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USAT MOD-2 SATELLITE COMMUNICATIONS SYSTEM PROJECT

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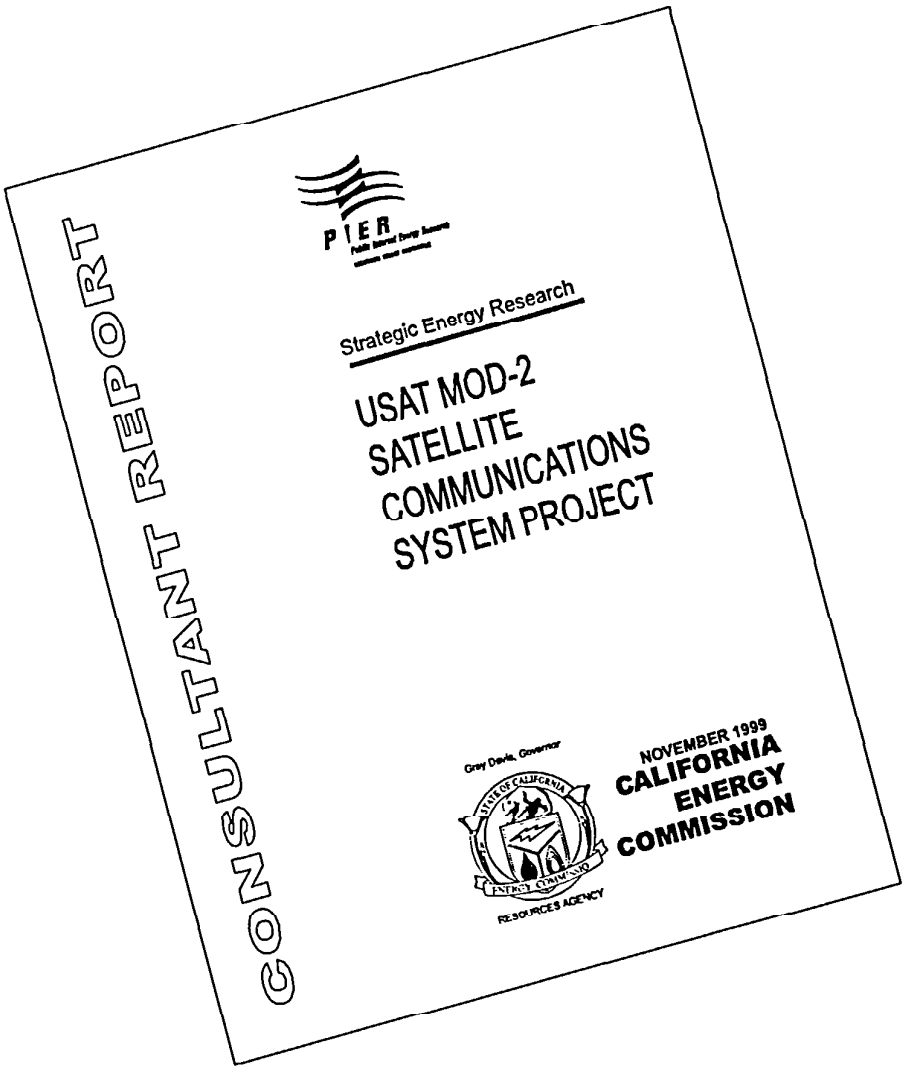

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Table of Contents

Section **Page**

PREFACE ..... **VIII**

EXECUTIVE SUMMARY **1**

ABSTRACT **6**

1.0 INTRODUCTION **8**

1.1 Background 9
1.1.1 Technology Concept 9
1.1.2 Project Approach 12
1.2 Project Objectives 12
1.2.1 Technical Objectives 12
1.1.2 Project Economic Objective 13
1.1.3 Commercialization Potential 13
1.1.4 Benefits to California 14

2.0 TECHNICAL DISCUSSION **16**

2.1 Concept Development and System Design 16
2.1.1 Hub System Conceptual Design 16
2.1.1 Network Management 18
2.1.2 DNP 3.0 Protocol 18
2.1.3 Micro-RTU Conceptual Design 19
2.1.4 Circuit Design, Fabrication, and Testing Process 19
2.2 System Testing Procedures 20
2.2.1 Laboratory Testing 20
2.2.2 Field Testing at Southern California Edison 20

3.0 CONCLUSIONS AND RECOMMENDATIONS **22**

3.1 Conclusions 22
3.2 Recommendations 23
3.3 Benefits to California 24

Appendices

Appendix I Operational Theory for the ULTRA-NET™ Satellite System

Appendix II Mod-2 USAT Test Report

Appendix III New Transmitter-Receiver Card Test Report

Appendix IV Network Monitoring System with TCP/IP Protocol Test Report

List of Figures

Figure **Page**

Figure 1. TDMA vs. CDMA 10
Figure 2. ULTRA-NET™ System Components 11
Figure 3. Hub Equipment 16
Figure 4. Transmit/Receive Board Block Diagram 17
Figure 5. Demodulator Board Block Diagram 18

Preface

The Public Interest Energy Research (PIER) Program supports public interest energy research and development that will help improve the quality of life in California by bringing environmentally safe, affordable, and reliability energy services and products to the marketplace.

The PIER Program, managed by the California Energy Commission (the Commission, Energy Commission), annually awards up to $62 million through the Year 2001 to conduct the most promising public interest energy research by partnering with Research, Development, and Demonstration (RD&D) organizations, including individuals, businesses, utilities, and public or private research institutions.

PIER funding efforts are focused on the following six RD&D program areas:

- Buildings End-Use Energy Efficiency
- Industrial/Agricultural/Water End-Use Energy Efficiency
- Renewable Energy
- Environmentally-Preferred Advanced Generation
- Energy-Related Environmental Research
- Strategic Energy Research.

In 1998, the Commission awarded approximately $17 million to 39 separate transition RD&D projects covering the five PIER subject areas. These projects were selected to preserve the benefits of the most promising ongoing public interest RD&D efforts conducted by investor-owned utilities prior to the onset of electricity restructuring.

Edison Technology Solutions (ETS) is an unregulated subsidiary of Edison International and an affiliate of Southern California Edison Company (SCE). As a result of a corporate restructuring, ETS ceased active operations on September 30, 1999. ETS' remaining rights and obligations were subsequently transferred to SCE.

What follows is the final report for the USAT Mod-2 Satellite Communications System project, 1 of 10 projects conducted by ETS. This project contributes to the Strategic Energy Research programs.

For more information on the PIER Program, please visit the Commission's Web site at: http://www.energy.ca.gov/research/index.html or contact the Commission's Publications Unit at 916-654-5200.

Executive Summary

Supervisory control and data acquisition (SCADA) systems have been used by utilities for many years to monitor and control transmission and distribution systems. The information collected at the substations includes analog readings (such as voltage, current, watts, and Volt-Amperes Reactive (VARs)) and digital readings (such as breaker position and security alarms). In addition, the central control center is also able to exercise control through commands (such as open breaker, close breaker, or disable automatic reclose). These systems furnish this information every few seconds to a SCADA master for display of the data and remote control operations. Satellite communication systems are increasingly being considered for SCADA communications because of their ability to cover large areas with high reliability.

The intent of this project was to continue the development of a high-data-rate satellite communications system to be used for SCADA and emergency event-driven applications. The goal was to develop an improved satellite hub terminal and other system improvements for the satellite communications system. The satellite system, the ULTRA-NET™ Mod-2 network, has a central hub and highly compact satellite earth stations called ultra-small aperture terminals (USATs). These USATs are rapidly installable (less than 15 minutes). This system is designed to operate with high reliability in a utility environment. The hub will demonstrate fiber-optic level communication performance (error rate of 10^{-7}), even in heavy rain conditions. The system operates at data rates up to 9.6 kilobits per second (kbps) two-way.

The ULTRA-NET™ satellite system uses code division multiple access (CDMA) spread spectrum communications to help maintain high reliability. There are several methods of communicating data using geostationary satellites. The two most popular technologies are time division multiple access (TDMA) and CDMA, or spread spectrum. While a CDMA system uses more satellite bandwidth and is more complex than a TDMA system, it supplies many benefits for SCADA applications. Because of the way the transmitted power is spread over more bandwidth, more power is available to transmit each bit of data. This translates into higher immunity to RF noise and interference, since the system operates at higher margins of up to 16 decibels. Another issue that applies to the design of satellite systems used for SCADA is determinism. A system designed for SCADA will always be able to poll the required number of remote stations in a known amount of time. The best system for the needs of SCADA communications appears to be a system such as ULTRA-NET™, which was developed further under this contract. Details of the system theory of operation are described in Appendix I.

This project took the existing Mod-1 ULTRA-NET™ hub concept and redesigned it to be more versatile and reliable. In the previous year, the USAT was upgraded to the Mod-2 level.

Due to hardware and software developmental problems that slowed the pace of work progress, some of the objectives of this project were not completely achieved by the end of the contract term. Southern California Edison (SCE) has agreed to complete any unfinished objectives of the project and file an addendum report with the California Energy Commission upon completion.

- This project had three primary tasks, each of which had its own objectives:

Task 1. Design, Install, and Test Mod-2 USATs and Micro-Remote Terminal Unit (RTU) (Section 2.1.4 and Appendix II)

Objectives:

- Install and test 50 Mod-2 USATs in substations.
- Test the Mod-2 USATs.
- Design, install, and test a micro-RTU board installed in the USAT.

Outcomes:

- Fifty Mod-2 USATs, capable of 9.6 kbps data transfer, were installed at SCE substations to replace the older Mod-1 USAT units.
- The USATs were connected to existing SCADA RTUs.
- Testing was performed to characterize the network at data rates from 0.6 kbps up to 1.2 kbps with the existing Mod-1 hub hardware (Appendix II).
- Tests showed that the new Mod-2 USATs performed as expected and were able to communicate with low bit error rates at speeds up to 9.6 kbps (5% of USATs out of specification at Bit Error Rate of 1×10^{-7}).
- Micro-RTU hardware was designed, built, and installed inside the case of a Mod-2 USAT.
- The installation of five micro-RTUs in the field and testing for proper operation was not completed under this contract. An addendum to this report will be filed with these test results.
- RTU tests to show that control relays could be operated under control of the satellite hub were not completed under this contract. These test results will be included in a report addendum.

Recommendations:

- Perform testing to determine what can be done to reduce the number of units that do not meet the target BER.
- Continue testing the USATs to obtain long-term reliability information.
- Complete installation and testing of five micro-RTUs.
- Perform RTU tests to show that control relays could be operated under control of the satellite hub.

