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DESIGN AND INSTALLATION OF RURAL TELECOMMUNICATIONS NETWORKS: LESSONS FROM THREE PROJECTS

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PREFACE

The past three decades have seen a revolution in telecommunications—from the first television transmissions via satellite in the early 1960s to the video- and computer-conferencing activities of the 1980s. Today, telecommunications serve as the "nervous system" of many societies; they are multi-purpose in use and pervasive in effect. Telecommunications provide significant social and economic benefits critical to improving and maintaining national economies and, by extension, the quality of life.

In the relatively short time that communication satellites have been with us, satellite technology has displayed amazing range and versatility. The technology has demonstrated its value to telephone and telex communications, radio and television broadcasting, business communications, and the delivery of public services to isolated communities.

It has also proved a sound financial and, according to many, productive development investment. Indeed, telecommunications' vital contribution to development was noted in The Missing Link, a report by the ITU's Independent Commission for Worldwide Telecommunications Development:

> Henceforth no development program of any country should be regarded as balanced, properly integrated or likely to be effective unless it includes a full and appropriate role for telecommunications and accords a corresponding priority to the improvement and expansion of telecommunication.

In the last decade, it has become evident that the developing world also considers telecommunications a worthwhile investment. Indonesia, India, Brazil, Mexico, China, and a coalition of 22 Arab nations have launched their own satellites. Through INTELSAT, 27 other developing nations have established internal satellite-based communications systems.

Satellite communications offer the potential to reach the isolated and rural areas which characterize much of the Third World and which have long remained outside the vital flow of information.

In 1980 the U.S. Agency for International Development initiated the AID Rural Satellite Program to explore the potential of telecommunications as a means of extending scarce expert resources and expanding educational opportunities to remote and rural areas. Building on simple, interactive, and inexpensive telephone-based technologies, the Program developed teleconferencing systems for use as a development tool. Three pilot projects—in Indonesia, the West Indies, and Peru—were implemented to test and demonstrate that audioteleconferencing could reliably and affordably support development activities in education, health, and agriculture.

In Indonesia and the West Indies, distance education programs were established with national universities. Linking 13 distant universities in Indonesia and six universities in the West Indies, audioconferencing systems are used to provide academic courses to university students, to upgrade faculty skills through in-service training programs, and to

facilitate administrative and institutional communication. The effect is to make the expert resources of each institution available to all members of the network, thus multiplying each professional's outreach and effectiveness. Over 15 courses are taught each semester to thousands of university students in Indonesia. The University of the West Indies trained over 500 doctors and nurses in 1985 and doubled the annual number of teaching certificates awarded because of expanded training opportunities offered by the teleconferencing system.

In Peru, the Rural Satellite Program provided basic telephone service to seven rural communities and established an audioconferencing link for in-service training of health workers, agriculture extension agents, and teachers—connecting them for the first time with experts in the capital city of Lima. Over 300 audioconferences were requested by field personnel in 1985; over 92 percent of users indicated that the training improved their work.

The experiences of the Rural Satellite Program in Indonesia, the West Indies, and Peru have shown that:

- Telecommunications can be adapted to provide affordable communication services in rural areas and provide a cost-effective means of extending social services to these areas.

- Telephone-based technologies can be made to operate reliably in the developing world. The RSP pilot project networks operate at a 90 to 98 percent reliability rate.

- Teleconferencing, specifically audioconferencing, is an effective means of providing quality instruction and essential training to rural and isolated public service personnel.

Beyond these major research conclusions, the Rural Satellite Program projects have afforded valuable lessons in the planning and implementation of distance education programs, the design of appropriate technical systems, the programmatic and technical management required by these programs, the process of technology transfer, and the identification of the most suitable uses and audiences.

The following report, one of a monograph series, describes one aspect of the experience of the Rural Satellite Program.

INTRODUCTION

The AID Rural Satellite Program represents the first attempt to use telephone technology, namely **audioconferencing** and related services, to support development efforts in the Third World.

The feasibility and utility of teleconferencing has been widely demonstrated in the United States and Canada; **two-way, interactive communications systems hold much promise as a tool for Third World development.** Although satellites are expanding the availability of telecommunications services, simple telephone service does not yet enjoy widespread usage in the rural areas of the developing world. The challenge of the Rural Satellite Program was to adapt and transfer telephone technologies to these areas and to make them work for rural development.

Four years after the initial design efforts, three teleconferencing networks are in place and supporting development applications in Indonesia, the West Indies, and Peru. Personnel have been trained in their use, operation, and repair, and the networks are regularly used by their sponsoring institutions. The technical reliability of the systems is between 90 and 100 percent.

Yet these positive results of a unique technology transfer experiment reveal little of the efforts required to design, install, and operate the technical systems. The Rural Satellite Program has proved telephone-based systems can be made to work in the Third World. This report explores the steps the Program took to arrive at fully functioning technical networks.

The Rural Satellite Program developed many innovative solutions to overcome the typical LDC problems of "line noise," erratic power supply, tropical heat and humidity, equipment shortcomings, and limited human, material, and financial resources. These challenges resulted in new network configuration designs, equipment adaptation, and procedures for technical management, such as:

- the design of a small, solar-powered earth station for rural use
- the first-time use of a six-meter earth station with INTELSAT domestic service
- satellite bridging to conserve channel use
- a network "gating" system to reduce line noise
- auxiliary power systems to compensate for brown-outs and black-outs

Most importantly, the Rural Satellite Program made the perhaps unoriginal discovery that the technical and "human" systems are intimately linked. For true technology transfer to occur in the developing world, new and appropriate training and management procedures must be developed for even the most "old-hat" technologies.

The ultimate outcome of the Rural Satellite Program is that the experience and knowledge now exist within AID and each of the project countries to provide a sound technical foundation for others interested in establishing innovative uses of satellite technology, sparing them the need to repeat the arduous "trial and error" technical transfer process.

The following report is a description and analysis of the teleconferencing systems and end equipment performance of the Rural Satellite Pilot Projects in the West Indies, Indonesia, and Peru. Its purpose is to review the design, installation, and operation processes of the three teleconferencing systems. Because these aspects differ from project to project, this report will consider each of them separately while attempting to relate each to overall program and technical goals.

As is often the case, those components of the technical systems that functioned well are given relatively less discussion space than the components which proved problematic. It is hoped that, based on the experience of the Rural Satellite Program, others might benefit from its triumphs and its pitfalls to more effectively design and implement similar projects in the future.

BACKGROUND

The Rural Satellite Program (RSP) goals were developed from NASA's Applied Technology Satellite (ATS) experiments in Alaska, the Rocky Mountain states, Appalachia, India, the Caribbean, and the South Pacific during the 1970s. This experience clearly demonstrated that satellite technology could be a valuable tool in supporting the development of remote areas. Satellites, operating from the geostationary orbit, had access to any point on the ground without regard for the problems of distance, climate, or terrain. This made them ideal for reaching widely dispersed communities that would otherwise have to depend on costly or unreliable forms of terrestrial radio communications. These experiments demonstrated that inexpensive and rugged satellite technologies could be developed for rural uses. The NASA experiments, however, were limited and were intended to be a one-time use of technology. NASA had no plans to launch additional satellites for further experimental communications after the ATS-6 and, more importantly, was not going to offer any ongoing satellite service beyond that already accommodated on the aging ATS satellites.

AID, wishing to continue the momentum gained from these experiments, developed the AID Rural Satellite Program. Its focus was narrow-band, interactive technologies which could "bridge the distance" between isolated communities and urban centers and take advantage of the two-way communications capability to extend scarce resources. The technical goals of the RSP were relatively straightforward:

- to demonstrate the feasibility of using two-way telecommunications technologies within the severe operating constraints of developing nations
- to find means of reducing the costs associated with the technology to make the large-scale implementation of such systems economically feasible
- to work in cooperation with equipment manufacturers to modify technologies to make them more "appropriate" in terms of costs and operations in developing nations
- to develop operational systems which would continue after the initial AID funding period ended

In the interest of emphasizing the applications over the hardware, AID also wanted to use "end equipment"--that is, the equipment which was actually provided on the premises of these agencies--which was commercially available and therefore. presumably

reliable and affordable. The experimental component of the audioconferencing systems was to be kept to a minimum, except in the area of certain graphics equipment. A separate research and development effort was planned for the development of a small, solar-powered earth station suitable for rural use.

In approaching the technology transfer, the RSP wanted to avoid the experience of other communications projects where the applications agency had to assume major technical functions. The RSP emphasized at the planning stage that health or education ministries should not be telephone companies and vice versa. This goal derived from the poor maintenance and operations records of other projects as well as from the good results achieved in the Guyana Medex project where two-way radios, installed to support rural health services, were maintained by the Ministry of Telecommunications. In the AID Rural Satellite Program the local user institutions' responsibilities were limited to the operation and maintenance of the end equipment.

The Rural Satellite Program was to provide and install the project-specific equipment and provide technical assistance and training in operating and maintaining the equipment. In doing this, AID contracted with the Academy for Educational Development (AED) to oversee technical design, procurement, and installation. AED subcontracted with an engineering firm to actually design the equipment and supervise its testing and installation.

DESIGN OBJECTIVES AND CONSTRAINTS

The Rural Satellite Program goals had to be realized in terms of the various constraints presented by developing nations. The major design objectives were:

- Interactivity: The RSP wanted to move beyond the distance demonstration projects which had separated the urban centers from the remote areas when providing broadcasting, print materials, and the like. The RSP instead wanted the remote areas actually to converse with the urban areas, a move toward eliminating the asymmetry of resource distribution between urban and rural areas.

- Use of Satellite Transmission: The RSP was intensely interested in demonstrating that existing commercial satellite systems could meet the communications needs of remote areas. Thus, the projects were designed to use satellite communications--either a domestic system (where available) or INTELSAT. It was only in the absence of any cost-effective means of using a satellite system that alternate forms of transmission were chosen.

- Low Costs: The RSP wanted to show that advanced communications technologies could be used in remote areas at affordable costs. Thus, both capital and operating costs had to be low to make the program successful. The use of expensive technologies would make if difficult to continue or expand the project after the RSP's departure. In cases where this could not be shown in the short term, as with earth station equipment for use with INTELSAT, a strong case had to be made that the equipment costs would drop in the future.

The following factors were considered during system planning and implementation:

- Climate: Communications equipment had to be designed to accommodate the often extreme climates in developing countries which may include high heat, humidity, and dust. Communications technologies are generally designed to operate in controlled environments. Thus, careful selection and adjustment was necessary to ensure that equipment which functions well in the United States would not fail in tropical Indonesia.

- Power: Repeated studies have shown that the major operational problem for communications technology in rural areas is the unreliability of power supplies. Unstable power in particular can severely damage equipment as power levels spike for short periods. Thus, the program could succeed only if reliable and safe power were assured.

- Ease of Operation: Because many developing nations lack sufficient trained personnel to operate and maintain communications equipment, the program had to utilize equipment which was appropriate to locally available skills as well as develop training programs to teach the necessary skills.

- Innovative Means of Distributing Local Signals: Developing countries often have poor local distribution "plant" (i.e., the wires which carry the signal from the earth station to the project site). Poor local plant can cause line noise, signal and frequency attenuation, and cutouts. Obviously, any equipment design had to take the local plant's condition into account. Unfortunately, many of these problems cannot be solved except by replacing the local plant. This can be very expensive.

- Reliable Equipment Operation: Because the project sites were to be located in relatively remote locations with varying degrees of access to transportation, equipment had to be sufficiently reliable, and to minimize the amount of time the facilities would be out of service there had to be ample spare parts.

THE PROJECTS

THE UNIVERSITY OF THE WEST INDIES

The University of the West Indies Distance Teaching Experiment (UWIDITE) developed out of Project Satellite, a joint AID/University experimental project using the ATS-3, which demonstrated the use of satellites to link UWI's island campuses and extension stations. UWIDITE's purpose was to implement a distance education program among UWI's separate island campuses. Initially, the project was to serve the three main UWI campuses in Jamaica, Barbados, and Trinidad and two extension campuses in St. Lucia and Dominica. A third extension campus in Antigua was added during 1984. The project territory is shown in Figure 1.

Transmission System Options

When the project was being designed there were three transmission options for the Caribbean basin: leased service on INTELSAT, use of the ATS-3 on an "experimental" basis, and leased private lines on existing terrestrial and satellite systems from the various carriers serving the area. Leased service from U.S. domestic satellites was not available during 1981.

INTELSAT

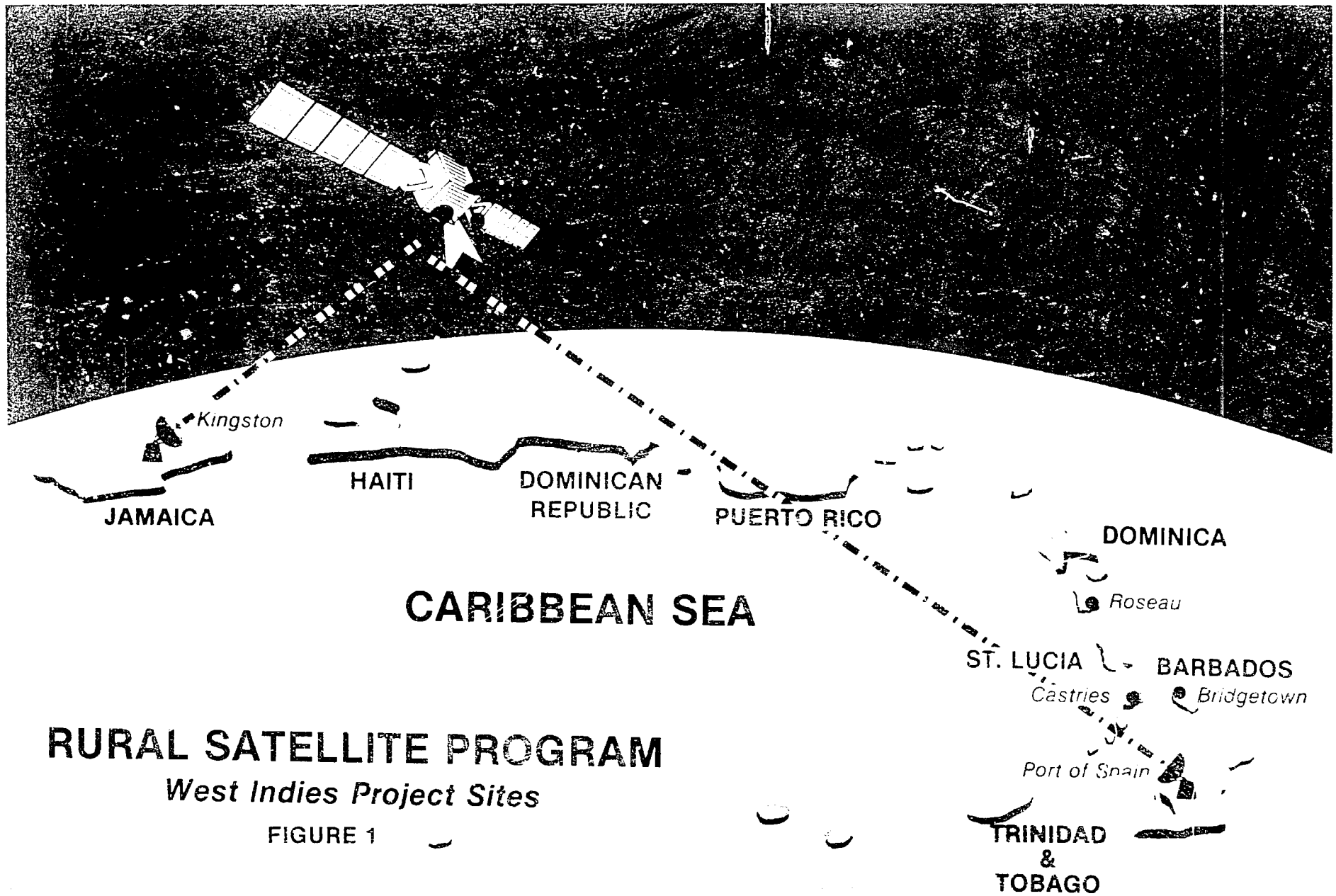
The INTELSAT option was quickly dismissed on the basis of cost. The cost of multiple earth stations for use with the INTELSAT system was too high for the limited applications of the project. Also, INTELSAT did not then offer single channel leases, but only quarter "transponder" leases (800-1,200 channels), which provided more capacity than was needed.

NASA

NASA's ATS-3 satellite offered limited but generally reliable service. Because the ATS-3 was well past its design life, its transmission quality was poor. More importantly, NASA could not guarantee the satellite's continued operation. Although the satellite's electronics could last well into the future, its available fuel, its guidance system, and NASA's budget for maintaining the satellite were all in question. Also, because the ATS-3 did not transmit in commercial radio bands, any equipment designed for use with the satellite would not work with any other satellite.

The major advantage of the ATS-3 was that it was inexpensive to use. The space time would be provided free by NASA, and the earth terminals cost as little as $3,000. Both of these features were attractive to UWI and the RSP. Because of a limited budget, UWI's management saw the free use of the satellite as critical for continued project operation. UWI also believed that the physical presence of an earth station would generate interest in the project.

After examining other projects using the ATS series, however, the RSP discovered that the most inexpensive ground stations could transmit only for short periods of time without overheating, which would make the transmission of lectures problematic. Adjusting the system for teaching would require more expensive electronic equipment.



RURAL SATELLITE PROGRAM

West Indies Project Sites

FIGURE 1

The ATS-3 also had to be shared with emergency services like the Federal Emergency Management Administration (FEMA), thus requiring the earth stations to be equipped with a remote interrupt device so that NASA could quickly bring the satellite into use for emergency communications.

Taking into consideration these parameters, several manufacturers were approached for bids. Only General Electric was willing to bid, and its high price, $28,000 per station, was discouraging given the satellite's uncertain future.

Finally, AID and UWI did not know if the Trinidad Government would permit an ATS-3 earth station in the country. The government had previously refused permission for Project Satellite to operate an ATS-3 earth station there.

Existing Capacity

Using existing capacity was the final possibility. A series of inquiries indicated that Cable & Wireless (C&W) provided a microwave chain connecting St. Lucia, Dominica, and Trinidad, as well as a "troposcatter" adding a connection to Barbados. Transmission between Jamaica and the other sites could be achieved by a satellite link from Kingston, Jamaica, to Port of Spain, Trinidad, and to the other islands by microwave.

This method offered the possibility of rapid system development and relatively reliable transmission quality. The system could be expanded as required simply by leasing more channels. It also posed no political problems for Trinidad as it used existing telecommunications facilities. This system, however, would have recurring annual lease costs. Although these costs would initially be paid for by AID, they would eventually have to be assumed by the University.

After considering these options, and several variations, the RSP recommended the C&W option because of cost and long-term practicability. The C&W option's projected costs were approximately the same as the ATS-3 over the project's two years of operation, but it did offer the possibility of long-term operations until a less expensive solution, presumably a U.S. domestic satellite lease, could be found. The ATS option was viewed as risky, given uncertainty about the satellite; costly, given the high price for the earth stations; and limited, only demonstrating the use of obsolete equipment.

