(JPL PUBLICATION 80-48, VOLUME I)

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

Volume I: Summary Final Report

A. Vaisnys

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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

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ABSTRACT

This report sets forth the results from the JPL/Boeing Contract; A Study of a Space Communication System for Electric Utility Load Management, Number 955267.

It, 1) provides a definition of distribution control and monitoring functions and quantifies associated communications traffic, 2) describes a "baseline" conceptual design in terms of operating capability and equipment, 3) examines some of the more important factors to be considered in designing a system, 4) provides preliminary cost data, 5) discusses factors associated with implementation, and 6) provides conclusions and recommendations.

Supporting analyses and data are contained in Volume II.

KEYWORDS

Space Communications
Distribution Automation
Electrical Load Management
Satellite Communications

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:

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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.

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GLOSSARY OF ABBREVIATIONS AND ACRONYMS

CRT	Cathode-ray Tube
CONUS	Continental United States
DSG	Dispersed Storage and Generation
DAC	Distribution Automation and Control
DCC	District Control Center
IUS	Inertial Upper Stage
JPL	Jet Propulsion Laboratory
MCS	Master Control Station
RT	Remote Terminals
SCS	Satellite Control Station
SC system	Space Communication System
SCADA	Supervisory Control and Data Acquisition
SSV	Space Shuttle Vehicle
STS	Space Transportation System
TWTA	Traveling Wave Tube Amplifier

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1.0 INTRODUCTION

The nation finds itself in a period between an era of abundance of relatively inexpensive electrical energy and one of scarcity and high costs. As a result, increasing emphasis is being placed on conservation and efficiency.

Much of the Department of Energy's involvement in control and monitoring systems for electric distribution have been under a program for Distribution Automation and Control (DAC)*. The DAC program is in direct support of the Department of Energy's Load Management program, which has as its basic objectives:

- Improved overall system efficiency in the use of capital and energy
- Increased use of coal, nuclear, and renewable domestic energy sources
- Reduced requirements for reserve generation and transmission capability, and
- Increased reliability of service.

DAC systems of the future will require that large amounts of data and instructions flow between centralized control facilities and numerous dispersed remote terminals. Such dispersion has a significant impact on the methods used for intersite communications. This study is directed toward determining whether a Space Communication System (SC system) is a viable means of implementing the required communication links.

A satellite offers a unique and effective method of linking up numerous communication nodes to form a cohesive network. A SC system differs from other alternatives in that it is a "national" resource, i.e., one satellite in geostationary orbit can serve the entire electric utility industry within the contiguous United States. Because of its universal application, the cost per user can be very modest, both in terms of communication channel costs and ground equipment costs. Channel costs are shared among many users, while equipment costs benefit from the economies of scale since production rates of millions of units per year are indicated.

The objectives of this study were:

(1) To determine the technical feasibility of the Space Communication System Concept, and

(2) To estimate system element costs.

* As used in this report, DAC functions include load management, real-time operations management, and remote meter reading.

Participating in the study with The Boeing Company were Pacific Gas and Electric Company of San Francisco, who provided guidance regarding utility requirements and interfaces, and System Controls Inc., of Palo Alto, who helped with industry-wide requirements and forecasts. The material presented herein may or may not be totally consistent with the views of these supporting organizations.

2.0 TECHNICAL DISCUSSION

2.1 Functional Requirements

This Section defines distribution automation and control functions, describes the methodology used to quantify communications traffic, and illustrates a typical result. More detailed information is contained in Volume II.

2.1.1 Elements of an Electric Power System

The primary purpose of an electric power system is to efficiently generate, transform, and distribute energy. These operations are geographically dispersed and require functionally complex monitoring and control systems. The element of the electric power system that exercises overall control is defined as the Energy Management System. That part which handles generation and transmission is identified as the Supervisory Control and Data Acquisition System (SCADA System), and the portion which is of interest in this study is the Distribution Automation and Control System (DAC System), Figure 2-1.

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

The motivations for considering implementing a DAC system are by-products of the basic energy problems facing the United States and the electric utility industry; 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 2-2. 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 transformers convert feeder voltage to consumer utilization voltage, and secondaries provide service to the consumer's property. Large commercial and industrial customers may be served directly from the subtransmission system via special industrial substations.

In the future, electric power systems will likely 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.

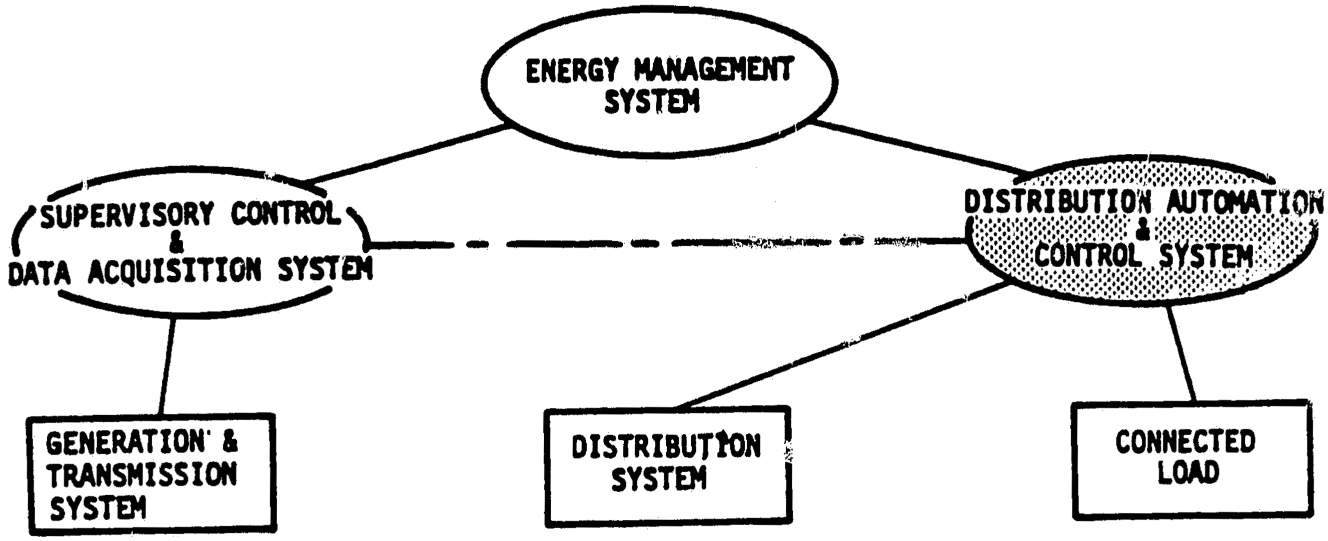


Figure 2-1 MONITORING & CONTROLLING AN ELECTRIC POWER SYSTEM

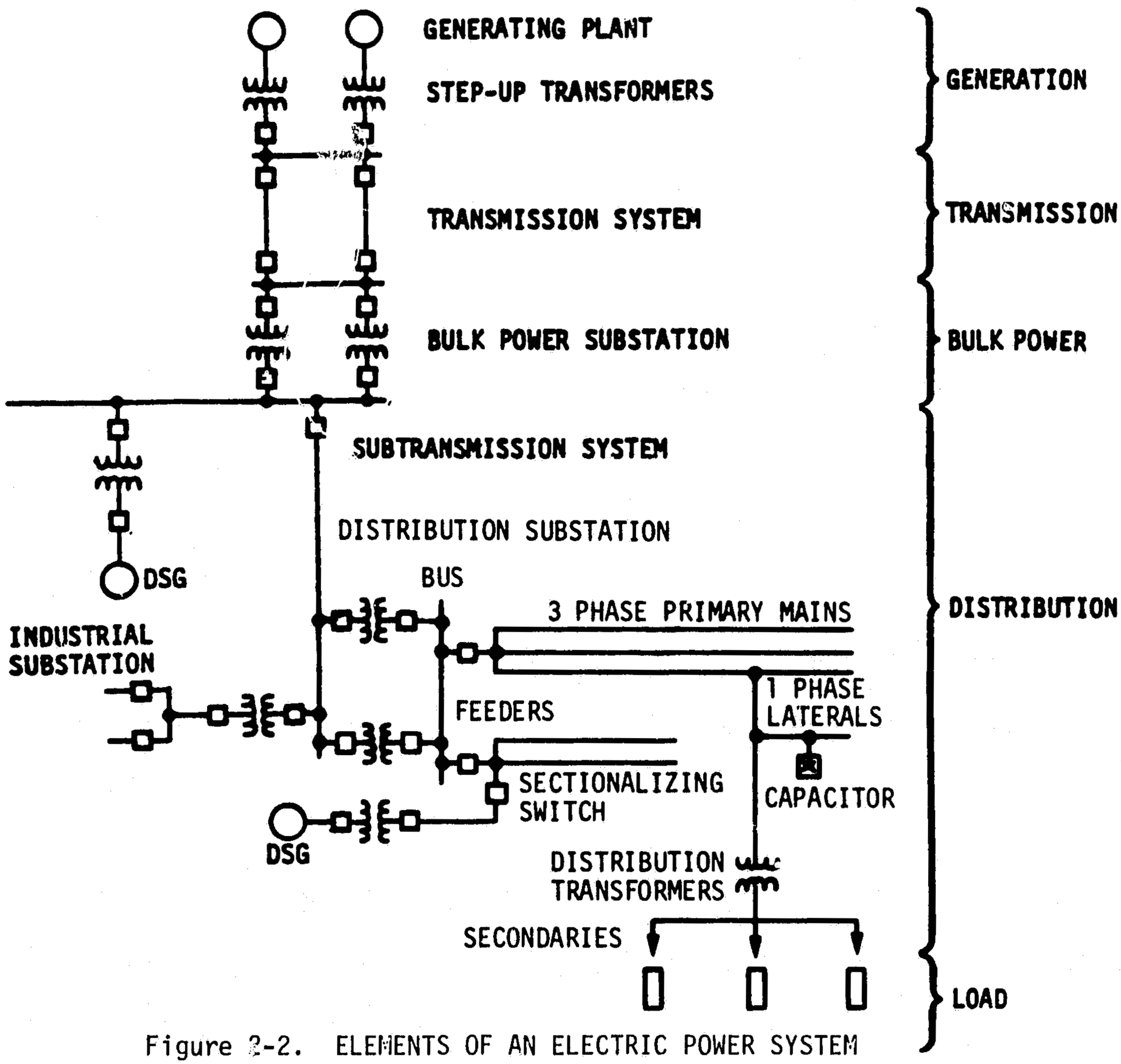


Figure 2-2. ELEMENTS OF AN ELECTRIC POWER SYSTEM

Such Dispersed Storage and Generation (DSG) capability will increase DAC system communication traffic, however, because of the present nebulous state of DSG penetration its ramifications were not examined in detail.