Task 2. High-Speed Hub Development (Section 2.1.1 and Appendix III)

Objectives:

- Design upgraded satellite hub equipment for 9.6 kbps transmission from the hub to the USAT.
- Design and test the satellite hub with two-way communications at 9.6 kbps.

Outcomes:

- Designed, built, and installed two versions of prototype transmitter-receiver hub hardware: one version for bench testing and a second version for the Mod-2 hub chassis.

- The new transmitter-receiver card was installed in the new Mod-2 hub and successfully transmitted outbound data to the USATs to test all analog circuits, digital logic, and computer interfaces. These tests were done at 0.6 kbps and 9.6 kbps data rates, and at two different chipping rates (different bandwidths).
- Designed and built a new demodulator circuit card to decode 9.6 kbps receiver data. It has 56 times the processing capability of the older demodulator board.
- Designed, built, and installed a new enclosure for the Mod-2 hub hardware.
- Because the demodulator software was not complete at the end of this project term, tests to receive data at the 9.6 kbps data rate could not be completed. These test results will be included in a report addendum.

Recommendations:

- Complete the demodulator board software to decode the received data at the hub and run tests to receive data at 9.6 kbps.
- Continue testing the complete hub to prove the reliability of the new hardware and software.
- Add features to the user interface to make the operator interface at the hub terminal more user-friendly.

Task 3. Satellite System Improvements (Section 2.1.2 and 2.1.3, and Appendix IV)

Objectives:

- Develop a network monitoring system communicating with Transmission Control Protocol / Internet Protocol (TCP / IP).
- Implement the Distributed Network Protocol (DNP).

Outcomes:

- Developed and successfully tested a Network Monitoring System to communicate satellite system status to a central network monitoring system.
- Developed and successfully tested the ability of the system to communicate network monitoring data over a TCP / IP network to a network monitoring computer.
- Implementation and testing of DNP 3.0 protocol between the USATs and the Mod-2 satellite hub was not completed by the end of the contract term. Test results will be included in a report addendum.

Recommendations:

- Complete software work in the hub and USATs to implement DNP protocol and test. These test results will be included in a report addendum.
- Complete further testing of the network monitoring system with the SCE central network monitoring system, so that this feature of the hub can be put in operation at SCE.

While no specific economic objectives were established in the project plan for this project, the implied objective was to build a satellite hub for lower cost relative to other competing satellite technologies. This goal should be achieved with equipment at production levels. In this type of satellite system, the costs are divided into several areas. There are costs associated with the hub,

the USATs, and satellite “air” time lease. In a large installation, the cost of the USATs dominates the project economics. In small installations, the costs of the hub and satellite air time are dominant.

Edison Technology Solutions (ETS) actively marketed the ULTRA-NET™ system during 1998 and the first part of 1999. In April 1999, ETS decided to discontinue its marketing efforts and return the technology license to SCE. Active marketing efforts showed that many U.S. utilities were interested in this technology. Most utilities had substations or other monitoring points without radio or telephone communications. On the down side, most of these companies only needed 5 to 20 USATs. Because of the cost of the hub and satellite time lease, the system was too expensive. An alternate business model that could meet utility needs at a lower cost would be a public hub service that could pool the needs of several transmission operating utilities through an independent system operator or other entity. There was substantial interest in this concept by utilities across the United States.

A possible path to commercialization of this technology would be to license it to a company or an agency, such as the California independent system operator. They would then charge a fee per USAT to operate the hub service. Such a widespread application of this technology would create a backup communications system for electric and other utility SCADA systems. This system would work to greatly improve power system reliability and reduce customer minutes of interruption during both normal operations and disasters, such as earthquakes or other major system disturbances.

The ULTRA-NET™ satellite communications system is capable of collecting high-speed SCADA data from any location in the United States, no matter how remote. This data would not be available using conventional communications technologies. The SCADA data is valuable in ensuring that the highest reliability is maintained for transmission and distribution systems by enabling real-time monitoring of system loading and quick execution of control commands. In addition, it would no longer be necessary for service vehicles to visit remote sites on a regular basis. Over the lifetime of the system, this would cause a reduction of over 3 million vehicle miles (250,000 to 500,000 miles per year) resulting in fuel conservation and a corresponding reduction in environmental pollution.

Another benefit is the use of the satellite communications system during emergency conditions. Because of its high reliability and “communications anywhere” capability, the system is invaluable during major fires, storms, and earthquake emergencies. Communication during these emergencies is vital to locating problems, assessing damage, and returning equipment to service quickly. The ULTRA-NET™ USATs are easily installed and can be in service within a few hours at new sites. Communications could be restored quickly when the infrastructure for other systems has been damaged or destroyed. Data from stream flows during flash flooding conditions or seismic monitoring stations could lead to significant public safety improvements.

The Mod-2 satellite system not only provides public safety benefits; it has pioneered highly compact, rapidly installable, satellite earth station communication links, particularly in remote rural areas at low cost. Deployment of this system also would result in high-technology jobs to benefit California’s economy. About 75 percent of the unique system is manufactured in California.

Abstract

This project improves emergency operations and reduces restoration times by producing an improved version of the Southern California Edison satellite communications system that can transmit and receive data at up to 9.6 kbps. This system is used for second-by-second utility system supervisory control and data acquisition (SCADA) to remotely operate transmission and distribution system equipment. The system is used in remote locations or other areas that are hard to reach by conventional communications technologies. The use of spread spectrum satellite technology makes the system reliable even during storms, earthquakes, and other natural disasters that may cause other land-based communications systems to fail. The satellite communications system hub was designed, developed, and tested with 50 ultra-small aperture terminals (USATs) installed as part of this project.

More field operation is required before it can be considered a commercial product. To increase the commercial potential of the system, work should be undertaken to reduce the cost of the USATs, since one hub communicates with many USATs in a complete system. In addition, operating manuals and processing software should be created to ease implementation and operation of the system. The bottom line is to improve power system reliability and reduce customer minutes of interruption during normal operations and during disasters such as earthquakes or other major system disturbances.

Key words: satellite communications, SCADA, disaster recovery, utilities

1.0 Introduction

Supervisory control and data acquisition (SCADA) systems have been used by utilities for many years to monitor and control transmission and distribution systems. The information collected at the substations includes analog readings (such as voltage, current, watts, and Volt-Amperes Reactive (VARs)) and digital readings (such as breaker position and security alarms). In addition, the central control center is able to exercise power system control through commands (such as open breaker, close breaker, or disable automatic reclose). These SCADA systems furnish information every few seconds to a SCADA master for display of the data and remote control operations at Energy Control Centers, where system operations monitor and control the transmission and distribution system.

In recent years there has been an increased push for more SCADA / automation due to deregulation and the need to reduce costs. Automation can reduce operating costs, improve system reliability, and increase utilization of transmission and distribution assets, all of which increase customer satisfaction. SCADA communication systems play an essential role in making these benefits a reality.

Near continuous communication is required to furnish SCADA information. This communication has traditionally been accomplished with telephone lines (owned either by the utility or by public telephone companies), multiple address radio systems (MAS), microwave links, or fiber optic cables. In addition to these traditional communications technologies, satellite communications is now being used in more locations.

Satellites are being considered because of their ability to cover large areas with high reliability. The costs of satellite links are not distance-sensitive, as are telephone or fiber optic cables. Satellite systems are capable of communicating across the country as easily as they can communicate across town. In addition, no ground isolation equipment is necessary, such as is required when copper wire telephone lines are routed into substations. Because only small ground stations are used, satellite systems are also unaffected by most weather conditions (ice, wind, or snow) or earthquakes that could cause damage to an earthbound infrastructure. This system can be used during normal as well as emergency conditions such as an earthquake that results in statewide blackouts. Since satellite systems are very different in design than other communications media, they are good candidates for backing up land-based systems.

The goal of this project was to continue the development of a high-data-rate satellite communications system to be used for SCADA and emergency event-driven applications. More specifically, the developed system will be a low-cost satellite communications system that operates with high reliability in a utility environment. This system operates at data rates up to 9.6 kilobits per second (kbps) two-way. This satellite system, the ULTRA-NET™ Mod-2 network, has a central hub and highly compact satellite earth stations called ultra-small aperture terminals (USATs). These USATs are rapidly installable (less than 15 minutes).

The goal was to demonstrate fiber-optic-level communication performance (error rate of 10^{-7}), even in heavy rain conditions, at one-tenth the cost of standard telephone or radio systems in remote areas. A low-cost hub was developed to handle frequent polled data from substations and allow fast control at remote locations. The system can also be used to retrieve environmental data from weather stations for multiple applications and seismic data for emergency preparedness. An efficient centralized network control system also was developed

to reduce installation, operations, and maintenance costs for the system. The bottom line is to improve power system reliability and reduce customer minutes of interruption during normal operations and during disasters such as earthquakes or other major system disturbances.

1.1 Background

1.1.1 Technology Concept

Satellite communications systems can be divided into two types: those utilizing satellites in geostationary Earth orbit (GEO), and those in low or medium Earth orbit (LEO / MEO).

GEO satellites are located in a special orbit at an altitude of 22,300 miles above the Earth's equator. At this altitude, the satellite orbit speed exactly matches the Earth's rotational speed. Because of this, the satellite remains over the same spot on the Earth's surface. This allows ground antennas to be fixed, meaning they do not need to track the satellite. In addition, at this altitude, a single satellite can cover approximately 35 percent of the Earth's surface at once. The disadvantages of these satellites are that they are large, in very high orbits, and require a lot of power to transmit and receive signals.

LEO and MEO satellites are located in a lower orbit, so they are always moving with respect to the Earth's surface. These satellites orbit at an altitude of 400 to 6,000 miles. At these lower altitudes, each satellite can only cover small portions of the Earth's surface. Because of the relative motion of these satellites with respect to the earth, antennas need to either track the satellite or use an omni-directional antenna. For a ground station to experience continuous conversation, the satellites need to hand off the conversation to a new satellite as it moves out of range. These satellites are relatively small and inexpensive compared to a GEO satellite. A large number of these satellites, however, are required for continuous coverage of any particular spot on Earth.

Most LEO and MEO satellite systems use store-and-forward techniques in their data operations. A message is sent from a remote station and stored on-board the satellite. When the satellite is within sight of a hub ground station, it transfers the message to the ground. The hub ground station stores the message and sends it to the proper location. Messages going to the remote station follow the reverse path. This entire operation may take from several seconds to several minutes to complete, depending on the satellite system design. There are also some LEO systems optimized for voice operation that could be used for SCADA data, but the cost is very high ($1.50 to $3 per minute).

