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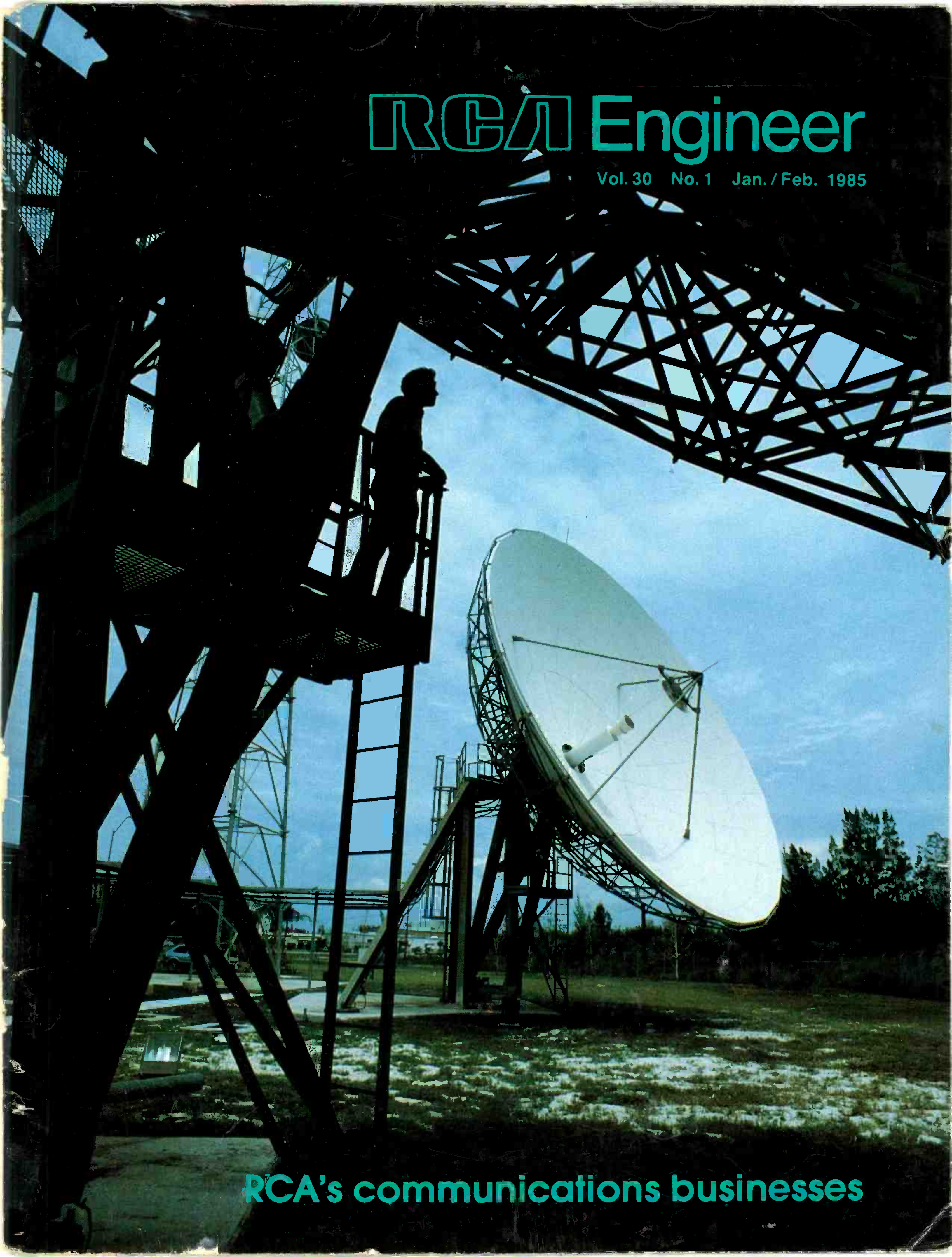

RCA's communications businesses

RCA Engineer

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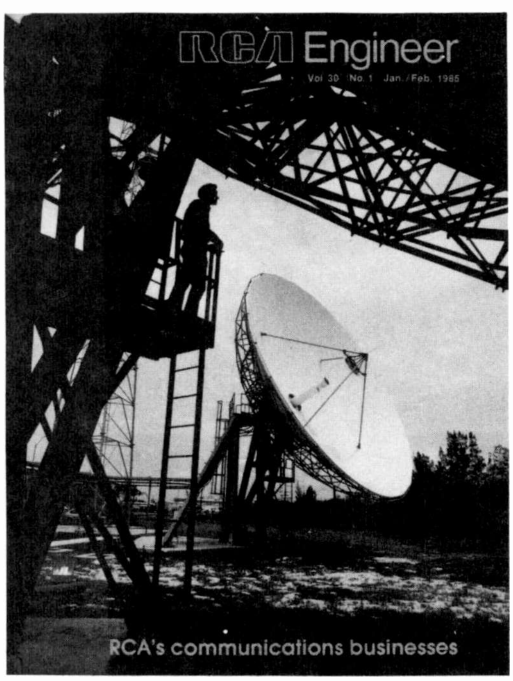

About the cover ...
Our cover shows the Vernon Valley, New Jersey earth station of RCA American Communications, Inc. Believed to be the largest such facility in the free world, this earth station handles voice, video, radio, and data telecommunications into and out of the New York area, and via terrestrial extensions, from Boston to Washington. The station is also one of two the company operates as tracking, telemetry and command centers to control its fleet of five communications satellites in geosynchronous orbit. The other facility is at South Mountain, near Los Angeles, California.

Photo courtesy of John Williamson, Americom.

□ To disseminate to RCA engineers technical information of professional value □ To publish in an appropriate manner important technical developments at RCA, and the role of the engineer □ To serve as a medium of interchange of technical information among various groups at RCA □ To create a community of engineering interest within the company by stressing the interrelated nature of all contributions □ To help publicize engineering achievements in a manner that will promote the interests and reputation of RCA in the engineering field □ To provide a convenient means by which the RCA engineer may review professional work before associates and engineering management □ To announce outstanding and unusual achievements of RCA engineers in a manner most likely to enhance their prestige and professional status.

RCA's roots are in communications

Shortly after World War I several American businesses, encouraged by the United States Government, purchased the assets of the British-owned American Marconi Company, and in 1919 formed what was to become known as the Radio Corporation of America—RCA.

Since that time, RCA has expanded its communications enterprise and embarked on many new businesses. Our work in broadcast radio, television, satellite technology, consumer electronics, telephone, and service businesses has made RCA a respected name, both here and abroad.

RCA has never lost sight of its beginnings in communications. Thornton F. Bradshaw, when he assumed the Chairmanship of RCA, identified communications as one of the company's core businesses—a focus for growth under his leadership. Today, RCA Communications and the many people who work in its four operating units are poised on the threshold of a new age in telecommunications, with opportunities and challenges never before experienced in our industry.

The AT&T divestiture and the FCC access charge decision represent the most dramatic changes ever in the telecommunications industry. The restructuring of the Bell System and its effects on U.S. telecommunications raise issues that will continue to be addressed in the coming years by the FCC, the Congress, the Executive Branch, and the courts. This regulatory climate, together with technological advances, position RCA Communications in the middle of a dynamically changing business environment.

RCA has been positioning itself to take advantage of the changes in the marketplace. Customers are looking for end-to-end service with system solutions for their communications needs. By focusing RCA's extensive communications resources on specialized market segments, and providing technically advanced, applications-oriented services, we can successfully meet their needs.

The success of RCA Communications also reflects our longstanding working relationship with other RCA units, including Astro-Electronics and RCA Laboratories. In the pages that follow, several new developments in communications technology are presented. These advances, and many more that have gone before, enable RCA Communications to offer the kind of services and service reliability that make us a leader in telecommunications. In reading through these articles, we are reminded that RCA's greatest asset is the talent and vision of its people.

Eugene F. Murphy

Eugene F. Murphy
Chairman and Chief Executive Officer
RCA Communications

RCA Engineer

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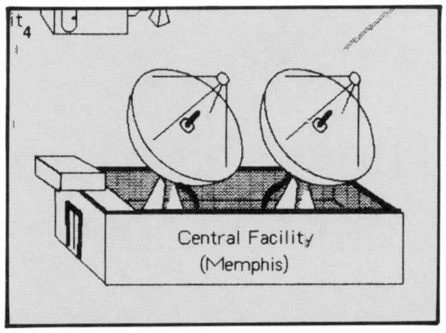

■ **Sutton:** *"RCA Cylix Communications Network offers communications that are embodied in transparent implementations of standard industry protocols."*

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Accessing NipperNet

■ **Adler:** *"The NipperNet network provides the means by which incompatible terminals and hosts can communicate via a standard communications protocol (X.25)."*

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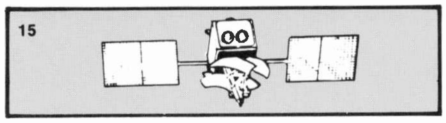

■ **Braun/Keigler:** *"Satellites of increased channel capacity, longer life, and higher reliability are under development for launch in the near future, and K-band versions of the Satcom spacecraft will supplement the current C-band system . . ."*

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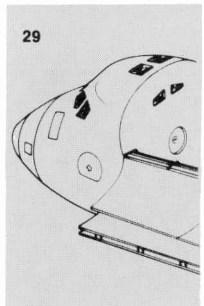

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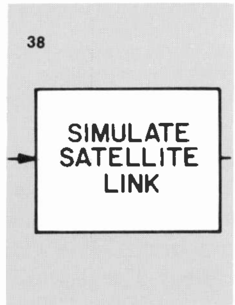

■ **Beck:** *". . . the ACTS program represents an essential step toward providing for the future growth of satellite communications."*

■ **Klensch/Waldman:** *"Recent advances in simulation techniques allow for real analog image signals to be captured, digitized, and processed on a digital computer, and eventually restored to analog form to be displayed for visual analysis."*

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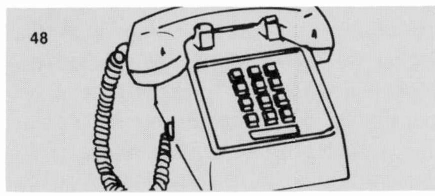

■ **Kaminsky:** *"To maintain our position in the marketplace, we needed a state-of-the-art integrated voice/data system (PBX) that can meet the requirements of the office automation equipment market as well as larger installations."*

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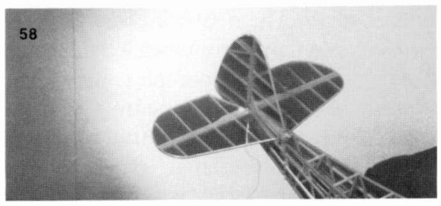

■ **Henderson:** *"Ground-wave reflections can create interesting cancelling signals that are not normally problematical, but they can add to the excitement of landing if a long, low approach is made."*

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in future issues...
automated testing
statistics in manufacturing
project management

F. R. Sutton

The architecture of RCA Cylix Communications Network

An underground complex in Memphis, Tennessee is the heart of RCA's nationwide data communications network.

RCA Cylix Communications Network, Inc. operates a value-added network that provides data communications services to customers within the United States and Canada. The network is designed for maximal performance when a customer's applications require medium- to high-speed, transactionoriented communications (see the sidebar for the definition of transaction). RCA Cylix assumes total end-to-end responsibility. This includes network planning, installation, and maintenance of all data communications components, except for the customer's terminals and host computer systems. The network consists of 35 earth stations that communicate by satellite to a central switching complex. By means of protocol conversion (done by intelligent microprocessor-based communications cards), data is translated, grouped into packets, and delivered with appropriate error checking techniques over virtual circuits between the RCA Cylix earth stations. The logical relationships of terminals and hosts that are implemented by means of these virtual circuits may be altered to change the flow of data from one terminal/host combination to another terminal/host combination. In this way, the reconfiguration of communications devices, which so frequently happens in large networks, can be done without installing a multiplicity of physical lines.

Abstract: *RCA Cylix Communcations Network provides a highly reliable data communications service to companies in the United States and Canada. Most common synchronous protocols are supported. This article describes the architectural design of the network that provides cost-effective, high-performance handling of transaction-oriented applications. Both the current deployment and planned service enhancements are explained.*

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The architecture of the network is a star topology. All data packets being transmitted from one earth station to another are switched through a central complex located in Memphis, Tennessee. Also located inside this complex is the Network Control System, which is responsible for the maintenance of the network. This system receives alarm messages and enables control terminal operators to issue status commands. This system is also used to coordinate repair activities for various vendors.

The following sections describe the service offered by the network, the characteristics of the remote earth stations, the central facility and the Network Control System, and services that are presently under development to add additional value to the network.

Services provided

RCA Cylix Communications Network offers communications services that are embodied in transparent implementations of standard communications industry protocols. In most cases, customers can use the network without altering or adapting the hardware or software in their host computer systems, front-end processors, or terminal devices. The protocols currently supported on the network are:

- 3270 BSC
- SDLC
- Burroughs Poll/Select
- X.25

In implementing a virtual circuit, protocol conversion and data packetization is done on both sides of the network. This means that each protocol except X.25 has two versions, corresponding to the terminal and host ends of the virtual circuit through the network. To terminal devices, the RCA Cylix implementation appears just like their host computer system would appear if the hosts and terminals were directly connected by permanent, leased communications lines. Similarly, to host computer systems, the RCA Cylix implementation appears just like their terminal devices would appear if they were directly connected. Implementing the protocols in this manner allows for the simplest conversion of customers from a leased-line environment to the RCA Cylix network.

The X.25 protocol differs from the other protocols on the network in that it has only one version. CCITT X.25 is an internationally accepted definition for a protocol intended to interconnect devices (either terminals or hosts) and public packet-switching networks such as the RCA Cylix network. X.25 is commonly thought to be an end-to-end protocol, which it is not. The RCA Cylix implementation of X.25 consists of only one element of software—that required for the direct connection (point-to-point) of an X.25 device into the network.

A special product provided by RCA Cylix is a customer-premises micronode. For customers with a large number of host lines, a micronode chassis may be placed at the customer's host site. This provides local attachment of the host lines and a high-speed data path into the network. The customer gains several operational advantages from this configuration, including simplified host attachment and improved performance.

Network reliability is the most important service objective of the RCA Cylix network. The "backbone" of the network consists of all network components on the data path from one remote earth station across a satellite link to the central switching facility, then across a second satellite link to the destination remote earth station. This backbone incorporates automatic monitoring, equipment redundancy, and other features to insure that it remains highly reliable. For local distribution, the modem hardware and network software provide alarms whenever performance degrades, and diagnostic tests to pinpoint failures.

RCA Cylix is a service company. This service is embodied in the customer interaction necessary to respond to customer inquiries and problem reports. The two departments that control most interaction with customers after the initial sales cycle are Customer Service and Network Control. The Network Control System (NCS) is the primary tool of Customer Service and Network Control. This system receives and displays all alarms coming from the network, and provides the facilities to initiate control and diagnostic commands to various network components. Network control personnel are assisted as necessary by RCA Cylix Field Engineers in performing on-line diagnostic measurements and in repairing or replacing defective network components.

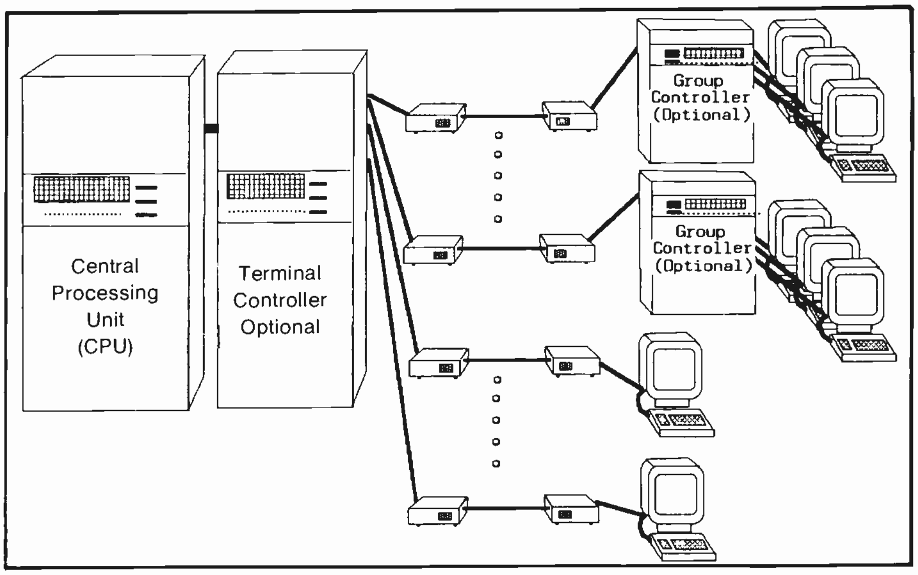

Fig. 1. *Conceptual representation of a customer equipment connection.*

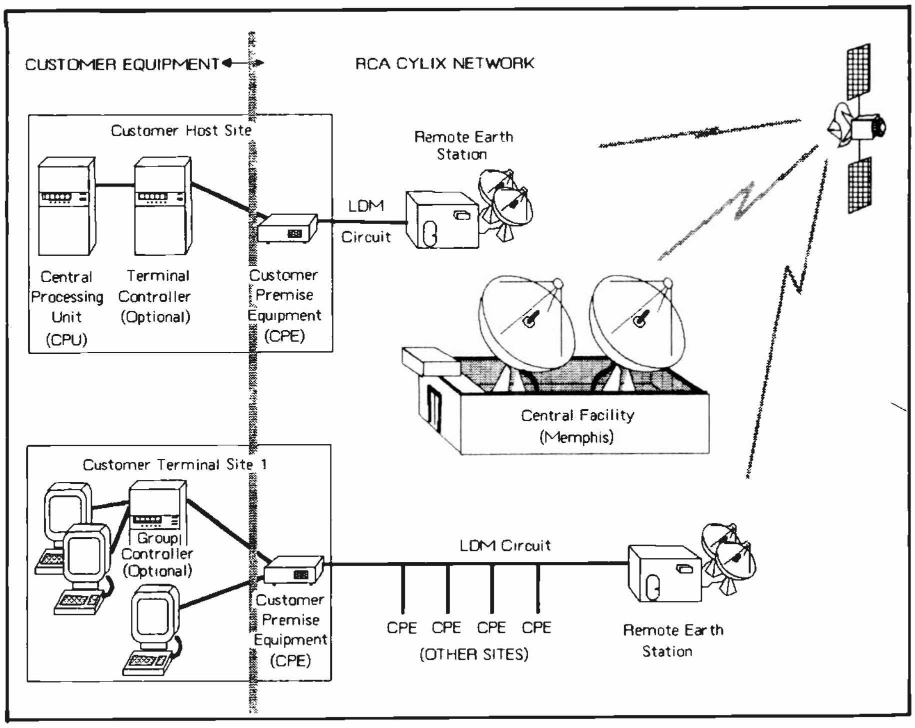

Fig. 2. *The physical connection to customer equipment.*

Value-added data flow description

The interconnection between a customer's host computer and the terminals served by that host computer is shown conceptually in Fig. 1. As shown, the host computer and its associated terminals appear to the customer to be directly connected. The actual path taken by customer data is shown in Fig. 2. Although only one terminal is shown for the hypothetical customer, host computers are connected by permanent virtual circuits to a number of terminals, each of which could in turn be physically connected to a different RCA Cylix earth station.

The RCA Cylix network interfaces to the customer's software, assuming the host computer and terminals use one of the protocol subsets mentioned earlier. The customer's host computers, terminal controllers, and terminals are connected directly to the customer premises equipment (CPE) installed by RCA Cylix at the customer location. The CPE provides all required modem functions. Outgoing digital data is converted to an audio frequency signal for transmission to the remote earth station, and incoming data is converted from an audio frequency signal to the required digital format.

Each set of CPE installed in the network is called a customer drop (or simply "drop"), and is categorized as either a host drop or a terminal drop. CPE at terminal drops can be connected to multiple customer terminals (called "virtual terminals") or to multiple terminal controllers (called "cluster controllers") that

What is a transaction?

RCA Cylix Communications Network is designed specifically to provide a cost-effective data communications facility for "transaction-oriented" applications. A transaction may be defined as a set of computerized messages that consist of an inquiry (input) and its associated response (output). Normally, there is a one-to-one correspondence between the inquiry and the response; that is, a data terminal user will send an inquiry to the host computer system, and will wait for the inquiry to be processed and the response to be received from the host computer.

Transaction-oriented applications are characteristic of a large number of businesses. Among these are financial institutions, insurance companies, wholesale and retail sales organizations, and the commercial transportation industry. A typical transaction has a 10:1 ratio of response data to inquiry data. For example, an insurance inquiry might consist of a client's name and identification number, for a total of 40 characters, with a response of 400 characters detailing the insured's coverage. In the transportation industry, a terminal operator might enter 150 characters of shipping information and receive 1500 characters of output data that would result in the automatic printing of a bill-of-lading.

The protocols supported by RCA Cylix are common to transaction-oriented applications. Furthermore, the internal network data handling procedures have been specifically optimized for high performance with transaction-oriented data traffic.

may in turn serve multiple physical terminals. Customer premises equipment at host drops is connected to a remote earth station by a point-to-point, voice-grade communications circuit (the Local Distribution Medium, or LDM), which is obtained from and installed by a telecommunications agency. CPE at terminal drops is connected to a remote earth station by a multi-point circuit. Terminal drops for different customers are generally combined on the same LDM circuit, but all terminal drops on the same circuit presently must use the same protocol. Host-drop LDM channels operate at 9600 bps. Multi-point lines operate either at 4800 bps or 9600 bps, depending upon the characteristics of end-user equipment and common carrier facilities.

Listed below are the actions taken by the various elements of the RCA Cylix network to implement the virtual circuits that connect customer host equipment to customer terminal equipment. The descriptions are keyed to Fig. 2.

(1) Data entered at a customer terminal is transmitted by CPE over an LDM circuit to the remote earth station. The remote earth station generates all the protocol-specific requests and acknowledgements required to make the terminal equipment think it is communicating directly with the host computer's terminal interface.

(2) At the source remote earth station, the data is formatted into multiple-character packets that contain no more than 273 bytes of customer data. The packets include the control and routing data used by the internal network protocol.

(3) The packets containing the data are sequentially mulitplexed with packets from other terminals or hosts by the remote earth station and transmitted across a satellite link to the RCA Cylix central facility in Memphis. (Note that when the host computer and the originating terminal are served by the same remote earth station, the packet is not transmitted to the central facility; instead, it is routed directly to the host computer as described in step 5.)

(4) At the central facility, the packets are routed by a computerized switching system (the central switching facility) to the remote earth station serving the host computer. Again, the packets are sequentially multiplexed with other packets onto the satellite link to the destination remote earth station.

(5) At the destination remote earth station, network routing data is stripped from the packets and, if necessary, the data from multiple network packets are buffered until a complete message for the host computer has arrived. This message is then transmitted, using the customer's protocol, to the customer premises equipment at the host computer across the LDM circuit. The remote earth station again generates all the protocol-specific requests and acknowledgements required to make the customer's host computer think it is receiving data directly from the originating terminal.

Data is transmitted similarly from the host computer to the terminal, except that the source and destination are reversed.

All virtual circuits connecting customer host equipment to customer terminal equipment work in the manner just described. The RCA Cylix network may thus be described as a hierarchical star configuration that optimizes throughput by using as much parallel processing as possible at the lower level of the hierarchy (the CPE), and processing at as high a speed as possible at the highest level of the hierarchy (the central switching facility).

The RCA Cylix Communications Network is able to add value to a customer's communications network that the customer is not be able to do with traditional leased lines. The first feature that RCA Cylix can offer is that of speed shifting. This means that the speed at which the terminal is operating does not have to match the speed at which the host processor interfaces to the network. For example, a terminal might deliver data to the network at a speed of 4800 bps, while at the host end the network might multiplex all of the customer's data into a 9600-bps data stream. In the case where a micronode has been placed on the customer premises, the link into the network is actually 56 kbps. The advantage of this type of approach is that it relieves the host processor from polling at a slow speed, and thus improves overall performance. The network assumes the workload of polling the individual devices at the terminal drop.

A second added value that is of great significance is the ability of the network to present an image of cluster controllers to the host processor that is different from the actual physical cluster controllers. For example, a customer may have ten cluster controllers, each with three devices at ten different locations. If the customer were to configure the network, several lines would have to be run to these ten different locations in order to support them. Using the RCA Cylix network, the customer connects to the network with a single host line. RCA Cylix installs lines to poll the cluster controllers at the ten locations, and may deliver the data to the host emulating a single cluster controller of 30 devices. This allows for more efficient polling at the host, improves overall response time, and minimizes the total communica-tions costs.

Remote earth stations

RCA Cylix remote earth stations are located throughout the continental United States. The locations of remote earth stations are chosen to accommodate current and predicted network traffic patterns. All existing remote earth stations are listed in Table I.

A typical remote earth station consists of two molded fiberglass equipment shelters and two 4.6-meter satellite antennas on an area of land enclosed by a chain link security fence. Most remote earth stations are located in relatively undeveloped areas near, but not in, major cities. Currently, most remote earth stations are manned during normal business hours (local time) by an RCA Cylix Field Engineer. Field Engineers are also on call for troubleshooting and maintenance 24 hours a day, seven days a week.

Both equipment shelters at the remote earth station are equipped with heating and cooling systems that maintain reasonable operating temperatures for the sheltered equipment. The smaller of the two shelters houses an Uninterruptible Power Supply of the rectifier/battery/inverter type that can maintain power to a fully-implemented remote earth station for 10 to 20 minutes. The larger of the two equipment shelters houses all digital and LDM circuit interface equipment and rf electronics gear, except for equipment physically associated with the antennas. Equipment inside the shelters is mounted in up to five standard 19-inch relay racks.

The remote earth station communications interface consists of any termination equipment required by the LDM used (such as Channel Interface Units for leased voice-grade lines) and the master modems associated with the point-to-point and multi-point LDM circuits. Master modems are connected to a digital computer complex of proprietary design. This digital equipment (called a "micronode") acts as a communications concentrator, protocol converter, and satellite channel driver as described earlier. The digital equipment connects to an rf chain to implement the satellite link between the remote earth station and the central switching facility. Due to the requirements for extremely high availability, all digital and rf components are duplicated in a one-for-one fashion. This total redundancy yields a much higher measure of reliability for the RCA Cylix network than a customer can achieve using traditional leased telephone lines.

Table I. *RCA Cylix remote earth stations, June 1984.*

Albany, N.Y.	Miami, Fla.
Atlanta, Ga.	Milwaukee, Wis.
Birmingham, Ala.	Minneapolis, Minn.
Boston, Mass.	Nashville, Tenn.
Buffalo, N.Y.	New York, N.Y.
Chicago, Ill.	Oklahoma City, Okla.
Cincinnatti, Ohio	Omaha, Neb.
Cleveland, Ohio	Orlando, Fla.
Columbia, S.C.	Philadelphia, Pa.
Dallas, Tex.	Phoenix, Ariz.
Detroit, Mich.	Pittsburgh, Pa.
Germantown, Md.	San Antonio, Tex.
Hartford, Conn.	San Diego, Cal.
Houston, Tex.	San Francisco, Cal.
Indianapolis, Ind.	Seattle, Wash.
Kansas City, Mo.	St. Louis, Mo.
Los Angeles, Cal.	Winston-Salem, N.C.
Memphis, Tenn.	

Satellite characteristics

The high-speed satellite communications links connecting each remote earth station to the central facility in Memphis use single-channel-per-carrier, multiple-access techniques with rate ⅞ encoding and sequential soft-decision decoding for forward error detection and correction. The links are designed to provide a typical bit-error rate of from 1 bit in 10^8 to 1 bit in 10^9.

The network design calls for two satellites. The primary satellite serves as the link between the primary antenna at each remote earth station and the primary antenna at the central facility. The backup satellite similarly links the secondary antennas at each remote earth station with the secondary antenna at the central facility. Both the primary and the backup satellites can be used at the same time, allowing individual remote earth stations to be switched to the backup satellite independently of the other remote earth stations if conditions warrant.

Central facility

The RCA Cylix central facility in Memphis, Tennessee is a specially constructed tornado-and earthquake-resistant building that houses all central site equipment necessary for the operation of the network. The building itself is built below ground, with the roof at ground level. The two 10-meter antenna systems that serve the central facility are mounted on the roof. A third antenna is warehoused several miles away and can be erected in approximately 48 hours to restore network operation in the unlikely event of natural catastrophe damaging both the primary and secondary antennas.

The central facility includes a comprehensive battery-float Uninterruptible Power Supply (UPS) system. Twin diesel generators provide power to the central facility UPS should a utility power outage persist past the float time of the UPS batteries.

The air conditioning system is designed to operate on free-flowing municipal water for cooling in the event that external dry coolers malfunction. Multiple Halon fire suppression systems are included to provide fire protection without equipment damage. Access to the central facility is restricted to authorized personnel by a full-surveillance electronic security system.

All rf equipment at the central facility is fully duplicated, with the redundant halves serving the primary and secondary satellite channels. In addition, specific equipment items in each redundant half are further duplicated for even greater reliability.

The central switching facility is composed of multiple high-speed ModComp minicomputers interconnected by 2-Mbps digital data channels. Each minicomputer (commonly called a "switcher") is nominally capable of supporting full-duplex 56-kbps channels corresponding to 25 remote earth stations. Each such channel is connected to the switcher by a Data Line Controller (DLC) that interfaces with the appropriate satellite QPSK modem. DLCs are also used to control the 2-Mbps links between switchers.

Every switcher in the central switching facility is connected to every other switcher (see Fig. 3), thus insuring that any data packet will travel through no more than two switchers—the switcher serving the source remote earth station and the switcher serving the destination remote earth station. Currently, only two switchers are required, with a third unit available to back up either of the operational switchers in the event of equipment failure. The

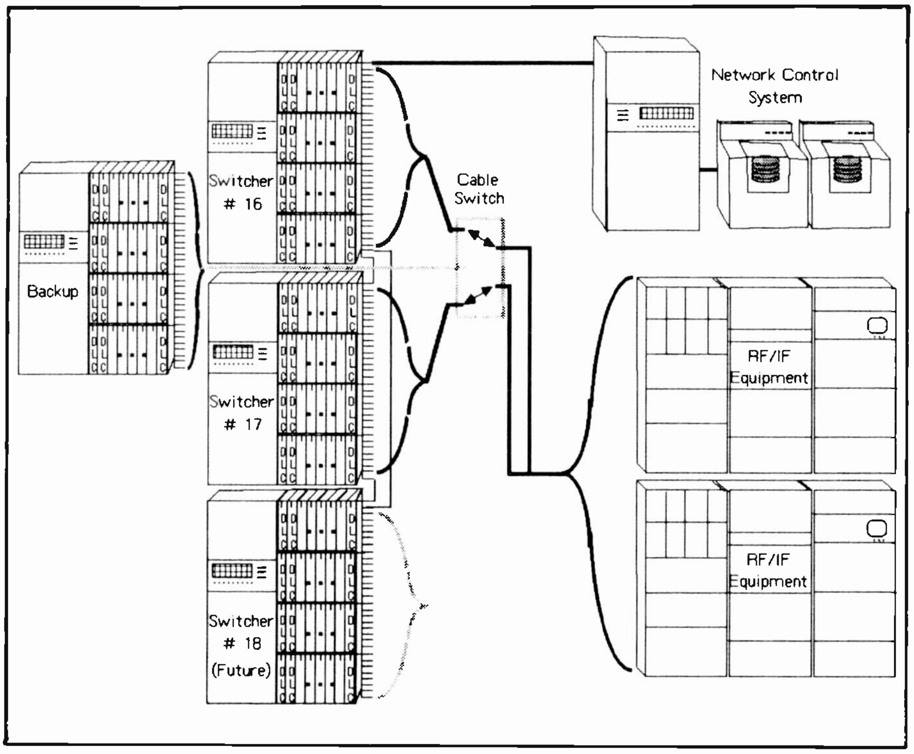

Fig. 3. *An overview of the central facility digital equipment (CSF).*

communications networks where several intermediate nodes are involved in a virtual circuit.

A second disadvantage is total availability. Since all nodes are not interconnected, the reliability of all network components must be high. In order to achieve the system availability goal of 99.5%, all components of the network are duplicated, allowing for the rapid backup of any failed component.

The advantages of the RCA Cylix architecture far outweigh the disadvantages. The star topology is simple, having only as many links as necessary to totally connect the remote earth stations. Network planning is straightforward, since each customer location may be connected to the nearest earth station. This also makes it extremely easy for customers to expand their data communications requirements without significant network analysis and reconfiguration. Finally, network monitoring and control is centralized. This reduces personnel requirements, while at the same time enhancing RCA Cylix's ability to coordinate installation and maintainance.

task performed by a switcher is very simple. The switcher inspects each incoming data packet for the destination remote earth station's address and consults a control table to determine which switcher serves that remote earth station. The packet is then passed to the proper switcher, which sends it out over the DLC/IF/rf satellite link to the destination remote earth station.

Services under development

There are projects currently underway within RCA Cylix to add new features to the network. These features will enable customers to perform their communications tasks in an even easier and more flexible manner. The first of these projects is the implementation of full switched virtual circuit support within the network. This will allow customers to select one of multiple host processors from their terminals. For example, many large corporations have more than one computing system, specialized for different applications. There are cases where a particular user needs access to all of these different types of applications. With the implementation of switched virtual circuits, and a menu selection approach at the terminal drop, the customer is able to easily select any one of the host computers and quickly move from one host to another.

A second project presently underway is the development of a special microprocessor-based communications processor to be integrated with the modem at each drop within the network. This processor, located on the customer's premises, allows for many new network services to be implemented. One of the services being anticipated is protocol conversion between dissimilar protocols; that is, one type of terminal device would be able to speak to a different type of host using different protocols. Another possible use of the communications processor is to provide personal computer types of software packages locally to the user. Other applications being considered are data compression, data encryption, and electronic mail.

Conclusions

The architecture of the RCA Cylix network is designed to provide a very reliable data communications facility for customers having transaction-oriented applications. Performing protocol translation/packetization at the edges of the network and transmitting the packets over a satellite-based star topology results in a cost-effective method with good performance characteristics. There are, however, disadvantages to this topology. Performance is not as good as that of a terrestrial point-to-point circuit. However, the performance may be compared to data

Fred Sutton is Assistant Vice President of Product and Market Development in the Marketing division of RCA Cylix. He joined RCA Cylix in December, 1980 as Director of Software Development and was promoted to Assistant Vice-President, Engineering and Development in 1982. He assumed his present duties in August of 1984. Mr. Sutton is responsible for defining the new product and market direction for RCA Cylix, coordinating the efforts of the company and vendors in the development of new products. He has over 18 years experience in technical design and development and technical project management. He holds a BS in Mathematics and Computer Science from the University of Illinois, and a MSEE from the University of Florida. He is an active member of the Association for Computing Machinery.

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R. Adler

NipperNet: RCA Network Services corporate packet switching network

Packet switching supports a number of communications modes such as low-speed terminal-to-host, terminal-to-terminal, and host-to-host.

Packet switching is an advanced technique of transmitting data. Information is assembled into "packets," or groups of characters destined for a particular location. A network control device, called the TP4052*, which will be discussed later, routes the packets over the shortest path available to the destination. This technique also provides the use of sophisticated error checking methods to increase data accuracy, and permits effective communication between a wide variety of terminals and computers. Packet networks, like NipperNet, can offer an economical method of connecting terminals and computers when long distance communication is required.

