COMSAT Laboratories

QUARTERLY TECHNICAL REPORT

# COMSAT PARTICIPATION IN DARPA PACKET SATELLITE INTERNETWORKING AND SPEECH APPLICATIONS PROGRAM

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COMMUNICATIONS SATELLITE CORPORATION
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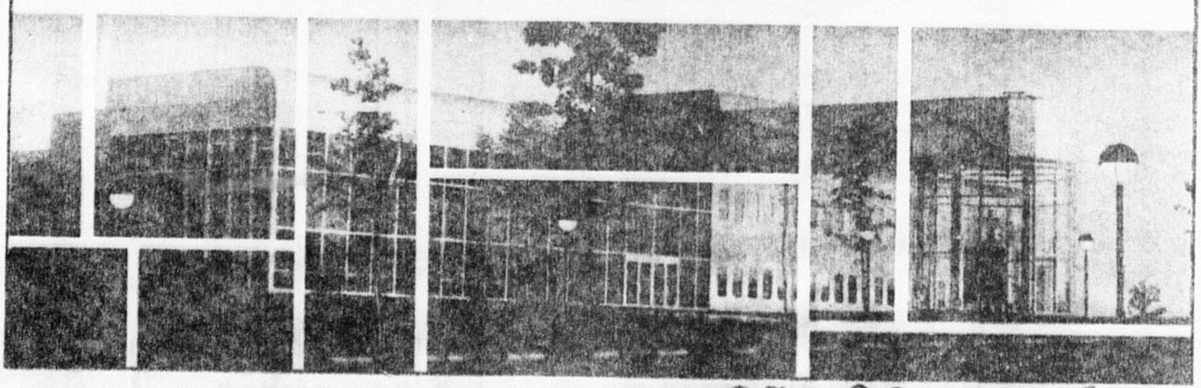

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# Second Quarterly Technical Report

15 June 1979 to 15 September 1979

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# 1. INTRODUCTION/SUMMARY

## 1.1 INTRODUCTION

This is the second Quarterly Technical Report issued under contract MDA 903-79-C-0308. This report covers COMSAT's activities from mid-June to mid-September 1979 under the three major task areas:

Task 1 - Transition of SATNET to Operational Status
Task 2 - Internetting Experiments
Task 3 - Wideband Integration/Coordination

of a contract under which COMSAT continues its participation in packet speech and internetting applications. Section 2 of this report review the work under Task 1 on SATNET's transition to operational status. Internetting activities are summarized in Section 3 and the technical work related to wideband system coordination is summarized in Section 4.

## 1.2 SUMMARY

Activities under Task 1 of this contract were restricted due to delays in completing delivery of the three Packet Satellite Program (PSP) terminals under a previous contract. The PSP terminal for Etam was delivered in late June 1979. The PSP terminal for the Goonhilly earth station was shipped at the end of August 1979 and initial installation was completed during the first week of September. Although the Etam PSP terminal operated in the network for a period of more than a month up through the end of August 1979, system problems arose at that time and the SPADE backup was restored.

A decision was made in mid-September to delay shipment of the third PSP terminal, which was scheduled for delivery to Tanum, Sweeden, until after the NTC demonstration in late November. Effort was therefore focused on resolving the SIMP/PSP incompatabilities in the terminals installed at Etam and Goonhilly.

The major effort under the contract during this reporting period was devoted to preparations for a live demonstration of the SATNET technology, which is scheduled for November 1979. This demonstration will be part of a session at the National Telecommunications Conference (NTC), which will be held in Washington, D.C. on 27-29 November. The demonstration will include packet speech and facsimile transmission between the conference site and University College London (UCL). COMSAT is presently coordinating the necessary hardware and software development between the major participants.

Activities under Task 3, wideband system coordination/integration, have concentrated on additional computer simulations of candidate frequency plans for the EISN carrier. Meetings were held at Western Union in April, and again in July, to receive the most recent planning information for the EISN communication link. This information was incorporated into the simulation model and additional simulation experiments were performed.

# 2. ACTIVITIES UNDER TASK 1: TRANSITION OF SATNET TO OPERATIONAL STATUS

## 2.1 INTRODUCTION

During the reporting period, two activities have been persued relative to the transition of SATNET to operational status. In July, the decision was made to request a nine month extension in the experimental status of SATNET. This status was due to expire in September 1979, but with a nine month extension, the experimental status would be extended until June 1980. The request for extension was submitted in August 1979.

A second activity under this task was continued monitoring of the SATNET data which is received each day from BB&N. A summary of these data for August and September is given in the remainder of this section.

## 2.2 SATNET PERFORMANCE DATA

Since January 1979, COMSAT has been compiling and summarizing the daily data on missed hello-packets in the SATNET system which is operating between Etam, Goonhilly, and Tanum. These data have provided useful information about the general quality of the nine SATNET links and their variability from day to day. It has also been possible to deduce link bit-error probability from the missed hello-packet data and to compare these results to the performance that would be expected in the SPADE transponder. The hello-packets are generated continuously

*Data prior to August is included in Section 6 of "Final Report, COMSAT Participation in ARPA Packet Satellite Program (PSP)," sponsored by DARPA, ARPA Order No. 3287, monitored by SAMSO/ YAPC under Contract No. F04701-C-0240, October 1979, by COMSAT Laboratories, Clarksburg, Md. 20734.

(approximately 66,000 per day) and are used only for synchronization. As such, the data on the success or failure of hello-packet reception gives useful, but indirect, evidence of the degree of success experienced by users who are transmitting message traffic via SATNET.

In April 1979, an additional summary of the SATNET channel data has been provided each day by BB&N. The new data applies directly to the efficiency of SATNET in handling the message traffic offered to it. The purpose of this subsection is to summarize the new data and to propose some overall "quality measures," for SATNET channel performance.

### 2.2.1 The SATNET Frame

The general format of the SATNET frame is shown in Figure 2-1. This frame structure has been in effect since April 1979. The data subframes are 27 virtual slots long. During a day there are 65,918 frames each of which contains 128 virtual slots. 84.4 percent of the virtual slots are available for sending message packets, and the rest are used for the hello-packets (3.1 percent) and the control packets (12.5 percent). With the total frame divided into four parts as shown in Figure 1, there are 4 x 65,918 = 263,672 PODA (priority-oriented demand assignment) frames in which data can be sent.

### 2.2.2 Proposed Measures for SATNET Performance

A simple model can be proposed to subdivide the total time in one day according to the following events:

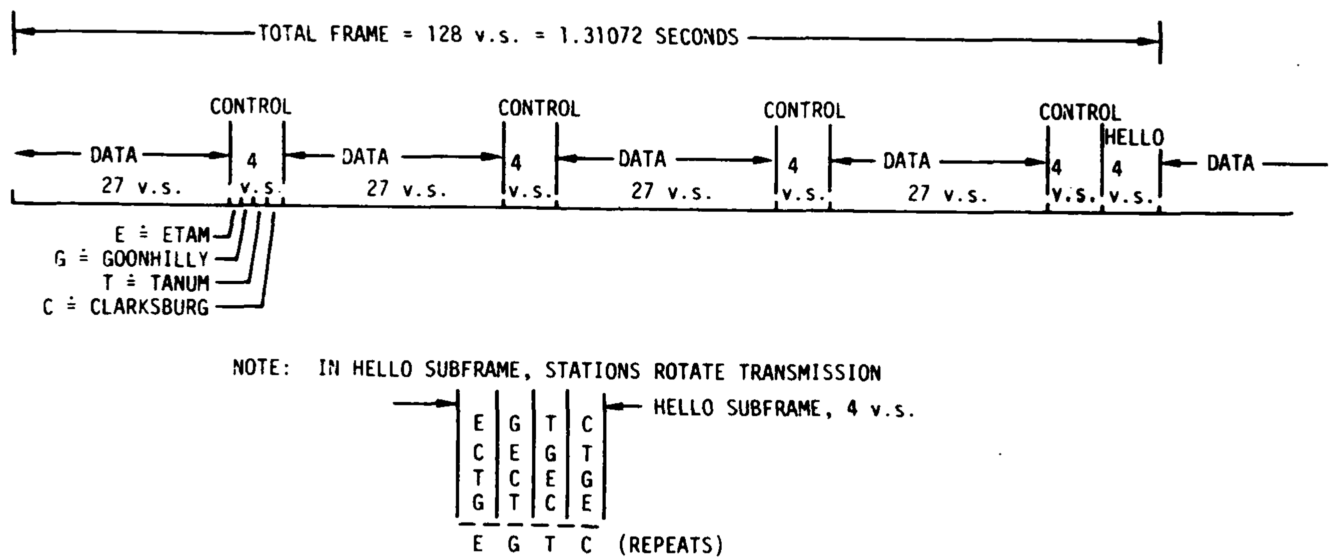


Figure 2-1. SATNET Frame as of April 1979

$O_1 \doteq$ the number of PODA Frames that are unavailable for transmission due to SIMP "outages." The SIMP outages fall into three categories; $m_1$ = minutes SIMP is cross patched, $m_2$ = minutes SIMP is in "loader/dumper," $m_3$ = minutes SIMP is not reporting. Using the conversion f $\doteq$ PODA Frames/minute = 263,672/1440 = 183.1, outage $O_1$ can be obtained as $O_1 = f(m_1 + m_2 + m_3)$ PODA Frames.

$O_2$ - The second form of outage occurs when the SIMP is operating and accepting traffic but the SATNET network is out of synchronization. These outages can be due to several causes i.e.,

(a) hello frames out of sync,
(b) SIMP is out of datagram reservation sync,
(c) SIMP is attempting datagram initial acquisition, or
(d) SIMP is out of stream sync

Note that $O_2$ should indicate the number of PODA frames that are unavailable for transmission due to synchronization problems. Presumably, the number of PODA frames in datagram reservation sync, which we can define as $F_{in}$ can be obtained as

$$F_{in}(k) = 263{,}672 - O_1(k) - O_2(k) \qquad (2.1)$$

where;

$F_{in}(k)$ - is the total number of PODA frames in datagram reservation sync at transmitting station k

$O_1(k)$ - number of elapsed PODA frames during SIMP outages (available from the data) at station k

$O_2(k)$ - number of PODA frames that transmitting station k is out of synchronization (likewise available from the summary data)

It is proposed that the first efficiency measure used is simply the ratio of $F_{in}/263,672$ denoting the "potential" PODA frames which are available for sending messages. That is,

$$\eta_1(k) \doteq \frac{F_{in}(k)}{263,672} = \text{"Availability"} \qquad (2.2)$$

This first efficiency measure asks the question, "is the system able to handle traffic if such traffic were presented to it?" The answer to this question can be "no" for two reasons; either the SIMP is down, or the station is out of synchronization. The measure $\eta_1(k)$ is an important first measure of "availability" and it seems to be readily available from the channel summary data.

A second important question is, how much traffic was the station called upon to transmit during the periods of time when it was "available" to transmit? This measures the loading presented to the earth station and this number also seems to be readily available from the data as the number of channel data packets transmitted, which will be denoted as $P_t(k)$. Unfortunately, the number of virtual slots consumed by each data packet are not known except that these are constrained as;

$$1 \leq \frac{\text{Virtual Slots}}{\text{data packet}} \leq 5$$

However, the average virtual slots per packet is not known. It is proposed for now that the loading is treated in terms of the parameter $V_p$, where $V_p$ is assumed to be either 2 or 3 (See Table 2-1). Until more accurate information is available, a reasonable average for $V_p$ will be assumed as 2.5; which will be denoted as $\bar{V}_p$.

Table 2-1. Assumed Format of Data Packets

Symbol Durations in Packet Excluding Data

| | |
|---|---|
| Symbols Times for Carrier Acquisition | 60 |
| Symbol Times for Clock Recovery | 60 |
| Unique Word | 16 |
| Syn-Syn-DLE-STX Sequence | 16 |
| Header (17 16-bit words) | 136 |
| Data (variable) | |
| DLE-ETX Sequence | 8 |
| Check Sum | 12 |
| Total Length of packet excluding data and guard times | 308 symbols = 9.63 ms |

Guard Times

| | |
|---|---|
| 800 μ seconds for transmitter "overhang" time | |
| 335 μ seconds for guard time (due to timing inaccuracies) | |
| 240 μ seconds for the "staggering" of the packet-start times among the four earth stations | |
| Total | 1.375 ms |

Data Bits in Packet (maximum)

| #Virtual Slots Assigned to a User | Maximum Number* of Data Bits in Packet |
|---|---|
| 1 | 0 |
| 2 | 592 |
| 3 | 1248 |
| 4 | 1904 |
| 5 | 2560 |

*Calculated for "N" virtual slots as [N x 10.24 ms - 9.63 ms - 1.375 ms] x 64 rounding to lowest number of 16 bit words.

Assuming an average packet length of $\bar{V}_p$ virtual slots, then the "loading" measure becomes

$$\eta_2(k) = \frac{P_t(k) \begin{pmatrix}\text{Data packets}\\ \text{Transmitted}\end{pmatrix} \cdot \bar{V}_p \ \frac{\text{V.S.}}{\text{packet}}}{F_{in}(k) \begin{pmatrix}\text{frames}\\ \text{Avail}\end{pmatrix} \cdot 27 \left(\frac{\text{V.S.}}{\text{frame}}\right)} \ (\text{avg}) \doteq \text{"Loading"} \quad (2.3)$$

An additional measure of effectiveness is the ratio of total packets received at all stations to total packets transmitted. This ratio

$$\eta_3 = \frac{\sum_{k=1}^{3} P_r(k)}{\sum_{k=1}^{3} P_t(k)} \doteq \text{"Success"} \quad (2.4)$$

applies to the total network.†

A final measure that reflects total network loading is:

$$\eta_4 = \frac{\sum_{k=1}^{3} P_t(k) \cdot \bar{V}_p \quad \text{Virtual Slots used for Data}}{263{,}672 \times 27 \quad \text{Total Virtual Slots/Day}} \doteq \text{Composite Loading}$$

The efficiency measures $\eta_4$ (Composite loading), $\eta_3$ (ratio total packets received to total transmitted), and $\eta_1(k)$ (availibility of station k; k = 1 for ETAM, = 2 for Goonhilly, = 3 for Tanum) are summarized in Table 2-2 for certain days in April 1979 when these data first became available.

†It has been found in reviewing subsequent summary data that the measure of success $\eta_3$ sometimes gives a number greater than one. When this number exceeds one, more packets are reported received than were reported as transmitted which simply means that some transmitted packets were not reported. The measure $\eta_3$ thus will not be very useful until the data reporting procedure is made more reliable.

## Table 2-2. Channel Summary, April 1979

| | | 20 | 21 | 22 | 23 | 24 | 25 | 26 | 27 | 28 | 29 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| PODA FRAMES AVAILABLE | | | | | | | | | | | |
| | E | 227,385 | 249,769 | 252,388 | 253,363 | 199,611 | 242,151 | 226,010 | 40,414 | 250,143 | |
| | G | 229,702 | 234,540 | 237,859 | 245,749 | 196,096 | 247,296 | 225,001 | 28,160 | 240,163 | |
| | T | 137,070 | 246,840 | 251,880 | 256,146 | 200,192 | 238,592 | 202,282 | 28,138 | 218,208 | |
| AVAILABILITY | | | | | | | | | | | |
| | E | 0.862 | 0.947 | 0.957 | 0.965 | 0.757 | 0.918 | 0.857 | 0.153 | 0.948 | |
| | G | 0.871 | 0.890 | 0.902 | 0.936 | 0.744 | 0.938 | 0.853 | 0.107 | 0.911 | |
| | T | 0.520 | 0.936 | 0.955 | 0.975 | 0.759 | 0.905 | 0.767 | 0.107 | 0.827 | |
| DATA PACKETS TRANS | | | | | | | | | | | |
| | E | 233,246 | 60,391 | 159,046 | 370,815 | 180,813 | 277,236 | 147,136 | 32,174 | 273,084 | |
| | G | 228,659 | 55,381 | 136,594 | 357,546 | 175,575 | 275,157 | 142,242 | 26,372 | 266,422 | |
| | T | 6,144 | 13,759 | 11,792 | 13,714 | 8,416 | 9,060 | 9,184 | 2,952 | 12,354 | |
| LOADING* | | | | | | | | | | | |
| | E | 0.076-0.114 | 0.018-0.027 | 0.047-0.070 | 0.108 -0.163 | 0.067-0.100 | 0.085-0.127 | 0.05-0.072 | 0.06 -0.088 | 0.08 -0.12 | |
| | G | 0.074-0.111 | 0.017-0.026 | 0.043-0.064 | 0.108-0.162 | 0.066-0.099 | 0.082-0.124 | 0.05-0.007 | 0.069-0.104 | 0.082-0.12 | |
| | T | 0.003-0.005 | 0.004-0.006 | 0.003-0.005 | 0.0004-0.006 | 0.003-0.005 | 0.003-0.004 | 0.003-0.005 | 0.008-0.012 | 0.004-0.006 | |
| COMPOSITE LOADING† | | 0.1643 | 0.0045 | 0.107 | 0.2605 | 0.128 | 0.1972 | 0.105 | 0.022 | 0.1938 | |
| TOTAL NETWORK SUCCESS RATE | | 0.991 | 0.990 | 0.992 | 0.9995 | 0.9987 | 0.9981 | 0.9927 | 0.9927 | 0.9938 | |

*First entry assumes 2 V.S. per data packet, second entry assumes 3 V.S. per data packet
†Composite Loading is based on an average of 2.5 V.S. per data packet, 263,672 x 27 virtual slots potentially available per day.