GEO satellite systems are generally used for SCADA applications because continuous data transfer is required. LEO and MEO systems are designed for voice communications or where the delay caused by the store-and-forward method of operation is acceptable. Since SCADA communication requires second-by-second update, geostationary satellites are the only ones that can be used at this time.

Types of Geostationary Satellite Systems

There are several methods of communicating data using geostationary satellites. The two most popular technologies are time division multiple access (TDMA) and code division multiple access (CDMA), or spread spectrum (Figure 1).

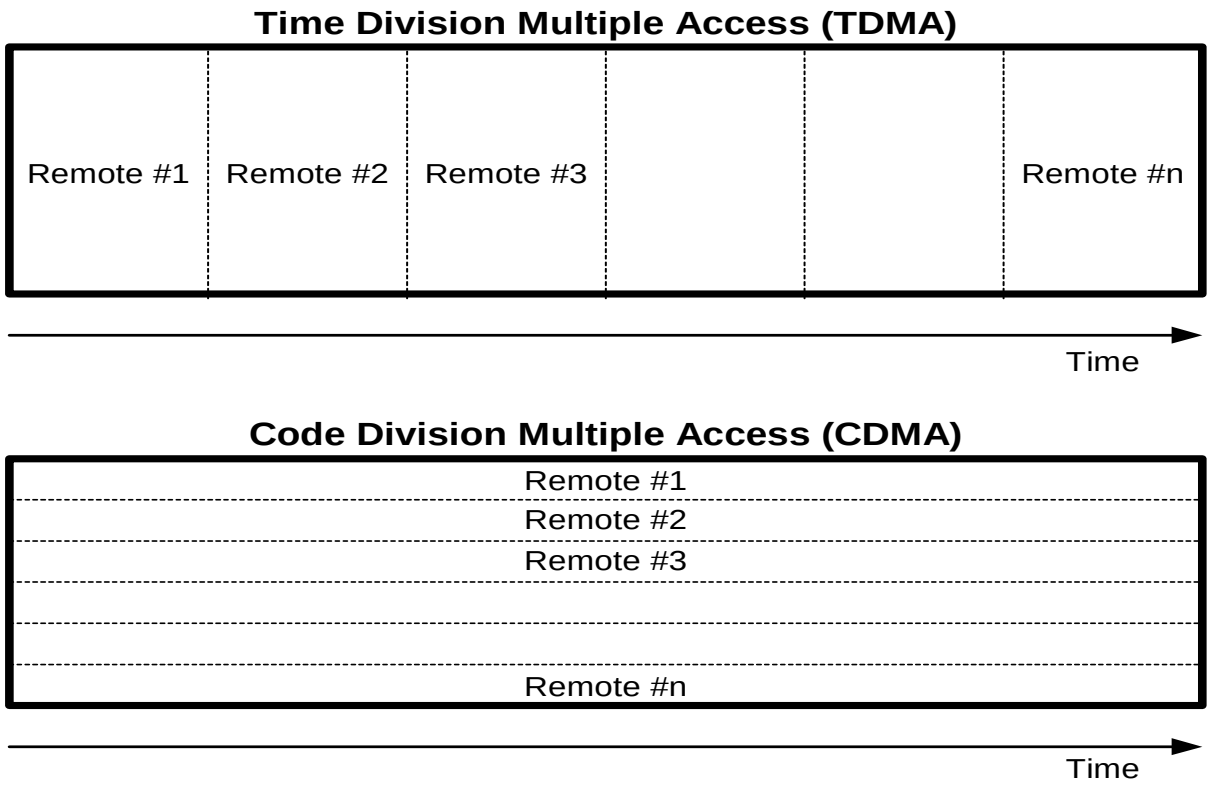

Figure 1. TDMA vs. CDMA

In a TDMA system, messages from many remote stations are interleaved on one radio channel. Each remote station sends or receives data, with each message taking its turn. To avoid interference, no two stations can transmit at the same time. The data rate that can be transmitted over this system is determined by the width of the satellite channel. The wider this satellite channel, the higher the data transmission rate can be.

CDMA, or spread spectrum systems, send coded messages from each USAT. This code, known as the spreading code, distributes the transmitted data over a wide section of the frequency band. Messages from many remote terminals can be transmitted at once, as long as each uses a different spreading code. At the hub ground station, the signal is received and decoded to distinguish each remote station's data.

While a CDMA system uses more satellite bandwidth and is more complex than a TDMA system, it supplies many benefits for SCADA applications. Because of the way the transmitted power is spread over more bandwidth, more power is available to transmit each bit of data. This translates into higher immunity to RF noise and interference, since the system operates at higher margins (16 decibels). A properly designed CDMA satellite system is highly resistant to sun-related outages (when the sun lines up directly with the satellite and terminal antenna) and rain fade (reduction of signal strength caused by absorption of the RF signal by water in the atmosphere). Availability of this greater margin also allows the use of a smaller antenna at the remote satellite terminals (at the central hub, a larger antenna is used to ensure error-free reception with all remote terminals connecting to the hub at the same time). Where a TDMA system might use a 6- to 8-foot antenna at the remote terminals, an equivalent CDMA system

might only need an 18- to 30-inch antenna. The spreading code applied to the data also makes the transmission highly secure. The transmission appears as background noise to anyone trying to eavesdrop.

Communications for SCADA vs. Other Applications

Another issue that applies to the design of satellite systems used for SCADA is determinism. A system designed for SCADA will always be able to poll the required number of remote stations in a known amount of time. The communications system will also be able to send out commands that will be executed in a known amount of time. Other satellite systems designed for credit card validation or other non-SCADA uses do not have deterministic operation. They are designed using a statistical process to determine the system loading. When these systems are lightly loaded, polling and commands are executed in a known time. When the system becomes highly loaded, polling and the execution of commands will be delayed.

The ULTRA-NET™ Satellite System

The ULTRA-NET™ system serves all the needs of SCADA communications. The ULTRA-NET™ system is composed of a central satellite transmit/receive station called the satellite hub, located at a regional control center, and a number of remote stations called USATs located at substations (Figure 2). The satellite hub is connected to the master SCADA system and controls the communications with the USATs. The USATs communicate with the substation's SCADA remote terminal unit (RTU) through an RS-232 connection.

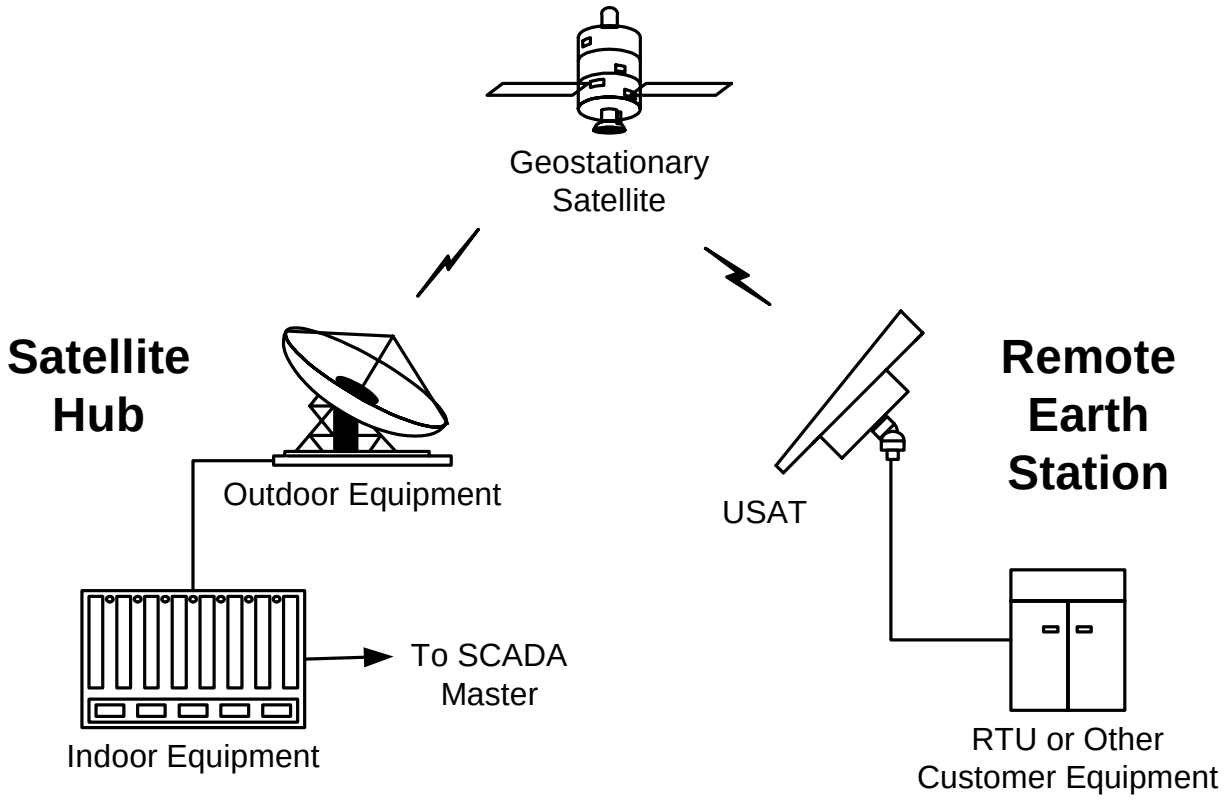

Figure 2. ULTRA-NET™ System Components

The satellite hub is composed of indoor and outdoor equipment. The outdoor equipment is standard, off-the-shelf Ku band components (Ku band is a widely used frequency band for satellite communications between 10.7 and 18 Gigahertz). The antenna is a 3.8-meter dish with a transmitter-receiver and up/down converter. The indoor equipment is a custom electronics rack with an embedded computer. The rack contains a transmit/receive card and demodulator cards. The demodulator cards are used to analyze the received signal and distinguish each USAT. The number of demodulator cards required depends on the number of USATs responding at the same time.

The USAT is a small, self-contained electronics unit with an integrated antenna. It is mounted on a pole, relay house, or switchgear enclosure. The only connections needed are power (12 volts) and RS-232 from the substation RTU. The antenna used is either an 18-inch flat or 30-inch reflector. This package is lightweight and easy to mount and align. Laptop software is available to ease the alignment and startup process. Further details of the system theory of operation are explained in Appendix I.

