

N O T I C E

THIS DOCUMENT HAS BEEN REPRODUCED FROM
MICROFICHE. ALTHOUGH IT IS RECOGNIZED THAT
CERTAIN PORTIONS ARE ILLEGIBLE, IT IS BEING RELEASED
IN THE INTEREST OF MAKING AVAILABLE AS MUCH
INFORMATION AS POSSIBLE

(JPL PUBLICATION 80-48, VOLUME II)

A Study of a Space Communication System for the Control and Monitoring of the Electric Distribution System

Volume II: Supporting Data and Analyses

A. Vaisnys

(NASA-CR-163478) A STUDY OF A SPACE
COMMUNICATION SYSTEM FOR THE CONTROL AND
MONITORING OF THE ELECTRIC DISTRIBUTION
SYSTEM. VOLUME 2: SUPPORTING DATA AND
ANALYSES (Jet Propulsion Lab.) 270 p

N80-30587

Unclas
G3/32 28476

May 1980

Prepared for
U.S. Department of Energy
Through an agreement with
National Aeronautics and Space Administration
by
Jet Propulsion Laboratory
California Institute of Technology
Pasadena, California



(JPL PUBLICATION 80-48, VOLUME II)

A Study of a Space Communication System for the Control and Monitoring of the Electric Distribution System

Volume II: Supporting Data and Analyses

A. Vaisnys

May 1980

Prepared for
U.S. Department of Energy
Through an agreement with
National Aeronautics and Space Administration
by
Jet Propulsion Laboratory
California Institute of Technology
Pasadena, California

ABSTRACT

This Volume provides supporting analyses and data from the JPL/Boeing Contract; A Study of a Space Communication System for Electric Utility Load Management, Number 955267.

The material, 1) presents an overview description of the system concept, 2) identifies and defines the functions associated with distribution automation and control, 3) defines communication system requirements, 4) examines important factors related to formulating viable communication concepts, 5) discusses the relationship of various design factors to utility operating practices, 6) reports the results of the cost analysis, 7) describes several ways in which the concept could be integrated into the utility industry.

This Volume supplements the information contained in Volume I.

KEY WORDS

Space Communications
Distribution Automation
Electrical Load Management
Satellite Communications

D180-25403-2

FOREWORD

This document is based upon Study Report D180-25403 by the Boeing Aerospace Corporation, and is basically a reprint of that report with some minor editorial revisions by the Communications and Control for Electric Power Systems Project staff at the Jet Propulsion Laboratory.

This document follows the format of the Boeing Report and consists of two Volumes: Volume I, Summary Final Report, and Volume II, Supporting Data and Analyses.

Copies of either Volume I or Volume II may be obtained from:

Ralph Caldwell, Project Manager, Mail Stop 507-108,
Jet Propulsion Laboratory
4800 Oak Grove Drive
Pasadena, California 91103
Telephone: (213) 577-9162, (FTS) 792-9162

PRECEDING PAGE BLANK NOT FILMED

SUMMARY

This study had two principal objectives. First, to determine with a reasonable degree of assurance whether it is technically feasible to design a satellite communication system to serve the United States electric utility industry's needs relative to load management, real-time operations management, and remote meter reading; and second, to determine the costs of various elements of the system.

The issue of technical feasibility was viewed in terms of launching a full-scale development effort within the next several years, which means the required technologies must already be in-hand, or well on their way. The large multi-beam antenna is the only spacecraft component which has not been "proven" in space. While this situation adds to development risk, the risk is considered acceptably low. All other spacecraft concepts and components are flight qualified, readily available items.

There appear to be no outstanding feasibility issues associated with the design and development of high volume production ground terminals.

The feasibility question was also examined in terms of potential frequency allocations since technological requirements shift from area to area as one moves across the frequency spectrum. The pin-pointing of probable frequency allocations is a key issue which requires early resolution in future work. A frequency assignment in the vicinity of 1 GHz appears to be desirable from cost and performance viewpoints. At higher frequencies (>10 GHz) component costs tend to increase rapidly, and weather related propagation effects are more pronounced. At lower frequencies (<500 MHz) antennas become large and the risk associated with developing the spacecraft antenna increases. Lower frequencies also lead to larger and aesthetically unattractive ground terminal antennas.

Based on the work done to date, a satellite based communication system which can meet electric industry requirements for the control and monitoring of the electric distribution system is believed to be technically feasible. Such a communications system can also provide a wider range of communications functions.

Total program costs are dominated by aggregate ground terminal costs because of the large quantities needed. One-way terminals for communications between the utility and its customers, for load control purposes, can be provided for \$40 per household, assuming ten houses are served by one radio frequency receiver. Two-way communications terminals, which permit reading power consumption meters, are estimated to cost \$175 per household. Both costs exclude installation.

Since space segment costs are relatively constant, wide participation results in low satellite cost on a per terminal basis.

Follow-on effort should be directed to doing a more in-depth design in order to obtain more refined costs, and to examining the use of a satellite for other utility communication needs. Two other potential applications of satellite communications surfaced during this study. It has been suggested that communication needs relative to generation and transmission be examined, and that the unique features of satellite communications should be assessed against the complete spectrum of utility communication requirements. Since these are natural extensions of the system concept, such investigations appear to be worthwhile and should be undertaken.

TABLE OF CONTENTS

1.0	INTRODUCTION	1-1
2.0	SYSTEM CONCEPT	2-1
2.1	<u>Spacecraft</u>	2-3
2.1.1	<u>Communication Subsystem</u>	2-7
2.1.2	<u>Attitude Control Subsystem</u>	2-7
2.1.3	<u>Command, Telemetry and Ranging Subsystem</u>	2-10
2.1.4	<u>Electric Power Subsystem</u>	2-10
2.1.5	<u>Thermal Control</u>	2-10
2.1.6	<u>Life Expectancy</u>	2-11
2.2	<u>Method of Operation</u>	2-12
2.3	<u>Remote Terminals</u>	2-17
2.3.1	<u>Customer Terminals</u>	2-17
2.3.2	<u>Substation and Monitor/Control Point Terminals</u>	2-19
2.4	<u>Master Control Station and Distribution Stations</u>	2-20
2.5	<u>Satellite Control Station</u>	2-23
3.0	FUNCTIONAL ANALYSIS	3-1
3.1	<u>Elements of an Electric Power System</u>	3-1
3.2	<u>Distribution Automation & Control Functions</u>	3-3
3.3	<u>Functional Analysis Methodology</u>	3-9
3.4	<u>Signaling Protocols</u>	3-17
3.5	<u>Traffic Analysis</u>	3-20
3.6	<u>Time Criticality & Priority of Functions</u>	3-29
3.7	<u>Ancillary Functions</u>	3-32
3.8	<u>Summary & Conclusions from the Functional Analysis</u>	3-35
4.0	SYSTEM & DESIGN REQUIREMENTS	4-1
4.1	<u>System Level Requirements</u>	4-1

D180-25403-2

4.2	<u>Requirements for System Elements</u>	4-2
4.3	<u>In-Service Environment</u>	4-5
4.3.1	<u>Climatic and Other Conditions</u>	4-5
4.3.2	<u>Electro Magnetic Interference</u>	4-7
4.3.3	<u>Power Outage Requirements</u>	4-9
4.4	<u>Installation Requirements</u>	4-11
4.5	<u>Reliability Objectives</u>	4-12
4.6	<u>Security Objectives</u>	4-13
5.0	SYSTEM DESIGN CONSIDERATIONS	5-1
5.1	<u>Frequency Considerations</u>	5-1
5.2	<u>System Concepts</u>	5-8
5.2.1	<u>System Connectivity & Time Distribution of Traffic</u>	5-8
5.2.2	<u>Multiple-Access Schemes</u>	5-11
5.2.2.1	<u>Multiple-Access Command Network</u>	5-16
5.2.2.2	<u>Multiple-Access Response Network</u>	5-18
5.2.3	<u>System Architectures</u>	5-19
5.2.3.1	<u>A Nationwide Command Network</u>	5-22
5.2.3.2	<u>Regional Command Networks</u>	5-23
5.2.4	<u>Timing Considerations</u>	5-23
5.3	<u>Communication Link Design</u>	5-26
5.3.1	<u>Transmitting Power</u>	5-26
5.3.2	<u>Antenna Systems</u>	5-28
5.3.3	<u>Propagation Path Losses</u>	5-32
5.3.4	<u>System Noise and Interference</u>	5-39
5.3.5	<u>Modulation and System Performance</u>	5-47
5.3.6	<u>On-Board Processing</u>	5-52
5.3.7	<u>System Margin and Confidence Factor</u>	5-54
5.3.8	<u>RF Links Analysis</u>	5-57
5.3.9	<u>Current-Carrier Communications</u>	5-75

5.4	<u>Terminal Design Considerations</u>	5-78
5.4.1	<u>Customer Terminals</u>	5-79
5.4.2	<u>Substation Terminals</u>	5-85
5.4.3	<u>Monitor/Control Point Terminals</u>	5-85
5.4.4	<u>Equipment Characteristics</u>	5-87
5.4.5	<u>Terminal Installation Considerations</u>	5-93

5.5	<u>Reliability Considerations</u>	5-97
5.5.1	<u>Reliability</u>	5-97
5.5.2	<u>Spacecraft Reliability</u>	5-99
5.5.3	<u>Satellite Failure</u>	5-105
5.5.4	<u>Ground Terminal Reliability</u>	5-106
5.6	<u>Earth Orbital Considerations</u>	5-108
5.6.1	<u>Achieving & Maintaining a Geostationary Orbit</u>	5-108
5.6.2	<u>Sun Transit Effects</u>	5-112
5.6.3	<u>Orbit Utilization</u>	5-114
5.7	<u>Spacecraft Design</u>	5-115
5.7.1	<u>Spacecraft Communication Subsystem</u>	5-115
5.7.1.1	<u>Spacecraft Antennas</u>	5-115
5.7.1.2	<u>Spacecraft Transponders</u>	5-122
5.7.1.3	<u>On-Board Signal Processing</u>	5-126
5.7.2	<u>Spacecraft Electrical Power Subsystem</u>	5-128
5.7.3	<u>Spacecraft Station-Keeping & Attitude Control Subsystem</u>	5-130
5.7.4	<u>Command Telemetry & Ranging Subsystem</u>	5-132
5.7.5	<u>Spacecraft Weight</u>	5-133
5.8	<u>Master Control Station & District Control Center Considerations</u>	5-134
5.8.1	<u>Centralized vs Dispersed Control</u>	5-134
5.8.2	<u>The Man-Machine Interface</u>	5-135
5.8.3	<u>Data Retention</u>	5-136
5.8.4	<u>Equipments</u>	5-136
5.9	<u>Satellite Control Station</u>	5-138

5.10	<u>System Security Considerations</u>	5-141
5.10.1	<u>Link Vulnerability</u>	5-141
5.10.2	<u>Spoofing</u>	5-143
5.10.3	<u>Customer Response Link Vulnerability</u>	5-144
5.10.4	<u>Site Tempering Protection</u>	5-145
5.10.5	<u>Wartime Vulnerability</u>	5-146
5.11	<u>Health Considerations</u>	5-149
6.0	OPERATING CONSIDERATIONS	6-1
6.1	<u>Manpower</u>	6-1
6.2	<u>New Installations</u>	6-1
6.3	<u>Hardware Maintenance</u>	6-2
6.4	<u>Software Maintenance</u>	6-2
6.5	<u>Satellite Control Station - Master Control Station Interface</u>	6-3
7.0	SYSTEM COSTS	7-1
7.1	<u>Costing Strategy</u>	7-1
7.2	<u>Customer Terminal Costs</u>	7-1
7.3	<u>Substation Terminal Costs</u>	7-3
7.4	<u>Master Control Station/District Control Center</u>	7-11
7.5	<u>Spacecraft Costs</u>	7-11
7.6	<u>Earth to Geostationary Orbit Costs</u>	7-16
7.7	<u>Satellite Control Station</u>	7-16
7.8	<u>Operating Costs</u>	7-16
7.9	<u>Initial Investment</u>	7-18
8.0	IMPLEMENTATION	8-1
9.0	BIBLIOGRAPHY	9-1

D180-25403-2

FIGURES

2-1	ELEMENTS OF THE SPACE COMMUNICATION SYSTEM -----	2-2
2-2	PUTTING THE SATELLITE IN GEOSTATIONARY ORBIT -----	2-3
2-3	AZIMUTH AND ELEVATION LOOK ANGLES TO GEOSTATIONARY SATELLITES -----	2-4
2-4	SATELLITE STOWED WITHIN THE ORBITER VEHICLE -----	2-5
2-5	SATELLITE IN DEPLOYED CONFIGURATION -----	2-6
2-6	SATELLITE COMMUNICATIONS SUBSYSTEM -----	2-8
2-7	SATELLITE ATTITUDE CONTROL SUBSYSTEM -----	2-9
2-8	UTILITIES WITHIN A REGION SHARE COMMUNICATION CHANNELS -----	2-13
2-9	TIME DIVISION MULTIPLEXING OF COMMUNICATION TRAFFIC -----	2-14
2-10	A TWO-WAY RESIDENTIAL INSTALLATION -----	2-18
2-11	NEIGHBORHOOD TRANSCEIVER UNIT -----	2-19
2-12	CONTROL STATION EQUIPMENT -----	2-22
3-1	MONITORING & CONTROLLING AN ELECTRIC POWER SYSTEM -----	3-2
3-2	ELEMENTS OF AN ELECTRIC POWER SYSTEM -----	3-4
3-3	DETERMINING COMMUNICATIONS TRAFFIC -----	3-10
3-4	ESTIMATED ELECTRIC POWER METERS, YEAR 2000 -----	3-12
3-5	RESIDENTIAL LOAD MANAGEMENT FORECAST -----	3-15
3-6	OPERATIONAL MANAGEMENT FORECAST -----	3-15
3-7	RESIDENTIAL REMOTE METER READING FORECAST -----	3-16
3-8	REAL-TIME OPERATIONAL MANAGEMENT PROTOCOLS -----	3-18
3-9	WESTERN U.S., PROJECTED TO THE YEAR 1995 -----	3-21
3-10	MID-ATLANTIC/NEW ENGLAND, PROJECTED TO THE YEAR 1995 -----	3-22

3-11	LOAD RECONFIGURATION OPERATIONS -----	3-26
3-12	ACCEPTABLE TIME LATENCIES OF DISTRIBUTION AUTOMATION & CONTROL FUNCTIONS -----	3-31
3-13	A SPACE COMMUNICATION SYSTEM FOR UTILITIES -----	3-34
4-1	MEDIAN OF AVERAGE NOISE POWER, OMNI-ANTENNA -----	4-8
5-1	CONNECTIVITY OF THE COMMUNICATION NETWORK -----	5-9
5-2	SOME COMMAND & CONTROL HIERARCHICAL ARRANGEMENTS -----	5-10
5-3	FREQUENCY DIVISION MULTIPLE ACCESS -----	5-12
5-4	TIME DIVISION MULTIPLE ACCESS -----	5-13
5-5	CODE DIVISION MULTIPLE ACCESS -----	5-14
5-6	GROUP EARTH STATION USING FREQUENCY DIVISION <u>COMMAND LINKS</u> -----	5-17
5-7	SYSTEM ARCHITECTURE HAVING ALL UTILITIES ON ONE TDMA NETWORK -----	5-20
5-8	SYSTEM ARCHITECTURE BASED ON REGIONAL TDMA -----	5-21
5-9	THE RELATIONSHIP BETWEEN EPOCH TIME & DATA RATE -----	5-25
5-10	CUSTOMER TERMINAL TRANSMITTER OUTPUT -----	5-27
5-11	ANTENNA APERTURE VS. FREQUENCY -----	5-30
5-12	ANTENNA GAIN VS. FREQUENCY, 1 FOOT APERTURE -----	5-31
5-13	ATMOSPHERIC ATTENUATION DUE TO OXYGEN AND WATER VAPOR -----	5-33
5-14	RAINFALL RATE OF A HEAVY RAIN SHOWER AS IT PASSED OVER AN EXPERIMENTAL SITE, NATIONAL RESEARCH COUNCIL IN OTTAWA, CANADA -----	5-35
5-15	PERCENTAGE OF TIME RAINFALL EXCEEDS A GIVEN RATE -----	5-36
5-16	ATTENUATION DUE TO RAINFALL. FOG OR CLOUD* -----	5-37
5-17	SKY NOISE FOR GROUND STATION ANTENNA -----	5-41
5-18	MEDIAN VALUES OF AVERAGE NOISE POWER (OMNI-ANTENNA NEAR SURFACE) -----	5-42

D180-25403-2

5-19	FREQUENCY IN MEGAHERTZ -----	5-44
5-20	NOISE TEMPERATURES FOR VARIOUS MICROWAVE DEVICES -----	5-48
5-21	COMPARISON OF BINARY DATA TRANSMISSION SYSTEMS -----	5-50
5-22A	CUSTOMER-SATELLITE LINKS C.F. 95% -----	5-60
5-22B	CUSTOMER-SATELLITE LINKS C.F. 85% -----	5-60
5-23A	CUSTOMER-SATELLITE LINKS C.F. 95% -----	5-66
5-23B	CUSTOMER-SATELLITE LINKS C.F. 85% -----	5-66
5-24A	UTILITY MCS-SATELLITE LINKS C.F. 95% -----	5-69
5-24B	UTILITY MCS - SATELLITE LINKS C.F. 99.87% -----	5-69
5-25A	SUBSTATION - SATELLITE LINKS POWER REQUIREMENTS C.F. 95% -----	5-73
5-25B	SUBSTATION - SATELLITE LINKS POWER REQUIREMENTS C.F. 85% -----	5-73
5-26	TYPICAL SIGNAL TRANSMISSION CHARACTERISTICS FOR ONE MILE OF OVERHEAD DISTRIBUTION LINE -----	5-77
5-27	SIGNAL LOSS AND NOISE LEVEL ON DISTRIBUTION FEEDERS -----	5-77
5-28	NEIGHBORHOOD TERMINAL, LOAD CONTROL & REMOTE METER READING -----	5-80
5-29	TRANSCEIVER UNIT -----	5-82
5-30	METER TRANSPONDER -----	5-82
5-31	CONTROL MODULE -----	5-84
5-32	PREMIUM RATE INDICATOR -----	5-84
5-33	CUSTOMER TERMINAL, LOAD CONTROL -----	5-86
5-34	SUBSTATION TERMINAL -----	5-86
5-35	CUSTOMER TERMINAL MICROSTRIP ANTENNA -----	5-90
5-36	SIZE OF PARABOLIC DISHES VS. FREQUENCY -----	5-91
5-37	TYPICAL RESIDENTIAL INSTALLATION -----	5-96

5-38	FAILURE RATES VS. TIME -----	5-98
5-39	GRAPH OF EXPONENTIAL RELIABILITY -----	5-98
5-40	FAILURE HISTORY OF SPACECRAFT -----	5-99
5-41	PAYLOAD RELIABILITY BLOCK DIAGRAM -----	5-104
5-42	CUSTOMER TERMINAL RELIABILITY BLOCK DIAGRAM -----	5-107
5-43	ORBITAL ARCS FOR SATELLITE COMMUNICATIONS -----	5-109
5-44	GEOSTATIONARY SATELLITES -----	5-109
5-45	TYPICAL FLIGHT PLAN TO ACHIEVE GEOSTATIONARY ORBIT -----	5-110
5-46	EFFECT OF OCCULTATION ON SOLAR ARRAY ILLUMINATION -----	5-113
5-47	SATELLITE ECLIPSE TIME AS A FUNCTION OF THE CURRENT DAY OF THE YEAR -----	5-113
5-48	SIDELOBE LEVELS FOR VARIOUS ILLUMINATIONS AS A FUNCTION OF RMS SURFACE ROUGHNESS -----	5-116
5-49	LOSS IN GAIN DUE TO SURFACE ROUGHNESS -----	5-117
5-50	PREDICTED ANTENNA DEVELOPMENT -----	5-119
5-51	ANTENNA MECHANICAL PACKAGING -----	5-120
5-52	ESTIMATES OF ANTENNA WEIGHT AS A FUNCTION OF ANTENNA SIZE -----	5-121
5-53	SPACECRAFT ANTENNA DEPLOYMENT SEQUENCE -----	5-123
5-54	FET AMPLIFIER CAPABILITIES -----	5-127
5-55	SPACECRAFT STABILIZATION -----	5-131
5-56	VULNERABILITY OF SUBSTATION LINKS -----	5-142
5-57	JAMMING THE UTILITY MASTER CONTROL STATION UPLINK -----	5-147
5-58	REQUIRED JAMMER ANTENNA FOR SIDELOBE JAMMING -----	5-148
5-59	MINIMUM SAFE DISTANCE FROM A RADIATING TRANSMITTER -----	5-151
7-1A	TRANSCEIVER UNIT -----	7-4

7-1B	TRANSCEIVER UNIT COST -----	7-4
7-2	TRANSCEIVER COSTS -----	7-5
7-3A	METER TRANSPONDER -----	7-6
7-3B	METER TRANSPONDER COST -----	7-6
7-4A	CONTROL MODULE -----	7-7
7-4B	CONTROL MODULE COST -----	7-7
7-5A	RECEIVER UNIT -----	7-8
7-5B	RECEIVING MODULE -----	7-8
7-6A	PREMIUM RATE INDICATOR -----	7-9
7-6B	PREMIUM RATE INDICATOR -----	7-9
7-7	RESIDENTIAL COMPONENT COSTS -----	7-10
7-8	COSTS VS. FREQUENCY FOR PARABOLIC DISH ANTENNAS -----	7-12
7-9	COSTS VS. FREQUENCY FOR YAGI-UDA ARRAY AND HELICAL ANTENNAS -----	7-13
7-10	COSTS VS. FREQUENCY FOR HORN AND MICROSTRIP ARRAY ANTENNAS -----	7-14
7-11	SPACECRAFT COST -----	7-15
7-12	ANTENNA DIAMETER VS. UNIT COST -----	7-17

TABLES

3-1	FUNCTIONS ASSOCIATED WITH DISTRIBUTION AUTOMATION & CONTROL -----	3-6
3-2	AUTOMATED DISTRIBUTION FUNCTIONS CORRELATED WITH LOCATIONS -----	3-9
3-3	POWER SYSTEM PARAMETERS -----	3-10
3-4	A PROFILE OF THE ELECTRIC UTILITY INDUSTRY IN YEAR 2000 -----	3-11
3-5	LOAD MANAGEMENT PARAMETERS -----	3-24
3-6	REAL-TIME OPERATIONAL MANAGEMENT PARAMETERS -----	3-27

D180-25403-2

3-7	COMMUNICATIONS TRAFFIC, WESTERN REGION -----	3-28
3-8	ANCILLARY FUNCTIONS -----	3-33
4-1	CUSTOMER TERMINALS, FUNCTIONAL CAPABILITIES -----	4-3
4-2	SUBSTATION TERMINALS, FUNCTIONAL CAPABILITIES -----	4-4
4-3	MONITOR/CONTROL POINT TERMINALS, FUNCTIONAL CAPABILITIES -----	4-5
4-4	CLIMATIC CONDITIONS FOR GROUND EQUIPMENT -----	4-6
4-5	FUNCTIONAL CAPABILITY DURING POWER OUTAGES -----	4-10
5-1	PRINCIPAL SATELLITE COMMUNICATION BANDS -----	5-3
5-2	COMMUNICATION BANDS HAVING OR PROPOSED FOR, LOAD MANAGEMENT ALLOCATIONS; TERRESTRIAL RADIO -----	5-3
5-3	FREQUENCY & BANDWIDTH REQUIREMENTS, TIME- DIVISION MULTIPLE ACCESS -----	5-5
5-4	ATTRIBUTES OF MULTIPLE-ACCESS TECHNIQUES -----	5-16
5-5	CONFIDENCE FACTORS VS STANDARD DEVIATIONS -----	5-56
5-6A	CUSTOMER TO SATELLITE UPLINK ANALYSIS -----	5-58
5-6B	SATELLITE TO CUSTOMER - DOWNLINK ANALYSIS -----	5-59
5-7	TYPICAL STANDARD DEVIATIONS FOR SATELLITE LINK ANALYSIS -----	5-62
5-8A	CUSTOMER TO SATELLITE UPLINK ANALYSIS -----	5-64
5-8B	SATELLITE TO CUSTOMER DOWNLINK ANALYSIS -----	5-65
5-9A	UTILITY MCS TO SATELLITE - UPLINK ANALYSIS -----	5-67
5-9B	SATELLITE TO UTILITY MCS - DOWNLINK ANALYSIS -----	5-68
5-10A	SUBSTATION TO SATELLITE - UPLINK ANALYSIS -----	5-71
5-10B	SATELLITE TO SUBSTATION - DOWNLINK ANALYSIS -----	5-72
5-10C	SUBSTATION TO SATELLITE EMERGENCY CONUS UPLINK ANALYSIS -----	5-74
5-11	CANDIDATE ANTENNAS FOR REMOTE TERMINALS -----	5-88

D180-25403-2

5-12	CUSTOMER TERMINAL RADIO TRANSCEIVER REQUIREMENTS -----	5-92
5-13	SPACECRAFT SUBSYSTEM RELIABILITY, 90% CONFIDENCE INTERVALS -----	5-100
5-14	ON-ORBIT FAILURE RATES FOR SELECTED SPACECRAFT COMPONENTS, 90% CONFIDENCE INTERVALS -----	5-102
5-15	ON-ORBIT FAILURE RATES FOR SELECTED PIECE- PARTS, 90% CONFIDENCE INTERVALS -----	5-103
5-16	SPACECRAFT RELIABILITY ESTIMATE -----	5-104
5-17	ELECTRIC POWER SUBSYSTEM PARAMETERS -----	5-129
5-18	SPACECRAFT WEIGHT -----	5-133
7-1	COST SENSITIVITY -----	7-2
7-2	INITIAL INVESTMENT -----	7-19

1.0 INTRODUCTION

Volume I provides the essence of the study. This Volume (II) provides more detailed supporting analyses and data. It is arranged as follows: Section 2 describes a "baseline" system concept to establish a frame of reference for follow-on discussions. Section 3 reports the results of the functional analysis. Section 4 defines objectives, requirements, and constraints to be used in formulating conceptual designs. Section 5 examines some of the more important design considerations associated with developing viable system concepts. Section 6 discusses the relationship of various design factors to utility operating needs and practices. Section 7 deals with costs, and Section 8 looks at some of the things to be considered in implementing a Space Communication (SC) system.

This study relates to technologies in the electric power field, the communications field, and the aerospace field. In an effort to achieve broadbased comprehension some material is included herein which is somewhat tutorial for those already knowledgeable in a particular field. Also, because of the desire to have this Volume "stand on its own" some material from Volume I is used again.

2.0 SYSTEM CONCEPT

This section provides an overview of what is termed the "baseline" system. Although this study was not intended to develop a "point" design, a specific configuration was deemed useful for exploring feasibility and cost questions in a total solution context. The baseline concept was chosen quite arbitrarily based on experience and industry trends, the baseline configuration was established and sized from data generated during the study.

The baseline should not be viewed as the optimum system, rather it should be looked upon as one of a number of viable contending alternatives. As will be discussed later, there are many considerations which can influence the selection of the preferred configuration. These must be studied in detail, and traded-off technologically and economically, before selecting a final design.

The baseline is presented here, early in this document, to provide a frame of reference for the more detailed discussions in follow-on sections.

The Space Communication system (SC system) consists of those spaceborne and ground equipments needed to provide direct communications between a utility's Master Control Station (MCS), or District Control Center and individual remote terminals (customer terminals, substation terminals, and monitor/control point terminals) located throughout the service area. The elements of the SC system are illustrated in Figure 2-1. Terminals located at residential, commercial, or industrial customers are used for load management and remote meter reading, those incorporated in the power distribution network are used for real-time operational management. These functions are defined and discussed in Section 3.

One Satellite Control Station (SCS) is needed to monitor and control equipments on-board the spacecraft, and to track and maintain the satellite in its assigned orbit.

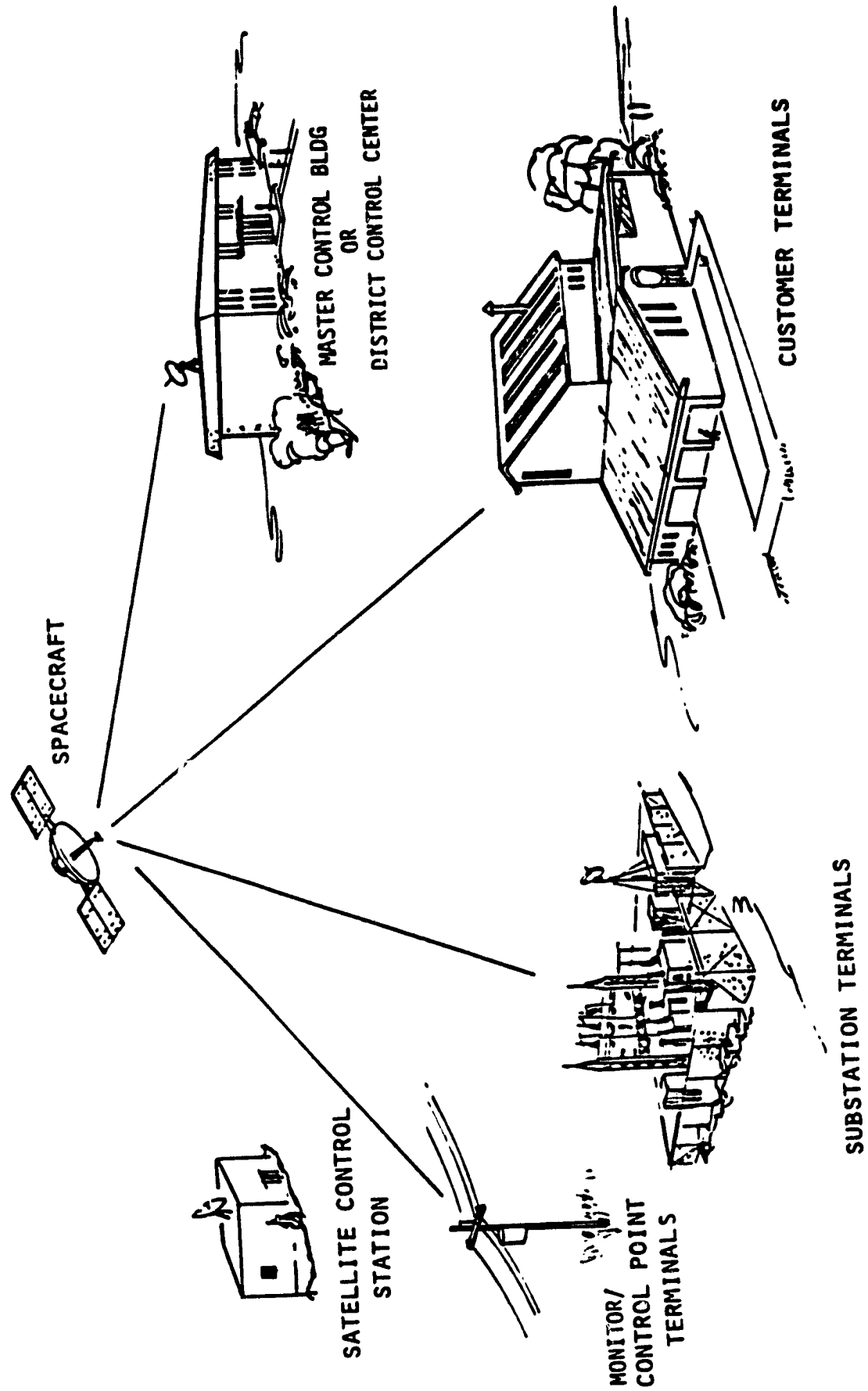


Figure 2-1: ELEMENTS OF THE SPACE COMMUNICATION SYSTEM

The satellite will be positioned above the equator somewhere between 50° and 140° west longitude depending on its assigned location. To an observer in Duluth Minnesota the satellite will appear about 35° above the horizon, to one in Brownsville, Texas, about 60° above the horizon.

The look angles to a geostationary satellite at ground sites of various latitudes and longitudes relative to a point directly under the satellite (subsattellite point) are shown in Figure 2-3.

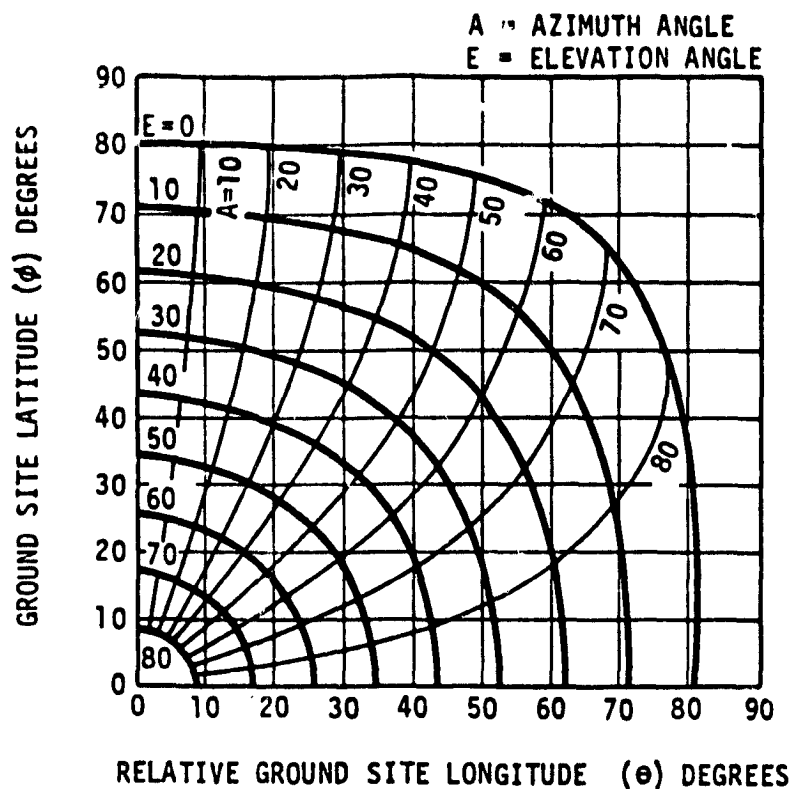


Figure 2-3 AZIMUTH AND ELEVATION LOOK ANGLES TO GEOSTATIONARY SATELLITES

Figures 2-4 and 2-5 depict the satellite in the stowed configuration within the orbiter vehicle, and deployed in space. The total weight of the satellite, including 1,100 pounds of hydrazine station keeping fuel, is approximately 5,000 pounds.

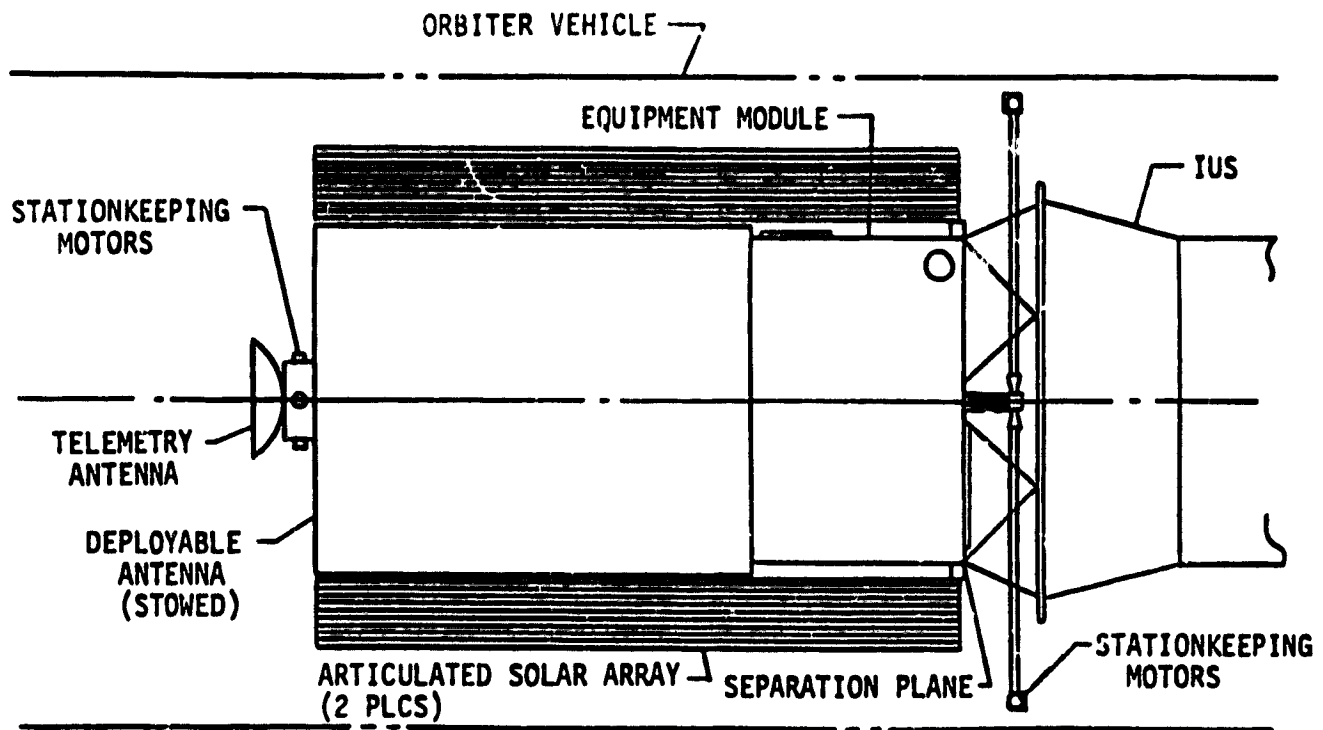


Figure 2-4 SATELLITE STOWED WITHIN THE ORBITER VEHICLE

The satellite is made up of six subsystems: communications, station-keeping and attitude control; command, telemetry and ranging; electrical power; structural and mechanical; and thermal control.

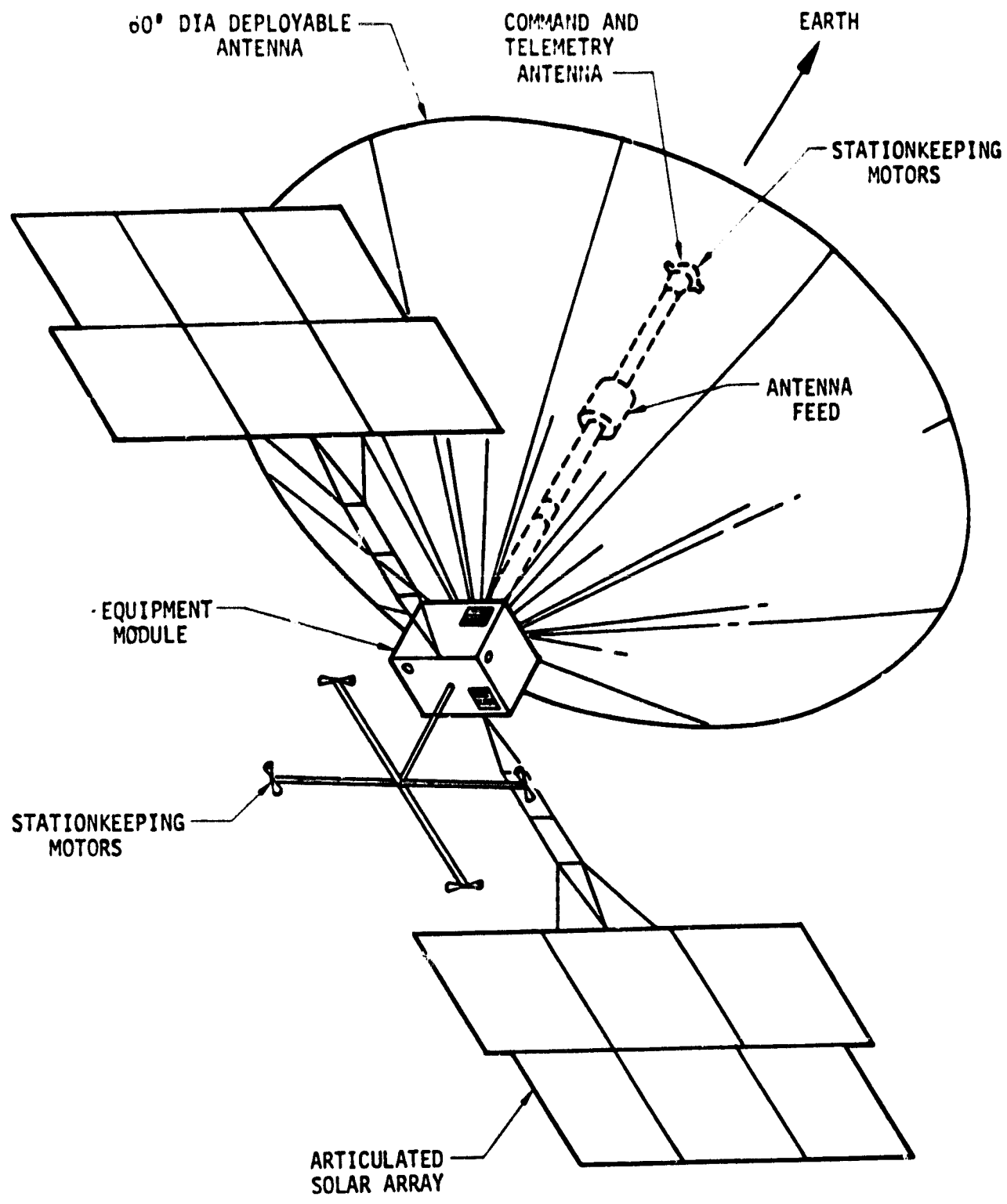


Figure 2-5 SATELLITE IN DEPLOYED CONFIGURATION

2.1.1 Communications Subsystem

The communication subsystem consists of a multibeam antenna, seven transponder channels, a message processor, and associated power supplies, etc. Each of six channels serves a single region of the United States providing a time-shared communication resource. The seventh channel serves all regions providing a rarely accessed communication resource. Figure 2-6. The antenna is a center-fed parabolic reflector illuminated by a cluster of feedhorns properly positioned to form six regional beams plus one continental U.S. (CONUS) beam, each with sharp edge rolloff, low sidelobes, and good isolation. The narrowest regional beam is 1.2° , the widest 3.4° . One 7° beam covers the entire United States.

Satellite receivers have equivalent noise temperatures of 500°K and are built with all solid-state microwave integrated circuit technology. Traveling wave tube amplifiers (TWTAs) supply RF power to the downlinks.

2.1.2 Attitude Control Subsystem

The satellite uses an array of inertia wheels for attitude control. A rate gyro with strapdown integration provides a reference. Star sensors are used to update the reference at appropriate intervals. Desaturation and velocity changes are obtained from an array of 12 hydrazine thrusters. The solar panels are directed to the sun using a sun sensor. An on-board computer is used to process sensor information and issue wheel, thruster and panel drive commands.

Four thrusters are mounted near the antenna feed (lower thrusters), and eight more are mounted on booms extending from the central body (upper thrusters). A change in velocity is obtained by firing two of the upper set of thrusters and one of the lower thrusters. For desaturation, torques are obtained by firing one of the lower units for pitch and roll, or an opposing pair of upper units for yaw. A block diagram of the attitude control system is shown in Figure 2-7.

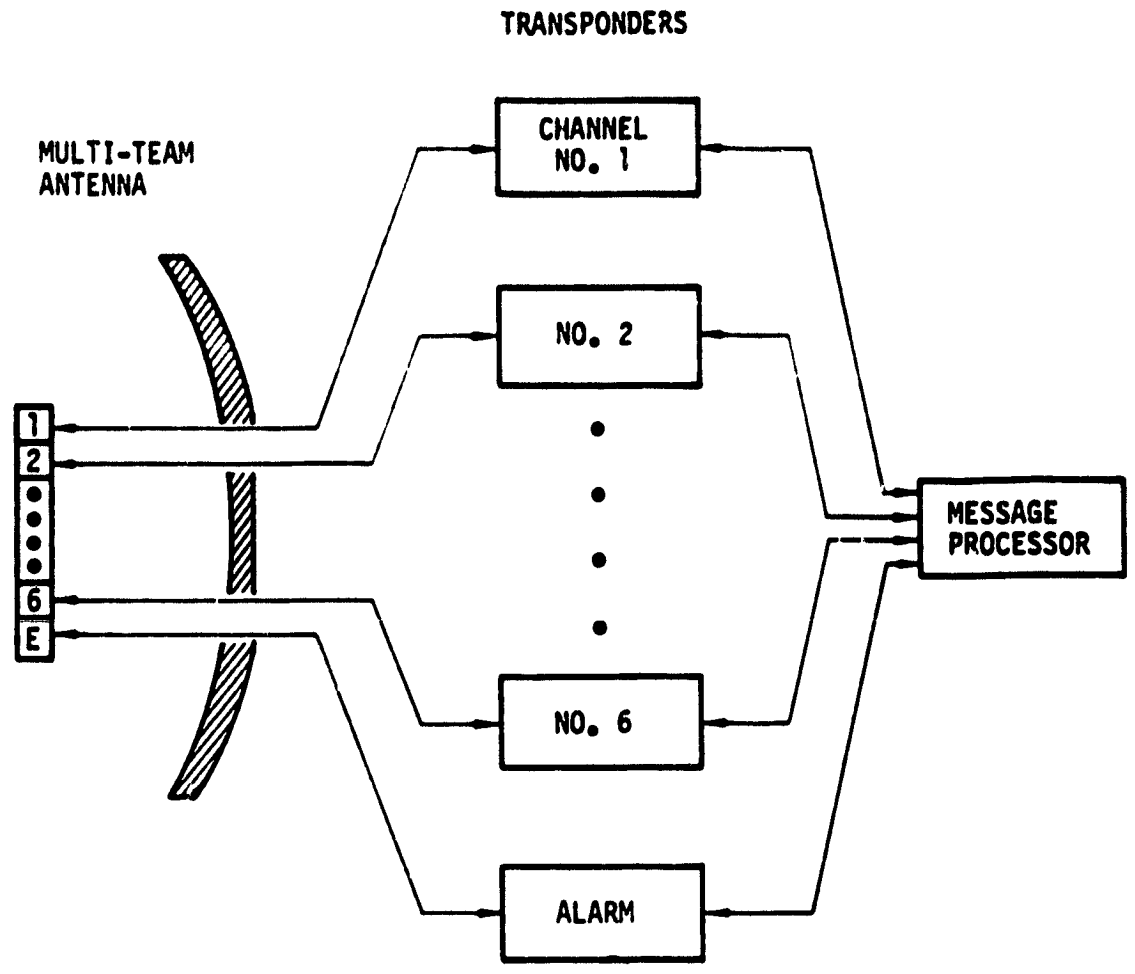


Figure 2-6 SATELLITE COMMUNICATIONS SUBSYSTEM

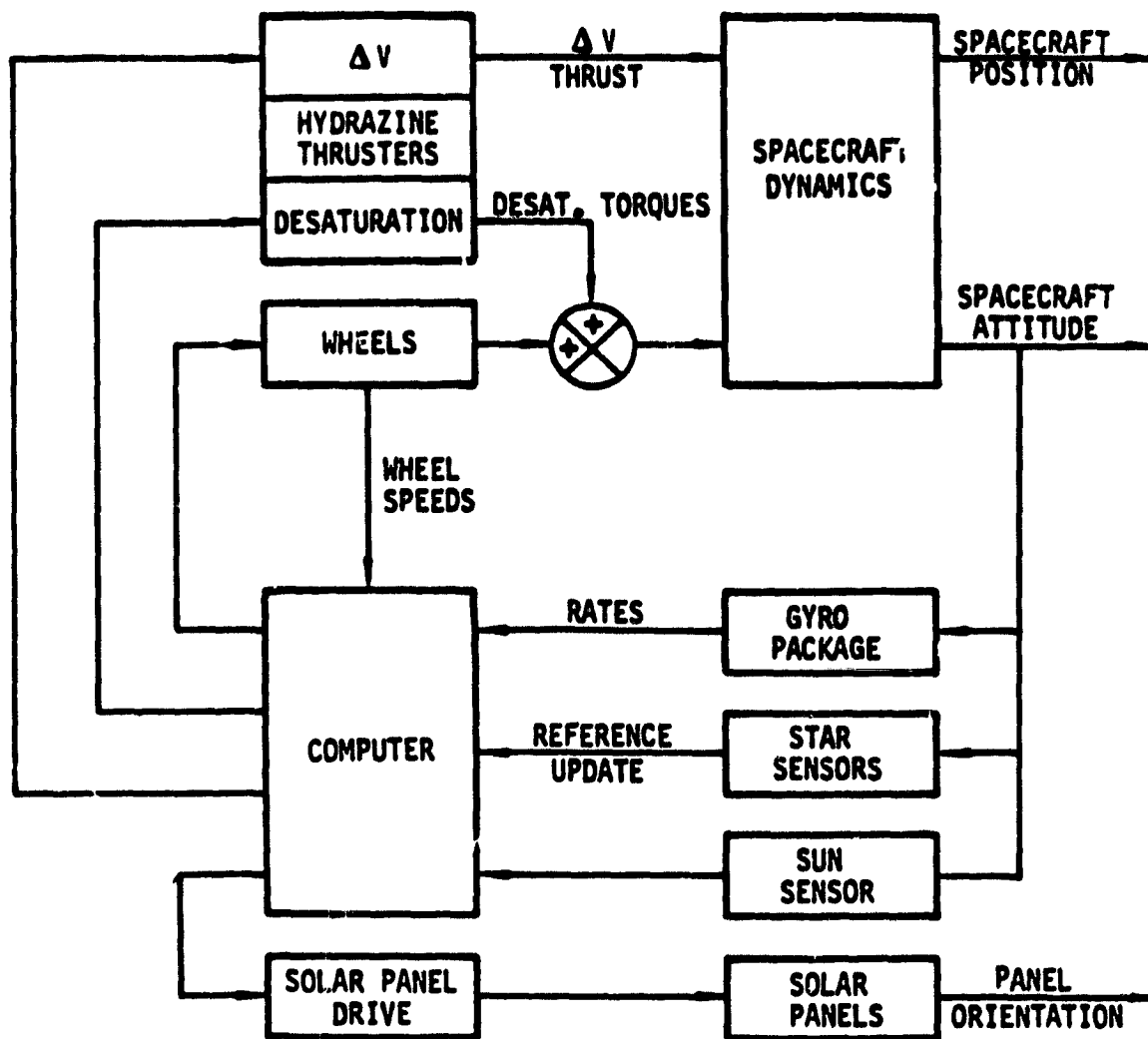


Figure 2-7 SATELLITE ATTITUDE CONTROL SUBSYSTEM

2.1.3 Command, Telemetry and Ranging Subsystem

The command, telemetry and ranging subsystem is made up of two functionally redundant and independent command and telemetry channels. The command channel provides for operational control from the ground for all spacecraft functions. Components of the subsystem are redundant and fully cross-strapped in all modes of operation.

The telemetry channel provides independent and redundant data channels for spacecraft-to-ground transmission of subsystem status and diagnostic data. The telemetry link has two operating modes; one associated with normal in-orbit operations (directional antenna), and a second used during the transfer orbit (omni-directional antenna).

2.1.4 Electric Power Subsystem

The electrical power subsystem is a dual-bus system designed to supply spacecraft power of up to 6 kilowatts for the spacecraft's lifetime. Primary power is provided by two separate sun-oriented planar solar arrays. The arrays consist of approximately 96,000 solar cells 2cm x 2 cm. During eclipses, nickel-cadmium batteries are used to support spacecraft loads.

2.1.5 Thermal Control

Thermal control of the spacecraft is achieved using conventional passive techniques such as selectively locating power dissipating components, the use of special surface treatments, and the regulation of conductive heat paths. Passive measures are augmented with heater elements for items having narrow allowable temperature ranges. High heat load items are located so that they

may efficiently radiate their energy to space via heat sinks. The heat sinks are oriented to minimize exposure to, and daily and seasonal variations of, incident solar flux.

Shields, multilayer insulation, and thermal coatings are also used for thermal control to maintain equipment temperature levels that will ensure specified performance throughout the mission life.

2.1.6 Life Expectancy

The satellite is configured to achieve a life-expectancy of at least 10 years. On-board equipments are highly redundant and manageable by telemetry links from the Satellite Control Station. The system is designed for "graceful degradation", which means the equipments are arranged to prevent catastrophic failures and to permit optimizing the complement of working (non-failed) resources.

After a failure is detected, the on-board fault correction algorithms will perform diagnostic tests and put the spacecraft into a "safe state" allowing a thorough analysis to be made on the ground, after which the spacecraft can be commanded into a new operational state.

An example of a typical resident fault detection and correction algorithm is a "command loss" algorithm which protects against the loss of commandability of the spacecraft. The command loss algorithm expects a command to be processed on-board the spacecraft at least once during a prescribed interval. If a command is not processed during this interval the command loss algorithm takes over and implements a systematic routine, switching thru element and functional redundancy until a command is successfully processed.

As the satellite approaches end-of-life, and its reserve resources become marginal, another unit (which has been in-orbit or ground standby will be put into operation. If for some reason all normal service is unexpectedly disrupted, the spacecraft can be commanded into a reversionary backup mode which permits carrying out critical functions until a reserve unit can be brought on-line. The reversionary mode uses whatever components are available to form a single working communications channel capable of serving users via the 7° (CONUS) beam which is normally reserved for substation-to-Master Control Station alarm messages.

2.2 Method of Operation

Before proceeding with descriptions of the ground elements a digression into how the system works may be helpful.

The United States is divided into operating regions. Each region is a contiguous geographical area whose boundaries are determined by design parameters such as communication traffic volume, allowable spacecraft antenna size, etc., and by industry factors such as the geographical dispersion of utility service areas, power pooling arrangements between groups of utilities, etc.

Regional boundaries establish antenna beamwidths. The widest beam, one that covers the Western U.S., is 3.4°, the narrowest 1.2°. Figure 2-8. At the frequency chosen for the baseline concept (1GHz) a 60 foot diameter antenna is needed to achieve 1.2°.

Each region uses one pair of up-down frequencies for outgoing messages (command messages) and another pair for incoming messages (response messages). By alternating frequency assignments among the regions, and between links, radio frequency spectrum is conserved.

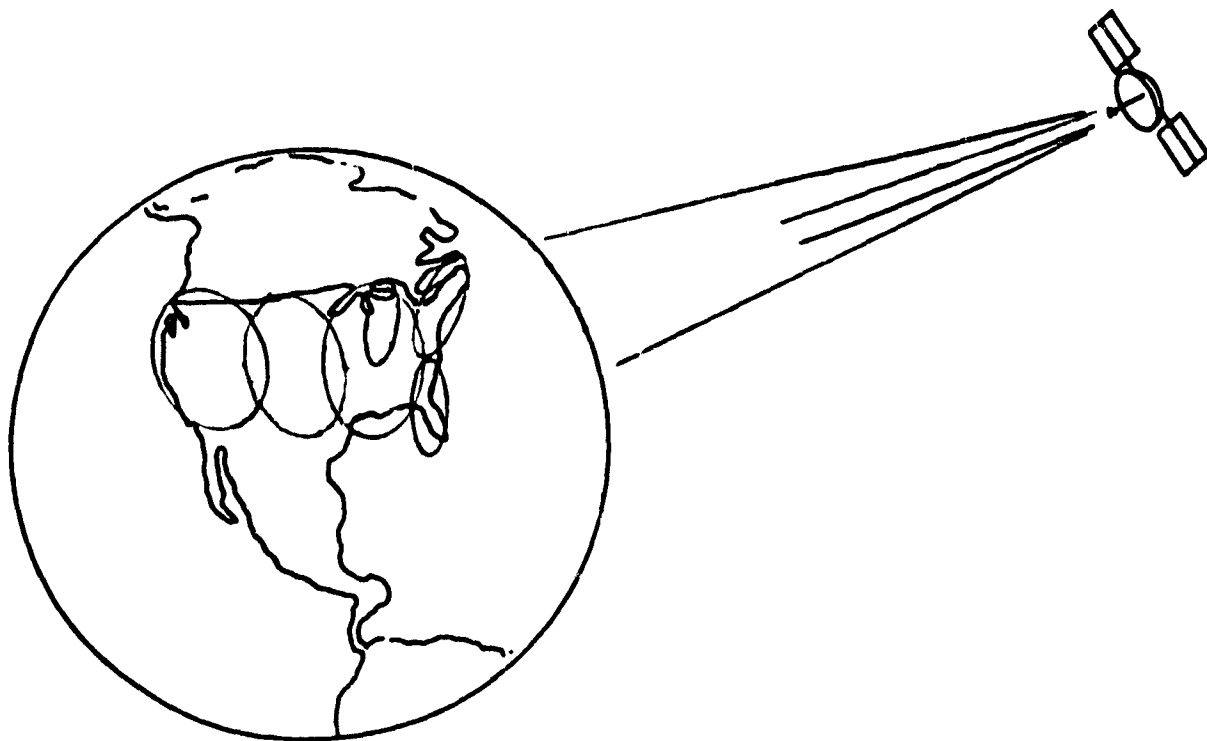


Figure 2-8 UTILITIES WITHIN A REGION SHARE COMMUNICATION CHANNELS

All utilities within a region jointly share a set of resources on-board the satellite (a channel) and operate as a synchronized network. Each utility is assigned one or more time-slots (frames) within a round-robin sequence (epoch) during which it may use the communication channel. The number of slots assigned is related to the utilities estimated traffic volume in relation to others, and by the maximum allowable time between demands for transmission opportunities as determined by time-critical functions. Each time slot is long enough to permit chaining a series of messages. A portion of epoch time is set aside for network synchronization, if required. Figure 2-9.

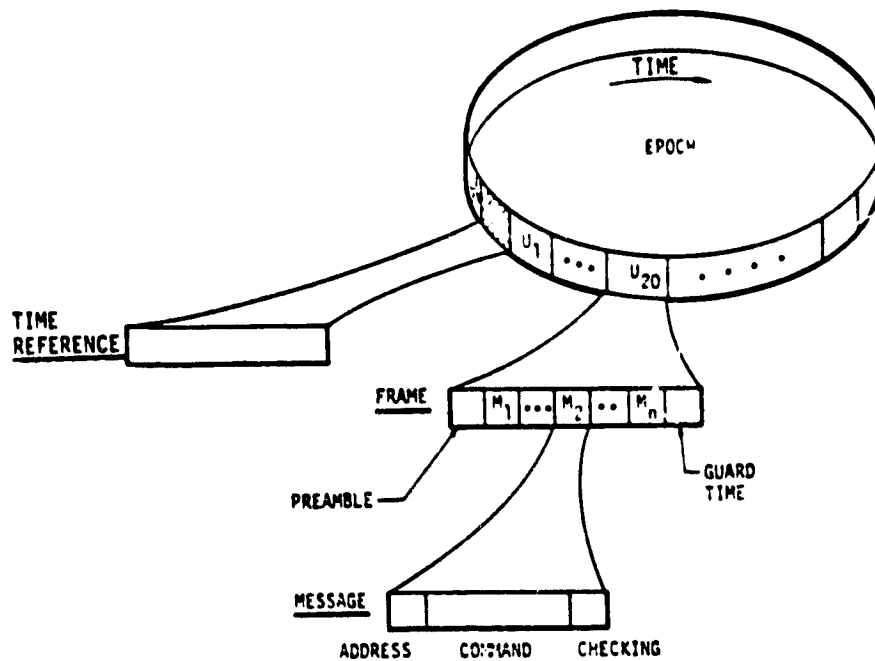


Figure 2-9 TIME DIVISION MULTIPLEXING OF COMMUNICATION TRAFFIC

All traffic, except alarm ("change of state") messages, are initiated from the utility's Master Control Station. The system operates in a command-response mode. Command transmissions are timed to arrive at the satellite within the assigned time slots (command channel). They are demodulated, regenerated, and retransmitted back to earth at a different frequency. Commands can be addressed to specific terminals, or to groups of terminals in a hierarchical arrangement. Commands precipitate control actions, initiate status reports, or request data. Because of their importance, they are protected against malicious interference.

Commands flowing from a Master Control Station stimulate immediate responses from addressed Remote Terminals (RT). Response transmissions arrive at the satellite with somewhat less precise timing than command messages due to variations in ground processing delays from one terminal to the next (time between receipt of the command and execution of the response). These variations are handled by allowing more guard time in response channel time slots.

Each utility may have tens of thousands, hundreds of thousands, or in some instances possibly millions of remote terminals (RT) with which it desires to maintain one-way or two-way communications. The traffic associated with a typical population of RT's is on the order of 17×10^6 messages per month, broken down by function as follows:

Load management	25%
Real-time operational management	18%
Remote meter reading	57%

While the traffic volume is substantial, the time available to handle this traffic is quite long, electronically speaking. Load management functions have allowable time latencies in terms of fractions of an hour, real-time operations management functions in terms of tens of seconds, and remote meter reading in terms of days. This situation permits the use of a relatively modest 5,000 bits per second data rate in the "baseline" system.

With the above overview of the "baseline" systems' modis operandi the discussion will now return to descriptions of system elements.

2.3 Remote Terminals

Terminals are built-up from standard modules, not only for quick-fix replacement but also for building functional capability. Through the use of modules, a terminal may be tailored to individual site needs.

2.3.1 Customer Terminals

The equipments which serve residential and commercial/industrial users are called "customer terminals." Customer terminals provide a means for implementing load management, and for remote meter reading.

Load management can be conducted with a one-way communication capability while remote meter reading obviously requires two-way links. A typical two-way residential installation is depicted in Figure 2-10.

A customer terminal provides the utility with the capability to remotely:

1. Open three circuits (which are reclosed automatically by a local timer).
2. Set reclosure time-delays for each circuit.
3. Read electric, gas, and water meters.
4. Read three electric power consumption registers to .1% accuracy.
5. Set up "time-blocks" for peak, partial peak, and off peak metering.
6. Indicate to the customer which rate schedule is in effect.
7. Monitor the "state" of each controlled circuit.

The Transceiver Unit intercepts transmissions broadcast from the satellite, demodulates the signal, and checks for its own address. A properly addressed command message initiates an action, such as switching off an appliance; or it initiates a sequence of events which ends in the transmission of a response message back to the satellite. For example, an incoming READ command results in the Transceiver Unit calling up the meter reading stored in its microcomputer,

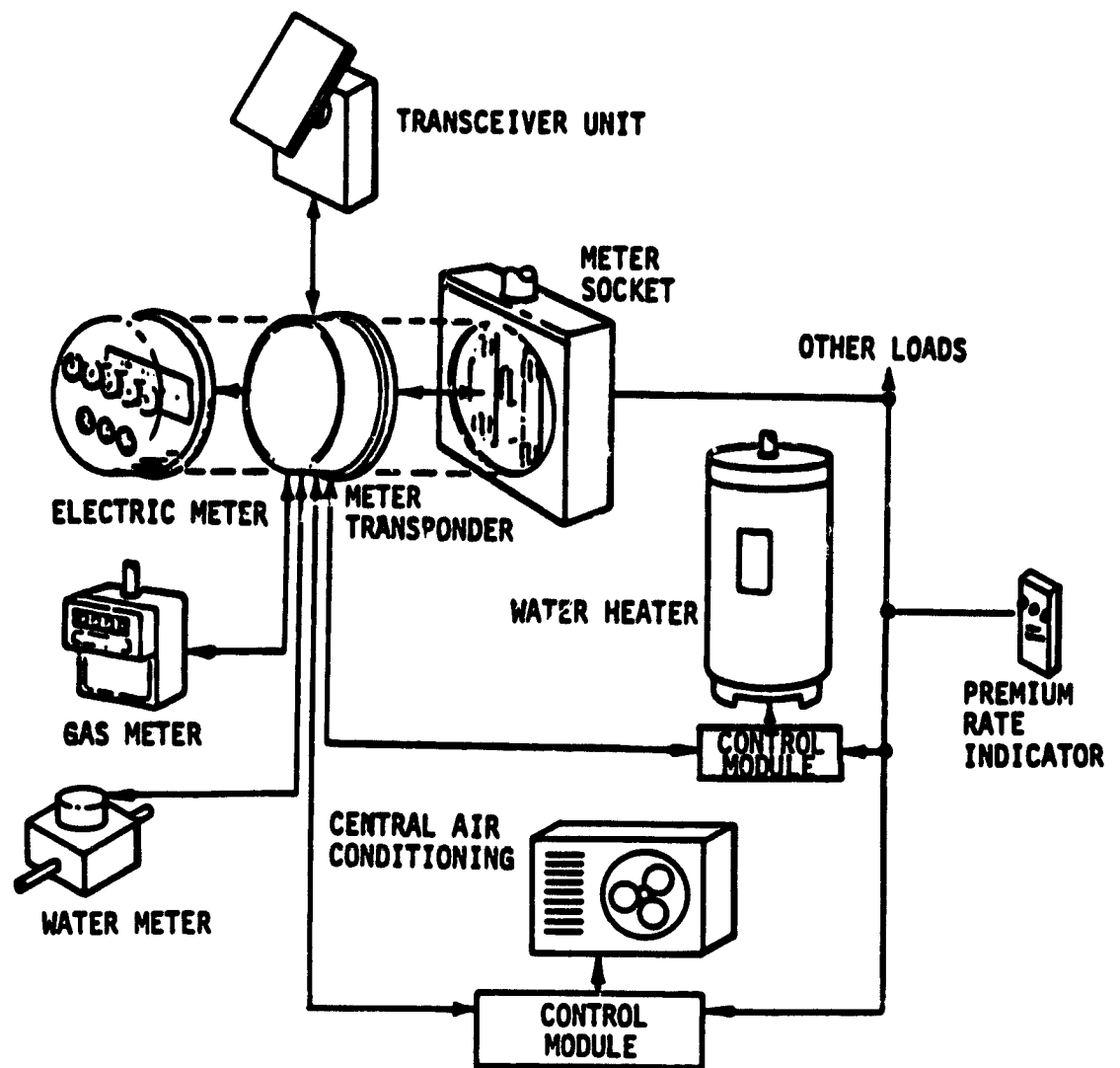


Figure 2-10 A TWO-WAY RESIDENTIAL INSTALLATION

formatting an outgoing message containing this reading along with the address of the parent Master Control Station, and transmitting the message to the satellite.