Abstract: *NipperNet is RCA's corporate private packet switching network (PSN). It was implemented in June 1984, and initial user cutover started in September 1984. It utilizes GTE Telenet hardware and software, and consists of switching nodes and X.25 concentrators connected via lines and trunks. Network capabilities include the ability to handle distributed processing, communicating word processors, terminal-to-host communications, electronic mail, computer-to-computer bulk transfer, and interconnection to public data networks and databases such as Dow Jones. The network software conforms to Consultative Committee for International Telephone and Telegraph (CCITT) 1980 X.25 standards.*

NipperNet serves geographically dispersed major operating units (MOUs), and represents a major step forward in data communications for the corporation. This paper describes the network topology, architecture, and capabilities of the system.

* TP4052 and TP3010 are trademarks of GTE Telenet, Inc.

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The reason for economies of scale are quite simple: packet switching time-shares communications lines and is usage-sensitive, which means that you pay for what you use. This, in some cases, allows elimination of costly, under-utilized private leased lines.

Background

As RCA has grown, so have its data communication requirements. In response to these increasing requirements, Network Services investigated various data communications methodologies in order to support present and future RCA communications needs. A number of networking alternatives for handling data communications were evaluated, including statistical multiplexing, continued use of voice-grade lines, lease of public packet switching network services, and the purchase of a private packet switching network. In the end, a combination of a private packet network and financially favorable use of GTE Telenet's public network was developed.

The following summarizes the advantages and disadvantages of various data communications alternatives:

- Statistical multiplexing, while less capital-intensive, requires more operational support, and when expanded to serve multiple hosts and higher speed, synchronous traffic becomes less economical. In addition, it does not provide individual call accounting or billing, and has limited capability in handling protocol conversions.
- Voice-grade lines are bandwidth-limited and cost-inefficient for multiple data transmissions.
- A leased public packet network service loses its economies as more traffic is sent over the system.
- Purchase of a private packet network facility provides for cost-effective interconnection of data through efficient "packetizing" of information over communications lines. The ability to accommodate a variety of terminal types and computer facilities throughout numerous RCA locations was instrumental in concluding that this was the best choice available.

Network Services' analysis of RCA's communications demands, facilities utilization, current service costs, expected economic trends, and the impact of new applications and requirements indicated that the major operating units and staff activities had sufficient traffic volume to support a private packet switched network.

Request for proposal

A request for proposal (RFP) was issued to 14 vendors, and seven responses were received. The field was reduced to three through an evaluation process.

The objectives in determining the preferred solution were:

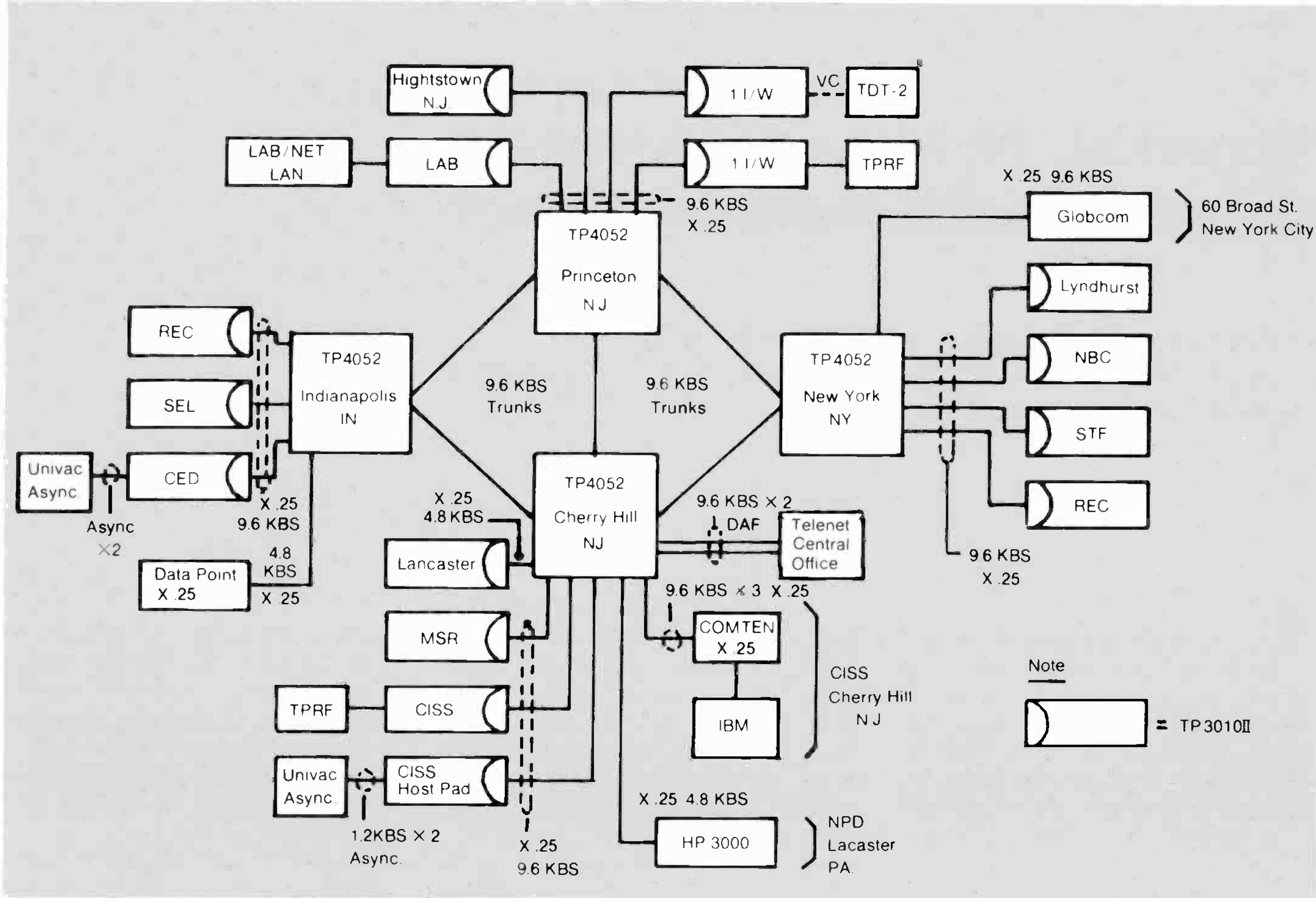


Fig. 1. *NipperNet topology. Switching nodes in Princeton, New Jersey, Cherry Hill, New Jersey, and Indianapolis connect to 15 concentrators throughout the network. Connections to various hosts, as well as Globcom in New York, are supported. The two 9600 BPS connections from the Cherry Hill TP4052 to the GTE Telenet public network allow access to NipperNet from Telenet's 350 locations.*

- To reduce RCA corporate data communications cost.
- To improve performance and features to MOUs and Corporate Information Systems and Services (CISS).
- To support a wide array of communications protocols.
- To cost-effectively manage a 20-percent or better annual growth rate.
- To support a variety of terminal types.
- To include network management tools such as online and offline diagnostics, downline loading of software, billing report generation, and traffic statistical analysis.
- To support transmission speeds up to 56 kbps.

On the basis of these objectives, and considering that packet switching has unlimited growth potential, RCA Network Services awarded the NipperNet contract to GTE Telenet, a pioneer in the application of packet switching. Telenet's expertise would provide the cornerstone on which to build the NipperNet system.

Project implementation

GTE Telenet assigned a dedicated project team to NipperNet that was responsible for the network implementation, acceptance test planning, scheduling, equipment and software installation, system acceptance, and overall program management.

A phased approach was used to implement the network. Initially, low-speed (110-1200 bps) asynchronous terminal access to NipperNet and communication between these terminals and the RCA Cherry Hill major data processing facility was supported.

The next step called for expanding NipperNet to other MOUs, and for providing intercommunications among all locations. Increased speeds (2400-9600 bps) and synchronous transmission would be provided to the users. The higher speeds would support synchronous terminals, such as IBM 3270 and 2780/3780, and would interface with other central computer facilities using X.25 protocol. It would also expand inter-MOU communications capabilities such as word processing, and would interconnect to public data networks.

NipperNet resources

The basic components of the network consist of switching nodes, concentrators, trunks, access lines, and a connection to the GTE Telenet public network.

NipperNet network architecture consists of four TP4052 switching nodes and 15 TP3010 concentrators (Fig. 1).

The backbone of the network is made up of switching nodes connected by 9600bps synchronous trunk lines. These provide the dynamic switching of traffic on the network. Connections established by the nodes employ virtual circuit routing whereby all packets of a particular call follow the same route. This technique requires that a routing table be kept at each node that records the logical channel number (LCN) and the network lines over which each active call is established. Multiple routes between switching nodes provide alternate routing in the

The TP3010 features hardware and software that allow extensive remotely-initiated diagnostics as well as a built-in self-diagnostic capability.

Two input lines and one output line are standard. If more than this is required, as is the case with NipperNet, extended line adapters (ELAs) are available. Each ELA adds eight input lines to the system, and the system is capable of supporting a maximum of three ELAs for a total of 26 ports.

The TP3010 operations consist of the following:

- Provides packet assembly/disassembly functions
- Establishes call connection via rotary sequence
- Verifies user identification
- Performs protocol conversion (asynchronous to X.25, for example)
- Provides flow control
- Provides echo
- Monitors data set signals
- Provides character or time delay padding on output to asynchronous terminals.

The NipperNet concentrators are located in the following cities:

- Cherry Hill, N.J.
- Hightstown, N.J.
- Indianapolis, Ind. (CED)
- Indianapolis, Ind. (REC)
- Indianapolis, Ind. (SEL)
- Lancaster, Pa.
- Lyndhurst, N.J.
- Moorestown, N.J.
- New York (NBC)
- New York (REC)
- New York (STF)
- Princeton (1-IW)
- Princeton (LAB)

The trunks and access lines are analog voice-grade type 3002 data circuits with C2D1 conditioning.

GTE Telenet public network connection

In addition to the switching nodes and concentrators, there are two dedicated access facilities (DAFs) that connect NipperNet to the Telenet public network via the switching node in Cherry Hill, New Jersey.

These links serve multiple purposes. If a NipperNet access line fails, the user can utilize the Telenet public network to gain access to a NipperNet-connected host computer.

Another purpose of the connection to the public network is to facilitate off-net access to NipperNet, other hosts, and other

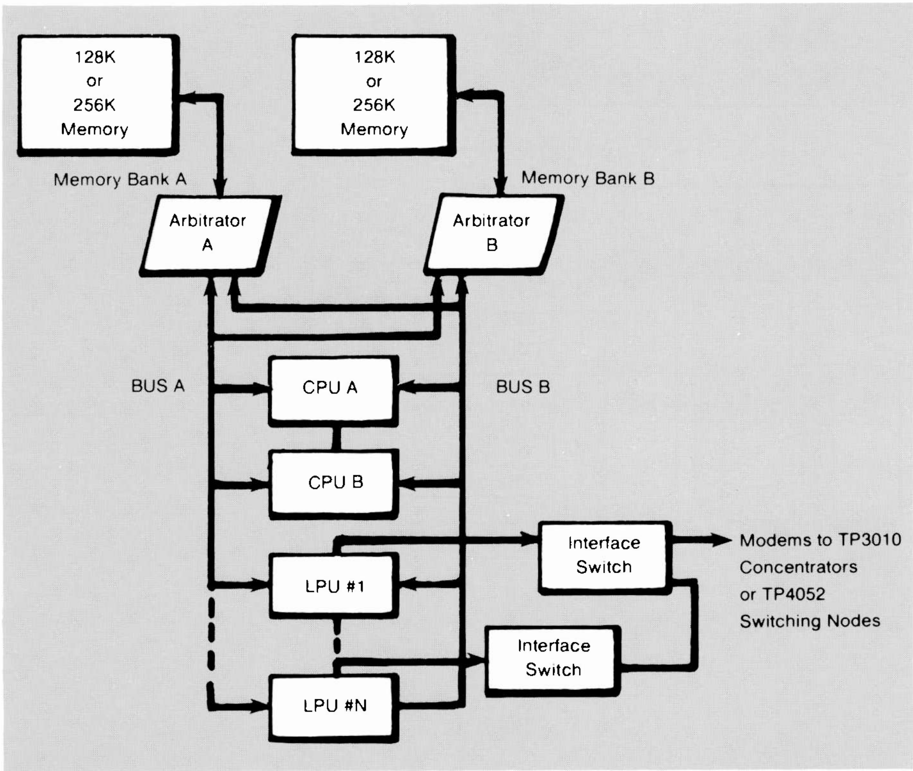


Fig. 2. *The arbitrator controls access to the main memory. In the event of line processing unit (LPU) failure, the interface switch will be automatically activated and switch the traffic to a backup LPU.*

event of a line failure. 9600-bps access lines connect the concentrators to the switching nodes.

The switching node

Primary hardware consists of TP4052 switching nodes (Fig. 2). The principle components of a TP4052 are:

- Main memory
- Arbitrator
- Central processing unit (CPU)
- Data and address buses
- Line processing unit (LPU)
- Maximum of 56 host/terminal ports
- Eight output lines supporting speeds up to 56 kbps each (memory dependent)

Both LPU and CPU cards contain a 6502A microprocessor. All microprocessors run asynchronously with one another. TP software takes full advantage of this operation by functionally partitioning the processing load among different microprocessors. The CPU is responsible for processing the TP operating system (TPOS) and the X.25 packet level protocol for all virtual circuits.

The TP4052 performs the following switching operations:

- Call routing
- Alternate routing
- Automatic reconnection during transmission
- Error checking
- Flow control
- Clocking for X.25 interfaces

The current NipperNet switching node locations are:

- Princeton, N.J.
- New York City, N.Y.
- Cherry Hill, N.J.
- Indianapolis, Ind.

The concentrator

The function of a concentrator is to interface terminals and hosts into the backbone network and to concentrate the traffic onto data circuits. These concentrators are connected to the switching nodes by 9600-bps synchronous lines supporting the X.25 interface protocol. The primary hardware consists of TP3010 concentrators (Fig. 3). The principal components of the TP3010 are:

- Communications line processor (CLP)
- Backplane and six-slot card case
- Power supply
- Control and status panel
- Local TTY and tape interface card
- 64-k main memory

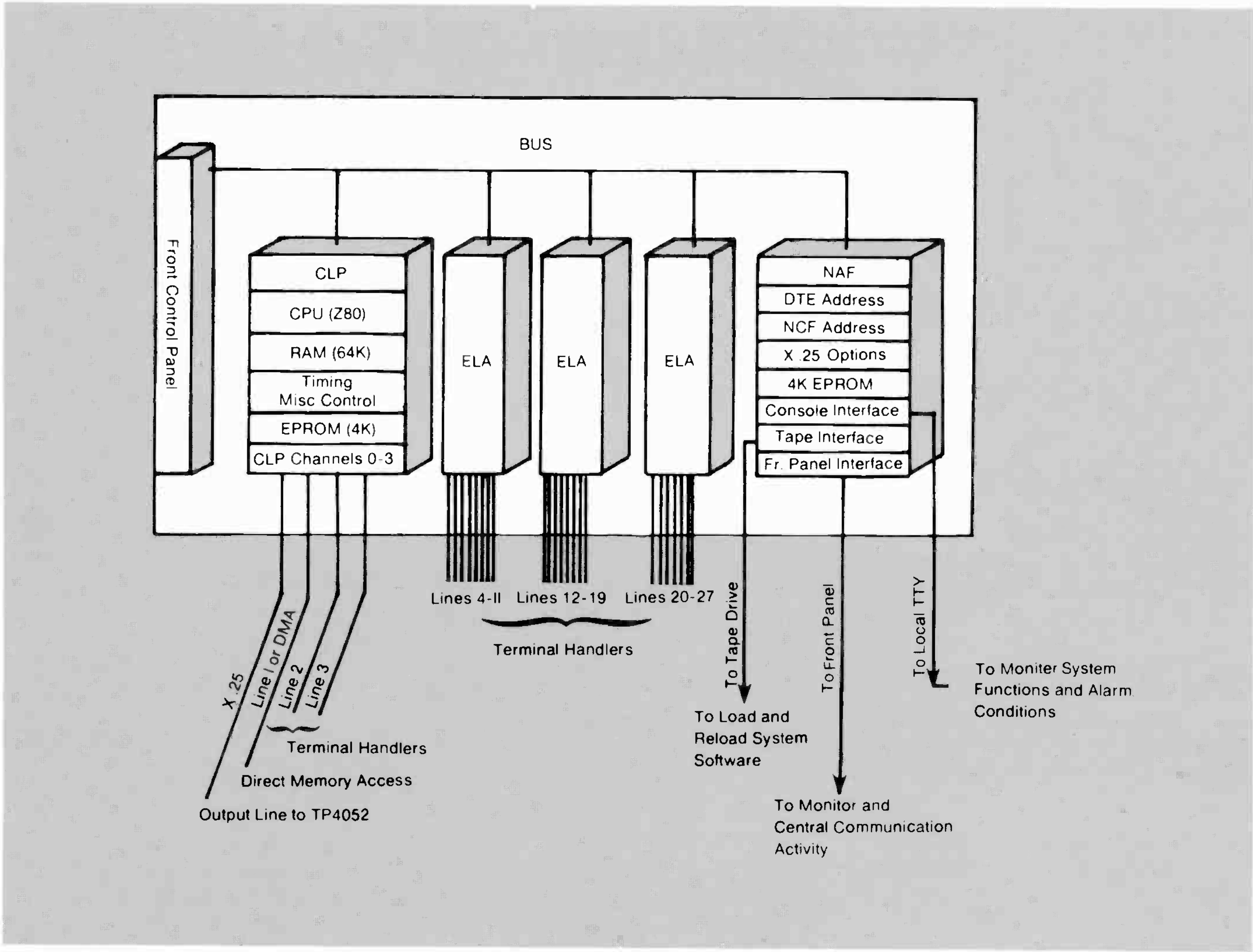


Fig. 3. *Block diagram of a TP3010 X.25 network concentrator.*

data bases from non-network locations, thus enabling NipperNet access from anywhere in the world.

These links also serve to provide the path for software down-line loading as well as performing system monitoring and diagnostics. The RCA Network Services technical staff can access the Telenet Processor Reporting Facility (TPRF) and the Telenet Diagnostic Tool Version 2 (TDT2) network management functions via these links.

Network management support services

There are two primary network management support service facilities provided by GTE Telenet that allow NSI to monitor network conditions. Telenet Processor Reporting Facility (TPRF) is a software-based automatic reporting module that resides in the GTE Telenet Network Control Center (NCC) in Vienna, Va. This is not an interactive facility. Network hardware, software, and circuit status messages are collected from network switches and concentrators, logged at the Telenet NCC, and printed in real time on alarm printers located at RCA Network Services in Princeton, N.J. as well as the RCA major data center facility in Cherry Hill, N.J. These reports are evaluated by network personnel to insure that the network is functioning properly.

Telenet Diagnostic Tool Version 2 (TDT2) is also a software-based diagnostic module residing in the Telenet NCC, and complements TPRF. This is an interactive facility that allows the introduction of system commands to check current hardware availability status, initiate remote software loads, perform loop-back test patterns, and retrieve statistics for diagnostic purposes.

In addition to the these network management tools, NSI can call upon the Telenet Customer Network Technical Assistance Center in Vienna, Va. to assist in problem diagnosis and solution.

Accessing NipperNet

Accessing NipperNet in an asynchronous dial-up mode is quite simple. The user simply dials the telephone number of the nearest TP3010 concentrator node. Once that connection is made, the user can then link to any host that is connected to the NipperNet system. Appropriate passwords and user identifications must pass security checks before total computer access is allowed. Assuming that the security requirement is met, the user has now established a switched virtual circuit (SVC). This SVC will remain in effect until the user logs off or otherwise disconnects from the system.

NipperNet allows the user to disconnect from a host without completely terminating a call. This allows the benefit of connecting to various hosts without employing full call establishment procedures.

Messages entered to a source node on NipperNet are assembled into small segments called packets. This function is performed by the TP3010. The packets are

RCA Network Services

RCA Network Services manages internal communications for RCA and its major operating units, providing facilities and expertise in the areas of voice and data networking, message services, and local operations, including on-premises provision of operators, message center facilities, PBX and station equipment, and local facilities management. These corporate communications services are provided at cost on a self-liquidating basis as a service to the corporation.

It operates one of the largest private voice networks in the United States, Tacnet. Tacnet is the corporate long distance voice network that currently serves over 138 locations directly, and an additional 90 locations by off-premises extension service. During 1984, the number of locations served by the network increased 17 percent. The Tacnet network presently handles over 1.2 million calls per month, which translates into a volume of 5.1 million minutes of conversations. Credit card service is also provided as a Tacnet offering and allows the corporate network to be utilized for both on-or off-net calling from any location in the United States. This service grew 27 percent in 1984.

Local operations services are provided to large RCA activities, and include the management of PBXs, local telephone and data services, telex and TWX operations, and other communications functions. At the present time, RCA Network Services manages over 16,000 phones in 16 locations throughout the corporation, with primary areas of concentration in New York, Princeton, Indianapolis, and the Cherry Hill-Camden area.

Another offering of RCA Network Services is NipperNet, RCA's private data network. NipperNet makes possible communication among the many data terminals and host computers throughout RCA, regardless of their compatability. Through the network, users are offered access to a variety of public data bases that provide timely information ranging from stock quotations to international news to abstracts of scientific papers.

In mid-1984, a new group was formed called Communications Consulting Services. This telecommunications consulting organization provides practical solutions to daily telecommunications problems and assists in long-range planning. The group offers information, insight, and analytical tools to its customers to help manage their changing communications needs. These customers are real estate developers, hospitals, hotels and motels, businesses of all sizes, and government agencies. The group's services include facilities analysis, network design, user support, and facilities management.

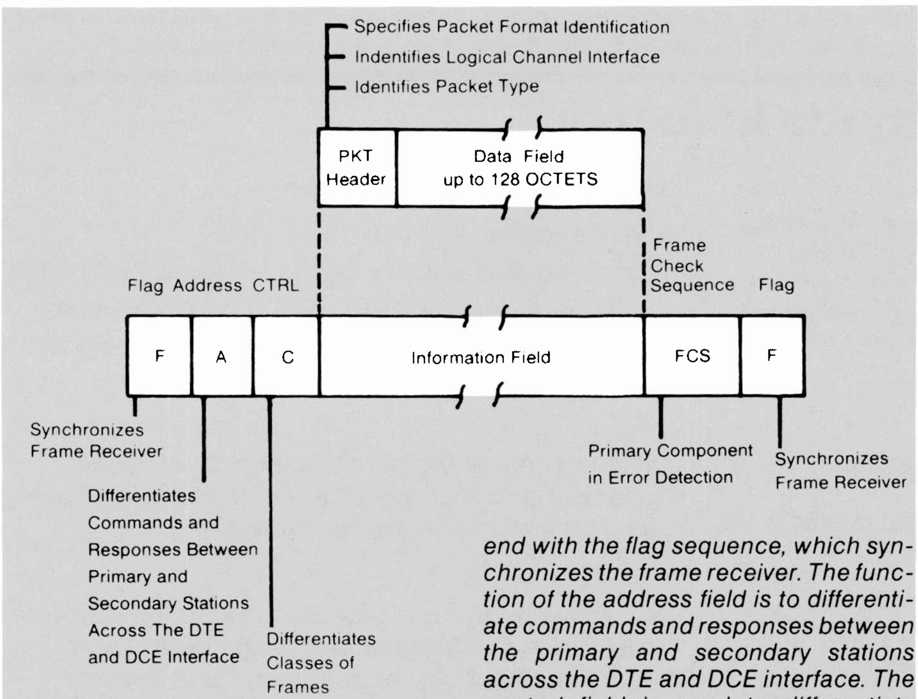


Fig. 4. *The entire information constitutes the frame. Appended to the front of a packet are the flag field, an address field, and a control field. Appended behind the packet are a check sequence field and a flag field. All frames start and end with the flag sequence, which synchronizes the frame receiver. The function of the address field is to differentiate commands and responses between the primary and secondary stations across the DTE and DCE interface. The control field is used to differentiate classes of frames. The packet header specifies packet format identification and identifies the Logical Channel Interface and packet type. The frame check sequence is the primary component in a complex error detection scheme.*

then placed in a frame (Fig. 4) for transmission through the network. At the destination node, the packet is disassembled and the data is fed into the host computer in the same format and sequence as those created by the terminal.

User interest

As part of the NipperNet initial implementation process, Corporate Information Systems and Services (CISS) has accepted NipperNet as the network vehicle by which their asynchronous terminal users will access the data center in Cherry Hill, N.J.

Also, a NipperNet connection to the Consumer Electronic Division's Univac 1100 in Indianapolis provides communications for CED users in the U.S., Korea, Japan, and Taiwan.

The Hewlett Packard hosts used by the New Products Division (NPD) in Lancaster, Pa., Montreal, Canada, and Sunbury, U.K. are connected via NipperNet. This is accomplished by interfacing with Telenet in the U.S., Datapac in Canada, and IPSS in the United Kingdom.

The David Sarnoff Research Center (DSRC) in Princeton, New Jersey has connected its local area network (LAB-

NET) to NipperNet. This allows traveling personnel to access the Labs office automation system. Users in Lancaster, Pa. and Indianapolis can access the LABNET as well. NipperNet will allow the Labs to remove a leased line to Indianapolis. Future plans call for the Zurich Labs to access the Princeton Labs via local packet networks.

Conclusion

The NipperNet network provides the means by which incompatible terminals and hosts can communicate via a communications standard protocol (X.25). NipperNet is a cost-effective system that introduces economies of scale for those users who might otherwise not be able to justify the communications hardware, software, and circuits necessary to access distant computers.

At present, the NipperNet program supports up to 1200 bps dial-up asynchronous data communications services from all locations listed earlier. In addition, through the 350 GTE Telenet locations, NipperNet supports services to and from all 50 states and over 50 foreign countries. These services are available to all RCA divisions at discounted rates negotiated through GTE Telenet specifically for RCA Corporation.

NipperNet access is currently provided to:

- Corporate Information Systems and Services (IBM)
- New Products Division (Hewlett-Packard)
- Consumer Electronics Division (Univac)
- RCA Laboratories (LABNET)
- GLOBCOM (Telex)
- RCA mail (electronic mail)
- Telenet public network (domestic and international)

The total number of hosts that can be placed on NipperNet for user access is unlimited.

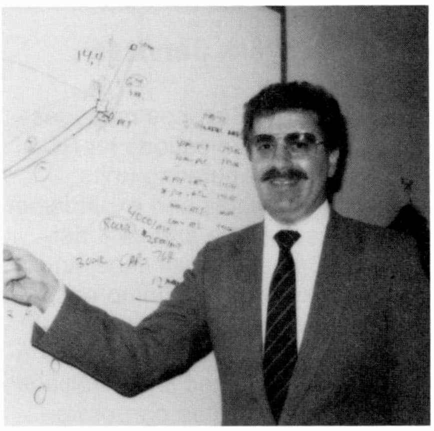
Future plans are for the availability of synchronous services such as 3270 and X780 transmission up to 4800 bps by the end of the first quarter of 1985. By the end of the second quarter, SNA will be supported.

RCA Network Services will continue to actively pursue division interconnection with NipperNet in order to provide cost-effective, efficient data communication service to the corporation.

For additional information concerning NipperNet, call **Tacnet: 272-7678** or **(609) 987-7678.**

Acknowledgements

Many people have directly or indirectly contributed to making this article possible. Technical suggestions, critical evaluations, and review of the various manuscript stages by our coworkers at Network Services have materially influenced the article's organization and content. Special thanks go to Tom Hammett, Lou Harbrecht, Fred Huffman, Peter Kuk, and Frank Lockwood for their invaluable assistance.



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Improvements to be made to Tacnet

Improvements will be made to Tacnet (RCA's Telecommunication and Computer Network) between March 15, 1985, and June 3, 1985. At the center of the program is the cutover of the six Tacnet switching centers from AT&T to RCA owned and operated facilities. This will permit a saving of $3 million per year and put a cap on increasing costs.

Additional benefits are:

- Greater flexibility and increased productivity.
- Better quality transmission through improved circuit access and testing.
- Improved Tacnet credit card service through closer administrative control, an easier dialing pattern, and improved transmission facilities.
- Better traffic engineering.
- Shorter intervals for ordering voice and data circuits.
- Increased availability of UDACs (User Dialed Authorization Codes).

Here is the schedule for cutover:

Los Angeles — March 15-18, 1985
Indianapolis, Atlanta, Dallas — March 29-31, 1985
Camden — April 12-15, 1985 (non-microwave)
— April 15-May 20, 1985 (microwave)
New York — May 31-June 3, 1985

RCA network Services in Princeton, New Jersey, operates and manages Tacnet and will be responsible for the new switching centers.

No user problems are expected during the cutover to RCA Network Services switching centers. However, should troubles occur, please call Network Operations control at Tacnet: 254-9898 or (609) 734-9898. In addition, recorded announcements will be updated periodically regarding the status of the cutover. The recorded announcement number is Tacnet: 272-7600 or (609) 987-7600. The announcements will begin Friday, March 1, 1985.

W.H. Braun | J.E. Keigler

The RCA communications satellite networks

Systems engineering, satellite design, and earth station optimization have shaped the RCA system for maximum profitability, and continue to be tightly coupled in the development of RCA's Ku-band satellites.

The communications satellite network operated by RCA American Communications, Inc. (Americom) has been in U.S. domestic operation since 1974, providing services to all 50 states. These services include private and message toll voice lines, radio and television interconnection for the broadcast networks, digital data transfer, and multipoint television distribution to local cable companies. Seven satellites are located at six authorized longitude stations to supply RCA's C-band service. The network consists of a broad complex of both customer-and RCA-owned earth stations, terrestrial microwave links, and central terminal offices throughout the 50 states. However, the system is not complete; new equipment and services are continuously being added. Satellites of increased channel capacity, longer life, and higher reliability are under development for launch in the near future, and K-band versions of the Satcom spacecraft will supplement the current C-band system for such services as small master antenna TV (SMATV) to group residences and direct digital data links to customer-premises terminals.

Abstract: *Channel demands on the RCA Americom domestic satellite communications system have continued to increase rapidly since the first launch in 1975. After deploying four of the first-generation 24-channel spacecraft, Americom introduced an advanced, all-solid-state design in 1982, which has more than twice the traffic capacity of the original series. To supplement the operational network of six C-band satellites, K-band satellites will be introduced in 1985 to serve the small master antenna TV market. Accompanying the continuous incorporation of state-of-the-art technology into successive satellites to achieve increased traffic capacity and longer life, new terrestrial equipment and efficient signal processing/modulation techniques are being exploited to continue the competitive reduction of cost per satellite circuit per year.*

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Reprint RE-30-1-3

RCA initiated its satellite service in January 1974 by leasing transponders on Telesat Canada's Anik A2 satellite, pending completion and launch of its own Satcom satellites. The Satcom system has been implemented, stressing low cost to be competitive in the commercial market. The prohibitively large capital investment required to introduce domestic satellite service using satellite and launch vehicle configurations derived from ongoing Intelsat programs forced major technological advancements to minimize costs. Development of a 24-transponder Delta-class spacecraft,[1] together with private (that is, RCA plus McDonnell-Douglas) funding for the upgrading of the Delta launch vehicle to the 3914 configuration, led to the necessary system economics. Frequency reuse was first used in the Satcom communications subsystem to double the channel capacity of the authorized 500-MHz bandwidth at C-band, and the spacecraft were the first commercial satellites with power and propellant capacities for continuous operation of all channels for at least eight years on-orbit. Satcom I was launched in December 1975, and Satcom II in March 1976. The capacity of these first two satellites was filled so quickly, due largely to the synergistic expansion of cable TV and satellite program distribution, that RCA launched two additional 24-channel C-band satellites in December 1981 and January 1982. Retaining the frequency reuse channelization plan, these two satellites provided modest increases in equivalent isotropically radiated power (EIRP), on-orbit life, and channel reliability, the latter by addition of four spare traveling wave tube amplifiers (TWTAs).

With the necessity of replacing the first two satellites and further expanding the satellite constellation, Americom selected a second-generation C-band satellite design with higher traffic capacity to realize reduced cost per satellite circuit per year. The all-solid-state Advanced Satcom satellites were launched in October 1982, March 1983, and September 1983, and one is scheduled in December 1986. This last spacecraft of the C-band series will incorporate a switchable spot beam providing six-transponder coverage of Western Europe and Africa.

As domestic C-band satellite systems and services have matured, satellite hardware technology and service opportunities have developed at K-band. Motivated primarily by the economics of small on-site terminals, and the limitations of C-band orbit assignments and terrestrial interference, K-band domestic satellite systems have proliferated rapidly since the initial demonstration of Telesat's Anik B in 1979. Americom's entry into this market, with

Table I. *RCA Satcom satellite summary*

Parameter	*Value*					
Spacecraft Number*	I, II	III, IV	V-VIII	IX	K1, K2	K3,K4
Frequency Band, GHz	6/4	6/4	6/4	6/4	14/12	14/12
Launch Dates	12/75 3/76	12/81 1/82	10/82 3/83 9/83 (Ground Spare)	(12/86)	(9/85) (11/85)	(1987) (1987)
Launch Vehicle	D3914	D3914	D3924	STS/SCOTS	STS/PAM	STS/SCOTS
Transfer Orbit Wt. kg (lb)	902 (1990)	975 (2150)	1110 (2440)	2040 (4500)	1880 (4135)	2270 (5000)
Mission Life, Yrs	8	10	9.5	12	10	10
Solar Array Area m^2 (ft^2)	7 (75)	8.4 (90)	12 (128)	14 (145)	27 (279)	30 (310)
End-of-Life Array Power, W	550	700	1100	1250	2450	2900
Active Power Amplifiers	24@5W (TWTA)	18@5.5W (TWTA)	24@8.5W (SSPA)	24@10W (SSPA)	16@45W (TWTA)	16@60W (TWTA)
Spare Amplifiers	0	4	4	8	6	6
CONUS EIRP, dBW	32	33	34	36	45	47

*The C-band series are here labelled sequentially for simplicity. For FCC purposes, III is IIIR, V is Aurora, VI is IR and VII is IIR.

its emphasis on SMATV service, will be Ku-band versions of Satcom scheduled for launch in 1985. These two larger, higher-power satellites will employ the frequency-reuse antenna technique pioneered on the C-band Satcoms, together with sixteen 45-watt transponders individually switchable in orbit to eastern, western, or CONUS coverage. The third and fourth Ku-band satellites are being designed with higher antenna gain by means of a deployable reflector and even higher power amplifier output per transponder channel. Characteristics of the Satcom satellites are summarized in Table I.

Corresponding to the evolutionary growth of the Americom satellite capability, the earth station complex has expanded both in numbers and in performance capabilities. From a rudimentary system using readily available transmission techniques and hardware to provide voice frequency channels via transponders leased from Telesat Canada, it has grown, expanded, and diversified into a complex telecommunications entity supplying sophisticated services to a wide range of customers in its chosen markets.

RCA satellite networks

RCA Americom serves three distinct domestic communications traffic markets—commercial, government, and video/audio. Commercial Communications Services provides private leased channels for voice and data traffic via an ever increasing number of facilities and commercial earth stations serving the major metropolitan areas of the United States (see Fig. 1). Expansion for 1984/85 includes Cleveland, Pittsburgh, and Kansas City. Traffic on these leased channels is primarily voice frequency transmission in the 300- to 3400-Hz band, plus some associated low-speed data up to and including 9600 bps (bits-per-second).

Government Communications Services provides voice, video, and high-speed data services to federal agencies (NASA, DoD, NOAA, GSA) via the RCA-owned earth stations located on various government installations. Locations are listed in Table II. The government digital traffic consists of two varieties:

- Frequency Division Multiple Access (FDMA), in which individual carriers continuously occupy discrete segments of a transponder's power and bandwidth. These are usually point-to-point duplex digital bit streams at widely varying speeds, the most common being 56 kbps and 1.544 Mbps (T-1).