1.1.2 Project Approach

This project took the existing Mod-1 ULTRA-NET™ hub concept and redesigned it to be more versatile and reliable. In the previous year, the USATs had been upgraded to the Mod-2 level. This project's work included installing upgraded Mod-2 USATs at 50 sites in preparation for testing of the Mod-2 hub being developed. The project's major task was to design, construct, and test the new Mod-2 hub. This hub design was divided into two parts. The first part of the work, called Mod-2 Phase I, implemented a new circuit board with combined transmit and receive functions. A new embedded computer, running under Windows NT, was also implemented. The second phase of the hub redesign effort implemented new demodulator circuit cards and a new housing for all the new cards. This new hub also contains greatly improved network management capability. In addition, the project implemented new communication protocols and rudimentary data collection ability at the USATs.

1.2 Project Objectives

1.2.1 Technical Objectives

Task 1. Design, Install, and Test Mod-2 USATs and Micro-RTU

- Install and test 50 Mod-2 USATs in substations.
- Design and test a micro-RTU board installed in the USAT.

A detailed description of the Mod-2 USAT test results is provided in Appendix II, which contains the actual field-test summary report from Southern California Edison (SCE). Tests of the micro-RTU board were not completed during the term of this contract and will be included in a later addendum. Design details of the Mod-2 USAT micro-RTU board are included in Section 2.1.4 of this report.

Task 2. High Speed Hub Development

- Design the satellite hub equipment for 9.6 kbps transmission from the hub to the USAT.
- Design and test the satellite hub with two-way communications at 9.6 kbps.

Design and testing of the high-speed hub are discussed in Section 2.1.1 of this document. Details of actual 9.6 kbps transmission tests are provided in Appendix III. Testing of the data reception at 9.6 kbps was not completed during the term of this contract and will be included in a later addendum.

Task 3. Satellite System Improvements

- Develop a network monitoring system communicating with Transmission Control Protocol/ Internet Protocol (TCP/IP).
- Implement the Distributed Network Protocol (DNP).

These functions will enhance the operation of the complete network including the satellite hub and USATs.

A description of the network management system is provided in Section 2.1.2 of this document. A complete description of the testing of the network management system and the implementation of the TCP/IP protocol is provided in Appendix IV. DNP protocol work was not completed during the term of this contract and will be included in a later addendum.

1.1.2 Project Economic Objective

No specific economic objectives were established in the project plan for this project. The implied objective was to build a satellite hub for lower cost relative to other competing satellite technologies. In this type of satellite system, the costs are divided into several areas. There are costs associated with the satellite hub, the USATs, and satellite "air" time lease. In a large installation, the costs of the USATs dominate the project economics. In small installations, the cost of the hub and satellite airtime is dominant. The actual cost of this system compared to other systems must be evaluated on an application-by-application basis.

1.1.3 Commercialization Potential

General economic objectives of this project resulted in efforts to make a product at the lowest cost possible. From the marketing efforts of Edison Technology Solutions (ETS), it was determined that the USAT price, with installation, was very competitive with alternate technologies (telephone and radio) in non-urban areas. The sale price is estimated to be between $6,000 and $10,000, depending on the quantity produced. The cost of the hub (equipment, installation, and satellite airtime lease), however, was a problem for most customers unless they were going to install 50 to 100 USATs.

ETS actively marketed the ULTRA-NET™ system during 1998 and the first part of 1999. In April 1999, ETS decided to discontinue its marketing efforts and return the technology license to SCE. Active marketing efforts showed that many U.S. utilities were interested in this technology. Most utilities had substations or other monitoring points that were inaccessible by radio or telephone communications. On the down side, most of these companies only needed 5 to 20 USATs. Because of the cost of the hub and satellite time lease, the system proved to be too expensive. An alternate business model, that could meet needs and be cost-effective, would be a public hub service that could pool the needs of several transmission-operating utilities through an independent system operator or other entity. Substantial interest in this concept was expressed by many utilities across the United States.

A possible path to commercialization of this technology would be to license it to a company or an agency, such as a California independent system operator. The operator would charge a fee per USAT to operate the hub service. Such a widespread application of this technology would create a backup communications system for electric and other utility SCADA. This system would work to greatly improve power system reliability and reduce customer minutes of interruption during normal operations, as well as during disasters such as earthquakes or other major system disturbances.

1.1.4 Benefits to California

The ULTRA-NET™ satellite communications system is capable of collecting high-speed SCADA data from any location in the United States, no matter how remote. This data would not be available if conventional communications technologies were used. The SCADA data is valuable in ensuring that the highest reliability is maintained for transmission and distribution systems by enabling real-time monitoring of system loading and quick execution of control commands. In addition, it would no longer be necessary for service vehicles to visit remote sites on a regular basis. Over the lifetime of the system, this would cause a reduction of over 3 million vehicle miles (250,000 to 500,000 miles per year) resulting in fuel conservation and a corresponding reduction in environmental pollution.

Another benefit is the use of the satellite communications system during emergency conditions. Because of the system's high reliability and "communications anywhere" capability, it is invaluable during major fires, storms, and earthquake emergencies. Communication during these emergencies is vital to locating problems, assessing damage, and returning equipment to service quickly. The ULTRA-NET™ USATs are easily installed and can be in service within a few hours at new sites. This would allow communications to be restored quickly when the infrastructure for other systems has been damaged or destroyed. Data from stream flows during flash flooding conditions or seismic monitoring stations, could lead to significant public safety improvements.

The Mod-2 satellite system not only provides public safety benefits; it also has pioneered highly compact, rapidly installable, satellite-earth station communication links, particularly in remote rural areas at low cost. Deployment of this system also would results in high-technology jobs to benefit California's economy. About 75 percent of the unique system are manufactured in California.

2.0 Technical Discussion

2.1 Concept Development and System Design

2.1.1 Hub System Conceptual Design

The Mod-1 hub system was designed to operate at 0.6 and 1.2 kbps. It has been in reliable operation for several years. With the increasing need for more information to be transmitted to and from substations, it was decided that the system would be expanded to a higher data rate. In previous projects, the hardware for the satellite USATs was upgraded to be capable of processing the higher data rate. This project was designed to make the same hardware and software upgrades to increase hub capability to 9.6 kbps data transmission and reception.

The satellite hub consists of indoor and outdoor equipment. The existing outdoor equipment is already capable of the higher data rates, as it merely amplifies and frequency shifts the signal going to and from the hub indoor equipment. The work was confined to the hub indoor equipment and software changes in the USATs. Another feature of the redesign was to build the hardware so that most future changes would require only software modifications. The operating system in the satellite hub embedded computer was also changed to Windows NT, to be more compatible with new software and networking.

The satellite hub indoor equipment is composed of three major parts: the transmit/receive board, demodulator board(s), and the embedded computer (Figure 3). Signals flow to and from the outdoor equipment over coaxial cables at 70 megahertz (MHz). These signals are modulated and demodulated by the transmit/receive board. This board also contains the data interface with the embedded computer. The demodulator boards are used to decode the spread spectrum signal. The number of demodulator boards required is determined by the number of USATs transmitting at the same time, and by the data rate used. The embedded computer communicates with the transmit/receive board over a SCSI II interface. It also communicates with the SCADA system in whatever protocol is required.

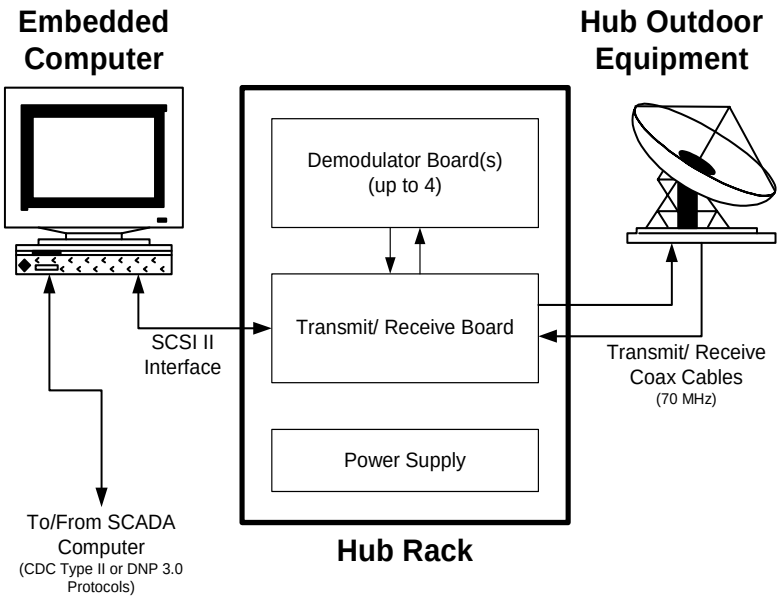

Figure 3. Hub Equipment

The transmit/receive board contains both digital and analog circuits (Figure 4). All real-time operations are contained on this board. First, SCADA system messages are received from the embedded computer. Error correction and spread spectrum codes are applied to the messages. Then the resulting digital signal is then sent to one of the modulator circuits and modulated at 70 MHz. This signal is sent over coaxial cable to the outdoor equipment to be frequency shifted up to Ku band, amplified, and transmitted to the satellite. The receive signal is captured by the outdoor equipment, where it is converted down to 70 MHz and amplified before it is sent to the transmit/receive card. Once on the card, it is demodulated, and routed to an analog-to-digital converter. This resulting digital data stream is routed to the demodulator cards to retrieve the actual data. Once the actual data is retrieved, it is error checked and sent to the embedded computer.

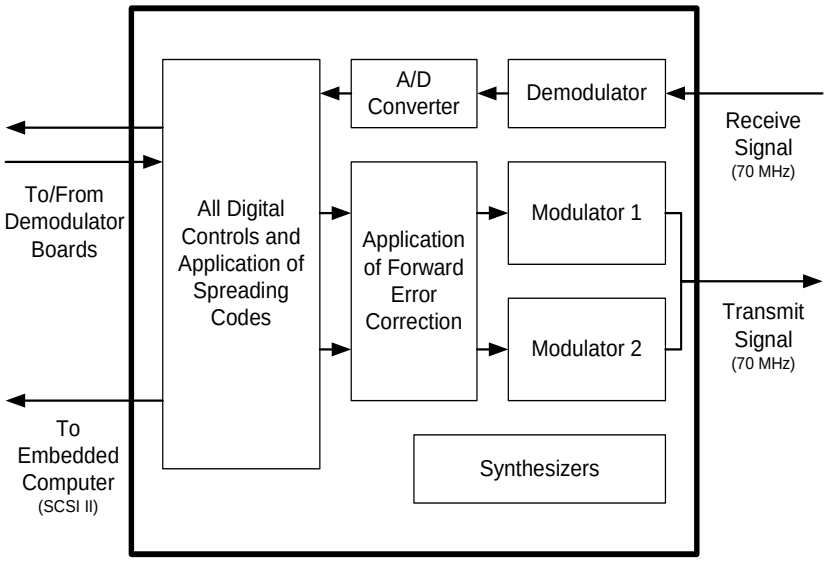

Figure 4. Transmit/Receive Board Block Diagram

The demodulator cards are used to decode the spread spectrum signal and fix errors (Figure 5). Each card has four computational units that take the digital data sample and attempt to correlate it to one of the spreading codes. Once this match is found, the actual data can be recovered. Forward error correction bits are used to repair any data problems detected. The recovered data is forwarded back to the transmit/receive card for distribution to the embedded computer.