2.1.2 Distribution Automation and 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 with load management, real-time operational management, and remote meter reading. 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 interruptable 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 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.

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.

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

Voltage Regulation -- This function covers 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 distribution 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 the capability to equalize loads over several feeders from one substation.

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

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.

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.

2.1.3 Functional Analysis Methodology

The principal objective of the functional analysis conducted for this study was to derive an estimate of the maximum amount of communications traffic which could be anticipated during the operating life of the first satellite.

As a first step toward this objective, a profile of the electric utility industry through the year 2000 was developed using census data and industry forecasts. This profile includes the projected number of utilities and meters and their geographical distribution. Figure 2-3.

Communications traffic was divided into two categories: traffic to customer terminals, and traffic to other types of terminals in the electrical power distribution network.

Traffic to customer terminals can be estimated from the number of meters and the number of electrical devices suited for load management. This data is summarized in Table 2-1.

Traffic to distribution network terminals can be derived from the size and characteristics of the electric power distributions network. Pertinent parameters of the distribution network were estimated and are given in Table 2-2. The parameters in the Table are normalized to a "per-meter" basis.

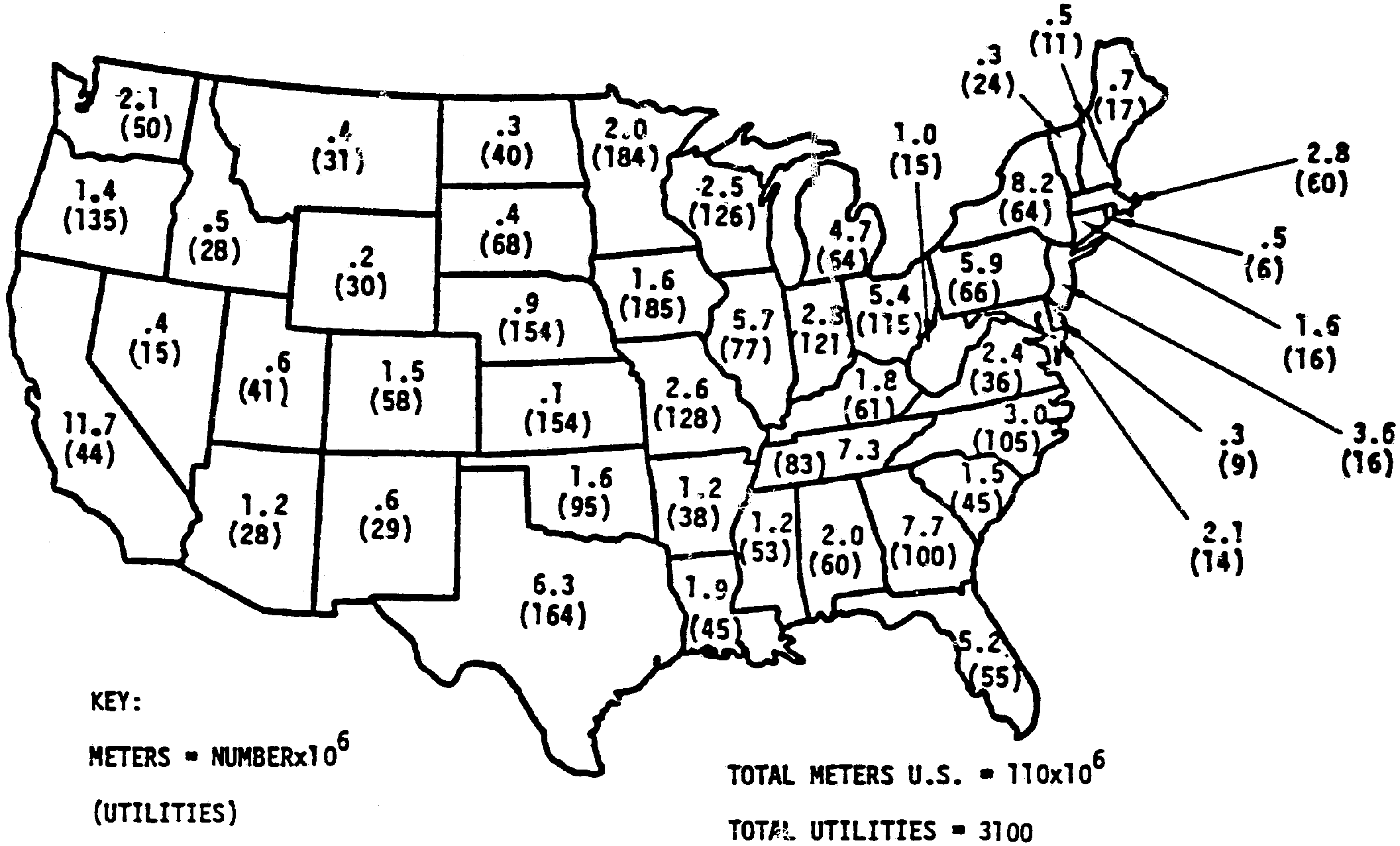


Figure 2-3 ESTIMATED ELECTRIC POWER METERS, YEAR 2000

Table 2-1 A PROFILE OF THE U.S. ELECTRIC UTILITY INDUSTRY THROUGH THE YEAR 2000

Total U.S. Population	250×10^6
Number of Electric Utilities	3100
Number of Electric Meters	110×10^6
Number of Residences with:	
Central Air-conditioners	33×10^6
Electric Water Heaters	25×10^6
Electric Space Heaters	7×10^6

Table 2-2 U.S. ELECTRIC POWER DISTRIBUTION SYSTEM NORMALIZED PARAMETERS

	Per Distribution Substation	Per Electric Meter
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}

With the data of Tables 2-1 and 2-2 it is possible to determine the universe of potential applications. Even though distribution automation has many positive attributes, its incorporation in the electric utility industry will take time and may not be 100% completed for a number of reasons. In order to take this situation into account, an estimate was made regarding the maximum expected application of each major function. These estimates are shown in Figures 2-4, 2-5 and 2-6. "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 actually sizing the communication traffic "maximum motivation" growth trends were developed which are intended to represent a condition wherein all factors influencing widespread incorporation are positive. Curves representing these trends are shown in Figures 2-4, 2-5, and 2-6.

For comparison purposes a "present trend" line was drawn which reflects an interpretation of current industry thinking 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. The ultimate penetration of remote meter reading is forecasted to be much lower, with a less rapid build-up.

Communication requirements were developed from the "maximum motivation" curve, at the year 1995.

2.1.4 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 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.

The projected conditions of the Western U.S. in the year 1995, the end-of-life year for the first satellite, are listed in Figure 2-7; those for the mid-Atlantic/New England are shown in Figure 2-8.

