension of the ISDN and so should meet these quality goals as well. One goal, that the bit-error rate should be less than 10^{-6}, can easily be met by a MAN because the distances are so much shorter than the distances of telephone trunks. A second goal, relating to "slip" caused by mismatched clock rates, is much more difficult to meet in a MAN.

The goal established for rate of slip is one byte inserted or deleted every 20 h. At 8000 bytes/s, this slip rate means an accuracy of 1.7×10^{-9}. National telephone networks deliver this accuracy on their digital trunks by synchronizing all trunks to a single national frequency standard. Therefore, every interface derives a clock from one incoming signal and locks all of the frequencies of its outgoing links to that clock. In this way, the national frequency standard is propagated through a net of links and nodes down to every trunk.

The most practical way to achieve a similar degree of accuracy in frequency throughout a MAN interfaced to a digital trunk is to synchronize the entire MAN to the trunk's clock. This synchronization means that every node in the MAN that is generating an 8000 byte/s stream (which includes potentially every node with either a telephone or an ISDN terminal) must have an incoming source of reference signal that ultimately derives from the trunk interface; otherwise, that node may generate bytes at too slow or too fast a rate for the trunk.

V. THE PROPOSED METROPOLITAN AREA NETWORK

The unique combination of marketing concerns that characterizes a metropolitan area network is not satisfied by any existing technology. PABX's do not provide sufficient concentrated data rates. The cost per connection to a broad-band network is too high for simple terminals. And, the baseband LAN's do not provide the connectivity and the distance coverage required by a MAN.

Fiber optics offer the high data rates needed at a cost that will drop considerably in the future. Sufficient area coverage is obtained by using a ring topology (avoiding end-to-end propagation constraints) and connecting multiple rings via bridges. A low-speed copper ring bridged to a high-speed backbone ring lowers the connection cost for low-speed devices.

The physical and topological strategies are relatively straightforward. The greater challenge is to develop a media-access protocol that effectively integrates voice, data, and video. The following section presents a proposal for a MAN that does provide this integration with the desired combination of speed, distance, and cost.

A. An Introduction to the MAN

The proposed MAN is based upon a new media-access control (MAC) protocol. Several features distinguish this MAC from existing local area networks.

- The MAC provides a constant low-bandwidth low-delay service for delivery of byte streams. The basic service delivers one byte every 125 μs, completely free of any of the standard MAC overhead: format control, addresses, CRC, receive status.
- It is a slotted ring. Therefore, data are transmitted in fixed-size packets.
- The complete protocol is designed to permit compatible versions with less capability, but at a lower cost.
- The MAC layer protocol includes the concept of a bridge as an integral component at that layer.

B. Relationship to the OSI Model

The data services provided by the proposed MAC are intended to fit into the evolving layered standards for data communications. Specifically, the MAC is the lower of two sublayers of the data link layer (Layer 2) in the OSI model.

Devices connected to the MAN can use existing or future standards for higher-layer protocols, for example, the IEEE 802.2 Logical Link Control for the upper sublayer of Layer 2 and the CCITT Recommendations for Layers 3 and 4.

The proposed MAC integrates voice and video services with its data services in a very natural manner. The proper

LEGEND:

- BACKBONE RING
- LOW-COST RING
- □ PROCESSING NODE
- ○ LOW-COST NODE
- ▭ BACKBONE BRIDGE
- ▭ LOW-COST BACKBONE BRIDGE

Fig. 1. Multiring metropolitan area network.

to use the more expensive optical technology of laser diodes and avalanche photo-diodes. In this case, an intermediate level in the hierarchy uses less costly, lower-speed LED's and p-i-n diodes for intrabuilding distribution. If the very high data rates are not needed, the hierarchy has only two levels, with the LED's and p-i-n diodes at the top level.

At the lowest level of every MAN hierarchy is the copper-medium-based ring interconnecting a small number of low-speed low-cost devices. Data rates on this ring are limited by the medium to less than 15 Mbits/s.

Bridges are used to interconnect different speed rings from adjacent levels of the hierarchy. Bridges are also used to interconnect rings at the same level, for the reasons described earlier—expanded capacity and/or isolation.

The ring topology is susceptible to a single point of failure. Because the only path between a given pair of nodes potentially passes through every other node, failure of any single node to at least repeat the bit stream causes the failure of the entire ring.

The most effective protection against a single point of failure is a redundant ring. The proposal here is for two counter-rotating rings, a primary and a backup. For each two adjacent nodes A and B, A's primary output is connected to B's primary input, and B's backup output is connected to A's backup input.

Normally, MAC-layer information flows only around the primary ring, and the backup ring is idling. In the event of a failure between A and B, A switches its MAC output to the backup ring, and B switches to receive its MAC input from the backup ring. The backup ring relays A's MAC output through all the other nodes, substituting the failed primary link from A to B.

The redundancy is expensive, requiring twice as many drivers, receivers, cables, and connectors. Consequently, a low-cost small network may choose to forego the backup ring. An alternative, used either separately or in conjunction with redundant rings, is a bypass relay, which protects against the most common ring "failure," an unpowered node.

D. Isochronous versus Nonisochronous

The basic concept of the design is to integrate full telephony signaling with computer data transfer. The properties of digitized voice place timing and synchronization limitations on the design. Standard digitized voice is transmitted at a fixed rate of one byte every 125 μs. The media-access method provided for voice and similar data is isochronous ("isochronous" meaning something that is uniform in time and recurring at regular equal intervals). The term synchronous is frequently used for this type of information, but "isochronous" is used here for clarity. "Synchronous" commonly has multiple meanings—guaranteed bandwidth, simultaneous, or common clock—and so does not clearly communicate the regular periodic property included in the term "isochronous."

approach to integration at higher layers, however, is not readily apparent. Certain higher-layer functions, notably connection establishment, are the keys to voice and video. Others, however, such as error and flow control, are totally unnecessary.

Because the proposed physical topology is not point-to-point wiring, the standard telephony protocols for controlling connections will not work: they do not provide for explicit addressing as called for by standard telephony. Therefore, the alternative is to use the packetized data services to support voice connection control. Beyond this, the issue of integrating telephony and data protocols above the MAC layer is completely open.

C. Topology

The physical structure of the proposed MAN is an acyclic hierarchy of rings interconnected by bridges (see Fig. 1). The speed of the rings decreases with descending levels of the hierarchy; i.e., the highest speed appears at the highest level. The speed that is needed at this highest level (approximately 50 Mbits/s) requires fiber optics.

In installations where the aggregate interbuilding data rates are very great, the highest speed rings may now need

Fig. 2. MAC slots.

Fig. 3. Isochronous channel in a frame.

The MAC also transports packetized data. These packetized data are *nonisochronous*. Nonisochronous data are used for communicating the kinds of information most commonly exchanged on LAN's. The primary function of the MAC is the integration of both isochronous (voice) and nonisochronous (normal) data.

E. Frame Structure

The MAC frame is similar in concept to frames used for telephony. In digital telephony, framing includes the synchronization of a receiver that permits the alignment of the telephone channels. Therefore, the frames are of fixed length to meet the 125 μs isochronous voice requirement.

Frames are divided into multiple fixed-length slots (see Fig. 2). Slots are dedicated to isochronous or nonisochronous use. The nonisochronous slots are used to transport data, whereas isochronous slots are used for real-time voice and video information transmission and are further divided into isochronous channels. During normal operations, a frame is transmitted once every 125 μs, and the space between frames is filled with Pad (a frame separator). The contents of the frame (number of slots) and the length of the Pad are dependent on the speed of the ring.

An isochronous channel is a single-byte position in every frame, as shown in Fig. 3. The channel is identified by counting from the start of the frame. The MAC transmits and receives information on specific channels, but the assignment of channels is external to the MAC.

One of the nodes on the ring operates as an active monitor. This monitor is responsible for generating frames at initialization and assuring the accuracy of the frame format during normal operation. The monitor also has specific physical layer responsibilities.

1) Frame Types: Each MAC transmits streams of data in frames separated by Pad. The Pad field consists of an integer number of idle symbols (each symbol is one byte). An idle is encoded in the transmission medium in a manner distinctive from a byte of 0's and 1's, and so serves as a robust separator. The minimum separation is a single idle.

The last idle preceding a frame, together with the frame header, constitutes a *delimiter*. The transition between idle and data reliably establishes the beginning of the frame. The frame header (FH) indicates the format and purpose

of the following data symbols and is encoded to provide some protection against errors. The kinds of frames are
- Connection Frame,
- Initialization Frame,
- Index Frame, and
- Following Frame.

The Connection Frame is sent during initialization as an indication that a MAC is ready to communicate. MAC's use the Initialization Frame during backbone initialization bidding to become the acting monitor. This frame is also sent by a monitor to clear the ring whenever it detects specific error conditions.

The Index Frame and Following Frame headers mark the beginning of the slotted frames used during normal operations. During normal operations, the monitor node transmits a slotted frame every 125 μs. In rings where the delay around the ring (latency) is greater than 125 μs, the monitor node transmits an Index Frame, and then it transmits Following Frames every 125 μs. When the Index Frame header returns to the monitor node after having traversed the ring, the monitor node repeats the Index Frame at the next 125 μs boundary.

The first byte of each slot is the slot identifier indicating its use and content (see Fig. 4). The identifiers, like the frame headers, are encoded to protect them from misinterpretation. They are
- Isochronous Slot,
- Empty Slot,
- Full Slot,
- Old Slot.

Slots that are not assigned to isochronous usage are free for nonisochronous purposes. While they are unused, they are marked by the Empty Slot identifier. The content bytes of the slot contain no information. Any node may use an empty slot to send a nonisochronous message of any kind.

Each nonempty nonisochronous slot contains a nonisochronous packet. When a node is about to fill an Empty Slot with a packet, the node changes the slot identifier to Full Slot. As the monitor node relays that slot, it changes the slot identifier to Old Slot. It is the transmitting node's responsibility, when that slot returns to it, to change the identifier back to Empty Slot. If it fails to do so, the monitor reclaims the slot by changing the Old Slot identifier to Empty Slot.

Fig. 4. Slots in a frame.

Fig. 5. Nonisochronous slot format.
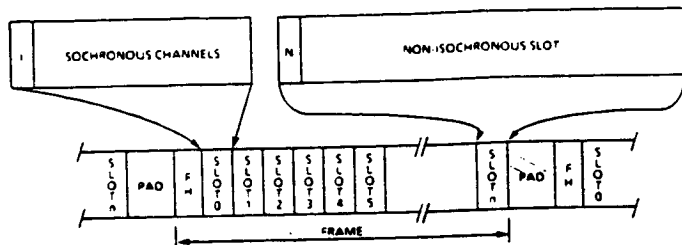
2) Ring Monitor Operation: A number of special functions are performed by a node selected to be a ring monitor. These include physical layer functions related to clocking and latency control in addition to MAC functions. Usually, all backbone nodes have a built-in monitor capability. Part of the initialization and latency protocol is the bidding that determines which node will become the monitor. The acting monitor node maintains the integrity and timing of the slots and frames circulating on a ring.

The monitor node controls the timing of frames by adjusting the total ring delay within the physical layer to an exact multiple of the frame period of 125 μs so that an integral number of frames continually circulate on the ring.

In addition to providing the latency adjustment, the monitor is responsible for correcting errors in the frame format. Any time the monitor discovers frames that are too long or too short, or ones in which the frame header has been corrupted, it re-forms proper frames. It also monitors slot identifiers and assures that the isochronous slots are marked Isochronous Slot. Nonisochronous slots are monitored to assure that the slot identifier is valid and that slots that have been filled are properly changed back to Empty Slot.

The monitor node is also responsible for controlling the number of frames on the ring. If ring latency exceeds 125 μs, multiple frames are transmitted at ring initialization. The monitor marks the first frame header as an Index Frame. The monitor marks the other frames Following Frames when there are multiple frames on the ring. The Index versus Following distinction permits nodes to identify slots by their position in the frame and the position of the frame relative to the Index Frame. The explicit location of slots is needed as part of the transmission protocol (the node that transmits a nonisochronous packet is responsible for marking the slot Empty Slot when it returns).

F. Isochronous Information Transfer

Each node has a list of its active channels called the isochronous template. When a frame arrives at a node, the MAC scans its isochronous template as the isochronous channel bytes pass through it. The template indicates if the channel is to be read, written, or both.

Isochronous management messages (IMM's) control the allocation and deallocation of isochronous network channels. Nonisochronous slots transport the IMM's; that is, IMM's are nonisochronous information that command the MAC layer at a node to transmit and/or receive on

specific isochronous channels. A full-duplex connection can use one or two isochronous channels. When a single channel is used, the path around the ring to the other end is used for transmission and the return trip around the ring is used for reception. IMM's are sent only to end points and bridges involved in the connection; intermediate nodes automatically relay isochronous data. These messages are used to create and maintain the isochronous template. By using multiple channels, connections with rates of $n \times 64$ kbits/s can be established.

The ring can be synchronized to the ISDN network (or other digital common carriers) if one of the nodes connected to an ISDN trunk is made the monitor node for the ring. The monitor node can then use the extracted 8 kHz clock from the trunk instead of an internally generated 8 kHz clock to control when a frame is started.

G. Nonisochronous Data Transfer

An upper-layer protocol is responsible for supplying packets, each of which can be sent in a single slot. The MAC in the source node waits for an Empty Slot and appends its own control information to the packet and transmits it. The MAC in the destination node strips off the control information added by the source MAC and passes the packet on to its upper layer. Neither the source nor the destination MAC's make any interpretation of the content fields of the packets.

1) Nonisochronous Slot Format: The format of the nonisochronous slot is shown in Fig. 5. The three valid, nonisochronous slot identifiers are: Empty Slot, Full Slot, and Old Slot.

The slot control field contains a collection of indicators describing slot contents and the manner in which they are to be handled. This field differentiates management messages from normal data and isochronous from nonisochronous management messages. In management messages, the slot control field also contains the management levels of both the source and the destination nodes. These management levels are used both for routing and privilege processing, privilege for security purposes. The slot control field is also used to indicate the MAC-level services for retries to bridges and to request notices of nondelivery.

The slot check sequence contains an error-detection code that protects the slot control field, destination address, source address, and content of the packet. The MAC generates and checks the slot-check sequence by a cyclic redundancy code (CRC) computation.

The last byte in a slot indicates the reception status. The values for receive status are

- Unreceived,
- Received,
- Inhibited,
- Multiply Received,

- Corrupted Received, and
- Corrupted Unreceived.

Unreceived is the initial value when the slot is transmitted. When a node addressed in the destination address field buffers an error-free packet, the node marks it Received, unless it is already marked Received, in which case, the node marks it Multiply Received. If an error-free packet cannot be buffered, it is marked Inhibited by the addressed node. Any node upon detecting a CRC error on the packet marks it Corrupted Received, or Corrupted Unreceived, based upon the current reception status.

2) Transmission: Whenever data are awaiting transmission, the MAC examines all incoming slots. When it detects an Empty Slot, it changes the slot identifier to Full Slot, starts the slot-check sequence, or SCS generator, and replaces the previous contents of the slot with the new slot control field, destination address, source address, and information field. The MAC then transmits the computed CRC into the SCS field and sets the status field to Unreceived.

The monitor node changes all Full Slot identifiers to Old Slot. The transmitting node later removes its own message by changing the Old Slot to Empty Slot again. If the reception status is Unreceived, Inhibited, or Corrupted Unreceived, if retries were requested, if the retry count is not exhausted, or if the retry count is decremented, the packet is requeued for transmission. If the slot type is not Old Slot, the transmitting node does not change it (this can occur because of transmission noise). The higher level is informed of the transmission status after the packet is either transmitted successfully or the retry count is zero. If the monitor finds an Old Slot, then the source node failed to remove it, and the monitor now marks it Empty Slot. The destination node sees Full Slot or Old Slot, depending on whether the slot passes through the monitor node before or after it reaches the destination.

3) Reception: Each node contains one or more receive buffers. The MAC examines all incoming slots. If the slot is an Empty Slot, it is ignored. If the slot is Full Slot or Old Slot, it begins computation of the CRC, and the slot is copied into a receive buffer if one is available. The MAC checks the destination address field. If the destination address does not match the node's address or, in the case of a bridge, one of the addresses for which the bridge is responsible, then it stops the copying and clears the receive buffer. After the SCS field has gone through the CRC checker, the MAC examines the CRC checker results. The receive status field in the slot is modified to indicate the status of the reception. The new value depends on whether the node was addressed, the slot was buffered, and the CRC was good, and what the previous status was.

During reception, the data can only be copied if there is a buffer available. When there is no buffer available in an addressed node, an Unreceived slot is marked Inhibited so that the transmitting node can retry later. An addressed node with a full buffer marks a slot that is already marked Received or Inhibited as Multiply Received even though the node cannot accept the data. To support network management, all nodes should count the number of slots that they inhibited.

4) Corruption of the Slot: All nodes check the SCS field in Full Slots and Old Slots, even if they do not recognize the destination address. The first node to detect a corruption in the SCS of a slot changes the receive status to indicate that the slot is corrupted. The status is set to Corrupted Received if the previous status was Received or Multiply Received; the status is set to Corrupted Unreceived if the previous status was Unreceived or Inhibited. To maintain the ring, each node should count the number of non-Empty slots (Full or Old) passing through the node and the number of slots on which the node changed the status to one of the two corrupted values.

H. Bridge Operation

A bridge connects two rings together and transfers data between them. Bridges perform MAC functions similar to other nodes on the linked rings. Bridges relay isochronous and nonisochronous information in both directions between the rings.

1) Nonisochronous Bridging: Each bridge has two templates, one for each direction of the bridge. Templates contain information on the physical addresses, both individual and group (contained in packets), that can use the bridge. Management messages provide this template information to the bridge. For simplicity, the following description assumes that a portion of the address constitutes a ring address.

The bridge compares the destination address in each packet, passing the packet on a ring against its template for that ring. Whenever the bridge finds a match, it copies the slot contents and marks the reception status as Received. If the bridge does not have an empty buffer, it marks the slot as Inhibited. A bridge accepts a slot already Inhibited, if it has an empty buffer, and marks the slot as Received to allow for more than one bridge between the same two rings.

Once a bridge has buffered a packet from one ring, it attempts to transmit the packet on the other ring. If the packet is accepted by a bridge or node on the other ring, the bridge discards its copy of the packet. If the packet is not accepted and retries are exhausted, the bridge action depends on whether the slot control field indicates that a notice of nondelivery is requested. If not (or if the packet is itself a Notice), the packet is discarded. Otherwise, the bridge changes the packet to a Notice packet, exchanges the source and destination addresses, and sends it back on the originating ring.

When a bridge transfers a management packet, it always retries if the packet is not accepted. After a limited number of unsuccessful retries, the bridge discards the management packet.
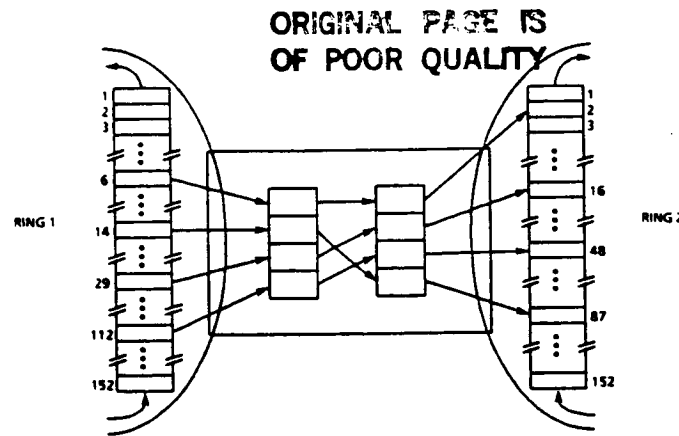
Fig. 6. Connecting isochronous channels through a bridge.

2) Isochronous Bridging: A bridge also connects isochronous channels from one ring to another. It has a pair of isochronous templates for each ring, specifying which channels it is to read from and which channels it is to write to on that ring. It also has a pair of mapping functions, specifying which channel being read from one ring is to be connected to which channel that is being written on the other ring.

Fig. 6 illustrates the capture of bytes from a frame on Ring 1, their rearrangement in the bridge, and their transmission into Ring 2 isochronous slots.

Propagating the external synchronization in one direction across the bridge is also provided for, implying that the bridge must be the monitor node on the ring toward which it is propagating synchronization.

Management of a bridge consists of managing the two MAC's on either ring, in addition to maintaining its various templates.

I. Initialization

The ring initialization process includes physical connection and synchronization, monitor selection, and latency adjustment. This process is controlled by the MAC, though it is invoked because of physical events, higher-level commands, or by the MAC itself.

Since only one node at a time can act as the monitor, a bidding process is used to elect the acting monitor. Without a monitor, no slot frames exist, and normal communication cannot be carried on. The selection process, therefore, is performed any time there is no acting monitor, or the previous acting monitor has failed.

Each node adheres to the following rules during the monitor selection procedure.

1) Start the initialization timer at bidding process entry.

2) Transmit repeated Connection Indicator delimiters and test received data for the Initialization Frame delimiter.

3) If an Initialization Frame delimiter is received before the initialization timer has expired, leave the monitor bidding procedure and enter normal operation.

4) If the initialization timer times out before receiving an Initialization Frame delimiter, transmit repeated Initialization Frames containing the node identification, while testing received data for Initialization Frames containing an identification greater than or equal to the node's own (the identification could be the node address or a device serial number).

5) If an Initialization Frame is received containing an identification greater than the node's own, leave the monitor bidding procedure and enter normal nonmonitor operation.

6) If an Initialization Frame is received containing the node's own identification, leave the monitor bidding procedure and enter the monitor initialization procedure as the acting ring monitor.

Because the minimum rotation period of the frame around the ring (the natural ring delay) is dictated by the number of nodes in the ring and the lengths of the links between the nodes, the monitor must adjust the ring's total delay to an integer multiple of 125 μs by adding extra delay (latency) within its physical layer.

The initialization proceeds in two stages: the first is the transmission of Initialization Frames to determine the length of the ring in frame periods, and the second is the adjustment of the latency buffer depth to complement the fractional part of a frame of the ring length.

VI. Conclusion

Imagine two users in different buildings on the same campus, sitting in front of their respective terminals, conversing in full view of each other via the screens of the terminals, interfacing their work through their respective terminals. One can expect such an activity to occur in the office of the near future.

Such an activity will require the real-time video, data, and voice integration of the metropolitan area network described in this paper. This MAN proposal meets a distinctive new challenge not met by the LAN's presently available. This challenge is met via a slotted ring media-access protocol that integrates voice, video, and data into a single bit stream.

Furthermore, the media-access structure is designed with a hierarchy of network speed as a premise. Consequently, network extentions with bridges can be made simple enough to increase the effective network size.

[4] *FDDI Token Ring Media Access Control,* ANSI X3T9/84-100/X3T9:5/83-16 Rev. 7.2, Oct. 26, 1984.

ACKNOWLEDGMENT

REFERENCES

[1] *Carrier Sense Multiple Access and Collision Detection,* ANSI/IEEE Draft. Int. Standard, ISBN 471-82749-5, IEEE.
[2] *Token Passing Bus Access Method and Physical Layer Specification,* IEEE Standard 802.4-1985 (ISO/DIS 8802/4).
[3] *Token Ring Access Methods and Physical Layer Specifications,* IEEE Standard 802.5-1985 (ISO/DIS 8802/5).

Daniel T. W. Sze (S'69–M'71) was born on May 27, 1941. He received the Ph.D. degree in electrical engineering from the University of Florida, Gainesville, in 1971. Since 1983, he has been employed as Director, Networks for Burroughs Corporation Advanced Systems Group in San Diego, CA.

Prior to his employment at Burroughs, he was Vice President of Research and Development, AMDAX Corporation, and was responsible for the 50 Mbit/s ring, Cablenet 7, and 14 Mbit/s network development from 1981 to 1983. From 1964 to 1981, he was with IBM Corporation in various capacities, including responsibilities ranging from large system to entry-level system architecture and development, Zurich Research ring development, and IBM worldwide local area network standards activity.

Dr. Sze is an active member of the IEEE 802 Committee for Standardization.

APPENDIX 9.   MORE COMMENTS ON EE2 MULTIPLEXER

LinCom

SUMMARY

In Appendix 7, it was commented briefly that the EE2 multiplexing scheme can only support telemetry transmission at 4.4 % of the link capacity. Hence, the data rate of the overall link must be higher than 2.3 Mbps in order to support a 100 Kbps telemetry rate. As such, the EE2 scheme is primarily designed to support simultaneous TV and telemetry (which includes audio) transmissions at medium to high data rates. In this appendix, a number of options to provide low data rate telemetry/audio support are considered. These options can be implemented independently, or in any reasonable combinations.

The EE2 Format

For the Space Station MA system channel, especially for the EVA involving high rate TV, the multiplexed scheme proposed by EE2 offers reduced complexity which is of primary importance to the user. The EE2 scheme is based on multiples of a TV frame with a fundamental line rate of 15.734 KHz. All data clocks are related to a common 42,954,502.5 Mhz source. Accordingly, all data rates are sub-multiples of this fundamental clock frequency. To adjust for reduced frame rate TV, one simply reduces the corresponding clock rates timing the multiplexer. Telemetry data are transmitted by overwriting up to 20 pixels of the Y component pixels per line.

In what follows possible enhancements to the EE2 scheme are considered. The first two are variations on the reduced frame concept; the last one is not.

LinCom

Separate Telemetry Slot

The original scheme shares the telemetry/audio with some of the Y component pixels. This can affect the TV picture at the left edge. A separate telemetry slot could be used. For example, if 20 pixels are used for the telemetry/audio slot, the overall data rate will be increased by 4.4 %. See Figure 1.

Skip a Frame

Telemetry can be transmitted once every N frames. N is selected based on the required telemetry rate. The telemetry frame will be identified by a unique Sync/Line Count pattern. When such a frame is encountered, the previous frame will be duplicated for display. If N = 2, this is equivalent to devoting alternate fields to telemetry data. If N = 1, only telemetry data is transmitted.

CCSDS Mode

For telemetry and audio only (only applies to low data rate links), the multiplexer can have a mode where the CCSDS frame format is followed.

SYNC	LC	TLM	Y	CHROMA
4	2	20	401	48

421

INSTEAD OF 401
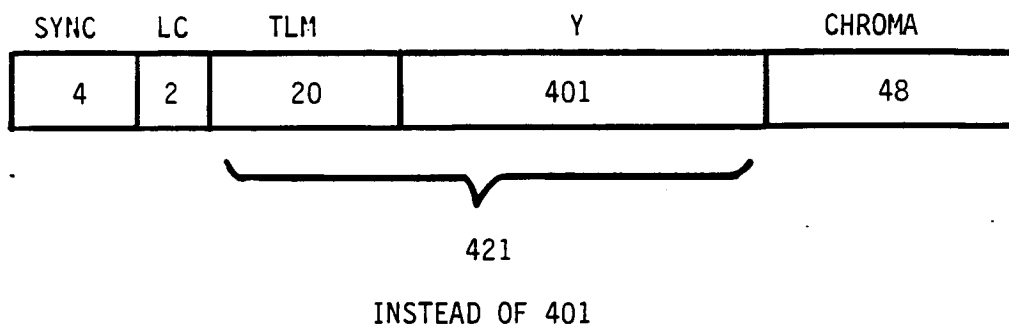
Figure 1. Dedicated Telemetry Slot.

APPENDIX 10.   ON THE APPLICABILITY OF CCSDS STANDARDS

TO THE SPACE STATION

SUMMARY

This appendix summarizes the issues affecting the C&T system raised or addressed in two separate meetings with the Phase-B contractors, at Rockwell in the morning and at MDAC in the afternoon. The main purpose of the two meetings was for the JPL representatives (headed by Adrian Hooke) to poll the contractors' assessment of the applicability of the CCSDS standards to the Space Station. This exercise was part of the JPL team preparation for a CCSDS meeting at Toulouse, France during the week of 27-31 January, 1986.

The people participated in the meetings are mostly involved with the DMS and SSIS. It appeared most of them are interested in the networking protocol aspects of the CCSDS standards. The 300 Mbps TDRSS link is their default "baseline". It also appeared that they have not given too much attention to audio and video data, important for the MA system.

JPL suggested another workshop for more technical exchange with the contractors when they are back from the trip to France.

The charts presented are attached in the appendices. Rockwell requested that pages 18-24 of their presentation be treated as "private data".