System Design

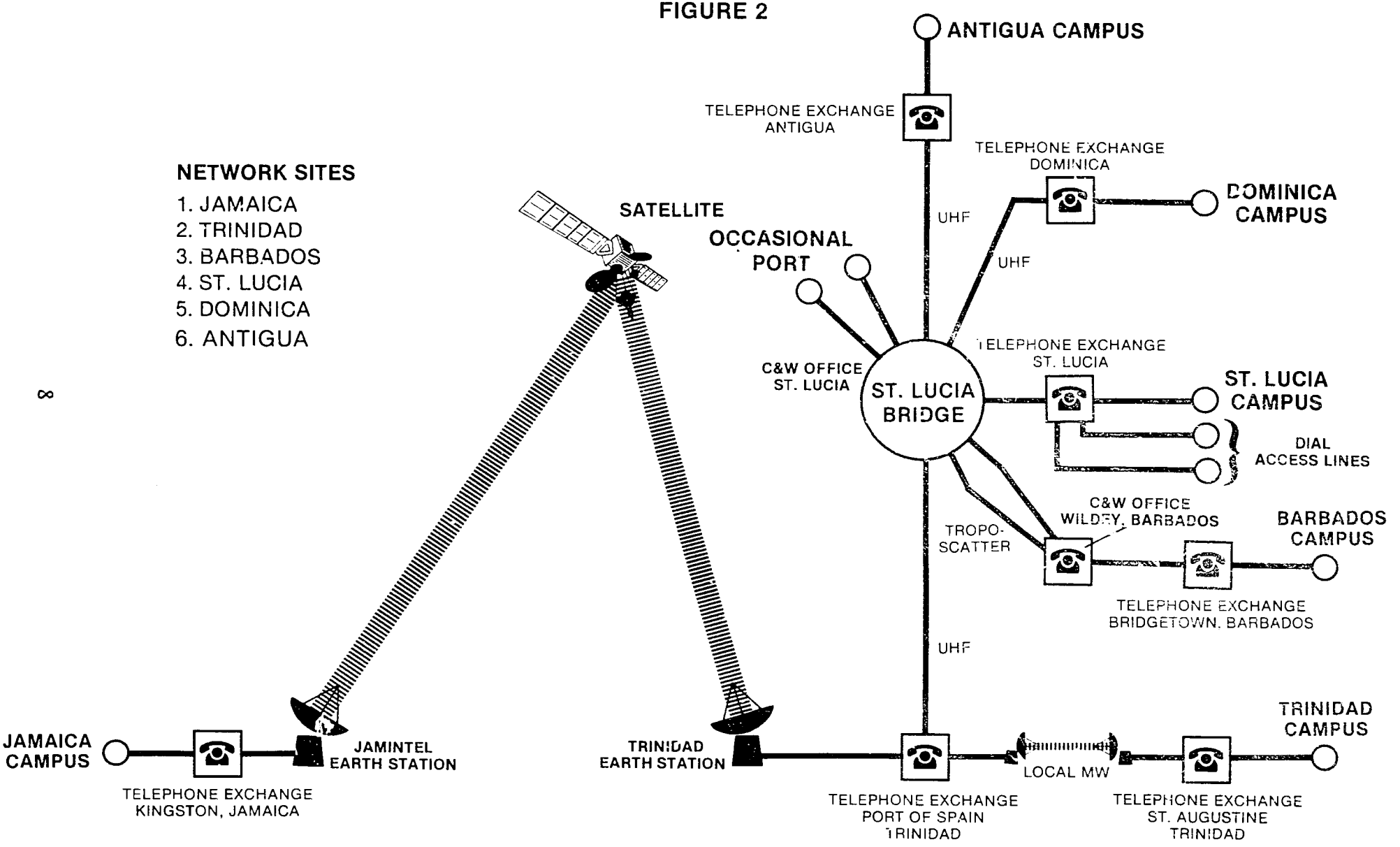
The system is designed as a large "party line," each site hearing every other site on the system. This is accomplished by using a telecommunications bridge (i.e., a device for electronically balancing and mixing multiple incoming signals) in St. Lucia. Given inter-island tariffs, St. Lucia was the least expensive place to locate the bridge. Each site connects to the bridge via a leased line. The bridge was provided under a lease arrangement with C&W and installed in the St. Lucia main telephone office. A network diagram of the project is shown in Figure 2.

Equipment

The RSP emphasized early in the planning that the system be designed primarily for interactive voice communications. Although UWI was interested in interactive graphics equipment, no real need for such equipment was identified. Further, there had been no

U.W.I.D.I.T.E. TELECOMMUNICATIONS NETWORK

FIGURE 2



overall project planning process which would have analyzed the need for graphics or other equipment, and therefore it was decided to forego any additional equipment.

Working with UWI, a classroom design for accommodating groups of approximately 20 was developed. The RSP recommended the use of the Darome audio convener, a well-tested device for amplifying telephone signals in a classroom and channeling the output of various microphones into a telephone channel. To accommodate the anticipated problems with humidity, the manufacturer, Darome, was asked to change the design of its microphones so that all contacts used precious metals. Screw connectors for the microphones were replaced with hard wiring, and military style connectors were used. All of these changes minimized the dangers of corrosion.

UWIDITE's project management was concerned that an open system (i.e., where every site could listen to an ongoing conference without exclusion) would be inappropriate for private administrative meetings. In addition, the ability to hold smaller teleconferences on short notice was desired. Therefore, a dialing system with a privacy feature was designed with a separate number assigned to each site. The organizer of a private conference had to dial the numbers of the participating sites. Any sites not included in the conference would only receive a busy signal if they attempted to use the system while it was engaged.

Implementation

The West Indies project was the first of the RSP projects, and there were a number of unexpected difficulties during installation. A key difficulty was the lack of a smooth working relationship with UWI's project management. UWI insisted that it act as the contact point for all technical communications between the carriers, which included C&W as well as the local telephone companies. This was impossible given the frequency of detailed contacts required between the engineers and the carriers. Coordination problems were exacerbated by the delay in appointing a local University technical director to act as liaison with the installation team.

A series of contractual agreements were signed with the regional and local carriers for the establishment of both inter-island and intra-island connections. This was not an easy procedure, given the diffusion of authority and the unique nature of the service request.

The international transmission system was established relatively easily. UWI arranged the local transmission systems in each of the islands. Local companies were relatively accommodating, but they were also passive in the installation. Transmission links were provided, but the installation team had to identify the problems with the carrier's systems.

The equipment, purchased through a competitive bidding process in the United States, was shipped and installed from January to March 1982. The initial transmission quality was uneven and generally unusable largely because of a poor transmission link from Jamaica, very poor local loops in Trinidad from the campus to the earth station, and problematic loops in Barbados. Trinidad's problems resulted from the use of old and deteriorated loops which were due for replacement. Unfortunately, the replacement occurred after the project was under way, resulting in months of noise interference. Barbados' problems were caused by both the shielding and loading of the outside plant. Like many LDCs, the telephone poles in Barbados carry both telephone and power lines.

These problems would require re-engineering of part of the outside plant. Most of these problems have been overcome by improved responsiveness of the local carriers to requests for repair and maintenance. Trinidad, however, continues to "dump" noise into the system and, of necessity, is often omitted from user activities.

Additional Equipment Provided by UWI

After the installation was completed, UWI purchased additional equipment to augment the system's operations. Scramblers were purchased to provide greater privacy for administrative meetings. Unfortunately, the scramblers were not designed to be used in point-to-multipoint applications and have been only marginally useful.

The University also purchased slow-scan video units followed by a set of electrowriters to augment the audio-based distance teaching. Both sets of equipment were purchased with little technical consultation with AID. Because the transmission system utilizes conventional telephone circuits, it is not possible to simultaneously transmit both a voice and graphics signal through the system. As a result, teaching must stop while the graphics image is being transmitted.

The graphics equipment has operated with limited success. The problems with local loops, particularly in Barbados, often prevent reliable signal transmission. Often images must be transmitted more than once, and even then not all sites will receive a usable image. There have also been problems with power stability at some of the campuses, leading to intermittent operation. Users of the slow-scan equipment, however, are enthusiastic, and, despite its less than optimum performance, it appears to offer a valuable and highly prized function in UWIDITE activities. The electrowriters have been much less successful. The light pens appear to be particularly vulnerable to damage and malfunction.

System Operation and Prognosis

The UWIDITE system has been operating for over four years with marked success. Although there are still problems with noise, on the whole the system provides adequate service for teleconferencing. The system is fully booked for regular classes, seminars, and outreach programs. The UWIDITE system is a regular feature of the University's educational program and enjoys tremendous popularity with the extension campuses. Since its inception, three sites and an auxiliary classroom have been added, and more have requested link-ups.

The University has developed staff skills and a close working relationship with the carriers to deal with problems in either the equipment or the transmission system. Some of the equipment still operates unevenly, but the University has developed a better sense of what equipment will and will not work, which should improve future technical decisions.

A major technical issue facing the University is how to accommodate growing demand. There is no question that the satellite systems now available in the Caribbean could provide better quality and more reliable services than are now available via the terrestrial facilities used by UWIDITE. Whether the University will move to a satellite system will depend on a mix of financial and political issues. Given UWI's experiences, however, this is clearly the next step for an investigation.

THE INDONESIAN SISDIKSAT PROJECT

The SISDIKSAT (Indonesian acronym for the Distance Education Satellite System) project has a long planning history. Initial AID interest and contacts in Indonesia date back to 1974 when PERUMTEL, the national telecommunications company and operator of the Palapa satellite system, held a planning conference on development applications for the satellite.

Detailed planning for the RSP began during 1981. The project plan called for a system to connect 11 widely separated and remote universities of the Eastern Islands University Association (BKS) and the Ministry of Education and Culture in Jakarta with two channels, one for voice and one for graphics. (The locations of the campuses are shown in Figure 3.)

This project posed a real challenge for demonstrating a special use of satellite systems for development. Indonesia already had the Palapa satellites, but was not using them for any national development purposes except for general telephony and broadcasting. The project offered both PERUMTEL and the Ministry of Education and Culture the opportunity to experiment with the use of the Palapa system for the support of national educational institutions.

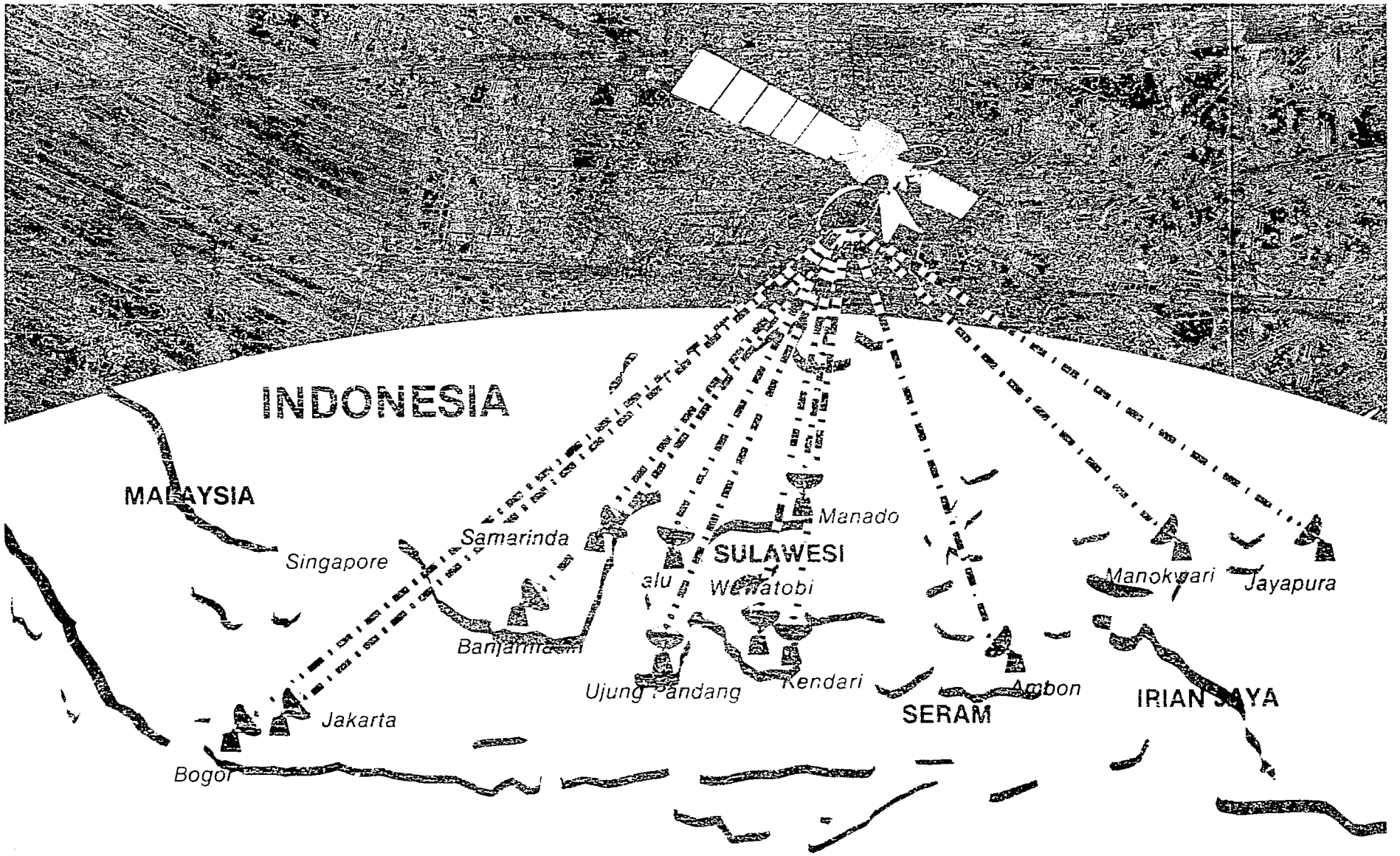
Transmission System Options

Because Indonesia already owned a domestic satellite, the initial set of decisions concerned the design of the satellite transmission system. Because the applications design anticipated that interactive graphics would support the lectures, two transmission channels were necessary. Given this requirement, the satellite architecture was a critical point for controlling costs.

Two basic options were possible (see Figure 4). The first, a loopback modeled on the Alaska Health Services Experiment on the ATS-1, called for each site to have two identical up-frequencies and two identical down-frequencies. In this way, a point-to-multipoint broadcasting system was established, with any point in the system being able to act as the transmitter. The result was the equivalent of a party line--the satellite connected all the sites using only four frequencies (i.e., two satellite channels).

The second option, terrestrial bridge, drawing upon the more conventional means for establishing audio-conferencing networks, would have each site working into a bridge located either in Jakarta or Ujung Pandang. This design would require each site to utilize two complete satellite channels, or 40 in total, rather than two. Each option had its virtues and problems.

Given the concern with system economy and the difficulties with the signal delays in double hops, PERUMTEL agreed to the satellite bridging technique. Two channels would be leased as part of the dedicated conferencing network--channel A for voice and channel B for graphics.



RURAL SATELLITE PROGRAM

Indonesia Project Sites

FIGURE 3

FIGURE 4

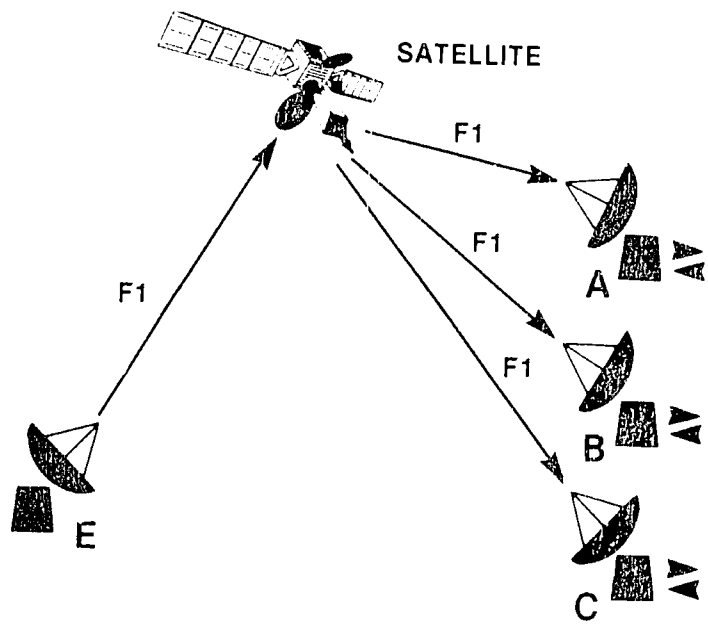
SATELLITE CONFIGURATIONS CONSIDERED FOR SISDIKSAT

OPTION ONE:

LOOPBACK:

Transmission of any one site goes up to the satellite and back down to all sites. All sites rely on echo suppressors to prevent their own transmitted signal from coming back into their classrooms.

Example: Site E Transmits to the satellite and all other sites receive on the same channel.

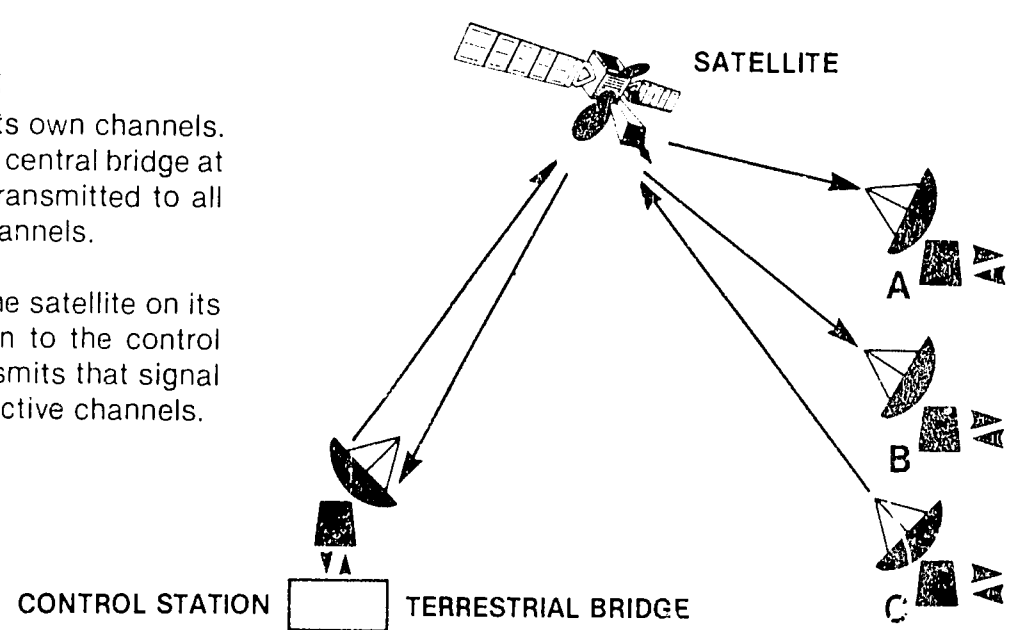


OPTION TWO:

TERRESTRIAL BRIDGE:

Each of the sites is assigned its own channels. All transmissions first go to the central bridge at one location and then are re-transmitted to all locations on their allocated channels.

Example: Site C transmits to the satellite on its own channel which goes down to the control bridge. The bridge then re-transmits that signal to all other sites on their respective channels.