- Time Division Multiple Access (TDMA), in which earth stations transmit digitally

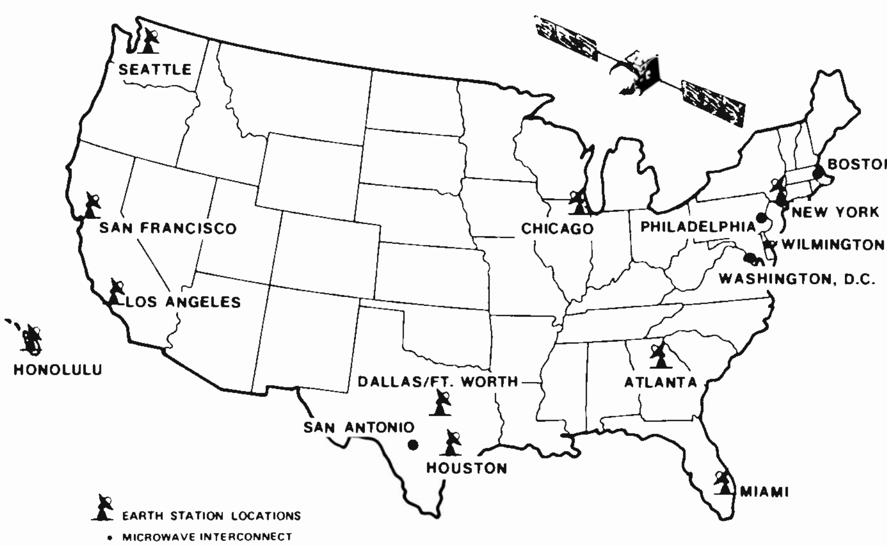


Fig. 1. *Cities served by RCA Americom.*

Table II. *Government station locations*

Suitland, Maryland	Rockville, Maryland
Cape Canaveral, Florida	Guantanamo Bay, Cuba
NASA Kennedy Space Center, Florida	Johnson Space Center, Texas (2)
Roosevelt Roads, Puerto Rico	Fort Hood, Texas
White Sands, New Mexico (2)	Offutt AFB, Nebraska
Sioux Falls, South Dakota	Sunnyvale AFS, California (2)
Dixon, California	Monterey, California
Delano, California	Pasadena, California
Edwards AFB, California	Hollywood, California
Goldstone, California	Barking Sands, Hawaii
Thule AFB, Greenland	Marshall SFC, Alabama
Wallops Island, Virginia	Ft. Belvoir, Virgina
Goddard SFC, Maryland	Vandenberg AFB, California

formatted traffic in discrete sequential bursts occupying a transponder's full power and bandwidth during an assigned time slot. Capacity of a Satcom-class C-band transponder for such applications is in excess of 60 Mbps.

Video and Audio Services provides point-to-point and point-to-multipoint distribution of television and radio services to broadcasters and the cable TV industry. Television transmissions of standard NTSC video are most often one-video-per-transponder, but occasionally two-per-transponder for special applications. The network of receive-only stations serving RCA Satcom satellites has expanded considerably since satellite distribution of cable television programming began in 1975. Owned by the local broadcaster or cable operator, these receive-only stations are now estimated to number over 10,000.

Each business sector has a unique character that strongly influences the engineering approaches needed to effectively support it. However, common to all technical activities at Americom has been the fundamental imperative of commercial viability as the system expands. To this end, developments and enhancements are measured against the twin benchmarks of improved performance and return on investment. The primary technical objectives of engineering activities are to increase traffic capacity per satellite, achieve longer satellite life with improved reliability, and assure compatibility of terrestrial and space transmission facilities with business requirements. Realizing a profit without sacrificing these primary objectives results in a system expansion plan that depends primarily on evolutionary enhancement rather than revolutionary innovation.

Satellite design

The characteristic RCA Satcom configuration (Fig. 2) of a three-axis-stabilized, rectangular box-shaped main body, carrying the fixed primary high-gain antenna and sun-oriented solar array panels is the result of power and weight optimization for the communications payload. In the early 1970s, the available options for domestic C-band satellites were either Delta-class 12-channel spacecraft (Anik, Westar) or Atlas/Centaur-class 24-channel spacecraft (Comstar), both spin-stabilized types. To achieve minimum cost per channel in this competitive market, RCA Global Communications, Inc. (from which Americom was started in 1975) specified that their satellite provide 24 channels in the commercial 6/4-GHz band, yet be compatible with the Delta launch vehicle. At the same time, Globcom joined with McDonnell-Douglas Astronautics Corporation in private funding of the Delta 3914 vehicle development to increase transfer orbit weight capability to 910 kg (2000 lb) from the 700 kg (1550 lb) capability of the government-funded 2914 vehicle. RCA Astro-Electronics proposed that a three-axis-stabilized satellite design could provide full eclipse power and stationkeeping fuel for a mission life of at least eight years within these constraints, while spinner designs were limited to some combination of reduced eclipse power and/or propellant life. Consequently, under a fixedprice contract with 24 months to deliver the first flight spacecraft, Astro supplied the satellite hardware, ground station command and telemetry equipment, and software for launch and in-orbit control. The basic Satcom spacecraft design has proven to be remarkably adaptable to communications payloads of increasing complexity, weight, and power, as shown in Table I.

Accommodation of 24 wideband transponder channels within the 500-MHz allocation of fixed satellite service at C-band (5.925 to 6.425 GHz for earth to space and 3.7 to 4.2 GHz for space to earth) requires a frequency reuse technique.

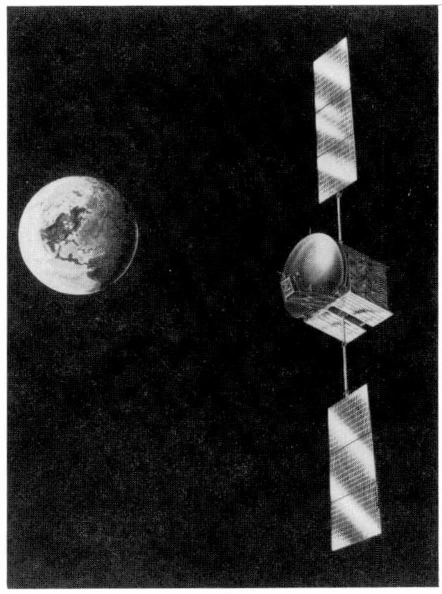


Fig. 2. *Satellite configuration.*

RCA Satcom introduced a cross-polarized antenna system to provide 12 standard 36-MHz channels on each polarization with an interleaving offset of 20 MHz, as shown in the frequency plan of Fig. 3. Crossed linear polarization was selected to provide maximum isolation between the two signals occupying the same spectral band while also minimizing hardware design complexity and weight.

Functionally, the 24-channel C-band transponder consists of two independent 12-channel transponders, as illustrated in Fig. 4. All channels have a fixed 2225-MHz translation between uplink and downlink signals, because the transponder design is a single-conversion, heterodyne amplifier (without frequency inversion). Following the broadband receiver on each polarization, 12 input bandpass filters divide the 500-MHz band into 12 channels prior to high-level amplification by the output power amplifier and subsequent recombination by the 12 output multiplex filters. As shown, the input and output manifolds combine alternate channels at 80-MHz spacing to avoid the higher insertion loss and weight of contiguous-channel C-band filters at 40-MHz spacing.

During the decade of evolution of the Satcom C-band satellites, the traffic capacity and reliability of the transponder has been enhanced significantly with the introduction of new technology into each component, together with the inclusion of switchable spare units. The original tunnel-diode amplifier receiver with a noise figure of 7 dB has been superseded by an all-GaAs FET receiver with a noise figure of 3.5 dB. In place of the simple redundancy on each

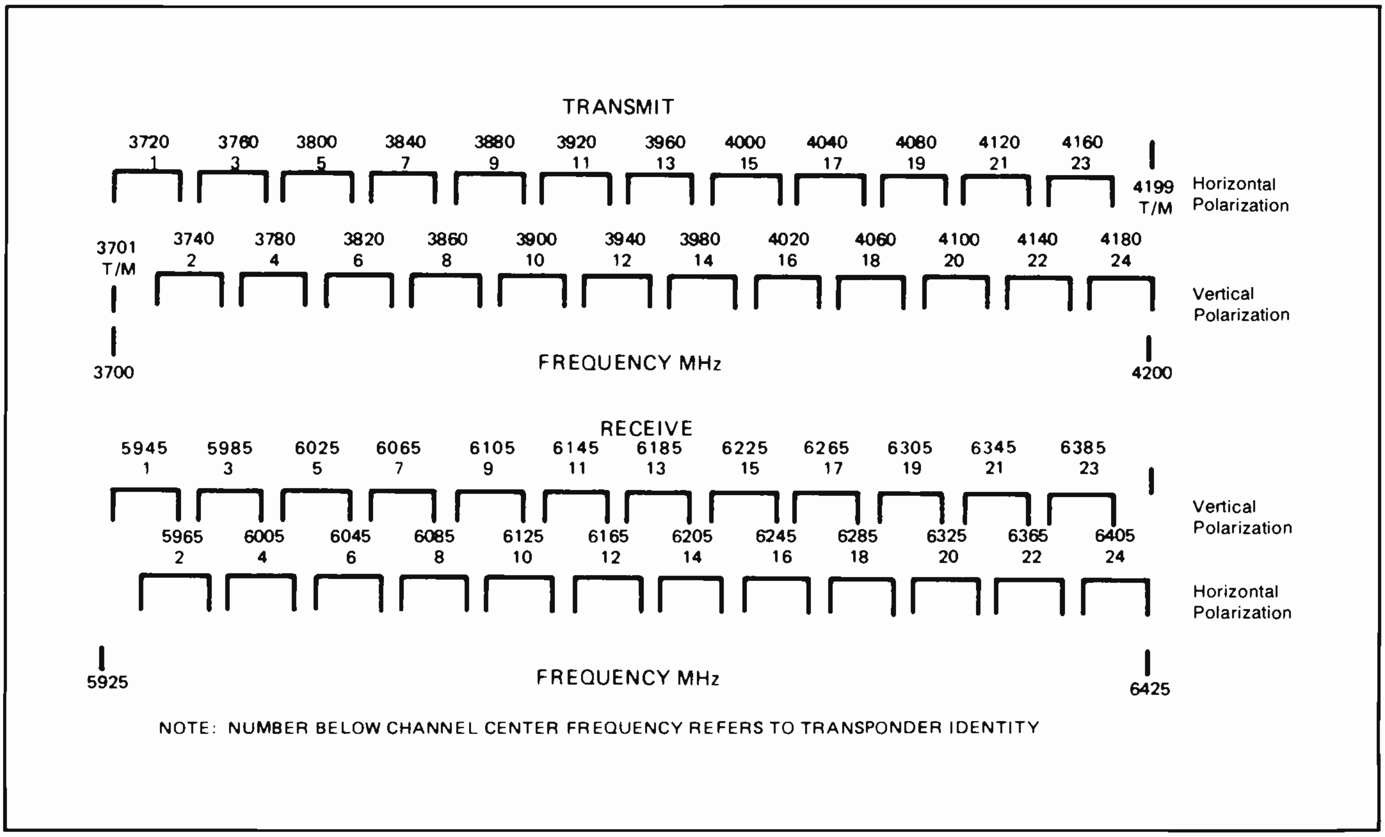


Fig. 3. *C-band frequency plan.*

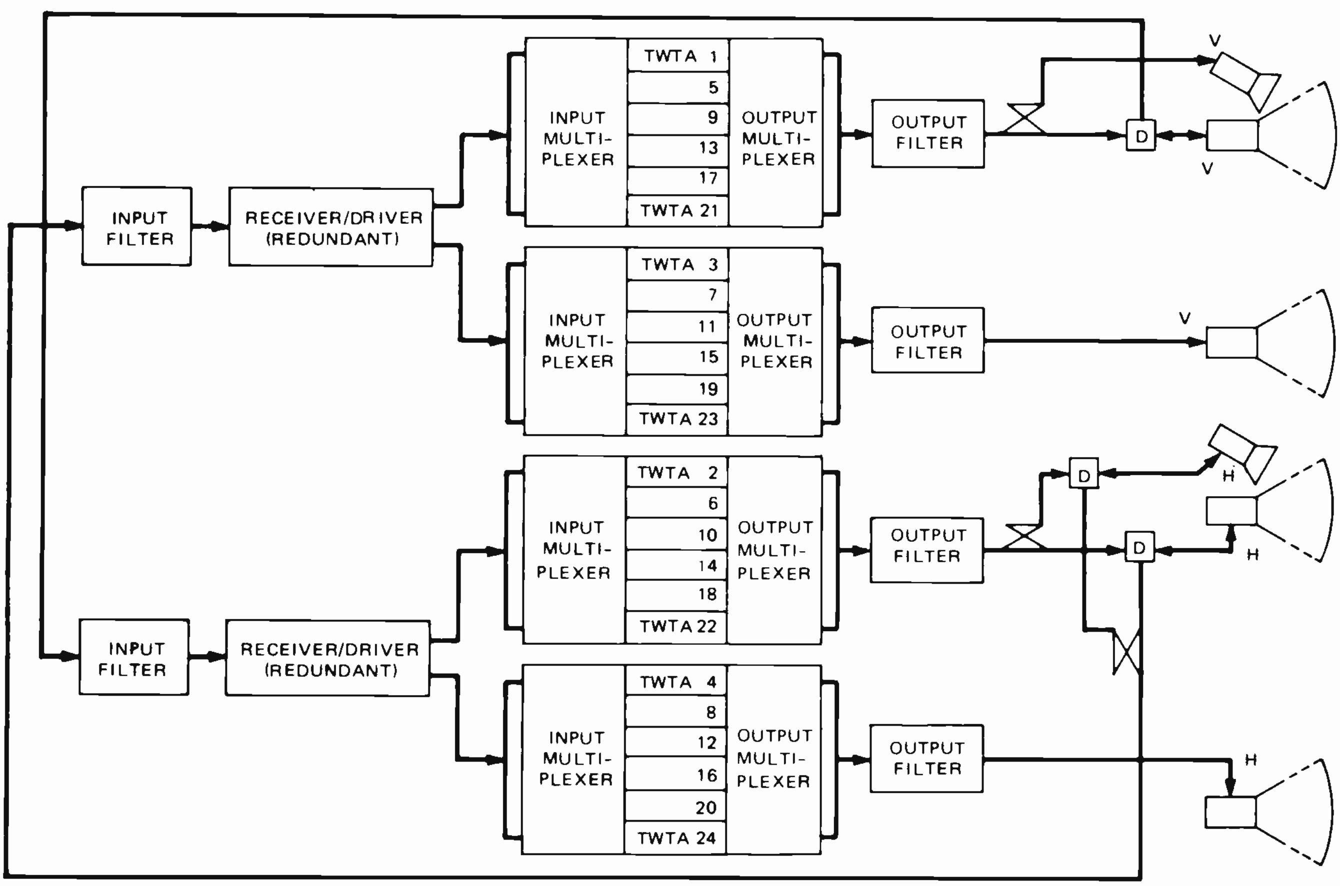


Fig. 4. *Original 24-channel C-band transponder.*

polarization, interconnection now allows any two of the four installed receivers to support both chains. Conventional Chebyshev response multiplex filters of lightweight graphite-fiber/epoxy composite (GFEC) fabrication have been replaced by dual-mode elliptic function designs of thin-wall Invar, which achieve flatter response and sharper roll-off at the same weight by reusing each waveguide cavity for two electrical filter sections. The most dramatic enhancement in transponder capability has been in the power amplifier section, in which redundancy and solid-state technology have been incorporated. Figure 5 shows the more sophisticated configuration of the current 24-channel C-band transponder compared to the original implementation of Fig. 4.

All-solid-state GaAs FET power amplifiers (SSPAs), now used instead of TWTAs, significantly improve both the performance and reliability of the transmitter section of the transponder.[2] In comparison with a TWTA, the SSPA is more linear, particularly near the full power operating point. This linearity of the power transfer function, with less gain compression at the nominal saturation level, is exibited in terms of the level of intermodulation between two (or more) carriers. With the SSPA, as shown in Fig. 6, the signal-to-third-order-intermodulation (S/IM_3) distortion between two carriers is 3- to 8-dB better than that of the TWTA. Hence, to achieve a given signal quality, for example 20-dB S/IM_3, the input back-off required for the SSPA is approximately 5 dB less than that for a TWTA, thus providing a higher signal-to-noise ratio and resultant greater channel traffic capacity. In addition, the significant decrease in phase variation with drive level provides improved AM-to-PM performance for FDM traffic and reduced bit error rate for digital traffic (see Fig. 7). Elimination of the hot-cathode life limitation and high-voltage power supply complexity of TWTAs greatly increases the probability that each power amplifier will survive a full ten-year mission. In the current redundancy scheme of one standby spare amplifier for each operating group of six, the improvement in channel availability throughout the mission life using SSPAs is shown in Fig. 8.

The unique antenna designs selected to achieve the combined requirements of gain, coverage, polarization isolation, alignment stability, and low weight are shown in Figs. 9a and 9b. Reflector surfaces are fabricated of Kevlar to achieve low thermal distortion and low rf loss with minimum weight, while the feed tower structure employs GFEC for its superior strength-to-weight properties. Polarization isolation specifications of at least 33 dB across the entire coverage area led to separate feed/reflector pairs for each polarization. The reflector surfaces comprise grids of parallel wires embedded in a low-loss dielectric parabolic surface, with the direction of the grid wires being parallel to the E-vector of each antenna and orthogonal to each other for the two polarizations. Gain and coverage requirements, within the volume constraints of the launch vehicle fairing, resulted in the overlapping reflector arrangment shown. Because the cross-gridded reflectors are virtually transparent to an orthogonally polarized wave, and because axial separation of the surface provides a corresponding separation of their focal points, this overlapping reflector design provides the desired 33-dB isolation over the full beam area across the 500-MHz band. The early Satcoms employed a single feed horn generating a simple elliptical beam per transponder/antenna port, hence the need for two reflectors per polarization (Fig. 9a). In contrast, the newer designs employ six or seven feed horns per polarization to generate a shaped beam, which is better matched to the coverage area and thus achieves higher gain (Fig. 9b). This shaped-beam design, with the oversize reflector required for multiple feeds, employs dual-mode transmit ports to combine the two sets of alternate six-channel signals per polarization. Different subsets of horns are associated with the three beam coverages of interest to Americom as shown in Fig. 10. On Satcom V, the 12 horizontally polarized horns are directed toward Alaska for the dedicated intrastate service of Alascom, while on Satcom VI, these same channels can be switched in orbit from the Alaska-only beam to the broader CONUS-plus-Alaska beam.

In response to Americom's plan to expand its service into the K-band markets of customer premises data terminals and small master antenna TV (SMATV), Astro-Electronics is developing the 14/12-GHz transponder and antenna for the first K-band Satcom, to be launched in mid-1985. Like the C-band series, it will employ frequency reuse as shown in the frequency plan of Fig. 11, but the channel bandwidth is widened from 36 to 54 MHz to accommodate high-bit-rate modems and multiple video transmissions. The K-band transponder shown in Fig. 12 combines both new technology and topology, as compared to the C-band transponder of Fig. 5.

A thermoelectrically cooled GaAs FET preamplifier, operating at -50°C, precedes the primary 14/12-GHz broadband receiver to provide an effective noise figure of 2 dB. This performance, comparable to that of more complex parametric amplifier front ends, maximizes satellite G/T for operation with small earth terminals while maintaining high satellite reliability.

The channelized power amplifier sections of the transponder use 45-watt TWTAs to obtain the high EIRP for SMATV service, and each is driven by a unique, commandable driver/amplifier. This GaAs FET driver/amplifier not only provides the additional gain beyond that available in the wideband receiver (within intermodulation specifications), but also compensates for the reduction in received uplink signal strength due to relatively large variations in atmospheric attenuation during precipitation. Either a linear mode of selectable gain or a limiting mode with selectable thresholds can be commanded individually for each channel to adjust to local earth station conditions and/or traffic type. The redundancy network for the power amplifier section is also different from that at C-band; for each polarization there are eight active amplifiers and three spares so that the loss of any three amplifiers will not disable any channel.

As shown in Fig. 12, variable power dividers at the TWTA outputs connect to duplicate sets of output multiplexers to provide individual channel steering by ground command to the eastern or western beam ports of the antenna or to both ports simultaneously. These K-band output multiplex filters combine contiguous channels into a single manifold, in contrast to the alternate-channel C-band output multiplexer, thus requiring only a single-mode antenna input instead of the dual-mode input of the C-band antennas, with their resultant beam displacement of alternate channels. With 45 watts per channel throughput of these filters, insertion loss self-heating imposes additional thermal design requirements on the multiplexer assembly, even though the elliptic function filter design insertion loss is only 0.7 dB.

The K-band antenna design, like the C-band antenna of the later Satcoms, uses a pair of large, fully overlapped, cross-gridded reflectors for frequency reuse via cross-linear polarization. Of 14 feed horns per polarization, 9 form a shaped beam covering the eastern states and the other 5 form a beam to the western states, as shown in Fig. 13. By means of the variable power dividers preceding the multiplex filters in the transponder, any channel can be directed to either beam or to both beams together to

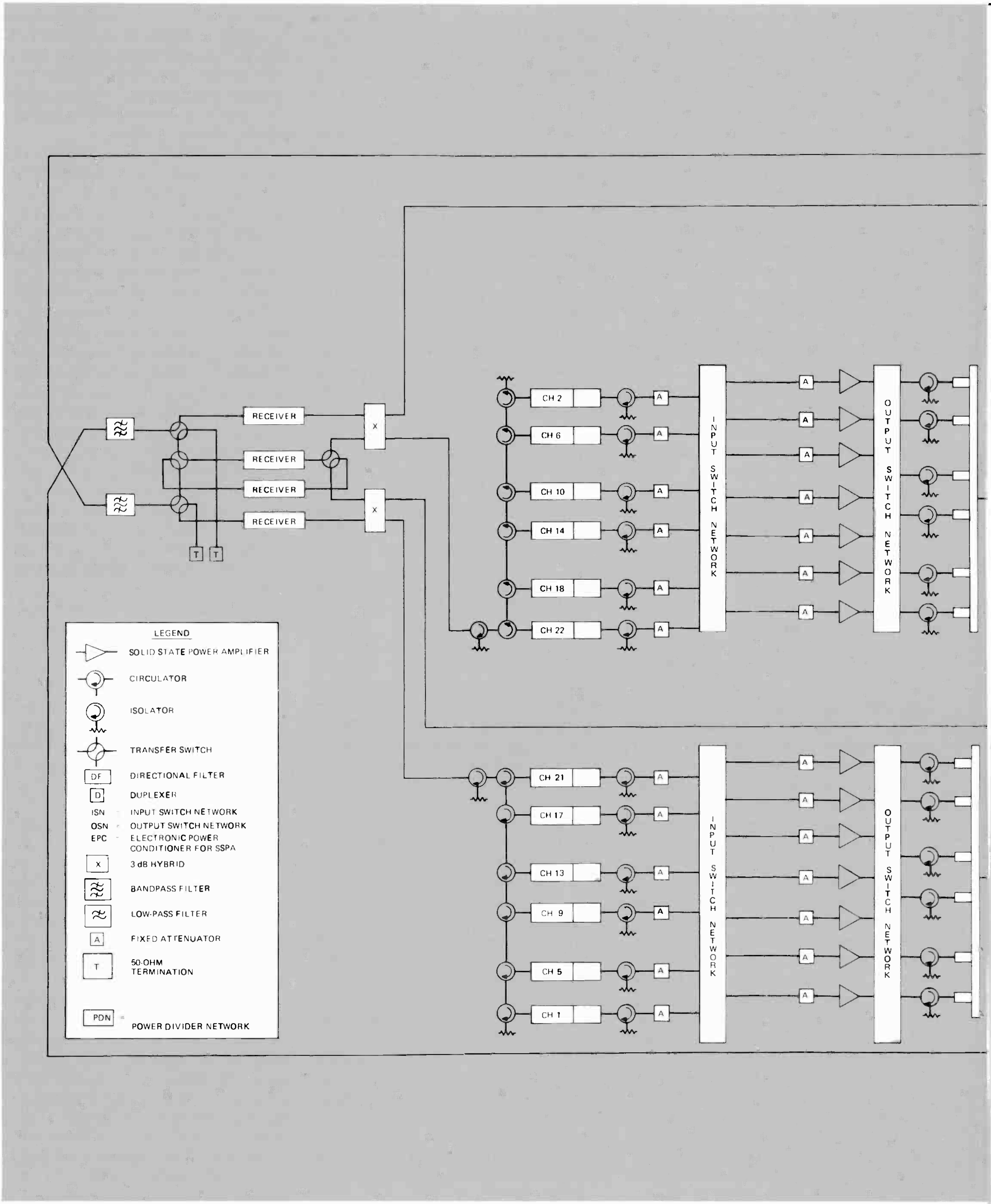
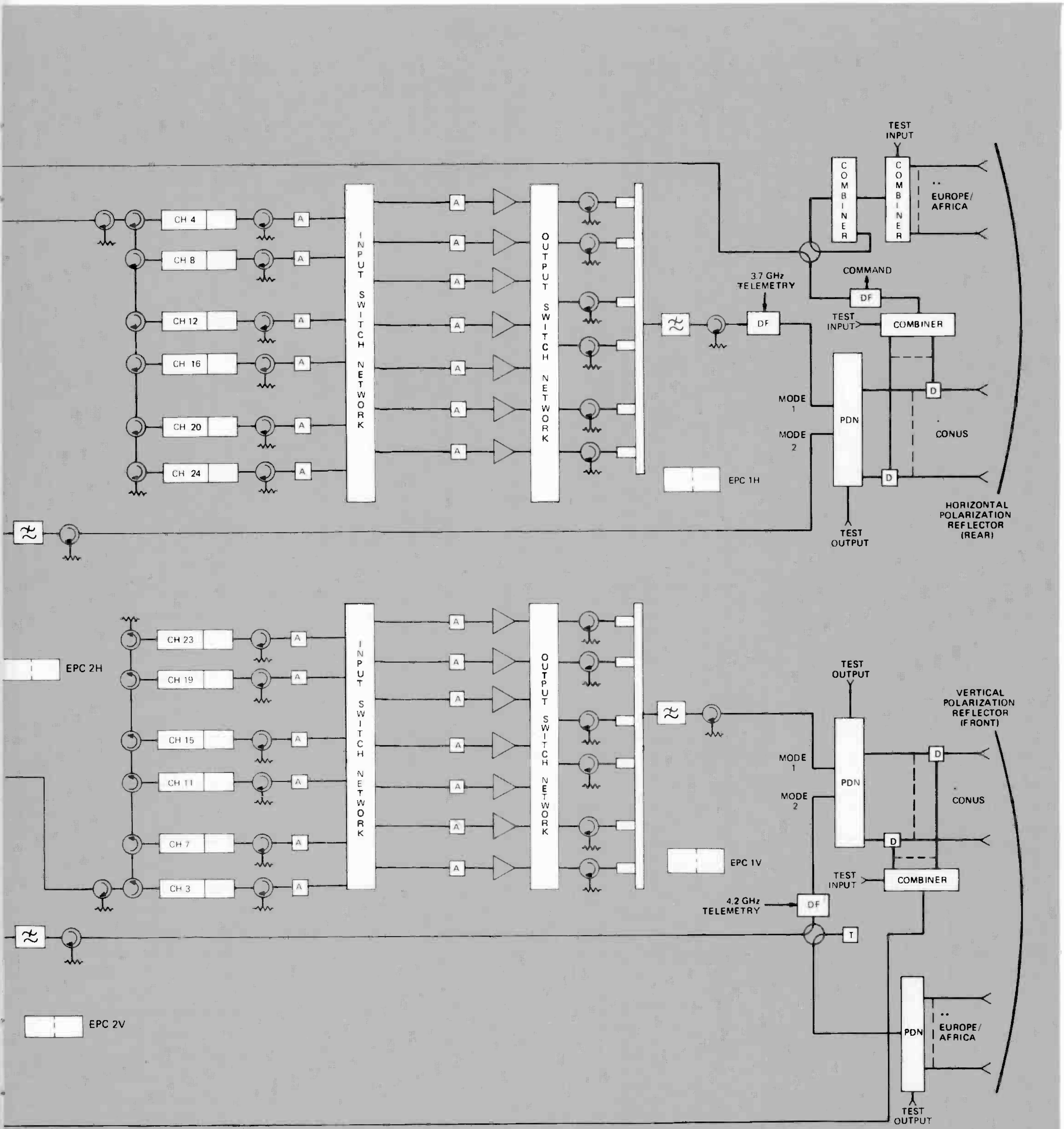


Fig. 5. *Current 24-channel C-band transponder.*



*THERE ARE SEVEN FEED HORNS PER POLARIZATION FOR CONUS.
**THERE ARE FIVE FEED HORNS PER POLARIZATION FOR EUROPE/AFRICA.

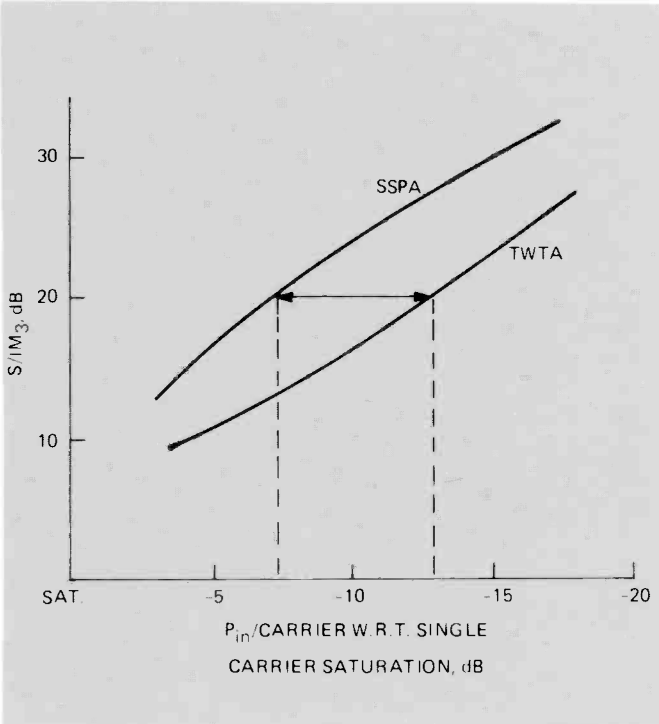


Fig. 6. *SSPA linearity.*

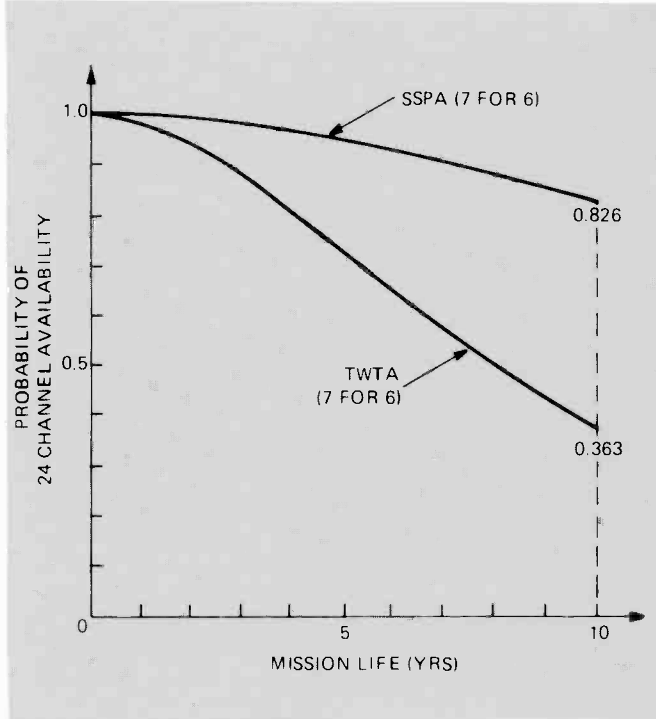


Fig. 8. *Power amplifier reliability.*

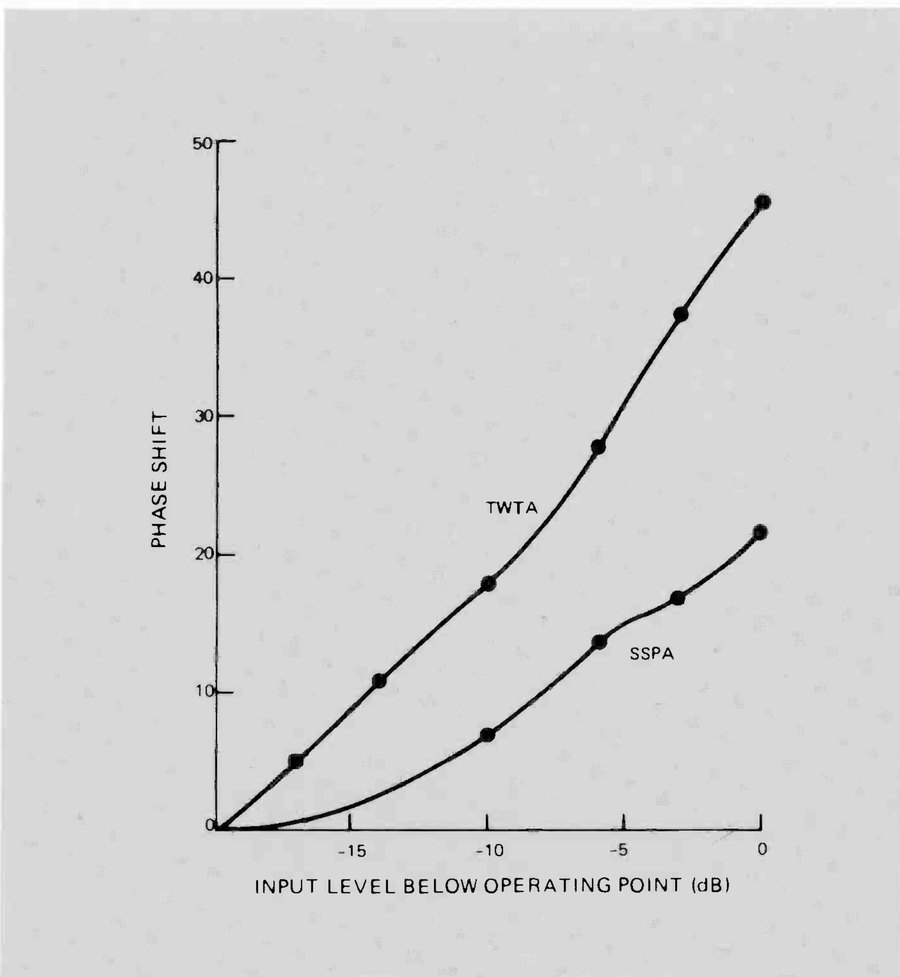


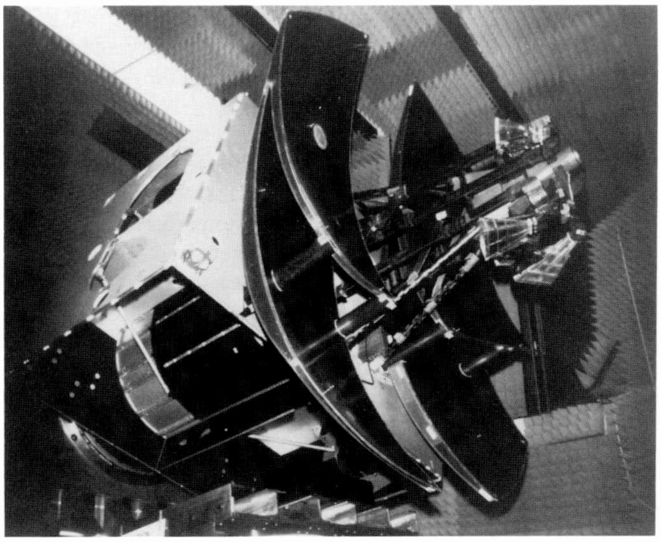
Fig. 7. *SSPA phase.*

form a composite U.S. beam. The antenna waveguide network between each antenna port and its corresponding subset of horns is a wideband design providing both power division for transmit and power combination for receive. This wideband technique not only halves the number of networks in the antenna system but reduces the number of diplexers from one per horn to one per antenna port; that is, from 28 to 4.