JPL

Adrian Hooke commented that it is regrettable that both contractors used the Version 2 format as a basis for their work. He stated that their preference was to use the Version 1 format. The version 2 format was a compromise solution to the ESA people for very simple spacecrafts.

JPL is currently favoring a frame format that uses a 16-bit field to address up to 256 virtual channels. The 16-bit field allows the use of a

distance-code to provide some error correction capability.

Rockwell

The bit-by-bit 8-channel demux is no longer the concept advocated. The virtual channel concept is currently implemented into a channel identified by a unique combination of service class, destination and routing, and data types. Hence, effectively many more (compared to 8 used by the green book) virtual channels can be supported.

MDAC

MDAC has a similar concept for expanding the number of the virtual channels. They also discuss a way of getting around the inherent buffer delay for audio by introducing a "Data Insert" zone for all transfer frame. This concept is very similar to the isochronous channel concept addressed in an earlier LinCom memo. (JPL would like to see the data insert enabled only for high data traffic virtual channels such as the ones carrying digital TV.)

APPENDIX I: ROCKWELL PRESENTATION

CCSDS PRESENTATION AND DISCUSSION

SPACE STATION

- AT LEAST TWO WORKING GROUPS WERE FORMED BY ROCKWELL TEAM TO STUDY CCSDS "GREEN BOOK".

- GROUPS LOOKING AT ISSUES INVOLVED ARE DMS, C&TS, AND SSIS. CONTRACTORS INCLUDE SPERRY, INTERMETRICS, TRW, CONTROL DATA CORPORATION, AND ROCKWELL.

- WHAT WE WANT TO DO IS

  - PROVIDE A SET OF PRESENTATIONS BY OUR DIFFERENT FUNCTIONAL AREAS ON ISSUES, CONCERNS, AND THEIR INDIVIDUAL SPECIFIC RECOMMENDATIONS.

  - HAVE AN OPEN DISCUSSION AFTERWARD.

- EDWARD V. DONG, 213 - 922 - 0640, WILL BE ROCKWELL TEAM'S POINT OF CONTACT ON CCSDS.

Rockwell International

Space Station Systems Division

END-TO-END COMMUNICATIONS
DIVIDED INTO SIX SEGMENTS

SPACE STATION

SPACE STATION ON-BOARD SEGMENT (SEGMENT 1)

DMS

GW

MACS

TDRS

SPACE STATION C&T SYSTEM

SPACE-TO-GROUND SEGMENT (SEGMENT 2)

SPACE USER COMMUNITY SEGMENT (SEGMENT 5)

GW

SPACE-TO-SPACE SEGMENT (SEGMENT 4)

SPACE USER COMMUNITY SEGMENT (SEGMENT 5)

GW

WSGT

NGT

GW

WHITE SANDS GROUND STATION

GROUND-TO-GROUND SEGMENT (SEGMENT 3)

GROUND USER COMMUNITY SEGMENT (SEGMENT 6)

GW

GROUND USER COMMUNITY SEGMENT (SEGMENT 6)

GW

TRW

Rockwell International

Space Station Systems Division

ON-BOARD SEGMENT
(SEGMENT 1)

SPACE STATION

SPACE STATION ON-BOARD SEGMENT (SEGMENT 1)

DMS

GW

SPACE STATION C&T SYSTEM

MACS

TDRS

SPACE-TO-GROUND SEGMENT (SEGMENT 2)

WSGT

GW

NGT

WHITE SANDS GROUND STATION

GROUND-TO-GROUND SEGMENT (SEGMENT 3)

GROUND USER COMMUNITY SEGMENT (SEGMENT 6)

GW

GROUND USER COMMUNITY SEGMENT (SEGMENT 6)

GW

SPACE-TO-SPACE SEGMENT (SEGMENT 4)

GW

SPACE USER COMMUNITY SEGMENT (SEGMENT 5)

GW

SPACE USER COMMUNITY SEGMENT (SEGMENT 5)

TRW

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Space Station Systems Division

Rockwell Space Station DMS Network

SPACE STATION

Station Bus

BRIDGE

Module Bus

MODULE 1

NIU — NODE

NIU — NODE / NODE

BRIDGE

Module Bus

MODULE 2

NIU — NODE

NIU — NODE

NIU — NODE

GATEWAY

To other SSIS Segments

C & T SYSTEM
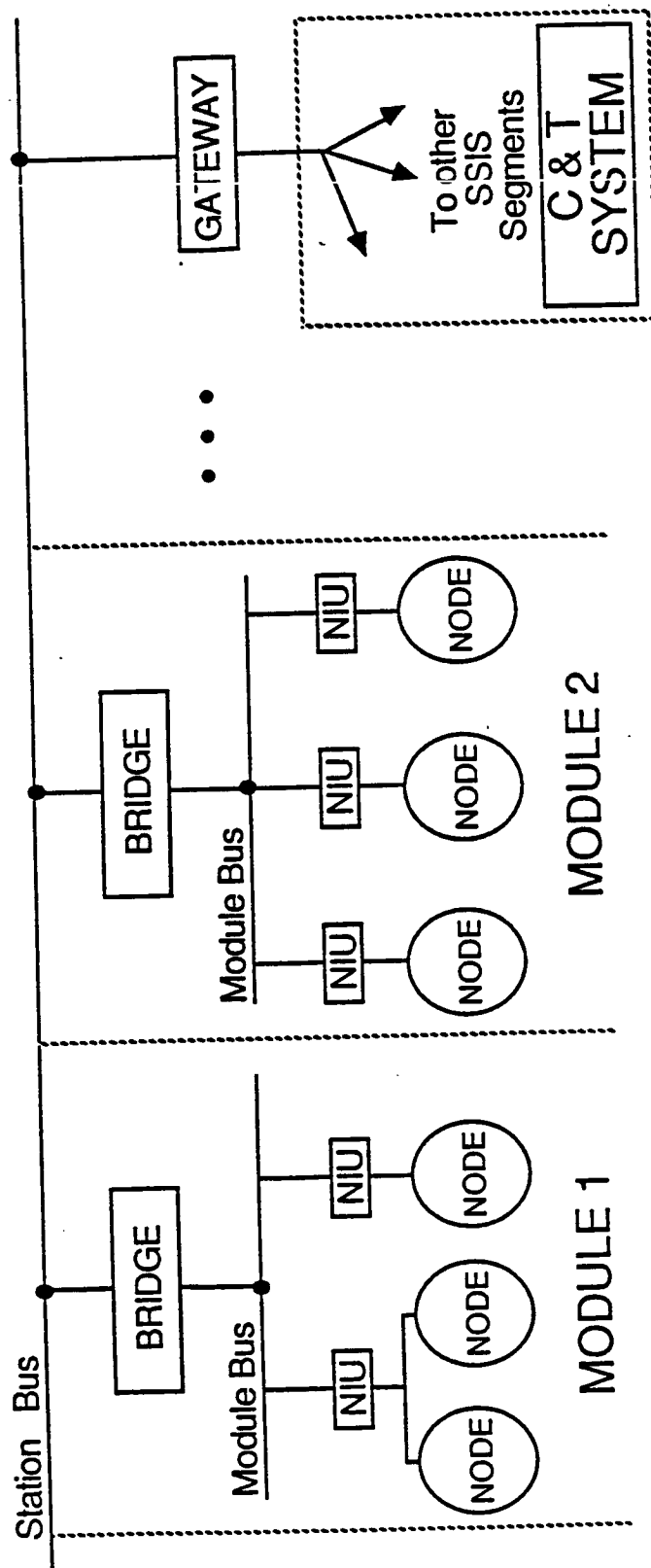
basic configuration
that is this is
satisfied other configs.
can be

4

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SSIS SEGMENT 1 NETWORK OBJECTIVES

SPACE
STATION

1. SSIS NETWORK DESIGN SHOULD NOT LIMIT USER MESSAGE SIZE.

2. PACKET FORMATS SHOULD SUPPORT NETWORKS HAVING VERY HIGH DATA RATES.

3. A NETWORK SERVICE SHOULD FORMAT USER MESSAGES INTO NETWORK PACKETS.

4. MULTIPLE PACKET TYPES AND SERVICE CLASSES SHOULD BE PROVIDED.

5. SHOULD HAVE MAXIMUM DECOUPLING AMONG DIFFERENT SSIS SEGMENTS:
   A) IN SOFTWARE SPECIFICATION AND DEVELOPMENT
   B) IN NETWORK DESIGN AND OPERATION

6. HARDWARE RECONFIGURATIONS SHOULD BE TRANSPARENT TO APPLICATION SOFTWARE.

7. MULTICAST MESSAGES FACILITATE ON-LINE TESTING AND REDUCE NETWORK TRAFFIC.

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10-9

Rockwell SSIS Strawman Segment 1 Format

SPACE STATION

Rockwell SSIS Terminology

CCSDS Terminology

User Message

(Up to 2^{27} Bytes)

Complete Message

Message Header

64Kbyte Submessage

Source Data of Source Packet

Packet

Packet Header			
	Local	Global	Data ~24byte	Error Control

Version 2 Telemetry Segment

logical address

Do Not use version -
Like version!

sample to
modify ESA
ur utilized
by NASA

6

smile
spacecraft

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Space Station Systems Division

pmS

10-10

PACKET FORMATS SHOULD SUPPORT VERY HIGH DATA RATES

1. HIGH DATA RATES SUGGEST THAT HEADER FIELDS CONTROLLING EN ROUTE PACKET HANDLING BE UP FRONT (NOT SPLIT BETWEEN PRIMARY AND SECONDARY HEADERS) TO FACILITATE FAST HANDLING (E.G., BY SPECIAL-PURPOSE HARDWARE).

2. RECOMMEND INCREASE IN NUMBER OF PERMISSIBLE SEGMENT SIZES – UP TO 2K OR 4K BYTES FOR DATA BODY (PERMITTED BY HIGH DATA RATES).

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10-11

MULTIPLE PACKET TYPES AND SERVICE CLASSES SHOULD BE PROVIDED

1. DIFFERENT PACKET TYPES NEED TO BE ACCOMMODATED: DATA, ACKNOWLEDGEMENT, TOKEN, ETC.

2. DIFFERENT MESSAGE TYPES REQUIRE DIFFERENT CLASSES OF SERVICE:

MESSAGE TYPE:	SERVICE CLASS REQUIRED:
PARAMETERS IN REAL-TIME CONTROL LOOPS	TOP PRIORITY FOR MINIMUM DELAY; ACK/NACK NOT NEEDED SINCE PREVIOUS VALUE CAN BE USED.
AD HOC MESSAGES (QUERRIES, SCREENS, COMMANDS, ETC.)	GOOD RESPONSE TIME NEEDED; GUARANTEED ERROR-FREE AND COMPLETE ARRIVAL REQUIRED.
LARGE DATA TRANSFER	ADDED FLOW CONTROL MEASURES MAY BE ADVISABLE; GUARANTEED ERROR-FREE AND COMPLETE ARRIVAL MAY BE REQUIRED.
FILE TRANSFER, OR DATA STREAM FOR PIPE-LINED, DISTRI-BUTED PROCESSING	SIMILAR TO LARGE DATA TRANSFER, BUT POSSIBLY WITH LOWEST PRIORITY. "CONCURRENT" OPTION CAN OVERLAP PROCESSING AND INPUT/OUTPUT BY NON-WAIT CALLS & SWINGING MESSAGE BUFFERS. THUS USER CAN SEND LARGE MESSAGES WITH SMALL MESSAGE BUFFERS.

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SSIS SEGMENT 1 PACKET ADDRESSING AND ROUTING APPROACH UNDER STUDY

SPACE STATION

OBJECTIVES:

* MAXIMUM DECOUPLING BETWEEN DIFFERENT SSIS SEGMENTS' SOFTWARE DEVELOPMENT

* POSSIBILITY OF DIFFERENT NETWORK DESIGNS IN DIFFERENT SSIS SEGMENTS

* HARDWARE RECONFIGURATIONS TRANSPARENT TO APPLICATION SOFTWARE

* MULTICAST MESSAGE CAPABILITY TO FACILITATE ONLINE TESTING AND TO REDUCE NETWORK TRAFFIC LOAD

IMPLEMENTATION IN PACKET HEADER FIELDS:

ROCKWELL SSIS STRAWMAN	CCSDS
* TWO SETS OF ADDRESSES PER PACKET. ONE REMAINS WITH PACKET THROUGH ALL SEGMENTS, AND IS USED BY APPLICATION SOFTWARE. THIS IS THE SOURCE AND DESTINATION "PROCESS NAMES" IN THE PACKET'S "GLOBAL" HEADER. THE OTHER SET OF ADDRESSES IS SEGMENT-DEPENDENT, IS USED ONLY FOR NETWORK ROUTING. IT IS THE SOURCE AND DESTINATION ID'S IN THE PACKET'S "LOCAL" HEADER.	* ONE SET OF ADDRESSES.
* BOTH SOURCE AND DESTINATION ADDRESSES IN EACH OF THE TWO SETS OF PACKET ADDRESSES.	* ONLY ONE ADDRESS IN THE SET.

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Space Station Systems Division

SSIS SEGMENT 1 PACKET ADDRESSING AND ROUTING APPROACH UNDER STUDY (cont'd)

SPECIFIC FIELDS IN ROCKWELL STRAWMAN:

A: SOURCE AND DESTINATION ID'S

- USED FOR PACKET ROUTING TO PROCESSORS WITHIN A SINGLE SSIS SEGMENT
- UNIQUE ONLY WITHIN A SINGLE SSIS SEGMENT, NOT GLOBALLY - THUS LESS COORDINATION REQUIRED BETWEEN SSPE'S DURING SOFTWARE DEVELOPMENT
- ID IS ASSIGNED TO A "LOGICAL" PROCESSOR (I.E., TO A PROGRAM LOAD), OR TO AN ARBITRARY GROUP OF LOGICAL PROCESSORS IMPLIED BY A MULTICAST DESTINATION
- ID IS BASED ON FUNCTION, NOT LOCATION - THUS CAN REMAIN UNCHANGED EVEN IF FUNCTION IS PHYSICALLY MOVED (E.G., TO A BACK-UP PROCESSOR)
- SOURCE APPLICATION PROCESS SPECIFIES DESTINATION PROCESS NAME, NOT DESTINATION ID. A DMS SERVICE PROVIDES THE DESTINATION ID, BASED ON THE DESTINATION PROCESS NAME.
- MULTICAST DESTINATIONS REDUCE NETWORK TRAFFIC, & FACILITATE "SHADOW" PROCESSOR TO ALLOW ON-LINE TESTING OF NEW RELEASE OF SOFTWARE
- EACH PROCESSOR MAY BE ADDRESSED VIA SEVERAL DESTINATION ID'S (SINCE EACH OF ITS PROCESSES MAY BE ADDRESSED INDIVIDUALLY OR AS A MEMBER OF SEVERAL MULTICAST GROUPS)
- FOR INTER-SEGMENT MESSAGES, INITIAL DESTINATION ID IS THE GATEWAY
- GATEWAY END IN NEXT SEGMENT CHANGES PACKET'S DESTINATION ID TO THAT OF ACTUAL DESTINATION NODE IN THAT SEGMENT
- SUGGESTED LENGTH: 18 BITS

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SSIS SEGMENT 1 PACKET ADDRESSING AND
ROUTING APPROACH UNDER STUDY (cont'd)

SPACE
STATION

SPECIFIC FIELDS IN ROCKWELL STRAWMAN (CONTINUED):

B: SOURCE AND DESTINATION PROCESS NAMES

-ASSIGNED TO A PROCESS OR AN ARBITRARY GROUP OF PROCESSES THAT
   REPRESENT A COMMON DESTINATION (HENCE MULTICAST CAPABILITY)
-GLOBALLY UNIQUE, HIERARCHIC NAMING CONVENTION BASED ON FUNCTION AND/OR
   RESPONSIBLE GROUP (TO REDUCE COORDINATION REQUIRED AMONG MULTIPLE
   SSPE'S, VENDORS AND SUBSYSTEMS DURING SOFTWARE DEVELOPMENT)
-EVERY PROCESS ASSIGNED AT LEAST TWO PROCESS NAMES – ONE OF THEM
   UNIQUE, THE OTHER A "GENERIC", MULTICAST NAME. THE PROCESS WILL
   NORMALLY BE ADDRESSED BY ITS GENERIC NAME, TO FACILITATE A "SHADOW"
   COPY FOR ON-LINE TESTING OF THE NEXT SOFTWARE RELEASE
-SOURCE PROCESS NAME USED BY DESTINATION PROCESS TO ASCERTAIN SOURCE
-DESTINATION PROCESS NAME USED BY GATEWAY NODE IN REMOTE SEGMENT TO
   DETERMINE NEW DESTINATION ID WITHIN THAT SEGMENT
-SUGGESTED LENGTH: 72 BITS

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ROCKWELL SSIS STRAWMAN: SEGMENT 1 PACKET HEADER FIELDS

BITS

MESSAGE HEADER FIELDS:

SECONDARY MESSAGE HEADER FLAG	1
NUMBER OF 2 KBYTE OR 4 KBYTE PACKETS IN MESSAGE	15
COMMUNICATION DATE/TIME STAMP *at source*	64
SUBTOTAL:	80

GLOBAL PACKET HEADER FIELDS (REMAIN WITH PACKET THROUGHOUT SSIS):

VERSION	3
SPARE/SECONDARY HEADER	4
PRIORITY	4
SERVICE CLASS	4
MESSAGE NUMBER	12
SUBMESSAGE NUMBER (Jth SUBMESSAGE IN MESSAGE)	9
SEQUENCE NUMBER (Kth PACKET IN SUBMESSAGE)	6
SEGMENT FLAGS (FIRST, MIDDLE, LAST PACKET IN SUBMESSAGE)	2
PACKET DATA LENGTH (BYTES)	12
SOURCE PROCESS NAME	72
DESTINATION PROCESS NAME	72
SUBTOTAL:	200

LOCAL PACKET HEADER FIELDS (REPLACED IN NEXT SSIS SEGMENT):

PACKET TYPE	4
PRIORITY	4
SERVICE CLASS	4
SOURCE ID	18
DESTINATION ID	18
SUBTOTAL:	48

TOTAL BITS:	328
TOTAL BYTES:	41

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SPACE-TO-GROUND and GROUND-TO-GROUND SEGMENTS (SEGMENTS 2 & 3)

SPACE STATION

SPACE STATION
ON-BOARD SEGMENT
(SEGMENT 1)

DMS

GW

MACS

SPACE STATION
C&T SYSTEM

TDRS

SPACE-TO-GROUND SEGMENT
(SEGMENT 2)

SPACE USER
COMMUNITY
SEGMENT
(SEGMENT 5)

GW

SPACE-TO-SPACE
SEGMENT (SEGMENT 4)

SPACE USER
COMMUNITY
SEGMENT
(SEGMENT 5)

GW

WHITE SANDS
GROUND STATION

WSGT

NGT

GW

GROUND-TO-GROUND
SEGMENT (SEGMENT 3)

GROUND USER
COMMUNITY
SEGMENT
(SEGMENT 6)

GW

GROUND USER
COMMUNITY
SEGMENT
(SEGMENT 6)

GW

TRW

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10-17

SPACE STATION Communication
Connectivity

SPACE STATION

Polar Orbiting Platform

Co-Orbiting Platform

Two TDRSS SA Links (Ku & S) Allocated:
One for Space Station
One Shared by COP & POP

IOC Return
S -   3 Mbps
Ku - 300 Mbps

IOC Forward
S -   300 Kbps
Ku - 25 Mbps

50 Mbps

STGT

WSGT
NGT

GSFC

RDC

RDC

JSC

100 to
400 Kbps

≤ 25 Mbps

Space Station
Users

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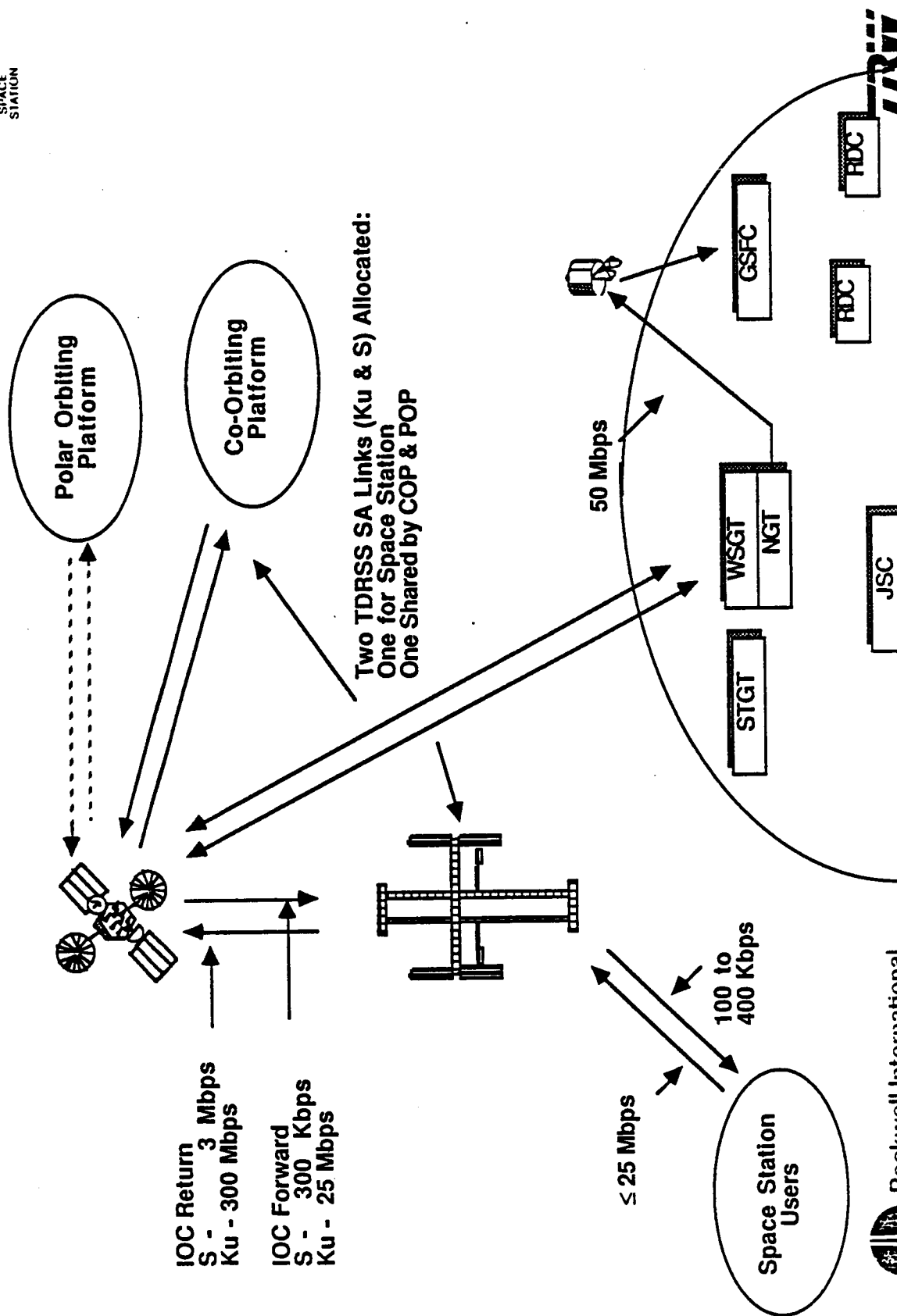
C&T OVERVIEW
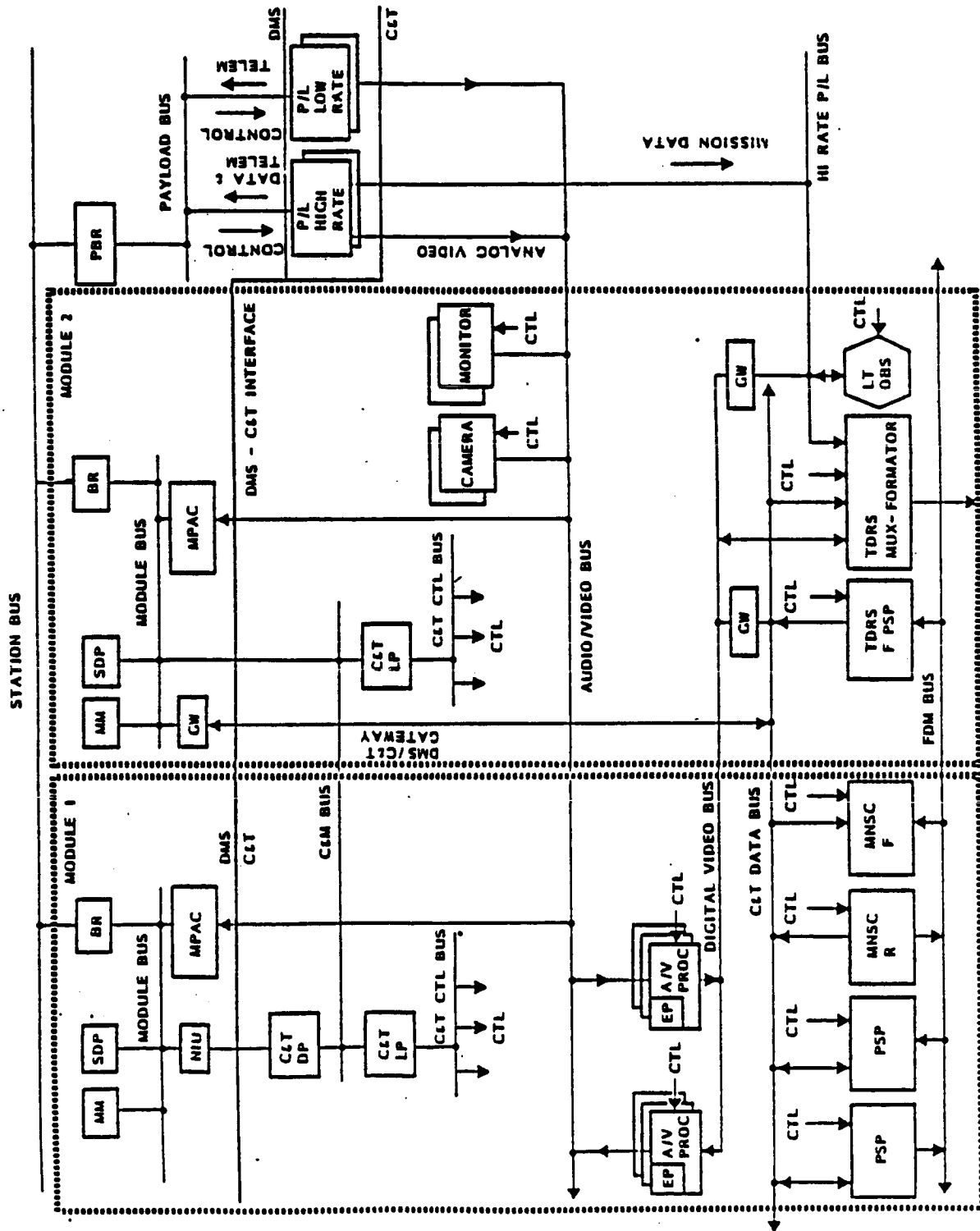
SPACE STATION MULTIPLEXER-
FORMATTER ARCHITECTURE

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To TDRSS Transmission Channels

Frames returned
for storage during
Zone of Exclusion

C&M Bus

Hi Rate P/L Bus
Digital Audio/Video Bus
C&T Data Bus

Onboard
Storage

Local
Controller

TDRSS
Link
Controller

Uplink
Control

Frame
Routing
Selector

Class 1
Frame
Storage

Min
Delay

Min
Delay

Frame
Formatter

Frame
Formatter

Frame
Formatter

Frame
Formatter

ANC
Data

ANC
Data

ANC
Data

GW

GW

GW

GW

GW

GW

1 x 5

1 x 5

1 x 4

1 x 4

1 x 5

S Q
Channel
Mux

S I
Channel
Mux

K Q
Channel
Mux

K I
Channel
Mux

SPACE
STATION

PRECEDING PAGE BLANK NOT FILMED

10-22

TDRSS Frame Formatter

SPACE STATION

Frame Formatter

From TDRSS Controller →

Packet Inputs →

Embedded Control Processor

Control Lines (C) →

1 x 2 Switch

(C)

Packet Buffer

(C)

Packet Buffer

(C)

Frame Data Field

Fill Packets

(C)

Frame Secondary Header

(C)

Frame Primary Header

(C)

Coded Frame Assembler

(C)

Uncoded Frame Assembler

(C)

• Grade 1 & 2 Frames

• Grade 3 & 4 Frames

2 x 2 Switch

(C)

Embedded Control Processor
• link setup control
• packet control data (eg, class of service)

Frame Primary Header
• Sync
• Virtual Channel ID
• Master/Virtual Channel Counts
• Data Field Status

Frame Secondary Header
• ID
• Channel Commands
• Audio Packets

Frame Data Field
• Spacecraft Application Data

Packet Buffer
• Buffers packets (or fragments) for asynchronous insertion into frames

Class of Service
• Transmission Grades 1 to 4 provided

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Ground Terminal Functional Units in Demultiplexer/Formatter

SPACE STATION

A Frame Header Processing

ACK/NAK
- Discard Corrupted Frames
- Missing Frames ACK/NAK (Class 1 only)

B Frame Decoder

ACK/NAK
- Error detect & discard
- ACK/NAK (Class 1 only)

C Frame Ordering Buffer

D Frame Disassembler

- Buffering

Class I Transmission Service
- transmission guaranteed complete (ACK/NAK)
- error free transmission (ACK/NAK)
- data transmitted in sequence
- data not duplicated in transmission

Class II Transmission Service
- transmission may be incomplete (outages)
- error free transmission (discard frames)
- data transmitted in sequence
- data not duplicated in transmission

Class III Transmission Service
- transmission may be incomplete (outages)
- transmission errors possible
- data transmitted in sequence
- data not duplicated in transmission

Class IV Transmission Service
- transmission may be incomplete (outages)
- transmission errors possible
- data transmitted may be out of sequence
- data may have been duplicated in transmission

Note: Classes III and IV are essentially the same for the space to ground link

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GROUND PROCESSING and Ground to Ground COMMUNICATIONS (segment 3)

MULTI-TRANSPONDER DOMSAT

SPACE STATION

WSGT OUTPUTS DISTRIBUTION INTERFACE

DOMSAT CHANNEL 1
DOMSAT CHANNEL 2
DOMSAT CHANNEL N

FRAME SWITCHING INTERFACE

PACKET SWITCHING INTERFACE

Level Zero Processing

Ground Network Interface

Ground Network Interface

Bit Stream?