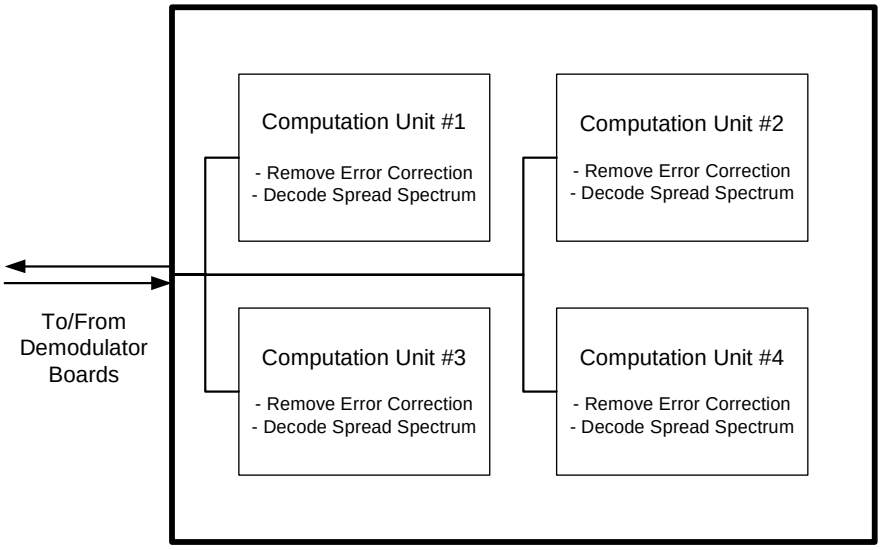

Figure 5. Demodulator Board Block Diagram

The embedded computer serves as the interface point between the satellite system and the transmission SCADA system or regional control center. It also is the display console for interaction with the internal operations of the satellite system. The embedded computer is responsible for the interface with the central network management system.

2.1.1 Network Management

The previous version of the hub required that the operator be at the satellite hub to look for system status. Problems with the satellite system were only detected when data was not received by the utility's transmission SCADA system. To eliminate this issue, a network management system was designed so that messages about satellite system problems could be communicated back to a central point. Since it is becoming increasingly common for utilities and other companies to operate a TCP/IP network to connect their vital communication nodes, this was the communication method selected for the network management system. These messages about satellite system problems can be received by a central network management system or any other computer on the network. The messages are constructed using simple American Standard Code for Information Interchange (ASCII) strings to make decoding easy. There are three levels of warnings, indicating a failure, need for maintenance, or component degradation in the satellite communication system. This determination is made by the hub software using status information received from each USAT as part of the normal polling process. Hub status information is also used to diagnose problems internal to the hub itself.

2.1.2 DNP 3.0 Protocol

To make the implementation of DNP protocol completely transparent to the user, the message received by the satellite hub is encapsulated in the satellite's transmission protocol and sent to the USAT. At the USAT, the satellite protocol is removed and the DNP message sent to the device connected to the USAT. Because of the satellite protocol structure, the outgoing message packet from the hub is limited to 160 bytes and the return message packet is limited to 700

bytes. These packet lengths are expected to be sufficient for all but the most specialized applications.

2.1.3 Micro-RTU Conceptual Design

The micro-RTU board was intended to be applied at locations requiring few monitoring or control points. There were not enough points, however, to justify the cost of installing a full RTU. From conversations with potential users of the micro-RTU board, it was decided that the micro-RTU would contain eight analog inputs, eight digital (status) inputs, and four control relay pairs. The analog input signals were to come from standard instrument transducers that had an output of 0 to 1 milliamperes. These transducers are capable of driving a load of up to 10k ohms, which equates to a 0- to 10-volt output to the micro-RTU. The use of transducers eliminates the need to have unconditioned signals from current transformers (CT) and potential transformers (PT) present inside of the USAT. It also eliminates the potential problem of breaking the CT current loop during operations and maintenance, and the damage it would cause to the CT. The digital inputs would detect the presence or absence of a voltage signal. The output relays were designed to drive the coil of a secondary relay that is located outside of the USAT. Because of this, the internal relays are capable of switching 2 amps at 120 volts. Relay pairs were used for each control point, so one relay would close the breaker and the other relay would open the breaker.

The micro-RTU board is designed to sit on top of the baseband board inside the USAT. This space was opened up when the baseband electronics was reduced from two boards to one in a previous project. The interface between the boards is through a connector built into the baseband board. The processing and interface capability is provided through excess capacity in the digital signal processor (DSP) and field programmable gate array (FPGA). The software in the USAT is modified to poll the inputs and control the outputs. Data are collected from the micro-RTU board and stored until polled by the satellite hub for delivery to the SCADA system.

2.1.4 Circuit Design, Fabrication, and Testing Process

System design began with the construction of a basic block diagram, which documented all the major components. For the hub design, additional block diagrams were constructed to show how the major functions were to be implemented. From these block diagrams, the circuit design process began. Analog section designs were implemented with traditional design tools and documented as schematic diagrams. Most of the digital portion of the design was implemented with DSP chips and FPGAs. This implementation was also done using schematic diagrams. The DSP chips were programmed in C and the FPGA was programmed in very high-speed integrated circuit hardware description language (VHDL).

Once the schematic diagrams were produced and checked, the layout portion of the process began. The board layouts were done with the High Wire software package. This package produced the files necessary for board etching, drilling, and labeling. These files were sent to a board fabricator who produced the required boards and then tested them for flaws. Once the boards were complete, they were sent out to mount critical chips. The FPGA and DSP chips were ball-grid type chips. These chips were mounted and soldered using a controlled-temperature profile oven. Once the critical chips were mounted, additional components were

then added in stages. This method of installation in stages allowed troubleshooting of each section of the board separately. It also allowed problems to be isolated early in the testing stage. Once all components were on the board and all portions were working properly, testing moved to the system testing level.

While these steps were underway, software to be run on the embedded computer under the NT operating system was written in C++ and tested. Communications between the transmit/receive board and the embedded computer was through a SCSI II differential bus. This bus allows high-speed data transfer and good immunity to interference.

2.2 System Testing Procedures

2.2.1 Laboratory Testing

Once the circuit boards completed initial testing, the system was assembled and tested as a whole in the laboratory. This test, called "low fly," was accomplished by directly connecting the hub to a USAT through coaxial cable. This was done at the 70 MHz intermediate frequency (IF) level without translating the signals to Ku band. In this test, all functions of the system can be tested in one room under controlled conditions. This type of testing also makes it easier to troubleshoot system problems and make fixes. Test limitations are that only one USAT can be communicated with at one time, and the time delay due to the satellite is not simulated. The solution to completely exercise the demodulators was to have them take the data from the one test terminal and duplicate it to simulate operations with 50 USATs. Once the system was working correctly with the low fly testing, it was ready to be shipped to SCE for actual on-the-air testing with the use of SCE's satellite.

2.2.2 Field Testing at Southern California Edison

In this project, the actual testing with a satellite was conducted at Mira Loma substation. This location is presently one of the operating Mod-1 hub sites. For Phase I testing (9.6 kbps transmit from the hub), the new transmit/receive card was inserted in the new Mod-2 hub. In addition, the new embedded computer was installed at the hub. A USAT was set up with a laptop computer on its monitor port to see if the massage was properly received. Since the satellite hub was not able to receive at 9.6 kbps yet, no return message was received by the hub.

Phase II testing (9.6 kbps two-way) was not completed during the term of this contract. When it is completed by SCE, it will use the new hub chassis with the new transmit/receive card and demodulator cards installed at Mira Loma substation. The embedded computer will be connected to software that simulates the operations of a SCADA master. Messages will be sent from the SCADA master software through the satellite system and received by USATs. The responses from the USATs will then be decoded and the return message sent back to the SCADA software. Error statistics will be recorded by the hub and compared with expectations. Another test will be to intentionally cause a USAT not to respond to a hub data request to see if the network management system will be able to issue the proper error message over the TCP/IP port. This message will be recorded by another computer hooked to the SCE network.

3.0 Conclusions and Recommendations

3.1 Conclusions

- Due to hardware and software developmental problems that slowed the pace of work progress, some of the objectives of this project were not completely achieved by the end of the contract term. SCE has agreed to complete any unfinished objectives of the project and file an addendum report with the California Energy Commission upon completion.

Task 1. Design, Install and Test Mod-2 USATs and Micro-RTU

Objectives:

- Install and test 50 Mod-2 USATs in substations.
- Design, install, and test a micro-RTU board installed in the USAT.

Outcomes:

- 50 Mod-2 USATs, capable of 9.6 kbps data transfer, were installed at SCE substations to replace the older Mod-1 USAT units.
- The USATs were connected to existing SCADA RTUs.
- Testing was performed to characterize the network at data rates from 0.6 kbps up to 1.2 kbps with the existing Mod-1 hub hardware (Appendix II).
- Tests showed that the new Mod-2 USATs performed as expected and were able to communicate with low bit error rates (5% of USATs out of specification at Bit Error Rate of 1×10^{-7}).
- Micro-RTU hardware was designed, built, and installed inside the case of a Mod-2 USAT.
- The installation of five micro-RTUs in the field and testing for proper operation was not completed under this contract. An addendum to this report will be filed with these test results.
- RTU tests to show that control relays could be operated under control of the satellite hub were not completed under this contract. These test results will be included in a report addendum.

Task 2. High-Speed Hub Development

Objectives:

- Design upgraded satellite hub equipment for 9.6 kbps transmission from the hub to the USAT.
- Design and test the satellite hub with two-way communications at 9.6 kbps.

Outcomes:

- Designed, built, and installed two versions of prototype transmitter-receiver hub hardware: one version for bench testing and a second version for the Mod-2 hub chassis.
- The new transmitter-receiver card was installed in the new Mod-2 hub and successfully transmitted outbound data to the USATs to test all analog circuits, digital logic, and computer interfaces. These tests were done at 0.6 kbps and 9.6 kbps data rates and at two different chipping rates (different bandwidths).