OPTION ONE

The chief virtue of the satellite bridging option was its economy--all sites could share a single channel. However, it also required the use of nonstandard procedures and equipment at each earth station which necessitated additional technician orientation. The use of the satellite as a bridge also made the system more susceptible to noise problems. Unlike a terrestrial channel where two users speaking at the same time would simply hear garbled speech, two users speaking at the same time on the same frequency via satellite causes crashing noises that are often diagnosed as technical rather than user problems. The satellite bridging plan allowed only one person to speak at a time. A speaker could not be interrupted as long as his site was transmitting.

OPTION TWO

The second option, which was supported by PERUMTEL, offered greater control over the overall transmission system because noise problems at a site could be identified and controlled by the bridge operator. A high level of noise coming from poor local lines at one location could be halted at the bridge and not retransmitted to every site in the network. This bridging system would also allow for "full duplex" communication--speakers could be interrupted if necessary. One of the problems with this option was that it created a one-second delay as transmissions from outside sites went through the satellite twice. The major drawback to this design, however, was its costly use of 40 satellite channels.

All of the project sites were located near earth stations, and access to the satellite system was to be achieved by using leased lines from the campus to the earth station. As with UWI, leased lines were seen as a means of avoiding any problems with access to a long distance circuit and as a way to bypass local telephone switches which tend to generate noise. RSP assumed that leasing a circuit would enhance control over circuit quality.

Transmission System Installation and Performance

The project was implemented in close consultation with PERUMTEL which designated a project liaison officer. Subsequently, all technical documents dealing with the system architecture and equipment specifications were forwarded to PERUMTEL for comment and recommendations.

Equipment availability was an early topic of discussion with PERUMTEL. Questions were raised about the availability of modems for the earth stations and, more important, whether local distribution plant was readily available. While PERUMTEL believed that it would have sufficient modems on hand by the time of installation, distribution plant was a greater problem. Many campuses were already drastically short of incoming circuits,

making it difficult to provide dedicated circuits to the project. Several campuses had no existing phone service at all. It was clear that new cables would have to be provided at many of the campuses and even at one campus, across a bay from the earth station, new radio circuits. As a result of these discussions, an installation schedule was developed to accommodate the availability of outside plant. It is important to note in reviewing the availability of transmission plant that PERUMTEL never gave any indication that, aside from the connection to the Bogor site, there would be any qualitative problems with the distribution plant once it was supplied. This would later prove crucial in attempting to bring the system into full operation.

The basic transmission system installation proceeded in a timely manner. After most of the facilities were installed, however, serious noise problems began to occur. Both channels had loud, intermittent crashes of sound, as well as intermittent white noise, cross-talk, and voice chopping. The noise made teleconferencing difficult and unreliable and precluded the use of the graphics equipment.

It is important to first discuss the nature of noise in a bridged system. The greater the number of sites, the greater the possibility of any one site adding noise into the overall system. A system that is also geographically widespread, such as the 2,500 mile length in Indonesia, is more likely to have at least one site in a storm area at any given time. A terrestrial bridge, such as that used by UWIDITE, can control the noise coming from one site by the simple expedient of blocking its transmission path so that the noise is not passed to all other locations. The Indonesian system used the satellite as the bridge, and therefore had no central point where noisy transmissions could be controlled. Both the UWIDITE and Indonesian systems were designed to minimize the possibility of ambient classroom noise being transmitted by using push-to-talk microphones. Classroom noise would be transmitted only when someone was actually using the microphone.

Compared with the UWIDITE project, however, the SISDIKSAT Project should have had fewer problems with additive noise due to the use of network thresholds. Each earth station modem is designed to transmit only when the incoming signal is above threshold level. This prevents the transmission of multiple carriers leading to "collisions" at the satellite. Such carrier collisions produce crashes and other types of noise. The threshold settings for these modems are set to accommodate the quietest speakers using poor equipment and lines. Because the modems are set for the variable signal levels generated in switched networks, they were too sensitive for a dedicated network. However, it was difficult to convince PERUMTEL to actually revise its policies and change the modem thresholds.

More importantly, the level of noise coming into the earth stations clearly exceeded any possible threshold adjustment. The most severe problem, the intermittent crashes, probably resulted from lightning. This explanation seemed reasonable because the interference diminished with the onset of the dry season. This problem could be corrected only by ensuring that cables were properly shielded.

Generally, the other noise problems resulted from cable with improper shielding, poor grounding, or water and insect damage. Noise could also result from improper balancing of lines, particularly where signals go through multiple links.

A series of diagnostic tests were designed to detect the source of the noise. All of the telephone terminals were tested. They proved negative, placing suspicion on PERUMTEL's plant.

Discussions with PERUMTEL indicated that assumptions previously made about its outside plant were unrealistic. PERUMTEL's outside plant staff indicated that certain procedures common in the United States, such as line balancing, were not followed. PERUMTEL suggested that the noise in the lines, in fact, might be normal and part of their system. PERUMTEL agreed to assign a team of engineers who would travel to each site and attempt to minimize the noise problem through corrective maintenance.

Given the uncertainty about PERUMTEL's ability to provide circuits sufficiently quiet for graphics transmission, the RSP engineer investigated the feasibility of designing, building, and installing "transmission gates." These devices would be attached to both ends of the local telephone line--the classroom side and the PERUMTEL side. They would "pass" signals to the earth station modems only when accompanied by a DC signal generated at the classroom. The signal would be transmitted to the gate whenever a piece of classroom equipment was actually transmitting. In this way, all line-generated noise would be eliminated except when a site was actually transmitting. The gate would not eliminate line noise; it would only protect the overall system from noise.

The design of the transmission gate circuits was done in the most simple manner possible, sending a direct current over the wires to operate a relay at the remote end (in the telephone central office). More sophisticated methods such as coded signalling were considered but discarded for reasons of cost and complexity. Such a method would have involved installing active circuitry at the telephone company and increased maintenance. In future designs, if the telephone company is directly involved in the equipment maintenance, this aspect could be reexamined.

Although the transmission gates appeared to offer a partial means of resolving the noise problem, continued system testing indicated that the problem might, in fact, be more complex. Although channel A became, even in the absence of the gating device, much quieter, channel B continued to produce noise. Upon further investigation, PERUMTEL discovered that changing the frequency for channel B significantly improved the signal quality. Apparently, the current transponder loading leads to intermodulation interference for the frequencies associated with channel B.

Problems have also resulted from the use of a loopback mode for the two channels. This is a simplex party line mode of operation and differs from the duplex mode used for telephone traffic. Using this mode required a change in operational procedures for PERUMTEL and an adjustment of the Single Channel Per Carrier (SCPC) model equipment at each earth terminal. A high level of cooperation has been required by the BKS and PERUMTEL to ensure the proper operations of the earth terminal equipment.

Clearly, an important lesson from these experiences is that the system should have been designed to assume far worse noise conditions in the transmission lines. The RSP assumed that the use of leased circuits would obviate the noise problems in the local loops and that the satellite system would instantly provide clear service. These assumptions might be reasonable in the United States or Europe, where enormous technical resources can be brought to bear on such problems, but they clearly are not reasonable assumptions in developing nations.

End Equipment Installation and Performance

Because the SISDIKSAT project includes large lecture classes, smaller seminars, faculty meetings, and document and research exchanges far more extensive than the

UWIDITE project, the equipment supplied for the classroom is elaborate. Figures 5 and 6 illustrate the equipment configurations in the classrooms.

The Telephone Terminal

The central piece of equipment in each classroom is the telephone terminal. This device is the interface between the classroom equipment and the outside telecommunications network. The terminal is designed to:

1. Provide a means of setting signal levels for transmissions from the classroom equipment.

2. Provide "addressable" control for each of the pieces of classroom equipment (facsimile, telephone, and telewriter). Each unit at each site has an individual number which can be addressed. In addition, each category of equipment can be called in unison with a single code (e.g., "All Fax" or "All Telephones").

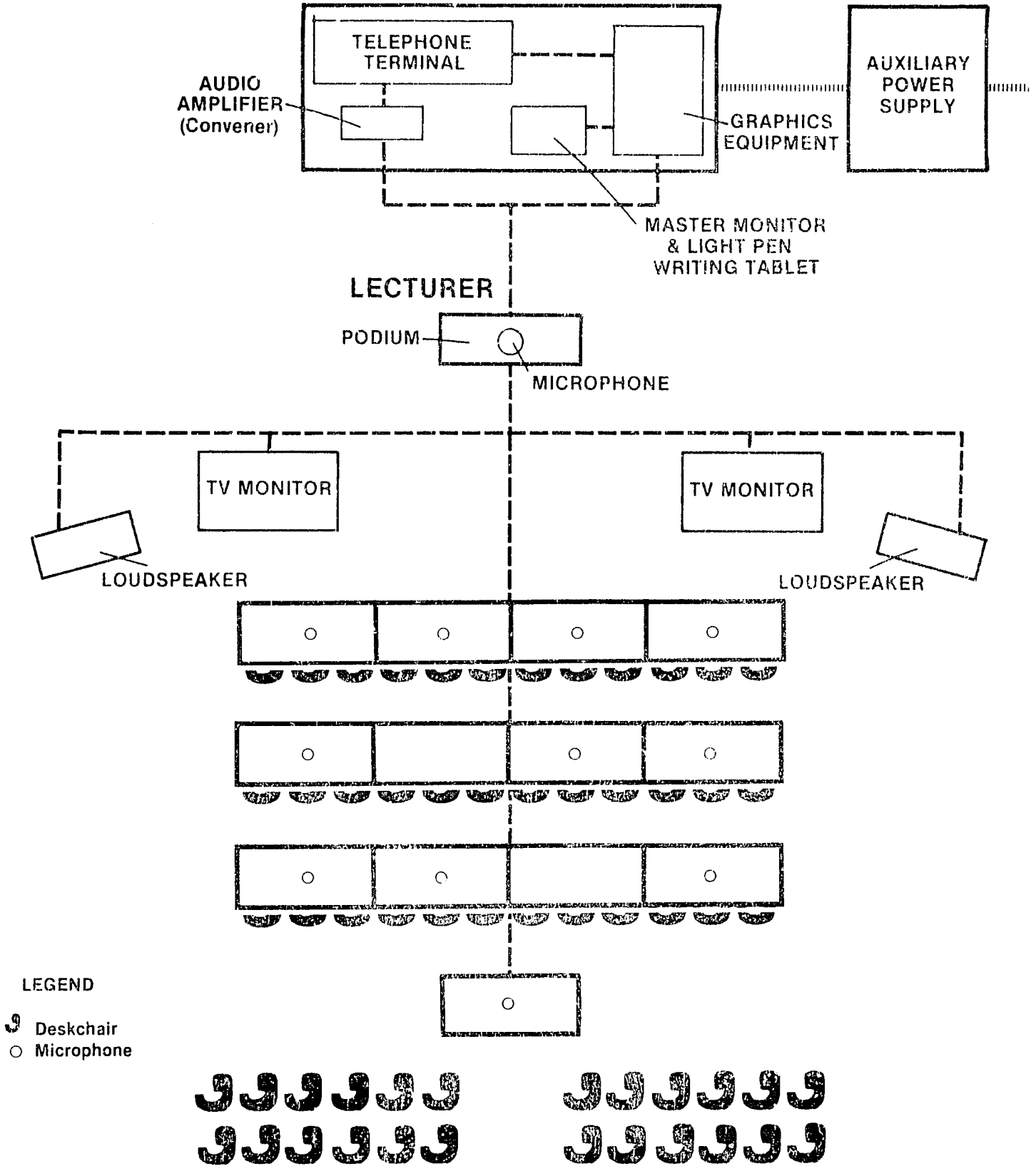
3. Exclude sites not participating in channel B conferences, thus ensuring privacy and also protecting graphics transmissions from noise.

4. Combine channels A and B to allow for full duplex operation with both channels being used for voice transmissions.

The telephone terminal was the first part of the system to be installed. It suffered an unexpectedly high rate of circuit card failures during the early installation period. The malfunctioning cards were returned to the manufacturer for diagnosis and repair. One of the main sources of failure was found to be in the logic circuit components on several of the circuit boards. This was apparently a result of the high humidity and temperature in the classrooms. Some cards were damaged by improper handling during installation, but many were in working order. In their haste to complete the installation, the engineers often resorted to component switching without determining if a card was actually faulty before replacing it. Fortunately, the rate of card failures greatly dropped after the equipment was in operation for a few months. The occasional failures that occurred later were repaired by SISDIKSAT technicians with inexpensive components.

As mentioned above, the telephone terminal was the subject of intense scrutiny in the attempt to determine the source of the continuing noise problems. Repeated testing confirmed that the terminal did not place any significant noise into the transmission system. Even then, some minor adjustments were made to lower its already low ambient noise production. After the initial problem of card failure, the telephone terminal worked extremely well.

A major concern during the system design was that it might be unduly complex. A wide range of functions was incorporated into the design, thus greatly increasing the size and complexity of the terminal equipment. This complexity made it more likely that technical problems would occur and also made it more difficult for local technicians to operate, maintain, and repair. A system evaluation by an Indonesian electronics firm noted that the system worked best when operated by technicians with a high degree of training. Because the terminal equipment was the key to the system, technical training programs were conducted over the system once a year for the local technicians and classroom operators.



TYPICAL CLASSROOM INDONESIA PROJECT

FIGURE 5

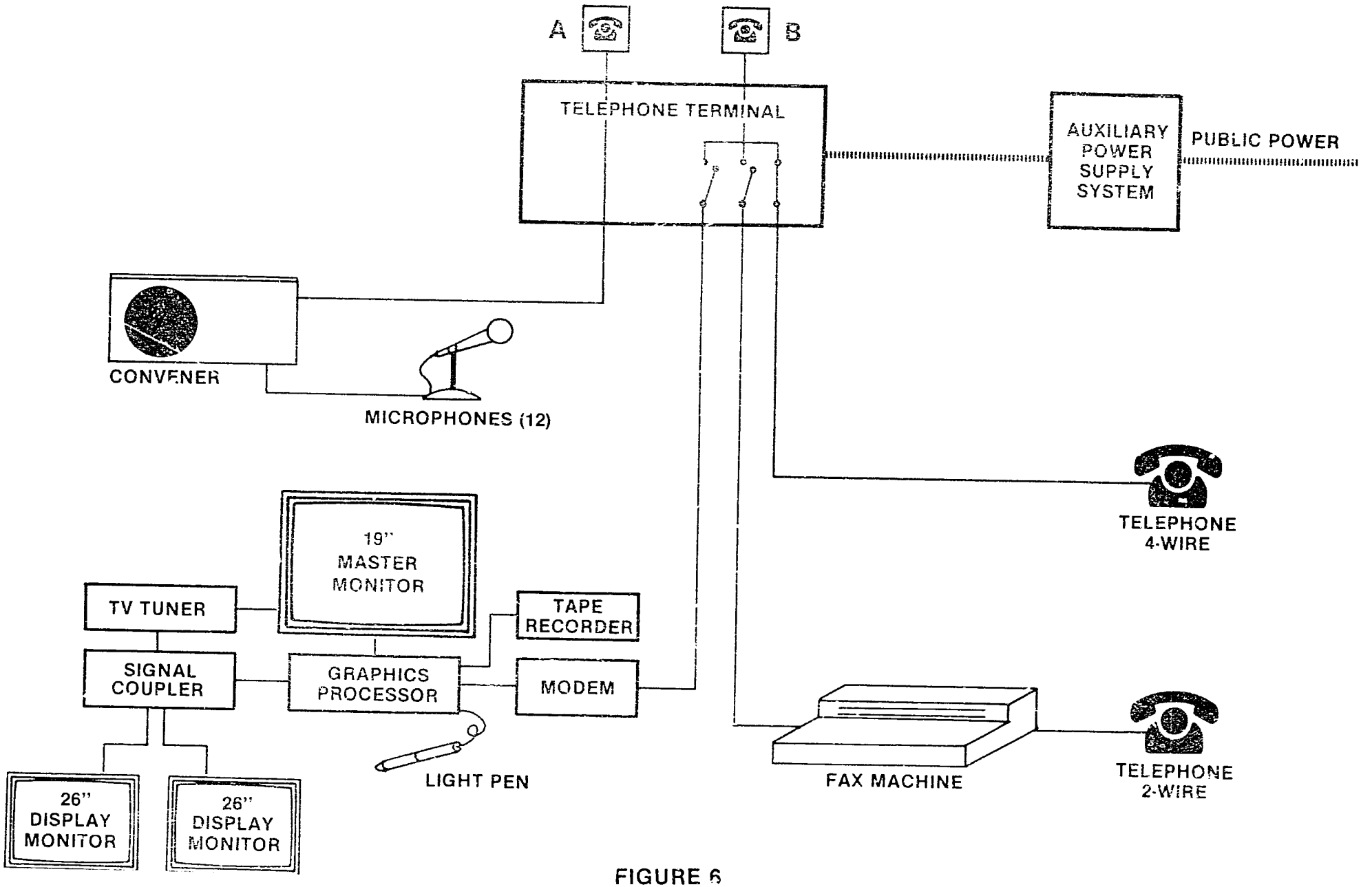


FIGURE 6

LAYOUT OF CLASSROOM EQUIPMENT IN INDONESIA

The requirement for strict privacy when utilizing the telephone for administrative purposes on channel B resulted in the circuit design becoming very complex. It was necessary to include several additional relays and timer circuits in each terminal to prevent eavesdropping by operators or unauthorized persons.

The requirement to provide both local and all-call signalling for the facsimile, telewriter, and telephone also resulted in additional circuit complexity. Likewise, such features as full-duplex operation and "transmit and receive reverse," although useful at times, resulted in additional relay circuitry.

The complexity of the design of channel B was increased by the desire to be able to select and switch from one to the other of the three peripheral services, either locally or, in some cases, remotely. This included the need to provide an exclusion feature so that when one of the three services was in use, interference could not be caused by someone trying to use another one. In retrospect, it appears that this equipment became overly complex as more functions were added, without rigorously enforcing the requirement for simplicity. This clearly led to problems later during installation and operations.

Audio Convener

Like UWIDITE, each classroom is equipped with a four-wire Darome convener. The SISDIKSAT Project had more microphones (12 per classroom) because the classes were large. Microphones were provided on the basis of one microphone for every four students.

The audio convener was, by far, the most well-established piece of technology purchased for the project. Obvious problems with humidity were avoided by using "military connectors" for the microphones and using silver contacts at points where corrosion might occur.

Some problems appeared in the second year of operations with the final power output amplifier. Overheating appears to be the primary cause. The heat sink on which the components were mounted may not be adequate. This mounting became oxidized on some of the units and probably did not dissipate the heat as efficiently as it should have. The conveners are easy to repair, however, and the maintenance can be done by the BKS technical staff. Overall, the conveners perform very well.

Graphics Writer

As an experiment in using interactive graphics to support lecturing, each classroom was also provided with an "electronic blackboard," or graphics writer. The experimental aspect was related to the relative newness of the graphics writer equipment. Unlike the audioconferencing component of the RSP technical systems, which were relatively assured of operational success, the addition of a graphics component to the system was in the interest of pure "research." Would it work in this environment? There had been little field experience in its application or use. This component is significantly more complex than the other classroom equipment.

