PROPAGATION CONSIDERATIONS
IN THE AMERICAN MOBILE SATELLITE SYSTEM DESIGN

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ABSTRACT

This paper presents an overview of the AMSC MSS system with special emphasis given to the propagation issues that were considered in the design. The aspects of the voice codec design that effect system performance in a shadowed environment are discussed. The strategies for overcoming Ku-Band rain fades in the uplink and downlink paths of the gateway station are presented. A land mobile propagation study that has both measurement and simulation activities is described.

INTRODUCTION

American Mobile Satellite Corporation (AMSC) is currently in the process of developing a satellite communications system to provide mobile satellite services (MSS) to North America. In 1990 contracts were awarded to Hughes Aircraft Company with SPAR as a major subcontractor for the development of an L-Band satellite to provide MSS services. The satellite will be launched in 1994 with an approximate service start date in late 1994.

Currently the Communications Ground Segment (CGS) of the MSS system is in the process of being developed by Westinghouse Electric Company (WEC). WEC was awarded the contract for the CGS in April 1992. WEC will also be providing production model mobile terminals (MT) for use by system subscribers. Mitsubishi Electric Company (MELCO) is a second supplier of production model MTs.

This paper will first provide an overview of the AMSC MSS system and then discuss details of the propagation issues considered in the design.

SYSTEM OVERVIEW

Figure 1 shows an overview of AMSC's MSS system. The MSAT satellite acts as a "bent pipe" repeater, receiving and transmitting modulated signals to/from the mobile terminals at L-band and relaying them to terrestrial users via Feederlink Earth Stations (FES) at Ku-band. The AMSC network will provide mobile telephony and data services primarily to vehicles like automobiles, trucks, ships, and aircraft. The basic electronics of the MT for each of these mobile applications will be similar with the major differences being

in the antenna and packaging to account for the special environmental conditions encountered. In addition, the aviation applications may require special electronic circuitry to accommodate the greater maneuverability and resulting higher doppler frequency shifts of these mobile platforms.

The MSS system will be designed to provide voice, data and facsimile services. The voice will be digitally encoded using the IMBE (Improved Multi-Band Excitation) algorithm developed by DVSI (Digital Voice Systems, Inc.) which operates at rate of 6.4 KPBS, including FEC. The digital voice signals and/or the data and facsimile signals will modulate a narrow band carrier using QPSK at a rate of 6.75 KBPS, including frame overhead. The modulated signals from the mobile terminals and the FESs will access the satellite using demand assigned SCPC.

There will be two types of FESs in the AMSC system; namely gateway stations and base stations. Gateway stations provide a means for signals from the MTs to be routed via the Public Switched Telephone Network (PSTN) to any terrestrial telephone in the world. Base stations are intended to provide service to a private network user. As such these base stations will allow for limited access to the PSTN.

AMSC will locate its principal gateway FES at a site in Reston, Va. adjacent to our new headquarters building. This FES site will use an 11 meter antenna to provide high availability.

The real time control of the AMSC system is accomplished from a Network Control Center (NCC). The system has been designed to operate with two NCCs, one active and one in a "hot" standby mode ready to take control in the event of a failure of the active station. The backup NCC will be provided and installed at a different location at a future date. The chief function of the NCC is to control the assignment of specific frequencies to the MTs and the FESs to set up a circuit (either voice, data or facsimile) over the satellite. These frequency assignments are made in real time for the duration of each call, so that the power and bandwidth resources of the satellite are available for all systems users on a demand basis.

The function of the Network Operations Center (NOC) is to administer the operation of the system. The NOC collects (from the NCC) and stores call detail records to allow the AMSC billing system to prepare customer bills. It also collects satellite circuit usage records to forward to various engineering and operations personnel for use in analyzing network performance and health. The NOC also contains displays to allow operators to monitor and control the status of the system.