### 2.2.3 Conclusions

The objective here has been to propose some possible ways to utilize the new channel summary data. These methods use the data as it is presently available. Useful changes in format or additional data would be:

a) to measure and record average data packet length $\bar{V}_p$ rather than having to guess that it is 2.5.

b) to break out the data packet "success" percentages by link rather than having to deal with a composite overall "success" percentage. Actually, the composite number may be a useful summary as long as the data on missed hello packets is available. The latter gives a more detailed measure of success by link.

## 2.3 SUMMARY OF SATNET DATA; AUGUST, SEPTEMBER 1979

A compilation of the SATNET performance data for August and September 1979 is given in Table 2-3 through 2-6. Tables 2-3 and 2-4 give data on missed hello packets for the two months. The monthly average miss percentage for all links is 0.06 percent in August and 0.12 percent in September. The trends of missed hello packets by day for selected links is given in Figures 2-2 and 2-3 for August and September, respectively.

SATNET summary data for August and September is given in Tables 2-5 and 2-6, respectively. As noted in Section 2.2.2, the network success rate often gives a number greater than one indicating more packets reported received than were reported transmitted. This is a useful overall performance measure, but

Table 2-3. Hello Packet Data, August 1979

| DAY | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Missed Hello Pkts. | | | | | | | | | | | | | | | | |
| Link 1 | 1 | 57 | 26 | 0 | 0 | 0 | 1 | 0 | 2 | 1 | 0 | 0 | 0 | 0 | 0 | 3 |
| 2 | 8 | 23 | 80 | 0 | 16 | 18 | 11 | 5 | 5 | 99 | 24 | 22 | 215 | 11 | 24 | 3 |
| 3 | 1 | 51 | 22 | 4 | 15 | 2 | 16 | 1 | 1 | 18 | 2 | 1 | 5 | 1 | 15 | 7 |
| 4 | 2 | 1 | 0 | 0 | 2 | 1 | 2 | 1 | 1 | 0 | 0 | 1 | 3 | 1 | 0 | 0 |
| 5 | 2 | 6 | 5 | 1 | 2 | 4 | 7 | 1 | 4 | 2 | 5 | 3 | 167 | 11 | 11 | 15 |
| 6 | 0 | 3 | 3 | 60 | 1 | 3 | 20 | 2 | 3 | 14 | 4 | 3 | 9 | 6 | 6 | 1 |
| 7 | 7 | 168 | 17 | 15 | 14 | 15 | 17 | 5 | 12 | 39 | 15 | 7 | 19 | 10 | 11 | 6 |
| 8 | 9 | 15 | 44 | 21 | 26 | 23 | 24 | 10 | 17 | 43 | 15 | 10 | 76 | 22 | 21 | 10 |
| 9 | 7 | 102 | 39 | 22 | 20 | 18 | 20 | - | 17 | 46 | 14 | 10 | 16 | 13 | 15 | 7 |
| Daily Avg. | 4.1 | 47.3 | 26.2 | 13.7 | 10.7 | 9.3 | 13.1 | 3.1 | 6.9 | 29.1 | 8.8 | 6.3 | 56.7 | 8.3 | 11.4 | 5.8 |
| Outage Corr. Fac. | 1.17 | | 1.46 | | | | | 1.44 | 1.34 | 1.41 | | 1.13 | | | | |
| * E | 6 | 3 | 1 | 2 | 16 | 16 | 10 | 5 | 5 | 96 | 24 | 18 | 24 | 6 | 26 | 5 |
| G | 0 | 0 | 0 | 0 | 1 | 1 | 4 | 0 | 2 | 0 | 2 | 3 | 6 | 1 | 2 | 4 |
| T | 4 | 10 | 16 | 22 | 18 | 18 | 18 | 5 | 14 | 6 | 16 | 10 | 44 | 12 | 14 | 4 |

| DAY | 17 | 18 | 19 | 20 | 21 | 22 | 23 | 24 | 25 | 26 | 27 | 28 | 29 | 30 | 31 | Avg. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Missed Hello Pkts. | | | | | | | | | | | | | | | | |
| Link 1 | 3 | 2 | 5 | 0 | 0 | 0 | 781 | | 50 | 4 | | 3 | 93 | 45 | 31 | [illegible] |
| 2 | 0 | 0 | 0 | 3 | 41 | 0 | 248 | | 81 | 10 | | 12 | 100 | 2 | 703 | 44 |
| 3 | 3 | 7 | 52 | 1 | 2 | 0 | 2056 | | 0 | 3 | | 0 | 12 | 1 | 54 | [illegible] |
| 4 | 0 | 0 | 0 | 34 | 1 | 0 | 0 | | 114 | 2 | | 70 | 138 | 298 | 66 | [illegible] |
| 5 | 0 | 0 | 0 | 41 | 4 | 0 | 32 | | 20 | 4 | | 71 | 52 | 0 | 46 | [illegible] |
| 6 | 0 | 0 | 0 | 37 | 2 | 0 | 0 | | 0 | 12 | | 63 | 87 | 1 | 117 | [illegible] |
| 7 | 8 | 4 | 2 | 7 | 4 | 1 | 853 | | 0 | 9 | | 16 | 63 | 237 | 31 | [illegible] |
| 8 | 0 | 0 | 0 | 44 | 13 | 0 | 0 | | 0 | 10 | | 28 | 86 | 0 | 91 | [illegible] |
| 9 | 11 | 4 | 21 | 13 | 6 | 1 | 741 | | 0 | 15 | | 25 | 73 | 0 | 7 | [illegible] |
| Daily Avg. | 2.8 | 1.9 | 8.9 | 20 | 8.1 | 1.2 | 523 | | 29.4 | 7.7 | | 32.0 | 78.2 | 64.9 | 70.7 | [illegible] |
| Outage Corr. Fac. | | | | | | 2.72 | 1.60 | | 1.46 | | | 1.14 | | 1.46 | 1.33 | [illegible] |
| * E | 4 | 2 | 7 | 2 | 34 | 0 | 29 | | 3 | 5 | | 1 | 4 | 54 | 72 | [illegible] |
| G | 0 | 0 | 0 | 3 | 0 | 0 | 0 | | 1 | 1 | | 1 | 1 | 2 | 2 | [illegible] |
| T | 7 | 4 | 1 | 9 | 5 | 1 | 6 | | 0 | 3 | | 0 | 1 | 1 | 1 | 9 |

*Hello packets received with hardware checksum errors

Table 2-4. Hello Packet Data, September 1979

| DAY | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 | 24 | 25 | 26 | 27 | 28 | 29 | 30 | Monthly Average |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Missed Hello Pkts. | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Link | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 1 | 5 | 2 | | 9 | 5 | 18 | 48 | 25 | 6 | 10 | 31 | 17 | 79 | | 106 | 38 | 53 | 27 | 39 | 114 | 723 | 149 | 24 | 26 | | 6 | | 183 | 70 | 44 | 69 |
| 2 | 2 | 1 | | 350 | 44 | 177 | 281 | 8 | 21 | 6 | 27 | 6 | 64 | | 49 | 21 | 24 | 12 | 17 | 32 | 43 | 53 | 4 | 8 | | 2 | | 42 | 30 | 61 | 51 |
| 3 | 1 | 0 | | 7 | 9 | 1183 | 458 | 1405 | 5 | 689 | 787 | 15 | 669 | | 18 | 81 | 149 | 3 | 1 | 2 | 99 | 2 | 4 | 7 | | 0 | | 20 | 66 | 61 | 213 |
| 4 | 6 | 2 | | 14 | 5 | 447 | 297 | 23 | 69 | 3 | 9 | 15 | 6 | | 12 | 10 | 10 | 8 | 19 | 5 | 109 | 14 | 12 | 6 | | 7 | | 67 | 5 | 24 | 46 |
| 5 | 42 | 2 | | 115 | 114 | 135 | 682 | 126 | 92 | 2 | 6 | 16 | 52 | | 16 | 10 | 22 | 19 | 36 | 12 | 2 | 23 | 8 | 3 | | 2 | | 103 | 14 | 12 | 73 |
| 6 | 4 | 0 | | 11 | 5 | 61 | 133 | 36 | 63 | 28 | 173 | 8 | 78 | | 11 | 45 | 10 | 5 | 19 | 5 | 50 | 11 | 4 | 6 | | 20 | | 81 | 8 | 7 | 66 |
| 7 | 2 | 1 | | 5 | 6 | 0 | 11 | 6 | 7 | 16 | 19 | 9 | 109 | | 11 | 133 | 12 | 3 | 3 | 5 | 124 | 8 | 13 | 12 | | 30 | | 14 | 5 | [illegible] | 24 |
| 8 | 40 | 0 | | 1827 | 1712 | 41 | 479 | 10 | 91 | 16 | 16 | 2 | 100 | | 11 | 132 | 5 | 10 | 13 | 4 | 66 | 5 | 57 | 7 | | 30 | | 81 | 2 | 4 | 176 |
| 9 | 1 | 0 | | 5 | 11 | 2 | 52 | 19 | | 25 | 200 | 8 | 207 | | 3 | 151 | 19 | 1 | 1 | 2 | 30 | 8 | 13 | 9 | | 19 | | 9 | 0 | 3 | 30 |
| Daily Avg. | 11.4 | 0.9 | | 258.8 | 212.3 | 229.3 | 271.2 | 184.2 | 36.4 | 88.3 | 140.9 | 10.7 | 151.6 | | 26.3 | 69.0 | 33.8 | 9.8 | 16.4 | 20.2 | 138.4 | 30.3 | 15.4 | 9.3 | | 12.9 | | 66.7 | 22.2 | 31.2 | 78 |
| Cutover Corr. Fac. | | 1.27 | | | | | 1.14 | | | | | | 1.02 | | | 1.41 | | | 1.31 | | 1.57 | | 1.16 | 1.13 | | 1.43 | | 1.65 | 1.73 | 1.07 | N/A |
| * | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| E | 5 | 1 | | 103 | 35 | 1141 | 670 | 1580 | | 650 | 877 | 15 | 239 | | 96 | 36 | 117 | 21 | 22 | 54 | 24 | 11 | 15 | 13 | | 3 | | 17 | 7 | 0 | 213 |
| G | 3 | 1 | | 1 | 7 | 19 | 214 | 202 | 4 | 3 | 57 | 15 | 24 | | 14 | 11 | 17 | 13 | 4 | 5 | 3 | 8 | 7 | 3 | | 3 | | 4 | 3 | 4 | 24 |
| T | 2 | 1 | | 0 | 18 | 1 | 22 | 20 | 0 | 31 | 111 | 9 | 63 | | 15 | 2 | 15 | 5 | 2 | 7 | 0 | 3 | 2 | 5 | | 1 | | 1 | 2 | 0 | 12 |

*Hello packets received with hardware checksum errors

Table 2-5. SATNET Summary Data, August 1979

| DAY | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 | 24 | 25 | 26 | 27 | 28 | 29 | 30 | 31 | Monthly Average |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| % FCDA Frame Avail. | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| E | 86.3 | 90.1 | 88.2 | 99.1 | 100 | 98.8 | 98.7 | 67.0 | | 92.6 | 98.8 | 97.8 | 97.6 | 97.9 | 93.9 | 98.8 | 98.4 | 99.7 | 99.4 | 97.8 | 77.9 | 54.2 | 60.1 | | 100 | 97.2 | 97.2 | 81.9 | 93.9 | 61.3 | 94.7 | 90 |
| G | 87.3 | 52.4 | 47.4 | 98.9 | 99.9 | 80.8 | 98.9 | 66.3 | | 94.2 | 99.3 | 97.9 | 97.8 | 98.1 | 94.8 | 27.9 | 0 | 0 | 0 | 33.3 | 76.2 | 0 | 8.6 | | 76.4 | 97.4 | 98.4 | 70.0 | 61.2 | 61.0 | 94.6 | 66 |
| T | 87.5 | 96.7 | 89.7 | 98.4 | 99.8 | 99.7 | 98.4 | 66.0 | | 94.1 | 99.7 | 98.1 | 97.6 | 97.6 | 95.1 | 85.9 | 100 | 99.7 | 99.7 | 97.7 | 74.0 | 54.4 | 59.8 | | 31.3 | 63.6 | 58.4 | 29.7 | 69.9 | 60.7 | 94.4 | 78 |
| Ntwk. Avg. | 87.0 | 79.7 | 75.1 | 98.9 | 99.9 | 93.1 | 98.7 | 66.5 | | 93.6 | 99.3 | 97.8 | 97.7 | 97.9 | 94.6 | 70.9 | 66.1 | 66.5 | 66.4 | 76.3 | 76.0 | 36.2 | 42.8 | | 69.2 | 86.1 | 84.7 | 60.6 | 75.0 | 61.0 | 94.6 | 78 |
| Con. Pkt. Suc. Rate (%) | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| E | 95 | 99 | 84 | 81 | 81 | 81 | 80 | 79 | | 83 | 89 | 99 | 82 | 83 | 89 | 96 | 99 | 99 | 99 | 88 | 81 | 99 | 96 | | 98 | 88 | 86 | 96 | 98 | 99 | 100 | 91 |
| G | 96 | 100 | 91 | 90 | 90 | 89 | 89 | 89 | | 92 | 97 | 99 | 86 | 90 | 89 | 92 | 0 | 0 | 0 | 89 | 87 | 0 | 94 | | 98 | 93 | 91 | 93 | 97 | 100 | 99 | 80 |
| T | 95 | 99 | 86 | 81 | 84 | 82 | 80 | 79 | | 86 | 93 | 99 | 87 | 88 | 95 | 99 | 99 | 99 | 99 | 89 | 82 | 99 | 97 | | 94 | 80 | 85 | 95 | 98 | 100 | 99 | 88 |
| Ntwk. Avg. | 95 | 99 | 87 | 84 | 85 | 84 | 83 | 82 | | 87 | 93 | 99 | 85 | 87 | 91 | 96 | 66 | 66 | 66 | 89 | 83 | 66 | 96 | | 97 | 87 | 87 | 95 | 98 | 100 | 99 | 86 |
| Data Pkt. Suc. Rate (%) | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| E | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| G | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| T | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Ntwk. Avg. | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| App. Ntwk Load. (%) | 1.7 | 1.8 | 7.3 | 13.6 | 13.7 | 13.1 | 30.4 | 24.2 | | 13.3 | 13.3 | 5.1 | 14.9 | 14.4 | 13.0 | 6.0 | 1.3 | 1.4 | 1.4 | 9.2 | 19.8 | 4.7 | 0.9 | | 0.7 | 9.2 | 10.8 | 6.2 | 6.7 | 8.7 | 14.9 | 9.7 |