- Designed and built a new demodulator circuit card to decode 9.6 kbps receiver data. It has 56 times the processing capability of the older demodulator board.
- Designed, built, and installed a new enclosure for the Mod-2 hub hardware.
- Because the demodulator software was not complete at the end of this project term, tests to receive data at the 9.6 kbps data rate could not be completed. These test results will be included in a report addendum.

Task 3. Satellite System Improvements

Objectives:

- Develop a network monitoring system communicating with TCP/IP.
- Implement the DNP.

Outcomes:

- Developed and successfully tested a Network Monitoring System to communicate satellite system status to a central network monitoring system.
- Developed and successfully tested the ability of the system to communicate network monitoring data over a TCP/IP network to a network monitoring computer.
- Implementation and testing of DNP 3.0 protocol between the USATs and the Mod-2 satellite hub was not completed by the end of the contract term. Test results will be included in a report addendum.

3.2 Recommendations

General

While most of the technical objectives were met for this project during the contract period, some objectives will be finished by SCE and test results will be included in a future addendum. Additional field testing is needed, however, before this product would be marketable. As part of this project, communication at 9.6 kbps has been demonstrated. Additional testing is required to be sure there are no remaining bugs in the computer code or hardware. In addition, operation and maintenance documentation as well as training manuals for installation are required.

Commercialization Potential

General economic objectives set out as part of this project resulted in efforts to make a product at the least cost possible. From the marketing efforts of ETS, it was determined that the USAT price, with installation, was very competitive with other alternate technologies (telephone and radio) in non-urban areas. This sale price is estimated to be between $6,000 and $10,000, depending on the quantity produced. The cost of the hub (equipment, installation, and satellite airtime lease), however, was a problem for most customers unless they were going to install 50 to 100 USATs.

ETS actively marketed the ULTRA-NET™ system during 1998 and the first part of 1999. In April 1999, ETS decided to discontinue its marketing efforts and return the technology license to SCE. Active marketing efforts showed substantial interest in the technology by utilities across the United States. Most utilities had substations or other monitoring points without radio or telephone communications. On the down side, most of these companies only needed 5 to 20

USATs. Because of the cost of the hub and satellite time lease, the system was too expensive. An alternate business model, which could meet their needs at a lower cost, would be a public hub service that could pool the needs of several transmission operating utilities through an independent system operator or other entity.

A possible path to commercialization of this technology would be to license it to a company or an agency, such as the California independent system operator. They would then charge a fee per USAT to operate the hub service. Such a widespread application of this technology would create a backup communications system for electric and other utility SCADA. This system would work to greatly improve power system reliability and reduce customer minutes of interruption during normal operations and disasters such as earthquakes or other major system disturbances.

3.3 Benefits to California

The ULTRA-NET™ satellite communications system is capable of collecting high-speed SCADA data from any location in the United States, no matter how remote. This data would not be available using conventional communications technologies. The SCADA data is valuable in ensuring that the highest reliability is maintained for transmission and distribution systems by enabling real-time monitoring of system loading and quick execution of control commands. In addition, it would no longer be necessary for service vehicles to visit remote sites on a regular basis. Over the lifetime of the system, this would cause a reduction of over 3 million vehicle miles (250,000 to 500,000 miles per year) resulting in fuel conservation and a corresponding reduction in environmental pollution.

Another benefit is the use of the satellite communications system during emergency conditions. Because of its high reliability and “communications anywhere” capability, the system is invaluable during major fires, storms, and earthquake emergencies. Communication during these emergencies is vital to locating problems, assessing damage, and returning equipment to service quickly. The ULTRA-NET™ USATs are easily installed and can be in service within a few hours at new sites. This would allow communications to be restored quickly when the infrastructure for other systems has been damaged or destroyed. Data from stream flows during flash flooding conditions or seismic monitoring stations could lead to significant public safety improvements.

Widespread application of the technology in California would result in production of about 200 additional units. Use of this technology in California would result in significant reduction in restoration time and help avoid millions of dollars in associated insurance costs due to prolonged power outages. In addition, widespread United States adaptation of the technology could result in additional local economic benefits to California for manufacture of system elements.

The Mod-2 satellite system not only provides public safety benefits; it has pioneered highly compact, rapidly installable, satellite earth station communication links, particularly in remote rural areas at low cost. Deployment of this system also would result in high-technology jobs to benefit California’s economy. About 75 percent of the unique system is manufactured in California.

Appendix I
Operational Theory for the ULTRA-NET™ Satellite System

Purpose

This document provides a functional description of the ULTRA-NET™ satellite communications system, focusing primarily on the system interfaces and system data flows. This document represents the present implementation of the system.

System Interfaces

Three separate data interfaces exist, one for supervisory control and data acquisition (SCADA) data operations, one for network management, and one for administrative functions.

The SCADA data is communicated to and from the SCADA master computer through an RS-232 interface. The interface card used at this time contains eight RS-232 connectors per card. The data stream going to and from the SCADA master computer is Control Data Corporation (CDC) Type II or DNP 3.0 protocol. This message structure is well defined in the protocol documents for each protocol. Multiple RS-232 connections are used to simulate more than one remote terminal unit (RTU) connected to the SCADA master. This is necessary because many of the older protocols will only allow a small number of points to be retrieved from any one RTU.

The network management interface is through an Ethernet twisted pair interface (10BaseT). Information is communicated over this interface using TCP/IP protocol encapsulating ASCII messages. These messages contain:

- Message sequence number
- Problem device identification number
- Urgency type code
- Type of failure message
- Satellite hub identification number
- Satellite hub site name
- Ultra small aperture satellite (USAT) site name

The message is received by the central network management system and parsed, and the proper person is notified of the problem.

A number of administrative functions are available at the console of the hub embedded computer. These functions are carried on simultaneously with SCADA functions, with SCADA function having priority. Typical administrative functions are:

- Download software to a USAT
- Download configuration to a USAT
- Edit configuration databases for the satellite hub
- Monitor satellite hub and USAT performance statistics
- Control RF power level for the satellite hub and USATs
- Set frequencies for the satellite hub and USATs
- Configure newly installed USAT in the satellite hub database
- Read and write USAT memory for software diagnostic purposes

Signal Descriptions

Both the outbound signal (satellite hub to the USAT) and the inbound signal (USAT to the satellite hub) are direct sequence spread spectrum with Binary Phase Shift Keying (BPSK) modulation. Forward Error Correction (FEC) at a rate of 1 bit per two bits in the original message is employed in both directions. Spread spectrum on the outbound channel provides high rain fade margins with a small receiving antenna at the USATs. The outbound channel consists of a single signal. The purpose of spread spectrum on the inbound channel is to reduce interference imposed on adjacent satellites when using a small antenna, provide high rain fade margins, and allow transmission by 50 USATs simultaneously.

Data Channel Overview

All operations on the system are done in one-second frames. Each outbound frame is divided into four packets. These packets can be either SCADA or network commands/data. The network commands/data are used for remote software downloads or modifying the configuration of the USATs. The satellite hub is capable of transmitting and receiving simultaneously (full duplex). The USATs are only capable of half-duplex operations. The satellite hub keeps track of the state of each USAT and only sends messages when the USAT is listening. The inbound message is made of the requested data plus some diagnostic information. Twenty-four words of diagnostic information are collected, with two words collected in each return frame.

Autonomous Polling Operation

The satellite system uses autonomous polling to collect data from the RTUs. In this method of operation, the USAT sends polling commands to its associated RTU. The response data is then placed in the memory of the USAT. The satellite hub polls the USAT and retrieves the RTU status stored there. The satellite hub stores this data in an internal database to be used to answer a poll request from the SCADA master. At SCE, the satellite hub polling rate is set so that no data in the satellite hub's database is any older than four seconds. If more than one packet is needed to retrieve data, several packets can be chained together to send the complete message.

To avoid delays in the execution of commands, any command received by the satellite hub is passed directly to the USAT on the next available frame. Special spread-spectrum codes are reserved to allow a quick confirmation of the command's execution at the USAT. Commands are executed in two to three seconds after receipt by the hub. With the present system design, up to seven commands can be issued from the satellite hub every second.

Additional Features

The present ULTRA-NET™ system has several additional features. A notebook computer can be attached to any USAT without interruption of the SCADA operations. This computer can be used for performance monitoring, installation aid, antenna alignment, and software download. A messaging mode is also available to allow "mail" to be sent back and forth between the USAT and the satellite hub. The status of any satellite hub may also be monitored remotely by connection of a computer to a dedicated USAT. All remotely accessible satellite hub functions are password protected to avoid unauthorized access. An additional feature that is a by-product of the spread spectrum system allows all USATs to be time synchronized to one another with a time tolerance of 0.2 misro-seconds.

Appendix II
Mod-2 USAT Test Report

Executive Summary

The ULTRA-NET™ system is a supervisory control and data acquisition (SCADA) system that monitors voltages, thermal limits, and tests for instabilities. The system is composed of remote terminal units (RTUs), ultra small antenna terminals (USATS), a satellite, regional hubs, and a SCADA Master. This system allows Southern California Edison (SCE) engineers to monitor remote substations quickly and cost effectively. It operates with a bit error rate (BER) of less than one error in 10-million bits (e.g. $1x10^{-7}$).

The BERs for the USAT Mod-2 data entries can conveniently be grouped into eight categories: zero errors, 1×10^{-10}, 1×10^{-9}, 1×10^{-8}, 1×10^{-7}, 1×10^{-6}, 1×10^{-5}, and 1×10^{-4}.

The proportion of in-specification vs. out-of-specification readings for the given sites was also analyzed. Out of a total of 7,999 entries, using the conservative BER specification (1×10^{-7}), 4,441 entries (56%) showed no errors, 2,267 entries (28%) showed errors that were within specification, and 1,291 entries (16%) showed errors that were out of specification. In summary, out of 7,999 data entries, 6,708 of the readings or 84% were within specification, while 1,291 or 16% were out of specification.

When the data are compared against the required SCE BER specification (1×10^{-6}), 4,441 entries (56%) showed no errors, 2,959 entries (37%) showed errors that were within specification, and 599 entries (7%) showed errors that were out of specification. In summary, out of 7,999 data entries, 7,400 or 93% of the data sets were within specification, while 599 or 7% of the data sets were out of specification.

For the 8/10/99 to 8/11/99 time period, using the conservative BER specification (1×10^{-7}), 10 out of a total of 207 units or 5% were determined to be out of specification. When the regular BER specification of 1×10^{-6} is used, this number drops to 3 or 1.5% of the units out of specification. Fifty percent of the units were tested at 0.6 kbps and fifty percent of the units were tested at 1.2 kbps.