Figure 2 is an artist's conception of the AMSC satellite. The satellite is a three axis stabilized

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spacecraft built by Hughes Aircraft Co. with SPAR responsible for the communication subsystem, including antennas. The satellite uses HAC's 601 bus. The spacecraft is being specified to be launched with either an Altlas 2A or Ariane 4 vehicle. The dry mass of the satellite is approximately 2700 lbs with a separation weight of 6425 lbs (Atlas 2A).The solar arrays are capable of providing 3600 watts at end-of-life, equinox.

When the satellite is fully deployed (antennas and solar panels) in-orbit, it will extend to 825 inches (tip-to-tip solar arrays) and 745 inches (antenna edge-to-antenna edge). The design life of the satellite is 15 years with a fuel life of 10 years.

Elliptical unfurlable mesh antennas provide the L-band coverage for the satellite. These antennas are offset feed and are 6 by 5 meters in size. There are separate transmit and receive L-Band antennas. The L-band antennas provide 6 spot beams that cover CONUS and the off-shore points of Alaska, Hawaii, and Puerto Rico.

A single Ku-band antenna, for transmit and receive, is mounted on the earth viewing face, or sub-nadir panel. This antenna is a 30 inch shaped reflector designed to provide coverage for all the land masses of North America including Hawaii and Puerto Rico using two feed horns. The main feed provides nearly uniform coverage over the continental areas plus Puerto Rico while the second feed provides a spot beam over Hawaii.

SERVICE QUALITY CONSIDERATIONS

AMSC will be the one of the first entities to provide MSS services to land mobile platforms. There have been many experiments and field trials of land mobile MSS services throughout the world, that support the viability of these services. However, these experiments and field trials can not be used to accurately predict the quality of the AMSC system throughout our diverse and extensive service area

The remainder of the paper describes those key elements of the AMSC system that determine the overall quality of the system and how these elements have been designed to enhance system performance. These key elements are the voice codec and the RF links or propagation paths between the satellite and the land mobile terminal. In addition, an overview of a propagation study program that will help predict AMSC's service quality, will be provided.

LINK BUDGET OVERVIEW

General

A full presentation of the AMSC link budget and the underlying assumptions is beyond the scope of this presentation, but Table 1 summarizes the results of our link analysis.

In Table 1, the uplink margin is defined as that additional loss that can occur in the uplink path before the received BER into the voice codec exceeds a specified bit error rate (BER), in this case 1×10^{-2}. Similarly, the downlink margin is defined as that additional loss that can occur in the downlink before the specified BER is exceeded. (Note that results of extensive subjective testing on the DVSI IMBE voice codec shows that good voice quality is obtained at a BER of 1×10^{-2}. Actually, acceptable voice quality is obtained with a codec input BER of 4×10^{-2}.

TABLE 1   LINK BUDGET SUMMARY

PARAMETER	FORWARD LINK	RETURN LINK
DOWNLINK MARGIN	$\simeq 4.0$ dB (K= 10dB) $\simeq 5.5$ dB (AWGN) @ L-BAND	≥ 10 dB @ Ku-BAND
UPLINK MARGIN	$\simeq 3.0$ dB (K= 10dB) $\simeq 4.5$ dB (AWGN) @ Ku-BAND	$\simeq 5.0$ dB (K=10 dB) $\simeq 6.5$ dB (AWGN) @ L-BAND
UPLINK POWER CONTROL	≥ 10 dB	NONE

Ku-Band

Since the links from the FES are at Ku-Band, the MSAT link design must account for infrequent periods of severe rainfall induced attenuation. In the forward link uplink, an uplink power control system has been designed into the FES. This power control system will adjust the uplink power transmitted to the satellite based upon the received level of the Uplink Power Control Beacon (UPC) of the satellite. This UPC beacon has been specifically designed to be used as a stable reference for controlling the transmitted power of the FESs in the MSS. The dynamic range of this power control system is in excess of 10 dB.

The return link downlink is also at Ku-Band. With an 9 to 11 meter antenna at our Reston, Va FES site, a downlink margin in excess of 10 dB is obtained on this link. In order to account for periods when the rain attenuation is greater than 10 dB, which occur for about 2 to 4 hours per year total in the Washington, DC area, a diversity RF site will be installed.