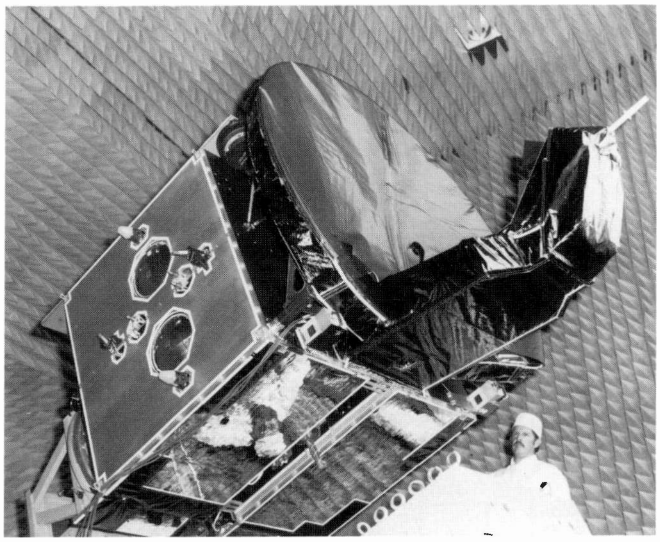
Ground segment design

A network of earth stations used primarily for private leased service voice channel serving the metropolitan area is shown in Fig. 1. Each ground segment has a Central Telecommunications Office (CTO), a terrestrial microwave link, and a commercial earth station. The CTO is a concentration point for local loops originating at customer premises. It also provides monitoring, control, and alarm functions. At the CTO, channels are frequency-division multiplexed (FDM), using standard single-sideband multiplex plans, into a composite baseband for transmission over the terrestrial microwave link to the earth station. A short-haul microwave system accommodating up to 2700 voice channels* uses heterodyne repeaters and is equipped with redundant, hot-standby

* Note that advantage has been taken of compandors and reduced loading to achieve this capacity, which was previously 1800 channels.



(a)



(b)

Fig. 9. *Satcom antennas.*

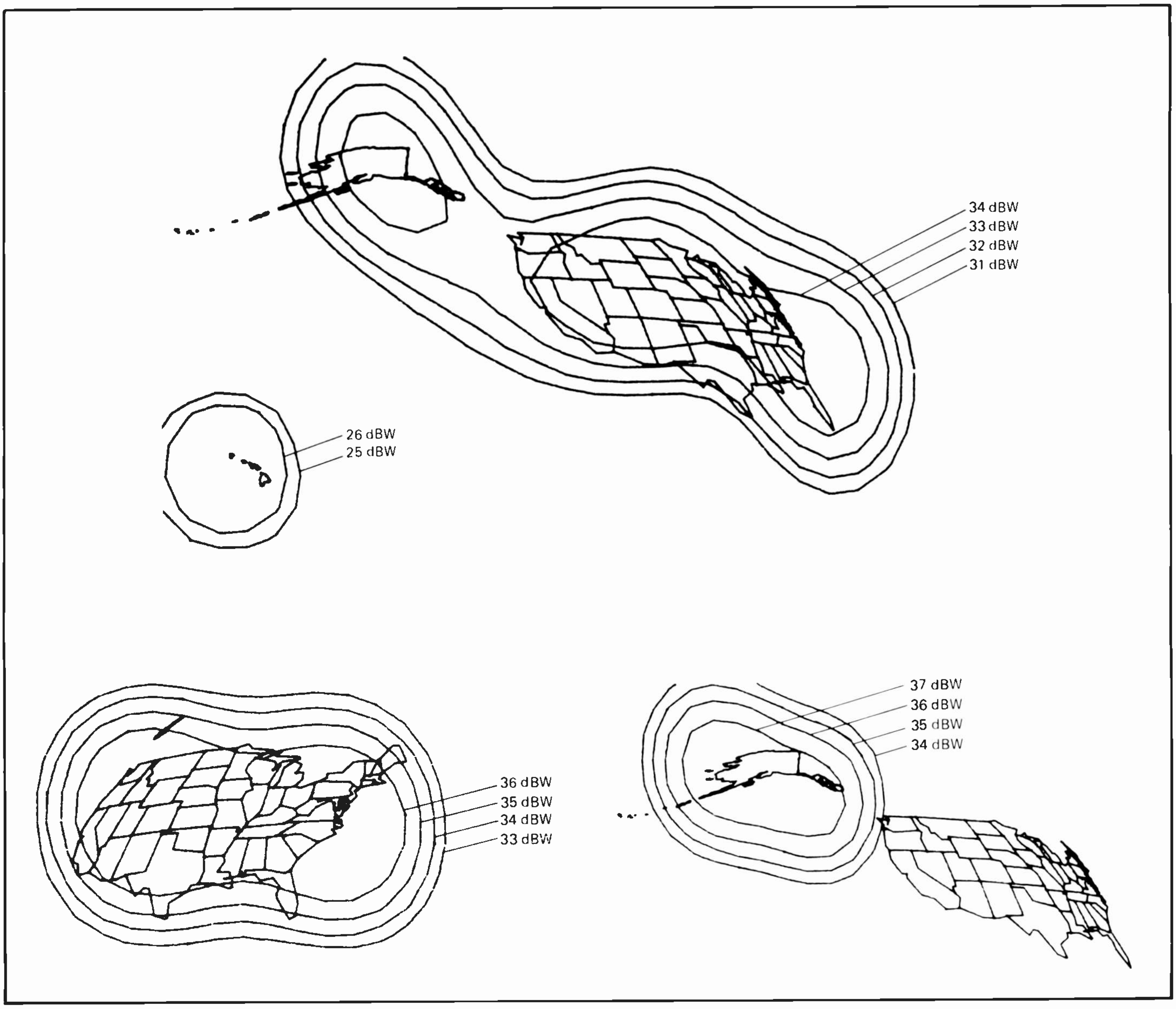


Fig. 10. *Antenna coverage pattern.*

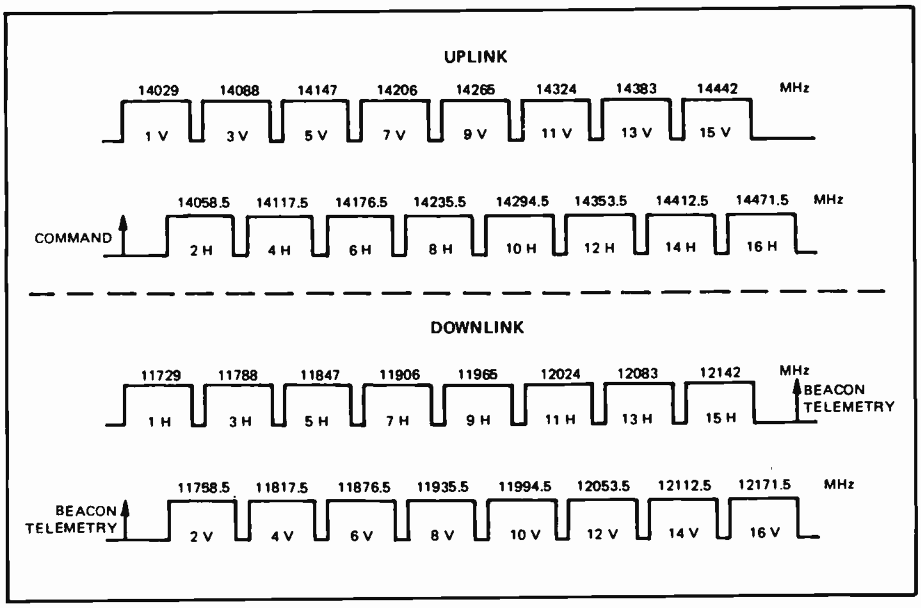


Fig. 11. *K-band frequency plan.*

electronics and backup battery power to assure a high system availability.

The standard Satcom commercial earth station consists of a minimum of two 11-meter antennas equipped with full frequency reuse Cassegrain feed systems to permit simultaneous transmission and reception to and from all 24 transponders. Manual adjustment, rather than automatic polarization tracking, has been found to be satisfactory in assuring system link purity. A critical component of system capacity is the G/T of the receiving earth stations in the system. Americom has installed thermoelectrically cooled low-noise amplifiers (LNAs) that provide noise-temperature performance on the order of 45 K to achieve a G/T of 32.0 dB/K. Cryogenically cooled amplifiers, which held sway for so long in satellite communications systems, have given way to units of this kind because of the inherently superior reliability and reduced maintenance expense of the non-cryogenic devices.

Eleven meters is a standard antenna size for a number of commercial and structural reasons, not the least of which is the fact that it is the largest aperture that does not require electronic tracking of the spacecraft. Such tracking systems are avoided because they have been found to be a major cause of earth station unreliability; instead, the Satcom spacecraft is maintained to relatively tight stationkeeping tolerances.

Earth stations contain communications electronics, a backup 275-kW diesel generator, uninterruptible power supply, heating ventilation and air conditioning (HVAC), and fire detection and suppression facilities. A representative earth station (Honolulu) is pictured in Fig. 14. The selected sites for such facilities must not only be free of microwave interference, which imposes certain terrain restrictions, but the property must be acquirable at reasonable prices. In fact, earth station siting entails resolution of as many jurisdictional problems as technical ones. Interconnect via microwave to the central city should be possible generally with no more than one hop.

The transmission path for telephone channels is shown in Figs. 15 and 16; 4-kHz telephone channels are multiplexed in

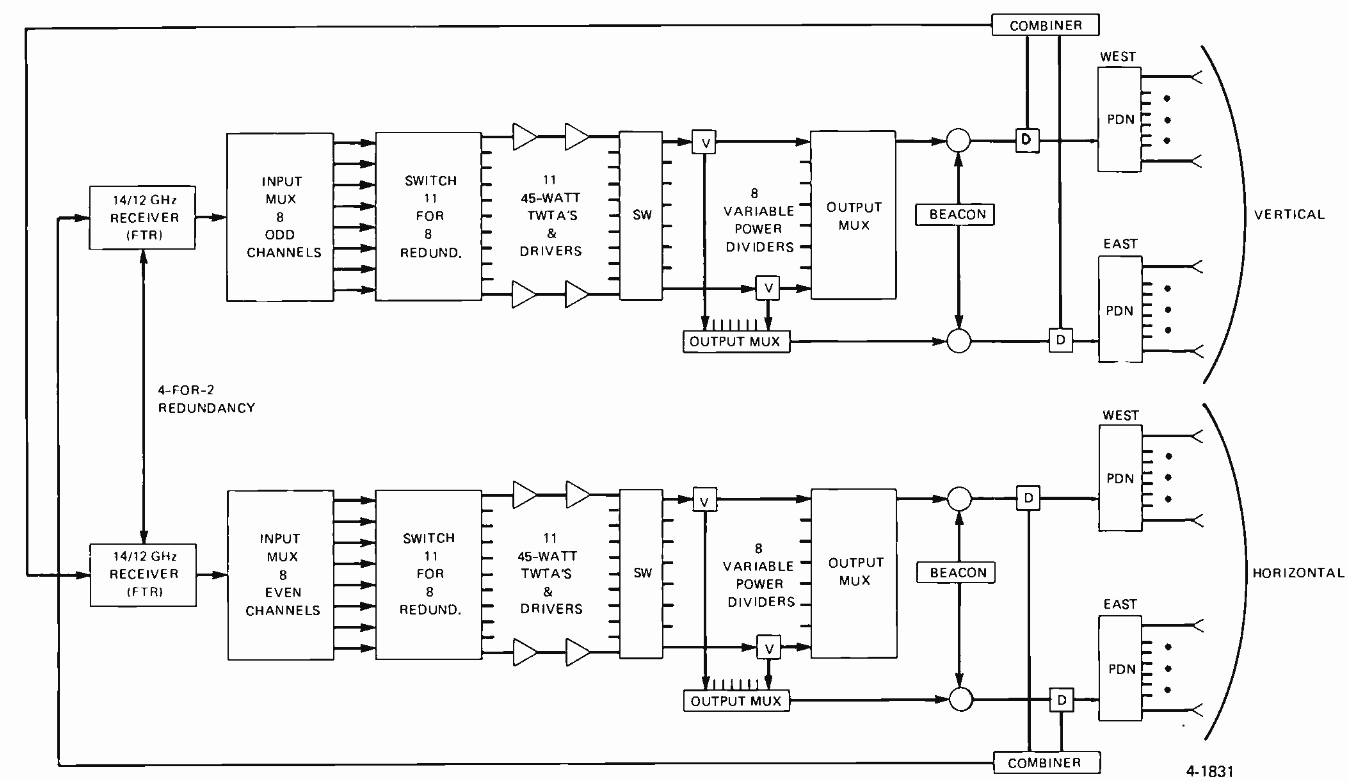


Fig. 12. *K-band transponder.*

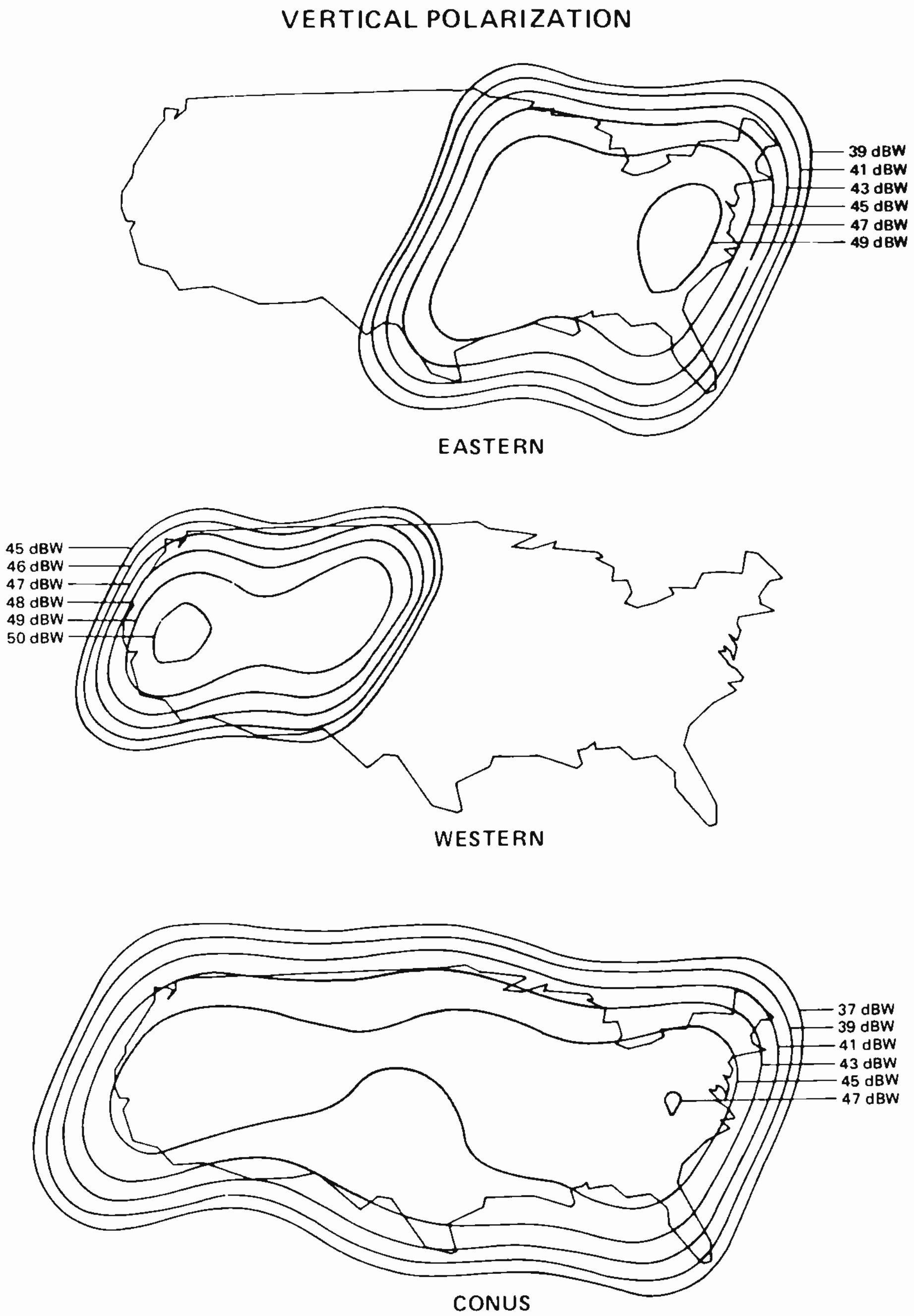


Fig. 13. *K-band coverage areas.*

groups/supergroups/mastergroups at the CTO and modulated onto a terrestrial microwave rf carrier. Typically such microwave interconnects use the 11-GHz common carrier band to avoid co-interference with an earth station operating in the 4-GHz and 6-GHz bands. At the earth station, the composite FDM baseband is frequency-modulated onto a 70-MHz IF carrier, upconverted to the 6-GHz band, and transmitted as a multi-destination rf carrier to the satellite using a 3-kW klystron high-power amplifier (HPA). Each multi-destination 4-GHz message carrier received at the earth station is downconverted to 70 MHz and then demodulated using FM threshold-extension demodulators. The supergroups and groups destined for that city are demultiplexed for transmission along the terrestrial microwave system.

Data services are also provided within these channels, supporting data rates up to 9600 bps (on a voice channel) at bit error rates less than 1×10^{-6}. Higher-speed data services, at 56 kbps, are provided within a group (48 kHz) with bit error rates less than 1×10^{-7}.

The commercial ground facilities are also used to provide video and audio services between the major cities listed earlier. Television operating centers within a CTO monitor and control video and audio signals going to and from that city. The Satcom system carries 20,000 hours of video programming a month for cable distribution alone in addition to occasional video applications for network television, radio broadcasting and international video in which signals are handed off from an RCA earth station to Intelsat at designated gateways for overseas distribution. All impose stringent operational requirements, because most such transmissions now originate from customer-owned earth stations. A Network Monitoring Center established at RCA's flagship earth station at Vernon Valley, N.J. provides continuous surveillance of all such transmissions.

Digital transmission networks in the Americom system encompass a multiplicity of technologies. A system block diagram representative of earth stations used for FDMA point-to-point applications is shown in Fig. 17. Such a station carrying data traffic would achieve a G/T of 22.0 to 30.0 dB/K at 4 GHz with a 5-to 11-meter nontracking dish and a low-noise GaAs FET amplifier.

In the RCA Americom dedicated earth station system, most stations are designed for unmanned operation, with automatic switching to fully redundant "hot standby" backup subsystems should an on-line subsystem fail. These unmanned stations are monitored and controlled via a voice-grade dial-up line from a master station. In this way, a design goal of 99.95-percent system availability can be achieved. This availability level includes the effects of rain, wind, and depolarization on the availability of the propagation medium. A master station monitors each subsystem's digital alarm indicators and controls both subsystem switching and power levels with a remote fault/monitor system that converts these data to tones transmitted via a voice-grade modem over the dial-up line.

The early C-band CATV facilities used 10-meter antennas and cost an estimated $90,000 installed (1975 dollars). At present one can purchase 2.8-meter antenna systems providing good quality reception in high EIRP locations for as little as $5,000. This dramatic reduction in costs and the concommitant proliferation of installations has been the most visible effect of satellite communications in this country.

A representative system block diagram of a receive-only earth station (ROES) is shown in Fig. 18. The rf carrier from the spacecraft is received by a GaAs FET LNA with a noise temperature generally in the 80-to 150-K region. The signal is then down-converted to 70 MHz for demodulation of video and audio. Variations on this include the following:

- Phase-locked loops with FM demodulation rather than simple FM discriminators.
- Auxiliary audio subcarrier demodulator for the reception of music or other programming not related to the video.
- Block downconversion of an entire polarization so that multiple receivers can be fed from the same downconverter.
- Motorized high-speed slew and polarization adjustment.

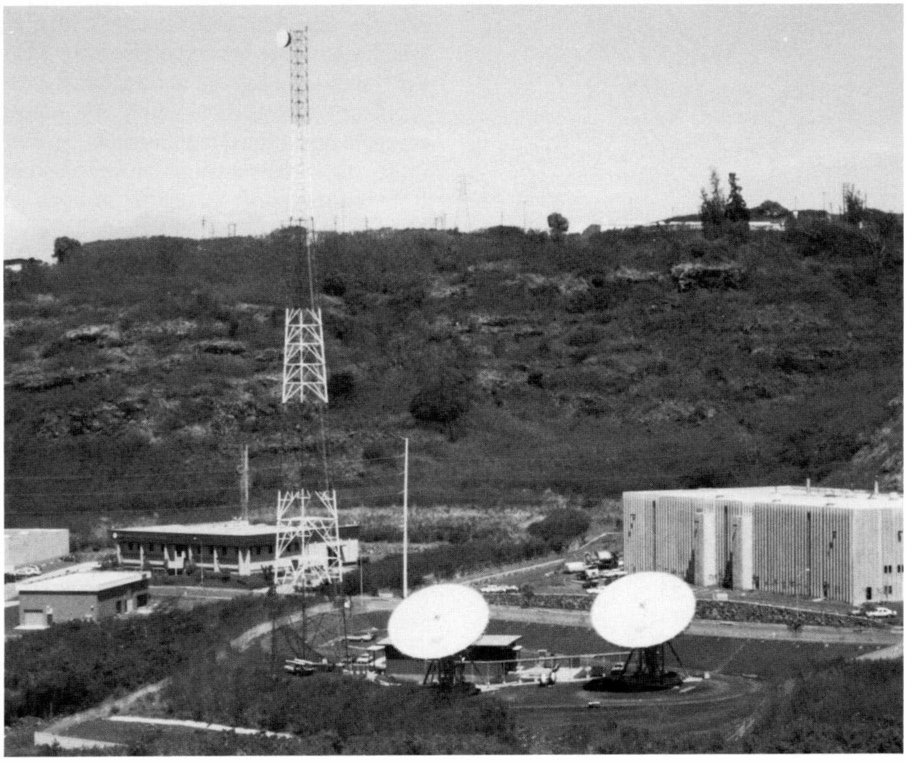


Fig. 14. *Honolulu earth station.*

The earth station described herein represents a generic class. A ROES for DBS or Ku-band applications will be functionally simiular, with modifications only in such features as antenna size (expected to be on the order of 1 meter or less) and receiver noise temperature.

The several transmission techniques employed to achieve maximum capacity of each link in the heterogeneous RCA network are described in detail in reference 3.

Conclusion

The RCA communications satellite network provides economically competitive services with appropriate technologies by treating satellite communications system design as an integrated whole. Throughout its development, the RCA Satcom system has followed a course that pursues those markets wherein a satellite system possesses maximum advantage over alternative technologies. Communications satellites, by virtue of their wide geographical coverage areas, inherent point-to-multipoint character, and distance-insensitive cost structure, determine the nature of terrestrial facilities that evolve to support business requirements, specifically long-distance point-to-

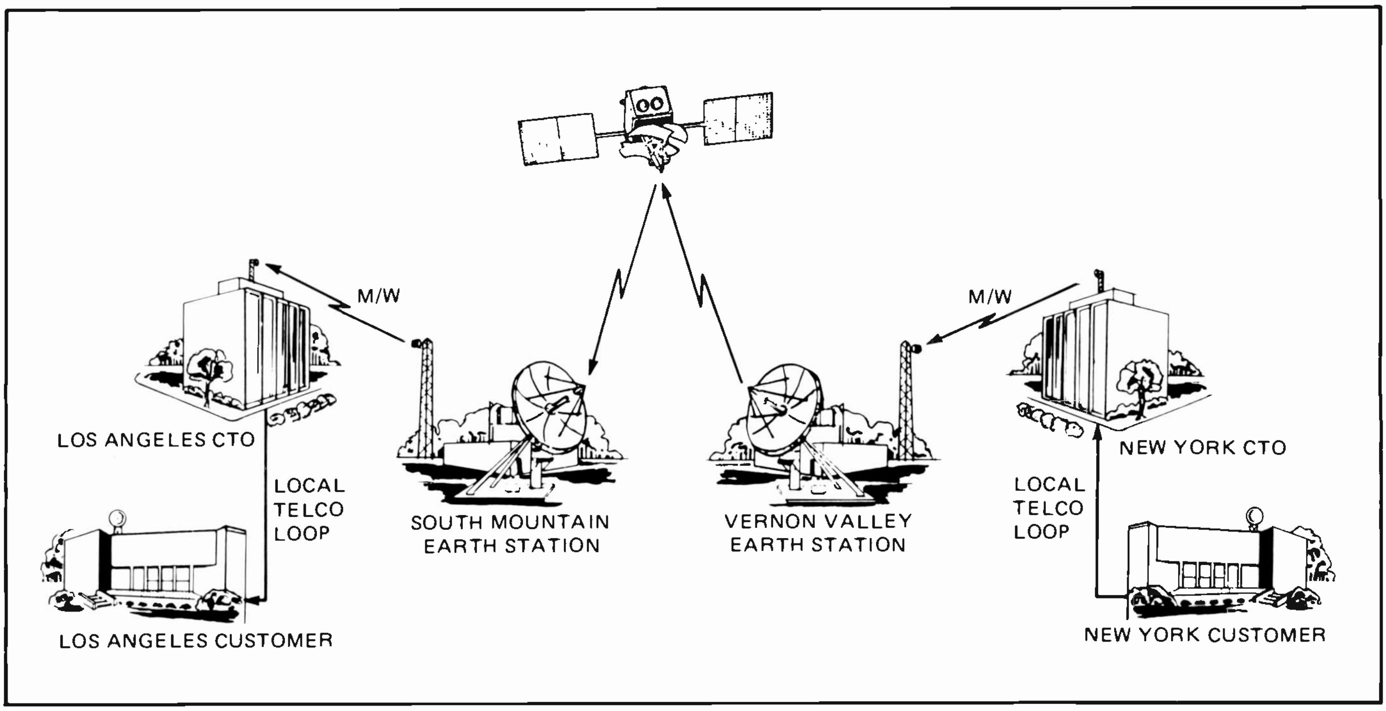


Fig. 15. *Typical leased channel signal flow.*

point data and voice services in addition to nationwide television distribution.

The evolutionary growth of the RCA Satcom system has been supported by the introduction of advanced transmission techniques, enhanced spacecraft performance, and the prudent realization of terrestrial equipment. Economic advantages have been achieved by accommodating multiple types of traffic with a mixed terrestrial system while increasing the traffic capacity per satellite transponder. The disciplines of systems engineering, satellite design, and earth station optimization, which have shaped the RCA system for maximum profitability, continue to be tightly coupled in the development of the RCA's Ku-band and DBS ventures.

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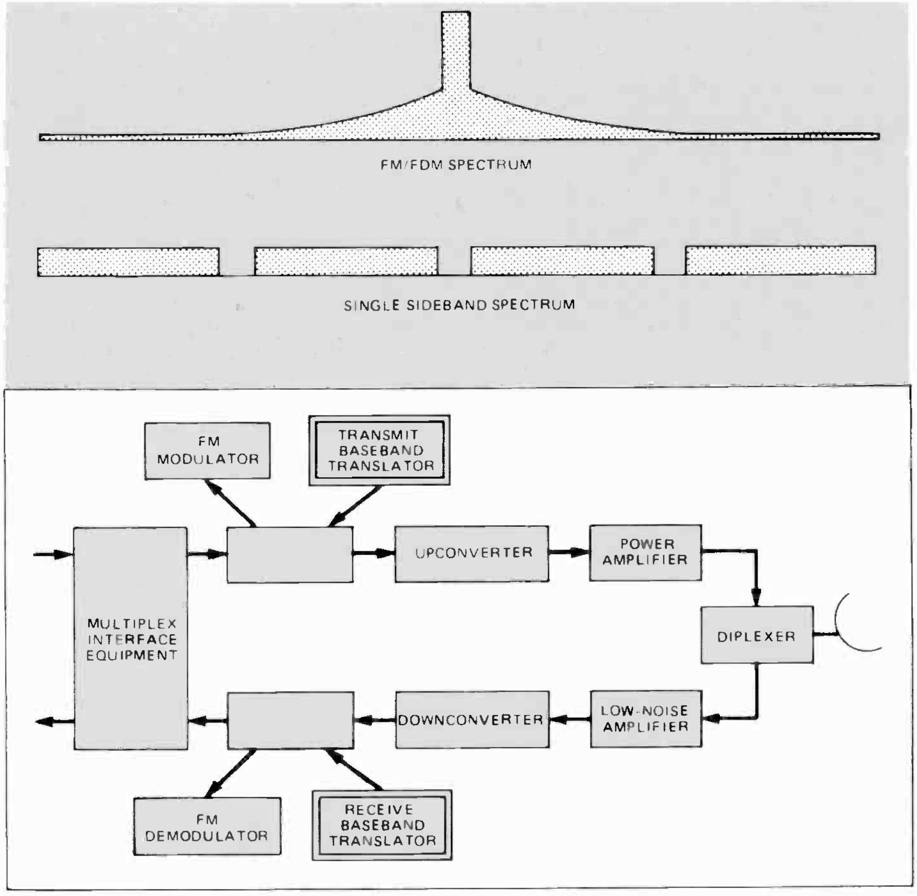

Fig. 16. *Single sideband implementation.*

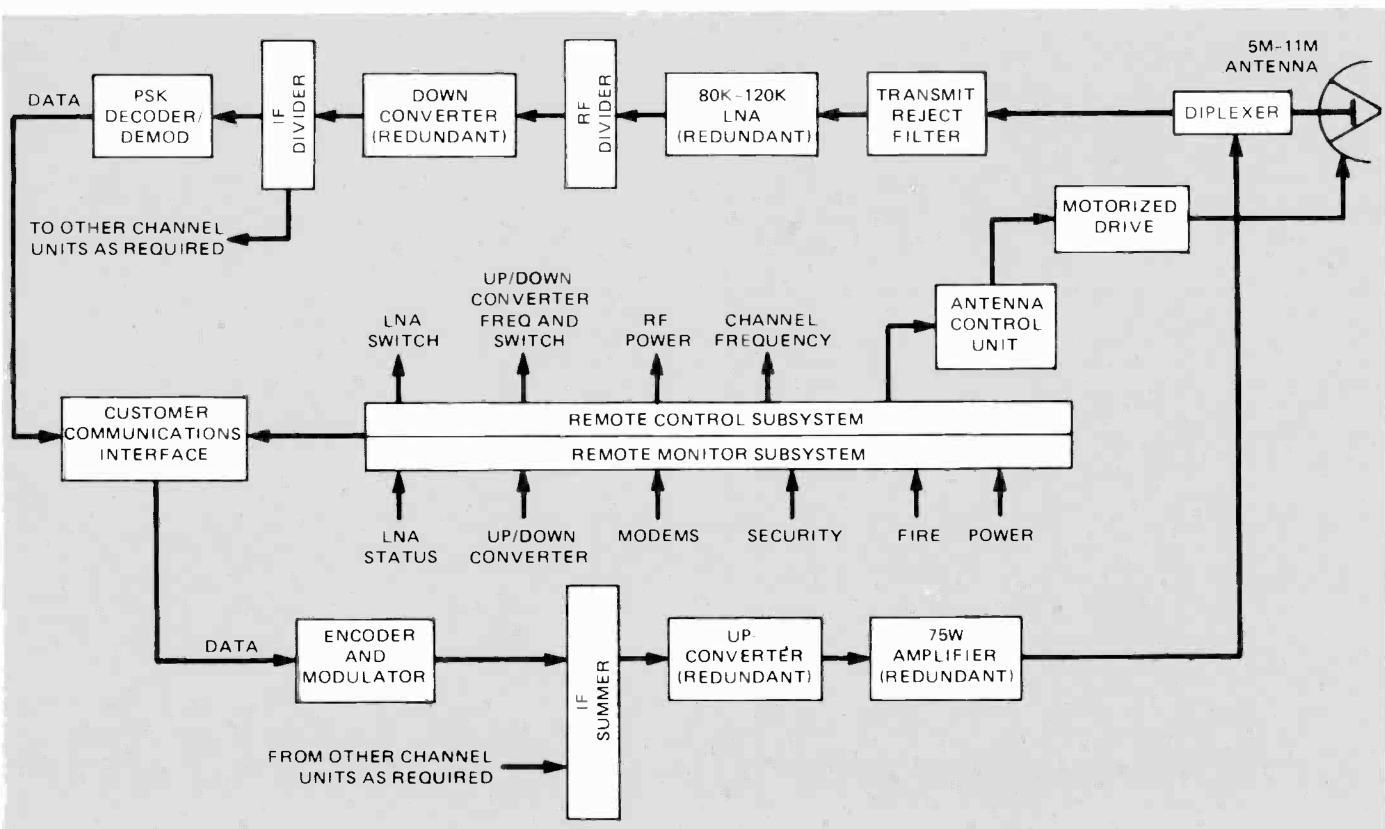

Fig. 17. *Transmit/receive digital earth station.*

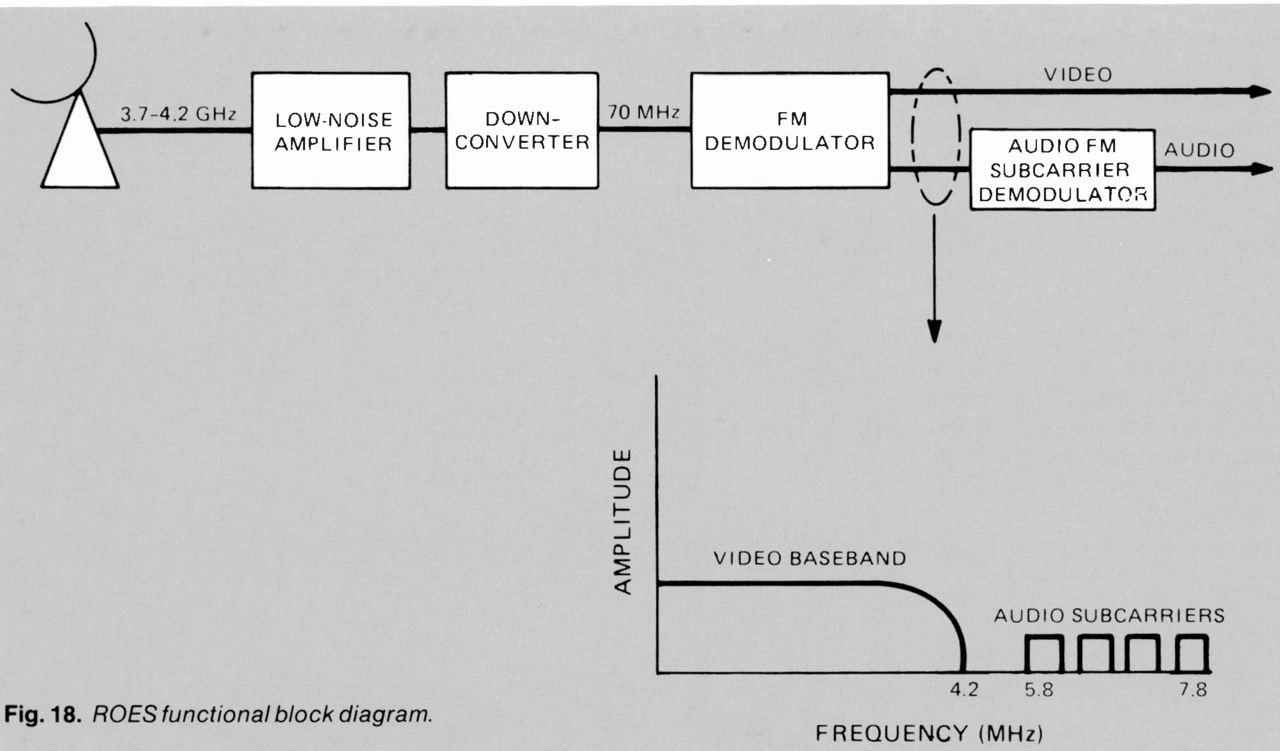

Fig. 18. *ROES functional block diagram.*

Authors, Braun (left) and Keigler.