Table 2-6. SATNET Summary Data, September 1979

| DAY | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 | 24 | 25 | 26 | 27 | 28 | 29 | 30 | Monthly Average |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| % FODA Frame Avail. | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| E | 99.5 | 89.3 | 99.7 | 99.4 | 97.4 | 94.2 | 86.0 | 99.1 | 99.8 | 93.0 | 93.0 | 94.6 | 92.0 | 80.7 | 95.4 | 94.2 | 96.9 | 97.8 | 95.8 | | 61.1 | 91.0 | 23.2 | | | 80.9 | | | 74.7 | 50.4 | 87.1 |
| G | 99.2 | 89.1 | 99.0 | 95.8 | 95.2 | 36.6 | 61.4 | 73.6 | 80.0 | 91.4 | 91.4 | 95.8 | 90.1 | 82.3 | 96.0 | 93.9 | 97.3 | 97.2 | 94.9 | | 38.9 | 89.8 | 23.3 | | | 81.5 | | | 42.5 | 74.7 | 80.4 |
| T | 99.4 | 89.1 | 99.7 | 68.2 | 71.8 | 85.1 | 84.7 | 99.3 | 99.7 | 92.1 | 92.1 | 92.2 | 92.5 | 82.4 | 96.6 | 93.6 | 95.9 | 91.7 | 95.8 | | 16.6 | 27.6 | 23.4 | | | 53.4 | | | 81.0 | 96.0 | 80.8 |
| Nwk. Avg. | 99.4 | 89.2 | 99.5 | 87.8 | 88.2 | 72.0 | 77.4 | 90.7 | 93.2 | 92.2 | 92.1 | 94.2 | 91.6 | 82.0 | 96.0 | 93.9 | 96.7 | 95.5 | 95.5 | | 38.8 | 69.4 | 23.3 | | | 71.9 | | | 66.1 | 73.7 | 82.8 |
| Con. Pckt. Suc. Rate (%) | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| E | 100 | 100 | 100 | 77 | 93 | 99 | 94 | 94 | 94 | 96 | 96 | 94 | 92 | 93 | 93 | 100 | 97 | 92 | 93 | | 95 | 94 | 84 | | | 87 | | | 91 | 93 | 94 |
| G | 86 | 100 | 100 | 83 | 96 | 99 | 90 | 91 | 91 | 95 | 95 | 94 | 92 | 93 | 92 | 99 | 95 | 92 | 91 | | 95 | 94 | 88 | | | 94 | | | 89 | 92 | 93 |
| T | 100 | 100 | 100 | 45 | 85 | 99 | 93 | 92 | 94 | 91 | 91 | 92 | 93 | 92 | 92 | 100 | 96 | 93 | 93 | | 91 | 85 | 82 | | | 84 | | | 90 | 91 | 91 |
| Nwk. Avg. | 95 | 100 | 100 | 68 | 91 | 99 | 92 | 92 | 93 | 94 | 94 | 93 | 92 | 93 | 92 | 100 | 96 | 92 | 92 | | 94 | 91 | 85 | | | 88 | | | 90 | 92 | 93 |
| Data Pckt. Suc. Rate (%) | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Nwk. Avg. | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| App. Nwk. Load. (%) | 15.0 | 12.7 | 13.2 | 22.2 | 13.7 | 7.8 | 7.3 | 11.0 | 12.7 | 26.3 | 26.3 | 41.5 | 28.0 | 13.2 | 20.5 | 16.1 | 32.6 | 25.6 | 20.3 | | 0.5 | 2.1 | 4.7 | | | 18.9 | | | 1.0 | 5.9 | 16.0 |

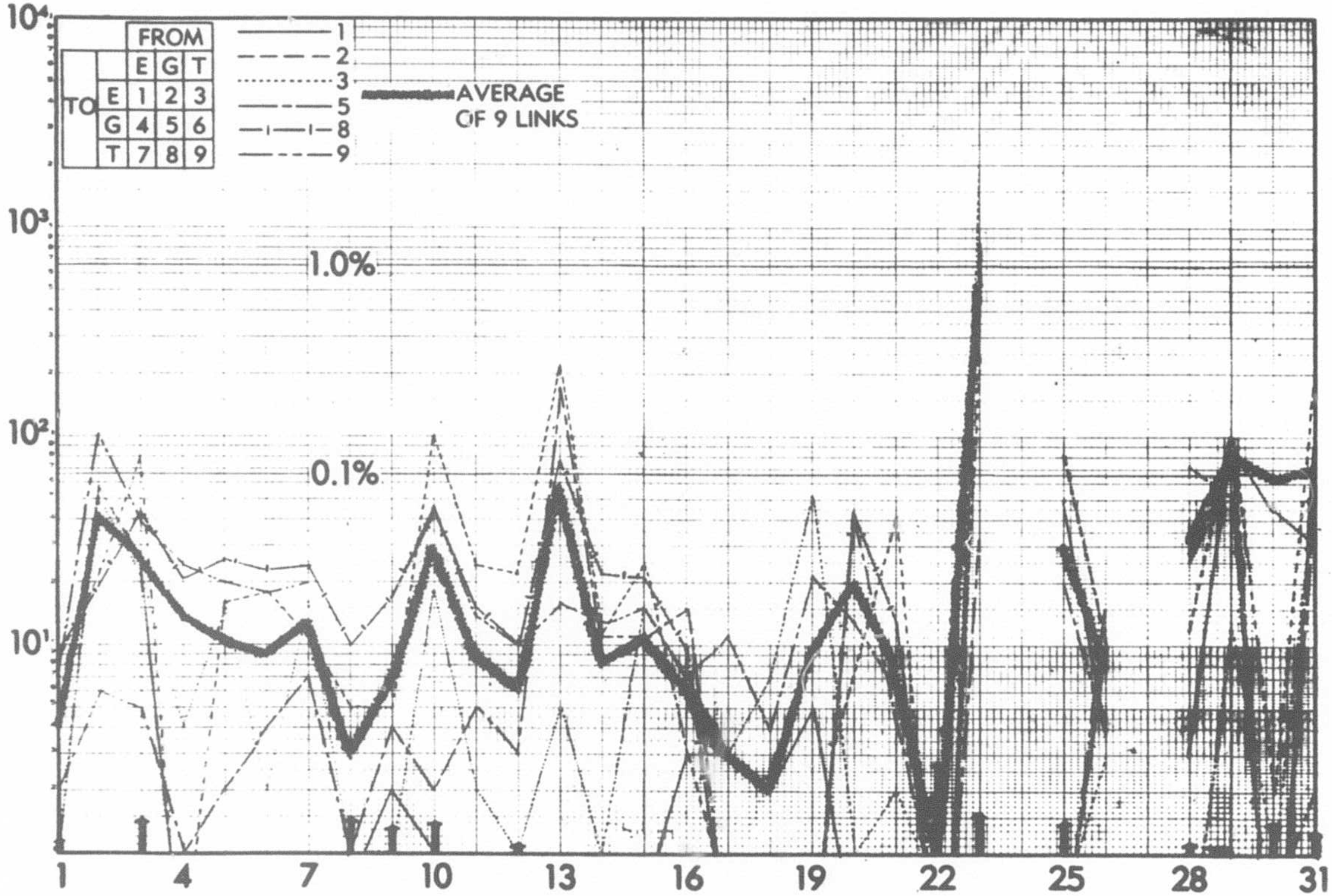


Figure 2-2. Missed Hello Packets per day by Link, August 1979

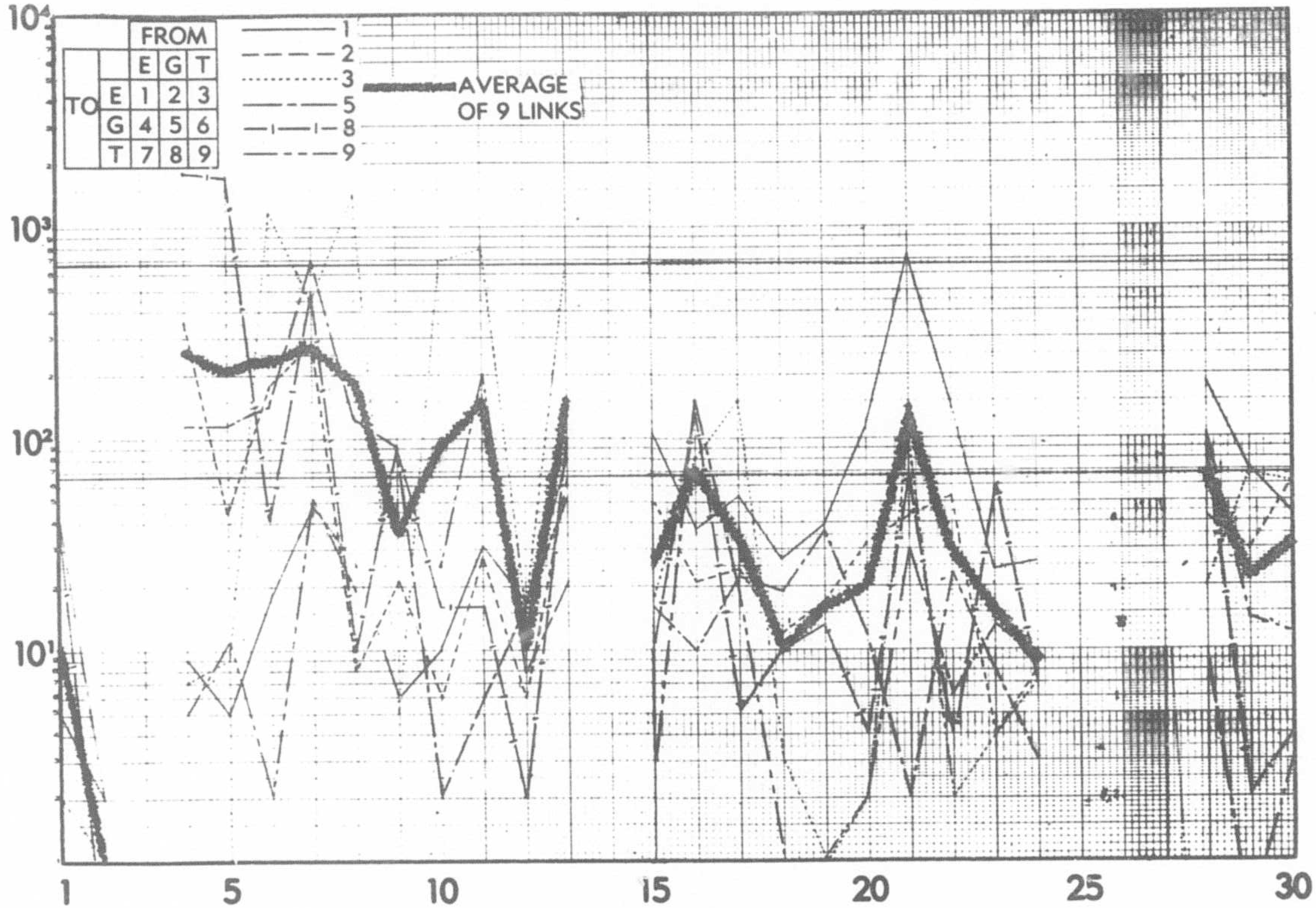


Figure 2-3. Missed Hello Packets per day by Link, September 1979

it cannot be included in the performance summary until reporting procedures are improved. These procedures as well as the processing of the summary data is expected to evolve and be refined as SATNET progresses toward applications support status.

# 3. ACTIVITIES UNDER TASK 2 - INTERNETTING EXPERIMENTS

## 3.1 PREPARATIONS FOR SATNET DEMONSTRATION

A major part of COMSAT's activities under Task 2 has been the coordination of a demonstration of SATNET technology to be held in conjunction with a technical session at NTC-79, to be held in Washington in late November, 1979. The demonstration is to highlight the multi-media and internetworking capabilities of the system and is to involve packet speech, facsimile and record traffic of various kinds. The vehicle for conducting this demonstration is to be a small computer system, called the Demo Terminal, which includes interfaces for the Lincoln Laboratory LPCM vocoder and Dacom 450 facsimile scanner/printer, together with a number of peripheral devices. The software for this system, now under development, is compatible with recent internet protocols developed within the ARPANET community, including TCP-4, TELNET and special protocols developed for real-time speech.

For the purposes of demonstrations and experiments, the Demo Terminal is to be connected to a PDP 11 gateway computer now located at COMSAT Laboratories in Clarksburg. This machine, which functions as an interface to SATNET, is connected to the Clarksburg SIMP satellite channel interface computer in a manner similar to other gateways, including those at BBN (Etam), NDRE (Tanum) and UCL (Goonhilly). However, in the Clarksburg case the earth station is capable of receiving only at a 16 kbit/s rate, rather than the 64 kbit/s rate used by the other stations. This fact considerably complicates the channel scheduling algorithm used to determine which station transmits at a particular time, and the software to support this mixed rate operation is not yet completely developed.

From the standpoint of the November demonstration, it is highly desirable to demonstrate those aspects of the SATNET design which advance the state of the art vis-a-vis current systems. Probably the most important of these is the integration of real-time speech, which must be delivered subject to critical delay limitations, and record data, which can be delayed in the interest of efficient channel utilization. The equipment now in place at the various experiment sites provides the capability to support real-time speech and record data between domestic U.S. gateways and UCL (London) and between these sites and the U.S. and European ARPANET. It would be highly desirable to demonstrate facsimile transmission via SATNET, and work is now proceeding on implementing appropriate interface software. While it is probable that the demonstration could take place even without the facsimile capability, real-time speech is considered to be necessary for a meaningful demonstration and hence will be given priority.

An additional important goal for the demonstration is to be able to demonstrate full SATNET connectivity via the Clarksburg gateway and the UET; however, the present software can support this only in a marginal way. This is because of two factors. The first is that a special temporary connection has had to be made via SATNET to support older protocols until use of these protocols can be phased out. The second is that control information coordinating the channel scheduling process is now sent at the rate of the lowest-rate earth station in the net, 16 kbit/s when Clarksburg is active. Accordingly, at least for the demonstration, Clarksburg cannot be used on the operational SATNET channel, at least for speech.

To provide an effective demonstration including real-time speech, a connection to a gateway other than Clarksburg is required. This can be done in two ways, as shown in Figure 3-1. The only domestic U.S. earth station, other than Clarksburg, connected to

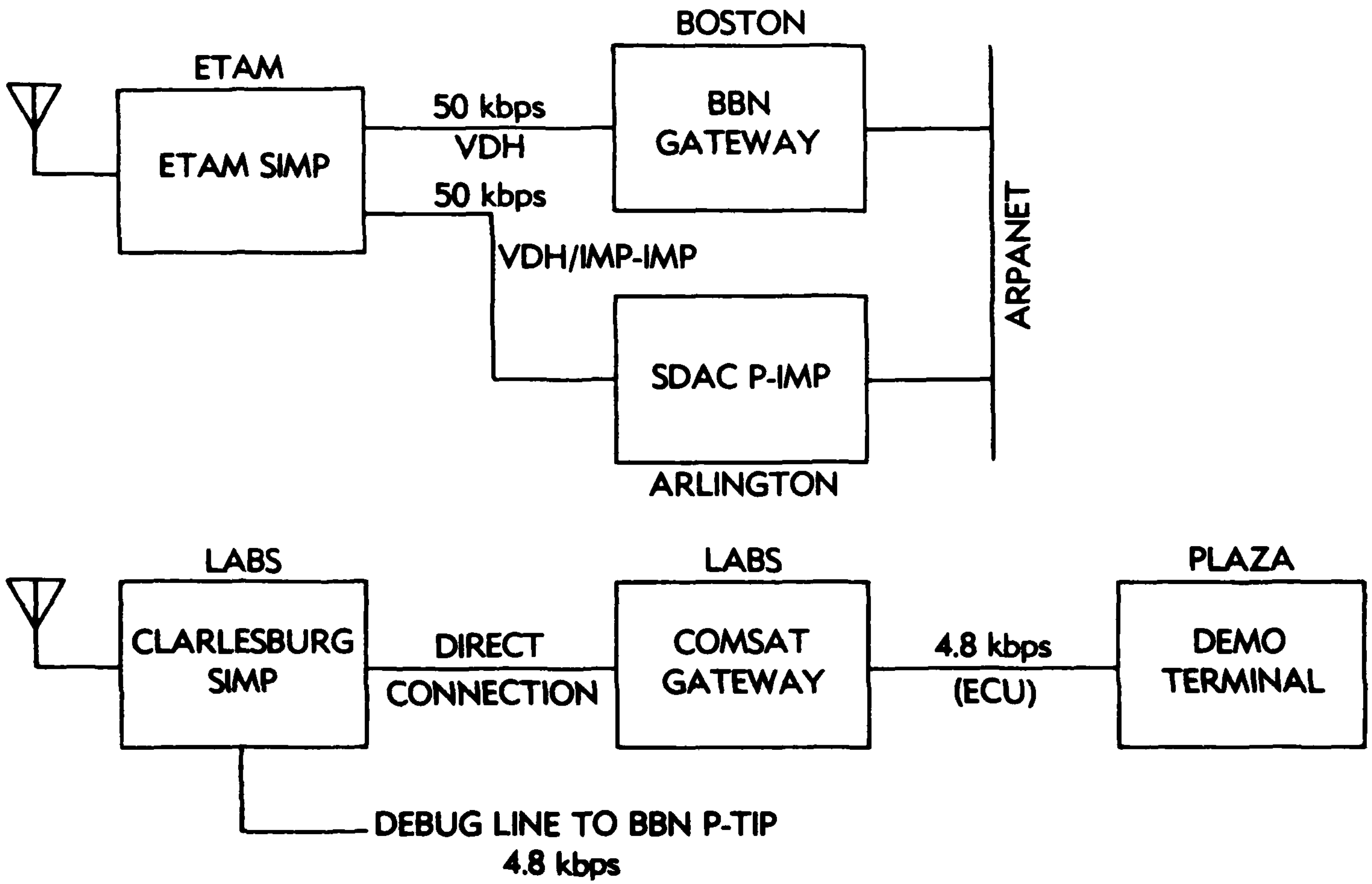


Figure 3-1. Possible Demonstration Configuration

SATNET is Etam. Normally it is connected via a line to the BBN gateway in Boston and by another line to the SDAC Pluribus-IMP in Arlington. The SDAC connection is operated on an IMP-IMP basis in order to support the European direct-connection mentioned above and on a Host-IMP (VDH) basis in order to perform certain tasks related to maintenance and development. The BBN connection is operated on a Host-IMP basis for SATNET traffic only. As a possible solution for Demo Terminal access to SATNET, a line could be run from Clarksburg the COMSAT gateway to Etam and used instead of the Etam-Boston line during the demonstration. The COMSAT gateway would then temporarily replace the BBN gateway. Connectivity via the Clarksburg SIMP could be restored by manually switching or replugging the lines as required. However, reconfiguration on-the-fly in this manner has previously been a source of considerable trouble and, in any case, requires complex and time-consuming software reconfiguration as well.