Figure 3 is a simplified block diagram of the FES showing the RF diversity site. The RF diversity site will replicate the RF portions (i.e.; antenna, LNA, HPA, & up-down-converters) of the FES at a site about 10 to 15 miles from Reston, Va. An innovative feature of this diversity scheme is the fiber-optic interconnection between the prime and diversity site.

The fiber-optic interconnecting facility will be leased from either TELCO or other private fiber optic providers in the Washington D.C. area. This fiber optic link will carry the IF output of the approximately 2000 channels units located at Reston, Va. Thus the IF signal will be 2000 narrow band QPSK carriers occupying a 200 MHz bandwidth at approximately 1 GHz.

AMSC investigated the state-of-the-art in fiber optic transmission and found a company in California, Ortel, that made several devices that were capable of handling these analog signals. AMSC also found the local Bell operating company quite receptive in exploring the possibility of providing us with a service using these Ortel devices and their extensive fiber facilities.

As far as we know, AMSC's will be the first domestic satellite company to use site diversity to improve service availability. There have been several experiments done to verify and quantify the improvement to be expected through the use of site diversity, but no system has gone operational. AMSC expects that the use of diversity will decrease the downtime due to rainfall attenuation by a factor of 20. Thus resulting in rainfall attenuation induced outages at the two sites of 6 to 12 minutes per year.

L-Band

The L-band uplink and downlink margins vary from 4 dB to about 6 dB, depending on the which link (forward or return) and the link conditions, AWGN or a multipath Ricean K factor of 10 dB. AMSC anticipates that the demodulator in the MT and channel units at the FES will use a form of MSDD (Multi-Symbol Differential Detection) that will perform quite well in a multipath environment without losing much performance over coherent detection.

The margins are limited at L-Band due to the constraints that are placed on the mobile antenna in order to be economical and attractive to AMSC's typical customers. These

margins will not be sufficient to overcome the blockage when the vehicle is fully shadowed by a tree trunk or building. The voice codec selected by AMSC has been designed to overcome outages of short durations, about 100 ms or less, so that when the vehicle is moving past a tree at any typical speed, acceptable voice quality will be obtained in spite of the short blockage.

However, AMSC expects there will be conditions of such dense vegetation and or terrain blockages, that even AMSC's robust codec will experience a temporary outage. AMSC's propagation research effort has been focused on determining to what extent and at what locations these outages will occur. This propagation program will be described later.

CODEC

The DVSI IMBE codec was selected after several rigorous competitive subjective listener tests that were conducted for both INMARSAT and AMSC. A key part of the test was the evaluation of the codec's voice quality when subjected to periodic bursts of high BER. In fact, these high bursty BER conditions were designed to match the road conditions of both heavily and moderately shadowed roads. Actual roadside shadowing data was used to create the burst error patterns.

The DVSI codec scored the best (i.e.; provided the highest voice quality according to the test listeners) among those tested, while experiencing these bursty error conditions. The strategy employed by the decoder is to repeat certain model parameters of the previous good frame of encoded voice (a typical frame is 20 ms) when a frame with high error rate is received. By repeating these model parameters, natural sounding voice is obtained although there may be a slight loss in speech content. This strategy of repeating frames continues for about 5 bad frames or 100 ms, if more bad frames are received after this period, the output of the codec is muted.

Furthermore, in the subjective testing of the codec over simulated roadside shadowing conditions, it was observed that the acceptable voice quality was obtained even if as much as 10% of the voice frames are badly corrupted.

Thus, the purpose of AMSC's propagation research effort is to determine how well the robust strategies of the DVSI codec will perform when exposed to the roadside conditions that exist throughout our service area. To accomplish this task, a two-pronged approach was adopted, measurements and simulations as described in the next section.

