REPORT ON THE DEVELOPMENT OF
THE MANNED ORBITAL RESEARCH LABORATORY (MORL)
SYSTEM UTILIZATION POTENTIAL

TASK AREA IV
MORL SYSTEM IMPROVEMENT STUDY

BOOK 4

SM-48818
DECEMBER 1965

MISSILE & SPACE SYSTEMS DIVISION
DOUGLAS AIRCRAFT COMPANY, INC.
SANTA MONICA/CALIFORNIA

DOUGLAS

REPORT ON THE DEVELOPMENT OF
THE MANNED ORBITAL RESEARCH LABORATORY (MORL)
SYSTEM UTILIZATION POTENTIAL

Task Area IV
MORL System Improvement Study

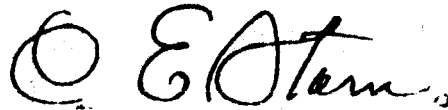$\mathcal{N}67$ 19860

BOOK 4

SM-48818

DECEMBER 1965

PREPARED BY D. R. ANDELIN   AND   D. C. BORN
SECTION CHIEF   TECHNICAL STUDY COORDINATOR
COMMUNICATIONS   IBM FEDERAL
AND TELEMETRY   SYSTEMS DIVISION

APPROVED BY
C. E. STARNS
PROGRAM MANAGER

SUBMITTED BY
DOUGLAS AIRCRAFT COMPANY, INC.

PRESENTED TO
NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
LANGLEY RESEARCH CENTER
CONTRACT NO. NAS1-3612

APPROVED BY
R. J. GUNKEL
DIRECTOR, ADVANCED MANNED SPACECRAFT SYSTEMS

DOUGLAS MISSILE & SPACE SYSTEMS DIVISION

The Manned Orbital Research Laboratory (MORL) is a versatile facility for experimental research which provides for:

- Simultaneous development of space flight technology and man's capability to function effectively under the combined stresses of the space environment for long periods of time.

- Intelligent selectivity in the mode of acquisition, collation, and transmission of data for subsequent detailed scientific analyses.

- Continual celestial and terrestrial observations.

Future application potential includes use of the MORL as a basic, independent module, which, in combination with the Saturn Launch Vehicles currently planned for the NASA inventory, is responsive to a broad range of advanced mission requirements.

The laboratory module includes two independently pressurized compartments connected by an airlock. The larger compartment comprises the following functional spaces:

- A Control Deck from which laboratory operations and a major portion of the experiment program will be conducted.

- An Internal Centrifuge in which members of the flight crew will perform re-entry simulation, undergo physical condition testing, and which may be useful for therapy, if required.

- The Flight Crew Quarters, which include sleeping, eating, recreation, hygiene, and liquids laboratory facilities.

The smaller compartment is a Hangar/Test Area which is used for logistics spacecraft maintenance, cargo transfer, experimentation, satellite checkout, and flight crew habitation in a deferred-emergency mode of operation.

The logistics vehicle is composed of the following elements:

- A Logistics Spacecraft which generally corresponds to the geometric envelope of the Apollo Command and Service Modules and which includes an Apollo Spacecraft with launch escape system and a service pack for rendezvous and re-entry maneuver propulsion; and a Multi-Mission Module for either cargo, experiments, laboratory facility modifications, or a spacecraft excursion propulsion system.

- A Saturn IB Launch Vehicle.

Integration of this Logistics System with MORL ensures the flexibility and growth potential required for continued utility of the laboratory during a dynamic experiment program.

In addition to the requirements imposed by the experiment program, system design parameters must reflect operational requirements for each phase of the mission to ensure:

- Functional adequacy of the laboratory.

- Maximum utilization of available facilities.

- Identification of important parameters for consideration in future planning of operations support.

For this reason, a concept of operations was developed simultaneously with development of the MORL system.
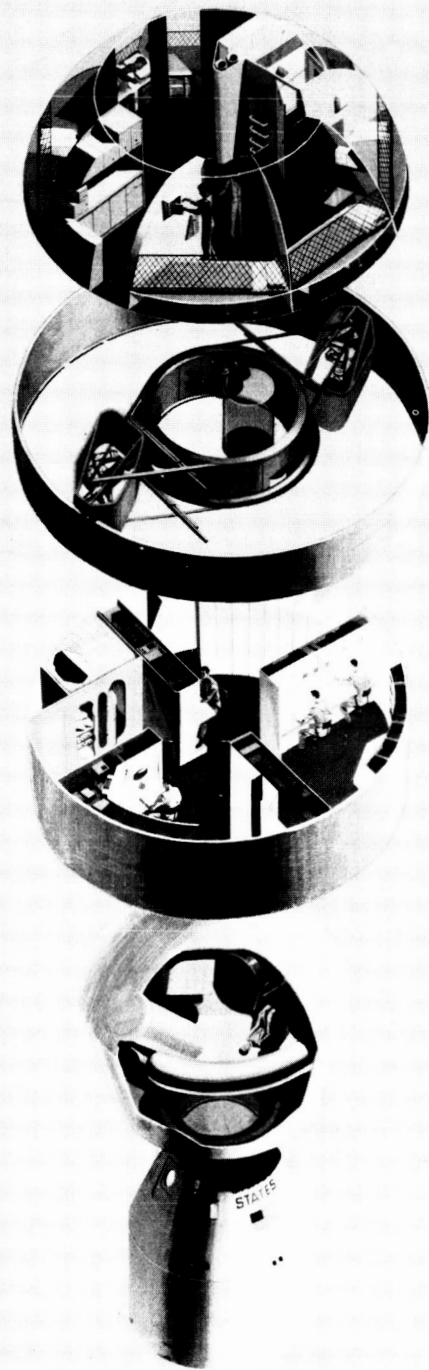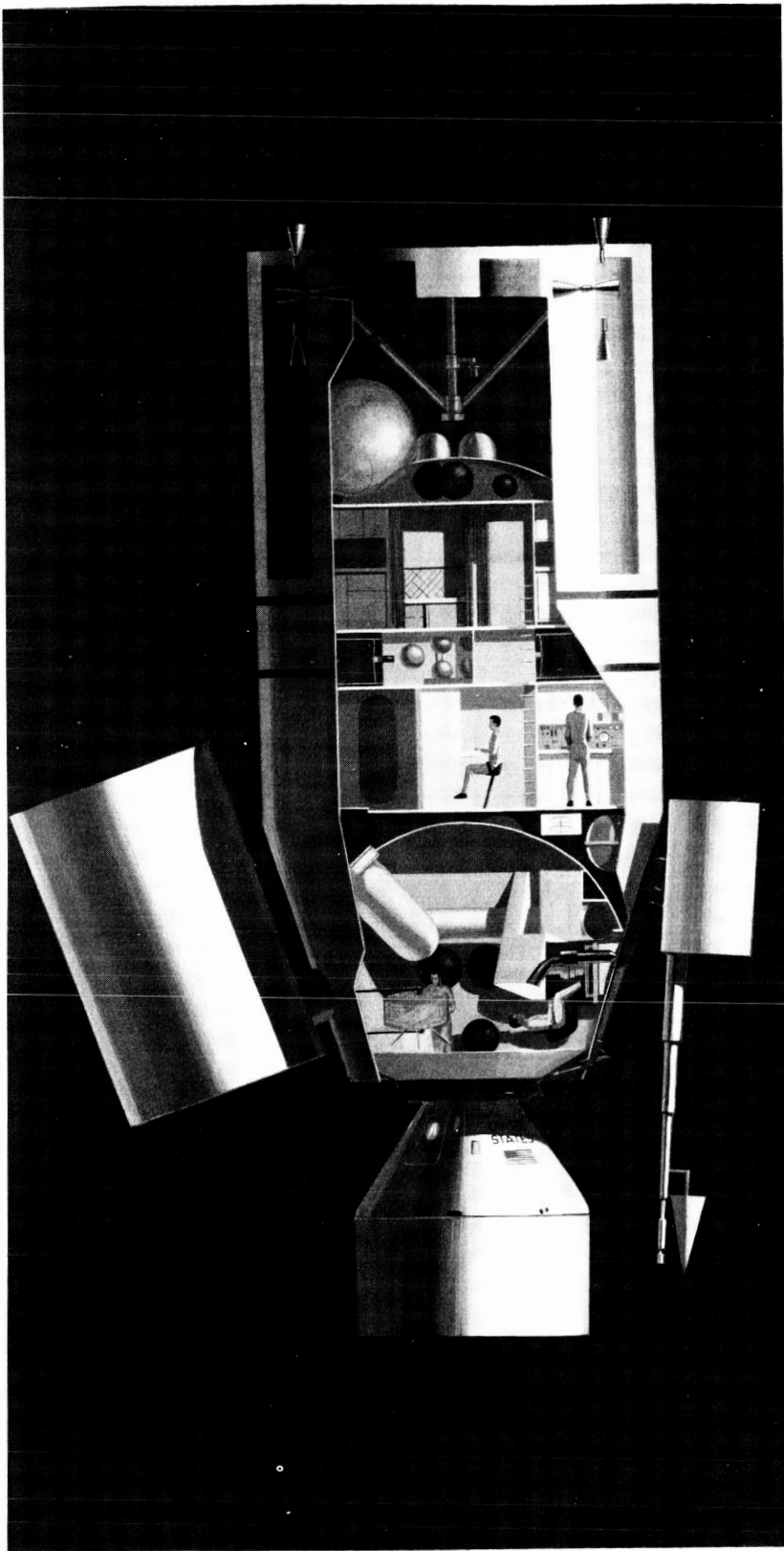
PREFACE

This report is submitted by the Douglas Aircraft Company, Inc., to the National Aeronautics and Space Administration's Langley Research Center. It has been prepared under Contract No. NAS1-3612 and describes the analytical and experimental results of a preliminary assessment of the MORL's utilization potential.

Documentation of study results are contained in two types of reports: A final report consisting of a Technical Summary and a 20-page Summary Report, and five Task Area reports, each relating to one of the five major task assignments. The final report will be completed at the end of the study, while the Task Area reports are generated incrementally after each major task assignment is completed.

The five Task Area reports consist of the following: Task Area I, Analysis of Space Related Objectives; Task Area II, Integrated Mission Development Plan; Task Area III, MORL Concept Responsiveness Analysis; Task Area IV, MORL System Improvement Study; and Task Area V, Program Planning and Economic Analysis.

This document contains 1 of the 5 parts of the Task Area IV report, MORL System Improvement Study. The study evaluates potential improvements to the MORL, necessitated by the limitations identified in Task Area III, and evaluates those improvements stemming from investigations aimed at increasing the effectiveness of the MORL through the addition of new system elements.

The contents and identification of the five parts of this report are as follows: Book 1, Douglas Report SM-48815, presents the summary of the Task Area effort and the results of the configuration, structure, electrical power, logistics system and performance analyses; Book 2, Douglas Report SM-48816, presents the results of the analyses performed on the Environmental Control/Life Support subsystem; Book 3, Douglas Report SM-48817, presents the results of the analyses performed on the Stabilization and Control subsystem; Book 4, Douglas Report SM-48818, presents the results of the analyses performed on the Communications and Telemetry subsystem; Book 5, Douglas Report SM-48819, presents the results of the analyses performed on the Propulsion subsystem.

Requests for further information concerning this report will be welcomed by R.J. Gunkel, Director, Advance Manned Spacecraft Systems, Advance Systems and Technology, Missile & Space Systems Division, Douglas Aircraft Company, Inc.

CONTENTS

FIGURES

TABLES

Section 1
INTRODUCTION AND SUMMARY

The combined Phase IIa and Phase IIb studies have seen the total MORL concept progress from a first generation space station supporting a relatively modest 1-year experimental program to a second generation space station with an anticipated mission duration of more than 5 years in which a major objective is to conduct a vastly expanded experimental program. In this transition, the baseline orbit inclination has been shifted from 28.7° to 50°, and the projected launch date has been moved to the early 1970's.

In keeping with this evolution of MORL, the baseline communication/telemetry system and the ground support network configured in the early part of the Phase IIa study have been subjected to a system improvement study, the basis for which was formulated in the Task Area III MORL concept responsiveness analysis. Briefly, support of the expanded experimental program, coupled with the extension of the MORL operational life, dictates the need for a highly flexible, general-purpose data management system-- one which is characterized by a readily reprogrammable data acquisition and processing capability, has an increased data storage capacity, and can accommodate much higher data rates than are provided by the baseline system. The increased role of man in the experimental program suggests that the man/data-management-system interface be enhanced to allow the crewmen greater control of the data acquisition, monitoring, editing, and analysis functions. The rescheduled launch date gives an opportunity for further system optimization, which may involve the integration of the data management function into the data transfer requirements of all subsystems, the utilization of a unified carrier system for all MORL/ground communications, the implementation of an automated hard-copy data storage and retrieval capability, or the incorporation of data compaction techniques into the telemetry data acquisition function. The change in baseline orbit to a 50° inclination

makes the coverage time provided by the baseline ground-support network inadequate. A series of major studies stemmed from a consideration of these facts. These studies are summarized in the following paragraphs.

In the baseline communication/telemetry system, the greater part of the data management function is implemented by two digital acquisition systems known as the low-rate and the medium-rate PCM systems, their associated tape recorders, a general-purpose computer, and a data adapter. With the exception of a few specialized computer input-output functions handled directly by the data adapter, all data inputs to both the telemetry system and the computer are handled through a central addressable multiplexer that can be interrogated on a time-shared basis by the telemetry programmer or by the computer (through the data adapter). The data acquired for computer input is completely under the control of the program stored in the computer memory, and the program can readily be changed by command from the ground through the digital command system. The data acquisition sequencing for the telemetry systems is limited to two or three fixed programs, with some flexibility afforded by a manual patch panel.

The advanced data management concept developed in this phase of the study extends to the telemetry data acquisition function the same flexibility provided the computer. This flexibility is achieved through a programmable central information control and storage unit (CSU). Besides controlling the acquisition of data for telemetry, this unit also controls all data interchange between vehicle operational and experimental subsystems, including the computer and the human operator. Departing from the conventional analog data distribution technique in which a separate circuit is used to carry data from each source to the central multiplexer and analog-to-digital (A/D) converter, the advanced data management system utilizes an all-digital data distribution bus (DDB) for the parallel transfer of digital data from any source to any desired receptor. This approach is shown to be feasible through the use of a data source-point terminal (DST) located at each data source or receptor. The DST's contain the required signal conditioning circuitry, A/D converter, address decoding logic, and control logic. With the DST's implemented with integrated circuits, the system is comparable in size,

weight, cost, and power requirements to conventional systems. The other major system element is a general purpose control and display console (GPC), one of which is located at each system control station. All operator-inserted data, requests for information, and system control are implemented through the GPC. This advance system provides the flexibility and speed required to efficiently perform the data management function of a second generation space station. The study was carried to the point of defining a system conceptional organization and doing sufficient detail design to indicate feasibility; definition of a detailed system specification and incorporation into the baseline communication/telemetry system await further definition of detailed requirements.

The primary functions of the ground systems for MORL include tracking, command, telemetry, and voice communications to satisfy the requirements for data transfer, navigation, and mission control. The baseline network consisting of remote sites at Corpus Christi and Cape Kennedy was adequate to support the operational and experimental requirements of the MORL in a 28.7° inclination orbit. A pacing factor in ground network configuration is the baseline requirement for 45 min./day of telemetry dump time. Only 43 min./day contact time with the ground are provided for a MORL with a 50° inclination orbit by the baseline network. When the orbit inclination is increased to 90°, the coverage drops to 28 min./day. The need to expand the network is evident.

In this study, a satellite simulation computer program was used to calculate coverage times provided by various combinations of ground sites. Based on the data obtained, it is recommended that Hawaii be added to the baseline network to support MORL in a 50° inclination orbit. Coverage provided is nearly 66 min./day. For the case of the 90° inclination orbit, it is recommended that both Hawaii and Guaymas be added to the baseline network. Coverage in this case is nearly 53 min./day. Another aspect of the study shows that the tracking which can be provided by the baseline network, or any reasonable extension of this network, to support the navigation requirements of the oceanographic experiments severely restricts the number of

ocean targets. In conclusion, it is recommended that an autonomous naviga-
tion system be investigated for use on the MORL.

Because a unified rf carrier system offers possible advantages of flexibility,
low weight, low power, low volume, ease of installation and maintenance,
and lower cost redundancy, an investigation of the feasibility of implementing
such a system to handle the MORL/ground communication requirements was
undertaken. A significant consideration, in addition to technological and
operational practicality, is the extent to which an appropriate spacecraft
configuration is compatible with existing or proposed ground terminals.
Therefore, the study determined the compatibility of the unified S-band sys-
tem (USBS), being developed for Apollo, with the MORL baseline communica-
tion requirements. The evaluation was made relative to the MORL in both
the baseline and synchronous orbits, and for two separate cases; the first
case allowed essentially no change to the system as implemented for Apollo;
the other permitted significant spaceborne system changes if these changes
implied only minor additions to the ground system data demodulators. The
first case proved inadequate in both quantity and quality of data transmission.
In the second case, a modified system was configured employing subcarriers
at frequencies different from those used in the Apollo configuration. A suf-
ficient number of channels were thus obtained to handle all MORL baseline
data requirements. However, the system can accommodate the full 2. 16 mc
television signal and the telemetered data on the FM transmitter only on a
time-shared basis. This requirement causes no hardship in the synchronous
case, where continuous ground contact is possible. When the FM transmit-
ter handles telemetry and television signals simultaneously, the television
video signal must be restricted to a 750-kc bandwidth. Another restriction
noted is that the phase coherent ranging system will not function properly
with MORL in the rotating mode because the periodic switching between
MORL antennas will introduce large phase transients in the PM transmitter
signal. In this case, the C-band transponder and ground-based FPS-16
radar could be employed to support MORL in the baseline orbit.

The conclusion of the unification analysis is that it appears feasible to con-
figure a unified communication system for MORL which will use the major

4

elements of the Apollo USBS ground stations. An optimum design of such a system may profitably be pursued when an updated communication baseband configuration reflecting the results of the advanced data management system study is defined.

Section 2

REQUIREMENTS SUMMARY

The requirements of the Phase IIb Communications/Telemetry system and
of the Ground Support system are presented below.

2.1 COMMUNICATIONS/TELEMETRY SYSTEM

The communications/telemetry system is responsible for the acquisition,
distribution, storage, and processing of data on board the MORL; the sys-
tem is also responsible for the transmission and reception of data as well
as voice communications between the laboratory and the ground, between
the laboratory and other orbiting vehicles, and between the crew members
of the laboratory. Requirements for these functions are based on the opera-
tional and experimental aspects of the MORL mission.

The present definition of experiments and the lack of a fully definitive
operations time-line analysis, including operational and experimental
events, preclude a precise specification of various prime system parameter
requirements at this time. Evaluation of the fundamental data management
factors shown in Table 2-1 should also include definition of operationally
and experimentally dependent parameters. The level of information avail-
able for these parameters necessitates system requirements evaluation on
the basis of parametric maxima and minima, pseudo-statistical and general-
functional implications.

Table 2-2 presents a summary of requirements that were determined in
Task III for word length, sample rate, and storage rate. A significant
number of measurements require word lengths in excess of the six-bit data
word used in the baseline system. Also, a significant number of sensors
require sample rates exceeding the maximum available in the baseline sys-
tem (120 samples/sec). The necessary amount of cross-strapping required

Table 2-1

PRIMARY DATA MANAGEMENT SIZING FACTORS AND INFLUENTIAL
OPERATIONAL/EXPERIMENTAL PARAMETERS

System Factors		Operational/Experimental Parameters	
1.	Signal conditioning circuitry	1.	Electrical characteristics of sensor outputs
2.	Converter types, analog-to-digital/ digital-to-analog (A-D/D-A)	2.	Scale range of measured variable
3.	Digital word length and bit rate	3.	Rate of change of physical quantities measured
4.	Multiplexer sampling speed	4.	Accuracy and resolution of sensors
5.	Multiplexer size (quantity of address-able data points)	5.	Total number (per type) of data sources sampled as a function of time
6.	Buffer storage including sample and hold circuitry	6.	Data processing algorithms for each processing function
7.	Central processor parameters (computational rate, storage, and so forth)	7.	Time phasing of processing functions

Table 2-2

PHASE IIb EXPERIMENTAL DATA MANAGEMENT
REQUIREMENTS DISTRIBUTION SUMMARY

Note   1. Word lengths required for sensor output quantization are fairly evenly distributed over a range from 4 to 18 bits.

        2. Data point sample rates, necessary to preserve the desired resolution of the sensors, range uniformly from 1 sample/min. to 24,000 samples/sec.

        3. Upper and lower storage rates are 3 K bits/orbit and 75 M bits/ orbit, respectively.

        4. Percentages determined on the basis of the total number of sensors in the respective measurement groups.

Parameter	Experiment Groups			
	48-Hour Analysis Group (principally oceanographic)		Meteorological Experiments	
Word length	1 to 10 bits:	50%	6 bits:	50%
	11 to 18 bits:	50%	10 bits:	50%
Sample rate	1 sample/min.:	30%	1 to 75 samples/sec:	50%
	1 to 25 samples/sec:	69%	0.1 to 2.4 K samples/sec:	50%
	1 K samples/sec:	1%		
Storage rate	3 K bits/orbit:	50%	40 to 500 K bits/orbit:	30%
	0.7 to 3 M bits/orbit:	50%	1 to 8 M bits/orbit:	30%
			35 to 75 M bits/orbit:	20%
			Video Data	20%

for the baseline system would not be practical with the 16 channels available at 120 sample/sec or the 12 channels available at 40 samples/sec.

The data generation rates present a potential medium-rate recording and telemetry (T/M) transmission problem. If the ground network permits a daily dump time of 45 min., the medium-rate recorder can accept data at an approximate rate of only 13×10^6 words/orbit without any loss of data.

If equivalent 8-bit words are assumed, the meteorological measurements indicate average data generation rates from 5×10^3 to approximately 10×10^6 words/orbit. The maximum allowable rate could be exceeded if these experiments are not scheduled properly. The physiological measurements considered in Phase IIa also contribute to the severity of the problem.

The vehicle system storage problem could be reduced by an increase in T/M dump time through ground network expansion. A more reasonable solution appears to evolve from an increased PCM storage, readout, and telemetry bandwidth capability.

Several experiments considered in Phase IIb (Oceanographic and Meteorological measurements) impose severe requirements in the handling, storage, and analysis of photographs. Three of the meteorological measurements, cloud types, cloud patterns, and cloud coverage, indicate the generation of 300 pictures per day. It may be difficult to return all of the accumulated hard-copy photographs with the logistics spacecraft because of the bulk involved. Total data transmission and provisions of quick look information for the ground may require both on board photographic data reduction and high-resolution film scanning associated with wide-band telemetry capability. A scan resolution on the order of 1,000 lines/mm is needed. The time required to manually reduce photographic data further implies the desirability for automated reduction techniques. The demands on telemetry bandwidth further indicate the need for the development of pertinent compaction techniques for data.

Simultaneous viewing of common briefing charts and other material by widely separated crew members indicates the desirability of an automatic microfilm retrieval and intralaboratory display system addressable from various monitor stations.

The recording of voice comments relative to various qualitative observations concerning equipment performance, operating procedures, malfunctions, problems, and observations of unusual phenomena encountered is indicated. The probable bulk of verbal recording and the relatively short ground contact times dictate the requirement for an analog transmission channel with a large information bandwidth.

The rf transmission/reception channels identified for the MORL are tabulated in Table 2-3. This requirement is largely independent of mission factors such as orbit inclination and orbit altitude. However, significant system parameters including bandwidths and gain margins are dependent on the transmission distance as well as the required channel intelligence, bandwidth, and ground transmitter/receiver characteristics. The baseline rf system characteristics are satisfactory for all 200-nmi missions when associated with the baseline data management and ground systems.

The additional 25 dB space loss for synchronous altitude eliminates the possibility of using the omnidirectional MORL antennas as well as the C-Band ground radar systems for this mission. Directional antennas are required in order to achieve higher system gains, and the operational complexity associated with the number of directional antennas that would be required by the baseline configuration further emphasizes the desirability of a unified rf carrier system such as the Apollo Unified S-Band system.

2.2 GROUND SUPPORT SYSTEM

The primary functions provided by the ground systems for MORL include tracking, command, telemetry, and voice communications. The operational and experimental aspects of the MORL mission establish requirements on (1) the use of remote site and IMCC facilities, (2) the use of the data and voice communications circuits between IMCC and the remote sites, and

11

Table 2-3

RF TRANSMISSION/RECEPTION REQUIREMENTS

Note

1. Specific link requirements are dependent on data management, MORL-to-ground and MORL-to-logistics interfaces.

2. Space loss (therefore, transmission/reception gain requirement) is dependent on orbital altitude and carrier frequency. The following comparison is made for the S-band spectrum:

Altitude	Space Loss
200 nmi (1,100 nmi max. slant range)	166 dB
19,300 nmi (synchronous)	191 dB

Functional Requirements

	Voice Communications	PCM Telemetry	Analog Telemetry	Tracking/ Acquisition Aids	Digital Command
General channel requirements	MORL/ground (real time)	High bit rate (recorded)	Low frequency (1-2 kc)	Transponder (ground radar)	Receiver
	MORL/ground (recorded)	Low bit rate (real time)	High frequency (TV, film scanner)	Transponder (logistics radar)	
	Intercommunications and EVA	DCS verify		Acquisition beacon	

(3) the number and locations of the remote sites. For the first two items, the requirements depend largely on the MORL and IMCC equipments to be interfaced. No significant changes have been identified in Phase IIb.

Network requirements were given major emphasis in Phase IIb because of the coverage implications associated with the consideration of the 50° and 90° inclination missions. These requirements are set by the contact opportunities and durations necessary to support the mission.

2.2.1 Tracking

If the baseline navigation technique is to provide the accuracies given in Table 2-4, operational tracking requires at least one tracking opportunity per orbit for three successive orbits with a succeeding occultation period of no greater than 13 orbits.

Additional navigation accuracy requirements associated with critical experimental measurements require significantly more tracking opportunities, and may require tracking just prior to the collection of experimental data.

2.2.2 Command

The baseline navigation technique requires a command opportunity for ephemeris update within one orbit after the three successive tracking opportunities. In addition, commands relative to MORL orbitkeeping must be issued approximately once every 7 days.

Experiment related commands, such as sensor pointing angles, are related to the specific experiment tracking problem. For high accuracy requirements, timing for the track-compute-command cycle presents a difficult network problem, and suggests that serious consideration be given to alternate navigation techniques including autonomous navigation.

Table 2-4

NAVIGATION SYSTEM OPERATIONAL REQUIREMENTS

Function	Requirements (nmi)
Rendezvous	10*
Orbit keeping	1**
Cargo module deorbit	50
Laboratory deorbit	50
Data capsule deorbit	2
Ferrycraft deorbit	2

*Ground track only

**Vertical only

2.2.3 Telemetry

Network requirements for telemetry are based on the telemetry recording rate and capacity, playback rate, as well as the need to eliminate recorded PCM overflow. The maximum occultation period and the minimum dump rate combine with these factors to determine the requirements which must be provided by the ground network.

The baseline low-rate PCM recorder, operating in the prescribed continuous record mode at 15/32 ips, can record for approximately 17 hours. A dump time of 32 min. is required every 17 hours for the 2,400 ft of tape at the playback rate of 15 ips. Thus, the total required dump time for this system is 45 min./day with a maximum allowable occultation period of 17 hours.

The medium rate recorder, with a tape length of 2,400 ft and a playback speed of 15 ips requires 32 min. for complete tape dump.

2.2.4 Voice Communications

Availability of at least one voice contact per orbit has been indicated as desirable. Since the baseline MORL can transmit in a high power emergency voice mode (20 W instead of the normal 5 W), this capability is achieved with special ground transceivers at selected emergency ground sites.

Section 3
MORL IMPROVEMENT STUDIES

3.1 ADVANCED DATA MANAGEMENT SYSTEM ANALYSIS

The results of Task III identified the need to expand the MORL data management capability, primarily in terms of the total number of channels, range of sample rates, and wordlengths required, to preserve measurement accuracies. The projected weight-power-volume requirements associated with upgrading the baseline system indicated the desirability of investigating a new system concept. Advances in technology since the definition of the baseline system permit consideration of a data management system which would satisfy the new requirements, facilitate greatly increased operational flexibility, and allow increased crew control of the data management functions. Furthermore, the nature of the concept is compatible with significant system definition prior to firm commitment of requirements.

The proposed data management system consists of a central programmable information control system (ICS) which handles data point sampling, information routing, console data insert and display servicing, and information storage, retrieval, and formatting. The system also includes a general purpose information processing system (IPS) for logical and computational operations. It is recognized that the ICS control function could be handled by the IPS, particularly in view of the expected advances in aerospace computers indicated in Table 3-1. However, separation was maintained in this study to facilitate the analysis and maintain flexibility to accommodate other processing requirements not yet defined. This study consisted primarily of an organization definition, necessary initial tradeoff analyses, and a fundamental feasibility evaluation with respect to the new requirements.