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G. A. Beck

The NASA Advanced Communications Technology Satellite (ACTS)

Expected increases in the demand for satellite communications capacity require innovative approaches to satellite system design.

The Advanced Communications Technology Satellite (ACTS) will operate in the 30/20-GHz frequency band. The program will develop the necessary transmitter, receiver, and antenna technology, and incorporate methods to counter the attenuating effects of rain in the frequency range.

The ACTS system includes the Flight System and the NASA Ground Station/Master Control Station. The Flight System comprises the Spacecraft Bus and the Multibeam Communications Package. During the two-year operational period, these facilities will be supplemented by experimenter stations, provided by commercial communications operators and other interested organizations, to constitute experimental communications networks. This paper describes the ACTS Flight System. The Spacecraft Bus is essentially a modification of an existing satellite bus. The Multibeam Communications Package incorporates state-of-the-art technology and is designed to be readily scaleable to an operational 30/20-GHz TDMA communications system.

Abstract: *The NASA Lewis Research Center's Advanced Communications Technology Satellite (ACTS) system will provide a flight demonstration of new technologies for reliable, efficient, point-to-point communications. ACTS will also demonstrate satellite-switched time-division multiple access (TDMA) communications using fixed narrow spot beams, and baseband-switched TDMA communications using scanning spot beams. Demand access is provided for both types of TDMA systems.*

Presented at the 35th Congress of the International Astronautical Federation, held in Lausanne, Switzerland, October 1984.

The demand for communications service, particularly within the United States, has grown enormously in recent years, and continued growth is forecast. The corresponding increase in capacity in response to the demand has been provided by Ku-band (14/12-GHz) spacecraft in addition to those at C-band (6/4-GHz), and by evolutionary improvements in technology. However, forecasts indicate that saturation of capacity will occur in the U.S. domestic market by the early 1990s. To prevent saturation, advanced technologies must be developed to provide substantial additional capacity—a process involving risks that private industry alone is not likely to accept.

NASA's Lewis Research Center has been addressing the problem since 1978. One key is the exploitation of the Ka-band (30/20-GHz), which is much wider than the C and Ku bands together. Another is the use of multiple narrow antenna beams in the satellite to achieve large frequency reuse factors with very high antenna gains. NASA has completed a number of studies and developed proof-of-concept hardware components that form the basis for a flight demonstration. The ACTS system will provide this demonstration in a realistic operating environment.

ACTS system overview

The architecture of the ACTS system is that of a very large scale satellite with multi-gigabit capacity. Two types of point-to-point communications will be demonstrated, both utilizing time-division multiple access (TDMA). The first is the high burst rate (HBR) system, providing trunking service between localized areas with heavy concentrations of traffic. The HBR system utilizes an IF switch matrix on the satellite to provide interconnection among various fixed antenna spot beams. The second type is the low burst rate (LBR) system, providing thin-route service to users not located in a major center. The LBR system utilizes scanning spot beams to provide wide area coverage. The key to the LBR system is the on-board baseband processor, which demodulates uplink TDMA signals, stores and routes messages, and remodulates signals for downlink to their proper destina-

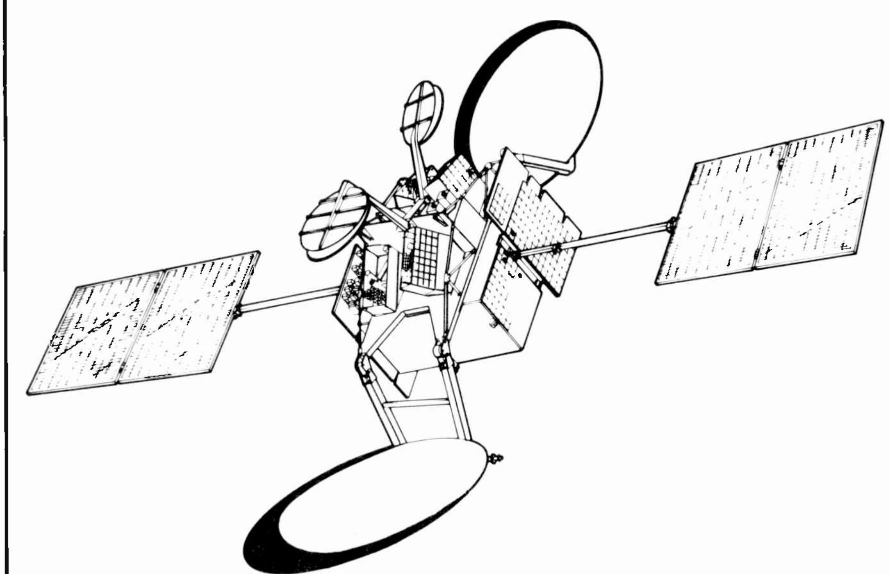

Fig. 1. *ACTS flight system.*

Table I. *Acts flight system weights.*

Item	*Weight (Pounds)*
Multibeam Communications Package	729.6
Spacecraft Bus	796.4
AKM Case	138.4
Design Contingency Allocation	185.7
Balance & Margin	118.2
Dry Spacecraft Weight	1968.3
Fuel (including 4 yrs station-keeping)	344.0
AKM Expendables	1967.2
Transfer Orbit Weight	4279.5

tions. Both the HBR and LBR systems include demand access features under centralized control.

The ACTS program will develop flight-qualified components operating in the 30/20-GHz band. In addition, ACTS will demonstrate adaptive methods for overcoming the attenuation in signal that occurs at these frequencies due to rain. This will be accomplished by rf power control in the HBR system and by use of burst rate reduction and forward error correction (FEC) coding in the LBR system.

The ACTS program will provide a scaled-down version of the type of communications satellite system envisioned for the 1990s. Enough capability will be included to demonstrate economic solutions to the 30/20-GHz variable propagation loss problem, provide hands-on experience to experimenters in a domestic satellite operational environment, and provide proven space and ground hardware that can meet operational system requirements directly or by a defined process of scaling up.

ACTS program definition

The ACTS equipment consists of the Flight System (Fig. 1) and a ground segment. The ground segment consists of NASA-provided equipment, which will be supplemented during the two-year operational period by facilities provided by private entities. The experimenters will include commercial communications operators, equipment suppliers, and others with an interest in space communications. The NASA facility provides overall control of satellite housekeeping as well as control of the experimental communications operations.

The NASA ground station provides rf and baseband equipment for communications and satellite control. This station consists of a primary and secondary site located in the Cleveland, Ohio, area. The two sites will be separated physically to provide rain diversity operation for the satellite tracking, telemetry, and control housekeeping functions. The NASA ground station will be used as an experiment site in conjunction with experimenter-provided communications terminals. Because ACTS uses very high gain narrow antenna beams for communications, the NASA ground station will also be used as an attitude reference point for the Flight System, which will autotrack the uplink signal.

The other NASA-provided facility is the Master Control Station, which controls the ACTS communications system. It communicates with the satellite and experimenter-provided terminals through the NASA ground station to control HBR and LBR communications network operations.

Two types of experimenter-provided terminals will be supported. HBR terminals operate at 220-Mbps burst rates through the satellite-switched TDMA system. LBR terminals use either 110- or 27.5-Mbps burst rate through the baseband processing system.

Table II. *ACTS Flight System Power Requirements.*

Component	Power (watts)
Multibeam Communications Package	
TWTAs (3 @ 40W Output)	480
Baseband Processor	185
Other Units	157
Total MCP	822
Spacecraft Bus	
TT&C	65
Attitude Control & Propulsion	37
Thermal Control	42
Power Supply & Losses	49
Total Spacecraft	193
Design Contingency Allocation	152
Total	1167
Power Available (135 ft² array, 4 years, summer)	1200
Margin	33

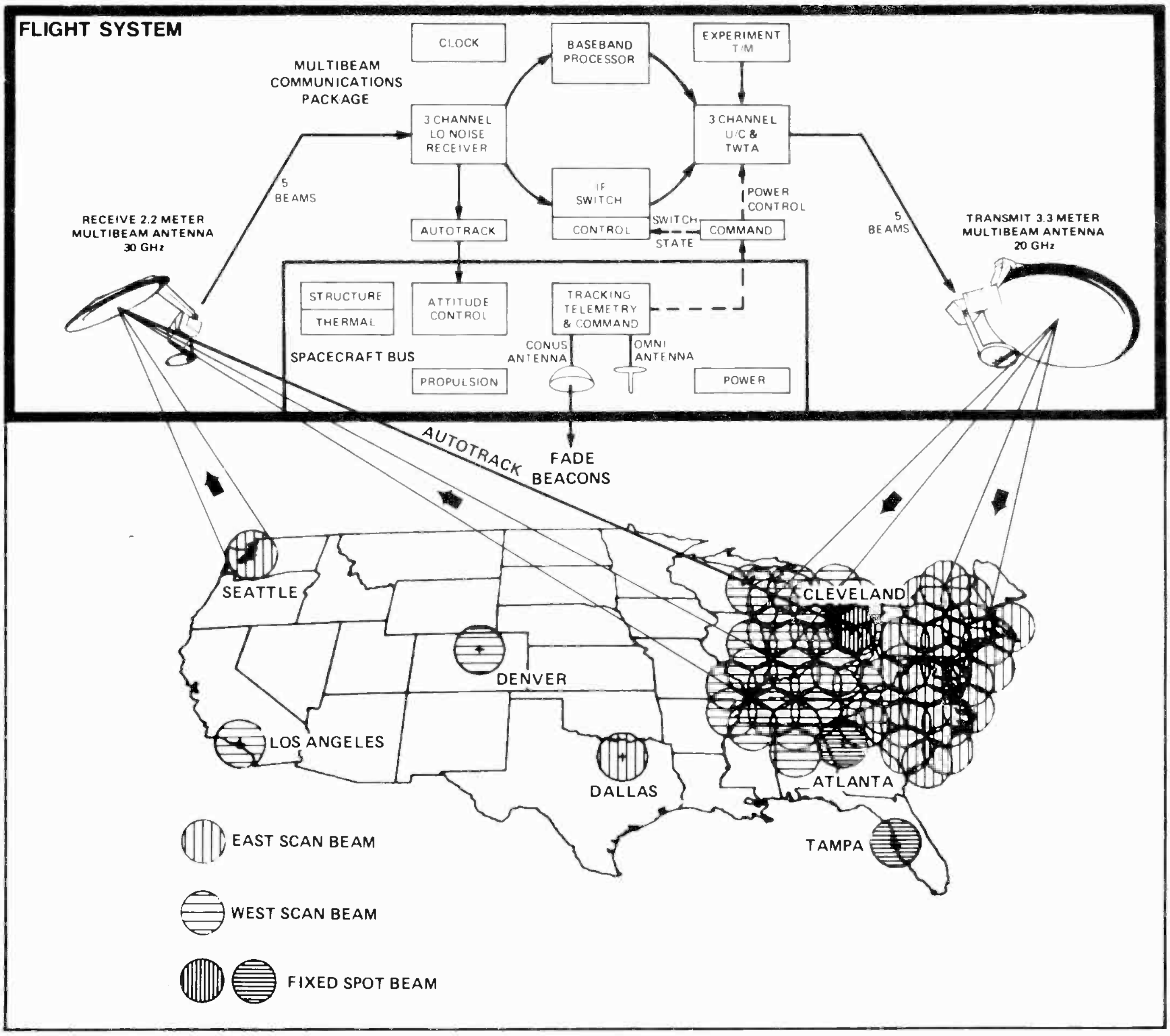

Fig. 2. *Flight system block diagram.*

ACTS flight system

The ACTS Flight System consists of the Spacecraft Bus and the Multibeam Communications Package (MCP), and is illustrated in Fig. 2. ACTS will be launched by the STS, using the PAM-A perigee stage and an integral STAR-37XF apogee stage. Figure 3 shows the spacecraft and perigee stage installed in the Shuttle bay; their combined overall length is 18.2 feet. The spacecraft weight and power estimates are shown in Tables I and II.

The MCP includes the IF Switch Matrix to support HBR communications and the Baseband Processor to support LBR communications. The receivers and transmitters are common and are shared by both the HBR and LBR systems. The antennas

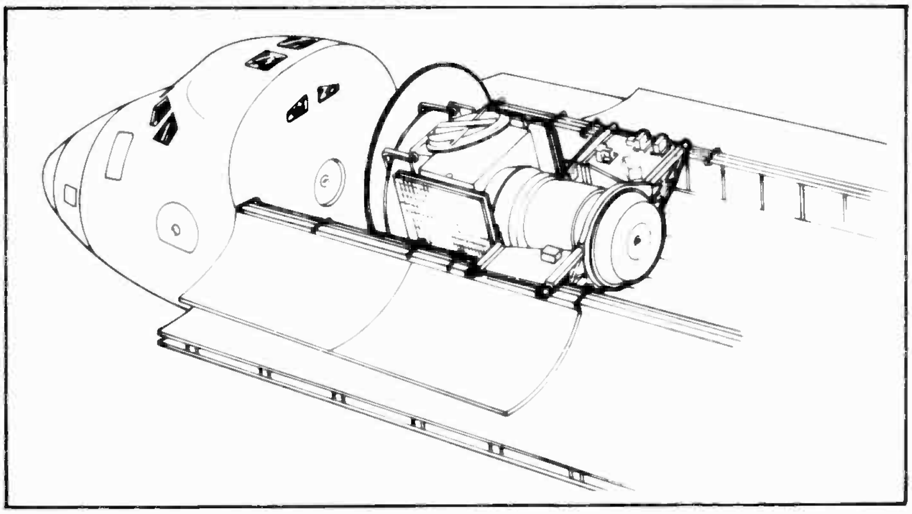

Fig. 3. *PAM-A/ACTS in STS.*

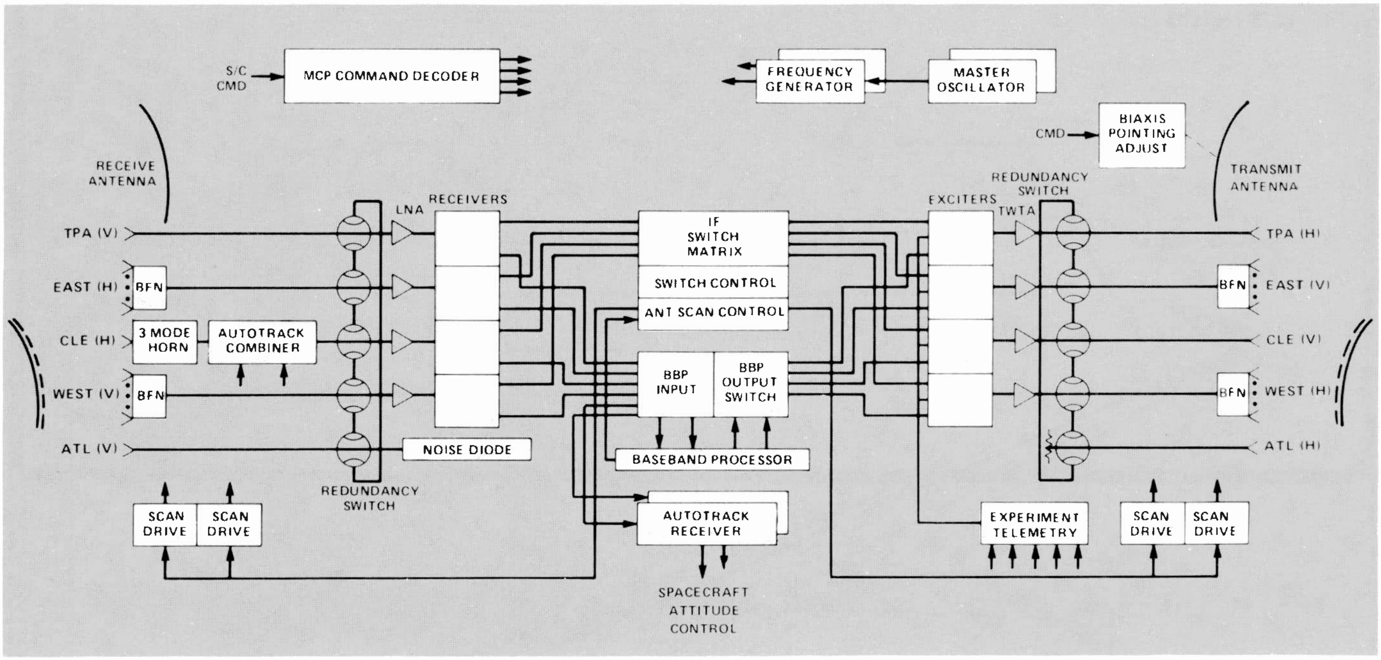

Fig. 4. *MCP block diagram.*

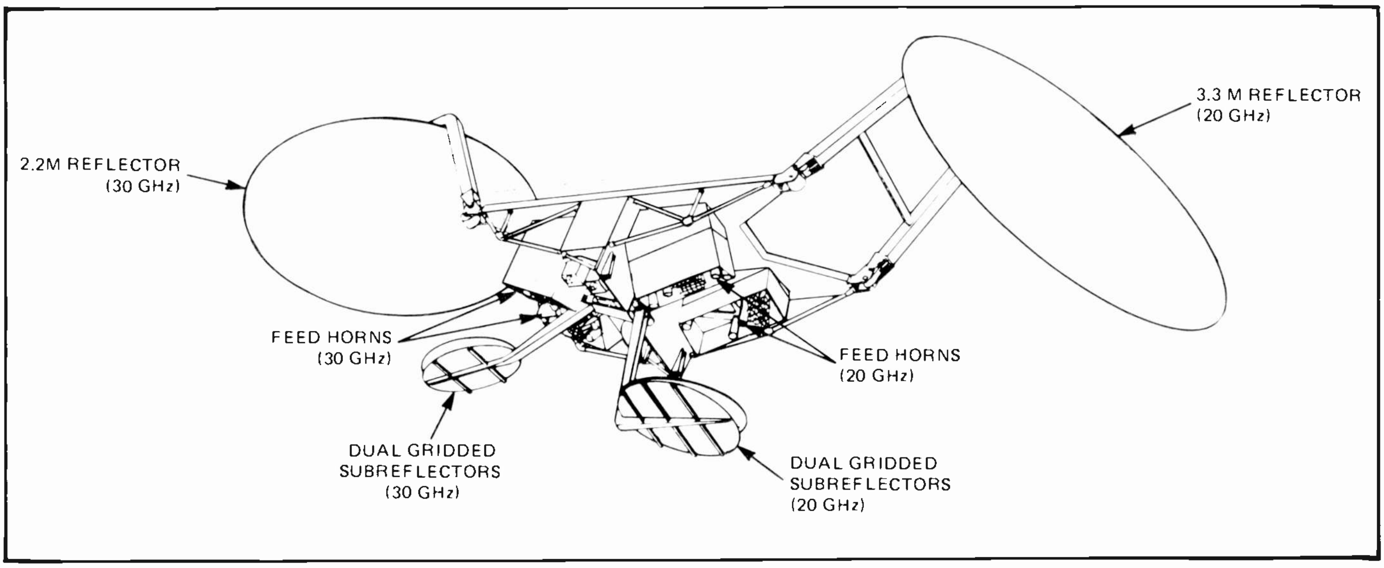

Fig. 5. *Multibeam antenna.*

provide three fixed beams and two scanning beams, giving the coverage indicated in the figure. These coverage areas were selected to demonstrate operation in a wide range of climates and to stress the antenna design, demonstrating off-axis operation and minimum-separation beam isolation. However, the coverage is subject to revision, if necessary, to better satisfy the experiment objective of the program.

Multibeam communications package

Figure 4 is a more detailed block diagram of the MCP. There are five antenna beams: three fixed and two scanning beams. The fixed beam that covers the NASA ground station at Cleveland, Ohio, is equipped with a multimode feed horn to generate pointing error signals for autotracking. A set of switches provides flexibility for selecting subsets of the antenna beams for various experiment configurations and for redundancy selection. A redundancy of 4-for-3 is provided in the receiving and transmitting equipment and in the IF switch matrix; the baseband processor contains internal redundancy.

When demonstrating HBR communications, the MCP supports three fixed beams with a total throughput of 220 Mbps per beam, for a total HBR capacity of 660 Mbps. Any three of the five antenna beams can be used for HBR experiments. Normally, the beam covering the NASA ground station would always be active because the HBR network is controlled by the Master Control Station via this beam. The scan beams may be stopped in any of their spot locations and used as fixed beams for HBR experiments. For LBR communications, each scan beam has 220 Mbps throughput, for a total LBR capacity of 440 Mbps.

The multibeam antenna (Fig. 5) consists of receive and transmit antennas that are identical except for frequency scaling

RCA's Series 4000 communications satellites

The proliferation of video and audio programming and the creation of private voice and data communications networks have put severe demands on the current communications satellite system designs. Communications satellite users require higher satellite rf power output, more payload capacity, and longer satellite lifetime. To satisfy these demands and fully exploit the higher performance of today's launch vehicles, RCA Astro-Electronics has introduced its Series 4000 communications satellite. The Series 4000 spacecraft, an evolution of the space-proven, 3-axis body-stabilized RCA Satcom and Series 3000 spacecraft, incorporates engineering improvements that result in greater communications capacity and lower operating costs to the user community. The most significant design drivers to the spacecraft manufacturer—weight, size, lifetime, primary dc power requirements of the communications payload, and the thermal dissipation requirements of the rf power amplifiers—led to the design of the Series 4000 spacecraft.

Design features of the Series 4000 include the following:

- Larger payload panels (up to 100 percent increase) for equipment mounting area and thermal dissipation.
- Oversized, deployed reflectors (up to 130 inches in diameter) for shaped-beam antennas.
- Accommodation of solar arrays up to 500 ft^2.
- Larger, pivoted momentum wheel for more precise control of antenna pointing.
- Nickel-hydrogen batteries that provide 25-percent greater depth-of-discharge than nickel-cadmium batteries.
- Heat pipes for improved thermal distribution over the payload panels.
- Electrically augmented hydrazine thrusters for north/south station-keeping with a 30-percent increase in mission lifetime
- Launch compatibility with the Space Shuttle and the dual-launch Ariane 4.
- Integrated spacecraft/perigee kick motor (SCOTS) for STS launches.

Larger than current RCA communications satellites, the Series 4000 spacecraft, when injected into the geosynchronous transfer orbit (GTO), will weigh from 4000 to 5800 pounds. The Space Shuttle and Ariane launch vehicles can place larger and heavier payloads into orbit. However, the GTO weight of the Series 4000 spacecraft exceeds the capability of existing or planned Shuttle upper stages, such as the PAM-DII. RCA (in cooperation with Morton Thiokol, Inc.) is developing its own upper stage called the Shuttle Compatible Orbit Transfer Subsystem (SCOTS) that will have the capability of injecting a 4000- to 5800-pound payload into GTO from the STS parking orbit. At the upper weight limit, the total cargo element will require less than 30 percent of the STS Orbiter capability with a nearly optimum weight/length charge factor.

A main objective of the Series 4000 spacecraft is to provide design flexibility to accommodate various payloads for the Fixed Satellite Service (FSS) and the Direct Broadcast Satellite Service (DBS). The use of a common bus design minimizes the nonrecurring cost elements resulting in a more economical space segment. For FSS missions, Series 4000 can offer 16, 20, or 24 channels with a total output power ranging from 752 to 960 watts rf; it can also provide sufficient propellant for 10 to 12 years of life in orbit. For DBS missions, the Series 4000 can accommodate 6, 8, or 16 channels ranging from 1200 to 1600 total watts rf, plus sufficient propellant for up to 10 years of life in orbit. Although DBS missions do not require operation during eclipse, the Series 4000 spacecraft can provide eclipse protection as desired. This flexibility permits satellite operators to optimize their payload for a specific system's need, thus providing the lowest possible cost per channel-year, and yielding a higher return on investment.

The Series 4000 spacecraft will also accommodate hybrid C-band/Ku-band payloads or Ku-band/Ka-band payloads.

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of dimensions. Offset Cassegrain optics are employed, with dual-gridded subreflectors to facilitate separate feed arrays for horizontal and vertical polarization. Figures 6 and 7 show how the ACTS coverage is implemented. These figures show the arrays of feed horns as projected in the focal plane and as isometric sketches. Each of the two scanning beams covers approximately 10 percent of the CONUS in a contiguous area plus the isolated spots. The array of feed horns is necessarily somewhat larger than the covered area; hence the adjacent scanned area is of the opposite polarization. For ACTS the antenna focal planes are not fully populated with feed horns, but the design can be scaled readily for an operational system. Figure 8 shows an example of an operational coverage plan with six scan beam sectors and 18 fixed beams.

The scanning beams are formed by selecting either an isolated horn or a three-horn subset of the contiguous array of horns. Beam forming is controlled by trees of ferrite circulator switches driven from digital memories. Each uplink and downlink scan beam is independently controlled with a switching time of less than 1 microsecond. In LBR operation a beam might typically point to 10 different locations each TDMA frame (1 millisecond); it can be seen that the time lost to beam switching is minimal.

The antenna beamwidths are about 0.45 degree. Fixed beams have a gain of 52 dBi or more on axis; minimum gain in the region covered by a scan beam is 48 dBi. Spatial isolation goals are 30 dB between individual spots separated by two beamwidths or more.

HBR communications are controlled by

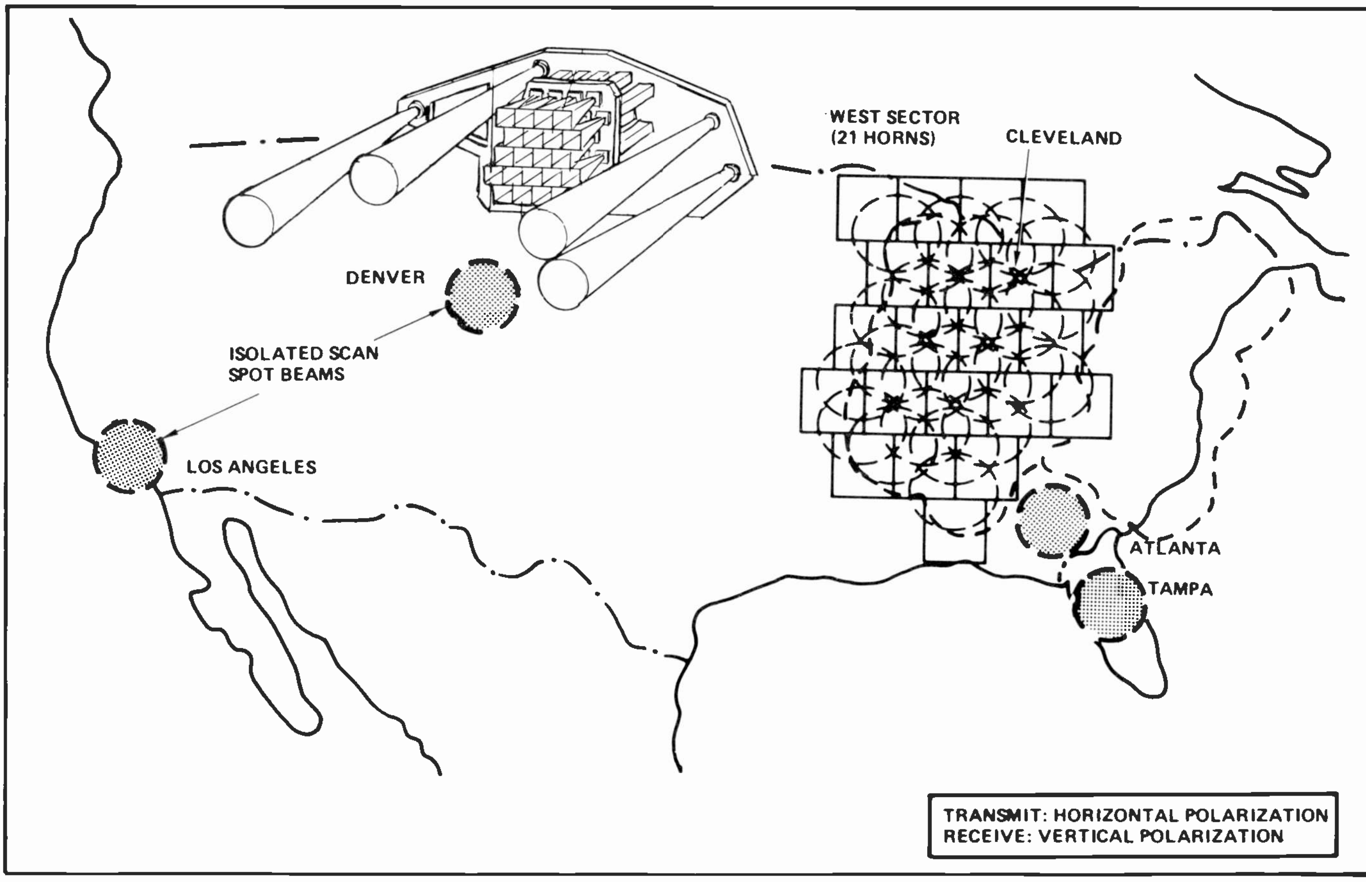


Fig. 6. *Coverage plan: Transmit horizontal/receive vertical.*

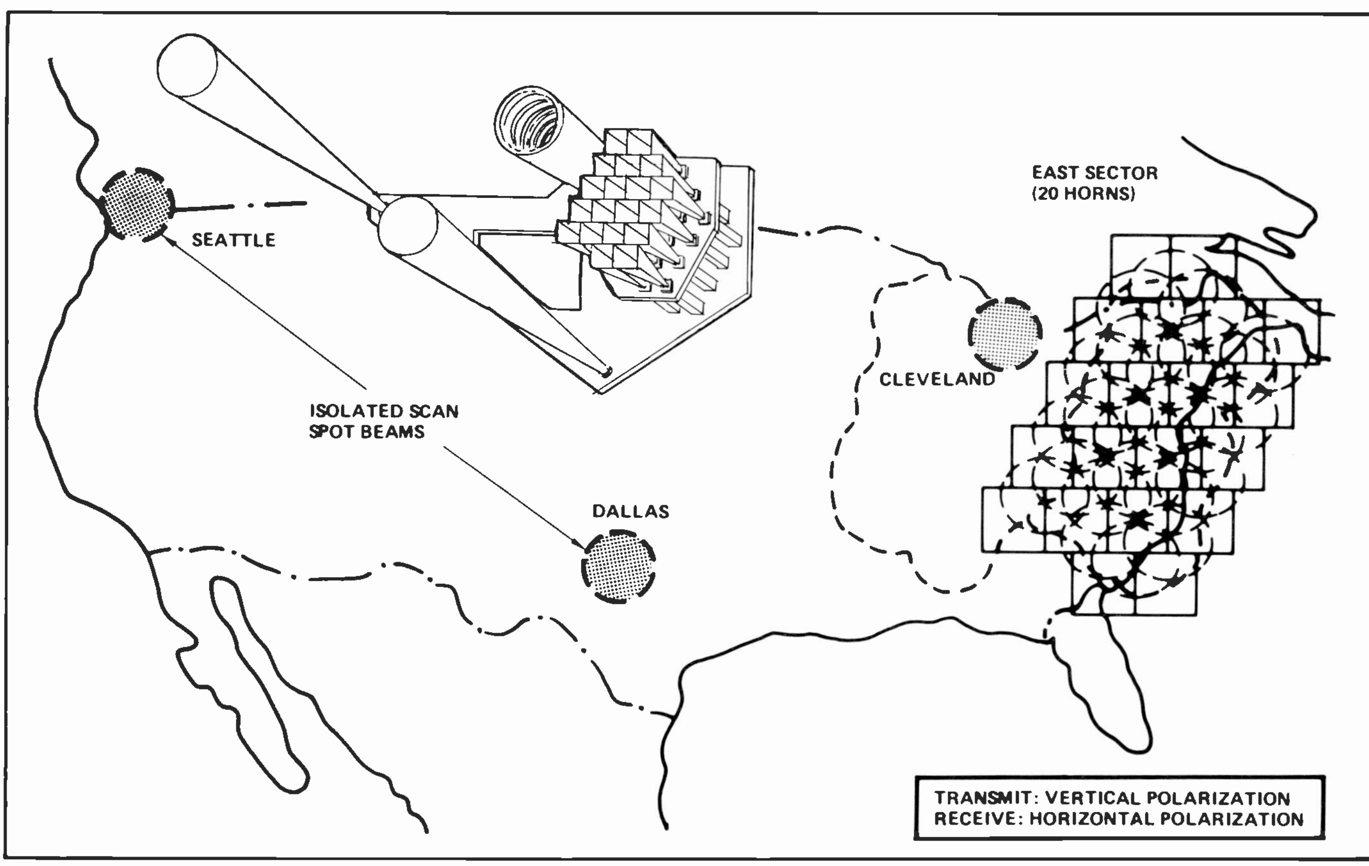


Fig. 7. *Coverage plan: Transmit vertical/receive horizontal.*

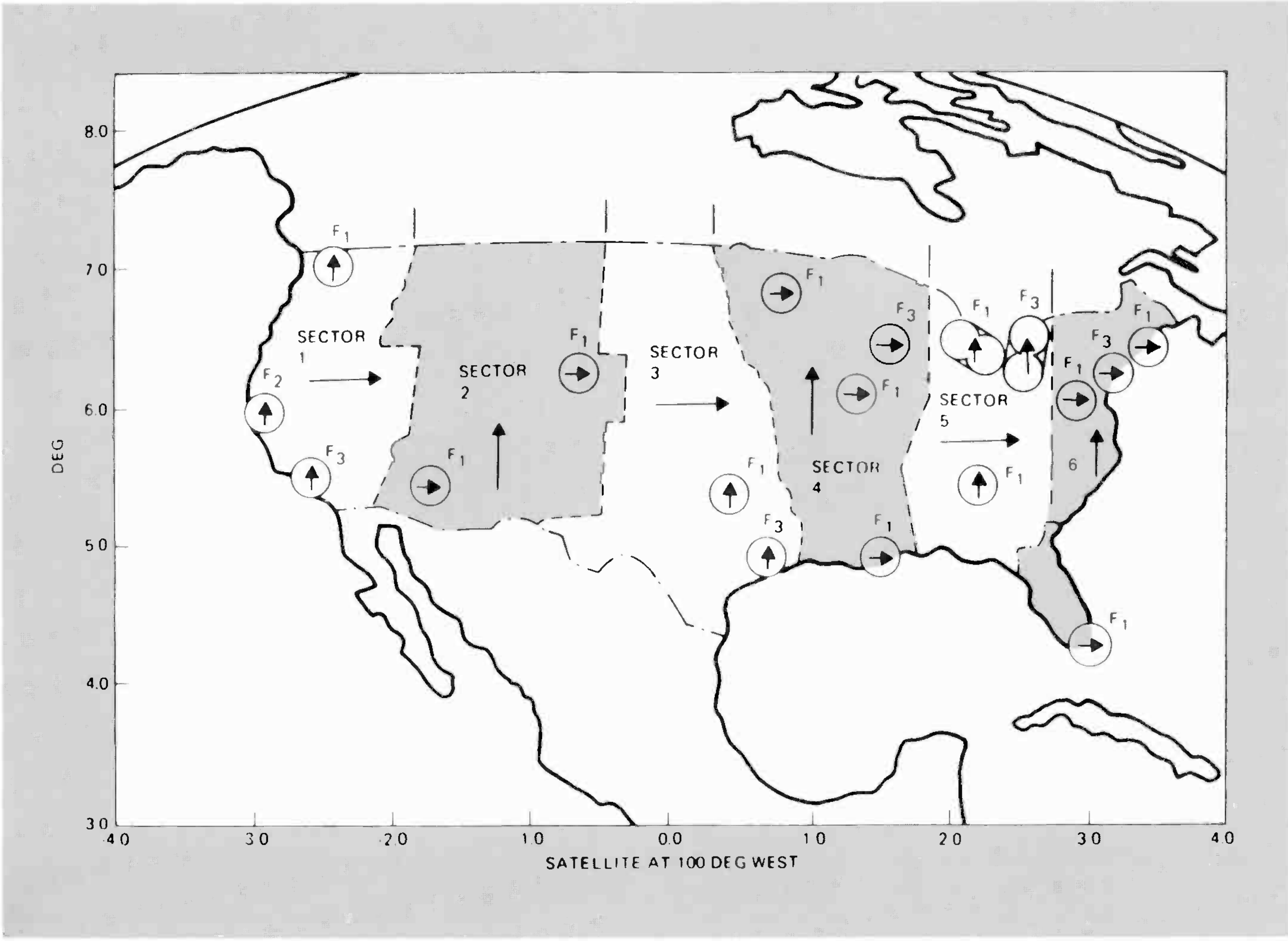


Fig. 8. *Example of MBA operational coverage.*

the IF Switch Matrix, which is shown schematically in Fig. 9. For the ACTS demonstrations, a 4 × 4 switch is provided to support a three-beam HBR network with 4-for-3 redundancy. The design is scaleable to operational-system requirements for 16 to 20 channels (plus redundancy). The IF Switch Matrix executes a sequence of input/output connectivity states as required by the TDMA traffic among the various beams. Program data are uplinked from the Master Control Station; up to 64 switch states can be defined with 1-microsecond granularity in each TDMA frame. The switching time is less than 20 nanoseconds.