To be succinct, the Aregon audio graphics equipment has been a major disappointment. Despite the expenditure of much money on spare parts, repair visits, and

training, the equipment does not operate reliably and probably will never be an integral part of the teleconferencing system. A detailed discussion of the graphics writer equipment performance is included in Technical Note One at the end of this report. At this juncture, it is telling that the manufacturer no longer markets the equipment.

Television Receivers

As an auxiliary display system for the graphics writer in addition to the master monitor, two Philips 26-inch television monitors were provided to each classroom. The combination of the three monitors was sufficient for a classroom of 50 students. A Philips tuner was provided to receive broadcast signals. The Philips system was chosen largely because of price and, more importantly, the existence of extensive repair services for Philips in Indonesia. Finally, VCRs were provided by the Indonesian Government through another foreign assistance project. These VCRs were connected to the classroom monitors through the Philips tuners.

Facsimile

It was clear early in the planning that physically moving paper around the BKS was a problem. It is difficult to exchange course notes, research articles, and administrative memoranda quickly and inexpensively. It was obvious that a facsimile component would be a valuable addition to the system.

An extensive review of available facsimile machines was conducted with the following considerations:

1. The number of moving parts had to be minimal to keep maintenance low; at a minimum, this meant the use of flat-bed image scanning rather than a rotating drum.

2. Because a large volume was expected, reception had to be unattended and automatic. This required a reliable paper feed system and the use of humidity-resistant paper.

3. The machine had to have a high "mean-time-between-failures" rate because arranging for repairs would be difficult.

4. To minimize transmission time as well as to ensure compatibility with other machines, the facsimile had to offer rapid transmission speeds and be compatible with existing CCITT Group One and Group Two facsimile standards.

5. The machine had to tolerate noisy lines for both transmission and reception.

6. The machines had to be capable of operating from point-to-multipoint so that, for example, a memo from Jakarta to each of the campuses would be transmitted only once.

State-of-the-art digital machines were rejected after several manufacturers warned that the digital machines required extensive software maintenance and would not operate reliably in the high temperature and high humidity in the classrooms.

The Burroughs Dex 2100, an analog desk-model machine, was chosen as the least expensive machine offering a full range of features. The Dex 2100 pr vides transmission in a proprietary standard in 35, 50, and 100 seconds per page, depending on the desired level of resolution, and is compatible with the major CCITT analog standards. In the presence of line noise, the machine automatically defaults to the CCITT three-minute mode which is far less susceptible to noise.

The machine offers automatic unattended reception, uses roll paper with plastic coating (preventing moisture absorption), and tolerates Indonesia's climate.

Unfortunately, the machine's sophisticated electronic "hand shake," used to establish synchronization with the receiving machine, made point-to-multipoint telephone transmission problematic. The RSP engineer tried to circumvent this by altering the terminal's circuitry so that when the facsimile machines are addressed in the All Fax mode, the telephone terminal in all but one location disengages the receiving machines' return path. Thus, all but one of the multiple handshakes are suppressed. This adaptation, however, was not successful, and the All Fax function was never used. All successful transmissions are made point to point.

Finally, there was a relatively minor problem related to the need to adjust the Burroughs machines' two-wire interface with the SISDIKSAT system's use of four-wire interfaces. This necessitated a conversion from four-wire to two-wire at the terminal interface, adding complexity to the design and the adjustment of signal levels. Arranging for a four-wire design of the Dex 2100 would have required expensive customizing of the machines.

Like the audio convener, the facsimile machines were commercially available long before their purchase. There have been few problems with the machines, although increased maintenance probably will be necessary as their use increases. Because the machines are very complex, further maintenance training will be required before the SISDIKSAT technicians can diagnose problems and repair the machines. A repair contract may have to be arranged with an electronics shop in Jakarta.

Telephone

A four-wire telephone was provided at each site for University and system administrative applications. In addition, a two-wire telephone for use with the facsimile machine was supplied because the facsimile machines, in some cases, are located outside of the classroom. To ensure privacy where the facsimile is removed from the classroom, the telephone terminal is designed to automatically disengage the facsimile telephone during a teleconference.

Auxiliary Power

Because of the unstable and unreliable power at all of the project sites, equipment had to be provided to stabilize incoming voltage and ensure power in the event of a power outage. The system is designed so that incoming power from the public utility is routed through a voltage stabilizer. In addition, a series of batteries, operating with a battery charger, are connected to a DC/AC inverter. During a power outage the inverter will automatically switch on and provide AC power to the classroom equipment. The auxiliary power system is designed to provide a maximum of five hours of power. The

batteries are designed to be discharged and recharged without damage. Conventional automobile batteries, the most obvious alternative, would not provide the necessary operating longevity because they cannot be continually discharged to the levels anticipated in the project operation. The auxiliary power system is shown in Figures 7 and 8.

This equipment has operated reliably for over two years. In most locations power failures have occurred almost daily so that these units are used often. The batteries, which can sustain major charging/discharging cycles, have an estimated lifespan of nine years. Future designs should consider the addition of a low battery voltage cut-off relay in the power lead to the equipment to eliminate the possibility of draining the batteries if commercial power is out for two days or more. This will also protect less sophisticated replacement batteries from being severely damaged by deep power discharges.

System Maintenance and Staffing

SISDIKSAT has developed a large technical staff and has achieved mixed results--technical ability appears to be greater than managerial capability. Two engineers work out of the central project office and have responsibility for overall system maintenance and operations. Each campus has a local technician who is either an engineer or someone with hands-on electronics experience. He supervises the maintenance of the classroom equipment and the work of the local operators who run the equipment every day. Some operators have had formal technical training; some have only an interest in electronics. The chief engineer went to the United States and Great Britain for training. He and his assistant worked closely with PERUMTEL and the RSP engineer during the installation of the equipment. The RSP and SISDIKSAT engineers trained the local technicians in a seven-day training program. The operators were trained initially on the job and now receive yearly refresher courses over the satellite system.

A major problem with maintenance has been that the project engineers and the local technicians are not full-time personnel. They also serve as regular faculty members at their campuses. Most operators are on the job full time, and they generally have performed well, even doing complicated tasks like leveling. It was initially thought that only the local technicians would be able to perform that task.

There have been only minor problems in passing on the technical knowledge to staff members, but there has been a greater difficulty in helping them to manage the system and maintain discipline among the sites. Although system-wide technical problems generally are dealt with very quickly, equipment problems at the sites often persist for days or weeks. Problems are not reported quickly to the central office, or the central office fails to respond because the engineers are busy with their other jobs. Broken equipment is not repaired quickly despite the availability of spare parts. The technical personnel know how to do their jobs, but the weakness lies in poor management of the whole system. The two project engineers do not have time for constant monitoring of the system, and they do not have direct authority over the personnel at each of the sites.

The lack of full-time central project staff has been compounded by inadequate national funding to pay for more staff, to purchase spare parts manufactured in-country, and to transport parts, technicians, and equipment where needed. Without such a budget, long-term maintenance cannot be successful, particularly after the initial foreign assistance funds are depleted.

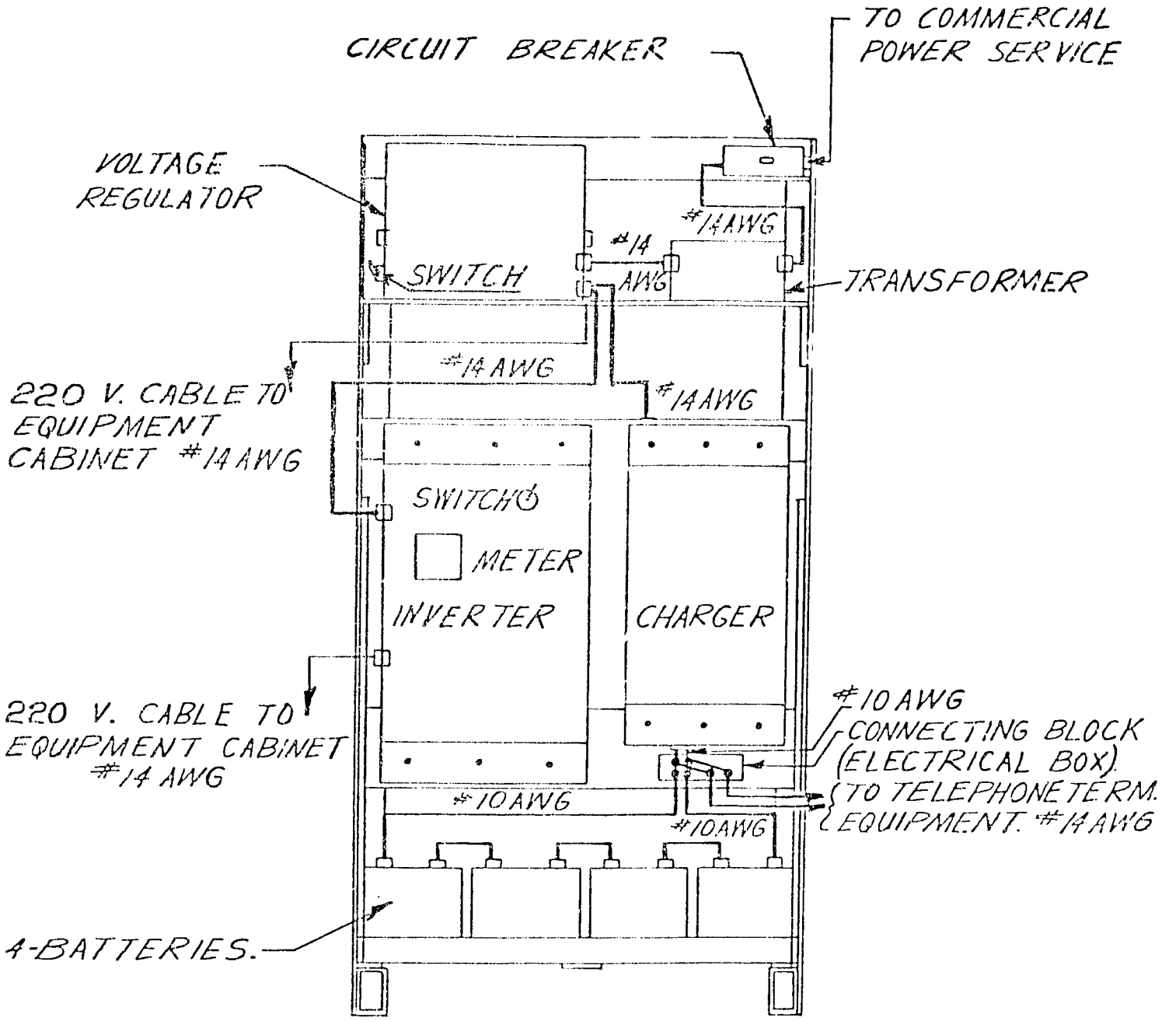
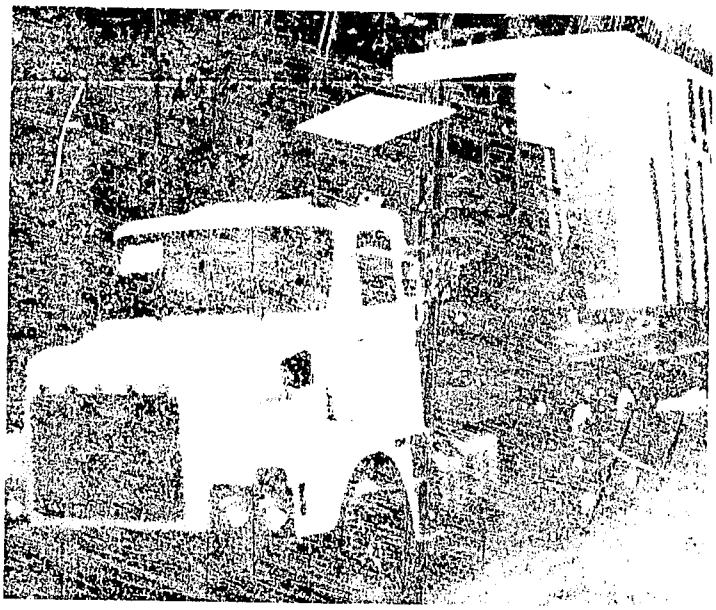


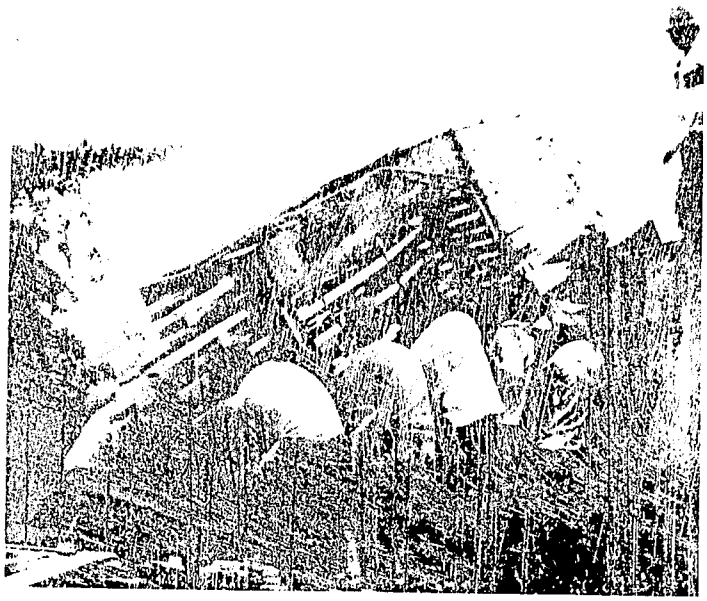
FIGURE 7

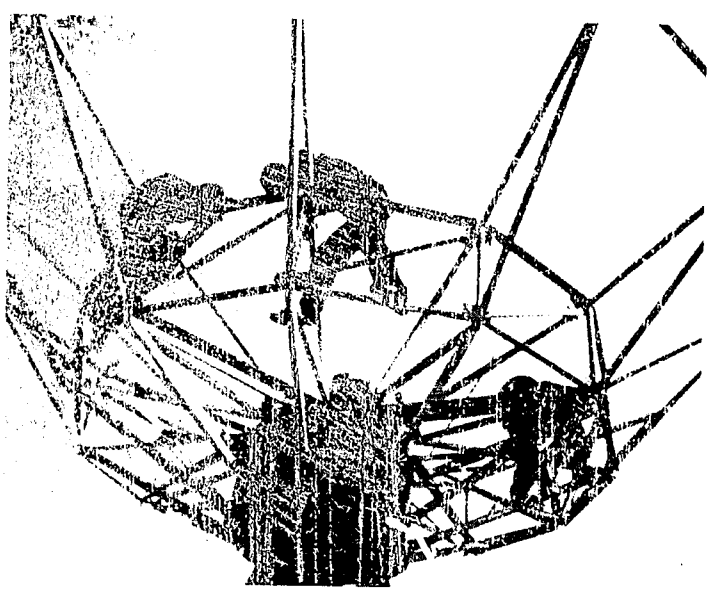
WIRING DIAGRAM

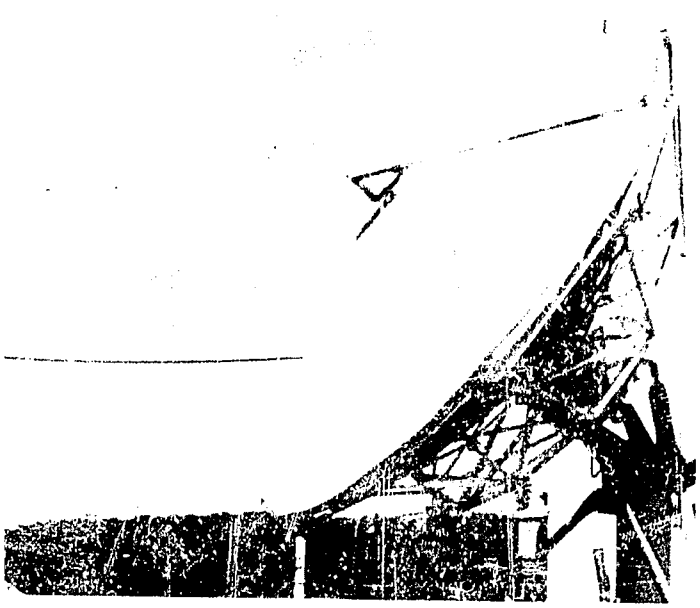
AUXILIARY POWER SUPPLY RACK

Images from the AID Rural Satellite Program



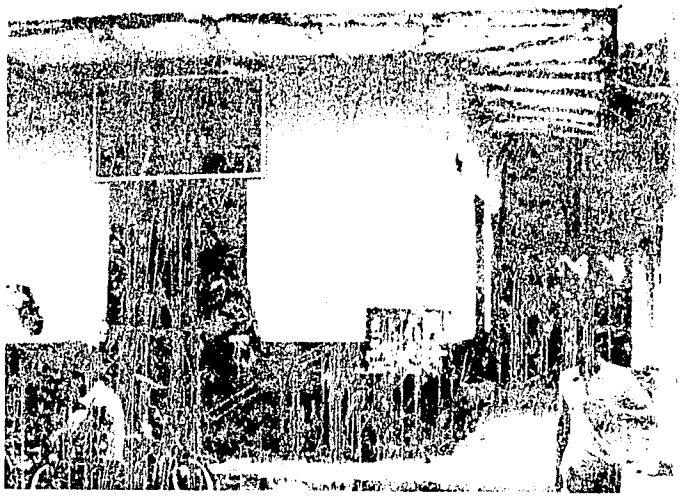


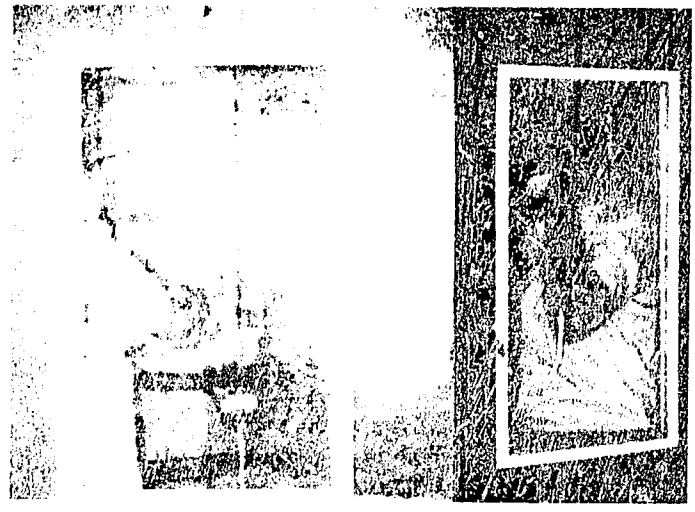




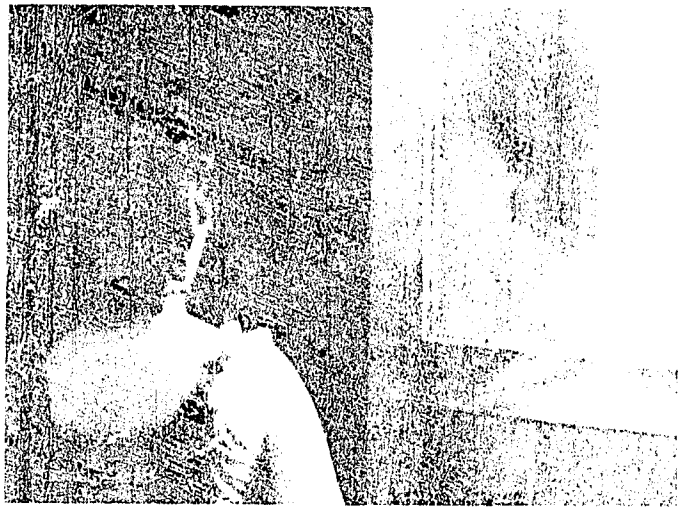
Satellites can provide telecommunications services to remote and rural areas. The smaller the earth stations, the lower the costs. The Peru Rural Satellite Project is the first to successfully use small six-meter stations with the international satellite system for internal communication.