PROPAGATION STUDY PROGRAM

Measurement Program

In the summer of 1993, AMSC intends to perform a

propagation experiment using a Standard M terminal and INMARSAT satellites in the Atlantic Ocean region. (Note that the Std M terminal uses nearly the identical codec that AMSC will use.) This test will probably be made over the same Route 295 that was part of Vogel and Goldhirsh's (see Reference) earlier propagation experiments.

In the planned AMSC test a Standard M voice channel will be setup over INMARSAT III satellite at 55° W. Longitude to a terminal that will be specially mounted in a pickup truck. The pickup truck will be equipped with an video camera that will be used to visually record the surrounding landscape while recording the voice quality received by the Std M terminal. In this fashion, AMSC engineers will be able to correlate voice quality with roadside conditions. The test run will be repeated using the AORE INMARSAT III satellite at 15° W. Longitude.

In order to extrapolate the experimental data obtained in the test described above to areas throughout CONUS the simulation program described below was developed for AMSC by CS Communications of Vienna, Va.

Propagation Simulation Program

AMSC will also develop a computer simulation model to estimate communications availability taking into account blockage due to terrain and vegetation.

The foundation of the model is built using dBase III and Clipper 5.0. For terrain information the model uses US Geologic Survey (USGS) electronic topographic data. The model further includes the aggregate effects of vegetation via USGS Land Use/Land Cover (L-series) data. Potential customers are primarily concerned with communications performance along transportation routes: Interstate, primary, secondary, rail line, inland waterways, etc. To provide this feature, US Census Bureau "TIGER" files are used.

The model combines the topographic, land cover, and transportation route information to provide an estimate of satellite visibility at points selected along a user specified route. The points can either be automatically generated based upon on equal spacing between points or selected by hand. At each point, an estimate of link margin is used to determine the communications availability of the point.

The link margin estimate is computed assuming user tolerance of 4 to 6 dB, of codec performance degradation. It was deemed unreliable to make point-wise availability estimates with the level of data detail provided by the topographic and land cover data sources, since L-band propagation is specific to the individual tree limb level. AMSC's intent is to use the estimate path length through any trees and the density of the tree cover to calculate a path

loss due to tree absorption. The calculated path loss is then subtracted from the margin to determine if the point is "available" for communications. In aggregate, the points along the route will converge to the approximate mobile communications availability along the selected route.