The Baseband Processor (BBP) is the key to the LBR system; its block diagram is shown in Fig. 10. With scanning antenna beams, two stations that want to communicate are rarely illuminated by the antenna at the same time. Therefore the Baseband Processor demodulates and stores data bursts received on the uplink. The stored data bursts are then routed to different time slots and/or the other scan beam, then

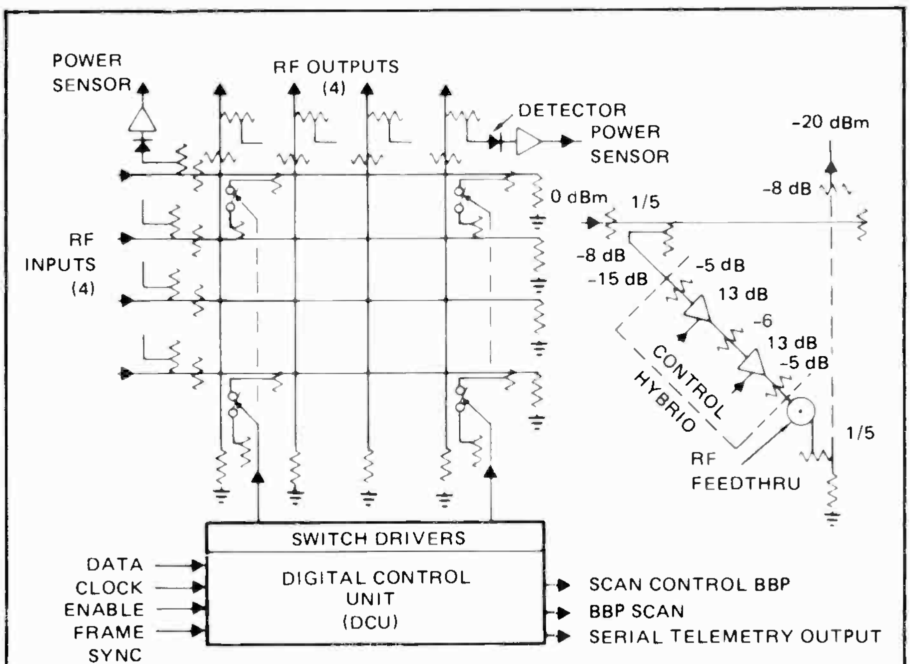


Fig. 9. *IF Switch Matrix.*

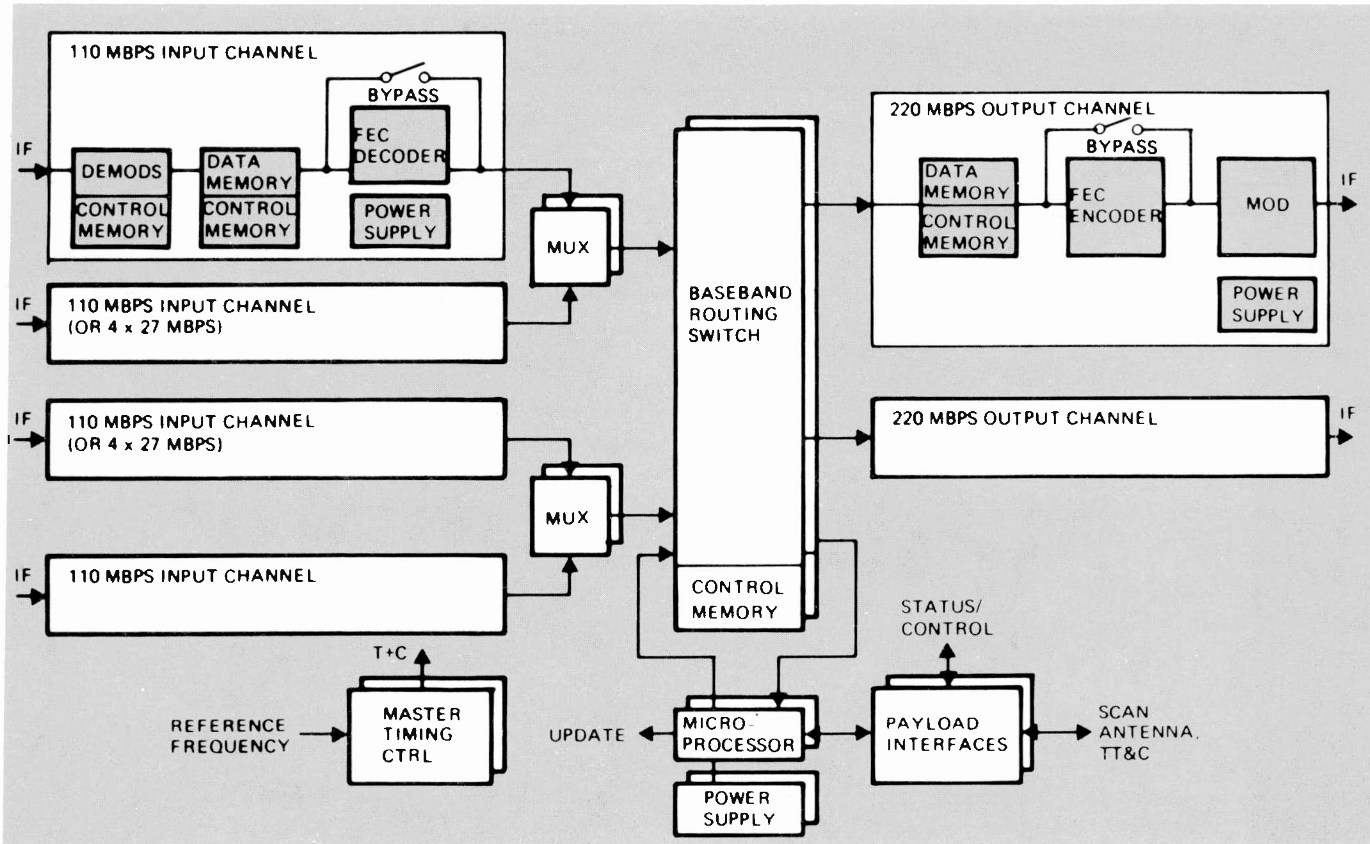


Fig. 10. *Baseband processor block diagram.*

remodulated and transmitted to their destinations. The system provides quick-response demand access for users to request channel capacity in units as small as 64 kbps.

The 220-Mbps capacity of each LBR uplink beam is organized into either two channels of 110 Mbps or eight channels of 27.5-Mbps capacity, or various combinations of 110-and 27.5-Mbps channels totaling 220 Mbps. The uplink TDMA burst rates can thus be lower for smaller users, reducing the requirements on their ground terminal equipment. The Baseband Processor input channels can be configured as 110-or 27.5-Mbps channels from time slot to time slot in accordance with traffic demands. (For the ACTS demonstration, only 8 of the 16 low-rate demodulators are provided, enough to support the experimental program.)

The LBR system handles rain attenuation by adaptively allocating more capacity so that the data burst rate can be halved and a rate ½ forward-error-correcting code can be applied. The Baseband Processor therefore contains decoders and encoders that are used as required for stations experiencing fades.

Control of the LBR system in response to capacity requests, fades, etc., is performed by the Master Control Station. The data required to program the various functions of the Baseband Processor and the antenna scanning are transmitted from the NASA ground station using the communications channel. For this reason the NASA ground station in Cleveland is included in a scan beam as well as a fixed beam. Approximately 0.9 Mbps of system capacity is required to program the BBP.

Other advanced MCP technology items include the dual-mode 8/40-watt 20-GHz TWTA transmitters (Table III) and the 30-GHz FET low-noise amplifiers. The TWTAs change power level to compensate for HBR system downlink rain losses. Similarly, the HBR terminals change uplink power levels to compensate for uplink rain losses. For a full-scale system, this ability to change the downlink power level affords a considerable saving in satellite primary power, because only the TWTAs directed to areas actually experiencing a rain fade need operate in the high-power mode. When supporting the LBR scanning beams, the TWTAs always operate in the high-power mode. The 30-GHz FET low-noise amplifiers (Table IV) provide a 4.5-dB noise figure up link performance to minimize user terminal transmitter requirements.

Scaling to an operational system includes increasing antenna size by a factor of 1.5 (more than 3-dB uplink and downlink improvement) and increasing TWTA high-mode output to 75 watts (nearly 3 dB more on the downlink). We would expect the LNA noise figure to decrease significantly due to FET technology improvements, and perhaps due to cooling the FET either actively or passively.

Spacecraft bus

Although the ACTS program will develop innovative technology for its communications missions, the spacecraft bus is of entirely conventional design, based primarily on previous successful commercial communications satellite subsystem and component designs. This approach leads to minimum cost and low risk in developing the spacecraft bus.

The only area in which significant new design is required is the Telemetry, Tracking, and Command subsystem. A Ka-band command and telemetry capability will be provided for operational control in lieu of the conventional C-band equipment once the assigned orbit station is reached. The 20-GHz telemetry transmitter and a separate 30-GHz beacon, utilizing an antenna with CONUS coverage, will measure rain

Table III. *20—GHz dual-mode TWTA characteristics.*

Parameter	High Power Mode	Low Power Mode
RF Power Out	40W	8W
Saturated Gain	33.3 dB	22 dB
Cathode-Helix Voltage	-10.75 kV	-10.75 kV
Control Anode Voltage (WRT Ground)	-3.35 kV	-6.85 kV
Beam Current	57 mA	25 mA
TWT Efficiency*	34%	20%
PPU Efficiency	75%	57.5%
Overall TWTA Efficiency	25%	11.5%

*TWT efficiency optimized for 75 watts rf out.

Table IV. *MCP LNA performance characteristics.*

Parameter	Value
Frequency	27.5 to 30.0 GHz
Noise Figure	4.5 dB, max
Gain	20.0 dB
Gain Variation	±1.0 dB
Output 3rd Order Intermod.	+15 dBm
VSWR	1.3:1
DC Power	0.50 watt
Size	4.0 × 1.75 × 1.0
Weight	0.25 pound
Temperature	-10° to +30°C

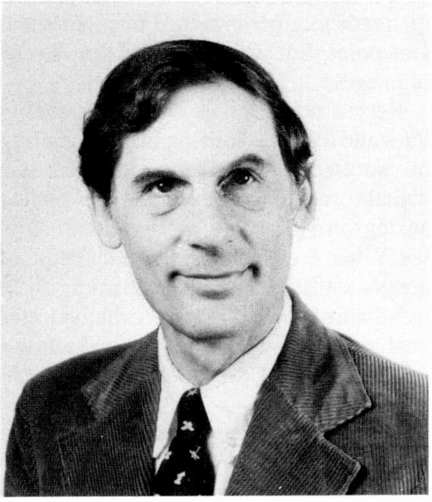
attenuation at any experimenter's location. These fade beacons will support experiments on propagation effects and will also be used operationally in controlling the ACTS communications system to overcome the effects of rain fading.

Conclusion

The ACTS communications technologies will allow economical, reliable operation of point-to-point communications systems with small, inexpensive ground terminals. The point-to-point communications system architecture contrasts strongly with the broadcast system architectures used at lower frequencies. The adaptive rain-loss approach requires relatively complex system control, but provides an economical solution by moving system resources to the locations actually affected by rain.

Opening the 30/20-GHz communications band greatly expands the U.S. orbit/spectrum resource. There is a 2.5-GHz bandwidth allocation available. Narrowbeam antennas as used by the MCP can provide frequency reuse factors as large as 10, resulting in a communications bandwidth as wide as 25 GHz from a single satellite. Ground station antennas are inherently narrowbeam at these high frequencies, providing at least twice the number of orbit slots available at lower frequencies. These factors all combine to provide a 30/20-GHz communications capacity many times greater than the lower-frequency bands combined.

The communications architecture of the ACTS system requires new developments in numerous areas. Some of these developments are comparatively straightforward and might well occur without active support by NASA. However, other individual developments, and the ACTS system as a whole, involve significant risk. Thus the ACTS program represents an essential step toward providing for the future growth of satellite communications.



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R. J. Klensch | H. Waldman

New simulation techniques for video provide powerful investigative tools

What goes up may come down . . . impaired.

When television signals are transmitted, the most important consideration is the final image quality. However, measuring the quality of an image includes many different parameters, and they may be difficult to quantify, largely because they are often highly subjective. People frequently disagree on the relative quality of two images, especially when they contain different types of defects. Because these defects are most easily observed visually, and because of the subjective nature of image quality, TV signals are usually characterized by displaying the transmitted images and then analyzing them visually. Mathematically measurable image parameters are used to verify and support this visual analysis.

In a recent issue of the *RCA Engineer*, modeling and simulation of various engineering systems were described by Guida et al[3] They discussed the computer simulation of communication links through the RCA Satcom satellites, including both digital and analog signals.

The approach they used was to simulate a test signal waveform of limited duration, and then simulate the effects of the link on it. Their outputs included prediction of the final waveform shape, generation of graphical descriptions (like the eye pattern), and calculation of mathematically derivable statistics or signal characteristics such as signal-to-noise ratio or differential phase. These types of outputs, in the case of TV transmission, were primarily useful for predicting performance from a system viewpoint, but did not allow the display of images.

Recent advances in simulation techniques allow for real analog image signals to be captured, digitized, and processed on a digital computer, and eventually restored to analog form to be displayed for visual analyses. When coupled with the calculation of image statistics or characteristics, these techniques form a powerful combination of analytical and visual analyses, and allow a full spectrum of system evaluation techniques.

Simulation of the transmission of one or a sequence of TV images involves problems usually associated with the actual transmission and reception of TV signals, such as keeping track of the synchronizing pulses imbedded in the waveform (called sync). Also, it involves additional problems related to simulating a continuous waveform on a digital computer. The latter, for example, typically includes concerns about the length of the signal to be digitized, the appropriate sampling rate, and the degree of quantization. These problems are discussed in more detail under System Description below.

Hardware simulations long have had the feature of processing and displaying actual images. They have the advantage of using real components or subsystems, often the actual counterparts of those used in the system being simulated. Hardware simulations differ from prototypes in that they are intended to simulate the system processes and not necessarily the actual system under consideration. Therefore, many shortcuts can be taken, and simulation results are usually available well before a prototype can be constructed. Simulations also have the advantages of flexible system configuration and easy modification of system parameters.

Hardware and software simulations sometimes compete, but most often complement one another in the study of complex systems. Hardware simulations have the advantage of being capable of handling a continuous stream of signals. Software simulations, however, are limited by the large, but finite, amount of data that can be stored in a computer.

A typical hardware simulator allows rapid and continuous change of individual system parameters, such as the relative level between two signals, with immediate objective measurements and/or subjective observations of the results. A software simulator, on the other hand, allows easy modification of deeply imbedded system values, such as a parameter that may appear in several subsystems, and it offers even more flexibility in modifying the system configuration than does the hardware simulator.

Hardware and software simulations, when performed simultaneously, also have the complementary advantage of verifying one another. The development of the C-band hardware simulator preceded that of SATLINK (both are described in this paper). Therefore, the C-band simulator was available to verify and strongly influence the development of the latter.

In the following sections, some typical new hardware and software video simula-

Abstract: *Satellite simulations in the laboratory can predict system performance before field implementation. Both hardware and software approaches may be used to achieve this desirable goal.*

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tors are discussed, and the power of these techniques will be apparent.

SATLINK—A detailed example of a software simulator

SATLINK is a series of computer programs designed to obtain a sequence of real TV images, simulate the effect of a satellite link on them, and then output the "received" images for display on a monitor for visual analysis. Mathematical and statistical parameters are also calculated to support this analysis. The original criteria for SATLINK were that it be capable of simulating the present Satcom satellites, but be flexible enough to simulate future satellite systems and TV formats other than standard NTSC. What was written, therefore, was a highly modular program conceptually divided into two parts.

One part of SATLINK is an overall control framework largely transparent to the investigator. It obtains information pertinent to the individual run, calculates key run parameters, obtains image or video data as needed, tracks horizontal sync, simulates a sufficiently high video sampling rate to support the highest bandwidth expected in the run, and formats the data, one horizontal line at a time, for link simulation. Once link processing is completed, the program compiles the appropriate statistics, returns the video data to its original format, and outputs them.

The link portion of SATLINK is highly modular. Filters, nonlinear amplifiers, modulators, and noise sources can be assembled in the order that best represents the system under simulation. Specification of the parameters of these functions are standardized and simplified so that the investigator can pay maximum attention to the system under simulation.

Another criterion for SATLINK was that it use existing hardware and software to the greatest extent possible to minimize development costs. Practically speaking, this meant using SATLINK in conjunction with the Digital Video Facility (DVF) recently built at RCA Laboratories. The DVF is hardwired to a VAX11/780 computer, and it consists of a large memory for video storage, memory-scanning devices, monitors, and associated controls. Utility programs written on the VAX control the DVF by means of commands entered through the computer. SATLINK, therefore, is a series of computer programs resident on the VAX and designed to use the DVF for acquisition of TV images and their display both before and after simulated transmission.

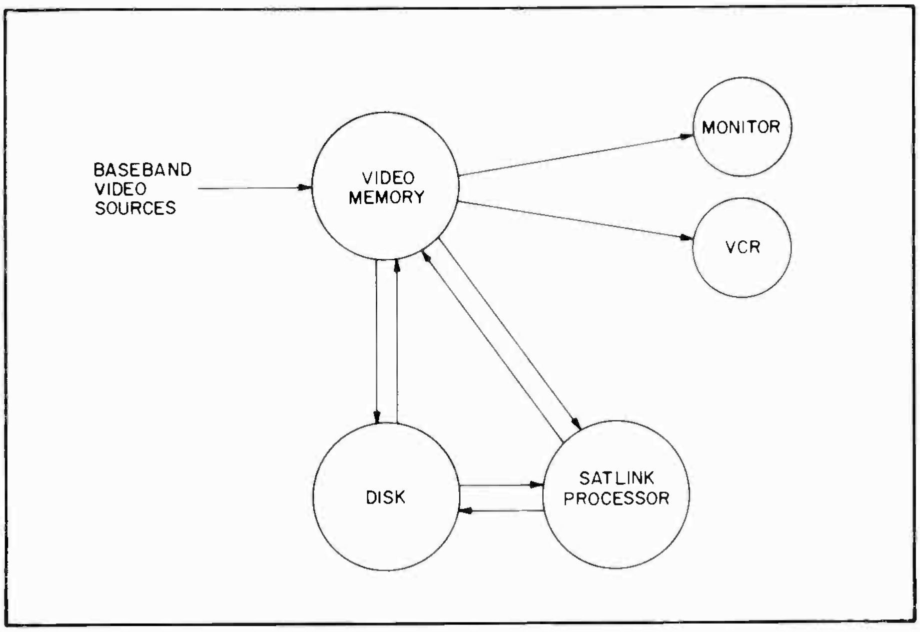


Fig. 1. *Video data paths. Images typically pass from a source to the video memory and then to disk files. Later they are processed and returned to disk. Before images are displayed they are transferred to the video memory.*

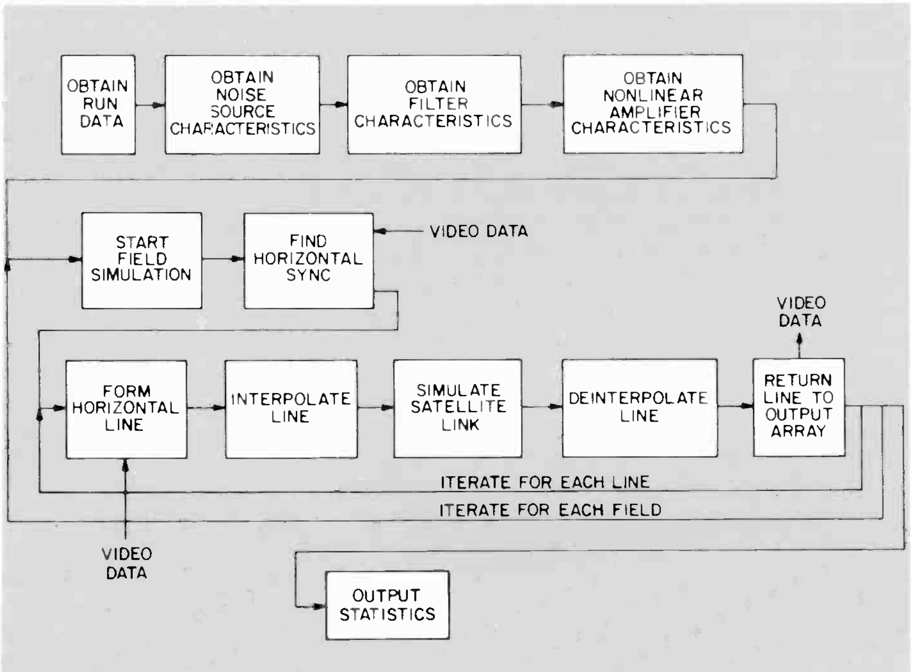


Fig. 2. *SATLINK processor control diagram. Video data are read and written as needed by the processor.*

System description

The possible video data paths are shown in Fig. 1. Images may be captured and digitized from several sources, including a TV camera, network broadcasts, instrument-generated test patterns, or special test patterns mathematically produced by com- puter. From the video memory these ages may be displayed on a monitor by a video cassette recorder, or t to disk files.

The most important co SATLINK system is t 2), because it incl simulator. It obta disk files or t locates horizontal sync for later reference when forming individual lines. The data are grouped by fields and then each line of the field is processed individually.

At the beginning of a run, satellite link data, including circuit and channel characteristics, are obtained from a disk file created by the user. These are applied later by the standardized link function modules. Each field is then processed in turn. Horizontal sync is located for the first line of the field, and its locations are projected for subsequent lines. Then the individual lines are formed, the effects of the link are simulated on them, and they are returned to an output array. Image statistics, compiled as each line is processed, are written to a disk file at the conclusion of the run.

As the individual lines are formed, input video data are read in blocks as needed. Similarly, processed video data are written to disk files or the video memory when the output array is filled.

Baseband video usually is sampled by the DVF digitizer at four times the NTSC color subcarrier frequency. By the sampling theorem, this rate is sufficient for frequencies higher than the usual video bandwidth. After modulation, however, the signal bandwidth may greatly exceed its original value, and this sampling rate may not be high enough. Therefore, within the SATLINK processor, each line to be simulated is sampled at a high-enough rate to carry the modulated signal before link simulation. This is accomplished by interpolating the amplitude of each horizontal line at the new sampling points from the amplitude values at the original points. Similarly, after link simulation, amplitude values are estimated by interpolation back to the original sampling points. This is often called decimation [illegible] is termed "deinterpolation [illegible]

The interpolation algorithm selected for SATLINK maintains high accuracy with [illegible] computer running time, and [illegible]eration is very simple. Each new sampling point is addressed in turn. First, a third degree algebraic equation is fitted through the four nearest original sampling points (two before and two after). Then [illegible] new sampli[illegible] amplitude is cal[illegible] from th[illegible] equation. [illegible] accurate than simple linea[illegible] [illegible]n. The deinterpolator acts in [illegible] fashion, transferring values [illegible]ted points back to the [illegible]

[illegible] been shown to act [illegible]ack tests of the interpolator, cascaded with the deinterpolator, produced very small errors—about 40 to 60 dB below the original sampled amplitudes.

In a typical transmission of TV by satellite, the baseband video signals first frequency-modulate an intermediate frequency (IF) carrier, which is then upconverted to the output or transmitted radio frequency (rf). The IF carrier frequency is about 70 MHz and the rf frequency is 6 GHz for C-band. The FM modulator increases the bandwidth of the signal. The upconverter, however, does not change the shape of the signal spectrum.

Simulation of the video signal at the IF or rf frequencies requires an extremely high sampling rate. Both the amount of data that must be stored and the required running time are far too great for practical computation. Therefore, most simulations of this type set the carrier frequencies to zero. This has the effect of transferring the transmitted signal spectrum from the rf region down to zero frequency. It then is spaced about zero, but its shape is preserved, and the maximum frequency is determined by the bandwidth of the signal. This transferral eliminates the need for an upconverter model, since it does not change the spectrum shape, and it reduces the signal sampling rate required by the sampling theorem.

In the SATLINK processor, the bandwidth of the IF or rf signal is estimated by applying Carson's Rule[4] for FM modulation. The interpolator output sampling rate is then automatically chosen by the processor to exceed that predicted by the sampling theorem for this bandwidth. If the user is interested in a higher frequency range, however, the automatic selection of the sampling rate may be overridden.

After interpolation, the image data are [illegible]ated as a signal waveform. Mathematic[illegible], each sampled data point amplitude is [illegible]resented as a complex number or pha[illegible] with its imaginary part carrying the [illegible]-of-phase portion of the signal referred [illegible]he IF or rf carrier.

[illegible]he satellite link simulator is the mod[illegible] portion of the processor. Each stand[illegible]zed module may be a filter, nonlinear [illegible]lifier (traveling-wave-tube or rf solid [illegible] amplifier), modulator, demodulator, [illegible]e source, or any other circuit or function needed. The specific parameters of each function, their number, and their order are determined by the satellite system under investigation.

An ideal FM modulator integrates the signal, multiplies it by an appropriate factor determined by the desired deviation ratio or modulation index, and then adds it to the carrier phase. This is simulated in SATLINK for an arbitrary sampling point n by summing the signal from the beginning of the line, multiplying by the above factor, and then considering this the phase of the modulated signal referred to the carrier phase.

$$\phi_n = \beta \sum_{p=1}^{n} s_p$$

$$S_n = \cos(\phi_n) + i \sin(\phi_n) \qquad (1)$$

where s_p is the signal amplitude at point p, ϕ_n is the sum at point n, and S_n is the FM-modulated signal at n.

Demodulation is the reverse of the above process. First, the phase of the signal at each instant is found, and then it is differentiated. On a digital computer this is closely approximated by finding the phase of the signal at each sampling point and then taking phase differences at successive points. However, the phase of a complex number is calculated by use of inverse trigonometric functions, and there is a discontinuity at π radians. This discontinuity adds 2π to the phase differences when it is crossed by successive phasors. In SATLINK this difficulty is avoided by first taking the ratios of successive sample point phasors, and then finding the phases of these ratios. The latter are the phase differences between the sample points without the 2π ambiguity. Mathematically this process may be expressed as,

$$D_n = \frac{S_n}{S_{n-1}} = \frac{|S_n|}{|S_{n-1}|} \angle\, \phi_n - \phi_{n-1}$$

$$s_n = (1/\beta)\arctan[\mathrm{Imag}(D_n)/\mathrm{Real}(D_n)] = (\phi_n - \phi_{n-1})/\beta \qquad (2)$$

Filters are characterized in the frequency domain. When a filter is described mathematically, its gain and phase responses are given in a separate subroutine of SATLINK. Alternatively, when the filter is described numerically, these data are read from filter response files.[3]

When an image data line is to be filtered, it is first transferred to the frequency domain by means of a Fast Fourier Transform (FFT). Filtering is accomplished by multiplying the frequency response thus obtained by the filter response, expressed as a series of complex numbers, one for each frequency. Each complex number represents the filter gain and phase at that frequency. Then the line is returned to the time domain by means of an inverse FFT.

The rf amplifiers used in satellite systems are traveling wave tubes (TWT) or solid state power amplifiers (SSPA). When operated near full power, these devices generally have a nonlinear response, and introduce both amplitude and phase distortions in the signal. They are modeled by empirically determining their effects as a function of signal power and writing these to a data file.[3] The file is read by SATLINK at run time, and the amplifier distortions are combined with the simulated signal as each line is processed.

SATLINK includes a white-noise generator developed by C.H. Lu at RCA Laboratories. The generator simulates uplink and downlink noise, and its amplitude and phase are calculated at each frequency as follows;

$$A = B\,[\,-2 \log_e r_1\,]^{1/2}$$
$$\theta = 2\pi\, r_2 \qquad (3)$$

where r_1 and r_2 are two pseudo-randomly generated numbers uniformly distributed from 0 to 1, B is a multiplying factor determined by the desired carrier-to-noise ratio, A is the noise amplitude at the given frequency and θ is its phase. It can be shown that the in-phase and out-of-phase components of A are both normally distributed, and that its spectrum is flat over the user-specified bandwidth. The pseudorandom noise generated by equation 3 is transformed to the time domain by use of an FFT and then added to the signal being simulated.

Another technique developed by Lu is the cyclic palindromic display. It is intended to be an answer to the following problem: Video memory is limited in the DVF, and only a finite sequence of frames can be stored. When these are displayed, the frames are scanned from the first to the last, and then the process is repeated starting from the first frame again. The instantaneous transition from the last frame to the first introduces a highly objectionable artificial rapid jerking motion in the display, making image analysis difficult.

Lu's solution is to capture only about half the number of frames originally intended for display. The sequence of frames is reversed and then added at the end of the original sequence. In the resulting display, the jerkiness is largely removed, allowing more accurate visual analysis.

The exact sequence of frames depends on the specific TV format used. Standard NTSC signals are divided into interleaving fields (two to a complete frame), with half-integral numbers of lines in each. The phase of the color portion of the signal must be maintained continuously throughout these lines and fields. Lu has carefully worked out the reverse sequence of fields to be used with NTSC, and this technique is used with SATLINK.

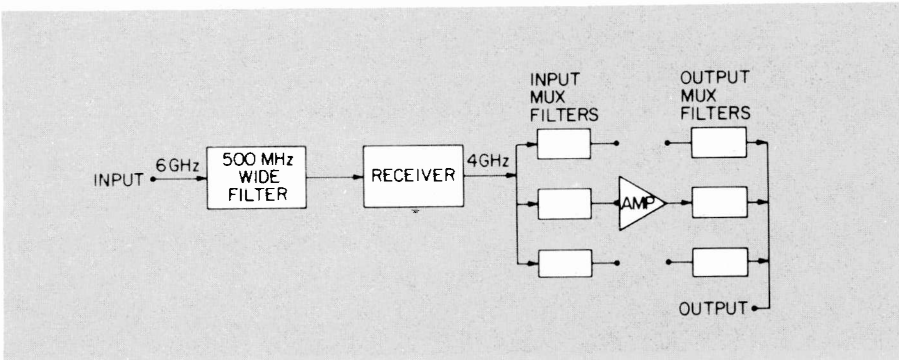


Fig. 3. *C-band satellite simulator block diagram.*

C-band simulator—an example of a hardware simulator

RCA Laboratories has developed a C-band satellite simulator that can be made to have electrical transfer characteristics closely approximating any one of Americom's five orbiting communication satellites. Differences from one satellite design to another can be accommodated by a change of subsystems within the simulator hardware. Whereas early satellite designs use traveling-wave-tube amplifiers (TWTA) for signal transmission, the newer satellites use solid state power amplifiers (SSPA) in that role. Also, the channel filter types used in one satellite are not necessarily identical to their counterparts in another satellite. By having a complete set of filters and amplifiers for all operational satellites, it is possible to simulate a transponder on any satellite.

Figure 3 is a block diagram of the C-band simulator. The frequency band for C-band satellite operation is 5.7 to 6.2 GHz for the uplink, and 3.7 to 4.2 GHz for the downlink, as indicated. On the actual satellite, the "input" terminal of the 500-MHz-wide filter is connected to the satellite receiving antenna. The terminal designated "output" is connected to a satellite transmitting antenna.

All the C-band satellites have a 500-MHz-wide input filter that prevents any out-of-band signals from entering the receiver. The receiver accepts all the uplinked channels of a given polarization (usually 12) and amplifies the signals, translating them from the 5.7- to 6.2-GHz band to the 3.7-to 4.2-GHz band. The input filter and receiver combination is essentially transparent to the incoming signals. These two components are, therefore, not changed when changes are made to reconfigure the simulator for a particular satellite.

Following the receiver are a number of filters called the input multiplex (MUX) filters. These bandpass filters are each tuned to a different transponder and are used to separate the signal (or signals) intended for one transponder from any signal intended for all the other transponders. Once separated, the signal or signals are individually amplified (by either a TWTA or SSPA) and recombined in the output MUX filters. Each output MUX filter is a bandpass filter tuned to the same frequency band as its respective input MUX filter.

The combining of all the amplified signals is accomplished essentially without loss in the satellite, and then the combined signals are delivered to the "output" port. It takes 30 minutes, at most, to reconfigure the simulator. This includes changing the input and output MUX filters and the active device (TWTA to SSPA or vice versa).

The up and down links

Most experiments are performed on signals (carriers) that reside within the 70 ± 20-MHz IF band. This IF band must therefore be "up-converted" to the 6-GHz band to gain access to the satellite simulator. Likewise, we must "down-convert" the 4-GHz output of the simulator to the 70-MHz IF band for demodulation. Figure 4 shows a block diagram that includes not only the simulator, but also the up- and down-converters and the modems (modulator-demodulators).