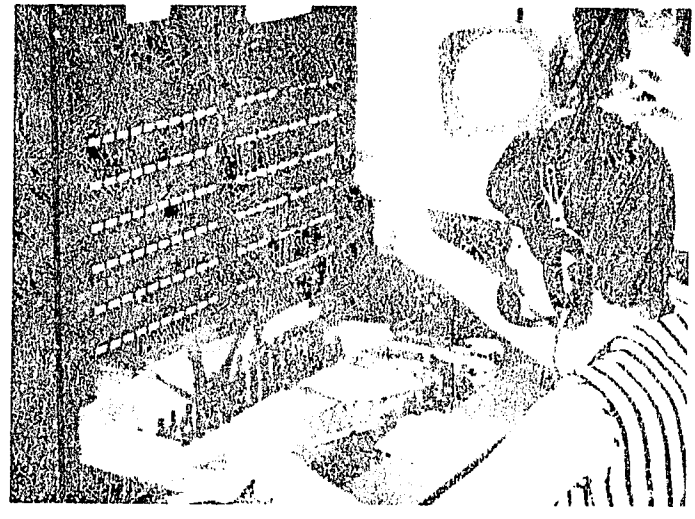
a

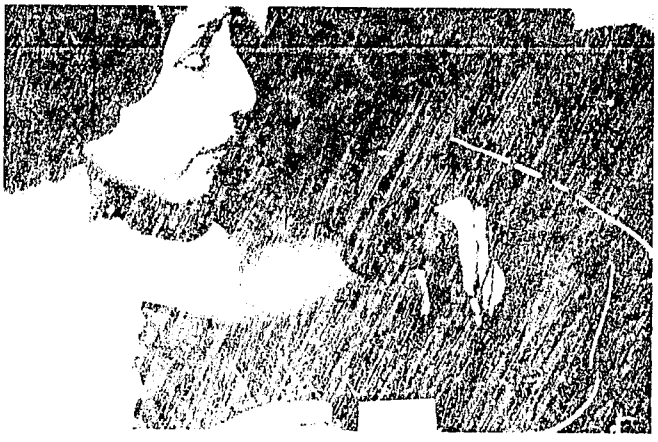




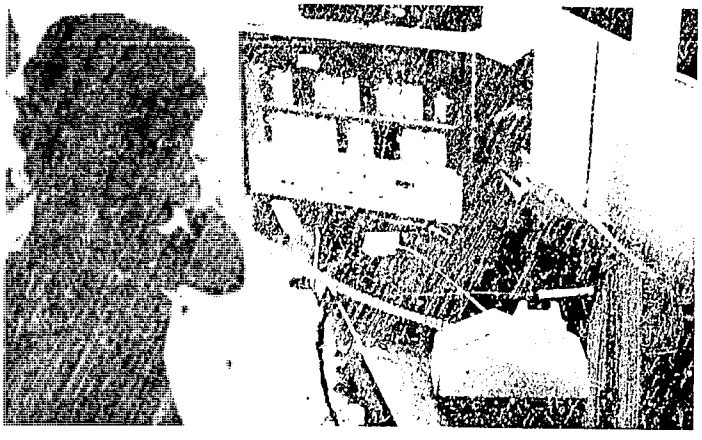
Basic telephone service is essential to rural development. For the first time, the rural Peruvians in the remote San Martin region are connected with the nation's commercial and political centers—and with each other. Within months, the new telephone system was used to capacity and has since been expanded twice to accommodate heavy usage. Over 110,000 phone calls were made in 1985, generating over $100,000 in revenues.



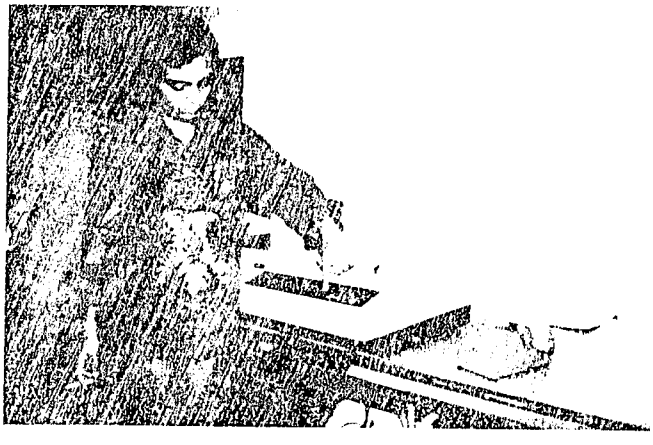




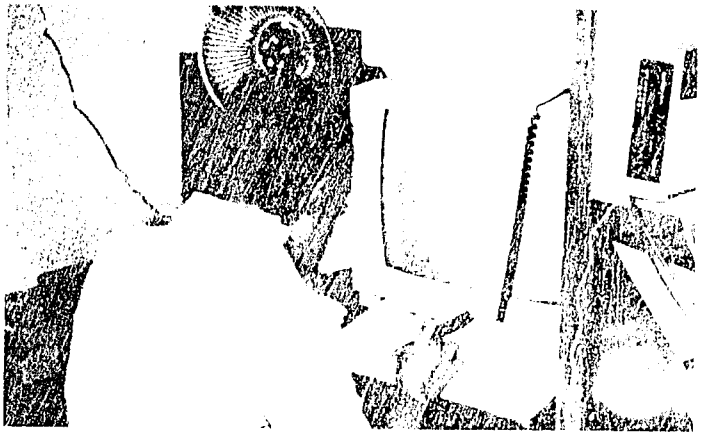
Push-to-talk microphone



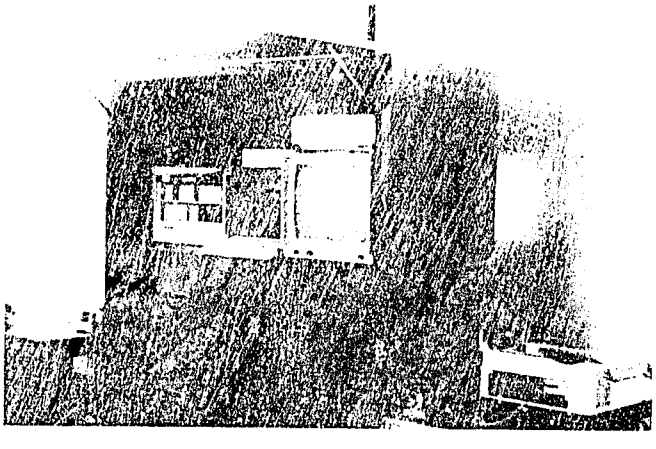
Telephone terminal and private telephone



Facsimile machine



Telewriter/graphics display



Typical classroom layout

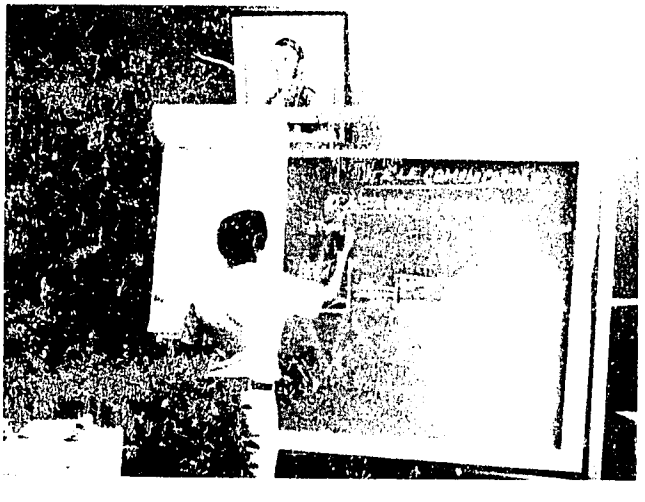
Special equipment attached to telephone lines can transform ordinary telephones into audioconferencing systems linking many groups over vast distances. Using a simple telephone circuit, groups of people can talk, view pictures transmitted by telewriters, and receive text via facsimile. The Rural Satellite Program installed 25 "electronic classrooms" for three different projects.

C

In-service training of primary school teachers

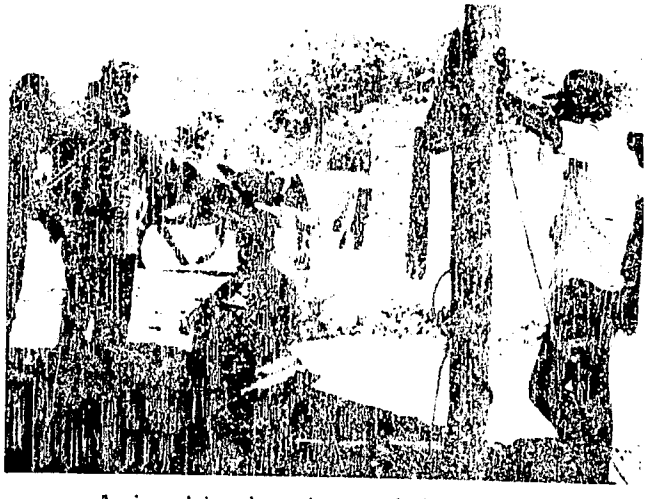
Administration of rural institutions

University teaching to thousands of students



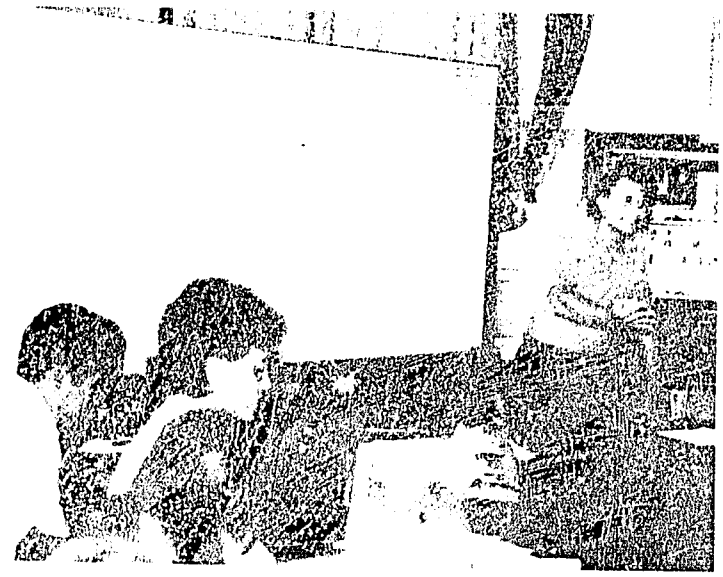
Technical training for telecommunications personnel

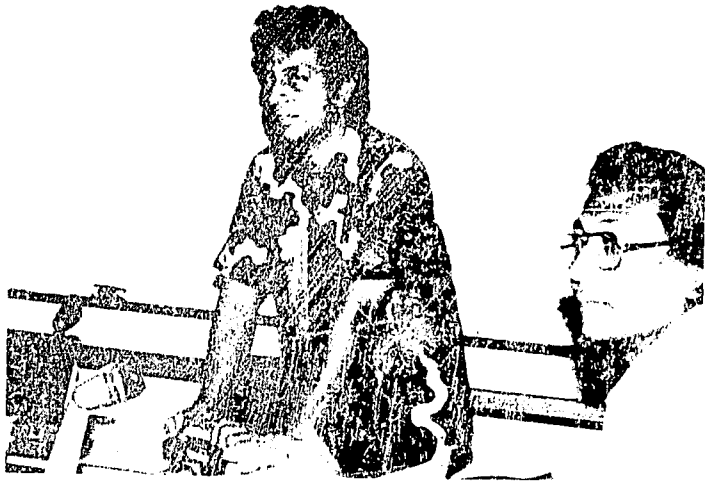
Interactive audioconferencing networks can reliably and affordably support many different development activities. Audioconferencing provides a means of extending scarce expert resources and educational opportunities to remote and rural areas. The Rural Satellite Program explored its applications for health, education, and agriculture. The Pilot Projects in Indonesia, the West Indies, and Peru used audioconferencing for university teaching, in-service training of health care workers, teachers, and agricultural extension agents, medical consultations, research exchange, and rural administration. Over 92 percent of the participants indicated it helped them do their jobs better.



Animal husbandry training for extension agents

Coordination of Child Health Campaign

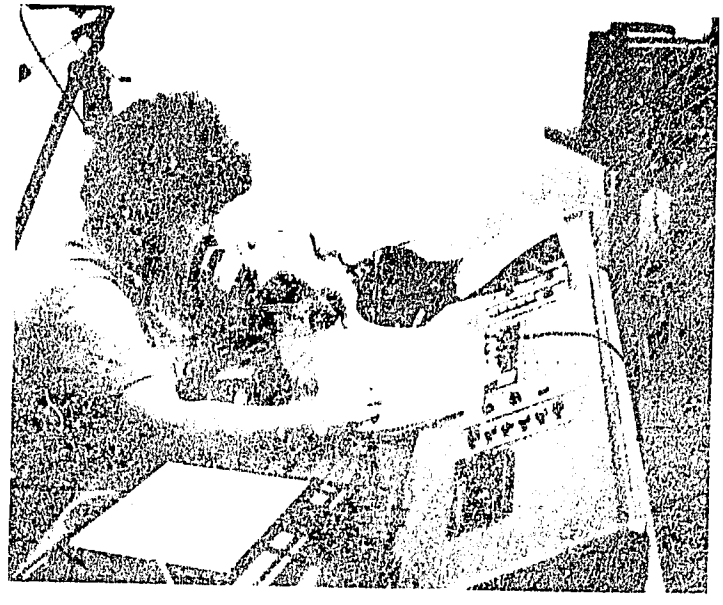




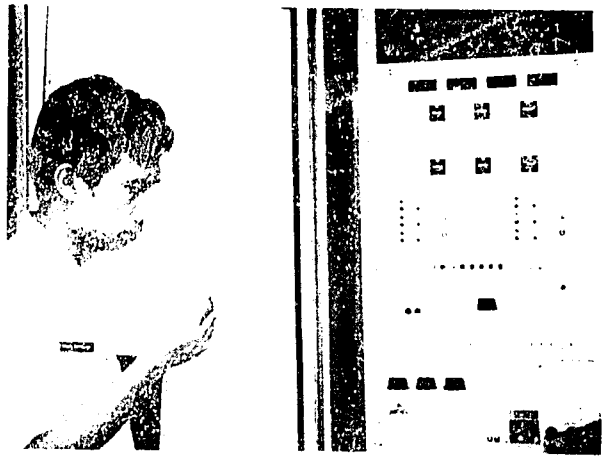
DEPARTEMEN PENDIDIKAN DAN KEBUDAY
UNIVERSITAS HASANUDDIN
KANTOR PUSAT
PROYEK PENDIDIKAN JARAK JAUH
MELALUI SATELIT
USAID - BKS PTN INTIM

Effective audioconferencing programs need careful coordination and management of programming, technical, and administrative components. General requirements for successful communications support projects include:

- a central coordinating office supported by staff at all sites
- accurate identification of user needs and appropriate program development
- thorough training of management and technical staff, as well as program presenter and general users
- development and distribution of educational support materials
- adequate budget for central office and local site operations

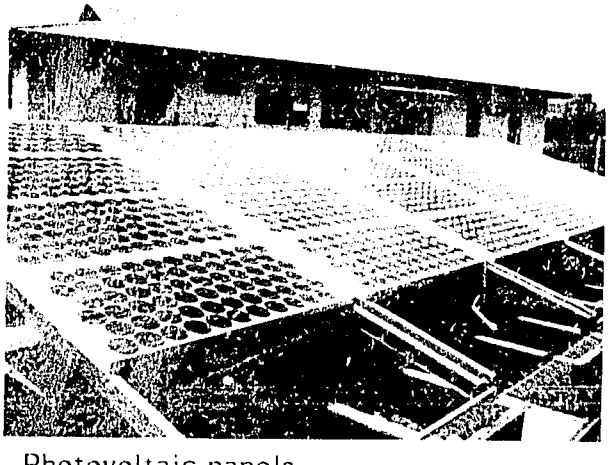


Earth station, photovoltaics, and audioconferencing room

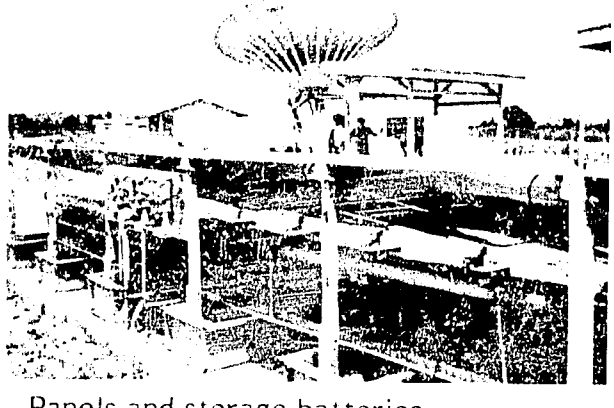


Station requires only quarterly maintenance visits

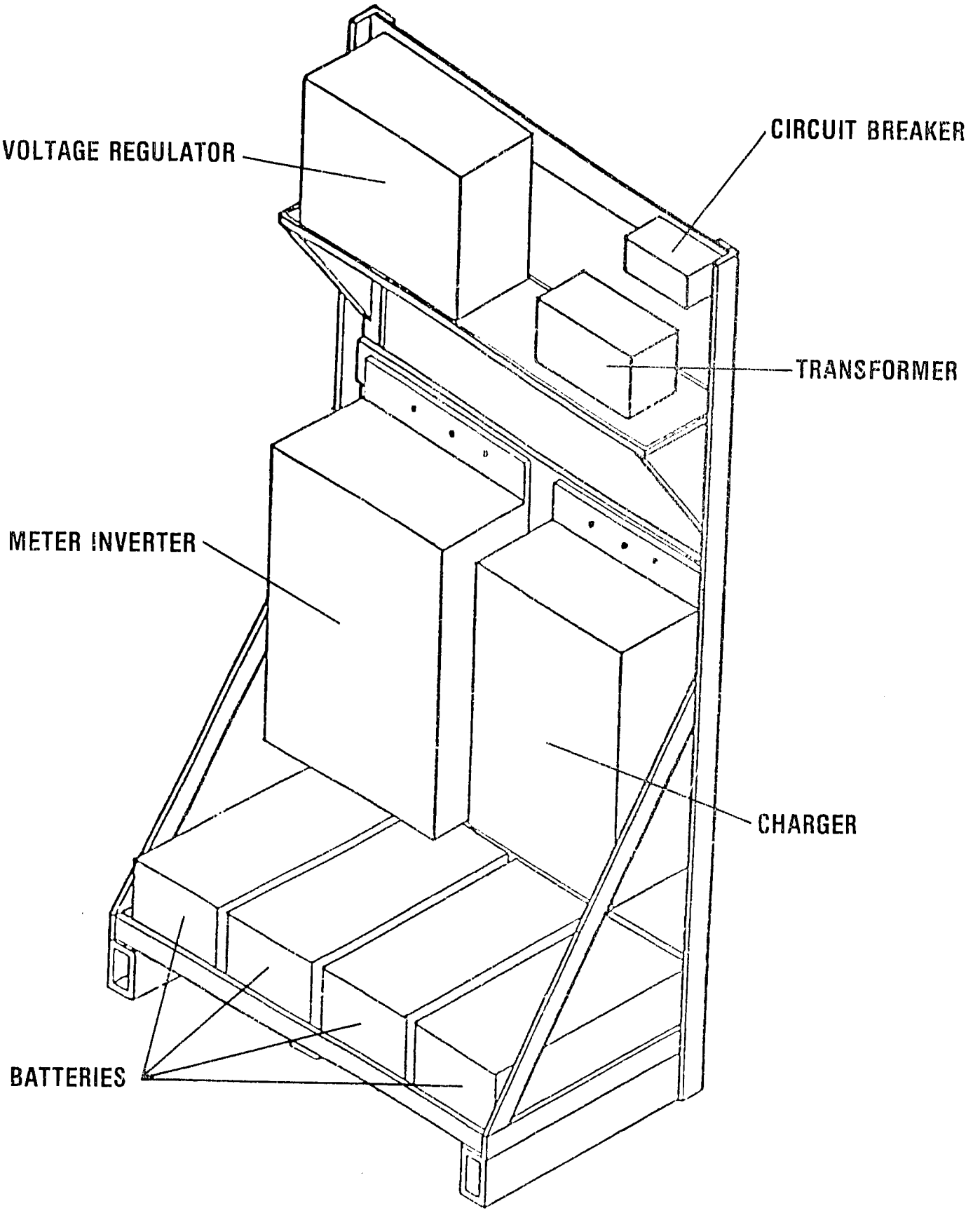
Satellite technology can be adapted to withstand the rugged conditions prevailing in rural areas. In the remote Indonesian village of Wawatobi, the Rural Satellite Program designed and installed a small solar-powered earth station and photovoltaic array. The station provides multi-channel telephone service with low maintenance and power requirements. It operates on less electricity than a home steam iron.