A single Transceiver Unit can serve one or more customers. It can be connected to the Meter Transponder and Control Modules by means of dedicated wires, or it may use power line carrier current for interconnection. A Unit serving a neighborhood via carrier current is illustrated in Figure 2-11.

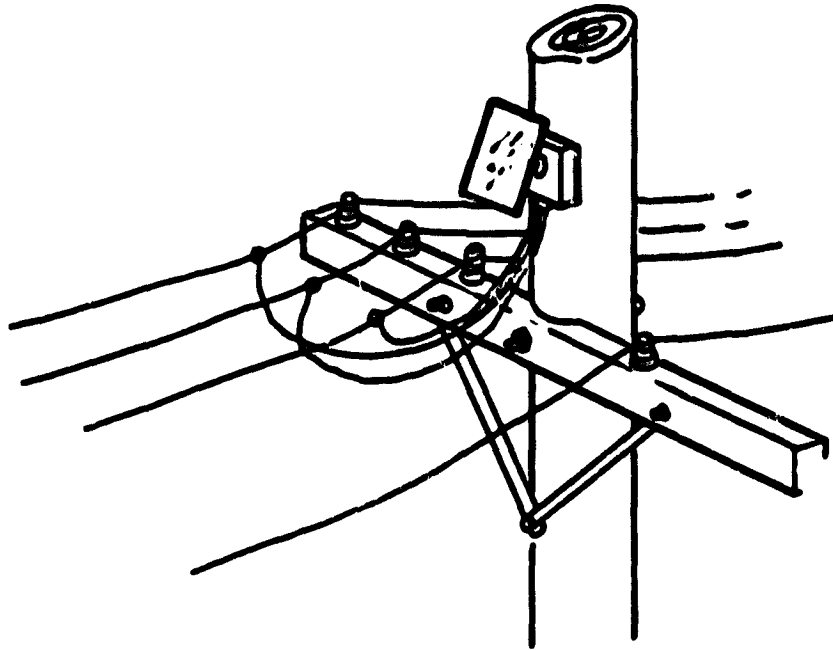


Figure 2-11 NEIGHBORHOOD TRANSCIEVER UNIT

A Transceiver Unit with a Multiplexer Module can interface with a bank of meters such as those serving a commercial building or an apartment house.

2.3.2 Substation and Monitor/Control Point Terminals

Equipment installed at substations for purposes of real-time operational management are designated "substation terminals," and equipment used at other points throughout the distribution network are called "monitor/control point terminals." These latter units are used to monitor the distribution network for faults and irregular operation, and to perform functions such as capacitor bank switching, feeder sectionalizing, etc.

A "basic" substation terminal provides the utility with the capability to remotely:

1. Activate 32 devices; pilot relays, contactors, meters, instrumentation, etc.
2. Read digital and analog instrumentation.
3. Determine status from 32 monitoring points.

Using modular building block, additional capability can be provided as necessary to meet the needs of the largest substations.

A monitor/control point terminal provides the capability to remotely:

1. Activate three devices; relays, contactors, etc.
2. Read three meter registers to .1% accuracy.
3. Determine status from three monitor points.

2.4 Master Control Stations and District Control Centers

Master Control Stations (MCS) and District Control Centers (DCC) are the operational control centers for Distribution Automation and Control (DAC). Control stations can be sited anywhere within the satellite beam, however, for economic reasons they are likely to be located at or near major utility facilities.

A control station is the operating entity responsible for managing all or a part of the distribution network. From this station flow command messages addressed to individual customer terminals, substations, or monitor/control point terminals. To this station come response and alarm messages flowing from these remotely located terminals.

Utilities which use a centralized control philosophy will have one station, a MCS; those using a dispersed control philosophy will have several stations, DCC's.

As discussed in previous paragraphs, the "baseline" concept is structured to use time-division techniques as a means for accommodating a group of utilities on a common communications channel.

For utilities using a dispersed control philosophy, time slots within the round-robin sequence can be assigned to each DCC as though it were an independent entity, or an alternate arrangement may be adopted wherein one station acts as a master network controller allocating time slots to individual DCC's on a dynamic, real-time basis.

Customer meter-reading is estimated to represent the largest volume of DAC traffic. A station, therefore, will normally spend most of its time sending out READ commands. During a peak load condition, the supervisory algorithms will turn to load management tasks, and interspersed with both functions will be real-time operational management.

Because the system is sized to handle the estimated maximum traffic volume at the end of the satellites' life with a 100% margin, under more typical conditions the control stations will be "on-the-air" substantially less than one-half of the time.

The equipment at a control station includes RF transmitters and receivers, time-base generators, message encoders and decoders, and data processors, all housed within an equipment rack. A console is provided for the DAC operator.

Figure 2-12.

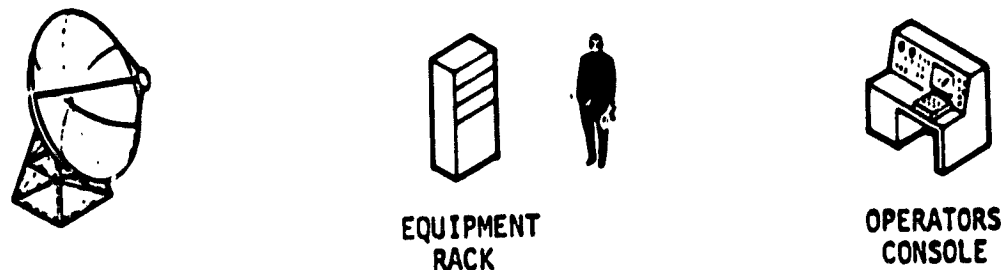


Figure 2-12 CONTROL STATION EQUIPMENT

Application programs (software) are executed by dedicated mini-computers, which also drive cathode-ray tube (CRT) terminals and accept keyboard inputs from the operator consoles.

Since control stations are key elements in the automation scheme, equipment redundancy is used to insure a high degree of reliability. Also, a good size (10 ft.) parabolic antenna is used to assure high quality performance. The parabolic antenna provides a high-gain directional main beam with low side-lobe levels. These characteristics make for higher effective radiated power and less susceptibility to RF interference from sources outside the main beam, be they environmental or man-made.

2.5 Satellite Control Station

The Satellite Control Station (SCS) is responsible for maintaining the spacecraft in an optimum condition, both with regard to on-board functional capability and with regard to orbital position. It also serves the important task of providing master timing to regional communication networks. From this timing, Master Control Stations (MCS) synchronize their transmissions so that they arrive at the satellite within allocated time slots.

Spacecraft functional capability is monitored and controlled via encrypted telemetry channels. Orbital position is determined by means of a tracking beacon carried on the spacecraft. Orbital corrections are computed on the ground and sent to the spacecrafts' station-keeping subsystem via telemetry.

The material set forth in this Section has described the "baseline concept." The baseline is a useful frame of reference for the more detailed discussions which follow. It is one of several candidate system concepts.

3.0 FUNCTIONAL ANALYSIS

This Section summarizes the results of the Functional Analysis task. The analysis was structured to develop the following information:

- The number of control, monitor, and data acquisition nodes to be handled by the communication system in terms of function and geographical dispersion, both with respect to a given utility, and on a nationwide basis.
- Monitor, control, and data acquisition requirements including information rates, data formats, frequency of occurrence, signaling protocols, etc.
- The criticality of functions in terms of priority, allowable response times, and permissible error rates.

The results from the Functional Analysis task serve as a basis for establishing system and equipment level performance requirements.

3.1 Elements of an Electric Power System

The primary purpose of an electric power system is to efficiently generate, process and distribute energy. These operations require geographically dispersed and functionally complex monitoring and control systems, Figure 3-1. The system that exercises overall control is defined as the Energy

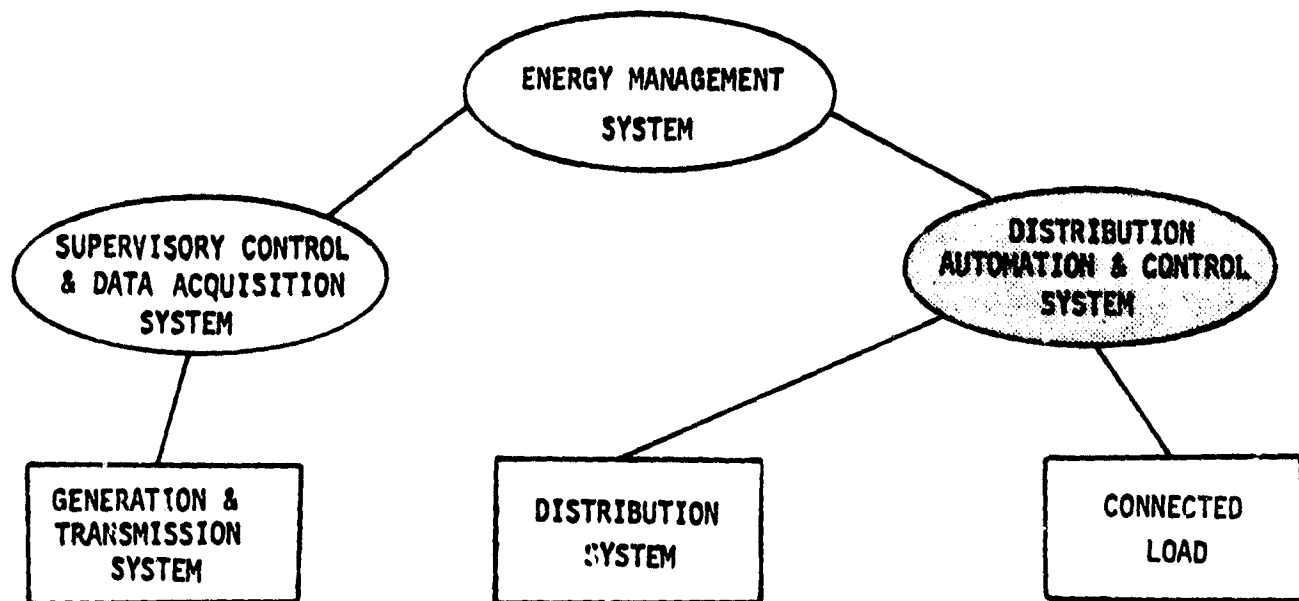


Figure 3-1 MONITORING & CONTROLLING AN ELECTRIC POWER SYSTEM

Management System. That part which handles generation and transmission is identified as the Supervisory Control and Data Acquisition System (SCADA System). The portion which is of interest in this study is the Distribution Automation and Control System (DAC System).

Automatic monitoring and control features have long been a part of the SCADA system. More recently automation has crept into overall energy management, however, it has yet to be applied to any great extent in the distribution system.

The motivations for considering implementing a DAC system are to improve system efficiency, to shift fuel dependency from limited to more abundant energy sources, to reduce reserve requirements for generation and transmission capacity, and to improve reliability of service.

The elements comprising an electric power system are depicted schematically in Figure 3-2. For purposes of this study, the Distribution System includes the subtransmission system, distribution substations, primary feeders and laterals, distribution transformers, and secondary services.

The subtransmission system consists of those circuits emanating from bulk power substations which supply distribution substations. Distribution substations in turn supply primary feeders and their laterals. Distribution transformers convert feeder voltage to consumer utilization voltage, and secondaries provide service to the consumers property. Large commercial and industrial customers may be served directly from the subtransmission system via special industrial substations.

In the future, electric power systems may incorporate relatively small energy sources and storage devices scattered throughout the system. Such items as fuel cells, solar photovoltaic power supplies, wind generators, thermal storage devices, cogeneration, etc., are likely to be widely dispersed. Such Dispersed Storage and Generation (DSG) capability could impact DAC system communication traffic, however, because of the present nebulous state of DSG, its ramifications were not examined.

3.2 Distribution Automation & Control Functions

There is no universal consensus as to the types of functions which should be handled by a DAC system, and there are reasons to anticipate considerable variation from one utility to another. For purposes of this study, distribution automation and control includes the functional requirements associated

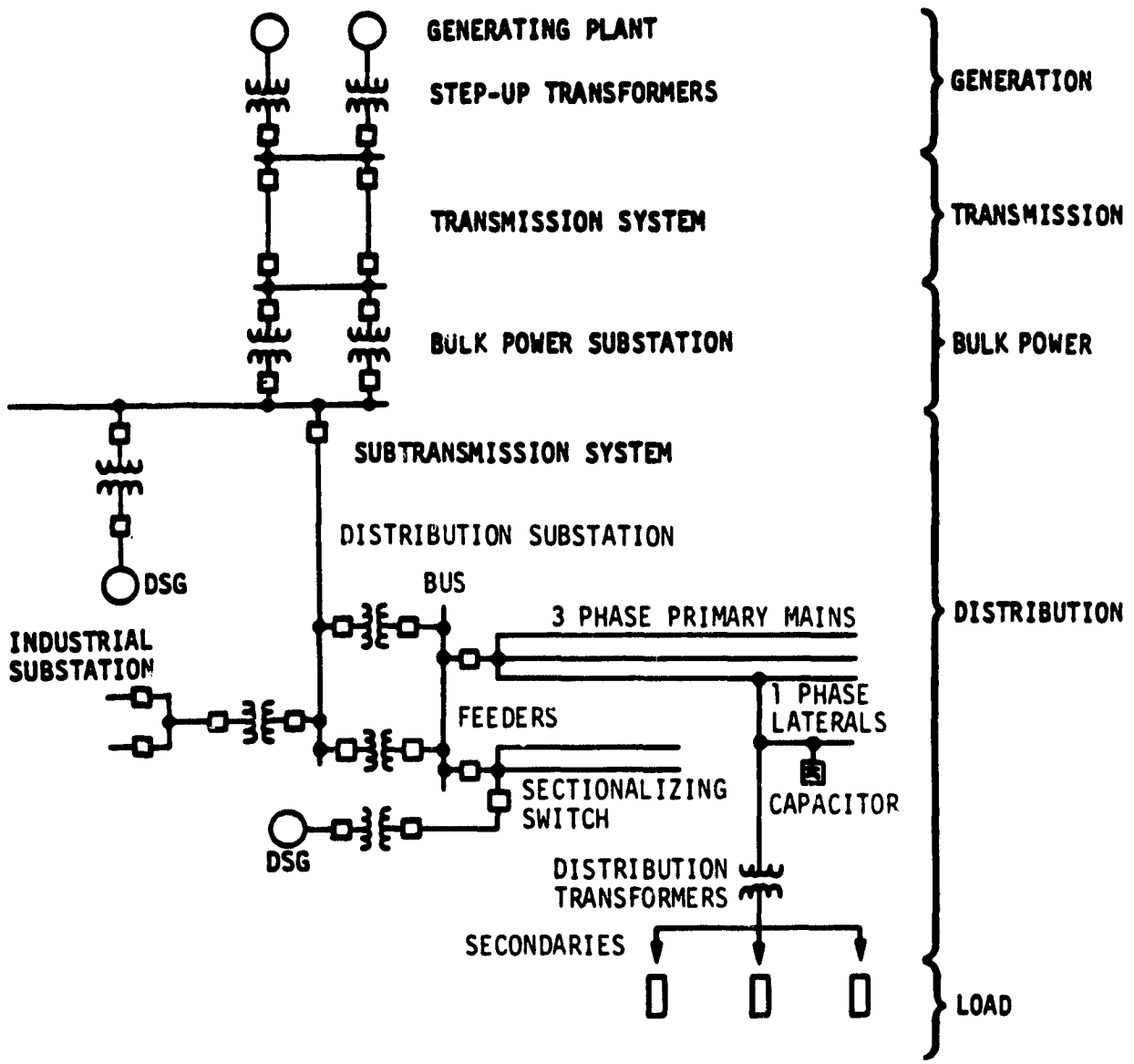


Figure 3-2: ELEMENTS OF AN ELECTRIC POWER SYSTEM

with load management, real-time operational management, and remote meter reading Table 3-1. These terms are defined below.

Load Management is considered to encompass the following functions:

Discretionary Load-Switching -- This function allows direct control of loads at individual customer sites from a remote central location. Control may be exercised for the purpose of overall system load reduction or to reduce the load on a particular substation or other element of the system. Customer loads suitable for control include water heating, air conditioning, space heating, thermal storage heating, etc., and industrial loads supplied under interruptible service contracts.

Peak Load Metering -- This function permits remote switching of meter registers for purposes of time-of-day metering, however, it does not include remotely reading time-of-day meters.

Load Shedding -- Under certain conditions large amounts of load must be rapidly disconnected. The load shedding function enables blocks of load to be dropped on a priority basis.

- LOAD MANAGEMENT
 - DISCRETIONARY LOAD-SWITCHING
 - PEAK LOAD METERING
 - LOAD SHEDDING

- REAL-TIME OPERATIONAL MANAGEMENT
 - LOAD RECONFIGURATION
 - VOLTAGE REGULATION
 - TRANSFORMER MANAGEMENT
 - FEEDER MANAGEMENT
 - CAPACITOR CONTROL
 - FAULT DETECTION, LOCATION AND ISOLATION
 - LOAD STUDIES
 - CONDITION & STATE MONITORING
 - COLD LOAD PICK-UP

- REMOTE METER READING
 - AUTOMATIC CUSTOMER METER READING

Table 3-1 FUNCTIONS ASSOCIATED WITH DISTRIBUTION AUTOMATION & CONTROL

Real-Time Operational Management includes the following capabilities:

Load Reconfiguration -- This function involves remote control of switches and breakers to permit reconfiguration of circuits for purposes of load diversity, maintenance, or new construction. Such actions may occur randomly or on a daily, weekly, or seasonal basis, as applicable.

Voltage Regulation -- This function covers the remote control of selected voltage regulators within the distribution network to effect coordinated system wide control from a central facility.

Transformer Load Management -- This item includes monitoring and reporting transformer loading, core temperature, etc., in order to prevent overloads and burnouts, or abnormal operation.

Feeder Load Management -- This function covers the monitoring of feeder loads, and equalizing loads over several feeders.

Capacitor Control -- This function is defined to include "state" monitoring and remote switching of distribution capacitors.

Dispersed Storage and Generation -- Storage and generation equipment may be located at various places throughout the distribution system. This function includes remote management of these sites.

Fault Detection, Location and Isolation -- Sensors located throughout the distribution network can be used to detect and report abnormal conditions. This information can be used to automatically locate faults, isolate the faulted segment, and initiate circuit reconfiguration.

Load Studies -- This function encompasses the automatic gathering and recording of load data for special off-line analysis.

Condition and State Monitoring -- This function includes real-time data gathering and status reporting, from which the minute-by-minute health of the electric power system is determined.

Cold Load Pick-up -- A corollary function to load-shedding is the controlled pick-up of dropped load.

Remote Meter Reading is defined to encompass the following:

Automatic Customer Meter Reading -- This function includes remote reading of customer meters for total consumption, peak demand, or time-of-day consumption.

The above functions are correlated with customer sites and power system elements in Table 3-2.

	CUSTOMER SITES			POWER SYSTEM ELEMENTS				DISPERSED STORAGE & GENERATION FACILITIES
	RESIDENTIAL	COMMERCIAL & INDUSTRIAL	AGRI-CULTURAL	DISTRI-BUTION CIRCUITS	INDUSTRIAL SUBSTATION	DISTRIBUTION SUBSTATION	BULK POWER SUBSTATION	
LOAD MANAGEMENT								
DISCRETIONARY LOAD-SWITCHING	X	X	X					
PEAK LOAD PRICING	X	X	X					
LOAD SHEDDING	X	X	X					
COLD LOAD PICK-UP	X	X	X					
OPERATIONAL MANAGEMENT								
LOAD RECONFIGURATION				X	X	X	X	
VOLTAGE REGULATION				X	X	X	X	
TRANSF. LOAD MGT.						X	X	
FEEDER LOAD MGT.					X	X		
CAPACITOR CONTROL				X	X			
DISPERSED STORAGE & GENERATION								X
FAULT DETECTION, LOCATION & ISOLATION				X	X	X	X	
LOAD STUDIES	X	X	X	X		X	X	
CONDITION & STATE MONITORING		X	X	X	X	X	X	X
REMOTE METER READING								
AUTOMATIC CUSTOMER METER READING	X	X	X					

Table 3-2 AUTOMATED DISTRIBUTION FUNCTIONS CORRELATED WITH LOCATIONS

3.3 Functional Analysis Methodology

The principal objective of the functional analysis conducted for this study is to derive an estimate of the maximum amount of communications traffic which could be anticipated during the operating life of the first satellite. The process used is illustrated in Figure 3-3, with the various tasks described below.

Normalize Utility Data -- Parameters representative of a typical power system must be normalized to a common denominator which is useful for extrapolating requirements to the national level.

Table 3-4 characterizes cogent parameters of a "typical" system on a per-meter basis. It is recognized that each utility is unique and therefore likely to deviate from the "typical", however for purposes of communication traffic analysis, the aggregate is of more interest than the requirements of an individual utility.

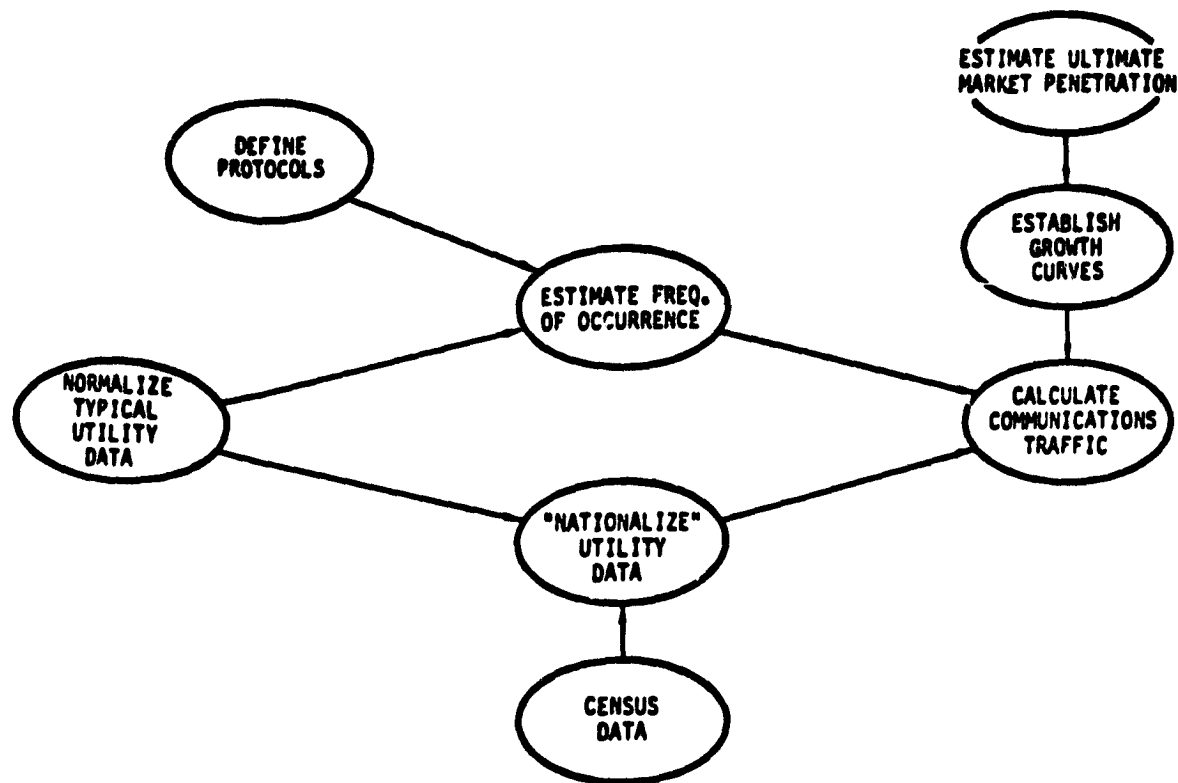


Figure 3-3 DETERMINING COMMUNICATIONS TRAFFIC

	<u>Per Distribution Substation</u>	<u>Per Electric Meter</u>
Distribution Substations	1	3×10^{-4}
Distribution Substation Transformers	4	12×10^{-4}
Voltage Regulators	6	1.7×10^{-3}
Sectionalizing Switches	10	3×10^{-3}
Capacitors	10	3×10^{-3}

Table 3-3 POWER SYSTEM PARAMETERS

Nationalize Data -- Census data and industry forecasts were used to form a profile of the electric utility industry in the year 2000, and estimate the number and geographical distribution of meters. The results are shown in Table 3-4 and Figure 3-4, respectively.

Define Protocols -- Operating procedures and practices of several utilities were examined to establish "standard" protocols for carrying out various functions. They are discussed in paragraph 3.4.

THE YEAR 2000

TOTAL U.S. POPULATION	—	250 x 10 ⁶
NUMBER OF ELECTRIC METERS	—	110 x 10 ⁶
NUMBER OF RESIDENCES WITH:		
CENTRAL AIRCONDITIONERS	—	33 x 10 ⁶
ELECTRIC WATER HEATERS	—	25 x 10 ⁶
ELECTRIC SPACE HEATING	—	7 x 10 ⁶
NUMBER OF ELECTRIC UTILITIES	—	3100

Table 3-4 A PROFILE OF THE ELECTRIC UTILITY INDUSTRY IN YEAR 2000

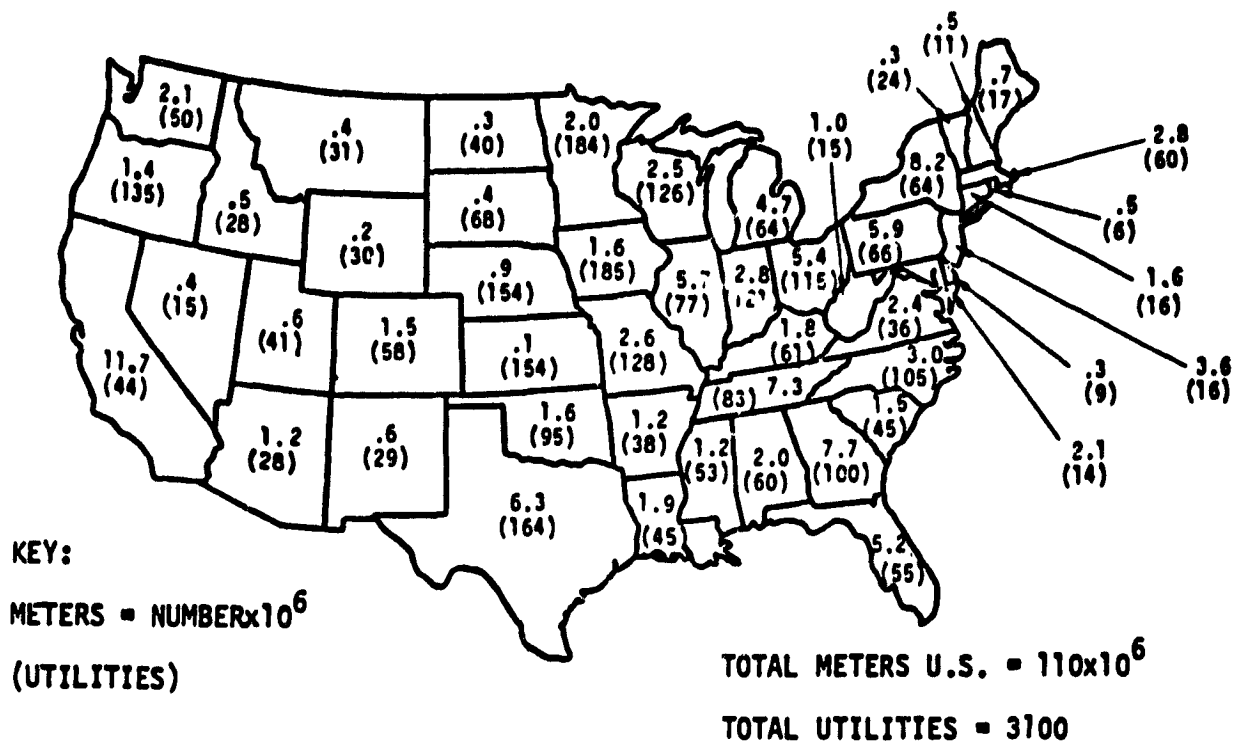


Figure 3-4 ESTIMATED ELECTRIC POWER METERS, YEAR 2000

Estimate Frequency of Occurrence -- Distribution automation and control traffic is of several distinct types:

- 1) Near continuous data gathering which is not time-critical, i.e., customer meter readings, circuit monitoring, etc.
- 2) Cyclical commands which are somewhat time-critical i.e., load management refresh commands.
- 3) A nearly stable amount of randomly distributed, time-critical and non time-critical traffic, i.e., switch closures, etc.
- 4) Infrequent batch traffic, i.e., condition reporting during a storm.
- 5) Infrequent, randomly distributed, time-critical emergency messages initiated at remote terminals, i.e., change-of-state reports.

Communications traffic associated with each function was characterized within this framework.

Estimate Ultimate Market Penetration -- Eventhough distribution automation has many positive attributes its complete and universal incorporation in the electric utility industry is highly unlikely, for a number of reasons. In order to take this situation into account, an estimate was made regarding the maximum potential application of each major function. These estimates are shown in Figures 3-5, 3-6 and 3-7. "Ultimate penetrations" were derived from concensus estimates of those participating in the study and from other industry sources. They represent upper bounds unlikely to be achieved by the year 2000.

For purposes of this study it was assumed that the first satellite would be operational in the year 1985, and would have a design life of 10 years.

Establish Growth Curves -- For purposes of sizing communication traffic "maximum motivation" growth trends were developed which represent a condition wherein all factors influencing industry wide incorporation are positive. Curves representing these trends are also shown in Figures 3-5, 3-6, and 3-7.

For comparison purposes a "present trend" line was estimated which reflects current industry motivations projected into the future. This line appears to represent a lower bound which probably will be exceeded as energy scarcity and public policy force more widespread adoption of conservation measures.

It should be noted that of the three basic functions, load management has the potential for the highest degree of ultimate penetration and the most rapid incorporation. On the other hand, the ultimate penetration of remote meter reading is forecasted to be much lower, with a less rapid build-up. The reasoning behind these projections will be explained later.

Calculate Communications Traffic -- Using the material developed in the preceding tasks, the end-of-life traffic (year 1995) was calculated. See paragraph 3.5.

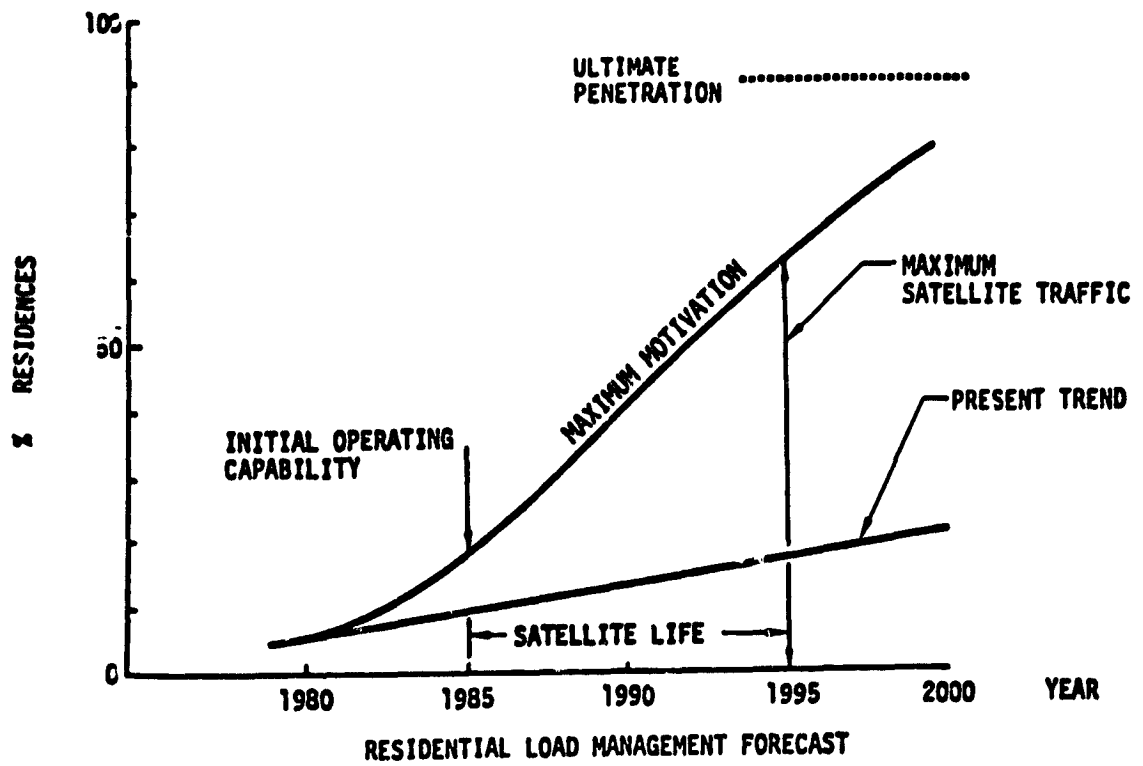


Figure 3-5 RESIDENTIAL LOAD MANAGEMENT FORECAST

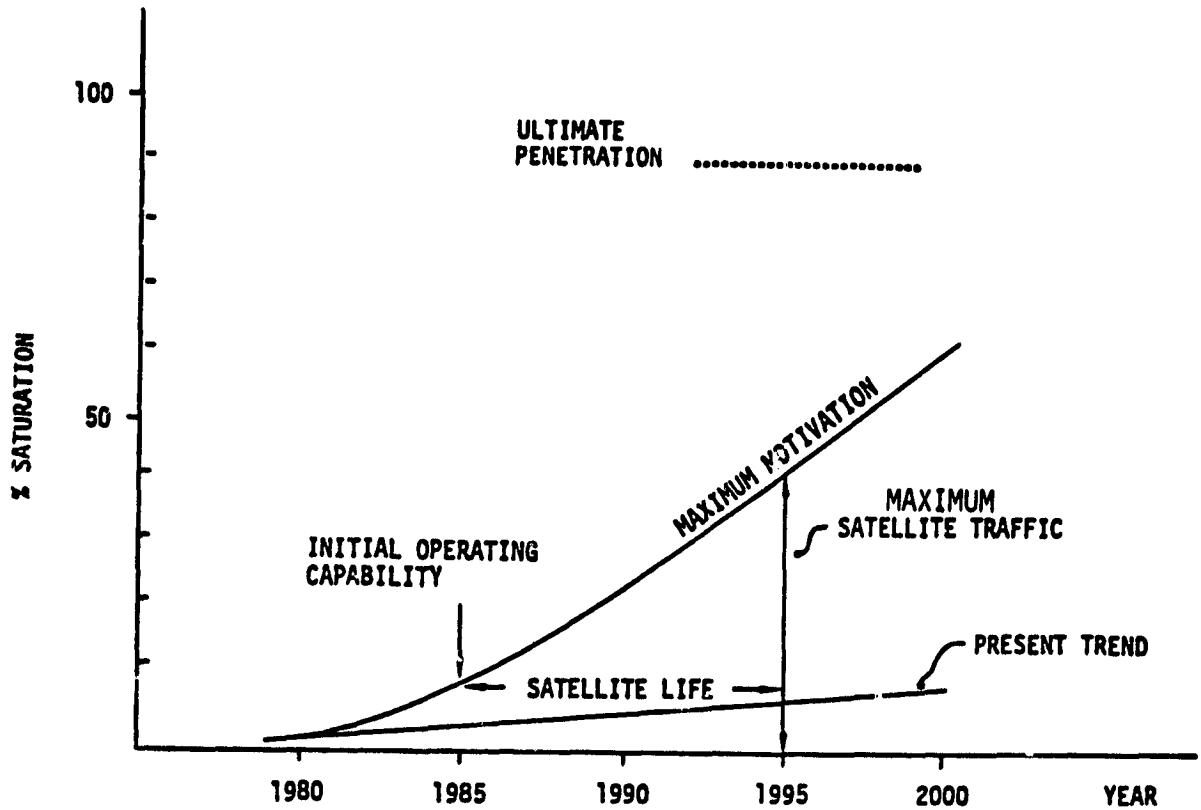


Figure 3-6 OPERATIONAL MANAGEMENT FORECAST

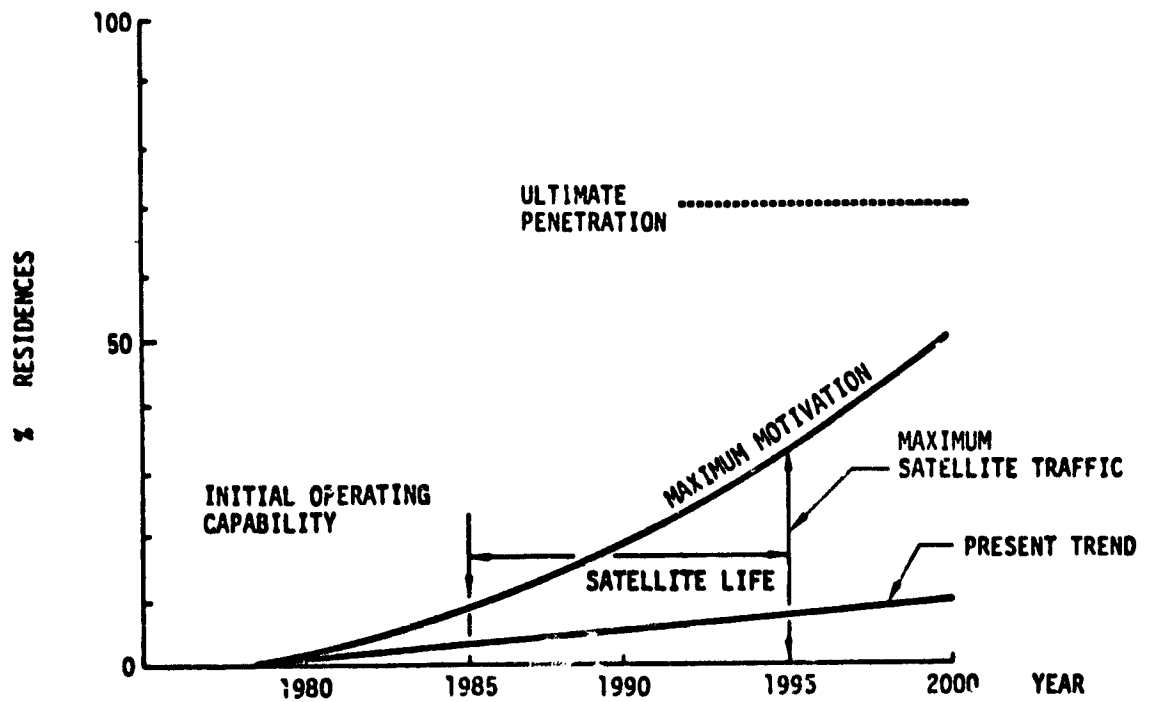


Figure 3-7 RESIDENTIAL REMOTE METER READING FORECAST

3.4 Signaling Protocols

Because the most complex protocols are associated with real-time operational management, this area will be discussed first, followed by load management protocols and then by remote meter reading protocols.

Real-time operational management of the distribution system can be handled using four types of protocols. These have been named the ACTION sequence, the MONITOR sequence, the METER READ sequence, and the ALARM sequence, Figure 3-8. They are described in the following paragraphs.

Action Sequence -- The Action Sequence is used for device control. It is initiated by a REPORT message, sent from the control center to the Remote Terminal, which identifies the device to be controlled. The Remote Terminal responds with the STATE of the device, i.e., open or closed, on or off, etc. The control center verifies that the device's state was as expected, then sends a COMMAND message indicating what action is to be taken, i.e., close or open the device, etc. The Remote Terminal stores the received command and echoes back to the control center the command as RECEIVED. The control center compares the received command with that sent, thereby verifying proper reception. It then sends an ACTIVATE message. If the ACTIVATE message received by the terminal matches the command held in storage, the control function is carried out, i.e., the device is closed or opened, etc. Once the function is completed, the Remote Terminal reports the new STATE of the device.

This rather elaborate protocol is believed to be appropriate in view of the potential consequences of mismanagement of some key elements of the power distribution system.

Monitor Sequence - The Monitor Sequence is quite straight forward. It is used to determine status. A REPORT message is sent identifying the device whose status is desired. The Remote Terminal responds with a STATE message.

Meter Read Sequence - The Meter Read Sequence is used for data gathering. It is initiated with a READ message, and the Remote Terminal responds with a REGISTER reading.

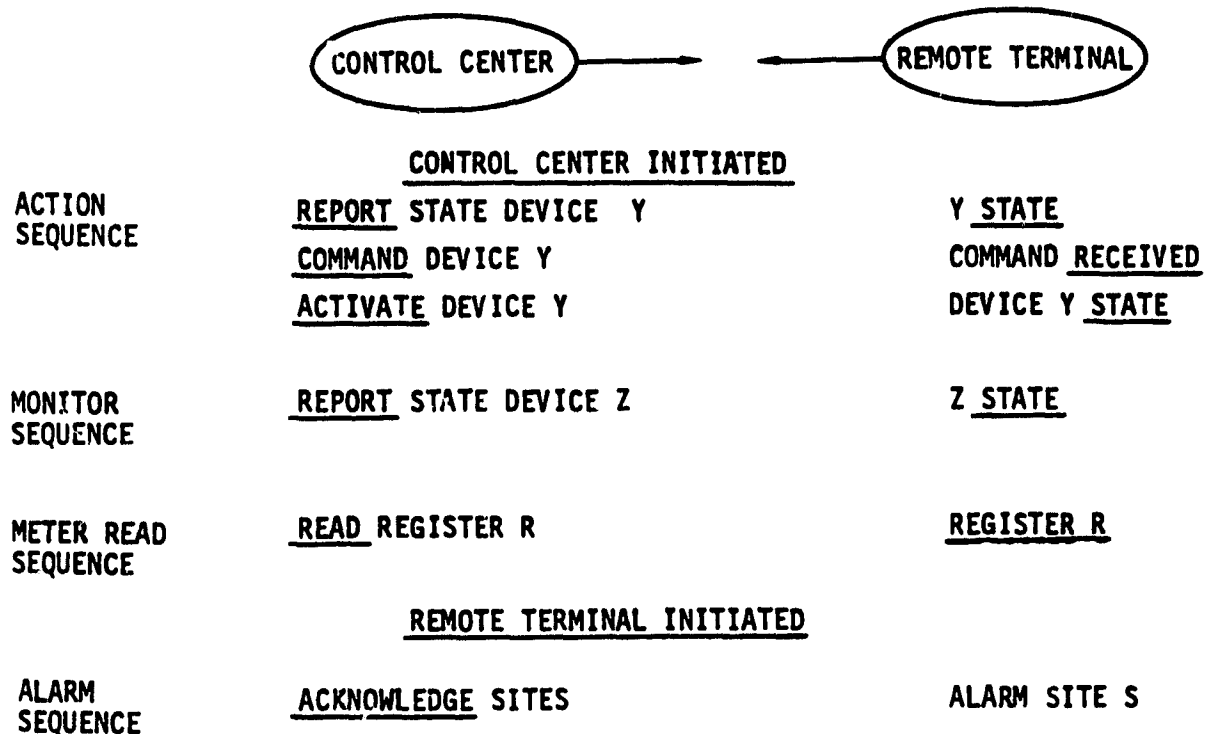


Figure 3-8 REAL-TIME OPERATIONAL MANAGEMENT PROTOCOLS

Alarm Sequence -- The Alarm Sequence is unique in that it originates at the Remote Terminal, reporting an out-of-tolerance condition or unplanned change of state. It consists of an ALARM message addressed to the parent Control Center.

Load Management functions can generally be handled by COMMAND type messages addressed to one, or a group of remotely controlled devices. Load-switching and load-shedding usually can be accomplished by a single disconnect message, since local timers at the devices are used to initiate reconnection. However, in some applications, service must be reestablished by remote control. In these cases an ACTION sequence is required.

Remote meter reading as defined in this study refers solely to reading power consumption at customer sites. The communication system servicing these sites must be able to handle single and multiple register meters eventhough most meters today are single register devices. The multi-register requirement stems from the growing trend toward time-of-day pricing, which is forecasted to become the norm for a large number of customers in the near future.

The use of time-of-day metering may require the capability to selectively read any of several time-block registers, as opposed to a capability to read all registers sequentially by means of a single READ command. To handle a selective reading requirement,

a READ sequence identifying a specific target register would be used, followed by a second READ sequence for the second register, etc. Typically, three sequences would be needed for residential meters, and possibly several more for certain classes of industrial customers.

3.5 Traffic Analysis

The amount of nationwide communications traffic associated with distribution automation and control is projected to be great enough to consider dividing the United States into regional communication networks, each operating independently using its own resources onboard the satellite. Such an arrangement permits the use of lower data rates and has other advantages which will be discussed subsequently in other Sections.

In order to "size" a representative regional communication system, two areas of the United States were chosen for study, the Western states and the mid-Atlantic/New England states.

In applying the regional concept to the western U.S., the unique characteristics of this area, and the nature of the utilities therein, significantly influence communication requirements. First, the region has a low population density. There are only a few very large utilities, and many small publicly owned ones. These utilities are connected together to form a vast power pool. Many systems serve groups of customers over widely dispersed areas. For instance, Pacific Power and Light has customers scattered in parts of Oregon, Washington, Idaho, Montana, Wyoming, and California. Pacific Gas and Electric serves 94,000 square miles of California.

What this means is that in order to encompass all facilities of a given utility, to cover all participants in the power pool, and to pick up an economic volume of traffic the territory included in the western communication network must cover an extensive geographical area.

The projected conditions for the Western U.S. in the year 1995 are listed in Figure 3-9, the end-of-life year for the first satellite.

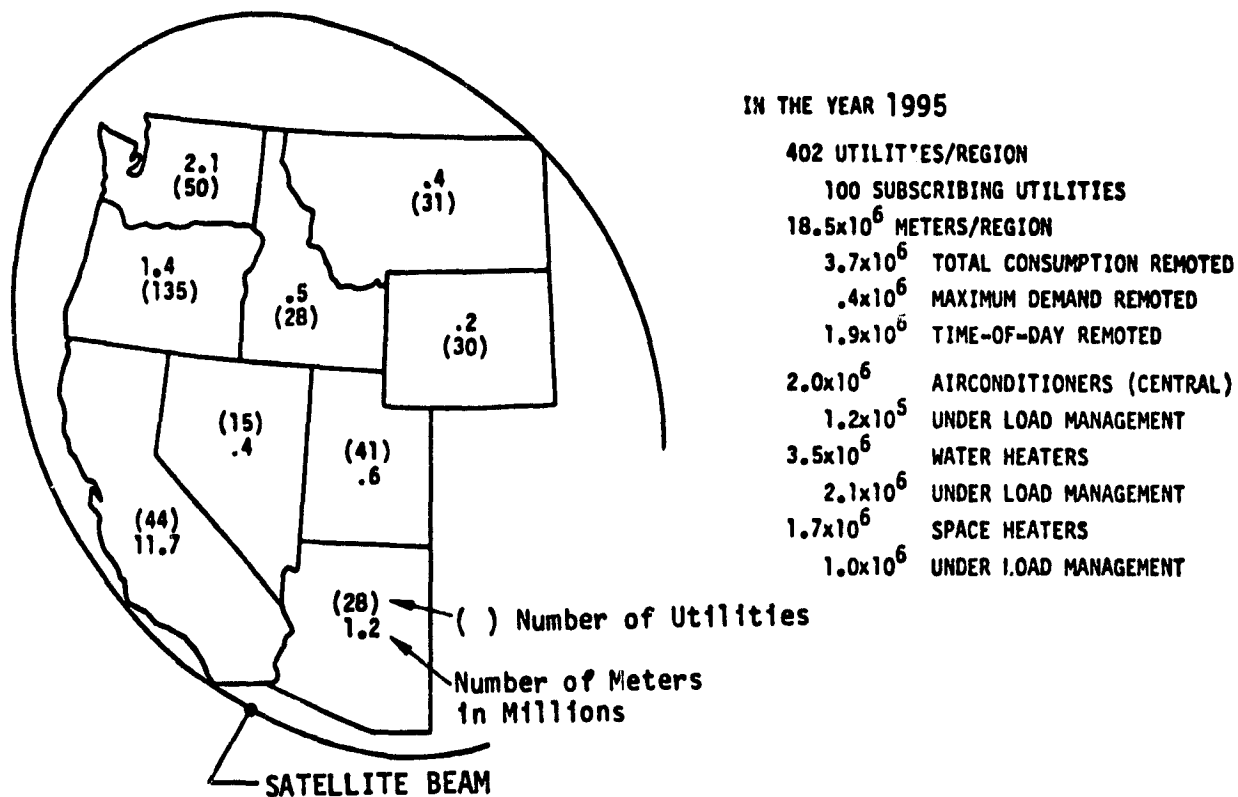


Figure 3-9 WESTERN U.S., PROJECTED TO THE YEAR 1995

In the mid-Atlantic/New England states, an entirely different set of circumstances exist, almost the antithesis of that in the west. The region has a high population density and most of the utilities are investor-owned. Their service areas are relatively compact, and usually cover contiguous areas. The geographical extent of power pooling is less extensive. The projected conditions for the mid-Atlantic/New England area in the year 1995 are given in Figure 3-10.

It is of interest to note that while the total meter populations of both regions are projected to be about equal (18.5×10^6 vs 18.2×10^6 meters) the nature of the electric loads is different. The west will have less airconditioning, less electric space heating, and somewhat fewer electric water heaters. It is also projected that the west will have fewer utilities with a bona fide need for load management.

IN THE YEAR 1995

- 214 UTILITIES/REGION
- 120 SUBSCRIBING UTILITIES
- 18.2x10⁶ METERS/REGION
- 3.5x10⁶ TOTAL CONSUMPTION REMOTED
- .3x10⁶ MAXIMUM DEMAND REMOTED
- 3.2x10⁶ TIME-OF-DAY REMOTED
- 3.0x10⁶ AIRCONDITIONERS (CENTRAL)
- 2x10⁶ UNDER LOAD MANAGEMENT
- 3.6x10⁶ WATER HEATERS
- 2.5x10⁶ UNDER LOAD MANAGEMENT
- 4.4x10⁶ SPACE HEATERS
- 2.9x10⁶ UNDER LOAD MANAGEMENT

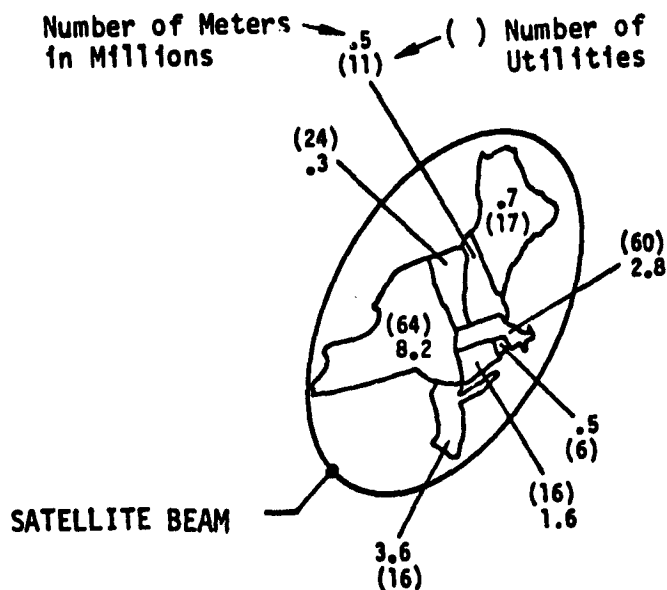


Figure 3-10 MID-ATLANTIC/NEW ENGLAND, PROJECTED TO THE YEAR 1995

Two representative traffic analyses are discussed in the following paragraphs.

Discretionary Load Switching, Air Conditioners -- The calculation of communication traffic associated with air conditioner management is based on the data given in Table 3-5.

It was determined that in the western United States a typical summer peaking utility may have a peak-load problem amenable to load management as infrequently as once per month, or as frequently as 15 days per month. It was also found that in a few localized areas, hot weather requiring air conditioning may last several months. In order to keep the analysis conservative, the value used in traffic calculations assumed all utilities require a capability to manage their airconditioning loads day after day.

A load control strategy was assumed wherein four "turn-off" commands are sent each hour, 8 hours per day, to temporarily disconnect a group of 512 airconditioners, the equivalent of 1.5MW of load. From Figure 3-5 a value of 60% was used to represent the proportion of airconditioners subject to load management at the end-of-life of the first satellite (1995).

	<u>RANGE OF VALUES</u>	<u>VALUE USED</u>
<u>AIR CONDITIONERS</u>		
OCCURRENCE	1 - 15 DAYS/PEAK MONTH	30 DAYS/PEAK MONTH
COMMANDS	2 - 8 CYCLES/HR	4 CYCLES/HR
	6 - 8 HRS/DAY	8 HRS/DAY
ADDRESSING	2 - 6 GROUPS/FEEDER	2 GROUPS/FEEDER
	1000 CUSTOMERS/FEEDER	512:1 ADDRESSING
SATURATION	20 - 90% APPLIANCES	60% (1995)
<u>WATER HEATERS</u>		
OCCURRENCE	1 - 30 DAYS/PEAK MONTH	30 DAYS/PEAK MONTH
COMMANDS	1 - 2 CYCLES/HR	2 CYCLES/HR
	1 - 6 HRS/DAY	6 HRS/DAY
ADDRESSING		512:1
SATURATION	30 - 90% APPLIANCES	60% (1995)

Table 3-5 LOAD MANAGEMENT PARAMETERS

Using the above values, average traffic was calculated to be 2.3×10^6 commands per month, and the peak traffic to be 9.4×10^3 commands per hour.

$$\text{TOTAL TRAFFIC: } \frac{30 \text{ DAYS}}{\text{MN}} \frac{(4 \text{ COMMANDS})}{\text{HR}} \frac{8 \text{ HR}}{\text{DAY}} \left(\frac{1}{512 \text{ CUSTOMERS}} \right) 1.2 \times 10^6 \text{ CUSTOMERS} = 2.3 \times 10^6 \text{ COMMANDS/MN}$$

$$\text{PEAK TRAFFIC: } \frac{4 \text{ COMMANDS}}{\text{HR}} \left(\frac{1}{512 \text{ CUSTOMERS}} \right) 1.2 \times 10^6 \text{ CUSTOMERS} = 9.4 \times 10^3 \text{ COMMANDS/HOUR}$$

Total traffic is defined in terms of messages per month, in recognition of the fact that remote meter reading (power consumption) must be keyed to the usual monthly utility billing cycle. Peak traffic is defined in terms of messages per hour to reflect the time criticality of some functions. Shorter peak traffic time frames such as minutes or seconds were considered and found to be no more meaningful than the longer time base (hours).

Load Reconfiguration -- Load reconfiguration involves rerouting power through the distribution network. The operations postulated to accomplish this function are illustrated in Figure 3-11. First a tie-switch is closed using an ACTION sequence as discussed in Section 3.4. Next, a sectionalizing switch is opened with a second ACTION sequence. To check the voltage condition on the new circuit a METER READ sequence is used. Assuming the voltage is not within tolerance, an adjustment would then be made by changing transformer taps, again through an ACTION sequence. To establish the circuits' power factor a second meter would be

read, and if corrective action is needed, capacitor bank switching may be necessary. Finally, it may be of interest to know the new circuits' load. In total, 15 separate messages are needed to carryout the assumed reconfiguration task.

From Table 3-6 it is seen that it is possible to have 6% of all the feeders require reconfiguration on a given day during a worst case month. From Figure 3-6 40% saturation is obtained. Traffic is then computed as follows:

TOTAL TRAFFIC:

$$15 \text{ MESSAGES/RECONFIG} \times (.06) \frac{\text{RECONFIG./DAY}}{\text{FEEDER}} \left(\frac{.001 \text{ FEEDERS}}{\text{CUSTOMER}} \right) \left(\frac{18.5 \times 10^6 \text{ CUSTOMER}}{\text{REGION}} \right)$$

$$(40\% \text{ SATURATION}) = 6,800 \text{ DAILY, } 6.8 \times 10^3 \frac{(30 \text{ DAYS})}{\text{MONTH}} = .2 \times 10^6 \frac{\text{MESSAGES PER MONTH}}{\text{REGION}}$$

PEAK TRAFFIC:

ASSUME DAILY TRAFFIC OCCURS OVER 2 HOUR PERIOD,

$$\frac{6.8 \times 10^3 \text{ MESSAGE}}{2 \text{ HOURS}} = 3.4 \times 10^3 \text{ MESSAGES PER HOUR/REGION}$$

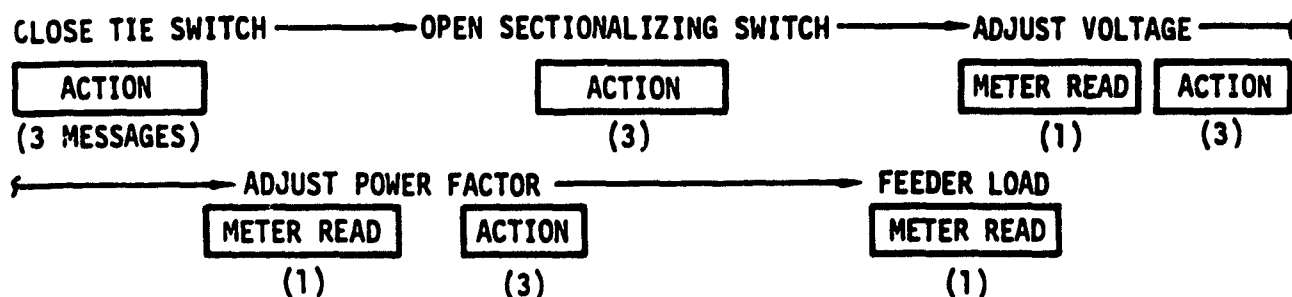


Figure 3-11 LOAD RECONFIGURATION OPERATIONS

	<u>FREQUENCY OF OCCURRENCE</u>
LOAD RECONFIGURATION	6% OF FEEDERS/DAY DURING WORSTCASE MONTH
VOLTAGE REGULATION	TWICE DAILY DURING WORSTCASE MONTH
TRANSFORMER MANAGEMENT	EVERY 15 MINUTES DURING PEAK-LOAD, OTHERWISE ONCE PER DAY
FEEDER MANAGEMENT	10 SAMPLES PER HOUR DURING PEAK-LOAD, OTHERWISE ONCE PER DAY
CAPACITOR CONTROL	TWICE DAILY DURING WORSTCASE MONTH
FAULT DETECTION, LOCATION, ISOLATION	1% OF FEEDERS/MONTH
LOAD STUDIES	10% OF SUBSTATIONS/YR.

Table 3-6 REAL-TIME OPERATIONAL MANAGEMENT PARAMETERS

Using methods similar to those described in the above examples, the total communications traffic generated by the Western Region was calculated. As tabulated in Table 3-7, the monthly traffic is estimated to be 17.1×10^6 messages, with a peak traffic of 89.7×10^3 messages per hour. Remote meter reading accounts for 57% of the monthly traffic, load management 25%, and real-time operational management 18%. Peak traffic is dominated by operational management (83%). Since remote meter reading can be temporarily deferred to make way for higher priority traffic, it does not influence peak message rates.

	<u>MONTHLY TRAFFIC MESSAGES/MONTH</u>	<u>PEAK TRAFFIC MESSAGES/HR</u>
LOAD MANAGEMENT	4.2x10 ⁶	19.2x10 ³
AIR CONDITIONERS	2.3x10 ⁶	9.4x10 ³
WATER HEATERS	1.5x10 ⁶	8.2x10 ³
MISCELLANEOUS	.4x10 ⁶	1.6x10 ³
REAL-TIME OPERATIONAL MANAGEMENT	2.8x10 ⁶	66.0x10 ³
LOAD RECONFIGURATION	.2x10 ⁶	3.4x10 ³
TRANSFORMER MGT.	1.1x10 ⁶	14.0x10 ³
FEEDER MGT.	.6x10 ⁶	40.0x10 ³
VOLTAGE REGULATION	.8x10 ⁶	8.0x10 ³
CAPACITOR CONTROL	.3x10 ⁶	4.5x10 ³
FAULT DETECTION, ISOLATION	.1x10 ⁶	0.6x10 ³
REMOTE METER READING	9.8x10 ⁶	NA
TOTAL CONSUMPTION	3.7x10 ⁶	
MAXIMUM DEMAND	.4x10 ⁶	
TIME-OF-DAY	5.7x10 ⁶	
TOTAL	17.1x10 ⁶ MESSAGES/MONTH	89.7x10 ³ MESSAGES/HOUR

Table 3-7 COMMUNICATIONS TRAFFIC, WESTERN REGION

3.6 Time Criticality & Priority of Functions

It is of interest to establish acceptable "time latencies" for the various functions associated with distribution automation and control, i.e., the maximum permissible elapsed time between recognition of need and actual initiation of the function. For example, the question arises as to timing requirements associated with discretionary load-switching. Consider the situation during a peak-demand period. As demand approaches the critical reserve capacity, blocks of load must be dropped to arrest the rising trend. Normally the first to go are industrial loads supplied under interruptible tariffs. As demand continues to build, additional measures must be taken and other classes of customers become eligible for load management. The next loads to be dropped are likely to be customers who are served by marginal distribution facilities which are, or are trending into a localized overload condition. As demand continues to build, a broad spectrum of residential customers become subject to cyclical management of their appliances.

In a large utility a reasonable size for each residential load block appears to be around 50 MW, corresponding to about .5% of peak-demand. The short-term rate of demand build-up may be 1000 MW per hour. Under these conditions, a minimum rate of 20 controllable blocks per hour would be required to contain the developing load. But since appliance type loads must be cycled (10% duty cycle) a rate of 200 blocks per hour may be required during a rapid increase in demand. This is equivalent to a time latency of 18 seconds per block control message.

A question also arises as to how fast the DAC system must respond to a load shedding command should the power system become unstable, or for any other reason require dropping large blocks of load. In this situation a minimum reaction time of 10 seconds is considered reasonable in view of the probable decision making time involved in arriving at an appropriate course of corrective action (man-machine), and in light of power system mechanical time constants.

Another function which would seem to be time critical is "fault detection, location, and isolation." On closer examination, however, this is not the case. The faults themselves are usually cleared immediately by local protective devices. The problem then becomes one of knowing that a fault has occurred; a line is down, a fuse is blown, etc. Current practice tends to rely on customer outage reports. Maintenance crews are then dispatched to search an area for the trouble. Once located the faulted circuit is isolated, repaired, and service restored by the onsite crew.

This scenario takes time, typically hours, or even days with extensive storm outages. Since "outage time" is a measure of operating effectiveness, there is a desire to restore service more expeditiously. A capability to detect, locate, and isolate a fault within a fraction of an hour would constitute a major improvement.

An examination of each functional requirement revealed no instances where response times shorter than 10 seconds seemed necessary. In fact most functions can be considered virtually non-time critical as shown in Figure 3-12.