The example shown in Fig. 4 represents an implementation for video signal transmission. The baseband video signal source is derived from a camera, video-

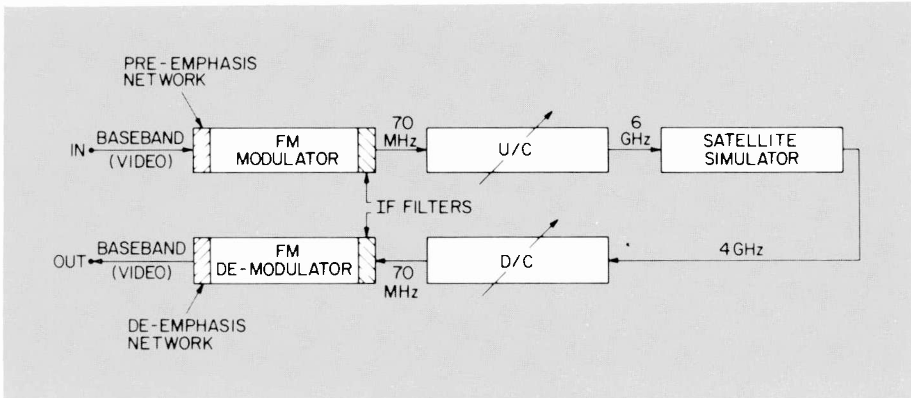


Fig. 4. *Overall C-band system simulator.*

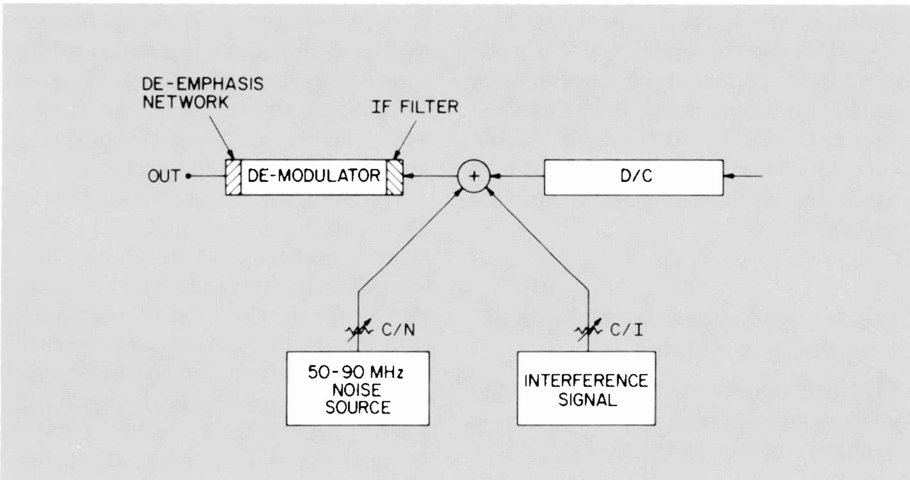


Fig. 5. *Insertion of noise and interference.*

tape, video signal generator, or demodulated terrestrial TV signal. The baseband video is pre-emphasized, and then FM modulates a 70-MHz carrier. The resulting spectrum is band-limited by the IF filter. The synthesized frequency-agile up-converter is adjusted to place the FM carrier in the desired transponder (perhaps in the center of that transponder). The desired transponder is the one for which there is an input MUX filter, an amplifier, and an output MUX filter. After the signal passes through the satellite simulator, a synthesized, frequency-agile down-converter is adjusted so that its output carrier frequency is 70 MHz. At this point, the signal is passed through an IF filter, FM-demodulated, and finally deemphasized.

If the baseband input to the modulator were changed from video to a number of frequency division multiplex (FDM) voice channels, an FDM-FM transmission system could be simulated. Likewise, if the FM modulator/demodulator were replaced by phase-shift modems, such as quatra-phase-shift-keying (QPSK), data transmission systems could be simulated.

For the simulation of the complete satellite link to be complete, the effects of noise and interference must be included. Figure 5 shows the usual arrangement for noise and/or interference insertion. Wideband Gaussian-distributed noise is summed with the desired signal at the 70-MHz IF band immediately prior to inputting the signal to the demodulator's IF filter. An interference signal may also be added at this summing point. Calibrated decade attenuators with 0.1-dB resolution are used to set carrier-to-noise ratio (C/N) and carrier-to-interference ratio (C/I).

The C/N can be adjusted from 0 dB to approximately 38 dB when measured in a 25-MHz bandwidth (the upper limit is set by the noise floor of the satellite simulator). In a typical TV earth station operation, the value of C/N lies between 10 and 20 dB.

C/I can be made infinite by total removal of the interfering signal. The adjustment, therefore, can cover the range of 0 dB to ∞ dB. In practice, a C/I of less then 25 dB (for a co-channel FM TV signal interfering with another similar signal) may cause just-perceptible effects in the received image.

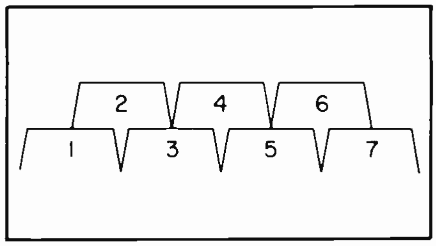


Fig. 6. *Channel schematic frequency plan of a C-band satellite.*

When the main goal of an experiment is to determine the effects of interference on picture quality, the implementation is slightly altered. In such a case, the desired signal and the interference signal change roles. This allows the interference signal to be moved in frequency (by virtue of the agile down-converter), and thus to simulate offset (rather than co-channel) interference effects. Offset interference, sometimes called cross-polarization or adjacent-channel interference, can occur in practice, as shown in Fig. 6. For example, channel 3 has possible interference from adjacent channels 1 and 5 (of the same polarization), as well as from channels 2 and 4 (of orthogonal polarization). The output MUX filters of channels 1 and 5 prevent most of the undesired spectral components of those channels from entering channel 3. Channels 2 and 4, whose center frequencies are closer to those of channel 3, are inhibited from entering channel 3 by virtue of the orthogonal (cross-polarized) polarization. (This technique of using orthogonal signals is commonly called frequency reuse.) The degree of polarization isolation can be as great as 30 to 35 dB.

Other sources of interference can originate from adjacent satellites in the orbital arc. A recent FCC ruling allows satellites to have minimum spacings of only two degrees. Prior to that ruling, four degrees was the minimum-allowable spacing. With satellites this close to one another, it is possible to get some adjacent-satellite interference, especially if the earth-station receiving antenna is not carefully pointed, or has a beam width that is too broad. If the adjacent satellite has a frequency plan different from that of the desired satellite (it may have more, or fewer, transponders of different bandwidths), then it is possible for the interfering signal to be frequency-offset from the desired signal by an arbitrary amount.

From this it is apparent that the simulator can be used in either of two basic modes. One is to determine the effects of a transponder on a variety of traffic conditions (single-channel TV, multichannel TV, single-or multicarrier FDM-FM, single-or multicarrier data or voice, etc.). The other mode used is to determine the effects of noise and interference on the desired traffic due to signals in adjacent or overlapping channels. This dual capability makes it possible to simulate the operation of a satellite communication channel, including the effects of receiving antenna size and pattern. (The receiving antenna size and type influence both the C/N and some forms of interference, such as interference originating from adjacent satellites and/or terrestrial sources.)

A multichannel simulator can be used to observe the effects of yet another possible problem area—that of multipath. When a desired signal reaches its destination by more than one path, distortions of unacceptable magnitudes can occur. The phenomenon is frequently observed in terrestrial transmission, as in the case of "airplane flutter" on TV signals. The direct signal path is interfered with by an indirect path of varying length. Thus, the combined received signals can add their carriers in phase or out of phase to produce this well known effect. In a satellite, portions of the desired signal fall into the adjacent transponders, where they are amplified and transmitted back to earth. The earth station receives the desired signal plus a portion of the desired signal that was transmitted by the adjacent transponders. This mechanism is illustrated in Fig. 7. The portion of the desired signal's spectrum near the filter's edges will experience the effects of multipath.

Examples of experiments

There are several ways to categorize the types of transmission modes to be considered. One approach is to consider single-carrier systems as one class of operation, and multicarrier systems as another. Single-carrier systems are usually distinguished by their using the full saturated power output of the satellite. Frequently, as in the case of C-band satellite television, the full transponder bandwidth is used as well.

Multicarrier systems share both the total available power and the total available bandwidth. A multicarrier system of interest employs two television channels per transponder. In this approach, two TV FM carriers are located in a single transponder, each offset from center by roughly one quarter of the transponder bandwidth. Optimization of the system requires refinements on carrier spacing, as well as the carrier's deviation and output power back-off. The received FM TV signal at all earth stations provides an improved signal-to-noise ratio for increased deviation and carrier level. The deviation, therefore, should be as large as possible, and the output back-off should be as small as possible.

Satellite output amplifiers are usually TWTAs (more recently, SSPAs). Both of these devices have nonlinear input/output characteristics at maximum output power, and are capable of generating intermodulation products when more than one carrier is present. Conversion of amplitude modulation (AM) to phase modulation (PM) also takes place in these amplifiers and can result in crosstalk between the two signals. Reduction in both deviation and output power reduces these problems.

Distortion of a video signal occurs in most communication channels. Generally, the magnitude is sufficiently small to be subjectively invisible to a viewer. Objective measurements of a number of signal characteristics can be made. This helps define picture quality in terms of differential phase, differential gain, short-time distortion, chroma-luma delay, frequency response, etc. Various organizations, such as the Network Transmission Committee, have published specifications giving limits on these characteristics. Their report, NTC Report No. 7[5] details all the measurements and their limits to meet what is considered to be broadcast quality. Some operators, such as cable operators, may use less rigid constraints and this is reflected in their specification for acceptable picture quality.

Video distortions are strongly dependent on deviation and the bandwidth through which the FM-modulated signal passes. As deviation increases beyond the Carson's Rule[4] constraint, some of the spectral components fall outside the limiting bandwith prior to demodulation. When this happens the demodulated signal is not faithfully reproduced, as indicated by degraded objective measurements.

Several experiments have been made to determine the dependence of video distortions on deviation. Table I lists some of the measured characteristics for different deviations (Δf, given in megahertz peak). The bandwidth used in these experiments is given in the table, as is the dependence of FM threshold on deviation.

Two-for-one video experiments were performed on a wide variety of filter/amplifier combinations (different input MUX filters used in conjunction with either a TWTA or an SSPA.) A small sampling of these data is shown in Table II. Note that the variables are carrier spacing and output power back-off. The measured characteristics are chroma crosstalk and interference. Chroma crosstalk is caused by AM-to-PM conversion, and the interference is a result of intermodulation and adjacent channel feedthrough.

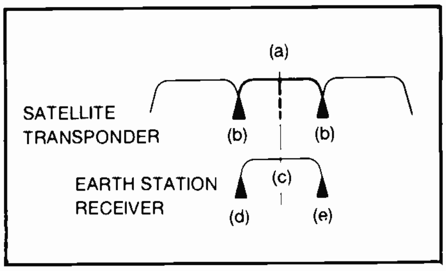


Fig. 7. *The desired signal passes through the transponder (a). Portions of the desired signal pass through the shaded area of the adjacent transponders (b). The desired signal is received at the earth station via three paths: the desired main path (c), the undesired path from the lower adjacent transponder (d), and the undesired path from the upper adjacent transponder (e).*

Other software simulation results

Video simulation on a digital computer has been in ongoing use in recent years, with constant refinement of its techniques. Some applications of simulation described here were pursued before the development of SATLINK. Nevertheless, they all conform to the principles described earlier in this paper.

Teleconferencing bandwidth reduction

An important goal in the development of video teleconferencing systems is to minimize costs. One way of reducing them for analog signals is to transmit with the narrowest possible bandwidth. However, bandwidth reduction techniques are always accompanied by image quality degradation, so the design goal of most teleconferencing systems is to minimize bandwidth while maintaining acceptable subjective image quality at the receiver.

S. Ng and others at RCA Laboratories have used simulation to develop a technique for reducing the bandwidth of a video signal by a factor of 8. Some image quality is lost, but the received images are still quite acceptable for teleconferencing applications.

This 8:1 bandwidth reduction system (Fig. 8) treats the luminance and chrominance signals separately, and views the TV image as existing in three dimensions: horizontal, vertical, and extended in time. Only the horizontal direction signal is continuous. In the vertical direction the image is divided into discrete lines, and temporally it is organized by frames. The amount of information to be transmitted is reduced equally in the three dimensions by a factor of 2, yielding an overall reduction of 8.

Since the horizontal signal is continuous, it is simply low-pass-filtered, eliminating the high-frequency half of its spectrum. In the vertical direction, however, information reduction is accomplished by eliminating every other line. Similarly, every other frame is eliminated to accomplish the temporal reduction.

A true TV signal, however, is continuous in time with one line following another until each frame is transmitted, and then the next frame is started. The actual bandwidth reduction of this signal is accomplished as follows. The entire signal is low-pass-filtered to attain the horizontal bandwidth reduction. Then it is prefiltered vertically, and every other line is eliminated. Since twice as much time is thus available to transmit a line, each line is stretched out in time, yielding another 2:1 bandwidth reduction. This stretch can be realized only by digitizing the signal, storing one line at a time, and then reading the line at half the original rate. Similarly, since every other frame is eliminated, the transmission time for each frame is doubled, producing the final 2:1 reduction.

At the receiver, the images must be reconstructed with the original number of lines and frames. This is done by taking advantage of the high degree of information redundancy present in any sequence of TV images. It is assumed that corresponding picture elements in two successive lines are highly correlated and, therefore, each missing line is reconstructed by linearly interpolating pixel amplitude values between the lines immediately preceding and following it. Similary, each missing frame is reconstructed by linearly interpolating pixel values from the preceding and following frames (Fig. 8). Since frame-to-frame differences are due primarily to motion, this technique is very effective for teleconferencing, where relatively little motion is anticipated.

The effect of the 8:1 bandwidth reduction system is to low-pass-filter the image horizontally, vertically, and temporally. Spatially this results in the loss of high-frequency detail and blurring of object edges within the image. This edge loss may be partially recovered by spatially high-pass-filtering, peaking near the maximum transmitted spatial frequencies. Temporally, however, frame-to-frame changes are due to motion, with only moving objects being blurred. Here it is found that temporal peaking also helps produce crisper object edges and an overall improvement in image quality.

Subjective tests of simulated 8:1-reduced images showed that image quality was quite good, with only moderate losses in resolution. Only when processed images were compared to their originals was it evident that some image degradation was present. The 8:1 reduction system works well stand-alone, and it can reduce a typical 4.2-MHz bandwidth video signal to about 0.5 MHz. However, even lower bandwidths or equivalent bit rates are needed for many teleconferencing applications. Here the bandwidth reduction system can be used as a preprocessor for a digital adaptive

Table I.
Selected video distortions as a function of deviation (Δf) for transmission through 2 cascaded 25 MHz-wide IF filters.

Video Distortion Parameters		*Peak Deviation in MHz*						*Nonimpaired Value*
		6.3	7.1	8.0	9.0	10.0	11.3	
2T/PB	IRE	99.8	99.6	98.8	97.7	95.6	92.3	100
C/L Gain	%	98.7	97.9	97.2	95.9	93.9	91.8	100
C/L Delay	ns	-2.7	-1.7	- .1	1.9	4.9	9.0	0
Lum. Non-linear Distortion	%	1.0	.9	1.0	.9	1.2	.9	0
2TK	%	.7	.7	.7	.8	1.1	1.7	0
Diff. Gain	%	3.2	3.2	3.1	3.1	2.9	2.6	0
Diff. Phase	%	1.3	1.7	2.0	2.3	2.8	3.3	0

Onset of threshold vs. deviation (Δf) for a 25-MHz IF filter using two types of video signals.

	C/N in dB for Just-Noticeable Impulses	
Δf MHz (peak)	*0 IRE Flat*	*75% Color Bars*
4.0	9.5	10.0
6.3	9.4	10.1
7.1	9.5	10.3
8.0	9.5	10.4
9.0	9.4	10.5
10.0	9.5	11.1
11.3	9.3	11.6

Data obtained from measurements carried out by K.M. Kelly.

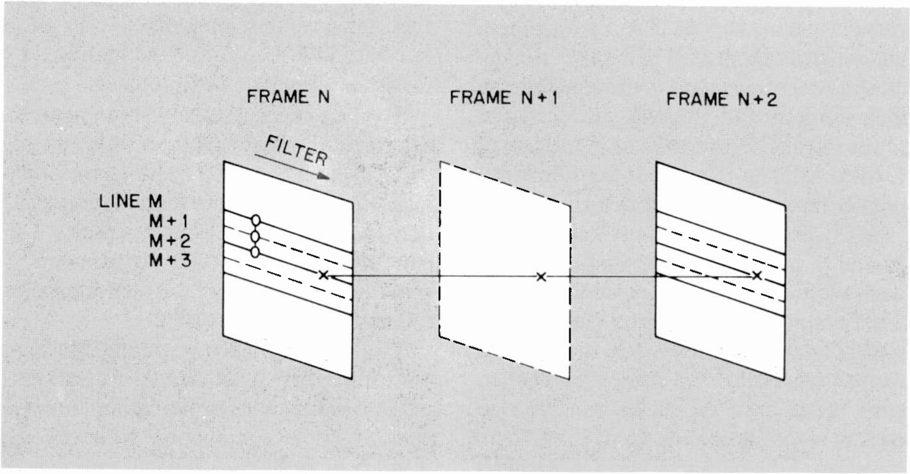


Fig. 8. *8 : 1 video bandwidth reduction. Alternate lines and frames are removed (dashed), allowing more time for transmission of the remaining data. Horizontal bandwidth reduction is accomplished by filtering. Typical picture elements used in reconstructing the original sequence are shown as upper case Os (vertical) and Xs (temporal).*

Table II

Triple collector traveling wave tube amplifier (TWTA) power output vs power input.

Total Input Power Backoff (TIBO) dB	*Single Carrier Output Power Backoff (OBO)* dB*	*2 Carriers OBO* Per Carrier, dB*
0	0	4.6
3	.4	4.8
6	1.4	5.8
9	3.6	7.6
12	6.8	11:6
16	10.0	15.6
20	14.6	17.0

*OBO Referenced to single carrier saturation.

Triple collector TWTA chroma crosstalk vs. TIBO.
$\Delta S = 9.9$ MHZ $\Delta f = 6.3$ MHz (Peak) IF BW = 17.5 MHz

TIBO dB	*Chroma Crosstalk%*	
	No IF Equalization	*With IF Equalization*
0	2.2	1.7
3	1.7	≤1.7
6	≤1.7	1.1
9	1.1	≤1.1
12	≤1.1	<1
16	<1	<1
20	<1	<1

Triple collector TWTA chroma crosstalk and interference vs. carrier offset from transponder center frequency (Δs) and deviation (Δf).
6-pole equalized input mux filter, 6-pole unequalized output mux filter, IF BW = 17.5 MHz

Δf (peak) MHz	*ΔS MHz*	*Chroma Crosstalk %*	*Interference indegrees phase shift*	*Δf (peak) MHz*	*ΔS MHz*	*Chroma Crosstalk %*	*Interference indegrees phase shift*
	7	4.5	9		7	8.4	19
	8	≤1.1	4		8	1.1	4
	9	≤1.1	4	6.3	9	1.7	6
4.0	10	1.7	≤2		10	2.8	≤2
	11	2.8	2		11	3.9	5
	12	5.0	≤2		12	7.3	3
	7	5.6	14		7	9.0	22
	8	1.1	4		8	1.7	5
	9	1.1	6		9	1.7	8
5.0	10	2.2	≤2	7.1	10	2.8	≤2
	11	3.4	3		11	4.5	8
	12	6.7	≤2		12	7.3	3

Data obtained by K.M. Kelly

data compression scheme, greatly reducing the load on the latter.

Infrared Camera Simulation

Recent advances in Schottky-barrier device technology have led to the development of high-sensitivity CCD-readout infrared imaging sensors. Kosonocky and others[6] have developed infrared imaging arrays with peak amplitude-to-noise ratios as high as 10,000: 1. These arrays typically have low element densities with accompanying low resolution. Cantella[7] and Klein[8] have incorporated these sensors into temperature-sensitive imaging cameras. These instruments are particulary suited to night vision, remote guidance, and automatic target acquisition applications.

The high sensitivity of the sensors cannot be fully utilized directly when the displayed scene is viewed by an observer. The intensity dynamic range of most visual display systems is matched to the human eye, and is typically 40:1. Therefore, fine differences in temperature within the scene viewed by the camera are indistinguishable by the display system and the eye, and cannot be detected.

Image features can be enhanced by nonlinear processing. In the case discussed here, amplitude differences in regions of interest may be increased while the total effective amplitude range is held within the dynamic range of the display system. The effect is to increase the perceivable details in the enhanced regions at the expense of the other image areas. The trick is to decide algorithmically which amplitudes are to be enhanced, and in what manner. An adaptive technique frequently suggested is histogram equalization. It enhances detail in larger areas and objects in the image, but at the expense of smaller objects.

Dion and Cantella[9] proposed a processor using histogram equalization, but in conjunction with a two-dimensional high-pass filter to compensate for the limitations of the equalizer. The filter precedes the equalizer. It acts as a differentiator and it enhances the edges of image features, facilitating the identification of smaller objects. This system is accompanied by other smoothing filters in the camera and processor. Since the system included new and poorly understood image processing techniques, it was decided to simulate it both to study the system and to optimize its parameters.

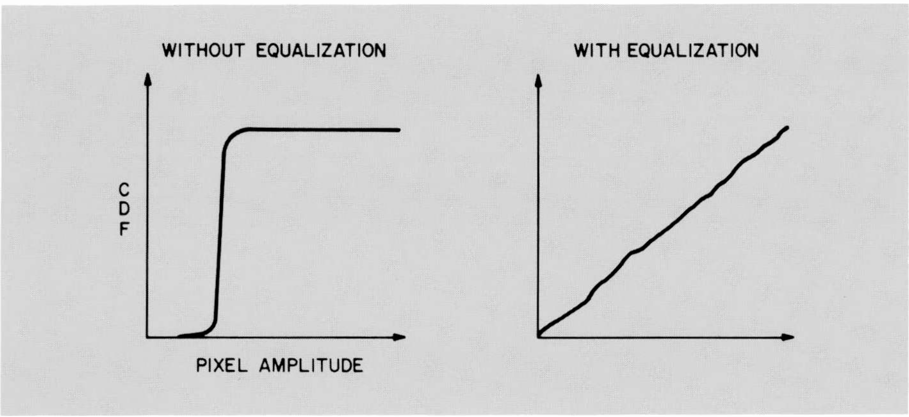


Fig. 9. *Effect of histogram equalization on a typical image amplitude cumulative distribution function (CDF). The equalizer linearizes the CDF. Since the image distribution function is the derivative of the CDF, it becomes uniform after equalization.*

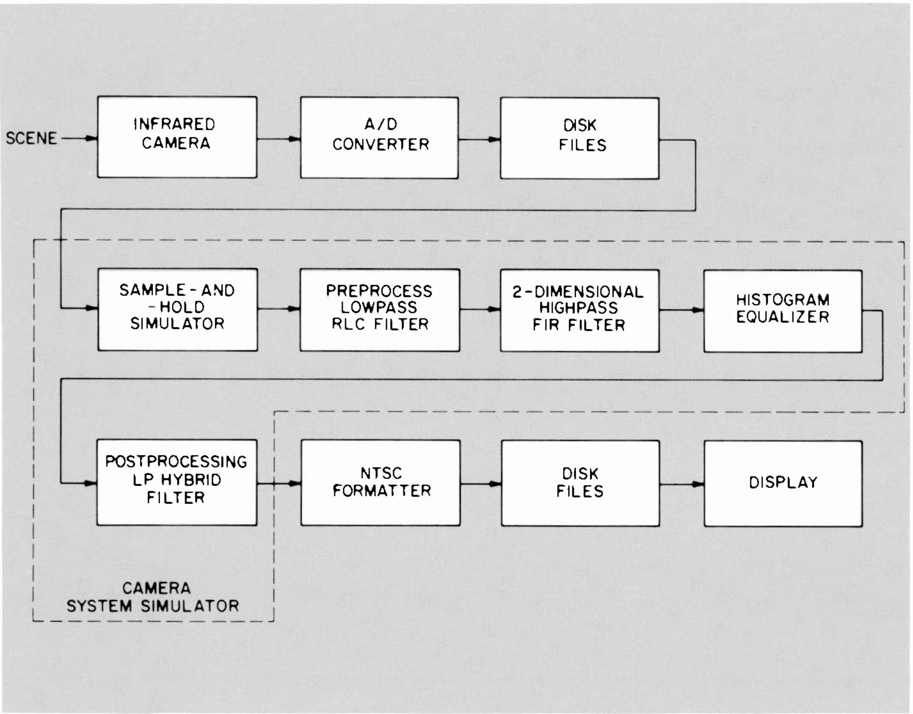


Fig. 10. *Infrared camera system simulator. Scene data are obtained by the infrared camera and then digitized. After simulation, they are formatted for display on a standard monitor.*

The histogram equalizer may be viewed as a variable-gain normalizing amplifier. For each image element, gain is a function of the amplitude of that element and the overall image amplitude distribution function. The amplifier gain curve is adaptively selected so that the amplitude distribution function of the output image is uniform for any input distribution.

Usually, elements are ordered by their position within the image. The histogram equalizer, however, considers only the amplitude of each element relative to the amplitude of the other elements and independent of position. If the set of amplitudes is labeled x, and the set of processed amplitudes is labeled y_1, then for ith element,

$$y_1 = y_{max}\, P_x(\, x_i\,) \qquad (4)$$

where $P_x(x_i)$ ranges from zero to one and is the cumulative distribution function for variable x at x_i. The term y_{max} is the maximum value for y determined by the dynamic range of the system.

An example of histogram equalization is shown in Fig. 9. The original image cumulative distribution function is highly nonlinear. After equalization, however, it is very linear, implying a uniform amplitude distribution function.

Simulation of the system is shown in Fig. 10. After a scene is viewed by the infrared camera, the image pattern on the sensor is scanned and the amplitude values are digitized. Then the effects of the camera head electronics and enhancement processor are simulated. Lastly, the data are formatted for display on the DVF.

The camera head electronics consist of a sample-and-hold circuit and a low-pass resistor-inductor-capacitor (RLC) filter. The sensor obtains one amplitude value for each of its elements, yielding a discrete horizontal and vertical pattern of values. The camera head electronics scan this pattern one horizontal line at a time, generating a continuous waveform. Scan time between succesive horizontal elements is filled by holding the sampled value from one element over the time interval until the next element. This process is called sample-and-hold. The camera head includes a low-pass RLC circuit filter designed to provide smoothing in the horizontal direction only. This also is simulated.

Enhancement is begun by the two-dimensional filter. This is a high-pass filter of the finite-impulse-response (FIR) type. This is followed by the histogram equalizer.

The low sensor-element density combined, with the sample-and-hold type of signal generator, produces a low-resolution image with a strong checkerboard or mosaic pattern superimposed. This is distracting to the camera user, and makes identification of objects in the scene more difficult. A two-dimensional low-pass filter follows the enhancement processor, and smoothes the pattern. It has a unique design, combining both analog and digital characteristics. Horizontally it is a simple RLC filter, while vertically it is of the FIR type. Filtering the images has the effect not only of removing the mosaic pattern, but also of producing a higher apparent image resolution.

The simulator was used to perform several studies of the enhancement process and the camera system in general. The configurations and parameters of all the subsystems were established, as well as their order. For example, the optimum frequency response of the two-dimensional high-pass filter was found, and a unique two-pass histogram equalizer was developed. Additionally, the post-processor filter was conceived and optimized.

The simulator also served to demonstrate the feasibility of the enhancement processor concept. It was found that objects within the scene were made much more visible and identifiable.

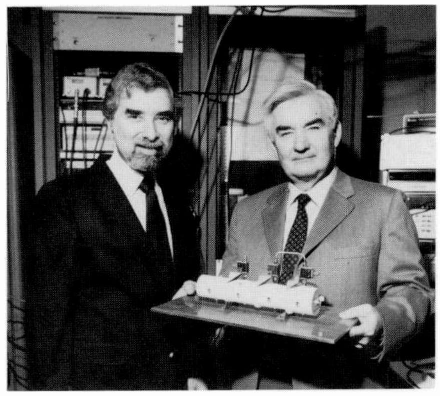
Conclusions

Video simulation has evolved into a powerful tool for analyzing TV signal processors and transmission systems. Its major advantage is that it can accurately produce a processed image for subjective analysis accompanied by objective or mathematically measureable parameters.

Simulators can be hardware or software in form. Each type has advantages, and the two complement one another. The C-band simulator was used to verify the predictions of SATLINK, and therefore influenced its development. SATLINK, however, is more flexible and can be used to simulate systems far different from the C-band Americom communications satellites.

The teleconferencing and infrared camera simulations demonstrated the breadth of applications of this tool. Each involved shortcuts, extensions, and departures from the techniques developed for SATLINK. However, each was adapted to and accurately emulated the systems under consideration to the point where system behavior could be demonstrated. In the case of the infrared camera, later experiments using hardware prototypes confirmed the conclusions reached with the simulation.

The two-for-one video program has been carried out primarily in hardware because of the difficulty of accurately characterizing the performance of the system components in software. Since subjective evaluation plays an important role in the setting of operating parameters, such as the tradeoff between chroma crosstalk and interference due to intermodulation products, it becomes difficult to quantify all the important characteristics. When a hardware system is quantifiable in all the aspects that determine its subjective quality, then a software model can be accurately designed.



Authors, Waldman (left) and Klensch.

Dick Klensch is a Member of the Technical Staff of the Communications Research Laboratory. He began his career at RCA Labs in 1952. His early work has included research on microwave radar systems and scanning antennas, miniature TDM circuits, digital communication systems and color television. Later, his research was directed toward high resolution CRT systems and a harmonic radar automatic collision avoidance system. Since 1975 he has been engaged in research on terrestrial and satellite communication techniques. Dick has received two RCA Laboratories Outstanding Achievement Awards and has published or presented more than 20 technical reports and papers. He has chaired a DBS working group on Protection Ratio for RARC '83. He is President of the Princeton Chapter of Sigma Xi and Secretary of the Princeton Section of IEEE.

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Harvey Waldman received the BSEE and MS degree in Physics from Drexel University, and the PhD in Physics from Temple University. Since joining RCA Laboratories in 1976, he has worked on a number of analytical projects including antenna anti-jamming techniques, characterization of the ionosphere, simulation of ionospheric probes, simulation of infrared camera systems, and the work described in this paper. He is presently engaged in the development of new video teleconferencing techniques.

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Tacnet: 226-2745

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M.F. Kaminsky

Mitel SX2000™ Integrated Communications System

RCA Service Company's integrated voice/data communications system is designed to meet office automation and EPBX needs through the year 1990.

RCA Service Company markets, distributes, installs, and services customer-premises telephone products and systems for small-to medium-sized businesses, and for large businesses with several geographically-separate small-to medium-sized locations. RCA's combined offering of state-of-the-art products with financing, installation, and service is one the most appealing packages in the industry. From our customer's perspective the RCA name insures stability, committment, and confidence in electronics and communications.

RCA Service Company entered the telecommunications business in 1964 when it received its first telephone installation and maintenance contract. To date, Service Company has installed and has under contract well over 1.2 million lines of telephone equipment. Initially, hotel/motel installations accounted for more than 60 percent of our business. However, we have been pursuing the business market since the mid-1970s, and today business installations account for more than half of our base.

Abstract: *The Mitel SX2000 Integrated Communications System is designed to meet office automation and EPBX needs over a wide range of ports. The SX2000SG system (single group) provides economical coverage from approximately 250 ports up to 3000 ports. The SX2000MG system (multigroup) provides coverage for between 2,500 and 10,000 ports. Both systems provide high traffic capacity and partial or full redundancy.*

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The interconnect market grew rapidly through the 1970s as several manufacturers were able to provide PBXs that would offer enhanced performance at lower costs than they were able to get with their older Bell system installations. The market began to saturate in the early 1980s at about the same time that AT&T was split into Regional Bell Operating Companies and a deregulated AT&T organization. The result was a great deal of market turmoil, equipment dumping, and price competition. Particularly in small systems, where minimum service and support are required, price became the key purchase decision.

Clearly, Service Company's future emphasis must be on larger installations where our sales support, technical support, installation, and service capabilities offer us a clear market advantage. There is also increasing market pressure for larger PBXs to support the growing use of telephone circuits to switch and carry data. These larger PBXs must be able to switch both voice and data effectively and efficiently.

To maintain our position in the marketplace, therefore, we needed a state-of-the-art integrated voice/data system (PBX) that can meet the requirements of the office automation equipment market as well as larger installations. Over three years ago, we surveyed and studied a number of competitive switches that would fit our needs from 1983 through 1990. After considering a number of systems that were then on the drawing board, we selected the Mitel SX2000 system. Initial installations of the SX2000 system were made by the Service Company at RCA's Cherry Hill, Gibbsboro, and Moorestown, New Jersey facilities. The following description provides a look at the capabilities and architecture of the SX2000 system.

System description

The SX2000 system is a family of digital integrated communications systems designed to meet the needs of the integrated electronic office, as well as to meet electronic private branch exchange (EPBX) requirements over a wide range of line sizes—from 150 ports (lines plus trunks) to over 10,000 ports. The SX2000SG system (single group) is the first member of the family, and has been designed for economical coverage of from approximately 250 ports up to 3,000 ports. The flexible architecture and modularity of the SX2000 system permit another member of the family, the SX2000MG system (multigroup), to use the same building blocks employed in the SX2000SG system. The SX2000MG system covers the upper port ranges of the SX2000 system family (from 2,500 to 10,000 ports).

High traffic capacity for both voice and data is provided in all SX2000-system products. There is a 2-level switching hierarchy, with the top level (circuit switch) nonblocking and some concentration at the lower level. Concentration normally exists only at the peripheral switch level (typically 2:1 with eight circuit switch links). When engineered with 16 circuit switch links, a peripheral switch equipped with a normal mix of lines and trunks encounters practically no concentration. All members of the product line are available with certain partial or full redundancy options for those applications where very high reliability is essential.

Architecture

The organization of the SX2000SG system is hierarchical, both in its logical structure and physical implementation. The hierarchy consists of a number of relatively independent subsystems that communicate and interact with each other in a well-defined manner (see Fig. 1).

The **main control complex**, **message switch subsystem, circuit switch subsystem**, and the **digital service units** (DSUs) form the control part of the SX2000SG system, and reside in the control shelf. The **peripheral switches** and their **peripheral interface cards** reside in peripheral shelves. The processors for the main controller, the message switch, the circuit switch and the peripheral switches are identical.

The **main control complex** is the highest level of intelligence in the distributed-processor, hierarchical architecture of the SX2000SG system. It consists of four functional units: the main controller, the mass storage, the bulk data transfer and the communication RAM (two-port interface to the message switch and circuit switch subsystems).

The **main controller** consists of the main processor (the CPU card), a bus manager and memory manager that manage the main control complex, and a minimum of four control RAM cards. The main controller is responsible for the overall operation of the machine, including call processing, record keeping, maintenance functions, and system control such as auditing activity control and fault recovery.

The software in the main controller directs the major control and switching functions in the system. Software in the other controllers provides services in response to main controller commands and provides a reporting service to the main controller software upon detection of data and/or voice events (such as off-hook). The message switch software provides the command communication with the rest of the system processors over the message switch links. The circuit switch software provides connection and/or disconnection of circuit-switched channels. The peripheral switch software monitors and controls the states of telephony and/or data peripheral interface cards.