Photovoltaic panels



Panels and storage batteries



AUXILIARY POWER SUPPLY

FIGURE 8

There are also problems with the quality and the discipline of PERUMTEL's staff at the smaller transmission sites. This needs constant surveillance because the cooperation of PERUMTEL is essential.

Because some of the equipment requires more technical knowledge than the small maintenance staff has, the project has developed maintenance contracts with electronics firms in Jakarta. This has resolved some of the more difficult technical failures, particularly in the data-related equipment, thus sparing the project from shipping poorly functioning equipment back to the United States. Modems, keyboards, meters, and processor boards have been repaired in Jakarta.

Conclusion

Although the above description is of a complex system with many initial problems, the overall prognosis for the Indonesian system is positive. Many of the problems with the system's complexity have been overcome, operational problems with PERUMTEL minimized, and staff sufficiently trained to keep the system in operation. An independent technical evaluation of the system and a rigorous technical monitoring system established by the RSP indicate the basic design is sound and that the audioconferencing system is 98 percent reliable.

The key issue is whether the BKS and the Indonesian Ministry of Education and Culture are able to provide the resources necessary to sustain and manage the technical system in light of the massive budget cuts induced by the falling price of oil. In the meantime, the system continues to provide reliable service for 17 courses to over 3,500 students each semester. Three sites have been added and several classrooms expanded with host-country funds, and both the Open University and the Directorate of Primary and Secondary Education are regular "guest" users. It appears that the Ministry of Education will decide it cannot afford not to continue to support SISDIKSAT.

THE PERU RURAL COMMUNICATIONS SERVICES PROJECT (RCSP)

The Peru Project is quite different from the University of the West Indies and Indonesia projects because its primary orientation is basic rural telephone services rather than formal education. The Peru Project was designed to demonstrate how satellite earth stations combined with radio end links could be used to open very remote areas to communications and do so cost effectively. The system provides both governmental teleconferencing for rural development and public telephone services to seven sites in the district of San Martin in northeastern Peru.

The project, which has deployed three earth stations and four radio links, now has ten teleconferencing sites connected by a combination of project equipment and existing Peruvian facilities. Figure 9 provides a map of the project area.

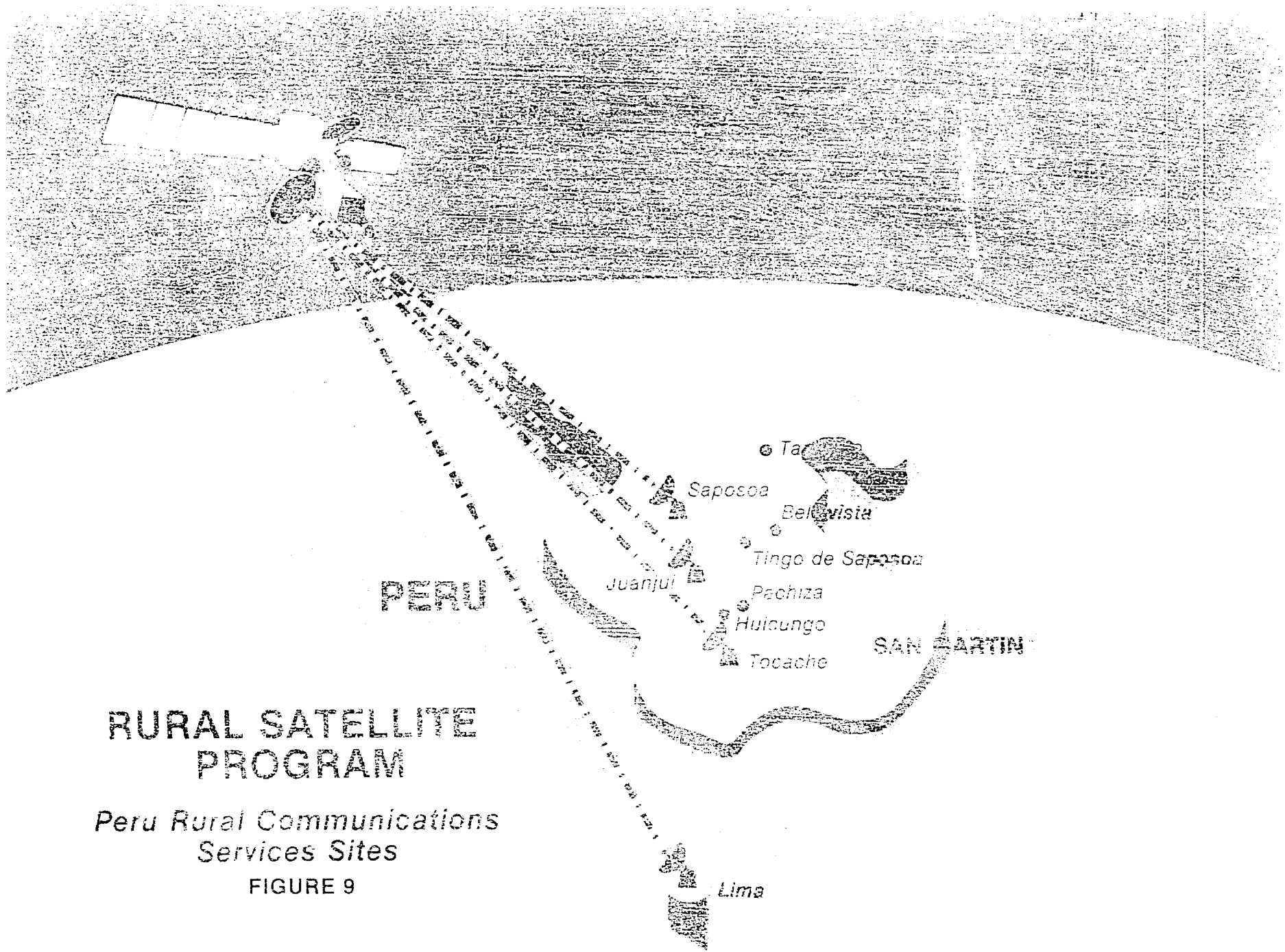
The Peru Project has a different administrative structure from the other two projects which affected its development and implementation. Initially the Peru Project was to be administered by Human Resources Management, inc. (HRM), a Washington-based consulting firm. Engineering planning, however, was to be done jointly by ENTEL-Peru (the Peruvian telephone company), AID, and HRM. After most of the equipment procurement was under way, the contract was transferred to the Academy for Educational Development and became part of the Rural Satellite Program. The RSP, in turn, participated in the design and procurement of the teleconferencing equipment and in the negotiations among ENTEL, AID, and the equipment suppliers to remedy some of the problems discussed below. No one person was ever designated as project engineer, and there was never overall engineering supervision of the project technical system. Instead, the project was planned piece by piece because of the need to make specific decisions at given points in time.

Finally, while the Peru counterpart agency was ENTEL and there was an ENTEL project director, responsibility for the project within ENTEL was fragmented. Specific project components including equipment construction, installation of radio links and telephone offices, and earth station supervision were under separate divisions of ENTEL. Often, the ENTEL project director served as negotiator among the divisions of ENTEL. This administrative fragmentation had serious ramifications for the project's final implementation and operation.

Transmission System

The Peru Project went through a series of design phases. The basic design was tied to the expansion of the domestic satellite communications system into the more remote areas of Peru. The initial design, proposed by the AID project team, recommended the acquisition of two three-channel earth stations which would be tied to surrounding villages by radio UHF/VHF circuits. One channel would be used for the public telephone system, one for government calling, and one for redundancy. The system was to employ manual (i.e., operator) switching.

This design was rejected when the initial procurement led to bids more than five times the estimated costs for the community radio-telephone installations. After reviewing the overall network design, a greater emphasis was placed on satellite linkages rather than terrestrial ones because satellite links would eliminate the need for costly and maintenance-intensive terrestrial radio links.



RURAL SATELLITE PROGRAM

Peru Rural Communications Services Sites

FIGURE 9

After substantial technical and financial review, AID and ENTEL agreed that AID would provide three earth stations and that ENTEL would connect them to four remote communities by radio. The contract for the earth stations was let to the Harris Corporation and for redundant diesel power systems to Johnson Towers Company of Baltimore, Maryland. ENTEL supplied the radio equipment and civil works needed to establish public call and earth station facilities.

Two stations, Juanjui and Tocache, were to operate with four SCPC channels and Saposoa, a smaller community, with three (although wider modification channel capacity could be expanded to up to 12). All three of these sites comprised the primary network and were to devote one channel full time to teleconferencing. The full-time designation was to prevent competition between the teleconferencing activities of the project and commercial activities. Each site was also to offer public telephone service. The exact nature of the public service (e.g., to have home subscriber service or simply public call offices) was not determined prior to the final system design. The final network design is shown in Figure 10.

Each of the secondary sites, those connected to the primary network by radio, was to receive one VHF channel which was to be shared by the telephone and teleconferencing services; Bellavista, a larger community, was to receive two channels.

As part of the effort to reduce capital costs, thus showing that rural communications could be affordable, the standard earth station design was modified in three ways. First, AID and ENTEL specified 6.1-meter earth stations, never before used with INTELSAT domestic service and smaller than standard antennas, as part of a calculated risk to conserve costs. Second, the earth stations were designed to be non-redundant on the premise that rural telecommunications could forego some reliability if system costs could be significantly reduced. A corollary of this decision, however, was that the non-redundant equipment had already proved relatively reliable, although this decision forced Harris to modify its standard design. Third, system installation would forego the usual "security net" of a "turnkey" contract, whereby the manufacturer is legally responsible for the earth station's installation and the successful completion of all INTELSAT acceptance tests.

Instead, at ENTEL's request, Harris was responsible only for supplying the earth stations and "supervising" their installation. ENTEL did not want a turnkey operation because of the high cost of such a contract. (ENTEL preferred that it be given the money to purchase more equipment.) ENTEL believed it had a staff with the necessary experience to install the earth stations and that by installing the earth station its personnel would gain technical skill which would benefit the project and similar endeavors over the long term.

Earth Station Installation and Performance

The earth station equipment arrived in Peru in August 1982. It was assembled and installed over a six-week period beginning in early November. Although ENTEL actually installed the earth stations, Harris supervisors oversaw the process at each site.

TELECOMMUNICATIONS NETWORK OF THE PERU RURAL COMMUNICATIONS SERVICES PROJECT

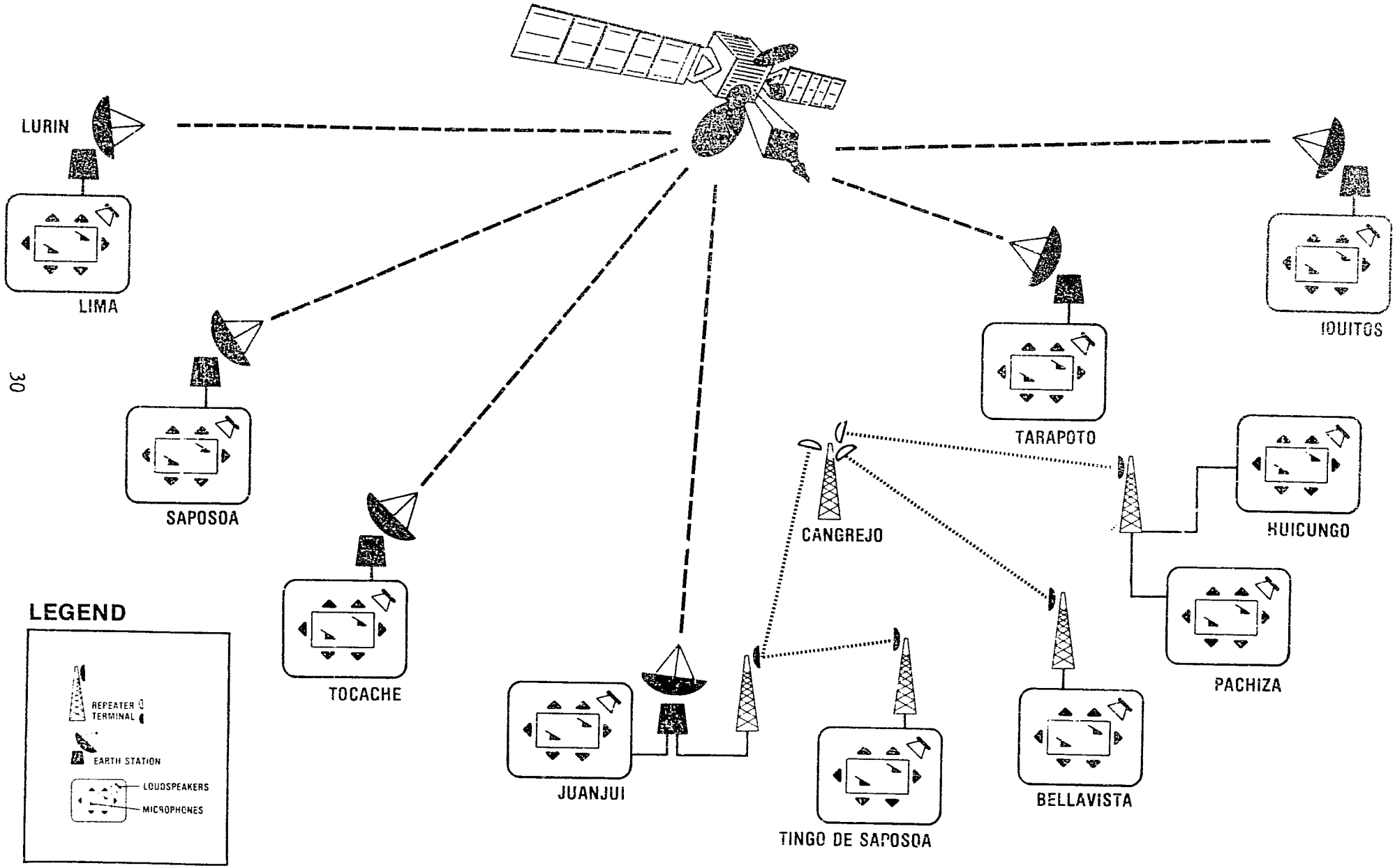


FIGURE 10

Installation of the Harris earth stations was problematic from the start. The fragmented responsibility for engineering combined with problems with ENTEL's organizational structure and the very limited experience of its supervising engineer with earth station construction and operation may have offset the economy of local installation. (In fact, the RSCP was ENTEL's first attempt at non-turnkey earth station installation.)

Because Peru leases domestic satellite service from INTELSAT, all earth stations must meet INTELSAT's transmission standards. Two of the antennas, in Saposoa and Juanjui, do not meet these standards. Although antenna installation was supervised by two Harris engineers, the antennas do not provide appropriate propagation characteristics. In part, the problems with antenna patterns may be caused by the proximity of the antennas to buildings. ENTEL maintains, however, that the antennas did not fit together properly during installation. The two antennas still do not meet INTELSAT standards. This could have serious ramifications if INTELSAT were to withdraw the stations' temporary operating licenses. At present, however, this appears unlikely.

There have been major problems with the power supply for the transmitters. These transmitters use 40-watt Traveling Wave Tubes (TWTs). All four units supplied (three operational units and one spare) have become defective or, more accurately, have burned out. This is a very high failure rate, and reasons for it have not been established. ENTEL maintains that there are some inherent faults in the transmitters. Harris has denied that the equipment is faulty and has indicated that poor installation and maintenance led to the failures. The failures might have been caused by unregulated power supplies, but this could not be confirmed during diagnostic visits to the sites. ENTEL has kept the earth stations operating by replacing the TWTs with power amplifiers from other manufacturers, by drawing upon the spare parts of other earth stations, and by adding voltage regulators. These amplifiers operate at a lower power (five to ten watts) and use solid state electronics. They worked satisfactorily with the low number of channels, but could not sustain any major increase in earth station capacity. ENTEL wanted Harris to replace the original 40-watt TWT with 10- or 20-watt amplifiers, preferably solid state type. Harris, arguing that it had no responsibility for the TWT problems, resisted making the replacements. Eventually, ENTEL itself made the necessary modifications to expand channel capacity.

There also were problems with the SCPC modems which burned out repeatedly. This was apparently caused by maladjusted power levels.

All of these problems were compounded by the instability of the INTELSAT IV-A satellite providing domestic leased service to Perú. This satellite was near the end of its life and began deviating from orbit more than expected, requiring the earth stations to track the satellite to maintain service. Two of the earth stations, however, did not have functioning pilot monitor indicators, and the satellite was tracked by technicians listening to background noise on the channel as the earth station was repositioned. The tracking problem was worsened by the technicians' relatively casual approach to readjusting the station's position, often awaiting complaints from telephone operators that the noise levels had reached unacceptable levels. In 1985 the quality and reliability of the satellite links improved markedly when the system began using INTELSAT's series V-A satellite, resulting in 365 days of uninterrupted service.