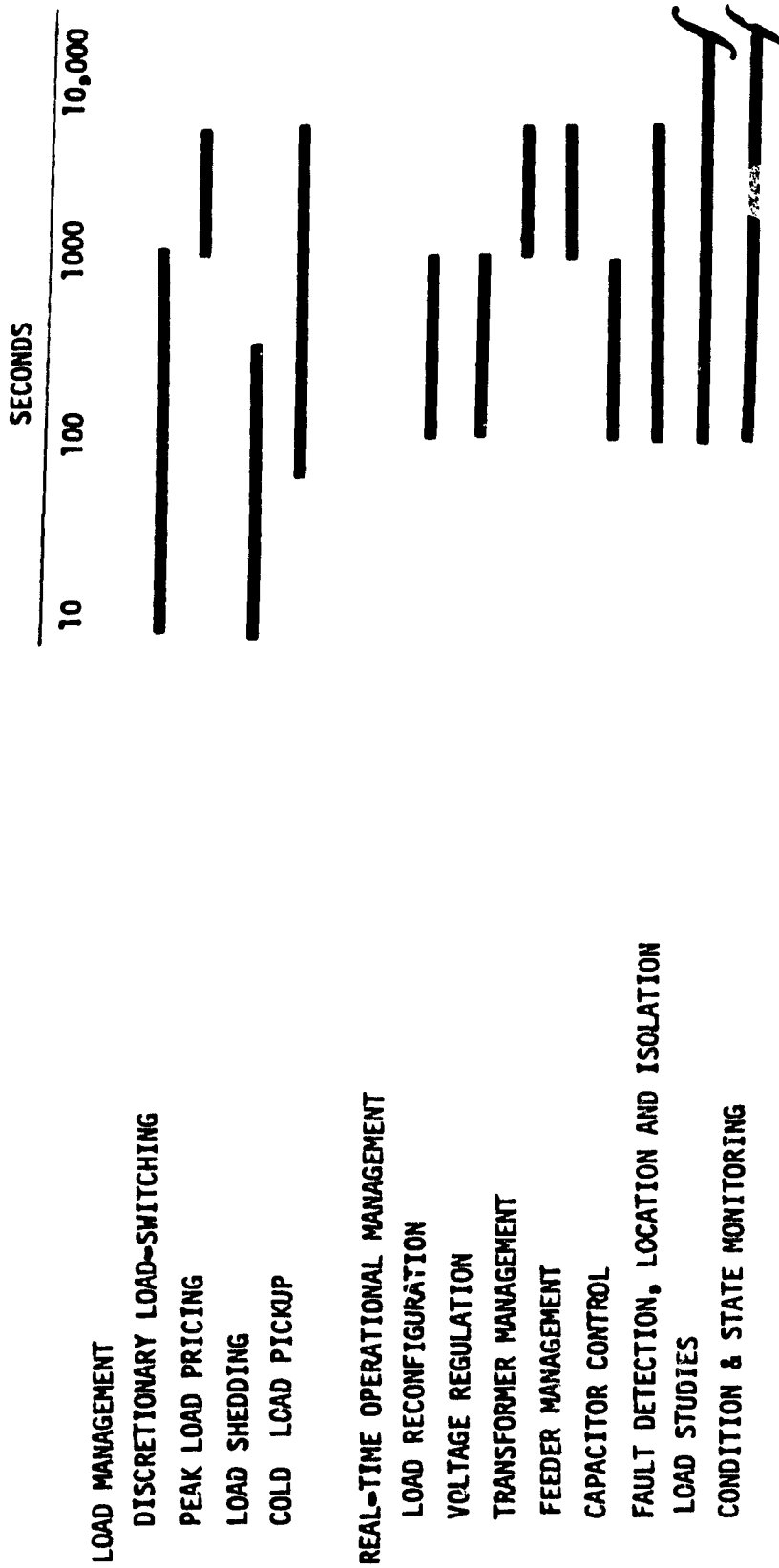


Figure 3-12 ACCEPTABLE TIME LATENCIES OF DISTRIBUTION AUTOMATION & CONTROL FUNCTIONS

3.7 Ancillary Functions

The unique features of a satellite communication system make it a contender for providing a number of ancillary functions not related to distribution automation. Some of these are listed in Table 3-8.

It is a natural extension of the remote meter reading function to include gas meters, and possibly water meters. There is also great similarity between remotely reading an electric power meter and remotely reading a stream-flow meter, or a snow-pack indicator, or a rain gauge, or almost any other remote sensor.

A satellite communication resource is useful where long haul data or voice communications may be needed, or where communication problems exist because of adverse terrain, or where site remoteness is a factor. Figure 3-13.

It is also of interest to consider the ramifications of having a two-way data link between a customer and his utility. Remote billing and bill-paying (electronic funds transfer) become possibilities. Not to be overlooked is the potential for interoffice business communications; voice, facsimile, computer-to-computer ties, etc.

While there appears to be many applications of a space communication system beyond distribution automation, they were not examined in this study.

- GAS, WATER, AND OTHER UTILITY METERING
- COMMUNICATIONS WITH MAINTENANCE PERSONNEL
- STREET LIGHTING CONTROL
- REMOTE DATA GATHERING, SUCH AS
 - STREAM FLOW
 - SNOW PACK
 - RAIN FALL
 - SEEPAGE
 - POLLUTANTS
 - CLOUD COVER
 - WIND VELOCITIES
- EMERGENCY SERVICE REQUESTS FROM ISOLATED AREAS
- FIRE, TAMPER, AND TRESPASS ALARMS
- STRUCTURAL STRAIN MONITORING
- PERSONNEL PAGING/ALERTING, DISPATCHING
- REMOTE BILLING AND BILL-PAYING (ELECTRONIC FUNDS TRANSFER)
- INTEROFFICE BUSINESS COMMUNICATIONS, INCLUDING FACSIMILE

Table 3-8 ANCILLARY FUNCTIONS

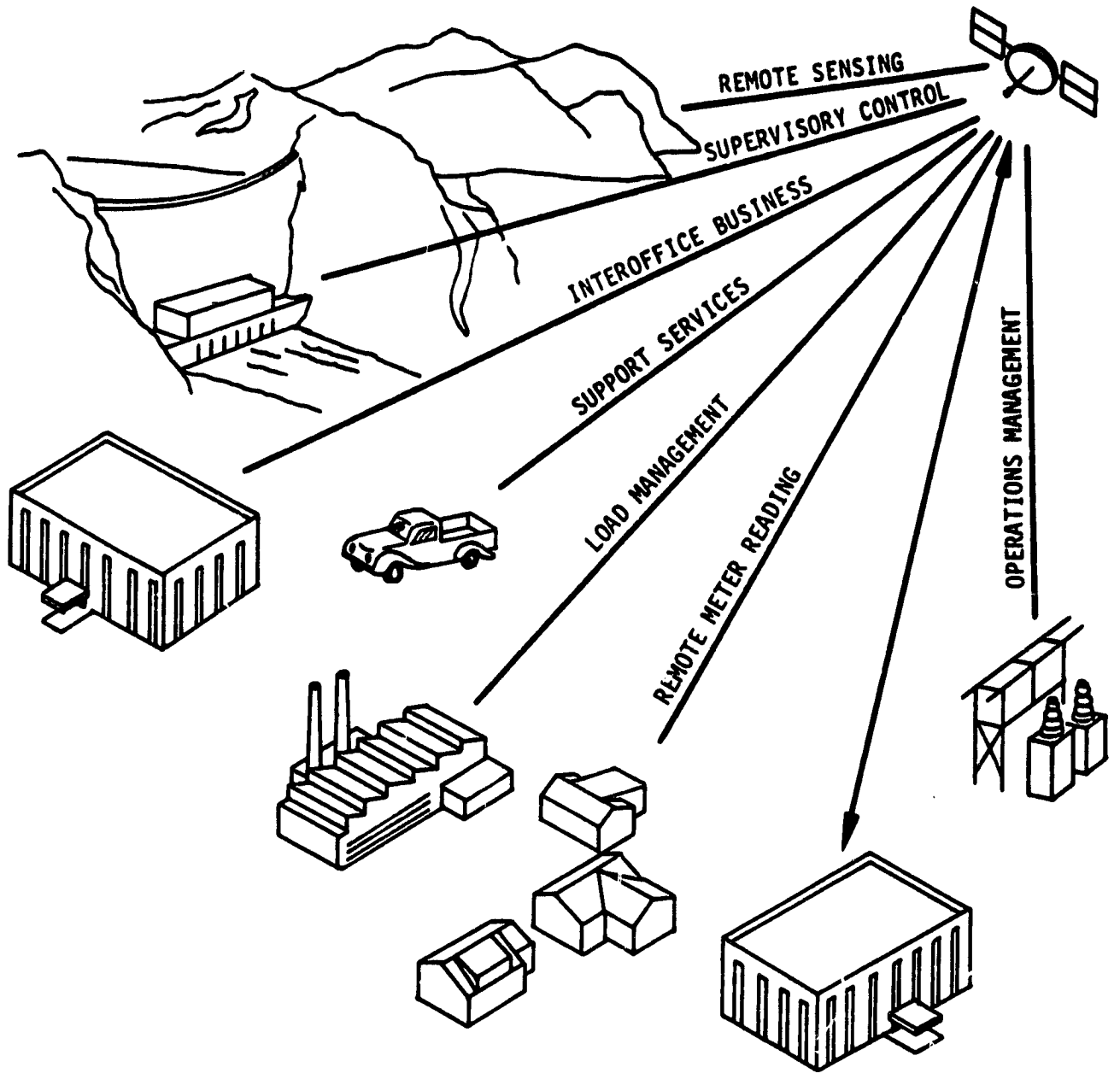


Figure 3-13 A SPACE COMMUNICATION SYSTEM FOR UTILITIES

3.8 Summary & Conclusions From the Functional Analysis

It is appropriate to present here a recap of the results and conclusions from the Functional Analysis.

- While 70-90% of potential installations may ultimately be realized, achieving this level of penetration will take many years (> 30 years) even under the most favorable conditions.

- Communication requirements vary considerably from utility to utility.

- Nationwide communications traffic associated with distribution automation and control appears to be sufficiently voluminous to require dividing the country into regions, each region having its own communication network.

- Remote meter reading accounts for most communication traffic, followed by load management, and real-time operational management.

- A small repertoire of command messages will handle all functional needs.

- Of all the functions examined, none were found to be highly time critical.

- There appears to be many other uses for a Space Communications System serving the electric utility industry, beyond distribution automation and control.

4.0 SYSTEM AND DESIGN REQUIREMENTS

This Section identifies some of the more important requirements and objectives to be considered when formulating system concepts and defining equipment configurations. System level requirements will be discussed first. The principal requirements on various elements of the system will then be identified, followed by a definition of the in-service environment, installation requirements, reliability objectives, and finally security objectives.

Not all of the requirements discussed below are derivatives of the preceding Functional Analysis, many are in fact based on subjective engineering judgements. Others result from interface considerations of one kind or another. And still others come from utility industry practices or desires as interpreted by the study participants.

4.1 System Level Requirements

The SC system is to be capable of handling the communications traffic associated with the 1995 forecasts for load management, real-time operations management, and remote meter reading as derived from the Functional Analysis (Section 3).

The SC system shall have the following specific capabilities and attributes:

- (1) Accommodate at least 500 utilities nationwide, up to 150 utilities per region.
- (2) Permit operation with at least 15×10^6 remote terminals per region; 25% used for load management, 18% used for real-time operational management, and 57% for remote meter reading
- (3) Allow each utility to operate independently
- (4) Use one active satellite to service the entire Continental United States.
- (5) Accommodate electric utilities using either centralized or distributed operating control philosophies

- (6) Permit individual addressing of remote terminals
- (7) Provide one-way or two-way communications with customer terminals
- (8) Provide two-way communications with substation terminals
- (9) Provide two-way communications to remote monitor/control terminals
- (10) Be fail safe
- (11) Conserve radio frequency spectrum
- (12) Be suitable for near term implementation with minimal risk.

4.2 Requirements for System Elements

Specific requirements related to each of the major system elements are identified below.

The Spacecraft shall:

- (1) Be suitable for geostationary orbit deployment
- (2) Weight no more than 5,000 pounds (based on use of an Inertial Upper Stage)
- (3) Have a mission life of 7 to 10 years
- (4) Be powered in orbit (electrical) by solar energy
- (5) Not require extra vehicular activities during deployment

Remote Customer Terminals shall:

- (1) Have the functional capabilities identified in Table 4-1
- (2) Be of modular design to accommodate a variety of site peculiar requirements
- (3) Use an antenna no larger than 18 inches, preferably less than 12 inches
- (4) Cost no more than \$250 per customer served
- (5) Be suitable for very high volume, automated production
- (6) Provide universal mounting features
- (7) Be resistant to vandalism, tampering, and spoofing
- (8) Operate with a meter multiplexer serving up to 100 meters (commercial or apartment house)

	<u>ONE-WAY SYSTEM</u>	<u>TWO-WAY SYSTEM</u>
● FUNCTIONAL CAPABILITY	<ul style="list-style-type: none"> ● CONTROL 3 LOADS ● LOCALLY SET POWER RESTORATION TIMER ● PROVIDE LOCAL TAMPER INDICATOR 	<ul style="list-style-type: none"> ● CONTROL 3 OR MORE LOADS ● READ "STATE" OF 3 OR MORE LOAD CIRCUITS ● REMOTELY SET POWER RESTORATION TIMER ● PROVIDE LOCAL TAMPER INDICATOR & REMOTE READ-OUT ● READ THREE KW-HR REGISTERS TO .1% ● REMOTELY SET TIME-OF-DAY METERING TIME-BLOCKS (PEAK, PARTIAL PEAK & OFF-PEAK HOURS)
● INTERFACE	<ul style="list-style-type: none"> ● CLOSE/OPEN 1 AMP RELAY CIRCUIT 	<ul style="list-style-type: none"> ● CLOSE/OPEN THREE OR MORE 1-AMP RELAY CIRCUITS ● PROVIDE LOOP-CHECK CURRENT ● ACCEPT 30 BPS SERIAL DATA FROM METER-ENCODER ● PROVIDE REGISTER SHIFT COMMAND TO METER TIME-OF-DAY

TABLE 4-1 CUSTOMER TERMINALS, FUNCTIONAL CAPABILITIES

Remote Substation Terminals shall:

- (1) Have the functional capabilities enumerated in Table 4-2.
- (2) Be of modular design so as to accommodate a variety of functional requirements
- (3) Be capable of operating in a high electromagnetic interference environment
- (4) Incorporate standby power
- (5) Use an antenna no larger than 5 feet in diameter
- (6) Be resistant to malicious intent

Terminal to Provide - 16 Contact Closures 16 Discrete Outputs	} Device Control
Terminal to Accept - Serial Data Parallel Data	} Meter Reading
Terminal to Sense - Logic Levels (Voltage or Current) from 32 Monitor Points	} Status Monitoring

TABLE 4-2 SUBSTATION TERMINALS, FUNCTIONAL CAPABILITIES

Remote Monitor/Control Point Terminals shall:

- (1) Have the capabilities tabulated in Table 4-3
- (2) Be of modular design
- (3) Be capable of operating in a high electromagnetic environment
- (4) Incorporate standby power
- (5) Use an antenna no larger than 18 inches, preferably less than 12 inches
- (6) Be resistant to physical abuse
- (7) Provide universal mounting features

- Terminal will provide 3 contact closures for device control
- Terminal will accept serial or parallel data from 3 meters
- Terminal will sense voltage or current logic levels from 3 monitor points

TABLE 4-3 MONITOR/CONTROL POINT TERMINALS, FUNCTIONAL CAPABILITIES

The Master Control Station shall:

- (1) Provide the utilities' "base station" communication capability
- (2) Provide the Distribution Automation and Control (DAC) system information processing and control equipment, and algorithms
- (3) Provide the man-machine interface with the DAC system.
- (4) Be redundantly configured
- (5) Incorporate standby power
- (6) Use an antenna suitable for roof-top mounting, no larger than 20 feet in diameter

4.3 In-Service Environment

Three aspects of the in-service environment will be considered here; climatic and other conditions, the electromagnetic environment, and the requirements resulting from power outages.

4.3.1 Climatic and Other Conditions

Exposed equipment can be subjected to a variety of climatic conditions. The climate of the United States, while generally temperate, ranges from semi-tropical, through desert, to near arctic. Temperate areas are quite benign. Semi-tropical regions are hot and wet, promote fungus growth, and are subject

to a great deal of thunderstorm activity. Desert areas tend to be very hot and dry, with blowing sand and dust. Nights can be comparatively cold.

Cold weather regions usually provide a broad spectrum of weather, with the possibility of very low temperatures, freezing rain, and other extreme conditions in the winter, and relatively high temperatures and high humidity during the summer.

The climatic conditions defined in Table 4-4 are representative of the extremes likely to be encountered by exposed equipments and, therefore, should be used for conceptual design purposes.

TABLE 4-4: CLIMATIC CONDITIONS FOR GROUND EQUIPMENT

CONDITION	DESIGN VALUE	
ALTITUDE	10,000 FEET	
FUNGUS	TROPICAL	
HAIL	1.0 INCH DIA.	VELOCITY, 150 FT/SEC.
HUMIDITY	UP TO 100%	
ICING	0.5 INCH BUILD-UP	
LIGHTNING	FAIL-SAFE PROTECTION	
RAIN	5 INCHES/HOUR	SHORT DURATION
RAIN, FREEZING	0.5 INCH BUILD-UP	
SALT SPRAY	SEASHORE FOG	
SAND & DUST	< 150 MICRONS	AIR VELOCITY ~ 30 FT/SEC
SLEET	0.5 INCH BUILD-UP	
SNOW	10 INCHES/HOUR	24 INCH MAX. DEPTH, LEVEL GROUND
SOLAR RADIATION	105 WATTS/FOOT ²	
TEMPERATURE, HIGH	+110°F AMBIENT	MAX. OF 160°F WITH SOLAR RADIATION
, LOW	-40°F	
WIND	100 MILES/HOUR	

Consideration must also be given to the effects of, and protection against, lightning induced surges on the power lines, and transients due to line faults.

It is axiomatic that equipment shall not suffer damage or subsequently fail to provide the desired performance when subjected to impact shocks or vibration resulting from transportation or normal handling.

It is also important that equipments be designed for long-term exposure to the in-service environment. Utility equipment is usually considered to require a service life in excess of 20 years.

4.3.2 Electro Magnetic Interference

Electromagnetic noise originates from two principal sources, natural phenomenon and man's activities. Natural noise includes atmospheric static, cosmic noise, sun noise, etc. Man-made noise includes spurious emissions from communication and electronic equipment, noise from automotive ignition systems, leakage from high voltage power equipment, radiation from industrial and diathermy equipment, and electromagnetic interference from a multitude of other commercial and consumer sources. Figure 4-1.

Man-made noise is significantly higher in urban areas than it is in rural areas. It is also of a different character than that of natural noise. Natural noise can be approximated by a Gaussian distribution whereas man-made noise tends to be "impulsive." A value of 20 dB above Gaussian is commonly used for conceptual design purposes to account for impulse noise.

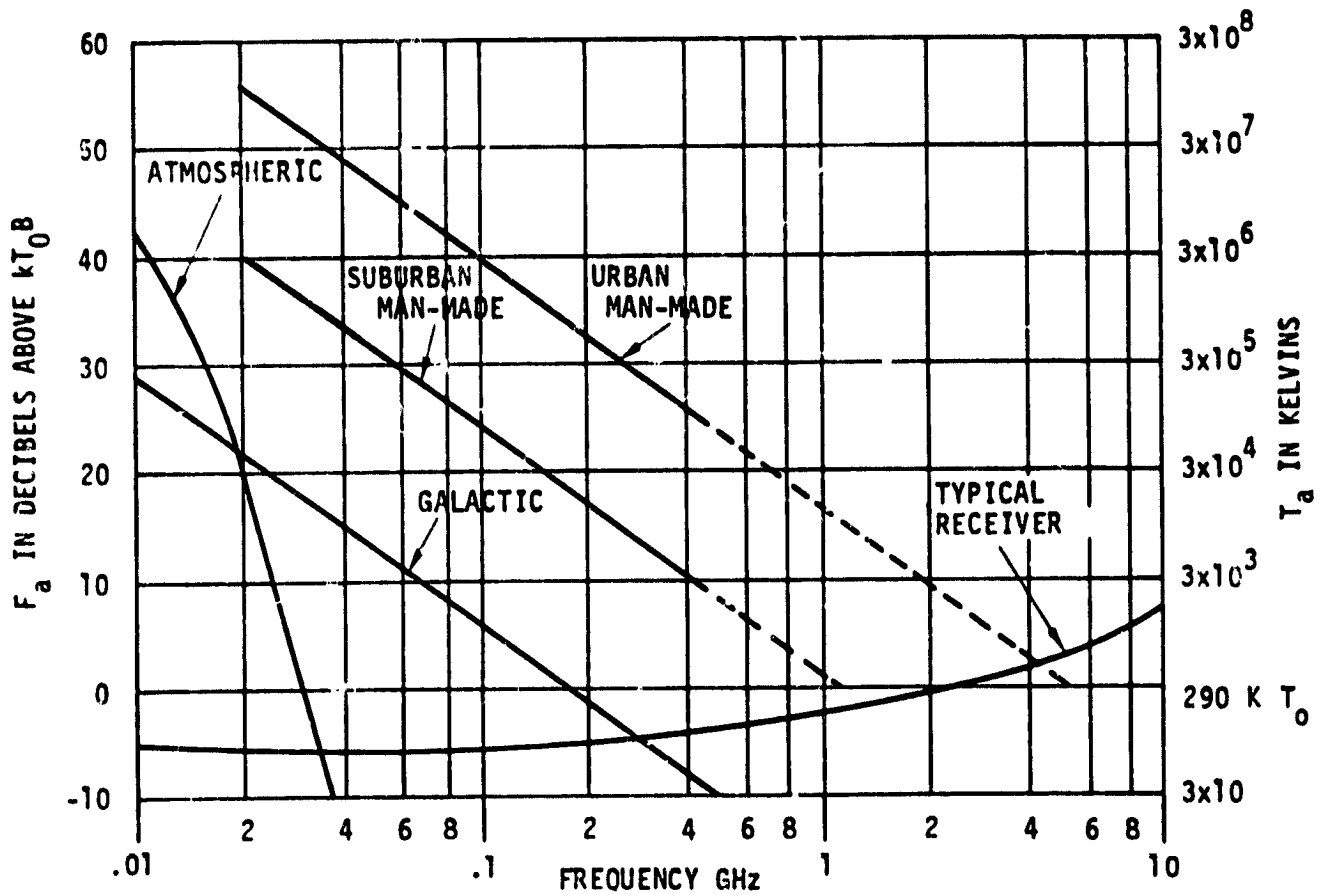


FIGURE 4-1 MEDIAN OF AVERAGE NOISE POWER, OMNI-ANTENNA

Terminal units installed at a substation will be in close proximity to equipment which may generate a considerable amount of interference. Radiated interference is to be expected from corona discharge, switching actions, and system faults. This noise environment must be taken into account in communication link design.

Another source of potentially troublesome interference is that which is "conducted" to a terminal unit. This type of interference occurs as a result of transient voltages on the power lines, and as a result of coupling between noise sources and power or control and monitor circuits going to the terminal.

Because of the hostile electromagnetic environment, terminals designed for use at substations may require features which tend to minimize the effects of potential interferences. Locally generated, man-made radiated noise can usually be handled

by adequate signal levels and by properly locating the terminal to take advantage of the discrimination provided by its antenna pattern. Methods to be considered to negate conducted interference include the use of adequate signal levels, filtering and shielding incoming lines, proper grounding and bonding of equipments, segregating wiring according to signal level, the use of balanced lines, decoupling of DC wiring, etc.

4.3.3 Power Outage Requirements

Some SC system equipments must be capable of operating during power outages, other equipments can be allowed to become non-operative. Communication needs and functional capabilities during power outages for various types of installations are defined in Table 4-5.

Customer terminals are not required to function during power outages. Substation terminals and monitor terminals, on the other hand, must be capable of operating on self-contained power for at least 48 hours.

During an outage, the communication system must be either operable, or in a fail-safe state. In some instances this may mean that stored data must be retained via battery power even though the unit itself is considered functionally inoperable.

In order to ease the burden of a cold-load pickup after an outage it may be necessary to remotely disconnect some loads which assumed a fail "on" state when power was lost (before restoring power), for example, loads subject to discretionary switching.

INSTALLATION	TERMINAL CONDITION DURING POWER OUTAGE	FUNCTION	STATE DURING OUTAGE	REQUIREMENTS UPON POWER RESTORATION
CUSTOMER TERMINAL	NON-OPERABLE	DISCRETIONARY LOAD CONTROL	LOAD CONNECTED	NONE
		REMOTE METER-READING	REGISTERS RETAIN DATA	SELF-ENABLING
		LOAD SHEDDING	LOAD REMAINS CONNECTED	MAY REQUIRE REMOTE RECONNECTION
		SERVICE CONNECT/DISCONNECT	STATUS QUO	NONE, STATUS QUO
SUBSTATION TERMINAL & MONITOR/CONTROL POINT TERMINAL	TERMINAL OPERABLE FOR 48 HOURS UNDER SELF-CONTAINED POWER	DEVICE CONTROL	DEVICE CONDITION REMAINS STATUS QUO	NO CHANGE, STANDBY POWER REJUVENATED
		STATUS REPORTING	STATUS REPORTS AVAILABLE	AS ABOVE
		DATA REPORTING	DATA REPORTS AVAILABLE	AS ABOVE
	EMERGENCY POWER EXPENDED	DEVICE CONTROL	DEVICE ASSUMES FAIL-SAFE CONDITION	MAY REQUIRE REMOTE ENABLING
		STATUS REPORTING	NOT AVAILABLE	STATUS REPORTING AUTOMATICALLY BECOMES AVAILABLE
		DATA REPORTING	NOT AVAILABLE	AUTOMATICALLY RESTORED
		PRIORITY CHANGE-OF-STATE REPORTING	NOT AVAILABLE	AUTOMATICALLY RESTORED

TABLE 4-5 FUNCTIONAL CAPABILITY DURING POWER OUTAGES

4.4 Installation Requirements

Remote terminals are used in a variety of locations; single family dwellings, apartment houses, commercial buildings, industrial plants, electric substations, overhead lines, etc. Each location has some unique installation requirements. The challenge is to come up with a universal design suitable for across-the-board usage.

Each remote terminal interfaces with one or more appliances, meters, controlled devices, etc. This interface must be handled in such a way that the antenna/receiver/transmitter unit remains "visible" to the satellite.

Residential appliances of interest include water heaters, space heaters, and air conditioners. Water heaters and space heaters are usually located indoors where conditions may not be right for receiving radio frequency transmissions. Air conditioner compressor/evaporator units are usually located outdoors, however, it is by no means certain that the look-angle to the satellite will be acceptable.

Meters are usually mounted in close proximity to the electric service entrance. They may be either outdoors or indoors. Apartments and commercial/industrial buildings may have banks of meters located in basements, or in other out-of-the-way places. The SC system concept must be able to handle such diverse installations.

There is a growing trend toward putting electrical distribution facilities underground. In such installations, controllable devices of the DAC system are likely to be housed in concrete vaults, some of which may be many feet beneath the surface. Undergrounding is most extensive in the central business districts of cities, but is spreading to urban residential areas and also is being used extensively in new suburban developments. Because of this trend a comprehensive communication system must be able to serve underground facilities.

Particular attention must be given to assure that equipment installed in hazardous areas will not cause ignition of an ambient explosive gaseous mixture.

4.5 Reliability Objectives

Reliability objectives for the SC system can be expressed in terms of utilities' needs. In general these needs are related to cost and features. For load management, an equipment failure rate in keeping with electric power meter replacements appears acceptable, 2-3% per year.

The reliability requirement associated with obtaining a monthly meter reading should be at least 99.5%, and a real-time operational management function should be carried out with virtually 100% success.

The spacecraft must be configured to provide each region with full operating capability throughout its life, with an expectation of success greater than 70%.

4.6 Security Objectives

The SC system, as with any communication system, may be subjected to overt or covert attempts to spoof or disable the system. Threats could conceivably vary from vandals, to disgruntled customers, to technological pranksters ("blue-box" artists), to urban guerilla extremists, or even to international adversaries.

The SC system is not required to survive direct physical attack or to foil the acts of an international adventurer. Also, it is not viewed as a meaningful objective to make the system totally secure, for there are many DAC functions which if temporarily lost create no more than minor annoyances. On the other hand, great care should be taken to ensure that the system is not sensitive to large scale disruption by inadvertent or relatively sophisticated threats.

Public service utilities have the dubious distinction of being fair game for cheats. With regard to attempts to steal power, or to wire-around managed loads, or to override time-of-day metering, etc., an appropriate guideline appears to be one based on "making it easy for the honest man to stay honest," for if someone is strongly motivated, ways can probably be found to defeat any but the most sophisticated security features.

The SC system should be configured to provide a high degree of protection against large scale disruptions, a more modest degree of protection against losing real-time operational control functions, and a basic level of protection for customer oriented functions.

5.0 SYSTEM DESIGN CONSIDERATIONS

This section examines some of the more important factors associated with technical feasibility.

5.1 Frequency Considerations

In postulating any radio communication system, frequency allocations become of immediate interest. In satellite communication systems involving the use of the geostationary orbit frequency allocation and orbit station assignments must be considered together.

The United States is a member of the International Telecommunications Union (ITU), one of 148 members of the one-nation, one-vote organization. The ITU is the supreme regulatory of worldwide radio communications. Agreements reached by this body have the status of treaty obligations.

Within the United States non-governmental use of radio communications is controlled by the Federal Communications Commission (FCC), and governmental use falls under the Interagency Radio Advisory Committee of the National Telecommunications and Information Administration in the Department of Commerce.

As a matter of policy the FCC will not authorize systems which do not generally comply with the radio regulations of the ITU. Also as a matter of policy, the rules and regulations for governmental use are patterned after those of the FCC for applications within the United States, and after those of the ITU for governmental applications outside the United States.

For regulatory purposes there are various methods of classifying satellite communications. In making frequency allocations the ITU recognizes function (i.e., broadcasting, radio navigation, radio astronomy, etc.), and type of earth terminal (i.e., fixed, mobile, aeronautical mobile, etc.). No other classifications are currently recognized, even though other types of service have been implemented (by exception) or are being planned.

The principal frequency bands assigned for satellite communications are listed in Table 5-1. The band from 2.50 to 2.69 GHz is for broadcast satellites, the band from 3.70 to 4.2 GHz for satellite downlink service to specified fixed points on the ground, the band from 5.925 to 6.425 GHz for fixed uplinks, the band between 11.7 and 12.2 GHz for broadcast satellites and for fixed downlinks, and the band from 14.0 to 14.5 GHz for fixed uplinks. All of these allocations share frequencies with terrestrial services. As a consequence powerflux density limitations were established because of concerns expressed by terrestrial communicators that satellite signals could interfere with their systems. The significance of these limitations on the Space Communication System (SC system) design are discussed in paragraph 5.3.

The frequencies most heavily used are the 3.70-4.20 GHz (downlinks) and 5.925-6.425 GHz (uplinks). These bands are also heavily used by ground services. Because of this overcrowding future satellite telecommunication systems are headed toward higher frequencies.

It should be noted that several radio frequency bands are being used, or have been proposed for use in load management using terrestrial radio links. Some of these frequencies are good candidates for use in the SC system.

Table 5-2.

BAND	BANDWIDTH	DOWNLINK	UPLINK	POWER FLUX DENSITY
1.5 GHZ (L-BAND) MARITIME	7.5 MHZ	1.535 to 1.542 GHZ	1.635 to 1.644 GHZ	
1.5 GHZ AERONAUTICAL	15 MHZ	1.543 to 1.558 GHZ	1.645 to 1.660 GHZ	
2.5 GHZ (S-BAND) BROADCAST	35 MHZ	2.500 to 2.535 GHZ	2.655 to 2.690 GHZ	-137 DBW/M ² /4KHZ
4 AND 6 GHZ (C-BAND) TELECOMM	500 MHZ	3.7 to 4.2 GHZ	5.925 to 6.425 GHZ	-142 DBW/M ² /4KHZ
12 AND 14 GHZ (K _u -BAND) TELECOMM	500 MHZ	11.7 to 12.2 GHZ	14.0 to 14.5 GHZ	-138 DBW/M ² /4KHZ
19 AND 29 GHZ TELECOMM	2.5 GHZ	17.7 to 21.2 GHZ	27.5 to 31.0 GHZ	-105 DBW/M ² /1MHZ

*FOR ANGLES ABOVE THE HORIZONTAL > 25°

Table 5-1 PRINCIPAL SATELLITE COMMUNICATION BANDS

BAND	SERVICE	CHANNEL BANDWIDTH	
150 MHZ to 173 MHZ	FIXED, MOBILE	7.5 KHZ	OMNIDIRECTIONAL LOAD MANAGEMENT 300 WATTS; DIRECTIONAL TELEMETRY, 50 WATTS
450 MHZ to 512 MHZ	FIXED, MOBILE	25 KHZ	OMNI OR DIRECTIONAL, 100 WATTS
800 MHZ to 900 MHZ	FIXED, MOBILE	25 KHZ	
925 MHZ to 950 MHZ	FIXED, MOBILE	25 KHZ	OMNI DIRECTIONAL, 100 WATTS DIRECTIONAL TELEMETRY, 30 WATTS, 20° BEAM

Table 5-2 COMMUNICATION BANDS HAVING OR PROPOSED FOR, LOAD MANAGEMENT ALLOCATIONS; TERRESTRIAL RADIO

A companion consideration closely related to frequency assignment is bandwidth needs. The SC system has been postulated as a multi-beam system, each beam serving a particular region of the country. Since uplink characteristics must be different from downlink characteristics to prevent mutual interference, multiple frequencies may be needed; just how many depends on the multi-access concept, system architecture, and the feasibility of frequency reuse and polarization diversity.

The number of operating frequencies needed for various system architectures using time-division multiple access is shown in Table 5-3. A "CONUS" beam is one that illuminates the entire United States. A "regional" beam is one that illuminates only a portion of the United States. Two conditions are tabulated; with and without frequency reuse. Not included is the possible use of up-down frequency swapping or polarization diversity. Bandwidths identified are based on a 5,000 bits per second data rate, and differentially coherent biphase-shift keying. (See paragraph 5.2.3 for a discussion of system architectures.)

As mentioned previously, the type of service provided by the SC system does not fit within presently designated frequency bands for satellite use. This situation will be addressed at the 1979 World Administrative Radio Conference (WARC). The United States is currently formulating its recommendations, which are said to include the designation of portions of the L and S-bands for low data rate satellite communications. In the absence of a decision from WARC, the frequency spectrum from 150 MHz through 20 GHz was considered in this study.

Command Links		Response Links		Number of Frequencies		Approximate RF Bandwidth
Sat. Rcv. Ant.	Sat. Tx. Ant.	Sat. Tx. Ant.	Sat. Rcv. Ant.	*	**	
1. CONUS	CONUS	CONUS	CONUS	4	4	55KHZ
2. CONUS	CONUS	REGIONAL	REGIONAL	2+2N	10	120
3. REGIONAL	REGIONAL	REGIONAL	REGIONAL	4N	16	190
4. CONUS	REGIONAL	REGIONAL	REGIONAL	1+3N	13	155
5. CONUS	REGIONAL	CONUS	REGIONAL	2+2N	10	120



Key:

CONUS - Antenna beam covers entire United States

REGIONAL - Antenna beam covers a portion of the United States

N - Number of regional beams

* No freq. reuse

** Assumes freq. reuse criteria

△ Baseline concept

Table 5-3 FREQUENCY & BANDWIDTH REQUIREMENTS, TIME-DIVISION MULTIPLE ACCESS

For purposes of expressing study results, the spectrum was considered in bands as follows:

L-Band	390 MHz to 1.6 GHz
C-Band	4 to 6 GHz
Ku-Band	10.9 to 18 GHz

L-Band: The lower portions of this band require large antennas on the spacecraft to obtain the desired earth foot-print, and on the ground to obtain gain to balance the power budget. Large space antennas are considered feasible but inject an element of risk which is better avoided if possible. Large ground antennas are not aesthetically pleasing and could inspire public opposition. (See paragraph 5.3.8 for power budgets.) The upper part of this band seems to be a practical compromise of a number of factors and is the preferred choice.

C-Band: This band is so heavily committed to telecommunications, it has virtually no potential for accommodating other services. It also poses substantial possibilities for interferences.

Ku-Band: The Ku-Band suffers from difficult propagation conditions. Reasonable link availabilities require high radiated power to overcome the effects of rain. The use of a high gain spacecraft antenna gives a small earth foot-print and requires precise spacecraft stabilization.

Putting all these considerations together, the order of preference is: high L-band, low L-band, Ku-band, and C-band. This compares with the estimated order of likelihood of frequency assignments of Ku-Band, high L-Band, low L-band, and C-Band. Since high L-Band appears to be a good compromise, it was selected for the "baseline" system. However, since allocations have been trending toward higher frequencies, work should be done in configuring systems suitable for operation at Ku-Band, for example, a system based on the use of small earth foot-prints with a foul weather "burn through" mode should be explored.

Since it is beyond the scope of this study to deal more affirmatively with the frequency allocation problem design considerations will be addressed parametrically, with special attention being given to concepts operating outside the overcrowded telecommunications bands.

5.2 System ^ pts

This Section examines another aspect of technical feasibility; structuring the Satellite Communication System (SC system) to handle the communications traffic.

5.2.1 System Connectivity and Time Distribution of Traffic

When contemplating possible system configurations it is useful to first characterize intersite communications in terms of signal sources and sinks, and in terms of the time distribution of communication traffic.

The system must accommodate a large number of Master Control Stations (MCS) (>500), each interested in maintaining two-way communications with specific individual units within a very large population (>10⁴) of its own remote terminals (RT). In the outgoing command network "sources" (MCS's) must have the capability to communicate with "sinks" (RT) without interferences between sources. In the response network, a multiplicity of sources (RT's) must have the capability to contact their parent (sink), again without mutual interferences, Figure 5-1.

The command and response networks could be designed to operate independently, or alternatively, in some conjunctive manner. Within the response network itself, activities could be structured for synchronous or asynchronous operation, however, in view of the very large number of terminals, asynchronous operation may tend to be chaotic. On the other hand, the MCS's collectively constitute a more modest size group and consequently could be configured to operate either synchronously or asynchronously, depending on other design considerations.

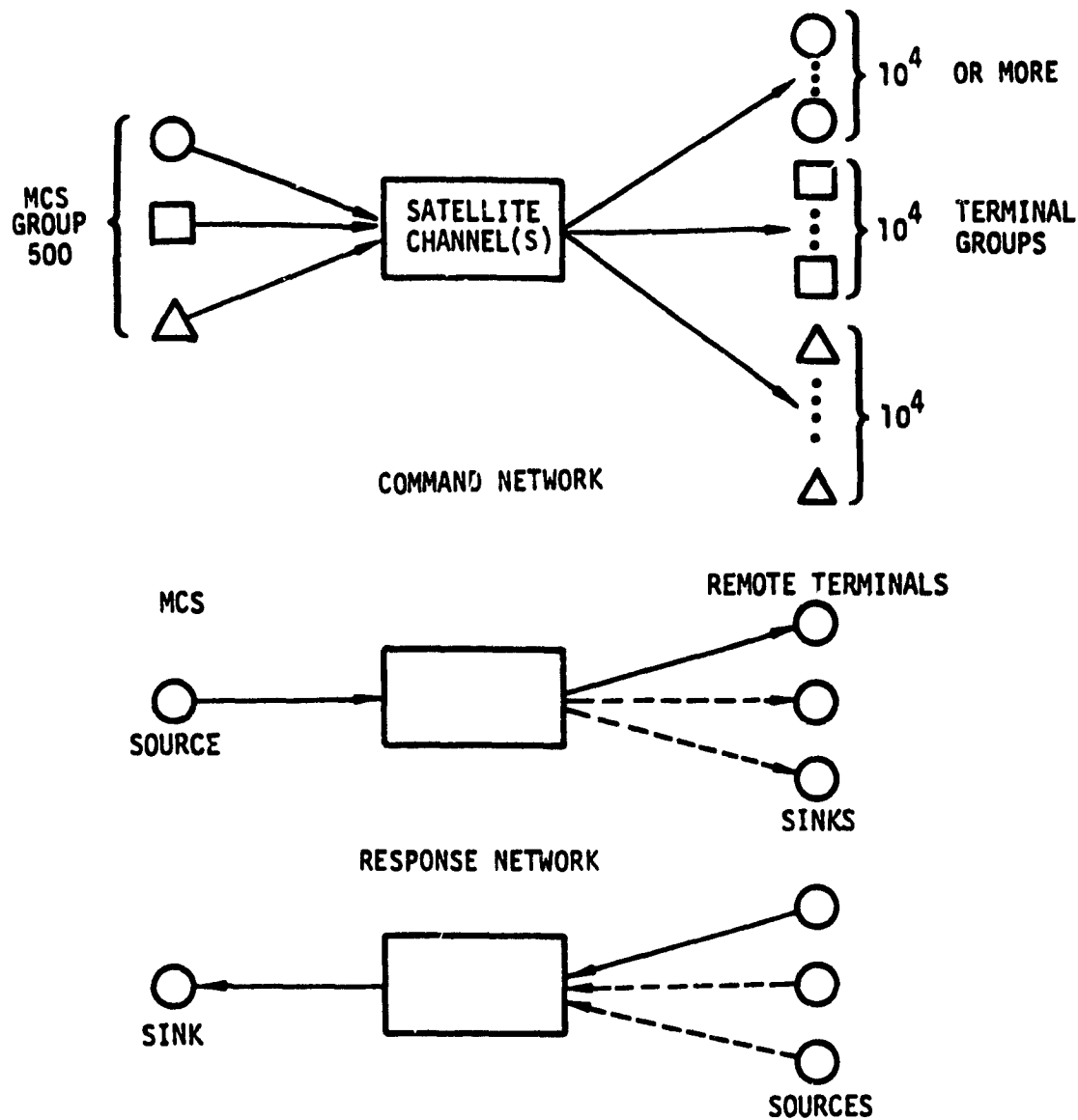


Figure 5-1 CONNECTIVITY OF THE COMMUNICATION NETWORK

Electric utilities tend to conduct their operations using either a single centralized authority, or a multi-level authority with specific functions and responsibilities delegated to lower echelons (dispersed sites).

In implementing the SC system, two basic command and control hierarchical arrangements may be needed to interface command centers with remote terminals. Figure 5-2. With centralized control, all command communications flow from a single master station. With dispersed control, functions are delegated to district control centers. For example, in one dispersed arrangement only meter reading is handled by the master control station, all other traffic emanates from district centers. In another arrangement, all distribution automation traffic is handled by district centers, which accumulate meter reading data for eventual transfer to a billing center. Other configurations are conceivable since they must reflect the operating practices of the utility industry. It is apparent that the SC system must be designed with enough flexibility to accommodate a variety of command and control structures.

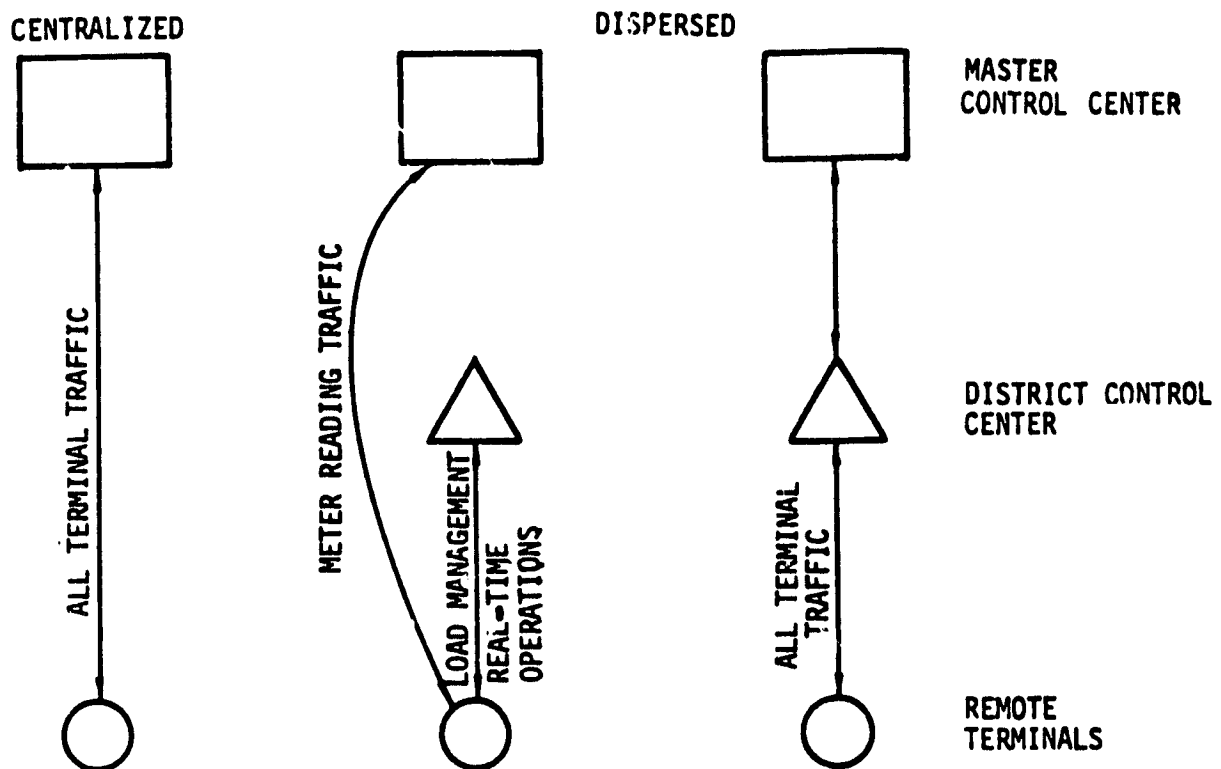


Figure 5-2 SOME COMMAND & CONTROL HIERARCHICAL ARRANGEMENTS

As pointed out in Section 3, traffic between sites tends to be of several distinct types.

1. A large volume of near continuous data gathering which is not time-critical, i.e., customer meter readings, circuit monitoring, etc.
2. A large volume of cyclical commands which are somewhat time-critical, i.e., load management refresh commands.
3. A small, but nearly stable amount of randomly distributed, time-critical and non time-critical traffic, i.e., switch closures, etc.
4. Infrequent, high volume, batch traffic, i.e., condition reporting during a storm.
5. Infrequent, randomly distributed, low volume, time-critical emergency messages, i.e., change-of-state reports originating at remote sites.

With the above system connectivity and time distribution characterizations, the suitability of various means for accessing the satellite will now be assessed.

5.2.2 Multiple-Access Schemes

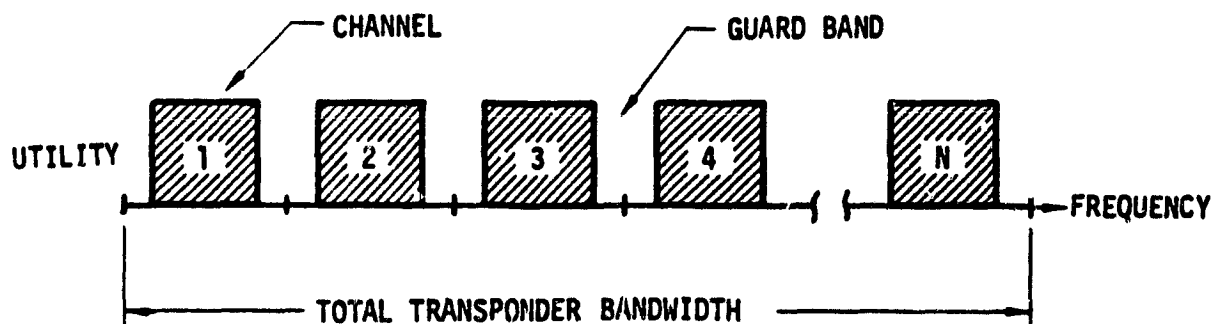
Several multiple-access schemes have been proposed for allowing a large population of ground stations to work with a single communication resource in space. These schemes are usually categorized generically as follows:

- Space-Division Multiple Access (SDMA)
- Frequency-Division Multiple Access (FDMA)
- Time-Division Multiple Access (TDMA)
- Random Access (RA), and
- Code-Division Multiple Access (CDMA).

Each of these schemes are defined below.

Space-Division Multiple Access - This approach is based on the use of separate antenna beams and separate satellite transponders for each user.

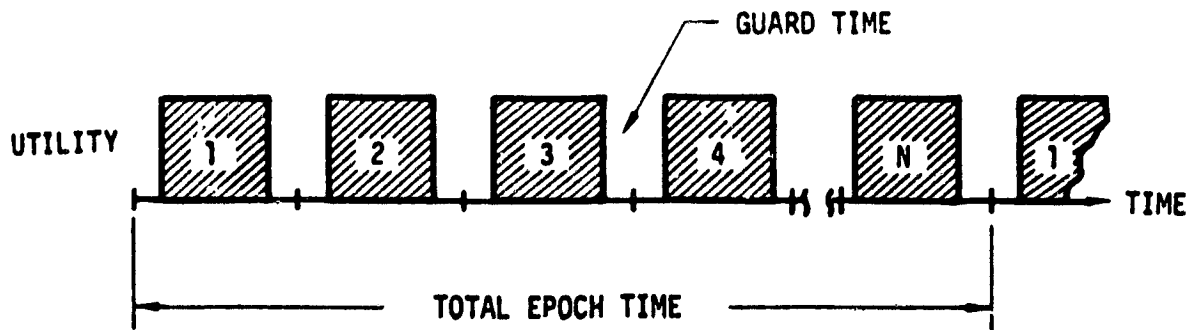
Frequency-Division Multiple Access - The FDMA concept mandates different carrier frequencies for each ground station. A number of carriers use the same wide-band transponder, (see Figure 5-3). Many data channels can be multiplexed on each carrier, or separate carriers may be used for each data channel. This latter approach is referred to as "single channel per carrier" (SCPC).



- MANY UTILITIES USE THE SAME TRANSPONDER SIMULTANEOUSLY
- USERS MUST ADHERE TO FREQUENCY ASSIGNMENTS
- GUARD BANDS MINIMIZE MUTUAL INTERFERENCE
- SIGNALS SEPARATED BY FREQUENCY FILTERING

Figure 5-3 FREQUENCY DIVISION MULTIPLE ACCESS

Time-Division Multiple Access - In this scheme all ground stations are synchronized and each is assigned a time slot for its transmissions, with all stations using the same carrier frequency and satellite transponder, (Figure 5-4).

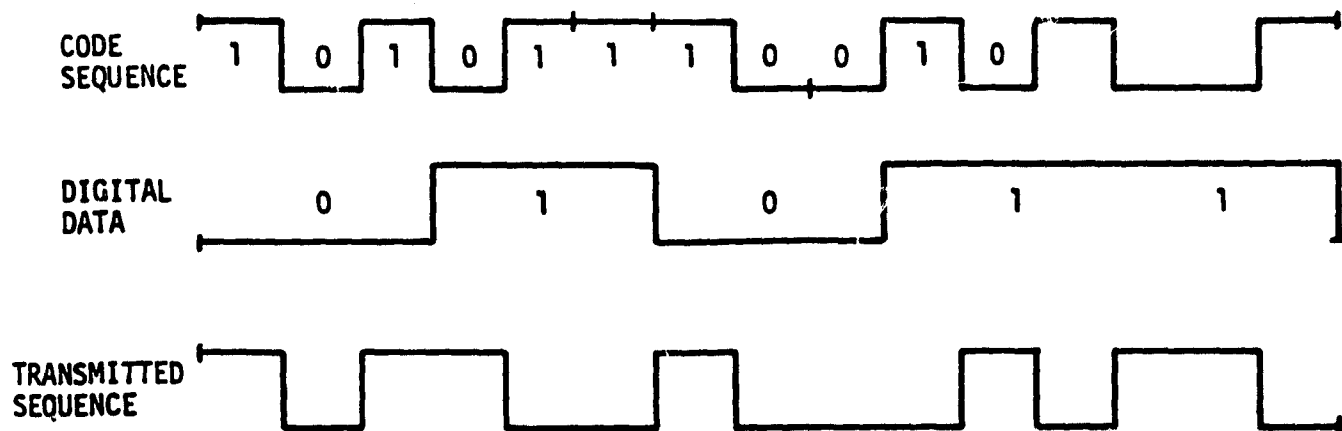


- ONLY ONE UTILITY MAY USE THE TRANSPONDER (CHANNEL) AT ANY TIME
- USERS MUST ADHERE TO TIME-SLOT ASSIGNMENTS
- GUARD TIME MINIMIZES INTERFERENCE
- SIGNALS SEPARATED BY TIME-GATING

Figure 5-4 TIME DIVISION MULTIPLE ACCESS

Random Access - The random access method does not require users to be synchronized in any way. Each transmits on the same frequency at any time. Each monitors the down-link to determine whether his message got through the satellite transponder ungarbled. Should two or more messages "collide" at the satellite, each user retransmits his message after a random delay. The randomizing process is responsible for achieving multiple access and a reasonable throughput without undue delay.

Code-Division Multiple Access - This method is based on the use of pseudo-random codes, with each transmission occupying the entire transponder bandwidth. The terminal for whom a transmission is intended has a duplicate of the code and can extract the message from the "noise" created by simultaneous transmissions from many other stations, (Figure 5-5).



- MANY UTILITIES MAY OCCUPY THE ENTIRE TRANSPONDER BANDWIDTH AT ANY TIME
- USERS NEED NOT ADHERE TO ANY NETWORK DISCIPLINE
- SIGNALS ARE SEPARATED BY CROSS-CORRELATION WITH A RECEIVER GENERATED REPLICA OF THE USERS CODE
- INTERFERENCE MINIMIZED BY USE OF ORTHOGONAL CODES

Figure 5-5 CODE DIVISION MULTIPLE ACCESS

D180-25403-2

The principle attributes of each of the above multiple access schemes are summarized in Table 5.4. Practical systems, however, are seldom "pure" implementations of any one technique, rather they are hybrids designed to match specific operational requirements.

Another traffic management approach to be considered is "demand assignment." Because traffic originating from a given ground station may not be continuous, methods have been developed for "pooling" channels to increase their efficiency, with channels assigned according to user demand. In such a system, idle channels are made available to others in accordance with the instantaneous traffic load. Since such a system is generally sized to handle somewhat less than peak demand, delays and queues can occur at times of peak activity.

	ADVANTAGES	DISADVANTAGES
SDMA	<ul style="list-style-type: none"> ● SIMPLE USER EQUIPMENT 	<ul style="list-style-type: none"> ● INFLEXIBLE ● INEFFICIENT USE OF SATELLITE
FDMA	<ul style="list-style-type: none"> ● SIMPLE USER EQUIPMENT ● COMPATIBLE WITH VARIOUS MODULATION TECHNIQUES 	<ul style="list-style-type: none"> ● REQUIRES BACK-OFF IN SATELLITE POWER AMP. TO AVOID INTERMOD. NOISE ● DIFFICULT TO SEPARATE & SWITCH CHANNELS IN MULTIPLE BEAM & DEMAND ASSIGNMENT
TDMA	<ul style="list-style-type: none"> ● EFFICIENT USE OF SATELLITE POWER 	<ul style="list-style-type: none"> ● COMPLEX USER EQUIPMENT TO SYNCHRONIZE
CDMA	<ul style="list-style-type: none"> ● DOES NOT REQUIRE CALLING CHANNEL FOR DEMAND ASSIGNMENT OPERATION 	<ul style="list-style-type: none"> ● LARGE BANDWIDTH ● COMPLEX RECEIVING TERMINALS
RA	<ul style="list-style-type: none"> ● SIMPLE USER EQUIPMENT 	<ul style="list-style-type: none"> ● "BURSTY" COMMUNICATIONS

Table 5-4 ATTRIBUTES OF MULTIPLE-ACCESS TECHNIQUES

Demand assignment concepts can be overlaid on multiple-access techniques to further tailor a system to traffic characteristics and user needs.

5.2.2.1 Multiple Access, Command Network

To gain insight into the use of multiple-access methods for the SC system, the application of candidate techniques in the command network will be explored.

The space-division technique, in its elemental form, does not appear too attractive in light of the 500 or more antenna beams needed to service the utility industry nationwide. However, it should be noted some public service communication systems presently being proposed by NASA, and others,

require even a larger number of beams, in the 1000's. Variations of the elemental form, when combined with FDMA, TDMA, or CDMA, provide potentially viable solutions.

The need to accommodate 500, or more, utility stations also presents a challenge in the frequency domain (FDMA). Here it manifests itself in terms of channel bandwidth. A variation of system connectivity which conserves spectrum is illustrated in Figure 5-6. In this concept a group of utilities within a region would pipe their communications to a common earth station. There the messages would be formatted and sent on to the satellite. While the introduction of a group earth station is a departure from the premise that each utility should use "stand alone" resources, this concept could be an attractive way to accommodate a number of small utilities.

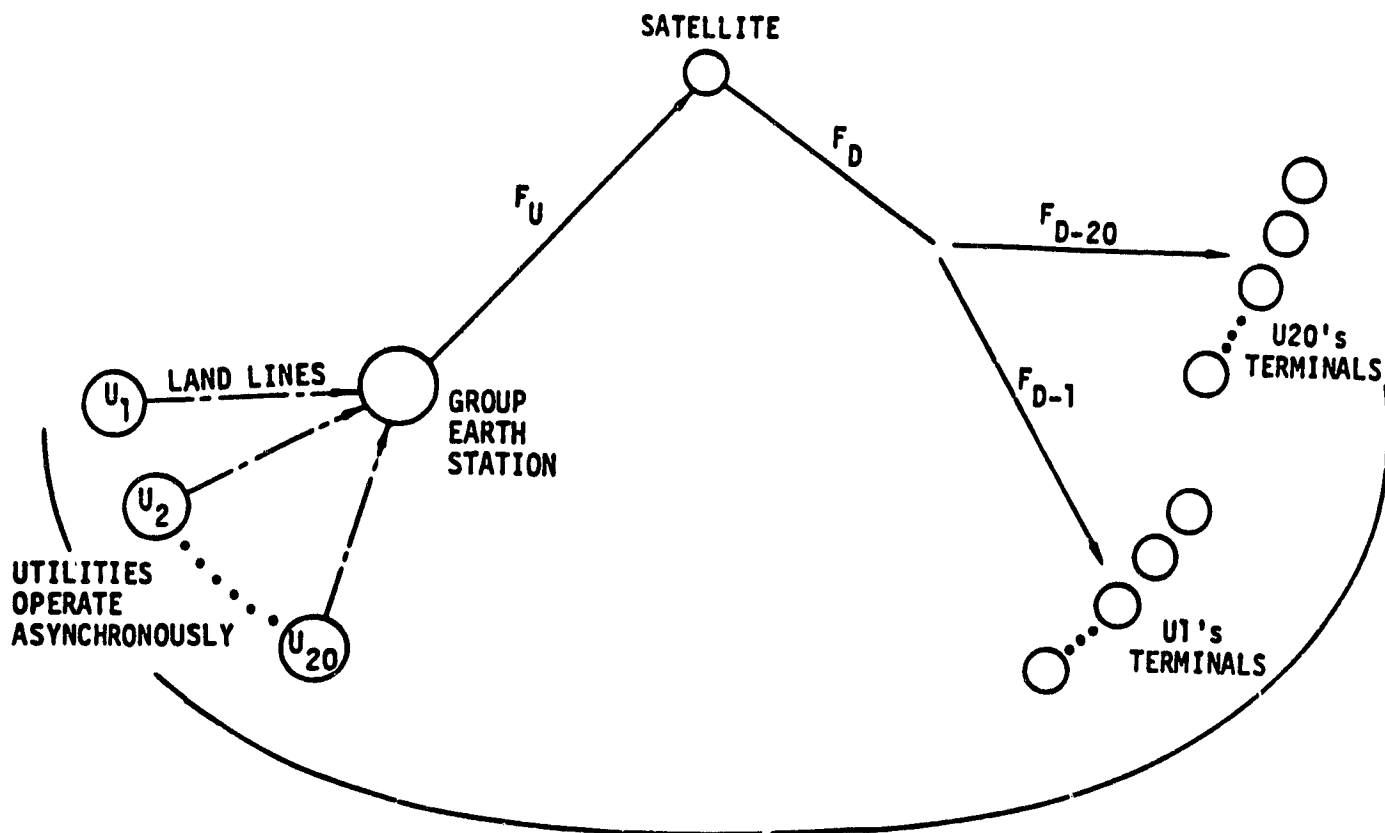


Figure 5-6 GROUP EARTH STATION USING FREQUENCY DIVISION COMMAND LINKS

The use of TDMA places the impact of a large station population in terms of time. The question here is whether the volume of command traffic can be handled at reasonable data rates within the available time.

One candidate TDMA implementation would include all 500, or more, utility stations in one timing regime. A second approach would group the stations by regions, with each region operating independently of all others with its own timing system. More will be said about such TDMA concepts later.

Random access schemes tend to be most suitable for situations wherein users generate traffic in "bursts." Since only a small amount of SC system traffic is inherently of this nature, a random access implementation of the command network may not be promising.

Code-division multiple access is interesting for the command network because it inherently provides protection against interference, malicious or otherwise. Its feasibility for this application will likely depend on cost factors.

The selection of the optimum multiple-access technique for the command network is a design consideration deserving in-depth analysis.

5.2.2.2 Multiple Access, Response Network

The situation with regard to formulating an optimum response network is somewhat different. Since there could be up to 100 million remote terminals, the number of viable multi-access options rapidly diminishes. First, space-division (separate beams, separate transponders) can be ruled out, and FDMA

is suspect (separate frequencies). Random access may not be feasible with this number of terminals. CDMA is a possibility, but TDMA is a more likely contender.

Asynchronous operation does not look good. Synchronous operation of the response network using satellite timing may be feasible, but appears to have undesired cost ramifications. Synchronous techniques based on operating both the command and response networks in a joint mode seems to be more attractive.

In such a concept, each utility is assigned a time-slot during which it transmits addressed command and interrogation messages to its remote terminals. Outgoing messages flow continuously, one after another. At the remote terminal, commands may or may not require an acknowledgement. Interrogations, on the other hand, always invoke an immediate response. Response messages are timed to arrive at the satellite within an established time slot. In other words, the outgoing interrogation message stream from the utility control station gives rise to an incoming message stream composed of time-ordered responses from remote terminals.

5.2.3 System Architectures

Two candidate multiple-access architectures for the total system based on using TDMA in a "command-response" mode are depicted in Figures 5-7 and 5-8. The first concept has all utilities nationwide working into a common command network, with regional response networks. The second concept is based on having both command and response networks configured on a regional basis.

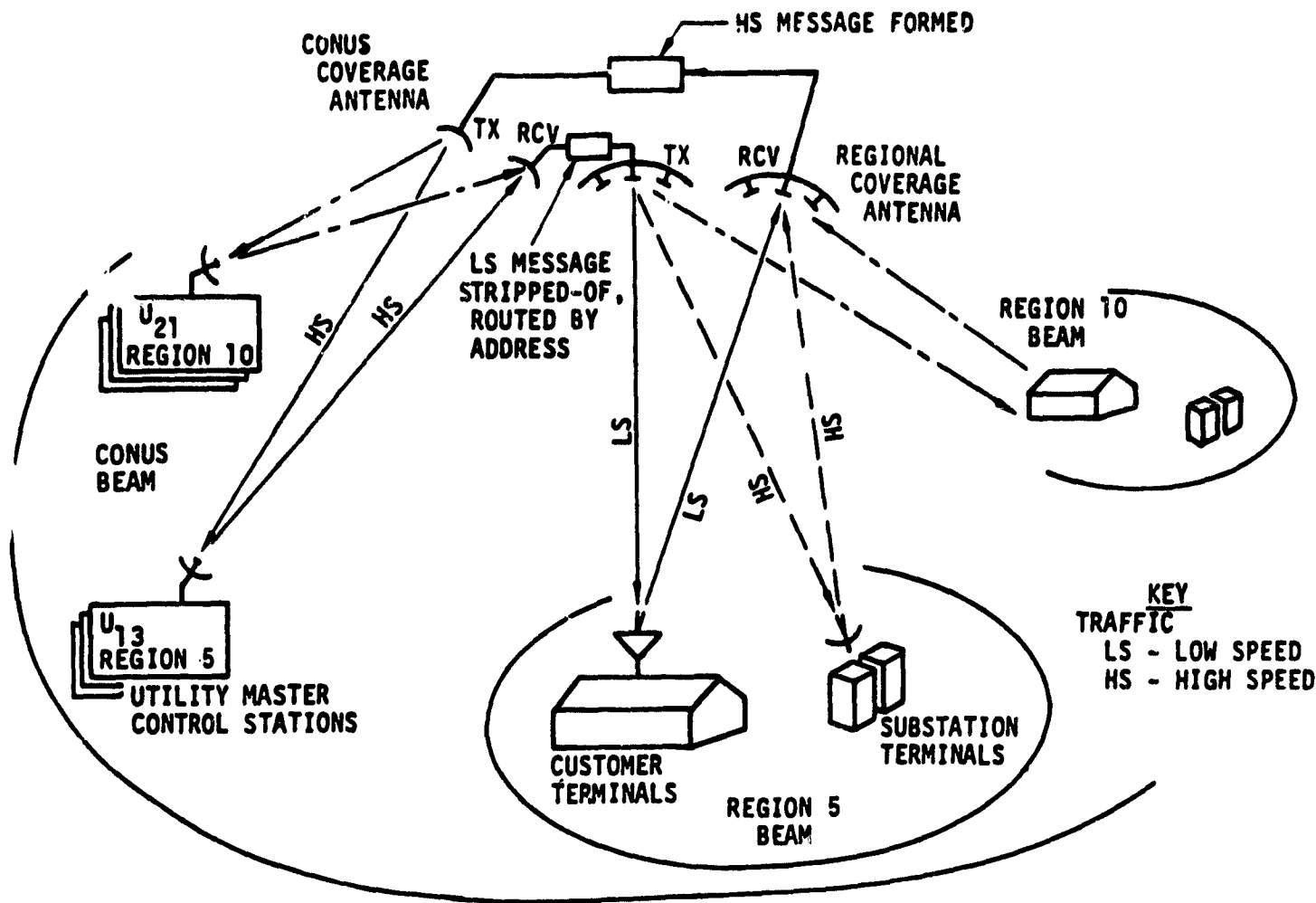


Figure 5-7 SYSTEM ARCHITECTURE HAVING ALL UTILITIES ON ONE TDMA NETWORK

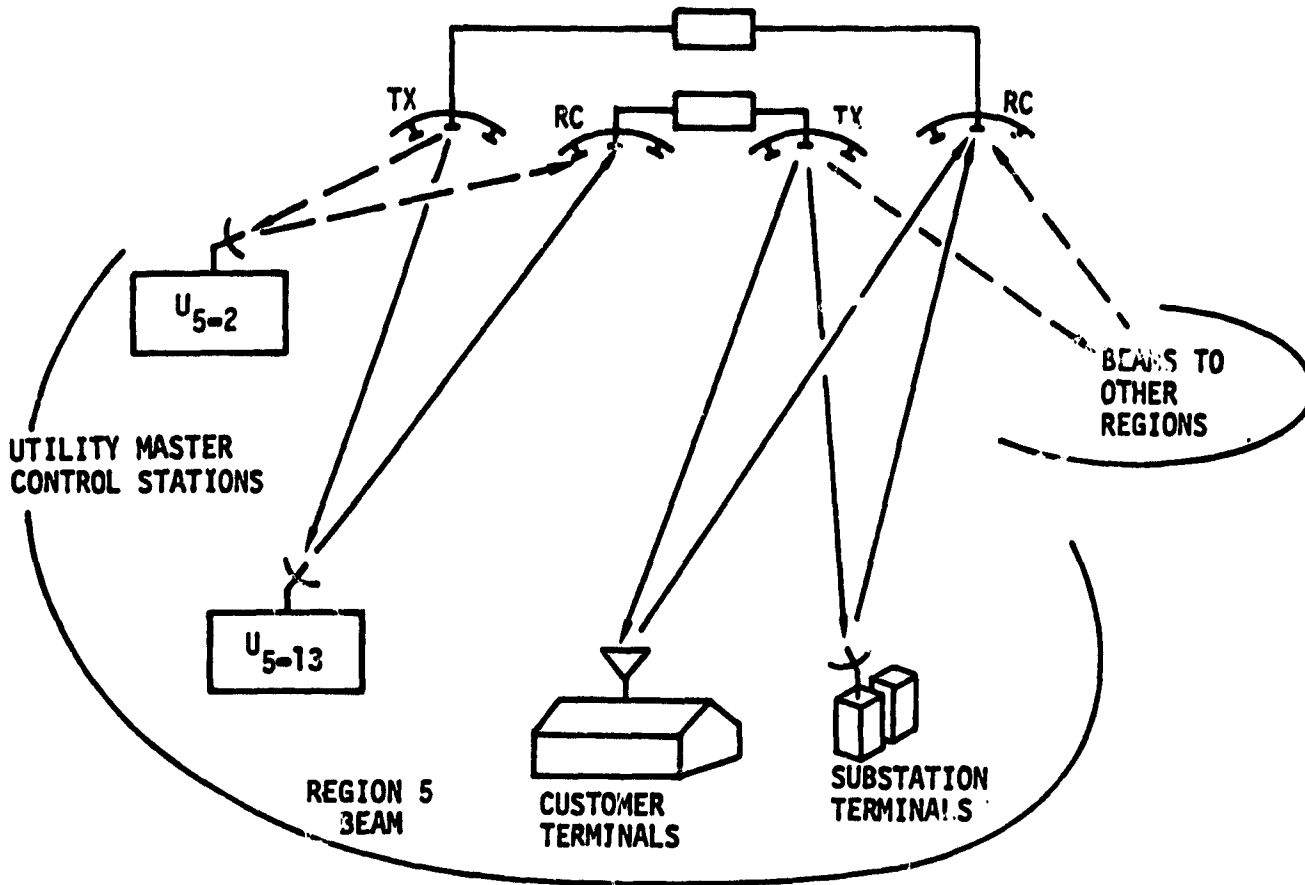


Figure 5-8 SYSTEM ARCHITECTURE BASED ON REGIONAL TDMA

5.2.3.1 A Nationwide Command Network

Consider first the system architecture based on having all utilities within the Continental United States (CONUS) working into a single command network with regional response networks, Figure 5-7.