The second option, which is by far the most attractive, is to run a line from the demonstration site to the BBN gateway. This configuration, shown in Figure 3-2, provides full access to SATNET via either Etam, Clarksburg or both. A problem with this connection, however, is that connection to the domestic ARPANET is possible only via a second satellite hop via Norway, which introduces additional delay for this traffic. Nevertheless, this connection provides the most reliable scenario, as well as allowing direct comparisons between Etam and Clarksburg.

Although the Demo Terminal will support point-to-point speech, it does not yet support conference speech, where several users can share the common satellite channel in a controlled, dynamic fashion. Software to support this mode has been implemented by Lincoln Laboratories but runs only in the PDP 11 gateway machines. The operational and logistic factors to support a demonstration of conference speech would seem so extreme as to preclude its

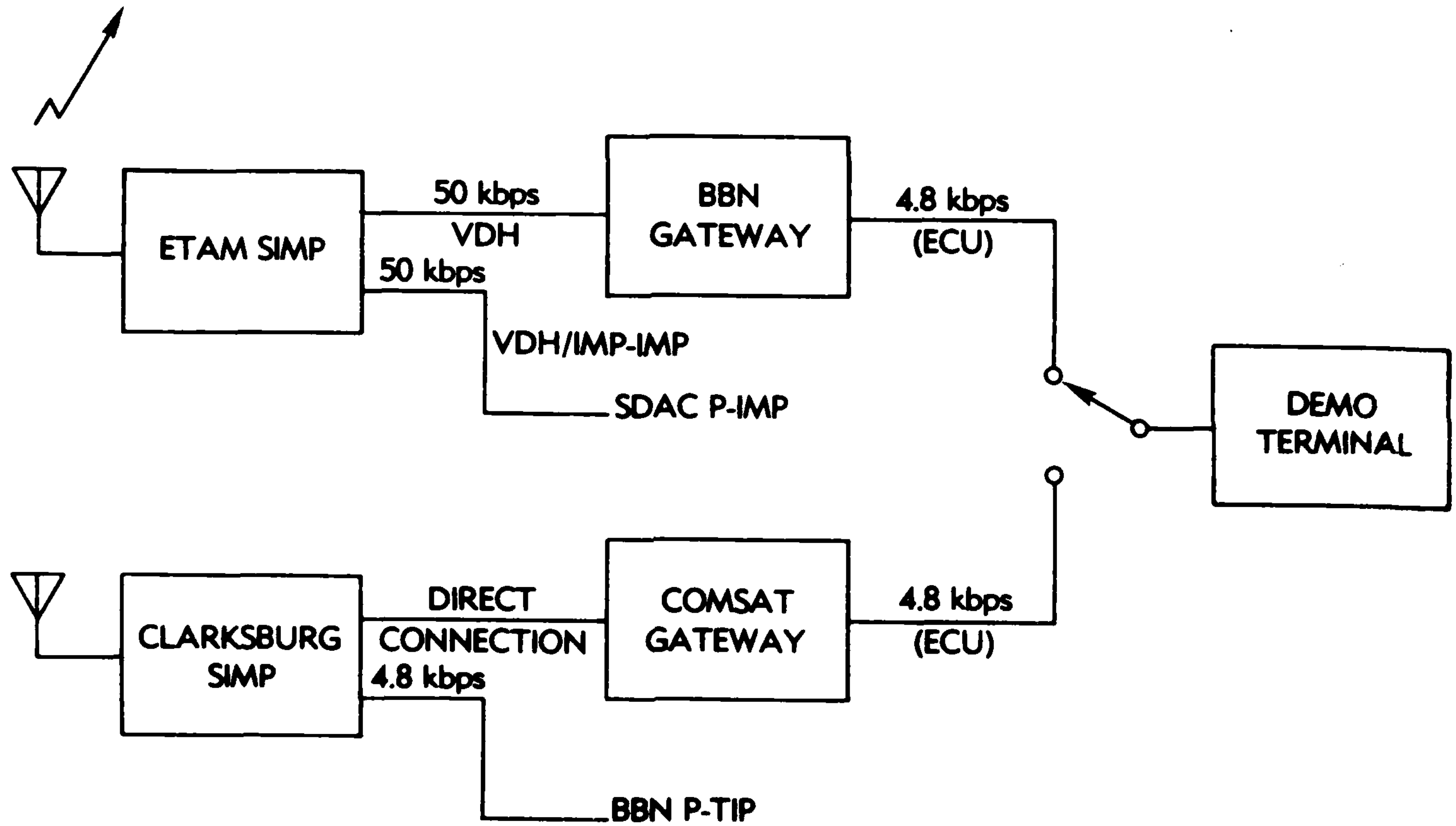


Figure 3-2. Alternative Configuration

possibility; however, a movie is now being prepared which shows a live conference in progress, and it may be almost as effective to show this instead.

There is an issue regarding connectivity between the Demo Terminal and gateways. With the present configuration, a pair of Error Control Units (ECU) are required for connection to each gateway. DARPA has agreed to provide a pair of these for connection between the COMSAT gateway and Demo Terminal; however, a second pair will be required for connection to the BBN gateway. Since the latter pair will be necessary only for a short time bracketing the demonstration, efforts will be made to borrow these units from another site.

In summary, the following seems an appropriate plan to implement the November demonstration:

a. Order a 4.8 kbit/s digital line from the convention site to Clarksburg and Boston. These would be installed approximately a month before the demonstration and removed shortly after.

b. Borrow an additional pair of ECU's from elsewhere in the ARPANET community for about a month, coinciding with the above.

c. Lease a Dacom 450 facsimile terminal for a period of about three months. This would allow time to develop the hardware and software interfaces between it and the Demo Terminal and, finally, to demonstrate the capability for transmission between it and UCL (which also has compatible equipment and can run the same software) and for archiving, etc., with ARPANET hosts.

d. Plan on moving the Demo Terminal and the Dacom 450 to the convention site a few days before the demonstration for last minute checkout.

The overall configuration planned for the November demonstration is shown in Figure 3-3.

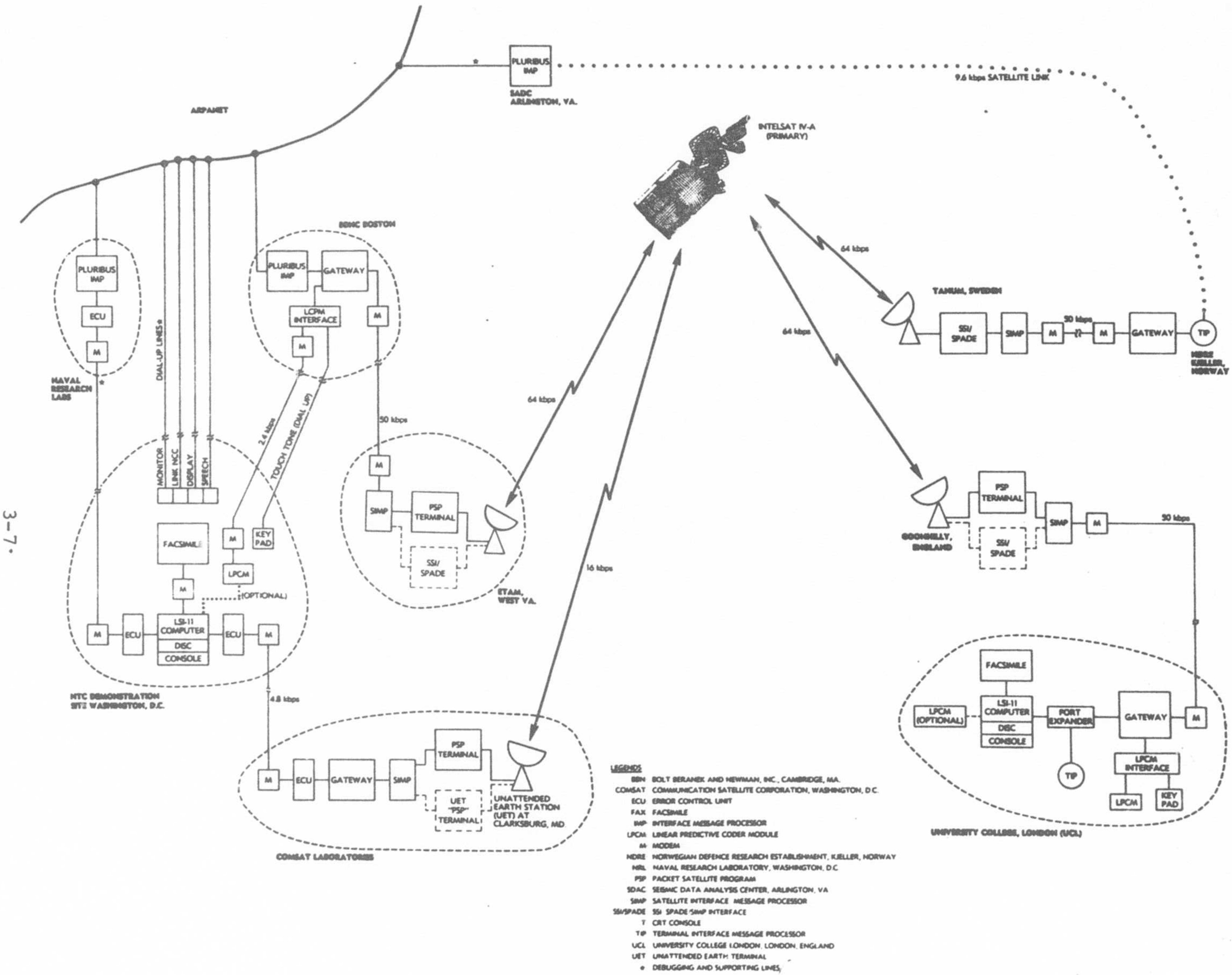


Figure 3-3. Network Configuration for Demonstration

## 3.2 INTERNETTING ISSUES

### 3.2.1 USE OF TCP AND RTP IN THE DEMO TERMINAL

Several issues are explored concerning operation of internet protocol modules in the Demo Terminal which runs DCN software. These protocol modules are designed to support internet connections with hosts on other networks, including SATNET, PRNET and ARPANET for real-time (speech) and record traffic.

The DCN supports user processes which can run the RT-11 system and user programs. Insofar as practical, the internet interfaces to these processes have been cast in a manner compatible with the RT-11 programming conventions, so that application programs can be constructed in high-level languages such as FORTRAN. The implementation described here supports multiple-connection user and server access to TCP, as well as raw internet datagram access for real-time speech.

### 3.2.2 ARCHITECTURE OVERVIEW

The basis for much of the implementation is the TCP4 and TELNET modules for SRI. These have been modified for use in the Basic Operating System (BOS), which supports the DCN in LSI-11 machines. In general, the modifications required have been minor and preserve the general philosophy and integrity of the original design. The general organization, shown in Figure 3-4, includes a single process as the internet attachment for a number of connections, all of which must be in the same machine (called a hostel) as this process. A gateway process, which can be in a different hostel, interfaces the internet process to the outside world (that is, outside the collection of hostels which represent the DCN)

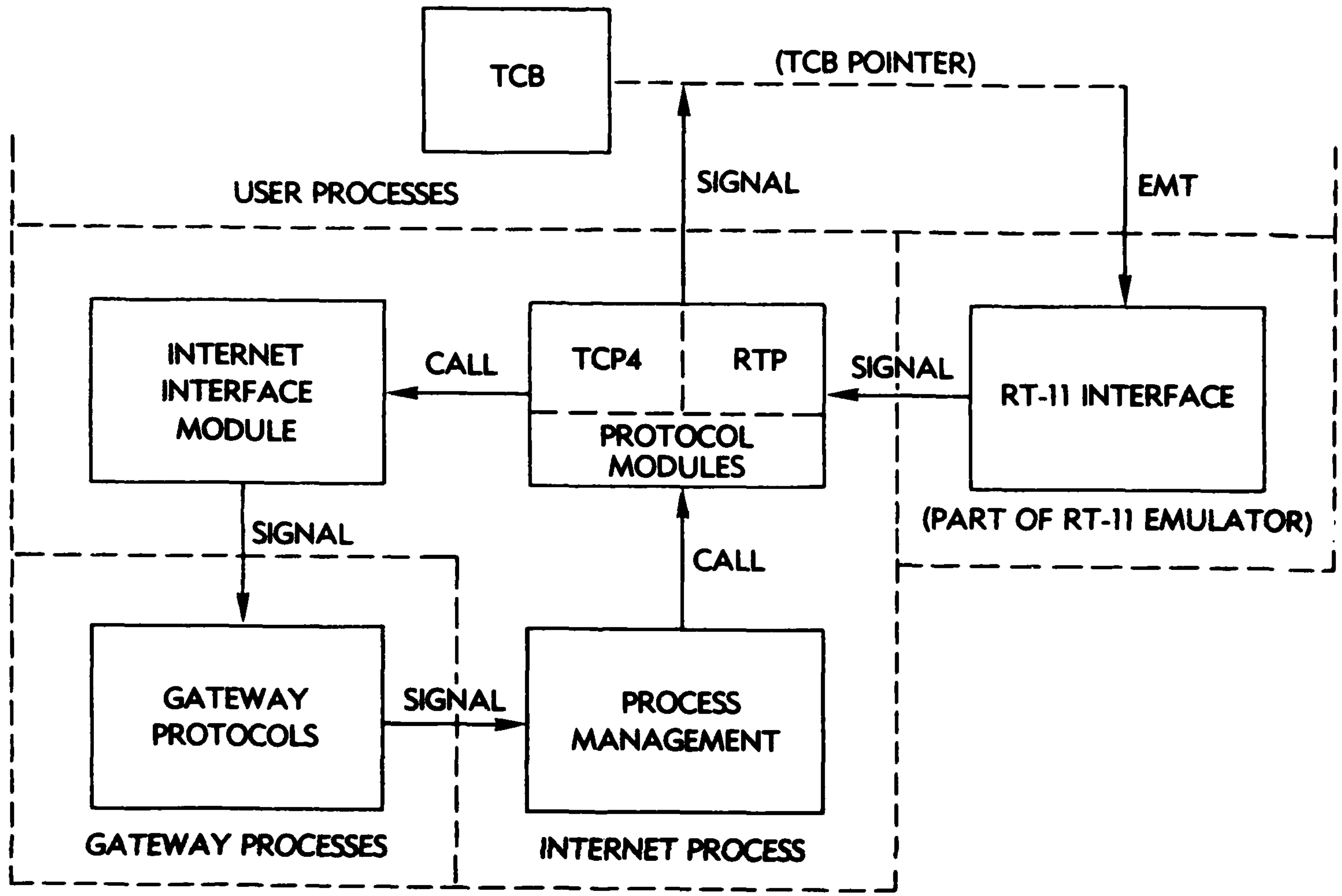


Figure 3-4. System Architecture

via a network-specific driver. In the COMSAT case this driver connects to the COMSAT gateway via an 1822 link and is compatible with the Port Expanders.