Table 3-1

ADVANCES IN AEROSPACE COMPUTERS

Computer	Add (μsec)	Multiply (μsec)	Divide (μsec)	*Thousand Operations/sec	Double Precision	Weight (lbs)	Power (W)	Volume (cu ft)	Max. Memory Capacity (words)	Data Word Length (bits)
Baseline	84	336	672	12.2	No	77	131	2.2	32K	26
1970 to 1975 Period (approximately)	1	10	10 to 20	815	Optional	20 to 40	100	0.35	Greater than 250K	24 to 64

*Defined as 80% add, subtract, and so forth (short instructions)
    15% multiply
    5% divide (long instructions)

3.1.1 Information Control System Organization

The information control system (ICS) architecture is physically and functionally separable into four major hardware groups: central information control and storage unit (CSU), data distribution bus (DDB), data source-point terminal (DST), and general purpose control and display console (GPC). The CSU serves as the central information routing and switching control and implements the performance monitoring requirement. All normal automatic and manual signal selection and distribution is controlled by the CSU. In the system test mode, the CSU directs test stimuli to all subsystems, evaluates test results, and provides fault isolation data to the operator's console. All information formatting, storage, and retrieval control is mechanized in CSU logic. The CSU also includes the memory required for the storage of data, program instructions, and constants.

The data distribution bus consists of a group of lines with their associated line drivers and line receivers. All CSU-controlled information transfer within MORL is routed over this common bussing array. Provision is made in the DDB for the servicing of 512 signal source/destination terminals. Because specific source/destination pairing is accomplished by the double address control of the CSU, the complete flexibility inherent in the CSU-DDB affords arbitrary addition, deletion, or modification of interfacing sensors without altering the ICS hardware.

Located physically and functionally at the interface of each of the information sensors and effectors is a data source point terminal. Circuitry contained in in these units provides the individual data sensor with the necessary electrical signal conditioning and analog-to-digital (A-D) conversion. In addition, logic within the terminal continuously interrogates the address and control lines of the DDB and, upon detection of the appropriate truth condition, transfers its quantized sensor output to the DDB data lines for transmission to the destination dictated by the address field of the CSU instruction in control. The DST operates in the reverse fashion at an effector point; thus, when the DDB

address line decoder satisfies truth conditions unique to the specific terminal logic structure, information is taken off the data lines and transferred to the terminal's buffer register for subsequent conversion, conditioning, and effector stimulation. While the DST logic permits two-way data transfer as required (for example, by test stimulus routing), most of the terminals used in normal system operation will be either inputs or outputs, but not both.

The general purpose control and display consoles (GPC), located at the system control stations, mechanize the man-machine interface. All operator-inserted data, requests for information, and system interrupts are mechanized, under CSU control, by the GPC. Information appropriate to the mode selected at the console, emergency alarm indications, and the hard-copy file control and facsimile displays are presented to the operator at the GPC. This portion of the system is not further defined in this study.

Figure 3-1 is a simplified block diagram of a preliminary DMS mechanization. Subsystems which require large quantities of information and whose real-time demands are such that they cannot conveniently be programmed into the ICS central control sequencing, are indicated as having separate bussing arrangements.

3.1.2 Control and Storage Unit (CSU)

Figure 3-2 is an illustration of the general organization of the CSU. Principal control functions programmed in the CSU include: (1) data acquisition multiplexing, (2) information storage and retrieval, (3) T/M and display data formatting, (4) failure history compilation, and (5) computer input/output mechanization. To facilitate these functions, the following three basic transfer instructions are provided under CSU executive loop control (Figure 3-3):

1. Point-to-point--Completes the logic path between a sensor, specified by the x-field, and an effector indicated by the y-field of the address portion of the instruction. The source and destination are outside the CSU.
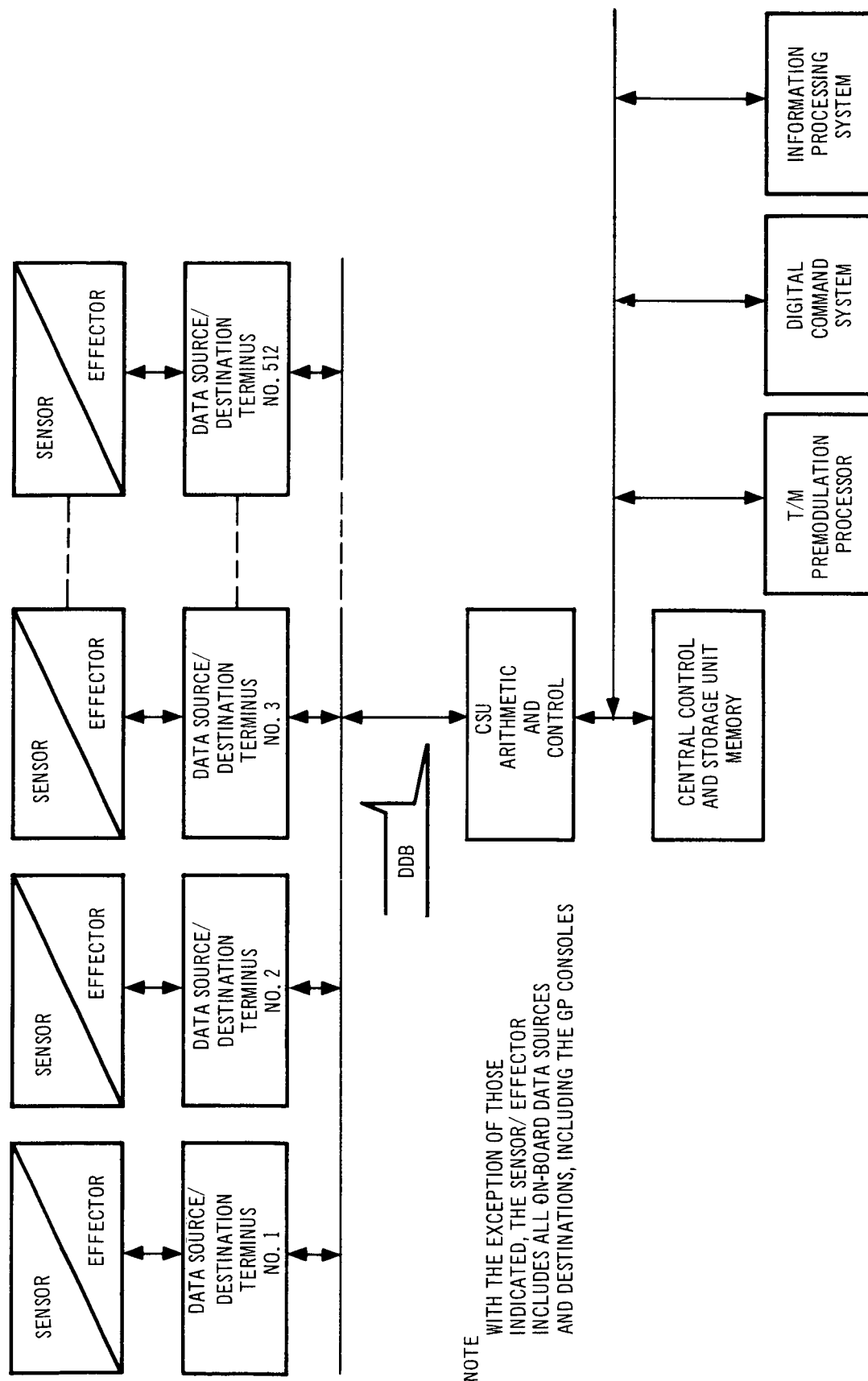
Figure 3-1. General Block Diagram of Information Control System

NOTE

WITH THE EXCEPTION OF THOSE
INDICATED, THE SENSOR/ EFFECTOR
INCLUDES ALL ON-BOARD DATA SOURCES
AND DESTINATIONS, INCLUDING THE GP CONSOLES

19
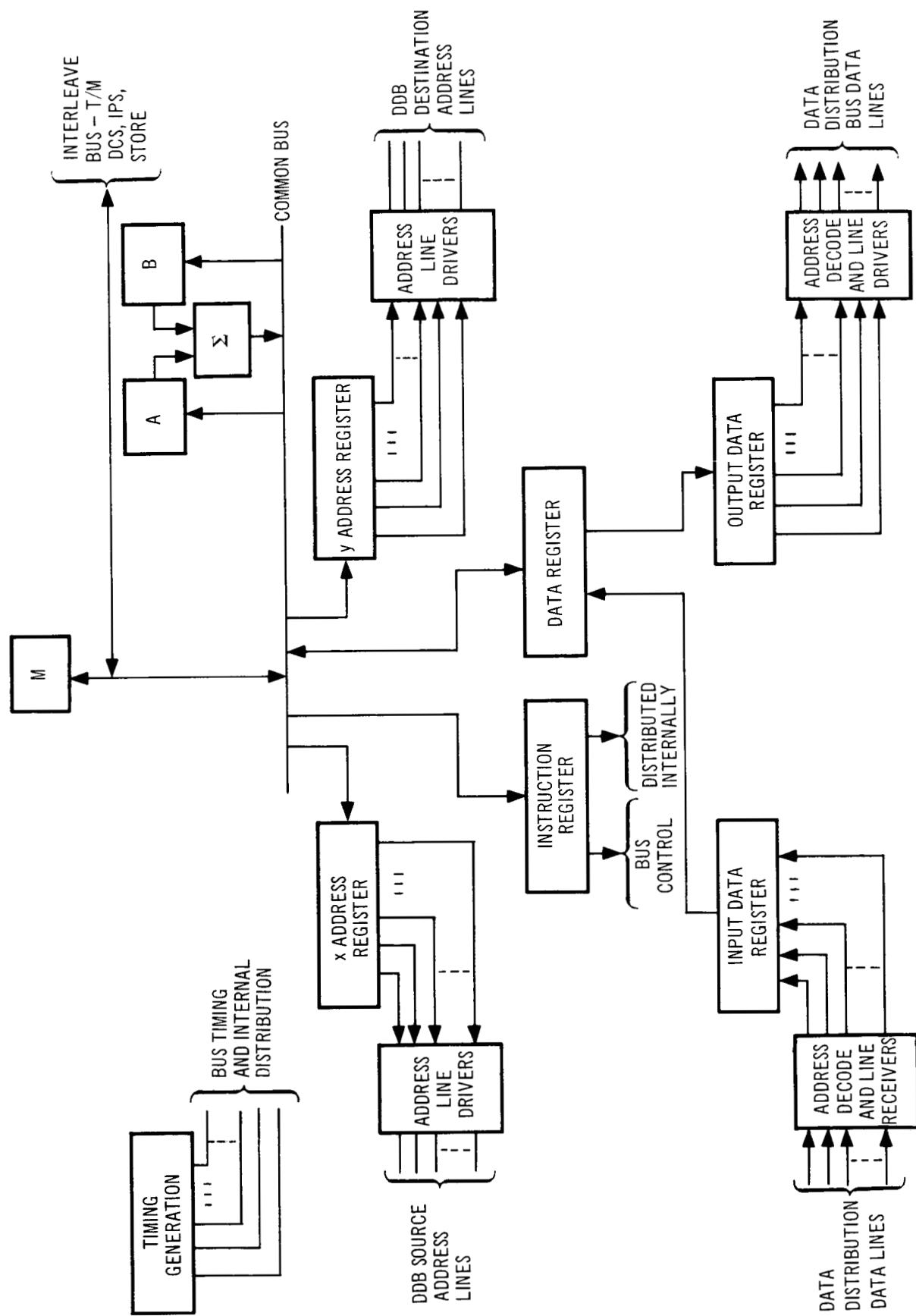
Figure 3-2. Architecture of the ICS Central Control Function

2. Control-to-output--Accesses information from the CSU output data register (ODR) and gates it to the external destination specified in the instruction address y-field.

3. Input-to-control--Transfers data from an external sensor, designated by the x-address field, to the input data register (IDR) of the CSU.

The notation of Figure 3-3 is as follows:

1. Memory register--M

2. Data source address--ARS

3. Destination address register--ARD

4. Instruction register--IR

5. The symbol ( ) indicates "contents of," while subscripts refer to the instruction word field diagrammed in Figure 3-4.
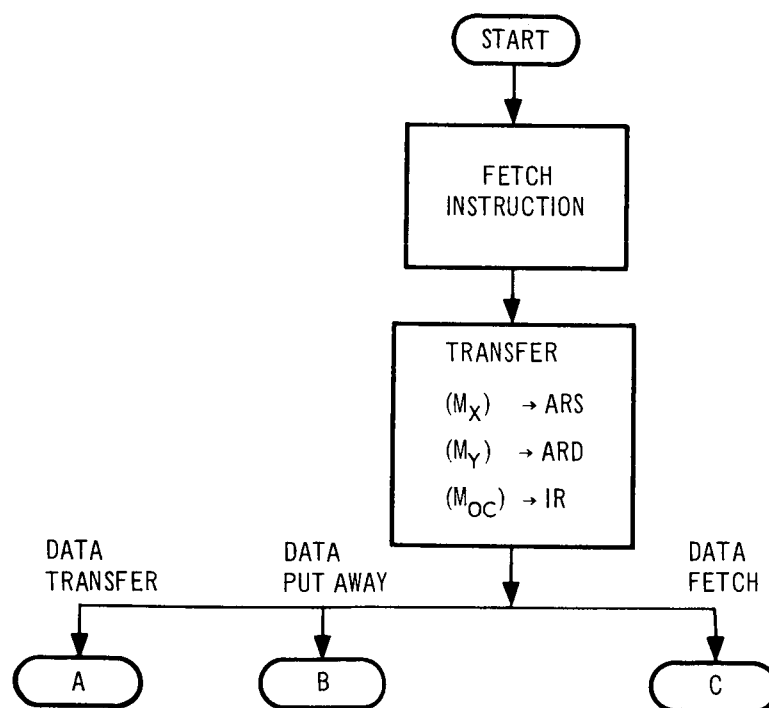
Figure 3-3. CSU Executive Loop

As an example of the transfer sequences, Figure 3-5 illustrates the logic associated with the point-to-point transfer. A typical operation is described below. Assuming the fail tag test is met and the source address is NON-ZERO, the appropriate source (sensor) is addressed and the transfer data command goes true. If the source point buffer is busy completing a conversion, the CSU control logic enters an idle loop for a preselected time. Continuation of the busy condition past this time indicates a failure on the source bus, or in the DST, and a failure alarm is presented to the operator. The operator can then force an override or monitor the sensor output and exercise judgments as to its acceptability. The use of a failure counter eliminates the possibility of permanently shutting down a sensor for intermittent failures, such as a noise burst.

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
x (SOURCE) ADDRESS FIELD OR HIGH ORDER BITS OF MEMORY ADDRESS									X FAILURE COUNTER FIELD					y (DESTINATION) ADDRESS FIELD OR LOW ORDER BITS OF MEMORY ADDRESS							y FAILURE COUNTER FIELD				OPERATION CODE			

x FAIL TAG   y FAIL TAG   INDEX BIT
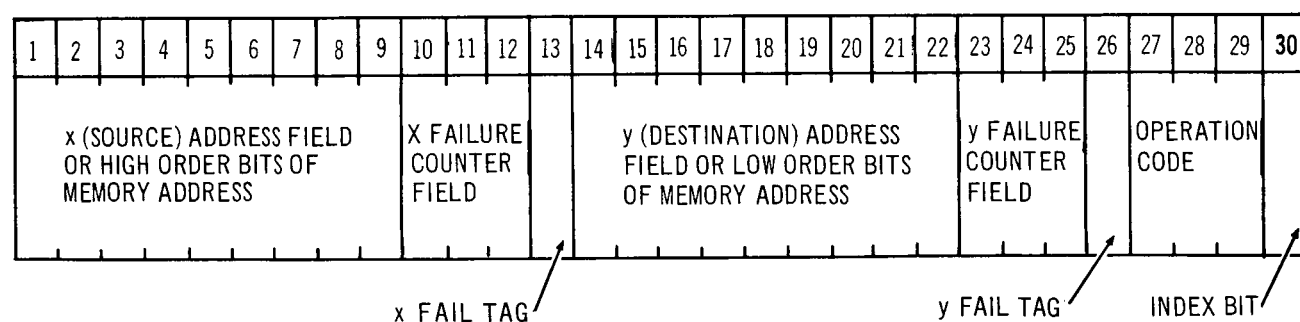
Figure 3-4. CSU Instruction Word Format
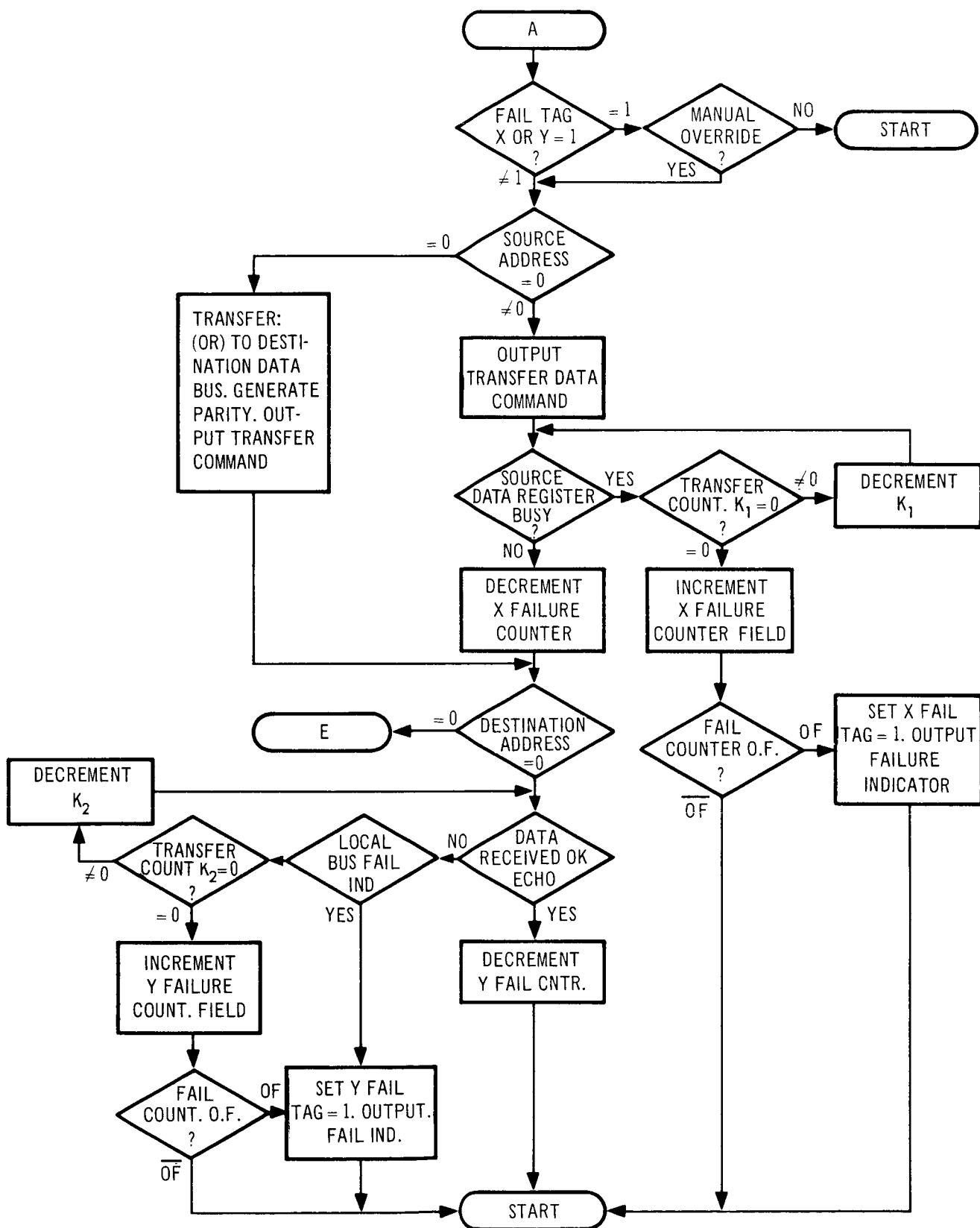
Figure 3-5. Transfer Instruction Sequencing

A non-zero destination address permits the source data lines to be gated to the appropriate destination (effector) buffer. The CSU logic enters an idle loop until a data received echo is returned on the control bus line.

If the destination address is zero, the appropriate destination is the input data register (IDR). In this case, the sequence exits to branch E, which is a data bus confidence testing routine (Figure 3-6).

The maximum time through the point-to-point transfer sequence is approximately 1.2 μsec, including instruction access time. This assumes worst-case idle loop times, and is based on delay times achievable in integrated molecular circuits commercially available today. Assuming that the total sensor complement is 512, and that each point is sampled once per iteration, the "multiplexer" is scanning at approximately an 800kc rate so that each data point is interrogated at a 1.6-kc rate, or once every 0.6 msec.

These rates assume that 100% of CSU program time is devoted to sensor interrogation, which is not the case. For example, no time is allotted for storage in memory, which typically requires as much as 1 μsec. Other considerations which reduce the effective sensor sampling rate of the CSU are the execution times required for operations other than point-to-point transfers and interrupt servicing delays. For example, telemetry data may be stored either in CSU memory or in an auxiliary store. In either case, the formatting function is implemented by the sequence of sensor-to-control and control-to-memory instructions programmed in the CSU. Clearly, the data memory insert will take time from the CSU multiplexing operation. Moreover, a manual interrupt, when detected by the CSU logic, will take additional time to: (1) decode the data address inserted by the operator, (2) retrieve the information from memory (CSU or auxiliary), and (3) transfer the information to the appropriate display buffer. In addition, the CSU logic must also retrieve up-link (DCS) data from storage and route it to the appropriate destination points. If it is assumed that these instruction execution times are twice that of the point-to-point transfer, and a typical program instruction mix is two long instructions per short instruction, the effective multiplexing rate for 512 sensor points is approximately 0.3 kc. Both the long instruction execution time and the instruction mix time are probably exaggerated.
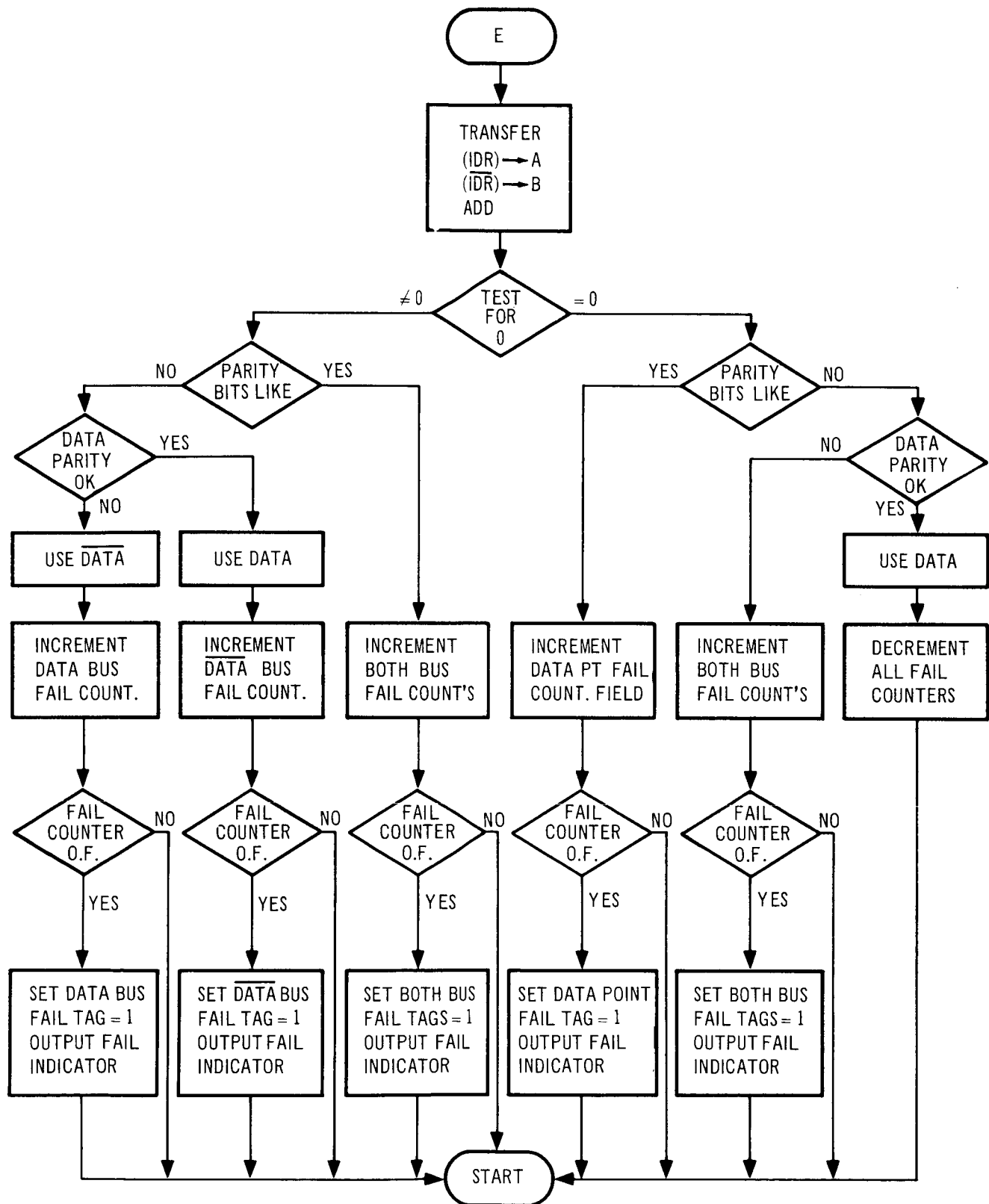
Figure 3-6. A Data Bus Confidence Testing Concept

Also, of course, not all 512 sensors require a sampling rate this high. Therefore, the 2.4-kc requirement identified in Task III for a limited number of sensors could be readily accommodated.

An advantage, both in speed and logic simplicity, derives from the separation of program and bulk data storage indicated in Figure 3-2. This results from the fact that DCS and T/M data servicing can be asynchronous with CSU operation. Moreover, the IPS input-output can be interleaved; that is, the central processor can access CSU or T/M store, through the common memory bus, for input-output operations during long instruction periods of the CSU when the bus is free. Thus, no time is taken from the IPS program for IPS input-output servicing. Furthermore, where the IPS merely addresses CSU or T/M memory for computer input-output data, the central computer architecture is free of the complex, special-purpose logic structure normally required for input-output.

Since telemetry data formatting is an integral part of the CSU program, it is obviously necessary that this program be duplicated in the ground decommutation equipment if interpretation of T/M data is to be possible. An operational technique might be to develop and debug these programs on ground equipment and transmit them to the laboratory by DCS or hard-copy program tapes. Moreover, it may be desirable to provide CSU instruction storage sufficiently large to accommodate three or more separate programs with the branching controlled by operator selection. This would enable rapid switching from one group of experimental measurements to another without time and power consuming memory fill operations. Each of the programs stored would, of course, require an identifying header for decommutation recognition. As a result of their inherent speed and weight advantage, consideration should be given to the use of core or thin-film memories for T/M and DCS bulk store. Memories of this type are particularly attractive because telemetry word rates of 2 mc are achievable with today's technology, with further improvements expected by 1970.

3.1.3 Data Distribution Bus (DDB)

In general, information transferred between the CSU and DST can be routed in one of three ways: (1) all data can be multiplexed on a single, common bus, (2) a line may be provided for each signal so that external multiplexing is not required, or (3) a compromise between these extremes might be employed.

Such information transfer schemes, however, must not only provide for data transmission lines, but also must incorporate an address and sequencing capability, including clock timing which is under CSU master control. Thus, the digital data bus consists of: (1) an information line or wire, (2) a control line or series of control lines, and (3) a timing or clock line. An immediate advantage of digital data transmission techniques is that large numbers of signals, or data words, can be serviced by a single bus at relatively high data rates using straightforward multiplexing techniques. Moreover, digital data lines yield to confidence testing techniques far more readily than do their analog counterparts. To incorporate a digital data transmission network within a system without taking full advantage of these characteristic properties would represent an unsound engineering practice. Several design approaches to the MORL data transmission system have been investigated, with a view to optimizing the maintainability, reliability, and expandability of the transmission system.

The common bus is physically composed of the following three separate functional line groups:

1. Input-output address bus--18 lines.
2. Input-output data bus--20 lines.
3. Input-output control bus--3 to 4 lines.

Figure 3-1 illustrates the organization of the MORL system around this central data transfer complex. A typical input-output cycle is described below. Upon decode of the input-output transfer instruction within the CSU, the address portion of the instruction is loaded into the CSU input-output address registers. Each register flip-flop is connected, through a line driver, to the input address lines of the DDB. After sufficient time has

elapsed for the bus lines to stabilize, the CSU delivers a transfer command signal to one of the control lines of the DDB. This signal appears as a continuous true state on the line until the received OK echo advances the CSU cycle counter. The immediate effect of the transfer command is to enable the unique DST data-buffer-to-data-line gate which is satisfied by the address on the source address lines. A parallel transfer of data occurs between the addressed source and the destination buffer registers. In addition to the transfer command and data received echo control signals, the CSU provides a master timing reference to the DST through bus clock control lines.

Instead of the bit-parallel data transmission scheme, a serial bus might be implemented reducing to one (or two, for backup) the number of data lines required. In this case, the transfer command would be a time envelope which would remain true for the number of clock times equivalent to the number of serial bits transferred. Coincident with this envelope would be a clock pulse train delivered by the CSU to the bus clock control line. This clock train would then be gated to the addressed DST output shift register, serially driving its contents into the destination buffer shift register.