WSGT PROCESSING

NASA/USER SITE

PACKET SWITCHING INTERFACE

Bit Stream?

???

???

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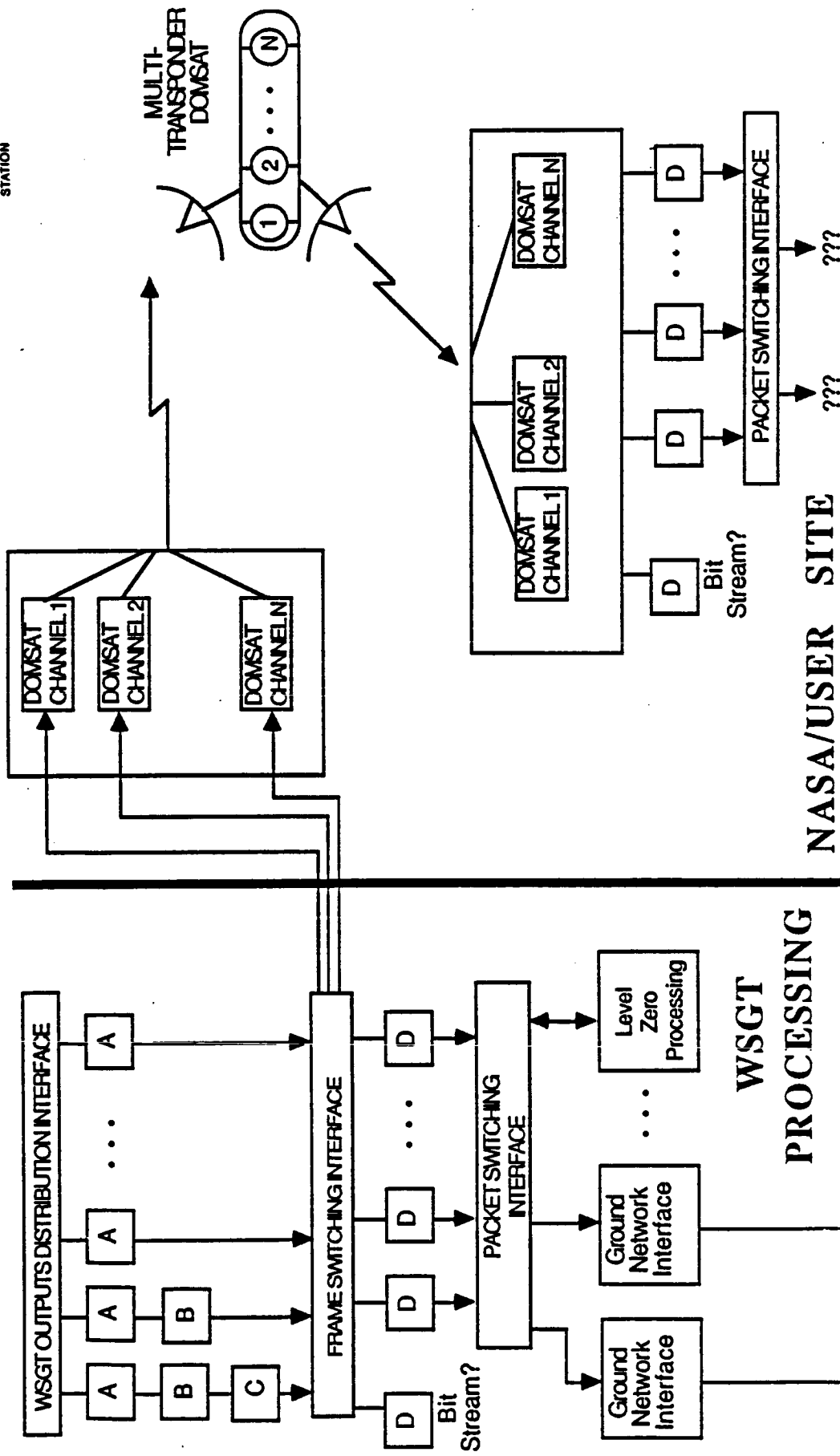
TRW

PRELIMINARY ASSESSMENT of CCSDS TELEMETRY TRANSFER FRAMES

1. Telemetry Transfer Frames appear suitable for the space to ground link (segment 2) and the subsequent DOMSAT links (segment 3).

  • Reed-Solomon code provides good error-correction capability for noisy RF links such as space-ground links.

2. The Telemetry Transfer Frames may or may not be suitable for the space to space links (segment 4).

  • Frame sizes and link rates need to be examined.

3. The frame "secondary header" can be used to provide additional capabilities.

  • Provides extra space for other necessary header fields.
  • Except for real-time audio insert, format is left undefined (determined by mission/agency).

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SPACE STATION

ISSUES, RELATED QUESTIONS, and OPTIONS
for CCSDS FRAMES (segments 2 & 3)

1. Are the four grades of service proposed in the CCSDS Green Book adequate?

2. How should we use the virtual channel concept on the space to ground link?

   - Class of Service
   - Destination and routing
   - Data Types (audio, video, etc.)
   - Data rate reduction

3. How can we (should we) provide frame retransmission capability on links using CCSDS frames?

   - Explicit ACK/NAK on frames
   - Buffering, sequence numbering, time stamping

4. How can we provide flow control capability?

5. How do we accomodate an order wire capability?

6. Will we allow a "bit stream" interface to the frame data fields?

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ISSUES, RELATED QUESTIONS, and OPTIONS for CCSDS FRAMES (cont'd)

7. How should frame and packet lengths be chosen?

- Should packets extend across frames?
- Should frame lengths be related to high-rate video scan frames?

8. Should we allow coded and uncoded frames on the same link?

9. What type of header error protection can we provide for frames?

- CRC (error-detection)
- Hamming code or other with error-correcting capability

10. Should we provide provide privacy/encryption services on links?

- Encrypt packet data fields (source)
- Encrypt frame data fields
- Bulk link encryption

SPACE STATION

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TELEMETRY TRANSFER FRAME:
ADDITIONAL FIELDS BEING CONSIDERED

SEQUENCE NUMBER: large enough to allow for 20Mbps outstanding if retranmission service is implemented; otherwise, can be smaller.

ACKNOWLEDGEMENT: sequence number of rejected/acknowledged frames.

TIME: A standard coded time field. Could be used for unique sequence numbering.

ERROR PROTECTION: CRC or Hamming code, etc., to protect primary header and vital secondary header fields.

TYPE OF SERVICE: Indicates the status of error-coding, retransmission, and priority associated with the frame. For example, some combinations are:

- CODED, ARQ, HIGH PRIORITY
- CODED, No ARQ, HIGH PRIORITY
- UNCODED, No ARQ, LOW PRIORITY
- CODED, No ARQ, HIGH PRIORITY, DATA FIELD ENCRYPTED

ROUTING: This requires either a connection id (similar to a circuit number) or a destination address (ground network number) field.

FRAME TYPE: Used to distiguish control and data frames for purposes of link control exchange (flow control, status, etc.). This field defines the expected format of the rest of the header. It should be large enough to allow for growth and design flexibility.

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CANDIDATE FRAME FORMAT
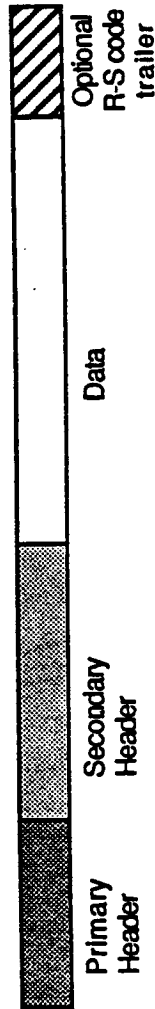
commended 16 bit channel Count (handwritten)

SPACE STATION

EXISTING PRIMARY HEADER ▮

Additional Secondary Header Fields ▨

Primary Header | Secondary Header | Data | Optional R-S code trailer

SYNC MARK	V e r	Spacecraft ID	Virtual Channel ID	O C F	Total Frame Count	Virtual Channel Count	Sec Hdr	Sync Flag	Ord. Flag	Seg. Length	First Header Pointer
32	2	10	3	1	8	8	1	1	1	2	11

R-S Code	ARQ	Secure
1	1	1

→ Reed-Solomon coded
→ ARQ (retransmission service)
→ Data Field Encrypted

≥152 bits

New Use of Virtual Channel Id

Sec. Hdr. Ver.	Sec. Hdr. Length	Priority	Frame Type	Destination Address or Connection Id	Sequence Number Extension	Ack/Nak Seq. Num. Field	Time	Error Protection
2	6	1-4	8	12	8	17	64	≥32

NOTES: (1) The frame type defines the rest of the secondary header. Some of fields shown exist only within certain frame types and channel types. Other fields can be developed and assigned to different frame types.
(2) This represents one option under consideration.

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TENTATIVE ANSWERS to ISSUES and RELATED QUESTIONS for TELEMETRY TRANSFER FRAMES

1. Are the four grades of service proposed in the CCSDS Green Book adequate?

   Although the four proposed grades of service are almost adequate for service across the space to ground link, we feel that several additional services should be provided in the network (for example, prioritization).

2. How should we use the virtual channel concept on space to ground link?

   The virtual channel concept itself does not dictate any particular usage; however, due to the 3-bit field size, we are considering using this particular field to indicate the classes of service on links using frames. Other concepts such as routing and prioritization are covered in additional fields.

3. How can we (should we) provide frame retransmission capability on links using CCSDS frames?

   We are considering providing frame retransmission capability; in order to provide this service, the sequence number field must be extended and an acknowledgement field added.

4. How can we provide flow control capability?

   Flow control can be acheived on a single link by exchanging window or other buffer status information. We are considering providing some frame types which would allow control and status information exchange between the link controllers at either end of the link.

TENTATIVE ANSWERS to ISSUES and RELATED QUESTIONS for TELEMETRY TRANSFER FRAMES

5. How do we provide an "order wire" capability?

The "order wire" functions can be handled by specific control frame types (see answer to number 4 above).

6. Will we allow a "bit stream" interface to the frame data fields?

We do not have a "yes/no" answer to this question. It would be desirable to have all sources send packets of one type to the frame assemblers. However, this does not preclude the possibility of extracting the packet data and inserting it directly into frames.

7. How should frame and packet lengths be related/chosen?

Our current design so far allows for the DMS packets to extend up to 2K or 4K bytes. Since this exceeds a frame size, the packets must either be broken down further at the DMS/C&T gateway, or allowed to extend across frames. In addition, other subsystems such as audio and video may have other desirable packet sizes for data (although this is still TBD). This is an open question.

8. Should we allow coded and uncoded frames in the same link?

Because the Reed-Solomon code overhead is ~13%, we are considering providing it as a service on the links (rather than a requirement). This requires at least one bit to differentiate between coded and uncoded frames. Also, since the header of a frame may now be unprotected, a special error-protection field is required for frame headers.

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TENTATIVE ANSWERS to ISSUES and RELATED QUESTIONS for FRAMES (cont'd)

9. What type of header error-protection can we provide for frames?

Since the bit-error rate of the "raw" TDRS link is 10^{-5}, we may expect up to one frame header in 500 to contain a single-bit error. Some error-correction capability is therefore desirable. For uncoded frames, the entire primary and new secondary header should be protected to some degree. Almost all fields (virtual channel id, priority, frame type, sequence number, and destination id) are vital. A specific error-correcting code for the headers has not yet been determined.

10. Should we provide privacy/encryption services on links?

At this point, encryption of the frame data fields has not been considered. Bulk link encryption is the current recommendation. The effect of the decryption process on introducing errors in the Reed-Solomon coding process should be examined.
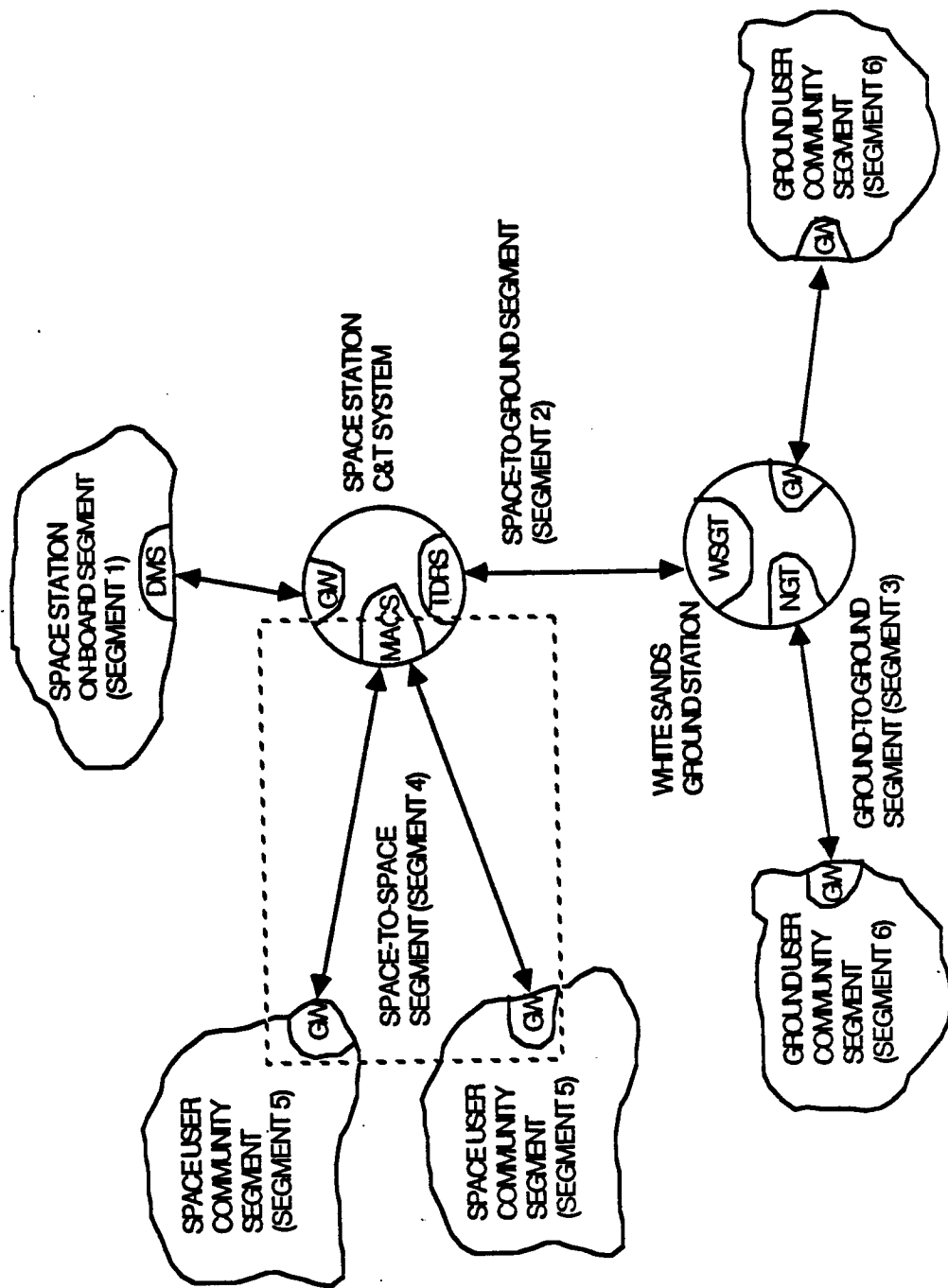
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SPACE-TO-SPACE SEGMENT
(SEGMENT 4)

SPACE STATION

SPACE STATION
ONBOARD SEGMENT
(SEGMENT 1)

DMS

GW

SPACE STATION
C&T SYSTEM

MACS

TDRS

SPACE-TO-GROUND SEGMENT
(SEGMENT 2)

SPACE-TO-SPACE
SEGMENT (SEGMENT 4)

GW

GW

SPACE USER
COMMUNITY
SEGMENT
(SEGMENT 5)

SPACE USER
COMMUNITY
SEGMENT
(SEGMENT 5)

WSGT

NGT

GW

WHITE SANDS
GROUND STATION

GROUND-TO-GROUND
SEGMENT (SEGMENT 3)

GW

GROUND USER
COMMUNITY
SEGMENT (SEGMENT 6)

GW

GROUND USER
COMMUNITY
SEGMENT
(SEGMENT 6)

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ISSUES, RELATED QUESTIONS, and OPTIONS for CCSDS FRAMES on Space-to-Space LINKS

1. Traditional systems use relatively fixed command and telemetry formats

   - Data rates may vary, and formats can be selectable or reprogrammable
   - CCSDS frames and packets are new and have not been used.

2. CCSDS frames have 10,080 bits, with approximately 8800 or 9900 data bits per frame (depending on Reed-Solomon coding and secondary header overheads)

   - At low data rates, the frame arrival rate will be low, and transport delay may be on the order of 100 milliseconds to multiple seconds.
   - Certain systems like data in closely spaced bursts (e.g. audio); others may not be able to afford the overhead in packetization and framing (e.g. EVA's).

3. Should we use CCSDS frames and packets for space-space links?

   - Investigate ways to sequence packets for close bursts inside frames.
   - Use frames only (without packets; data field is TDMA-style divided)
   - Design independent frames formats for space-space links.
   - Provide packetization on-board space station (translation from link format to on-board formats).

4. Related issue: systems with special requirements or existing formats:

   - NSTS, OMV, MRMS

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DETACHED USER COMUNICATION RATES

SERVICE	MAX DATA RATES	
	FORWARD	RETURN
CO-ORBITER PLATFORM	100 KBPS	150 KBPS 10 MBPS
FREE FLYER	100 KBPS	128 KBPS 22 MBPS
EMU/EVA	40 KBPS 400 KBPS	72 KBPS 22 MBPS
OTV/OMV	2 KBPS	32 KBPS 8 MBPS
SS ORBITER	72 KBPS	128 KBPS 22 MBPS
MRMS	8 KBPS	32 KBPS 72 KBPS

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OPTIONS for FORMATS on Space to Space LINKS (segment 4)

SPACE STATION

FREE-FLYER

SEGMENT 1

GATEWAY

GATE WAY

PACKETIZER

GATEWAY

MUX/ DEMUX

SEGMENT 5

FRAMES and PACKETS

or

CONVENTIONAL COMMAND and TELEMETRY FRAMES

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Other Global Issues

SPACE
STATION
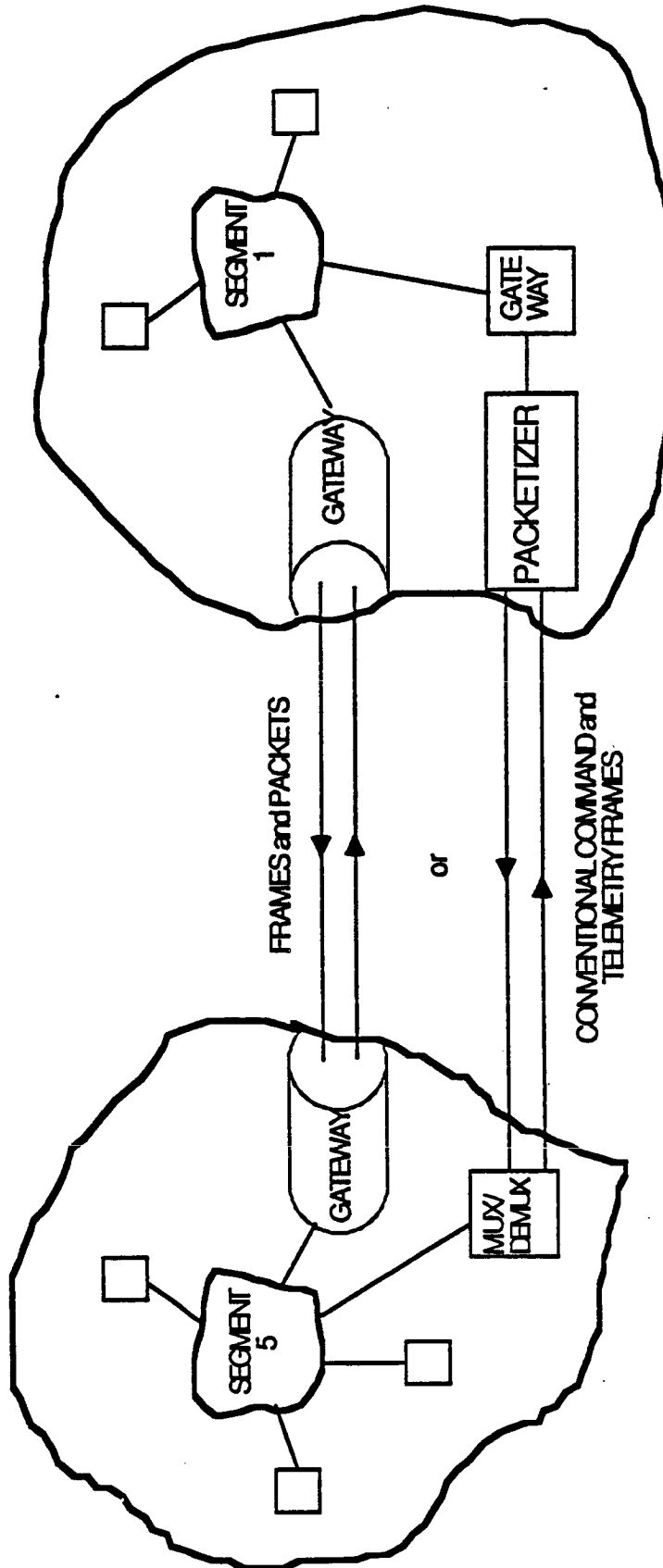
CCSDS Data Delivery Grades

- Grade I - C, EF, IS ,WD
- Grade II - EF, IS ,WD
- Grade III - IS ,WD
- Grade IV

Characteristics:

- Complete (C)
- Error Free (EF)
- In Sequence (IS)
- Without Duplicates (WD)

- Does not appear to allow users capability to get complete data which may have errors. i.e. C, IS, WD.

- There may be more or different characteristics which need to be used to define Data Delivery Grades

Data Delivery Grades

?

Characteristics:

- Error Correction
  - Completeness
  - Bit Error Correction
- Priority
- Encryption
- Blocking
  - Sequencing
  - Duplicate Removal
  - Separation into Data Set
- Deferment Capability
- Short Term Storage
- Error Accounting
- Pre-Delivery Sampling

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Other Global Issues (cont'd)

- BACK-UP SYSTEM FOR SPACE STATION COMMAND AND CONTROL NOT SELECTED (IF CSOC/AFSCF IS SELECTED, WHAT PROBLEMS MUST BE ADDRESSED?)

- IS CCSDS DRIVEN BY CURRENT TECHNOLOGY

  - ARE PACKET SIZES ADEQUATE FOR HIGH RATE PAYLOAD DATA?

  - DOES PACKET CONCEPT SUPPORT TELEPRESENCE IN SPACE?

  - WHAT NEW TECHNOLOGY IS EXPECTED?

  - HOW WILL NEW TECHNOLOGY IMPACT CCSDS?

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APPENDIX II: MDAC PRESENTATION

NASA CCSDS REVIEW
AGENDA

1. OVERVIEW OF SSIS DR-02   TERRY LANDEN (MDAC)

2. OVERVIEW OF C&T DR-02   B. MAURER (RCA)

3. DR-02 C&T UPDATE   B. MAURER (RCA)

4. "GREEN BOOK" ISSUES   E. CLELLAND (MDAC)

Physical Application of NASA and Commercial Standards

Telemetry End-To-End Formats

Source Packet

- Created at Source
- Variable Length
- Ancillary Data Included By Payload

ISO/NSI LAN Transport Format / Source Packet

- DMS Transport Service Via Network & NIU
- Segmentation of Source Packets Into Fixed-Length Frames is DMS Service C for Packets Exceeding Frame Length

C&T Gateway

CCSDS Frame Format / Source Packet

- ISO/OSI LAN Format Removed at C&T Gateway
- C&T Adds CCSDS Frames for Space/Ground Transport
- Source Packets Merged Into Frames by C&T (For Packets Less Than Frame Length)
- R-S Encoding Optional Service
- Virtual Channel Concentrator per High Rate Serial Stream per S/G Transport Via TDRSS

Space | Ground

DIF/NGT

NASCOM Format / CCSDS Frame Format / Source Packet

- CCSDS Frames Split Into Virtual Channels by Dif
- R-S Decoding CCSDS Frame
- Routing to NASA Centers Based on Virtual Channel Assignment and S/C ID Over NASCOM

A Typical NASA Center

ISO/OSI LAN Format / Source Packet

- Intracenter Transport

802.X, etc. → **Local Users**

ISO/OSI WAN Format / Source Packet

- Remote User Transport (Public Networks, etc.)