Interface to user processes is via a set of routines which operate as part of the RT-11 emulator package for the BOS. A number of programmed requests (EMT's) are provided to perform the TCP4 functions of $OPEN, $CLOSE, $SEND, $RECV and $INT (the last is not implemented yet).

The internet process, user processes and gateway process communicate with each other using short messages similar in function to the $SGNLI primitives of MOS. Where necessary, these point to packet buffers allocated from a common pool shared by all processes in the hostel.

In the original TCP4 design the network drivers were closely coupled to the TCP process itself. In the DCN design the gateway process (and possibly the user process) may be required to reside in different hostels. For this reason the TCP4 packet-allocation strategy was changed so that packets are always allocated by the process that fills them and deallocated by the process that empties them. In the case of packets exchanged between hostels, for example, the gateway process allocates a packet buffer for a packet received from the COMSAT gateway and passes it to the internal device driver for transmission to the hostel containing the internet process. Once transmitted (and ACKed if required) the packet buffer is de-allocated. The internal device driver in the internet hostel allocates its own packet buffer and passes it to the internet process, which consumes its contents and then deallocates it. Flow control is maintained by end-to-end acknowledgements (in this case from the internet process to the gateway process via the internal drivers) which take a form similar to the $SGNLI messages mentioned above. These mechanisms require no packet buffers and are buffered separately.

### 3.2.3 INTERNET CONNECTIONS

Each internet connection supported by a single internet process is described by a control block called the TCB. At present there are two protocol modules that can run in such a process -- TCP4 and RTP. The choice of which of these modules to use for a particular connection is determined by a protocol field in the TCB and by the protocol field in the internet header. The user interface to each of these is the same, with the exception that the full complement of connection-related signals (open/close complete, etc.) is available only with TCP. Date exchanged via TCP is, of course, guaranteed reliable and in sequence, while date exchanged via RTP consist of raw internet datagram packets. Present plans call for implementation of certain internet options necessary for SATNET stream access only in RTP, although they may be incorporated into TCP in the future.

The present design can support a number of internet processes and protocol modules in the same or different hostels, but it is not necessary that each hostel has every module. In these cases data are exchanged using the existing DCN protocols, which assume reliable, sequenced delivery using the same message system used to transport packets and $SGNLI messages. A practical scenario might include an internet process and RTP protocol module in one hostel, a speech module in another and a control program in a third, with operator terminal and gateway access in any of these or in a separate hostel. Present plans call for all of these functions in a single 30K-word hostel which provides, for example, about 8K words for a speech application program and 4K words for a TELNET user/server.

A particularly crucial issue is where to put the largish TCB, currently about 2000 (decimal) words. In a multiple-connection application such as FTP these TCB's, together with packet buffers, can consume a large fraction of the available hostel storage. A frequent problem with MOS and ELF implementations has been exhaustion of what can loosely be called supervisor storage, or storage that is not mapped in the virtual sense. In the BOS implementation TCB's are in user space, so that potentially a moderately large number of connections can be sustained without straining supervisor storage, which is then available for packet buffers and other storage structures required to be "wired down" for DMA data transfers. This philosophy requires the internet protocol modules to perform a virtual-windowing operation to map the TCB into the address space of the supporting internet process. In the structure shown in Figure 3-4 the internet protocol modules are implemented as subroutines using register R5 as a base register. It is a simple matter to extend this base by means of a reserved segment in the kernel-space memory-management hardware, so long as the TCB itself is wired down and not swapped to secondary storage. Extensions to the implementation to provide these features would be simple and possible with PDP11/40 or LSI-11/23 hardware.

### 3.2.4 MULTIPLEXING BEYOND THE TCP/RTP

The internet address uniquely specifies an internet process in the DCN, while the protocol field specifies whether TCP4 or RTP protocol module is selected. It is natural and inviting to interpret the 16-bit port field in the internet header as the DCN port address of the user process. Unfortunately, such an interpretation does not provide for multiple connections to a single process and does not match with the interpretation used by the Terminal Interface Unit (TIU) software. In the present implementation the port field is left uninterpreted and is established by the user process in an $OPEN operation. An incoming message received by the internet process is associated with the proper connection by simply searching and matching the corresponding port fields in the message and the TCB. The only requirement is that this association is unambiguous.

In the TIU software the internet address itself is used to provide this multiplexing function, since the port field is conventionally used within the ARPANET to establish the type of server (TELNET, FTP, etc.) requested. This hack would cause much grief in the DCN and is replaced by the mechanism described above. Further discussion is advisable on this point.

By convention, port 23 on the TCP for every internet process is reserved for an RT-11 server process compatible with TELNET. The TCB for this server is allocated "out of band" in an area normally used by device drivers in RT-11. Additional TCB's for other connections can be allocated elsewhere in this and other user processes. Also by convention, port 1 is reserved for a TELNET user process, which runs SRI TELNET virtually unchanged. Internet echo and sink processes are included in the system for testing. Internet datagrams from TCP or RTP are simply returned to the sender with local and foreign address fields interchanged.

### 3.2.5 OTHER ISSUES

At present there is no support for the urgent or interrupt mechanism in either TCP or TELNET. Facilities already exist in DCN to propagate these functions beyond the TCP, and they will be required in any real application. TELNET itself is largely superfluous in the system and its functions can be provided by using existing DCN mechanisms augmented by suitable TELNET option-negotiation mechanisms.

A provision for file transfer between DCN hosts separated by SATNET is urgently needed, as well as a provision for file transfer between these hosts and an ARPANET host. Using the facilities currently implemented (namely multi-connection TELNET) it is possible to implement a minimal version of ARPANET FTP. A workable, if unatractive, interim file-transfer mechanism might be to use the present DCN file-transfer package, designed to work through a TIP, on a TELNET connection to an ARPANET host.

# 4. ACTIVITIES UNDER TASK 3: WIDEBAND INTEGRATION/COORDINATION

## 4.1 INTRODUCTION

COMSAT's participation in the wideband domestic network planning (also referred to as EISN, for Experimental Integrated Switched Network) has concentrated on a review of communications link performance predictions and simulations of several candidate frequency plans. Information collection began in April of this year when the implementing organizations (Western Union and Linkabit) provided information relative to communication link characteristics and modem design parameters. This information was incorporated into a simulation of overall link performance. This detailed information was summarized in the First Quarterly Report.

In this report, EISN link budgets are reviewed in the next subsection. Simulation results are presented in the next two subsections for candidate frequency plans that are the most likely final configurations of the WESTAR transponder that will contain the EISN QPSK carrier.

## 4.2 REVIEW OF LINK BUDGETS

The link budgets for the up-link of the wideband channel are summarized in Table 4-1. Up-link C/N is obtained as:

$$(C/N)_{up} = \psi_{sat} \cdot bo_i \frac{G\lambda_u^2}{4\pi} M_u/(kT_s B_a)$$

Table 4-1 Up-link Characteristics for Transmission of QPSK Carrier

| Earth Station | Reston | Lexington | Menlo-Park | Marina Del-Ry | Remarks |
|---|---|---|---|---|---|
| <u>Up-link</u> Saturation Flux Density $\psi_s$ ($dBW/m^2$) | - 82.0 | - 82.8 | - 82.3 | - 81.2 | |
| Satellite TWTA Input Backoff (dB) | - 21.0 | - 21.0 | - 21.0 | - 21.0 | QPSK-carrier |
| $\lambda_0^2/4\pi$ (dB) | - 37.1 | - 37.1 | - 37.1 | - 37.1 | Assumes frequency |
| Satellite $G/T_s$ (dB/°K) | - 6.8 | - 6.0 | - 6.5 | - 7.6 | |
| Rain Attenuation Margin (dB) | - 0.5 | - 0.5 | - 0.5 | - 0.5 | |
| Bandwidth (dB-Hz) | - 63.0 | - 63.0 | - 63.0 | - 63.0 | $B_a$ = 2 MHz |
| k (dBW/Hz/K) | +228.6 | +228.6 | +228.6 | +228.6 | |
| $(C/N)_{up}$ (dB) | + 18.2 | + 18.2 | + 18.2 | + 18.2 | |

where

$(C/N)_{up}$ = is the up-link C/N ratio in the allocated spacecraft bandwidth

$\psi_s$ = spacecraft saturation flux density

$bo_i$ = input backoff to the transponder

$G$ = satellite receive antenna gain

$\lambda_u$ = operating wavelength on up-link

$M_u$ = up-link rain attenuation margin

$k$ = Boltzmann's constant

$T_s$ = satellite receive noise temperature

$B_a$ = allocated bandwidth.

The HPA requirement ($P_{HPA}$) to produce the correct carrier level at the satellite can be obtained from:

$$\frac{P_{HPA} \cdot G_{ES} L_T}{4\pi R^2} = \psi_s bo_i \qquad (4.2)$$

where

$P_{HPA}$ = required power from HPA

$G_{ES}$ = earth station antenna gain

$L_T$ = line loss HPA to antenna

$R$ = distance from earth station to satellite.

The required earth station HPA capability is tabulated in Table 4-2.

The down-link C/N levels can be obtained from the relationship

$$(C/N)_{DN} = \frac{e.i.r.p._s \; bo_o}{4\pi R^2} M_D \frac{\lambda_D^2 G_{ES}}{4\pi} \frac{1}{kT_{ES}B_a} \qquad (4.3)$$

Table 4-2. Required HPA Capability

| | Reston | Lexington | Menlo Park | Marina Del-Rey | Remarks |
|---|---|---|---|---|---|
| Saturation Flux Density $\psi_s$ (dBW/m$^2$) | -82.0 | -82.8 | -82.3 | -81.2 | |
| Satellite TWTA Input Backoff (dB) | -21.0 | -21.0 | -21.0 | -21.0 | |
| Beam Spreading Loss ($4\pi R^2$) (dB) | 162.5 | 162.7 | 162.5 | 162.4 | |
| Transmit Antenna Gain (dB) | -47.9 | -47.9 | -47.9 | -47.9 | |
| Line Loss (dB) | 0.9 | 0.9 | 0.9 | 0.9 | From HPA to antenna feeds |
| Power required from HPA (dBW) | +12.5 | 11.9 | 12.2 | 13.2 | |
| Maximum HPA power available | 18.75 | 18.75 | 18.75 | 18.75 | 75 W tube |
| Margin for HPA backoff, clear sky (dB) | 6.3 | 6.9 | 6.6 | 5.6 | |

where the terms not previously defined are

$e.i.r.p._s$ = saturated e.i.r.p. of satellite

$bo_o$ = output backoff of QPSK carrier

$M_D$ = down-link loss due to rain

$\lambda_o$ = down-link operating wavelength

$G_{ES}$ = gain of earth station

$T_{ES}$ = effective noise temperature of earth station

The down-link relationships are tabulated in Table 4-3.

Table 4-3. Down-Link Relationships and Overall Performance

| | Reston | Lexington | Menlo Park | Marina Del-Rey | Remarks |
|---|---|---|---|---|---|
| e.i.r.p. at saturation (dBW) | 35.0 | 33.9 | 34.3 | 33.9 | QPSK-carrier |
| Output backoff (dB) | -16.0 | -16.0 | -16.0 | -16.0 | |
| Path-Loss (dB) | -195.7 | -195.8 | -195.7 | -195.7 | |
| Rain Margin (dB) | -0.1 | -0.1 | -0.1 | -0.1 | |
| G/T (dB/K) | 22.0 | 22.0 | 22.0 | 22.0 | |
| Bandwidth (dB-Hz) | -63.0 | -63.0 | -63.0 | -63.0 | $B_a$ = 2 MHz |
| k(dBW/Hz/K) | 228.6 | 228.6 | 228.6 | 228.6 | |
| $(C/N)_{DN}$ (dB) | 10.8 | 9.6 | 10.1 | 9.7 | |
| $(C/N)_{UP}$ (dB) | 18.2 | 18.2 | 18.2 | 18.2 | From Table 4-1 |
| Total Interference Allocation C/I (dB) | 19.0 | 19.0 | 19.0 | 19.0 | (Assumption) |
| Total Available Overall $(C/N)_T$ | 9.6 | 8.6 | 9.0 | 8.7 | C/N in 2 MHz BW |
| Overall Available $C/N_o$ (dB-Hz) | 72.6 | 71.6 | 72.0 | 71.7 | |
| $E_b/N_o$ Required for $5 \times 10^{-3}$ Raw Channel Error Rate (dB) | 5.3 | 5.3 | 5.3 | 5.3 | Theoretical |
| Modem Implementation Loss (dB) | 1.5 | 1.5 | 1.5 | 1.5 | Assumed |
| Conversion from $E_b/N_o$ to $E_s/N_o$ (dB) | 3.0 | 3.0 | 3.0 | 3.0 | $E_s/N_o = \frac{\text{Energy per QPSK Symbol}}{\text{Noise Density}}$ |
| Bandwidth Correction $(1.544 \times 10^6/2 \times 10^6)$ (dB) | -1.1 | -1.1 | -1.1 | -1.1 | C/N above computed in 2 MHz Bandwidth |
| Required "C/N" in 2 MHz Bandwidth (dB) | 8.7 | 8.7 | 8.7 | 8.7 | |
| Marginal Overall (dB) | +0.9 | -0.1 | +0.3 | 0 | Comparing $(C/N)_T$ available to Required |

In the lower part of the table, overall C/N is obtained, $(C/N)_T$. This value is compared to the C/N required to guarantee a "raw" channel error rate of $5 \times 10^{-3}$. This raw channel error rate would, of course, be improved by any error control coding used on portions of the transmitted packets. These results apply to QPSK transmission at a symbol rate of $1.544 \times 10^6$ symbols/second and an information bit rate of 3.088 Mbit/s.

## 4.3 EVALUATION OF CANDIDATE FREQUENCY PLANS

### 4.3.1 INTRODUCTION

Several candidate frequency plans have been evaluated by computer simulation to determine overall losses to be expected for the 1.544 M symbol/second EISN carrier. These plans were recovered from Western Union at two different meetings. The cases examined can be summarized as follows:

a. At a meeting held with Western Union (McLean, Virginia) on 27 April 1979, a frequency plan was obtained where the EISN carrier would share the WESTAR transponder with a single 660-channel FDM/FM carrier.

b. On 9 July, another meeting was held at Western Union (Upper Saddle River, New Jersey) where three additional candidate frequency plans were obtained. One of these involved the exclusive use of the transponder by the EISN carrier. The second, referred to as the "hybrid transponder" plan, was the most likely final configuration, and emphasis was focused on investigating this plan. A third possible plan called for the EISN carrier to share a transponder with six T-1 carriers. To date, this third additional plan has not been simulated.

Preliminary simulation results for the two plans simulated to date are given in the next two sections. The detailed simulation model and most of the element characteristics were described in the First Quarterly Progress Report.*

### 4.3.2 SIMULATION RESULTS FOR ORIGINAL TWO CARRIER FREQUENCY PLAN

The examination of the original EISN frequency plan addresses the case where the EISN carrier shares the transponder with one other relatively wideband FM carrier.

For the computer simulations, the 36 MHz transponder is assumed to be accessed by the 1.544 M symbol/second QPSK ARPA carrier and by a 660-channel FDM/FM carrier. The general frequency plan is shown in Figure 4-1. Baseline modem back-to-back simulations were made giving the eye diagram and scatter diagram shown in Figure 4-2a and b, respectively. Simulated modem performance with ideal synchronization is shown in Figure 4-3.