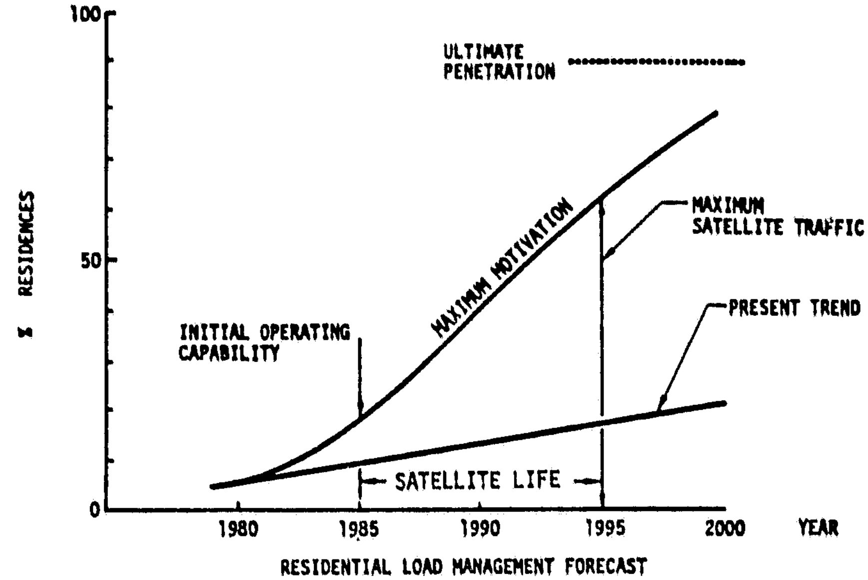


Figure 2-4 RESIDENTIAL LOAD MANAGEMENT FORECAST

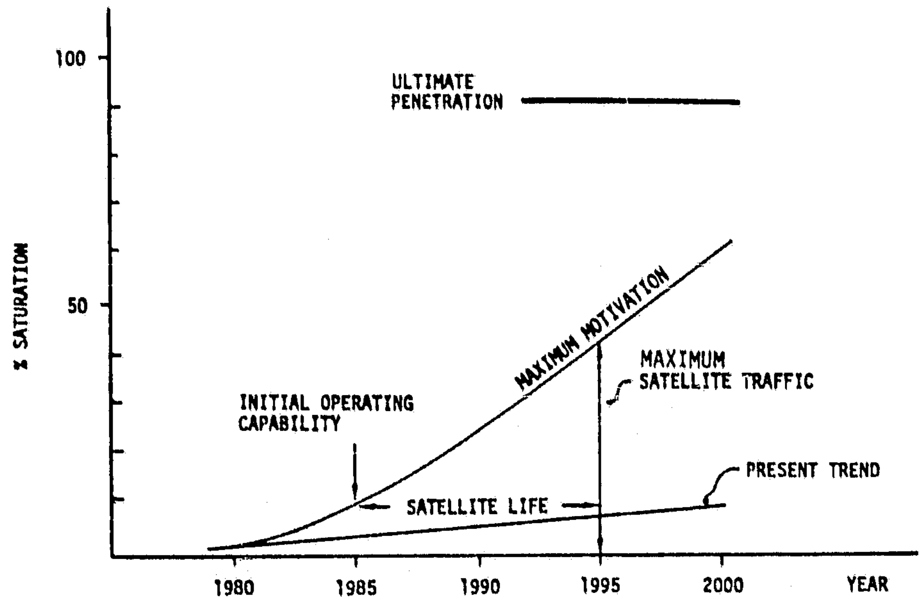


Figure 2-5 OPERATIONAL MANAGEMENT FORECAST

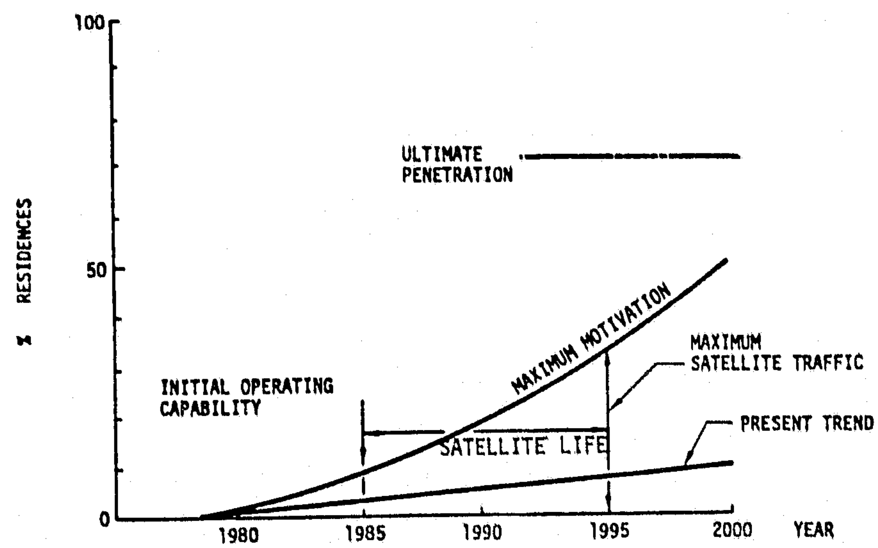
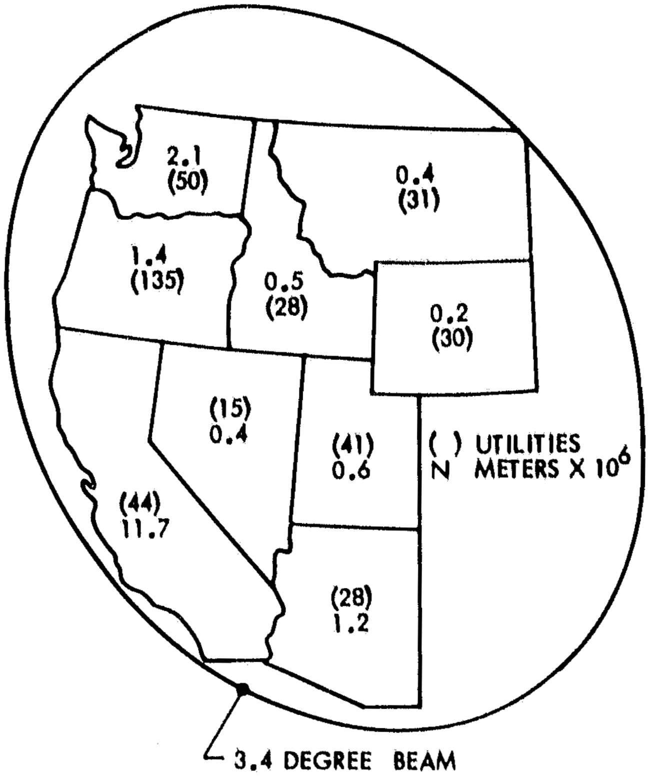


Figure 2-6 RESIDENTIAL REMOTE METER READING FORECAST



IN THE YEAR 1995

402 UTILITIES/REGION
  100 SUBSCRIBING UTILITIES
18.5 x 10^6 METERS/REGION
  3.7 x 10^6 TOTAL CONSUMPTION REMOTED
  0.4 x 10^6 MAXIMUM DEMAND REMOTED
  1.9 x 10^6 TIME-OF-DAY REMOTED
2.0 x 10^6 AIRCONDITIONERS (CENTRAL)
  1.2 x 10^6 UNDER LOAD MANAGEMENT
3.5 x 10^6 WATER HEATERS
  2.1 x 10^6 UNDER LOAD MANAGEMENT
1.7 x 10^6 SPACE HEATERS
  1.0 x 10^6 UNDER LOAD MANAGEMENT

Figure 2-7. WESTERN U.S., PROJECTED TO THE YEAR 1995

IN THE YEAR 1995

214 UTILITIES/REGION
  120 SUBSCRIBING UTILITIES
18.2 x 10^6 METERS/REGION
  3.5 x 10^6 TOTAL CONSUMPTION REMOTED
  0.3 x 10^6 MAXIMUM DEMAND REMOTED
  3.2 x 10^6 TIME-OF-DAY REMOTED
3.0 x 10^6 AIRCONDITIONERS (CENTRAL)
  2.0 x 10^6 UNDER LOAD MANAGEMENT
3.6 x 10^6 WATER HEATERS
  2.5 x 10^6 UNDER LOAD MANAGEMENT
4.4 x 10^6 SPACE HEATERS
  2.9 x 10^6 UNDER LOAD MANAGEMENT

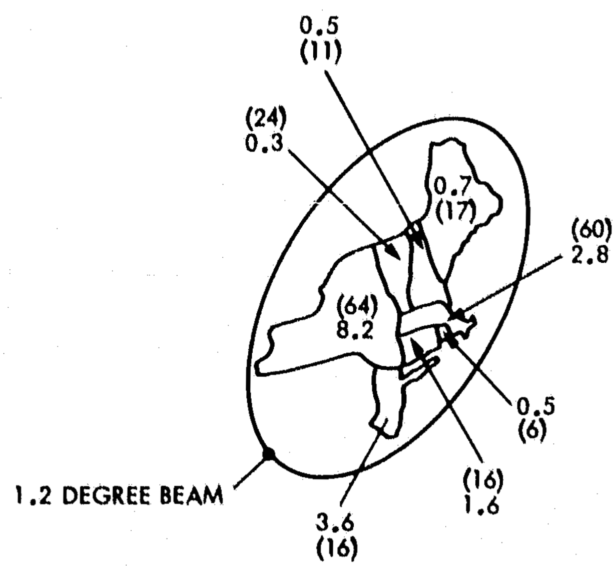


Figure 2-8. MID-ATLANTIC/NEW ENGLAND, PROJECTED TO THE YEAR 1995

It is of interest to note that while the total populations of both the Western and mid-Atlantic/New England regions are projected to be about equal ($18.5x10^6$ vs. $18.2x10^6$ meters) the nature of the electric loads are different. The West will have less air conditioning, less electric space heating, and somewhat fewer electric water heaters.

Using the 1995 projections, the total communications traffic generated by the Western Region was calculated. Table 2-3. The monthly traffic is estimated to be $17.1x10^6$ messages, with a peak traffic of $89.7x10^3$ 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.

	MONTHLY TRAFFIC MESSAGES/MONTH	PEAK TRAFFIC MESSAGES/HR
LOAD MANAGEMENT	4.2×10^6	19.2×10^3
AIR CONDITIONERS	2.3×10^6	9.4×10^3
WATER HEATERS	1.5×10^6	8.2×10^3
MISCELLANEOUS	$.4 \times 10^6$	1.6×10^3
REAL-TIME OPERATIONAL MANAGEMENT	2.8×10^6	66.0×10^3
LOAD RECONFIGURATION	$.2 \times 10^6$	3.4×10^3
TRANSFORMER MGT.	1.1×10^6	14.0×10^3
FEEDER MGT.	$.6 \times 10^6$	40.0×10^3
VOLTAGE REGULATION	$.8 \times 10^6$	8.0×10^3
CAPACITOR CONTROL	$.3 \times 10^6$	4.5×10^3
FAULT DETECTION, ISOLATION	$.1 \times 10^6$	$0.6\ 10^3$
REMOTE METER READING	9.8×10^6	NA
TOTAL CONSUMPTION	3.7×10^6	
MAXIMUM DEMAND	$.4 \times 10^6$	
TIME-OF-DAY	5.7×10^6	
TOTAL	17.1×10^6 MESSAGES/MONTH	89.7×10^3 MESSAGES/HOUR

Table 2-3 COMMUNICATIONS TRAFFIC, WESTERN REGION

2.2 System Concept

This section provides an overview of what has been 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 should not be viewed as the optimum system, rather it should be looked upon as one of a number of viable contending alternatives.

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) and individual Remote Terminals (RT) located throughout the service area. Figure 2-9. 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. A 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. Only one SCS is required nationwide.

The SC system is capable of handling the communications traffic associated with the 1995 forecasts for load management, real-time operations management, and remote meter reading. It will:

(1) Accommodate at least 500 utilities nationwide, and up to 150 utilities per region.

(2) Permit operation with at least 15 x 10^6 remote terminals per region.

(3) Allow each utility to operate independently.