Currently, AMSC is using the model to prepare an overall availability estimate for CONUS and on a region by region basis. A matrix of 5 terrain types and 5 vegetation types was created. A matrix applies to an elevation range ($30°$ to $40°$, $40°$ to $50°$, and $50°$ to $60°$). Geographic areas from the US were selected which met the terrain/vegetation characteristics and the elevation angle ranges. Each geographic area will be simulated with a set of routes chosen such that satellite orientation will not effect the availability estimates. The entire contiguous US has been divided into $0.5°$ by $0.5°$ blocks. The blocks are characterized and categorized into the appropriate terrain/land cover type and elevation angle range. The aggregate availability for the US and other geographic divisions can then be calculated.
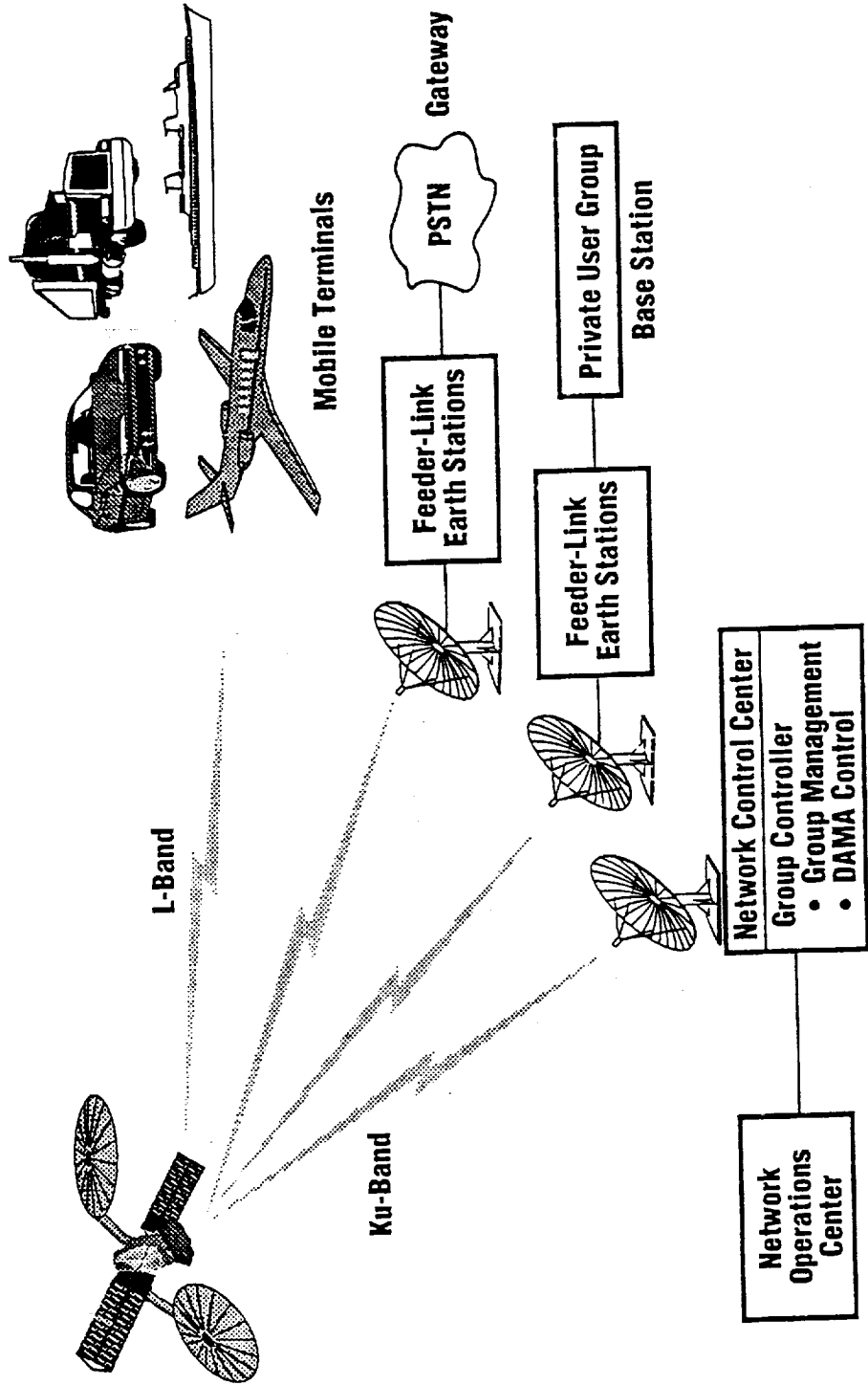
By comparing the results of the measurement program using the Std M terminal with the model derived availability estimate for the same route, AMSC can establish the validity of the simulation model. Additional measurements versus model comparisons will be performed on routes with varied terrain and vegetation to further validate the propagation model.

SUMMARY

The AMSC MSS system has been designed to provide good quality voice services throughout CONUS and the off-shore regions of Alaska, Hawaii, and Puerto Rico. Uplink power control and site diversity will ensure high availability from the FES or gateway earth station. Characterization of the L-Band land mobile satellite path for the AMSC service areas, is an on-going AMSC activity involving measurements and computer modelling and simulations. A robust voice codec, that has been rigorously tested in several competitive evaluations, has been selected for the AMSC system. These competitive tests included subjective evaluations of the voice codec performance over simulated roadside shadowed environments.