This represents a dramatic improvement since the units' upgrade to the latest revision. Further improvements can be expected as more opertional time is accumulated. Improvements in production line testing and quality control have also contributed to the improved field performance.

Introduction

Because of the successful operation of this system, SCE is expanding the system and implementing improvements. One upgrade currently in progress phases out the Mod I USATs in favor of the more versatile Mod-2 version. The Mod-2 versions of the USATs have been installed at the Devers, Lugo, Mira Loma, Moorpark, and Rector sites. USAT performance data from these units was collected and the BERs from these data sheets were compared against the 1×10^{-7} BER specification for the October 1998 to July 1999 time period.

USAT Performance Data Sheet

The USAT performance data sheet provides such information as the hub terminal location, time/date of reading, USAT unit number, signal magnitude, signal to noise ratio, and the Receive and Round Trip BERs for the USAT communication link. The Round Trip BER reading includes both the Receive and Transmit BER, and will provide the data for this analysis.

It is important to note that the reported errors can sometimes be caused by a phenomenon other then a faulty unit. Errors can occur when a USAT is powered down without notifying the engineers recording the BERs, which results in erroneous error readings. These errors can be distinguished by looking at the Actual Error, denoted as Error,Acc in the USAT data legend, Errors, denoted as Errors in the Hub data legend, and the signal magnitude, denoted as Signal[pwr] in the USAT data legend. When the USAT Actual error and/or the Hub Errors are quite large and the signal magnitude is 0.0, one can assume that the USAT in question has been powered down, and that any errors resulting from this are erroneous.

The erroneous error readings were identified by bold type in the Excel spreadsheet entries, but were not included in the spreadsheet graphs. Furthermore, USAT unit numbers with entries containing missing data indicate that the particular unit was not installed yet. These incomplete entries were also removed from all plots and analysis.

Error Data

The Round Trip error data for Devers, Lugo, Mira Loma, Moorpark, and Rector were tabulated in Excel spreadsheets. Included in the spreadsheets were the USAT unit number, Receive BER, Round Trip BER, error specification (1 x 10^{-7}), unacceptable error indication, and the date and time the data were taken.
The USAT unit number is the SCE site number, Receive BER indicates the error at the USAT end from the RTU, the Round Trip error indicates the combined Receive and Transmit error from the Hub station, and the unacceptable error is a yes/no indication of whether the Receive error and/or the Round Trip error was greater than the error specification of 1 x 10^{-7}.

USAT Mod-2 Error Summary

From the recorded data, the number of out-of-specification USATs was determined. A unit was determined to be out of specification if its Round Trip error met or exceeded the error specification for 5% or more of the given time period. It should be noted that the 1 x 10^{-7} BER specification is a conservative error specification that the Technology Integration group of SCE uses for error analysis. The SCE BER specification that the ULTRA-NET™ system must meet is 1 x 10^{-6}, as set by SCE's Information Technology group. Both error specifications were used in this study.
For the 10/98 to 7/99 time period, using the conservative error specification (1 x 10^{-7}), 63 out of a total of 108 Mod-2 units were determined to be out of specification. When the official error specification of 1 x 10^{-6} is used, this number drops to 36. Moreover, the BERs for the USAT Mod-2 data entries can conveniently be grouped into 8 categories: zero errors, 1 x 10^{-10}, 1 x 10^{-9}, 1 x 10^{-8}, 1 x 10^{-7}, 1 x 10^{-6}, 1 x 10^{-5}, and 1 x 10^{-4}. Figure II-1 provides a bar graphs comparing Round Trip error magnitudes vs. frequency for the 10/98 to 7/99 period.

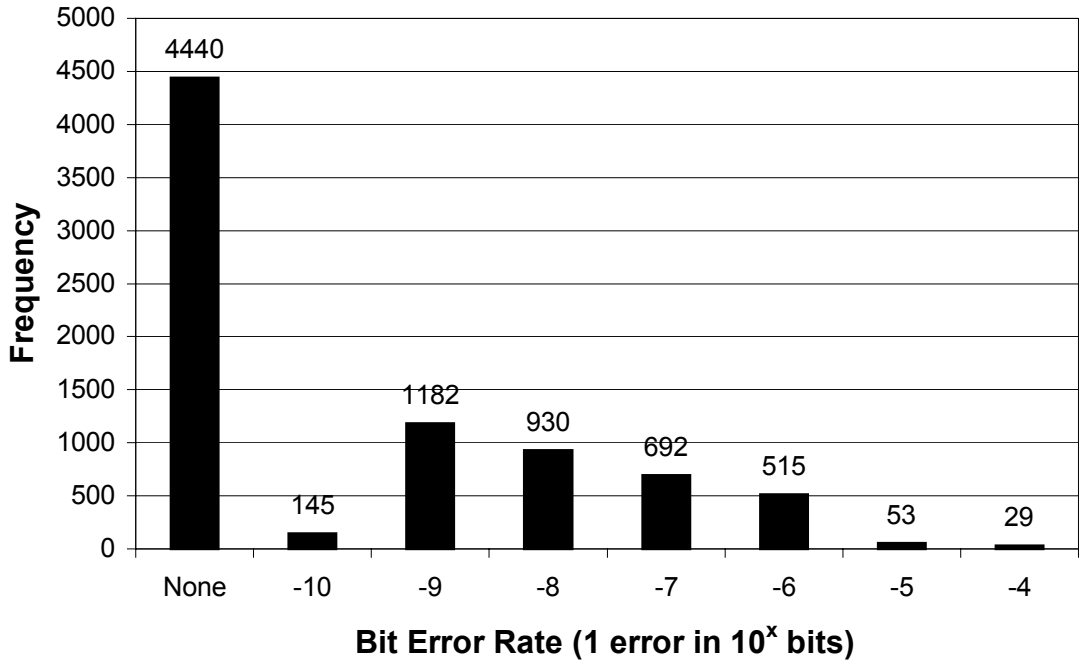

Figure II-1 - USAT Mod-2 Round Trip Bit Error Rate vs. Frequency for 10/98 to 7/99

The proportion of in-specification vs. out-of-specification readings for the given sites was also analyzed. Out of a total of 7,999 entries, using the conservative BER specification (1 x 10^{-7}), 4,441 entries (56%) showed no errors, 2,267 entries (28%) showed errors that were within specification, and 1,291 entries (16%) showed errors that were out of specification. In summary, out of 7,999 data entries, 6,708 of the readings or 84% were within specification, while 1,291 or 16% were out of specification.
When the data are compared against the required SCE BER specification (1 x 10^{-6}), 4,441 entries (56%) showed no errors, 2,959 entries (37%) showed errors that were within specification, and 599 entries (7%) showed errors that were out of specification. In summary, out of 7,999 data entries, 7,400 or 93% of the data sets were within specification, while 599 or 7% of the data sets were out of specification.

USAT Current Error Data

In order to judge the current performance of the USATs, USAT performance data was taken from Devers on 8/10/99, and Lighthipe, Lugo, Mira Loma, Moorpark, and Rector on 8/11/99. In this study, data were obtained from all USATs, both Mod-1 and Mod-2. The Lighthipe station was also included in the study in order to get a complete perspective of the entire

ULTRA-NET™ system. Round Trip data was recorded and plotted in the exact same manner as the previous study. Figure II-2 provides a bar graphs comparing Round Trip error magnitudes vs. frequency for the 8/10/99 to 8/11/99 period.

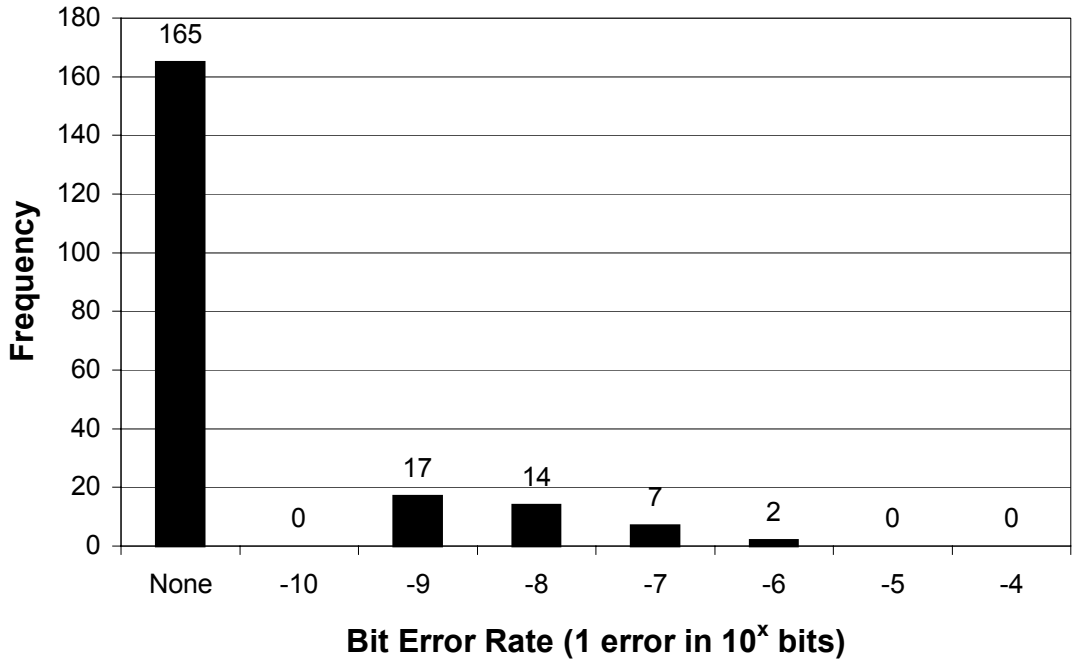

Figure II-2 - USAT Mod-2 Round Trip Bit Error Rate vs. Frequency for 8/10/99 and 8/11/99

For the 8/10/99 to 8/11/99 time period, using the conservative BER specification (1×10^{-7}), 10 out of a total of 207 units or 5% were determined to be out of specification When the regular error specification of 1×10^{-6} is used, this number drops to 3 or 1.5% of the units out of specification.

Out of a total of 207 units and using the conservative BER specification (1×10^{-7}), 166 units (80%) showed no errors, 31 units (15%) showed errors that were within specification, and 10 units (5%) showed errors that were out of specification. In summary, out of 207 units, 197 of the units (95%) were within specification, while 10 (5%) were out of specification using the more stringent BER specification.