From the simulation results, the maximum (worst case) out-of-band emission levels can be predicted using the simulated spectra in Figure 4-4. This spectral density applies to the case where the earth station HPA is operated with no output backoff. An estimate of the reduction in out-of-band emission levels, as the earth station HPA is backed off, is given in Figure 4-5. Note, for example, that operation with 6 to 7 dB output backoff (see Table 4-2) would reduce the out-of-band emission levels by approximately 5 dB.

*"First Quarterly Progress Report," under Contract MDA-903-79-C-0308, by COMSAT Labs, dated December 1979.

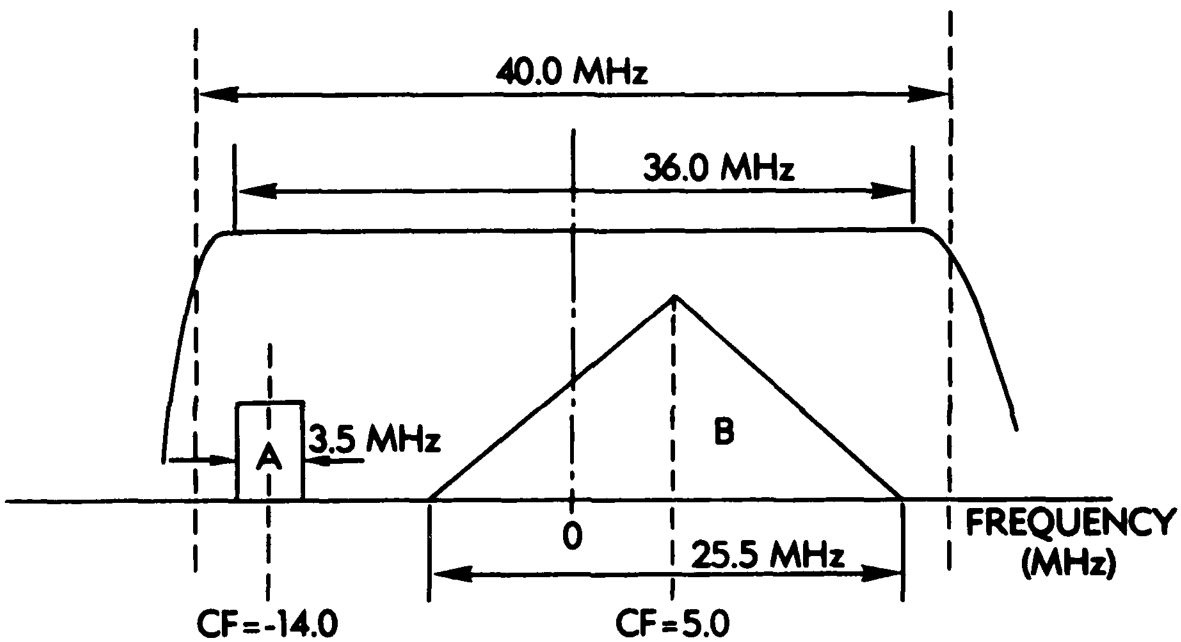


Figure 4-1. Original Frequency Plan for the Westar Satellite Transponder Carrying the 1.544 Mbaud QPSK ARPA Carrier

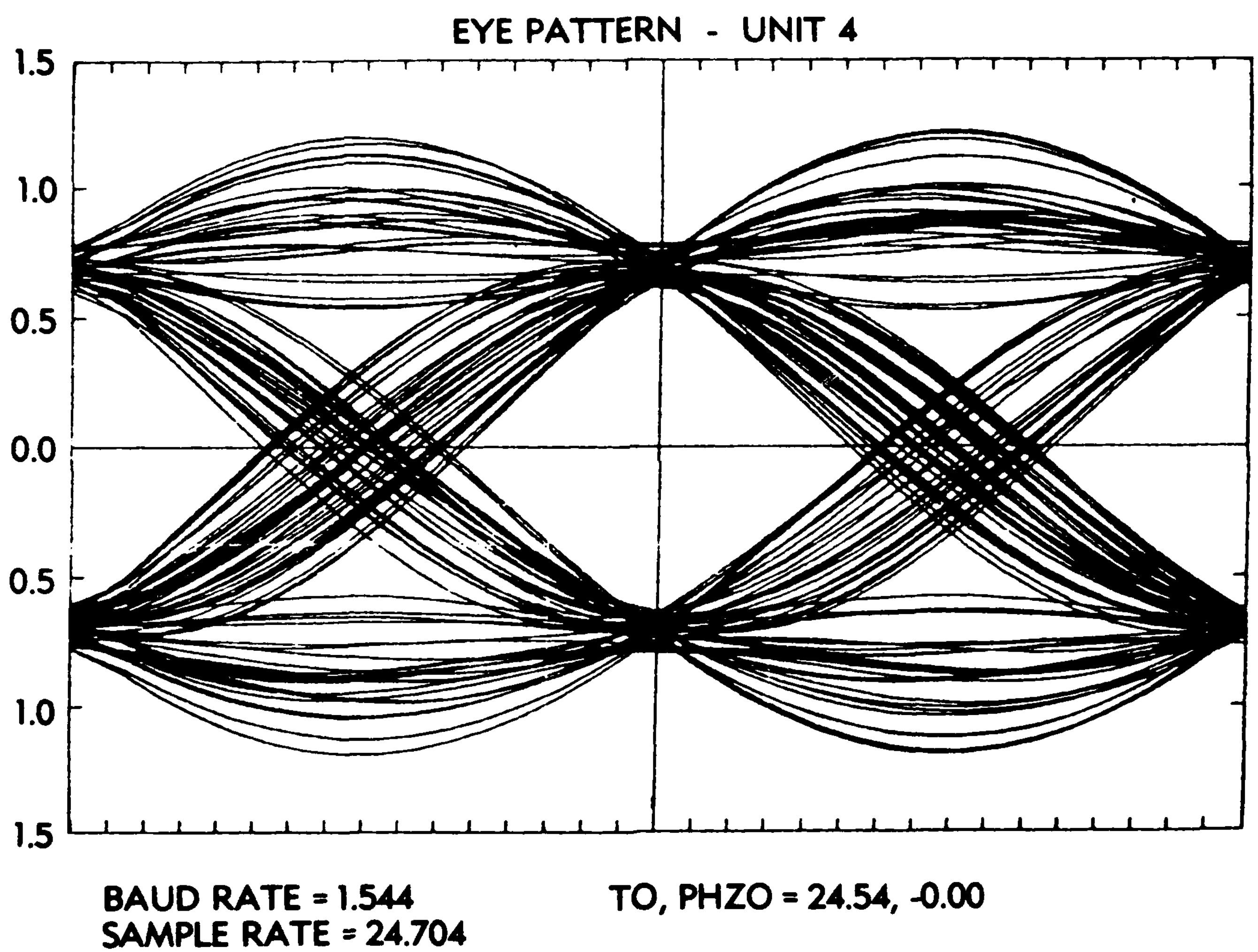


Figure 4-2a. Modem Back-to-Back - Eye Diagram

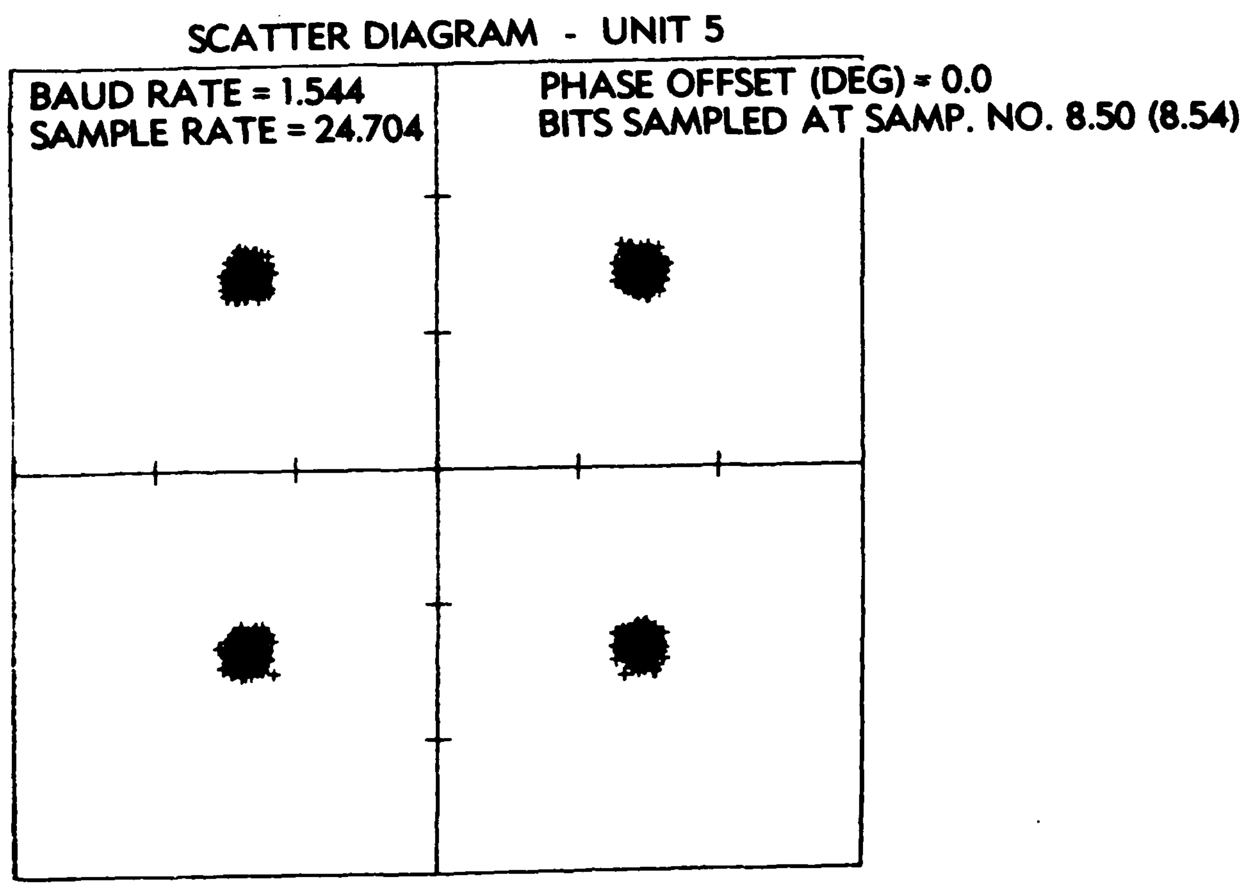


Figure 4-2b. Modem Back-to-Back - Scatter Diagram

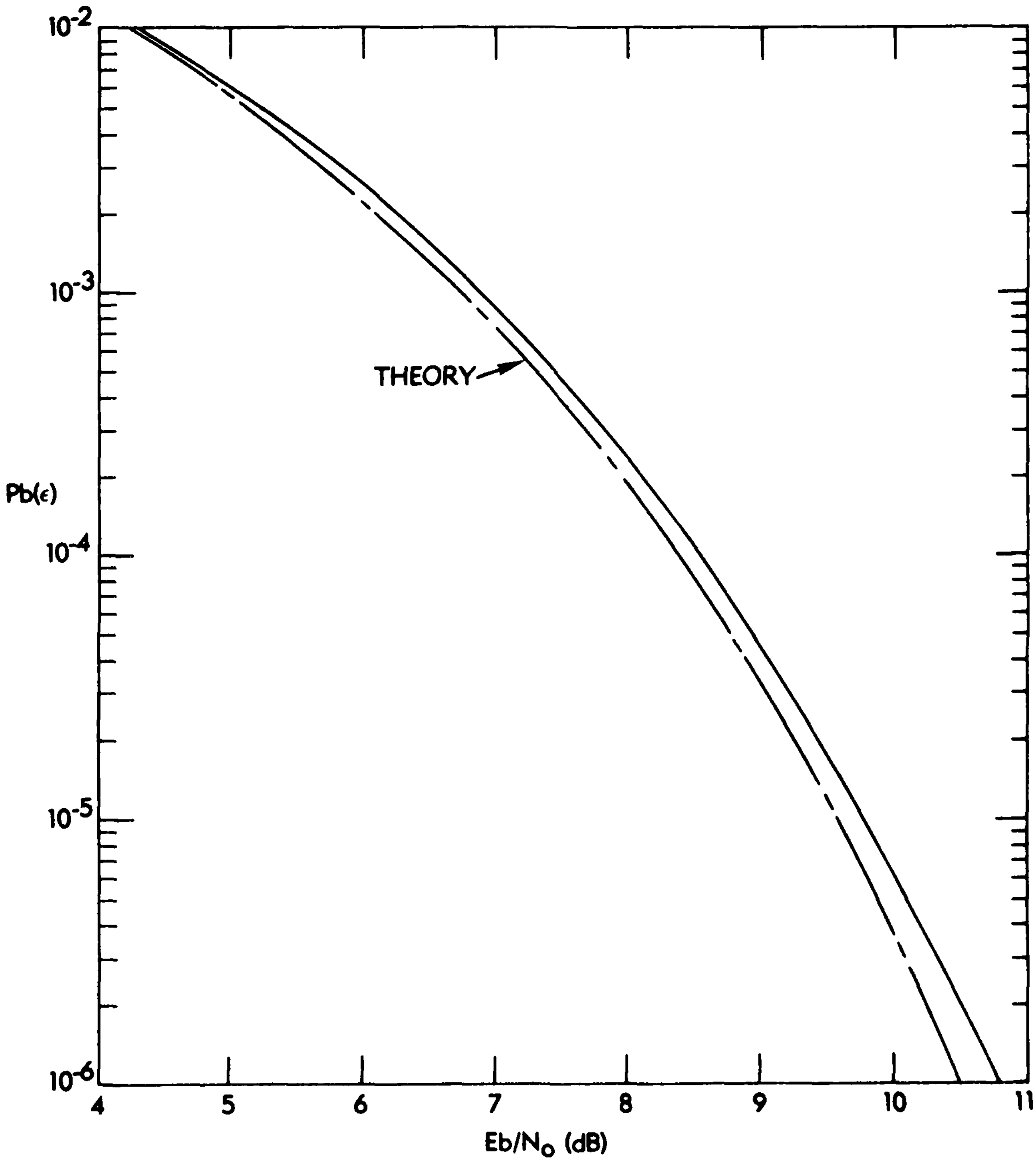


Figure 4-3. Back-to-Back Performance - No Synchronization Errors

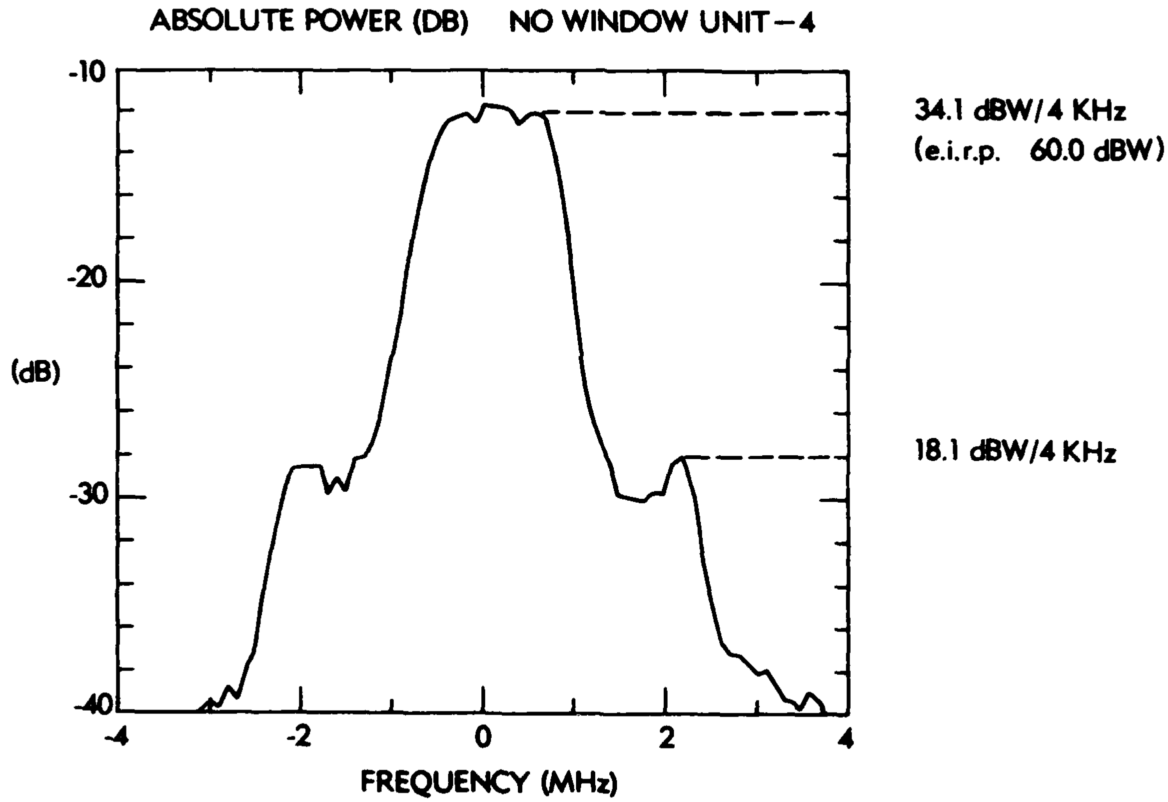


Figure 4-4. Maximum QPSK Out-of-Band Emission at HPA Output (HPA Saturated)