A sentinel bit, the input word control bit, arriving at the end of the destination shift register would indicate that the transmission is completed. This bit could set the address decode envelope into the false mode, and inhibit further clock pulses to the DDB control bus clock line. The destination logic is then free to perform the bus confidence test and data put-away function. The timing diagram, Figure 3-7, is intended to assist in the understanding of the cycle described above.

The serial transfer scheme provides economy of hardware purchased at the price of reduced sampling speeds. Transmission line problems might become severe where high-frequency digital data is gated onto long line (for example, 20 to 30 ft) runs. These are only two of the detailed design trade-off considerations that warrant further investigation.

The bus lines described in the previous paragraphs are terminated at the sensor and effector in gated line receiver and driver amplifiers, illustrated in Figure 3-8. In the figure, the number of data lines does not agree with
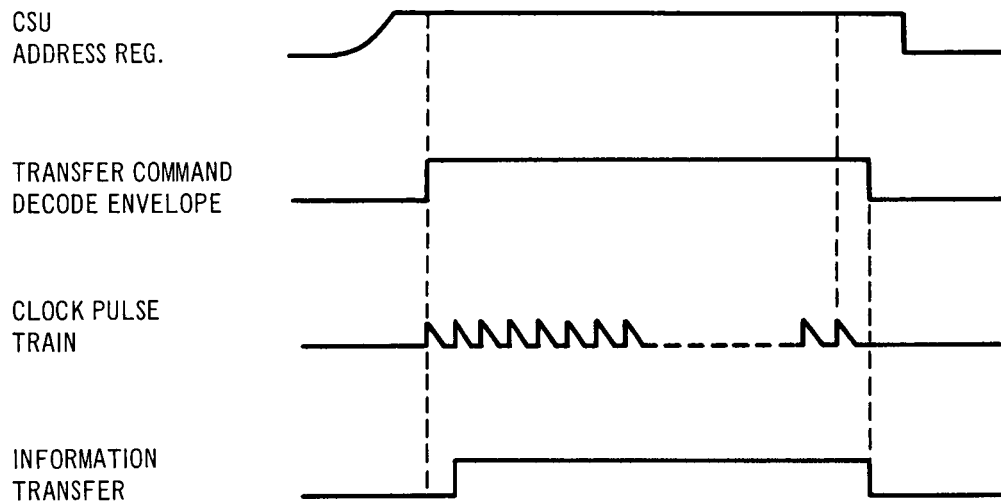
Figure 3-7. Serial Information Transfer Sequencing

that indicated in the DDB discussion, and the two-way path necessary for the built-in system diagnostic testing function has been omitted. However, the figure is complete enough to illustrate a possible conceptual mechanization technique.

When the truth condition of the address lines on the DDB are such as to bring true the address decode gates at the output of the line receivers (LR), and when both the Transfer Command and OK To-Transmit lines are true, the converter register flip-flop gates to the data line drivers are enabled, and information is dumped, in parallel, onto the bus data lines. Although the diagram does not illustrate it, the OK To-Transmit signal is also gated to a bus control line (for example, C_3) and this signal indicates to the CSU that valid data are present on the bus.

Two conditions could inhibit this signal and, therefore, the line driver input gates. First, the timing and control logic will hold the OK To-Transmit line false until the conversion cycle control counter has timed out, that is, until

Figure 3-8. Data Point Terminus of Common Bus

C.A. = COMPARATOR
         AMPLIFIER
L.D. = LINE DRIVER
L.R. = LINE RECEIVER
F.   = FLIP-FLOP
         (TOGGLE, LATCH)
D_N = N'TH DATA LINE
A_N = N'TH ADDRESS LINE
C_1 = "TRANSFER DATA"
         COMMAND
C_2 = CLOCK-TIMING
         SYNC. SIGNAL

the converter has completed a quantizing operation, leaving the flip-flop register loaded with valid data. Secondly, a no-go indication from the sensor device will hold the line down and prevent transfer of erroneous information. Of course, the self-test gating built into the DST control and timing logic could be or'ed with the device no-go signal to inhibit the OK To-Transmit line in case of local logic failure.

The figure indicates incorporation of a resistance ladder converter, or current weighter. The converter operates on a servo principle, that is, timing logic will reset the flip-flop register, leaving the most significant stage true. A one in this flip-flop enables a logic switch connecting a precision, scaled-current (n μA) path to the input of the comparator amplifier. If the scaled current is greater than the conditioned analog input, the flip-flop is turned off. Conversely, if the precision current is less than that due to the input variable, the flip-flop is left on. In either case, the conversion-control cycle counter advances and sets the second most significant flip-flop. This enables a second current path (n/2 μA) to the comparator amplifier input, where it is algebraically added to the input current. This process, set-compare and reset (or leave set), continues until all flip-flops have been serviced. The resulting magnitude number in the register is a scaled binary representation of the measured current entering the comparator, where the difference between this current and the analog input signal current has been adjusted to be as nearly zero as the round-off limits permit. Hence, the register contains a binary number scaled to the input analog signal. Figures 3-9 and 3-10 clarify the above discussion. The type of conversion technique employed at each data point cannot be specified until the signal conditioner output characteristics are known. This, in turn, requires specification of the sensor instrumentation.

The concept of local conversion (that is, replication of converter hardware at each data source point throughout the system) represents a significant departure from classic central, time-shared conversion. Many of the concepts presented here rest on the feasibility of this mechanization.
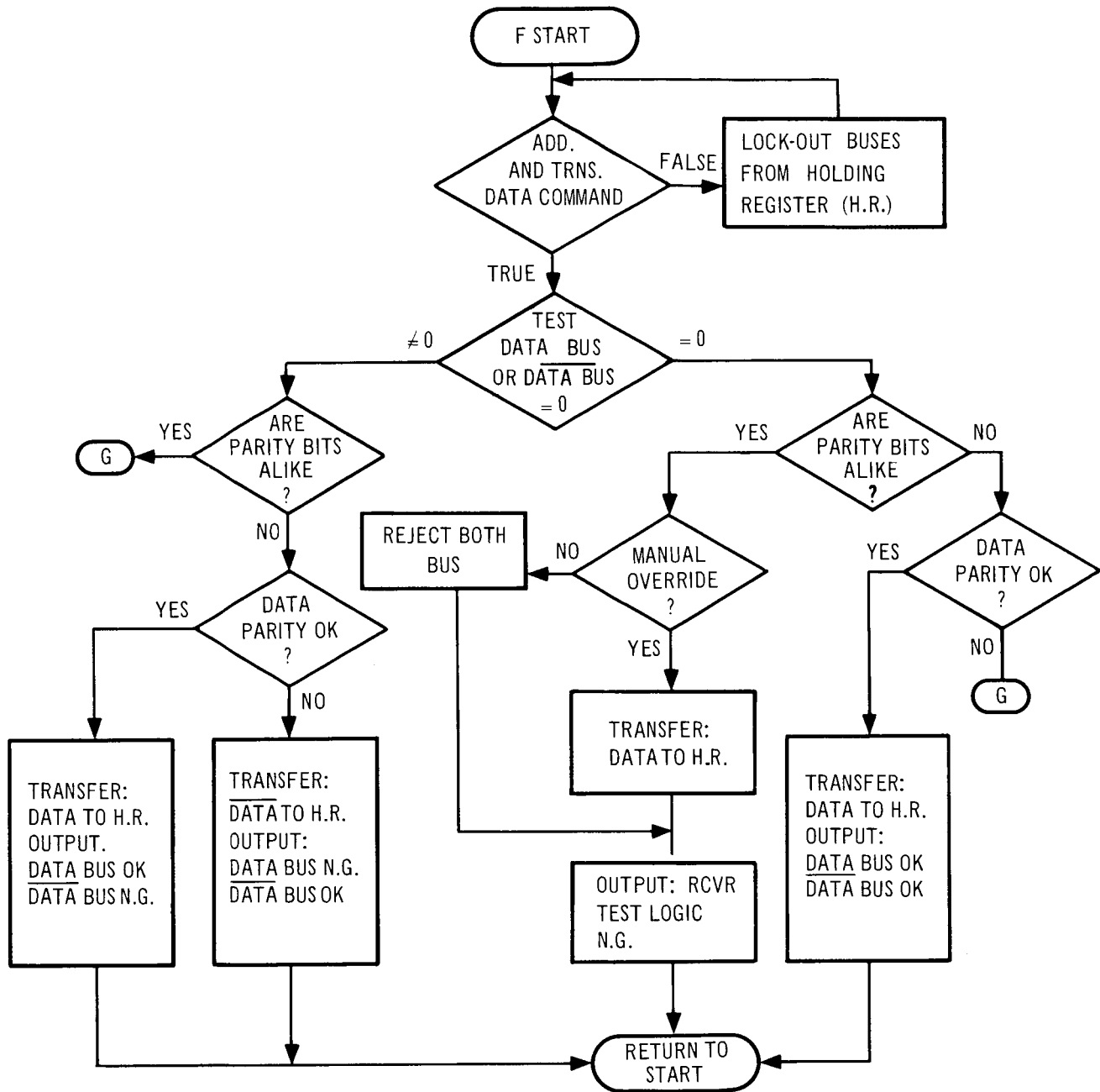
Figure 3-9. Remote Destination Point Algorithm (a)
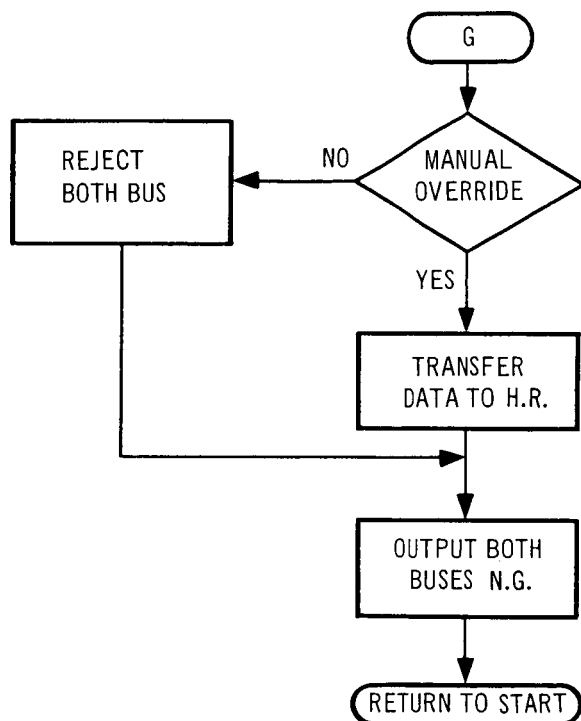
Figure 3-10. Remote Destination Point Algorithm (b)

Assuming current, off-the-shelf microcircuits and a total of 512 data source terminals for the system, the following figures are derived from manufacturer's data:

Weight--Approximately 40 lb.

Volume--Approximately 0. 9 cu ft.

Power--Approximately 150 W (assuming the one-sample-at-a-time duty cycle).

The weight and volume figures represent the summation of weights and volumes of current state-of-the-art microchips and an equal weight and volume for mounting boards, interconnection printing, and so forth. Advanced super-chip technology, well through development now and available in the MORL period, is expected to reduce these values significantly. For example, the converter will require three chips, one containing the flip-flop register with its associated input gating, a second mechanizing the resistive ladder and electronic switches, and a third providing the comparator

amplifier and summing circuits. The above weights and volumes assume individual chips for each flip-flop, gate, amplifier, and switch. These considerations indicate the feasibility of considering the concept presented for ultimate incorporation in the MORL DMS.

Advances in microelectronics will also result in improvement of analog multiplexing and transmission networks. Consequently, the time-shared central converter, and concomitant analog switching and transmission alternative cannot be totally discounted as a MORL DMS system candidate.

3.2 GROUND NETWORK ANALYSIS

The baseline network of Texas (Tex) and Cape Kennedy (Ken) which was defined for the 28.5° inclination mission results in an average daily contact time of only 43 and 28 min. for the 50° and 90° inclination missions, respectively. Therefore, various sites (Table 3-2) were considered for addition to, or replacement of the baseline sites to establish satisfactory networks for these additional missions.

The study used a computer-based simulation system known as SRMS (the IBM surveillance, reconnaissance, and mission simulation) to generate site contact data. The program considers an ellipsoidal Earth model and posigrade (west to east) motion. It does not include the effects of drag; however, this is not a limiting factor because the MORL will maintain an almost constant altitude by utilizing reboost.

The resultant site contact data were reduced considering contact redundancy for several selected networks. Comparative network effectiveness was evaluated based primarily on the average coverage time obtained, the day-to-day coverage consistency, the size of the network, the location of the sites, the number of orbits during which contact is made, the status of the on-site instrumentation, and site-to-center communication links.

The networks selected for the 50° and 90° missions, Tex-Ken-Haw and Tex-Ken-Haw-Gym respectively, were also evaluated in terms of average occultation period, average number of successive orbit contacts, and average contact duration to ensure responsiveness to the related requirements, for example, tracking duty cycle.

Table 3-2

SITE LOCATIONS

Station Name	Abbreviation	Latitude North° (deg/min. / sec)	Longitude East° (deg/min. / sec)	Notes
Cape Kennedy	Ken	28/28/55	-80/34/34	Existing NASA
Bermuda	Bda	32/20/49	-64/39/14	Existing NASA
Antigua	Ant	17/08/13	-61/46/26	Existing USAF
Ascension	Asc	-7/55/48	-14/24/11	Existing USAF
Grand Canary	Cyi	27/43/48	-15/36/00	Existing NASA
Guam	Gua	13/27/00*	144/47/00*	-
Hawaii (Kauai)	Haw	22/07/46	-159/40/04	Existing NASA
Guaymas	Gym	27/57/29	-110/43/16	Existing NASA
Corpus Christi	Tex	27/39/18	-97/22/48	Existing NASA
Canberra	Can	-35/13/10	148/58/48	DSIF
Goldstone	Gol	35/23/24	-116/51/00	DSIF
Madrid	Mad	40/20/02	-4/11/58	DSIF
Carrnarvon	Cro	-24/58/01	113/43/01	Existing NASA
Boston	Bos	42/21/24	-71/03/25	-
Minneapolis	Mpls	44/58/57	-93/15/43	-
Seattle	Se	47/36/32	-122/20/12	-

---

*These figures are not exact

Three hypothetical sites, Boston, Minneapolis, and Seattle, were used in examination of the effectiveness of these high-latitude locations (Tables 3-3 and 3-4). These sites were also used in a short analysis on the influence of site latitude on the number of contacts obtained per day, the average time per contact, and the average coverage over a 5-day period. Table 3-5 indicates the general trends for the $50°$ case. These trends are the result of the following factors: (1) the density of the orbital paths increases with latitude so that a more northerly site's coverage boundary would be crossed more often, (2) any site located so that its coverage boundary extends beyond a latitude equal to the orbital inclination angle would waste part of its coverage capability, and (3) the crossing time of the coverage boundary is greater for the higher latitude sites as the result of factors such as the angles of crossing and the effect of Earth rotation.

The Goldstone site was investigated because it is at a latitude ($35° 23'$) which is near optimum, as viewed in light of factor 2 in the previous paragraph; that is, the northerly edge of the coverage boundary is approximately tangent to the $50°$ line of latitude. (The Earth-centered angle between the site and its coverage boundary is $14° 43'$ for a $50°$ elevation angle and a 200 nmi orbital altitude.)

For the $90°$ mission, it can be seen, in Table 3-6, that both the number of contacts and the coverage duration per contact increases with site latitude. This occurs because the orbit trace density and, thus, the number of traces which pass through the site coverage area increases as the site location approaches the pole. Furthermore, a greater percentage of the traces which pass within the site coverage area approach a full coverage area diameter trace. (For a site at the pole, all traces pass through the coverage area and all are full coverage diameter traces.)

The data generated by use of the SRMS are summarized in tabular and graphical form in the Appendix. It should be noted that since completion of this analysis, the MORL orbital altitude has been changed from 200 nmi to 164 nmi. Although the general conclusions of the study remain valid, it should be noted that the identified coverage times would be reduced by approximately 10%, and the times at which contacts will occur will be different.

Table 3-3

NETWORKS FOR 50° INCLINATION AND TOTAL USABLE TIME

Network Number	Basic		Variations						5-Day Total (min.)	Increase Over Baseline (%)
	Texas	Kennedy	Guaymas	Hawaii	Goldstone	Seattle	Minneapolis	Boston		
1	x	x	-	-	-	-	-	-	216.25	
2	x	x	x	-	-	-	-	-	285.13	32
3	x	x	-	x	-	-	-	-	328.25	52
4	x	x	-	-	x	-	-	-	370.75	71
5	x	x	x	x	-	-	-	-	397.20	84
6	-	-	-	-	-	x	x	x	470.12	118

Table 3-4

NETWORKS FOR 90° INCLINATION AND TOTAL USABLE TIME

Network Number	Basic		Variations						5-Day Total (min.)	Increase Over Baseline (%)
	Texas	Kennedy	Guaymas	Hawaii	Goldstone	Seattle	Minneapolis	Boston		
1	x	x	-	-	-	-	-	-	142.16	-
2	x	x	x	-	-	-	-	-	180.98	27
3	x	x	-	x	-	-	-	-	222.33	56
4	x	x	-	-	x	-	-	-	212.17	49
5	x	x	x	x	-	-	-	-	263.07	85
6	-	-	-	-	-	x	x	x	280.42	97

Table 3-5

AVERAGE COVERAGE TIME PER CONTACT

$(i = 50^{\circ}$, Altitude = 200 nmi)

Site and Latitude

Description	Seattle 47°	Minneapolis 44°	Boston 42°	Goldstone 35°	Texas 27°	Kennedy 28°
Total contacts in 5 days	29	29	29	34	24	24
Average time per contract (min.)	7.00	6.86	7.02	5.71	5.56	5.53
Average 5-day coverage (min.)	203	199	204	194	133.5	133

39

Table 3-6

AVERAGE COVERAGE TIME PER CONTACT

($i = 90°$, Altitude $= 200$ nmi)

Site and Latitude

Description	Seattle 47°	Minneapolis 44°	Boston 42°	Goldstone 35°	Texas 27°	Kennedy 28°
Total contacts in 5 days	20	20	19	18	16	16
Average time per contact (min.)	6.37	6.01	5.91	5.50	5.28	5.58
Average 5-day coverage (min.)	127.5	120.2	112.5	99	84.5	89.4

3. 2. 1 The 50° Inclination Mission

The Hawaii and Guaymas sites were given prime consideration as additions to the baseline network for the 50° mission. Table 3-3 shows the 5-day coverage time for the baseline network, the individual and collective additions of Hawaii and Guaymas to the baseline network, the Gol-Tex-Ken network, and the hypothetical Seattle-Minneapolis-Boston network. The latter two networks are included for comparison. Figure 3-11 shows the average daily coverage for these networks (exept the hypothetical network), as well as the day-to-day coverage variations.

The addition of either Guaymas or Hawaii to the baseline network will result in more than the required 45 min. of coverage per day. However, Hawaii is more effective than Guaymas because of the large contact redundancy between Tex and Gym. Furthermore, the Haw-Tex-Ken network has a much better day-to-day coverage consistency.

The large redundancy between Tex and Gym also makes the addition of Gym very ineffective in increasing the number of orbits contacted; that is, Guaymas provides contact for only approximately 14% of the orbits not already satisfied by either Tex or Ken. On the other hand, Hawaii results in contact with 53% of all orbits not contacted by either Tex or Ken. Thus, a Haw-Tex-Ken network would require the emergency voice services of only the Canary Island and Kano sites to ensure contact on approximately 97% of all orbits.

Based on these factors, Hawaii was selected for addition to the baseline network for the 50° inclination mission.

The important coverage duty cycle parameters for this network are as follows:

1. Average usable contact time per day--66 min.
2. Average occultation period--3 orbits.
3. Average number of successive orbits contacted--8 orbits.
4. Average contact duration--5. 54 min.

Table A-3 (Appendix) presents the contact sequence, redundant contacts, usable time per contact, and daily and total coverage for a typical 5-day period.
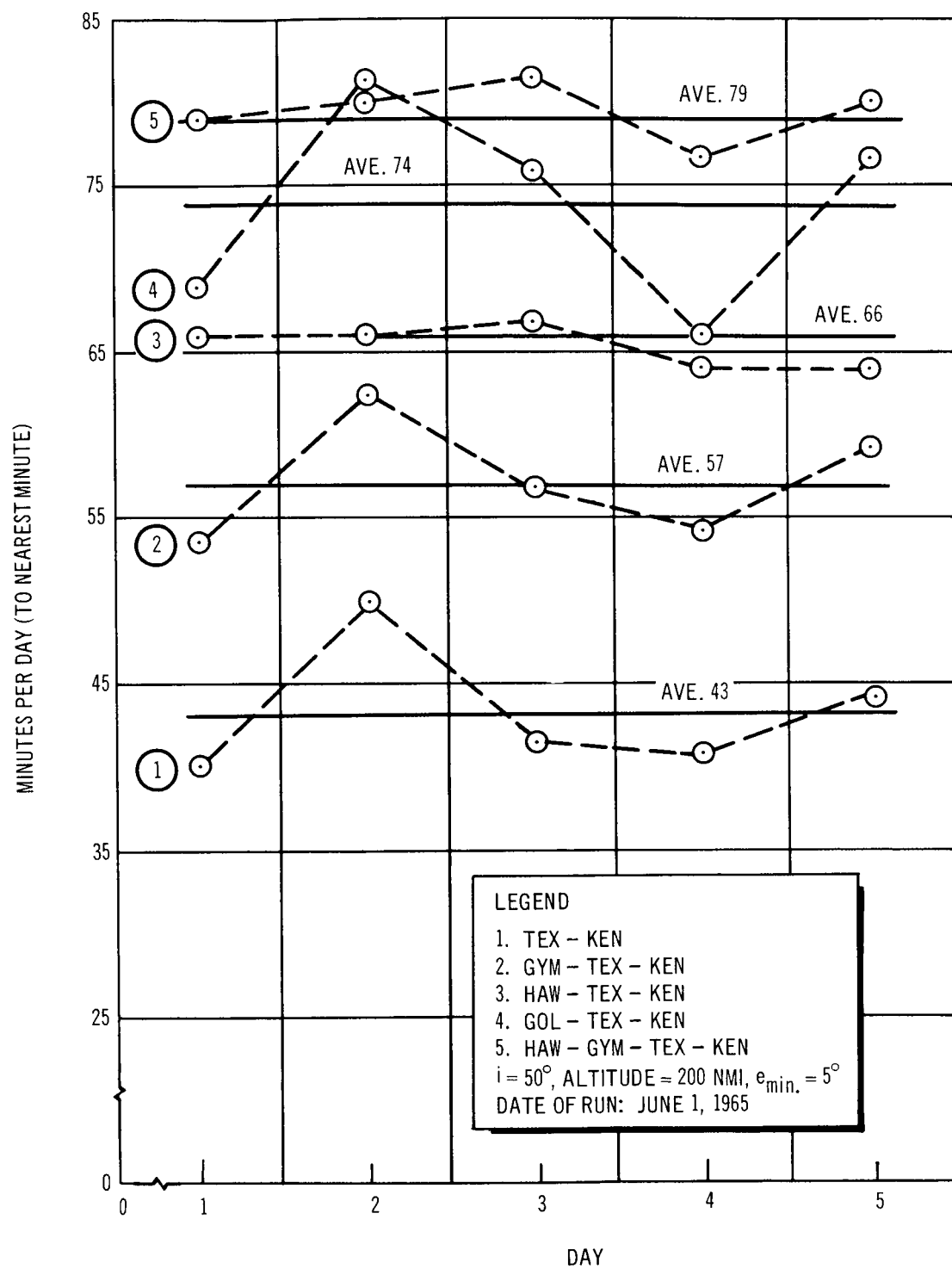
Figure 3-11. Total Usable Contact Time (Min./Day) (a)

3.2.2 The 90° Inclination Mission

Table 3-4 and Figure 3-12 present the tradeoff data for the 90° inclination network selection. It is seen that the addition of Gym to the network selected for the 50° case provides sufficient daily coverage (52 min./day) and a satisfactory day-to-day coverage consistency. Further, the Gym-Haw-Tex-Ken network requires only the use of the Canary Island and either the Bermuda or Antigua sites to provide the emergency voice one-contact-per-orbit situation for approximately 97% of all orbits.

The important duty cycle parameters for the selected network are as follows:

1. Average usable contact time per day--52 min.
2. Average occultation period--2 orbits.
3. Average number of successive orbits contacted--3 orbits.
4. Average contact duration--5.87 min.

Table A-12 (Appendix) presents the detailed contact data for this network.

Although the MORL requirements can be met with existing sites, the hypothetical site coverage data were included to indicate the value of high-latitude sites for the 90° mission. An average of 56 min. coverage per day can be realized with this three-site network. However, because of the high redundancy between the three northerly sites, virtually identical coverage would be provided by adding only one such site (for example, Seattle) to the baseline network. This three-site network would afford an average of approximately 54 min. of coverage per day, as compared to the Gym-Haw-Tex-Ken network daily coverage of 52 min.

3.3 RF UNIFICATION ANALYSIS

The following paragraphs present an introduction and summary of the rf unification analysis.
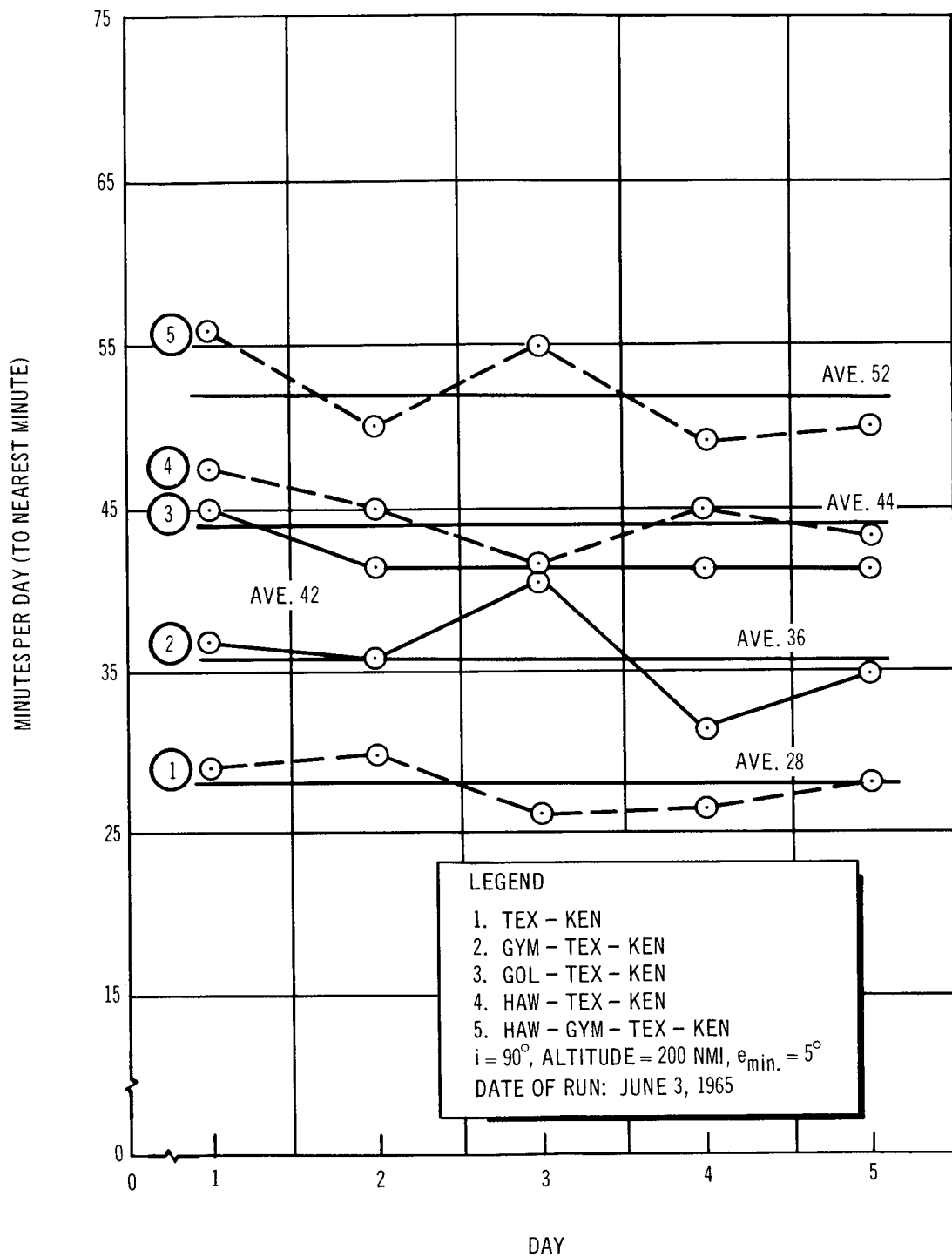
Figure 3-12. Total Usable Contact Time (Min./Day) (b)

3.3.1 Introduction and Summary

A unified rf carrier system for MORL is one in which the MORL/ground voice, telemetry, television, command, and tracking links are implemented with a minimum number of rf links (ideally one up-link and one down-link). Because such a system offers possible advantages in flexibility, lower weight-power-volume requirements, ease of installation and maintenance, and lower cost redundancy, consideration has been given during the various phases of the development of the MORL communication/telemetry system to the use of a unified rf carrier system. As an alternate to a system based on Gemini technology, the Phase I study presented a conceptual design of a unified S-band system, in which two modes of operation of a single rf link provided for all MORL-to-ground communication. The system was patterned after the Apollo unified S-band system (USBS), with the same ranging and tracking scheme as the USBS, but with a completely different premodulation processor and with different subcarrier frequencies. Since the unified system did not accommodate MORL/logistics vehicle voice communications, a separate vhf voice link had to be provided for that function, and the total system implementation resulted in a weight increase over the selected system.