X.25, etc. → **Remote Users**

NASCOM IPSCN Format / Source Packet

- Intercenter Transport

NISDN, PSCN, etc. → **Users At Other NASA Centers**

Other / Source Packet

- Non-ISO/OSI User Gateways

TBD → **Other Users**

- International
- Non-ISO/OSI Conforming Users
- Non Electronic
- Others

Destination

Breakdown Of Virtual Channels

GSFC

LeRC

JPL

MSFC

JSC

International community

DIF

SN

Channel labels (to GSFC):

- COP/POP/SS HDR playback P/L science data (TBD channels)
- SS payload video *
- SS P/L engr data
- SS playback science data
- SS LDR payback P/L science data
- SS LDR playback P/L science data
- SS LDR P/L engr data
- COP P/L engr data
- COP playback P/L engr data
- COP LDR P/L science data
- COP LDR playback P/L science data
- POP P/L engr data
- POP playback P/L engr data
- POP LDR P/L science data
- POP LDR playback P/L science data
- COP/POP/SS HDR P/L science data *
- COP/POP/SS HDR playback science data
- COP core realtime data
- COP core playback data
- COP core video
- COP core real-time data
- POP core playback data
- POP core video
- SS payload video (TBD channels)
- COP/POP/SS P/L engr data *

Other labels:

- COP/POP/SS HDR P/L science data *
- COP/POP/SS HDR playback P/L science data
- COP/POP/SS playback P/L science data *
- COP/POP/SS P/L engr data *
- COP/POP/SS P/L engr data *

- COP/POP/SS playback P/L science data *
- COP/POP/SS HPR P/L science data *
- COP/POP/SS HDR playback P/L science data *
- SS payload video (TBD channels)

- Payload video (TBD channels)
- Japanese exp module data *
- European modules/platforms *
- Canadian data *

- SS core video (6-8 virtual channels)
- SS core RT data
- SS core playback data

* TBD virtual channels

RGA
Communication
and Information
Systems Division

BASEBAND PROCESSING

0 GENERAL

    0 CONSTRUCT AND MANAGE PROTOCOLS AND DATA FORMATS FOR ALL DATA
       COMMUNICATION SOURCES AND SINKS

    0 MUX/DEMUX DISPARATE INFORMATION TYPES ON ALL EXTERNAL COMMUNICATION
       LINKS (TDRSS, S-BAND, MULTIPLE ACCESS)

    0 SWITCH/RELAY INFORMATION BETWEEN SOURCES AND SINKS AS REQUIRED

    0 PROVIDE EXTERNAL COMMUNICATION LINK SERVICES TO ONBOARD SOURCES AND
       SINKS (AUDIO, VIDEO, DMS, PAYLOADS)

    0 COORDINATE LINK CONFIGURATIONS (VIA C&M PROCESSOR) WITH GROUND AND
       SPACE NETWORK ELEMENTS

ONBOARD/OFFBOARD DATA COMMUNICATIONS BLOCK DIAGRAM

WITH CORRESPONDING BASEBAND PROCESSOR INTERFACES

OFFBOARD
EXTERNAL
COMMUNICATIONS
LINK ELEMENTS

EVA/MMUs
COPs
OMVs
OTVs
FFs
MRMS
SSO
GSTDM
WSGT VIA TDRSS
NASCOM (et al)
GROUND NETWORK END-USERS

R F   L I N K S

ONBOARD
EXTERNAL
COMMUNICATIONS
LINK ELEMENTS

MA SYSTEM

(MRMS) S-BAND SYSTEM (SSO, GSTDM)

(SSA) SSA,KSA TDRSS SYSTEM (KSA)

BASEBAND
PROCESSING
ELEMENTS

DUAL
ABUNDANT
BASEBAND
PROCESSORS
(BBPs)

OUTBOUND

RELAY

INBOUND

INTERMEDIATE
DATA DISTRIBUTION
ELEMENTS

INTER-BUS BRIDGES

CORE BUSES
C&M BUSES
LDR PAYLOAD BUSES
AUDIO BUSES
VIDEO BUSES
A/D D/A
HDR PAYLOAD BUSES
ZOE MASS STORAGE

SPACE STATION
ONBOARD DATA
SOURCES AND SINKS

MPACS
OTHER CORE SYSTEM PROCESSORS
C&M PROCESSORS
C&T CONTROLLERS
PAYLOAD PROCESSORS
AUDIO TERMINALS
VIDEO MONITORS & CAMERAS
HDR PAYLOADS

il channels (according header concept every frame, vertical?

10-49

Baseband Processor Functional Topology
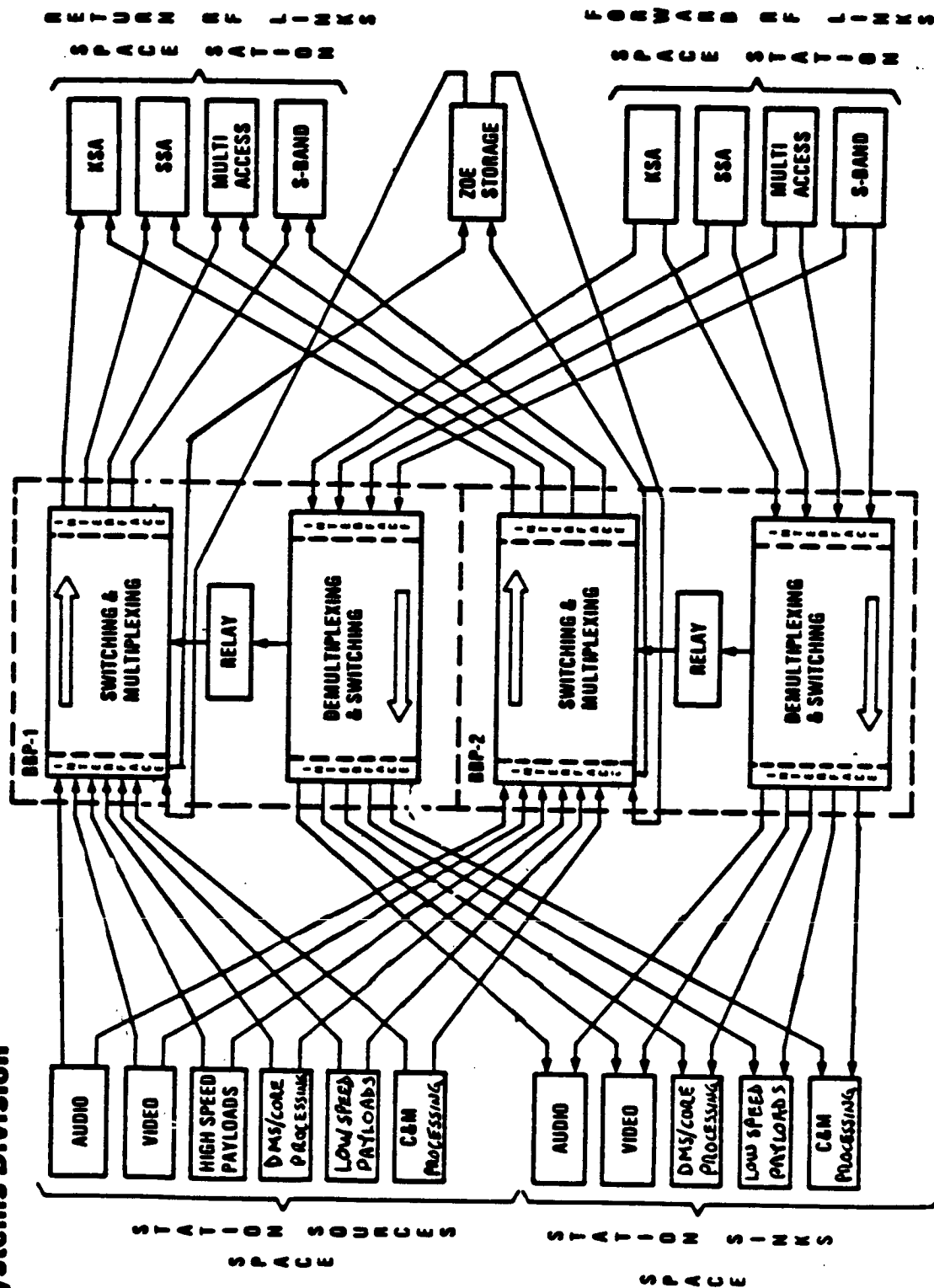
RCA

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and Information
Systems Division

KSA SSA MULTI ACCESS S-BAND ZOE STORAGE KSA SSA MULTI ACCESS S-BAND

SWITCHING & MULTIPLEXING RELAY DEMULTIPLEXING & SWITCHING SWITCHING & MULTIPLEXING RELAY DEMULTIPLEXING & SWITCHING

BBP-1 BBP-2

AUDIO VIDEO HIGH SPEED PAYLOADS DMS/CORE PROCESSING LOW SPEED PAYLOADS C&M PROCESSING AUDIO VIDEO DMS/CORE PROCESSING LOW SPEED PAYLOADS C&M PROCESSING

Adaptive multiplexing

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BASEBAND PROCESSING

0   DATA LINK SERVICES

   0   TWO DATA FORMAT CLASSES SUPPORTED

       -   FORMATTED DATA   -   BIT STREAM DATA

   0   TWO QUALITIES OF SERVICE SUPPORTED

       -   RETRANSMIT DATA ON ERROR

       -   NO RETRANSMISSION OF DATA

   0   MINIMAL DELAY OF AUDIO/REAL-TIME INSERT DATA

   0   MULTIPLE VIRTUAL CHANNELS PER LINK

   0   RESPOND TO MULTIPLE PRIORITY LEVELS

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PROTOCOLS AND DATA FORMATS

0 APPLICABILITY OF CCSDS PROTOCOL STANDARDS

   o CAPTURE EXTENSIVE STANDARDIZATION EFFORTS OF CCSDS

   o BBP IMPLEMENTS TRANSFER LAYER OF CCSDS PROTOCOL MODEL

      - MODIFIED CCSDS TELEMETRY TRANSFER FRAME FORMAT USED
         BI-DIRECTIONALLY ON SPACE LINKS

      - STANDARDS MUST BE UPGRADED TO EFFECTIVELY SUPPORT SPACE
         STATION COMMUNICATIONS

   o PROTOCOL/FORMAT CONVERSIONS REQUIRED TO MAINTAIN COMPATIBILITY WITH
      EXISTING SYSTEMS

      - SS - SSO   (VOICE CMD/TLM)

      - SS - GSTDN (VOICE CMD/TLM)
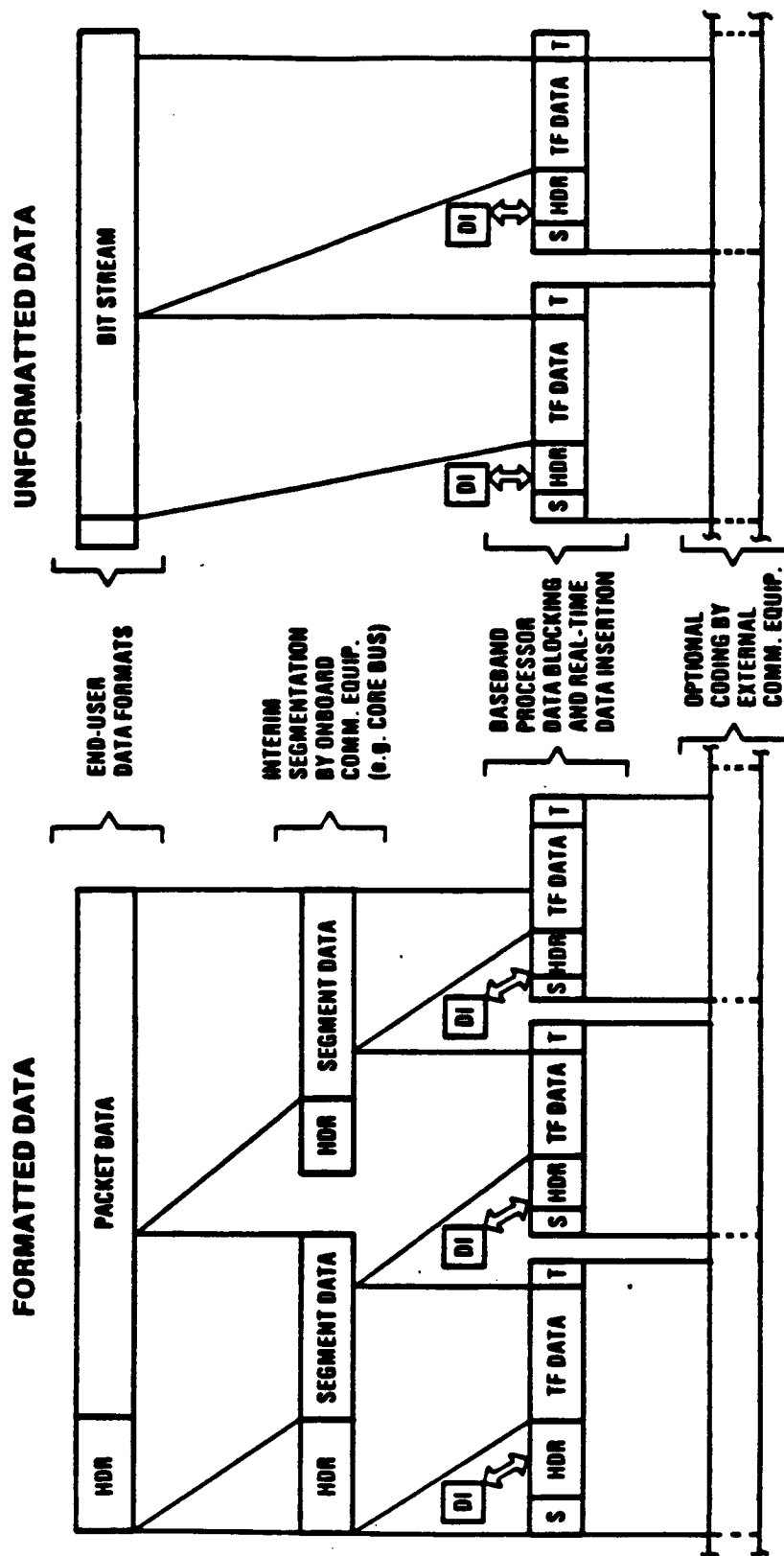
Data Encapsulation

UNFORMATTED DATA

BIT STREAM

S HDR TF DATA T

S HDR TF DATA T

DI

FORMATTED DATA

END-USER DATA FORMATS

INTERIM SEGMENTATION BY ONBOARD COMM. EQUIP. (e.g. CORE BUS)

BASEBAND PROCESSOR DATA BLOCKING AND REAL-TIME DATA INSERTION

OPTIONAL CODING BY EXTERNAL COMM. EQUIP.

HDR PACKET DATA

HDR SEGMENT DATA

HDR SEGMENT DATA

S HDR TF DATA T

S HDR TF DATA T

S HDR TF DATA T

DI

DI

DI

Candidate Transfer Frame Format
With Optional FEC CODING

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ORIGINAL PAGE IS
OF POOR QUALITY

10-54
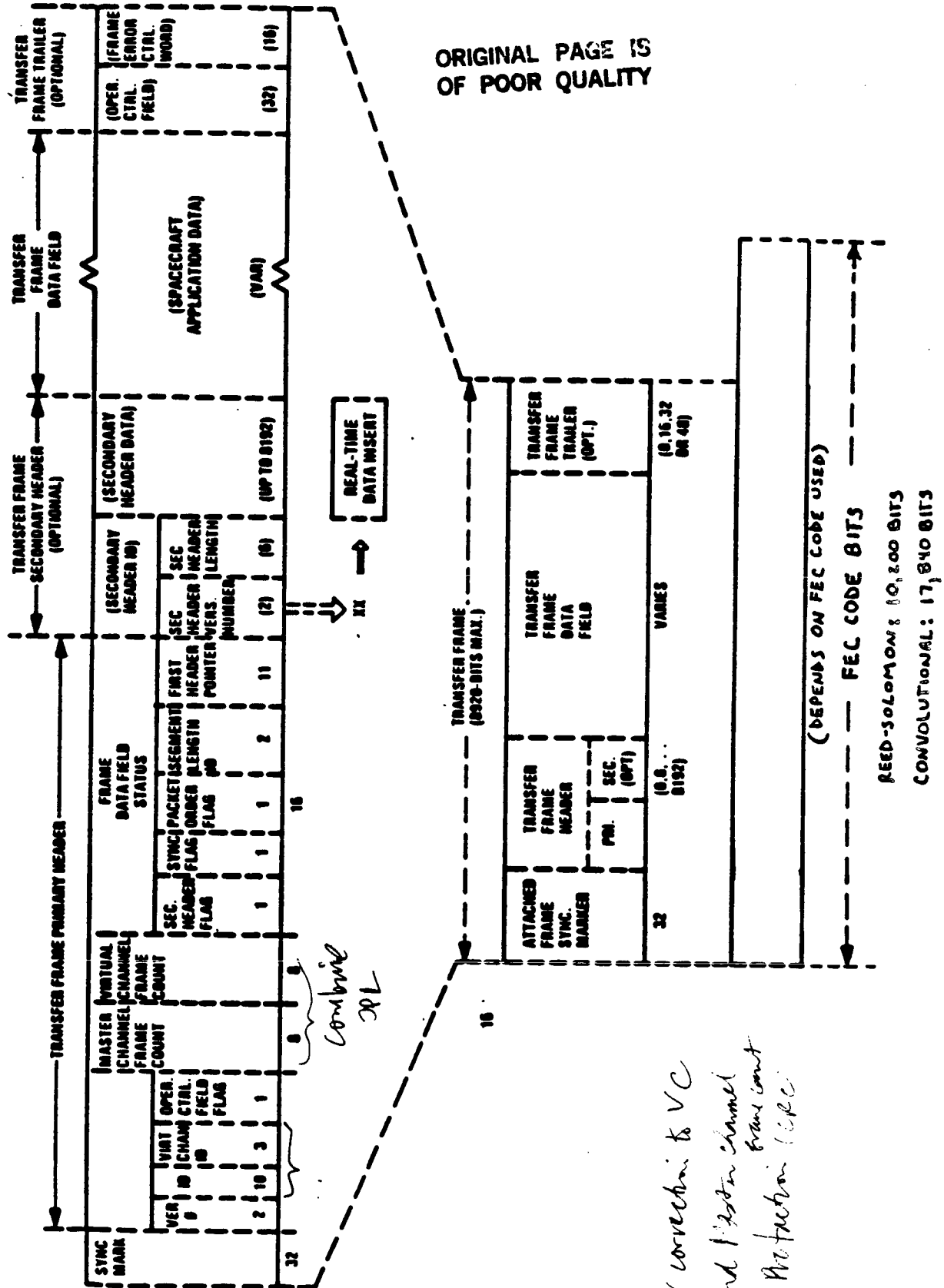
CANDIDATE VERSIC. "01" SECONDARY HEADER FORMAT

TRANSFER FRAME
(FIXED SIZE, 8920 bits)

FRAME SYNC. MARKER	TRANSFER FRAME HEADER		TRANSFER FRAME DATA FIELD	TRANSFER FRAME TRAILER (opt.)	
	PRI. HDR	SEC. HDR		OPEN.	FR. ERROR CTRL. FIELD CTRL. WD.
32	48	(0,8,.. ..,8192)	(VARIES)	(0,32)	(0,16)

(N) OCTETS

2 OCTETS			(K) OCTETS			(N-K) OCTETS
SEC. HDR. VER. #	DIZ FLAG	(RSVD) (ALL'0)	SEC. HDR. LENGTH	DIZ TYPE #	(RSVD) (ALL'0)	DIZ LENGTH	DIZ DATA FIELD	SEC. HDR. DATA FIELD
"01"			(N-1)	#		(K-1)		
2	1	3	10	4	2	10	8*(K-1)	8*(N-K)

⤷ define channel ~ 10

NOTES: 1) SEC. HDR. VER. # = "01"; DIZ FLAG = "1" (FORMAT # CASE SHOWN)

2) DIZ DENOTES: DATA INSERT ZONE

3) STRUCTURE OF DIZ DATA FIELD DEPENDS ON DIZ TYPE #

4) POSITION OF INFORMATION UP TO AND INCLUDING THE DIZ DATA FIELD IS FIXED RELATIVE TO THE FIRST BIT OF THE TRANSFER FRAME

Data Flow Diagram

APPLICABILITY OF CCSDS STANDARDS
TO THE SPACE STATION

RECOMMENDATION FROM THE "GREEN BOOK"

MDAC TEAM POSITION

1. EXPAND & STANDARDIZE SOURCE PACKET SECONDARY
HEADER TO INCLUDE:
   ○ DESTINATION ID
   ○ TIME CODE FORMAT
   (SECTION 3.2.4.1)

CONCUR - SUPPORTS DATA AUTONOMY, SHOULD BE
COMPATIBLE WITH END-TO-END ROUTING SERVICES

2. USE OF SYMMETRICAL & BI-DIRECTIONAL TELEMETRY
SOURCE PACKETS
(SECTION 3.2.4.2)

CONCUR - IMPLEMENTED IN LEVEL A STUDY &
REFLECTED IN DR-02

3. EXPAND & STANDARDIZE TRANSFER FRAME
SECONDARY HEADER TO INCLUDE:
   ○ HIGH SPEED DATA ROUTING
   ○ EXPAND VIRTUAL CHANNEL FIELD
   ○ EXPAND SEQUENCE COUNT
   ○ ADD HEADER ERROR PROTECTION
   ○ "COP" RETRANSMISSION PROTOCOL
   (SECTIONS 3.2.4.2 & 3.2.4.3)

CONCUR - "COP" IMPLEMENTATION & EXPANDED VIRTUAL
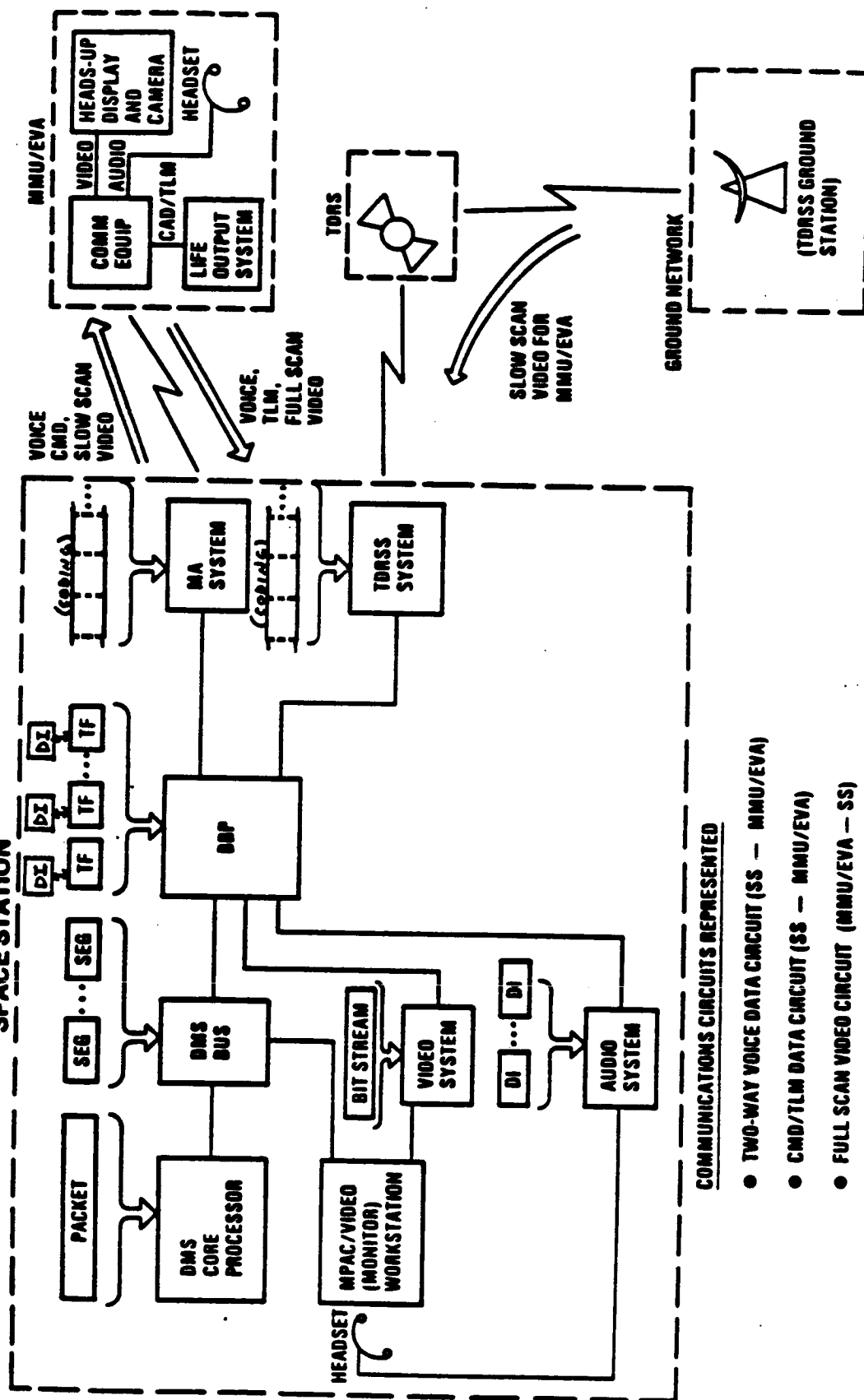CHANNEL ID FIELDS REFLECTED IN DR-02. PREFER
HEADER CONSOLIDATION/REDESIGN.

4. ADDITION OF "STATUS INSERT ZONE" FOLLOWING
TRANSFER FRAME SECONDARY HEADER FOR
SYNCHRONOUS DATA
(SECTION 3.2.4.4)

PROPOSED NEW SECONDARY HEADER DATA STRUCTURE
EFFICIENTLY SUPPORTS REAL TIME DATA INSERT.

5. ELIMINATION OF CONVOLUTIONAL CODING
(SECTION 3.2.4.3)

CONCUR FOR TDRSS Ku-BAND AND NEED REED-SOLOMON
IMPLEMENTATION SUPPORT RATIONALE. CONVOLUTIONAL
CODING STILL BEING CONSIDERED FOR SPECIFIC
APPLICATIONS.

APPLICABILITY OF CCSDS STANDARDS
TO THE SPACE STATION

RECOMMENDATION FROM THE "GREEN BOOK"	MDAC TEAM POSITION
6. "DETERMINISTIC" MULTIPLEXING EVOLVING INTO "ADAPTIVE" MULTIPLEXING (SECTION 3.2.4.4)	BASELINE ASSUMES USE OF ADAPTIVE MULTIPLEXING.
7. REDUCTION OF CODE BLOCK FROM 10,200 TO ~~10,800~~ BITS (SECTION 3.2.4.4) *10,080*	CONCUR - GOOD IDEA FOR 32-BIT PARALLEL PROCESSING
8. USE OF VIRTUAL CHANNELS FOR SIMPLIFYING PROCESSING OF HIGH DATA RATE BIT STREAMS (SECTION 3.2.4.4)	CONCUR - REFLECTED IN DR-02 & USED EXTENSIVELY
9. DATA ENCRYPTION SUPPORTING SOURCE PACKET, HEADERS MUST REMAIN IN THE CLEAR FOR ROUTING THROUGH SYSTEM (SECTION 3.2.4.5)	CONCUR - REFLECTED IN DR-02
10. AUTHENTICATION FIELD ATTACHED TO THE USER DATA IN PACKET OR FRAME (SECTION 3.2.4.5)	CONCUR - SUPPORTS DATA AUTONOMY, SHOULD BE COMPATIBLE WITH END-TO-END ROUTING SERVICES
11. SFDU STRUCTURE APPLIED AT APPLICATION PROCESS LAYER TO SUPPORT GENERAL DATA/COMMAND TRANSFER (SECTION 3.2.4)	SFDU ACKNOWLEDGED IN DR-02 - SUPPORTS DATA AUTONOMY.
12. GRADES OF DATA DELIVERY SERVICE (SECTION 3.2.2)	CONCUR - "COP" PROCEDURES ARE REQUIRED & EFFECTIVELY IMPLEMENTED IN DR-02. SUGGEST EXAMINE EXISTING DATA LINK STANDARDS (E.G., 802.2, SDLC, HDLC)

APPENDIX 11. COMMENTS ON PROPOSED TESTS OF RCA EVA RADIO BREADBOARD

The following provides comments on the proposed EVA radio breadboard tests. As an overall comment it appears that the plan is very ambitious; it appears that little thought has been given to the amount of time required to perform, analyze and draw conclusions from the test data.

Comments on Section 2.1 Transmitter

1. The phase-frequency response should be measured such that the signal group delay can be determined. An alternate approach is to measure the group delay.

2. How does EE-3 (or EE-7) plan to measure BER without a modem? The scope cannot be used to obtain carrier phase sync nor bit sync.

3. Forward/Return Interference measurement probably has no meaning unless the adjacent channels modulations are present. (Place minimum priority on this measurement.)

4. Power Amplifier Linearity. Need to measure AM/AM and AM/PM conversion vs backoff.

5. How is C/N_0 to be measured by EE-3? ESTL can measure this; however, what does it mean when no modem is used for BER tests? Suggest EE-3 alleviate this test.

6. The noise figure should be associated with the receiver and not the transmitter.

7. A phase noise measurement would be more significant than the frequency stability test; in fact, the equipment list does not contain the equipment necessary to measure stability. The phase noise measurement was discussed via the telephone.

Comments on Section 2.2 - Receiver

1. Phase-Frequency response should be measured; see comment 1 on transmitter section.

2. System Gain is ill-defined. Needs clarifying.

3. The noise figure is probably difficult to measure for EE-3.

4. Same as comment 2 regarding the transmitter.

5. See comment 3 above regarding Forward/Return Interference.

6. As before the BER measurement will require a QPSK modem with a 70 MHz IF.

7. Desensitization is not a term which LinCom understands.

8. The phase noise spectrum on the 70 MHz IF should be measured.

9. Measure the bandpass characteristics of the IF so that it can be incorporated into the SCSS simulation.

10. Acquisition tests will require a modem and will have to be made in the ESTL; I recommend using SLA.

Comments on 2.3 Component/Subsystems

1. To test components will require getting "into the box with a soldering iron." Chances are, the box will perform differently when reconnected and sent to ESTL, etc.