Reference: Vogel, W.J. & J. Goldhirsh, "Mobile Satellite System Propagation Measurements at L-Band Using MARECS-B2" IEEE Trans. Antennas & Propagation, Vol AP-38, no 2, pp 259-264 Feb.1990
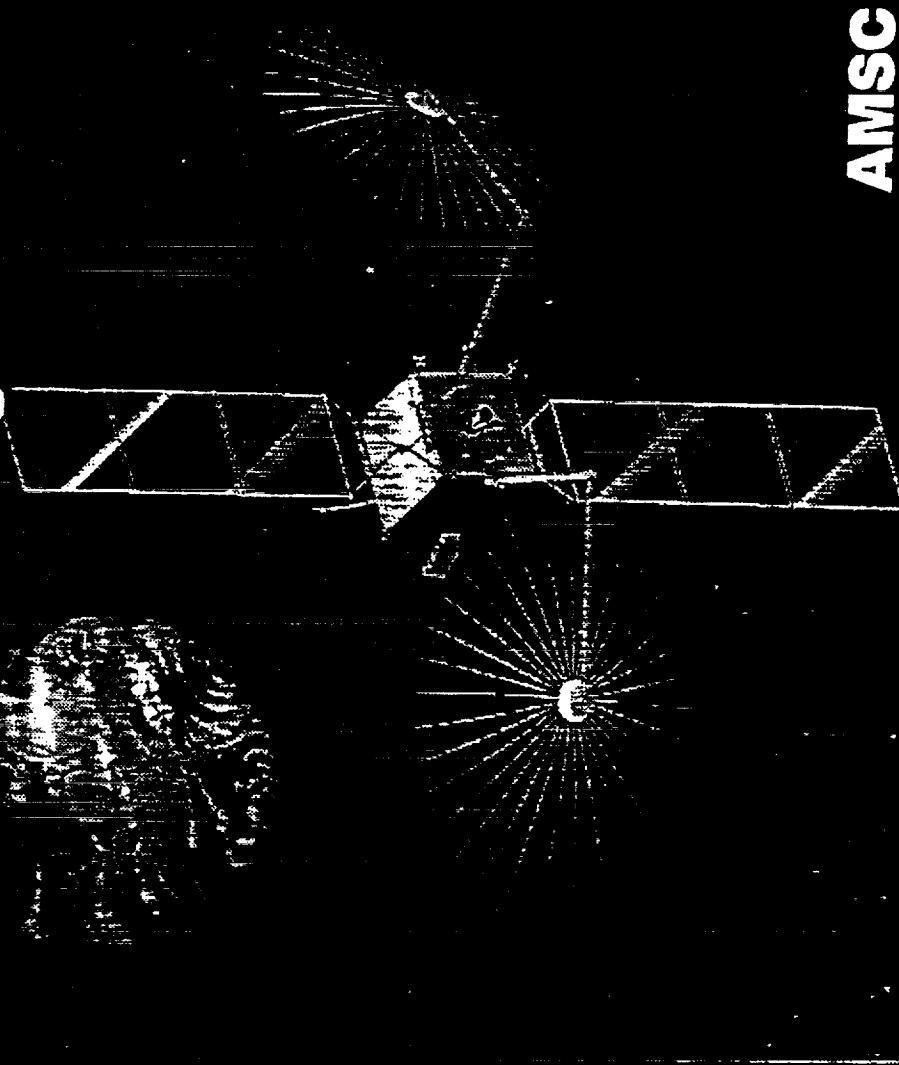
MSS System Overview