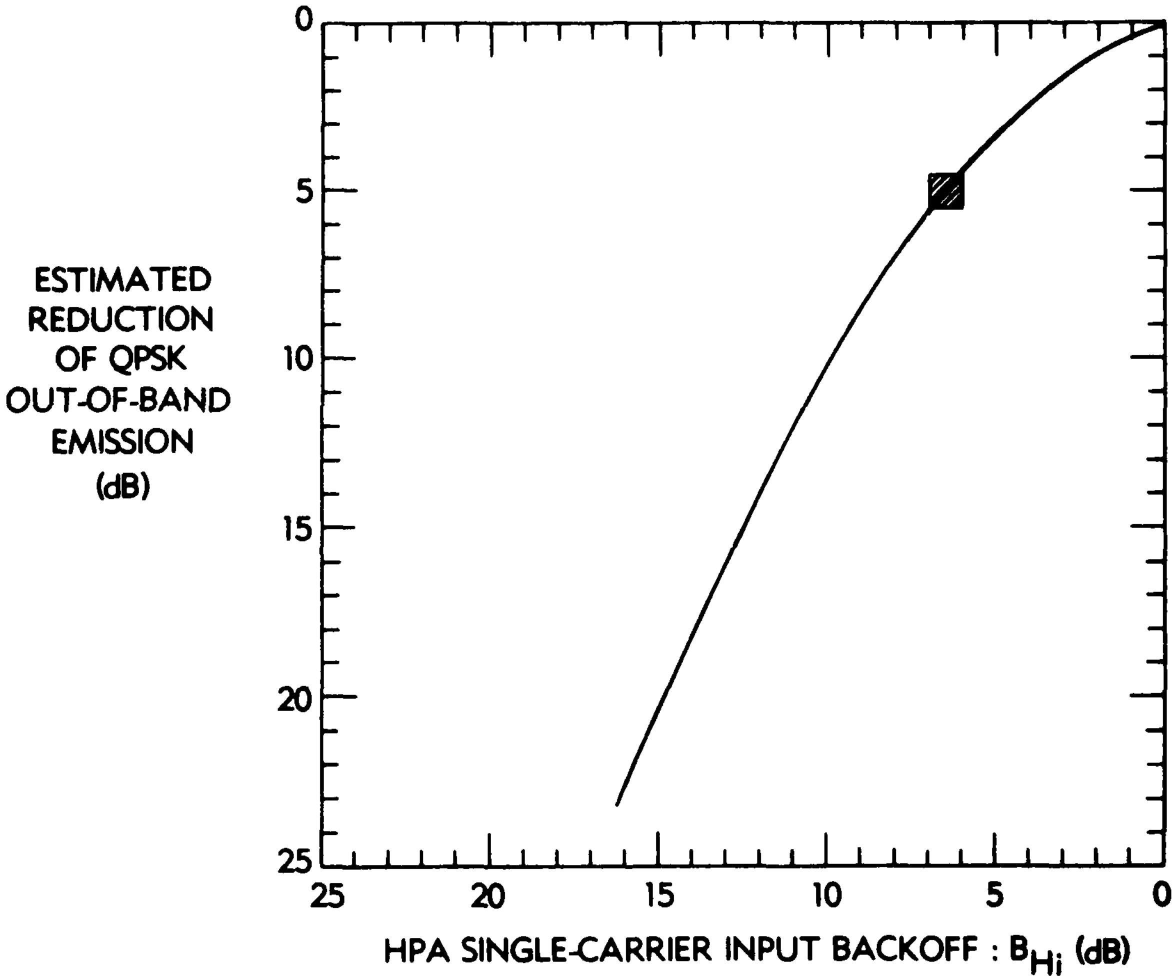


Figure 4-5. Assumed Relation of Relative Out-of-Band Emission to HPA Input Backoff

The analysis results in Figure 4-6 give intermodulation distortion (IM) levels falling into the ARPA QPSK carrier. These IM levels are caused by common amplification by the satellite TWTA of the QPSK and FM carriers. This same figure gives estimates of the levels of intermodulation distortion falling into the 660-channel FDM/FM carrier.

Adjacent transponder interference levels caused by IM distortion are shown in Figure 4-6, and all interference levels are summarized in Table 4-4.

Table 4-4 - Interference Levels into ARPA QPSK Carrier

| | | | Remarks |
|---|---|---|---|
| $C/I_{IM}$. | (Intermodulation Distortion (IM)) | | No Appreciable IM Expected |
| $C/I_{ATrI}$. | (Out-of-Band Emission from Adjacent Transponders) | 27.0 dB | Same as previous estimates |
| $C/I_{ext}$. | (Adjacent Satellite Interference) | 26.0 dB | Same as previous estimates |
| $C/I_{ext}$. | (Terrestrial System Interference) | 26.0 dB | Same as previous estimates |
| Total C/I Estimate | | 21.5 dB | (Previous estimate of 19.0dB) |

Note: The slightly higher (better) C/I estimate will not significantly affect previous link margin estimates.

Relative Out-of-band emission (OBE) levels caused on the up-path by the OPSK carrier (due to spectrum spreading caused by the nonlinear HPA characteristics) are summarized in Table 4-5.

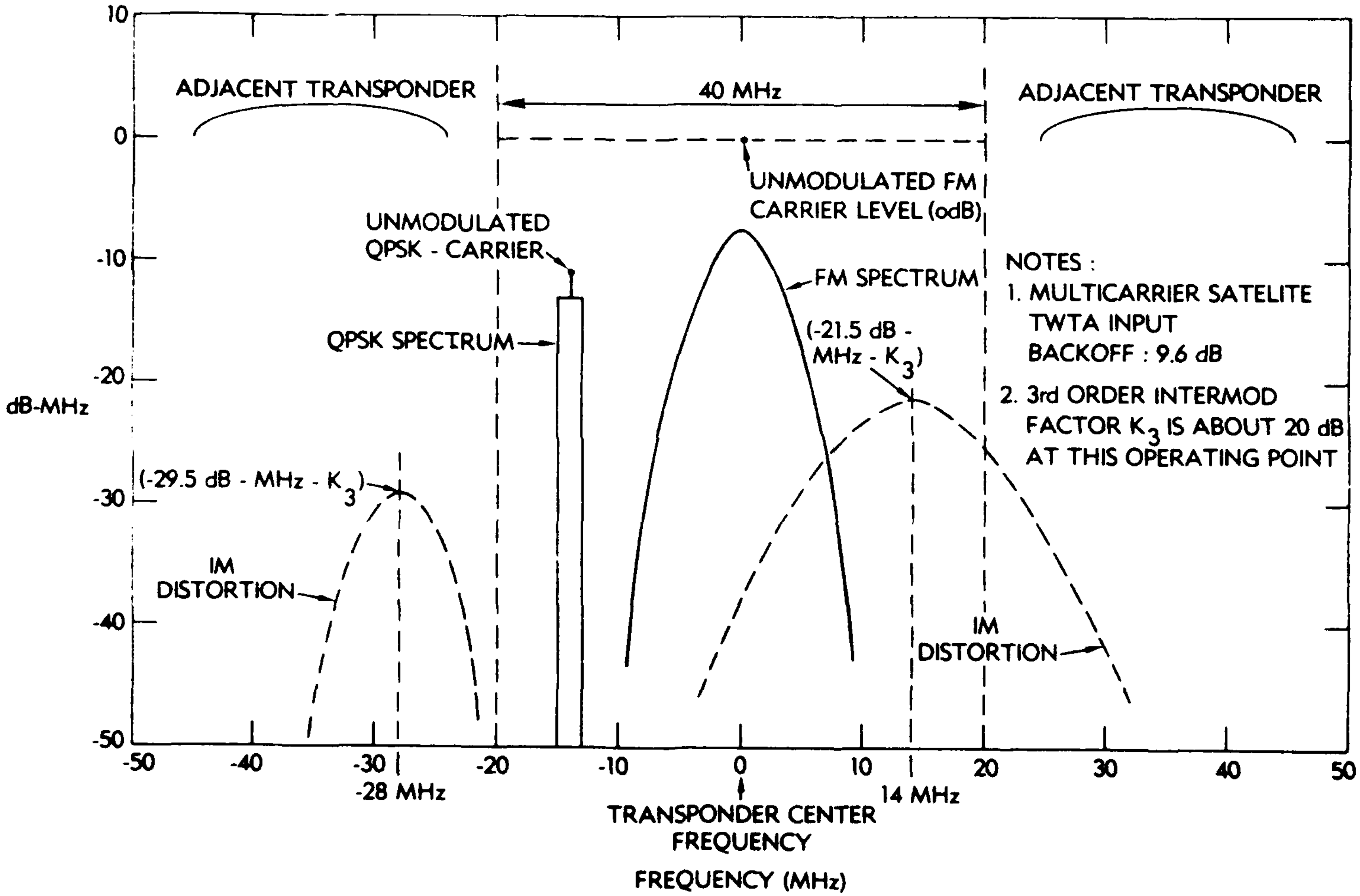


Figure 4-6. Estimated Intermodulation Distortion Spectrum at Satellite TWTA Output

Table 4-5. Interference Caused by the ARPA Carrier into the FM Carrier in the Same Transponder and into Carriers in Adjacent Transponders

| | | Remarks |
|---|---|---|
| Maximum QPSK OBE (dBW/4 kHz) | ~8.1 | ±2 MHz from QPSK carrier center frequency |
| OBE into FM carrier | negligible | About 19 MHz separation |
| OBE into adjacent transponder (dBW/4 kHz) | <-2 | Near band-edge |
| IM distortion (C/I) into FM carrier (dB) | 50 dB | |
| IM distortion power density into adjacent transponder (dBW/4 kHz) | -39.5 | Near band-edge |

Note: These results show that interference effects are expected to be negligible.

For the original two-carrier frequency plan, the level of IM distortion falling into the FM carrier and into the adjacent transponders is concluded to be negligible. The level of out-of-band emission caused by the QPSK carrier on the up-path to the satellite is also negligible. The above conclusions should be reexamined for other frequency plans.

Estimates of overall in-band transmission impairments experienced by the QPSK carrier over the transmission path are given in Figure 4-7. This figure shows the increase of carrier-to-noise ratio required for a bit error rate (BER) of $5 \times 10^{-3}$ above theoretical ideal value. This estimate is obtained via a simplified computer simulation where modem synchronization circuits are assumed to be hard-wired. The satellite transponder filters and the FDM/FM carrier were not included in this particular simulation.

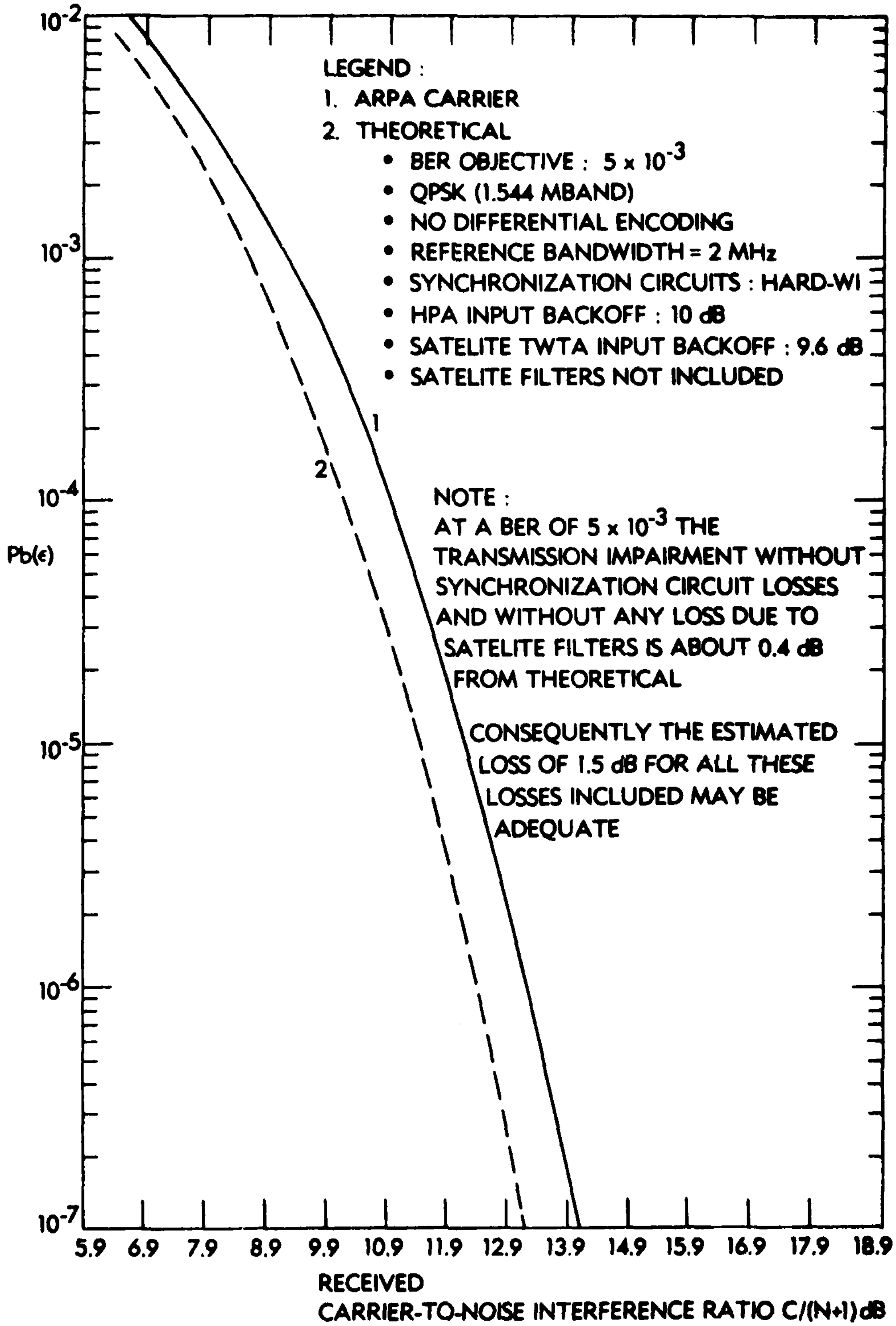


Figure 4-7. Bit-Error Rate versus Received C/N Ratio

The link budgets and margins are summarized in Table 4-6. The link margins obtained are slightly larger (by 0.3 dB) than the estimates in Table 4-3. This difference is caused by the fact that IM distortion levels falling into the QPSK carrier have been found to be negligible for the original two-carrier frequency plan. This accounts for the fact that the total C/I allocation for interference effects is slightly better than previous estimates (C/I of 21.5 dB instead of 19 dB). The IM levels would be different for other frequency plans.