Comments on Figure 1

1. The HP 8672-3 frequency synthesizer provides for signal source frequencies greater than 2 GHz!

2. When making PSD measurements connect the spectrum analyzer to the 70 MHz IF Input as well as the EVA radio output.

3. The SD 6057 frequency counter will give a nonsense output unless no modulation is present.

4. The test frequencies need defining.

5. To do loop back tests requires frequency converters. Where are these in the equipment list?

Comments on 3.1.11

A different test equipment configuration is required to measure frequency stability.

APPENDIX 12.   EE2 REMOTE SIGNAL PROCESSING (RSP) MULTIPLEXER

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SUMMARY

The purpose of this appendix is to comment on Brett Parish's memo entitled "Preliminary Status of Signal Processing Development for the TCD Baseband Test Bed". The emphasis here is on system level issues. Specific technical comments have already been discussed with Brett over the phone.

1. Enhanced Capability over the Last Version

In addition to the previously available selected frame rate video, the present version has incorporated the following capabilities:

   o Accommodate low data rate users

   o Provide an high fidelity audio channel

   o Accommodate asynchronous video/graphics

   o Provide a low to very low rate "status" channel.

To provide for these capabilities, the current frame format has provisions for both a synchronous video mode and a non-video mode. The synchronous video mode accommodates both the selected frame rate video and asynchronous data, whereas the non-video mode also uses the selected frame rate video portion of the frame for asynchronous packetized data. Because of this video-bypass feature, the RSP multiplexer acts as a re-clocking device for a stream of asynchronous data. At the output of the multiplexer the data stream becomes synchronous, with a clock rate related to the TV frame rate.

2. CCSDS issues

Since the RSP multiplexer can handle asynchronous data without modifying its content, the non-video mode is compatible with the CCSDS when the CCSDS

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format are used as an outer shell. The burden of formatting the async data now falls onto the data source.

It appears that the driver for developing the RSP multiplexer frame format for selected frame rate video is to ensure that the video data clock is "synchronous" with the TV frame rate clock. By synchronous we mean that the two clock frequencies are related by an integer multiple and that they are derived from the same source. Hence, the TV frame clock can be reconstructed from the data clock; each picture frame will contain exactly N data bits. The advantage is, of course, that there will not be a need for a mammoth data buffer on the receiving side (TV viewing side) to smooth out the realtime TV picture frames to eliminate motion jerkiness. The buffering requirement hence reduces to a simple buffer for only one or two TV frames. And provided that the correct frame sync has been established, the job of the receiving multiplexer is to simply display the content of the TV picture frame buffer at the recovered frame rate (which can be derived from the receiver bit sync). The transmission channel only adds a channel delay.

For the sake of argument, then, as long as the CCSDS frame rate is also "synchronous" with the TV frame rate, the aforementioned reduction in hardware complexity can also be achieved if a TV picture frame (or a fraction thereof) can fit into a CCSDS frame. Of course, the communication channel must be able to support the higher data rate due to the higher CCSDS overhead. One would also need an additional CCSDS buffer. The point is that the CCSDS is only a data standard - it does not specify how the frame rate is determined. One therefore cannot effectively argue that there is any significant incompatibility between CCSDS and the RSP multiplexer format regarding to the frame structure. It appears that this requirement for TV frame "synchronism" with the

CCSDS frame rate is the key issue to be resolved with the CCSDS people, rather than the exact format of how to provide a means of identifying data source and data sink which they seem to be preoccupied with.

3. Audio Delay

Since the high fidelity audio channel is only intended to be used with high rate TV, the buffer delay should not be significant as the audio channel data is inserted at every TV picture line after the TV picture frame has been buffered. On the other hand, since the asynchronous data is gated at the very final stage of the multiplexer output, there should not be any delay due to the RSP multiplexer for asynchronous packetized audio.

APPENDIX 13.   COMENTS ON RCA HIGH SPEED COMMUNICATIONS/DISTRIBUTION

NETWORK ADVANCED DEVELOPMENT BREADBOARD TESTING

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SUMMARY

Since we are not too familiar with the RCA FOLAN breadboard, we have had difficulty understanding and interpreting the objectives and the approach to the ESTL Test Plan. In order to more fully understand the Test Plan and to provide more valid comments, a more complete description of the FOLAN breadboard as well as functional block diagrams depicting the tests are required.

It appears that the ESTL test is basically an RCA demonstration of the FOLAN breadboard with some help from ESTL personnel.

1. Test Plan

1.1 General Comments

The test plan described in the ESTL document requires additional clarifications: the definitions of some of the parameters to be measured are unclear; a lot of the test instruments to be used are either not shown, e.g., in transmitter startup time measurement, or not specified, e.g., the 200 BPS (or 200 MBPS?) generator to be used in % modulation; the expected performance, e.g., the accuracy of the testing results, are not given; and the test procedures are not well explained. Before a more complete assessment can be made on the test plan, we need to have a document which renders a clear overview and provides enough information for each specific test:

- Test objective

- Parameter to be measured

- Test plan

- Test configuration and functional block diagrams

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o Instruments used (model #, manufacturer)

o Accuracy (Error analysis)

Furthermore, there are a few parameters which are important in helping us understand the system performance and they are not mentioned in the current test plan. They are: signal to noise ratio (S/N) at the O/E converter output, optical power stability (see Section 1.2.2), extinction ratio of the optical signal (see Section 1.2.3), signal quality measurements (data rise time, asymmetry, etc.), communication timing measurements (mean clock rate, rms jitter, & differential propagation delay), temperature tests (S/N versus temperature ... etc.), and the star coupler's variability test (see Section 1.2.9).

1.2 Review of the Current Test Plan

The test plan will be reviewed in the same order as in pp.2-3 to pp. 2-7 of the ESTL document.

1.2.1 System Setup

The functional data flow verification procedure is not shown.

1.2.2 Output Power

The power level measurement approach is clear. We would also like to have a power stability measure (amplitude jitter) which will serve as a performance degradation estimator.

1.2.3 % modulation

The definition is not given. The equipments are described but not the

measurement procedure. Unlike the conventional amplitude modulation the modulated optical signal power can not reach zero, hence an appropriate definition is the ratio of half the difference between the maximum and minimum power levels to the average power level of an intensity modulated wave. The extinction ratio, which is defined as the ratio of the minimum power level to the maximum one, can also be measured simultaneously. In fact, the average power level has already been obtained in 1.2.2 and moreover, the extinction ratio is a more widely used parameter in optical links.

1.2.4 Transmitter Startup Time

The definition is not given neither are the test configuration (say, the location of the receiver photo-diode has to be defined) and equipments.

1.2.5 Receiver Startup Time

Since the output of the APD is an electrical signal the difference between the APD output and the O/E output is not clear. The latter may refer to the input of the threshold detection circuitry or the output of the high speed comparator (see Fig. A-2 in the ESTL document). Also, the definition of this parameter and the location of the valid data indicator are not provided.

1.2.6 APD Voltage

Since no definition is given we do not know whether it is different from the APD dynamic range.

1.2.7 RF Path Calibration

The receiver current and power measuring point should be shown.

1.2.8 Star Coupler Insertion Loss

The input and output measuring points are not defined. A star coupler will normally have some variation in the power splitting ratio between a given pair of input and output. This variability should also be considered as a loss factor and be measured.

1.2.9 Static Dynamic Range

The definition of the upper dynamic range is ambiguous. It appears to require a destructive test. Besides, the location of the token valid indicator is not shown.

1.2.10 Intermessage Dynamic Range

Besides the problems mentioned in 1.2.9 it is not clear where and how the ability of the receiver to properly interpret strong then weak package will be determined.

1.2.11 Network Bandwidth

According to the test description, this parameter seems to refer to the difference between the highest and the lowest data rates that the token validator can be useful. Obviously, the test result will depend on the signal power, the system temperature, and bandwidths of the fiber, the APD, the pre-amplifier, and the post-amplifier. The fiber and the APD bandwidths can be found from manufacturers' specifications, the amplifiers' bandwidths, on the other hand, are designer's choices. It is necessary to have these values in advance so that comparisons can be made.

1.2.12 BER

A S/N measurement at the comparator's output (Fig. A-2) should be conducted at the same time. BER-versus-S/N is a more common test than BER-versus-attenuation.

1.2.13 TV & Voice Quality

The relationship between the BER or bit error per frame and the quality rating should be established.

1.2.14 Eye Patterns

This test is clearly explained. A test configuration, combined with that of 1.2.12, would be helpful.

1.2.15 Node Latency

The given definition is not clear.

1.2.16 Network Latency

We do not know, according to the description given in the ESTL document, how this test is to be carried out and how this parameter is to be related to network throughput.

2. Network Architecture

The laser stabilization problem associated with burst communications was discussed and so was the temperature control technique. However, probably because of space limitation some technical problems remain unaddressed. Among them, we would like to see the answers to the following problems.

(1) What is optical frequency being used?

(2) What is the token-passing rule of this distribution network?

(3) What is the packet format?

(4) What is the overhead percentage of a packet?

(5) How does the receiver recovers the clock at such a high data rate?

(6) Will it be more cost-effective, at 200 Mbit/s, to use other alternative networks?

(7) A typical link budget, including all transmit and coupling losses, to show how the available system gain is distributed to obtain a error rate of 10^{-10} is recommended.

(8) What is the expected throughput of the system?

(9) What is the mean information rate being carried over the network, compared to the maximum rate the links can support?

(10) What are the expected node and network latencies?

(11) Can the complexity of the interface electronics be traded against other options?

(12) How are the system's expandability and rearrangeability? How many terminals can the system handle? How difficult is it to add or remove input or output terminals?

(13) How are the system's vulnerability, reliability, and maintainability?

(14) What is the data format, NRZ or bi-phase?

(15) How to validate token and data?

(16) How do the laser stabilization and temperature control circuitries work?

Items (3) - (6) are related. The main concern is on (4) because the clock must be recovered before data can be decoded. Due to the lack of a central clock or a clock distribution scheme, the data are bursty & asynchronous in nature. Thus, the beginning of each packet must have a header

sequence of bits that allows the receiver clock to align itself with the incoming one. For a noncoherent (optical) system the length in bits of the header sequence is a function of data rate and S/N. In order to operate at 200 Mbit/s the package overhead may exceed 20%, which then lead to the question (5). Questions (8) - (11) were asked to assess the network economical and technical efficiencies. Finally, Manchester or bi-phase data are preferred due to the following reasons:

1) Clock recovery is easier.

2) Manchester code provides easy bit validation check. The states of the first and the second half of a Manchester bit are always different, unless an error is made. In effect, Manchester code provides an odd parity check on every bit.

3) The optimal threshold is always zero, independent of signal to noise ratio, hence a large variation in the peak signal power can be tolerated and the requirements on AGC design are less severe.

4) Because of the regularity of data format, the Manchester data can be used to stabilize the laser average power output.

c-4

APPENDIX 14. ESTL AUTOMATION STUDY

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ACKNOWLEDGEMENT

Portions of the material presented in this report are based upon discussions with and inputs provided by the following JSC/ESTL personnel: Jack Stoker, Bobby Vermillion, B. G. Smith, and Linda Bromley.

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EXECUTIVE SUMMARY

INTRODUCTION

The purpose of this final report is to document LinCom's study of ESTL (Electronics Systems Test Laboratory) automation. This final report is organized into two parts and three appendices. The first part of the report is an introductory overview of the ESTL including both its present status and its future use for the Space Station Communications and Tracking System Test Bed. The second part of the report addresses the specific issues concerning the specific issues concerning ESTL automation. Appendix I gives a more detailed example of how expert system techniques can be applied to ESTL automation; appendices II and III are inputs provided by ESTL personnel regarding automation.

WHY AUTOMATE?

The reasons for automating the ESTL are diverse. From a programmatic viewpoint, at least five are worthy of mention: (a) Space Shuttle/TDAS interface, (b) Space Station design efforts, (c) the Space Network 10 year plan, (d) the need to improve manpower efficiency and productivity, and (e) the advancement of knowledge engineering and automation.

In the future, as more users compete for ESTL facility resources, rapid test turn around will become a necessity. Furthermore, since operational tests will become more complex (e.g., by involving other resources such as the MCC and the TDRSS), test scheduling will prove to be correspondingly more difficult. Hence ESTL shuttle test performance must shuttle test performance must achieve the maximum possible efficiency. Fortunately, as the shuttle program matures, the types of tests to be performed at the ESTL will become

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more standardized, and therefore will be well-amenable to automation

As the scope of ESTL work expands to include Space Station communications tests, a myriad of new challenges will arise. With the ESTL work load increasing substantially, it is unlikely that there will not be a proportional increase in manpower support. The next generation Space Station hardware delivered by the Phase B and C/D contractors for system emulation and its associated test equipment will be implemented with computer-controlled control techniques. Since the diagnostics and maintenance required for facile space operation will require the wide use of internal, built-in test procedures, only a minimal number of conventional test points will be available. From this it follows that such future communications hardware only will be testable by means of standard data I/O interfaces. Hence any tests involving such devices probably will depend solely on their inputs and outputs. The increasing complexity of communication equipments will preclude traditional forms of manual operations. Adequately confronting these new difficulties will require the ESTL to computerize and to automate.

The United States Congress has taken a keen interest in how NASA will manage the Space Station Program. Driven by an awareness of the spectacular advances being made in electronics, computers, automation, robotics, knowledge engineering, and related fields, Congress is convinced that the Space Station program not only should incorporate these advances, but also should use this opportunity to stimulate national development. The importance of these goals is indicated by at least 10 percent of the total Space Station budget being dedicated to the development of systems which will advance automation and robotics technologies. Our proposal that many ESTL operations be automated by means of expert systems completely accords with these Congressional objectives.

Finally, automation will improve manpower efficiency and increase engineering productivity, thereby satisfying two long standing NASA concerns.

AUTOMATION GOAL

Figure 1 shows a conceptual block diagram of a fully automated ESTL. The test equipment and system modeling hardware of ESTL are connected to the ESTL VAX 11/785 computer through a local area network (LAN). The purpose of the network is to allow high speed data transfer (e.g. equipment setting parameters, test data, health and status, acknowledgement, etc.) between the VAX and the hardware pools. As an example, one can use DECNET (which accommodates the standard Ethernet as a subnet). Since the ESTL also communicates with other systems networks such as those of the MCC and the NASCOM, means for interconnecting with these additional networks also must be installed. DEC supplies a variety of software to program the network interface black-box (called a gateway) to support these links.

In this conceptual diagram, the ESTL equipment and hardware are grouped into pools, each pool served by either a subnet or a local area network. Figure 2 shows how a microprocessor can be used to interface within each pool of existing Shuttle-era hardware which may not be directly compatible with the LAN.

Test signals are routed to a central switch matrix pool where test setup configuration interconnections are made. The test equipment pool consists of standard laboratory equipments and gathers test data by tapping various points in the switch matrix of the test setup. The signal acquisition system is designed both to perform tests that cannot be adequately handled by standard test equipments and to serve as an I/O device for the VAX to monitor test status by means of observing signal points along the test setup.

FIGURE 1. AUTOMATED ESTL FUNCTIONAL BLOCK DIAGRAM
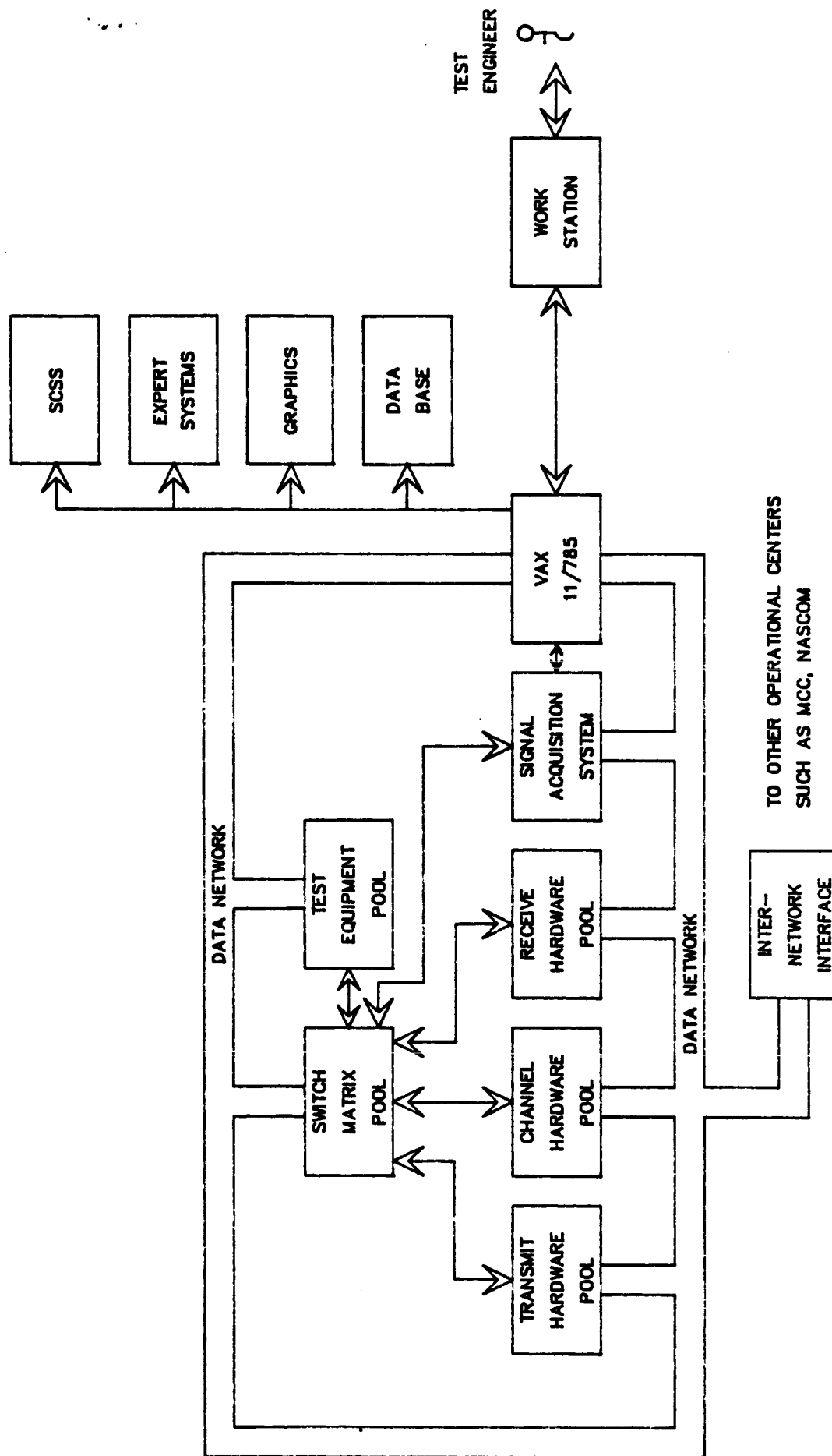
FIGURE 2. HARDWARE POOL INTERFACING WITH DATA NETWORK

NETWORK INTERFACE

ESTL
DATA
NETWORK
GATEWAY

NEW
HARDWARE

MICRO-
PROCESSOR
INTERFACE
CONTROLLER

EXISTING
"SMART"
HARDWARE

EXISTING
"DUMB"
HARDWARE
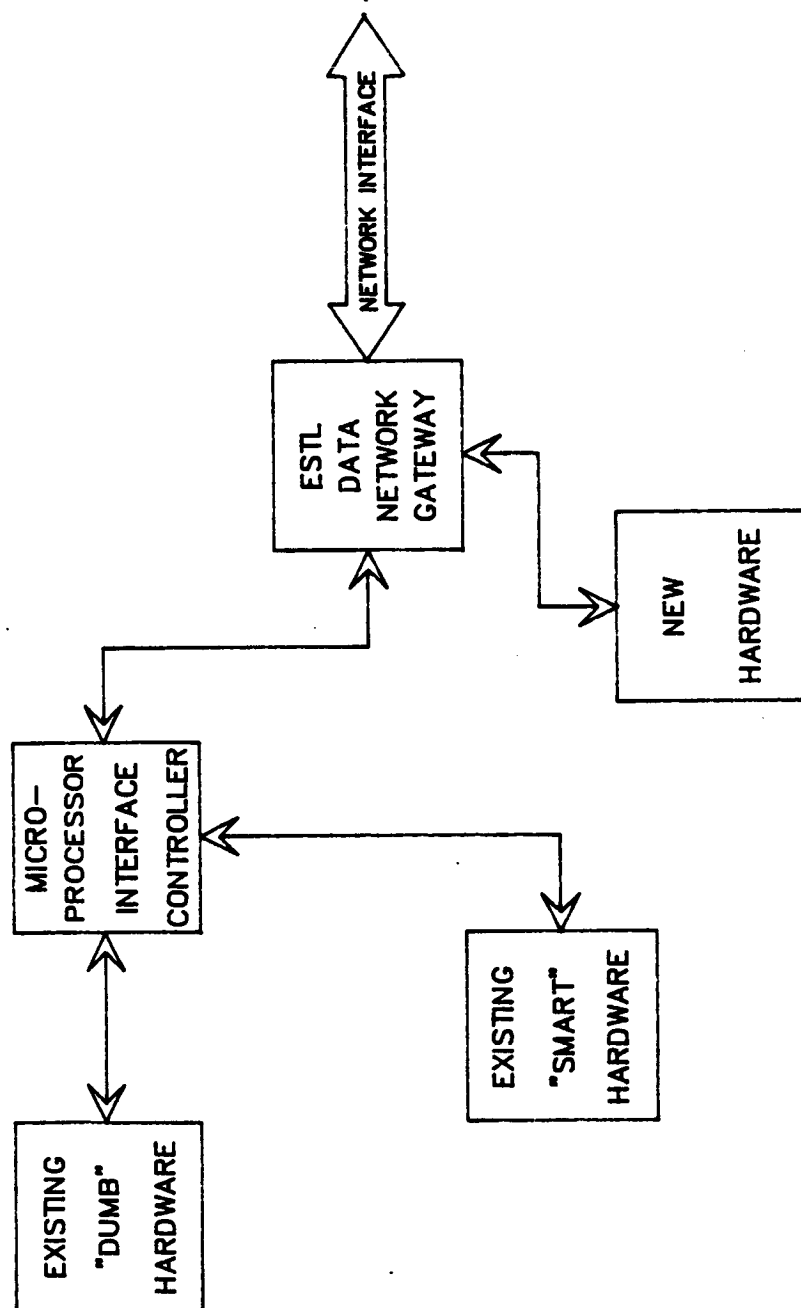
H = HARDWARE INTERFACE

D = DATA INTERFACE

Residing within the VAX are software packages required for automating the ESTL. The Space Station Communications Simulation System (SCSS), to be developed by the Systems Analysis Office, is used for test result production for Space Station tests. Various expert systems will be used to assist in test planning, test configuration, fault diagnosis, test control, and sequencing. Graphics software will provide a friendly user interface (e.g. multiple window applications), display test configurations and results. Finally, the data base software will be used to generate documentation and for archiving and retrieving test data.

Under the automated ESTL environment, the test engineer will be able either to assume complete test control via the selection of the appropriate options or to permit the expert systems to manage the test. Should the latter option be chosen, then, as the test proceeds, status report updates will be displayed on the work station and the test engineer will be permitted to assume control at any point. When test engineers themselves manage tests, they will be able to change the test setup or to alter the test sequence by directly controlling each piece of equipment via the work station. In this way the ability of ESTL personnel to operate equipment manually will be preserved, a capability that they regard as crucial.

WHAT TO AUTOMATE FIRST?

Any realistic answer to this question must depend upon the level of funding available. In general, one should start with efforts that are cost effective and that minimally impact the daily operation of ESTL. An example of such a project would be software development that increases the speed of any portion of the test process (including such tasks as test planning and documentation generation). By contrast, because it would require costly

hardware purchases and a disruptive installation, the automation of the switch matrix would not be a desirable initial automation effort.

RECOMMENDATIONS

For the near term, it is recommended (1) that a more detailed architecture of the automated ESTL be developed and (2) that a demonstration reflecting the advantages of this automated approach be made. The demonstration candidate can be one of the following: a data handling and verification system (updated RDAPS), a test planning advisor expert system, a test configuration advisor expert system, or an automated SNR calibration system. The cost associated with such an effort is estimated to be between a half to one man-year of effort.