(4) Accommodate electric utilities using either centralized or distributed operating control philosophies, and

(5) Accommodate underground circuits.

The "baseline" system is configured to service six contiguous geographical regions making up the conterminous United States.

Each element of the system is described briefly in the following paragraphs. More detailed information is contained in Volume II.

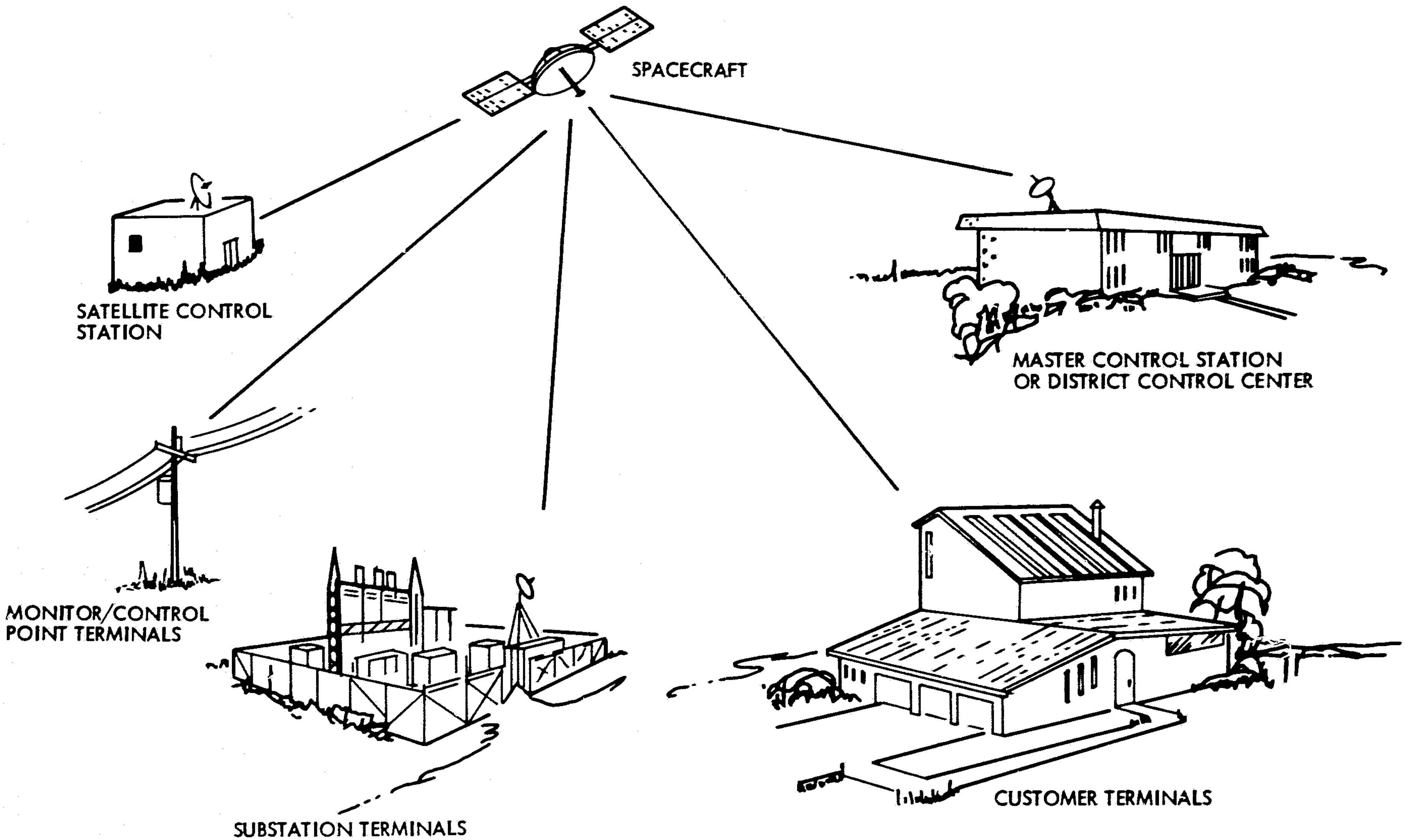


Figure 2-9 ELEMENTS OF THE SPACE COMMUNICATION SYSTEM

2.2.1 Spacecraft

The spacecraft is to be placed into geostationary orbit 22,300 miles above the earth. At this altitude, the satellite's angular velocity around the earth matches that of the earth's rotation so that the satellite's position remains fixed relative to a point on earth.

The satellite's weight and stowed dimensions are compatible with the Space Transportation System (STS) (commonly called the "space shuttle") and the Inertial Upper Stage (IUS) propulsion unit. The shuttle would carry the Satellite - IUS Unit into low earth orbit where the Unit is deployed. The IUS would then propel itself and the satellite into geostationary orbit where the satellite is separated from the IUS and deployed.

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.

Figures 2-10 and 2-11 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.

The satellite is made up of four subsystems: communications; attitude control; command, telemetry and ranging; and electrical power.

2.2.1.1 Communications Subsystem

The communication subsystem consists of a multibeam antenna, seven transponder channels, a message processor, and associated power supplies, etc. Figure 2-12. The antenna is a center-fed parabolic reflector illuminated by a cluster of feedhorns properly positioned to form seven beams with sharp edge rolloff, low sidelobes, and good isolation. The narrowest regional beam is 1.2°, the widest 3.4°. A 7° beam covers the entire United States.

Receivers have equivalent noise temperatures of 500°K and are built with all solid-state microwave integrated circuit technology. Traveling wave tube amplifiers (TWTA) supply down-link RF power.