During the early part of the Phase IIa study, when revisions stemming from a shift of the proposed launch date of MORL to the post-1970 time period were made to the communication/telemetry system, consideration was again given to the use of the Apollo unified S-band system for MORL. Since the USBS could not accommodate the video bandwidth of the MORL television system, and again since a separate vhf voice link would have to be provided for MORL/logistics vehicle communication, the USBS was not adopted for MORL. Rather, the baseline communication/telemetry system described in Reference 2 was specified.

During this time period, the Apollo USBS concept was evolving into a system utilizing two down-link S-band carriers and one up-link carrier. This concept

was not only for communication at lunar distances, but also to support Apollo in a near-Earth orbit. This extended concept required the implementation of a USBS receiving capability at several ground stations of the manned space flight network (MSFN). The 30-ft S-band antennas and the receivers installed at these sites are precisely the equipment required to receive the S-band telemetry and television links from the MORL baseline system. Of course, a data demodulator which is different from the one required for Apollo will be required, but it is important to note the significant area of support that the MSFN USBS ground stations can provide to the baseline MORL communication/telemetry system.

The last half of the Phase IIa study saw the expansion of the MORL mission to include operation in synchronous orbits. Clearly, the baseline communication/telemetry system could not operate over a range of 19, 300 nmi; the added 25 dB space loss would render the MORL-to-ground links ineffective. Also, the FPS-16 radar used for tracking in the baseline system will not track at that range. The first difficulty could be overcome by providing MORL with a high-gain antenna. The obvious solution to the second problem is to utilize the ranging and tracking capabilities of the USBS. While it is not a requirement that the same communication/telemetry system configuration be utilized for both near-Earth and synchronous missions, this feature is desirable. This fact prompted a more detailed investigation of the USBS concept as applied to the MORL during the early part of the Phase IIb study. It is this study which is summarized here and presented in detail in subsequent paragraphs.

The study assumed that the most significant consideration, in addition to technological and operational practicality, was the extent of compatibility of an appropriate spacecraft configuration with existing or proposed ground terminals. Therefore, the study examined the compatibility of the MORL baseline communication requirements with the Apollo unified S-band system vehicle and ground equipments. The generalized USBS configuration depicted in Reference 3 was used as the USBS model.

The study involved both the 200 nmi and synchronous orbit cases, and considered the applicability of the unmodified USBS, as well as possible

modifications which would enhance MORL requirements accommodation without compromising the use of the USBS ground terminals for the Apollo program.

For the purposes of evaluation, two specific USB system configurations were considered. The first, referred to as MORL/USBS No. 1, is essentially the same as the Apollo USBS with only minor modification to the premodulation processor. The second, referred to as MORL/USBS No. 2, makes extensive changes to the premodulation processor. Both of these systems were analyzed on the basis of the data quantity (bit rate/response) and data quality (dB margin in S/N) which they afforded. The results for the 200-nmi orbit case are summarized in Table 3-7, which also lists comparable parameters of the baseline system. It is evident from the tabulated data that the MORL/USBS No. 1 generally provides lower system margins and a reduced data handling capability. The MORL/USBS No. 2 meets the major data quantity requirement, except that the television signal bandwidth is reduced from 2.16 mc to 750 kc. System margins are also generally lower than those provided by the baseline system. Operation of either of the systems at synchronous altitude would require the use of a high-gain antenna on MORL. Sufficient gain could be obtained to not only overcome the additional 25 dB space loss, but also to improve the system margins tabulated in Table 3-7. The data handling capabilities would remain the same, however. An alternate configuration, making use of system time-sharing afforded by continuous communication capability from synchronous orbit, was also analyzed and the feasibility of operation shown. It is noted that in all cases these systems provide only one, rather than two, up-link voice channels. Additional provisions would be required for voice communications with the logistics vehicle. The ranging function will not operate properly when the MORL is in a rotating mode (caused by phase transients introduced in the transmitted signal by switching from one antenna to another).

While this study concludes that the unmodified Apollo USBS does not totally meet the MORL/ground baseline communication requirements, it does show that significant improvements can be obtained without major modification of the USBS ground terminal. It also points the way to the eventual incorporation

Table 3-7

DOWN-LINK COMPARISON SUMMARY--BASELINE TO MORL/USBS

(1100 nmi Slant Range)

Notes:
1. Not provided in Baseline System.
2. Command verification is via PCM telemetry.
3. Not provided in MORL/USB System No. 1.
4. Not calculated.

Channel	MORL Baseline Bit Rate/ Response	Margin (dB)	MORL/USBS No. 1 Bit Rate/ Response	Margin (dB)	MORL/USBS No. 2 Bit Rate/ Response	Margin (dB)
PCM data (recorder No. 1)	76.8 kbps	9.4	51.2 kbps	6.0	76.8 kbps	7.0
PCM data (recorder No. 2)	76.8 kbps	7.5	51.2 kbps	4.5	76.8 kbps	7.0
PCM data (real time)	2.4 kbps	13.0	2.4 kbps	22.4	2.4 kbps	23.3
DCS verification	640 bps	11.5	Note 2	–	Note 2	–
Continuous analog	1 kc	7.3	Note 3	–	1 kc	3.3
Continuous analog	2 kc	5.4	2 kc	3.3	2 kc	1.5
Television	2.16 mc	10.8	375 kc	2.6	750 kc	3.2
Voice (No. 1)	3 kc	8.0	3 kc	11.7	3 kc	6.7
Voice (No. 2)	3 kc	8.0	3 kc	5.8	3 kc	3.0
Ranging	Note 1		1,000 kbps	Note 4	1,000 kbps	7.1

of a unified rf carrier concept in the MORL communication/telemetry system. The prospect of this change is heightened by the NASA efforts to expand the capabilities of the Apollo USBS. For instance, information obtained since the completion of this study on the latest configuration of the Apollo USBS indicates that: (1) PCM bit rates as high as 200 kbps can be accommodated on the 1.024 mc subcarrier, (2) additional subcarriers are provided at 95, 125, and 165 kc, and (3) it would be a simple matter to add another subcarrier to the up-link transmitter to provide a second voice channel. Application of these factors could result in a system design for MORL which would be a considerable improvement over the MORL/USBS No. 2, which was analyzed in this study.

3.3.2 MORL Unified S-Band System (1,100 nmi Slant Range)

The following paragraphs discuss the MORL Unified S-band system at a 1,100 nmi slant range.

3.3.2.1 Unmodified USBS (MORL/USBS No. 1)

A communication/telemetry system utilizing the major features of the USBS for the MORL data requirement is shown in Figure 3-13. The shaded portions of the figure depict those functional components which must be added to the present USB system configuration to provide multiplexing of real-time telemetry and a continuous analog channel. These additions do not materially alter the basic USBS equipment.

It will be noted in the block diagram that present USBS data channels for PCM telemetry and voice have been retained for the MORL/USBS No. 1, and the television channel has been modified to the extent of reducing the video bandwidth from the 500 kc used in the Apollo USB system to 375 kc. The 1.25 mc subcarrier modulation above the voice channel baseband has been changed from the normal biomedical subcarrier composite (4.0, 5.4, 6.8, 8.2, 9.6, 11.0, and 12.4 kc subcarrier oscillators) to a single subcarrier oscillator at 12.5 kc. This makes it possible to carry either real-time PCM telemetry (2.4 kbps) for the coherent rf carrier or a 2-kc continuous analog data signal carrier for the FM carrier. The PCM telemetry bit rate, 51.2 kbps, used on the Apollo USBS equipment was retained for this MORL/USB system.

Figure 3-13. MORL/USB Spacecraft System No. 1

The information bandwidth of USB television video from the Apollo camera is 685 kc (320 lines, 10 frames/sec, and a 4:3 aspect ratio). The signal is filtered by a 500-kc low-pass filter, resulting in a horizontal resolution of 235 television lines. An analysis of the MORL system indicates that maintenance of the received television signal-to-noise ratio, 23 dB, requires an rf modulation index of at least 1.0. As a result, significant second-order side-current pairs are generated which, if a 500-kc video bandwidth were allowed, would result in serious interference in the passband of the 1.024 mc PCM subcarrier channel. For purposes of this study, the aspect ratio of the MORL/USBS television picture was reduced to 1:1. With this ratio, the horizontal resolution of the MORL/USBS is maintained at 235 lines.

The USB ground data recovery system provides adequate bandwidth to demodulate the biomedical FM telemetry composite. Utilizing this capability, the MORL/USB system shown in Figure 3-13 places the real-time PCM telemetry on a 12.5-kc subcarrier. This subcarrier output is mixed with baseband voice, and the resulting composite modulates the 1.25-mc subcarrier on the FM (noncoherent) rf carrier.

Table 3-7 is a summary of down-link data channels which were originally defined in the MORL baseline system, together with their counterparts (where applicable) in the MORL/USBS No. 1. System margins are referenced to the minimum output S/N ratios specified for each type of data in Reference 2.

Examination of Table 3-7 shows that, in all cases except real-time telemetry and one voice channel, performance margins for the MORL/USBS No. 1 are appreciably lower than those for the baseline system. In addition, the quantity of data transmitted on MORL/USBS has been decreased, namely, elimination of the 1,000 cps continuous analog channel and degradation of the television video bandwidth from 2.16 mc to 375 kc. Under the ground rules assumed for this part of the study, a MORL/USBS for the 200-nmi orbit case is not adequate for the MORL requirements. Also, it should be noted that the phase coherent ranging technique will not function for an MORL in the rotating mode because antenna switching will introduce large phase transients in the PM transmitter signal.

The performance of each data channel of the MORL/USBS was determined by using the system parameters listed in Table 3-8. As may be seen, two different signal-to-noise ratios are used for PCM data. This is necessary because the 51.2-kbps PCM data are not prefiltered, whereas the real-time 2.4-kbps PCM data are filtered before the subcarrier is modulated.

3.3.2.2 Modified USBS (MORL/USBS No. 2)

A modified unified S-band system configured to accommodate the major MORL communication requirements is depicted in Figure 3-14. A summary of the link quality analysis is included in Table 3-7. The entire baseline system data complex (except for DCS verification, which is proposed to be included in the real-time PCM data) has been incorporated. Additionally, transponded range information and two down-link voice channels have been provided. The increased capacity of System No. 2 over that provided by System No. 1 is the result of the removal of a constraint assumed in the first part of the study, namely, that no significant modification to the Apollo USBS equipment be permitted. Without this constraint a greater rf bandwidth can be utilized, thus providing greater data capacity. Although the number and response capabilities of the data channels available in System No. 2 have been increased, the television video bandwidth has been restricted to 750 kc, as compared to the 2.16 mc used in the baseline system. This restriction was necessary to allow the desired information to be handled on two carriers.

The individual data channel margins for MORL/USBS No. 2 approximate those given for MORL/USBS No. 1. The increased rf bandwidth available is used to provide greater data transmission capacity, namely, a 50% increase in each of the recorded PCM telemetry channels (51.2 kbps to 76.8 kbps), a 100% increase in television video bandwidth (375 to 750 kc), and the addition of a 1-kc analog channel.

The major functional components of the transmitting subsystem include the frequency multiplexing equipment (subcarrier oscillators, filters, and mixing networks), PM and FM transmitters, the up-link receiver, and the antenna system (including the coupling network).

Table 3-8

SYSTEM PARAMETERS FOR MORL/USBS NO. 1

Channel	Data Type	Effective Noise Bandwidth (B_n) (kc)	Required S/No (rms/rms) (dB)	M_1' Sub-subcarrier	M_1 Subcarrier	M_2 RF Carrier	Notes
1A	Range code						Accurate data not available
1-B	51.2-kbps NRZ PCM unfiltered	300	11	-	0.6	0.6	10^{-5} bit error rate with integrate and dump detector
1-C	1.25-mc subcarrier			-	-	0.6	
1-C$_1$	3-kc voice			-	0.6	-	
1-C$_2$	2,400 bps NRZ PCM filtered	9.6	13.5	1.5	1.0	-	10^{-5} bit error rate with filter and sample detector
2-A	375-kc television	750	23	-	-	1.0	
2-B	51.2-kbps NRZ PCM unfiltered	300	11	-	0.6	0.6	10^{-5} bit error rate with integrate and dump detector
2-C	1.25-mc subcarrier			-	-	0.6	
2-C$_1$	3-kc voice	12	10	-	0.6	-	
2-C$_2$	2-kc analog T/M	16	30	1.0	1.5	-	3% output data error
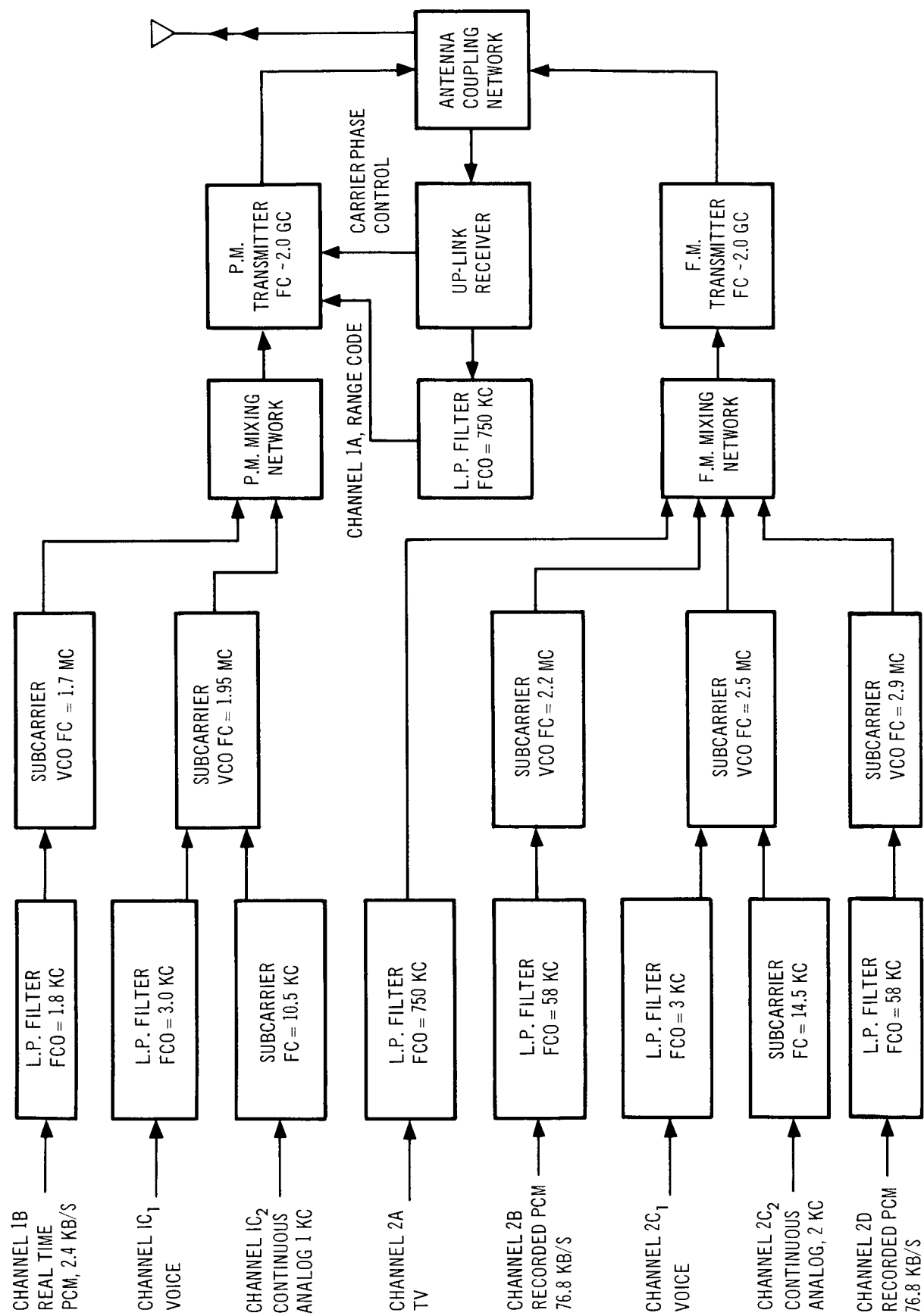
Figure 3-14. MORL/USB Spacecraft System No. 2

As indicated on the diagram, two rf carriers are employed. One carrier is phase modulated and is designated as the coherent carrier. The modulation complex of this carrier contains a baseband component representing the ranging code, and two subcarriers carrying voice and telemetry data. The frequency and phase of the coherent down-link carrier are locked to, and generated from, the received up-link carrier.

The ranging code is also recovered from the up-link in the on-board receiver. Assuming the use of the Apollo code, the characteristics of the code are defined as a continuously varying pseudorandom binary-waveform with a nominal bit rate of 1,000,000 bps (Reference 4). For lunar ranges encountered in the Apollo mission, a nonrepeating code period of 5.4 sec is used to prevent range ambiguity. For MORL, a shorter code would be used to reduce acquisition time.

The range code is filtered prior to application to the PM transmitter to restrict the modulation spectrum. Normally, this filter would be a linear-phase six-pole low-pass device with a cutoff frequency of 750 kc (0.75 x bit rate).

The other signals modulating the coherent carrier are developed by subcarrier VCO's operating at 1.7 and 1.95 mc. These signals are combined in a linear mixer (shown on the diagram as PM Mixing Network) and applied as a composite to the PM transmitter. The 1.7 mc subcarrier is modulated by serial PCM from the real-time PCM multiplexer/encoder. This signal is a binary, nonreturn-to-zero (NRZ) waveform with a nominal bit rate of 2.4 kbps. It is filtered by a six-pole linear-phase low-pass filter with a cutoff frequency of 1.8 kc. A data/subcarrier modulation index of 2.0 is used.

The 1.95 mc subcarrier has a composite signal as its input. The composite is the linear combination of a voice channel, restricted to 3 kc, and the output of a sub-subcarrier operating at 10.5 kc. The sub-subcarrier is modulated by a continuous analog signal which may have frequency components to 1 kc. The voice baseband modulation index is 0.6, while the sub-subcarrier index is 1.4. Since the PM rf carrier must be phase coherent with the up-link

ranging carrier, certain restrictions must be considered when applying modulation. These restrictions are as follows:

1. Carrier phase reversal as a result of modulation must be minimized to obviate Doppler tracking errors.

2. Modulation components must be kept out of the passband of the carrier (Doppler) tracking loop in the ground terminal receiver for the same reason as given in Restriction 1.

3. Sufficient power must remain in the rf carrier to permit proper tracking.

Restrictions 1 and 3 are satisfied by using relatively narrow deviation of the PM carrier. For this system, as with others (References 5 and 3), the rms carrier deviation is set at approximately 1 radian. Modulation spectrum restrictions, Restriction 2, are not serious in this system because the baseband modulation is a 1,000,000-bps code, and no significant very-low-frequency components are expected. The various rf channel modulation indices utilized are as follows:

1. Range code--1.0
2. PCM subcarrier--0.5
3. Voice/analog subcarrier--0.5

The second rf carrier is frequency modulated by a composite consisting of baseband television video and three subcarriers operating at 2.2, 2.5, and 2.9 mc respectively. The television signal bandwidth is limited to 750 kc by a low-pass filter. For this signal, an rf modulation index of 1.5 is used.

The two PCM data channels are each capable of accepting a PCM serial bit stream of 76.8 kbps. The PCM pulse train in each case is filtered with a six-pole linear-phase filter having a cutoff frequency of 59 kc (0.75 x bit rate). After filtering, the serial wave trains are applied as inputs to subcarrier VCO's. These VCO's each modulate the transmitter with an rf modulation index of 0.6. Data/subcarrier modulation indices for each case are 1.5.

The third subcarrier is modulated by a composite consisting of filtered (cutoff frequency equal to 3 kc) speech intelligence and the output of a sub-subcarrier. The sub-subcarrier is modulated by a continuous analog signal. This 2.4-mc subcarrier channel is similar to the 1.95-mc subcarrier channel on the PM

carrier except that, as a result of the higher response of the analog input (2 kc versus 1 kc), a sub-subcarrier frequency of 14.5 kc was selected. An rf modulation index of 0.6 is used. For the voice baseband, a subcarrier modulation index of 1.5 was selected, while an index of 2.0 is used for the sub-subcarrier.

A ground-receiving demodulation subsystem with a configuration that will accept the MORL/USBS No. 2 composites is shown in Figure 3-15. Similar equipment has been designated as the data demodulator in the Apollo system. Other functions provided by the Apollo ground subsystem, such as the antenna pointing servo, code detection and correlation, and Doppler detection, remain unmodified. The demodulator modification is actually an addition of equipment that is switched into operation when the ground station is required to serve the MORL mission.

The IF output frequency for PM operates at a center frequency of 10 mc and has a bandwidth of 6.5 mc. The composite video information is recovered from the carrier, amplified, and presented to two data subcarrier demodulators for further detection. One of these demodulators (1.7 mc) separates and detects the 2.4-kbps real-time PCM telemetry channel for further demultiplexing by a PCM processor. The other subcarrier demodulator (1.95 mc) produces an output which contains baseband speech intelligence and a modulated sub-subcarrier. The speech is separated by a low-pass filter and is made available for input to the intercommunications equipment. The sub-subcarrier detector (10.5 kc) recovers the 1-kc analog channel. The range code is detected and used in another section of the ground station receiver, and is not treated in this report.

The FM channel demodulator is from a 50-mc IF output, with a bandwidth of 10 mc. The demodulation system is essentially the same as the PM channel except that another subcarrier detector is used, and a baseband filter is used to separate the television signal.

Other data handling equipment, which would normally be available at the Apollo ground terminals, may be used for MORL. PCM processors, for
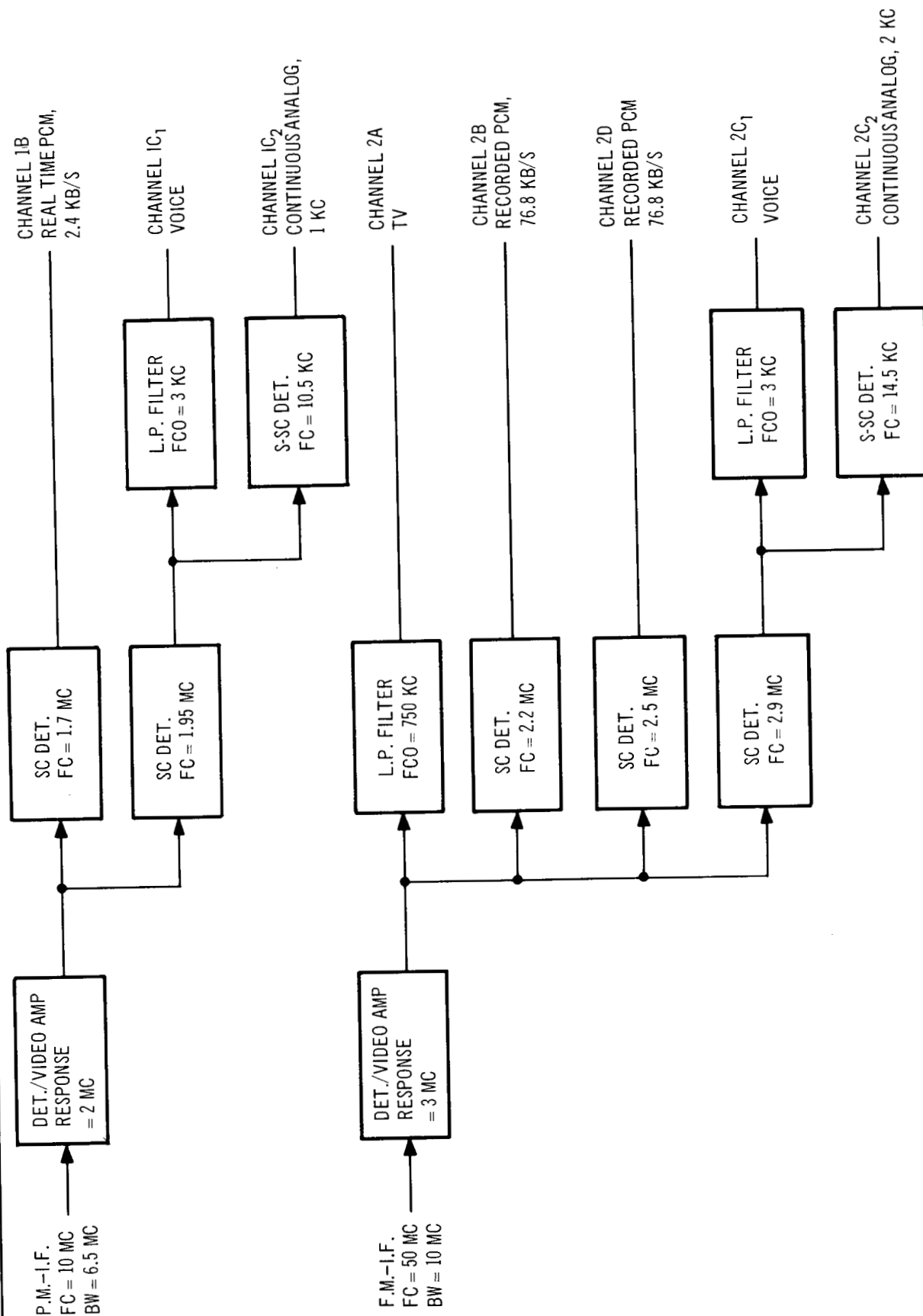
Figure 3-15. MORL/USB Data Demodulator

example, are usually mechanized for bit rates of from 10 bps to approximately 10^6 bps, and are capable of processing a wide variety of formats.

Consistent with the configuration of the MORL spacecraft transmitting system, the ground-terminal data demodulator is of new design. The demodulator is, however, only a small portion of the terminal and can be considered an accessory to the primary Apollo station. The IF outputs used are accessible, and switching networks should pose no design problem. Specific rf channel frequencies are not assigned to MORL; therefore, assumptions as to receiver rf frequency changes cannot be made.

3.3.3 The 19,300-nmi Range (Synchronous Orbit)

The following paragraphs discuss the synchronous orbit at the 19,300 nmi range.

3.3.3.1 General

The system configuration for the 19,300-nmi case could be identical to that for the 1,100-nmi system, with the exception of the antennas. The increase of range from 1,100 nmi to 19,300 nmi represents an additional 25 dB in transmission path loss (165 dB versus 190 dB). This eliminates the possibility of utilizing the MORL omni-antenna with the near space instrumentation facilities (NSIF) to achieve a workable system. It is, therefore, necessary to employ an appropriate combination of spacecraft directional antenna, DSIF ground antennas, and traveling wave maser receiving preamplifiers.

A directional antenna similar to that of the Apollo can provide from 16 to 32 dB gain over the MORL omnidirectional antenna, while the 85-ft DSIF parabolic antenna (noise temperature equal to $55^\circ K$) can provide approximately 13 dB over the NSIF.

Table 3-9 presents performance margins for the MORL/USBS No. 2 synchronous orbit case, showing margins for DSIF and NSIF (spacecraft antenna gain equal to 32 dB overall, compared to the MORL omniantenna).

Table 3-9

DOWN-LINK SUMMARY MORL/USB NO. 2

(19, 300 nmi range)

Channel	Bit Rate/ Response	NSIF Margin (dB)	DSIF Margin (dB)
PCM data (recorder No. 1)	76. 8 kbps	14. 0	20. 9
PCM data (recorder No. 2)	76. 8 kbps	14. 0	20. 9
PCM data (real time)	2. 4 kbps	30. 3	37. 2
Continuous analog	1 kc	10. 3	17. 2
Continuous analog	2 kc	8. 5	15. 4
Television	750 kc	10. 2	17. 1
Voice (No. 1)	3 kc	13. 7	27. 3
Voice (No. 2)	3 kc	10. 0	16. 9
Ranging	1, 000 kbps	14. 1*	21. 0*

*Approximate

When using a directional spacecraft antenna, the MORL/USBS No. 2 can transmit the modified baseline data composite with greater system margins than in the 1, 100-nmi case. The situation is further improved if DSIF facilities are utilized.

3. 3. 3. 2 Synchronous Orbit Time-Shared Data Link

When MORL is operated in a synchronous orbit, it becomes apparent that certain data channels may be time shared, primarily because full-time ranging/tracking is not required. Exploitation of time sharing can significantly reduce the amount of data transmission equipment.

A system configuration has been prepared to illustrate an example of such a time-shared system. A summary of data-link performance is shown in Table 3-10. The system link margins are shown for two modes: (1) the ranging mode and (2) the data mode.

Table 3-10

DOWN-LINK SUMMARY--TIME-SHARED
RANGING AND DATA MODE

(19, 300 nmi range)

Channel	Bit Rate/ Response	Ranging Mode Margin (dB)	Data Mode Margin (dB)
PCM data (recorded)	76. 8 kbps	Note 1	11. 9
PCM data (real time)	2. 4 kbps	22. 2	17. 9
Continuous analog	1 kc	6. 7	1. 7
Continuous analog	2 kc	3. 7	0. 9
Voice (No. 1)	3 kc	15. 4	11. 1
Voice (No. 2)	3 kc	10. 8	2. 9
Television	750 kc	Note 1	7. 9
Ranging	1, 000 kbps	14. 4 (approximate)	Note 2

Notes: 1. not provided in ranging mode.