It presently appears that the assumed transmission impairment allowance of 1.5 dB (for modem implementation, etc.) may be adequate. This is based on the estimated transmission impairment of 0.4 dB (Figure 4-7) obtained for the case where synchronization circuits are hard-wired and where the impact of the transponder filters is omitted. When these effects are included the total impairment would probably not exceed 1.5 dB. Any additional loss due to the satellite filters group delay distortion could be determined through the more complete computer simulation. If losses become excessive, the QPSK carrier could be shifted towards the transponder band-center where the group delay distortion is less pronounced. The additional loss due to synchronization circuits should be evaluated in future simulation efforts.

It appears that the transmitted e.i.r.p. should probably be increased to improve the link margins. Since a 75-W HPA will be used, there is sufficient available e.i.r.p. at each earth station to achieve this end. However, the level of off-axis radiation (adjacent satellite interference) must be examined before this can be recommended.

Table 4-6

Link Characteristics and Margins for ARPA QPSK Carrier

| Loop-Back Path | Reston | Lexington | Menlo Park | Marina Del-Rey | Remark |
|---|---|---|---|---|---|
| Up-Path | | | | | |
| HPA Output Backoff ($B_{Ho}$(dB)) | 5.8 | 6.4 | 6.0 | 5.0 | 75 Watt-HPA |
| HPA Input Backoff ($B_{Hi}$(dB)) | 10.8 | 11.5 | 11.0 | 9.8 | |
| Up-Path e.i.r.p. (dBw) | 60.0 | 59.4 | 59.7 | 60.7 | |
| Ratio of e.i.r.p. to Saturation Level | -21.0 | -21.0 | -21.0 | -21.0 | QPSK Carrier |
| (Multicarrier Satellite TWTA Input Backoff: ($B_{Si}$(dB)) | 9.6 | 9.6 | 9.6 | 9.6 | (QPSK & FM Carriers) |
| Rain Margin (dB) | 0.5 | 0.5 | 0.5 | 0.5 | |
| Up-Path Thermal C/N (dB) | 18.1 | 18.2 | 18.2 | 18.1 | Bandwidth=2 MHz |
| Down-Path | | | | | |
| Ratio of e.i.r.p. to saturation Level (dB) | -16 | -16 | -16 | -16 | QPSK Carrier |
| Rain Margin (dB) | 0.1 | 0.1 | 0.1 | 0.1 | |
| Down-Path Thermal C/N (dB) | 10.8 | 9.6 | 10.1 | 9.7 | |
| System Thermal (C/N (dB) | 10.1 | 9.0 | 9.5 | 9.1 | 2 MHz |
| Estimated Interference Level C/I (dB) | 21.5 | 21.5 | 21.5 | 21.5 | IM Negligible |
| System C/((N+I) (dB) | 9.8 | 8.8 | 9.2 | 8.8 | |
| Required C/((N+I) (dB) | 8.6 | 8.6 | 8.6 | 8.6 | 2 MHz |
| Margin (dB) | 1.2 | 0.2 | 0.6 | 0.2 | Slightly better than previous estimates |

### 4.3.3 COMPUTER SIMULATION OF THE "HYBRID TRANSPONDER" FREQUENCY PLAN

Preliminary digital computer simulations have been performed of the 17-carrier "Hybrid" Westar transponder frequency plan utilizing the CHAMP2 computer program. Table 4-7 summarizes the characteristics of each signal.

The FM signals in the transponder are all tone modulated and were simulated as such. All of the 32 kbit/s BPSK signals were simulated as sinusoids at their appropriate center frequencies. The eight QPSK signals were generated individually with the parameter values as shown in Table 4-7.

The EISN (Experimental Integrated Switched Network) signal was generated using the "short-pulse" technique. In this scheme, the modulating pulse driving the modulator prefilter exists for 25 percent of the symbol duration. Since the symbol rate, $R_s$, is 1.544 MSPS, the symbol duration is 648 ns. One-quarter of a symbol is, therefore, 162 ns. This signal was then passed through an equalized 7-Pole Butterworth filter having a $BT_s = 1.0$. The modulated signal was then passed through the HPA which was operated with an input backoff = -9 dB and an output backoff = -4.7 dB).*

The other QPSK signals in the transponder were generated utilizing the symbol rates shown in Table 4-7. These signals were simulated as conventional QPSK. After generations, each signal was passed through its own Butterworth filter. At this point, all the signals were attenuated individually such that the ratios of the power in each signal relative to the EISN signal were equal to the relative levels shown in Table 4-7. All sampled signals were then interpolated to change sampling rate in order to make the sampling rates for all signals approximately the same (within 2 percent of each other). This condition of equal sample rate must

*All filter and nonlinear amplifier characteristics used in the simulation came from: Devieux, C., "Preliminary Results for Link Margin Evaluation for the ARPA 1.544 Mband QPSK Carrier," COMSAT IOM to L. Palmer, 6/29/79. This data was summarized in the First Quarterly Progress Report under this contract.

Table 4-7. Description of "Hybrid Transponder" Frequency Plan

| Carrier # | Relative Carrier Freq. Location (MHz) | Modulation | Symbol Rate (Mbps MHz) (Noise - BW) | $BT_s$ | Power Relative to the EISN Carrier (dB) | Remarks |
|---|---|---|---|---|---|---|
| 1 | -3.5 | FM | (0.7) | - | -4.6 | Ranging |
| 2 | -2.5 | FM | (0.7) | - | -4.7 | Ranging |
| 3 | -16.0 | BPSK | 0.032 | - | -24.0 | |
| 4 | -13.0 | BPSK | 0.032 | - | -24.0 | |
| 5 | -11.0 | BPSK | 0.032 | - | -14.5 | |
| 6 | -10.5 | BPSK | 0.032 | - | -14.5 | |
| 7 | -9.0 | BPSK | 0.032 | - | -14.5 | |
| 8 | +0.2 | BPSK | 0.032 | - | -14.5 | |
| 9 | -16.5 | QPSK | 0.112 | 2.6 | -7.0 | FEC, r = 1/2 |
| 10 | -5.0 | QPSK | 0.450 | 2.7 | -2.2 | FEC, r = 3/4 |
| 11 | -14.5 | QPSK | 1.544 | 1.3 | +2.4 | FEC, r = 3/4 |
| 12 | +2.5 | QPSK | 0.772 | 1.49 | -2.1 | FEC, r = 7/8 |
| 13 | +4.5 | QPSK | 0.772 | 1.49 | -1.7 | FEC, r = 7/8 |
| 14 | +8.5 | QPSK | 0.772 | 1.49 | +1.2 | FEC, r = 7/8 |
| 15 | +10.0 | QPSK | 0.772 | 1.49 | +0.9 | FEC, r = 7/8 |
| 18 | -0.2 | FM | 0.075 | - | -9.0 | Ranging |
| 19 | +14.5 | QPSK | 1.544 | 1.0 | 0.0 | EISN |

exist in order to sum all the signals together at the satellite input. Four distinct QPSK symbol rates were used and Table 4-8 gives the signal parameters of interest for the interpolation operation.

Table 4-8. Interpolation Parameters for Hybrid Transponder Simulations

| Symbol Rate | Number of Samples per Symbol | Intermediate Sampling Rate | Interpolation Factor | Final Sampling Rate |
|---|---|---|---|---|
| 1.544 | 12 | 18.53 | 6 | 111.17 |
| 0.772 | 12 | 9.264 | 12 | 111.17 |
| 0.450 | 22 | 9.900 | 11 | 108.90 |
| 0.112 | 24 | 2.688 | 41 | 110.20 |

After interpolation and scaling, all signals were combined and passed through the filter/TWTA/filter combination that represents the satellite. The TWTA's input backoff was set at -11.79 dB from saturation (output backoff was measured as -7.09 dB). Frequency spectra were obtained at the input and output of the satellite, these are shown in Figures 4-8 and 4-9, respectively. These spectra cover a band of approximately three transponder bandwidths, 110 MHz, in order to show the magnitude of the adjacent transponder interference levels.

After the satellite, the combined signal was deinterpolated by a factor of six (the interpolation factor used for the EISN signal) and then passed through the receive modem filter which was an equalized Butterworth filter with a $BT_s$ - product equal to unity and centered on the EISN signal center frequency. Detection and bit-error-rate (BER) measurements were made on the EISN signal with the results, expressed in the form of dB-loss relative to theoretical as a function of BER, shown in Table 4-9.

Table 4-9. Loss (dB relative to ideal) as a Function of BER

| | Bit - Error - Rate (BER) | | | | | | |
|---|---|---|---|---|---|---|---|
| | $10^{-4}$ | $10^{-5}$ | $10^{-6}$ | $10^{-7}$ | $10^{-8}$ | $10^{-9}$ | $10^{-10}$ |
| Loss (dB) | 0.1 | 0.24 | 0.37 | 0.52 | 0.7 | 0.88 | 0.92 |

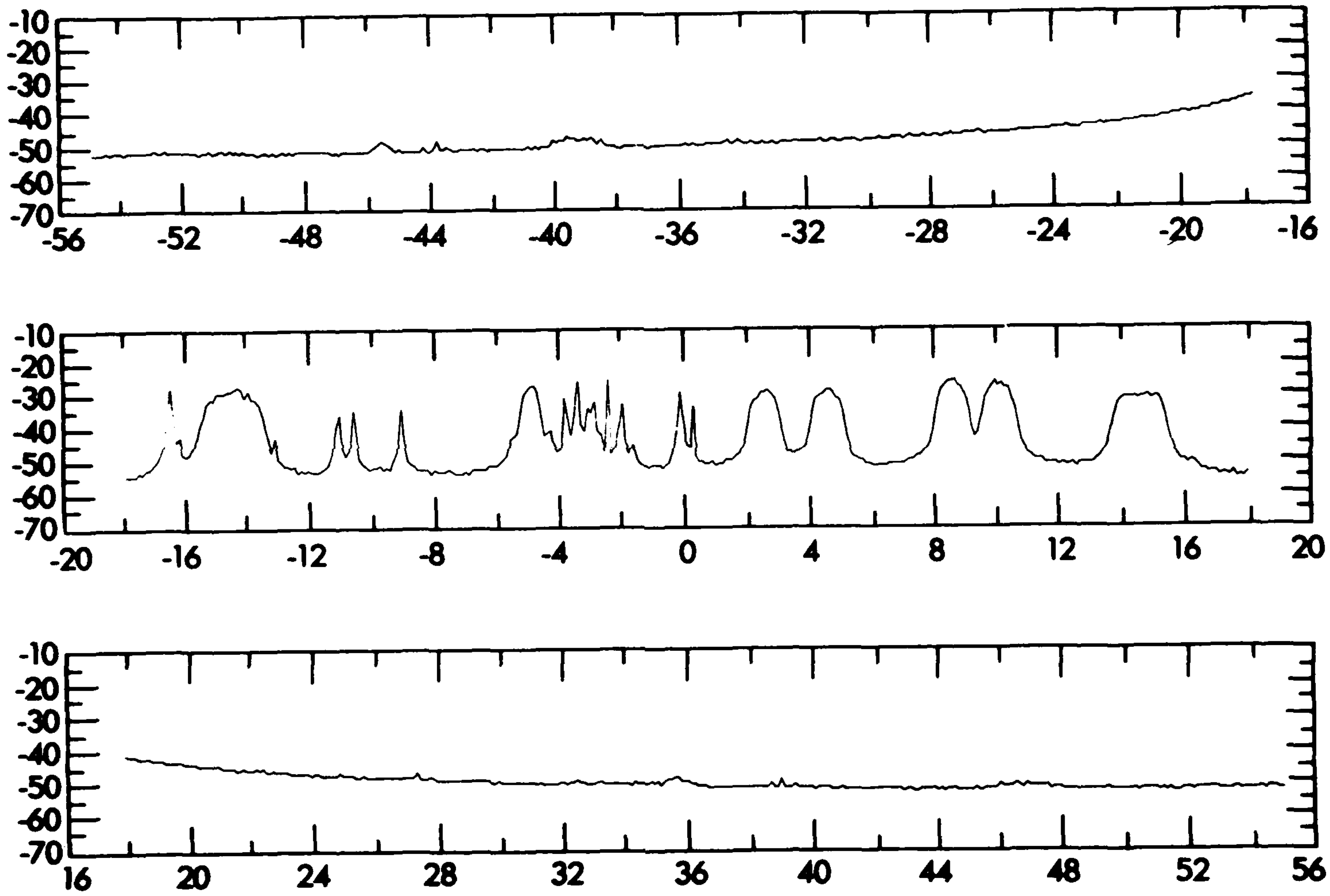


Figure 4-8. Spectral Density at Input to Hybrid Transponder

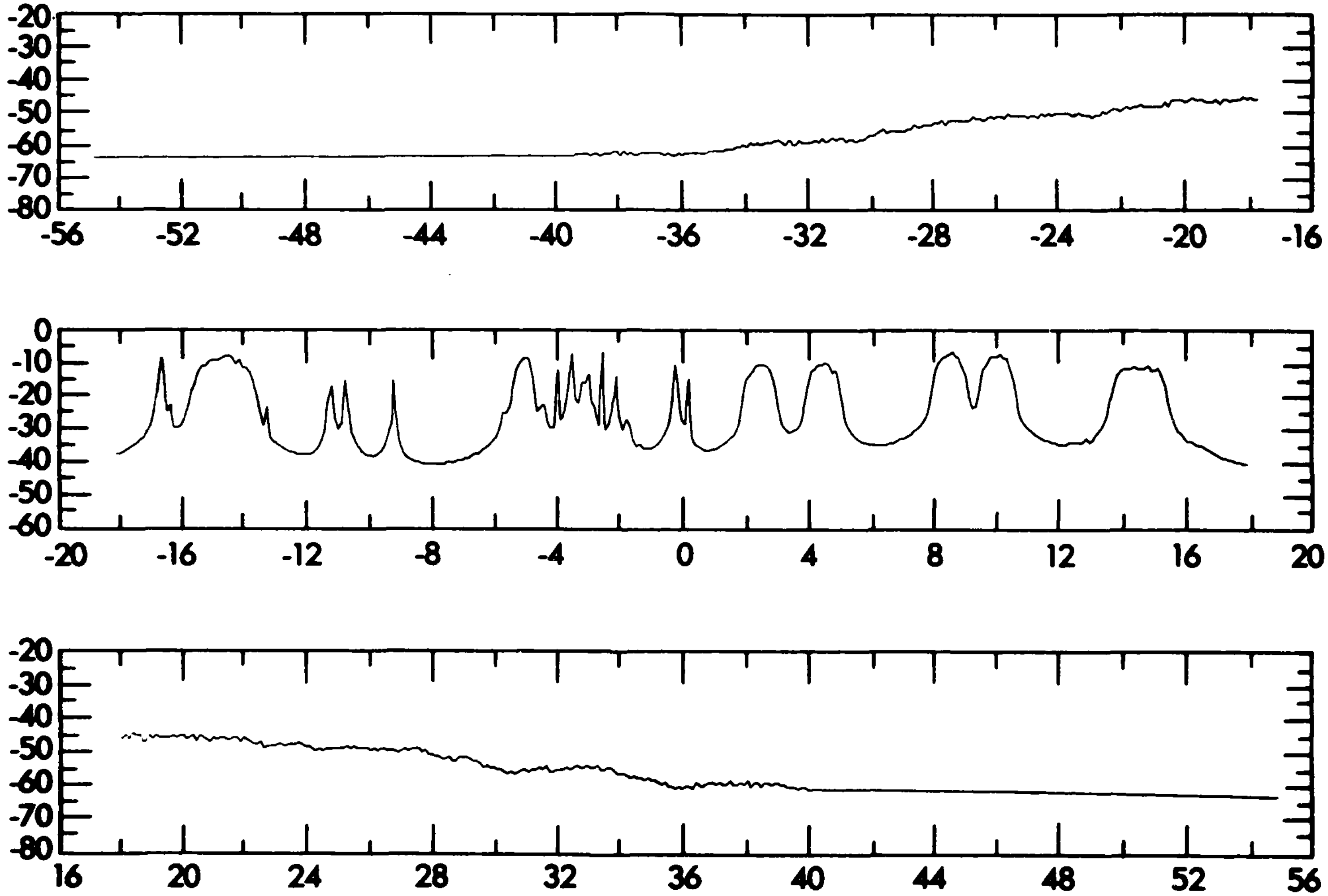


Figure 4-9. Spectral Density at Output of Hybrid Transponder