After installation was completed, ENTEL attempted to improve system performance and reduce the cost of rural service through the simplification of the network's configuration. ENTEL engineers reduced the number of satellite circuits from ten to two by placing the main audioconferencing bridge at the Lurin earth station near Lima.

Initially, the telephone system suffered serious traffic congestion problems. Not only had ENTEL twice expanded the subscriber service, but the gateway point--Juanjui--to the radio-linked sites was unable to accommodate both the local and remote villages' demand for telephone service. In consequence, the Juanjui operators gave preference to local calls, resulting in poor service to the secondary sites. ENTEL, however, has eased the congestion by adding two additional channels to each earth station and by routing the heaviest secondary site traffic--from Bellavista--through the least used earth station at Saposoa. Traffic flow is further facilitated by the recently installed automatic switching system at Tarapoto.

Power Generator

The power generators supplied by Johnson Towers were subject to rigorous use. Although performance specifications were based on a daily usage rate of eight hours, the generators were pressed into 24-hour service by heavy telephone service demands and the unanticipated facility support needs which required security lighting, etc. Not surprisingly, the overburdened generators began to fail, causing the "cannibalization" of the redundant generators for spare parts. This was exacerbated by Johnson Towers' slow response to ENTEL's request for spare parts.

Radio Links

Because AID did not have sufficient funds to provide both the earth stations and the radio links, ENTEL agreed to provide the links to the four remote sites. ENTEL wanted to purchase new equipment, but severe budgetary problems finally led it to propose using radio equipment manufactured by BUDAVOX, a Hungarian company. This equipment had been previously acquired from the Hungarian Government in exchange for fish meal. This equipment was rarely used by ENTEL because of its poor performance.

The secondary site radio linkages have suffered significant technical problems. ENTEL's hesitancy to use the BUDAVOX equipment is well justified. The units are unreliable and need frequent service. Most of these units are located in remote locations which are difficult to service (five of the units are at the top of a mountain and are reached only after a three-mile hike).

More important, the power subsystems are totally inadequate for any kind of reliable service. Power is provided by two 12-volt tractor batteries. These batteries must be recharged every ten days and sometimes more frequently. They must be physically transported to a central location for recharging. The administrative and transport problems have led to frequent system outages. Conditions at the secondary sites have not improved and, given the fundamental difficulties with both the equipment and the power source, will not improve without a complete replacement of the radio equipment and a change in the means for providing power and maintenance.

Also, because of inadequate system engineering, there were problems with the initial connection of the radio links to the earth stations. The interface, which required a two-wire/four-wire connection, was poorly engineered and caused significant transmission problems until an engineer was dispatched to correct the connection.

End Equipment

Because the primary orientation of the Project is to provide telephone service to the area, the majority of telephone service end equipment was provided by ENTEL. Public call facilities were installed at each site, and in Juanjui and Tocache manual switches and outside plant were provided for subscriber service.

Provision of the teleconferencing equipment was the responsibility of the Rural Satellite Program. All sites, including Lima, were equipped with the simplest audioconferencing capability. The conferencing facility consisted of Dantel terminal equipment for signaling, switching, and level adjustment, two Dantel bridges--at Tarapoto (later Lima) and Juanjui--and a Darome convener/speakers/microphones set-up. Conferencing rooms were either located at ENTEL offices or in municipal buildings.

The audioconferencing system itself has suffered from relatively few technical problems, primarily in interference and voice quality. Some were traced to the interface of the Dantel and Darome equipment with the Harris earth stations, some to electronic burn-out caused by unstable power and power surges, and some to the poor acoustical conditions of the conferencing facilities. The primary problem has been that of signal level adjustment, a routine maintenance task. This led to inconsistent and often incomprehensible signal transmissions. Fortunately, this problem eased as ENTEL became more familiar with system requirements.

The quality and reliability of the audioconferencing network, however, depend on the overall quality and dependability of the telephone system. As telephone service improved at the primary sites, so too did the audioconferencing service. The addition of channels reduced the competition with commercial users for access to telephone lines. Because of the fragile telephone linkages and myriad maintenance problems of the four radio-linked secondary sites, audioconferencing service to these sites was seriously degraded. The continuing malfunctions of the radio links have caused ENTEL to remove and reassign the audioconferencing equipment to more favorable locations.

Conclusion

With the exception of the radio links, the Peru Rural Communications Services Project has successfully provided telephone and teleconferencing service to an isolated rural area.

As with most new and sophisticated communications systems, it has experienced its share of start-up difficulties. During the first 18 months of operation, the number of service interruptions was quite high, although the incidence of completely lost days was largely confined to the four secondary sites. From 1985 onward, none of the three primary sites has suffered from problems severe enough to suspend a full day's service. The audioconferencing service operates at a 96 percent technical reliability rate. As discussed above, the prognosis for the secondary sites is grim unless the BUDAVOX radio equipment is replaced and operation and maintenance procedures revised.

The majority of problems stemmed from three primary sources: equipment manufacturer unresponsiveness, fragmented engineering responsibility, and unanticipated demand for rural telephone service.

The recalcitrance of the major equipment suppliers and their dilatoriness in responding to the unusually taxing requirements of installing a rural telephone system have had considerable ramifications for the project. Three years later, ENTEL and Harris are still negotiating over the antenna problems and retrofit of the feed horns to comply with new INTELSAT frequency reuse standards. At the very least, the Peru experience should cause any prospective purchaser of complex communications equipment to think twice about foregoing the guarantee--and added expense--of a turnkey agreement.

As mentioned at the beginning of this section, complete system design and oversight responsibility was never lodged with one party. This fragmented responsibility led to inadequate system engineering and consequent interface problems. Technical responsibility--or at least technical coordination--should rest with one organization.

Finally, many of the telephone system's problems were caused by its popularity. The unexpected heavy demand for rural telephone service resulted in inadequate power supply, inadequate spare parts to service the system, inadequate channel capacity, and overtaxed operators. Planners of future systems should keep in mind that rural users expect the same reliability and quality of service as their urban counterparts.

SMALL EARTH STATION SUBPROJECT

With the exception of the Peru Project, the Rural Satellite Program focused on using existing telecommunications infrastructure to provide rural teleconferencing services. The Program, however, recognized that many rural communities lacked even the most basic telephone service and would continue to do so because of economic constraints faced by Third World nations.

Although satellite technology costs have fallen significantly as the technology has matured, much of the "ground system"--specifically the earth station--is still too costly for national telecommunications carriers to routinely place in rural villages. Furthermore, the earth station technology is not always compatible with the conditions prevailing in rural settings--such as the lack of trained technicians, maintenance depots, adequate electrical power, and so on.

The goal of the small earth station subproject was to develop a prototype earth station appropriate for rural use which could support teleconferencing services as well as a photovoltaic power system to meet operational needs in areas lacking power.

Background

The Rural Satellite Program chose the remote Indonesian village of Wawatobi in Sulawesi Tenggara, 60 kilometers or a two- to three-hour drive from the small city of Kendari, as the site for the small earth station experiment and demonstration. Site selection was based on its rural location, absence of a telephone or any communications service, lack of a power supply, and the presence of numerous potential user groups. As a district center, Wawatobi conformed to PERUMTEL's goal to supply similar governmental administrative divisions with telephone service. With several large development projects in the area, many development applications were envisaged for the teleconferencing capability.

The Rural Satellite Program contracted with a small U.S. engineering firm to work with the RSP engineer in designing and assembling the earth station; it, in turn, subcontracted with an Indonesian firm, P. T. Elektrindo Nusantara, to provide the modems and related electronics equipment. At the same time, AID contracted separately with the NASA-Lewis Research Center to design the supporting photovoltaic system. NASA worked with Hughes Aircraft Company to manufacture the array. Again, P. T. Elektrindo would provide field services.

Within Indonesia, PERUMTEL was the designated principal. As the only legal owner and operator of satellite equipment in Indonesia, PERUMTEL was responsible for the operation, maintenance, and repair of the earth station and power supply. PERUMTEL was consulted in the earth station's design to ensure system compatibility and would play a major role in the system's installation. It agreed to make two channels available for SISDIKSAT use.

Design Considerations

Earth Station

The earth station was developed to provide audioconferencing and telephone service. The technical specifications called for:

- transmit/receive capability
- six duplex voice circuits
- 800-watt power budget to operate earth station and two-channel audioconferencing system with end equipment (see discussion of Indonesian Project)
- conformance with PERUMTEL and Palapa standards

The performance specifications called for:

- up to 10-channel capacity
- minimum prime power requirements
- operation in the absence of air conditioning
- easy installation
- simple, unmanned operation
- minimal maintenance requirements
- low cost

The earth station components are:

- five-meter antenna
- 11-watt solid-state low power amplifier (LPA)
- GaAs FET low noise amplifier (LNA)
- high stability frequency converters
- two FM single channel per carrier (SCPC) modems
- weatherproof fiberglass equipment shelter enclosure on an I-beam skid

Specific equipment items, with the exception of the shelter and the modems, were purchased from U.S. manufacturers based on known field performance and cost-effectiveness.

Total earth station power requirements were 461 watts when equipped with the two SCPC modems. The remainder of the power budget, 139 watts, was designated for end equipment operation. In all, the earth station and audioconferencing system operates on about the same power as the average home steam iron. Had air conditioning been required or different equipment used, the power requirements would have more than tripled, far exceeding the capacity of the photovoltaic power supply.

Significant power savings were achieved by two means: First, the 11-watt LPA draws considerably less power than the standard "travelling wave tube" LPA. Second, a day/night switch in the adjacent classroom de-activated the LPA and LNA when not in use, reducing power draw on the photovoltaics by an additional 120 watts.

To avoid the need for air conditioning in the tropical climate, the equipment shelter was insulated and treated with a white, heat-reflecting paint. Three fans were included in the design: two LL1 CFM fans were mounted on the equipment rack to cool the LPA which, in turn, was mounted on an aluminum plate with two oversized heat sinks. The 215 CFM was attached to the shelter wall and protected with a weatherhood.

Photovoltaics

Photovoltaic systems are a tried and tested technology with a history of use in the Third World. Thus, the specifications for the RSP photovoltaic array differed little from what is normally offered by photovoltaic systems: stand-alone power and reliability.

In conjunction with a small earth station, however, there were a few specific requirements:

- sufficient power output to operate the two-channel earth station and audio-conferencing system
- easy installation
- low maintenance requirements

For a description of the photovoltaic power system see Technical Note Two at the end of this report.

Because the NASA/Hughes contracts were effectuated before the RSP had selected a site and developed detailed earth station criteria, much of the photovoltaic array design was based on generic and incomplete information. To some extent, then, later earth station design was based on photovoltaic design--a somewhat unusual and not recommended procedure.

Installation, Operation, and Performance

In retrospect, it appears that the most trying task of the installation process was to transport 20,000 pounds of equipment to the remote site. In Indonesia, it was a five-month effort. Because poor transportation systems--poor roads and available shipping means--are generally a given in the rural setting, this should be planned for in future projects.

Once at the site, installation proved relatively easy. Civil works were limited to concrete pads for the earth station, the equipment shelter, and a security fence. For the photovoltaic array, a semi-enclosed shelter on a concrete pad was required to house the electronics equipment for controlling the power supply and the small emergency generator. A security fence enclosed the array.

Although installation of the photovoltaics was speedily concluded with few mistakes (a battery was damaged and some tools missing), installation of the earth station experienced a few days delay because of the Indonesian-based installation engineers' unfamiliarity with the system and water inadvertantly entering the microwave connectors. After these initial difficulties, however, alignment was completed and the system accepted by PERUMTEL.

Routine operation of the earth station and photovoltaics requires turning on the day/night switch to activate the system; this is done by the local technician/operator at the public call office. Should a problem occur within the system, an alarm located at the adjacent office is activated. In addition, a summary alarm panel is located within the equipment shelter. Routine system monitoring is limited to the equipment front panels which include several monitor ports and test points.

The normal maintenance program is based on three-month intervals, including lubricating the grease fitting in the antenna and cleaning the shelter dust filter. Once a year the crystal oscillators in the frequency converters are adjusted.

Since the earth station's installation in June 1985, it has not experienced a single failure or any down time. The design has proved reliable for the rugged environment. Slightly concerned by the heat load (at 121 watts in the antenna hub and 255 in the shelter), PERUMTEL plans to install additional fans which will add only slightly to overall power drain.

Conclusion

As stated above, the earth station and photovoltaic array have operated reliably, requiring little attendance or maintenance. Because its design was an instance of "putting the cart before the horse," however, the photovoltaic array does not completely respond to current usage requirements. It supports a two-channel system for eight to ten hours a day. This does not provide for evening telephone service nor simultaneous audioconferencing (using two channels per the SISDIKSAT model) and public call service. The standby generator has been pressed into service to supplement power output in response to the communications service popularity and thus has experienced some downtime. As in the Peru case, it appears that auxiliary generators in power-scarce areas will always be subject to overuse.

Since the installation of the Wawatobi earth station, PERUMTEL has tendered bids for the provision of similar stations.

LESSONS LEARNED

Although the Rural Satellite Program was to be a demonstration rather than an experiment, it is clear that in the execution much of it was experimental. Many of the technologies had been proven in various contexts, but the Rural Satellite Program was the first to attempt to develop specially designed telecommunications systems in developing nations.

The three projects have provided data which may prove useful for others who want to use modern telecommunications technologies for development. The most important lessons are:

1. Satellite telecommunications technology can be transferred to developing countries. With careful planning, close coordination with relevant developing country counterparts, clear objectives, adaptive design, and realistic schedules, rural telecommunications services can serve economic and social development, and systems can be operated and maintained by in-country technicians and effectively used for development purposes.

2. Strong local project management is the core of a properly operating technical system. This lesson is central to everything. Good local management can keep a system operating under even the most adverse conditions and can minimize down time, loss of interest, and other problems associated with new systems. Poor management exacerbates operational problems and can lead to more problems as equipment is lost, repairs are not made, and spare parts are not ordered. Also, the problems of the shakedown period can have minimal effects during application if there is strong local management. Good local management also minimizes many of the morale and organizational difficulties which can arise from delays in operation.

Although the technical assistance agency can provide some of the support, local management of staffs, budgets, and the like can be done only by national officials who have the authority to ensure that their instructions are carried out and, more importantly, who have the skills to continue good management long after the technical assistance has phased out.

3. Simplicity is the best policy. The higher the level of complexity the greater the problems. Although a major emphasis was simplicity, various forms of complexity crept into each project, to the disadvantage of each system. In some cases, operating complexity is unavoidable. (Earth stations and microcomputers, for example, introduce complexity into any program.) In designing a project for remote sites it may be best to sacrifice operating complexity, in terms of graphics capabilities, switching, and the like, in exchange for operating reliability.

4. Planners must learn how to work with engineers on the design of communications project systems. There are no straightforward solutions to engineering designs. Engineers often disagree among themselves about how systems should be designed and operated. Disagreement becomes more acute when there are operating problems with the system. Project management without substantial engineering expertise will be at a major disadvantage in trying to maintain control of project design and implementation.

With such expertise there will still be difficulties, but they will arise from sorting out the various solutions to engineering problems. Using in-house engineering advice to review plans and operations remains the best means of ensuring overall control of project planning and implementation. The in-house engineer, however, must be independent of any implementation functions.

5. Clear responsibility must be provided for all aspects of engineering design and implementation. Complex engineering systems cannot be designed successfully when there is no centralized responsibility for the engineering. Turnkey arrangements are the simplest because one firm undertakes design, procurement, and installation, but such turnkey arrangements must be carefully crafted to ensure the training and participation of host country nationals. Turnkey projects may be resisted in countries which have well-developed telecommunications sectors. Regardless of whether a turnkey contractor is chosen, one person must be responsible for ensuring that there is an engineering plan for the whole system. The result is that all parts of the system will interconnect and that the system will work.

6. Sophisticated electronic equipment using microprocessors is likely to be problematic, regardless of the manufacturer's promises. Microprocessors are sensitive to heat, humidity, and power fluctuations. All three of these conditions are characteristic of many developing nations. Unless reliable air conditioning is assured and power stabilization equipment provided, equipment performance will be erratic. Although some types of equipment perform better than others, it is reasonable to say that microcomputers will not operate at optimum capacity and other equipment will be, at best, unpredictable.

7. Do not be the first, or even among the first, to use a new technology for a field project. One of the most disappointing experiences of RSP has been getting the Aregon graphics equipment to operate. This equipment had not been broadly field tested, particularly under conditions which prevail in Indonesia. Furthermore, the company was relatively new and, therefore, poorly equipped to deal with problems in the field. From this experience, it is clear that only equipment which has been extensively field tested in comparable environments should be installed, even if it lacks the refinements associated with microcomputers and other advanced technologies.

8. Design the communications system with the assumption that the local distribution plant will be unsatisfactory. All three projects had problems with poor local loops. Because the quality of local distribution ultimately affects the quality of sound and graphic transmissions, it cannot be ignored. Making the local distribution problem a central part of project engineering may increase initial project costs, but most likely it will greatly improve project operations.

9. The technical system must be operating adequately to apply it successfully in development. This means that timetables for technical implementation must be adequate for design, procurement, shipping, installation, and testing. This seems obvious but was one of the continuing problems throughout the Rural Satellite Program. To meet project requirements, a rapid installation was attempted. The amount of time required for the procurement, shipping, customs clearance, installation, and testing of equipment is often beyond anyone's control. Attempting to keep the equipment procurement and installation moving evenly is an essential managerial goal, but one must realistically account for what are essentially exogenous forces which do not fit readily into project schedules.

10. For rural communications projects, assume that the manufacturer's recommended number of spare parts will be too few. It is a general rule of thumb that more complex equipment will require greater parts inventories than simple equipment, regardless of the manufacturer's assertions. Both the Indonesia and Peru projects were substantially understocked with spare parts. While in both cases the manufacturer's recommendations were followed, shortages of funds meant that the bare minimum were purchased. This resulted in delays in the field caused by the unavailability of parts and large additional expenditures for the parts.

11. Adequate funding for technical staff is essential to have a functioning project. In all of the projects there have been attempts to save money by not providing sufficient funds for a technical staff, including salaries and travel allocations. Unless there are ample computer and electrical repair shops near the project sites, an uncommon phenomenon, equipment will be kept functioning only by a maintenance staff. Maintenance services may be obtained through contracts with telephone companies or other institutions, particularly if the project does not require a full-time technical staff.

12. Good technical operation is absolutely dependent on a well-organized reporting and management system. This may be obvious, but all three projects suffered to some degree from poor reporting on equipment and weak technical management. Unfortunately, more attention is often spent on the problems of implementing the use of complex equipment than on the problems of operating and maintaining it. Project implementation must include the management of the technology.

TECHNICAL NOTE ONE: GRAPHICS EQUIPMENT

The Indonesian Government made it clear that graphics support for lectures would be important for both students and lecturers. In Indonesia blackboards are considered a major part of teaching.* Both RSP and the Indonesians believed that fully interactive graphics would encourage maximum student participation. In addition, there was agreement that the graphics device would have to transmit graphics and blackboard notes during lectures and that the graphics presentation had to be visually interesting and clear.