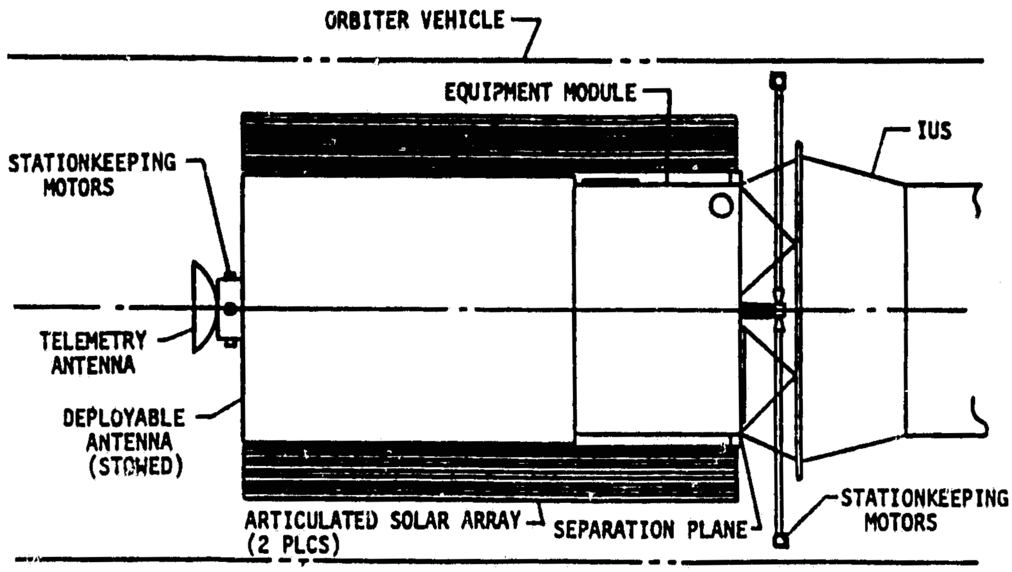


Figure 2-10 SATELLITE STOWED WITHIN THE ORBITER VEHICLE

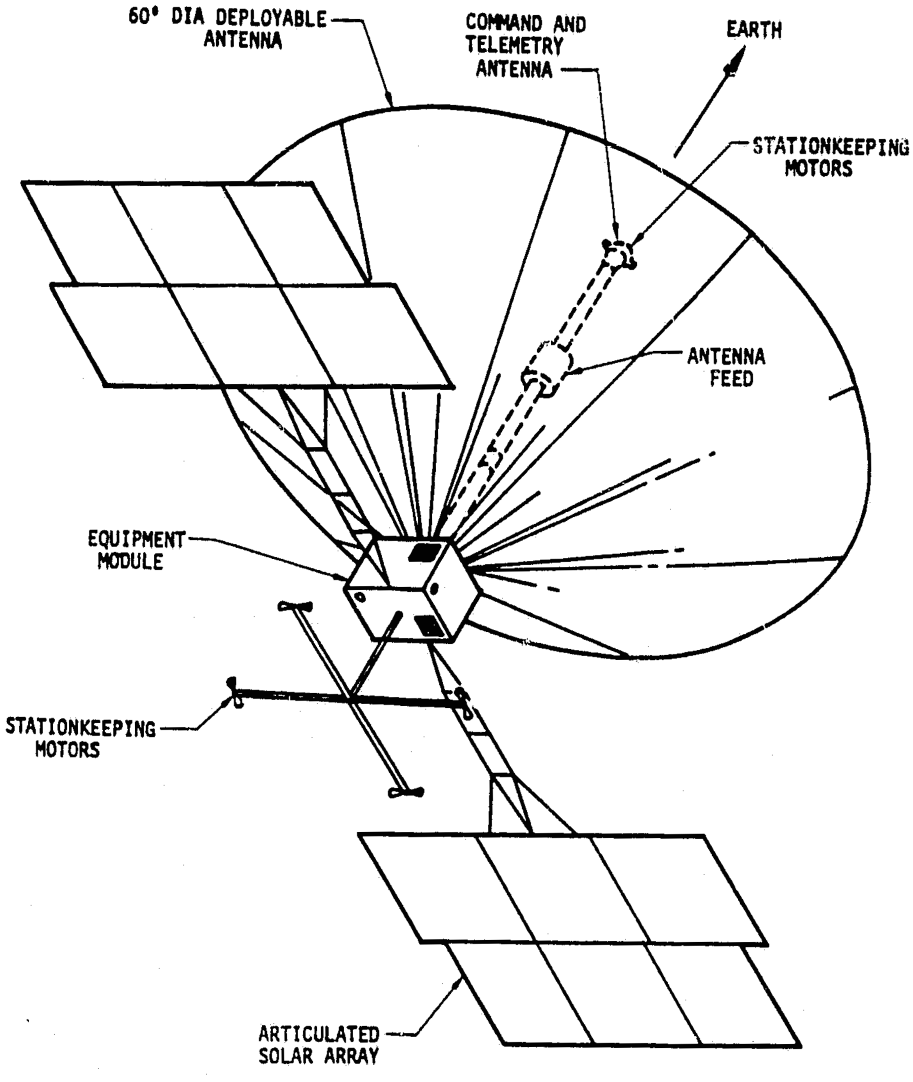


Figure 2-11 SATELLITE IN DEPLOYED CONFIGURATION

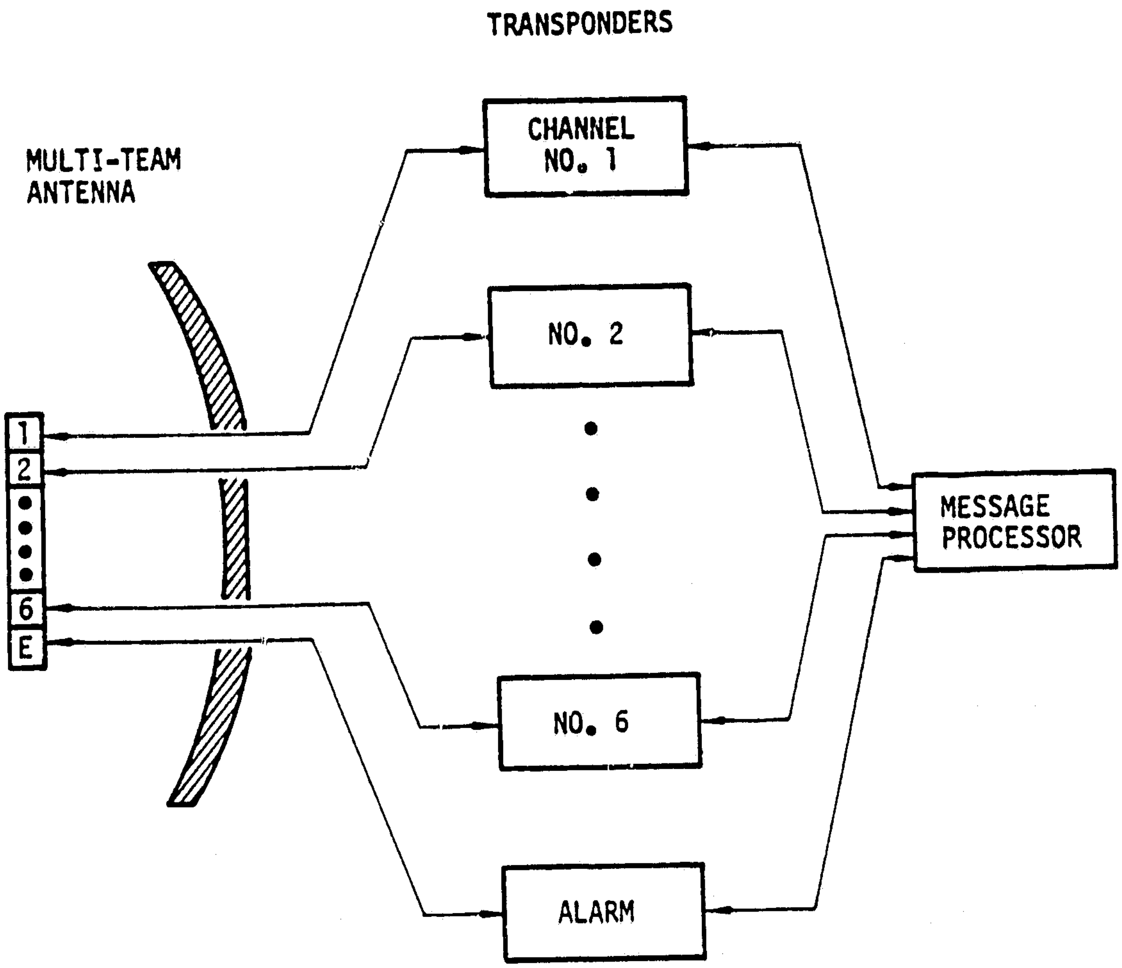


Figure 2-12 SATELLITE COMMUNICATIONS SUBSYSTEM

2.2.1.2 Attitude Control Subsystem

Antenna pointing to less than 0.1° is required to maintain the desired regional coverages (earth footprints). This is achieved by stabilizing the satellite's attitude. The satellite uses an array of inertial wheels for torquing. 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.

2.2.1.3 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 fully cross-strapped to give complete redundancy 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).

2.2.1.4 Electric Power Subsystem

The electric power subsystem is a dual-bus system designed to supply spacecraft power of approximately 6 kilowatts for a 10-year lifetime. Primary power is provided by two separate sun-oriented plannar solar arrays. The arrays consist of approximately 96,000 solar cells 2 cm x 2 cm (465 sq. ft.). During periods of insufficient solar power, nickel-cadmium batteries are used to support spacecraft loads.

2.2.1.5 Thermal Control

Thermal control of the spacecraft is accomplished 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 its mission.

2.2.1.6 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 (nonfailed) 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 through 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 limited to Substation-to Master Control Station alarm type messages.

2.2.2 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. Module configurations and their application are discussed in Volume II.

2.2.2.1 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: Remote meter reading obviously requires two-way links.

A two-way customer terminal provides the utility with the capability to <u>remotely</u>:

1. Open three circuits (which are reclosed automatically by a local timer).
2. Set reclosure time delay 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.

A two-way residential concept is depicted in Figure 2-13. It is but one of many possible configurations.

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, 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 is illustrated in Figure 2-14.

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.

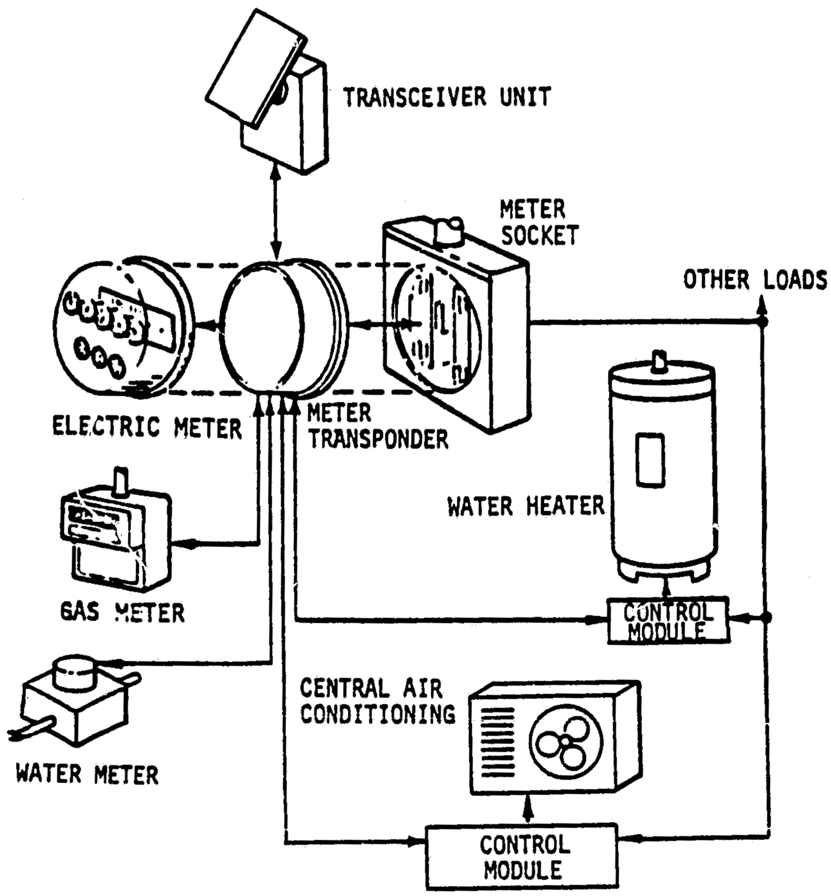


Figure 2-13 A TWO-WAY RESIDENTIAL INSTALLATION

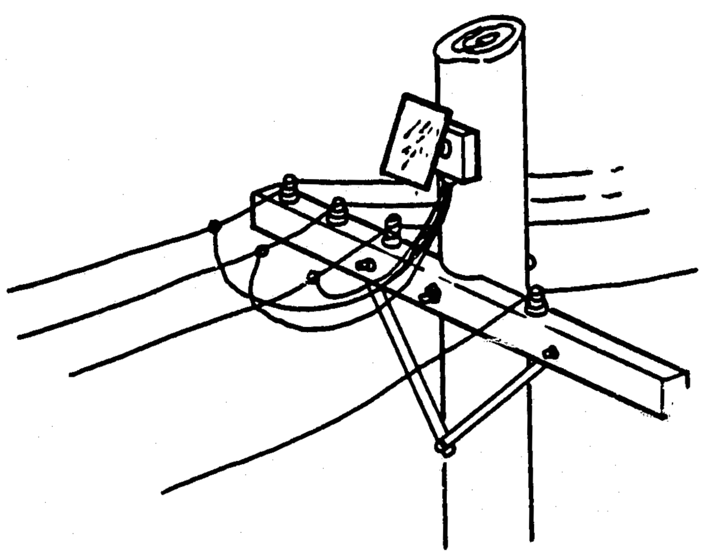


Figure 2-14 NEIGHBORHOOD TRANSCEIVER UNIT

2.2.2.2 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. Real digital and analog instrumentation.

3. Determine status for 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 major registers to .1% accuracy.

3. Determine status from three monitor points.

Both substation and monitor/control point terminals incorporate standby power.