Five hundred, or more, master control stations are assigned separate, nonoverlapping, sequential time slots. Each station sends its messages so as to arrive at the satellite within the assigned slot. Only one signal enters the spacecraft command receiver at any time via a CONUS coverage antenna. The received message is demodulated, reformed and routed to the antenna feed(s) which forms the down-looking regional beam which illuminates the addressed remote terminal. If the command mandates a reply, the remote terminal immediately sends its response message to the spacecraft where it is modulated, reformed, and routed to the CONUS antenna for transmission back to earth.

Two features of the command-response operation deserve note. First, the up-link commands may require a higher data rate than the subsequent down-link commands (and conversely the up-link responses from the remote terminals may be at a slower rate than the transponded down-link to the master control stations). The reason for the possible need for higher data rates stems from the large number of utilities in the "round robin" timing sequence i.e., the epoch time may be too long at low data rates to accommodate time-critical messages. The second item of note is the requirement for on-board switching between antennas.

5.2.3.2 Regional Command Networks

Some of the complications of a nationwide command network can be avoided by using regional networks. Since the operation of this concept was described in Section 2 as the "baseline" system, it will not be repeated here. It should be noted, however, that even though a regional concept was used in the "baseline" system it may not be the choice derived from a more detailed design study.

5.2.4 Timing Considerations

The concept of sharing a satellite's transponder in the time domain introduces the requirement for time synchronization of users. Synchronization is necessary so that transmissions from ground stations arrive at the satellite without overlap. To achieve this condition, "clocks" at each station must be running at the same rate and "start" times must be identical.

Figure 2-9 illustrates the essential features of a time-division multiple access (TDMA) timing hierarchy. An epoch is the time interval for an access assignment plan to repeat. Once each epoch a master timing burst is broadcast to all utility Master Control Centers (MCS) within a region by a network controller (a designated MCS). Each MCS uses this burst to establish frame timing. Frame timing is then adjusted to account for link delay so that synchronization is achieved at the satellite.

The precision with which synchronization is required (reflected in guard time) is a function of satellite station-keeping, frame length, and link design factors. A geosynchronous satellite slowly roams around in a volume of space determined by station-keeping requirements. With values of $\pm .1\%$ in altitude, round-trip delay variations of around .5 milliseconds are produced. A minimum frame length for the SC system, based on using 5,000 bits per second and a 40 bit message, is 8 milliseconds. The use of guard time to accommodate this situation does not make for good channel efficiency.

There are several methods for compensating for variable delays and achieving synchronization to tens of microseconds, or less. Determining the appropriate choice for the SC system is beyond the scope of this study.

Each MCS sends receiver synchronization information in its transmissions to its Remote Terminals (RT). A specially constructed message preamble provides carrier and bit timing. This is followed by the terminal address field, the message(s), and finally error detection bits.

As discussed in Section 3, some real-time operational management functions are time-critical, which means an assigned time slot must be available within the specified time. Under worse case conditions in which the MCS has just finished a transmission, a complete round-robin sequence (epoch) may be needed before the MCS again has access to the communication link. Since epoch time is related to data rate, message length, channel efficiency, and the number of MCS's being served, it is an important design parameter. The relationship between epoch time and data rate is shown in Figure 5-9.

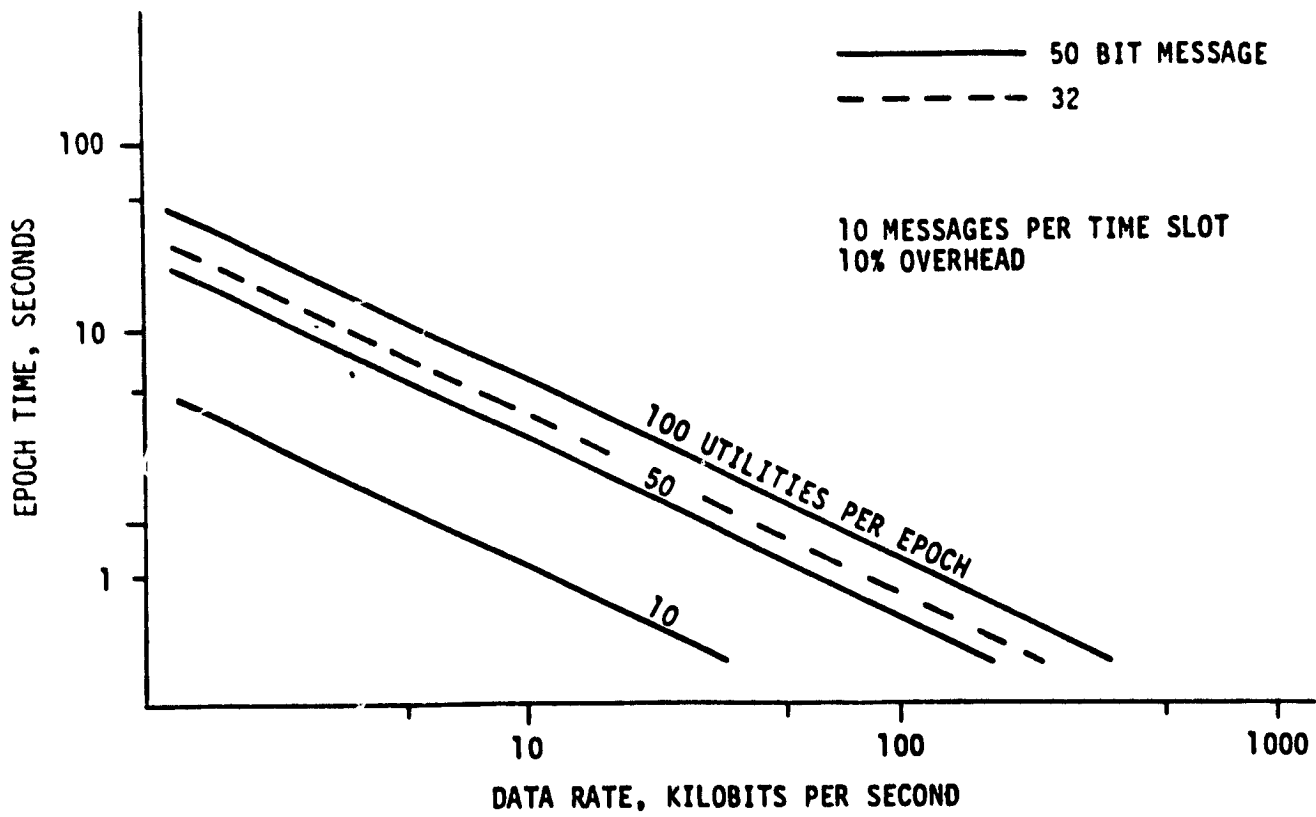


Figure 5-9 THE RELATIONSHIP BETWEEN EPOCH TIME & DATA RATE

5.3 Communication Link Design

Because it is difficult to foretell where frequencies may be allocated for the SC system, a broad spectrum of potential frequency assignments must be examined in terms of their possible influence on system concepts and components. In this study, link analyses cover the range from 150 MHz to 20 GHz.

The requirements and constraints placed on various parts of the system change significantly with frequency. For instance, at low frequencies antennas must be restricted to practical sizes for residential use. At high frequencies transmitters are limited in output, but high gain antennas are small and can be used. At low frequencies, environmental noise affects receiving parameters, at high frequencies noise in the receiver itself affects system performance. These are examples, it is the intent of this section to examine some of the more important link design considerations as one moves through the frequency spectrum.

5.3.1 Transmitter Considerations

Transmitters at customer terminals must be designed around solid-state devices, not only to achieve the high reliability demanded but also to permit high volume automated production.

The present capability of solid-state power output devices is shown in Figure 5-10, along with an estimate of near-term advanced technology. For design purposes, configurations should be based on presently available, proven devices.

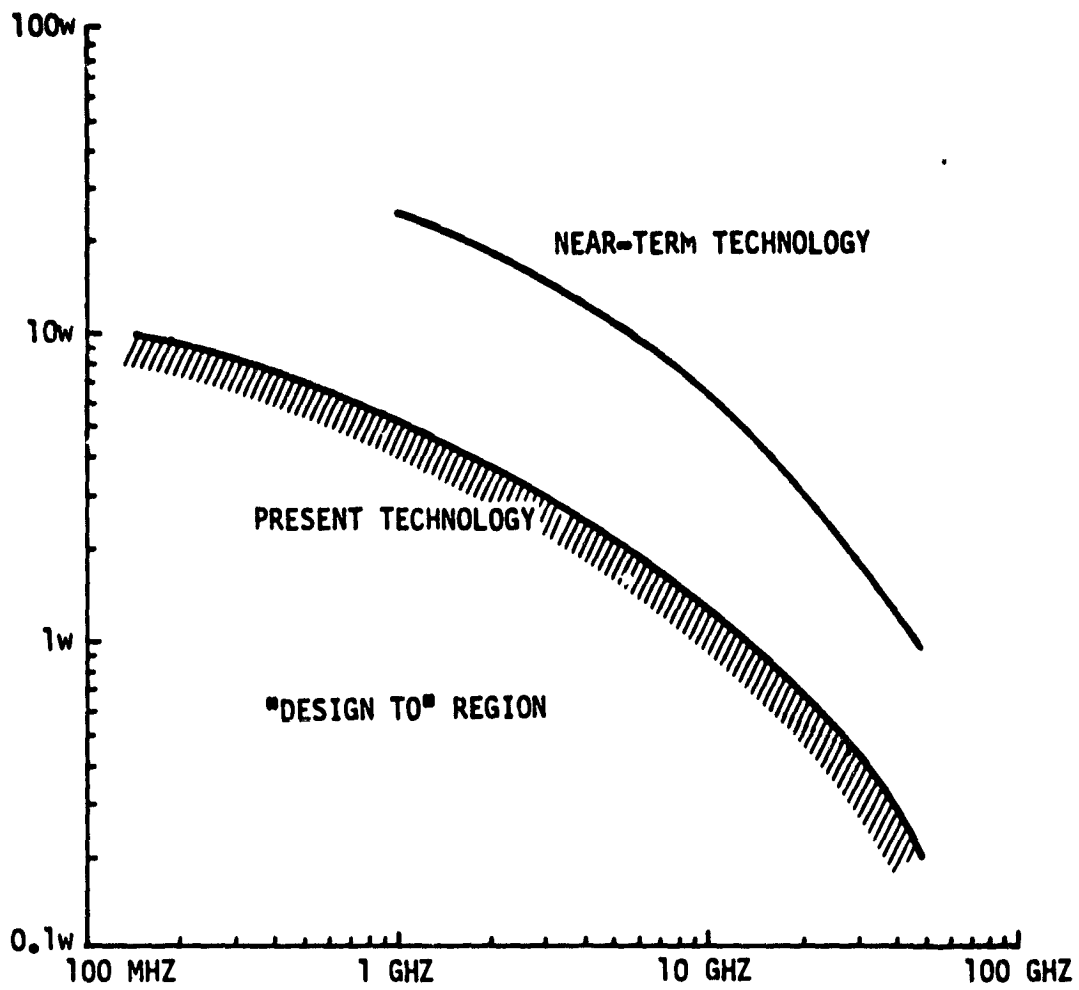


Figure 5-10 CUSTOMER TERMINAL TRANSMITTER OUTPUT

Transmitters destined for substation use are not as cost sensitive as customer terminals because only a relatively small number of units are needed. At these locations, performance is more significant than cost.

Because of the unique role of the utility's Master Control Station (MCS), its equipment emphasize both performance and reliability.

Transmitters on the spacecraft must be designed for exceptional reliability. Traveling wave tubes (TWT) have dominated the spacecraft market, particularly where relatively high power is required. Recently, solid-state devices have gained acceptance in applications requiring more modest outputs.

Link analyses should be constrained to specify only transmitter outputs falling well within the capabilities of proven RF power devices.

5.3.2 Antenna Considerations

Important elements in the design of a communication system are the transmit and receive antennas. Antenna gain (directivity), polarization, and side lobe levels are critical parameters in system performance, reuse of frequencies, and immunity to interference.

Antenna gain can increase the radiated power in the field of view thus reducing required transmitter output power. However, an increase in antenna gain requires a larger antenna, which increases the antenna's cost. Higher antenna gain provides narrower beamwidth which in turn may require a more sophisticated and costly antenna pointing adjustment system. Customer terminal antennas providing gains of up to 30 dBi*(approximately 5° beamwidth) require only coarse antenna pointing

* decibels relative to an isotropic radiator

adjustment; however, antenna size becomes impractical at the lower operating frequencies, as shown in Figure 5-11. If size is arbitrarily limited because of installation factors, gain suffers. Antenna gain versus frequency for a one-foot aperture is shown in Figure 5-12. A one-foot aperture appears to be a reasonable size for customer terminal antennas.

The utility's MCS can accommodate large antennas. Gains of 20-50 dBi are achievable and good system performance can be assured under severe operating conditions and potential attempts to disrupt the system.

The satellite requires a multibeam antenna with the capability of providing frequency and polarization diversity. Each beam must be designed for simultaneous transmit and receive capability. The beamwidth and shape must be adjustable to obtain the desired earth coverage and possibly geographical contouring. For the communication link analysis, two primary antenna beamwidths are considered, (1) 1.2 degrees for covering high density traffic regions, and (2) 3.4 degrees for covering low density regions, as shown in Figures 3-9 and 3-10. Wider antenna beamwidths for any desired earth footprint can be provided. Spacecraft antennas are discussed more fully in Section 5.7.

In summary then, SC system antennas reflect into link analyses primarily in terms of physical size; spacecraft antenna size because of production cost and developmental risk, and customer terminal antenna size because of customer acceptance (aesthetics).

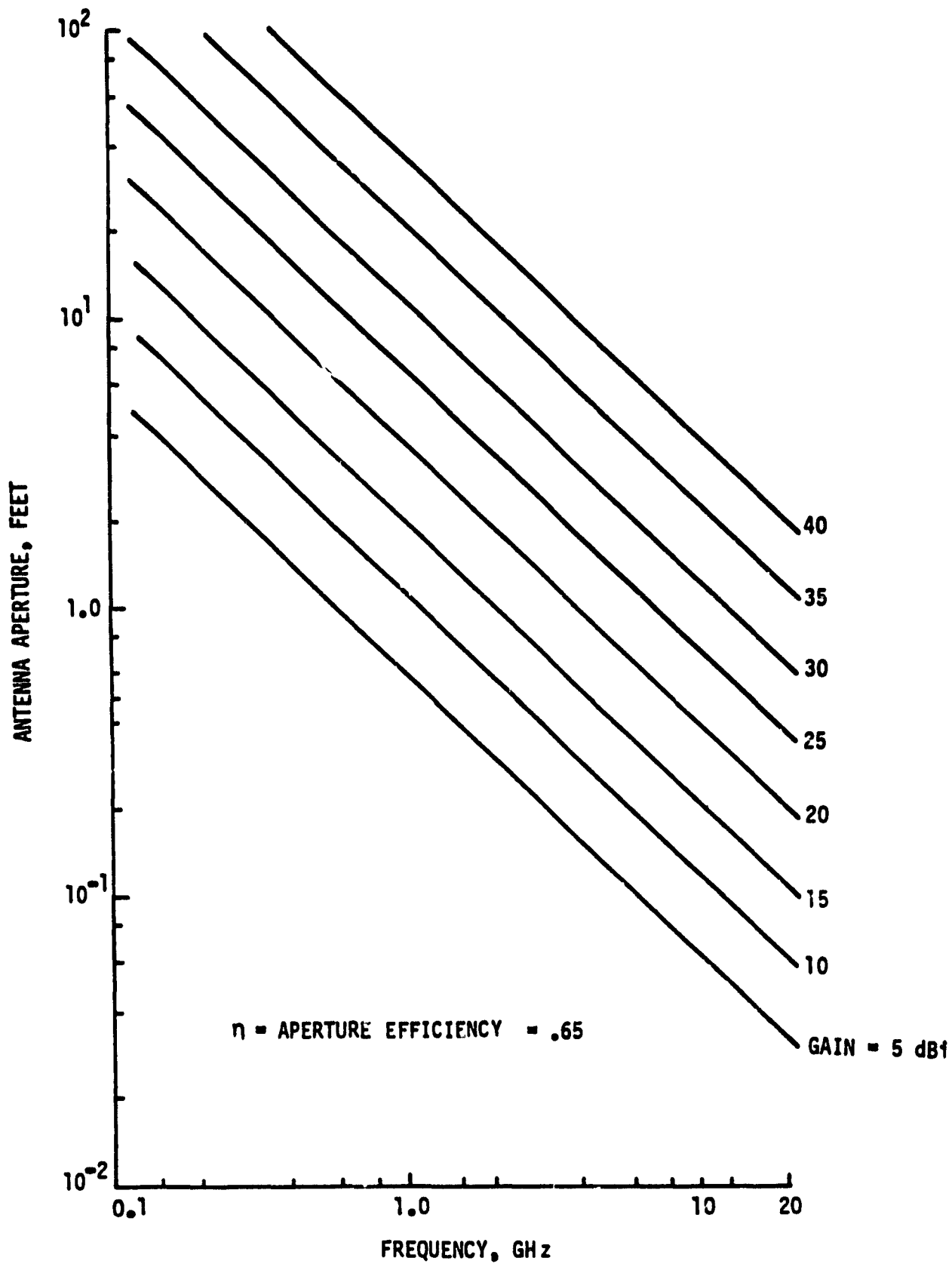


Figure 5-11 ANTENNA APERTURE VS. FREQUENCY

D180-25403-2
5-30

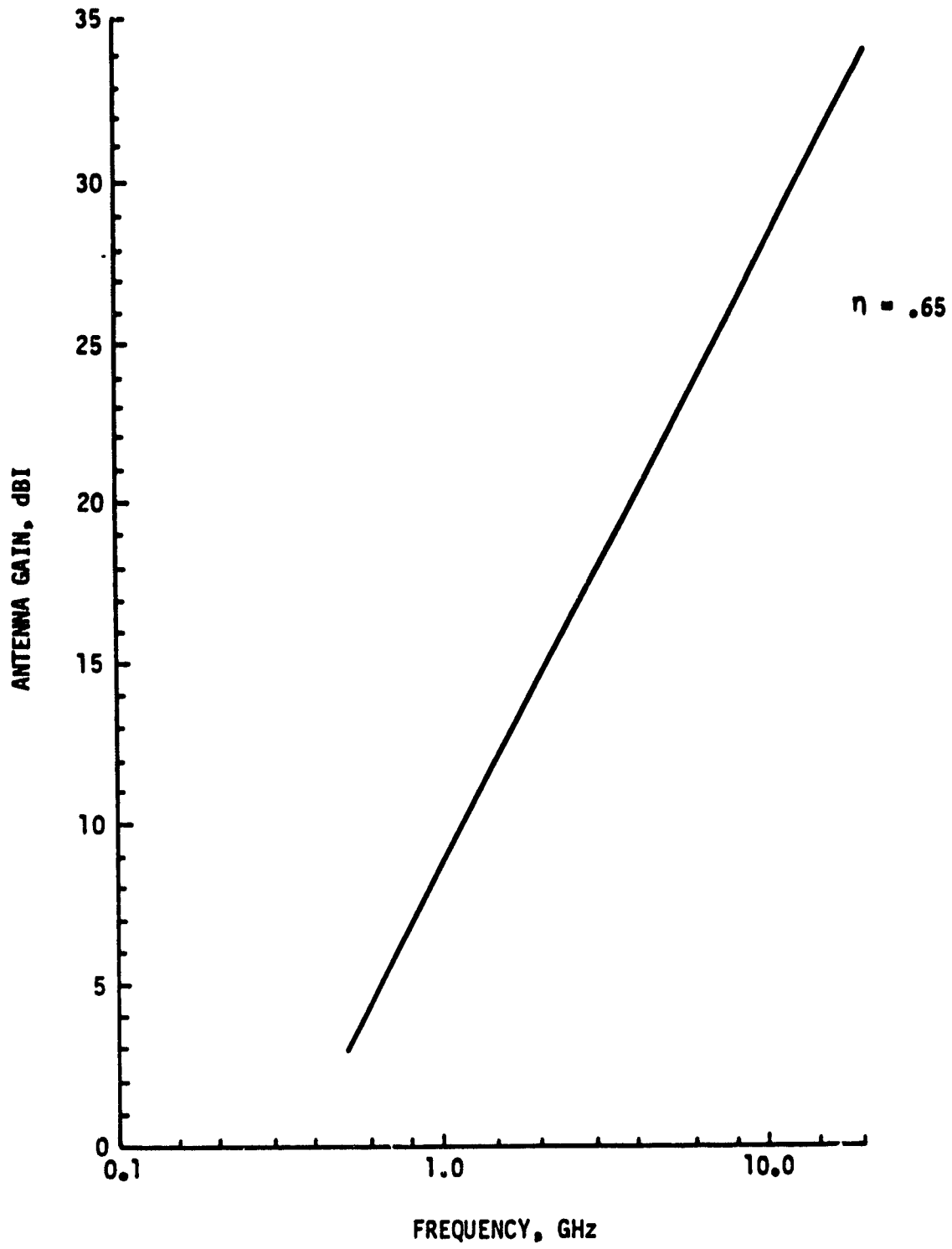


Figure 5-12 ANTENNA GAIN VS. FREQUENCY, 1 FOOT APERTURE

5.3.3 Propagation Considerations

Free Space Propagation Loss: Radio waves propagating from a transmitting antenna to a receiving antenna through free-space will suffer attenuation in signal level. Free-space attenuation is a function of frequency and distance. The average slant range from northeastern United States to a geostationary satellite at 97.5°W is 23,760 miles. The total attenuation is 168 dB at 150 MHz and increases with frequency to 210 dB at 20 GHz.

Atmospheric Absorption and Rain Loss: Actual propagation conditions may vary substantially from free-space conditions, particularly at the higher frequency bands. Transmission through a clear atmosphere is subject to attenuation due to absorption by oxygen and water vapor. The absorption is due to the permanent electric dipole moment of the water molecule and the permanent magnetic dipole of the oxygen molecule. Atmospheric attenuation will increase as the elevation angle of propagation is decreased as shown by the typical curves in Figure 5-13.

Radio transmission is also subject to attenuation by precipitation. Liquid water exhibits strong absorption which steadily increases as wavelength decreases, but the variation of attenuation becomes more complicated as the wavelength approaches the size of raindrops. Rainfall attenuation effects become quite significant above 9 GHz, and attenuation increases with increasing rate of precipitation.

Common rainfall rates are defined as follows:

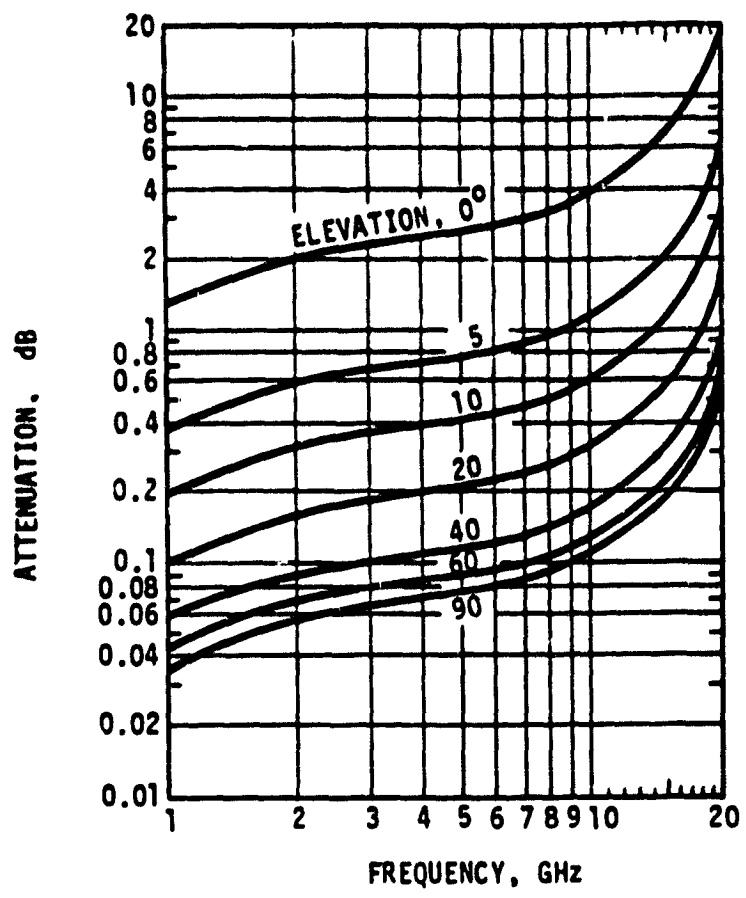


Figure 5-13 ATMOSPHERIC ATTENUATION DUE TO OXYGEN AND WATER VAPOR

Type	Rainfall rate mm/hr
Drizzle	0.25
Light Rain	1.0
Moderate Rain	4.0
Heavy Rain	16.0
Excessive Rain	40.0

When link availability requirements are specified in terms of a percent of time for all hours of the year, then the evaluation of the system's performance must include the effects of rainfall. Figure 5-14 shows the behavior of a heavy rain storm for 30 minutes as it passed over an experimental site in Ottawa, Canada.

Rainfall attenuation generally depends on the integrated rain content over the propagation path and on the shape and sizes of the drops. Not enough is known about water content and drop sizes at high altitudes to predict attenuation confidently on paths between the earth and spacecraft, although some measurements have been made using satellites beacons. As can be expected, the attenuation due to precipitation is a highly statistical phenomenon related to both time and location. Several rain models have been developed which indicate that the rain attenuation coefficient can be approximated by a log-normal distribution. The percentage of time that rain exceeds a given rate for several typical locations in the world is shown in Figure 5-15. For this study a light rain environment will be used for the nominal rainfall rate which corresponds approximately to 1 mm/hr and 2 percent of an hour. A moderate rain of 4 mm/hr which corresponds to 1 percent of an hour will be used as the standard deviation, i.e., 1σ estimated value.

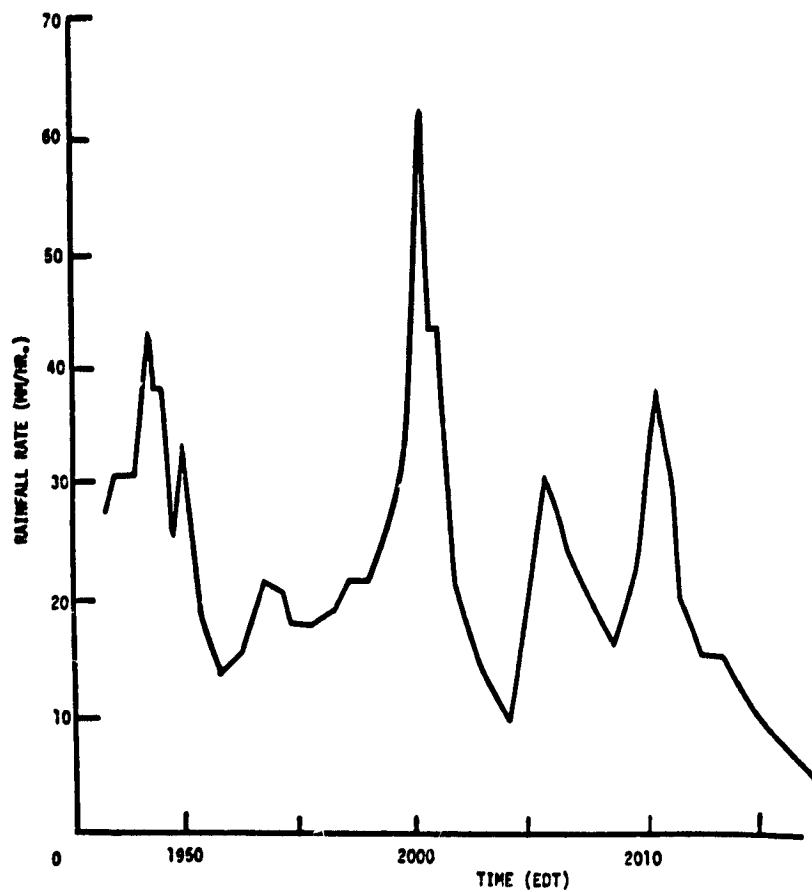


Figure 5-14 RAINFALL RATE OF A HEAVY RAIN SHOWER AS IT PASSED OVER AN EXPERIMENTAL SITE, NATIONAL RESEARCH COUNCIL IN OTTAWA, CANADA

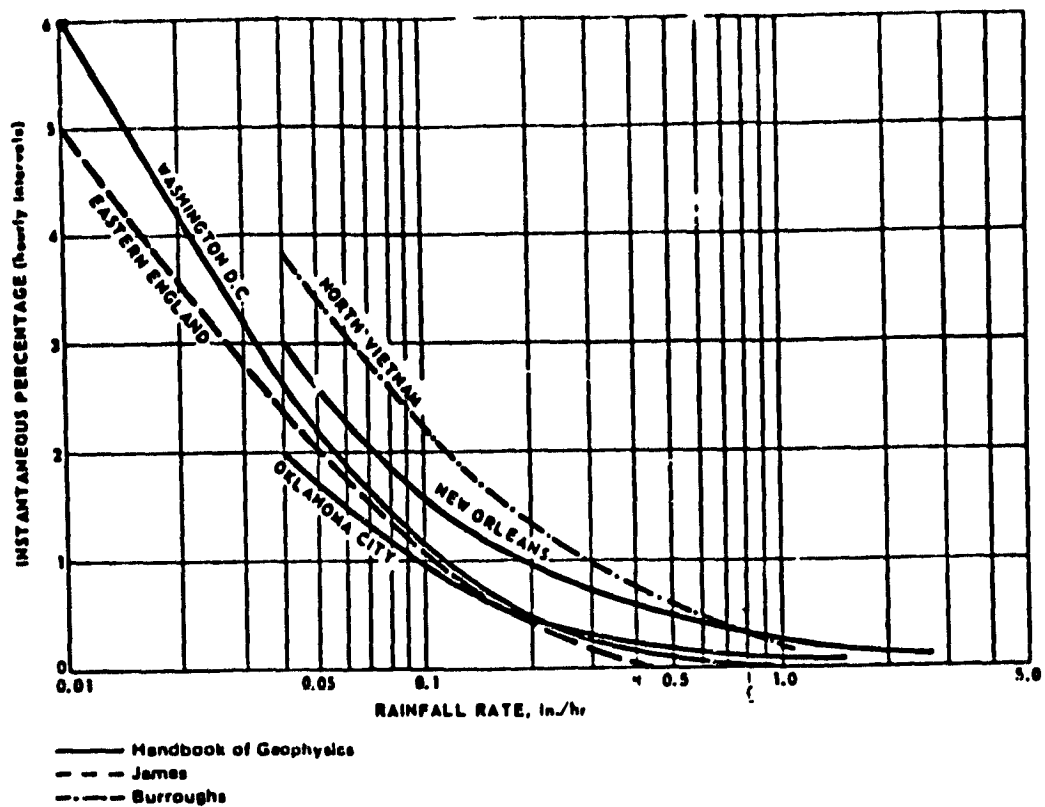


Figure 5-15 PERCENTAGE OF TIME RAINFALL EXCEEDS A GIVEN RATE

Figure 5-16 shows attenuation per 1 km of path due to rainfall, and to cloud and fog for a typical distribution of drop sizes observed near the ground. Path attenuation depends on the vertical and horizontal distribution of the rain and the ground antenna elevation angles. The size of a rain cell decreases with an increase in rain rate. A very heavy rain cell (over 100 mm/hr rate) is usually very localized, to less than 5 km in diameter. However a light rain cell can extend to 30 km or more.

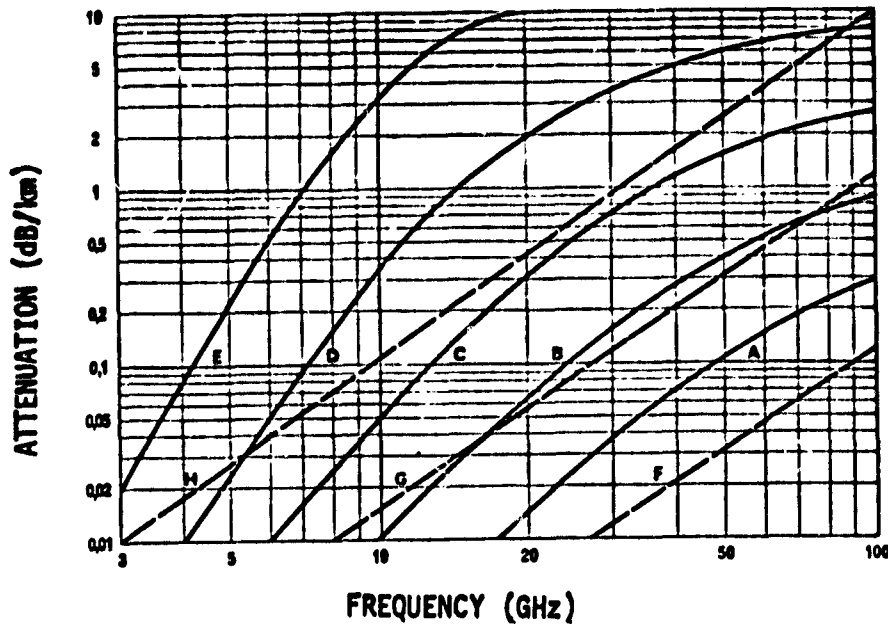
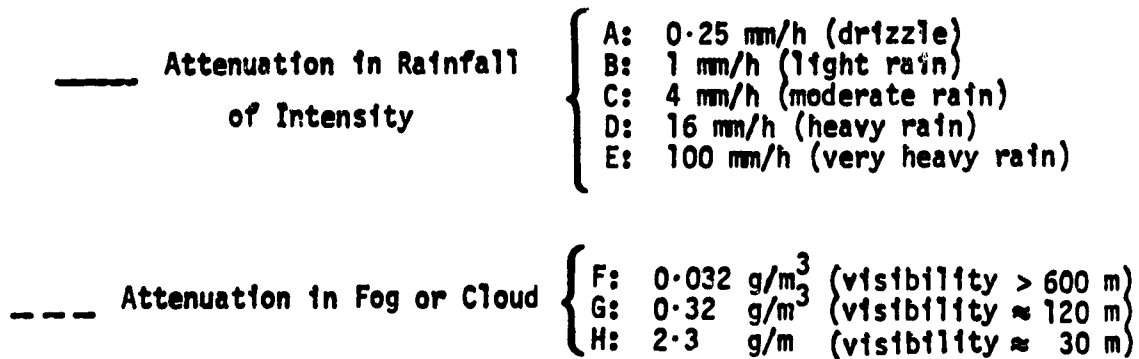


Figure 5-16 ATTENUATION DUE TO RAINFALL, FOG OR CLOUD*



*From CCIR Report 205-2

ORIGINAL PAGE IS
OF POOR QUALITY

Refraction, Scintillation and Polarization Losses: A radio ray passing through the lower non-ionized portion of the atmosphere undergoes bending caused by variation in radio refractive index. The effect is largely independent of frequency below 20 GHz and its magnitude is greatest at small angles of elevation.

Scintillation, i.e., fluctuation with time in the amplitude and direction or arrival of the signal, occurs because of inhomogeneities in the refractive index which vary in time. The time variation results from motions of these inhomogeneities in the atmosphere or from motion of the spacecraft. Under these conditions there may be a lack of phase coherence so that typical phase effects cease to be well defined. Large aperture antennas will not realize their full plane wave gain under these circumstances, so that an apparent pointing loss is observed.

Tropospheric scintillation occurs mainly at very low angles of elevation, although measurements show that the effect may not be negligible with high directivity antennas even at higher angles of elevation. Ionospheric scintillations have been observed quite frequently which we related to auroral phenomena. Such observations have been reported on frequencies up to 1 GHz. This ionospheric influence is, again, variable with time and location. Considerable effects have been observed at frequencies below 100 MHz.

The Faraday effect appears as a consequence of double refraction in the presence of the magnetic field of the earth. This gives rise to a rotation of the plane of polarization of a linearly polarized plane wave. The effect depends on the electron density and on the strength and

direction of the magnetic field. The total number of rotations is often several hundred in the HF band (3 to 30 MHz). The Faraday rotation may occasionally reach a value as high as 150° at 1 GHz. Considerable judgment must be exercised in applying propagation factors in the SC system link design. Many of the distribution automation (DAC) functions are not time-critical so that if for some reason a given message is not properly received another try can be made later with little or no penalty on DAC operations. If an intense rain storm interrupts customer meter reading in a localized area for 30 minutes, so be it. On the other hand such an interruption of some real-time operational management functions may be intolerable. It is evident that the time-sensitivity of DAC functions can have a significant affect on link design.

5.3.4 System Noise Interference Considerations

Many things contribute background noise within the transmission signal spectrum. Background noise arises from radiation from natural terrestrial and extra-terrestrial source, man-made noise, and equipment noise. Radio noise is commonly described in terms of an effective noise temperature (T_a) in degrees Kelvin (K).

Noise in the Receiving System - G/T: The quality of a receiving system can be quantified by measuring its G/T ratio, which serves as a figure of merit. G/T is the antenna gain (G) divided by the operating noise temperature (T) of the

receiving system; (T) includes antenna noise temperature, receiver noise temperature, and the effects of transmission-line losses.

Antenna Noise Temperature: A receiving antenna can be considered to be surrounded by a spherical surface. Each differential element of the surface has an absolute noise temperature peculiar to that particular elevation and azimuth from the center of the sphere. The equivalent noise temperature of the antenna can be described by an integral of the product of the antenna gain in various directions and the noise temperatures in those directions.

It should be noted that a radome will increase antenna noise temperature because of its attenuation, and because of ground noise reflections from the radome's inner surface into the antenna aperture.

Figure 5-17 is the familiar plot of sky noise versus frequency for two elevation angles above the horizon. The ideal antenna, with a finite main lobe and no side lobes, receives a minimum amount of noise when pointed vertically away from the galactic noise source (i.e., toward the galactic pole). Cosmic sources generate most of the noise below 1 GHz. Atmospheric absorption noise is responsible for antenna temperatures that increase rapidly above 10 GHz. The atmosphere also causes dramatic increases in realizable antenna temperatures as the antenna elevation angle is reduced.

The more important sources of external radio noise and their noise temperatures are shown in Figure 5-18 as a function of frequency. Noise levels are also shown as noise figure in dB above kT_0B , which refers to thermal noise power at a reference temperature T_0 of 290° Kelvin. (k) is Boltzmann's constant, and (B) is receiver bandwidth.

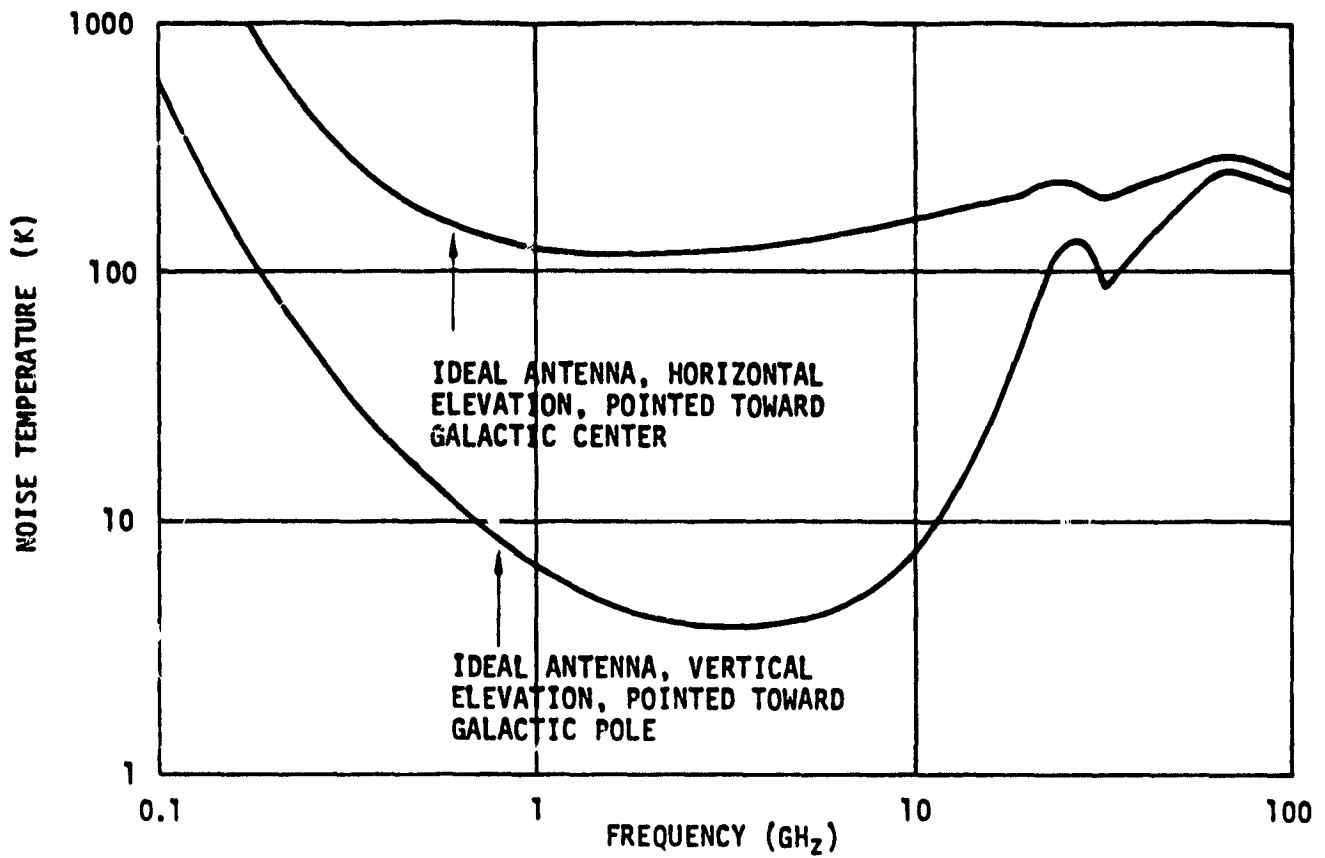


Figure 5-17 SKY NOISE FOR GROUND STATION ANTENNA

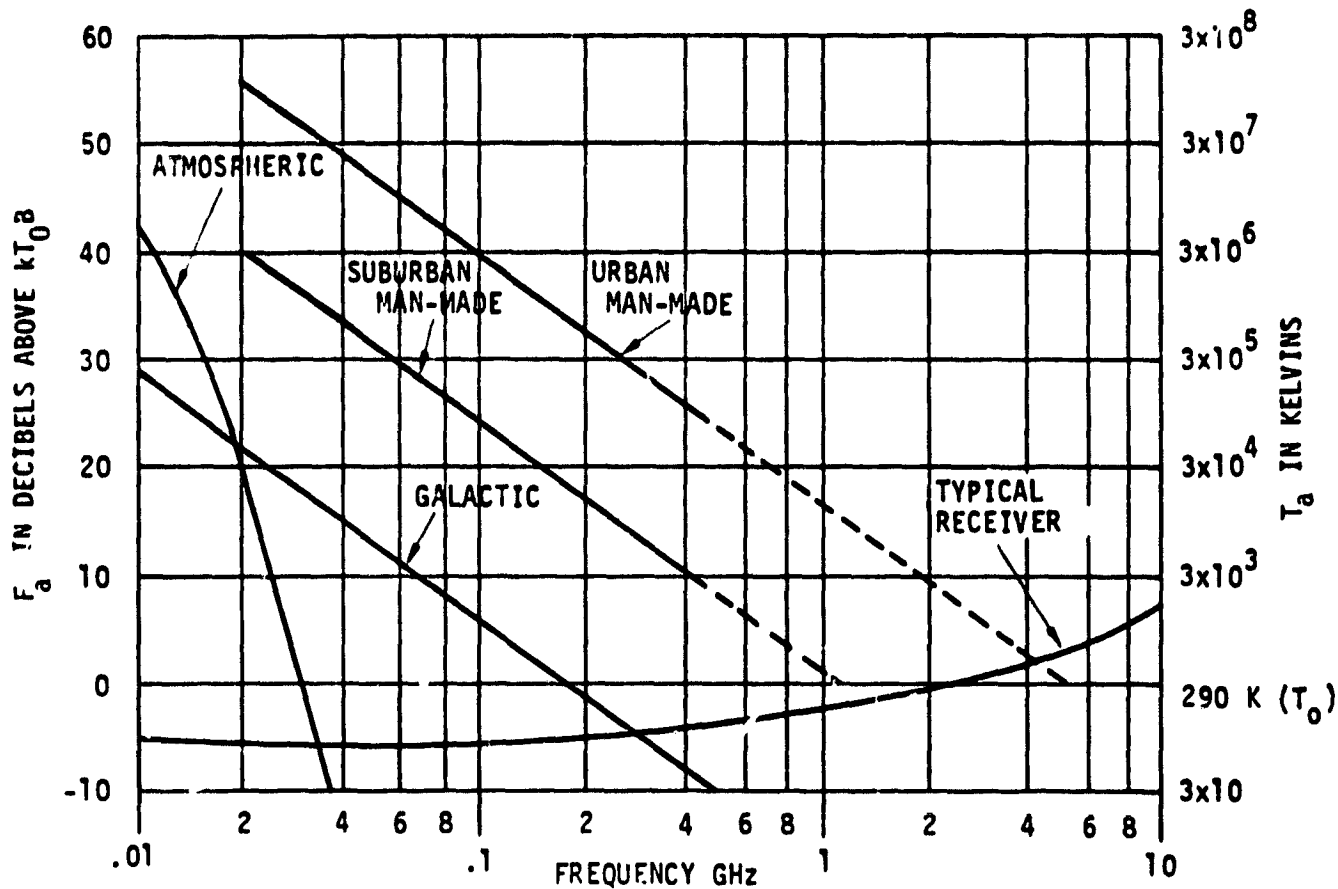


FIGURE 5-18 MEDIAN VALUES OF AVERAGE NOISE POWER (OMNI-ANTENNA NEAR SURFACE)

Atmospheric Noise: Atmospheric noise is produced by lightning discharges in thunderstorms and is a predominant factor in HF radio communications.

Cosmic Noise: There are three types of cosmic noise, namely the background radiation from the galactic plane, radiation from large numbers of discrete point sources, and solar noise. Galactic noise temperature decreases as the frequency is increased and becomes negligible in comparison with a typical receiver noise at frequencies above 500 MHz (Figure 5-18). Point sources have a very small angular width and magnitude and are rarely of concern to a ground station antenna.

Sun Transit Outage: A brief interruption may be expected from a sun transit outage. The sun's noise temperature as observed at ground terminals is shown in Figure 5-19. At 1 GHz the noise density of -175 dBw/Hz corresponds to a noise figure of 29 dB. An outage may occur when the pointing angle from the ground terminal antenna to the geostationary satellite also coincides with that to the sun. This happens for approximately six days twice yearly, at apparent noon at the satellite longitude. The potential outage time is the time for the satellite shadow to traverse the ground terminal, which may last several minutes depending on ground antenna beam width.

Man-Made Noise: Man-made noise sources include both intentional and unintentional radiations. The former comes from fundamental emissions by other communication or electronic equipment, such as radar, navigation, and telecommunications. Unintentional radiations include emissions at non-fundamental frequencies from

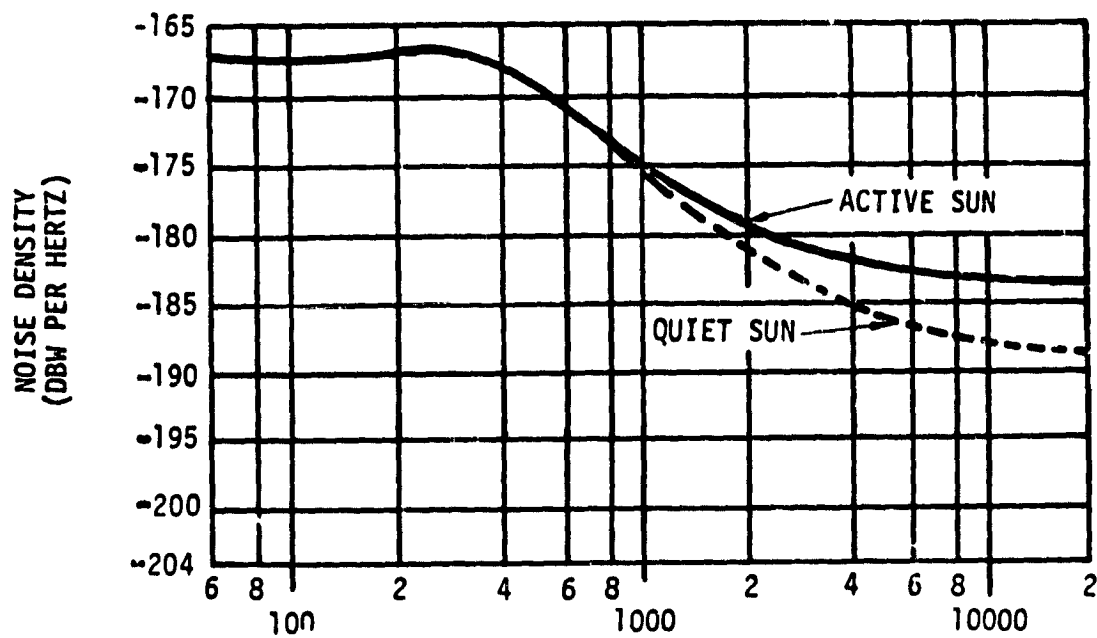


Figure 5-19 FREQUENCY IN MEGAHERTZ

the same communication or electronic equipment. They also include incidental emissions from high voltage power lines, automotive ignition systems, electric tools, machines, appliances, industrial devices and certain consumer products.

The intentional man-made noise sources do not generally become a serious source of interference due to governmental and international controls on their use, and careful user group coordination in their application.

Unintentional man-made noise is important to the SC system since customer and substation terminals are subject to this environment. This type of noise decreases with increasing frequency and varies considerably with location and proximity to the noise source (Figure 5-18). The average level of urban man-made noise can be 16 dB or more above that for suburban locations. As shown in the figure, high man-made noise levels can limit the sensitivity of a receiving system.

Electric power stations are known to be noise generators. Corona discharge from high voltage lines consists of a broad spectrum of frequencies, with electromagnetic interference (EMI) becoming more severe during foul weather. These fields can enter radio equipment through their antennas and result in desensitization of a typical receiver, provided the antenna does not give any discrimination against the radiating source. Data from unpublished tests using receivers operating in the VHF band in the yard of a 115/60 kV substation revealed desensitization of approximately 25 dB.

In addition to EMI from corona discharge, radiated fields from disconnect switching have been measured with composite field intensities of 600 volts/meter (176 dBuv/meter) with frequency content extending into the MHz range. This type of EMI can result in impulse type noise entering radio equipment either via the antenna or through direct coupling into the radio equipment wiring.

Automobile ignition interference can also cause problems. This is particularly true for equipment operating in the VHF range. The potentially severe noise environment at frequencies of interest points up the necessity for evaluating electric power stations for radiated EMI prior to selecting the frequency of operation, radio equipment, and antenna type.

Receiver Noise Temperature: Contributors to the receivers' effective noise temperature for both the earth and satellite units are the low noise amplifier (LNA), the second-stage amplifier, and the transmission line. The contributions of each element can be controlled during system design to a certain extent.

The LNA may add from 3 to 60°K to the system noise temperature, depending on the type of unit selected. Cost and performance tradeoffs tend to indicate that parametric amplifiers (paramps) are the most cost effective in the 4 and 6 GHz bands, the two most popular for telecommunication use. Noise temperatures of 20°K

are realizable with cooled paramps as shown in Figure 5-20. A maser can have a 3°K effective temperature, however, the improvement over a paramp does not justify their cost and complexity for satellite use. Solid-state transistor amplifiers and tunnel diode amplifiers cost less than paramps and can provide sufficiently low noise temperatures for the customer terminal receiver. Noise temperatures of low cost components for customer terminals could range from 2600°K at 4 GHz to $11,000^{\circ}\text{K}$ at 20 GHz. A noise temperature for the satellite receiver of 500° can readily be obtained with highly reliable devices.

Satellite Transponder Noise: The up-link signal-to-noise ratio (SNR) can be degraded on the down-link by transponder noise.

The signal radiated from the satellite has the background noise that is generated in the transponder itself. Receiver noise, intermodulation effects, the frequency translation process, and transmitter noise combine to produce an increased noise background for the signal from the satellite.

One approach to obtaining a desired overall SNR is to improve either the uplink SNR or the downlink SNR to compensate for the transponder noise degradation. A second approach used on satellites today is to provide on-board processing, thus decoupling the uplinks and downlinks so they perform independently and more efficiently. On-board processing is discussed further in paragraph 5.3.6.

5.3.5 Modulation and System Performance

Digital Modulation: A wide variety of digital modulation techniques have been developed to optimize performance in terms of required bandwidth, energy and data rate. Digital transmissions use two elementary signals, a "mark" and a

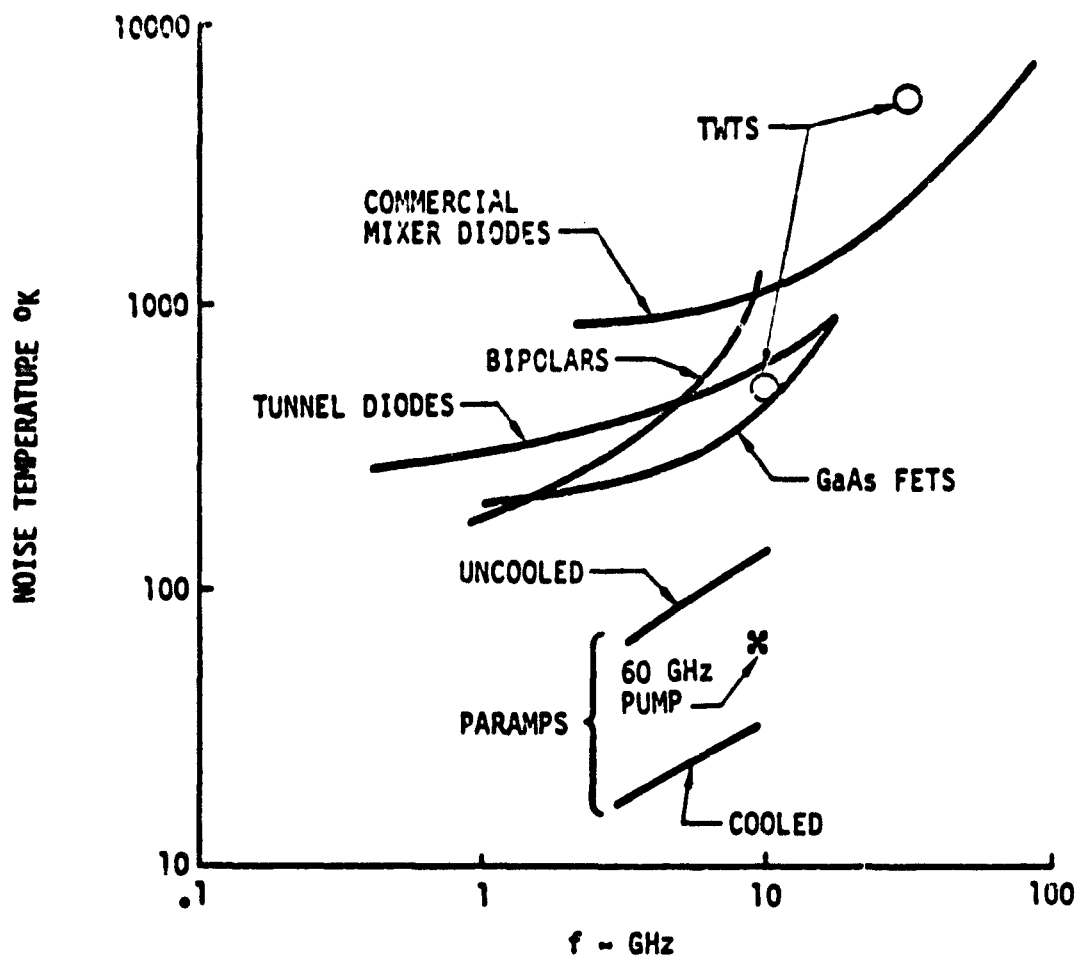


Figure 5-20 NOISE TEMPERATURES FOR VARIOUS MICROWAVE DEVICES

"space" ("one" and "zero"), generated by modulating an RF carrier. The modulation can change the carrier's amplitude, frequency, phase, or a combination of these, in a time sequence of two mutually exclusive states.

The receiver may sense the modulation by either coherent detection - where the receiver is phased-locked with the transmitter - or non-coherent detection. Usually a coherent system performs better than a noncoherent one, but at a higher equipment cost and complexity.

The most common modulation methods for digital transmissions are frequency-shift keying (FSK), phase-shift keying (PSK), and their derivatives.

1. FSK System: In an FSK system digital information is sent by a sequential transmission of carrier bursts of constant amplitude and duration; bursts at a frequency f_1 correspond to a "one", and bursts at f_2 correspond to a "zero."
2. PSK System: In a PSK system digital information is sent by a sequential transmission of carrier bursts of constant amplitude, frequency, and duration, but of different relative phases. In a differentially coherent PSK (DC-PSK) the information is conveyed by the phase transition between carrier bursts rather than by the absolute phases of the bursts. Usually a phase reversal (180°) indicates a "one", and no change (0°) indicates a "zero," or vice-versa.

The performance of a digital transmission link can be measured in terms of the bit-error-probability (BEP) vs normalized signal-to-noise ratio (E/No). A comparison of the "theoretical" BEP associated with FSK, PSK and DC-PSK is shown in Figure 5-21.

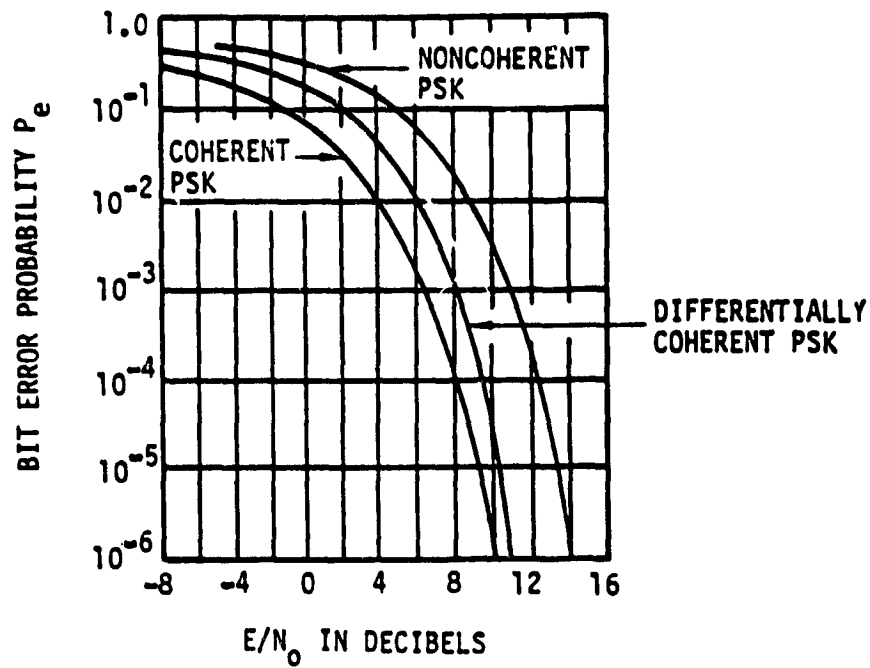


Figure 5-21 COMPARISON OF BINARY DATA TRANSMISSION SYSTEMS

The DC-PSK is one of the simplest modulation schemes which does not require coherent detection, and is considered a prime candidate for the SC system. There are several other techniques which also have merit and must be considered in more detailed design studies.

The performance of a typical digital receiver is usually less than the ideal theoretical value due to receiver mechanization and production tolerances. A good rule is to add 2 dB to the theoretical SNR (for a given BEP) for average performance.

Coding: The performance of a digital communication link can be enhanced by the use of orthogonal signalling, i.e., coding. This can reduce the required SNR, which in turn can be traded against transmitter power, antenna gain, etc. However, coding techniques require a more sophisticated receiving system which increases equipment complexity and cost.

System Degradation: A communication system's performance is affected by many factors, some of which are peculiar to a given system and are not predictable. Equipment design and operating characteristics will affect system performance. Such things as dynamic range, amplitude and phase distortions, temperature range, input power, cooling, mismatch of subsystems, susceptibility to electro-magnetic and other interferences can contribute to system degradation. On the other hand, periodic testing, maintenance, and equipment adjustments can contribute to superior performance. While any one of these factors may not be individually significant, they can add up. In the link analysis, 3 dB is allocated for system degradation. (Paragraph 5.3.8)

5.3.6 On-Board Processing

Processing on-board the satellite can provide several advantages compared with a linear transponder. Complex integrated circuits make it possible to introduce a high level of processing capability without adding significantly to weight or cost.

Some on-board processing functions to be considered are: (1) regeneration of uplink signals for the downlinks, thus decoupling these links so they can perform independently and more effectively; (2) active switching to distribute uplink signals among the various downlink channels; and (3) suppression of uplink jammers, and the denial of a transponder channel to unauthorized persons.

On-board Regeneration: On-board demodulation of the uplink signal and regeneration of the data for the downlink can improve link performance. For example, where up and downlink SNRs are equal, this regeneration can provide almost 2.6 dB improvement in performance relative to a linear transponder; while the error rate at the output of the ground terminal remains the same. If the SNR is the same at the regenerative satellite as at the receiving earth terminal, the bit error rates at the satellite and earth terminals are identical. Since these errors are independent, the total error rate at the earth terminal output includes those errors generated by the satellite as well as those generated by the earth terminal demodulation. Since these error rates are equal, the total error rate is double that of the satellite itself. This tandem error effect corresponds to <0.5 dB loss in signal power. On the other hand, a 3 dB performance degradation can occur in a conventional linear transponder operating at the same power level when the additional transponder terminal noise is added, and the error rate is thereby increased by approximately three orders of magnitude at low error rates.

Uplink SNRs of typical communication satellites are relatively high, and there is little advantage to on-board regeneration. However, for the SC system, where the customer terminal antenna is limited in size and transmission power, satellite regeneration is advantageous.