2. not provided in data mode.

When the system is switched into data mode, the ranging capability is replaced with a television channel, and a PCM telemetry channel for 76. 8 kbps recorded data is added.

The margins shown could be improved by using DSIF. In this case, 12. 9 dB would be added to each channel margin. The margins could be equalized by an adjustment of the modulation indices.

The implemented capacity of the MORL data communication link is set by the peak data exchange rate. In the case of nonsynchronous orbits, much information, including range/tracking data, must be transmitted to the ground while the spacecraft is within line-of-sight of the receiving station. This requirement not only places an upper limit on the time available for playback of any recorded data, but also sets a specific time of day for such trans-missions. These time-oriented transmissions cause a high peak load in the data transmission system.

Because a synchronously orbiting spacecraft is always in sight of a receiving station, it follows that a data transmission system for this specific orbit could be arranged so as to provide greater utilization of transmission equipment. The configuration of such a system could be based on time-sharing techniques. Basic considerations would include the facts that the ranging/tracking function would not be required on a full-time basis, and only one channel is necessary for the playback of recorded PCM telemetry.

A spacecraft time-shared transmitting subsystem for a synchronous orbit mission is shown on Figure 3-16. The subsystem has two modes of operation: (1) ranging and (2) data. The subsystem is quite similar to the MORL/USBS No. 2, except that only one rf carrier is used and a transmitter capable (by selection) of either PM or FM mode is required. Such a transmitter, with dual exciter capability, has been mentioned (Reference 3) for use with the lunar excursion module (LEM) of the Apollo program.

When set for tracking mode, the carrier of the transmitter is controlled by the recovered up-link ranging signal. One of the phase-modulation inputs of the transmitter is connected to a modulation composite consisting of two subcarriers. These subcarriers operate at 2.2 and 2.5 mc, and are modulated with baseband voice information and subcarrier in a manner similar to the MORL/USBS No. 2. The recovered range code is also applied to a separate phase-modulation input. By these means, the tracking mode provides for transmission of the following data:

1. Phase-coherent carrier for two-way Doppler tracking.
2. Turnaround range code.
3. Two voice channels.
4. A PCM telemetry channel with 2.4 kbps capability.
5. Two continuous analog telemetry channels of 1 and 2 kc response, respectively.

The quantity of data that can be transmitted in the ranging mode is restricted because of the necessity to maintain phase coherence with the up-link ranging signal. When tracking/ranging is not required, such as for the data mode, the frequency control of the carrier is removed from the up-link receiver and transferred to a locally generated signal. The baseband modulation
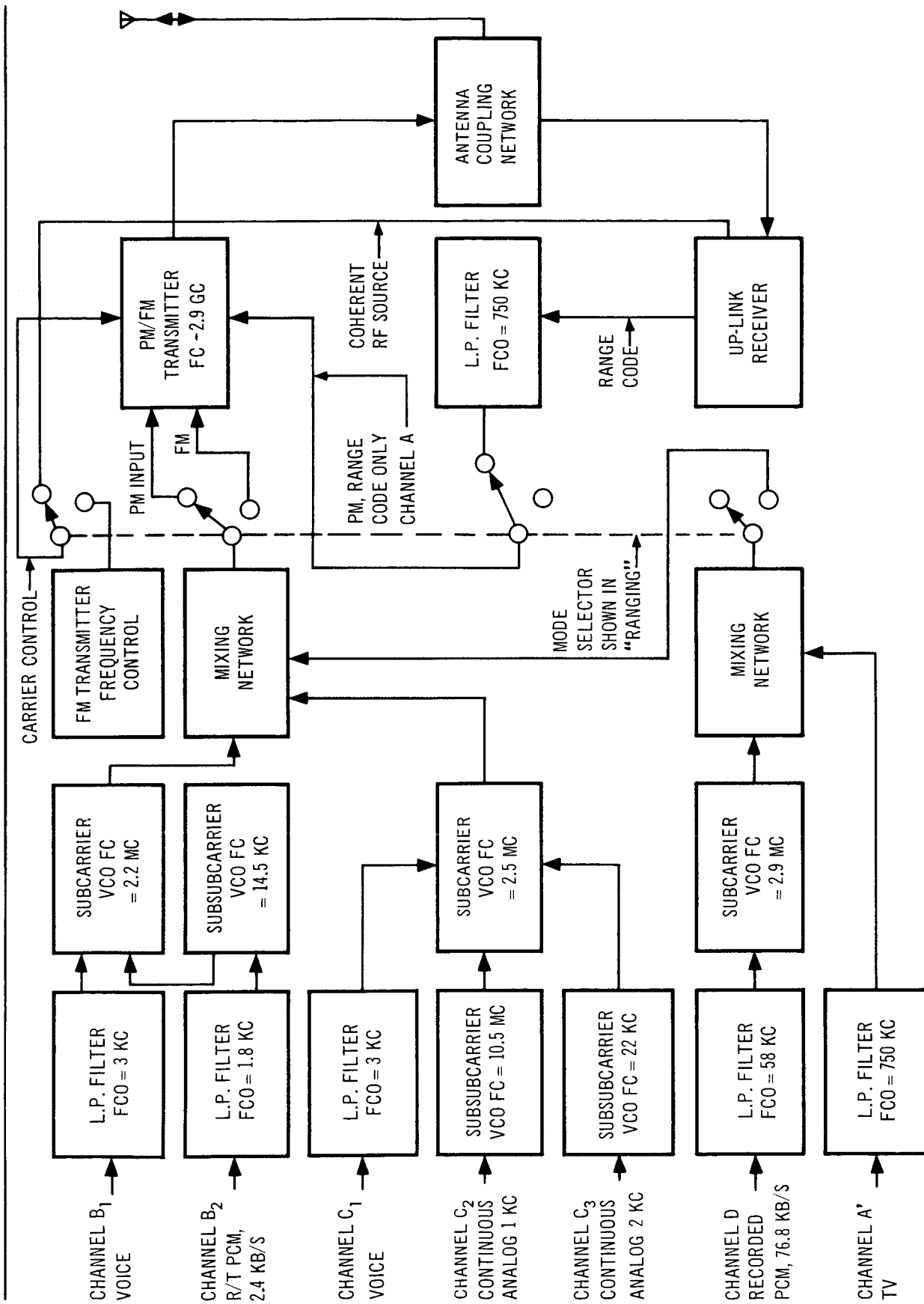
Figure 3-16. MORL/USB Spacecraft System (Time Sharing Configuration)

spectrum, occupied by the ranging signal in the ranging mode, is available for the television composite in the data mode. Because a greater rf deviation may now be used, an additional subcarrier, operating at 2.9 mc for the recorded PCM telemetry signal, is introduced into the modulation composite. The voice and telemetry modulation data used for the ranging mode is maintained. The modulation schedule for this system configuration is given in Table 3-11.

A data demodulator for the time-shared data link is shown in Figure 3-17. As in the case of MORL/USBS No. 2, the demodulator is proposed as an add-on, taking inputs from the ground receiver's IF amplifiers. Two inputs are shown because the IF response (-3 dB at 6.5 mc) of the primary receiver is not completely known and may be somewhat marginal. If such is not the case, one input and one rf receiver would be adequate. The demodulation of baseband, subcarriers, and sub-subcarriers are as described previously.

The technique of spectrum time sharing offers a convenient method to increase total communication efficiency. The system example used employs one rf carrier; however, it is still able to satisfy the essential data transmission function. The actual data channels which are to be shared depend on the exact nature of the mission and a detailed mission operations analysis.

3.3.4 Equations and Assumptions Used in Calculations

The calculations and assumptions used in this study of the MORL unified carrier system are as follows:

1. Required IF signal-to-noise ratio (S/N_{if})
   A. For baseband

$$S/N_{if} = \frac{S/N_o}{3 M_2^2}$$

Table 3-11

TIME-SHARED SYSTEM MODULATION INDICES

Channel	Sub-subcarrier Index	Subcarrier Index	RF Carrier Index	Data Content
A, ranging	-	-	1.0	Baseband mod
A', television*	-	-	1.5	Baseband mod
B, subcarrier	-	-	0.5	2.2 mc SC
B1, voice No. 1	-	0.8	-	2.2 mc SC baseband
B2, PCM, 2.4 kbps	2.0	1.0	-	2.2 mc SC/10.5 kc SC
C, subcarrier	-	-	0.5	2.5 mc SC
C1, voice No. 2	-	0.6	-	2.5 mc SC baseband
C2, continuous analog, 1 kc	2.0	1.2	-	2.5 mc SC/10.5 kc SC
C3, continuous analog, 2 kc	2.0	1.4	-	2.5 mc SC/22 kc SC
D, PCM, 76.8 kbps*	-	1.5	0.6	2.9 mc SC

*Channels A' and D are not used at the same time as Channel A.
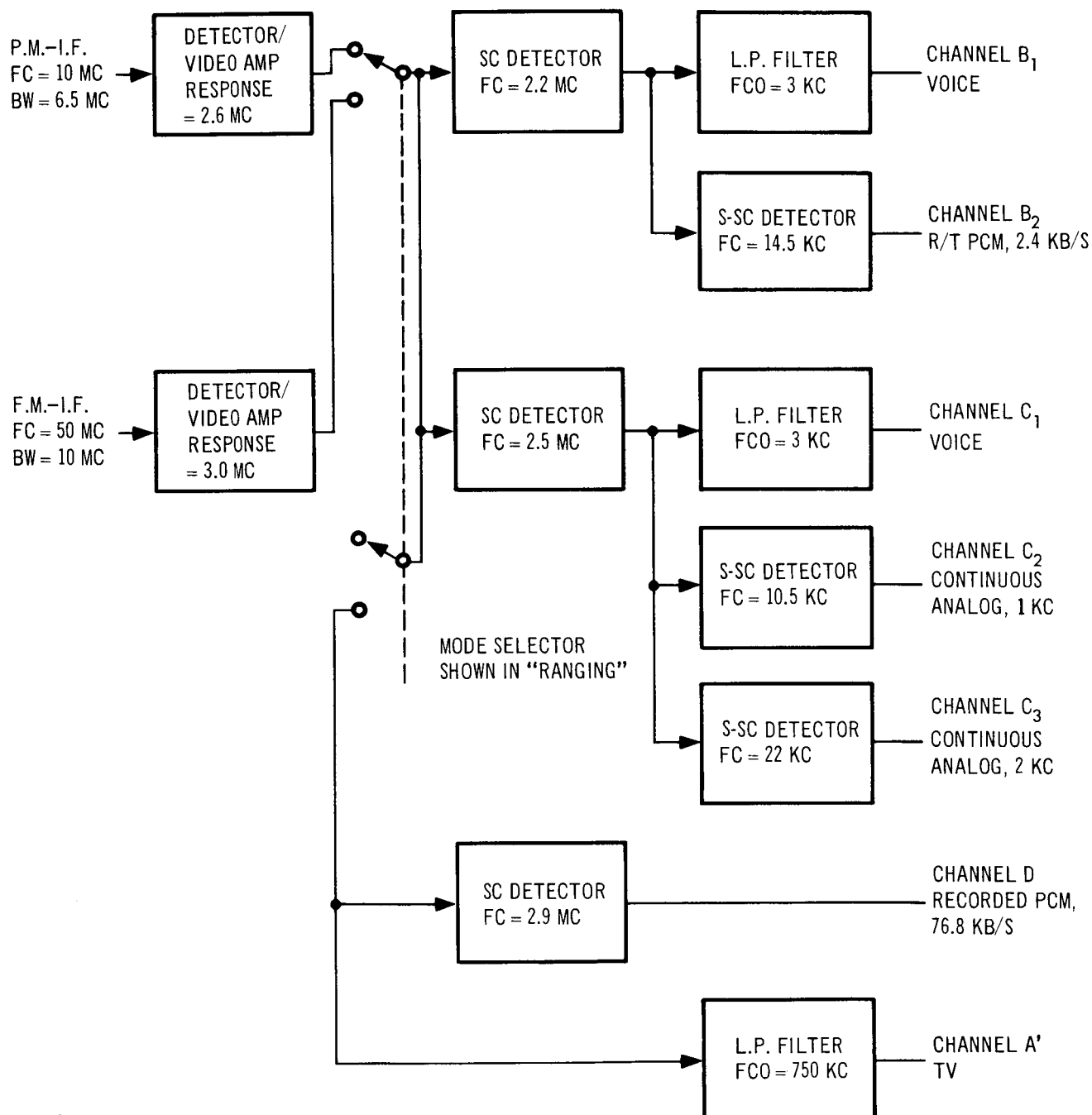
Figure 3-17. MORL/USB Data Demodulator (Time Sharing Configuration)

B. For FM/FM channel modulation

$$S/N_{if} = \frac{S/N_o}{3\,(M_1 M_2)^2}$$

C. For FM/FM/FM channel modulation

$$S/N_{if} = \frac{S/N_o}{3\,(M_1' M_1 M_2)^2}$$

where

S/N_o = signal-to-noise ratio for data

M_1' = sub-subcarrier modulation index

M_1 = subcarrier modulation index

M_2 = rf carrier modulation index

2. Required channel power (P_{T_i})

$$P_{T_i} = B_{N_i}\left(S/N_{if_i}\right) \times 5.9 \times 10^{-8}$$

where

B_{N_i} = noise bandwidth for Channel i

S/N_{if_i} = required IF signal-to-noise ratio

3. Available channel power (P_{SC_i})

$$P_{SC_i} = 2 P_{TOT} \left[J_1 \left(M_{2_i} \right) \prod_{\substack{K = 1 \\ K \neq i}}^{K = 3} J_o \left(M_{2_K} \right) \right]^2$$

where

P_{TOT} = unmodulated rf carrier power.

$J_o \left(M_{2_K} \right)$ = zero-order Bessel function corresponding to the rf modulation index (M_2) of the Kth channel.

$J_1 \left(M_{2_i} \right)$ = first-order Bessel function corresponding to the modulation index (M_2) of the ith channel.

4. Assumptions (1, 100-nmi slant range)

A. RF carrier frequency--2.25 gc.

B. Antenna gain, transmitting (MORL)-- -4 dB.

C. Antenna coupling losses, transmitting (MORL)--3 dB.

D. Polarization and pointing losses, combined--4 dB.

E. Near-space receiving antenna gain--44 dB.

F. Near-space receiving system noise temperature--260°K.

G. Deep-space receiving antenna gain--50 dB.

H. Deep-space receiving system noise temperature--55°K.

3.4 DATA COMPACTION

This section presents the results of a preliminary investigation of the applicability of data compaction to the MORL communications/telemetry system. A discussion of present compaction techniques and a survey of some experimental results are given, along with examples of how such methods might be utilized for the MORL program.

3.4.1 Summary and Conclusions

The results of data compaction experiments reported in published papers (References 7, 8, and 9) indicate that compaction techniques are potentially applicable to the PCM portion of the MORL communications and telemetry system. PCM channel bandwidth reductions resulting from compaction could be utilized to increase channel performance margins, increase the average data handling capacity of the system, or to reduce the rf carrier power required while maintaining the existing system performance margins. To counterbalance the potential advantages of compaction, its disadvantages include added system hardware complexity, data distortion, and (assuming that the uncompacted signal-to-noise ratio is maintained for the compacted case) the data error rate increases.

The extent to which data compaction can be used to increase message efficiency depends on the average redundant content of information to be transmitted, as well as on the amount of signal distortion that can be tolerated. These factors depend both upon the original signal form and the ultimate use of the data. The illustration given in Section 3.4.4 for the MORL PCM application assumes an average compaction ratio of 10:1. While this figure represents a mean of experimental results, it may not be typical of MORL data. Before the MORL PCM telemetry system can be committed to the use of data compaction, a study into the statistical nature of the source signals must be conducted. A portion of such a study should determine the average sampling rate necessary to adequately describe the activity of an input function, and should relate this to peak sampling rate requirements. These determinations will result in the definition of data redundancy required to set the operational criteria of the system.

The transmitted data, after compaction, is distorted both in time and amplitude. Ground recovery equipment can be organized to restore the original multiplex time base to eliminate timing errors in the processed data; however, as a result of the time delay through the output storage buffer in the transmitting system, exact real-time to time correlation is not available.

Amplitude distortion is present in the compacted output data because the prediction process is organized to accept or reject a sample for transmission on the basis of the degree of agreement between the data and some predicted value. The latitude of agreement allowed represents the transmitted error. In designing compaction system tolerances, each channel must be examined from a user's standpoint to determine the degree of error permitted. The predictor may be mechanized, of course, to provide a separate tolerance band for each channel, thereby permitting optimum tolerance assignment for each class of input signal.

Another consideration when utilizing compacted data, is the increase in relative importance of each transmitted symbol. Since one data sample represents many other samples which are not transmitted, those that are transmitted must be recovered with a higher error-free probability to maintain a fixed confidence in the message. In practice, this means that the performance margin for a compacted channel must be greater than for uncompacted channels.

3.4.2 Data Compaction Techniques

When it is necessary to transmit a large quantity of data under the restriction of limited carrier power, the efficiency of message transmission becomes an important factor in the choice of a communications system. Message transmission efficiency differs from electrical efficiency in that it is evaluated by comparing the amount of information which is essential to represent the message intelligence to that information which is actually sent. It is obvious that if a communications channel is burdened with unnecessary data, carrier power is wasted and, hence, lower overall efficiency results.

Several methods have been employed to restrict the transmitted data to essential message components. Among those employed are pretransmission

data reduction, signal conditioning, and minimization of data redundancy. The information which is considered essential to the message varies according to the final disposition of the data, thus setting the criteria for message improvement techniques. Pretransmission data reduction, as in combining two or more channel sources by computation and transmitting only the resultant, and signal conditioning (changing the form of the data; for example, envelope detection) are somewhat restrictive in that they are generally used on a small percentage of the total message complex. Data redundancy reduction, on the other hand, provides a means of increasing efficiency which is applicable to nearly all forms of data. It provides a match of the channel capacity to the information content of the signal to be transmitted.

Much effort has been directed toward obtaining proper channel matches. This effort is evident, for example, in PCM systems employing variable word lengths to represent data requiring differing resolutions and accuracies. Data sampling rates are chosen to be compatible with maximum expected channel frequency content. While such techniques as these are essential to good design, they consider only worst-case conditions. These systems are organized to acquire, transmit, recover, and process data according to some preset sequence of events. The input multiplexer samples the various signal sources at some constant time interval within a fixed input format. Although the sampling rate for the individual channel is set by the maximum expected rate of change, in actual practice, the data sampling rate is usually many times more than the average rate. Thus, a signal source is oversampled much of the time, resulting in low message efficiency.

Optimization of a communication channel capacity must, therefore, consider average characteristics of the information content, as well as the peak requirement. Compaction techniques have been devised to reduce much of the data redundancy by adaptive management of multiplexed signals. These techniques provide a dynamic match of the channel capacity to the average information content, while accommodating peak rate-of-change periods.

Some examples of data compaction techniques are discussed in the following paragraphs.

3.4.2.1 Redundancy Reduction by Prediction

Successive measurement samples of a signal source which are essentially the same value contribute to the total message only to the extent of indicating that the function has not changed value. If the communication system is organized such that no sample is transmitted until a significant change in the data occurs, signal quiescence or no-change conditions are inferred at the receiving terminal between periods of channel activity. When redundant samples are discarded in this manner, other data which is active may occupy the transmission time position, therefore increasing utilization of the transmission channel.

Redundancy of successive data samples may be detected by numerous prediction techniques. Among these techniques are two which have been evaluated by Medlin (Reference 7). These are designated as zero-order polynomial predictors. The first of these predictors is mechanized on the assumption that the present data sample is equal to the value of the previous sample to within some specified and fixed tolerance. A simplified block diagram of this predictor, arranged for a single channel, is shown in Figure 3-18.

To analyze the operation of this predictor, consider an input signal, S, such as that shown in Figure 3-19, applied to the device at sample time t_3. A previous sample of the source, S_{t2}, has been loaded into the storage unit and is made available to the comparator coincident with S_{t3}. In this case, since S_{t3} is outside the comparator tolerance band in which S_{t2} is located, the prediction is incorrect, and S_{t3} is gated out as significant data. The storage unit is also updated with S_{t3}, S_{t2} being discarded. The same evaluation process occurs when S_{t4} is compared to S_{t3}, producing the same outcome. At S_{t5}, however, the data is as predicted and the comparator inhibits the output gate from delivering S_{t5} data to the output line. Data prediction is correct for the succeeding samples through S_{t11}, resulting in no data output during this period. At S_{t12}, the prediction is incorrect, and a significant sample is delivered.

In this example, note that while the source sampling rate is regular, the output data is delivered only when the original prediction is incorrect, causing
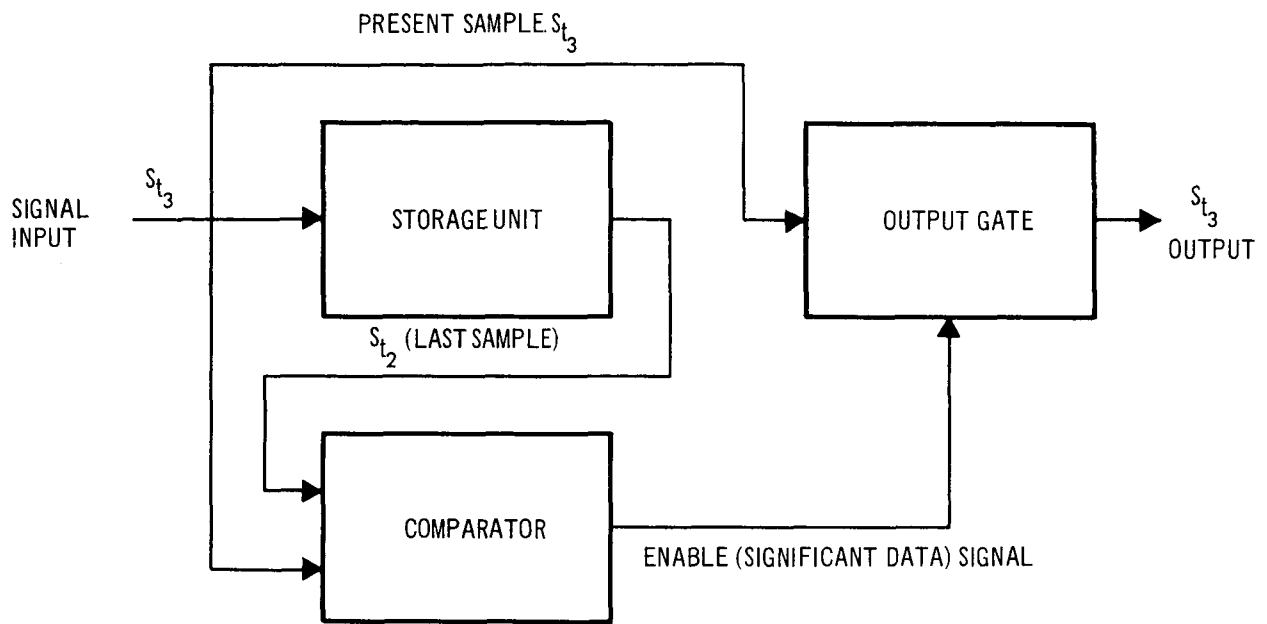
Figure 3-18. Fixed-Tolerance Zero-Order Predictor
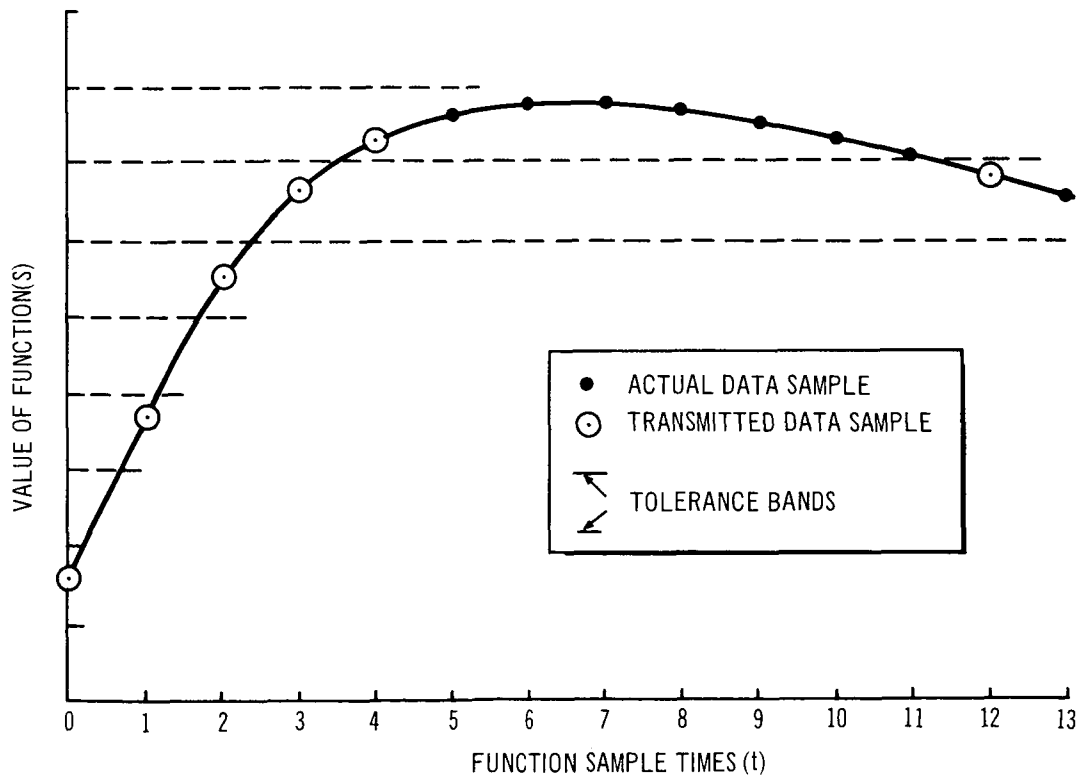
Figure 3-19. Source Signal Characteristics

73

an irregular output rate. A constant output rate may be achieved by routing the data through a buffer-storage unit and clocking out the data at a rate slower than the original source sample rate. The required storage capacity for significant data samples and the clock-out rate depend on the redundancy statistics of the source data. Assuming some finite buffer capacity, the probability exists that an overflow will occur in the buffer during periods of sustained data activity. To prevent overflow, either the clock-out rate may be increased or a greater tolerance may be assigned to the comparator. These operations can be made adaptive in the sense that automatic adjustment are performed whenever the buffer is occupied to near capacity.

Because any channel's output rate is asynchronous with respect to the sampling rate, the output-data time base is distorted. Where time correlation is required, it is necessary to transmit additional time-tag information. This can be accomplished, for example, by including an identification number along with, or as part of, each output (significant) data sample. To limit the length of the identification code, a recycle counter period equivalent to the longest propagation time through the buffer can be employed. Since the time tag requires additional transmission time, the net compaction is reduced.

The second predictor functions in a manner similar to the first, except that the comparator evaluates successive samples by using a floating tolerance band positioned symmetrically about the predicted sample value. This predictor, shown diagrammed in Figure 3-20, is comprised of a comparator, a tolerance and reference memory, an address generator, and a buffer. (Timing and control functions have been omitted.)