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OF POOR QUALITY

ABBREVIATIONS AND ACRONYMS

AFSCF	AIR FORCE SATELLITE CONTROL FACILITY
C/CIM	COMMAND COMPUTER INTERFACE MULTIPLEXER
CATSGT	COMMUNICATION AND TRACKING SPACE TO GROUND TEST PANEL
CDIU	CONTROL DISPLAY INTERFACE UNIT
CSTE	COMMAND SPECIAL TEST EQUIPMENT
DESTE	DOPPLER EXTRACTOR SPECIAL TEST EQUIPMENT
DETE	DOPPLER EXTRACTOR TEST EQUIPMENT
DFI	DEVELOPMENT FLIGHT INSTRUMENTATION
DR	DISCREPANCY REPORT
ERDS	ESTL RANGE AND DOPPLER SIMULATOR
EVCS	EXTRAVEHICULAR COMMUNICATION SYSTEM
FMS	FORM MANAGEMENT SYSTEM
GPC	GENERAL PURPOSE COMPUTER
GSTDN	SPACEFLIGHT TRACKING DATA NETWORK GROUND STATION
I/F	INTERFACE
MBER	MESSAGE BIT ERROR RATE
MCC	MISSION CONTROL CENTER
MDM	MUX/DEMUX
MFR	MULTIFUNCTION RECEIVER MRR MESSAGE REJECTION RATE
MSFTP	MANNED SPACE FLIGHT TELEMETRY PROCESSOR
MVP	MASTER VERIFICATION PLAN
NOM	NETWORK OUTPUT MULTIPLEXER NSP NETWORK SIGNAL PROCESSOR
PDL	PERCENT DATA LOSS
PI	PAYLOAD INTERROGATOR
PICS	PAYLOAD INTERFACE CONTROL SYSTEM

PIP	PAYLOAD INTEGRATION PLAN
RCU	RF CONVERSION UNIT
RDAPS	REALTIME DATA ANALYSIS AND PREDICTION SYSTEM
SAIL	SHUTTLE AVIONICS INTEGRATION LABORATORY
SCE	SHUTTLE COMMAND ENCODER
SCEIB	SHUTTLE COMMAND ENCODER INTERFACE BUFFER
SCV	SHUTTLE COMMAND VOICE MUX/DEMUX
SIR	SYSTEM INTEGRATION REVIEW (PANEL)
SLS	SPACE LOSS SIMULATOR
SOP	STANDARD OPERATING PROCEDURE
STDN	SPACEFLIGHT TRACKING DATA NETWORK
STPP	STANDARD TEST PROCEDURE PREPARATION
TCC	ESTL COMMAND CONTROLLER
TICS	TDRSS INTERFACE CONTROL SYSTEM
TPS	TEST PREPARATION SHEET
TRAS	TEST REQUIREMENTS AND STATUS REPORTS
TRASD	TEST REQUIREMENTS AND STATUS DOCUMENT
TRP	TOTAL RECEIVED POWER
TRR	TEST READINESS REVIEW

ESTL AUTOMATION TASK REPORT OUTLINE

PART I: GENERAL

o ESTL OVERVIEW - CURRENT STATUS

o ESTL AS A SPACE STATION COMMUNICATION AND TRACKING TEST BED

o TESTING AT ESTL - PRESENT STATUS

PART II: AUTOMATION

o TESTING AT ESTL - IDEAL AUTOMATED APPROACH

o INTEGRATING AUTOMATION WITH ESTL FACILITY

o A TIME TABLE FOR AUTOMATION

o DEMONSTRATION CANDIDATES

o RECOMMENDATIONS

PART III: APPENDICES

1. TEST CONFIGURATION ADVISOR EXPERT SYSTEM

2. ESTL TEST AUTOMATION UPGRADE

3. SELECTED TEST CONFIGURATIONS

ESTL OVERVIEW

o PURPOSE

o SCOPE OF ESTL TESTS

o ESTL TEST CONCEPT

o MAJOR TEST PROGRAMS FOR SHUTTLE

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PURPOSE

o PROVIDES THE CAPABILITY TO CONDUCT DETAILED SPACECRAFT-TO-SPACECRAFT
   AND SPACECRAFT-TO-GROUND RF COMMUNICATION SYSTEM VERIFICATION/
   CERTIFICATION TESTS ON AN END-TO-END BASIS BY TESTING THESE SYSTEMS
   IN A LABORATORY ENVIRONMENT WHERE LINK PARAMETERS AND DATA FLOW CAN
   BE PRECISELY CONTROLLED

o PROVIDES A TEST BED FOR THE EVALUATION OF BOTH SYSTEM DESIGN CONCEPTS
   AND THE EFFECT OF SUBSYSTEM CHANGES ON SYSTEM PERFORMANCE

o PROVIDES A CAPABILITY FOR ACCURATE SIMULATION OF APPROPRIATE MISSION
   CONDITIONS FOR IN-FLIGHT PROBLEMS AND POST-MISSION ANOMALY RESOLUTION

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SCOPE OF ESTL TESTS

TDRS

TDRS
GROUND STATION

Ku-BAND

S-BAND

Ku-BAND

NASA PAYLOAD

S-BAND

EVA
UHF

S-BAND
PM UPLINK AND
DOWNLINK
FM DOWNLINK

UHF

STDN
GROUND STATION

S-BAND

DOD PAYLOAD

S-BAND
PM UPLINK AND
DOWNLINK
FM DOWNLINK

SCF
GROUND STATION

ESTL TEST CONCEPT

EVA

SHUTTLE

VHF FORWARD LINK

Ku-BAND RETURN LINK
VHF RETURN LINK

Ku-BAND FORWARD LINK
S-BAND RETURN LINK

S-BAND FORWARD LINK

ORBITER S-BAND FORWARD LINK

ORBITER S-BAND RETURN LINK

PAYLOAD

S-BAND FORWARD LINK

RELAY SATELLITE

Ku-BAND SPACE-GROUND LINK

STDN RELAY SATELLITE SITE

S-BAND FM DOWNLINK

S-BAND UPLINK

S-BAND UPLINK

S-BAND DOWNLINK

AFSCF SITE

STDN SITE

TEST CONCEPT

RELAY SATELLITE EQUIPMENT

STDN RELAY SATELLITE EQUIPMENT

SPACE LOSS SIMULATOR

STDN AND AFSCF SITE EQUIPMENT

CONTROL AND DATA COMPARISON SYSTEM

PAYLOAD OR EVA COMMUNICATIONS TEST SYSTEM

HARDWARE INTERFACE

SHUTTLE ORBITER COMMUNICATIONS TEST SYSTEM

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ESTL MAJOR TEST PROGRAMS FOR SHUTTLE

o SYSTEM DEVELOPMENT AND DESIGN EVALUATION TEST

o TASK 501 COMMUNICATIONS AND TRACKING SYSTEMS GROUND TESTING

   - SYSTEM VERIFICATION/CERTIFICATION TESTS

   - MISSION SUPPORT

o OPERATIONAL INTEGRATION AND SPECIAL TESTS

   - SAIL/ESTL JOINT TESTS

   - ORBITER KU-BAND ANTENNA ACQUISITION AND TRACKING TESTS

   - OPERATIONAL TDRS INTERFACE TESTS

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ESTL AS A SPACE STATION COMMUNICATIONS AND TRACKING TEST BED

o   APPROACH

o   TEST CONCEPT

o   PHASED (B, C/D) EFFORTS

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SPACE STATION ERA ESTL TEST CONCEPT

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TDRSS

K-BAND
SPACE-GROUND
LINK

TDRSS
GROUND TERMINAL

SYSTEM TEST BED

RELAY SATELLITE EQUIPMENT	TDRSS GROUND TERMINAL EQUIPMENT	GSTDN SITE EQUIPMENT

SPACE LOSS SIMULATOR

CONTROL AND DATA COMPARISON SYSTEM

SPACE STATION COMMUNICATIONS TEST SYSTEM	SHUTTLE ORBITER COMMUNICATION TEST SYSTEM	SPACE STATION EXTERNAL RF ELEMENTS

REFERENCE SIGNALS

Ku-BAND FORWARD AND RETURN LINKS

S-BAND FORWARD AND RETURN LINKS

Ku-BAND LINKS

OMV

PAYLOAD

ORBITER

S-BAND FM DOWNLINK

STDN SITE

PLATFORM & FREE FLYERS

EVA

OTV

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SPACE STATION ERA ESTL CONFIGURATION

ESTL TESTING SUPPORT FOR SPACE STATION PHASE B, C/D EFFORTS

o PHASE B

 - ENGINEERING DESIGN PROPOSAL (CONCEPT/TECHNIQUES) EVALUATION

 - BREADBOARD EVALUATION

o EARLY PHASE C/D

 - VENDOR ENGINEERING BREADBOARD INTERFACE COMPATIBILITY

o LATE PHASE C/D

 - VENDOR PROTOTYPE HARDWARE COMPATIBILITY AND PERFORMANCE

TESTING AT ESTL – CURRENT STATUS

o SYSTEM HARDWARE (E.G., GROUND STATIONS) MODELLING CAPABILITY

o SOFTWARE CAPABILITY

o CONTROL/CONFIGURATION CAPABILITY

o MEASUREMENT

o DOCUMENTATION

o TYPICAL TEST EXAMPLE (ROSAT)

ESTL Functional Block Diagram

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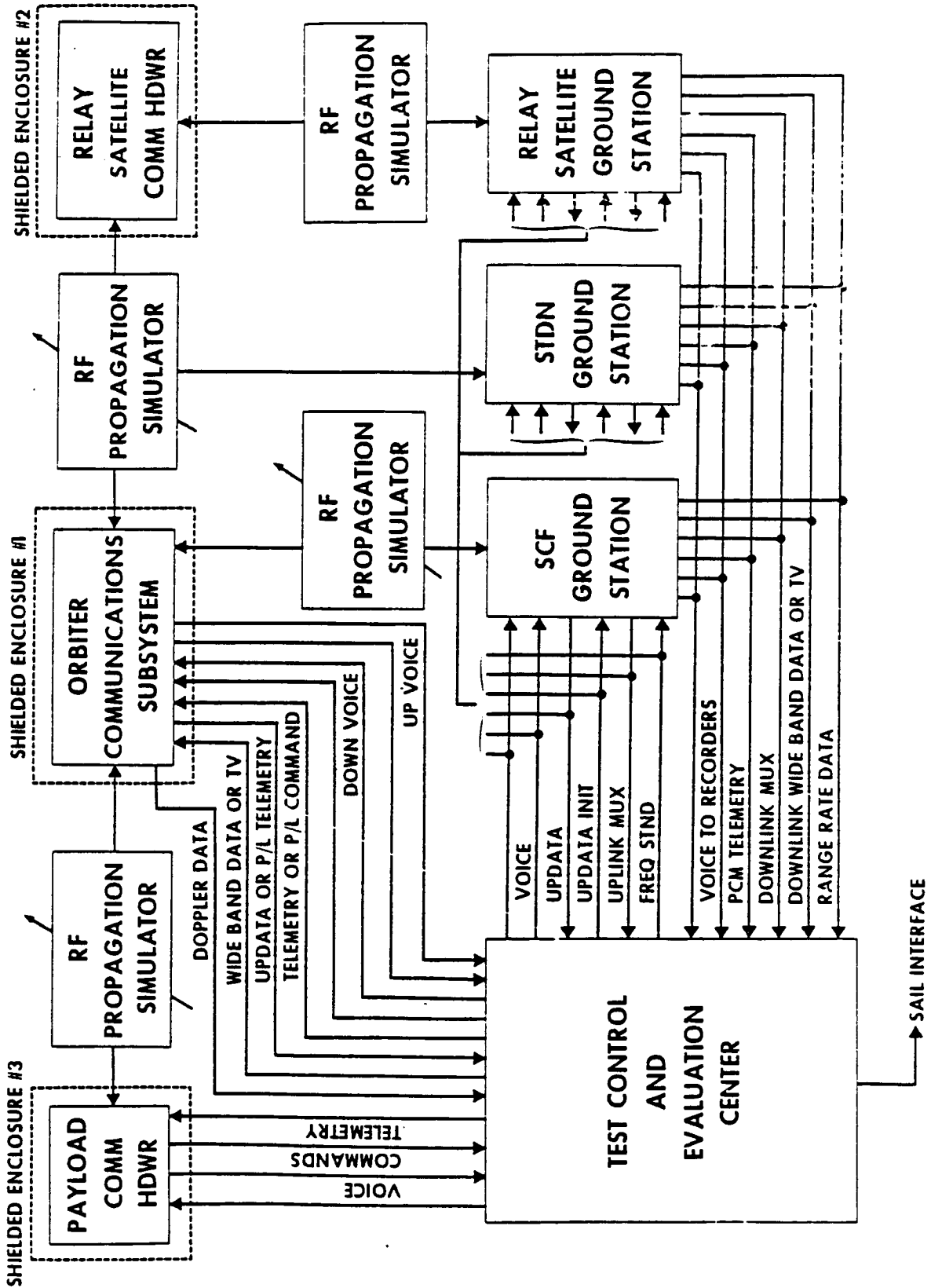
ESTL SYSTEM MODELING HARDWARE CAPABILITY

o ORBITER COMMUNICATION SUBSYSTEMS

o EXTRAVEHICULAR COMMUNICATION SYSTEM (EVCS)

o GROUND STATIONS

  - SPACEFLIGHT TRACKING AND DATA NETWORK

  - DIRECT LINK (GSTDN)

  - RELAY LINK (TDRSS)

  - AIR FORCE SATELLITE CONTROL FACILITY - REMOTE TRACKING

    STATION (AF/SCF - RST)

o SPECIAL EQUIPMENT

  - PAYLOAD SIMULATOR

  - TRACKING AND DATA RELAY SATELLITE SIMULATOR

  - RANGE AND DOPPLER SIMULATOR

  - SPACE LOSS SIMULATOR

  - UPLINK COMMAND SYSTEM

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ESTL SOFTWARE CAPABILITY

o REALTIME DATA ANALYSIS AND PREDICTION SYSTEM

o TT&C BER DETERMINATION

o DOPPLER PROFILE GENERATION AND DOPPLER ACCURACY DETERMINATION

o RANGE DATA PROCESSING AND ACCURACY DETERMINATION

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ESTL EQUIPMENT CONTROL/CONFIGURATION CAPABILITY

o WITH VAX 11/785 INTERFACE

- SHUTTLE COMMAND ENCODER (SCE)

- ESTL RANGE AND DOPPLER SIMULATOR (ERDS)

- MANNED SPACEFLIGHT TELEMETRY PROCESSORS 2 AND 3 (MSFTP)

- PAYLOAD INTERFACE CONTROL SYSTEM (PICS)

- TDRSS INTERFACE CONTROL SYSTEM (TICS)

- COMMAND SPECIAL TEST EQUIPMENT (CSTE)

o VIA KEYBOARD COMMAND (WITHOUT VAX INTERFACE)

- SHUTTLE KU-BAND SYSTEM

- STDN DATA GENERATOR

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EXAMPLES OF MEASUREMENT

- EXAMPLES OF MEASUREMENTS TAKEN DURING SYSTEM COMPATIBILITY AND PERFORMANCE EVALUATION TESTS:

  - THRESHOLD OF SPACECRAFT AND GROUND RF RECEIVERS, THE TELEMETRY CHANNEL THE COMMAND LINK, THE TELEVISION CHANNEL, AND THE UP-AND-DOWN VOICE CHANNELS

  - CAPABILITIES OF SPACECRAFT AND GROUND RF RECEIVERS TO "LOCK TO THE INCOMING SIGNAL AS A FUNCTION OF CARRIER FREQUENCY SHIFTS"

  - PERFORMANCE OF ALL CHANNELS UNDER WORST CASE EXPECTED CONDITIONS (BOTH MAXIMUM AND MINIMUM EXPECTED SIGNAL STRENGTHS, AND MODULATION LEVELS)

  - ACCURACY OF RECEIVED AND PROCESSED TELEMETRY DATA

  - RATE OF REJECTION OF COMMAND MESSAGES

  - WORD INTELLIGIBILITY OF VOICE CHANNELS

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ESTL TEST CAPABILITIES

TYPES OF DATA

VOICE CHANNELS	TRACKING	TV CHANNEL	DATA CHANNELS
SPEECH-TO-NOISE RATIOS	RANGE ACCURACY	RESOLUTION	BIT ERROR RATES
WORD INTELLIGIBILITY	DOPPLER ACCURACY	SIGNAL-TO-NOISE	MESSAGE REJECTION RATES
VOICE QUALITY		RATIOS	BIT ERROR STATISTICS
CROSSTALK LEVELS		PICTURE QUALITY	RECORDER JITTER EFFECTS
DISTORTION LEVELS		PHASE DISTORTION	BIT & FRAME SYNCHRONIZATION
		COLOR QUALITY	PREDETECTION SNR
			POSTDETECTION SNR
			CROSSTALK LEVELS
			DISTORTION LEVELS

- TEST CONDITIONS

  - PRECISELY CONTROLLED RADIO FREQUENCY ENVIRONMENT
  - CHANNEL PERFORMANCE MEASUREMENTS REQUIRE SEVERAL DATA POINTS PER TEST
  - MAINTAIN SINGLE SYSTEM TEST CONFIGURATION OVER LONG TERM
  - TRANSMIT CONSTANT DATA STREAMS (NOT VARYING DATA)
  - AUDIO SIGNAL INJECTION ELECTRONICALLY (NOT HEADSET)
  - CONTROLLED SYSTEM POWER BUS LOADING DURING TESTS
  - SPECIALIZED MONITORING/EVALUATION HARDWARE AT VARIOUS SYSTEM LOCATIONS
    (BIT ERROR DETECTORS AT COMMAND DECODER OUTPUT, AUDIO RECORDERS AT
    AUDIO PANEL EARPHONE BUS CONNECTOR, ETC.)

SUMMARY OF SYSTEM COMPATIBILITY AND PERFORMANCE EVALUATION TESTS

DATA OF INTEREST	EQUIPMENT TESTED	TESTS CONDUCTED
UPLINK DATA CHANNEL QUALITY	ALL SUBSYSTEMS INVOLVED IN UPLINK COMMAND SYSTEM	1. ERROR RATE 2. MESSAGE REJECTION RATE 3. PROBABILITY OF ACCEPTING ERRONEOUS MESSAGE 4. VARYING SIMULATED CONDITIONS AND OPERATIONAL MODES FOR EACH OF THE ABOVE
UPLINK VOICE CHANNEL QUALITY	ALL SUBSYSTEMS INVOLVED IN UPLINK VOICE COMMUNICATIONS SYSTEM	1. VOICE INTELLIGIBILITY 2. OUTPUT SIGNAL-TO-NOISE RATIO 3. VARYING SIMULATED CONDITIONS AND OPERATIONAL MODES FOR EACH OF THE ABOVE
DOWNLINK PCM CHANNEL QUALITY	ALL SUBSYSTEMS INVOLVED IN DOWNLINK PCM TELEMETRY SYSTEM	1. BIT ERROR RATE 2. WORD ERROR RATE 3. WORD RMS ERROR PERCENTAGE 4. RECORDED PCM TESTS 5. EFFECTS OF UPLINK SIGNAL LEVEL 6. VARYING SIMULATED CONDITIONS AND OPERATIONAL MODES FOR EACH OF THE ABOVE

SUMMARY OF SYSTEM COMPATIBILITY AND PERFORMANCE EVALUATION TESTS (CONCLUDED)

DATA OF INTEREST	EQUIPMENT TESTED	TESTS CONDUCTED
DOWNLINK VOICE CHANNEL QUALITY	ALL SUBSYSTEMS INVOLVED IN DOWNLINK VOICE COMMUNICATION SYSTEM	1. VOICE INTELLIGIBILITY 2. OUTPUT SIGNAL-TO-NOISE RATIO 3. VARYING CONDITIONS AND OPERATIONAL MODES FOR EACH OF THE ABOVE
TELEVISION PICTURE QUALITY	ALL SUBSYSTEMS INVOLVED IN TV SYSTEM	1. POSTDETECTION SIGNAL-TO-NOISE RATIO 2. VIDEO QUALITY 3. VIDEO RESOLUTION 4. BURST RESPONSE 5. LINEARITY
ACQUISITION TESTS	ALL SUBSYSTEMS INVOLVED IN FREQUENCY ACQUISITION (WITH AND WITHOUT DOPPLER)	1. TRANSPONDER FREQUENCY TRACKING CAPABILITY 2. RECEIVER FREQUENCY TRACKING CAPABILITY 3. ACQUISITION TIMES 4. PROBABILITY OF FIRST SWEEP ACQUISITION
INTERFERENCE	ALL SUBSYSTEMS INVOLVED IN GENERATING OR RECEIVING INTERFERING SIGNALS	1. BIT ERROR RATE 2. VOICE CHANNEL S/N RATIO 3. RANGING ACCURACY 4. EFFECTS ON CARRIER LOOP

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DOCUMENTATION

o TEST REQUIREMENTS

o TEST PLAN

o TEST PROCEDURES

o TEST RESULT PREDICTION*

o EQUIPMENT TEST PLAN

o EQUIPMENT CALIBRATION PROCEDURE

o TEST PREPARATION SHEET

o DATA PACKAGE

o TEST REPORT

* SEMI-AUTOMATED WITH ERDS

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EXAMPLE: ROSAT TEST

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WHAT IS INVOLVED IN A TYPICAL TEST
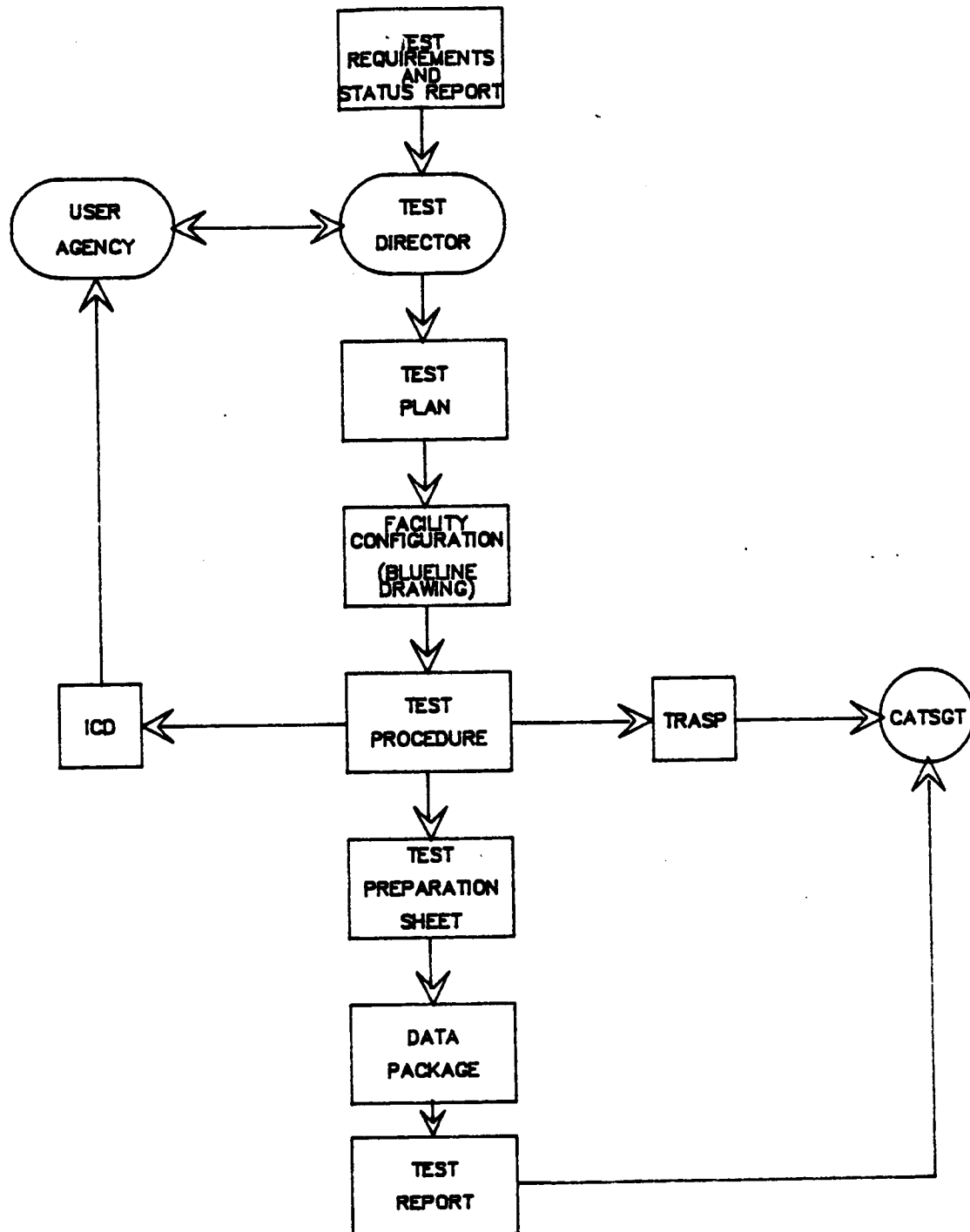
ROSAT/ORBITER PI FORWARD AND RETURN LINK RF CERTIFICATION TEST

o TEST REQUIREMENTS

    - VERIFY RF INTERFACE BETWEEN ROSAT AND ORBITER PAYLOAD

      INTERROGATOR

o TESTS

    - FORWARD COMMAND BER

    - RETURN TELEMETRY BER AND PDL

    - ACQUISITION AND TRACKING

o FACILITY CONFIGURATION

    - PAYLOAD RF INTERFACE PANEL

    - ORBITER PAYLOAD SYSTEM (PI AND PSP)

    - STDN DATA GENERATOR

    - MFR

    - PICS

ROSAT/ORBITER PI FORWARD AND RETURN LINK RF CERTIFICATION TEST

(CONTINUED)

o TEST PROCEDURE

- CALIBRATE AGC AND 0 DB CNR (MANUAL)

- ADJUST TRANSMIT SIGNAL POWER (MANUAL)

- RECORD ON STRIP CHART RECORDER:

  - ROSAT: PHASE LOCK, AGC, SPE, DECODER FOUND, AND LOCK

  - PI: SWEEP

  - PSP: FRAME SYNC, SPE, AGC, PHASE LOCK

  - TAKE BER AND PDL DATA (WITH VAX)

o TYPICAL SCHEDULE:

PLANNING   4-6 MONTHS

ACTUAL TEST   1 WEEK

DATA PACKAGE   2-4 WEEKS

TEST REPORT   4-12 WEEKS

TESTING AT ESTL - IDEAL AUTOMATED APPROACH

o   AUTOMATED TEST PLAN GENERATION

o   AUTOMATED BLUELINE DRAWING AND TEST PROCEDURE GENERATION

o   AUTOMATED EQUIPMENT CONTROL

o   AUTOMATED SIGNAL PATH SWITCHING

o   AUTOMATED TEST SIGNAL VERIFICATION OF TEST CONFIGURATION

o   AUTOMATED CALIBRATION AND SNR ADJUSTMENT

o   AUTOMATED MEASUREMENT

o   AUTOMATED DATA REDUCTION

o   AUTOMATED TEST DATA DISPLAY AND VERIFICATION

o   AUTOMATED FAULT ISOLATION AND DIAGNOSTIC

o   AUTOMATED TEST REPORT GENERATION

o   AUTOMATED ARCHIVING/RETRIEVING OF TEST DATA BASE

o   MANUAL OPTIONS

AUTOMATED TEST PLAN GENERATION

o TEST PLAN WILL BE GENERATED WITH THE HELP OF AN EXPERT SYSTEM

o TEST DIRECTOR INTERFACES WITH EXPERT SYSTEM BY ANSWERING

    − TYPE OF USER PAYLOAD

    − USER FUNCTIONAL CHARACTERISTICS: DATA RATES, OPERATING

       ENVIRONMENTS, ETC.

o EXPERT SYSTEM RECOMMENDS TESTS AND GIVES REASONS

o TEST DIRECTOR CAN MAKE MODIFICATIONS

o EXPERT SYSTEM COMPLETES TEST PLAN

AUTOMATED BLUELINE DRAWING AND TEST PROCEDURE GENERATION

o EXPERT SYSTEM APPROACH CAN BE USED

o A LIST OF REQUIRED HARDWARE AND HOW THEY ARE INTERCONNECTED WILL BE
  GENERATED BASED ON TEST PLAN

o A BLUELINE DRAWING FOR TEST CONFIGURATION IS PRODUCED USING THE
  APPLICON BASED ON LIST GENERATED

o A TEST PROCEDURE ALSO IS GENERATED IN CONJUNCTION WITH THE BLUELINE
  DRAWING

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AUTOMATED TEST EQUIPMENT CONTROL/CONFIGURATION

o EQUIPMENT (SYSTEM, MEASUREMENT, AND MONITORING) SETTINGS ARE
  CONFIGURED AUTOMATICALLY BASED ON TEST PLAN AND PROCEDURE

o EQUIPMENT MUST BE CAPABLE OF BEING CONTROLLED BY EXTERNAL COMMAND AND
  CONFIRMING ACTION TAKEN

o IN ORDER TO REDUCE THE NUMBER OF CABLE CONNECTIONS, EQUIPMENT SHOULD
  BE INTERCONNECTED VIA SERIAL DATA INTERFACE BUSES TO FORM EQUIPMENT
  CLUSTERS. EACH CLUSTER WILL BE SERVED BY A MICROPROCESSOR. THE
  EQUIPMENT CLUSTERS ARE THEN INTERCONNECTED TO FORM A LOCAL AREA
  NETWORK CONTROLLED BY THE VAX 11/785.

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AUTOMATED SIGNAL PATH SWITCHING

o PATCH PANELS WILL BE REPLACED BY SWITCH MATRICES UNDER SOFTWARE

   CONTROL

o SINCE SWITCHING MATRIX SIZE WILL BE PROHIBITIVELY LARGE FOR ARBITRARY

   N X N CONNECTION, THE CONNECTION TOPOLOGY MUST BE LAID OUT SO AS TO

   REQUIRE ONLY A FEW K X L SWITCHING MATRICES FOR SMALL VALUES OF K AND

   L

o SIGNAL LOSS AND REPEATABILITY OF SWITCHING WILL BE CONCERNS. WHILE

   SIGNAL LOSS CAN BE CALIBRATED OUT, REPEATABILITY CAN BE A PROBLEM.