2.2.3 Master Control Stations and District Control Centers

Master Control Stations (MCS) and District Control Centers (DCC) are the operational control facilities for Distribution Automation and Control (DAC). Control stations can be sited anywhere within a 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. <u>From</u> this station flow command messages addressed to individual customer terminals, substation terminals, or monitor/control point terminals. <u>To</u> 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. The "baseline" concept is structured to use time-sharing techniques as a means for accommodating a group of utilities on a common communications channel. (See para. 2.2.5).

For utilities using a dispersed control philosophy, time slots within a 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 DDC's on a dynamic, real-time need 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.

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

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

2.2.4 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 as required.

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 spacecraft's station-keeping subsystem via telemetry.

The material set forth so far has described the "baseline concept." The next section describes how the system operates.

2.2.5 System Operation

The coterminous 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. Six regions are postulated for the "baseline" system.

Regional boundaries establish antenna beamwidths. The widest beam, one that covers the western U. S., is 3.4°, the narrowest 1.2°. Figures 2-7 and 2-8. At the frequency chosen for the baseline concept (1 GHz) 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.

All utilities within a region jointly share a set of resources on-board the satellite (a channel) and operate as a synchronized net. 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 use in network synchronization. Figure 2-15.

All traffic, except alarm ("change of state") messages, are initiated from the utility's Master Control Station or District Control Centers. 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 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.

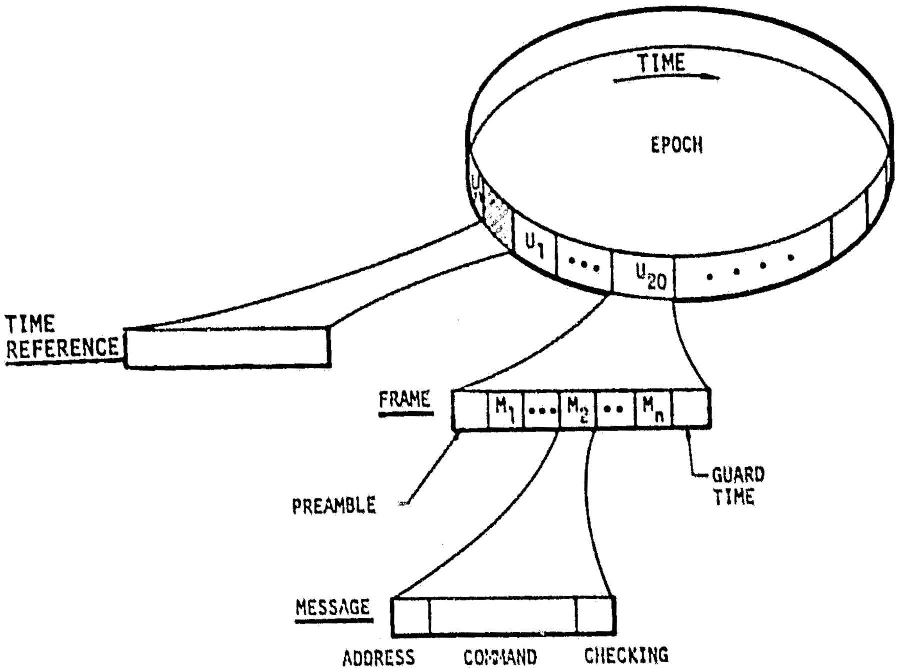


Figure 2-15 TIME DIVISION MULTIPLEXING OF COMMUNICATION TRAFFIC

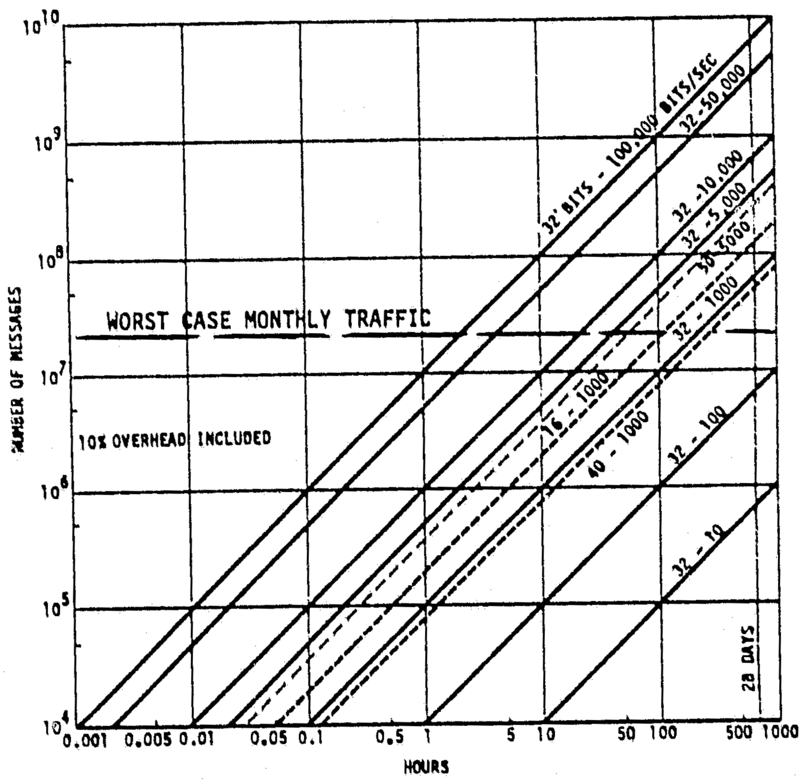


Figure 2-16 COMMUNICATION CAPACITY

Each utility may have tens of thousands, hundreds of thousands, or in some instances possibly millions of remote terminals 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 operational 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.

Figure 2-16 defines the number of messages which can be sent in a given amount of time for various message lengths (bits) and data rates (bits per second). The estimated worst case monthly regional traffic can be handled in less than 100 hours (at 5000 bps).

More detailed information concerning system operation is contained in Volume II.

2.3 SYSTEM DESIGN CONSIDERATIONS

This section examines some of the important factors associated with the formulation of a viable system concept. More detailed information is contained in Volume II.

2.3.1 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.

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 are needed; just how many depends on the multi-access concept, system architecture, and the feasibility of frequence reuse and polarization diversity.

The type of service provided by the SC system does not fit within presently designated frequency bands for satellite use. In the absence of regulatory restrictions, various portions of the frequency spectrum from 150 MHz through 20 GHz were considered in this study for technical suitability.

The influence of frequency on the system design is summarized below:

L-Band: (390 MHz - 1.6 GHz)

The lower part of this band requires large antennas on the spacecraft to obtain the desired earth foot-print, and large antennas 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. The upper part of this band seems to be a practical compromise of a number of technical factors and is the preferred choice.

C-Band: (4 - 6 GHz)

This band is so heavily committed to telecommunications it has virtually no potential for accommodating other services. Substantial possibilities for interferences would exist between this system and other space and terrestrial communications services in this band.

Ku-Band: (10.9 - 18 GHz)

The Ku-Band suffers from difficult propagation conditions. Reasonable link availabilities require high radiated power to overcome the effects of rain. The high cost of receiver/transmitter hardware would increase the cost of the ground terminals.

2.3.2 Reliability Considerations

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."

A high level of reliability can be achieved in the SC system spacecraft through the use of both block and functional redundancy. This redundancy may be employed such that no single failure can have a catastrophic effect on communications. 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.

Throughout its life the satellite's performance will be continually monitored and failures logged. When the number of fully operational elements reach an unacceptable level, a standby satellite will be brought on-line. The overall probability of a single "baseline" spacecraft operating continuously for ten years is estimated to be .744. This value increases to over .93 with one stand-by unit, and to .99 with two. The reliability rises rapidly as operating time is reduced. It should be noted that the reliability of the "baseline" system does not necessarily reflect ultimate need or the most cost-effective solution, it is merely the result associated with a specific configuration. Ultimate need and cost-effectiveness will be dealt with in follow-on work.

As with nuclear power and other systems touted to be highly reliable, it is possible to postulate a series of highly unlikely 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 temporarily without normal DAC communication links. What now?

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

Based on the present thrust of technology and the collective experience with communications satellites there is every indication that the SC system, with a spacecraft having block and functional redundancy plus reversionary modes can be made sufficiently reliable to negate a requirement for terrestrial backup resources. Commercial telecommunication satellites and vital military communication satellites have demonstrated reliabilities on the order of those postulated for the SC system.

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).

The estimated overall failure rate for a two-way customer terminal (most complex configuration) with one transceiver unit serving five customers, each having three appliances under control, is less than 1% per year.

2.3.3 Spacecraft Antennas

The earth foot-print of a 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°. The narrow beam is used where there is a high population density, the wider beam in less dense regions. To achieve a 1.2° beam at 150 MHz requires a 250 foot diameter antenna, at 20 GHz the diameter is about 3 feet. The baseline concept (1 GHz) requires a 60 foot diameter antenna.

Large antennas exceed the shroud dimensions of presently available launch vehicles and also the space available within the Space Shuttle's Orbiter Vehicle.

Three types of antenna designs have evolved to overcome space limitations of available launch vehicles; 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.

A recent study by the Jet Propulsion Laboratory (JPL) which included a prediction regarding antenna developments out to the year 2000 indicates that self-deployable reflector technology will be the most mature technology in the time frame of interest.

2.3.4 System Security Considerations

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 more widespread ramifications. At these sites, more elaborate precautions are in order.

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 somewhat 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 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 apprehend.

There are some design sophistications which can be incorporated into the system to make jamming more difficult, however, these have cost impact. It is axiomatic that a realistic level of protection must be provided.

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 minuscule.

While RF jamming or spoofing attempts are possibilities, it is more likely that remote terminals may be subjected to tampering. Sensors can be provided to detect and report violations of an equipment's physical integrity, and to report mechanical spoofing attempts.