Mobile Terminals

L-Band

Ku-Band

Gateway

PSTN

Feeder-Link
Earth Stations

Private User Group

Base Station

Feeder-Link
Earth Stations

Network Control Center

Group Controller
- Group Management
- DAMA Control

Network
Operations
Center

AMSC

FIGURE 1

Satellite Configuration

AMSC

FIGURE 2

PRIME SITE

DIVERSITY SITE
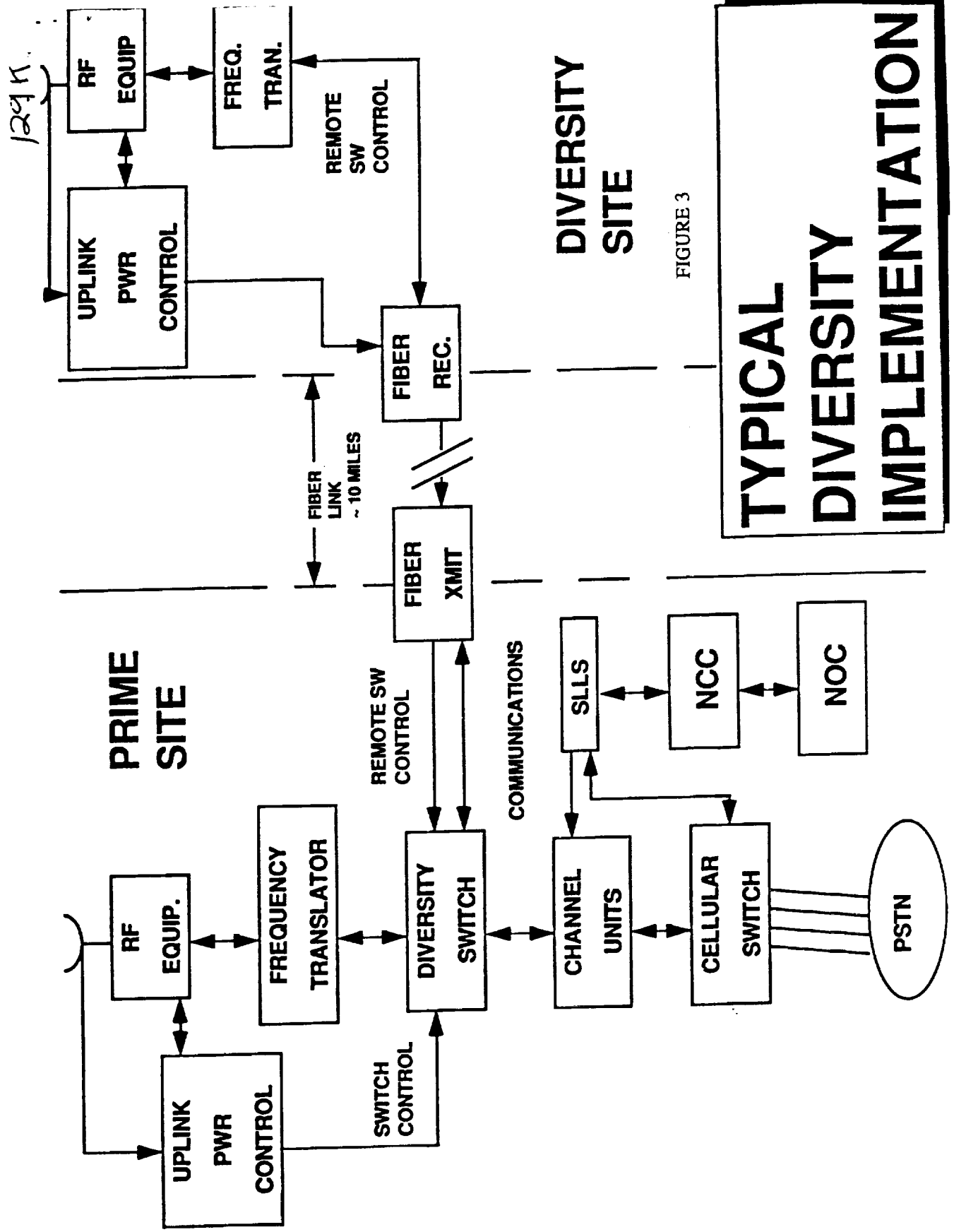
TYPICAL DIVERSITY IMPLEMENTATION

FIGURE 3

129 K.

RF EQUIP

FREQ. TRAN.

UPLINK PWR CONTROL

REMOTE SW CONTROL

FIBER REC.

FIBER XMIT

FIBER LINK ~10 MILES

REMOTE SW CONTROL

RF EQUIP.

FREQUENCY TRANSLATOR

DIVERSITY SWITCH

CHANNEL UNITS

CELLULAR SWITCH

PSTN

UPLINK PWR CONTROL

SWITCH CONTROL

COMMUNICATIONS

SLLS

NCC

NOC