AUTOMATED TEST SIGNAL VERIFICATION OF TEST CONFIGURATION

o   A TEST SIGNAL GENERATOR WILL BE AVAILABLE TO BE INJECTED INTO A TEST
    SETUP

o   SIGNAL PARAMETERS AT SELECTED LOCATIONS WILL BE MONITORED TO VERIFY
    THE VALIDITY OF THE TEST CONFIGURATION AND EQUIPMENT CONTROL SETTINGS

o   THIS OPERATION WILL BE PERFORMED BEFORE AND AFTER EACH NEW TEST SETUP

AUTOMATED CALIBRATION AND SNR ADJUSTMENT

o SIGNAL LEVEL WILL BE ADJUSTED AUTOMATICALLY BY DIGITAL PIN DIODE
ATTENUATORS CONTROLLED BY SOFTWARE RESIDENT IN THE VAX

o TO DETERMINE THE POWER LEVEL, AGC CHARACTERISTICS AND CHARACTERISTICS
OF THE PIN DIODE ATTENUATORS WILL BE DETERMINED PERIODICALLY. THESE
CALIBRATION CURVES WILL BE STORED IN THE COMPUTER AND WILL BE USED TO
COMPUTE THE ABSOLUTE POWER LEVEL AS A FUNCTION OF THE ATTENUATOR
SETTINGS

o SINCE THE POWER LEVEL IS DETERMINED BASED ON THE CALIBRATION CURVES,
THE ABSOLUTE ACCURACY OF THE ATTENUATOR IS NOT IMPORTANT. HOWEVER,
THE REPEATABILITY OF THE ATTENUATOR AND, HENCE, THE CALIBRATION
CURVES ARE IMPORTANT CONSIDERATIONS

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AUTOMATED MEASUREMENT

o LOCAL AREA NETWORK TECHNIQUES WILL BE USED TO SUPPORT DATA TRANSFER BETWEEN THE VAX 11/785 AND STANDARD TEST EQUIPMENT FOR CONTROL AND MEASUREMENT DATA ACQUISITION

o DEDICATED BUS WILL BE USED FOR HIGH-SPEED DATA TRANSFER BETWEEN THE VAX AND SPECIAL TEST EQUIPMENT IF NEEDED

o CALIBRATION AND SNR ADJUSTMENT WILL BE AUTOMATED

o A MANUAL MONITORING CAPABILITY WILL BE PROVIDED

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AUTOMATED DATA REDUCTION

o RAW DATA WILL BE PROCESSED TO EXTRACT PERTINENT INFORMATION TO BE
  STORED IN A DATA BASE. THIS DATA BASE WILL BE SUITABLE FOR RETRIEVAL
  AND EITHER GRAPHIC OR TABULAR DISPLAY

o DATA REDUCTION WILL BE DONE EITHER IN REAL-TIME (ON-LINE) OR IN BATCH
  (POST-PROCESSING) DEPENDING ON THE NEED

AUTOMATED TEST DATA DISPLAY AND VERIFICATION

o DURING A TEST, A QUICKPLOT ALONG WITH PREDICTED PERFORMANCE REFERENCES WILL BE DISPLAYED IN REALTIME ON A MEDIUM RESOLUTION GRAPHICS TERMINAL TO PROVIDE VISUAL VERIFICATION OF TEST DATA VALIDITY. ALSO VAX SOFTWARE WILL CHECK TEST DATA IN REALTIME IN ORDER TO ESTABLISH DATA VALIDITY. HENCE, SHOULD AN ANOMALY BE ENCOUNTERED, TESTS CAN BE REPEATED IN REALTIME

o PERFORMANCE PREDICTIONS FOR SPACE STATION COMMUNICATIONS AND TRACKING TESTS WILL BE GENERATED FROM THE SYSTEM ANALYSIS OFFICE (SAO) SCSS (SPACE STATION COMMUNICATIONS SIMULATION SYSTEM) SOFTWARE. THE REALTIME DATA ANALYSIS AND PREDICTION SYSTEM (RDAPS) WILL BE UPDATED TO SUPPORT SHUTTLE TESTS

o INTERFACE WILL BE ESTABLISHED BETWEEN THE ESTL VAX 11/785 AND THE SAO VAX 11/750 SO THAT ESTL DATA ALSO WILL BE AVAILABLE TO SCSS FOR MODELING REFINEMENT

AUTOMATED FAULT ISOLATION AND DIAGNOSTIC

o   AN EXPERT SYSTEM WILL BE DEVELOPED FOR FAULT ISOLATION AND
    DIAGNOSTICS

o   ADVANTAGES

    -   UPGRADES ACCURACY AND FAULT DETECTION RATE

    -   REDUCES MEAN TIME TO DETECT FAULTS

    -   TACKLES MULTIPLE FAULTS

    -   ALLOWS MAN-MACHINE INTERFACE SUCH AS PROVIDING OPTIONS FOR MANUAL
        INTERRUPTS AND FOR THE MANUAL OPERATION OF AUTOMATED TESTS

    -   TACKLES DYNAMIC FAULTS

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AUTOMATED DOCUMENTATION/TEST REPORT GENERATION

o A MAJORITY OF THE TEST REPORT CAN BE ASSEMBLED WHILE COMPLETING TEST SINCE THE TEST DATA HAS ALREADY BEEN VERIFIED

o THE VAX WILL HAVE A MERGED TEXT/GRAPHICS EDITOR CAPABILITY TO PRODUCE A FINISHED REPORT

o STANDARD FORMATS OF THE TEST REPORT CAN BE STORED IN THE VAX SO THAT THE TEST REPORT WRITING CAN BE REDUCED TO PRESENTING AND DISCUSSING THE TEST DATA AT THE APPROPRIATE PLACES

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AUTOMATED ARCHIVING OF TEST DATA BASE

o PAST TEST DATA/REPORT WILL BE STORED ON TAPES READY FOR INSTANT RETRIEVAL

o TEST DATA BASE ALLOWS ONE TO RECORD EQUIPMENT ANOMALIES

o TEST DATA BASE ALSO FACILITATES MAINTAINING EXPERT SYSTEMS

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MANUAL OPTIONS

o THE AUTOMATED ESTL SHOULD ENABLE A TEST ENGINEER TO CONTROL THE
  SOFTWARE IN ORDER TO PERFORM NON-STANDARD TESTS, MONITORING,
  CALIBRATION, TROUBLE SHOOTING, AND VERIFICATION

o THE AUTOMATED ESTL ALSO SHOULD PROVIDE THE CAPABILITY FOR COMPLETE
  MANUAL OPERATION

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INTEGRATING AUTOMATION WITH EXISTING ESTL FACILITY

o THE AUTOMATED ESTL MUST BE ABLE TO:

- ACCOMMODATE EXISTING HARDWARE AND TEST EQUIPMENT

- INCORPORATE EXPERT SYSTEMS

- FULL UTILIZATION OF THE REMOTE AND LOCAL CAPABILITY (E.G., VIA GPIB) OF A NEW GENERATION OF COMMUNICATIONS HARDWARE AND TEST EQUIPMENT

- INTERFACE WITH EXISTING DATA NETWORKS SUCH AS MCC AND NASCOM

o A MULTI-PURPOSE AUTOMATED TEST SYSTEM ARCHITECTURE IS REQUIRED

- VAX-BASED, SOFTWARE CONTROLLED

- INTEGRATED DATA ACQUISITION/MEASUREMENT SYSTEM

- LOCAL AREA NETWORK FOR DATA TRANSFER

- LOCAL CONTROLLER FOR EXISTING EQUIPMENT

o DEGREE OF AUTOMATION: STANDARD VERSUS NON-STANDARD TESTS

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ACCOMMODATING EXISTING HARDWARE AND TEST EQUIPMENT

o AUTOMATED ESTL ARCHITECTURE MUST ACCOMMODATE EXISTING EQUIPMENT

o IT IS DIFFICULT TO UPGRADE CERTAIN SHUTTLE-ERA HARDWARE FOR
AUTOMATION. HENCE AN OPERATOR INTERRUPT CAPABILITY MUST BE PROVIDED
FOR SUCH MANUALLY CONTROLLED EQUIPMENT

o SOME PRESENT EQUIPMENT CAN BE EASILY ADAPTED TO AN AUTOMATED ESTL
ARCHITECTURE. THESE SHOULD BE UPGRADED

o SOME DEVICES EMPLOY A CUMBERSOME PARALLEL INTERFACE. THIS EQUIPMENT
SHOULD BE GROUPED INTO CLUSTERS. EACH CLUSTER WILL BE SERVED BY A
MICROPROCESSOR CONTROLLER FOR LINKING THE VAX TO A STANDARD LOCAL
AREA NETWORK INTERFACE, THEREBY LOCALIZING ANY CABLING PROBLEMS.

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ACCOMMODATING A NEW GENERATION OF COMMUNICATION HARDWARE AND TEST EQUIPMENT

o AN AUTOMATED ESTL SHOULD UTILIZE THE NEW GENERATION OF SYSTEM HARDWARE AND TEST EQUIPMENT. THESE DEVICES WILL BE CAPABLE OF USING SUCH STANDARD INTERFACES AS THE IEEE 488 BUS (GPIB)

o AN AUTOMATED ESTL SHOULD PERMIT OPERATION OF THESE DEVICES FROM EITHER THE MONITOR/CONTROL CONSOLE KEYBOARD OR THE VAX SOFTWARE

o FOR THE SAKE OF EFFICIENCY, EVEN A NON-STANDARD MANUAL TEST INVOLVING THIS EQUIPMENT SHOULD PERMIT THE USE OF SEMI-AUTOMATED SOFTWARE PROCEDURES
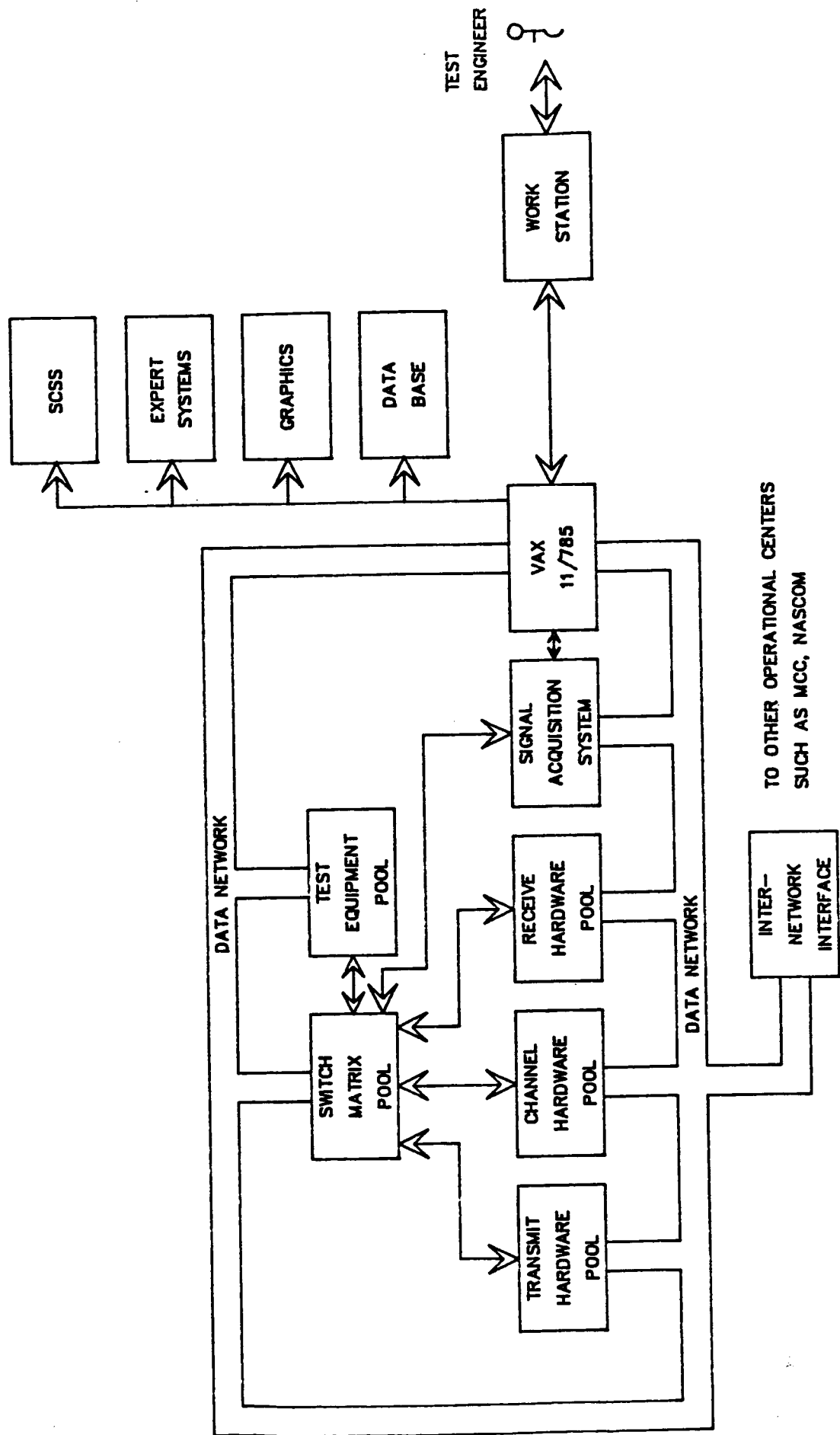
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INTERFACE WITH OTHER DATA NETWORKS

o OPERATIONAL TESTS REQUIRE THAT AN AUTOMATED ESTL INTERFACE WITH OTHER

MAJOR FACILITIES VIA DATA TRANSFERS

- MCC FOR SHUTTLE TESTS

- NASCOM FOR TDRSS TESTS

- SPACE STATION OPERATIONS CENTER FOR SPACE STATION TESTS

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MULTI-PURPOSE AUTOMATED TEST SYSTEM CONCEPT

o SINCE STANDARD LABORATORY EQUIPMENT IS DESIGNED FOR VERSATILITY IN A PARTICULAR AREA OF APPLICABILITY; IT CAN BE DIFFICULT TO ADAPT TO CERTAIN ESTL TESTS

o BECAUSE OF THE LIMITED COMMERCIAL MARKET, STANDARD LABORATORY EQUIPMENT OFTEN WILL NOT AVAILABLE FOR CERTAIN ESTL TESTS (E.G., ACQUISITION AND TRACKING)

o A SOFTWARE-BASED MULTI-PURPOSE AUTOMATED TEST SYSTEM IS A COST-EFFECTIVE APPROACH TO SUPPLEMENT STANDARD TEST EQUIPMENT

    - ACCOMMODATES STANDARD TEST EQUIPMENT

    - PERFORMS BOTH SIGNAL DISTORTIONS CHARACTERIZATION MEASUREMENTS AND SPECIALIZED ACQUISITION AND TRACKING TESTS

    - FACILITATES DATA INTERFACES BETWEEN MCC, NASCOM, ETC. FOR OPERATIONAL TESTS

    - VAX 11/785 BASED

AUTOMATED ESTL FUNCTIONAL BLOCK DIAGRAM

TEST ENGINEER

WORK STATION

SCSS

EXPERT SYSTEMS

GRAPHICS

DATA BASE

VAX 11/785

SIGNAL ACQUISITION SYSTEM

TEST EQUIPMENT POOL

RECEIVE HARDWARE POOL

SWITCH MATRIX POOL

CHANNEL HARDWARE POOL

TRANSMIT HARDWARE POOL

INTER-NETWORK INTERFACE

DATA NETWORK

DATA NETWORK

TO OTHER OPERATIONAL CENTERS SUCH AS MCC, NASCOM

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HARDWARE POOL INTERFACING WITH DATA NETWORK

NETWORK INTERFACE

ESTL
DATA
NETWORK
GATEWAY

NEW
HARDWARE

MICRO-
PROCESSOR
INTERFACE
CONTROLLER

EXISTING
"SMART"
HARDWARE

EXISTING
"DUMB"
HARDWARE

H = HARDWARE INTERFACE

D = DATA INTERFACE

INCORPORATE EXPERT SYSTEMS

o EXPERT SYSTEM CAN BE DEVELOPED INDEPENDENTLY ON THE VAX 11/785 WITH

  MINIMAL IMPACT ON ESTL OPERATION

o SINCE IT CAN SPEED UP THE TIME CONSUMING STAGES OF A TYPICAL TEST

  (SUCH AS TEST PLANNING AND DATA PACKAGE/TEST REPORT GENERATION) THE

  PAYOFF IS COST EFFECTIVE

o CAN MINIMIZE THE IMPACT UPON THE SCARCITY OF EXPERTS

DEGREE OF AUTOMATION: STANDARDIZED VERSUS NON-STANDARDIZED TESTS

o STANDARDIZED TESTS

- EXAMPLES: BER, RANGING, ACQUISITION, TRACKING, ETC.

- EASY TO AUTOMATE

- ARE WELL-DEFINED FOR EXPERT SYSTEM TECHNIQUES

o NON-STANDARDIZED ONE-OF-A-KIND TESTS.

- LESS COST-EFFECTIVE TO AUTOMATE COMPLETELY

- PARTIAL AUTOMATION CAN BE COST EFFECTIVE. FOR EXAMPLE, AUTOMATED MEASUREMENT AND CONFIGURATION WOULD ELIMINATE CERTAIN TIME-CONSUMING MANUAL OPERATIONS

CONSIDERATIONS FOR A TIME TABLE FOR ESTL AUTOMATION

o BUDGETARY ISSUES

o PAYOFF VERSUS COST

   - PAYOFF IS IN TERMS OF MANPOWER AND TEST TIME SAVINGS

   - COST CONSISTS OF EQUIPMENT ACQUISITION AND MANPOWER

o IMPACT ON DAILY OPERATION

   - ESTL MUST SUPPORT DAY-TO-DAY OPERATION DURING
      TRANSITION

   - A MASTER PLAN WITH CAREFULLY PHASED EFFORT IS REQUIRED

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PAYOFF, COST, AND IMPACT SUMMARY

	PAYOFF	COST	IMPACT
	======	====	======
TEST PLAN	H	M	L
BLUELINE DRAWING	H	M	L
TEST PROCEDURE	H	M	L
EQUIPMENT CONTROL	H	M	L
SIGNAL PATH SWITCHING	M	H	H
CONFIGURATION/SIGNAL PATH VERIFICATION	H	M/H	H
CALIBRATION/SNR ADJUSTMENT	H	M/H	H
MEASUREMENT	H	M/H	M
DATA REDUCTION	H	L/M	L
TEST DATA DISPLAY	H	L/M	L
DATA VALIDITY VERIFICATION	H	M	L
FAULT ISOLATION AND DIAGNOSTIC	H	M/H	L
TEST REPORT/DOCUMENTATION	H	M	L
ARCHIVING/RETRIEVAL OF TEST DATA BASE	H	L/M	L

LEGEND

H = HIGH   M = MEDIUM   L =LOW

TIME TABLE

FY86   DEMONSTRATION, ARCHITECTURE STUDY

FY87   DETAILED MASTER PLAN, CONTINUING SOFTWARE/EXPERT SYSTEM

DEVELOPMENT

FY88-89 AUTOMATION FOR NEW EQUIPMENT/HARDWARE (SPACE STATION RELATED);

UPGRADING SHUTTLE ERA EQUIPMENT

DEMONSTRATION CANDIDATES

o DATA HANDLING AND VERIFICATION (UPDATED RDAPS)

o TEST PLANNING ADVISOR EXPERT SYSTEM

o TEST CONFIGURATION ADVISOR EXPERT SYSTEM

o AUTOMATED SNR ADJUSTMENT AND CALIBRATION

RECOMMENDATIONS FOR THE NEAR-TERM

o DEMONSTRATE AN EXPERT SYSTEM WITHOUT IMPACTING ESTL OPERATION

o DEVELOP AN AUTOMATED ESTL ARCHITECTURE

APPENDIX I

TEST CONFIGURATION ADVISOR EXPERT SYSTEM

TEST CONFIGURATION ADVISOR EXPERT SYSTEM

o PURPOSE

- CONFIGURE ESTL HARDWARE TO SUPPORT TEST PLAN

o INPUT

- TEST PLAN

o OUTPUT

- BLUELINE DRAWING (APPLICON)

STEPS AN EXPERT TAKES TO CONFIGURE A TEST

1. IDENTIFY TESTS TO BE PERFORMED FROM TEST PLAN

2. DETERMINE:

   - REQUIRED SYSTEM HARDWARE

   - REQUIRED TEST EQUIPMENT

   - REQUIRED MONITORING EQUIPMENT

3. DETERMINE INPUT AND OUTPUT JUNCTION POINTS

4. DETERMINE INTERCONNECTIONS VIA PATCH PANELS AND TIE LINES

5. GENERATE A LIST FOR APPLICON

6. USE LIST TO DRIVE APPLICON

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EXAMPLE: ROSAT BER TEST

o REQUIRED HARDWARE

- SYSTEM: PAYLOAD INTERFACE PANEL, ORBITER PAYLOAD SYSTEM, PAYLOAD
  INTERFACE CONTROL SYSTEM, STDN DATA GENERATOR

- TEST: NARDA ATTENUATOR, POWER METER, FRAME SYNC STATUS DETECTOR,
  BIT ERROR DETECTOR, ESTL DIGITAL BUFFER, FILTERS,
  AMPLIFIERS

- MONITORING: SCOPE, SPECTRUM ANALYZER, VOLTMETER, STRIP CHART
  RECORDER

o JUNCTION CONNECTOR EXAMPLE

- RF SIGNAL INPUT TO PAYLOAD RF INTERFACE PANEL AT A6J5

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CONTINUED

o INTERCONNECTIONS EXAMPLE

- OUTPUT OF PAYLOAD RF INTERFACE PANEL (A3J5) CONNECTS TO
  ATTENUATOR "B" VIA A SERIES OF TIE LINES CONNECTING A3J5,
  A3J14, A1J17, A4J7, AND A8J20

o LIST EXAMPLE

- #2 STRIP CHART RECORDER TO PAYLOAD SUBSYSTEM AREA

  - CHANNEL 2, A7J11 (PHASE LOCK)

  - CHANNEL 3, A7J12 (AGC)

  - CHANNEL 4, A7J13 (SPE)

  - CHANNEL 5, A7J14 (DECODER LOCK)

  - CHANNEL 6, A7J15 (DECODER FOUND)

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BUILDING AN EXPERT SYSTEM TEST CONFIGURATOR AT ESTL

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WHAT IS AN EXPERT SYSTEM?

EXPERT SYSTEM = FACTS + RULES + INFERENCE ENGINE

CONVENTIONAL PROGRAM = DATA + ALGORITHM

EXPERT SYSTEM SHELLS AVAILABLE ON VAX

o AN EXPERT SYSTEM SHELL IS A DEVELOPMENT TOOL THAT FACILITATES
   BUILDING OF EXPERT SYSTEMS AS OPPOSED TO A LOW LEVEL ARTIFICIAL
   INTELLIGENCE LANGUAGE SUCH AS LISP

o MANY SHELLS ARE AVAILABLE FOR THE VAX SYSTEM:

   - OPS5

   - ART <--------- EXAMPLE USED HERE

   - KNOWLEDGE CRAFT

   - DUCK

   - KES

ART (AUTOMATED REASONING TOOL)

o DEVELOPED BY INFERENCE CORPORATION

o PERMITS SIMPLE REPRESENTATION OF FACTS

o PROVIDES A WIDE CHOICE OF STRUCTURES TO ORGANIZE FACTS

o ALLOWS BOTH FORWARD CHAINING OF RULES, I.E., REASONING FROM
  CONDITIONS (GIVENS) TO THEIR CONSEQUENCES (CONCLUSIONS) AND BACKWARD
  CHAINING OF RULES (VICE VERSA)

o CONTAINS POWERFUL INFERENCE ENGINE

o PROVIDES VIEWPOINTS TO PRESENT ALTERNATIVE STATES

o PROVIDES GOOD DEVELOPMENT ENVIRONMENT

KNOWLEDGE REPRESENTATION IN ART

o FACTS

o SCHEMATA

o RULES

WHAT ARE SCHEMATA?

o KNOWLEDGE CAN BE REPRESENTED BY EITHER DISCRETE FACTS OR SCHEMATA

o A SCHEMA IS A SHORTHAND NOTATION FOR AN ARBITRARY COLLECTION OF

   FACTS. THESE FACTS TYPICALLY PERTAIN TO ONE OBJECT OR CLASS OF

   OBJECTS. THEY ARE USUALLY RELATED IN SOME WAY IN THE USER'S MIND

o EACH SCHEMA CAN BE LINKED TO OTHER SCHEMATA, AND THUS THEY ARE USEFUL

   FOR REPRESENTING HIERARCHICAL DATA AS SHOWN IN THE FOLLOWING EXAMPLE

o THE PROPERTIES OF A SCHEMA ARE REPRESENTED BY SLOTS

AN EXAMPLE TO SHOW HOW SCHEMATA WORK IN THE ART EXPERT SYSTEM SHELL

o DIFFERENT TYPES OF TESTS PERFORMED AT ESTL ARE:

```
                          !ESTL_TESTS!

         !ACQUISITION!              !BER_TEST!         !VOICE_QUALITY!

!USER_TO_SHUTTLE_TEST!  !USER_TO_TDRSS_TEST!  !USER_TO_GSTDN_TEST!
```

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(DEFFACTS INFO_ABOUT ESTL_TESTS

(ESTL_TESTS DETERMINES PAYLOAD_COMPATIBILITY)

(ESTL_TESTS REQUIRES TEST_PLAN)

(ESTL_TESTS REQUIRES VARYING_POWER_LEVELS)

(BER_TEST DETERMINES PAYLOAD_COMPATIBILITY)

(BER_TEST REQUIRES TEST_PLAN)

(BER_TEST REQUIRES VARYING_POWER_LEVELS)

(BER_TEST REQUIRES BER_TEST_SETUP)

(BER_TEST IS-A ESTL_TESTS)

(USER_TO_SHUTTLE_TEST DETERMINES PAYLOAD_COMPATIBILITY)

(USER_TO_SHUTTLE_TEST REQUIRES TEST_PLAN)

(USER_TO_SHUTTLE_TEST REQUIRES BER_TEST_SETUP)

(USER_TO_SHUTTLE_TEST IS-A ESTL_TESTS)

(USER_TO_SHUTTLE_TEST REQUIRES VARYING_POWER_LEVELS)

(USER_TO_SHUTTLE_TEST INVOLVES PAYLOAD_INTERROGATOR)

(USER_TO_SHUTTLE_TEST IS-A BER_TEST)

)

. . .

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EXAMPLE OF SAME FACTS DEFINED BY MEANS OF ART SCHEMATA

(DEFSCHEMA ESTL_TESTS

  (DETERMINES PAYLOAD_COMPATIBILITY)

  (REQUIRES TEST_PLAN)

  (REQUIRES VARYING_POWER_LEVELS))

(DEFSCHEMA BER_TEST

  (IS-A ESTL_TESTS)

  (REQUIRES BER_TEST_SETUP))

(DEFSCHEMA USER_TO_SHUTTLE_TEST

  (IS-A BER_TEST)

  (INVOLVES PAYLOAD_INTERROGATOR))

WHAT CAN THE SCHEMATA (AND SLOTS) HIERARCHY REPRESENT?

o INVERSE

o HAS-SUBSETS

o SUBSET-OF

o KINDS

o ELEMENT-OF

o HAS-ELEMENTS

o PROTOTYPE-OF

o PROTOTYPE

o HAS-INSTANCES

o USER-DEFINED-RELATIONS

o IS-A

o INSTANCE-OF

o USER-DEFINED-INHERITANCE-RELATIONS

WHAT ARE RULES?

o RULES DRIVE THE EXPERT SYSTEM. THEY CAUSE THE EXPERT SYSTEM TO

TRANSITION FROM ONE STATE TO THE NEXT.

o ART SUPPORTS BOTH FORWARD- AND BACKWARD-CHAINING RULES

FORWARD-CHAINING RULE EXAMPLE IN ART

```
(DEFRULE MONITOR_RF_SIGNAL_POWER

     (TESTS_TO_PERFORM BER_TEST)

     (TESTS_TO_PERFORM THRESHOLD_TEST)
=>
     (ASSERT USE_HP8484A_POWER_SENSOR)

     (ASSERT USE_HP435A_POWER_METER)
)
```

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BACKWARD-CHAINING RULE EXAMPLE IN ART

```
(DEFRULE FRAME_SYNC_STATUS_DETECTOR_NEEDED

    (GOAL  TESTS_TO_PERFORM  BER_TEST )

=>

    (ASSERT EQUIPMENT_NEEDED

            FRAME_SYNC_STATUS_DETECTOR)

)
```

ART'S INFERENCING CAPABILITIES

o PATTERN MATCHING

- PROVIDES A WAY TO DEFINE A "VARIABLE"

o CONFLICT RESOLUTION

- WHEN MANY RULES HAVE BEEN SATISFIED, WHICH ONE IS FIRED?

o VIEWPOINTS

- IN COMPLEX PROBLEMS, MANY DIFFERENT SOLUTION PATHS CAN BE

  PURSUED IN PARALLEL TO ONE ANOTHER

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AN EXAMPLE OF PATTERN MATCHING

o THE PATTERN (TESTS_TO_PERFORM $X) WILL MATCH THE FACTS
(TEST_TO_PERFORM BER_TEST) AND (TEST_TO_PERFORM VOICE QUALITY). IT
CAN BE USED IN ART AS A WILDCARD TO DEFINE A RULE, E.G.,

```
(DEFRULE TOTAL_CONNECTIONS

   "this rule sums the total number of

   tie lines required for all tests to be

   performed"

   (TESTS_TO_PERFORM $X)

   (SCHEMA $X

      (CONNECTIONS_REQUIRED $Y))

=>

   (ASSERT

      (TOTAL_CONNECTIONS (+ TOTAL_CONNECTIONS $Y)))

)
```

WHAT THE TEST CONFIGURATION ADVISOR EXPERT SYSTEM DOES

o INPUTS

- WHAT TO TEST

o OUTPUTS

- A LIST OF THE TESTS TO PERFORM

- A LIST OF THE NEEDED EQUIPMENT

- A PLAN SHOWING HOW TO CONFIGURE THE TEST

- AN EXPLANATION OF THE TEST CONFIGURATION

APPROACH TO DEVELOPING THE TEST CONFIGURATION EXPERT SYSTEM

o DECOMPOSE THE INITIAL PROBLEM INTO A SERIES OF SUBTASKS FOR THE EXPERT SYSTEM TO PERFORM, E.G., IDENTIFICATION OF THE TESTS TO BE PERFORMED, DETERMINATION OF THE NECESSARY SYSTEM, TEST, AND MONITORING HARDWARE, AND THE DEFINITION OF ENTRIES FOR A BLUELINE DRAWING

o GATHER THE FACTS NEEDED TO PERFORM EACH SUBTASK AND ORGANIZE THIS DATA INTO SCHEMATA, E.G., A BER TEST REQUIRES A STRIP CHART RECORDER TO MONITOR RECEIVER STATUS; A STRIP CHART RECORDER HAS MULTIPLE CHANNELS; CHANNEL 1 IS ASSIGNED TO STATIC PHASE ERROR; CHANNEL 2 IS ASSIGNED TO LOCK INDICATOR, ETC.

o DEVELOP RULES FOR PERFORMING EACH SUBTASK, E.G. WHAT DEVICES ARE REQUIRED IN ORDER TO PERFORM A GIVEN TEST, HOW ARE CERTAIN TEST DEVICES TO BE CONNECTED, AND HOW OUGHT OUTPUTS BE INTERPRETED.

o DEVELOP A USER INTERFACE FOR PRESENTATION OF EXPERT SYSTEM RESULTS

o TEST EXPERT SYSTEM AND REITERATE UNTIL SATISFACTORY

APPENDIX II

ESTL TEST AUTOMATION UPGRADE

TO: EE/Assistant Chief, Tracking and Communications Division

FROM: EE7/Chief, Communications Performance and Integration Branch

SUBJECT: ESTL Test Automation Upgrade

This memorandum is being written with the express purpose of delineating the functional requirements to upgrade the test automation capability of the ESTL. The ESTL, classified as a multi-element major ground test facility, including five spacecraft test areas, two ground stations, and sophisticated integrated test and simulation equipment, must be capable of being used for the following:

O   Conduct early communications systems engineering development testing on an end-to-end basis of new, complex, high risk hardware configurations/concepts.