The main disadvantages of the regenerative transponder are: 1) the need for on-board processing, and 2) the constraints on signal modulation formats and the resulting lack of flexibility in changing modulation after the satellite is launched. However, this last disadvantage can be minimized by providing remote change-over to a linear transponder mode by a ground command.

On-board Switching: Connectivity and capacity are two system design features that can be significantly affected by the use of on-board processing. In most satellites the uplink to downlink interconnectivity is fixed, but with on-board processing, rapidly changing connectivity can be achieved. The usable capacity can be increased by dynamically assigning the satellite's resources to meet the communication load. The use of switching also permits the "switchboard in the sky" concept, wherein messages are routed by their address.

Switching and processing can be accomplished using RF or baseband signals. In its simplest form, the RF processor is a switch matrix having "n" inputs and "m" outputs, with any input being connectable to any output. A full baseband processor is more complicated. The digital RF signal is demodulated, decoded, re-encoded, and remodulated on the appropriate downlink carrier.

Jamming Suppression and Denial of Transponder Access: On-board baseband processing can be used to suppress uplink jamming and to deny the use of the transponder by unauthorized persons. The processor checks the received message for

validity before retransmitting it on the downlink. A typical message format can include several parity bits to serve as a minimum coding scheme. Thus, a valid message will have to pass the "parity check."

A noise message from an uplink jammer will not pass the "parity check" and thus could not capture the downlinks; this is not the case with a linear transponder where all signals within the operating bandwidth are retransmitted on the downlinks.

Unauthorized usage of the transponder can be prevented by incorporation of encryption, i.e., stored coding with periodic changes by ground command. This would require more complex equipment at the Master Control Stations (MCS).

A repeater-jammer in the vicinity of a utility MCS could intercept uplink signals and retransmit these valid messages at some later time prior to the next code change; thus the jammer could spoof the link. Access to the satellite can be denied an uplink spoofer by continuously transmitting in all time slots using dummy messages where necessary. The combined signals received at the satellite will not pass message format checks and will be ignored.

5.3.7 System Margin and Confidence Factor

A communication link analysis is usually based on the premise that system performance is a variable. The parameters used in the analysis fall into two categories, equipment parameters which can be measured, and meteorological or natural parameters which tend to be determined in a statistical sense.

The standard method of analysis is to use nominal or theoretical values for each term in a communication link equation. The standard method does not account for variability in terms except in a gross fashion where an allowance is made for "system margin."

The approach used in the SC system link analysis is somewhat different. Each term in the communication equation is characterized by a distribution function showing the percentage of time the parameter may fall within a given interval of values. For example, the output power of a transmitter will vary over its life cycle depending on the particular components used, the number of driving amplifiers stages, input power variations, etc. In the link analysis all parameters have been quantized in terms of a gaussian distribution. A gaussian distribution is a good approximation for most variables in the communication equation with the exception of rain attenuation and low frequency atmospheric noise, which is approximately a log-normal distribution. Each of the communication parameters has a central, or average, value and a standard deviation (SD). The values assigned to the SD may differ for the high and low side of the distribution, but in most cases the higher value is used in order to be conservative. Each parameter is considered to be an independent variable.

The overall variation in system performance is derived statistically from individual parameter variations. The SDs used are based on past experience, equipment specifications, analysis, or engineering estimates.

The probability of achieving a certain (or better) system performance during a period of time is defined as a "Confidence Factor." Table 5-5 lists confidence factors for various standard deviations. These are derived from the cumulative normal distribution function. A confidence factor of 50% implies that system performance will be equal to or greater than the nominal case 50% of the time. A system with a confidence factor of 95 percent will require a system margin corresponding to $\sigma = 1.644 \times \text{total SD}$.

Table 5-5 CONFIDENCE FACTORS VS STANDARD DEVIATIONS

<u>Confidence Factor (Percent)</u>	<u>Deviation from Mean Value in Units of σ</u>
99.87	3.000
95	1.644
90	1.282
85	1.040
80	0.841
75	0.676
60	0.254
50	0
40	-0.254
25	-0.676
10	-1.282
5	-1.644

5.3.8 RF Links Analysis

The design of a communication link involves a series of trade-offs to derive system parameters that will permit satisfactory output signal-to-noise ratios (SNR). The objective of the RF link design is to have a satisfactory probability of an adequate strength signal at the receiver so that when receiver noise and external noise are added, the SNR at the receiver output will provide the required data accuracy.

The analysis in this section will cover the uplinks and downlinks between the utility MCS's, the satellite, and the remote terminals. Each link analysis will examine seven operating frequencies from 150 MHz to 20 GHz to determine effects of frequency, transmitter power, antenna gain, etc. Usually two Confidence Factors will be examined for each link, such as 95% and 85%.

Customer Terminal to Satellite Link Analysis

The customer terminal configuration is the most sensitive element in the communication link.

The major link parameter entries were described in Paragraphs 5.3.1 through 5.3.7. The power budgets for the customer-satellite uplink and downlink are given in Tables 5-6A and 5-6B respectively. These correspond to a customer ground terminal antenna of 6"x6" (microstrip planar array) for frequencies above 1 GHz, and a short dipole antenna below that frequency; the ground antenna gain varies accordingly and at the lower frequencies is very low, i.e., omni-directional. The satellite antenna with a 3.4° beamwidth provides 34.4 dBi antenna gain. The ground transmitter power requirement is shown in Figure 5-22A and 5-22B; in solid lines when communicating with the satellite antenna of 3.4° beamwidth, in dashed lines with a satellite antenna of 1.2° beamwidth.

Parameter	F1	F2	F3	F4	F5	F6	F7
1. Operating Frequency	.15	.5	1.5	4	6	12	20
2. Transmitter Power	-0.2	8.8	12.4	6.6	6.7	8.1	12.3
3. Transmitter Circuit Losses	0.2	0.2	0.5	0.7	0.8	1	1.1
4. Transmitter Antenna Gain (6"/Dip)	0	0	6	14	17	23	28
5. Radome Loss	0	0	0.4	0.8	0.9	1.2	1.4
6. Uplink EIRP	-0.4	8.6	17.5	19.1	22	28.9	37.8
7. Free Space Propagation Loss (Ground E1 = 34.3°)	167.6	178	187.6	196.1	199.6	205.7	210.1
8. Atmospheric/or Rain Loss (1mm/hr Rain)	0	0	0.1	0.2	0.2	0.9	3.8
9. Polarization/Pointing Loss	2	1.7	1.5	1.3	1.2	1.1	1.0
10. Satellite Antenna Gain (3.4°)	34.4	34.4	34.4	34.4	34.4	34.4	34.4
11. Receiver Circuit Loss	1.2	1.6	2.0	2.4	2.5	2.8	3.0
12. Spacecraft Noise Temperature 500°K	27	27	27	27	27	27	27
13. Spacecraft G/T	6.2	5.8	5.4	5	4.9	4.6	4.4
14. Boltzman Constant	-228.6	-228.6	-228.6	-228.6	-228.6	-228.6	-228.6
15. Received C/N ₀	64.8	63.3	62.3	55.1	54.5	54.4	55.9
16. Signal Bandwidth (5 KBPS)	37	37	37	37	37	37	37
17. System Degradation	3	3	3	3	3	3	3
18. Required E _b /N ₀	11	11	11	11	11	11	11
19. Total Standard Deviation	8.41	7.50	6.88	2.49	2.14	2.04	2.97
20. Confidence Factor	95	95	95	95	95	95	95
21. System Margin	13.8	12.3	11.3	4.1	3.5	3.4	4.9

Table 5-6A CUSTOMER TO SATELLITE UPLINK ANALYSIS (ONE BEAM)

Parameter	F1	F2	F3	F4	F5	F6	F7
1. Operating Frequency	0.15	0.5	1.5	4	6	12	20
2. Transmitter Power	33.5	29.6	23.0	14.2	14.3	18.7	25.9
3. Transmitter Circuit Loss	1.2	1.6	2.0	2.4	2.5	2.8	3.0
4. Transmitter Antenna Gain (3.4°)	34.4	34.4	34.4	34.4	34.4	34.4	34.4
5. Downlink EIRP	66.7	59.4	55.4	46.2	46.2	50.3	57.3
6. Free Space Propagation Loss (Ground E1 = 34.3°)	167.6	178	187.6	195.1	199.6	205.7	210.1
7. Atmospheric/or Rain Loss (1mm/hr rain)	0	0	0.1	0.2	0.2	0.9	3.8
8. Polarization/Pointing Loss	2	1.7	1.5	1.3	1.2	1.1	1.0
9. Radome Loss	0	0	0.4	0.8	0.9	1.2	1.4
10. Ground Antenna Gain (6°/Dip)	0	0	6	14	17	23	28
11. Receiver Circuit Loss	0.3	0.4	0.5	0.7	0.8	1.0	1.1
12. Receiver Noise Figure	36*	23*	13*	10	10	13	16
13. Boltzman Constant	-204	-204	-204	-204	-204	-204	-204
14. Received C/N ₀	64.8	63.3	62.3	55.1	54.5	54.4	55.9
15. Signal Bandwidth (5 KBPS)	37	37	37	37	37	37	37
16. System Degradation	3	3	3	3	3	3	3
17. Required E _b /N ₀	11	11	11	11	11	11	11
18. Total Standard Deviation	8.4i	7.5	6.88	2.49	2.14	2.04	2.97
19. Confidence Factor	95	95	95	95	95	95	95
20. System Margin	13.8	12.3	11.3	4.1	3.5	3.4	4.9

*Note: Limited by Urban Man-Made Noise Level

Table 5-6B SATELLITE TO CUSTOMER - DOWNLINK ANALYSIS (ONE BEAM)

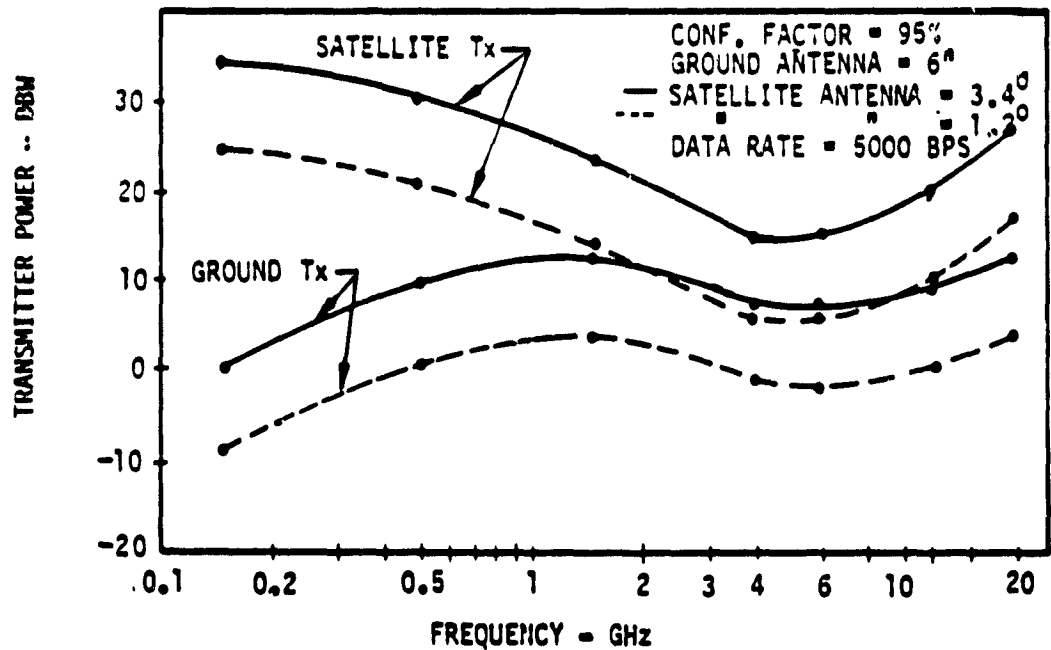


FIGURE 5-22A CUSTOMER-SATELLITE LINKS C.F. 95%

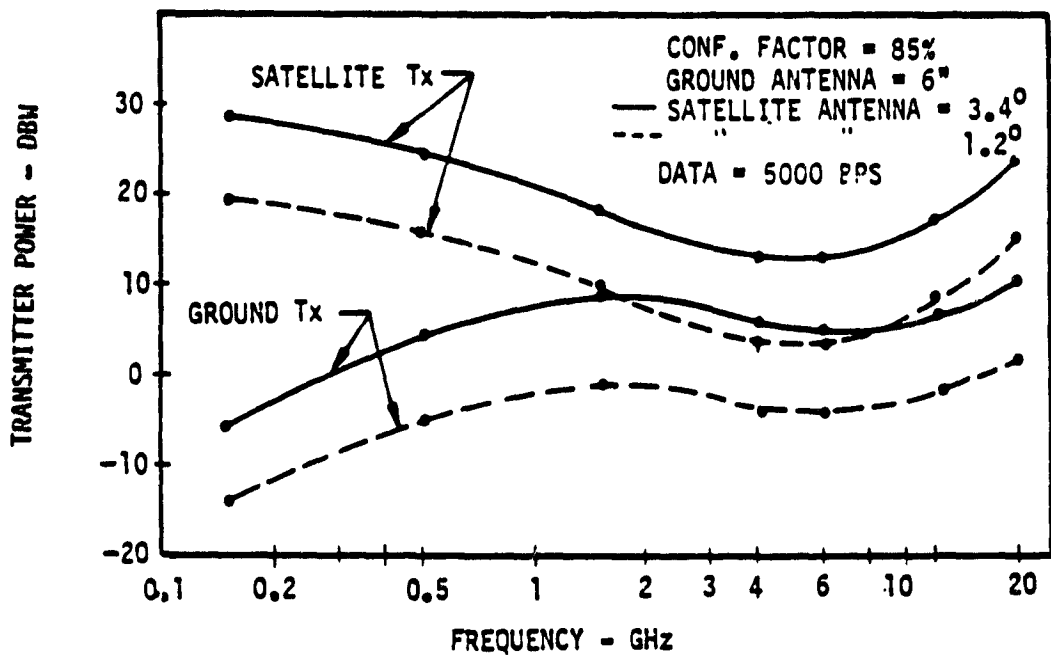


Figure 5-22B CUSTOMER-SATELLITE LINKS C.F. 85%

The variations between Figure 5-22A and 5-22B correspond to the system Confidence Factor of 95% and 85%, where less system margin is required for the latter. Thus the transmitter power for the 85% case can be reduced by $\Delta = 0.604 \times \text{Total SD}$ in dB relative to that of the 95% case.

The atmospheric loss used corresponds to that of a 20° elevation, or higher. The rain loss (combined with atmospheric losses) is estimated for a 1 mm/hr rate and a rain path of 27 km, as the nominal case. The standard deviation estimate for rain loss is based on a 4 mm/hr rate and a 12 km rain path.

The receiver circuit loss in the satellite allows for multiple-beam forming, switching, and other related losses. The same applies in downlink transmitter circuit losses.

The spacecraft receiver noise temperature is 500°K . It utilizes low noise microwave devices with no receiver cooling required.

In the downlink analysis a receiver noise figure as high as 36 dB at 150 MHz is used due to the high urban man-made noise which will limit a sensitive receiver; thus the satellite transmitter power requirement is increased in the low bands.

The system bandwidth is equal to the data rate, i.e., 5 KHz using differentially coherent phase shift keying type of modulation. The bit energy to noise density E_b/N_0 ratio provides a BEP of 10^{-4} or lower.

Typical standard deviations (SD) for individual link parameters are given in Table 5-7. The total SD is determined statically and system margin requirements

Parameter's Standard Deviation	F1	F2	F3	F4	F5	F6	F7
1. Operating Frequency	0.150	0.5	1.5	4	6	12	20
2. Transmitter Power	0.3	0.3	0.3	0.3	0.3	0.3	0.3
3. Transmitter Circuit Loss	0	0	0	0	0	0	0
4. Ground Antenna Gain	0.2	0.2	0.2	0.3	0.3	0.3	0.3
5. Radome Loss	0	0	0	0	0	0	0
6. Uplink EIRP	-	-	-	-	-	-	-
7. Propagation Loss Long Term Fading	5.5	4.0	2.7	1.5	0.8	0	0
8. Atmospheric/or Rain Loss (0 = 4 mm/hr rain)	0	0	0	0	0	0.5	2.2
9. Polarization/Printing Loss	1	0.8	0.6	0.5	0.5	0.5	0.5
10. Satellite Antenna Gain	1	1	1	1	1	1	1
11. Receiver Circuit Loss	0	0	0	0	0	0	0
12. Receiver Noise Figure	1	1	1	1	1	1	1
13. Spacecraft G/T	-	-	-	-	-	-	-
14. Boltzman Constant	0	0	0	0	0	0	0
15. Received C/N ₀	-	-	-	-	-	-	-
16. Signal Bandwidth	1	1	1	1	1	1	1
17. System Degradation	0.5	0.5	0.5	0.5	0.5	0.5	0.5
18. Required E _g /N ₀	0.5	0.5	0.5	0.5	0.5	0.5	0.5
19. Total Standard Deviation	5.90	4.50	3.36	2.49	2.14	2.04	2.97
20. System Margin	-	-	-	-	-	-	-

Table 5-7 TYPICAL STANDARD DEVIATIONS FOR SATELLITE LINK ANALYSIS (ONE BEAM)

Note: Add SD = 6 dB for multipath Variation for GR(10dB)

are obtained as discussed in Paragraph 5.3.7. The SD for long term fading is higher for lower frequencies. An addition SD=6 dB is included for multipath when using non-directive ground antenna because not enough side lobe isolation is available.

A second set of power budgets for customer-satellite uplink and downlink is give in Table 5-8A and Table 5-8B respectively. The second set corresponds to a customer ground terminal antenna of 12"x12" (microstrip array) or dipole antenna. The ground and satellite transmitter power requirements with two different satellite antennas are shown in Figures 5-23 A and B where a 6 dB reduction in power is realized due to a 6 dB increase in antenna gain. A microstrip antenna of 12"x6" provides only a 3 dB increase over a 6"x6" antenna.

Master Control Station - Satellite Link Analysis

The utility MCS to satellite link must be highly reliable and secure. The ground antenna is not critical with regard to size as in the case of the customer terminals. The ground antenna is a conventional parabolic dish above 1 GHz, but not to exceed 10 feet. Having directive antennas at both ends of this link makes for very reliable communications.

The power-budgets for these links are given in Table 5-9A and 5-9B. The corresponding ground transmitter power is very low as shown in Figures 5-24A and B. The uplink corresponds to a very reliable system having a Confidence Factor of 99.87%, i.e., 3σ case. The satellite transmitter power for the downlink is shown only for a Confidence Factor of 95% in order to keep the total power within reasonable satellite power limits.

Parameter	F1	F2	F3	F4	F5	F6	F7
1. Operating Frequency	.15	.5	1.5	4	6	12	20
2. Transmitter Power	5.8	5.8	0.6	0.6	0.7	2.1	6.3
3. Transmitter Circuit Loss	0.2	0.2	0.5	0.7	0.8	1	1.1
4. Transmitter Antenna Gain (12"/Dip)	0	3	12	20	23	29	34
5. Radome Loss	0	0	0.4	0.8	0.9	1.2	1.4
6. Uplink EIRP	-0.4	8.6	11.7	19.1	22	28.9	37.8
7. Free Space Propagation Loss (Ground E1 = 34.3°)	167.6	178	187.6	196.1	199.6	205.7	210.1
8. Atmospheric/or Rain Loss (1mm/hr Rain)	0	0	0.1	0.2	0.2	0.9	3.8
9. Polarization/Pointing Loss	2	1.7	1.5	1.3	1.2	1.1	1.0
10. Satellite Antenna Gain (3.4°)	34.4	34.4	34.4	34.4	34.4	34.4	34.4
11. Receiver Circuit Loss	1.2	1.6	2.0	2.4	2.5	2.8	3.0
12. Spacecraft Noise Temperature 500°K	27	27	27	27	27	27	27
13. Spacecraft G/T	6.2	5.8	5.4	5	4.9	4.6	4.4
14. Boltzman Constant	-228.6	-228.6	-228.6	-228.6	-228.6	-228.6	-228.6
15. Received C/N ₀	64.8	63.3	56.5	55.1	54.5	54.4	55.9
16. Signal Bandwidth (5 KBPS)	37	37	37	37	37	37	37
17. System Degradation	3	3	3	3	3	3	3
18. Required E _f /N ₀	11	11	11	11	11	11	11
19. Total Standard Deviation	8.41	7.50	3.36	2.49	2.14	2.04	2.97
20. Confidence Factor	95	95	95	95	95	95	95
21. System Margin	13.8	12.3	5.5	4.1	3.5	3.4	4.9

Table 5-8A CUSTOMER TO SATELLITE UPLINK ANALYSIS (ONE BEAM)

Parameter	F1	F2	F3	F4	F5	F6	F7
1. Operating Frequency	0.15	0.5	1.5	4	6	12	20
2. Transmitter Power	33.5	26.6	11.2	8.2	8.3	12.7	19.5
3. Transmitter Circuit Loss	1.2	1.6	2.0	2.4	2.5	2.8	3.0
4. Transmitter Antenna Gain (3.4°)	34.4	34.4	34.4	34.4	34.4	34.4	34.4
5. Downlink EIRP	66.7	59.4	43.6	40.2	40.2	44.3	51.3
6. Free Space Propagation Loss (Ground E1 = 34.30)	167.6	178	187.6	196.1	199.6	205.7	210.1
7. Atmospheric/or Rain Loss (1mm/hr Rain)	0	0	0.1	0.2	0.2	0.9	3.8
8. Polarization/Pointing Loss	2	1.7	1.5	1.3	1.2	1.1	1.0
9. Radome Loss	0	0	0.4	0.8	0.9	1.2	1.4
10. Ground Antenna Gain (12"/Dip)	0	3	12	20	23	29	34
11. Receiver Circuit Loss	0.3	0.4	0.5	0.7	0.8	1.0	1.1
12. Receiver Noise Figure	36*	23*	13*	10	10	13	16
13. Boltzman Constant	-204	-204	-204	-204	-204	-204	-204
14. Received C/N ₀	64.8	63.3	56.5	55.1	54.5	54.4	55.9
15. Signal Bandwidth (5 KBPS)	37	37	37	37	37	37	37
16. System Degradation	3	3	3	3	3	3	3
17. Required E _b /N ₀	11	11	11	11	11	11	11
18. Total Standard Deviation	8.41	7.5	3.36	2.49	2.14	2.04	2.97
19. Confidence Factor	95	95	95	95	95	95	95
20. System Margin	13.8	12.3	5.5	4.1	3.5	3.4	4.9

TABLE 5-88 SATELLITE TO CUSTOMER DOWNLINK ANALYSIS (ONE BEAM)

*NOTE: LIMITED BY URBAN MAN-MADE NOISE LEVEL

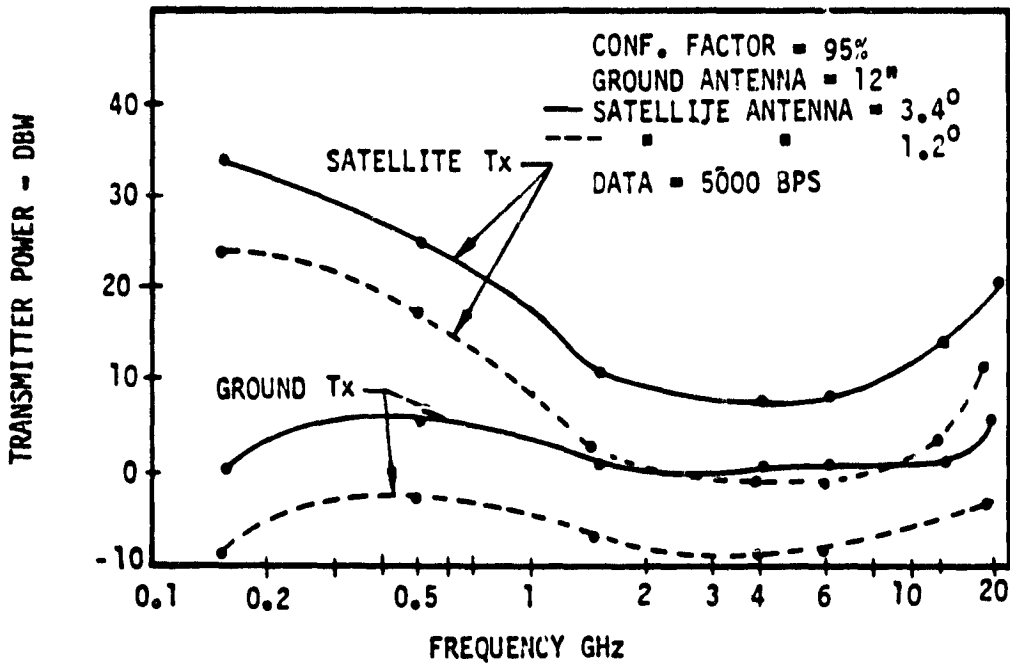


FIGURE 5-23A CUSTOMER-SATELLITE LINKS C.F. 95%

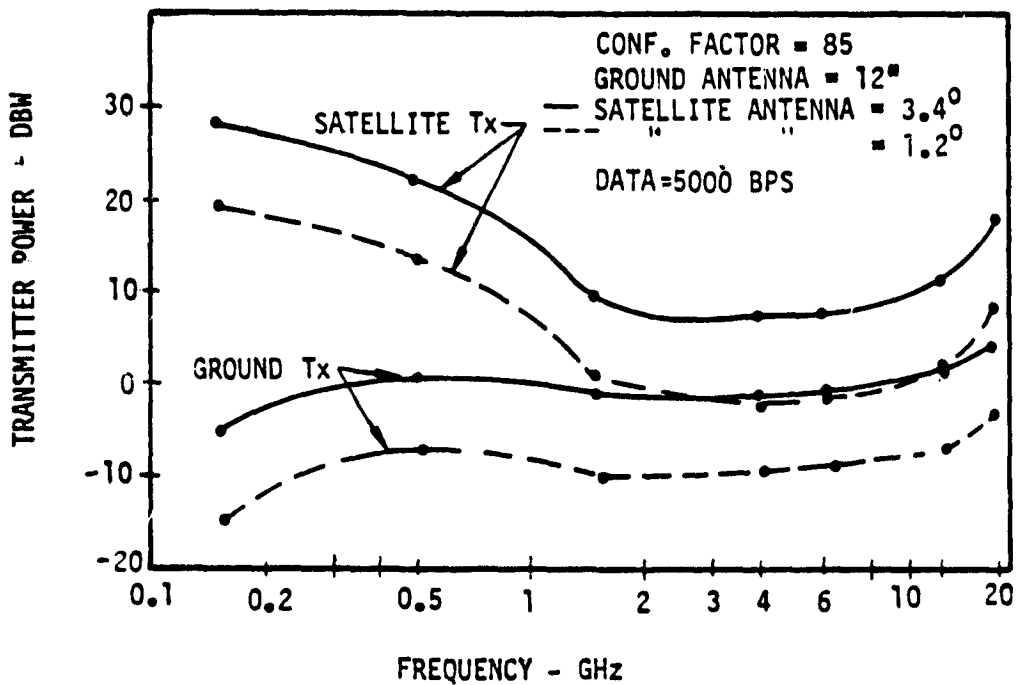


Figure 5-23B CUSTOMER-SATELLITE LINKS C.F. 85%

Parameter	F1	F2	F3	F4	F5	F6	F7
1. Operating Frequency	.15	.5	1.5	4	6	12	20
2. Transmitter Power	-14.3	-16.1	-17.4	-9.4	-6.3	1.1	6.3
3. Transmitter Circuit Loss	0.2	0.2	0.5	0.7	0.8	1	1.1
4. Transmitter Antenna Gain (10' Max)	10	20	30	30	30	30	34
5. Radome Loss	0	0	0.4	0.8	0.9	1.2	1.4
6. Uplink EIRP	-4.5	3.7	11.7	19.1	22	28.9	37.8
7. Free Space Propagation Loss (Ground E1 = 34.30)	167.6	178	187.6	196.1	199.6	205.7	210.1
8. Atmospheric/or Rain Loss (1mm/hr Rain)	0	0	0.1	0.2	0.2	0.9	3.8
9. Polarization/Pointing Loss	2	1.7	1.5	1.3	1.2	1.1	1.0
10. Satellite Antenna Gain	34.4	34.4	34.4	34.4	34.4	34.4	34.4
11. Receiver Circuit Loss	1.2	1.6	2.0	2.4	2.5	2.8	3.0
12. Spacecraft Noise Temperature 500°K	27	27	27	27	27	27	27
13. Spacecraft G/T	6.2	5.8	5.4	5	4.9	4.6	4.4
14. Boltzman Constant	-228.6	-228.6	-228.6	-228.6	-228.6	-228.6	-228.6
15. Received C/N	60.7	58.4	56.5	55.1	54.5	54.4	55.9
16. Signal Bandwidth (5 KBPS)	37	37	37	37	37	37	37
17. System Degradation	3	3	3	3	3	3	3
18. Required E_b/N_0	11	11	11	11	11	11	11
19. Total Standard Deviation	5.90	4.50	3.36	2.49	2.14	2.04	2.97
20. Confidence Factor	95	95	95	95	95	95	95
21. System Margin	9.7	7.4	5.5	4.1	3.5	3.4	4.9

TABLE 5-9A UTILITY MCS TO SATELLITE - UPLINK ANALYSIS (ONE BEAM)

Parameter	F1	F2	F3	F4	F5	F6	F7
1. Operating Frequency	.15	.5	1.5	4	6	12	20
2. Transmitter Power	19.4	4.7	-6.8	-1.8	+1.3	11.7	19.9
3. Transmitter Circuit Loss	1.2	1.6	2.0	2.4	2.5	2.8	3.0
4. Transmitter Antenna Gain	34.4	34.4	34.4	34.4	34.4	34.4	34.4
5. Downlink EIRP	52.6	37.5	25.6	30.2	33.2	43.3	
6. Free Space Propagation Loss (Ground E1 = 34.3°)	167.6	178	187.6	196.1	199.6	205.7	210.1
7. Atmospheric/or Rain Loss	0	0	0.1	0.2	0.2	0.9	3.8
8. Polarization/Pointing Loss	2	1.7	1.5	1.3	1.2	1.1	1.0
9. Radome Loss	0	0	0.4	0.8	0.9	1.2	1.4
10. Ground Antenna Gain (10' Max.)	10	20	30	30	30	30	34
11. Receiver Circuit Loss	0.3	0.4	0.5	0.7	0.8	1.0	1.1
12. Receiver Noise Figure	36*	23*	13*	10	10	13	16
13. Boltzman Constant	-204	-204	-204	-204	-204	-204	-204
14. Received C/N ₀	60.7	58.4	56.5	55.1	54.5	54.4	55.9
15. Signal Bandwidth (5 KBPS)	37	37	37	37	37	37	37
16. System Degradation	3	3	3	3	3	3	3
17. Required E _b /N ₀	11	11	11	11	11	11	11
18. Total Standard Deviation	5.90	4.50	3.36	2.49	2.14	2.04	2.97
19. Confidence Factor	95	95	95	95	95	95	95
20. System Margin	9.7	7.4	5.5	4.1	3.5	3.4	4.9

TABLE 5-9B SATELLITE TO UTILITY MCS - DOWNLINK ANALYSIS (ONE BEAM)

*NOTE: LIMITED BY URBAN MAN-MADE NOISE LEVEL

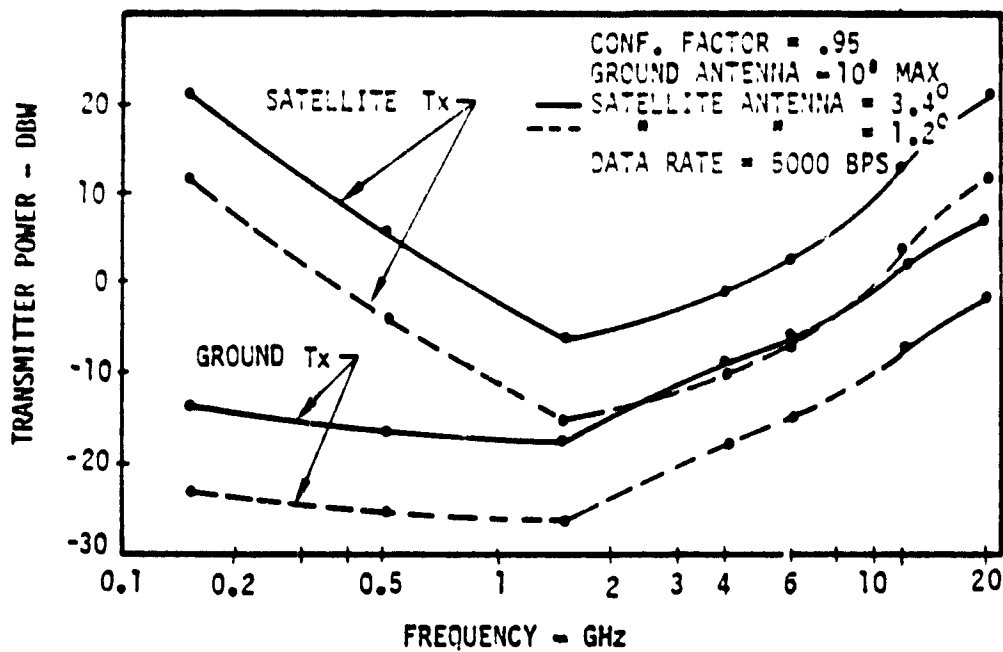


FIGURE 5-24A UTILITY MCS-SATELLITE LINKS C.F. 95%

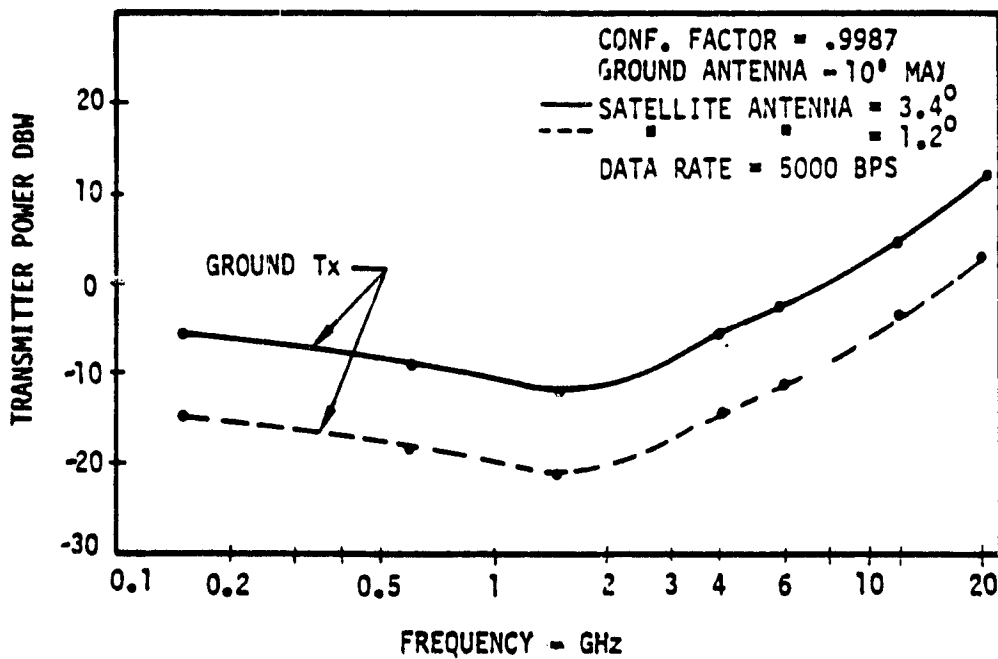


Figure 5-24B UTILITY MCS - SATELLITE LINKS C.F. 99.87%

D180-25403-2

5-69

Substation-Satellite Link Analysis

The substation satellite links can be highly reliable even though they are limited to some degree by the size of an acceptable ground antenna (mostly a cost factor), and the close proximity to the radio noise of the substation power lines, and to other noise sources.

The power-budget for the uplink and downlink is given in Table 5-9A and 5-9B respectively, and are similar to the customer satellite case. The ground antenna at the lower frequencies will be a reasonably directive type with a minimum gain of 10 dBi. The antenna could be an "off-the-shelf," Yaggi-UDA array, a Helix or a Horn. The ground and satellite transmitter power requirements are shown in Figure 5-25A and 5-25B.

An additional emergency uplink is shown in Figure 25A for the substation to satellite uplink only. The power budget for the emergency uplink is given in Table 5-9C. The satellite receiving antenna will provide a widebeam $3.8^{\circ} \times 7^{\circ}$ (25.6 dBi gain) for CONUS coverage.

Parameter	F1	F2	F3	F4	F5	F6	F7
1. Operating Frequency	.15	.5	1.5	4	6	12	20
2. Transmitter Power	-14.3	-6.1	-7.4	0.6	0.7	2.1	6.3
3. Transmitter Circuit Loss	0.2	0.2	0.5	0.7	0.8	1	1.1
4. Transmitter Antenna Gain	10	10	20	20	23	29	34
5. Radome Loss	0	0	0.4	0.8	0.9	1.2	1.4
6. Uplink EIRP	4.5	3.7	11.7	19.1	22	28.9	37.8
7. Free Space Propagation Loss (Ground E1 = 34.3°)	167.6	178	187.6	196.1	199.6	205.7	210.1
8. Atmospheric/or Rain Loss (1 mm/hr rain)	0	0	0.1	0.2	0.2	0.9	3.8
9. Polarization/Pointing Loss	2	1.7	1.5	1.3	1.2	1.1	1.0
10. Satellite Antenna Gain	34.4	34.4	34.4	34.4	34.4	34.4	34.4
11. Receiver Circuit Loss	1.2	1.6	2.0	2.4	2.5	2.8	3.0
12. Spacecraft Noise Temperature 500°K	27	27	27	27	27	27	27
13. Spacecraft G/T	6.2	5.8	5.4	5	4.9	4.6	4.4
14. Boltzman Constant	-228.6	-228.6	-228.6	-228.6	-228.6	-228.6	-228.6
15. Received C/N ₀	60.7	58.4	56.5	55.1	54.5	54.4	55.9
16. Signal Bandwidth (5 KBPS)	37	37	37	37	37	37	37
17. System Degradation	3	3	3	3	3	3	3
18. Required E _b /N ₀	11	11	11	11	11	11	11
19. Total Standard Deviation	5.90	4.50	3.36	2.49	2.14	2.04	2.97
20. Confidence Factor	95	95	95	95	95	95	95
21. System Margin	9.7	7.4	5.5	4.1	3.5	3.4	4.9

TABLE 5-10A SUBSTATION TO SATELLITE - UPLINK ANALYSES (ONE BEAM)

Parameter	F 1	F 2	F 3	F 4	F 5	F 6	F 7
1. Operating Frequency	.15	.5	1.5	4	6	12	20
2. Transmitter Power	19.4	14.7	3.2	8.2	8.3	12.7	19.9
3. Transmitter Circuit Loss	1.2	1.6	2.0	2.4	2.5	2.8	3.0
4. Transmitter Antenna Gain	34.4	34.4	34.4	34.4	34.4	34.4	34.4
5. Downlink EIRP	52.6	47.5	35.6	40.2	40.2	44.3	51.3
6. Free Space Propagation Loss (Ground E1 = 34.3)	167.6	178	187.6	196.1	199.6	205.7	210.1
7. Atmospheric/or Rain Loss	0	0	0.1	0.2	0.2	0.9	3.8
8. Polarization/Pointing Loss	2	1.7	1.5	1.3	1.2	1.1	1.0
9. Radome Loss	0	0	0.4	0.8	0.9	1.2	1.4
10. Ground Antenna Gain	10	10	20	20	23	29	34
11. Receiver Circuit Loss	0.3	0.4	0.5	0.7	0.8	1.0	1.1
12. Receiver Noise Figure	36*	23*	13*	10	10	13	16
13. Boltzman Constant	-204	-204	-204	-204	-204	-204	-204
14. Received C/N_0	60.7	58.4	56.5	55.1	54.5	54.4	55.9
15. Signal Bandwidth (5 KBPS)	37	37	37	37	37	37	37
16. System Degradation	3	3	3	3	3	3	3
17. Required E_b/N_0	11	11	11	11	11	11	11
18. Total Standard Deviation	5.56	4.5	3.36	2.49	2.14	2.04	2.97
19. Confidence Factor	95	95	95	95	95	95	95
20. System Margin	9.7	7.4	5.5	4.1	3.5	3.4	4.9

*Note: Limited by Urban Man-made Noise Level

TABLE 5-10B SATELLITE TO SUBSTATION - DOWNLINK ANALYSIS (ONE BEAM)

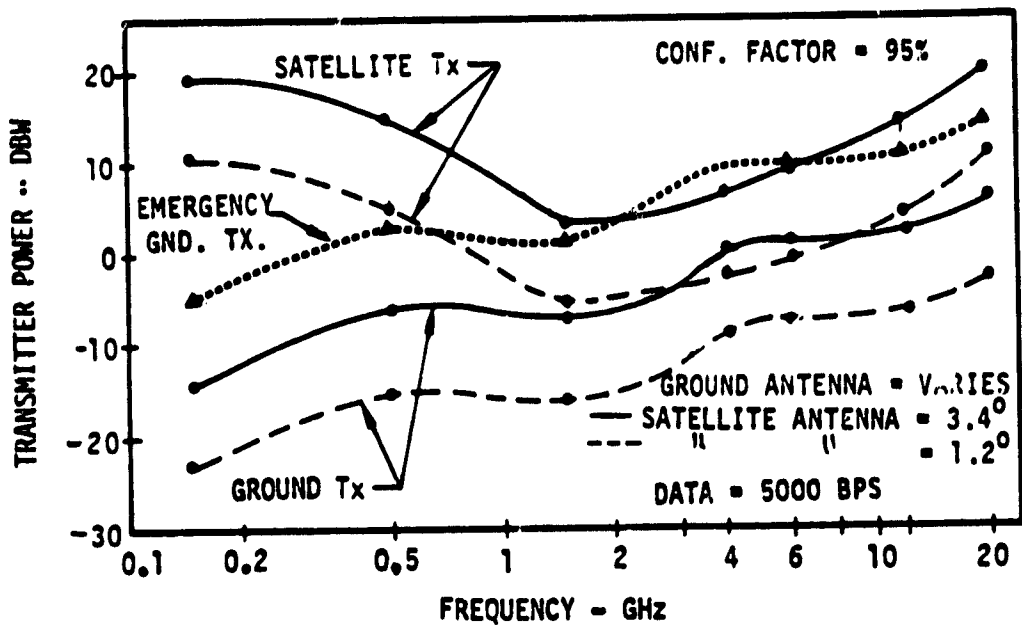


FIGURE 5-25A SUBSTATION - SATELLITE LINKS
POWER REQUIREMENTS C.F. 95%

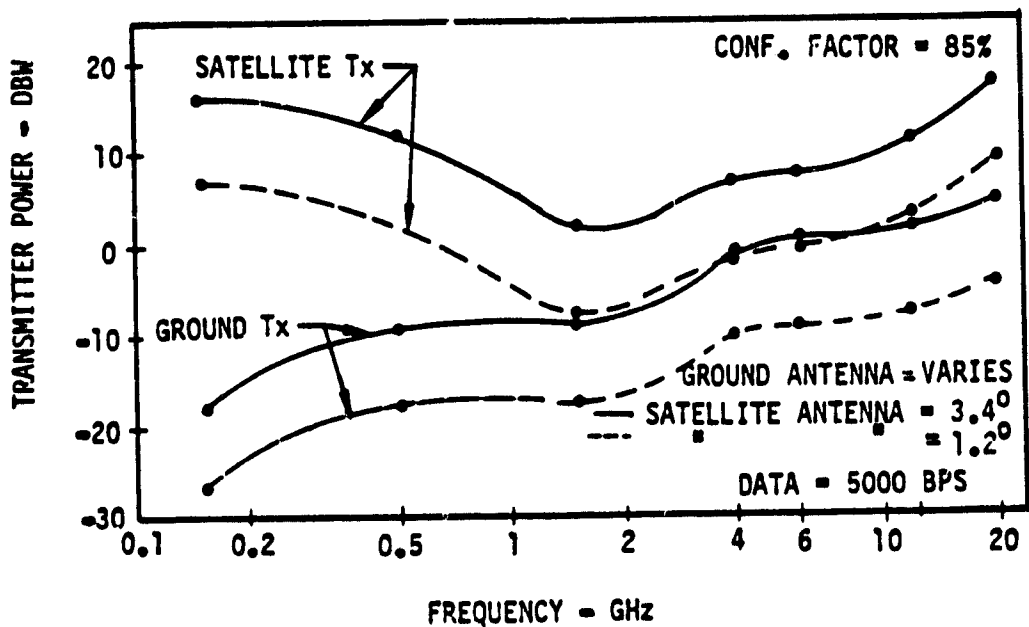


Figure 5-25B SUBSTATION - SATELLITE LINKS
POWER REQUIREMENTS C.F. 85%

Parameter	F1	F2	F3	F4	F5	F6	F7
1. Operating Frequency	GHZ	.15	1.5	4	6	12	20
2. Transmitter Power	dBW	-5.3	1.4	9.4	9.5	10.9	15.1
3. Transmitter Circuit Loss	dB	0.2	0.5	0.7	0.8	1	1.1
4. Transmitter Antenna Gain (10' max.)	dBi	10	10	20	20	29	34
5. Radome Loss	dB	0	0	0.4	0.8	1.2	1.4
6. Uplink EIRP	dBW	-4.5	3.7	11.7	19.1	28.9	46.6
7. Free Space Propagation Loss (Ground E1 = 34.3)	dB	167.6	178	187.6	196.1	205.7	210.1
8. Atmospheric/or Rain Loss (1 mm/hr Rain)	dB	0	0	0.1	0.2	0.9	3.8
9. Polarization/Pointing Loss	dB	2	1.7	1.5	1.3	1.1	1.0
10. Satellite Antenna Gain	dBd	25.6	25.6	25.0	25.6	25.6	25.6
11. Receiver Circuit Loss	dB	1.2	1.6	2.0	2.4	2.5	3.0
12. Spacecraft Noise Temperature 500°K	dB-°K	27	27	27	27	27	27
13. Spacecraft G/T	dB-°K	-2.6	-3.0	-3.4	-3.8	-4.2	-4.4
14. Boltzman Constant	dBW/k-Hz	-228.6	-228.6	-228.6	-228.6	-228.6	-228.6
15. Received C/N ₀	dB-Hz	60.7	58.4	56.5	55.1	54.4	55.9
16. Signal Bandwidth (5 KBPS)	dB	37	37	37	37	37	37
17. System Degradation	dB	3	3	3	3	3	3
18. Required E _b /N ₀	dB	11	11	11	11	11	11
19. Total Standard Deviation	dB	5.90	4.50	3.36	2.49	2.14	2.97
20. Confidence Factor	%	95	95	95	95	95	95
21. System Margin	dB	9.7	7.4	5.5	4.1	3.5	4.9

TABLE 5-10C SUBSTATION TO SATELLITE EMERGENCY CONUS UPLINK ANALYSIS

5.3.9 Carrier-Current Communication

One method for a number of customers to share a Receiver Unit or a Transceiver Unit is to use power line carrier-current communications between these Units and the Controllers, Control Modules, or Meter Transponders. Communication via power lines has been in existence for a long time. Utilities have used modulated carrier for voice and data communication on high voltage transmission lines for many years. Such applications typically involve only point-to-point communication along a single path in a relatively noise-free environment. In contrast, power line carrier systems using the distribution network must operate in the more complex topology of a distribution system that undergoes frequent reconfiguration, and in which there are many sources of electrical noise and signal loss. A typical signal transmission characteristic for one mile of overhead distribution line measured at the primary and at the secondary of a distribution transformer is reported to be as shown in Figure 5-26. Typical signal loss and noise levels have been reported as shown in Figure 5-27.

Because of the adverse environment, a power line carrier system reaching out any distance needs blocking circuits at shunt capacitors, and requires repeaters and transformer bypass circuits. Thus, the design and implementation of such a communication system is rather complicated and costly.

The SC system is not faced with long power line transmission paths, distance will generally be on the order of hundreds of feet, and the low voltage side of a customer service transformer is a comparatively benign environment essentially free of impediments and distractions.

A single Transceiver Unit mounted at a convenient location can be shared by customers, typically 10 to 15. Messages received from the satellite are processed and sent to the addressed device (meter transponder or control module) over the service lines, using carrier frequencies in the 200-240 KHz band. While the modulation techniques used are the same as those used at RF (differentially coherent bi-phase keying) the data rate is slower. A preliminary link budget indicates that a carrier current transmitter output of 1 watt should be satisfactory for distances up to 1000 feet.

Low power, short range carrier current communications such as that described are widely used in residential, commercial and industrial applications, for such things as intercoms, security systems, process control, etc.

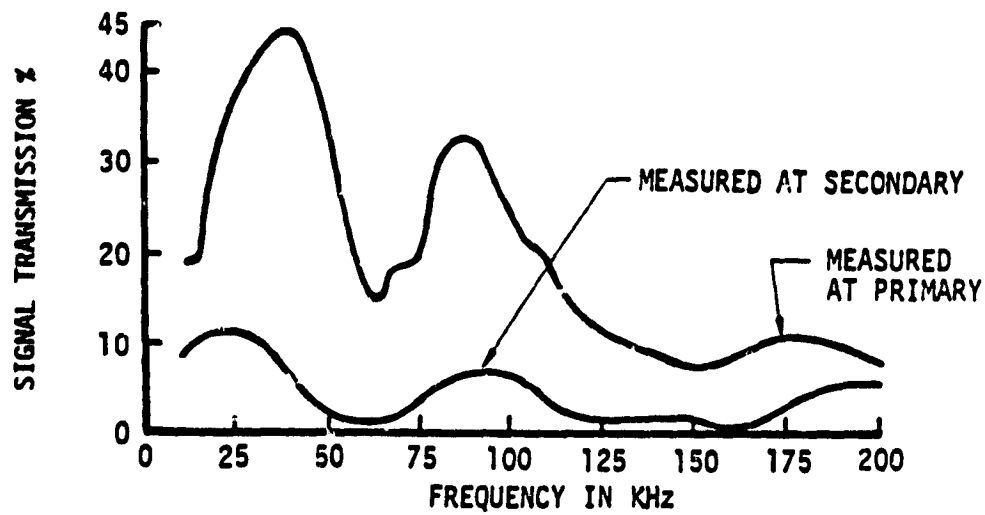


Figure 5-26 TYPICAL SIGNAL TRANSMISSION CHARACTERISTICS FOR ONE MILE OF OVERHEAD DISTRIBUTION LINE

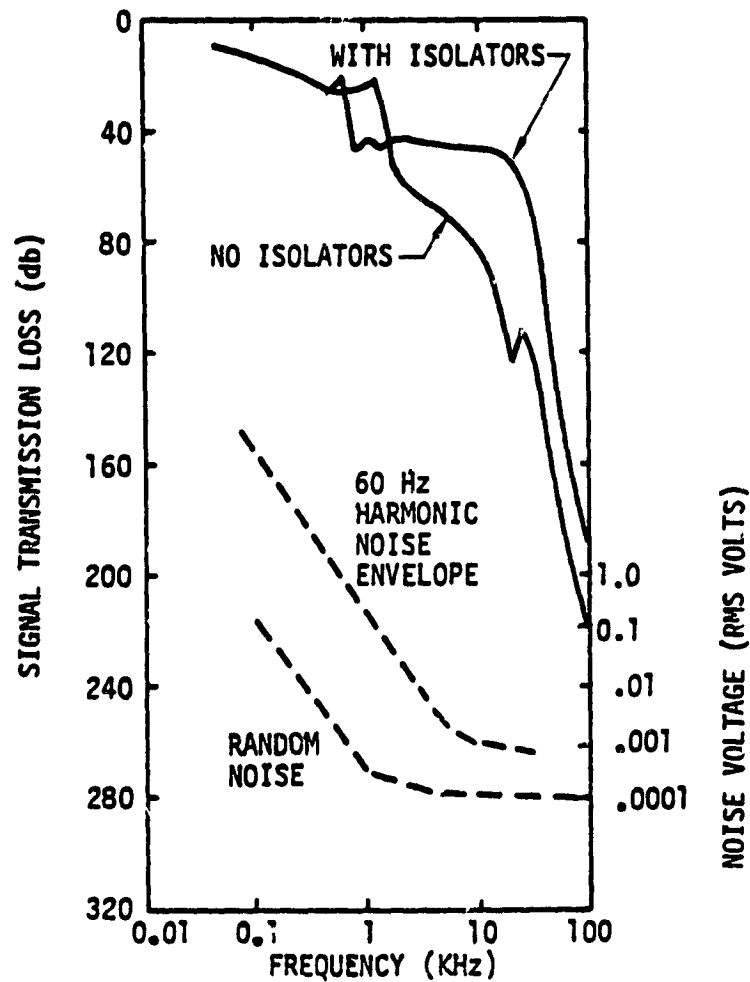


Figure 5-27 SIGNAL LOSS AND NOISE LEVEL ON DISTRIBUTION FEEDERS

D180-25403-2

5-77

5.4 Terminal Design Considerations

A key issue related to concept feasibility is whether suitable remote terminals can be mass produced at economic costs. As was shown in Section 3 many millions of terminals are required to implement distribution automation and control functions on a nationwide basis.

Three types of terminals are needed, Customer Terminals, Substation Terminals, and Monitor/Control Point Terminals.

These units are described below to a level of detail which permits cost estimating for concept feasibility purposes. Before they are discussed however, it is appropriate to list some basic assumptions that were used in formulating terminal concepts.

- 1) Frequency Allocation - Assume allocation may be anywhere within the 150 MHz to 20 GHz band.
- 2) Satellite vs. Ground Equipment Complexity - Put complexity where total program costs will be minimized.
- 3) System Efficiency - Sacrifice efficiency for simplicity.
- 4) Producibility - Emphasize producibility through use of parts and processes which are most readily automated.
- 5) Field installation - design for minimum skill levels.
- 6) Reliability - Assume use of high quality commercial/industrial components.

Specific requirements for remote customer terminals are identified in paragraph 4.2.

5.4.1 Customer Terminals

Customer terminals are intended to serve electricity users, be they residential, commercial, or industrial. How they are served depends on site peculiar conditions. A farmer at the end of a long distribution line presents a different situation from an apartment complex, or a residential neighborhood, or an industrial complex.

Because many customers are in close proximity to other customers, there are opportunities to share equipments.

Such a situation occurs in a residential neighborhood. Here one Transceiver Unit can be shared by all households connected to the low voltage side of the service transformer, using short range power line carrier-currents.

Neighborhood Terminal: A neighborhood terminal configured for load control and remote meter reading is shown diagrammatically in Figure 5-28. It consists of a Transceiver Unit, Meter Transponders at each customer, and up to three load Control Modules per customer. Premium Rate Indicators are provided each customer to display via colored lights the rate schedule in effect at any time, i.e., off-peak green, partial peak amber, or on-peak red.

Transceiver Unit: The Transceiver Unit is the link between the satellite and the carrier-current communication network serving the neighborhood. It consists of a microstrip antenna, an RF transceiver, a micro-computer, a carrier-current transceiver, a power supply, a standby battery, and tamper detection mechanisms. Figure 5-29. While this discussion is centered around

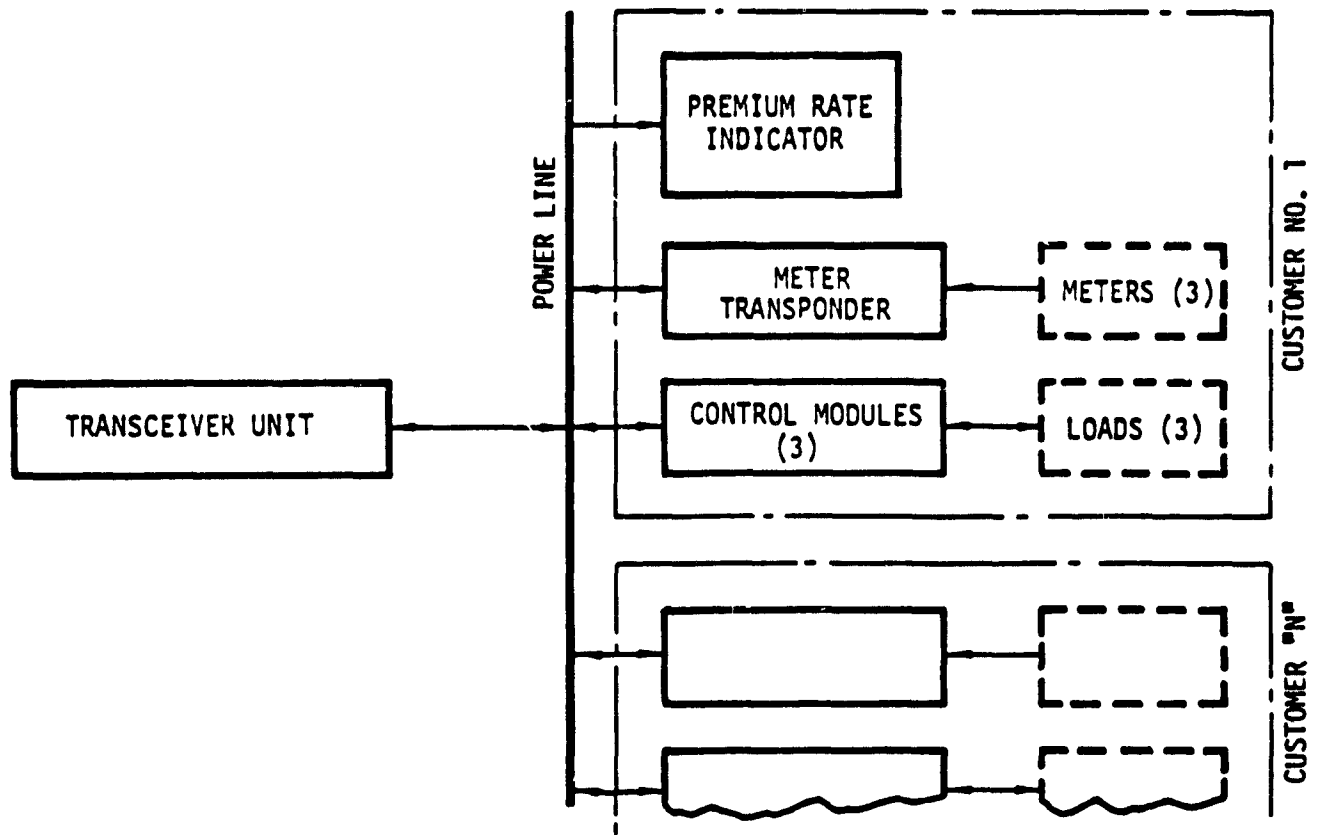


Figure 5-28 NEIGHBORHOOD TERMINAL, LOAD CONTROL & REMOTE METER READING

a neighborhood type of installation using power line carrier-current communications to individual homes, it should be noted that the Transceiver Unit can be used to service one or more customers using point-to-point control wires or other techniques.

Aside from processing messages from the satellite the Transceiver Unit periodically interrogates its slave Meter Transponders for up-to-date power consumption readings. These readings are processed and stored so as to be immediately available for retransmission to the satellite upon receipt of an appropriate READ command from the Master Control Center. A nickel cadmium battery is used to retain stored metering data during power outages.

Meter Transponder: The meter Transponder is shown in Figure 5-30. The transponder has a carrier-current transceiver for communications with the Transceiver Unit. A micro-computer, complete with read-only and random access memories, is used for message processing and formatting. A signal conditioner provides a universal interface capable of handling various types of meters. A field programmed read-only memory contains the customer's unique address. Metering data is constantly being transferred from the meter to the micro-computer. The micro-computer sends metering data to the Transceiver Unit when requested.

The Meter Transponder provides locally stored "register shift" commands to the meter in consonance with the utility's time-of-use (rate) strategy.

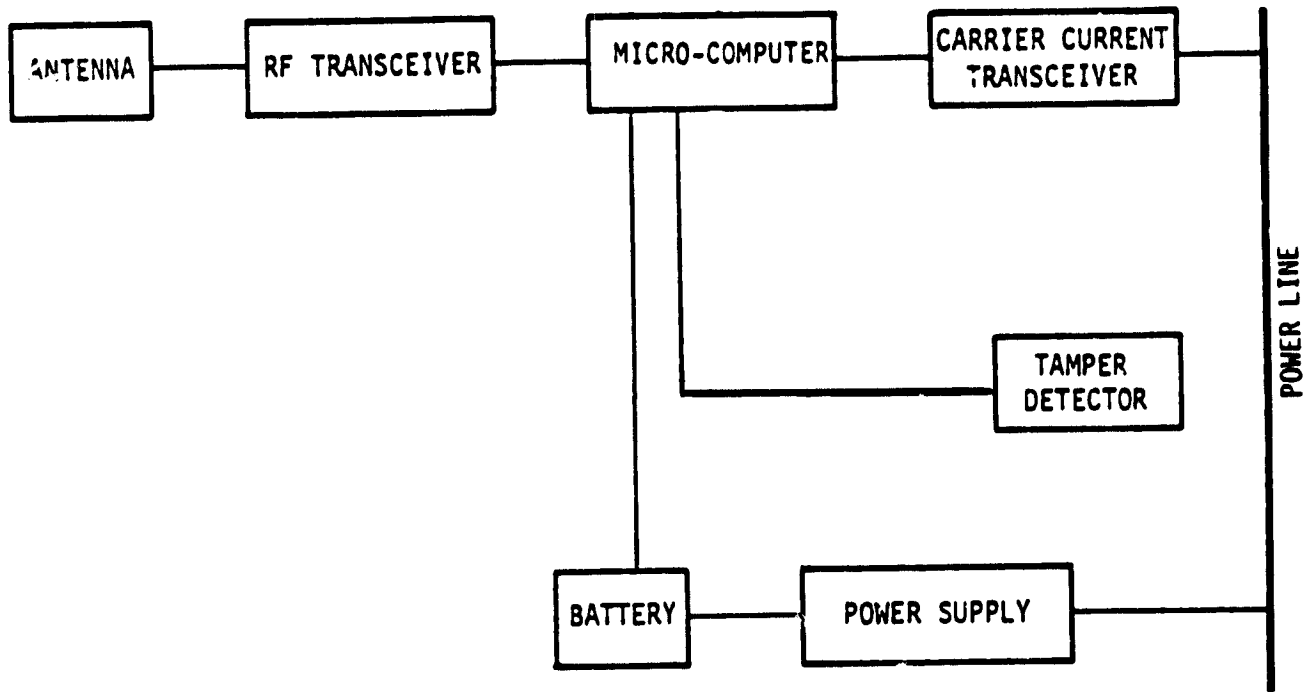


Figure 5-29 TRANSCEIVER UNIT

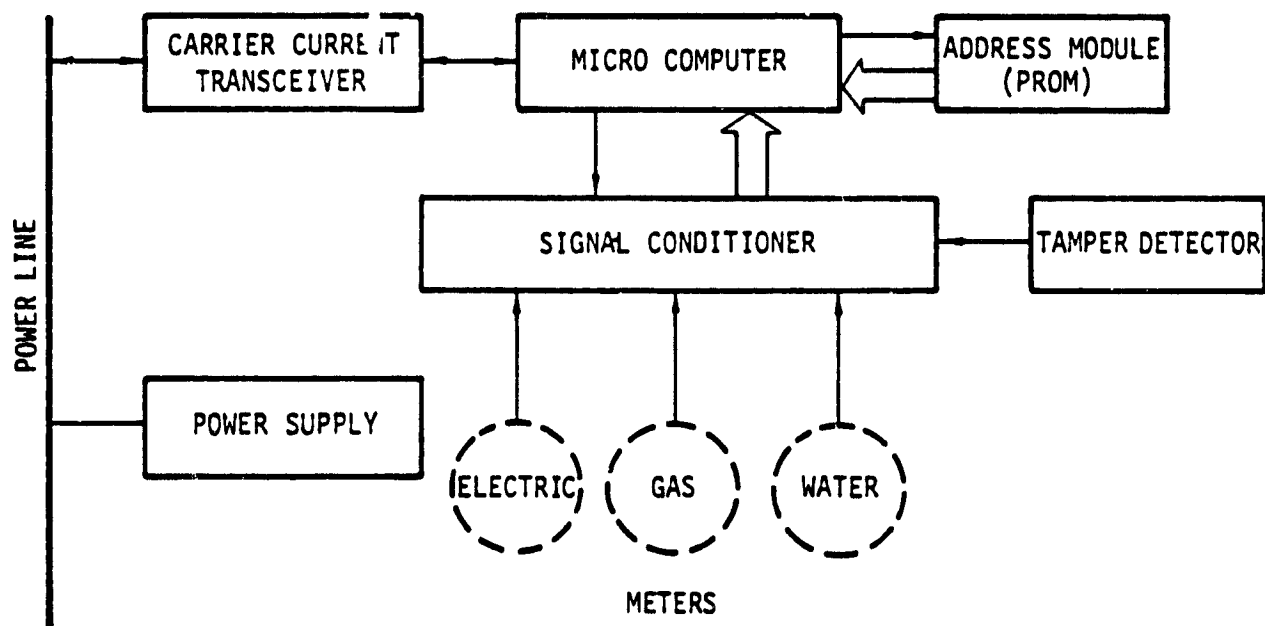


Figure 5-30 METER TRANSPONDER

These commands cause the meter to route power consumption to the appropriate meter register. The timing (time-blocks) for shift commands can be remotely changed as desired from the Master Control Station.