To illustrate a practical case, the discussion of this predictor will consider a multichannel application. In this case, a memory which stores the predicted (last significant) value for each channel of the input data format along with a tolerance for each channel is used. Consider an input signal, such as shown on Figure 3-21, applied to the predictor. Sample No. 2 of Channel S_i, $S_i|_2$, is applied to the comparator, together with the predicted value of S_i, $S_i|_1$, and the assigned tolerance from memory. As in the case of the fixed tolerance predictor, an evaluation is made of the present sample according to the prediction. For $S_i|_2$, the prediction is incorrect and the sample is
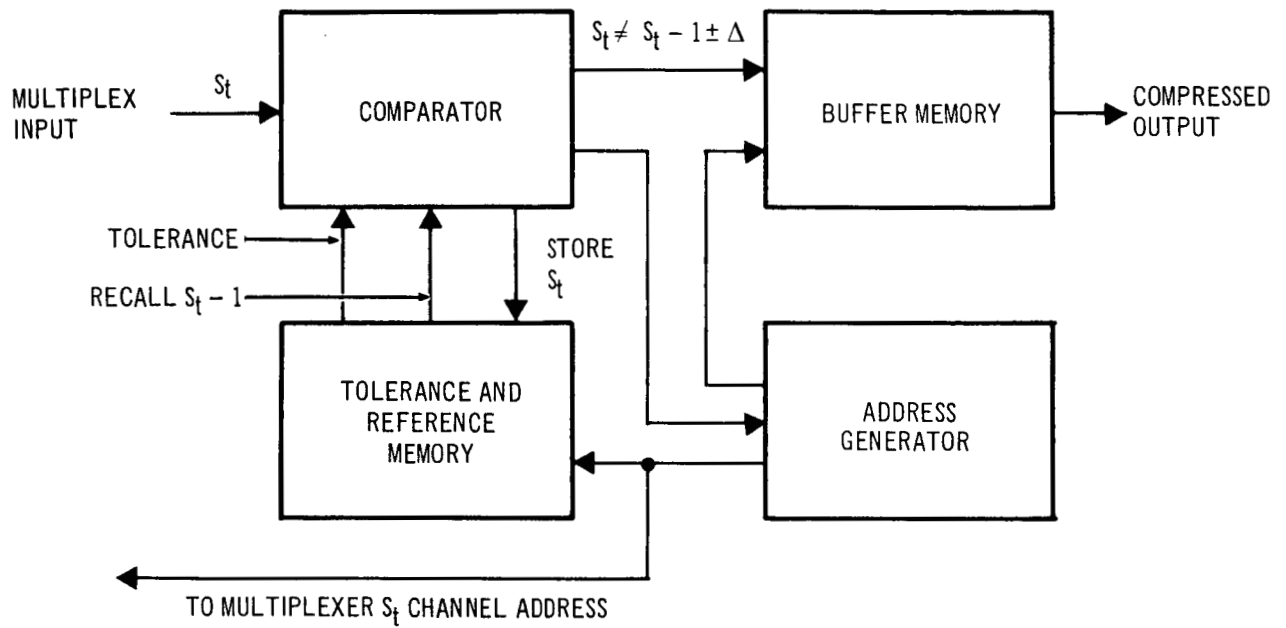
Figure 3-20. Floating-Tolerance Zero-Order Predictor
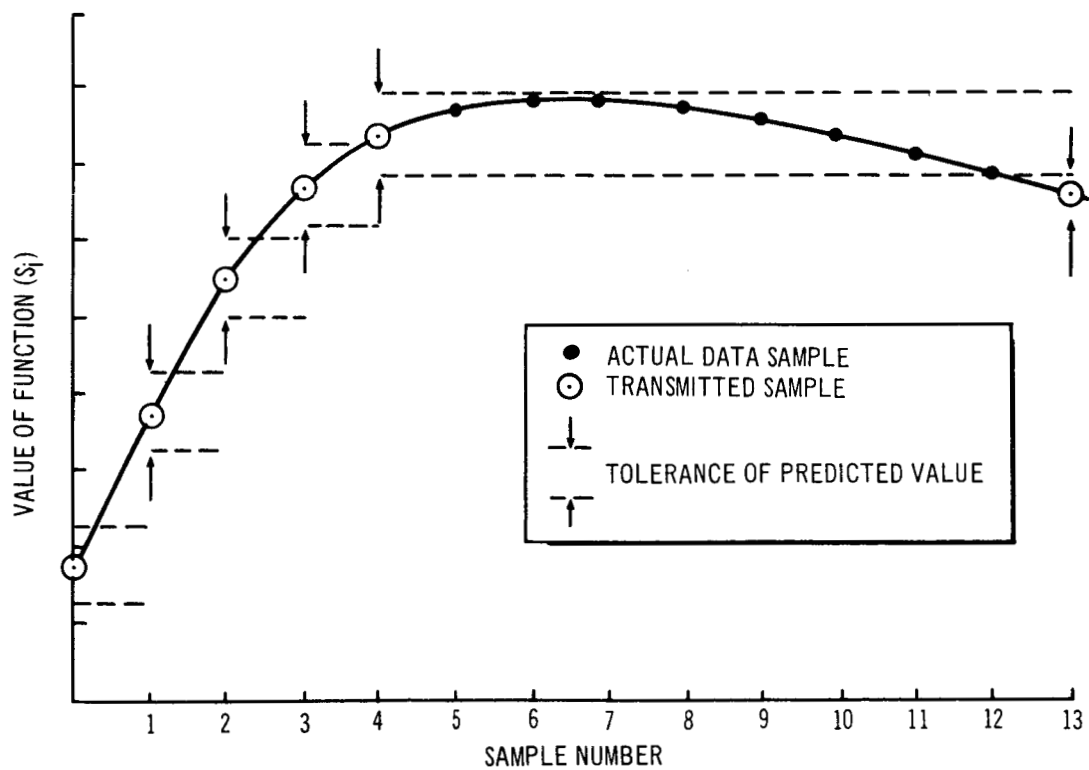
Figure 3-21. Source Signal Characteristics, Floating Tolerance Predictor

entered into the buffer for subsequent transmission. Because $S_i|_2$ is signifi-
cant, the succeeding prediction(s) are based on its value, $S_i|_1$ being discarded
as a reference value. This is accomplished as the new prediction value is
entered into memory. When the prediction is correct, as at Samples No. 4
and No. 5, the last correct (significant) value is restored to memory and
retained as the reference value.

By using a separate tolerance for each channel, a greater compaction latitude
is provided because it is not likely that all channels require the same toler-
ance. If an adaptive technique of tolerance adjustment is used to prevent
buffer overflow, the adjustment can be mechanized to apply on a selective
channel-by-channel priority basis to provide for the least critical data loss.

The address generator output is also routed to the buffer memory (Figure
3-20). Each time a sample is accepted for transmission, it is necessary to
identify that channel. Every channel within the multiplexed frame is assigned
a unique address. This address is used for multiplex operation, reference
and tolerance recall, and for identification of the transmitted channel. Indi-
vidual channel identification is necessary because the compacted frame-to-
frame channel format varies, that is, in successive transmitted frames,
appearance of the i th channel depends on the statistical redundancy of S_i
data, as well as all other channels in the frame. Therefore, one transmitted
frame may have several samples of S_i or none at all. As in the case of time-
correlated data, channel identification requires transmission time over and
above that associated with the data, thus reducing compaction efficiency.

3.4.2.2 Redundancy Reduction by Interpolation

The predictors discussed in the previous paragraphs use some previous data
sample to establish the prediction of future sample values. When the predic-
tion is incorrect, the actual value (within quantization tolerance) is trans-
mitted. Various approaches to redundancy reduction by interpolation have
been investigated; two of these approaches, the zero-order and first-order
polynomial interpolators, are described in Reference 8.

The zero-order interpolator is similar to the zero-order polynomial predictor,
in that a horizontal line is used to represent a redundant data set. The major

difference is that the reference sample is determined at the end of the redundant set, rather than at the beginning. The computed reference value is taken as the mean between the most positive and most negative values in the redundant set.

The first-order interpolator approximates the data by straight-line segments. Although several approaches to the first-order interpolator are used, they all involve fitting a best straight line to as many data points as possible within a given error tolerance.

3.4.3 Survey of Experimental Results

The effectiveness of data compaction can vary over wide limits as a result of system configuration, redundant content of the signal source, and the degree of distortion permitted in the output data. While it is not possible to assign a projected compaction efficiency to the MORL application at this time, an insight on which to base future MORL data compaction studies can be gained by reviewing the experimental work of others.

One comparative analysis of data compaction techniques has been reported by Medlin (Reference 7). In this work, approximately 150,000 data samples were subjected to five different polynomial prediction compaction techniques. The data used were obtained from PCM telemetry records of a satellite launch vehicle, and included the time from lift off through second-stage burnout. The data consisted of a 60-channel frame, sampled at 5 frames/sec, with each signal input encoded to 11 bits. Compaction ratios (total number of data points sampled to samples selected for transmission) were reported to be from 3 to 2,706, depending on the specific input channel and the prediction technique used. Average compaction ratios for this data, with tolerance error bands of approximately 1 to 3% of full scale, varied from 6 to 30, with a mean of approximately 10. It was noted that a zero-order floating tolerance band predictor consistently yielded the highest compaction ratios. This is an interesting point because this type of predictor can be readily mechanized.

Results of certain Polaris missile telemetry data compaction analyses have been reported by Weber (Reference 8). For the same error tolerance bands

as in Reference 8 (1 to 3% of full scale), compaction ratios of 15 to 100 (average) have been achieved. In this case, the telemetry data was in an FM/FM format.

Some examples of biomedical signal compaction are related by Specht and Drapkin (Reference 9). Using sample-to-sample redundancy reduction techniques, electrocardiogram and electroencephalogram signals were compacted in ratios of 6 to 30, again depending on the type of prediction and the assigned error bandwidth. A rather interesting extension of prediction for these signals yielded some very high efficiencies. An EKG signal was subjected to a cycle-to-cycle analysis and a compaction ratio of 1,790 for a subject at rest was obtained. Lower ratios were obtained when the subject was ambulatory.

3.4.4 MORL Data Compaction Applications

Experimental results of telemetry systems employing data compaction indicate that such techniques can be beneficial in improving system efficiency. Accordingly, the use of compaction for the MORL telemetry and data communications system has been investigated from a feasibility standpoint. The following discussion covers each major type of data transmission channel specified by the MORL basline requirement.

3.4.4.1 PCM Channels

The MORL baseline system requires three PCM telemetry channels (neglecting the DCS verification). These are: one channel for real-time data transmission (2.4 kbps bit rate), and two channels for transmission of recorded data (76.8 kbps bit rate). One potential system problem that has been identified is that of transmitting the recorded data during the limited time that the MORL is within line-of-sight of a ground receiving terminal. The use of data compaction appears desirable to minimize the peak transmission load. One of the potential side effects would be the elimination of one of the 76.8 kbps channels, thus allowing greater bandwidth allocation to the television channel (Section 3.3). Realization of this would require a net compaction ratio of 2:1, which appears quite possible if the results (References 7, 8, and 9) given may be assumed to be typical for MORL data.

78

Obviously, compaction can be used in other ways, such as increased channel performance margins, reduced rf carrier power, or higher bit rates (faster recording dump time) for the remaining 76.8 kbps channel.

The two 76.8 kbps playback channels originate from different data complexes. One source continuously monitors the low-rate (2.4 kbps) PCM data taken during occulation periods, while the other source intermittently records experimental data. Consider first the 2.4 kbps channel. According to the baseline requirements (Reference 2), 483 signal input channels are multiplexed onto this channel. These inputs are commutated to provide the following:

1. 240 channels sampled 1 time/min.
2. 90 channels sampled 10 times/min.
3. 121 channels sampled 1 time/sec.
4. 32 channels sampled 5 times/sec.

Arranging these channels (with synchronization words) into a typical PCM format would result in a main frame (MF) of 60 words and three subframes (SF's). Of the 60 words on the MF, 3 words are required for MF recycle synchronization, 24 words for SF 1, 3 words for SF 2, and 1 word for SF 3. With respect to the MF rate, SF 1 has a commutation ratio of 5:1, SF 2 ratio is 30:1, and SF 3 ratio is 240:1. Three words of SF 1 are reserved for a segmented recycle synchronization word. All words are eight bits in length. The main frame is sampled 5 times/sec. The net data channels available are as follows:

1. 240 channels sampled 1 time/min. (SF 3).
2. 90 channels sampled 10 times/min. (SF 2).
3. 117 channels sampled 1 time/sec (SF 1).
4. 28 channels sampled at 5 times/sec.

For the MORL compaction example, a zero-order floating tolerance predictor is used. Figure 3-22 illustrates this predictor in a typical airborne PCM transmission system. Because of the variety of data sources involved, each channel, as a first approximation, must be assigned a separate tolerance. This requires a tolerance and reference memory of 475 words.
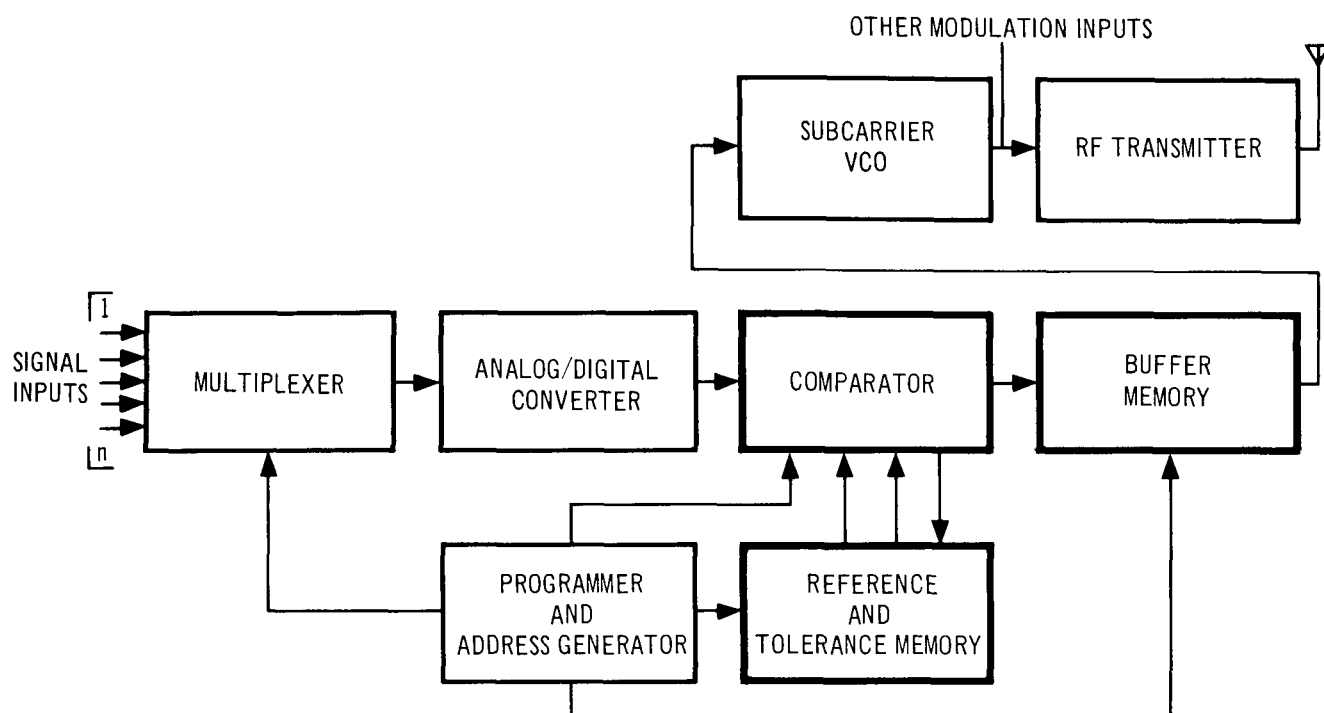
Figure 3-22. Airborne Data Compaction PCM System

From the standpoint of economy in the tolerance and reference memory (and associated address coding/decoding), it is desirable to evaluate the relative merits of compacting the entire input source data. Normalizing the MF and three SF's for spectral occupancy, it is found that the MF data requires approximately 46.6% of the total, while SF 1 uses 40% and SF's 2 and 3 require 5.0 and 1.7%, respectively. From an efficiency standpoint, even complete elimination of SF's 2 and 3 would not yield worthwhile results. Therefore, it is concluded that data on SF's 2 and 3 should be excluded from the compaction process. Another reason for excluding these data from compaction is what may be considered a minimum reporting interval to maintain confidence in the operation of any channel. For example, the value on a channel on SF 3 is normally reported every 48 sec. If the compaction process were to eliminate five successive samples of the channel, 4 min. would elapse before data update. This illustrates the fact that regardless of the redundancy ratio, every channel should be sampled a sufficient number of times during the mission/experiment run to provide an acceptable level of confidence.

Having determined that only the data multiplexed on the MF and SF 1 should logically be compacted, the reformatting of the compacted channels may be accomplished. Earlier in this report, the requirements for channel identification and timing information were established. The MF data (less synchronization and SF words) consists of 28 words, while SF 1 has 117 words. Since each word in these frames must be uniquely identified, a 5-bit channel identification (ID) tag must be included as part of each MF data word, and a 7-bit channel ID tag must be included for each SF word.

To provide time correlation, the 8-bit countdown ID word, which uniquely identifies each channel in SF's 2 and 3, is used. This MF ID word is inserted into the buffer storage at regular commutation intervals and, thus, any compacted data appearing between two ID words can be identified by frame number association.

Assuming a data compaction ratio of 10:1 for signals multiplexed on the MF and SF 1 for a typical format, the major frame can be organized. The compacted format maintains the MF sampling rate of 5 frames/sec, and uses the original subcommutation ratios; 5:1 for SF 1, 30:1 for SF 2, and 240:1 for SF 3. (For this example the basic word is considered 8 bits in length, which means that each composite word is a multiple of the basic word.)

The main frame consists of 21, 8-bit words, which are utilized as follows:

1. Three words for MF synchronization.
2. One word for MF countdown ID.
3. One word for SF 1 channel ID.
4. Six words for MF data words (three 16-bit words).
5. Six words for SF 1 data words (three 16-bit words).
6. Three words for SF 2 data words.
7. One word for SF 3 data words.

The net compaction, including synchronization and ID words, is 2.85, which yields an output bit rate of 840 bps (compared to 2,400 bps for the uncompacted case). If a variable word length were to be used (in cases where an integral multiple of the basic word length is not required, that is, MF word actually could be 13 bits), the compaction ratio could be raised to 3.3:1.

The medium rate (19.2 kbps) PCM channel defined in the baseline system may be compacted in a similar manner, except that a higher net compacted ratio should be possible considering a data compaction of 10. This is because no subframes are used and the frame consists of a small number of input sources; 28 for Mode A and 25 for Mode B. This reduction in channels reduces the length of the ID tags and eliminates the need for subframe ID. Also, all data is subjected to compaction.

The compacted format would consist of three 8-bit synchronization words, a time correlation frame ID word, and three data words. In this case, the data words would consist of 8 bits and a channel ID of 5 bits (28 channels), yielding a net compaction ratio of approximately 7:1.

One advantage that compaction could provide is that of combining the low-rate and medium-rate PCM channels. This would reduce the required record/reproduce facilities by one-half. In this case, the entire low-rate PCM channel would be handled as a complete subcommutation routine on the medium-rate PCM frame. Since the basic frame rate of the medium channel is 40 frames/sec and the low-rate channel is 5 frames/sec, an 8:1 subcommutation ratio would be required. An average compaction ratio of 5.8:1 would result. Because the two data multiplexes can be made independent of each other, either input could be stopped or started without affecting the other.

The baseline recording system specifies a bit-packing density of approximately 640 bits/in. The combined compacted PCM channel (320 words/sec) could be recorded at the normal 15/32 ips, using a bit packing density of approximately 680 bits/in. Using a 32:1 speed-up ratio, a complete 17-hour recording could be reproduced in 0.5 hours.

3.4.4.2 Analog Channels

The MORL baseline system specifies the use of three analog data channels. These are the television channel and two continuous channels of 1 and 2 kc response, respectively. Compaction is not recommended for these channels in their present form because it would require storage and comparison of analog amplitudes. If these signal sources were to be digitally encoded,

compaction techniques could be readily applied. However, the net reduction in bandwidths obtained might be somewhat marginal. For example, assume that the present baseline television system were converted to a digital system quantized to 64 grey levels. The uncompacted bandwidth of the digital system would be increased approximately six times over the analog system and would, therefore, require a net compaction of six to achieve the same spectral occupancy. Since experimental results reported by Weber (Reference 8) indicate that ratios of 2:1 to 5:1 are realistic, it does not appear justified to digitize television signals when compaction is the only consideration.

The two high-response continuous channels would also require a greater bandwidth if multiplexed and digitized. The source signal must be sampled at a rate equal to or greater than twice the highest frequency component. When each of these samples is encoded to 6 bits plus sign and parity, the resulting digital pulse train requires a net compaction ratio of 8:1 (for NRZ transmission) to be bandwidth-comparable to analog transmission. Pre-encoding signal conditioning (such as envelope detection and spectrum analysis) could be more advantageously employed if analog compaction is desired.

3.4.4.3 Mechanization Cost

Figure 3-22 presented the functional aspects of a typical PCM data compaction system (the heavy outlined blocks) in concert with the peripheral data acquisition and transmission functions. It will be noted that the aspects specific to data compaction are basically data processing functions and, therefore, could be performed by the MORL central data processor. However, as indicated in Section 3.4.1, before the impact of data compaction on processor requirements can be assessed, the statistical characteristics of the source signals must be defined. With this definition and decisions on the tradeoffs between algorithm complexity and buffer memory requirements (based on considerations such as compaction time criticality, adaptation of compaction to sensed memory load, and so forth), computer sizing requirements, beyond those indicated in Section 3.4.1, can be established.

Section 4

TECHNOLOGY AND SUBSYSTEM DEVELOPMENT REQUIREMENTS

This section identifies the subsystem developments and supporting techno-
logical advances that are considered desirable in the pre-Phase III time
period to ensure a low-risk development program for the MORL baseline
communication/telemetry system. Previous sections of this report indicate
the desirability of making significant changes to the baseline system to make
it responsive to the new requirements identified in the Phase IIb study. The
subsystem studies and supporting technological advances required to support
the development of an advanced communication/telemetry system are pre-
sented in Section 5.

Because the baseline communication/telemetry system was designed with the
specific objective of using subsystems and techniques which either existed
or were under development, only four development items were identified.
They are discussed in the following sections in the order of their relative
priority.

4.1 HIGH-POWER SOLID-STATE RF SWITCH

The automatic antenna selection circuitry of the antenna system utilizes a
solid-state rf switch which must be able to handle continuous rf power levels
of nearly 50 W, with an insertion loss of less than 1 dB, over the frequency
range of 250 to 2,300 mc. A switch with these characteristics must be
developed. Work that is applicable to the solution of this problem has been
accomplished during the past 2 years by Microwave Associates, Inc. for the
Navy Department, Bureau of Ships, under Contract NObsr-89463, Project
Serial No. SR0080302, Task 9604.

4.2 TELEVISION TRANSMITTER

To satisfy the TV video bandwidth of 2.16 mc at a modulation index of 1.5, the TV transmitter must have a 2-mc response and a peak deviation of ±3.24 mc. An S-band transmitter with these characteristics must be developed and a breadboard model tested.

4.3 EXTERNALLY MOUNTED TV CAMERAS

The external TV cameras and their associated pan and tilt mechanisms must withstand the ambient space environment. Final verification of proper system operation in this environment might be accomplished on an AAP flight test.

4.4 TELEMETRY MODULATOR

Six data sources are combined into the complex baseband signal which modulates the telemetry transmitter. To ensure a minimum bandwidth while providing adequate S/N ratio for proper data recovery, the theoretical modulation parameters must be optimized and verified by breadboard testing of the system.

Section 5
RECOMMENDED STUDIES

The rationale behind the recommended future stuides can best be understood when the work which has been accomplished to date is reviewed and the studies are placed within the framework of the overall communication/ telemetry system study plan. The major steps leading from mission definition to detail subsystem design are identified in Figure 5-1.

During the first half of the Phase IIa study, the subsystem requirements were derived based on a mission definition which visualized MORL as a first generation space station which would be launched into a 28.7°, 200 nmi orbit to conduct a relatively modest one-year experimental program. A subsystem concept based primarily on Gemini and Apollo technology was defined, concept feasibility and tradeoff studies were conducted, and a recommended subsystem configuration was specified. It is this subsystem which has been referred to extensively in this report as the baseline communication/ telemetry system. The technology and subsystem developments which would enhance a timely development of the baseline system were derived. They are essentially the same items reaffirmed in Section 4 of this report.

In the Phase IIb study, the MORL was defined as a second generation space station which would be launched during the early 1970's into a 50°, 164 nmi orbit to conduct a vast experimental program extending over more than 5 years. During the early part of the study phase, when this mission was being formulated, the opportunity was taken to go part of the way through the optimization loop (Figure 5-1) with two studies based on the baseline system: the rf unification and the data compaction analyses outlined elsewhere in this report. In these optimization studies, a system concept was presented and concept feasibility and tradeoff investigations were conducted. It was not the intent of these studies to revise the subsystem configuration

OPTIMIZATION

MISSION
DEFINITION

SUBSYSTEM
REQUIREMENTS
DEFINITION

SUBSYSTEM
CONCEPT
DEFINITION

CONCEPT
FEASIBILITY
AND
TRADEOFF
STUDIES

BASELINE
SUBSYSTEM
RESPONSIVENESS
ANALYSIS

SUBSYSTEM
CONFIGURATION
AND
SPECIFICATION

IS
SUBSYSTEM
RESPONSIVE

NO

SUBSYSTEM
TECHNOLOGY
DEVELOPMENTS

YES

DETAIL
SUBSYSTEM
DESIGN
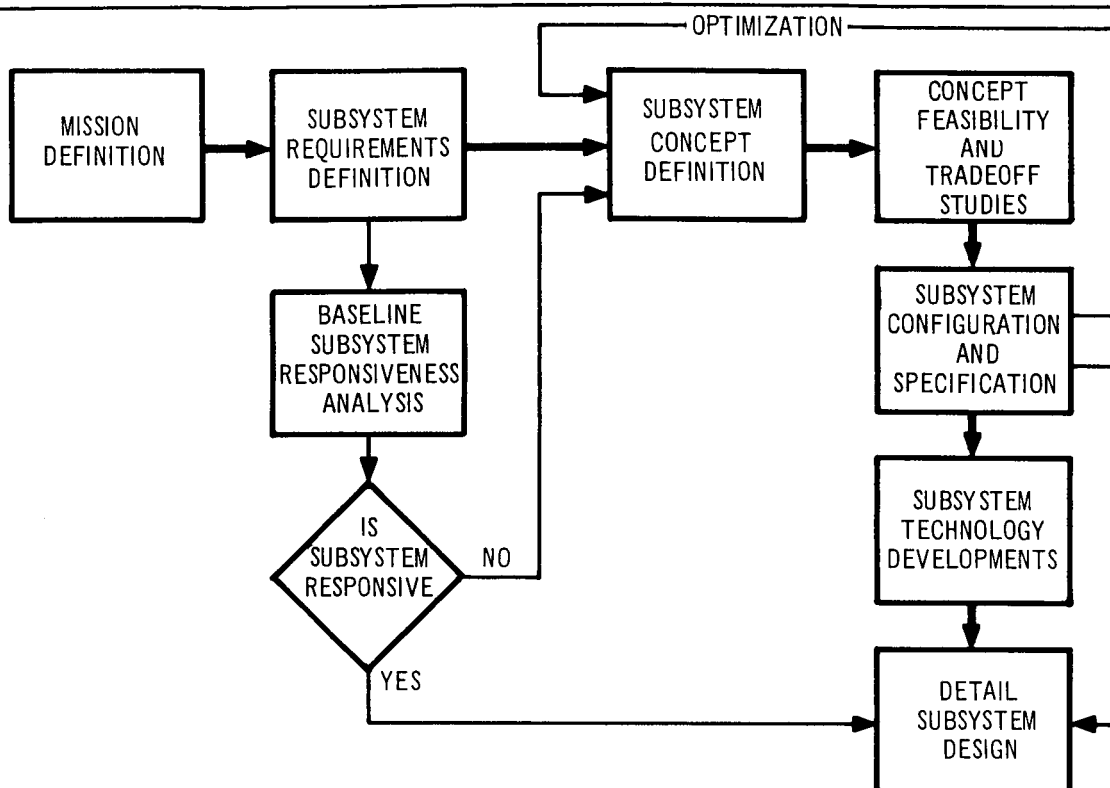
Figure 5-1. Study Plan – Communications/Telemetry System

and specification. That step must follow from future studies that will consider the new requirements of the revised mission development plan.

One of the primary efforts of the Phase IIb study derived new subsystem requirements from the expanded mission development plan and analyzed the responsiveness of the baseline system to these new requirements. The results of this analysis, documented in the Task Area III reports, particularly point to the need of a data management capability which, in terms of data capacity, sampling rates, and flexibility, is a considerable expansion over the capability of the baseline system. The analysis reported in Section 3.1 proposed a system concept to meet these requirements and conducted initial concept feasibility and tradeoff studies to evaluate, in general, the feasibility of the system concept.

At this point it is evident that significant groundwork leading to the required upgrading of the system has been accomplished. The eventual objective of

performing a detail design of a communication/telemetry system for MORL remains to be completed. The following recommendations are therefore made:

1. Future studies should review and summarize the subsystem requirements derived from the mission development plan.
2. Desirable new subsystem concepts should be defined.
3. Concept feasibility and tradeoff studies should be expanded.
4. The results of these studies should be reflected in a new subsystem configuration and specification.
5. Technological and subsystem development studies required by the new subsystem configuration should be determined and pursued.

Specific tasks in support of this general statement are detailed in the following sections.

5.1 SUBSYSTEM REQUIREMENTS DEFINITION

Re-examine the mission development plan formulated in the Phase IIb study and summarize those requirements which have an impact on the design of the communication/telemetry system. Data acquisition requirements need to be determined in sufficient detail to allow a reasonable estimate of the total number of data sources and the maximum bit rate which must be accommodated.

Inasmuch as the high data rate generated by the television system has a major impact on the design of a communication link (particularly for a USBS link) it is important that picture resolution and frame rate requirements be accurately determined. It is, therefore, desirable to conduct a study to confirm TV system parameters. This would involve observer participation in a simulation of the video system. The simulated system should include provisions for varying effective scanning resolution, aspect ration, and frame rate. Ideally, this evaluation could be performed in conjunction with the operation of the EC/LS space cabin simulator at LRC.

5.2 SUBSYSTEM CONCEPT DEFINITION

Revise the subsystem concept definition, as appropriate, to meet the requirements of Task 5.1. The system concept should include: (1) incorporation

of an advance data management capability similar to that defined in Section 3. 1, (2) provision of an independent tape recorder for computer auxiliary memory, (3) provision of voice and video recording, (4) automation of the retrieval and display of stored hard-copy data, (5) unification of the communication links into a minimum number of rf links, (6) provision of facsimile capability in place of the typewriter, (7) consideration of use of an autonomous navigation system, and (8) consideration of use of Apollo-type hardware for the rendezvous sensor.