Certain types of unattended facilities must have intrusion detection capability to initiate police actions. This situation is handled by an ALARM report dispatched to the Master Control Station via the special emergency communication channel. The SC system is uniquely geared to discovering and disclosing tampering.

The vulnerability of space communications for electric utility automation during a Major Power confrontation (war) must be considered separately. As of this time, it has not been established that the SC system would be 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. But for the sake of analysis the loss of satellite communications in a strategic attack on the United States may be postulated. In this situation, load management could be carried out by direct radio appeals to the surviving population. Real-time operational management would revert to manual on-site actions. At a few key sites, work-around communications might be desirable and possible, using whatever resources remain. In a post nuclear attack environment it is unlikely that utilities would be concerned with meter reading for customer billing purposes.

2.4 Costs

The cost of a customer terminal is related to the desired functional capability and installation peculiarities. Figure 2-17 shows block diagrams of the equipment which forms the basis for the cost estimates. A power line carrier approach was chosen for the link between the transceiver and the load switch or meter.

Equipment cost estimates were obtained from several sources and therefore show a range of values. Costs also vary as a function of the operating frequency. Details of the cost estimation process are provided in Volume II. The costs discussed in Volume I are average costs at the baseline design frequency of 1 GHz.

Customers terminal costs also vary as a function of the number of customers sharing a Receiver Unit or a Transceiver Unit. Using carrier current transducers between the Transceiver and indoor equipment allows a Transceiver to be shared by as many customer terminals as are on the same secondary of the transformer.

The number of customers sharing a transformer can vary over a considerable range. In rural areas, or industrial areas, as few as one customer may be served by a transformer. In dense urban areas fifty or more customers may be served by a single transformer. For example, PG&E's Shasta area has about 1.8 customers per transformer, while the San Francisco area averages twenty customers per transformer (which includes industry). Since densely populated areas offer more potential for load management, an assumption of ten customers per transformer, while possibly conservative, is a decent number to work with.

On the basis of 10 customers sharing the outdoor equipment, load control terminal cost (one-way communications) is estimated at $40 per house and remote meter reading (two-way communications) can be had for $175per house. A two-way terminal with the capability to remotely read-out the "state" of a controlled load is estimated at $205 per house. Figure 2-18 illustrates how per household cost varies with the number of households sharing a Receiver Unit or a Transceiver Unit. These costs appear competitive with alternative (terrestrial) techniques for DAC communications.

Substation terminals are more expensive, having added functional capability and higher performance. These terminals will vary from $600 to $1300 depending on site peculiar needs, with $650 being typical. Monitor/Control Point terminals are estimated at $275 each.

The equipment needed by a utility to operate the system from a central facility (Master Control Station) is estimated at $100,000 to $200,000, the range reflecting possible differences in levels of automation. Equipment for a typical control station should cost no more than $125,000.

Ground equipment costs are summarized in Table 2-4.

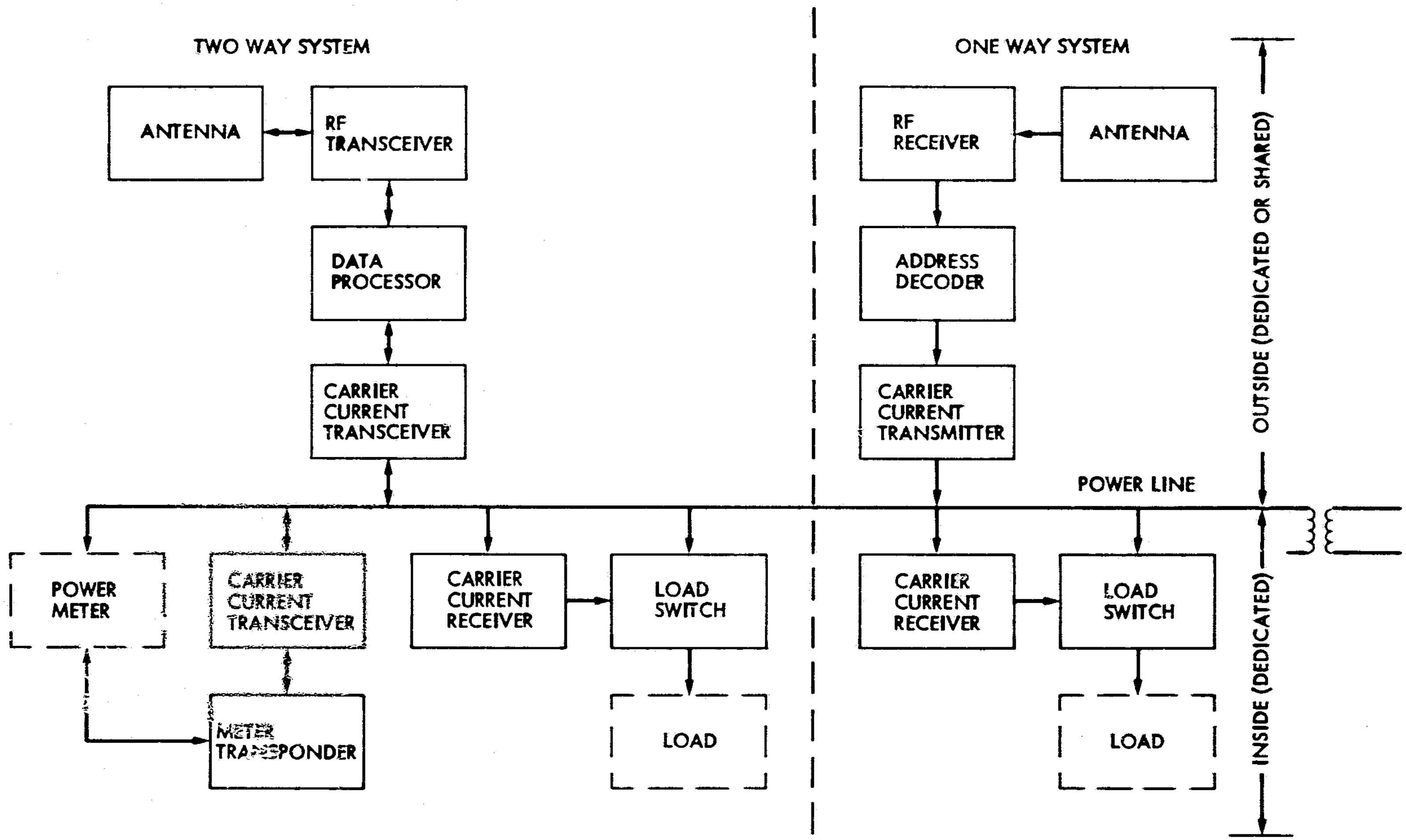


Figure 2-17 Customer Terminal Block Diagrams

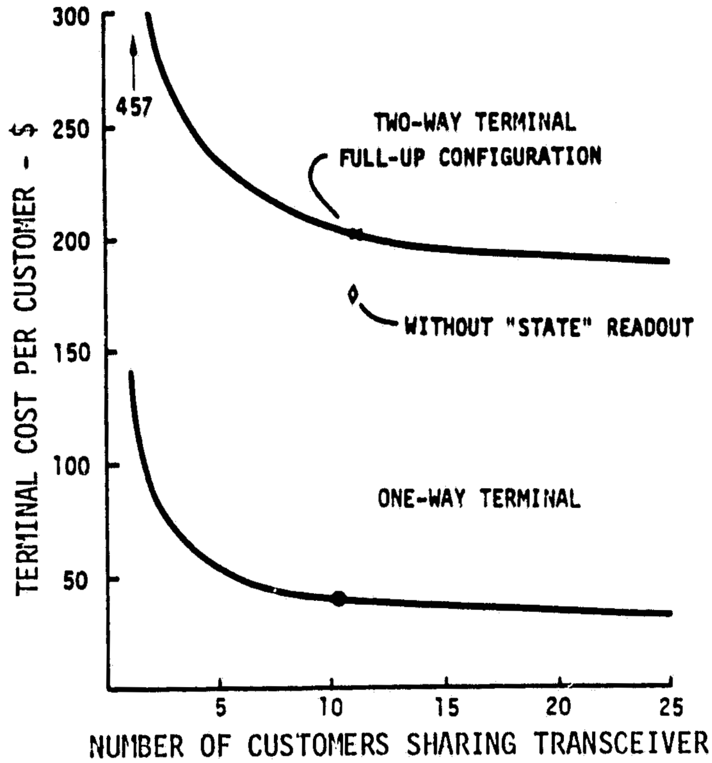


Figure 2-18 CUSTOMER TERMINAL COST

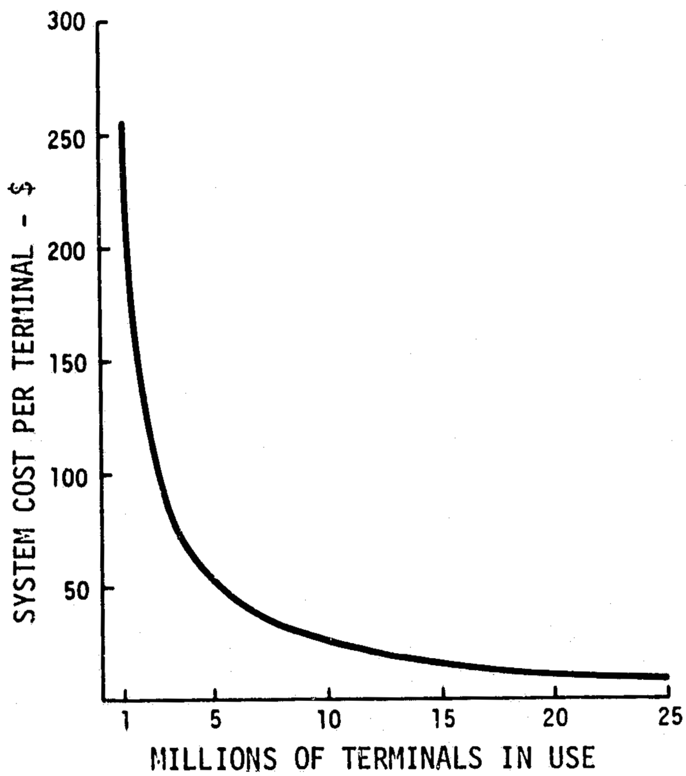


Figure 2-19 SYSTEM COSTS PER TERMINAL

Terminal	One-Way		Two-Way	
	Dedicated	Shared*	Dedicated	Shared*
Customer	$140	$40	$427	$175
Substation	N/A		$650	
Control/Monitor Point	$140		$275	
Master Control Station	$100,000		$125,000	