Control Module: The two-way Control Module block diagram is shown in Figure 5-31. The two-way module permits feed-back to the Transceiver Unit regarding the "state" of the controlled device, a one-way module does not. The one-way module is called a Controller.

The micro-computer processes all incoming messages and upon decoding its own address will enable the load control relay circuit. Each controlled appliance has a different address code to permit selective load management of such items as hot water heaters, air conditioners, spaceheaters, etc.

Power is reapplied to the appliances after a specified time-delay. The delay is remotely resetable from the utility's Master Control Station.

Premium Rate Indicator: The Premium Rate Indicator is shown diagrammatically in Figure 5-32. Lamp drivers are switched concurrent with the "register shift" command issued by the Meter Transponder.

Single Customer Terminal: Because of site peculiar circumstances, some customer will require dedicated equipment; they cannot share in a neighborhood arrangement. In such cases, service can be provided using the same components as described above (using either power line carrier-current links or point-to-point wiring), or by means of a simple Receiver Unit wired to the controllable loads, as depicted in Figure 5-33.

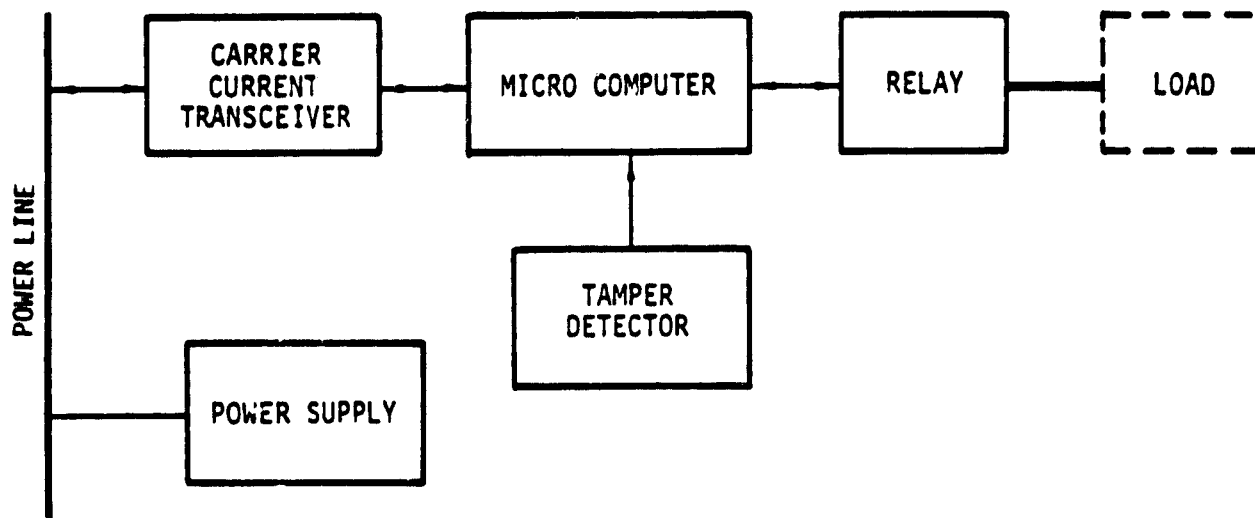


Figure 5-31 CONTROL MODULE

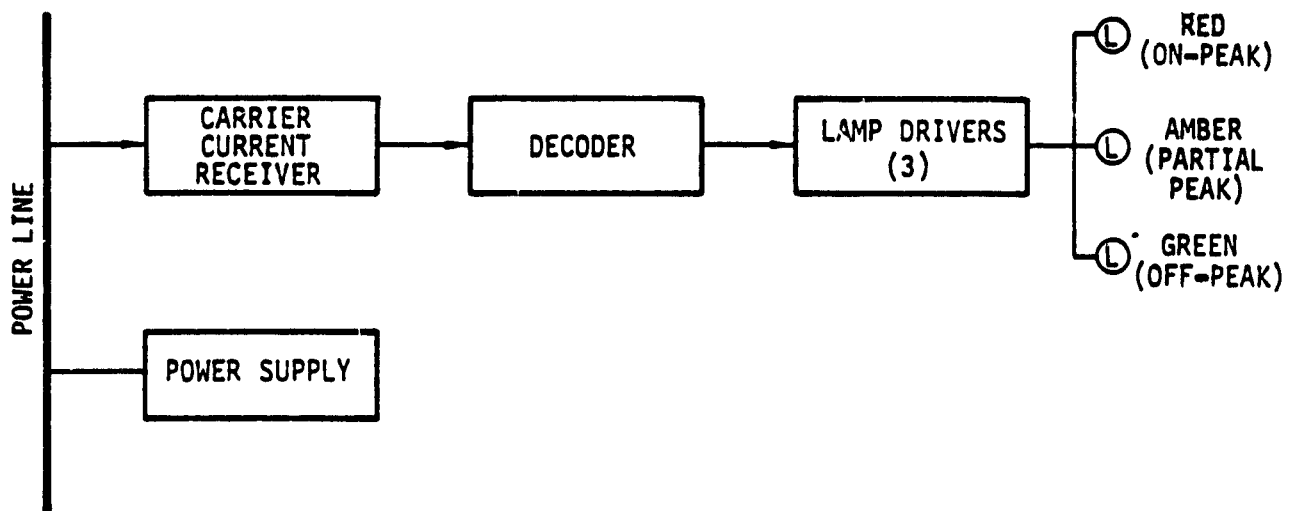


Figure 5-32 PREMIUM RATE INDICATOR

5.4.2 Substation Terminals

A block diagram of a Substation Terminal is shown in Figure 5-34. Besides an antenna, an RF Transceiver, and a micro-computer, the terminal requires an interface unit to condition and format signals going between the micro-computer and the connected devices, meters, and instrumentation. Connections to the interface unit are by means of point-to-point wiring.

Substation Terminals are unique in that they are the only remote terminals capable of sending emergency messages to the Master Control Station (MCS) without having first received a command message from the MCS.

In the "baseline" system all substations within the United States share a common satellite channel for such emergency communications. Because the satellite's CONUS coverage antenna has a 7° beam its gain is less than that of the regional beams, (substations normally work with 1.2° to 3.4°) which means this mode of operation requires more radiated power from the substation's transmitter.

The emergency message is transmitted periodically until acknowledged by the addressed (parent) MCS.

5.4.3 Monitor/Control Point Terminals

A Monitor/Control Point Terminal can be configured for receive-only, or two-way capability. Receive-only units are used for device control purposes. Two-way units are used for monitor and control functions.

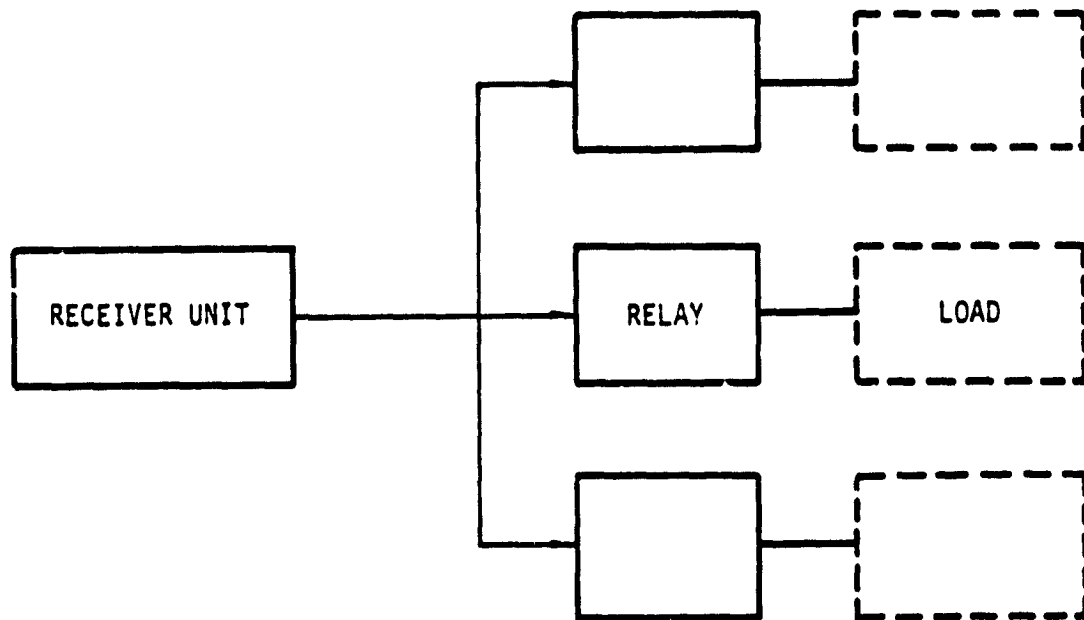


Figure 5-33 CUSTOMER TERMINAL, LOAD CONTROL (ONE-WAY)

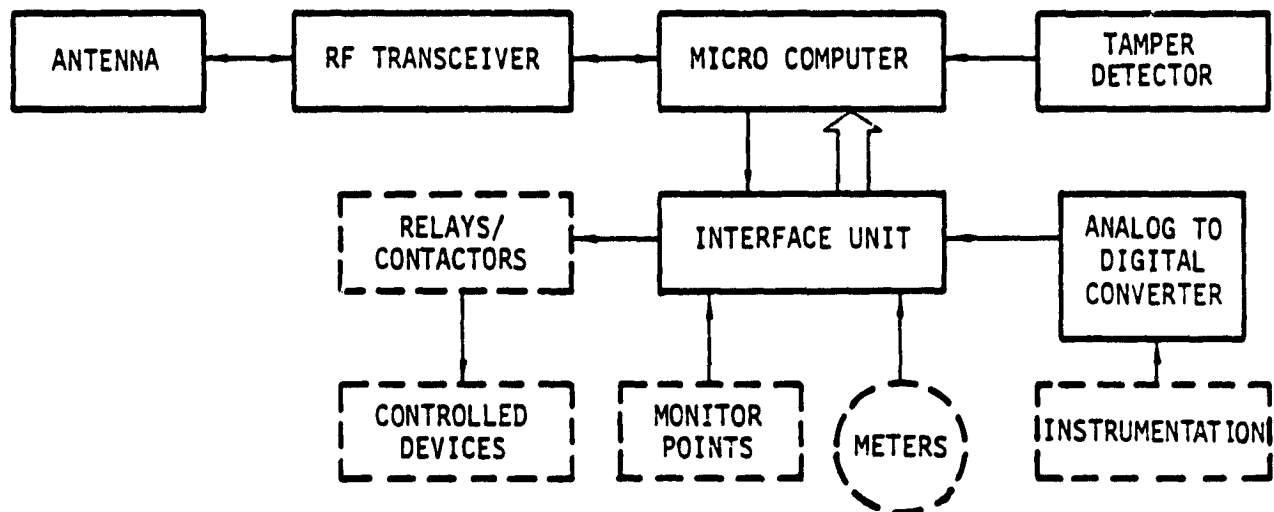


Figure 5-34 SUBSTATION TERMINAL

Monitor/Control Point Terminals are used for real-time operations management and will normally be pole or standard mounted depending on whether the power lines are overhead or underground.

5.4.4 Terminal Equipment Characteristics

Remote terminals require four basic functional capabilities:

1. Radio frequency reception and transmission
2. Signal generation and processing, housekeeping, and control
3. Transfer of information between various elements of the terminal and to the loads under control.
4. Signal conditioning associated with interface compatibility.

Terminal capabilities are formed from modules using a building block approach. Each module has its own power supply.

Radio Equipment: Important elements in the design of a communication system are the transmit and receive antennas. Antenna gain (directivity), polarization, and side lobe levels are critical parameters in system performance, reuse of frequencies and immunity to interference.

Table 5-5 presents candidate antenna types for remote terminals and compares their respective performance and figures of merit. The required antenna technology is readily available.

For reasons to be discussed below, circular polarization is preferred for the lower frequencies. Thus the helix appears to offer the best combination in performance and cost of any of the low frequency antenna candidates. At higher frequencies the microstrip planar array combines good performance and low cost.

FREQUENCY, GHz	ANTENNA TYPE	ANTENNA GAIN (dBi)	POLARIZATION OBTAINABLE	COST FIGURES OF MERIT		
				DESIGN*	MANUFACTURE**	ENVIRONMENT**
0.1 - 3.0	YAGI-UDA ARRAY	5 - 10	LINEAR, CIRCULAR	2	3	1
0.1 - 3.0	CORNER REFLECTOR	5 - 8	LINEAR, CIRCULAR	2	2	1
0.1 - 3.0	HELIX	8 - 13	CIRCULAR	1	1	1
0.7 - 12.0	CONFORMAL (MICROSTRIP) ARRAY	10 - 20	LINEAR, CIRCULAR	3	2	2
1.0 - 6.0	DIELECTRIC ROD	10 - 15	LINEAR, CIRCULAR	4	4	3
1.0 - 12.0	PARABOLIC REFLECTOR	20 - 40	LINEAR, CIRCULAR	3	3	3
1.0 - 12.0	PYRAMIDAL HORN	10 - 20	LINEAR, CIRCULAR	2	3	3

* 1 - SIMPLE
5 - DIFFICULT

** 1 - RUGGED, NOT PRONE TO ENVIRONMENTAL FAILURE
5 - PRONE TO ENVIRONMENTAL FAILURE

Table 5-11 CANDIDATE ANTENNAS FOR REMOTE TERMINALS

A typical microstrip antenna of 12" x 12", as shown in Figure 5-35, can provide 12 dBi gain at 1500 MHz. Additional information on the antenna system is presented in Paragraph 5.3.2.

The utility Master Control Station (MCS) antenna is a parabolic dish. The size of parabolic dish antennas vs frequency for several antenna gains is shown in Figure 5-36. In principal, any of the antennas listed in Table 5-11 could be employed at the MCS.

Because of Faraday Rotation the choice of polarization for the antenna system is predicated upon the operating frequency. For frequencies below 1.0 GHz circular polarization is preferred.

From a manufacturing and installation cost standpoint it appears that frequencies in the 1-6 GHz band are preferred. Below this band the large physical dimensions necessary for realistic performance result in high material and installation costs. Above this band tight mechanical tolerances will tend to increase manufacturing costs.

Radio Transmitter-Receiver: A primary assumption is that customer terminals must be as simple as possible to minimize cost. The radio frequency equipment must be designed for mass production. When contemplating production rates in terms of millions of units per year, complete integration into a single package becomes a candidate for consideration. In the last few years

$F_0 = 1500 \text{ MHz}$

$G = 12 \text{ DBI}$

$BW = 2\%$

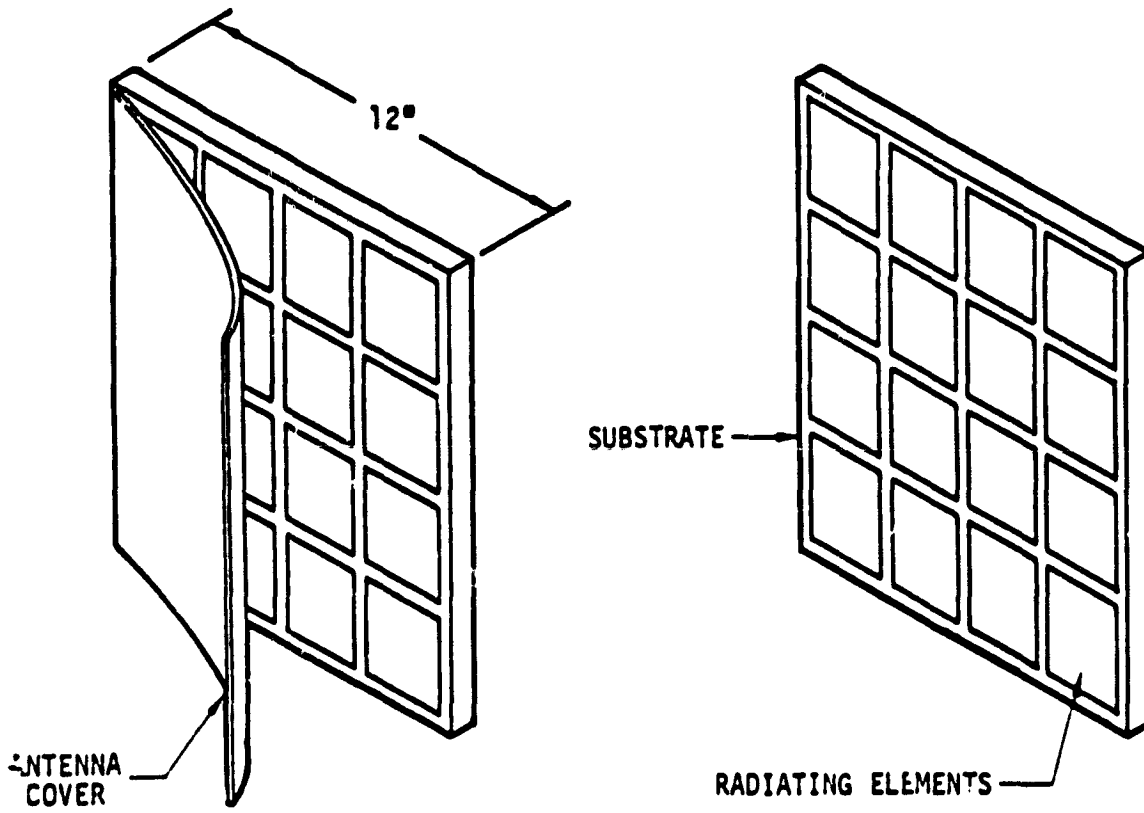


Figure 5-35 CUSTOMER TERMINAL MICROSTRIP ANTENNA

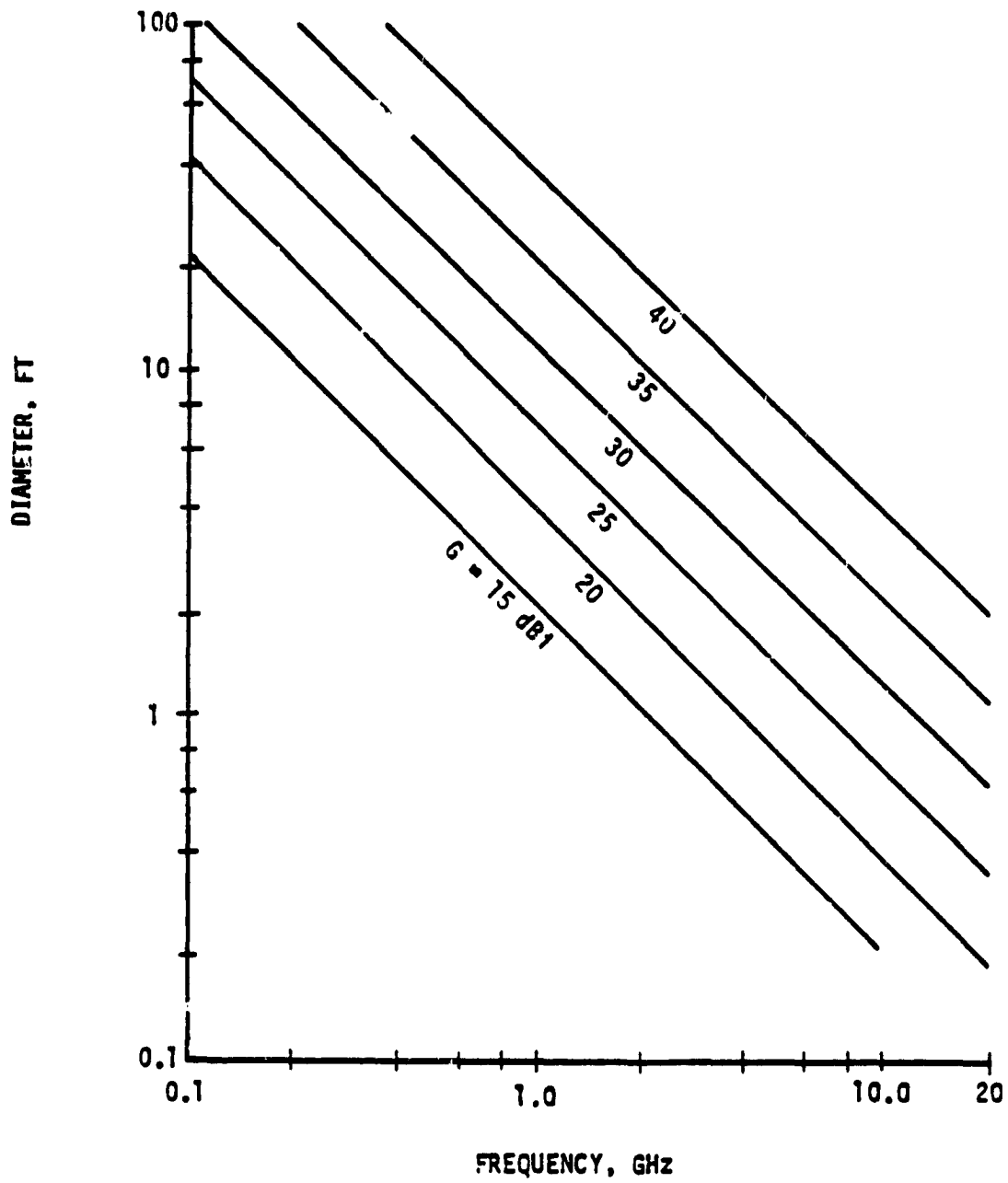


Figure 5-36 SIZE OF PARABOLIC DISHES VS FREQUENCY

D180-25403-2

5-91

integrated packages have gained wide acceptance for microwave applications since there have been many incentives to miniaturize and reduce costs. The latest manifestation of this trend is the growing use of "supercomponents" wherein a number of functions are put in a single package. Several "super components" form an end-item. This technology appears suitable for use in the frequency bands of primary interest.

It may be possible to integrate the microstrip array antenna with the transceiver unit. This possibility should be explored in more detail.

Typical output power for the customer terminal transmitter, and the receiver noise figure for various frequencies are listed in Table 5-12

<u>Frequency</u>	<u>Power Output</u>	<u>Receiver Noise Figure</u>
150 MHz	10 W	15 dB
500 MHz	7 W	15 dB
1.5 GHz	4.5 W	13 dB
4.0 GHz	2.5 W	10 dB
6.0 GHz	2 W	10 dB
12.0 GHz	1.2 W	13 dB
20.0 GHz	0.72W	16 dB

Table 5-12 CUSTOMER TERMINAL RADIO TRANSCEIVER REQUIREMENTS

Micro-computer: The digital processing system will utilize an off-the-shelf" micro-computer module consisting of a micro-processor, input-output, and various memories.

Carrier-Current Equipment: The carrier-current power line communication system is described in Paragraph 5.3.9. It is a low radio frequency system (200-240 KHz band) with a conventional digital data transmission capability. Variations of this system are widely used in intercom and security systems in apartment houses, schools, and in commercial, industrial, and military applications.

Carrier-current transceivers will be used at the Transceiver Unit, Meter Transponder and at the Control Modules. The transmitting power output is estimated at 1 watt for distances of up to 1000 ft., subject to local power line quality and installation features. The transmission data rate is low which helps overcome the anticipated high noise level present on power lines in urban areas.

Interface Unit Equipment: Interface and signal conditioning units require further analysis to determine preferred configurations.

5.4.5 Terminal Installation Considerations

Residential Installations: The number of terminals serving residences substantially exceeds all other types of terminals. Whenever possible residences are served by "neighborhood terminals". A neighborhood Transceiver Unit may be mounted on a pole, an electric light standard, a house, or on any convenient elevated structure. Because of the near infinite variety of siting conditions, the Transceiver Unit (and all other components) have

"universal" mounting features.

As was discussed in paragraph 5.3.8, customer terminals can have antennas as large as that of a typical TV antenna, or as small as 6 inches, depending on the final selection of operating frequency.

Load Control Installations: For load control (receive only terminals), several situations may be encountered. Some residential loads are normally located outdoors, such as air conditioners and swimming pools, while others such as water heaters and space heaters are located indoors.

Outdoor appliances - load management of residential air conditioners will be confined to central air conditioning systems, at least initially. These systems usually have a compressor-condenser unit located outdoors at ground level, or on the roof. For such installations, the Receiver Unit can be conveniently mounted on or near the load provided there are no significant obstructions between the Receiver Unit and the satellite.

Indoor appliance - Residential water heaters are almost always located indoors. The Receiver Unit can be installed inside the home, mounted directly on the heater if site conditions permit. It is more likely, however, that the Receiver Unit will require an outdoor mount, with either control wires, or power line carrier-current used to couple it to the appliance.

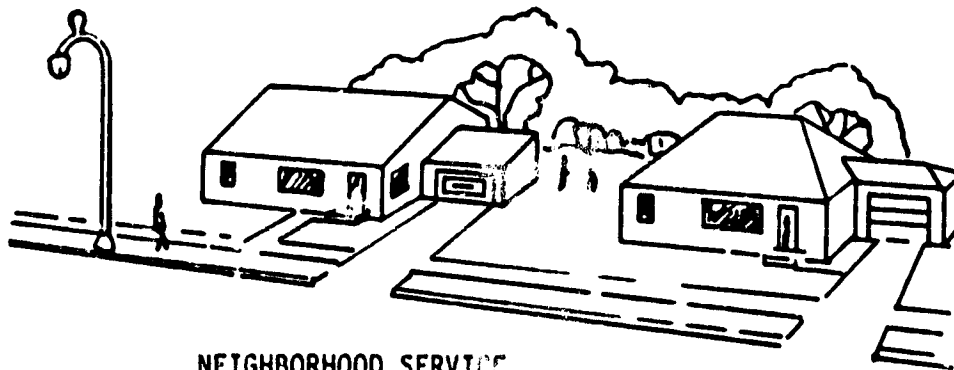
Typical residential installations using "baseline" equipment are illustrated in Figure 5-37.

Commercial Installations: Commercial office buildings, apartments and industrial sites are multi-load/multi-meter installations. In many sites the power lines are buried underground before entering the building. Functionally, this does not present a problem, physically it may. The requirement for a good line-of-sight path from the antenna to the satellite may mean that the Transceiver Unit is located tens, or even hundreds of feet from the power consumption meters and controlled appliances with which it must interface. One solution is the use of carrier current technology to interconnect units as in the case of the neighborhood terminal configuration. A second solution is the use of dedicated wires. The least cost approach must be determined on a site-by-site basis. To permit the choice of options, the Transceiver Unit is designed to accommodate either approach.

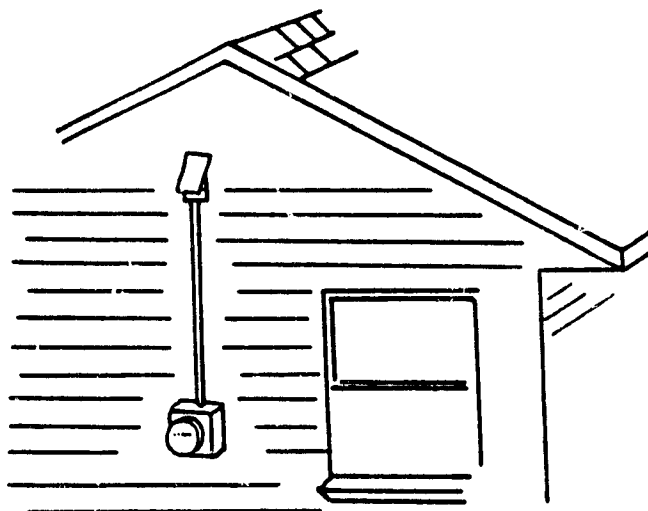
Apartments and commercial buildings can have a large bank of meters, too large to be handled by a "basic" transceiver. To serve such an installation, expanded capability is obtained by use of a Multiplexer Module between the transceiver microcomputer and its loads and/or meters. While a "basic" transceiver will handle either dedicated wire or carrier current, differently configured multiplexers are required for each communication technique.

Undergrounding: There is a growing trend toward running distribution lines underground, rather than on poles. In such installations, devices associated with real-time operational management will be located at ground level within metallic enclosures, or underground in vaults.

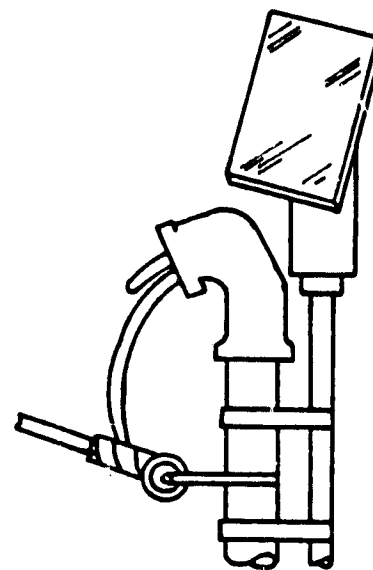
Undergrounding can be handled by the components described above, but at somewhat higher installed costs. The Transceiver Unit must be mounted to obtain a good look-angle to the satellite, and at an elevation making it not readily accessible to casual passerbys. In most instances, the lines supplying power to the Transceiver Unit can be used as the communication link to the controlled device.



NEIGHBORHOOD SERVICE



GABLE MOUNT



SERVICE ENTRANCE MOUNT

Figure 5-37 TYPICAL RESIDENTIAL INSTALLATION

5.5 Reliability Considerations

This section explores the likelihood of, and the possible impact of, a satellite failure -- key issues in determining technical feasibility. It will also discuss reliability considerations associated with other elements of the SC system.

5.5.1 Reliability

Reliability is ordinarily defined as "the probability of a device performing its intended purpose adequately for the period of time intended under specified environmental conditions."

Three distinct eras can be identified in the lifetime of most equipment. They are identified in Figure 5-38. Early failures are usually due to faulty workmanship or to latent defects. To improve a product's in-service reliability, a process of burn-in is often used to reduce these failures prior to delivery to the customer. Random failures are the result of uncontrolled processes or events. It is during this period that the exponential statistics of reliability apply. Wearout failures occur as end-of-life approaches and physical or chemical changes take their toll.

If the failure rate during the random failure era is approximately constant the probability of survival (reliability) is of the form depicted in Figure 5-39. Two features of this exponential distribution are worth noting. First, the probability of a device functioning successfully for a stated period of time (t) is the same today as it was yesterday, or as it will be tomorrow - as long as λ is constant. Second, at " t " equal to one MTBF only 37% of the equipments turned on at time zero will still be operating.

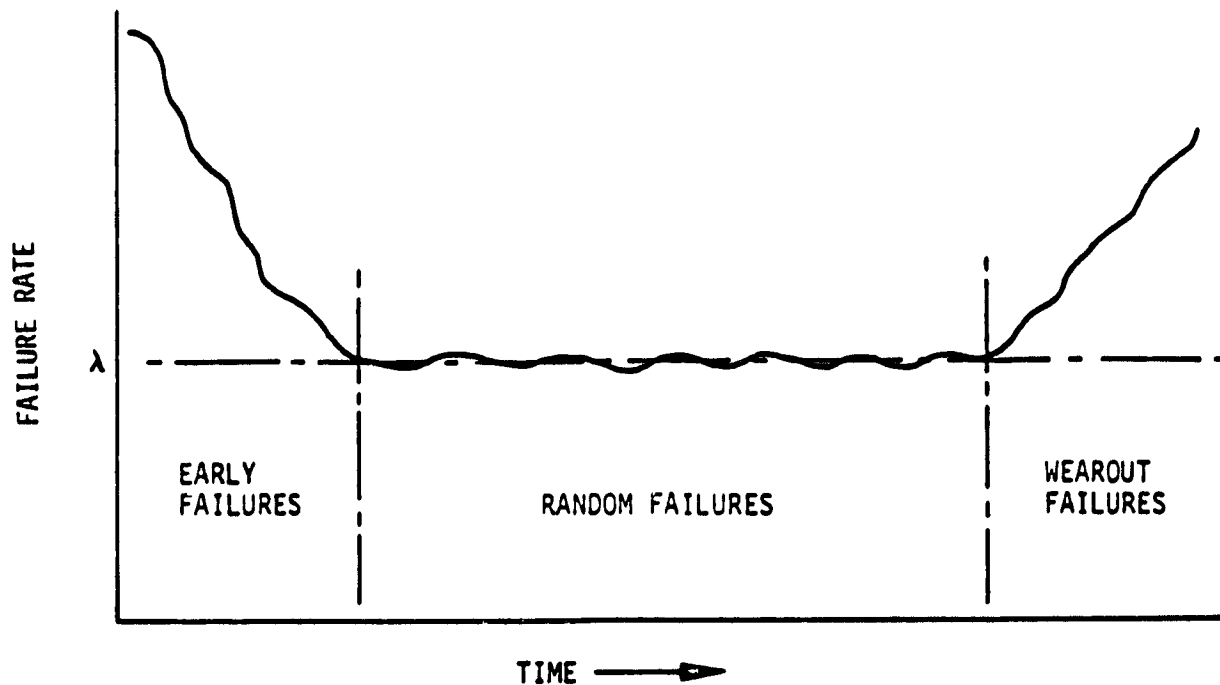


Figure 5-38 FAILURE RATES VS. TIME

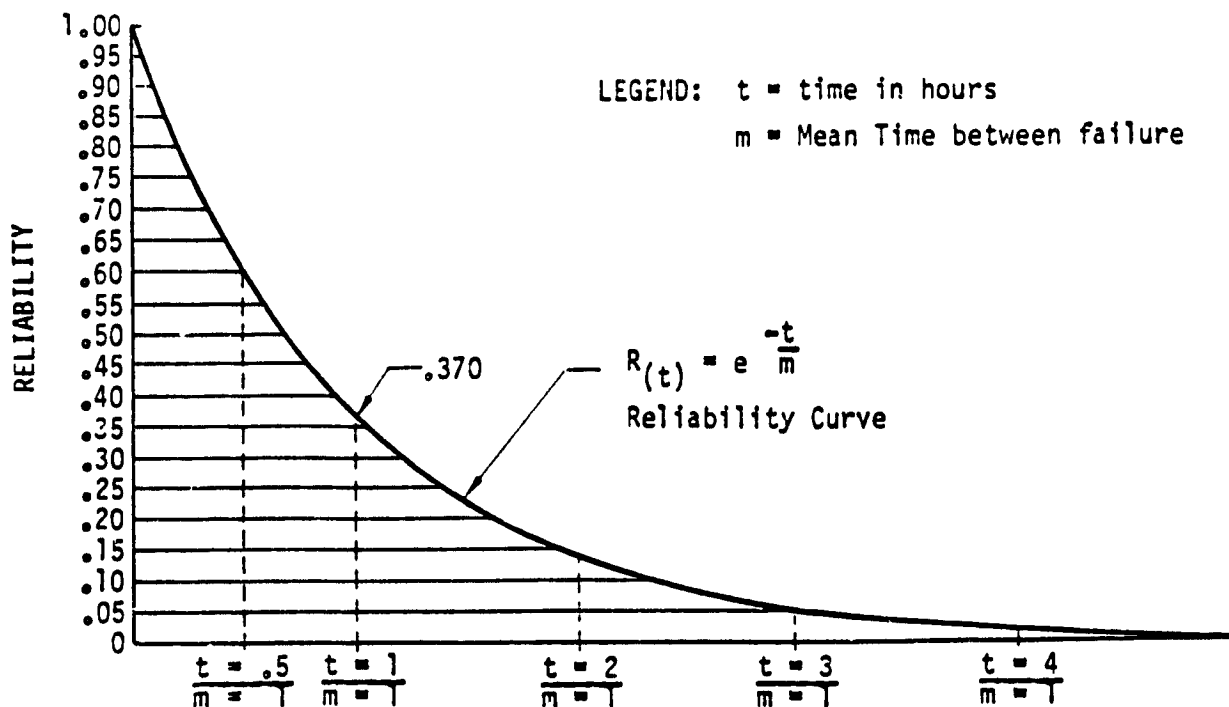


Figure 5-39 GRAPH OF EXPONENTIAL RELIABILITY

D180-25403-2

5.5.2 Spacecraft Reliability

There have been hundreds of successful space missions since the first satellites were launched two decades ago, and some failures. In analyzing the history of satellite reliability, the data is usually grouped into four time frames; launch, the first day after launch through the 30th day, the 31st day through the 365th day, and 366 days or longer. The partial record for the past 10 years is shown in Figure 5-40. The likelihood of achieving orbit is seen to be greater than 90%, and has remained so through the years. On the other hand early failures have been trending downward.

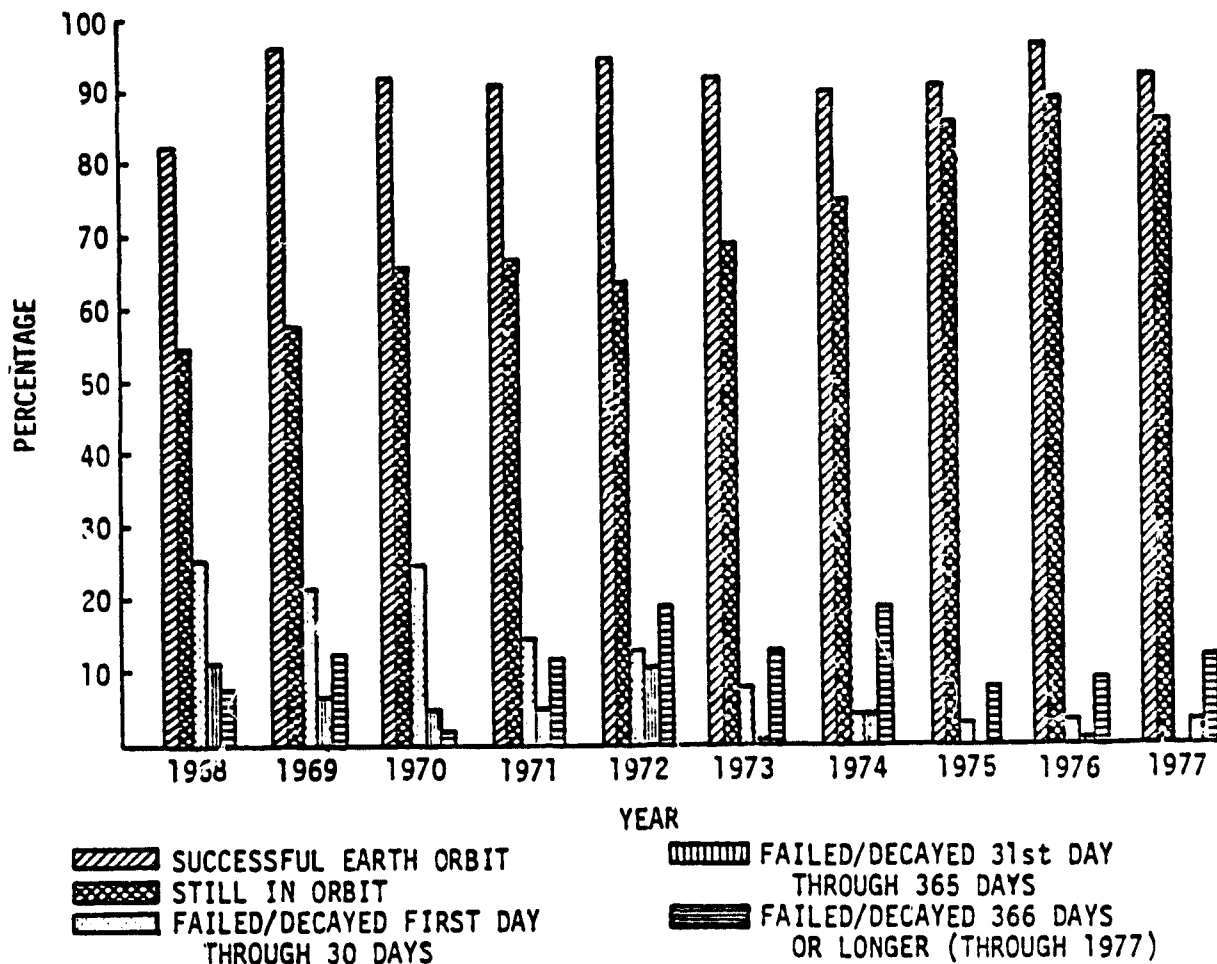


Figure 5-40 FAILURE HISTORY OF SPACECRAFT

D180-25403-2

5-99

A more detailed account of spacecraft reliability is given in Table 5-13 where failure rates for various spacecraft subsystems are identified for both launch and in-orbit conditions. It should be noted that launch data applies to the present generation of launch vehicles, the future Space Transportation System may be different.

SPACECRAFT SUBSYSTEMS	PROBABILITY OF FAILURE DURING LAUNCH			IN-ORBIT FAILURE RATE (FAILURES/MILLION HOURS)		
	q_1	\hat{q}	q_2	λ_1	$\hat{\lambda}$	λ_2
TIMING, CONTROL AND COMMAND	0.005	0.015	0.034	0.47	1.4	3.1
TELEMETRY AND DATA HANDLING	0	-	0.010	0.31	1.1	2.9
POWER	0.0048	0.014	0.033	4.5	7.4	12.0
ATTITUDE CONTROL AND STABILIZATION	0.0051	0.015	0.035	1.8	3.5	6.0
PROPULSION	0.0061	0.023	0.058	0	-	8.2
ENVIRONMENTAL CONTROL	0	-	0.057	0	-	3.0
STRUCTURE	0.0049	0.014	0.033	0	-	1.1
PAYLOAD	0.0037	0.011	0.025	0.11	0.61	1.9

Table 5-13 SPACECRAFT SUBSYSTEM RELIABILITY, 90% CONFIDENCE INTERVALS (q_1, q_2)

Table 5-14 extends the spacecraft reliability data to the component level, and Table 5-15 covers typical piece parts.

ON-ORBIT FAILURE RATE (FAILURES/MILLION HOURS)

<u>COMPONENTS</u>	<u>λ_1</u>	<u>λ</u>	<u>λ_2</u>
ACCELEROMETERS	0.08	1.6	7.7
AMPLIFIERS, (1)	0.0063	0.12	0.58
BATTERY CHARGE/DISCHARGE CONTROL CIRCUITS	0.012	0.23	1.1
BATTERY PACKS	0.62	1.3	2.3
COMMAND DECODERS	0.014	0.26	1.25
COMMAND DISTRIBUTION UNITS	0.31	1.8	5.6
COMPUTERS	0.012	2.3	11.0
CONTROL GAS ASSEMBLIES	0.65	3.1	9.7
DATA HANDLING UNITS	0.030	0.59	2.8
DC/DC CONVERTERS	0.022	0.84	2.2
GYROS	0.29	1.7	5.2
HEATERS	0.012	0.23	1.1
MAGNETIC SENSING DEVICES	0.097	1.9	9.0
MAGNETIC TAPE UNITS	14.0	24.0	37.0
MAGNETOMETERS	0.29	2.6	5.2
MOMENTUM WHEEL/REACTION WHEEL ASSEMBLIES	2.1	5.3	11.0
OSCILLATORS	0.019	0.36	1.7
RADIOMETERS	6.1	11.0	18.0
RECEIVERS	0.34	0.86	1.8
REGULATORS, PRESSURE	0.021	0.40	1.9
REGULATORS, VOLTAGE	0.30	0.75	1.6
SIGNAL CONDITIONERS	0.063	1.2	5.8

(CONTINUED)

D180-25403-2

5-101

ON-ORBIT FAILURE RATE (FAILURES/MILLION HOURS)

<u>COMPONENTS</u>	<u>λ_1</u>	<u>$\hat{\lambda}$</u>	<u>λ_2</u>
SUN SENSORS	0.33	1.2	3.2
STAR TRACKER	33.0	57.0	90.0
TELEMETRY ENCODERS	1.6	3.2	5.8
TIMERS AND CLOCKS	1.4	2.6	4.3
TRANSMITTERS, S-BAND	1.2	4.4	11.0
TRANSMITTERS, SPECIAL PURPOSE	0.14	2.8	13.0
TRANSMITTERS, WIDEBAND	1.4	5.0	14.0
TRANSMITTERS, VIDEO	2.5	9.2	24.0
TRANSMITTERS, OTHER (?)	1.4	2.3	3.9
TRANSPONDERS	0.45	2.5	8.0
VIDICON CAMERAS	2.2	5.1	10.0

(1) THESE AMPLIFIERS DO NOT INCLUDE POWER AMPLIFIERS.

(2) THESE TRANSMITTERS ARE OTHER THAN: BEACON TRANSMITTERS, DOPPLER TRANSMITTERS, FM TRANSMITTERS, S-BAND TRANSMITTERS, SPECIAL PURPOSE TRANSMITTERS, TRACKING TRANSMITTERS, WIDEBAND TRANSMITTERS, OR VIDEO TRANSMITTERS.

Table 5-14 ON-ORBIT FAILURE RATES FOR SELECTED SPACECRAFT COMPONENTS,
90% CONFIDENCE INTERVALS (λ_1 , λ_2)

<u>PIECE PARTS</u>	ON-ORBIT FAU ON-ORBIT FAILURE RATE (FAILURES/MILLION HOURS)		
	λ_1	$\hat{\lambda}$	λ_2
BATTERY CELLS	0.010	0.037	0.097
CAPACITORS	0.00057	0.0010	0.0016
DIODES	0.00047	0.00097	0.0019
FUSES	0.036	0.090	0.19
INTEGRATED CIRCUITS	0.00099	0.0025	0.0053
RELAYS	0.00031	0.0061	0.029
SWITCHES	0.18	0.47	0.98
THERMISTORS	0.053	0.12	0.24
TRANSISTORS	0.00050	0.0015	0.0033
TUBES, GENERAL PURPOSE	0.15	0.55	1.4
TUBES, SPECIAL PURPOSE	0.23	4.39	21.0
GEIGER MUELLER TUBES	5.4	16.0	37.0
PHOTOMULTIPLIER TUBES	0.24	4.6	22.0

Table 5-15 ON-ORBIT FAILURE RATES FOR SELECTED PIECE-PARTS, 90% CONFIDENCE INTERVALS

A high level of reliability is achieved in the SC system spacecraft through the use of both block and functional redundancy. This redundancy is employed such that no single-point failure can have a catastrophic effect on the mission. In block redundancy two identical elements are provided to perform the same function, either in an active mode wherein both elements are powered on-line simultaneously, or in a standby mode wherein the redundant element is switched on only in the event of failure of the primary element. Functional redundancy provides the capability to perform the same, or nearly the same, function in two different ways.

A reliability block diagram of the spacecraft payload is set forth in Figure 5-41. Generic failure rates were used at the component level, except for the deployable mesh antenna which was analyzed at the piecepart level. Reliability estimates for the spacecraft subsystems are summarized in Table 5-16.

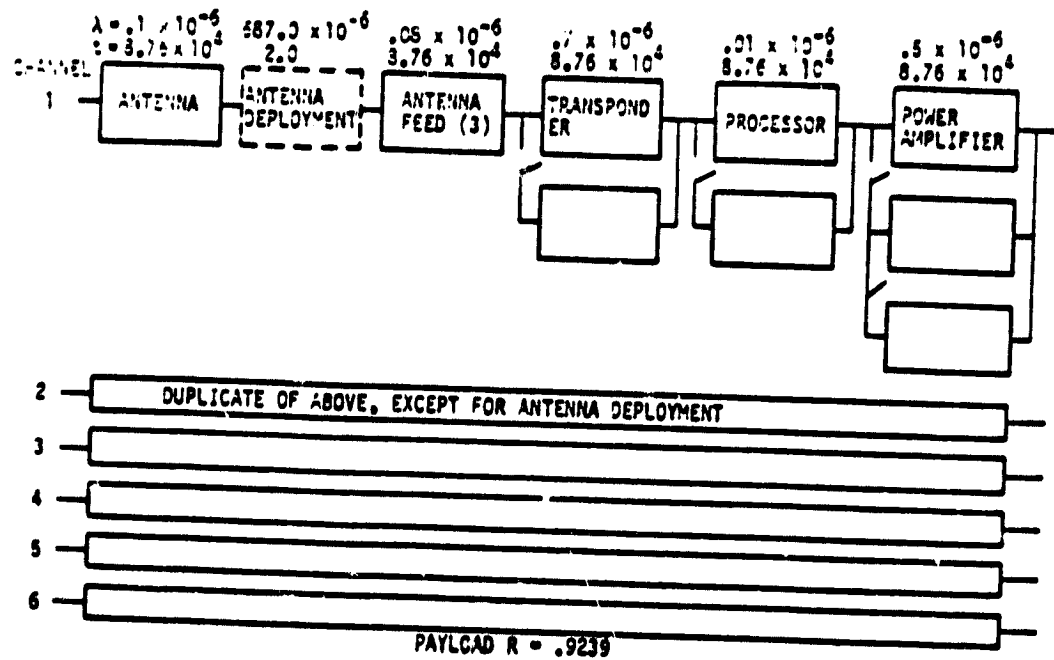


Figure 5-41 PAYLOAD RELIABILITY BLOCK DIAGRAM

STRUCTURE	.9986
THERMAL CONTROL	.9962
ELECTRICAL POWER	.9125
POINTING AND CONTROL	.9016
TELEMETRY AND DATA	.9846
PAYLOAD	.9239
OVERALL, 10 YEAR	.744

Table 5-16 SPACECRAFT RELIABILITY ESTIMATE

The overall mission reliability of one spacecraft is estimated to be .744. It is the probability that a complete functional capability will be provided for a period of 10 years. This value rises to more than .93 with one standby unit, and to .99 with two. The reliability increases rapidly as operating time is reduced. It should be noted that this reliability estimate does not take into account the possibility of remote reconfiguration of subsystem components to restore functional capability.

5.5.3 Satellite Failure

As with nuclear power and other systems touted to be highly reliable, it is possible to play the "What if ---?" game with the SC system. One can postulate a series of catastrophic events wherein all measures to assure reliable operation have been exhausted and the utilities are left with a dead satellite, and faced with the prospect of operating several months without normal DAC communication links. What now?

There are basically two options, revert to historic methods or bring into play special backup resources.

Load management could again be practiced, using such "soft" techniques as radio and TV appeals for public cooperation and conservation, and with large interruptable loads handled by person to person communications. Real-time operational management could revert to manual data gathering and manual on-site actions. Meter reading could be deferred until satellite service is restored, or an army of meter readers could again make their rounds.

On the other hand, some may argue that DAC may become such a powerful tool, so ingrained in utility operations that some backup resources are mandatory. Backup schemes can be structured to serve an individual utility, or to serve a group of utilities. Load management, which is normally in effect for only a limited time each

day, and remote meter reading, which need be accomplished only monthly or bimonthly, can be handled rather easily with an airborne communications relay. On the other hand, real-time operational management at key installations requires around-the-clock service and can be handled on a temporary basis by means of ordinary dial-up phone lines which are connected to on-site equipment through a local coupler.

At this point in time, it appears that the SC system, with a spacecraft having block and functional redundancy plus emergency modes, with the use of an in-orbit spare, and with a ground standby unit, is sufficiently foolproof to negate a requirement for terrestrial backup resources. However, the question should be addressed in more depth during detailed design studies.

5.5.4 Ground Terminal Reliability

Ground terminal reliability does not affect system operation in the same critical sense as does satellite reliability. The impact of a terminal failure manifests itself in terms of possible customer complaints, a potential loss of revenues, and in maintenance, repair, or terminal replacement costs.

The reliability objective for customer terminals is to keep failures below 2-3% per year (which is akin to replacing the entire population of terminals every 50 or 30 years). By way of comparison, good quality, high volume production citizen band transceivers, police radios, etc., are reported to exhibit failure rates of at least 16% per year of continuous operation.

Achieving the desired terminal failure rate is based on the use of integrated circuits and other solid state devices. Failure rates of integrated circuits range from $.0019 \times 10^{-6}$ per hour for high-reliability units to $.1 \times 10^{-6}$ per hour

for "standard" units. The basic factors responsible for this considerable difference are: device design, the number of on-line process control inspections, levels of rejection, and the amount of reliability screening performed.

The estimated failure rates for the components of a two-way customer terminal (most complex configuration) are given in Figure 5-42. With one transceiver unit serving five customers, each having three appliances under control, the overall failure rate is less than 1% per year.

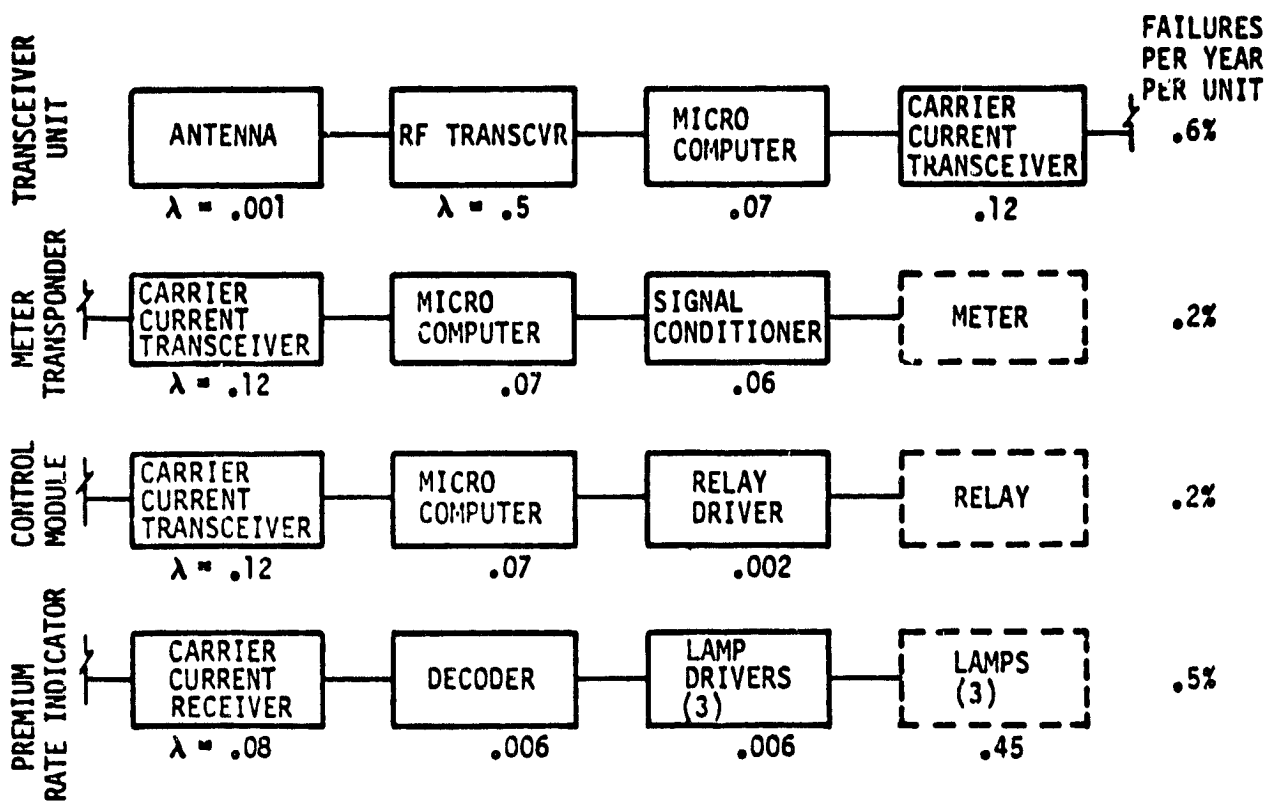


Figure 5-42 CUSTOMER TERMINAL RELIABILITY BLOCK DIAGRAM

5.6 Earth Orbital Considerations

5.6.1 Achieving and Maintaining a Geostationary Orbit

The period of a satellite in an elliptical or circular orbit is,

$$T = 2\pi \sqrt{\frac{a^3}{\mu}} \quad \text{seconds mean solar time}$$

where "a" is the semimajor axis (or radius) and μ is the earth's gravitational constant. For a satellite to be "synchronous," to have a period of one sidereal day, the value of "a" must be 22,763 nautical miles (an altitude of 19,320 NM). In the equatorial plane such a satellite will remain fixed relative to any point on the earth's surface and is said to be "geostationary."

Ever since satellite communication relays were suggested it was recognized that geostationary orbits provide unique advantages. From geostationary orbit more than one third of the earth's surface is visible, and with stationary orbits earth antennas can be fixed, eliminating the necessity for satellite tracking as is usually necessary for non-stationary orbits.

The locations available to a satellite in the geostationary arc are related to the locations of the ground terminals to be served, and to the minimum antenna elevation angle desired. Low elevation angles increase the receiving system noise temperature, increase atmospheric absorption, and can lead to increased interferences. The usable orbital arcs for the United States and other western hemisphere countries are shown in Figure 5-43, for minimum antenna elevation angles of 5° and 10°. The 1977 World Administrative Radio Conference (WARC) agreements regarding functional assignments are also shown.

Existing and planned satellites are shown in Figure 5-44.

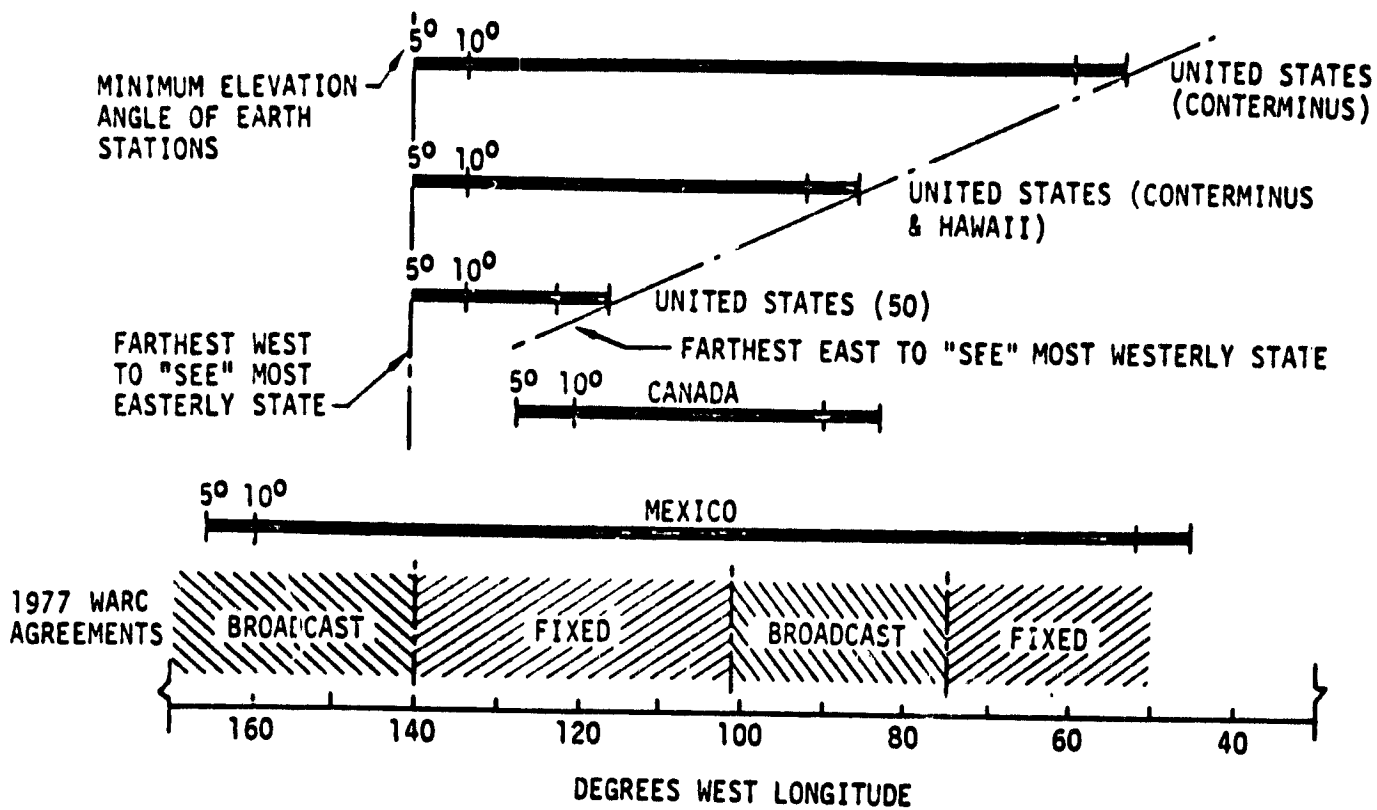


FIGURE 5-43 ORBITAL ARCS FOR SATELLITE COMMUNICATIONS

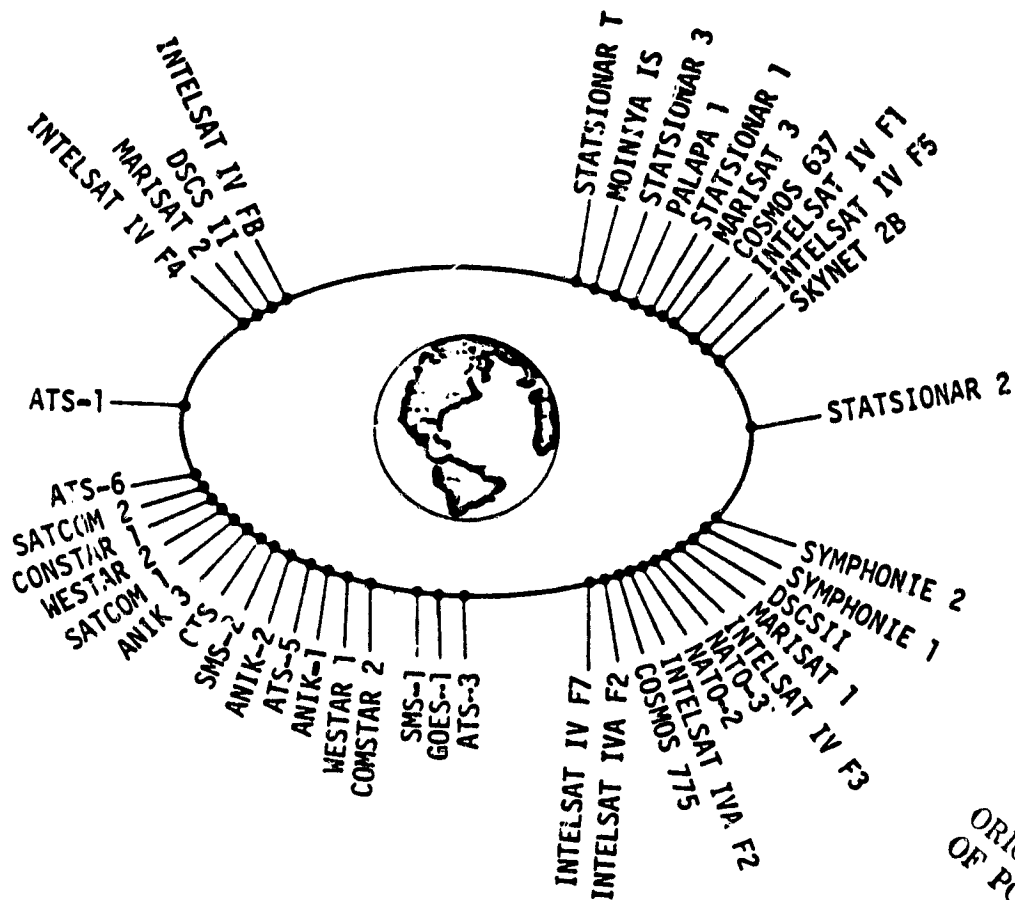


Figure 5-44 GEOSTATIONARY SATELLITES

D180-25403-2

ORIGINAL PAGE IS
OF POOR QUALITY

The mechanics associated with delivering satellites to geostationary orbits are somewhat unique. The satellite must be placed in a low earth parking orbit in the Earth's equatorial plane and sustained until the second equatorial crossing is reached. A transfer maneuver is then initiated and the satellite allowed to coast until it reaches geostationary altitude. At this point a final plane change and orbit circularization maneuver is undertaken.

Figure 5-45

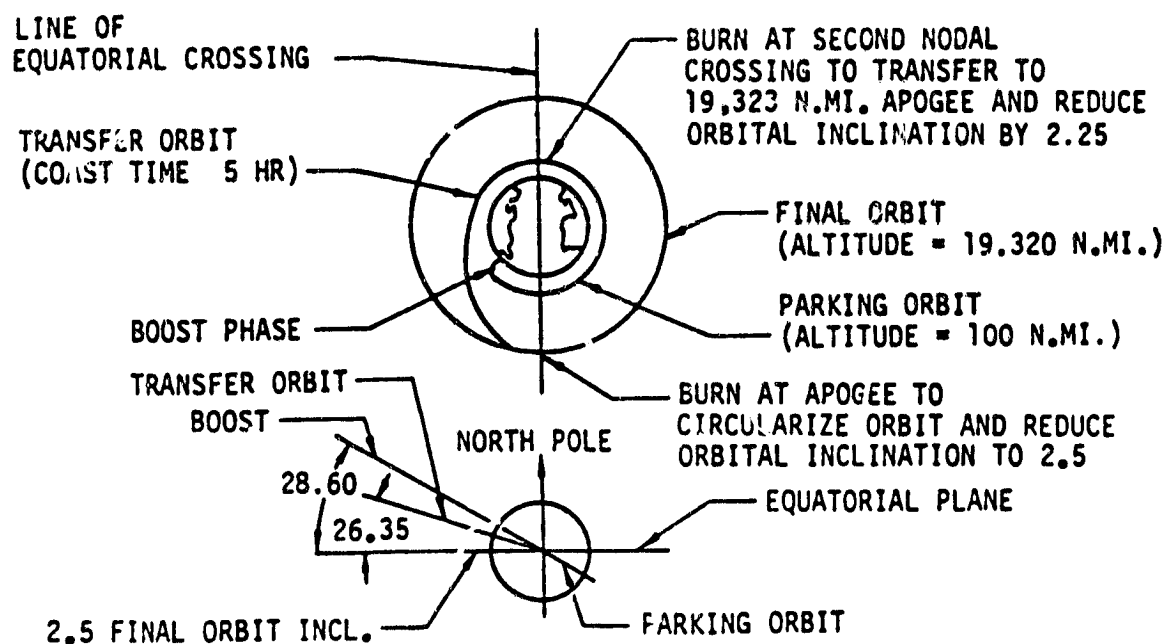


Figure 5-45 TYPICAL FLIGHT PLAN TO ACHIEVE GEOSTATIONARY ORBIT

Several variations of this technique can be used, primarily to achieve somewhat more payload in orbit with a particular launch vehicle configuration. One such technique uses an elliptical parking orbit, and a transfer orbit which is not initiated at equatorial crossings. This technique allows the use of ground-based downrange trackers to furnish telemetry during the transfer orbit instead of requiring on-station ships in support of the launch.