5.3 CONCEPT FEASIBILITY AND TRADEOFF STUDIES

The following paragraphs discuss the concept feasibility and tradeoff studies.

5.3.1 Digital as Opposed to Analog Transmission Tradeoff Analysis

Resolution of the tradeoff between the all-digital, single-bus system of information distribution and the more conventional analog signal routing techniques requires the completion of the study tasks outlined below.

1. The availability of low cost, reliable, microelectronic circuit arrays must be further investigated. It is on the indication of this availability that certain aspects of the proposed DMS organization are based. Analytic effort must be toward the following:

    A. To determine the specific electronic configuration of the circuits for sensor output conditioning.

    B. To determine the types and quantities of analog to digital (A-D) and digital to analog (D-A) converters required.

    C. To determine the detailed logical structure of the data source and destination termini (DST's).

    D. To determine the commonality of termini microfunctions for optimum packaging of circuit chips to ensure maximum interchangeability.

2. The technology and anticipated advances in analog switching techniques must be thoroughly assessed to develop parametric data on which a comparison of multiple converters versus multiple analog switching arrays can be based.

3. System philosophy must be sufficiently developed to allow assessment of the specific data compression and error evaluation techniques which might be applied to MORL data. For example, hardware can be included at the sensor output which will continuously monitor a

signal level, comparing it against a stored threshold value, and output data only when the threshold is exceeded. This function might also be implemented in a central, special purpose processor or in a computer program. The system maintenance philosophy must also be clearly defined to establish test levels to be implemented in hardware:

A. Within the sensor subsystem.

B. At the central processor (that is, diagnostic programming).

C. In special test equipment.

4. The data bus (DDB) must be analyzed for the following:

A. Identify and solve possible transmission line problems.

B. Evaluate the advantages and disadvantages of a single constant n-line digital bus against the one-line-per-analog signal harness.

C. Determine the impact, if any, of the DDB on operational crew procedures.

With regard to this final point, preliminary investigation would tend to favor the digital bus since no harness modifications are required when instruments are interchanged in the racks. Also, sensor output line lengths are kept to a minimum due to the physical proximity of the digital bus terminus to the instrumented laboratory location. However, intuitive evaluation is not acceptable; these points must be rigorously analyzed to evolve an optimized configuration.

5.3.2 Central Information Control and Storage

Perhaps the most obvious question which arises in connection with the information control function is whether it should be mechanized in a separate special purpose processor or included as part of a central computer program. Resolution of this problem must await development of a detailed mathematical model of the MORL systems operational/experimental interface. However, some fruitful investigations can begin prior to complete model specification. The transmission line confidence testing technique illustrates the role of this subfunction in information control. The exact method of implementing data confidence assurance requires further study. Present literature suggests many devices which might be employed including, for example, redundant signal routing and computer programmed reasonability checks. Clearly, the data format selected to ensure maximum confidence may be incompatible with data compaction considerations or the distribution

bus design. Redundant wiring wastes power, and analysis may indicate that the information control processor program would be overburdened beyond reasonable design limits with the addition of data reasonability testing requirements.

Inherent in the information control program are functions of data acquisition sequencing, T/M formatting, and data compaction processing. In the discussion of the CSU, a multiple program store with operator controlled branching was suggested. This is intended to facilitate operator selection of a program which meets the unique requirements of the specific configuration of sensor equipment necessary for the succeeding operational/experimental schedule. The programs are obviously unique to the various measurement groups. Here, study is required to compare the cost in additional memory for multiple program storage against that of memory fill equipment. Moreover, the desirability of rapid program switching has not been rigorously established; hence, the variability of the operational/experimental schedule must be investigated. The structure of the control program will require extensive analysis. For example, if data compaction is to be used, the method by which it is accomplished (for example, in hardware, computer program, and so forth) must be considered.

5.3.3 Study of Alternative Approaches to the Emergency MORL-to-Ground Voice Communications Link

This study would investigate the advantages of various alternative MORL-to-ground emergency voice communications link including VHF (as specified in the baseline system) and UHF (S-band). In the latter case, preliminary link analysis has shown the need for directional (high gain) antenna arrays either on board the MORL or at the receiving site.

5.3.4 Investigation into the Practicability of Replacement of On-Board Tape Recorders by Thin Film Memory

With the advances being made in thin film technology, a study is proposed to investigate the application of a thin film memory system to the MORL bulk storage requirement.

The study would include sizing of a thin film memory capable of storing the approximately 300 million bits generated during an occultation period, as well as performing cost, size, and power tradeoffs between the thin film and conventional storage approaches.

5.3.5 Autonomous Navigation for MORL

The problem of supporting navigation requirements for certain Earth-oriented experiments indicates the desirability of investigating the application of autonomous navigation to the MORL. A study would involve the comparative evaluation of various techniques in terms of such factors as hardware, operational and computer processing requirements, and the resultant system accuracy.

5.3.6 RF Unification Analysis

Continue the rf unification analysis reported in Section 3.3 to include the requirements of the revised system concept determined in Task 5.2 above. Take into account the capabilities of the Apollo USBS identified near the end of Section 3.3.1 of this report.

5.4 SYSTEM CONFIGURATION AND SPECIFICATION

Make revisions to the communication/telemetry system design to incorporate those system concepts determined in Task 5.2 which have been shown to be desirable and feasible as a result of the concept feasibility and tradeoff studies of Section 5.3. Work should be conducted in sufficient depth to produce system block diagrams, system descriptions, performance analyses, and hardware physical characteristics and power requirements. Revise the communication/telemetry system specifications to reflect these changes.

NOMENCLATURE

ARD	Data destination address register.
ARS	Data source address register.
bps	Bits per second.
CSU	Control and storage unit.
DCS	Digital command system.
DDB	Data distribution bus.
DMS	Data management system.
DST	Data source-point terminal.
GPC	General purpose control and display console.
HR	Holding register.
ICS	Information control system.
IDR	Input data register.
IPS	Information processing system.
IR	Instruction register.
kbps	Kilobits per second.
LR	Line receiver.
ODR	Output data register.
OF	Overflow.
USBS	Unified S-band system.

REFERENCES

1. Report on the Development of the Manned Orbital Research Laboratory (MORL) Concept Responsiveness. Task Area III, Book I, Douglas Report No. SM-48813, November 1965.

2. Report on the Optimization of the Manned Orbital Research Laboratory (MORL) System Concept. Vol. XIX, Laboratory Electrical/Electronic Systems - Communications and Telemetry, Douglas Report No. SM-46090, September 1964.

3. J. H. Painter and George Hondros. Unified S-Band Telecommunication Techniques for Apollo. NASA Technical Note TN D-2208 Vol. 1, Functional Description, National Aeronautics and Space Administration. Washington, D. C., March 1965.

4. Mark I Ranging Subsystem. SPS 37-21, Vol. III, pp 16-17, Jet Propulsion Laboratory, Pasadena, California, May 31, 1965.

5. Benn D. Martin. The Pioneer IV Lunar Probe; A Minimum-Power FM/PM System Design. Technical Report No. 32-215, pp 22-29 Jet Propulsion Laboratory, Pasadena, California, March 15, 1962.

6. John T. Knudsen. Unified S-Band Rendezvous Sensor. Presented At National Space Navigation and Communication Meeting, Houston, Texas, April 29-30, 1965.

7. J. E. Medlin. The Comparative Effectiveness of Several Telemetry Data Compression Techniques. International Telemetering Conference (proceedings), September 1963, pp 328-340.

8. D. R. Weber. A Synopsis on Data Compression. National Telemetering Conference (proceedings), April 1965, pp 9-16.

9. D. F. Specht and P. E. Drapkin. Biomedical Data Compression. National Telemetering Conference (proceedings), April 1965, pp 68-74.

Appendix
GROUND NETWORK COVERAGE DATA

The data used in the network tradeoff study were obtained by use of the satellite simulation program SRMS (Surveillance, Reconnaissance, and Mission Simulation).

The significant input parameters for the simulation are as follows:

1. Satellite altitude.
2. Satellite inclination.
3. Direction of satellite movement at initiation (north or south).
4. Sampling rate of checking for contact.
5. Site names and locations (latitude - longitude).
6. Horizon elevation angle (minimum elevation contact angle).
7. Sampling time interval for listing output.

The outputs generated by the computer from this simulation are as follows:

1. Clock times at which a site has line-of-sight (LOS) contact with a satellite.
2. During contact period.
   A. Subsatellite points
   B. Altitude
   C. LOS angle
   D. Slant range
3. Total duration of contact.
4. Digital tape with complete track of subsatellite points.

The sites selected for the analysis are given in Table 3-2. The data generated are summarized in Tables A-1 through A-13. Each table is headed by the following mission parameters, which are inputs of the simulation program:

1. Altitude (h).
2. Inclination (i).

3. Minimum elevation angle (e_{min}).

4. Maximum viewing angle (α_{max}).

5. Date that the simulation was performed (included so that ready future reference can be made to the applicable computer listings if required).

The use of the tables can be seen by referring to Orbit 31 of Day 2 on Table A-5. It will be noted that Guaymas (Site 8), Texas (Site 9), and Kennedy (Site 1) all have contact during this orbit. The "sites that are redundant" column shows that Site 8 makes contact first. While it is still in contact with Site 8, Site 9 is also making contact. Site 8 then loses contact, and at some later time Site 1 comes into contact. Thus, Sites 8 and 9 are redundant and Sites 9 and 1 are redundant; however, Sites 8 and 1 are not redundant. The total usable coverage time is that time from the contact with Site 8 through the loss of contact with Site 1. The asterisk on the Tex (Site 9) and Ken (Site 1) coverages in Orbit 32 show that these sites have continuous contact as Orbit 31 ends and Orbit 32 starts.

The table also shows that Orbit 32 continues through the end of Day 2 into Day 3. The fact that neither of the site coverage figures (Sites 8 and 9) contain an asterisk indicates that the coverages are not continuous with the preceding figures. In other words, Site 9 provides coverage at the beginning of Orbit 32 (during Day 2) and again near the end of the orbit (during Day 3).

To ensure the validity of the data generated, the influence of three important simulation factors was investigated; that is, sample size, model calibration, and errors induced by integration step size.

A.1 SAMPLE SIZE

To determine whether the results of a 5-day simulation sample would be typical of a longer run, a 31-day mission was simulated and the coverage times for two 78-orbit (5 days) periods were compared. The resultant total coverage time for each case compares to within 20 sec out of 6,000 sec. Thus, it is concluded that the average coverage is relatively constant for any 5-day period. However, it should be recognized that the details of contact occurrence vary.

A.2 CALIBRATION OF THE SIMULATION MODEL

The basis of model calibration is the comparison of the maximum measured single-contact coverage time with the theoretical maximum for a direct overhead pass. For a 200 nmi circular orbit, the maximum horizon-to-horizon time, T_h, is given as 10.4 min. (Flight Performance Handbook for Orbital Operations. Edited by R. W. Wolverton, NASA Contract No. NASA-8-863-MSFC-Huntsville, Alabama, 1963, John Wiley and Sons, Inc., New York and London.) This time can be adjusted to the $5°$ to $5°$ elevation situation, $T_{5°}$, by referring to Figure A-1 and considering that

$$B B^1 = R_O \theta_2 = 1893 \text{ nmi}$$

$$A A^1 = R_O \theta_1 = 2402 \text{ nmi}$$

and

$$T_{5°} = T_h \frac{B B^1}{A A^1} = 8.19 \text{ min.}$$

This theoretical maximum time is comparable to the maximum measured time of 8.17 min. in Table A-6.

A.3 ERROR RESULTING FROM INTEGRATION STEP SIZE

As a result of the nature of the simulation program, the error in determining when contact is made and lost is plus and minus the fine integration step size. For this study, a 5-sec step size was used.

STATION
ZENITH

SATELLITE PATH

$\alpha_{max.}$

$e_{min.}$

e_{min}

B

B^1

A

A^1

R_O

R_O

S

$90°$

EARTH

$\frac{\theta 1}{2}$

R_E

$\frac{\theta 2}{2}$

C

LEGEND:

S = SITE
C = CENTER OF EARTH
e_{min} = 5° (GIVEN)
α_{max} = 70.3° (GIVEN)

AA^1 = CONTACT PATH FOR
$\qquad e_{min.}$ = 0°
BB^1 = CONTACT PATH FOR
$\qquad e_{min.}$ = 5°
R_E = 3,440 NMI
R_O = 3,640 NMI

Figure A-1. Satellite Coverage Geometry

Table A-1

TWO-SITE NETWORK: TEX AND KEN (page 1 of 2)

Ground Site Coverage Times (Min.)

$h = 200$ nmi, $i = 50°$, $e_{min.} = 5°$, and $\alpha_{max.} = 70.3°$

Date of run: 1 June 1965--SRM simulation

Day	Orbit	Site 9 Tex	Site 1 Ken	Redundant	Total Nonredundant	Total Usable
1	1	2.58	3.84	-	6.42	6.42
	2	4.92*	-	-	4.90	4.90
	10	-	7.35	-	7.35	7.35
	11	7.75	6.25	3.83	6.25	10.08
	12	3.92	-	-	3.92	3.92
	15	1.75	5.33	1.33	4.42	5.75
	16	-	1.92*	-	1.92	1.92
	Total	20.92	24.69	5.16	35.18	40.34
2	16	4.25	0.92	0.92	3.33	4.25
	17	3.42*	5.08*	3.42*	1.66	5.08
	18	3.00	-	-	3.00	3.00
	25	-	4.92	-	4.92	4.92
	26	7.00	7.58	4.33	5.92	10.25
	27	6.58	-	-	6.58	6.58
	30	-	5.58	-	5.58	5.58
	31	5.42	3.17	3.17	2.25	5.42
	32	1.25*	4.50*	1.25*	3.25	4.50
	Total	30.92	31.75	13.09	36.49	49.58
3	32	1.67	-	-	1.67	1.67
	33	5.25*	-	-	5.25	5.25
	41	3.58	7.67	3.00	5.25	8.25

*Continuous with figure above

Day	Orbit	Site 9 Tex	Site 1 Ken	Redundant	Total Nonredundant	Total Usable
3	42	7.67	5.25	3.17	6.58	9.75
	43	0.92	-	-	0.92	0.92
	45	-	1.33	-	1.33	1.33
	46	4.17	4.75	2.83	3.25	6.08
	47	3.58	2.83*	-	6.41	6.41
	48	2.42*	1.83	1.83	0.59	2.42
	Total	29.26	23.66	10.83	31.25	42.08
4	48	1.75*	2.33	1.75	0.58	2.33
	56	-	6.42	-	6.42	6.42
	57	7.50	7.17	4.33	6.00	10.33
	58	5.67	-	-	5.67	5.67
	61	-	6.00	-	6.00	6.00
	62	5.00	2.25*	2.25	2.75	5.00
	63	2.33*	4.83*	2.33	2.50	4.83
	Total	22.25	29.50	10.66	29.92	40.58
5	63	0.42	-	-	0.42	0.42
	64	5.33*	-	-	5.33	5.33
	72	5.67	7.83	4.00	5.50	9.50
	73	7.33	3.75	2.08	6.92	9.00
	76	-	3.92	-	3.92	3.92
	77	5.58	4.08	3.75	2.17	5.92
	78	2.83	3.67*	-	6.50	6.50
	79	4.75*	-	-	3.08*	3.08*
	Total	31.91	23.25	9.83	33.84	43.67
Grand Total		133.59	132.85	49.57	166.68	216.25

*Continuous with figure above

Table A-2

THREE-SITE NETWORK: GYM, TEX, AND KEN (page 1 of 3)

Ground Site Coverage Times (Min.)

$h = 200$ nmi, $i = 50°$, $e_{min.} = 50°$, and $\alpha_{max.} = 70.3°$

Date of run: 1 June 1965--SRM simulation

Day	Orbit	Site 8 Gym	Site 9 Tex	Site 1 Ken	Redundant Sites	Total Usable
1	1	4.83	2.58	3.83	8 and 9	8.67
	2	2.58	4.92*	-	8 and 9	4.92
	3	5.08	-	-	-	5.08
	10	-	-	7.33	-	7.33
	11	6.00	7.75	6.25	8 and 9 and 1	11.33
	12	7.17	3.92	-	8 and 9	8.17
	15	-	1.75	5.33	9 and 1	5.75
	16	-	-	1.92*	-	1.92
Total		25.66	20.92	24.66		53.17
2	16	5.92	4.25	0.92	8 and 9 and 1	5.92
	17	0.25*	3.42*	5.08	8 and 9 and 1	5.08
	17	2.50	-	-	-	2.50
	18	4.92*	3.00	-	8 and 9	4.92
	25	-	-	4.92	-	4.92
	26	-	7.00	7.58	9 and 1	10.25
	27	7.75	6.58	-	8 and 9	9.50
	28	3.92	-	-	-	3.92
	30	-	-	5.58	-	5.58
	31	2.67	5.42	3.17	8 and 9 9 and 1	6.17
	32	-	1.25*	4.50*	9 and 1	4.50
Total		27.93	30.92	31.75		63.26

*Continuous with figure above

105

Day	Orbit	Site 8 Gym	Site 9 Tex	Site 1 Ken	Redundant Sites	Total Usable
3	32	4.25	1.67	-	8 and 9	4.25
	33	3.42*	5.25*	-	8 and 9	5.25
	34	2.25	-	-	-	2.25
	41	-	3.58	7.67	9 and 1	8.34
	42	7.08	7.75	5.25	8 and 9 and 1	11.59
	43	6.58	0.92	-	8 and 9	6.58
	45	-	-	1.33	-	1.33
	46	-	4.17	4.75	9 and 1	6.08
	47	-	-	2.92*	-	2.92
	47	5.50	3.58	-	8 and 9	5.50
	48	1.42*	2.42*	1.83	8 and 9 and 1	2.42
	Total	30.50	29.34	23.75		56.51
4	48	-	1.75*	2.33*	9 and 1	2.33
	48	1.50	-	-	-	1.50
	49	5.17*	-	-	-	5.17
	56	-	-	6.42	-	6.42
	57	3.75	7.50	7.17	8 and 9 and 1	10.42
	58	7.67	5.67	-	8 and 9	9.09
	59	1.17	-	-	-	1.17
	61	-	-	6.00	-	6.00
	62	-	-	0.50*	-	0.50
	62	4.58	5.00	2.25	8 and 9 and 1	6.25
	63	-	2.33*	4.83*	9 and 1	4.83
	Total	23.84	22.25	29.50		53.68

* Continuous with figure above

Table A-2 (page 3 of 3)

Day	Orbit	Site 8 Gym	Site 9 Tex	Site 1 Ken	Redundant Sites	Total Usable
5	63	3.50	0.42	-	8 and 9	3.50
	64	4.25*	5.33*	-	8 and 9	5.33
	72	-	5.67	7.83	9 and 1	9.50
	73	7.50	7.33	3.75	8 and 9 and 1	11.25
	74	5.67	-	-	-	5.67
	76	-	-	3.92	-	3.92
	77	-	5.58	4.08	9 and 1	5.92
	78	-	-	3.67	-	3.67
	78	5.00	2.83	-	8 and 9	5.00
	79	2.25*	4.75*	-	8 and 9	4.75
Total		28.17	31.91	23.25		58.51
5-day total		136.10	133.59	132.91		285.13

*Continuous with figure above

107

THREE-SITE NETWORK: HAW, TEX, AND KEN (page 1 of 3)

Ground Site Coverage Times (Min.)

$h = 200$ nmi, $i = 50°$, $e_{min.} = 5°$, and $\alpha_{max.} = 70.3°$

Date of run: 1 June 1965--SRM simulation

Day	Orbit	Site 7 Haw	Site 9 Tex	Site 1 Ken	Redundant Sites	Total Usable
1	1	-	2.58	3.84	-	6.41
	2	-	4.92*	-	-	4.92
	3	3.38	-	-	-	3.33
	4	2.33*	-	-	-	2.33
	5	7.00	-	-	-	7.00
	10	-	-	7.33	-	7.33
	11	-	7.75	6.25	9 and 1	10.08
	12	-	3.92	-	-	3.92
	13	6.67	-	-	-	6.67
	14	6.25	-	-	-	6.25
	15	-	1.75	5.33	9 and 1	5.75
	16	-	-	1.92*	-	1.92
Total		25.58	20.92	24.66		65.91
2	16	-	4.25	0.92	9 and 1	4.25
	17	-	3.42*	5.08	9 and 1	5.08
	18	-	3.00	-	-	3.00
	19	1.83	-	-	-	1.83
	20	5.83	-	-	-	5.83
	25	-	-	4.92	-	4.92
	26	-	7.00	7.58	9 and 1	10.25
	27	-	6.58	-	-	6.58
	28	1.58	-	-	-	1.58

*Continuous with figure above

Day	Orbit	Site 7 Haw	Site 9 Tex	Site 1 Ken	Redundant Sites	Total Usable
2	29	7.58	-	-	-	7.58
	30	-	-	5.58	-	5.58
	31	-	5.42	3.17	9 and 1	5.42
	32	-	1.25*	4.50*	9 and 1	4.50
Total		16.82	30.92	31.75		66.40
3	32		1.67	-	-	1.67
	33	-	5.25*	-	-	5.25
	35	6.67	-	-	-	6.67
	36	6.08	-	-	-	6.08
	41	-	3.58	7.67	9 and 1	8.34
	42	-	7.75	5.25	9 and 1	9.75
	43	-	0.92	-	-	0.92
	44	7.42	-	-	-	7.42
	45	4.83	-	1.33	-	6.16
	46	-	4.17	4.75	9 and 1	6.08
	47	-	-	2.92*	-	2.92
	47	-	3.58	-	-	3.58
	48	-	2.42*	1.83	9 and 1	2.42
Total		25.00	29.34	23.75		67.26
4	48	-	1.75*	2.33*	9 and 1	2.33
	49	3.33	-	-	-	3.33
	50	1.17	-	-	-	1.17
	51	6.50	-	-	-	6.50
	56	-	-	6.42	-	6.42
	57	-	7.50	7.17	9 and 1	10.42
	58	-	5.67	-	-	5.67
	59	5.00	-	-	-	5.00

*Continuous with figure above

Table A-3 (page 3 of 3)

Day	Orbit	Site 7 Haw	Site 9 Tex	Site 1 Ken	Redundant Sites	Total Usable
4	60	7.17	-	-	-	7.17
	61	-	-	6.00	-	6.00
	62	-	-	0.50*	-	0.50
	62	-	5.00	2.25	9 and 1	5.00
	63	-	2.33*	4.83*	9 and 1	4.83
Total		23.17	22.25	29.50		64.34
5	63	-	0.42	-	-	0.42
	64	-	5.33*	-	-	5.33
	65	2.58	-	-	-	2.58
	66	4.75*	-	-	-	4.75
	67	4.17	-	-	-	4.17
	72	-	5.76	7.83	9 and 1	9.50
	73	-	7.33	3.75	9 and 1	9.00
	75	7.67	-	-	-	7.67
	76	2.33	-	3.92	-	6.25
	77	-	5.58	4.08	9 and 1	5.92
	78	-	-	3.67	-	3.67
	78	-	2.83	-	-	2.83
	79	-	4.75*	-	-	2.25
Total		21.56	31.91	23.25		64.34
5-day total		112.13	133.59	132.91		328.25

*Continuous with figure above

Table A-4

THREE-SITE NETWORK: GOL, TEX, AND KEN (page 1 of 3)

Ground Site Coverage Times (min.)

$h = 200$ nmi, $i = 50°$, $e_{min.} = 5°$, and $\alpha_{max.} = 70.3°$

Date of run: 1 June 1965--SRM simulation

Day	Orbit	Site 11 Gol	Site 9 Tex	Site 1 Ken	Redundant Sites	Total Usable
1	1	7.52	2.58	3.83	11 and 9	11.25
	2	0.50*	4.92*	-	11 and 9	4.92
	2	2.33	-	-	-	2.33
	3	2.67*	-	-	-	2.67
	10	-	-	7.33	-	7.33
	11	-	7.75	6.25	9 and 1	10.08
	12	7.67	3.92	-	11 and 9	8.09
	13	6.92	-	-	-	6.92
	14	3.58	-	-	-	3.50
	15	4.08	1.75	5.33	9 and 1	9.83
	16	-	-	1.92*	-	1.92
Total		35.17	20.92	24.66		68.92
2	16	7.33	4.25	0.92	11 and 9 / 9 and 1	8.83
	17	4.92	3.42*	5.08	9 and 1	10.00
	18	2.33*	3.00	-	11 and 9	4.66
	25	-	-	4.92	-	4.92
	26	-	7.00	7.58	9 and 1	10.25
	27	6.25	6.58	-	11 and 9	8.25
	28	7.67	-	-	-	7.67
	29	5.00	-	-	-	5.00
	30	3.00	-	5.58	-	8.58

*Continuous with figure above

111

Day	Orbit	Site 11 Gol	Site 9 Tex	Site 1 Ken	Redundant Sites	Total Usable
2	31	6.25	5.42	3.17	11 and 9 9 and 1	10.17
	32	-	1.25*	4.50*	9 and 1	4.50
Total		42.75	30.92	31.75		82.83
3	32	6.67	1.67	-	11 and 9	6.67
	33	1.08*	5.25*	-	11 and 9	5.25
	33	0.42	-	-	-	0.42
	34	1.92*	-	-	-	1.92
	41	-	3.58	7.67	9 and 1	8.34
	42	-	7.75	5.25	9 and 1	9.75
	43	7.92	0.92	-	11 and 9	7.92
	44	6.33	-	-	-	6.33
	45	3.08	-	1.33	-	4.41
	46	4.75	4.17	4.75	9 and 1	10.83
	47	7.67	3.58	2.92*	11 and 9	11.25
	48	-	2.42*	1.83	9 and 1	2.42
Total		39.84	29.34	23.75		75.51
4	48	3.92	1.75*	2.33*	9 and 1	2.33
	49	2.58*	-	-	-	2.58
	56	-	-	6.42	-	6.42
	57	-	7.50	7.17	-	10.33
	58	7.08	5.67	-	11 and 9	8.42
	59	7.33	-	-	-	7.33
	60	4.33	-	-	-	4.33
	61	3.42	-	6.00	-	9.42
	62	-	-	0.50*	-	0.50

*Continuous with figure above

Day	Orbit	Site 11 Gol	Site 9 Tex	Site 1 Ken	Redundant Sites	Total Usable
4	62	6.75	5.00	2.25	11 and 9 9 and 1	9.58
	63	-	2.33[*]	4.83[*]	9 and 1	4.83
Total		35.41	22.25	29.50		66.07
5	63	6.00	0.42	-	11 and 9	6.00
	64	1.75[*]	5.33[*]	-	11 and 9	5.33
	72	-	5.67	7.83	9 and 1	9.50
	73	4.58	7.33	3.75	11 and 9 9 and 1	9.16
	74	7.92	-	-	-	7.92
	75	5.75	-	-	-	5.75
	76	2.92	-	3.92	-	6.84
	77	5.50	5.58	4.08	9 and 1	10.92
	78	7.58	2.83	3.67	11 and 9	11.25
	79	-	4.75[*]	-	-	4.75
Total		42.00	31.91	23.25		77.42
5-day total		195.17	135.34	132.91		370.75

[*]Continuous with figure above

FOUR-SITE NETWORK: HAW, GYM, TEX, AND KEN (page 1 of 4)

Ground Site Coverage Times (Min.)