Several other equipment selection criteria were considered. First, the system had to be easy to use and maintain. Thus, components like television receivers and tape cassette recorders (for recording graphics) were chosen rather than more sophisticated and costly studio machines. Second, because television receivers for the graphics were also to be used for receiving broadcast and video cassette signals, they also had to be able to receive signals in the Indonesian television standard--CCIR Standard B format (PAL). (Although neither off-the-air television broadcasts or video cassettes were not functional aspects of the RSP plan, it was believed prudent to integrate the reception capability into the equipment should, in the future, educational broadcast become a standardized facet of the Indonesian higher educational system.) Third, the graphics equipment had to interface with the voice channel via a CCIR standard modem to meet Indonesian requirements for data transmission over telephone lines. Two types of devices were considered--slow-scan video and a computer graphics system.

SLOW-SCAN VIDEO

Slow-scan video transmits a single frame of video--similar to a photograph--over a telephone line in as few as 17 seconds for minimal resolution and about one minute for good resolution. Slow-scan video was a new technology at the time the project was being designed and thus was very expensive. In addition, although slow-scan video is useful for showing prepared graphics and objects, it has several drawbacks. First, it is a relatively complex system which posed operational problems. At minimum, lighting and a television camera have to be used for transmission, creating two additional elements to operate. Operators must be trained and readily available to operate the lighting and video cameras which are central to the system. Second, although the video image is adequate for showing charts or objects, it does not show blackboard writing well. The image is transmitted in black and white, and writing must be very distinct to be read in a large classroom. It would be difficult to ensure clear

* After four years of observation, the Rural Satellite Program concludes that in actuality the average lecturer seldom employs the blackboard or does so with little efficacy.

writing by teachers. Third, the slow-scan system would be extremely expensive to provide on a fully interactive basis (i.e., every classroom being able to transmit graphics to every other classroom) because of the cost of the television cameras and ancillary equipment (i.e., lighting, graphics boards, and the like).

COMPUTER GRAPHICS

A computer graphics system makes use of microprocessors to generate and transmit high resolution and multi-colored graphics. Graphics writers are capable of transmitting hand-drawn line drawings, simple diagrams, words, and equations which are written on an electronic surface with a special light pen. The writing or drawing by a lecturer is instantly transmitted to remote locations and shown on television monitors. Students at each location can interact with the lecturer by "writing" on the system's main television receiver with the pen. This writing will be received at all locations participating in the conference. Both audio and graphic information can be recorded on a regular audio tape for playback at a later time or prepared in advance of a lecture. Also, more sophisticated graphics, like graphs and charts, can be generated using computer graphics software. It is important to note in this context that electrowriters, unlike slow-scan video, are highly dependent on software. Thus, although they are subject to software errors, they can be upgraded through improved software during the hardware's operational life.

RSP and BKS agreed that clear blackboard writing would be the most important graphic information required and that the graphics writer would be the best way of providing it.

The Aregon Audio Graphics System (AGS) was chosen after review of several systems. Unlike the other equipment decisions, however, this choice was not based on a full examination of the system's overall technical features, but on its operational features and price.

The AGS was initially developed and tested in the British Open University to support distance education. Although other computer graphics systems were examined, most notably the French-made FTS System, which is in use in the UWIDITE system, none matched the range of software and low price of AGS.

AGS combines the features of telewriters and slow-scan video. The AGS terminal has a microprocessor which interprets transmitted signals and converts them into pictures for display on a television screen. Diagrams and charts may be drawn on the screen with a light pen and transmitted immediately or stored in short-term memory. With the addition of a keyboard, text can be typed onto the screen, and all created graphics can be stored on audio cassette tape. The system offers a selection of eight background and foreground colors. Lines can be erased, and point-to-point lines can be drawn automatically.

Television sets with RGB (red/green/blue) leads must be utilized. Although Aregon's original specification sheets stated that the AGS signal could be modulated for use by conventional receivers, Aregon never developed the necessary RF converters to perform this function.

The processor uses software for creating pictures "drawn" by a light pen on a video screen or by a pen on a digitizing pad, and the digital signals that produce this picture can be sent over a telephone line. Each site can see the drawing produced by any other site and can add or delete parts of the picture. Keyboards may be added to allow teletext graphics to be generated and transmitted. This function can be used to generate labels and text and offers greater control over the unit's software, particularly for storing material on tape cassettes.

After considering the average classroom size and the available budget, each classroom received the basic Aregon system of an Aregon Graphics Processor, a 19-inch master monitor, and a light pen. Two large display monitors were added to this system to provide better viewing for the expected large classes. Because the project budget could not provide all sites with digitizing tablets and keyboards, five sets of these units were purchased and placed at the sites which most often delivered programming.

The interface between the audio graphics system and the telephone lines is through a data modem connected to the telephone terminal equipment. The data modem is a standard 1,200 band device designed to CCITT interface requirements. The levels can be adjusted to conform to telephone company specifications. The figure below shows the layout of the system.

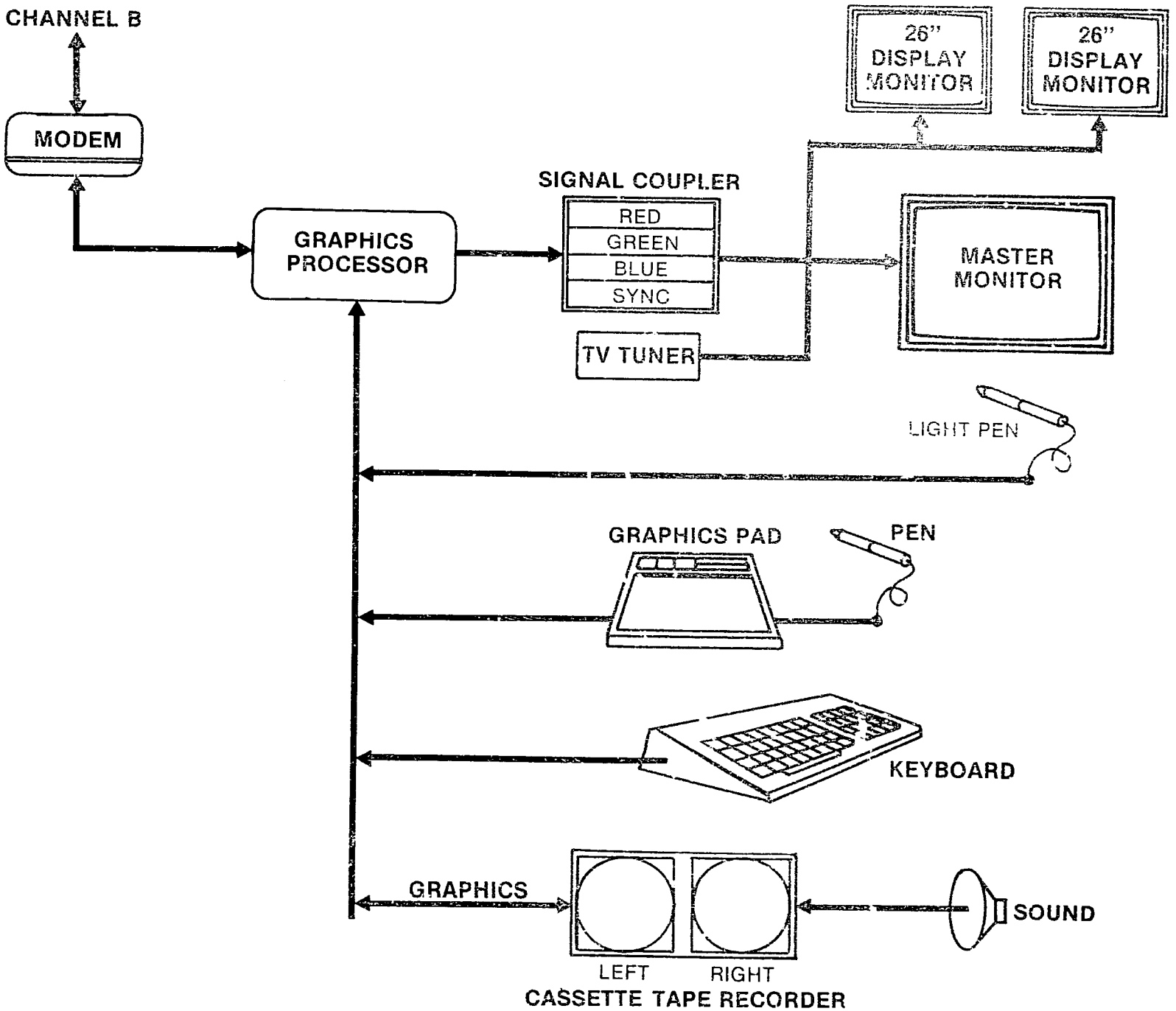
The AGS system also includes a computerized production studio which can be used to produce more sophisticated graphics support. This equipment allows charts, photographs, and other graphics, as well as writing, to be recorded on audio cassette tape and later either be transmitted over the satellite system during a lecture or used at individual campuses. This equipment includes a keyboard, graphics tablet, dot matrix printer (for reproducing graphics), microprocessor, visual display unit, television camera and lighting, audio reel-to-reel tape recorder, graphics processor, software license, cables, and switches. One of these studios was purchased and installed in the project's central office.

It is important to note here that at the time of the purchase, Aregon assured RSP that the AGS was an operational piece of equipment, which had been fully tested, was in use, and complied with all of the operational requirements in the project's specifications. This claim proved questionable in practice.

The first major problem, quite apart from the equipment's operational problems, is its complexity. Because of the number of options provided by the AGS, an excessive number of instructions must be learned by casual users. For example, a slide-tape presentation on basic instruction for operating the AGS equipment requires more than 90 slides. This compares with fewer than 10 slides for each of the other pieces of equipment.

Second, the noise levels on the transmission system, which provides perfectly acceptable voice quality, have significantly impeded the operation of the graphics equipment. It is doubtful that the teleconferencing system will ever be quiet enough to permit reliable graphics transmission.

LAYOUT OF GRAPHICS WRITING SYSTEM



Third, particular components of the equipment often failed. Early in the project, major failures were experienced in the modems, master video monitors, light pens, keyboards, and main processor boards. Most monitor failures were caused by burned out potentiometers affected by high humidity, but there were no other simple answers to the causes of problems. Technicians noticed that the main processor operated better in air conditioned rooms or when a fan was placed directly behind it, but there was no pattern found in the actual parts that failed. The same thing happened in the case of the modems. No one part was failing; each repaired modem had a different part fail. Engineers looked for electrical problems, such as spikes or surges that were not being controlled by the classroom power system, and for other causes, but no single cause was identified. Perhaps the major cause was just the heat and humidity of the classrooms. Although the manufacturer had maintained that the AGS would work properly in the tropics without air conditioning, experience indicated that the equipment was suffering from the environment as well as from poor design.

Fourth, the equipment is complex and not easily repaired by the SISDIKSAT technical staff. This problem is exacerbated by the often lax maintenance procedures used by SISDIKSAT. While technician expertise is not as crucial with the other equipment, the more exacting requirements of the audio graphics equipment increases the maintenance difficulties. The light pen, for example, should be tuned to the monitor three or four times a year by a highly trained technician using an oscilloscope. This type of maintenance is time consuming and very expensive for a Third World country. The untoward number of AGS equipment failures far exceeded the technical support resources available.

Fifth, and most importantly, there were serious informational problems at the time of the equipment purchase. Aregon maintained that its units were not prototypes, but were commercial products which had been field tested and that the equipment would be able to function in Indonesia. Aregon also maintained that the equipment did not require special expertise to install.

None of these assertions proved true. The equipment had been field tested in an earlier form, but not in its commercial form. Field testing of the commercial equipment had been slight, shown most readily in software problems which the RSP had to bring to Aregon's attention. Although these were relatively minor problems, a field-tested system would not have had them. Furthermore, Aregon later criticized the RSP for not using Aregon technicians in the installation. The RSP had initially been assured and believed that its engineering consultants could install the equipment, particularly given the claim that no special expertise was required.

The number of spare parts also was severely underestimated by both parties, and the additions later proposed by Aregon greatly exceeded any numbers which had ever been suggested during the purchase period.

Currently, the AGS equipment is used sporadically. Because of its complexity, its continuing technical problems, and the difficulties with the graphics transmission channel, however, it is doubtful that it will ever become a fully functioning and reliable component of the system. In the meantime, the manufacturer has discontinued production of the AGS. Indonesian-assembled microcomputers have been installed at four sites, and they appear to be functioning far more effectively than the AGS.

TECHNICAL NOTE TWO: PHOTOVOLTAIC SYSTEM DESCRIPTION*

The major components of the photovoltaic power system are the system controller, PV array, battery, inverter, battery charger, and the engine-generator.

The earth station electronics are powered by 221 volts AC, and the cooling fans are powered by 48 volts DC. This increases the system efficiency by reducing the amount of power passing through the inverter. The DC power normally comes directly from the PV array and batteries. The fans operate from the fan power supply only when the engine-generator is furnishing power to the system in a back-up mode.

The system controller is the primary mode of power system operation for the array, battery, and inverter. The engine-generator serves as a back-up power source in two back-up modes. In the first mode, the engine-generator and battery charger charge the battery if it becomes discharged below a certain level. In the second mode, the engine-generator powers the loads directly if power is unavailable from the array, battery, or inverter.

The controller performs various functions as the battery state-of-charge (SOC), as measured by the system (and battery) voltage, changes. The controller has six comparators that sense the voltage levels and initiate the appropriate actions. Battery SOC control is performed by temporarily and successively switching off the two array sections at high levels of SOC or turning the engine-generator on at low levels of SOC. Extreme over- and under-voltage system protection is also included in the controller functions.

The PV array modules are rated at 66 watts (15.6 volts and 4.23 amps at 28 degrees C). Four modules in series provide a nominal system voltage of 48 volts. Each 48-volt series string has a rated current and power output of 4.23 amps and 264 peak watts (28 degrees C). Hughes' power system sizing calculations resulted in a PV array size of 1,584 watts (28 degrees C) resulting is six series strings wired in parallel. The rated output power is 1,414 peak watts at the expected operating temperature of 48 degrees C.

The array structure is a simple above-ground structure composed of foundation troughs, module support rails, upright supports, and cross straps. The troughs are filled with ballast material, such as rocks or earth, obtained from the installation site. The system battery is mounted on rails on top of the troughs to add additional ballast weight to the structure.

The battery is composed of 24 C&D Power Systems, type 3KCPSA-5, three-cell packs. Each three-cell pack is rated at 341 AH (511 hr rate) at 25 degrees C. The battery configuration consists of three parallel strings with each string containing eight packs in series. This results in a battery with nominal voltage of 48 volts and a nominal capacity of 1121 AH or 49 kWH.

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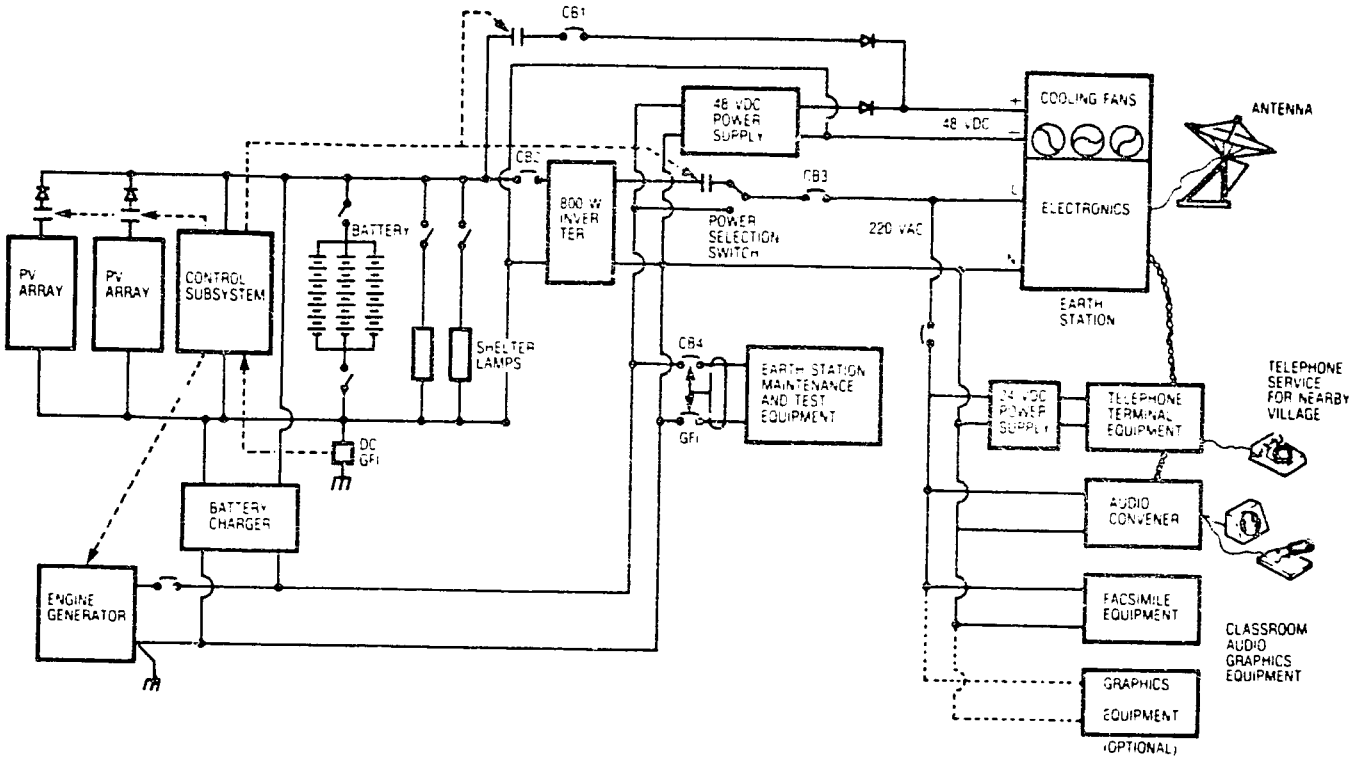
* Prepared by Richard DeLombard, National Aeronautics and Space Administration, Lewis Research Center, 1985.

The inverter provides an AC output of 221 volts at 51 Hertz which is compatible with Indonesian commercial utility power. The output power rating is 811 watts. This provides the AC power needed by the earth station electronics and the classroom equipment. The inverter output voltage is a step synthesized sine wave.

The battery charger provides a controlled voltage and current to charge the battery from the engine-generator. The output capacity of the battery charger is 2.4 kW, which is sufficient to power the loads and simultaneously charge the battery in approximately 10 hours.

The engine generator provides a 2.5 kVA AC output at 221 volts at 51 Hertz, and is primarily used for back-up power for the earth station and the classroom. The output capacity of 2.5 kVA is sufficient to simultaneously power the loads and charge the battery. The engine-generator is started automatically by the controller, or manually, if necessary, by an operator. The engine-generator is also used to provide AC power for earth station test equipment rather than using the inverter output.



SCHEMATIC DIAGRAM OF THE PHOTOVOLTAIC SYSTEM

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