The NASA Space Transportation System (STS), commonly referred to as the Space Shuttle, in conjunction with the Inertial Upper Stage (IUS) could be used to place the satellite in orbit. The STS payload bay is about 15 feet in diameter and 60 feet in length, it is designed to carry 65,000 pounds into a low earth orbit. However, to put a satellite in geostationary orbit after it is launched from the STS, additional propulsive capability must be provided. This is the job of the IUS. Two separate impulses are required. The first must be applied to place the satellite into an elliptical transfer orbit from the low earth orbit, and the second to transition it from the transfer orbit into the circular synchronous orbit.

The STS-IUS combination can place 5,000 pounds in geostationary orbit (as opposed to about 4,000 pounds for the Titan T34D launch vehicle and IUS).

In order to maintain a given location in synchronous orbit, corrections must be made periodically. East-West corrections compensate for longitudinal drift and North-South corrections compensate for drift in orbital inclination. Drift is caused by many factors, the principle ones being the intrinsic properties of the earth and the gravitational attraction of the moon and sun. These factors produce a diurnal oscillation of the orbit radius and a cumulative change of the inclination plane. The mean rate of change of inclination varies slowly. In the present decade it is about 0.86° /year and will increase up to a maximum value of 14.67° in somewhat over 25 years, then gradually return to zero in a like period of time. A velocity change of about 150 ft/sec/year will presently maintain near zero inclination.

A satellite can be put into an inclined orbit which tends to minimize the effects of inclination drift throughout its lifetime. In such an orbit, drift during the first half of its life is toward 0° inclination, and during the

second half toward the initial inclination. This approach is useful for missions where inclination angles up to several degrees are acceptable over the satellite's lifetime. If such angles cannot be tolerated, North-South station keeping is required.

East-West station keeping is needed to keep the satellite within its assigned orbital location. Station keeping is usually accomplished by periodically making velocity corrections with small gas jets.

While the mechanics of station-keeping present no problem, the amount of fuel necessary to maintain a precise location may pose a weight problem.

5.6.2 Sun Transit Effects

Synchronous satellites are subjected to eclipses part of each day for a 46-day period during the spring and autumn equinoxes. Figure 5-46. The duration of the eclipses vary from about 10 minutes at the start and end of the eclipse cycle to a maximum of approximately 72 minutes at the equinox as shown in Figure 5-47.

During eclipses, batteries must supply power to essential equipment onboard the satellite.

Another sun-induced effect occurs when the satellite and sun are in conjunction as observed from the earth terminal antenna. An earth station sees the sun as a disc of approximately 0.5° diameter with a minimum noise temperature of $25,000^\circ\text{K}$. This condition is discussed in paragraph 5.3.

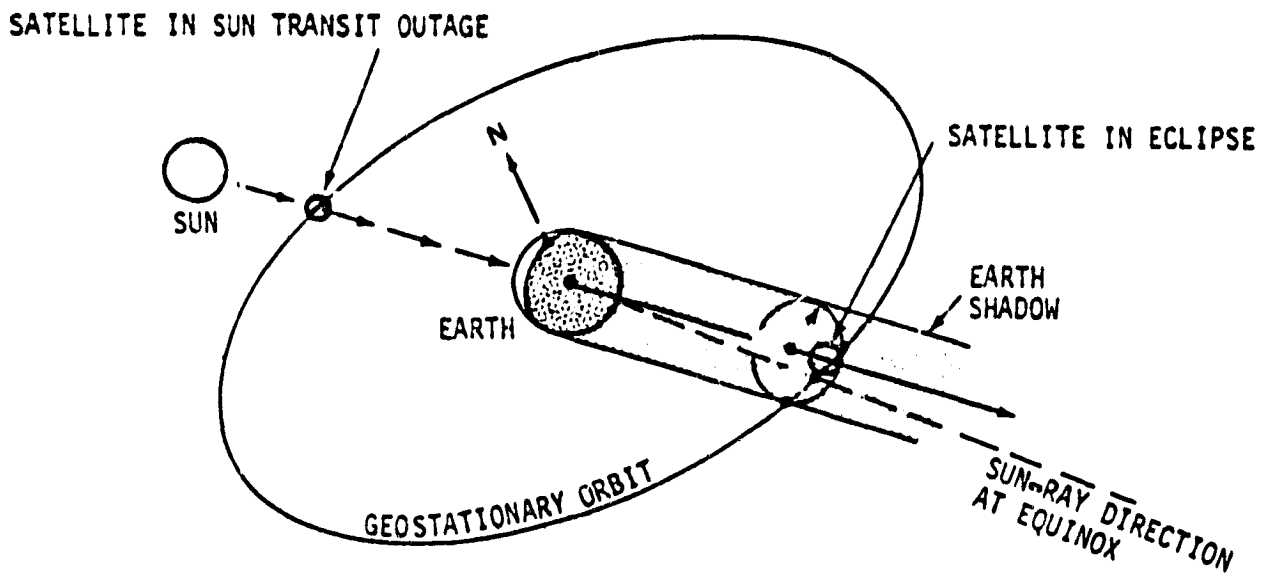


Figure 5-46 EFFECT OF OCCULTATION ON SOLAR ARRAY ILLUMINATION

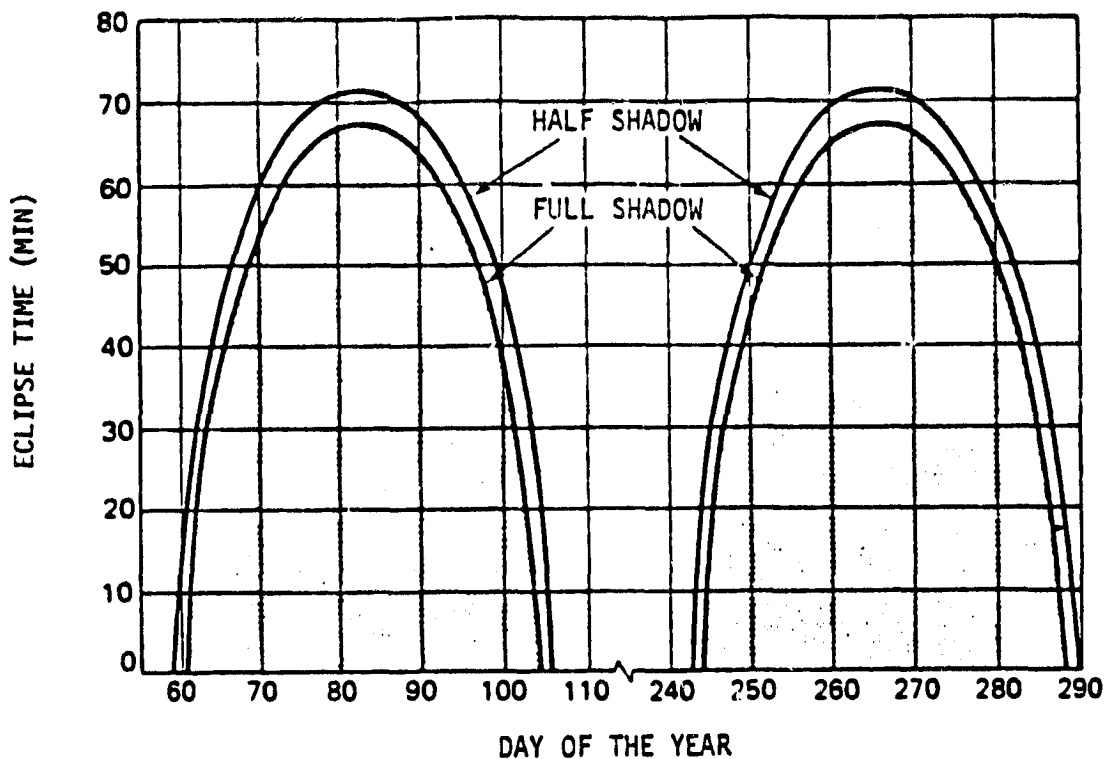


Figure 5-47 SATELLITE ECLIPSE TIME AS A FUNCTION OF THE CURRENT DAY OF THE YEAR

5.6.3 Orbit Utilization

Ever since the possibility of using satellites as communication relays was recognized, it was realized that geostationary orbits provide unique advantages. It soon became apparent, however, that the orbital arc is a finite resource capable of handling only a limited number of communications satellites. The limitation is not a physical one (bumping), but one of electromagnetic interference.

The present procedures for obtaining orbital positions and frequencies are based on a first-come; first-served principle. Economically developing nations have objected to this concept, claiming the developed nations are pre-empting the most desirable orbital locations, and are attempting to modify present policies through the 1979 World Broadcasting Satellite Administrative Radio Conference (WARC) of the International Telecommunications Union (ITU).

5.7 Spacecraft Design

This section touches on some of the more significant areas of spacecraft design related to the feasibility of the SC system concept. The communication subsystem will be discussed first, followed by the electrical power subsystem, the attitude control subsystem, and the command, telemetry, and ranging subsystem.

5.7.1 Spacecraft Communication Subsystem

Many components of the communication subsystem are "frequency sensitive," either in terms of physical size, complexity, cost, or reliability. Some aspects of this situation will be covered along with other design considerations.

5.7.1.1 Spacecraft Antennas

As mentioned earlier, the earth footprint of the communication antenna beam is dictated by a combination of requirements. A reasonable minimum beamwidth appears to be around 1.2° and the maximum around 3.4° . To achieve a 1.2° beam at 150 MHz requires a 250 foot diameter antenna, at 20 GHz the diameter is about 3 feet. Operating at either of these two extremes is not very attractive for a number of reasons, but operating around 1 GHz looks promising. At 1 GHz a 60 foot antenna is needed.

Three types of antenna designs have evolved to overcome launch vehicle space limitations; space deployable, space erectable, and space manufacturable. Deployable antennas are launched in a folded configuration, then fully extended in space. Erectables are transported as piece-parts, then assembled in space. Manufacturables are launched as raw materials, then fabricated and erected in space.

Candidate configurations for the SC system spacecraft antenna include reflectors, arrays, and lenses. Reflectors are the most widely used class of large antennas. A reflector is quite broadband, but limited by its surface roughness which can cause increased sidelobe levels and decreased peak gain. Figures 5-48 and 5-49. At frequencies below the roughness limit the bandwidth is determined by the feed. Reflector antenna performance, particularly for paraboloids, is highly predictable.

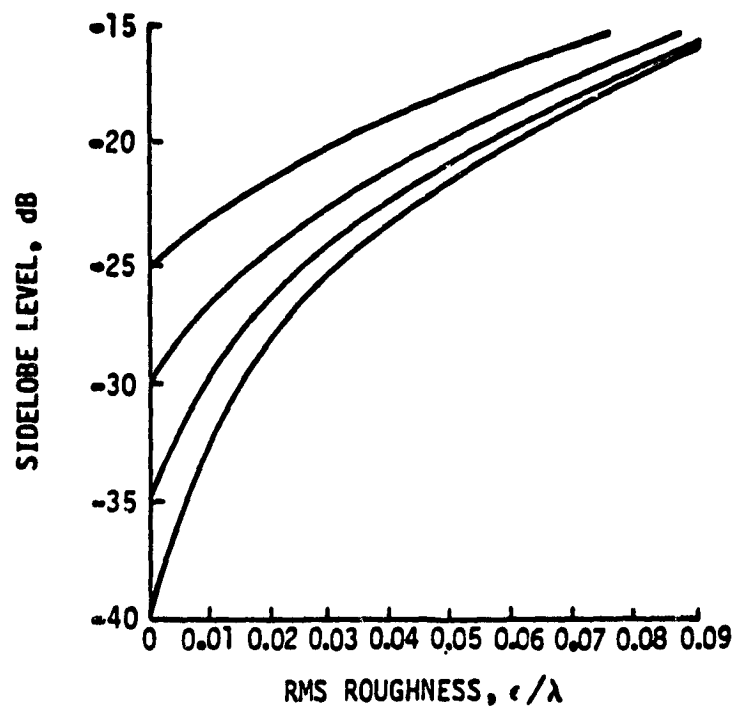


Figure 5-48 SIDELobe LEVELS FOR VARIOUS ILLUMINATIONS AS A FUNCTION OF RMS SURFACE ROUGHNESS

D180-25403-2

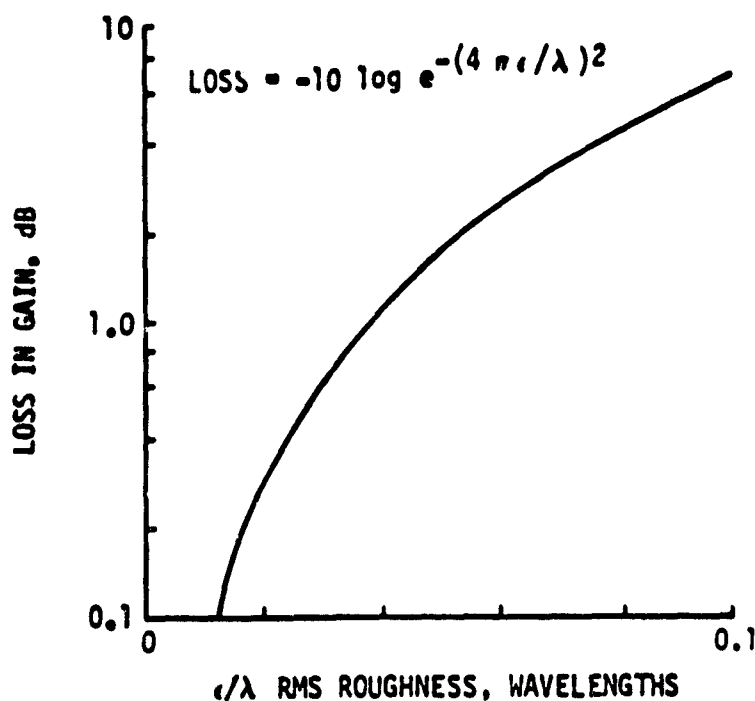


Figure 5-49 LOSS IN GAIN DUE TO SURFACE ROUGHNESS

Feed arrangements include axial, offset, cassegrain, and gregorian illuminations. Performance degradation due to aperture blockage by the feed structure can be eliminated or minimized through the use of offset feed arrangements, however, a large body of design data and experience exists for front-fed reflectors, which makes this type of antenna one of the most economical in terms of design, development, and manufacturing costs.

An array is a collection of radiating elements properly excited in both phase and amplitude to form the desired beam(s). Arrays can be made highly efficient, and can be designed to scan large angles. Array design is much less predictable than other types of antennas, because of the difficulty of developing the feed structure. Development costs tend to be high and fabrication costs increase rapidly as the aperture size is increased.

Of the three classes, lenses are the least common. Lenses are similar to reflectors in that a small feed is used to illuminate a large beam forming element. Unlike reflectors lenses are fed from the rear. They also provide three "degrees of freedom" which can be used in the design, i.e., two surfaces and an index of refraction.

The choice of antenna is influenced by the maximum off-axis look angle of a beam. Single reflectors are usually considered acceptable for angles equivalent to 2 or 3 beamwidths, lenses for up to 5 beamwidths, and arrays for up to 60° .

As noted earlier the SC system requires a simultaneous multi-beam antenna. A simultaneous multi-beam antenna is one capable of providing noncoherent beams pointing in different directions at the same time. This implies that there is one input port per beam.

An antenna providing multiple conical beams may not prove acceptable for the SC system because of earth footprint spill-over into Canada and Mexico. This situation could mandate the use of a summed multibeam antenna which produces earth footprints contoured to the geographical area of interest. A summed multibeam antenna creates the desired beam shapes through the contributions of many narrow beams each of which has a different look angle.

The need for high beam-to-beam isolation will sometimes dictate complex feed arrangements for better sidelobe control and for more precise beam contouring.

A recent study by the Jet Propulsion Laboratory (JPL) included a prediction regarding antenna developments out to the year 2000. As shown in Figure 5-50, mature deployable reflector technology should be available in the time frame of interest.

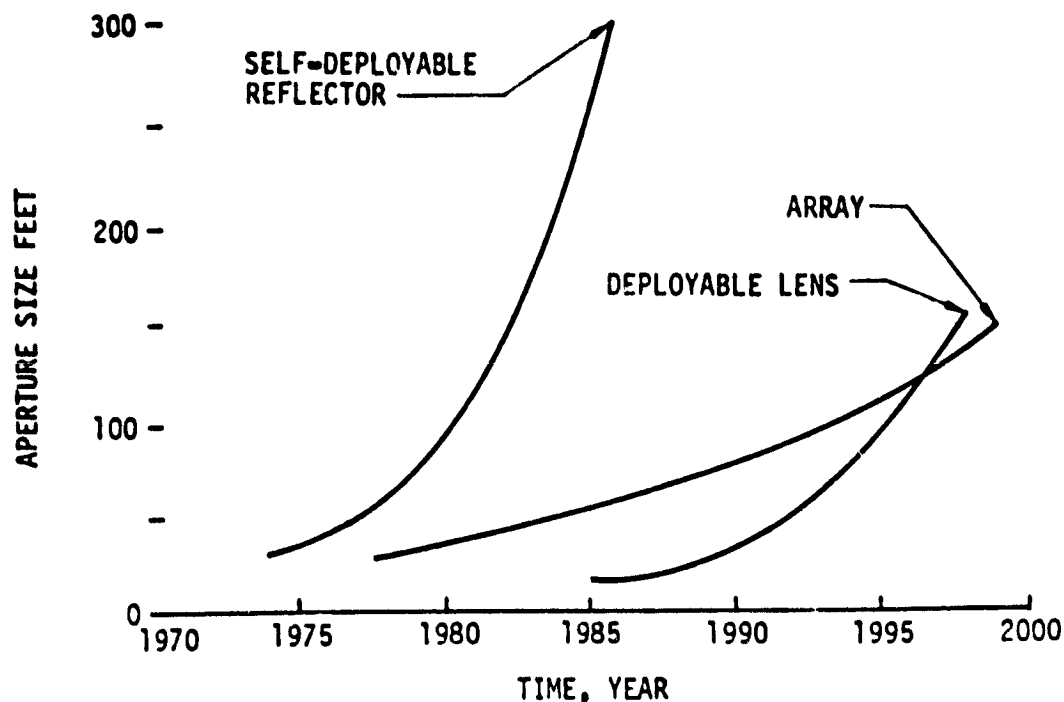


Figure 5-50 PREDICTED ANTENNA DEVELOPMENT

Estimate of antenna mechanical packaging efficiency, and weight were made by JPL. This information is shown in Figures 5-51 and 5-52.

Precision deployable antennas utilize designs composed of rigid, articulated elements which unfurl into place to form a precision surface without the use of active surface forming control systems.

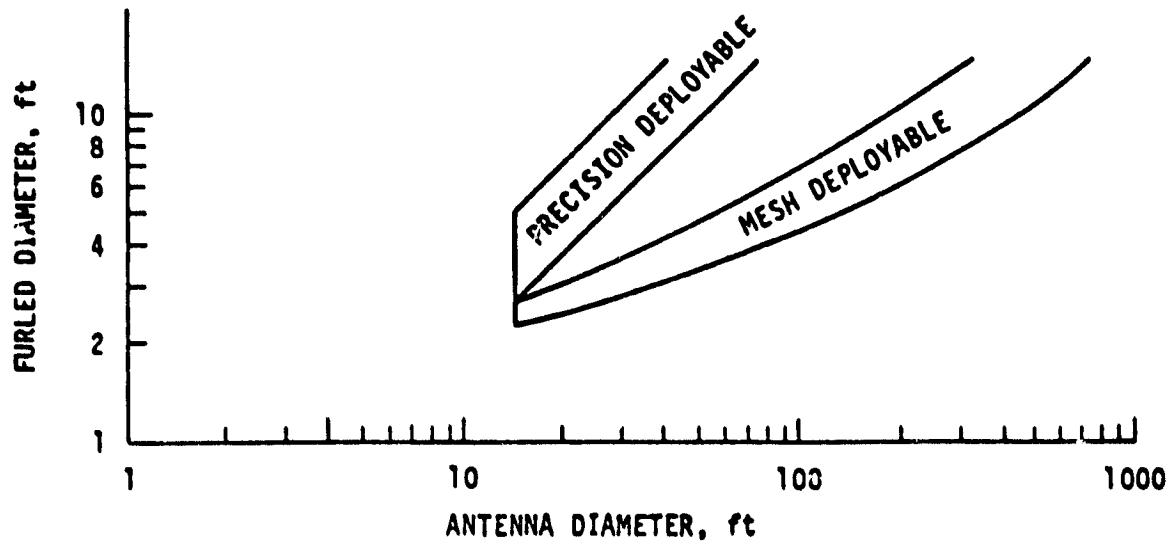
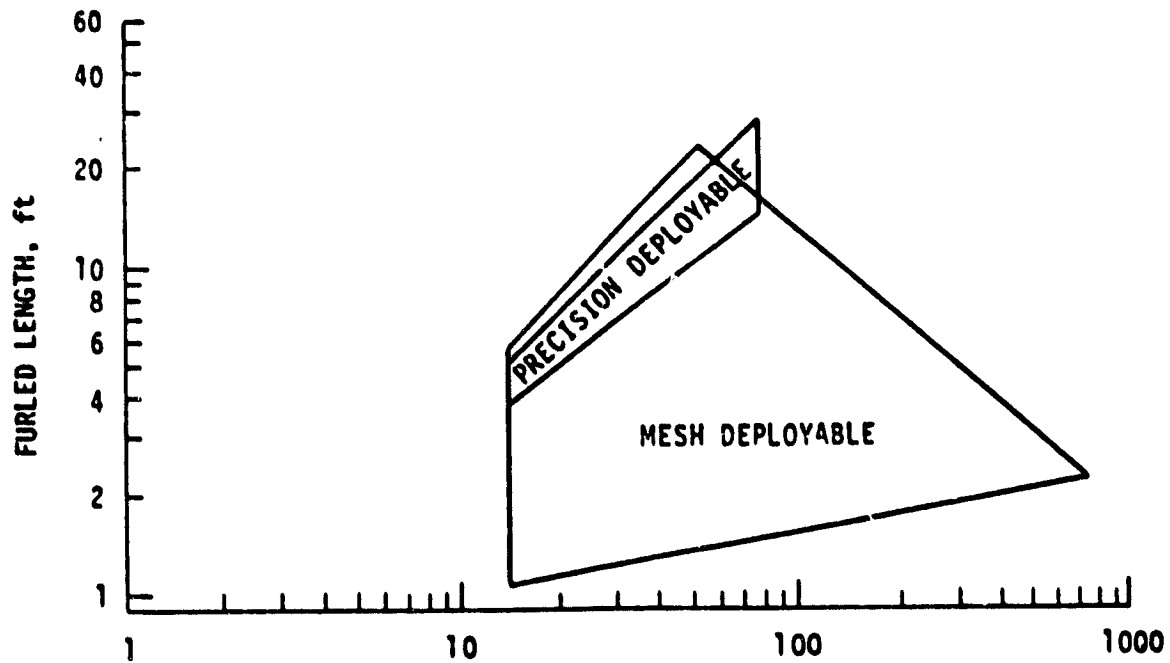


Figure 5-51 ANTENNA MECHANICAL PACKAGING

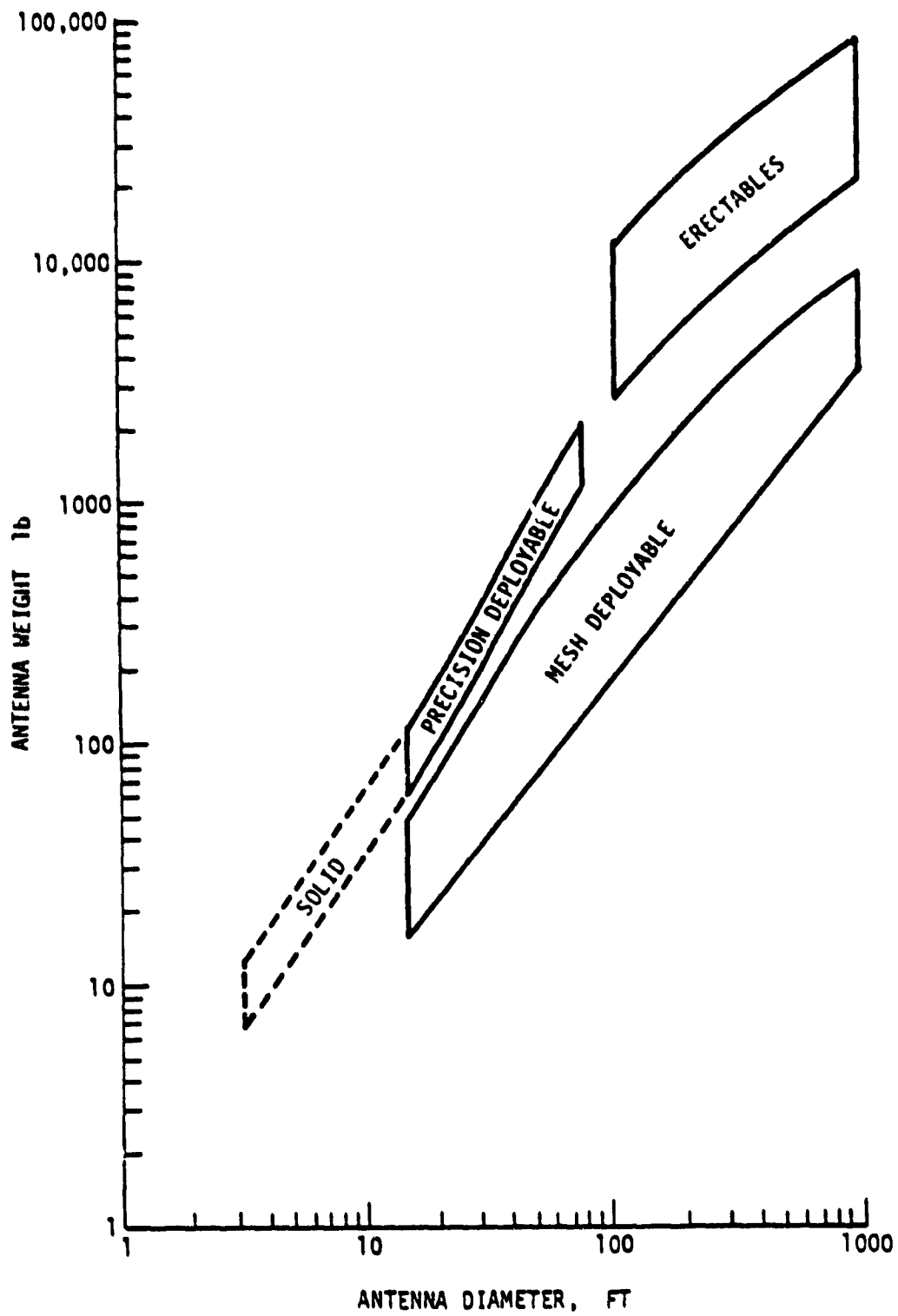


Figure 5-52 ESTIMATES OF ANTENNA WEIGHT AS A FUNCTION OF ANTENNA SIZE

D180-25403-2

5-121

Precision deployable antennas utilize designs composed of rigid, articulated elements which unfurl into place to form a precision surface without the use of active surface forming control systems.

Mesh deployable antennas are formed from non-rigid elements (umbrella-like configurations).

The concept included in the SC system "baseline" (Section 2) is a configuration studied by NASA's Langley Research Center. In the launch configuration the antenna is folded into a compact package. In orbit the deployment sequence begins with the extension of the telescoping mast and proceeds as illustrated in Figure 5-53. For antennas larger than 50-100' in diameter special techniques may be required to precisely control the surface.

Of all the components making up the spacecraft the large, multi-beam antenna is the only item which has not been "proven" in space. Although studies and structural modeling efforts have, or are, being funded, the SC system may be the first bona-fide commercial application.

5.7.1.2 Spacecraft Transponders

The transponder provides the basic functions of (1) receiving an uplink signal arriving at one frequency, (2) converting this signal to a second frequency and (3) amplifying the signal to produce sufficient radiated power to make possible effective communications with a specified ground receiver.

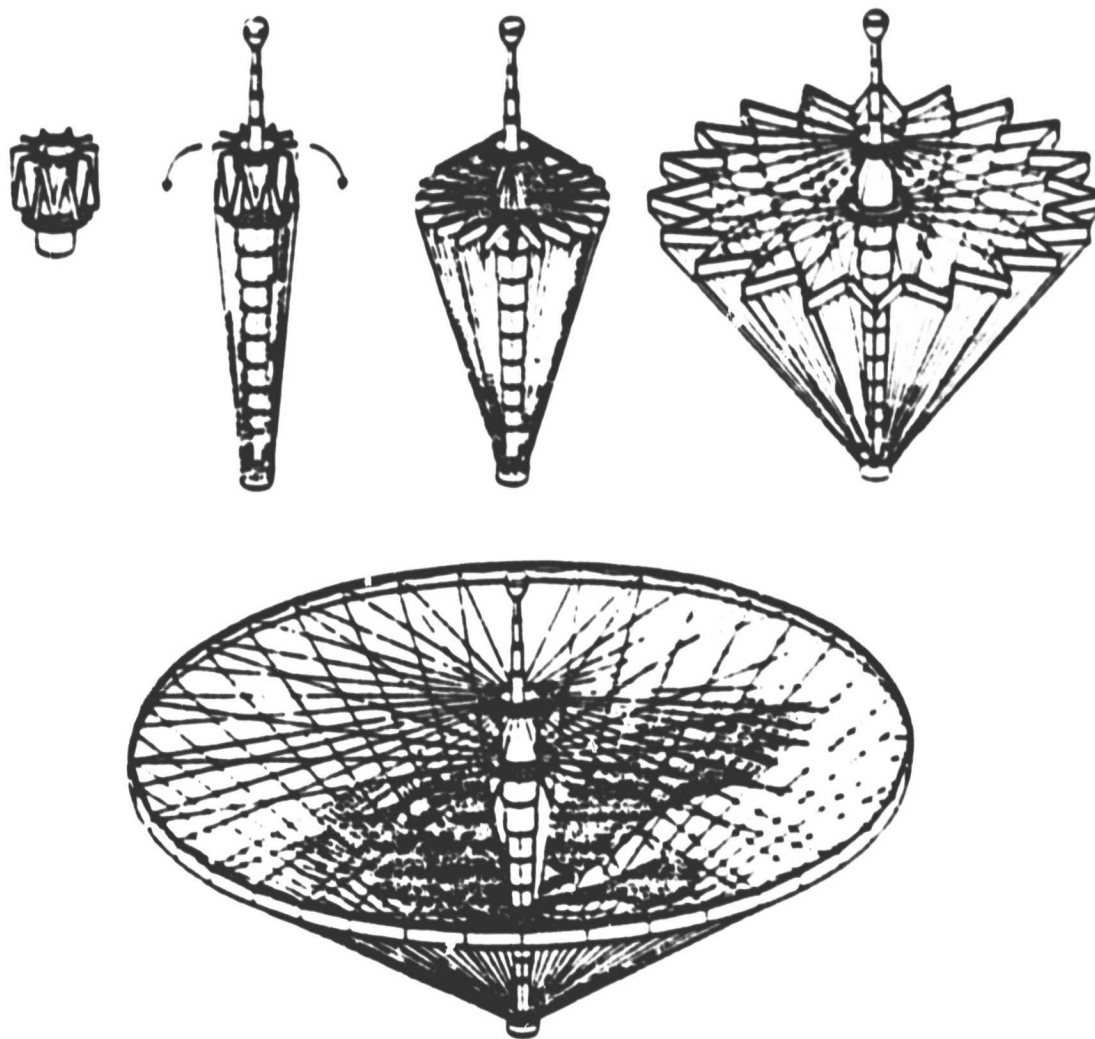


Figure 5-53 SPACECRAFT ANTENNA DEPLOYMENT SEQUENCE

ORIGINAL PAGE IS
OF POOR QUALITY

Transponder requirements vary according to the type of multiple-access scheme used. Frequency-division multiple access (FDMA) and code-division multiple access (CDMA) are inherently wide-band concepts whereas time-division multiple access (TDMA) tends to be narrow-band.

The low data rates sufficient for the SC system coupled with the need for only a small number of communication channels permit considering either narrow-band or wide-band transponder concepts for the TDMA. In the narrow-band approach, each incoming signal is handled separately by a single transponder channel. In the wide-band approach signals are co-mingled in common output power amplifiers.

Single-channel transponders can be categorized by the method of transferring information from the received carrier to the transmitted carrier. The four principle methods are:

- 1) Linear frequency translation
- 2) Limiting
- 3) Modulation Conversion
- 4) Demodulation-Remodulation

The linear frequency translating transponder is designed to provide sufficient dynamic range to permit the received signals to be linearly amplified, then frequency translated to the downlink transmitter frequency. The transponder is nearly transparent in terms of its operations on the input signal, simply adding noise in the process.

The limiting transponder has been the most common form used in communication satellites because of its better efficiency and somewhat reduced susceptibility to interference. The input signals are either hard-limited before reaching the final power amplifier, or are merely allowed to saturate the final amplifier.

Single-conversion RF to RF, and double-conversion RF to IF to RF, versions of the linear and limiting transponders are used, the choice is subject to the requirements and peculiarities of a particular application.

The modulation conversion transponder changes the received modulation into another form for retransmission on the downlink.

The demodulation-remodulation repeater is attractive for some applications where it is desirable to optimize the uplink and downlink modulation formats individually. For example, spread spectrum modulation may be required for an uplink, with a more conventional modulation used for the downlink.

Radiated power level requirements, and thus power amplifier requirements, are dictated by link design considerations. Low power levels permit the option of solid-state amplifiers or traveling wave tube amplifiers (TWTA). High power levels mandate TWTAs. Historically, the TWTA, with its excellent life and reliability, has been extensively used in spacecraft. It has been the foundation for the confidence in satellite communications.

Recently solid state power amplifiers have challenged the TWTAs in many space applications. The present capabilities of field-effect-transistor amplifiers in the telecommunication bands are shown in Figure 5-54.

Satellite transponders have changed very little since the early 1970's. The concepts and components required for the SC system transponders are readily available, off-the-shelf items.

5.7.1.3 On-Board Signal Processing

Communications equipment in a spacecraft can be designed for "bent pipe" operation wherein received signals are simply amplified and rebroadcast at a different frequency, or for "on-board processing" wherein received signals are demodulated and processed in some manner before being retransmitted. The requirements of the SC system favor the use of the latter.

On-board processing is deemed desirable for several reasons. First it allows a great deal of flexibility in dealing with link security. Incoming messages can be checked for proper addressing and/or validity. Coding or encryption may be used. Antenna beam can be reformed to "null out" interfering sources, and mono-pulse techniques may be used to locate such sources.

On-board processing also permits channel and beam switching arrangements for restructuring links. And, finally, it allows the use of different data rates for incoming and outgoing messages, a key feature for certain system architectures. However, on-board processing adds to spacecraft complexity and weight.

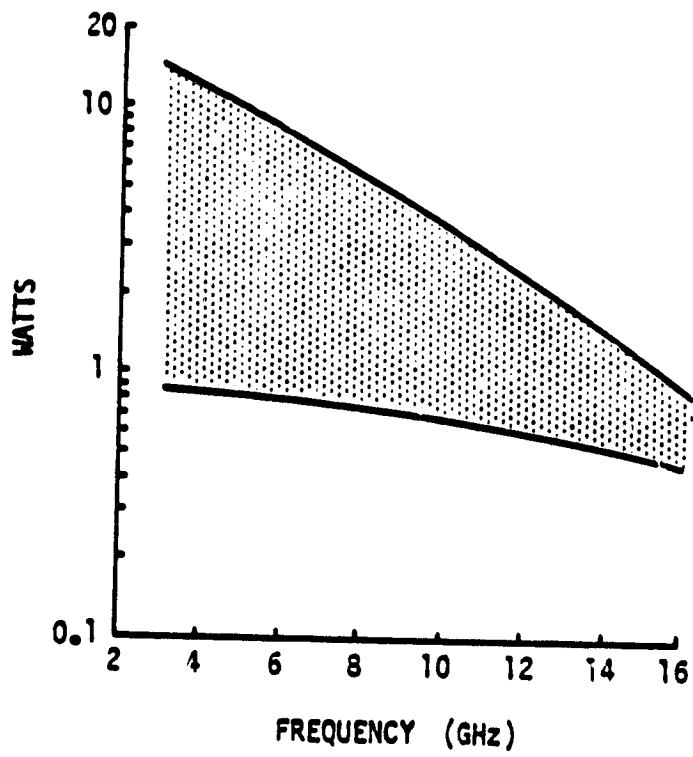


Figure 5-54 FET AMPLIFIER CAPABILITIES

5.7.2 Spacecraft Electrical Power Subsystem

The spacecraft electrical power subsystem must provide power for operating all electrical components for a mission life of 10 years. This must be accomplished by the conversion of solar energy into electrical energy when solar flux is available, and by means of batteries at other times.

The power system consists of a solar array, batteries, array drive, and electrical control devices.

The array is sized to provide operating power to the communication payload, the housekeeping loads, and to charge the batteries. Two types of structural arrangements can be used, a lightweight flexible array, or a stiff array. The choice is a matter for detail design studies.

Three battery options can be considered; nickel-cadmium (NiCd) an advanced NiCd, and a nickel-hydrogen cell (NiH₂). The choice between the heavier NiCd batteries and the lighter weight NiH₂ batteries is a function of payload operating requirements, and considerations relative to design maturity.

The assumptions used in configuring the electrical power subsystem for the "baseline" concept (Section 2) are listed in Table 5-17. The technology required to implement such a system is well in hand.

Solar Array	Batteries	Operation
Power Density 13w/Ft ²	Conversion Eff. 65%	Life - 10 Years
Degradation	Loss to Load 10%	Occultation - 70 Min. Max. 50 Min. Avg.
System Losses 15%	Loss to Array 10%	
Weight 1 Lb/Ft. ²	Spec. Mt. 12 MW/Lb.	
	Volume Ratio 1	
	Duty Cycle 1%	

Table 5-17 ELECTRIC POWER SUBSYSTEM PARAMETERS

5.7.3 Spacecraft Station-Keeping and Attitude Control Subsystem

Various forces act to displace a satellite from its desired orbital location relative to the earth. The primary long-term perturbation is longitudinal drift due to the ellipticity of the earth at the equator, and an increase in the inclination of the satellites' orbital plane due to lunar and solar influences. Secondary effects are induced by the earth's gravity field and by solar radiation pressure. These forces generate a need for both longitudinal and latitudinal station keeping.

Geostationary satellites are usually constrained to remain within a region of space bounded by a square with sides of 0.1° . The synchronous altitude also varies by about $\pm 0.1\%$ due to orbit ellipticity.

There are two basic methods for stabilizing the spacecraft's attitude with respect to the earth, spin stabilization and three-axis stabilization. Figure 5-55. Spin stabilization uses a spinning cylindrical drum covered with solar cells in conjunction with a despun central platform containing the earth-pointing antennas and other equipment. The three-axis approach stabilizes the entire spacecraft, with solar cells mounted on planar paddles which are oriented to the sun. Both concepts have been used extensively, however, because of the size of the antenna required for the SC system, three-axis stabilization is the preferred choice.

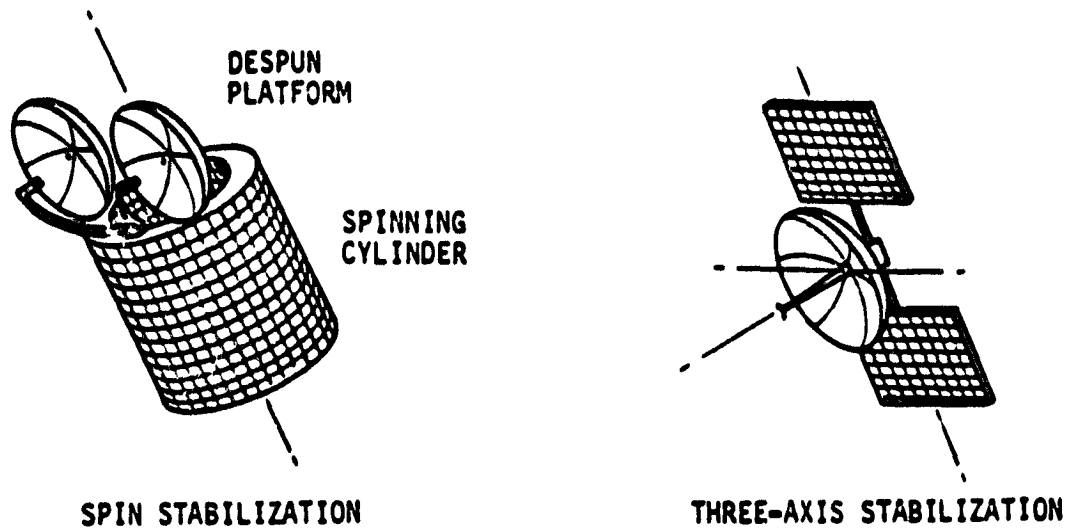


Figure 5-55 SPACECRAFT STABILIZATION

The requirements which influence the attitude control and station keeping subsystem were assumed to be:

- Synchronous, near equatorial orbit with near zero inclination
- Antenna pointing to less than 0.1 degree, all axes
- V latitude correction of 150 ft/sec/year
- V longitude correction of 6 ft/sec/year
- Weight limited to 5000 pounds IUS payload, and
- Ten year life time

Using the above parameters, the propellant requirement of hydrazine thrusters is very large. Two alternatives should be examined: (1) replacement of the hydrazine motors with ion engines, (2) relaxation of the lateral station-keeping requirements, and (3) the use of a ground based reference to provide pitch and roll information.

5.7.4 Command, Telemetry, and Ranging Subsystem

The Command, Telemetry, and Ranging (CTR) subsystem provides the means by which control information is received by the spacecraft, and through which status and tracking information is returned to the Satellite Control Station (SCS) on the ground. A relatively low data rate pulse-code modulated communication link is required for general spacecraft housekeeping data. All data requires encryption on both the up and down links to prevent potentially serious perturbations of the spacecrafts functional capability and orbit.

The CTR subsystem must be completely redundant. Provisions must be included for switching from an omni-directional antenna to a directional antenna during the launch-orbit transfer process.

The CTR subsystem can be built from mature components with minimal risk.

5.7.5 Spacecraft Weight

The Space Transportation System (STS) has a 65,000 pound payload capacity, and the Inertial Upper Stage (IUS) can take a 5,000 pound payload from low earth orbit to geostationary orbit.

Weight estimates for various spacecraft subsystems are listed in Table 5-18 for the "baseline" system. The 5,000 pounds total estimated spacecraft weight is, for now, considered acceptable. Four items make up 66% of the weight; the station-keeping fuel, the batteries, the solar panels, and the antenna. Each of these afford some opportunity for weight reduction.

STRUCTURE AND MECHANICAL	694 POUNDS
THERMAL CONTROL	56
ELECTRICAL POWER	1,940
STATION-KEEPING & ALTITUDE CONTROL	217
COMMAND, TELEMETRY, AND RANGING	74
COMMUNICATIONS	969
FUEL	<u>1,050</u>
TOTAL SPACECRAFT WEIGHT	5,000 POUNDS

Table 5-18 SPACECRAFT WEIGHT

5.8 Master Control Station and District Control Center Considerations

5.8.1 Centralized vs Dispersed Control

Master Control Stations (MCS) and District Control Centers (DCC) are functionally quite similar, both act to manage an electric distribution network. The MCS plays its roll in centralized management authority. DCC's are used in a horizontal management structure wherein the network is partitioned into districts, each controlled by a separate DCC.

It was pointed out in paragraph 5.2 that the use of DCC's may lead to a hierarchical communication arrangement. Certain types of functions may be performed by a DCC without any requirement for intersite communications (between DCC's or between DCC's and a central office). Other functions require, as a minimum, an awareness of on-going and planned events of associates. Still other functions require real-time cooperative actions between sites.

The SC system must be able to handle both centralized and dispersed control. While it appears that the most viable system concepts can accommodate either approach, certain concepts may be better suited to one or the other.

Because the centralized management philosophy is believed to predominate, it was used as a basis for formulating SC system concepts in this study. In follow-on work more attention should be given to dispersed management concepts since the multi-node nature of dispersal may give rise to unforeseen problems.

In tying together a number of DCC's it is quite possible that computer-to-computer links are mandated and a distributed data processing network must be formed. The need for a capability which permits any DCC computer to talk with any other DCC

computer presents an access problem not unlike the communication channel access problem discussed in paragraph 5.2, only now a number of computers must access a data-bus channel. While the problems and candidate solutions are related, design considerations are different. The impact of implementing the required communications should be addressed in later studies.

It should be noted that from the perspective of a satellite offering a total solution to a utility's communication needs, other operations (beyond distribution automation and control) are likely to mandate computer-to-computer ties.

5.8.2 The Man-Machine Interface

The role of the "man" in the control loop deserves scrutiny.

Under most circumstances, it is possible for the processing algorithms to take real-time data, manipulate it, and derive optimum control strategies without manual intervention. This is not necessarily a very comforting situation for an Operator in responsible charge, nor may it be the best approach from other standpoints. However, it is a possibility which should be considered.

One way to use the "brains" of the computer yet leave the final decision in human hands is to display a computer-derived list of potential strategies, with the algorithm's best choice flagged. The final decision, however, is left to the Operator. Such computer-aided decision making has the potential for coping with complex situations which may otherwise be beyond the "spur of the moment" reasoning capacity of the Operator.

5.8.3 Data Retention

The majority of communication traffic associated with DAC has little or no long term retention value, however, some of this information can be useful in reconstructing condition immediately prior to an unscheduled event. To temporarily store this data, a continuous loop recording of 30 minutes duration can be provided. It is played back in "fast time" for off-line analysis purposes.

5.8.4 Equipments

Antenna Size - One of the variables associated with the MCS/DCC equipment compliment is antenna size. Since the MCS/DCC is likely to be located at an existing facility it may be necessary to mount the antenna on the roof. Structural considerations, building codes, aesthetics, etc., then come into play. However, a 10-20 foot antenna does not seem too large to be accommodated at most sites.

Interfaces - Customer meter reading is a precursor of customer billing. The coupling between meter-reading operations and billing operations needs examination. One possibility is to record meter readings on magnetic tape, then manually transfer tapes to the billing computer. Other possibilities involve direct coupling between MCS/DCC equipment and billing equipment.

Redundancy - Reliability considerations lead to the need for redundant equipments, and possible back-up modes of operation. In a system based on dispersed control the possibility of using DCC's in a hierarchy of back-up roles deserves detailed examination.

Emergency Power - Because of their key role in DAC operations, MCS/DCC's require emergency power supplies. Capacity and endurance requirements are subjects to be explored in the detail design.

The development of MCS/DCC concepts and equipments are well within the state-of-the-art and pose no feasibility questions or undue risks.

General

The Satellite Control Station (SCS) is used as a command and control center of the spacecraft in orbit. The key mission requirements of the SCS are: 1) assist during satellite launch; 2) control the satellite in geostationary orbit, 3) provide continuous monitoring of satellite status; and 4) provide command and control functions as necessary for optimizing the satellite communication capabilities including remote trouble-shooting.

The basic design considerations for the SCS are operational reliability and economy of operation, which require a high degree of system redundancy, automation and autonomy.

The SCS has three basic functional areas; RF receiving and transmitting, signal-processing, and spacecraft operations control. The SCS will be an autonomous facility separated from all utility operations.

Tracking, Telemetry & Control Systems

The spacecraft in orbit has two functionally redundant and independent command and telemetry channels for communicating with the SCS. During spacecraft launch and initial orbit positioning the command and tracking communications are accomplished using spacecraft's earth coverage antenna system.

Tracking System: The SCS antenna is equipped with auto-track capability. Four tracking elements will comprise the monopulse feed system. The pointing accuracy of the antenna is 0.025° . The shaft position readout for azimuth and elevation will have a resolution of 0.01° ; it will be transmitted to the data computer for use in conjunction with spacecraft ranging and orbit positioning when its on-station. The satellite positioning requirements are $\pm 0.1^{\circ}$ in longitude and latitude.

The auto-track antenna and the monopulse receiver can track the spacecraft beacon signals. Several schemes of different antenna polarization are used to improve tracking capabilities to secure the command link.

Command System: The command system is designed to minimize errors on several levels; coding, transmission, and command generation.

Under routine operating conditions commanding is performed using "canned" command lists to execute the desired functions. Command messages are time-tagged and once authorized will be executed in accordance with the predetermined sequence.

Spacecraft commanding entails the sequence of load, verify, and execute. The received command is retransmitted via the spacecraft beacon to the SCS where it is compared to the original command. Upon verification, an "execute" command is sent to the spacecraft.

Securing commands from unauthorized control of the spacecraft is achieved through command message formatting and coding techniques that can be changed periodically by software.

The command transmission data rate is low, such as 100 BPS. The modulation could be similar to that used for utility communications, but the use of conventional telemetry modulation is more likely (PCM/FSK/FM).

Telemetry: The telemetry subsystem in the spacecraft can transmit two telemetry signals simultaneously, one on each beacon. A 14.5-KHz subcarrier is FM-modulated by either PAM or analog data. The modulated subcarrier in turn phase-modulates the beacon RF carrier.

Telemetry data is updated from the spacecraft every several seconds and depends on the total points of information to be relayed down to the SCS telemetry receivers and data processing. The telemetry signal is recorded on analog tape recorders for future use, in addition to real time processing.

Ranging: Slant range to the spacecraft is measured by using the spacecraft command receiver and beacon transmitter in transponder fashion. Several coherently generated sine-wave tones are transmitted one at a time via the command uplink, then received via the beacon downlink. The ranging system employs FM/FM modulation on the uplink and FM/PM on the downlink. The range is determined by measuring the shift in phase angle between each transmitted and received tone. Using four separate tones, range can be resolved to within 5 to 6 km. Using all four tones together, the range measurement can be made to within 25 meters.

Spacecraft Operations Control Center

The Spacecraft Operations Control Center is the command control room for satellite operations. The spacecraft status is continuously monitored and displayed on the operators consoles. Displays and keyboards are the prime monitoring and control devices. An operations analyst in conjunction with the control computer acts as the executive-command input to the system. A console operator can monitor and control the TT&C equipment: e.g., computer, stripchart recorder, and analog tape-recorder.

Intersite voice and data routing is also performed at the console. A mission-time clock and a GMT clock round out the console equipment. Both clocks are driven from a time-code generator that is synchronized with a WWV receiver.

5.10 System Security Considerations

Another key issue relating to concept feasibility is system security. The Master Control Station (MCS) to Remote Terminal (RT) communication links must be designed to minimize their susceptibility to attempts to disrupt operations by jamming or spoofing. Because of the topology of a power distribution network, disruptions at a single site will not normally have a large scale effect. However, there are usually a few key facilities where such activity could have widespread ramifications. At these sites, more elaborate precautions are in order.

5.10.1 Link Vulnerability

The receiving system at a substation is more vulnerable to incoming "command" message disruption than the receiving system at the satellite, as illustrated in Figure 5-56. Uplink receivers at the spacecraft are far from the jammer and can be protected by making sure that the desired signal is of such magnitude that it competes favorably with that from the jammer. On the other hand, down-link receivers at the substation can be exposed to nearby interference attempts. The amount of protection needed for this case relates to functional criticality. At most sites a reasonable level of protection can be achieved through signal power and by the use of modest size, narrow-beam receiving antennas located to minimize side lobe exposure. For truly critical sites, additional security can be provided by means of addressing restrictions and coded transmissions.

"Response" messages flowing to the MCS are in general not as important as "command" messages. There are exceptions, such as "change of state" messages and replies to certain interrogations which are needed to determine equipment status for purposes of correcting emergency situations.

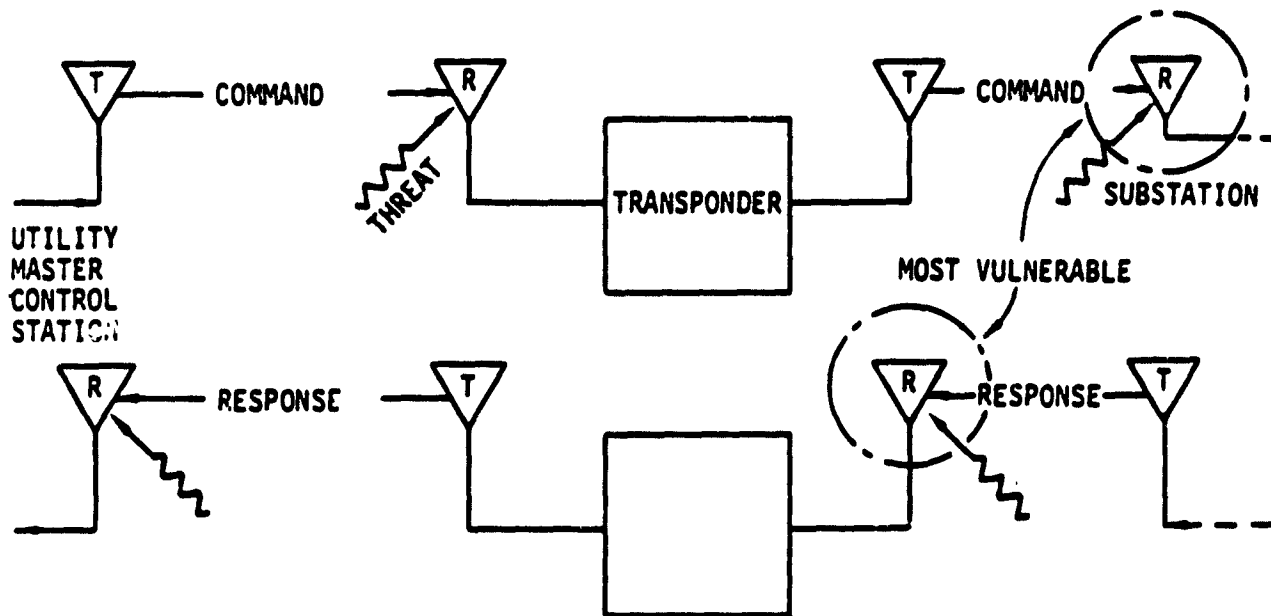


Figure 5-56 VULNERABILITY OF SUBSTATION LINKS

For messages flowing to the MCS the satellite receiver is more vulnerable than the MCS receiver. This situation exists for two reasons. First, the MCS receiver by virtue of its antenna size and location is not easily accessed by nearby threats using portable equipments, and second, a worse case threat model must recognize the possibility of a remotely located clandestine operation with substantially more antenna and equipment capability than is likely to be usable in more populated areas. This situation presents a greater challenge since it would allow a well equipped jammer to compete more favorably against a substation's transmissions.

For purposes of establishing specific design requirements, further insight into realistic threat models and protecting methods may be gleaned from reviewing requirements imposed on typical domestic-military communication satellites.

5.10.2 Spoofing

Successful spoofing requires sophisticated equipment and knowledgeable operators. First the system parameters such as operating frequency, modulation, bit-rate, message structure, terminal address, etc., must be determined. These could be acquired through employee contacts or by direct measurement using readily available, but rather expensive equipment. Spoofing gear can be fabricated by a knowledgeable individual in a basement workshop. The simplest technique is "repeat jamming" using previously recorded messages.

The degree of mischief created by spoofing depends on the functions being emulated. At a customer terminal the results may prove annoying but would probably be of minimal consequence. On the other hand, spoofing certain selected substations could be more serious.

Measures to counter spoofing are available and include:

- 1) Denial of access to the satellite by filling all time slots
(erroneous messages will not be relayed).
- 2) Random changes of terminal addresses and/or message structure.
(This could be done remotely over the normal communication links.)
- 3) Coded transmissions using pseudo random codes and match filters.
- 4) Encrypted transmissions.

While all these countermeasures increase costs and add to complexity, they are not necessarily beyond consideration for this application in view of the present trend in microelectronics and microprocessors.

Before countermeasures are brought into play, however, the use of features inherent in the system should be considered. Already built into the SC system concept are means for detecting and locating most kinds of spoofers. For example,

the data gathering capability of the system can be used to detect unauthorized messages and put together profiles of "normal" conditions at individual sites. Deviation from normal limits can be flagged by the controlling computer and routines set in motion to examine in more detail specific suspicious cases.

5.10.3 Customer Response Link Vulnerability

The transmitter at the customer terminal need only be a low power unit to satisfactorily effect a communication link meeting functional requirements. Unfortunately the use of low power makes the link quite vulnerable to jamming. A perverted person with modest equipment could attempt to interrupt the customer response network by broadcasting a strong signal toward the satellite. The degree of disruption created would be a function of the amount of time the jammer remains on-the-air, as would his potential for apprehension.

The architecture of the SC system and its operational protocols are such that a jamming condition can be detected immediately. The speed with which the jammer is located varies with his mobility. A fixed installation broadcasting continuously could be located in a relatively short time, in a matter of minutes to a few hours. On the other hand, a highly mobile jammer operating intermittently could prove to be a difficult nuisance to suppress or apprehend.

There are some design sophistications which can be incorporated into the system to make jamming much more difficult, however, these have a cost impact, and may not be entirely effective against a highly knowledgeable individual or organization with high power equipment.

Spread spectrum techniques can be employed which provide 20 to 30 dB of processing gain, which means the jammer must supply 100 to 1000 times more radiated power than that of the customer terminal. Although this would make jamming a lot more difficult, it would not necessarily thwart an extremely hostile individual with malicious intent. This technique would increase equipment cost and may not be justified for customer terminals.

Another technique for countering a jammer is to reshape or reposition the spacecraft antenna pattern so that the jammer is placed in a pattern null. While this technique would black-out a number of customer terminals in the vicinity of the jammer (and probably at a few other locations within the region) it would permit most of the region's terminals to function while the jammer was active. Another feature of this approach is its inherent capability to localize the jammer and, therefore, speed his apprehension. The use of monopulse receivers in lieu of, or in addition to, antenna nulling could provide improved jammer localization.

It is worth noting that although radio modes of communication are widely used in commerce and industry, and present a continuing target for harassment, the number of deliberate disruptive attempts against such systems has been miniscule. This favorable situation is believed to stem from a general recognition among the intelligensia capable of perpetrating such deeds that interfering in the radio spectrum can be a Federal offense resulting in large fines and jail sentences.

5.10.4 Site Tampering Protection

Remote terminals may be subjected to tampering. Detectors can be provided to report violations of an equipment's physical integrity and to report local spoofing attempts. Tripped detectors will set flags in the terminal's message

formatting routines so that the violation will be reported to the MCS during its next routine transmission. On the other hand, certain types of unattended facilities necessitate intrusion detection capability which immediately involves a police action. This situation is handled by an ALARM report dispatched to the MCS via the special emergency communication channel.

The SC system is uniquely geared to discovering and disclosing tampering.

5.10.5 Wartime Vulnerability

The vulnerability of space communications for electric utility automation during wartime must be considered separately. If it is concluded that electronic warfare against the SC system would sufficiently disrupt electric service in the United States to constitute a viable threat then substantive protective measures and/or work-around emergency procedures may be needed.

A geostationary satellite positioned to illuminate the continental United States would be located somewhere between 60 and 135° West longitude, possibly hovering over such nations as Brazil, Columbia, or Ecuador, or over the Pacific Ocean. First order sidelobes from the spacecraft antennas are likely to be visible from parts of Mexico and several other Central and South American countries, and from various locations in the Pacific, Gulf of Mexico, Caribbean, and Atlantic.

One might postulate the surreptitious conversion of an INTELSAT or similar telecommunication station to function as a jammer/spoofers at an appointed time. (Other unexplained installations having large antennas would probably create enough interest by the military to be properly characterized in advance.)

Under the conditions depicted in Figure 5-57, the vulnerability of the SC system to such a covert conversion may be assessed as follows:

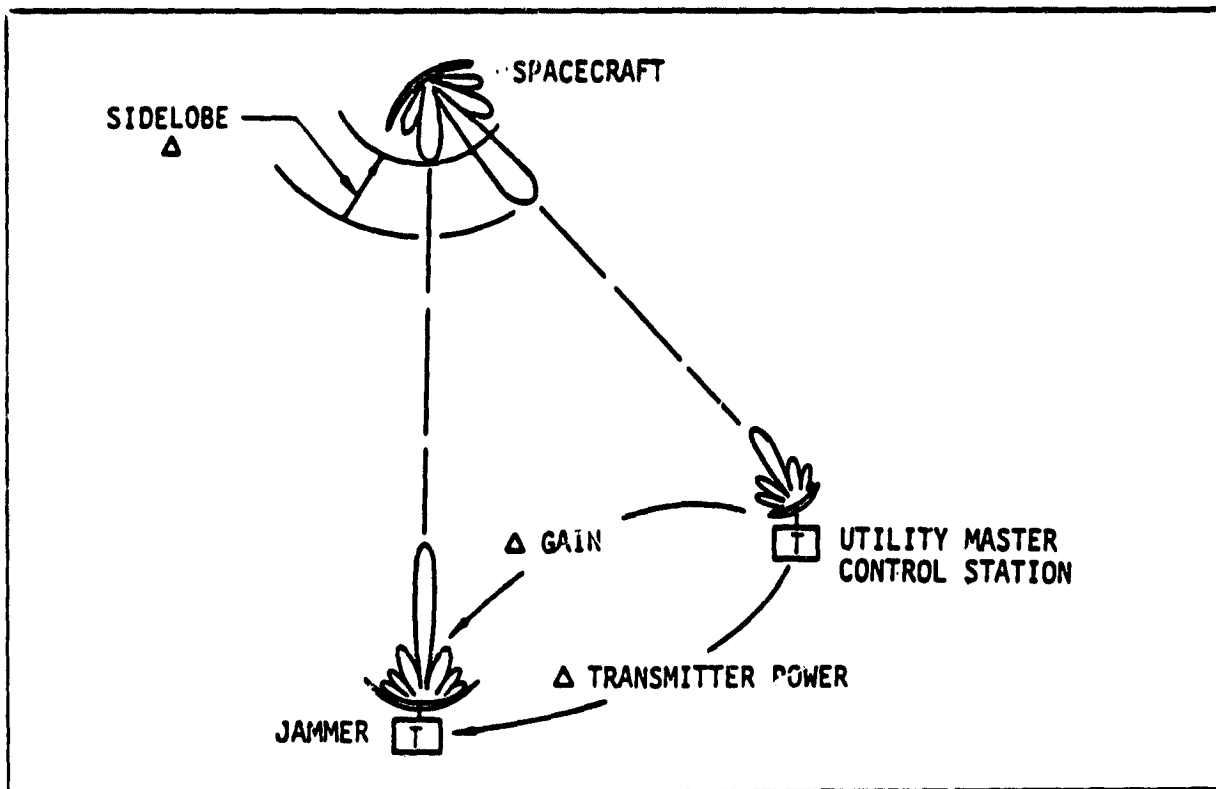


Figure 5-57 JAMMING THE UTILITY MASTER CONTROL STATION UPLINK

A ground-based jammer attempting to defeat the satellite through its sidelobes probably works at a disadvantage of 20 dB or more. This differential is "made up" at the jammer by its greater inherent radiated power (as compared with that from the MCS).

A typical 60' diameter telecommunication antenna would make up about 15 dB when competing with a 10' diameter MCS antenna, the remaining 5 dB could be obtained through transmitter output. As the MCS antenna becomes larger in size, the demands on the jammer go up, Figure 5-58. A 20' MCS antenna, and a 60' jammer antenna requires at least a 10 dB power differential between transmitters.