When this data is compared against the official BER specification (1×10^{-6}), 166 units (80%) showed no errors, 38 entries (18%) showed errors that were within specification, and 3 units (1.5%) showed errors that were out of specification. In summary, out of 207 units, 204 or 98.5% of the units were within specification, while 3 or 1.5% of the units were out of specification.

Proportion Test

In order to compare the current performance of the USATs (8/10/99 and 8/11/99) with the 10/98 to 7/99 time period, a two-sample proportion test was conducted. Actual calculations for the test were performed using Statistix for Windows analytical software. It should be noted that the 10/98 to 7/99 sample data contains BER readings from Mod-2 USATs from Devers, Lugo, Mira Loma, Moorpark, and Rector, while the 8/10/99 and 8/11/99 data contains data from both Mod-1 and Mod-2 USATs from Devers, Lighthipe, Lugo, Mira Loma, Moorpark, and Rector.

Through the proportion test, it was shown that the USAT BERs for the 8/10/99 and 8/11/99 time period were significantly lower than the 10/98 to 7/99 test period.

Appendix III
New Transmitter-Receiver Card Test Report

Introduction

Southern California Edison and Wasatch Aerospace Company conducted tests of the new transmitter-receiver card at the Mira Loma Regional Control Center over a four-day period from October 25 through 28, 1999. These tests used the new Mod-2 hub with the new transmitter-receiver card installed. The new demodulator card was also installed, but testing was not possible because some software was incomplete.

Test Objectives:

- Install and establish Mod-2 ULTRA-NET™ hub and Ultra Small Aperture Terminal (USAT) communications.
- Demonstrate communications between the Mod-2 Hub and the USAT at a data rates of 0.6 kbps, 1.2 kbps, and at 9.6 kbps with 255 kHz and 1025 kHz outbound bandwidths.
- Establish the minimum signal strength point at which the USAT fails to track the hub signal.
- Establish signal-to-noise ratios at the FCC transmit power maximum limit.
- Determine the Bit Error Rate.
- Demonstrate successful transmission and receipt of the Control Data Corporation (CDC) commands.

The Mod-2 hub was installed at the Southern California Edison (SCE) Mira Loma Regional Control Center (RCC). The radio frequency (RF) connections of the hub were made to the existing satellite outdoor equipment and antenna. This was done in parallel with the Mod-1 operational hub at this RCC site. The new embedded computer was connected to the new Mod-2 hub indoor equipment. The RS-232 port on the embedded computer was connected to a SCADA master test set, emulating the Harris SCADA master interface through a modem connection using CDC protocol.

A Mod-2 USAT was installed, powered up, and made operational on the new Mod-2 Hub. This provided a complete end-to-end connection for the Mod-2 Hub. The Mod-2 hub had all the components of a complete hardware prototype chain involving a Transmit/Receive card, demodulator card, hub computer, and monitor with an NT operating system. The entire system worked as planned.

Test Results

The RF transmit spectrum was checked to verify that the hub transmit synthesizer was operating at the right frequency and that the bandwidth utilized was consistent for the full range of data rates from 0.6 kbps to 9.6 kbps. At 9.6 kbps, the spectrum was also checked for both the 255 kHz and 1024 kHz spread spectrum bandwidths or code lengths.

Tests were conducted to determine the minimum signal strength at 0.6 kbps at which signal track with the satellite was lost. The diagnostic metrics were noted at this signal/noise ratio, which was 14.1 dB. Initially, the metrics turned out to be a factor of three above projected levels. The spectrum analyzer was used to check the transmit pattern. A small spur was detected, causing the very high digital data and phase-related measurements. The problem was fixed after eliminating the synthesizer spur.

Two of the four command packets at the 0.6 kbps data rate were found to be in error for every command update. This was traced to a data formatting error. The error rate at 0.6 kbps was zero for short-term measurements. The Mod-2 USAT hub power output was measured with an 18 dB hardware attenuation and a 19 dB software attenuation in place. The predicted design output power of -23.8 dBm was measured at the indicated total attenuation. The Mod-2 USAT lost track of the satellite at this attenuation level.

Ten dB of attenuation was then removed and no short-term errors were experienced at the signal/noise ratio of 23.0 dB. However, the system metrics were still about twice the projected design level. With the hub attenuation at 9.0 dB, the transmit power was -14.5 dBm as expected.

With the outbound hub transmit signal at the FCC threshold of -6 dBw/4 khz, the signal/noise ratio at 0.6kbps was about 28 dB and the system metrics approximately a factor of two higher than projected. The hub output power was -9.8 dBm at a hub attenuation level of 4 dB.

The above tests were repeated at a data rate of 9.6 kbps and a transmit bandwidth of 255 kHz. At a power spectral density of -6 dBw/4 khz, the Mod-2 USAT terminal signal-to-noise ratio was 20.3 dB with the hub attenuation at 10 dB and a transmit power level of -15.2 dBm. This was the predicted design level data.

The hub attenuation level was then increased by 9 dB. The resulting signal/noise level of 12.5 dB was as predicted by design. This was the satellite loss-of-tracking threshold power level corresponding to the 0.6 kbps case. The data verified the projected design level satellite tracking loss threshold at 9.6 kbps and 255 kHz bandwidth.

Tests were repeated for the 9.6 kbps data rate and 1024 kHz transmit bandwidth. The data correctly matched the projected levels corresponding to the 0.6 kbps baseline design.

Performance Tests for Mod-2 ULTRA-NET™ Hub

Two twelve-hour performance tests were conducted to determine the error rates at the 9.6 kbps data rate and transmit bandwidths of 255 kHz and 1024 kHz. Only two errors were noted at the end of each performance run. This confirmed a projected bit error rate (BER) of 6.02×10^{-9} with 240 bytes transmitted per packet.

Other tests were run and results obtained as follows:

- CDC commands sent through the hub were received at the USAT without error.
- Trip/close commands were sent through the hub and routed to the correct USAT without error.
- Different command sequences were sent per the CDC protocol and were all received by the USAT from the Mod-2 hub without error.
- CDC scan requests were sent and pre-established data were received at the USAT without error.
- The CDC protocol was 100% successfully tested.

As noted on the spectrum analyzer for both the wide and narrow-band hub transmissions, the USAT Mod-2 hub is fully compliant with FCC regulations.

Appendix IV
Network Monitoring System with TCP/IP Protocol Test Report

Introduction

The previous version of the hub required that the operator be at the satellite hub to look for system status. Problems with the satellite system were only detected when data was not received by the utility's transmission SCADA system. To eliminate this issue, a network management system was designed so messages about satellite system problems could be communicated back to a central point. Since it is becoming increasingly common for utilities and other companies to operate a Transmission Control Protocol/ Internet Protocol (TCP/IP) network to connect their vital communication nodes, this was the communication method selected for the network management system. These messages about satellite system problems can be received by a central network management system or any other computer on the network. The messages are constructed using simple American Standard Code for Information Interchange (ASCII) strings to make decoding easy. There are three levels of warnings to indicate a failure, need for maintenance, or component degradation in the satellite communication system. The determination is made by the hub software using status information received from each USAT as part of normal polling process. Hub status information is also used to diagnose problems internal to the hub itself. The main goal of this system is to identify problems with the satellite system as quickly as possible, and dispatch personnel to make the needed repairs.

TCP/IP Interface

For the new Mod-2 satellite hub, Ethernet was chosen for the communications media. At SCE, Ethernet is used to connect most devices and computers to the company LAN/WAN. At the present time, 10BaseT is the standard connection. Since the hub embedded computer is running on Windows NT, the standard TCP/IP stack was used for communications. The network management messages were packaged in an unacknowledged packet using the UDP standard. These packets were then sent over the network to a specified IP address. At this device, the UDP package was stripped off and the original network management message recovered. The message can be sent to any address required with a simple change in the IP address.

Operation of the Network Management System

Initially, use of Simple Network Management Protocol (SNMP) protocol was investigated for use in sending messages to the central network management system. After some investigation, it was determined that Windows NT did not support SNMP as well as required for the satellite hub implementation. The SCE network management group was consulted, and it was determined that the best format for the network management messages was simple ASCII strings embedded in a UDP packet.

The network management message data stream was defined as follows:

- Packet Sequence Number - 4 characters
- Problem Device ID number - up to 7 characters
- Urgency Type number - 1 character
- Type Of Failure message - up to 31 characters
- Hub ID Number affected by the problem - up to 5 characters
- Hub Location Name - up to 10 characters

- USAT Location Name - up to 15 characters

The message length is up to 79 characters, including 6 comma delimiters. An example of the packet structure is:

9999,0005125,1,rtu experiencing packet loss,05000,Mira Loma,Canyon Sub

The data fields used in this message are:

- Packet Sequence Number (9999): a field that is used internally to help track problems on the ULTRA-NET™ system.
- Problem Device ID (0005125): a system ID number that identifies the problem device (USAT or satellite hub).
- The Urgency Type (1) is a character with three possible values: 1 means a failure of the problem device; 2 means the problem device is degraded, but has not failed completely; and 3 means the problem device will need service soon.
- The Type of Failure message (rtu experiencing packet loss) is a text string that defines the type of failure that occurred. This string is displayed as it is received from the satellite hub.
- The Hub ID Number (05000) identifies which satellite hub is associated with the problem device. If the hub is the problem device, the Problem Device ID will be the same as the Hub ID.
- The Hub Location Name (Mira Loma) is a text string that translates the satellite Hub ID number into a human readable location identifier.
- The USAT Location Name (Canyon Sub) is a text string that translates the Problem Device ID number into a human readable location identifier.

The above information is used by the central network management system to decode the network management messages. The central network management staff has been given a list of phone/pager numbers to call when various types of problems are encountered.

System Testing

The network management software was integrated into the software running on the NT-embedded computer in the satellite hub. For the system testing, a second computer, utilizing software that receives and displays the network management message, was connected to the first using a standard Ethernet hub. Because the satellite hub is not in full operation (only transmit capability), a drop-down menu item was added to the satellite hub software to initiate sending a network management alert message. Whenever this menu option is selected, a message is assembled, encapsulated in a UDP packet, and shipped over the Ethernet interface. The second computer, the receiver, listens for messages directed to its IP address. When it receives a message, the network protocol information is stripped off and the message parsed and sent to the screen.

Testing Results

Using the test setup mentioned in the previous section, network management messages were initiated from the satellite hub and received at the monitoring computer. Single messages were sent, as well as a series of messages back-to-back. In all cases, all messages were received and

decoded properly. When the satellite hub is in complete operation (both transmit and receive capability), the same tests will be rerun. With the hub in full operation, real events can be simulated and messages sent. In addition, testing should be done with the actual SCE network management system. This will take some software modifications by SCE to properly parse the network management messages.