*Ten Customers share one Transceiver Unit

Table 2-4 GROUND EQUIPMENT COSTS

		ONE SATELLITE IN ORBIT	ONE SATELLITE IN ORBIT, ONE ON GROUND STANDBY
Satellite Cost		$40M	$85M
Launch Cost		41M	41M
Satellite Control Station Cost		10M	10M
RDT&E Cost		122M	122M
Terminals	$ 5M		
Satellite	105M		
Satellite Control Station	12M		
Total Investment		$213M	$258M

Table 2-5 SATELLITE SYSTEM PLUS DESIGN COSTS

The spacecraft is the most expensive system element, estimated to cost between $33 and $53 million, depending on the antenna size, amount of functional redundancy, level of on-board processing, etc. A unit cost of $40 million seems probable. To put the spacecraft into geostationary orbit using the Space Transportation System and an Inertial Upper Stage will require another $41 million.

The last element of the system, the Satellite Control Station, could cost between $3 and $10 million depending on factors mostly unrelated to functional capacity, such as land and building requirements.

Initial investment costs including design, development, test evaluation, and other non-recurring costs, plus space system costs are given in Table 2-5. These costs are plotted on a per terminal basis, as a function of the number of terminals in the system, in Figure 2-19.

More detailed information regarding costs can be found in Volume II.

2.5 Implementation

It seems probable that the first widespread use of the distribution automation and control will be for load management. The time scale for its introduction is likely to be in the early 1980's. To be a viable contender the SC system development must be started within the next few years.

The conventional approach to introducing new technology into the utility industry involves a sequence of events which includes field demonstrations of one or more alternative approaches, and culminates in the gradual phase-in of operational equipment.

2.5.1 Demonstration

Demonstrating every facet of the concept end-to-end without a satellite is virtually impossible. Existing satellites can be used to demonstrate some functions, others can be proven using ground and/or airborne simulations. Some features which may warrant demonstration are:

1) Two-way operation of a shared channel.

2) All weather operation.

3) Operation in a substation environment.

4) System security.

5) Flexibility to accommodate a variety of site peculiar installation conditions.

6) Equipment reliability.

2.5.2 Development and Use

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, long term commitments from a group of users.

An alternate approach based on joint use of the spacecraft by commercial or public interests outside the utility industry may prove more attractive. The strength of this approach is that even a small number of utilities could take a first step at a modest cost.

Implementation is discussed further in Volume II.

3.0 CONCLUSION

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 electric utility industry's needs relative to load management, real-time operational management of the distribution system, and remote meter reading, and second, to determine the costs for various elements of the system.

The issue of technical feasibility must be viewed in terms of launching a full-scale program within the next several years, which means the required technologies must already be in-hand, or well under way. Feasibility must also be examined in terms of potential frequency allocations since technological requirements tend to be frequency sensitive. In the paragraphs which follow, conclusions associated with specific topics are summarized.

Functional Requirements: The volume of traffic generated by load management, real-time operational management and remote meter-reading can be readily accommodated by a low data rate system. While remote meter-reading generates most of the traffic, load management appears to be of greater interest to the utilities at this time. A system sized around load management as the driving force behind implementation would result in more modest communications requirements.

Looking beyond the near term, it is clear that basic improvements in the power distribution system will not substantially change its character as far as communication requirements are concerned, except for the addition of Dispersed Storage and Generation (DSG). DSG could have a significant impact on communication needs and warrants a separate investigation.

Frequency Allocations: The pin-pointing of probable frequency allocations is a key issue which requires early resolution. From a system designer's viewpoint the high portion of the L-band (1 GHz) appears to be a good choice. Fortunately there are indications that this may indeed be acceptable to regulating authorities. The issue should be pursued. Even though there is a possibility at L-band, it must be recognized that allocations generally have been trending toward higher frequencies. In view of this fact, more work should be done in configuring suitable Ku-band systems.

System Architecture: There appear to be several viable ways in which a satellite communication system could be structured to handle the communication traffic associated with distribution automation and control (DAC). A key item is the selection of the best method for allowing users to share communication channels. While time-sharing is one obvious choice, other schemes also appear to have substantial merit. Detailed trade studies are required to select the preferred method.

It is apparent that any viable satellite communications system must have the flexibility to accommodate a variety of hierarchical control philosophies. The ramifications of this requirement must be studied in more depth.

Link Design: The size of the customer terminal antenna weighs heavily on link design. At 150 MHz an aesthetically permissible ground antenna leads to excessive transmitter power in the spacecraft and/or increase in spacecraft antenna size, which in turn diminishes ground coverage. At 20 GHz a sizeable ground antenna could help overcome rain attenuation. One alternative is again more radiated power from the spacecraft, another is accepting reduced link availability, a third is using a "burn through" mode on critical links during severe weather.

Cost and reliability considerations dictate modest customer terminal transmitter outputs. With reasonably small size ground antennas, the required ground transmitter power at high frequencies becomes excessive.

All factors considered, the region around 1 GHz looks to be the preferred operating band.

Ground Terminals: There appear to be no outstanding technical feasibility issues associated with the design and development of high volume production ground terminals. This is not to say that Ku-band terminals are as easily dealt with as L-band terminals, the lower frequencies are definitely preferred.

Reliability: Spacecraft reliability and life, in keeping with operational requirements, can be achieved through the use of current technology. The possible need for an in-orbit spare spacecraft requires further study, as does the mechanics and flow time necessary to place a ground stored unit into orbit.

The requirement for a 10 year life is a reasonable goal, however, a somewhat shorter life could prove more cost effective. This trade should be addressed.

Orbital Considerations: Use of the geostationary orbit does not appear to present a problem as long as operating frequencies are outside the telecommunications band (C-band).

Spacecraft: The relatively large (60 foot) 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 acceptably small. All other spacecraft concepts and components are flight qualified, readily available items.

The launch capability of NASA's Space Transportation System (STS) permits consideration of very large and heavy spacecraft. The Inertial Upper Stage (IUS) is presently in development and will be available to support the Space Transportation System (STS). Since the STS/IUS is capable of placing a 5,000 pound payload in geostationary orbit, attention must be given to limiting spacecraft weight to this amount.

System Security: The communication system can be made reasonably tamper-proof. However, strongly motivated and well equipped individuals can probably find ways to defeat any but the most sophisticated (and possibly uneconomic) means of protection. Overt or covert attempts to spoof or jam the system could result in limited successes, however, such attempts are not likely to cause widespread disruptions, or go undetected. Additional work must be done to determine practical levels of protection.

Health: The communication system poses no radio frequency (RF) radiation hazard under present standards. In most cases RF sources are not accessible for continuous, close proximity exposure.

Utility Operating Practices: It is quite clear that a satellite communication system will fit in well with utility operating practices. One of the attributes of such a system is its inherent ability to handle a variety of functional and physical situations.

Costs: Total program costs are dominated by aggregate customer terminal costs. Load control equipment (one-way communications) is estimated at $40. per household, remote meter reading (two-way communications) adds another $135., bringing the total to $175. Substation terminals will vary in cost according to functional capability with $650. being typical. Control/Monitor Point terminals will cost around $275.

The "baseline" spacecraft is estimated to cost $40 million (1979 $). Launch costs to geostationary orbit are estimated at $41 million. Master Control Stations will run between $100 and $200 thousand, and the Satellite Control Station $3 to $10 million.

Implementation: At least five years are needed to bring a space communication system into being. In order to have a satellite in place by the mid to late 1980's (the projected era of first widespread use of load management) the program must be started within the next few years. The form and scope of such a venture must be thoroughly researched.

A program built around a satellite <u>dedicated</u> to distribution automation and control (DAC) functions should be considered. On the other hand a spacecraft designed for commercial and public interest functions, <u>and</u> DAC functions, could be an attractive way of introducing space communication into the utility industry. Another alternative based on offering multi-function communication capabilities to the utility industry may also be of interest, i.e., operating communications, interoffice business communications, etc.

4.0 RECOMMENDATIONS

This study was structured in consonance with the Department of Energy's desire for a multi-phase program to explore the application of satellite communications to distribution automation and control, each phase to be viewed as a "decision gate," with favorable results leading to follow-on work.

The first phase (this study) had as its objectives to establish system requirements, to assess the concept's technical feasibility, and to estimate "ball park" type costs.

From the work done in this study it is our considered judgement that the SC system is a viable concept worthy of carrying forward. The problem of operating frequency assignments should be addressed as a first order of business. Second, the concept should be developed in more depth and refined costs obtained. Other potential applications of satellite communications in the utility industry should be examined. The specific communication needs associated with generation and transmission operations should be studied, and the unique features of satellite communications assessed against the complete spectrum of utility communication requirements. Table 4-1. Since these are natural extensions of the basic concept, such investigations appear to be eminently worthwhile.

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

NUCLEAR MONITORING

STRUCTURAL STRAIN MONITORING

PERSONNEL PAGING/ALERTING, DISPATCHING

REMOTE BILLING AND BILL-PAYING (ELECTRONIC FUNDS TRANSFER)

INTEROFFICE BUSINESS COMMUNICATIONS, INCLUDING FACSIMILE

Table 4-1 ANCILLARY FUNCTIONS

5.0 NEW TECHNOLOGY

The "new technology" provisions of the contract under which this study was conducted does not require technology items to be reported.

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