O   Conduct space/ground systems performance certification/ verification testing approximately one year prior to first manned spaceflight utilization.

O   Conduct/support TDRS Network Integration and mission support activities. Four categories of activities performed:

    O   STS TDRS Network Simulations - Conducted on a premission basis to verify operational readiness to support the upcoming mission.

    O   TN Integration - Hardware/Software engineering evaluation of changes/upgrades.

O   TDRS (B, C) Engineering Performance Verification -
    After initial insertion into synchronous orbit,
    followed by scheduled delta certifications on periodic
    basis.

O   Pre/post Mission Operational Support - problem
    investigations/resolutions.

O   Conduct operational readiness testing of the ESTL.

O   Demonstrating acceptance and operational readiness.

O   Conducting maintenance at the same time as on-going activities.

O   Conducting characterization testing.

O   Conducting end-to-end system test and evaluation activities for
    both STS and Space Station configurations (perhaps simultaneously).

O   Conducting Payload Certifications/Verifications.

These functions must be factored into the detailed specifications for ESTL Test
Automation Upgrade Package as it is prepared. Key requirements to consider are:

a. The eight functions above must be capable of being exercised without
isolated dependence on ADPE. One of the major short comings of the WSGT
facility is the lack of the ability to configure/reconfigure the system via a
manual means during a scheduled activity. The ESTL test system must have the
capability to reconfigure manually (or in isolated cases under ADPE control).
These reconfigurations include items such as frequency, mode, bit rate, PCM code,
etc., such as that currently accomplished by the existing TICS (TDRS Interface
Control System) and PICS (Payload Interface Control System). As a minimum,
all the reconfigurable parameters currently designed into the existing
equipment should be included.

b. The automated test functions must be controlled from either, 1) the TCC (Test Control Center) by ADPE and/or manually, 2) a separate, dedicated configuration management/test automation ADPE complex, and 3) manually controlled from several strategic locations.

c. Although final acceptance of the ESTL from an operational readiness viewpoint should be accomplished from the TCC, equipment should be located at various points to monitor/record message and data traffic flow for the purpose of integration testing and initial acceptance. After the system has been accepted, these equipments can be used for fault isolation tools and initial acceptance of follow-on software deliveries or system modifications.

d. During the integration test phase of the automated upgrade, the existing ESTL will be operationally on line and using the existing simulation/verification capability for in-house testing, maintenance, fault isolation activites, as well as for on-going TDRS Network and STS operational support activities. The existing ESTL simulation/verification capability should be considered as available for use in the ESTL upgrade (both integration, acceptance and test operational phases).

e. The operational concept for upgrade of the ESTL and the systems design and architecture of the simulation test system and operational system should include sufficient equipment/services/and ADPE to simulteneously conduct software development and acceptance of new software deliveries with the end-to-end test and evaluation capability without impacting on-going activities.

Additional Considerations:

a. The ESTL test system should be developed in a phased manner. This test system operated in the manual control mode must be capable of exercising all technical specifications/requirements for the ESTL. Acceptance of the final test system software for ADPE control should follow acceptance of the manually controlled system. Considerations should be given of how the existing TDRS Network can participate in the acceptance of the ESTL test system.

b. Consideration should be given to the test system design/architecture of operating or running simultaneous in-house testing and in-orbit spacecraft testing. This may be necessary in the 1990 - 1995 time frame.

c. A separate software maintenance system should be considered for all software development/maintenance activity relative to the ESTL test system.

There may be other considerations, additions, deletions, etc., as time goes on. Enclosures 1, 2, and 3 to this memorandum provide additional information for further discussion and development.

cc
EE/R. S. Sawyer
EE7/B. K. Vermillion
    W. E. Teasdale
    L. K. Bromley
    O. L. Schmidt
    B. G. Smith
    L. T. Walker

ELECTRONIC SYSTEMS TEST LABORATORY

AUTOMATION OF LABORATORY OPERATIONS

* S-BAND ANTENNA CONFIGURATION

    - ENGINEERING TESTS TO SPACE NETWORK SUPPORT

* INTRA-LABORATORY CONFIGURATION MANAGEMENT AND CONTROL
  (19 FUNCTIONAL AREAS)

    - PATCHING (TIE LINES)
    - GROUND STATIONS (2)
    - COMMAND, TELEMETRY AND RECORDING AREA
    - SPACECRAFT RF COMMUNICATIONS SYSTEMS (5)
    - SPECIAL TEST SYSTEMS (PICS, TICS)

* TEST AUTOMATION

    - SYSTEM CALIBRATION (RF PATH, S/N, NF, AGC'S, ETC.)
    - TELEMETRY PERFORMANCE TESTS (SBER, Eb/No, PDL, PBER, ETC.)
    - RANGING ACCURACY
    - DOPPLER ACCURACY/SYSTEM PERFORMANCE
    - RF SPECTRUM ANALYSIS, FREQUENCY RESPONSE, INTERFERENCE
    - TELEVISION LINK PERFORMANCE (S/N, RESPONSE, LINEARITY,
      PICTURE QUALITY, ETC.)
    - PAYLOADS (MULTIPLE CONFIGURATIONS, TANDEM LINKS)

* DATA COLLECTION, PROCESSING

APPROACH: SPECIAL INTERFACE DEVICES
            NETWORK COMMUNICATIONS
            ARTIFICIAL INTELLIGENCE COMPUTERS AND SPECIAL ALGORITHMS
            INCORPORATING EXPERT SYSTEMS CONCEPTS

Enclosure 1

SCOPE OF LAB AUTOMATION STUDY

I. DEFINITIONS
    A. ARTIFICIAL INTELLIGENCE
    B. EXPERT SYSTEMS
    C. LAB AUTOMATION

II. CONFIGURATION MANAGMENT
    A. INITIAL PHASE
        1. CABLE ROUTING SUGGESTIONS
        2. MANUAL PATCHING
        3. MANUAL INPUT
        4. CABLE LOGS
        5. LIBRARY OF PAST CONFIGURATIONS
    B. GRAPHICS
        1. BLUELINE GENERATOR
        2. GRAPHICAL INPUT
        3. SIGNAL FLOW DESCRIPTION
            a. CONNECTIONS BETWEEN OBJECTS REPRESENT MULTIPLE SIGNALS
            b. FRAME BASED EXPERT SYSTEM
    C. HARDWARE
        1. ANALOG/DIGITAL SWITCHING MATRICES
            a. AVAILIBILITY
            b. RELIABILITY, REPEATABILITY AND VERIFIABILITY
            c. EFFECT ON TEST ACCURACY
        2. RADIO FREQUENCY SWITCHING MATRICES
            a. AVAILIBILITY
            b. RELIABILITY, REPEATABILITY AND VERIFIABILITY
            c. EFFECT ON TEST ACCURACY
        3. REVIEW OF TDRS GROUND STATION
            a. RELIABILITY
            b. COMPLEXITY
            c. SPEED

Enclosure 2

III. DATA COLLECTION

    A. PREPARATION OF DATA PACKAGE

        1. MANUAL ENTRY

        2. CURVE FITTING AND PLOTTING

        3. TEST REPORT GENERATION AND ARCHIVAL

        4. REASON FOR FAILURE OF PAST AUTOMATION

    B. EQUIPMENT INTERFACE

        1. REDESIGN OF EQUIPMENT

        2. USE OF COMMERCIAL TEST EQUIPMENT

        3. INTERFACE STANDARDS AND METHODOLOGY

IV. COST

    A. IMPLEMENTATION

        1. MANPOWER

            a. EXISTING PERSONNEL WORKLOAD

                i. COMPUTER PESONNEL

                ii. TEST EXPERTS

            b. DEMAND/AVAILABILITY OF EXPERIENCED KNOWLEDGE ENGINEERS

                i. LEMSCO/NASA SALARIES CANNOT MATCH MARKET DEMAND

                ii. SHORTAGE OF KNOWLEDGE ENGINEERS

        2. COMPUTATIONAL POWER

            a. EXTENT CURRENT SYSTEMS COULD BE UTILIZED

            b. AI DEVELOPEMENT ENVIROMENTS

            c. GRAPHICS WORK STATIONS

            d. COMPUTERIZED TEST EQUIPMENT

    B. MAINTAINENCE

        1. MANPOWER COST

        2. HARDWARE COST

7. KNOWLEGE AND SKILL LEVEL DISPLACEMENT

  A. CURRENT ESTL SKILL LEVEL MIX

    1. ADEQUATE RF EXPERIENCE

    2. ABILITY TO INVESTIGATE UNIQUE SITUATIONS

  B. SKILL LEVEL MIX AFTEP SOME AUTOMATION

    1. FEWER LOW SKILL POSITIONS

      a. RETRAIN DATA TAKERS FOR DATA ENTRY

      b. INCREASED SKILL LEVEL AND COST

    2. MORE COMPUTER MAINTAINENCE PERSONNEL

    3. FEWER TEST TEAM MEMBERS

      a. AUTOMATIC PATCHING

      b. AUTOMATIC DATA TAKING

      c. ANALYZING TEST RESULTS

      d. AUTOMATIC DATA PACKAGES

VI. CONCLUSIONS

  A. JUSTIFY NEED

    1. CURRENT INEFFICIENCIES

    2. PROJECTED PRODUCTIVITY

  B. RECOMMEND EXTENT OF IMPLEMENTATION

    1. CONFIGURATION CONTROL

    2. DATA COLLECTION

  C. COST REDUCTION

    1. PRODUCTIVITY AND EFFICIENCY

    2. PERSONNEL

ELECTRONIC SYSTEMS TEST LABORATORY

AUTOMATION POSSIBILITIES

I. <u>EXPERT CONFIGURATION SYSTEM</u>:

a. <u>Patching Advisor</u>: The various ESTL sources and sinks along with all tie lines and their corresponding patch panel interface locations would become a part of computer memory. When a test configuration was being planned, the general requirements could be given to the computer and it would then provide detailed pathing information. This data base would have to evolve and grow with time.

This approach would be non-invasive in that it would not require changing actual ESTL operations at the moment, but would allow confidence in and refinement of the system to develop with time.

(1) <u>Verbal Approach</u>: Each device must have a specific name and that name would be typed into the computer (sink and source) and connections would be defined.

(2) <u>Applicon Approach</u>: A "birdseye view" block diagram input to the Applicaon would be converted to a detailed patching diagram.

b. <u>Automatic "Blue Line" Preparation</u>: From the data available in the computer from the previous effort, the computer could draw a "blue line" test configuration

II. <u>OPERATION AND MEASUREMENT</u>:

a. <u>Data Collection</u>: When BER, PDL or MRR measurements are made in the ESTL, it should be possible to construct a computer interface such that the computer can read and store the data realtime. Once test conditions were typed into the computer it could produce a data sheet and a plot immediately.

b. <u>Path Variation</u>: Computer controlled (digital control) attenuators could be built into the system and the computer could be told to run a BER curve from TRP, to TRP_2 or BER_1 to BER_2, and the entire test would be done automatically.

At this point, the danger of violating ESTL quality appears. Presently, we do not think remotely controlled attenuators with .1 or .2 dB repeatability are available, but this is an open question.

c. <u>Path Calibration</u>: It would be necessary to establish permanent paths with dedicated trim attenuators and power meters plus path attenuators and terminal power meters, etc., and the computer would simply verify the calibration had not changed. Again repeatable attenuators would be required. This is an ESTL brain surgery. <u>Can not make mistakes here</u>.

III. <u>SET-UP</u>:

    a. RF Path Switching:

        (1) S-Band

        (2) Ku-Band

        (3) UHF

    b. Signal Patching:

        (1) Digital

        (2) Analog

The above would require switches that could connect anything-to-anything with repeatable loss. This could be very expensive but once confidence in the expert system had been established, it would become a hardware problem. ESTL would always require manual override capability.

Our biggest problem with automated ESTL ground station has been poor computer construction. We could not tollerate these kinds of problems on a large scale. It would be necessary to have shipboard quality construction of all computers and interface cables.
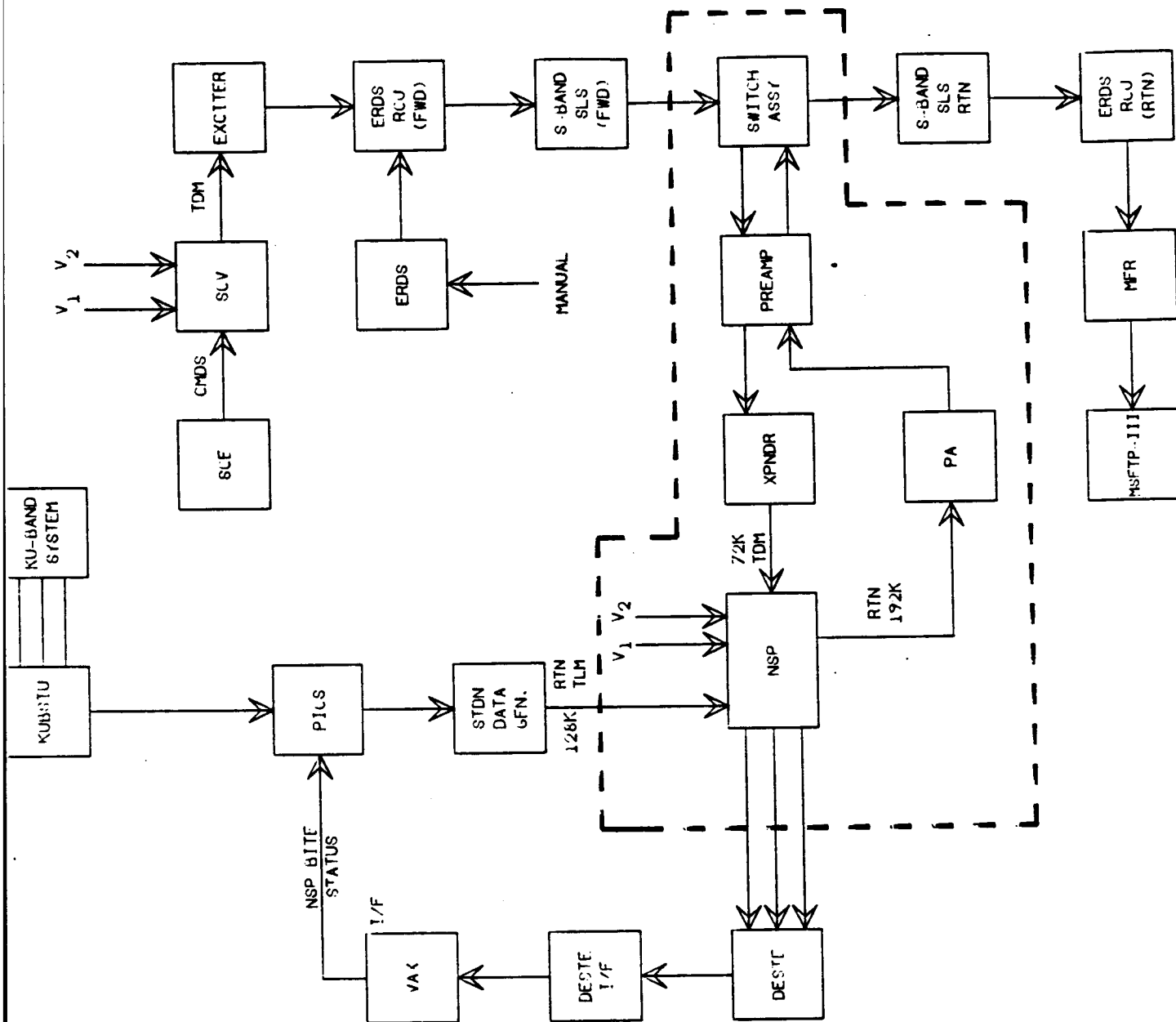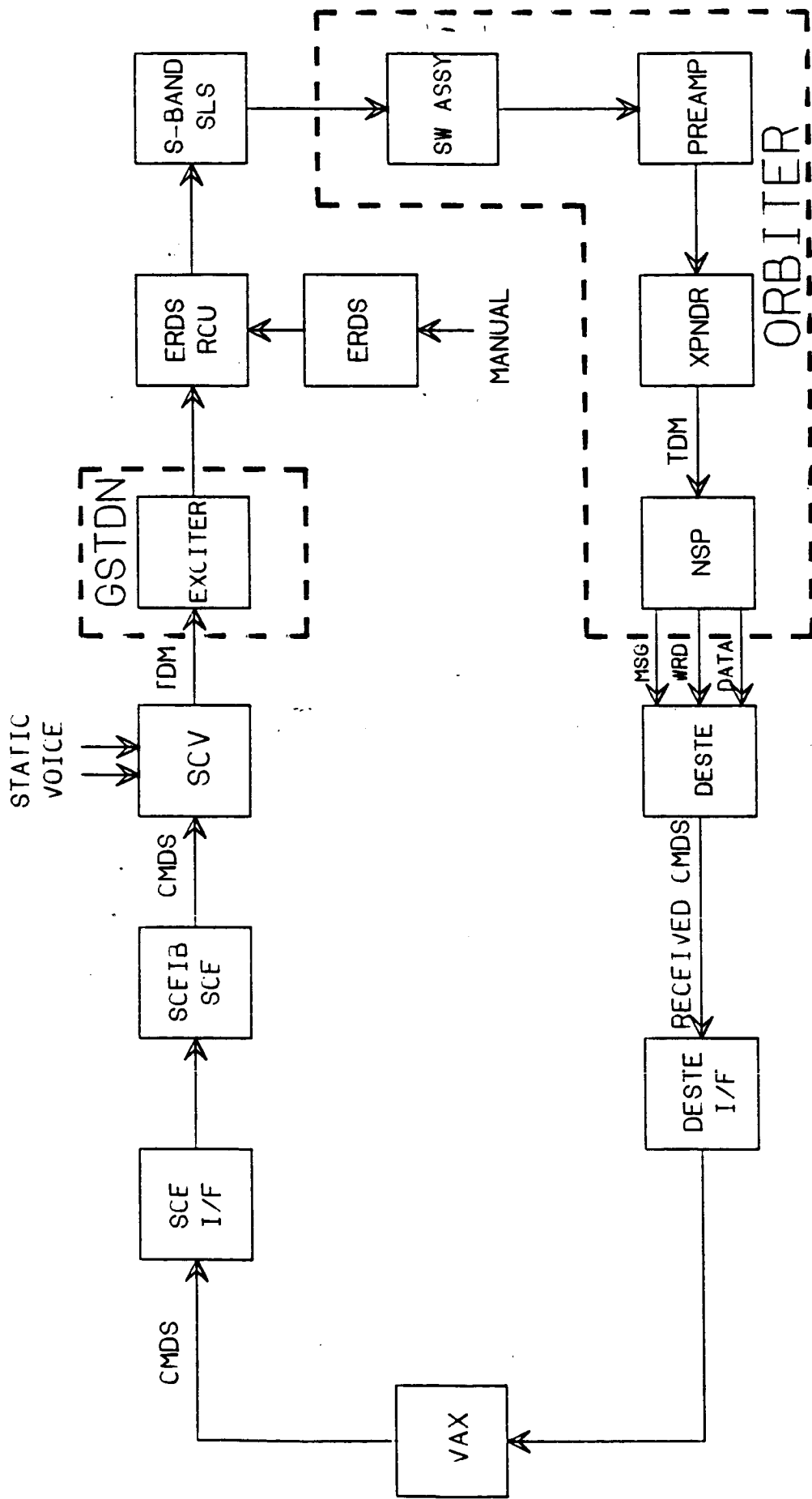
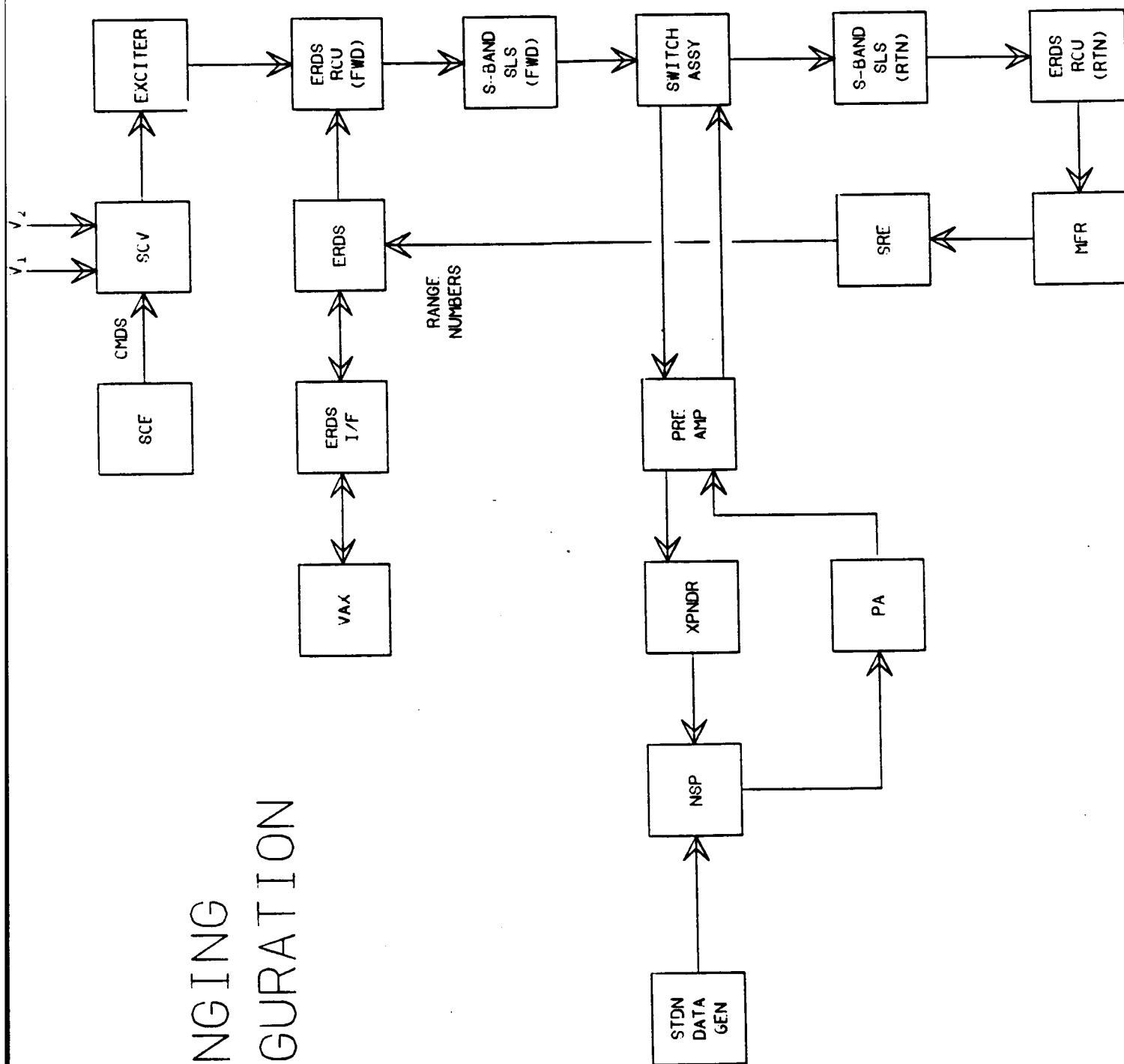C-5

APPENDIX III

SELECTED ESTL TEST CONFIGURATIONS

REAL-TIME
TELEMETRY
CONFIGURATION

COMMAND CONFIGURATION

RANGING
CONFIGURATION

DOPPLER CONFIGURATION

THE FOLLOWING SYSTEMS ARE AVAILABLE (TO VARYING DEGREES) FOR LAB AUTOMATION
USE/INCLUSION:

1. VAX 11/785

   Hardware/software currently available:

                a.   6 MB RAM memory
                b.   1.4 GB hard disk memory (fixed)
                c.   VMS 4.2 operating system
                d.   FORTRAN, Macro
                e.   LXY line printer
                f.   LA120 system console
                g.   VT241 Terminal
                h.   Interface cards for the following test equipment:
                     1)   Spacecraft Command Encoder   (SCE)
                     2)   Payload Interface Control System (PICS)
                     3)   TDRS ground station Interface Control System (TICS)
                     4)   Command Special Test Equipment (CSTE)
                     5)   ESTL Range and Doppler Simulator (ERDS)
                     6)   GMT time
                     7)   MSFTP-2 decom
                     8)   MSFTP-3 decom

   Hardware/software to be added this year (dependant on funding)

                a.   More terminals -- VT220, VT240, VT241 and perhaps
                                       TEK 4107 class terminals
                b.   Forms management and Datatrieve (databasing)
                     software
                c.   Perhaps an Aptec I/O processor (funding shakey)
                d.   Interface cards for the following new equipment:
                     1)   Command Processor
                     2)   Ethernet interfacing for Applicon CAD,
                          new Data Systems Data Management Control
                          System, and

LABORATORY INSTRUMENTATION

1. Task 1: -- Terminal Input: Manual data entry on a displayed form.
   Graphical display--[??] rough and final

   Option 1:
   a. Using F[??] on the VAX 11/7[?]5 display form and manually enter data.
   b. Plot data "real-time" using R[?]L on terminal for rough form.
   c. Plot on HP plotter for final.
   d. Include capability for pretest predictions.
   e. Test configuration diagrams drawn on Applicon.

   Option 2:
   a. Put F[??] on the Applicon VAX 11/750, add VT241 terminals and plotters.
   b. Perform the above except use Applicon VAX.

   Option 3:
   a. Draw forms using Applicon and use GPSDC's to enter data onto forms.
   b. Plot data realtime onto drawn graphpaper for rough.
   c. Plot on HP plotter for final.
   d. Perform [??] as for Option 1.
   e. All data would reside on same disk and in same data base.

   Option 4:
   Use spreadsheet techniques or programs with split-screen and graphics capabilities.

2. Task 2: -- Automated Configuration Drawings

   Use [??] systems techniques to produce configuration drawings for upcoming tests. Work in conjunction with the [??] system for drawings.

   Option 1: Total use of EXPERT techniques with minimal operator inputs in the form of menu picks (-DE?/ACQUISITION/ AUDIO/VIDEO/TEST, [?] AM/R=SYNC/BWF, UPLINK/DOWNLINK/ [??]/ TEST/ [??], etc)

   Option 2: [?] have an operator assist. Have generalized functional blocks (DECOM, BIT SYNC, FRAME SYNC, ETC) as menu buttons. Operator constructs a general signal flow diagram. EXPERT program then selects the type of bit sync, decom, etc to use and constructs detailed configuration diagram complete with recommended patching.

- ... -- automatically ____ ____ from test equipment.

____ ____ capability ____ in Phase 1 with the ability
to automatically ____ ____ from a specified piece of test
equipment (____ ____ detector) and display result on appropriate
form and plot.

4. ____ ____ -- automatic reconfiguration of Lab

____ Perhaps using AI techniques, augment capability in Phase 2
with the ability to automatically configure part or all of the
lab as necessary to perform a given test.