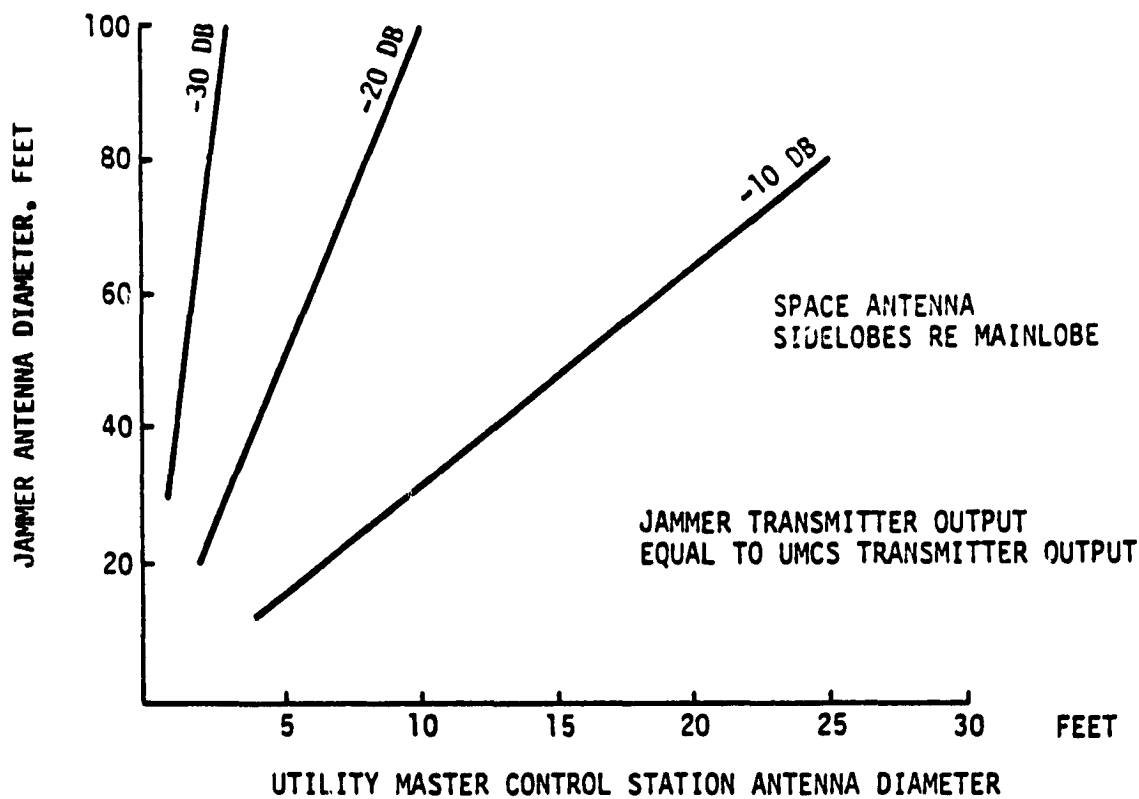


Figure 5-58 REQUIRED JAMMER ANTENNA FOR SIDELOBE JAMMING

As a practical matter, the MCS antenna is probably limited to 30 feet. With such an antenna, and with coded transmissions having >20 dB processing gain, a powerful sidelobe jammer would likely be negated.

It should be emphasized that it is by no means established that the SC system would be an attractive, militarily worthwhile target. The likelihood of having the SC system added to the enemy's list of meaningful targets can only be assessed through a detailed examination of possible aggressor strategies.

5.11 Health Considerations

Long duration exposure to RF radiation can be a health hazard. In 1966 the United States developed an exposure Safety Standard, ANSI C95.1, which states that a whole-body exposure of up to 10 milliwatts/cm² is safe for unlimited duration, under normal environmental conditions. With the wide-spread use of microwave ovens, the concern over potential radiation hazards increased, which lead to the Radiation Control for Health and Safety Act of 1968 (P.L. 90-602).

Radiation hazard levels are also defined by the U.S. Air Force (T.O. 312-10-4, "Electromagnetic Radiation"). Exposure is limited to a power density of 10 milliwatts per square centimeters continuously over an 8-hour period; which is more restrictive than the Safety Standard's "unlimited duration." Other countries and organizations have proposed safe levels which are mostly lower than current U.S. levels.

A new proposal by a national technical organization, the Bio-Electromagnetic Society, recommends an exposure level of 1 mw/cm² between 30-300 MHz, and 5 mw/cm² beyond 3 GHz. This is based on radiation of .4 watt/Kg of exposed tissue.

Radiation hazard is measured in terms of thermal effects on a living tissue. In a recent experiment, a man weighing 70 Kg and a height of 1.74 meter was found to have a resonance frequency of 79 MHz, which caused maximum thermal effects on his body compared to other frequencies at the same radiation level.

The Transceiver Units serving residential customers are normally installed at elevated locations in order to have a line-of-sight path to the satellite. These

units could radiate an effective isotropic power of 100 to 10,000 watts (EIRP), depending on choice of operating frequency and design configuration. The duty cycle, however, is extremely low, normally just tens of milliseconds per month.

Emissions from the Master Control Station (MCS) is on the order of 1,000 watts EIRP, and is of near continuous duration. However, long term personnel exposure can only come about through illumination from the antenna's side lobes, which are about 10 watts EIRP. Emissions from a substation antenna's side lobes are estimated at less than 10 watts EIRP, here again the duty cycle is very low.

The safe distance from a radiating antenna is:

$$\text{Safe distance in feet} = 3 \sqrt{0.00096 \times P \times G}$$

where, P = average transmitter power in watts, and

G = antenna gain ratio relative to isotropic radiation

It can be seen that the minimum safe distance from a Transceiver Unit, if it were operating continuously, is between one and thirty feet; from MCS antenna less than one foot, and from a substation antenna also less than one foot.

The minimum safe distance vs effective radiated power is shown in Figure 5-59 for a continuous transmission over an 8-hour period.

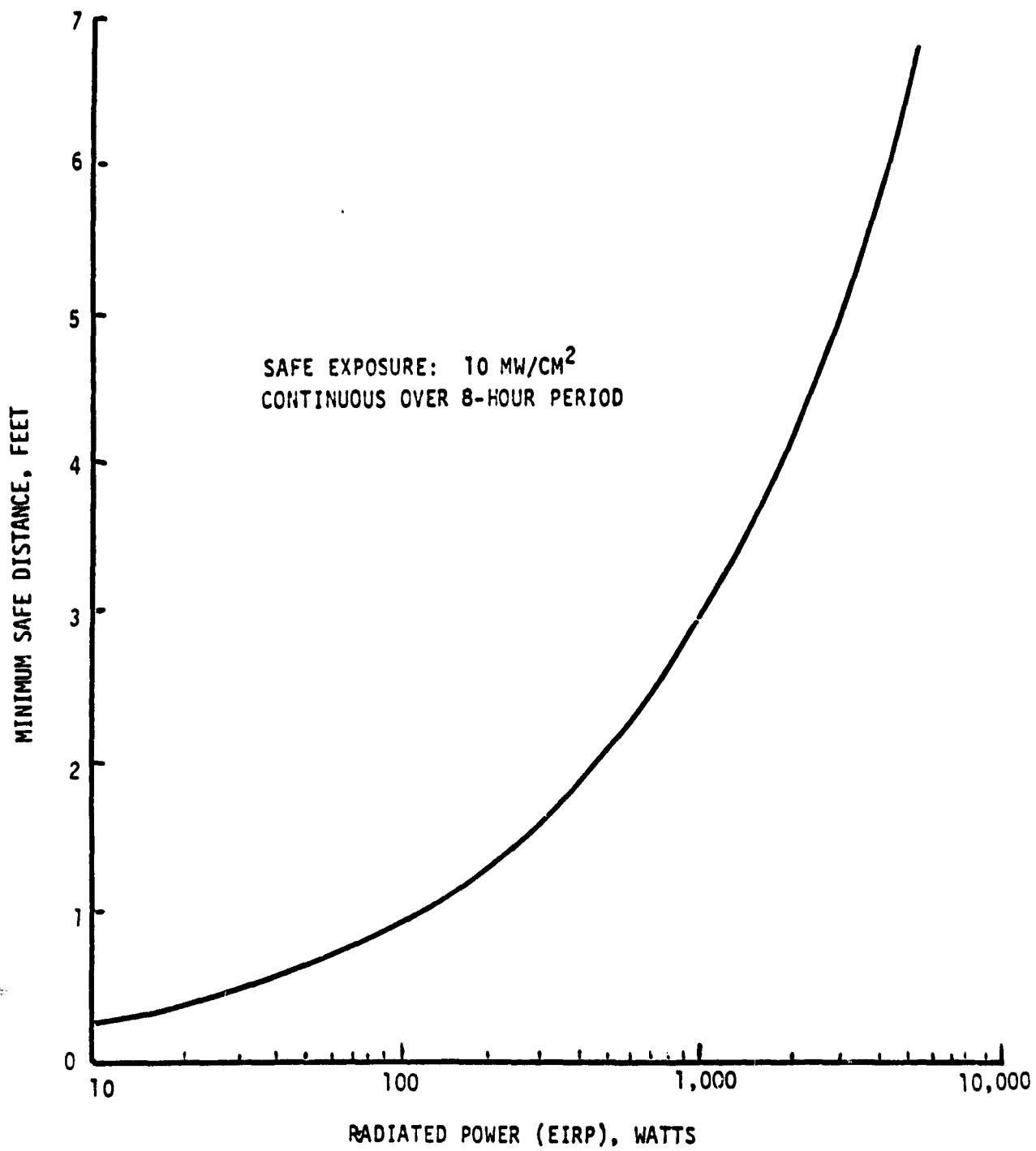


Figure 5-59 MINIMUM SAFE DISTANCE FROM A RADIATING TRANSMITTER

D180-25403-2

5-151

6.0 OPERATING CONSIDERATIONS

This Section discusses a few of the factors associated with the day-to-day operation of the SC system.

6.1 Manpower

The incorporation of distribution automation and control (DAC) implies a desire to achieve a level of automation which requires only minimal around-the-clock operating personnel. In most cases DAC operations require only part-time attention.

The equipment of the SC system with which the utilities are directly involved are primarily of an electronic nature. However, the skills required to operate and maintain this equipment are already available in most utilities. Certain tasks, such as initiating the system, are engineering functions. Other tasks, such as installation and maintenance, are service department responsibilities requiring skill levels comparable to those already used.

In general, there is every reason to believe that SC system equipment can be integrated into utility operations without excessive manpower burdens.

6.2 New Installations

It is anticipated that most Transceivers will be "neighborhood" units; mounted on a utility pole, light standard, or a designated residence. Installation is rather simple; attach the unit to the structure, adjust the antenna for maximum signal, and connect the unit's pig-tail to the power line.

For automatic meter reading a Meter Transponder must be interposed between the meter and its socket. Aside from removing (and replacing) the meter, interface connections must be made between the meter and the Meter Transponder. The exact nature of this interface depends on the type and make of meter.

Installing the Control Module on the appliance is basically a straight forward task.

It is estimated that a typical "neighborhood" installation will require a total of 1.5 hours per household.

6.3 Hardware Maintenance

In general, electronic equipment produced in high volume is not worth repairing. This situation is likely to prevail with most SC system ground terminal modules. With a "throw-away" philosophy, maintenance boils down to isolating the failed unit, verifying that the suspected unit is indeed bad, and then replacing it with a new one from the package; a process which can be accomplished with low skill-level personnel.

6.4 Software Maintenance

In order to provide flexibility in accommodating functional changes and physical additions to the distribution system, the automated monitor and control routines are handled by programmable processors rather than by fixed logic. It is likely that program changes will be desired as the systems grow and as experience leads to new operating philosophies. With modularized software such changes can be handled rather easily.

6.5 Satellite Control Station - Master Control Station Interface

The Satellite Control Station (SCS) is primarily responsible for assuring that the spacecraft is in an optimum operating mode. It also serves, via the satellite, as a source for master timing for those communication networks which operate in synchronous modes.

The SCS is capable of manipulating the spacecraft antenna to reform beams as necessary to effect special operating modes such as interference nulling.

The SCS operates on a day-to-day basis independently of the utilities' Master Control Stations (or District Control Stations). It is only under unique circumstances that the SCS and MCS's coordinate their activities, consequently there are no dedicated direct communications between these facilities.

7.0 SYSTEM COSTS

The foregoing sections addressed some of the more important technical aspects of the SC system; this section deals with system costs.

7.1 Costing Strategy

When formulating a strategy for conducting a cost analysis a question arises as to the degree of precision required for a conceptual design study of this nature. In an attempt to answer this question, a "quick look" analysis was run to establish the sensitivity of various items in relation to total program costs. The results confirmed intuition. Customer terminals do indeed have the largest effect on program costs, everything else has a lesser effect. Table 7-1.

With relative sensitivities determined, the following costing strategy was settled on:

1. Use a well established cost model as the principal tool to derive terminal costs. Use at least one other approach to develop independent numbers.
2. Estimate other system element costs from extrapolations of recent historical data.

7.2 Customer Terminal Costs

As pointed out in Section 5.0 several units/modules are needed to form a working ground terminal. The exact compliment of units/modules making up the terminal depends on functional and site peculiar requirements. In order to prevent costing a variety of configurations, costs have been developed at the unit/module level.

SYSTEM ELEMENTS	INFLUENCE ON COSTS		
	1st ORDER EFFECT	2nd	3rd
SPACE VEHICLE		●	
ANTENNAS	X		
PAYLOAD		X	
POWER		X	
HOUSEKEEPING			X
CUSTOMER TERMINALS	●		
ANTENNA		X	
TRANSCEIVER	X		
PROCESSOR			X
SOFTWARE			X
SUBSTATION TERMINALS			●
ANTENNA		X	
TRANSCEIVER	X		
PROCESSOR			X
SOFTWARE			X
UTILITY MASTER CONTROL STATION		●	
ANTENNA		X	
TRANSCEIVER			X
PROCESSOR		X	
SOFTWARE	X		
SATELLITE CONTROL STATION			●
EARTH TO ORBIT		●	

● INFLUENCE ON TOTAL COSTS
 X INFLUENCE ON ELEMENT COSTS

Table 7-1 COST SENSITIVITY

Unit/Module costs were derived from a well known cost model developed by RCA (PRICE) and used extensively by Boeing and others for estimating electronic costs for conceptual design purposes. "PRICE" is a parametric cost estimating model. The model develops costs from physical hardware descriptions such as equipment type, weight, design and fabrication complexity, learning curves, program schedules, etc.

ORIGINAL PAGE IS
OF POOR QUALITY

To gain additional insight into probable costs, equipment vendors were contacted for their inputs, and separate in-house engineering estimates were also made. These results are shown separately in the appropriate graphs which follow.

Figure 7-1 provides a block diagram of the transceiver unit and shows estimated unit costs as a function of frequency (10^6 unit production). The top line is the estimate obtained from the cost model. The curved line represents the engineering estimate, and the bottom line is a smoothed version of vendor inputs. Figure 7-2 illustrates how production volume influences per unit cost.

Similar diagrams and cost curves are provided in Figure 7-3 through 7-6 for other ground terminal elements. The Control Module shown in Figure 7-4A provides two-way communication to the Meter Transponder. A Controller (not shown) provides receive only capability.

Data for a 1 GHz system for three typical residential installations is shown in Figure 7-7. Using a neighborhood Receiver Unit serving ten houses, load control can be provided at \$40 per house, equipment cost. For two-way communication capability, providing both load control and meter reading, equipment costs are estimated to be \$175 per house. A full-up capability with load control "state" reporting is estimated at \$205. The cost-benefit of this feature is somewhat questionable.

7.3 Substation Terminal Costs

Substation terminals are built from the same type modules used for customer terminals, with some additions. The requirements to control a number of different types of devices, to monitor a lot of items, and to read a variety

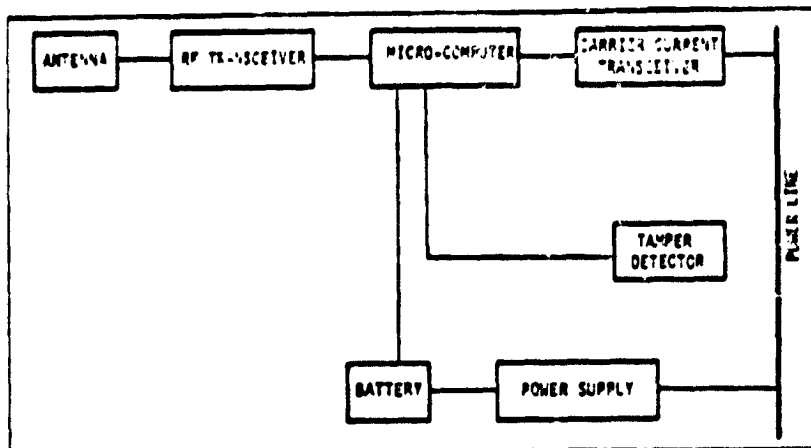


Figure 7-1A TRANSCEIVER UNIT

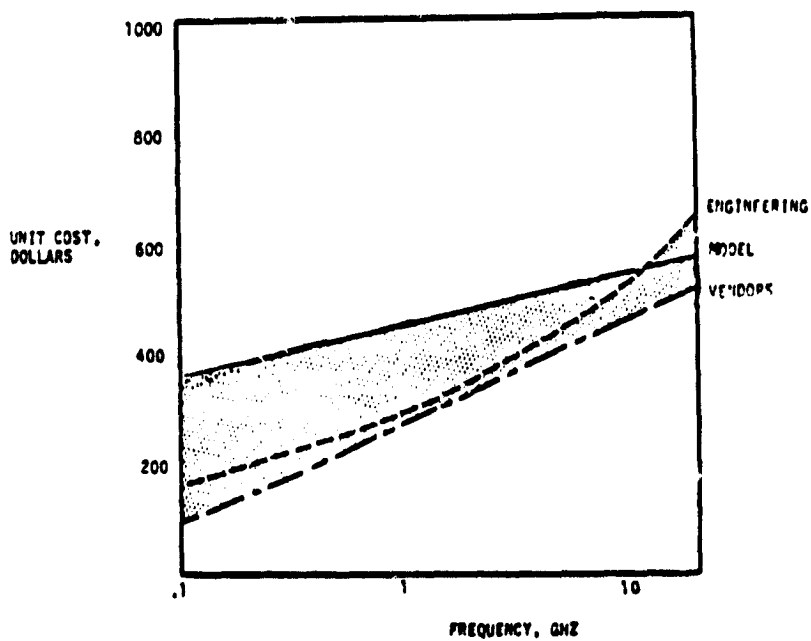


Figure 7-1B TRANSCEIVER UNIT COST

D180-25403-2

ORIGINAL PAGE IS
OF POOR QUALITY

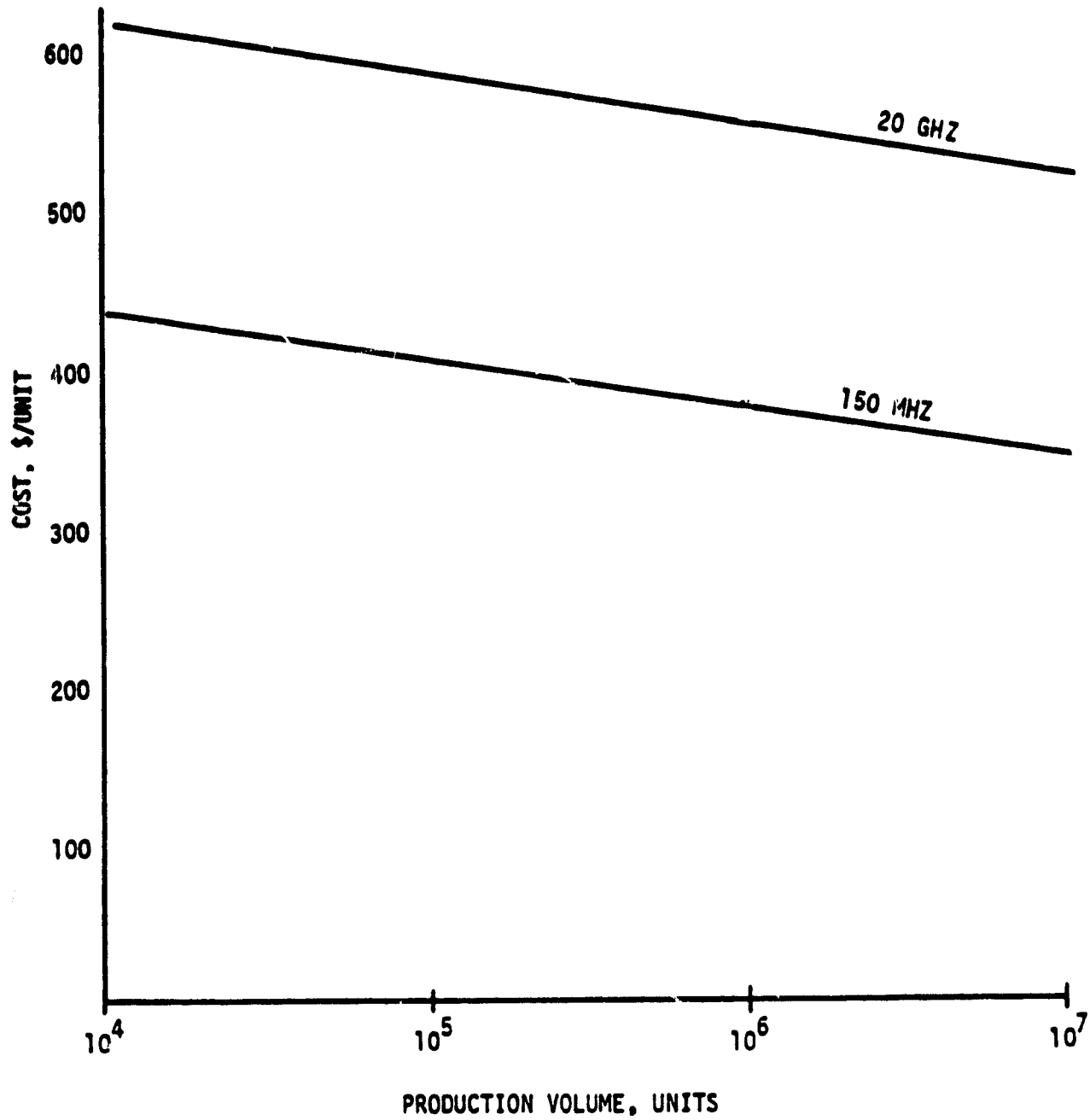


Figure 7-2 TRANSCEIVER COSTS

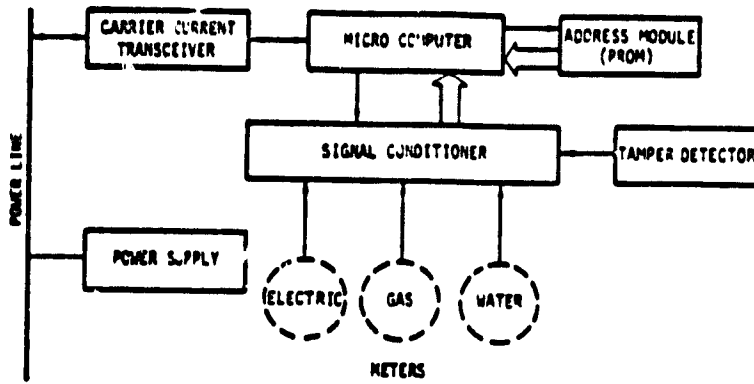


Figure 7-3A METER TRANSPONDER

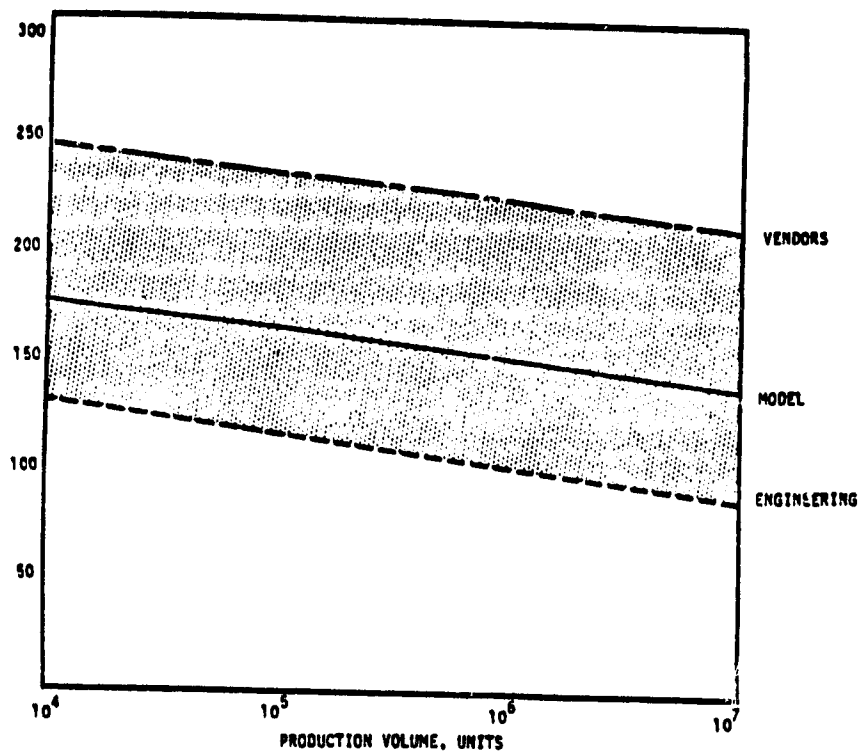


Figure 7-3B METER TRANSPONDER COST

D180-25403-2

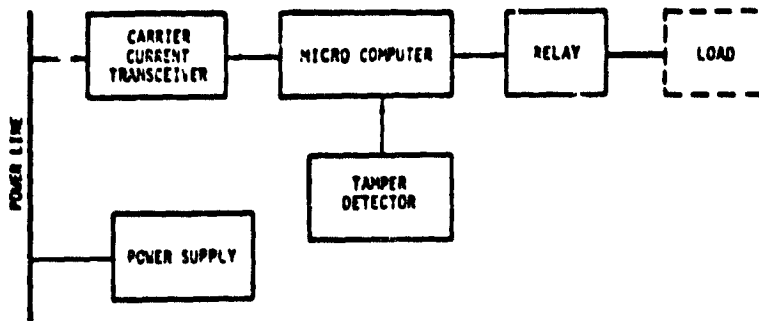


Figure 7-4A CONTROL MODULE

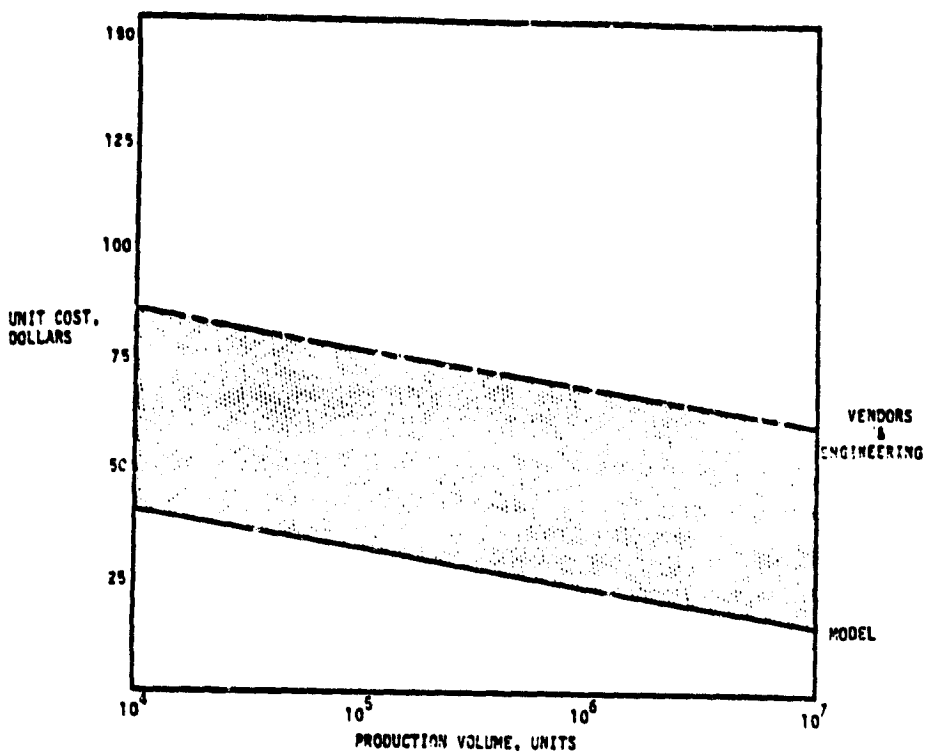


Figure 7-4B CONTROL MODULE COST

D180-25403-2

ORIGINAL PAGE IS
OF POOR QUALITY

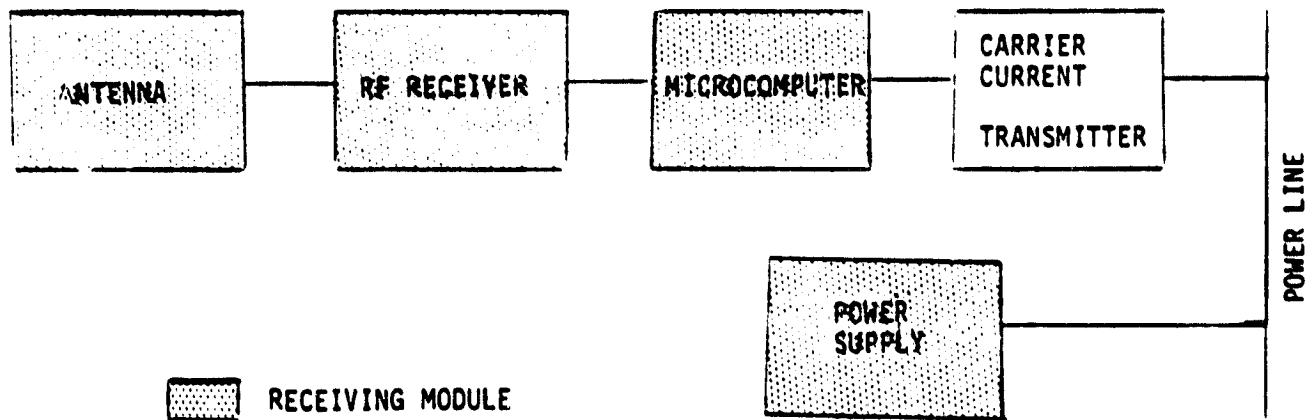


Figure 7-5A RECEIVER UNIT

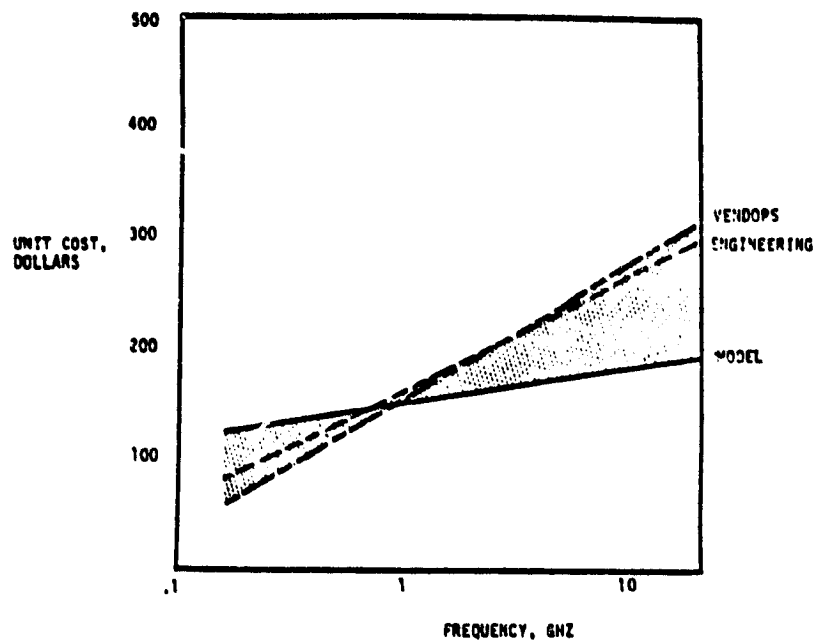


Figure 7-5B RECEIVING MODULE

D180-25403-2

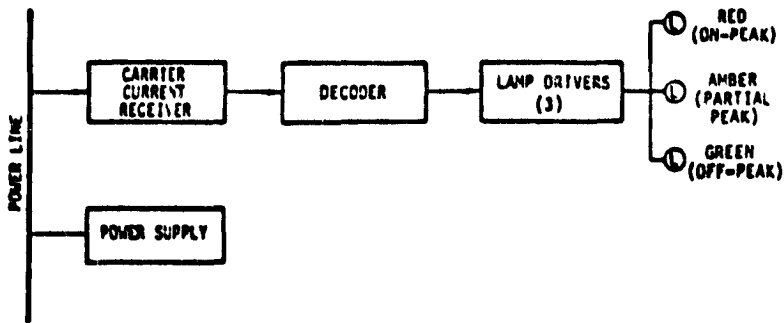


Figure 7-6A PREMIUM RATE INDICATOR

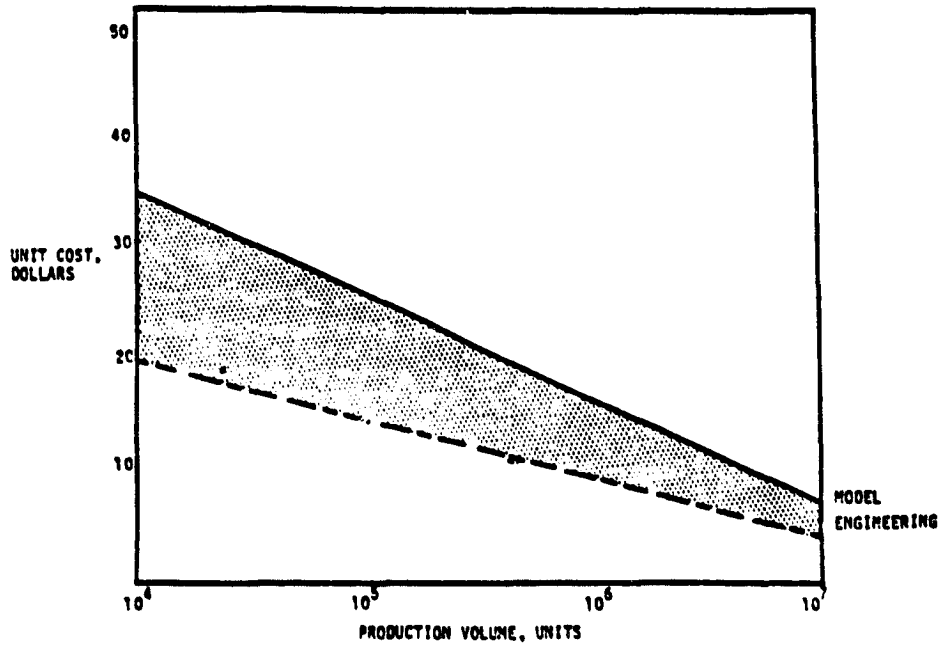


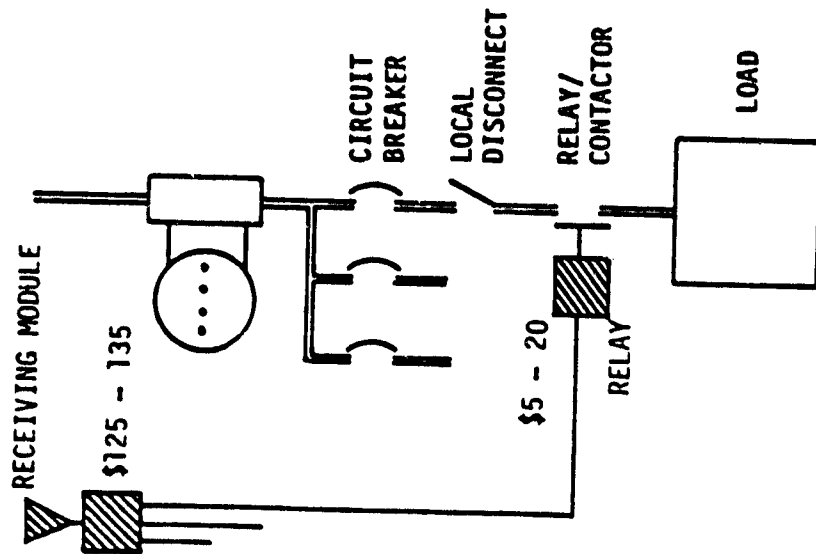
Figure 7-6B PREMIUM RATE INDICATOR

D180-25403-2

7-9

ORIGINAL PAGE IS
OF POOR QUALITY

ONE-WAY TERMINAL

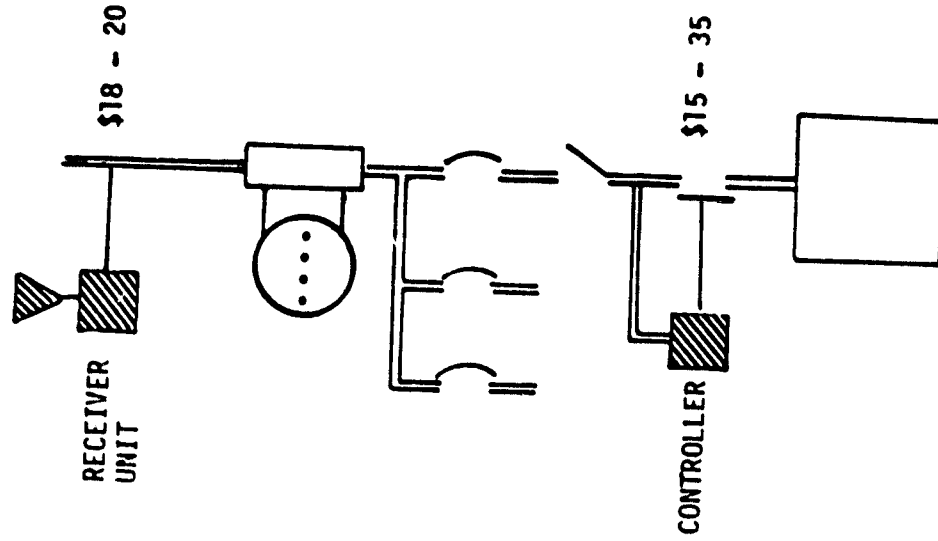


RANGE

MOST LIKELY \$130 - 155/HOUSE

\$140/HOUSE

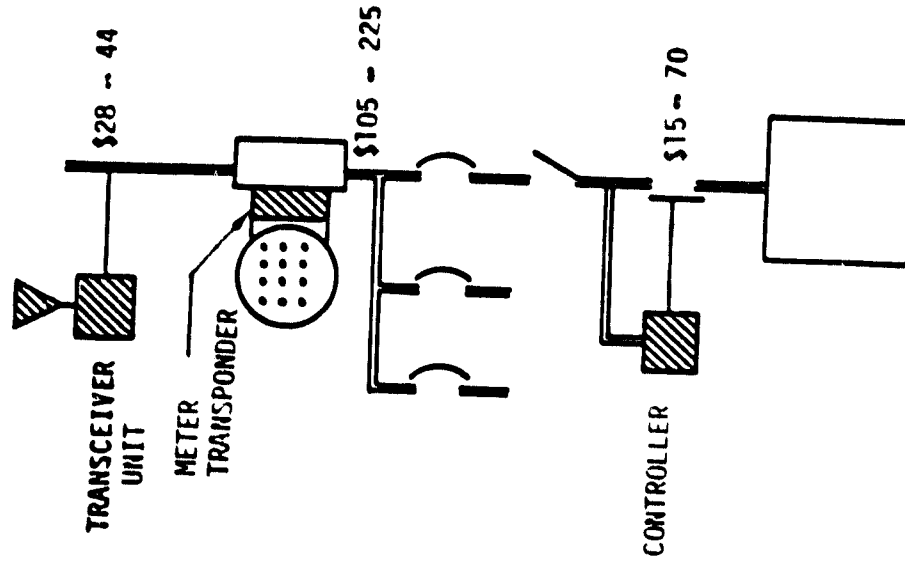
ONE-WAY TERMINAL



\$33 - 55/HOUSE

\$40/HOUSE

TWO-WAY TERMINAL



\$158 - 339/HOUSE

\$175/HOUSE

Figure 7-7 RESIDENTIAL COMPONENT COSTS

of instrumentation necessitates a special Interface Unit and possibly an Analog to Digital Converter. Also, as pointed out earlier in Section 5, there is a need for a more directive antenna. Figures 7-8, 7-9, and 7-10 give antenna cost estimates by type and operating frequency.

Substation terminals operating at 1 GHz were estimated to cost between \$600 and \$1300. The larger values associated with more functional capability and higher performance. Equipment for a typical site is estimated at \$650.

7.4 Master Control Station/District Control Center

The equipment complement at a MCS is comprised of a parabolic antenna; redundant transmitters, receivers, modems, time-base generators, etc.; a redundant mini-computer with various input/output devices and storage media; and an operator's console. This equipment is estimated to cost between \$100,000 and \$200 000. No attempt was made to estimate the cost of site peculiar software, but it is reasonable to assume that such costs will be comparable to hardware costs.

DCC equipment is expected to cost between 30% and 80% of that of an MCS, depending on functional and redundancy requirements of particular sites.

7.5 Spacecraft Costs

Spacecraft cost was estimated on a dollars-per-pound basis using historical data escalated to 1979 dollars, and modified to take into account the multi-beam antenna. Figure 7-11. Assuming a need for a 5,000 pound spacecraft, the cost is estimated to lie between \$33 and \$53 million, with \$40 million a likely value.

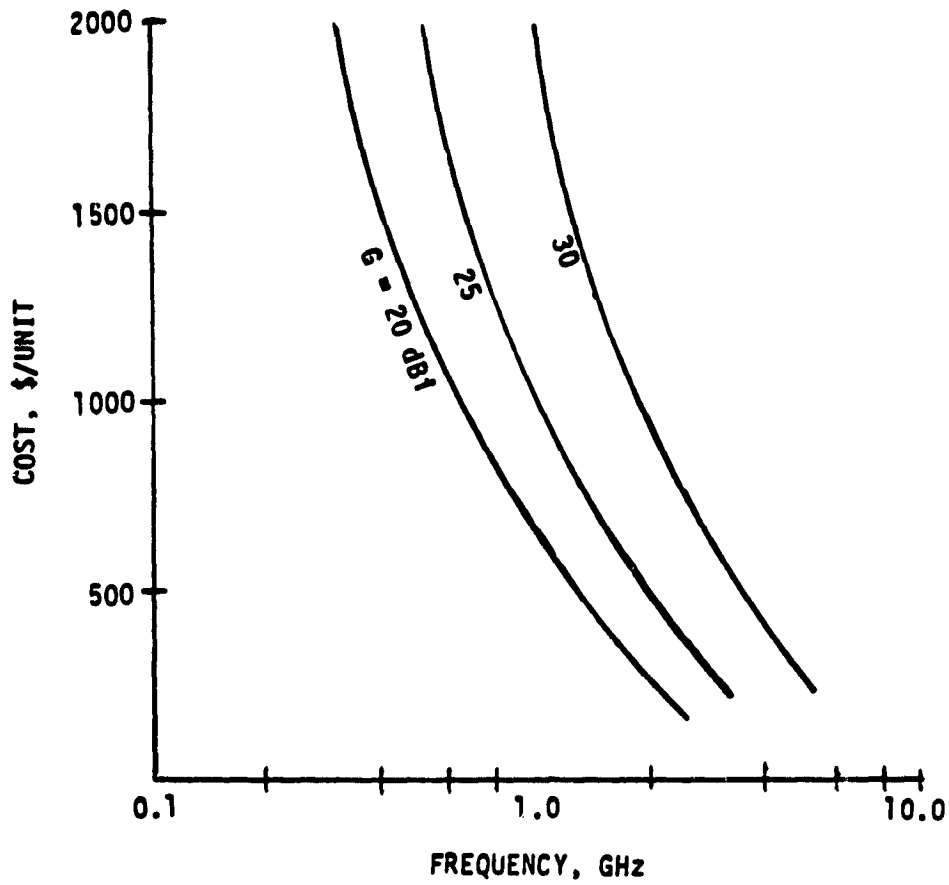
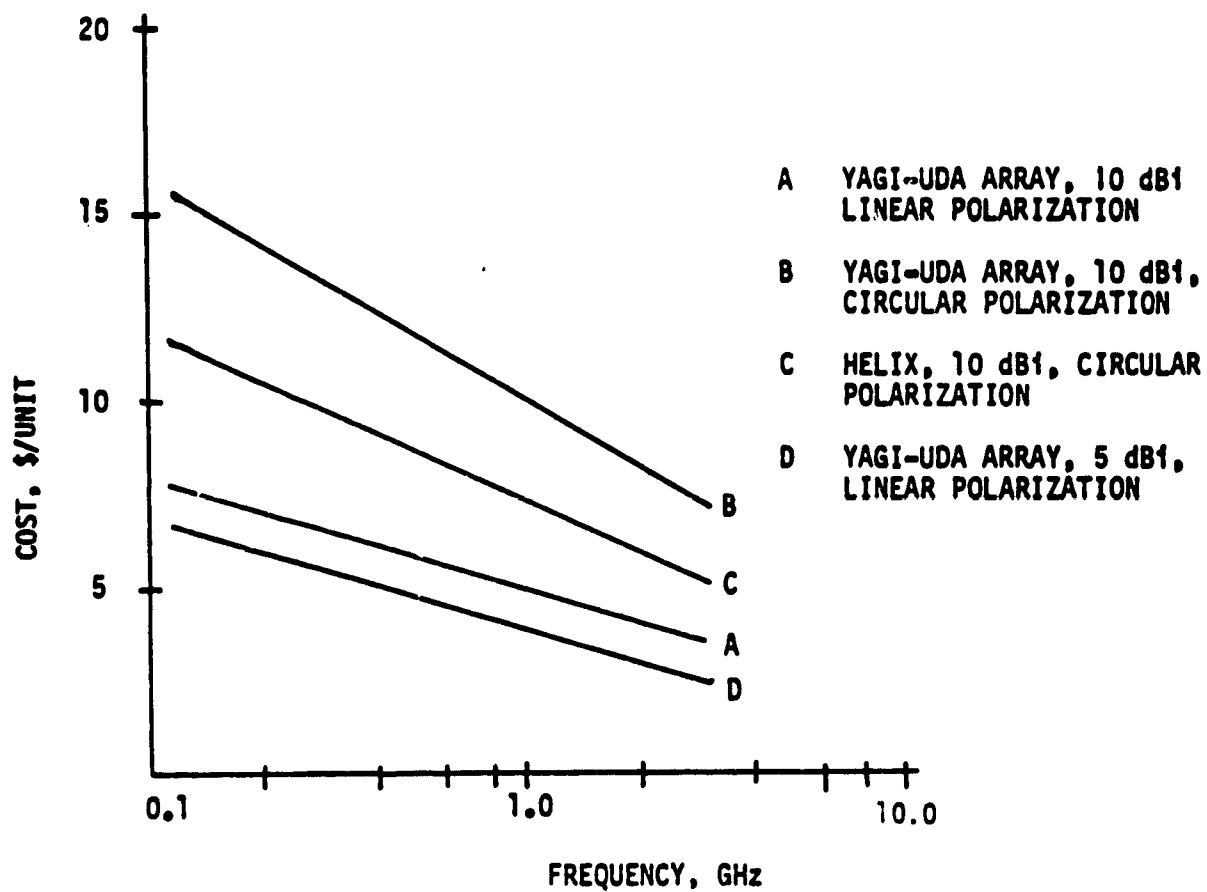


Figure 7-8 COSTS VS FREQUENCY FOR PARABOLIC DISH ANTENNAS



NOTE: THESE ANTENNAS BECOME IMPRACTICAL AT FREQUENCIES ABOVE 3 GHz

Figure 7-9 COSTS VS FREQUENCY FOR YAGI-UDA ARRAY AND HELICAL ANTENNAS

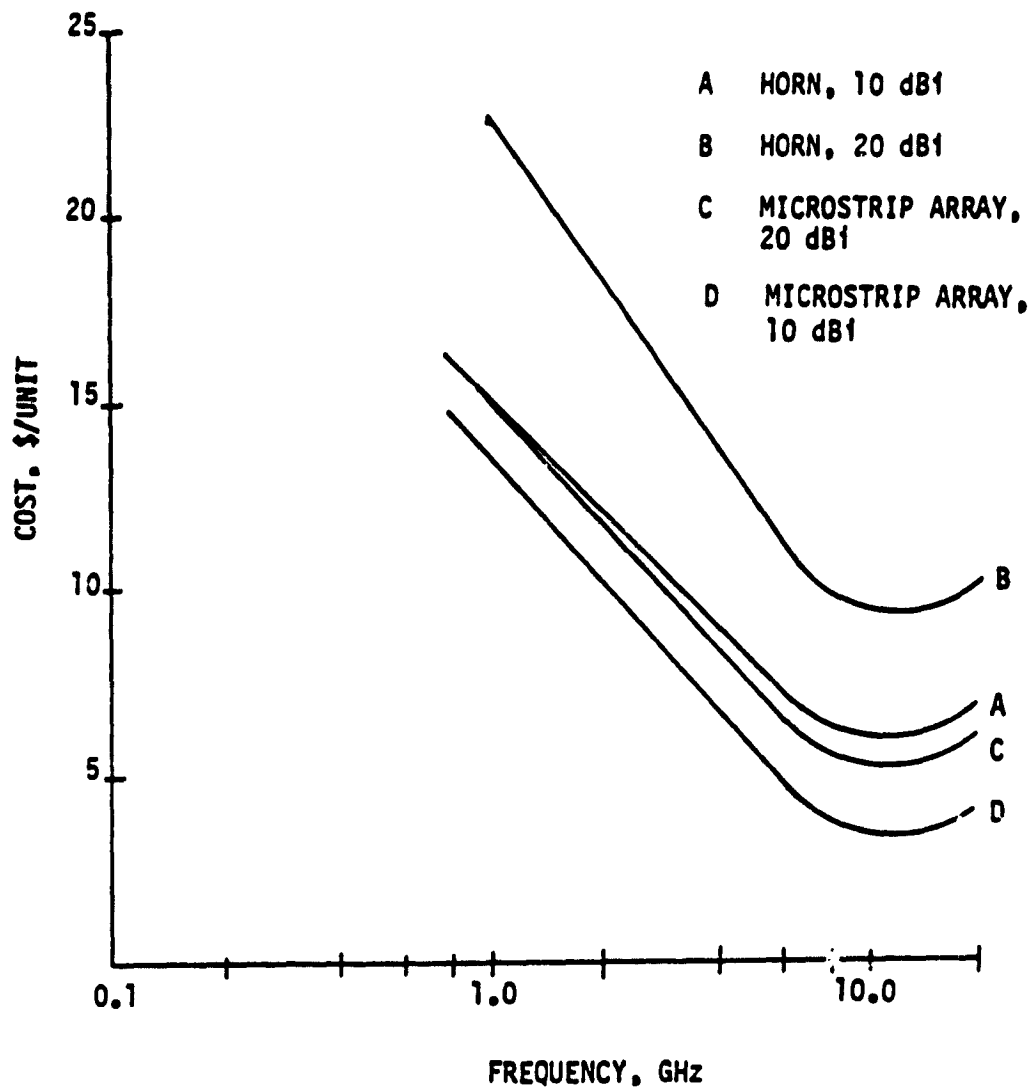


Figure 7-10 COSTS VS FREQUENCY FOR HORN AND MICROSTRIP ARRAY ANTENNAS

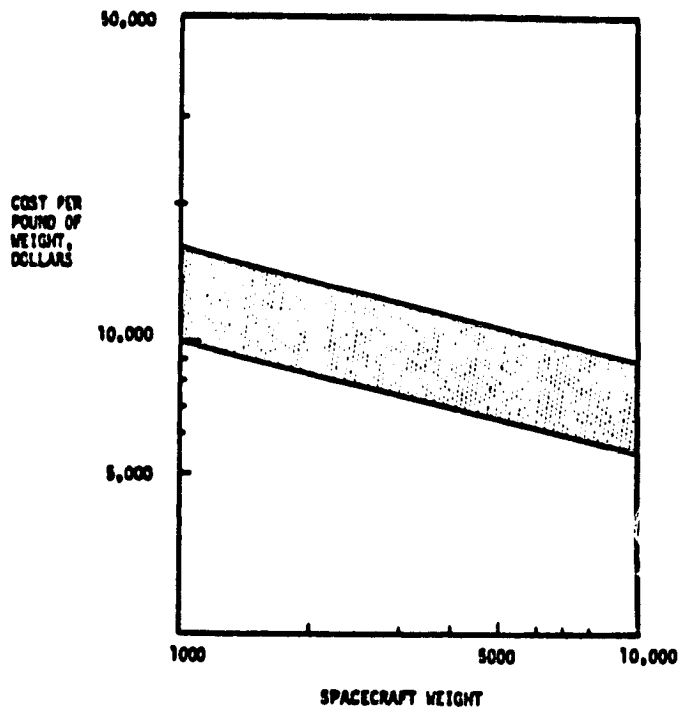


Figure 7-11 SPACECRAFT COST

ORIGINAL PAGE IS
OF POOR QUALITY

The top end of the range reflects the use of larger antennas, higher output transmitters, more extensive on-board processing, added redundancy, etc. Antenna costs are shown in Figure 7-12.

7.6 Earth to Geostationary Orbit Costs

The cost for using the NASA Space Transportation System (STS) was established in 1975 at \$22 million for a large payload. In 1979 dollars these costs are \$30 million. The cost of transporting the spacecraft from low earth orbit to geostationary orbit using a two-stage Inertial Upper Stage is estimated to be \$11 million dollars. The earth to geostationary orbit cost will then be about \$41 million, which includes payload integration hardware.

7.7 Satellite Control Station

The cost of a Satellite Control Station may vary considerably depending on the need for land acquisition, new buildings, etc. A cost ranging between \$3M and \$10M can be expected.

7.8 Operating Costs

It was originally thought that it would be useful to develop operating costs as well as equipment costs. After considerable research and a few exploratory costing exercises, it became clear that any numbers generated during this study would be virtually meaningless. It was concluded that operations in support of the SC system are so unique to a particular utility and likely to be so interwoven with other activities that there is no rational way to estimate them.

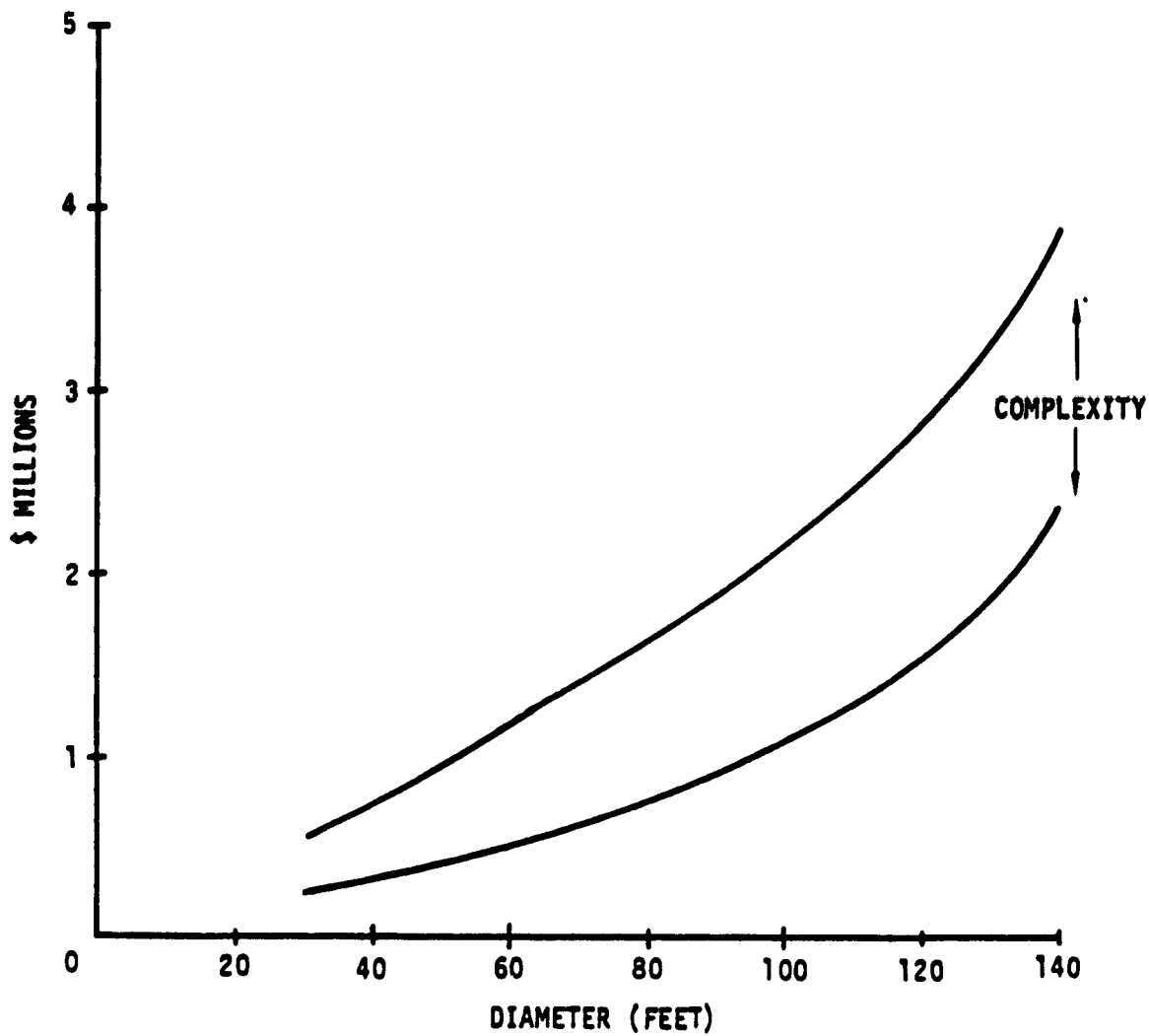


Figure 7-12 ANTENNA DIAMETER VS UNIT COST

For example, it is quite likely that as more experience is gained using DAC concepts, and as the distribution network grows, changes in real-time operational management software will be desired to expand functional capability. The extent of such changes throughout the system's life time obviously cannot be forecast with any degree of certainty. Consider another example, we know terminal units will fail. While it is possible to predict failure rates and to predict the most probable failure modes (from a detailed design), maintenance costs are largely a function of the repair vs throw-away strategy adopted by a given utility.

Other examples could be cited to support the conclusion that operating costs are intractable at this time and better left to costing exercises directed toward a specific detailed design for a specific application.

7.9 Initial Investment

It is of interest to estimate the initial investment required to implement the system. Table 7-2 lists various investment costs. Satellite production and launch costs have already been discussed, as has Satellite Control Station costs. Research, development, test and evaluation costs (RDT&E) are estimated to total \$141 million, which includes a "proof of concept" demonstration. When RDT&E is added to production and launch costs the total initial investment required to make one satellite operational is \$232 million; with a ground standby unit the investment rises to \$277 million. These numbers equate to \$8.85 and \$10.55 per terminal served (\$0.89-\$1.06 per year), based on the average number of terminals served during the life of the satellite. The number of terminals (26×10^6) was derived from the data presented in Section 3 for a "maximum motivation" scenario.

	ONE SAT. IN ORBIT	ONE SAT. IN ORBIT, ONE ON GROUND STANDBY
Satellite Cost	\$40M	\$85M
Launch Cost	41	41
Satellite Control Station Cost	10	10
RDT&E Cost	122	122
Terminals \$5M		
Satellite 105		
Satellite Control Station 12		
Total Investment	\$213M	\$258M
Investment per Terminal*	\$8.19	\$9.92

*Based on the estimated average number of terminals served during life of satellite, 26×10^6 .

Table 7-2 INITIAL INVESTMENT

The cost estimates developed in this study are satisfactory for concept feasibility purposes. However, because of the large number of terminals to be used, their costs should be determined more precisely by detailed estimates. Precision estimates require detailed equipment definitions such as could be expected from follow-on work.

8.0

IMPLEMENTATION

It seems evident that the first widespread use of distribution automation and control will be for load management. The time scale for its introduction is likely to be in the early 1980's. Interest is increasing and numerous terrestrial demonstration projects are currently underway. A few States have mandated specific near-term load management goals.

It is obvious that to be a viable contender in the 1980's the SC system development must be launched within the next few years.

In developing an implementation plan, the modis operandi of the utility industry must be considered. The conventional approach to introducing new technology into this industry involves a sequence of engineering and economic studies, field demonstrations of one or more alternative approaches, possibly pilot projects, and finally a gradual phase-in of operational equipment. It is the last step which presents a potential problem for introducing a satellite based system.

The use of a satellite dedicated to utility operations does not lend itself to the "gradual phase-in" approach. The investment required for the spacecraft is sufficiently large that a go-ahead would, of necessity, be predicated on obtaining firm precursor commitments from a group of users, probably not less than fifty. Whether an initial cadre of fifty sponsors can be brought together in the near-term is a key issue.

The use of a shared satellite may prove more attractive. "Sharing" in this case refers to joint use of the spacecraft by commercial or public interests outside the utility industry. Each user group would have its own dedicated on-board resources. The advantage of this approach is that even a small number of utilities could take a first step at a modest cost.

Demonstrating every facet of the concept end-to-end without a satellite is virtually impossible. However, meaningful tests of selected features can be done using ground and/or airborne partial simulations. Such features which may be selected for demonstration, after further study are:

- 1) Two-way operation of a shared channel.
- 2) All weather operation
- 3) Operation in a substation environment
- 4) System Security
- 5) Feasibility to accommodate a variety of site peculiar installation conditions
- 6) Equipment reliability

It can be argued that more complex systems went directly from bench testing to full scale implementation without a field demonstration phase. While this is true, it is an approach somewhat foreign to utility practices.

All things considered, it appears that at least five years are needed to put an operational satellite in place. During this period a ground terminal production facility must be set-up, and production initiated so that a worthwhile number of terminals are available concurrent with satellite startup.

As with many pioneering endeavors, implementation issues tend to overshadow technical issues.

The material identified below was reviewed while conducting this study.

Communications

1. International and Domestic Regulations affecting the Efficiency of Orbit and Spectrum Utilization, Richard G. Gould, IEEE Conference ICC '78
2. 1979 WARC: Advisory Committee Meets for First Time, Satellite Communications, August 1978
3. Recommended Installation Practices for Radio Equipment in Electric Power Substations, IEEE Transactions on Power Apparatus and Systems Vol. PAS-96 No. 3 May/June 1977
4. The Automated Distribution System: An Assessment of Communication Alternatives, Electric Power Research Institute, EPRI EL-151 September 1976
5. Field Demonstrations of Communication Systems for Distribution Automation, J. A. Serfass, IEEE Region 6 Conference 1978
6. Synchronization Methods for TDMA, Peter P. Nudsl, et al., Proceedings of the IEEE ICC '78
7. Military Satellite Communications Using Small Earth Terminals, P.R.W. Webb, IEEE Transactions on Aerospace and Electronic Systems, Vol AES-10 No. 3 May 1974
8. Satellite Multiaccess Schemes for Data Traffic, Simon S. Lam, IBM Thomas J. Watson Research Center.
9. Demand Assigned Multiple Access Techniques, C. E. Faflick, IEEE EASCON '77
10. TDMA, The State-of-the-art, G. D. Dill, IEEE EASCON '77

Cost Estimating

11. A Critique of Spacecraft Cost Models, The Rand Corp., ASTIC 201674
12. Communication Satellites, Issues and Trends, Ivan Bekey, The Aerospace Corporation, ElSegundo, California

Distribution Automation & Control

13. Proceedings of the Distribution Automation & Control Working Group. Volumes I and II, JPL Publication 79-35

14. Detroit Edison's Experience with Load Management, A presentation to the California Energy Resources Conservation and Development Commission, San Francisco, CA, June 27, 1978, B. F. Hastings
15. Evaluation of Customer Load Management and Its Impact on Energy Management Systems, Charles H. M. Saylor, Systems Control, Inc., Palo Alto, CA
16. Electrical Load Management: The British Experience, John Platts, IEEE Spectrum February 1979
17. Studies of the Effect of Distribution Automation and Load Management on the Design of an Energy Management System, Charles H. M. Saylor, Systems Control Inc., Palo Alto, CA.
18. Data Estimates by State to Help Establish Communications Requirements for: Remote Meter Reading, Customer Load Management, Distribution Automation, Charles H. M. Saylor
19. An Analysis of the Pacific Gas and Electric's Anticipated Requirements for Electric Load Management, M. E. Koszulka, G. B. Fernstrom, Pacific Gas and Electric May 1979
20. Automate Distribution for Better Reliability, R. F. Wolff, Electric World, June 15, 1979
21. Load Management and PURPA, Robert G. Uhler, Bonneville Power Administration's Sixth Annual Energy Conservation Management Conference, March 27, 1979
22. Electrical Transmission and Distribution Reference Book, Westinghouse Electric Corp.

Reliability

23. Elements of Semiconductor-Device Reliability, C. Gordon Peattie, et al., Proceedings of the IEEE, Vol. 62, No. 2, February 1974
24. A Study of Total Space Life Performance of GSFC Spacecraft, A. R. Timmins, NASA Technical Note NASA TN D-8017
25. A Study of First-Day Space Malfunctions, A. R. Timmins, NASA Technical Note NASA TN D-6474
26. A Study of First-Month Space Malfunctions, A. R. Timmins, NASA Technical Note NASA TN S-7750
27. Spacecraft Hardware Element Reliabilities, PRC Report R-1863
28. Design Reliability Methods Manual, Boeing Document D2-3246

Spacecraft

29. A Review of the State-of-the-Art in Large Spaceborne Antenna Technology, C. A. Smith, JPL Publication 78-88

30. Industry Capability in Large Space Antenna Structures (selected sections only), R. E. Freeland. JPL internal document 710-12
31. Design Concepts of Geostationary Platforms, E. C. Hamilton, AIAA Conference on Large Space Platforms. Paper 78-1642
32. Big Comsats for Big Jobs at Low User Cost, Ivan Bekey, Astronautics and Aeronautics, February 1979
3. AAFE Large Deployable Antenna Development Program, Final Report NASA Contract NAS 1-13943, September 1976
34. Space Stations, Walter L. Morgan, Satellite Communications, April 1978
35. A Future for Large Space Antennas, R. V. Powell, Jet Propulsion Laboratory, California Institute of Technology, Pasadena, CA
36. Orbital Antenna Farms, Burton I. Edelson, Astronautics and Aeronautics September 1977