$h = 200$ nmi, $i = 50°$, $e_{min.} = 5°$, and $\alpha_{max.} = 70.3°$

Date of run: 1 June 1965--SRM simulation

Day	Orbit	Site 7 Haw	Site 8 Gym	Site 9 Tex	Site 1 Ken	Redundant Sites	Total Usable
1	1	-	4.83	2.58	3.83	8 and 9	8.67
	2	-	2.58	4.92*	-	8 and 9	4.92
	3	3.33	5.08	-	-	-	8.41
	4	2.33*	-	-	-	-	2.33
	5	7.00	-	-	-	-	7.00
	10	-	-	-	7.33	-	7.33
	11	-	6.00	7.75	6.25	8 and 9 and 1	11.33
	12	-	7.17	3.92	-	8 and 9	8.17
	13	6.67	-	-	-	-	6.67
	14	6.25	-	-	-	-	6.25
	15	-	-	1.75	5.33	9 and 1	5.75
	16	-	-	-	1.92*	-	1.92
Total		25.58	25.66	20.92	24.66		78.75
2	16	-	5.92	4.25	0.92	8 and 9 and 1	5.92
	17	-	0.25*	3.42*	5.08	8 and 9 and 1	5.08
	17	-	2.50	-	-	-	2.50
	18	-	4.92*	3.00	-	8 and 9	4.92
	19	1.83	-	-	-	-	1.83
	20	5.83	-	-	-	-	5.83
	25	-	-	-	4.92	-	4.92

*Continuous with figure above

Day	Orbit	Site 7 Haw	Site 8 Gym	Site 9 Tex	Site 1 Ken	Redundant Sites	Total Usable
2	26	-	-	7.00	7.58	9 and 1	10.25
	27	-	7.75	6.58	-	8 and 9	9.50
	28	1.58	3.92	-	-	-	5.50
	29	7.58	-	-	-	-	7.58
	30	-	-	-	5.58	-	5.58
	31	-	2.67	5.42	3.17	8 and 9 9 and 1	6.17
	32	-	-	1.25*	4.50*	9 and 1	4.50
Total		16.82	27.93	30.92	31.75		80.08
3	32	-	4.25	1.67	-	8 and 9	4.25
	33	-	3.42*	5.25*	-	8 and 9	5.25
	34	-	2.25	-	-	-	2.25
	35	6.67	-	-	-	-	6.67
	36	6.08	-	-	-	-	6.08
	41	-	-	3.58	7.67	9 and 1	8.34
	42	-	7.08	7.75	5.25	8 and 9 and 1	11.59
	43	-	6.58	0.92	-	8 and 9	6.58
	44	7.42	-	-	-	-	7.42
	45	4.83	-	-	1.33	-	6.16
	46	-	-	4.17	4.75	9 and 1	6.08
	47	-	-	-	2.92*	-	2.92
	47	-	5.50	3.58	-	8 and 9	5.50
	48	-	1.42*	2.42*	1.83	8 and 9 and 1	2.42
Total		25.00	30.50	29.34	23.75		81.51
4	48	-	-	1.75*	2.33*	9 and 1	2.33
	48	-	1.50	-	-	-	1.50

*Continuous with figure above

Day	Orbit	Site 7 Haw	Site 8 Gym	Site 9 Tex	Site 1 Ken	Redundant Sites	Total Usable
4	49	3.33	5.17*	-	-	-	8.50
	50	1.17	-	-	-	-	1.17
	51	6.50	-	-	-	-	6.50
	56	-	-	-	6.42	-	6.42
	57	-	3.75	7.50	7.17	8 and 9 and 1	10.42
	58	-	7.67	5.67	-	8 and 9	9.09
	59	5.00	1.17	-	-	-	6.17
	60	7.17	-	-	-	-	7.17
	61	-	-	-	6.00	-	6.00
	62	-	-	-	0.50*	-	0.50
	62	-	4.58	5.00	2.25	8 and 9 and 1	6.25
	63	-	-	2.33*	4.83*	9 and 1	4.83
Total		23.17	23.84	22.25	29.50		76.85
5	63	-	3.50	0.42	-	8 and 9	3.50
	64	-	4.25*	5.33*	-	8 and 9	5.33
	65	2.58	-	-	-	-	2.58
	66	4.75*	-	-	-	-	4.75
	67	4.17	-	-	-	-	4.17
	72	-	-	5.67	7.83	9 and 1	9.50
	73	-	7.50	7.33	3.75	8 and 9 and 1	11.25
	74	-	5.67	-	-	-	5.67
	75	7.67	-	-	-	-	7.67
	76	2.33	-	-	3.92	-	6.25
	77	-	-	5.58	4.08	9 and 1	5.92

*Continuous with figure above

Day	Orbit	Site 7 Haw	Site 8 Gym	Site 9 Tex	Site 1 Ken	Redundant Sites	Total Usable
5	78	-	-	-	3.67	-	3.67
	78	-	5.00	2.83	-	8 and 9	5.00
	79	-	2.25*	4.75*	-	8 and 9	4.75
Total		21.56	28.17	31.91	23.25		80.01
5-day total		112.13	136.10	133.59	132.91		397.20

*Continuous with figure above

THREE-SITE NETWORK: SE, MPLS, AND BOS (page 1 of 3)

Ground Site Coverage Times (Min.)

$h = 200$ nmi, $i = 50°$, $e_{min.} = 5°$, and $\alpha_{max.} = 70.3$

Date of run: 6 July 1965--SRM simulation

Day	Orbit	Site 1 Se	Site 2 Mpls	Site 3 Bos	Redundant Sites	Total Usable
1	1	7.42	-	-	-	7.42
	10	-	-	6.42	-	6.42
	11	-	5.92	8.00	2 and 3	10.00
	12	2.00	8.08	7.25	1 and 3 2 and 3	12.25
	13	7.67	7.83	7.33	1 and 2 2 and 3	16.50
	14	8.08	7.92	8.00	1 and 2 2 and 3	17.50
	15	8.08	7.92	5.67	1 and 2 2 and 3	15.67
	Total	**33.**25	37.67	42.67		85.76
2	16	8.00	4.58	0.25[*]	1 and 2	11.17
	17	5.25	-	-	-	5.25
	25	3.00	-	-	-	3.00
	26	-	1.17	7.83	2 and 3	7.83
	27	-	7.75	7.58	2 and 3	11.17
	28	6.75	6.00	7.17	1 and 2 2 and 3	15.50
	29	8.17	7.75	7.83	1 and 2 2 and 3	17.42
	30	8.08	8.08	7.50	1 and 2 2 and 3	17.08
	31	8.08	6.83	-	1 and 2	12.33
	Total	47.33	42.10	38.16		100.75

[*]Continuous with figure above

118

Day	Orbit	Site 1 Se	Site 2 Mpls	Site 3 Bos	Redundant Sites	Total Usable
3	32	7.00	-	-	-	7.00
	41	-	-	7.08	-	7.08
	42	-	6.75	7.92	2 and 3	10.50
	43	4.42	8.08	7.20	1 and 2 2 and 3	13.75
	44	7.92	7.83	7.50	1 and 2 2 and 3	16.92
	45	8.17	7.92	8.00	1 and 2 2 and 3	17.50
	46	8.08	7.75	4.58	1 and 2 2 and 3	14.92
	47	7.75	2.00	0.25*	1 and 2	9.67
	Total	43.34	40.33	42.53		93.34
4	48	3.67	-	-	-	3.67
	56	-	-	5.08	-	5.08
	57	-	4.33	8.00	2 and 3	8.92
	58	-	8.00	7.50	2 and 3	11.42
	59	7.25	7.92	7.25	1 and 2 2 and 3	16.00
	60	8.17	8.17	8.00	1 and 2 2 and 3	17.58
	61	8.08	8.00	6.92	1 and 2 2 and 3	16.67
	62	8.08	4.42	-	1 and 2	11.92
	Total	35.25	40.50	42.75		91.26
5	63	6.42	-	-	-	6.42
	72	-	-	7.58	-	7.58
	73	-	7.25	7.83	2 and 3	10.92

*Continuous with figure above

119

Table A-6 (page 3 of 3)

Day	Orbit	Site 1 Se	Site 2 Mpls	Site 3 Bos	Redundant Sites	Total Usable
	74	5.75	8.08	7.17	1 and 2 2 and 3	14.67
	75	8.00	7.75	7.67	1 and 2 2 and 3	17.17
	76	8.08	8.00	7.83	1 and 2 2 and 3	17.33
	77	8.08	7.42	1.67	1 and 2 2 and 3	13.42
	78	7.50	-	-	-	7.50
Total		43.83	38.50	37.75		95.01
5-day total		203.00	199.10	203.80		470.12

TWO-SITE NETWORK: GOL AND BDA (page 1 of 3)

Ground Site Coverage Time (Min.)

$h = 200$ nmi, $i = 50°$, $e_{min.} = 5°$, and $\alpha_{max.} = 70.3°$

Date of run: 1 June 1965--SRM simulation

Day	Orbit	Site 11 Gol	Site 2 Bda	Redundant Sites	Total Usable
1	1	7.42	3.33	-	10.75
	2	0.50*	-	-	0.50
	2	2.33	-	-	2.33
	3	2.67*	-	-	2.67
	9	-	4.33	-	4.33
	10	-	7.75	-	7.75
	11	-	4.50	-	4.50
	12	7.67	-	-	7.67
	13	6.92	1.33	-	8.25
	14	3.58	7.16	-	10.74
	15	4.08	3.33	-	7.41
	16	-	3.58*	-	3.58
Total		35.17	35.31		70.38
2	16	7.33	-	-	7.33
	17	4.92	-	-	4.92
	18	2.33*	-	-	2.33
	25	-	7.58	-	7.58
	26	-	6.41	-	6.41
	27	6.25	-	-	6.25
	28	7.67	-	-	7.67
	29	5.00	5.75	-	10.75
	30	3.00	5.25	-	8.25
	31	6.25	1.91	-	8.16
Total		42.75	26.91		69.66

*Continuous with figure above

Day	Orbit	Site 11 Gol	Site 2 Bda	Redundant Sites	Total Usable
3	32	6.67	-	-	6.67
	33	1.08*	-	-	1.08
	33	0.42	-	-	0.42
	34	1.92*	-	-	1.92
	40	-	6.00	-	6.00
	41	-	7.50	-	7.50
	42	-	3.16	-	3.16
	43	7.92	-	-	7.92
	44	6.33	3.33	-	9.66
	45	3.08	6.83	-	9.96
	46	4.75	0.75*	-	5.50
	47	-	2.16	-	2.16
	47	7.67	3.75*	-	11.42
Total		39.84	33.48		73.42
4	48	3.92	-	-	3.92
	49	2.58*	-	-	2.58
	56	-	7.75	-	7.75
	57	-	5.66	-	5.66
	58	7.08	-	-	7.08
	59	·7.33	-	-	7.33
	60	4.33	6.41	-	10.74
	61	3.42	4.50	-	7.92
	62	6.75	3.08	-	9.83
Total		35.41	27.40		62.81

*Continuous with figure above

Day	Orbit	Site 11 Gol	Site 2 Bda	Redundant Sites	Total Usable
5	63	6.00	-	-	6.00
	64	1.75*	-	-	1.75
	71	-	6.91	-	6.91
	72	-	7.16	-	7.16
	73	4.58	1.00	-	5.58
	74	7.92	-	-	7.92
	75	5.74	4.41	-	10.16
	76	2.92	6.16	-	9.08
	77	5.50	1.58*	-	7.08
	77	-	0.75	-	0.75
	78	7.58	7.00	-	14.58
Total		42.00	34.97		76.97
5-day total		195.17	158.07		353.24

*Continuous with figure above

123

Table A-8

TWO-SITE NETWORK: TEX AND KEN (page 1 of 2)

Ground Site Coverage Times (Min.)

$h = 200$ mni, $i = 90°$, $e_{min.} = 5°$, and $\alpha_{max.} = 70.3°$

Date of run: 3 June 1965--SRM simulation

Day	Orbit	Site 9 Tex	Site 1 Ken	Redundant	Total Nonredundant	Total Usable
1	1	3.42	3.58	-	7.00	7.00
	2	3.50	-	-	3.50	3.50
	8	-	7.33	-	7.33	7.33
	9	7.33	-	-	7.33	7.33
	15	-	2.00	-	2.00	2.00
	16	-	2.08*	-	2.08	2.08
Total		14.25	14.99		29.24	29.24
2	16	3.08	3.50	3.08	0.42	3.50
	17	3.42*	3.00*	3.00*	0.42	3.42
	17	2.00	-	-	2.00	2.00
	18	1.58*	-	-	1.58	1.58
	24	5.17	7.25	5.17	2.08	7.25
	25	5.58	-	-	5.58	5.58
	31	-	3.50	-	3.50	3.50
	32	-	3.50*	-	3.50	3.50
Total		20.83	20.75	11.25	19.08	30.33
3	32	3.67	0.58	0.58	3.67	3.67
	33	3.83*	-	-	3.83	3.83
	39	-	6.08	-	6.08	6.08
	40	7.25	4.58	4.58	2.67	7.25
	47	1.75	3.83	1.75	2.08	3.83
	48	1.92*	2.42*	1.92*	0.50	2.42
Total		18.42	17.49	8.83	18.83	27.08

*Continuous with figure above

124

Day	Orbit	Site 9 Tex	Site 1 Ken	Redundant	Total Nonredundant	Total Usable
4	48	3.25	1.17*	-	4.42	4.42
	49	3.17*	-	-	3.17	3.17
	55	-	7.50	-	7.50	7.50
	56	7.17	-	-	7.17	7.17
	62	-	2.67	-	2.67	2.67
	63	-	2.50*	-	2.50	2.50
	Total	13.59	13.84		27.43	27.43
5	63	3.33	3.17	3.17	0.16	3.33
	64	3.67*	2.58*	2.58*	1.09	3.67
	70	-	2.58	-	2.58	2.58
	71	6.00	6.75	6.00	0.75	6.75
	72	4.50	-	-	4.50	4.50
	78	-	3.75	-	3.75	3.75
	79	-	3.50*	-	3.50	3.50
	Total	17.50	22.33	16.33	16.33	28.08
5-day total		84.59	89.40	31.83	110.91	142.16

*Continuous with figure above

Table A-9

THREE-SITE NETWORK: GYM, TEX, AND KEN (page 1 of 2)

Ground Site Coverage Times (Min.)

$h = 200$ nmi, $i = 90°$, $e_{min.} = 5°$, and $\alpha_{max.} = 70.3°$

Date of run: 3 June 1965--SRM simulation

Day	Orbit	Site 8 Gym	Site 9 Tex	Site 1 Ken	Redundant Sites	Total Usable
1	1	3.33	3.42	3.58	8 and 9	7.00
	2	3.50*	3.50*	-	8 and 9	3.50
	2	1.58	-	-	-	1.58
	3	0.83*	-	-	-	0.83
	8	-	-	7.33	-	7.33
	9	5.67	7.33	-	8 and 9	7.33
	10	5.08	-	-	-	5.08
	15	-	-	2.00	-	2.00
	16	-	-	2.08*	-	2.08
	Total	19.99	14.25	14.99		36.73
2	16	-	3.08	3.50	9 and 1	3.50
	17	-	3.42*	3.00*	9 and 1	3.42
	17	3.67	2.00	-	8 and 9	3.67
	18	3.75*	1.58*	-	8 and 9	3.75
	24	-	5.17	7.25	9 and 1	7.25
	25	7.33	5.58	-	8 and 9	7.33
	31	-	-	3.50	-	3.50
	32	-	-	3.50*	-	3.50
	Total	14.75	20.83	20.75		35.92
3	32	2.33	3.67	0.58	8 and 9 and 1	3.67
	33	2.25*	3.75*	-	8 and 9	3.75

*Continuous with figure above

Day	Orbit	Site 8 Gym	Site 9 Tex	Site 1 Ken	Redundant Sites	Total Usable
3	33	3.17	-	-	-	3.17
	34	2.83[*]	-	-	-	2.83
	39	-	-	6.08	-	6.08
	40	-	7.25	4.58	9 and 1	7.25
	41	7.00	-	-	-	7.00
	47	-	1.75	3.83	9 and 1	3.83
	48	-	1.92[*]	2.42[*]	9 and 1	3.58
	Total	17.58	18.34	17.49		41.16
4	48	3.50	3.25	1.17[*]	8 and 9	4.67
	49	3.67[*]	3.17[*]	-	8 and 9	3.67
	55	-	-	7.50	-	7.50
	56	6.42	7.17	-	8 and 9	7.17
	57	3.67	-	-	-	3.67
	62	-	-	2.67	-	2.67
	63	-	-	2.50[*]	-	2.50
	Total	17.26	13.59	13.84		31.85
5	63	-	3.33	3.17	9 and 1	3.33
	64	3.67	3.67[*]	2.58[*]	9 and 1	7.33
	65	3.58[*]	-	-	-	3.58
	70	-	-	2.58	-	2.58
	71	-	6.00	6.75	9 and 1	6.75
	72	7.50	4.50	-	8 and 9	4.50
	78	-	-	3.75	-	3.75
	79	-	-	3.50[*]	-	3.50
	Total	14.75	17.50	22.33		35.32
5-day total		84.33	84.51	89.40		180.98

[*]Continuous with figure above

127

Table A-10
THREE-SITE NETWORK: HAW, TEX, AND KEN (page 1 of 3)

Ground Site Coverage Times (Min.)

$h = 200$ nmi, $i = 90°$, $e_{min.} = 5°$, $\alpha_{max.} = 70.3°$

Date of run: 3 June 1965--SRM simulation

Day	Orbit	Site 7 Haw	Site 9 Tex	Site 1 Ken	Redundant Sites	Total Usable
1	1	-	3.42	3.58	-	7.00
	2	-	3.50*	-	-	3.50
	3	1.33	-	-	-	1.33
	4	4.50*	-	-	-	4.50
	4	0.75	-	-	-	0.75
	5	3.17*	-	-	-	3.17
	8	-	-	7.33	-	7.33
	9	-	7.33	-	-	7.33
	11	3.33	-	-	-	3.33
	12	6.08	-	-	-	6.08
	15	-	-	2.00	-	2.00
	16	-	-	2.08*	-	2.08
	Total	19.16	14.25	14.99		48.40
2	16	-	3.08	3.50	9 and 1	3.50
	17	-	3.42*	3.00*	9 and 1	3.42
	17	-	2.00	-	-	2.00
	18	-	1.58*	-	-	1.58
	19	2.08	-	-	-	2.08
	20	5.25*	-	-	-	5.25
	24	-	5.17	7.25	9 and 1	7.25
	25	-	5.58	-	-	5.58
	27	6.92	-	-	-	6.92
	31	-	-	3.50	-	3.50

*Continuous with figure above

Day	Orbit	Site 7 Haw	Site 9 Tex	Site 1 Ken	Redundant Sites	Total Usable
2	32	-	-	3.50*	-	3.50
	Total	14.25	20.83	20.75		44.58
3	32	-	3.67	0.58	9 and 1	3.67
	33	-	3.75*	-	-	3.75
	35	1.92	-	-	-	1.92
	36	4.67*	-	-	-	4.67
	39	-	-	6.08	-	6.08
	40	-	7.25	4.58	9 and 1	7.25
	43	7.25	-	-	-	7.25
	47	-	1.75	3.83	9 and 1	3.83
	48	-	1.92*	2.42*	9 and 1	3.58
	Total	13.84	18.34	17.49		42.00
4	48	-	3.25	1.17*	-	4.42
	49	-	3.17*	-	-	3.17
	50	1.67	-	-	-	1.67
	51	4.92	-	-	-	4.92
	52	0.75	-	-	-	0.75
	55	-	-	7.50	-	7.50
	56	-	7.17	-	-	7.17
	58	4.92	-	-	-	4.92
	59	5.08	-	-	-	5.08
	62	-	-	2.67	-	2.67
	63	-	-	2.50*	-	2.50
	Total	17.34	13.58	13.84		44.77

*Continuous with figure above

Table A-10 (page 3 of 3)

Day	Orbit	Site 7 Haw	Site 9 Tex	Site 1 Ken	Redundant Sites	Total Usable
5	63	-	3.33	3.17	9 and 1	3.33
	64	-	3.67[*]	2.58[*]	9 and 1	3.67
	66	2.08	-	-	-	2.08
	67	5.25[*]	-	-	-	5.25
	70	-	-	2.58	- -	2.58
	71	-	6.00	6.75	9 and 1	6.75
	72	-	4.50	-	-	4.50
	74	7.17	-	-	-	7.17
	78	-	-	3.75	-	3.75
	79	-	-	3.50[*]	-	3.50
Total		14.50	17.50	22.33		42.58
5-day total		79.09	84.51	89.40		222.33

[*]Continuous with figure above

THREE-SITE NETWORK: GOL, TEX, AND KEN (page 1 of 3)

Ground Site Coverage Times (Min.)

$h = 200$ nmi, $i = 90°$, $e_{min.} = 5°$, and $\alpha_{max.} = 70.3°$

Date of run: 3 June 1965--SRM simulation

Day	Orbit	Site 11 Gol	Site 9 Tex	Site 1 Ken	Redundant Sites	Total Usable
1	1	4.58	3.42	3.58	11 and 9	8.16
	2	0.58*	3.50*	-	11 and 9	3.50
	2	5.42	-	-	-	5.42
	3	1.17*	-	-	-	1.17
	8	-	-	7.33	-	7.33
	9	3.50	7.33	-	9 and 11	7.91
	10	7.08	-	-	-	7.08
	15	-	-	2.00	-	2.00
	16	-	-	2.08*	-	2.08
	Total	22.33	14.25	14.99		44.65
2	16	-	3.08	3.50	9 and 1	3.50
	17	5.58	3.42*	3.00	11 and 9 / 9 and 1	6.92
	17	-	2.00	-	-	2.00
	18	1.75*	1.58*	-	11 and 9	1.75
	18	2.33	-	-	-	2.33
	24	-	5.17	7.25	9 and 1	7.25
	25	6.83	5.58	-	11 and 9	6.83
	26	4.42	-	-	-	4.42
	31	-	-	3.50	-	3.50
	32	-	-	3.50*	-	3.50
	Total	20.91	20.83	20.75		42.00

*Continuous with figure above

Day	Orbit	Site 11 Gol	Site 9 Tex	Site 1 Ken	Redundant Sites	Total Usable
3	32	-	3.67	0.58	9 and 1	3.67
	33	5.75	3.75*	-	-	9.50
	34	1.75*	-	-	-	1.75
	39	-	-	6.08	-	6.08
	40	-	7.25	4.58	9 and 1	7.25
	41	7.58	-	-	-	7.58
	47	-	1.75	3.83	9 and 1	3.83
	48	-	1.92*	2.42*	9 and 1	2.42
	Total	15.08	18.34	17.49		42.08
4	48	5.00	3.25	1.17*	11 and 9	6.17
	49	1.08	3.17*	-	11 and 9	3.17
	49	5.25	-	-	-	5.25
	50	0.67*	-	-	-	0.67
	55	-	-	7.50	-	7.50
	56	4.92	7.17	-	9 and 11	8.51
	57	6.67	-	-	-	6.67
	62	-	-	2.67	-	2.67
	63	-	-	2.50*	-	2.50
	Total	23.59	13.59	13.84		41.94
5	63	-	3.33	3.17	9 and 1	3.33
	64	5.75	3.67*	2.58*	9 and 1	9.42
	65	1.75*	-	-	-	1.75
	70	-	-	2.58	-	2.58
	71	-	6.00	6.75	9 and 1	6.75
	72	7.17	4.50	-	9 and 11	7.92
	73	2.50	-	-	-	2.50

*Continuous with figure above

Table A-11 (page 3 of 3)

Day	Orbit	Site 11 Gol	Site 9 Tex	Site 1 Ken	Redundant Sites	Total Usable
5	78	-	-	3.75	-	3.75
	79	-	-	3.50^{*}	-	3.50
	Total	17.17	17.50	22.33		41.50
5-day total		99.08	84.51	89.40		212.17

*Continuous with figure above

Table A-12

FOUR-SITE NETWORK: HAW, GYM, TEX, AND KEN (page 1 of 3)

Ground Site Coverage Times (Min.)

$h = 200$ nmi, $i = 90°$, $e_{min.} = 5°$, and $\alpha_{max.} = 70.3°$

Date of run: 3 June 1965--SRM simulation

Day	Orbit	Site 7 Haw	Site 8 Gym	Site 9 Tex	Site 1 Ken	Redundant Sites	Total Usable
1	1	-	3.33	3.42	3.58	8 and 9	7.00
	2	-	3.50*	3.50*	-	8 and 9	3.50
	2	-	1.58	-	-	-	1.58
	3	1.33	0.83*	-	-	-	2.16
	4	4.50*	-	-	-	-	4.50
	4	0.75	-	-	-	-	0.75
	5	3.17*	-	-	-	-	3.17
	8	-	-	-	7.33	-	7.33
	9	-	5.67	7.33	-	8 and 9	7.33
	10	-	5.08	-	-	-	5.08
	11	3.33	-	-	-	-	3.33
	12	6.08	-	-	-	-	6.08
	15	-	-	-	2.00	-	2.00
	16	-	-	-	1.75*	-	2.08
	Total	19.16	19.99	14.25	14.66		55.89
2	16	-	-	3.08	3.50	9 and 1	3.50
	17	-	-	3.42*	3.00*	9 and 1	3.42
	17	-	3.67	2.00	-	8 and 9	3.67
	18	-	3.75*	1.58	-	8 and 9	3.75
	19	2.08	-	-	-	-	2.08
	20	5.25*	-	-	-	-	5.25
	24	-	-	5.17	7.25	9 and 1	7.25
	25	-	7.33	5.58	-	8 and 9	7.33

*Continuous with figure above

Day	Orbit	Site 7 Haw	Site 8 Gym	Site 9 Tex	Site 1 Ken	Redundant Sites	Total Usable
2	27	6.92	-	-	-	-	6.92
	31	-	-	-	3.50	-	3.50
	32	-	-	-	3.50*	-	3.50
	Total	14.25	14.75	20.83	20.75		50.17
3	32	-	2.33	3.67	0.58	8 and 9 and 1	3.67
	33	-	2.25*	3.75*	-	8 and 9	3.75
	33	-	3.17	-	-	-	3.17
	34	-	2.83*	-	-	-	2.83
	35	1.92	-	-	-	-	1.92
	36	4.67*	-	-	-	-	4.67
	39	-	-	-	6.08	-	6.08
	40	-	-	7.25	4.58	9 and 1	7.25
	41	-	7.00	-	-	-	7.00
	43	7.25	-	-	-	-	7.25
	47	-	-	1.75	3.83	9 and 1	3.83
	48	-	-	1.92*	2.42*	9 and 1	3.58
	Total	13.84	17.58	18.34	17.49		55.00
4	48	-	3.50	3.25	1.17*	8 and 9	4.67
	49	-	3.67*	3.17*	-	8 and 9	3.67
	50	1.67	-	-	-	-	1.67
	51	4.92	-	-	-	-	4.92
	52	0.75	-	-	-	-	0.75
	55	-	-	-	7.50	-	7.50
	56	-	6.42	7.17	-	8 and 9	7.17
	57	-	3.67	-	-	-	3.67
	58	4.92	-	-	-	-	4.92
	59	5.08	-	-	-	-	5.08

*Continuous with figure above

135

Table A-12 (page 3 of 3)

Day	Orbit	Site 7 Haw	Site 8 Gym	Site 9 Tex	Site 1 Ken	Redundant Sites	Total Usable
4	62	-	-	-	2.67	-	2.67
	63	-	-	-	2.50*	-	2.50
	Total	17.34	17.26	13.59	13.84		49.19
5	63	-	-	3.33	3.17	9 and 1	3.33
	64	-	3.67	3.67*	2.58*	9 and 1	7.33
	65	-	3.58*	-	-	-	3.58
	66	2.08	-	-	-	-	2.08
	67	5.25*	-	-	-	-	5.25
	70	-	-	-	2.58	-	2.58
	71	-	-	6.00	6.75	9 and 1	6.75
	72	-	7.50	4.50	-	8 and 9	7.50
	74	7.17	-	-	-	-	7.17
	78	-	-	-	3.75	-	3.75
	79	-	-	-	3.50*	-	3.50
	Total	14.50	14.75	17.50	22.33		49.82
5-day total		79.09	84.33	84.51	89.40		263.07

*Continuous with figure above

136

Table A-13

THREE-SITE NETWORK: SE, MPLS, AND BOS (page 1 of 2)

Ground Site Coverage Times (Min.)

$h = 200$ nmi, $i = 90°$, $e_{min.} = 5°$, and $\alpha_{max.} = 70.3$

Date of run: 7 July 1965--SRM Simulation

Day	Orbit	Site 1 Se	Site 2 Mpls	Site 3 Bos	Redundant Sites	Total Usable
1	1	4.08	7.05	-	1 and 2	7.08
	2	7.75	-	-	-	7.75
	7	-	-	4.91	-	4.91
	8	-	5.58	7.33	2 and 3	7.58
	9	3.50	7.33	-	1 and 2	7.33
	10	7.83	-	-	-	7.83
	15	-	-	7.41	-	7.41
Total		23.16	19.96	19.65		49.89
2	16	-	7.58	4.50	2 and 3	7.58
	17	6.91	4.66	-	1 and 2	6.91
	18	6.83	-	-	-	6.83
	23	-	-	7.16	-	7.16
	24	-	7.41	5.33	2 and 3	7.41
	25	6.58	5.25	-	1 and 2	7.08
	30	-	-	1.33	-	1.33
	31	-	3.41	7.50	2 and 3	7.50
Total		27.40	28.31	25.82		58.46
3	32	-	7.66	-	-	7.66
	33	7.83	-	-	-	7.83
	34	4.16	-	-	-	4.16
	39	-	2.25	7.75	2 and 3	7.75
	40	-	7.75	-	-	7.75

Day	Orbit	Site 1 Se	Site 2 Mpls	Site 3 Bos	Redundant Sites	Total Usable
3	41	7.55	-	-	-	7.55
	41	7.55	-	-	-	7.55
	42	4.66	-	-	-	4.66
	46	-	-	6.33	-	6.33
	47	-	6.66	6.50	2 and 3	7.08
	Total	24.50	24.33	20.58		60.77
4	48	5.16	6.67	-	-	6.67
	49	7.58	-	-	-	7.58
	54	-	-	5.75	-	5.75
	55	-	6.33	7.00	2 and 3	7.58
	56	4.75	6.91	-	1 and 2	7.00
	57	7.75	-	-	-	7.75
	62	-	-	7.58	-	7.58
	63	-	7.75	3.00	2 and 3	7.75
	Total	25.24	27.66	23.33		57.66
5	64	7.25	3.33	-	1 and 2	7.25
	65	6.33	-	-	-	6.33
	70	-	-	7.41	-	7.41
	71	-	7.66	4.25	2 and 3	7.66
	72	7.00	4.25	-	1 and 2	7.00
	73	6.66	-	-	-	6.66
	77	-	-	3.83	-	3.83
	78	-	4.75	7.50	2 and 3	7.50
	Total	27.24	19.99	22.99		63.64
5-day total		127.54	120.25	112.37		280.42