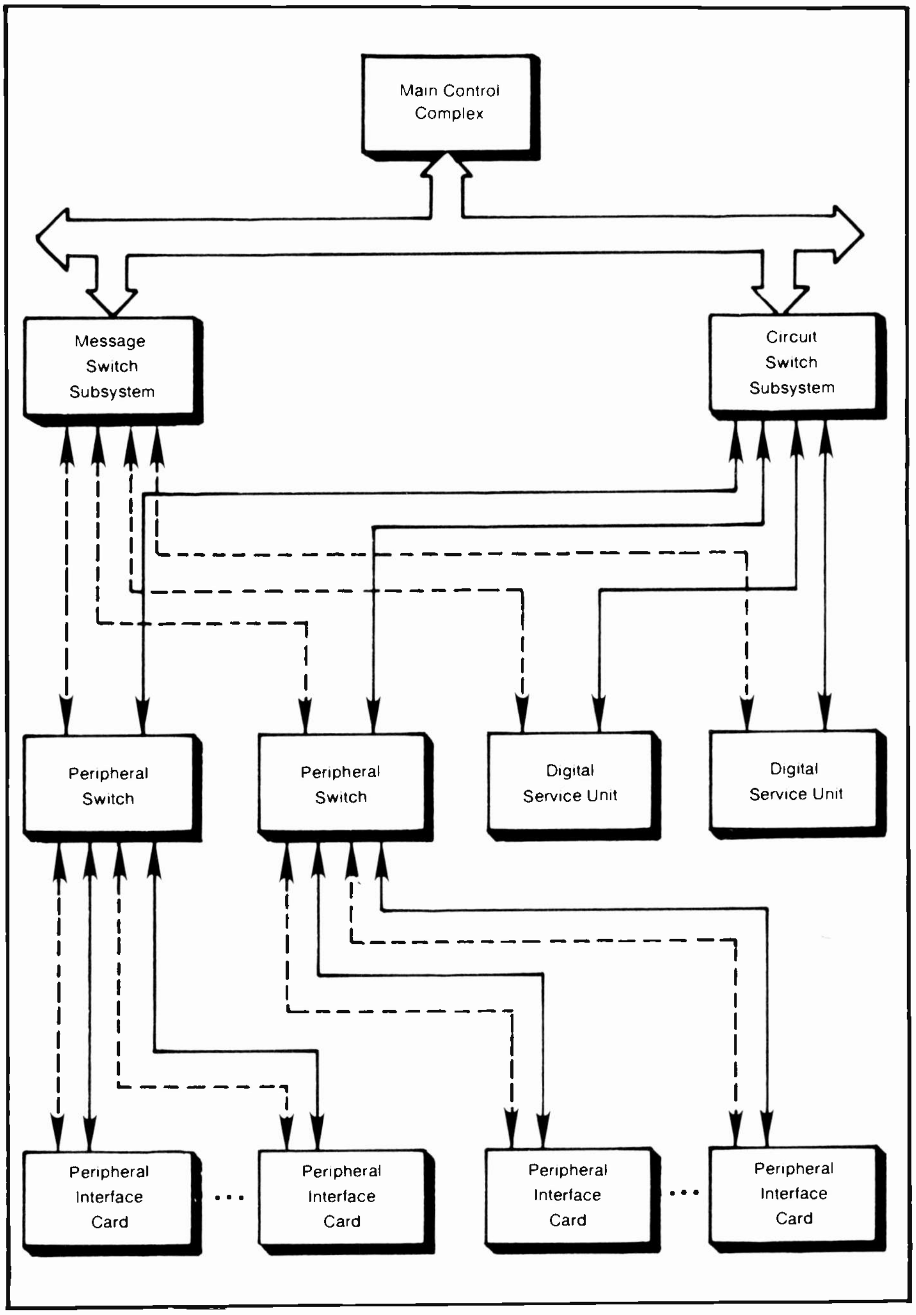

Fig. 1. *The SX2000 Integrated Voice/ Data Switch is controlled by the main control complex microprocessor—a 68000. To relieve the processing load on this microprocessor, the message switch, circuit switch, and peripheral switch microprocessors (also 68000s) are assigned a series of appropriate tasks. Further task assignments are made to microprocessors contained in other blocks shown above.*

The mass storage consists of non-volatile bulk memory storage. At present, this consists of a bulk data controller (BDC) on each backplane, each controlling a 16-Mbyte Winchester disk unit. In addition, each BDC jointly controls one floppy disk unit used for loading and/or updating system software.

The bulk data transfer provides a high-speed bidirectional file/block transfer communication path out of the main control complex. Currently, it consists of a bulk data controller, and a bulk data interface card that connects to the circuit switch via serial circuit switch links.

The communication RAM card contains two 2-port RAM buffers. These buffers provide a communication path between the main control complex and the circuit switch subsystem, and between the main control complex and the message switch subsystem.

The **message switch subsystem** forms the main message collection and distribution center in a star-configured message network that links the main control complex to every intelligent entity at the peripheral level or below. These include the DSUs, the peripheral switch controllers, and intelligent peripheral interface cards.

Message transfer between the message switch and peripheral switches is by means of 2.048-megabit serial message links. The message switch is responsible for scanning and protocol control of the message links, i.e., handshaking, message processing, error checking, reformatting, redirection, queueing and maintenance functions.

The message switch subsystem consists of a message switch processor, which contains the intelligence of the subsystem, and up to three message switch matrix cards, each providing 32 bidirectional serial message links. Also contained within the message switch is the clock/tone generator, which generates the system clocks, call progress tones, and test tones required in the system.

The **circuit switch subsystem**, when fully equipped, provides a 64 × 64 matrix of bidirectional, serial-circuit switch links. Each 2.048-megabit link consists of 32 channels of 8 bits each. Each channel handles one voice circuit, or 64 kilobits for data transmission. The circuit switch subsystem consists of the circuit switch processor and up to four circuit switch matrix cards. The circuit switch processor controls the circuit switch matrix in setting up and taking down circuit-switched connections and providing tone cadencing.

Each circuit switch matrix card is equipped with a Digital Crosspoint (DX) chip-switching matrix (64 × 16 links) to perform both time and space switching, in a nonblocking manner. The four circuit switch matrix cards form a 64 × 64 matrix that provides the maximum-size switching matrix in the SX2000SG system. If only one card is equipped, then a 16 × 16 matrix is available. Two cards form a 32 × 32 matrix, and three make up a 48 × 48 matrix.

Each **peripheral switch** controls up to 48 peripheral interface cards placed in two shelves of up to 24 cards each. The peripheral switch performs the following major functions:

- It sets up connections between the peripheral interfaces and circuit switch link channels to the circuit switch, following instructions from the main controller.
- It performs a processing function in the system hierarchy, and substantially reduces the computing load on the main controller by performing all the simple but real-time-intensive tasks associated with controlling a large number of different peripheral interfaces.
- It scans and controls the peripheral interface functions.

The peripheral switch consists of one peripheral processor, one or two balanced transceiver cards, one or two peripheral switch matrix cards, and one peripheral bus extender card. The second balanced transceiver card is fitted when the circuit switch link capacity to the peripheral switch must be increased from 8 to 16 circuit switch links. The second peripheral switch matrix card is used if the peripheral switch is controlling two peripheral shelves. The peripheral switch matrix card contains two DX chip matrices: one to provide a first level of circuit switch, and one to provide the interface between the peripheral processor and the message control link to 24 peripheral interface cards. The peripheral bus extender card is required to extend the peripheral processor bus to a second peripheral switch matrix if the peripheral switch is used to control two peripheral shelves (48 cards). It also contains links to control the balanced transceiver cards and provides a link to the second peripheral switch in a duplicated peripheral switch configuration. The balanced transceiver card terminates eight circuit switch links from the circuit switch. It also terminates message links from the message switch.

The **peripheral interface cards** are the primary interfaces between the SX2000SG system and the external world. They include the analog interface cards that contain codecs to convert analog inputs such as speech to digital PCM (and conversely convert digital PCM to analog output), and digital interface cards that connect to digital devices such as the Superset 7. The Superset 7 serves as the system and attendant's console, and is similar in construction and capability to a general-purpose personal computer. The on-premises (ONS) line card is an example of an analog interface card. Each peripheral interface card provides a number of identical interface circuits. For instance, there are 16 line interfaces on the on-premises line card and 8 trunk interfaces on the LS/GS trunk card. Each peripheral shelf card slot has the capability of supporting up to 2.048 megabits of transmission throughput. Thus each peripheral shelf provides a 49.15-megabit transmission throughput capability.

Digital service units (DSUs) are resources that can be accessed by the circuit switch links to perform a function, such as providing voice conferencing. DSUs include cards such as the conference card and the tone detector card, and interface with the control-level hardware in the same manner as peripheral switches. DSUs are grouped together, forming a DSU zone. This zone resides on the control shelf and can accommodate up to six DSU cards.

The system maintenance unit, which resides at the top of the SX2000SG system cabinet containing the control shelves, monitors the overall system integrity and reports back to the main control complex. It monitors the power system, temperature, and sanity of the main control complex. In a redundant system, it allows the maintenance personnel to manually switch control activity and perform other maintenance functions. It contains an alphanumeric display and alarm indications, which provide the prime method of restoration of the main control complex after a major failure.

In a multi-cabinet SX2000SG system configuration, each of the remaining cabinets has a cabinet maintenance unit. These all report back cabinet status to the system maintenance unit in the cabinet containing the control shelves and, ulimately, to the main control complex.

Intercommunication

A packet of data, called a "message," is used for communication within and between the subsystems to pass information such as control requests and event reports. A standard message format is used universally throughout the the SX2000SG system. The physical method of passing the messages varies, however, depending on requirements such as data rate and distance between the source and destination. A number of different methods are used to interconnect the various subsystems in the switch.

The most prevalent form of communication is over a DX-chip-based message link. Each link supports a 2.048-megabit data rate. Message links originate at the message switch subsystem and form a star network out to the peripheral switches (and ultimately the peripheral interface cards) and DSUs. The message links are implemented using a balanced transmission scheme, allowing the source and destination to be located some distance apart, which is necessary in a multiple cabinet configuration.

Between the main control complex and the message switch there is a two-port memory (communication RAM) through which messages can be passed. This provides a more tightly controlled method of intercommunication to support the higher data rates required. Also, since the main control complex and the message switch reside on the same shelf, a two-port approach is practical.

The simplest type of connection that can be switched through the SX2000SG system is an analog end-to-end connection. An analog signal (audio signal from a telephone, for instance) enters the switch at a line circuit on an analog peripheral interface card, such as the ONS line card. There the analog signal is converted to digital 8-bit PCM using a single chip codec-filter, available either in North American mu-law or European A-law format. Once in digital form, the signal goes to the peripheral switch matrix (PSM) card over one of the channels of a circuit switch link between the line card and the PSM. At the PSM, it is switched through a DX-chip array to a channel on one of eight circuit switch links going to the circuit switch in the control shelf. At the circuit switch subsystem, the PCM signal is time- and space-switched to another channel on another linked connected to the peripheral switch controlling the destination peripheral interface card. It is routed to the PSM in the destination peripheral switch, where it is switched to the channel and link corresponding to the line circuit of the destination.

The destination's line circuit converts the PCM signal back to an analog signal. To set up the call, the source must dial the destination's number. The dial pulses are monitored and reported to the main control complex by the peripheral processor through the message switch. A DTMF receiver, temporarily connected to the incoming PCM stream, ignores rotary dial pulses (which are passed to the main control complex), but accepts DTMF tones from a DTMF telephone. The DTMF receiver then reports the destination to the main control complex.

For applications requiring higher data rates, such as the Superset 7, a high-speed digital line card can be used. A proprietary digital line interface circuit (DLIC) chip is used to connect the source to the circuit switch. Each DLIC can provide a data rate of up to 256 kilobits.

Glossary of terms

Blocking. The condition existing in a PBX or switching system when two parties are unable to be connected together. This may occur if one party is calling a second party but is unable to be connected because there are insufficient switching connections available in the system at that time.

Bulk data transfer. A combination of the bulk data interface and bulk data controller cards. They provide a high-speed interconnection interface arrangement between the circuit switch subsystem and the main control complex for rapid transmissions of large blocks of data.

Circuit Switch. Provides a 64 × 64 matrix of bidirectional switch links, with each link accommodating 32 channels, each of which can be used for voice or dating transmission. It consists of circuit switch processors and up to four circuit switch matrix cards.

Line. A circuit providing station or phone terminations from a PBX. The line is considered the drop side of a PBX, and usually has either a telephone set or a business machine interface attached.

Message switch. The primary message collection and distribution facility of the SX2000SG system. It links the main control complex with intelligent entities at the peripheral level or below. In effect, it is the "nervous system" of the SX2000SG system, in that it passes messages and commands between the lowest and highest levels of the system.

Multigroup. A configuration of single group systems (up to 17) that can provide service for well over 10,000 ports, and which functions as a single PBX system.

Peripheral switch. Controls the peripheral interface cards (cards connected to lines and trunks) on two peripheral shelves. It is installed in one of the peripheral shelves and provides for the setup of the required switching connections for peripheral equipment to the circuit switch. It performs some of the preprocessfunctions and controls the interface functions.

Single group. The smallest operable configuration of SX2000 integrated communications system, consisting of a main control complex, a message switch and circuit switch subsystem and/or associated peripheral switches, and digital service units. An SX2000SG system can provide PBX service for up to approximately 3,000 ports.

Trunk. A circuit that concentrates telephone calls (usually by time sharing) and connects PBXs to PBXs, telephone exchanges to PBXs, or telephone exchanges to telephone exchanges.

Redundancy

System redundancy is one of the main features of the SX2000SG system architecture. All the control-level subsystems (main control complex, message switch, and circuit switch) and all peripheral switches and digital service units can be duplicated if required for reliability. In a redundant configuration, the peripheral interface cards (lines and trunks), the maintenance units, and the ac power are the only non-redundant parts of the system. In the event of a major hardware or software fault in a redundant system, activity will automatically switch from the active to the inactive unit. This ensures continued service and integrity of all established calls in progress.

With control shelf redundancy, two identical control shelves are equipped in adjacent positions in the control cabinet. The main control complex, circuit switch, and message switch are part of the same activity unit, so that a failure detected in any of these subsystems causes all three to switch to their redundant units as one block. Switchover is automatic when the main control complex discovers a nonrecoverable problem. Sanity monitors ensure that a faulty main control complex will surrender activity. In addition, control activity can be switched manually by maintenance personnel by means of the maintenance unit or maintenance terminal.

Peripheral switches can also be configured as redundant pairs. One peripheral switch can control two peripheral shelves. In a nonredundant configuration, the area in the second peripheral shelf reserved for the peripheral switch is left vacant. In a redundant system, both peripheral switches are installed. Depending on the peripheral switch activity signal generated by the main control complex, one or the other

Features of the SX2000 system

The following features are available with the present, or soon to be released software for the SX2000 system:

System features

Tones (U.S./U.K.)
Flexible numbering plan
Station to station dialing
Direct outward dialing (DOD)
Direct inward dialing (DID)
Direct in line
Ring cadence
Group hunting (terminal and circular)
Automatic route selection
Distinctive ringing
Zone paging (voice)
Dialing plan
Hold (soft/hard) user
Hold retrieve—user
Night services
Automatic Night Service
Class of service
Class of restriction
SMDR
Trunk answer from any station (TAFAS)
Speed calling
System rerouting
Message notification
System-programmable items
Tone demonstration package
Account codes
Direct inward system access
Multi-digit toll control
DID/Dial-in/CCSA vacant/illegal access intercept to attendant
Outgoing audio inhibit until answer supervision
Alarms (critical, major, minor)

Station features

Ground button support
Call transfer
Callback busy/don't answer
Hotline
Busy override security
Camp-on
Camp-on retrieve
Camp-on tone security
Last number redial
Music on hold
Data line security
Broker's call
Transfer With Privacy
Station-controlled conferences
Call forwarding
Call pickup
Executive busy override
Do not disturb
Speed calling (personal list)
Inward restriction

Superset 4 features

Account codes
Call hold and retrieve (key hold)
Direct line select
Display
Hands-free operation
Messaging
Multiple-line appearance
Prime line
Personal speed call
Time and date display
Last number redial
Camp-on
Callback
Conference
Call forwarding activation
Night answer
Programming function
Swap/transfer

Attendant features

Answer call (internal and external)
Selective answer

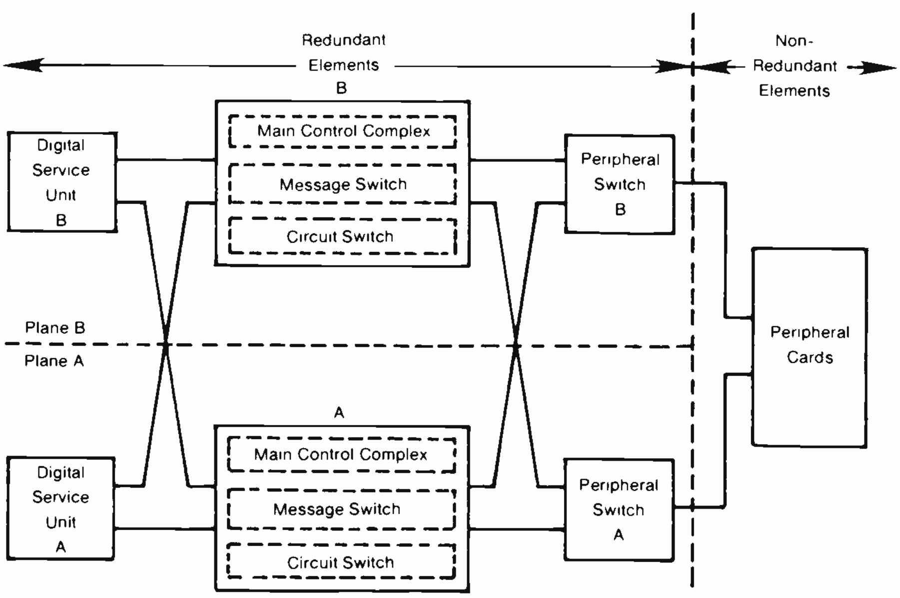

Fig. 2. *The design for redundancy shown here provides options that will satisfy the purchaser's needs and budget. Redundant elements may be provided at a reasonable cost, and all switching to duplicate hardware is fully automatic.*

peripheral switch has control over the peripheral interface cards on both shelves.

The power system also provides redundancy. Each control shelf has its own associated converter. Redundancy at the rectifier level can be simulated by using battery backup in case of a rectifier or commercial power source failure.

The main control complex also controls DSU activity. Each DSU can switch independently of any other in the system.

Figure 2 illustrates the redundancy principles. It consists of the redundant or nonredundant elements just described. Each redundant element is switchable independently, so that a fault in one of them causes a plane switch of only that element. Peripheral cards are nonredundant.

Maintenance and diagnostics

The maintenance philosophy of the SX2000SG system is to detect, isolate, and

Attendant individual trunk access
Attendant individual directory numbers
Call extending (call transfer)
Attendant camp-on
Handle calls recalling to attendant
Call splitting
Hold and retrieve calls
Connect answered call to held call
Source and destination display
Graphical display of call arrival/waiting
User assignment of call stack labels
Attendant paging
Serial call
Night service control
Corporate directory
Dial by name
Dial from directory (phone book lookup)
Attendant feature cancel
Attendant position busy
Attendant interposition calling and transfer
Attendant-controlled conference
Attendant busy-override
Time and date display
Alarms
Multiple-attendant consoles
Specialized attendant service
Class of service display
Superset 4 used as a sub-attendant

Basic networking
Tandeming
Uniform numbering plan

Basic data—transparent data switching
Origination
Telephone/Associated Data Line
Basic ADL originate
Speed call
ADL hotline
Modem pooling outgoing
Account code access
Personal speed call
Modem pooling incoming
EIA hotline originate

Data transceiver features
Auto-baud detection
Auto-parity detection
Basic DTRX originate/disconnect
Dial from terminal
DTRX Hotline
Speed call
Mnemonic dialing (dial by name)
Modem pooling outgoing
Help

Termination
Hunt groups
Echo
Direct in line data

Administration features
Authorized access (login)
Customer data entry
Customer data entry dialogue
Changes to customer database
Moves and changes
Save, restore, and transfer of customer database
Customer database output
Calender and time-of-day
Customer data entry on ASCII terminal
Range programming
Traffic analysis

recover from a fault before the faulty condition affects the user. Also, the system should isolate a fault down to the smallest field-replaceable module, whether it be a power converter, printed circuit board, or hybrid module. This philosophy is accomplished by dedicating approximately 30 percent of the software to maintenance. To a large extent, these goals are achieved by means of diagnostics that run at power-up time and background diagnostics that run on a regularly scheduled basis to achieve a high level of fault detection. Faults are indicated to the maintenance personnel on the maintenance terminal. In addition, status lights on each card indicate the faulty unit to be replaced.

The system can also be interrogated from a remote location, allowing remote diagnostics to be performed. This is useful in servicing a system located at a distance from the maintenance center. The faulty unit can be determined and a replacement then taken to the site. Interim corrective action, such as performing an activity switch, can also be done remotely.

After a fault is detected and isolated, the affected unit is removed automatically from service and the appropriate alarm is given. This may result in a degradation of service, but in most cases the SX2000SG system will still function normally and the failure will not be apparent to the user.

All maintenance activities are logged automatically in a maintenance log. This log is a history of maintenance actions, and can be interrogated through the maintenance terminal or automatically printed from the maintenance panel. The maintenance log provides maintenance personnel with data helpful in isolating failures within the system. The maintenance log is also used to record failures that have occured and what corrective action was required. Thus, the maintenance personnel need only read the log to determine the failure history of the system and the corrective actions taken. This information is extremely helpful in trend analysis.

Software

The SX2000SG system software is written primarily in PASCAL, and a proprietary operating system is used. The software operates on the main controller, message switch, circuit switch, and peripheral switch systems, which utilize 68000 microprocessors.

The software consists of a series of hierarchical logical layers, where each layer provides a set of facilities for the subsequent layer. Although the functions performed by the SX2000SG system processors vary a great deal, the software in each processor has a similar layered structure. On any particular processor, the software consists of two to six layers, each of which provides a new layer of facilities. The layered structure is shown in Fig. 3. The functions of each

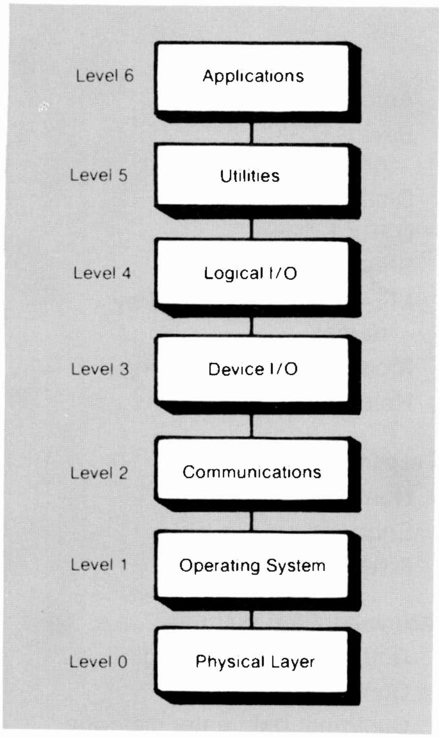

Fig. 3. *Hierarchical, logically-layered software is employed in the SX2000 system design. Although similar 68000 microprocessors are used to perform very dissimilar functions in the main control processor, the message switch, circuit switch, and peripheral switch all utilize a layered structure similar to the one shown above.*

layer are as follows:

- **Level 0**, or the physical layer, is the microprocessor hardware with its associated memory and I/O devices.
- **Level 1** consists of the operating system software. This layer organizes the run-time enviroment for the software to be executed on the processor. This includes the provision of timing services and the scheduling of all activities in the processor. The operating system layer presents a process (or task) environment to the higher software layers.
- **Level 2** is the communications layer, which provides interprocessor communication of both small and large volumes of data using the message circuit links and the circuit switch.
- **Level 3**, the device I/O layer, isolates the bulk of the software from the low-level details necessary to interface with the switching/interfacing hardware. Additionally, it absorbs many of the "glare" or race-hazard conditions that can arise from the distributed nature of the system. The software in this layer implements I/O drivers and handlers for de-

Bringing communications down to earth—a brief look at Service Company's current work in communications.

As the service arm of the Corporation, RCA Service Company represents a microcosm of RCA's total involvement in communication technologies. However, because we install, operate, and maintain communication systems that are proven in the marketplace, our products and services provide a sharp contrast to the more advanced technologies represented elsewhere in this issue. This note briefly reviews some of our "down to earth" communications work, including:

- Broadcast equipment service
- Direct broadcast satellite earth stations
- Teletext service
- Commercial television products and services
- Videoconferencing
- Telephone interconnect systems
- Data communications products and services
- Multifunction, multiuser workstations
- Atlantic undersea test and evaluation center (AUTEC) communications
- Eastern space and missile center (ES&MC) communications

Broadcast Service. Our Broadcast Service technicians maintain:

- Studio cameras
- AM/FM transmitters
- VHF/UHF transmitters
- Antennas
- Tape and cartridge recorders
- Slide/film chains

Our services include field maintenance, installation, overhaul, and proof of performance—primarily in support of the RCA Broadcast Division.

DBS. RCA Service Company is currently the only installer/servicer of 1.2-meter DBS earth station systems. Under contract to USCI, we installed more than 9,000 of these systems in consumers' homes last year.

Videotext/Teletext. RCA Service Company has worked with RCA Laboratories, Consumer Electronics, and NBC to support a potential Teletext offering. In actual field experience we modified, shipped, installed, and maintained receivers in support of Teletext field tests. Thus, we were able to provide Laboratories and NBC developers with a wealth of useful empirical information.

Commercial TV. Annually we sell, to the commercial market, more than 225,000 TVs manufactured by Consumer Electronics (about 10 percent of their total production). RCA Service Company dominates the hotel/motel market for televisions, with a 55-percent market share. Our domination in this market has allowed us to offer other communications products and services , including:

Premium channel programming
Earth stations
Master antenna TV systems
Information processing systems
Telephone systems
Call accounting systems
Large screen television
Service on all these products.

And we've been able to extend these efforts to parallel markets, including:

Healthcare
Education
Commercial video systems
Videoconferencing

Videoconferencing. Earlier this year, we tested our capability to provide quality videoconferencing services. In the test, we used studio facilities at WHYY in Philadelphia. Our signal was scrambled and sent by microwave to Vernon Valley, where it was transmitted using WNET's facilities. The signal was sent to 13 cities across the U.S., reaching about 400 sales and management personnel. The audience could then question the panel via telephone lines. The total cost was only a fraction of that required to pull that many people together, when you consider time lost to travel, as well as the travel expenses themselves.

Telephone systems. We started offering telephone systems and products to our lodging customers soon after the 1968 Carterfone decision. By the mid 1970s we had established a fairly solid installed base in the lodging market, and we branched into the business telephone marketplace. Today, we are one of the nation's leading interconnect companies, with over 1.2 million lines of installed base. Mitel's newest product, the SX2000 system, will allow much more efficient use of telephone lines for data and voice communications. We are among the first of the interconnect companies to introduce this product in the U.S. market. Our telephone work also includes full service on the equipment we install.

Data communications services. We have been supporting several major customers who have complex data communications through our Data Communications operations. For the NBC Communications System, for instance, we have CRTs, printers, and modems on site at 239 affiliate locations, as well as at NBC-owned facilities. This equipment primarily monitors and communicates purchased network time. We also have service people dedicated to keeping these vital communication links on line.

RCA workstation. RCA Service Company introduced a new family of high performance data communication/data processing products in May 1984. These products are multiuser, multitasking workstations. That means several people can use them for a lot of different things (including word processing, financial spreadsheets, graphics, communications all at the same time. These systems will provide our customers with an integrated information management system designed for maximum efficiency in data communications and office processing.

Data earth stations. Similar to our consumer and commercial earth station work, our Data Operations also work at bringing satellite technology down to earth. We have installed, and currently maintain, over 2500 of the Equatorial Earth Stations for several major communications suppliers. A typical receive-only system includes a 2-foot antenna (dish), a monitor, a controller, and a printer.

AUTEC communications. Our Government Services operation offers a broad range of communications capabilities. For example, on Andros Island in the Bahamas, as "the tongue of the ocean," we operate and maintain the Navy's Atlantic Undersea Test and Evaluation Center. Part of our responsibilities there are to operate and maintain all communications on, to, and from the island. This includes a two-way data, voice, and weather link via Kennedy Space Center with public and secure communications networks.

ES&MC communications. We operate and maintain a very complex communications system for the Eastern Space and Missile Center, headquartered at Kennedy Space Center on Cape Canaveral. We have undersea cable links down the Eastern Test Range through Grand Bahama Island, Grand Turk, Puerto Rico, and the Antilles, complemented by high-frequency radio and satellite communications to Acension Island. This system provides all the network feeds for spacecraft launches out of the Cape. The following statistics are an indicator of the magnitude of the ES&MC system.

- 200 PA systems (5000 speakers)
- 4700 intercom units
- 160 terminals of HF/SSB (up to 45 kW)
- 8500 lines of telephone central office equipment
- Data transmission capability from 75 bps to 1.54 bps
- Over 950 terminals of wideband transmission equipment
- 120,000 circuit miles of cable
- 2,200 miles of underwater cable
- Three major 24-hour technical control centers
- 110 TV camera systems—300 TV monitors

This issue discusses several exciting ways to apply advanced technologies to communicate more reliably, at higher speed, with better quality, and at lower cost than ever before. RCA Service Company provides the expertise needed to capture those communications and deliver them with corresponding reliability, speed, quality, and efficiency.

—John Phillips

RCA Service Company

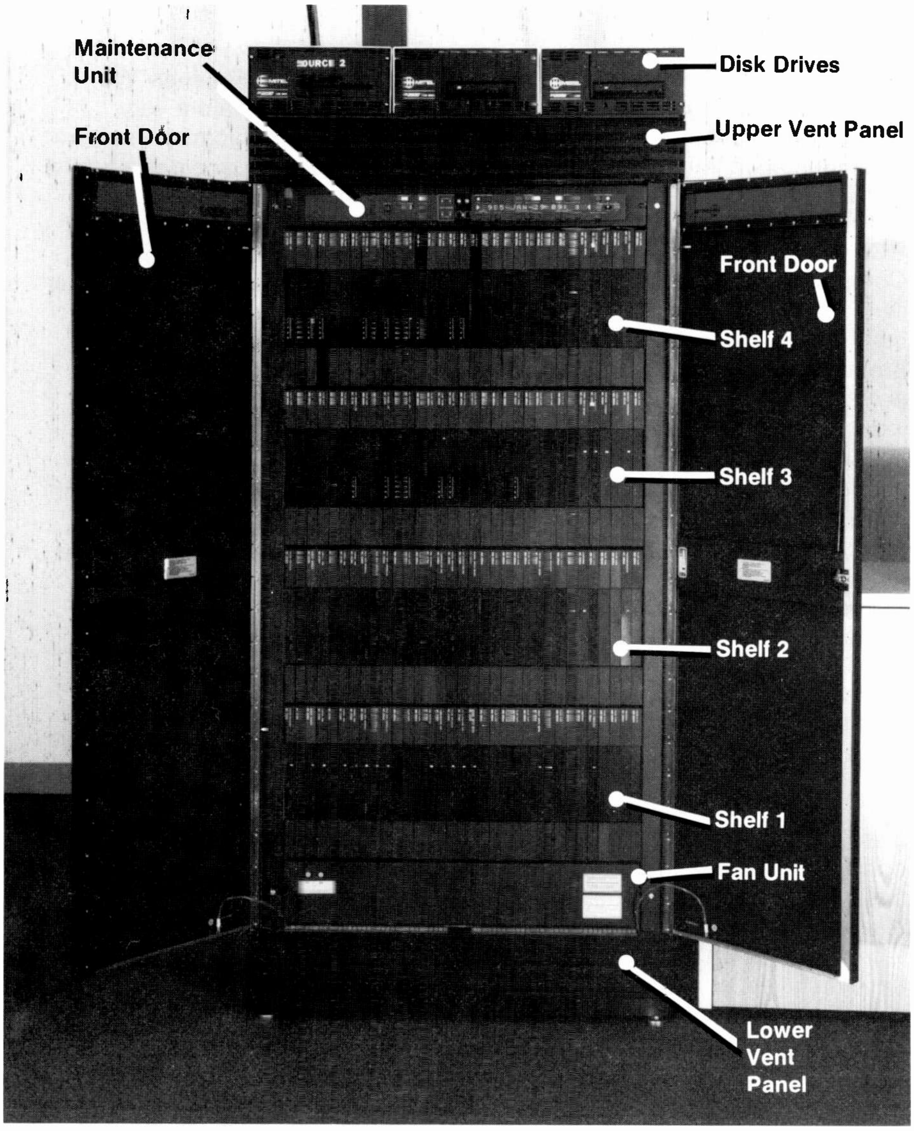

Fig. 4. *Cabinet, front view, showing the major assembly locations. The maintenance unit shown at the top of the cabinet is used to assist in fault isolation.*

vices as diverse as lines, trunks, and other telephony devices, the Superset 7 video and keyboard, tone detectors and speech synthesizer units, the bulk data transfer unit, teleprinters, and other devices.

- **Level 4** is the logical I/O layer. It provides both physical alnd logical file systems.
- **Level 5**, the utilities layer, provides general tools and facilities required by the applications software, such as error handling, resource management, and command interpretation.
- **Level 6**, the applications layer, implements processes or tasks for the various applications supported by the SX2000SG system. These include such applications as call processing, electronic mail, the message system manager, the maintenance system manager, and others.

Each processor in the SX2000SG system may not contain all the layers of software. However, Level 1 (the operating system) and Level 2 (the communications software) are essential. For the processor to provide useful work, software for Level 3 (device I/O) or Level 6 (applications) must be present.

The bulk of the software in the main control complex and for the Superset 7 is written in the programming language PASCAL. Software in the remaining controls is coded in structured assembler for the Motorola 68000 or 68009 processor.

In each processor, the executive provides a task or process environment. This means that software to perform a particular task may execute independently of, and be unaware of, other software programs in the same controller. In general, a software task will be activated by a message that either reports the occurrence of the same event or commands the task to perform some action.

In addition to providing real-time performance, the software is designed to make the SX2000SG system fault-tolerant. The motivating strategy is to detect faults early, to isolate their impact, and to perform the appropriate recovery steps. In particular, a sound strategy for tracking and recovery of system resources (both hardware and software) is the key to providing a reliable fault-tolerant system.

Physical description

The SX2000SG system consists of one or two cabinets. The first cabinet, containing at least one control shelf, is called the control cabinet. The remainder are called peripheral cabinets.

The control and peripheral cabinets are the same size (approximately 69 inches high by 34 inches wide by 29 inches deep) and weigh, fully loaded, approximately 1225 lbs.

The cabinets contain up to four standard size shelves, the power converters for the shelves, an optional rectifier, power distribution, a maintenance unit, and cooling fans. Doors front and rear provide access to the field-replaceable units and the cabling. All line and trunk connections are made directly by cabling from the backplane connectors to the distribution frame (MDF), using standard 25-pair connectorized cables. Figures 4 and 5 show the cabinet viewed from the front and back, respectively.

The control cabinet contains at least one control shelf in the lowest shelf position (position 1). In a redundant configuration, the second shelf position contains the second control shelf. Shelf positions three and four contain peripheral shelves.

The system maintenance unit, housed in the control cabinet, contains circuitry to monitor its own cabinet and any remaining cabinets in the installed system. It also contains the circuitry to interface with the main control complex as well as the alphanumeric display, activity switch control, and load and initialize buttons.

Each peripheral cabinet contains from one to four peripheral shelves. Two peripheral shelves that are driven by the same peripheral switch are installed in adjacent shelves, and are termed a "peripheral shelf pair." The cabinet maintenance unit for the peripheral cabinet contains circuitry to monitor its own cabinet and report the data to the system maintenance unit.

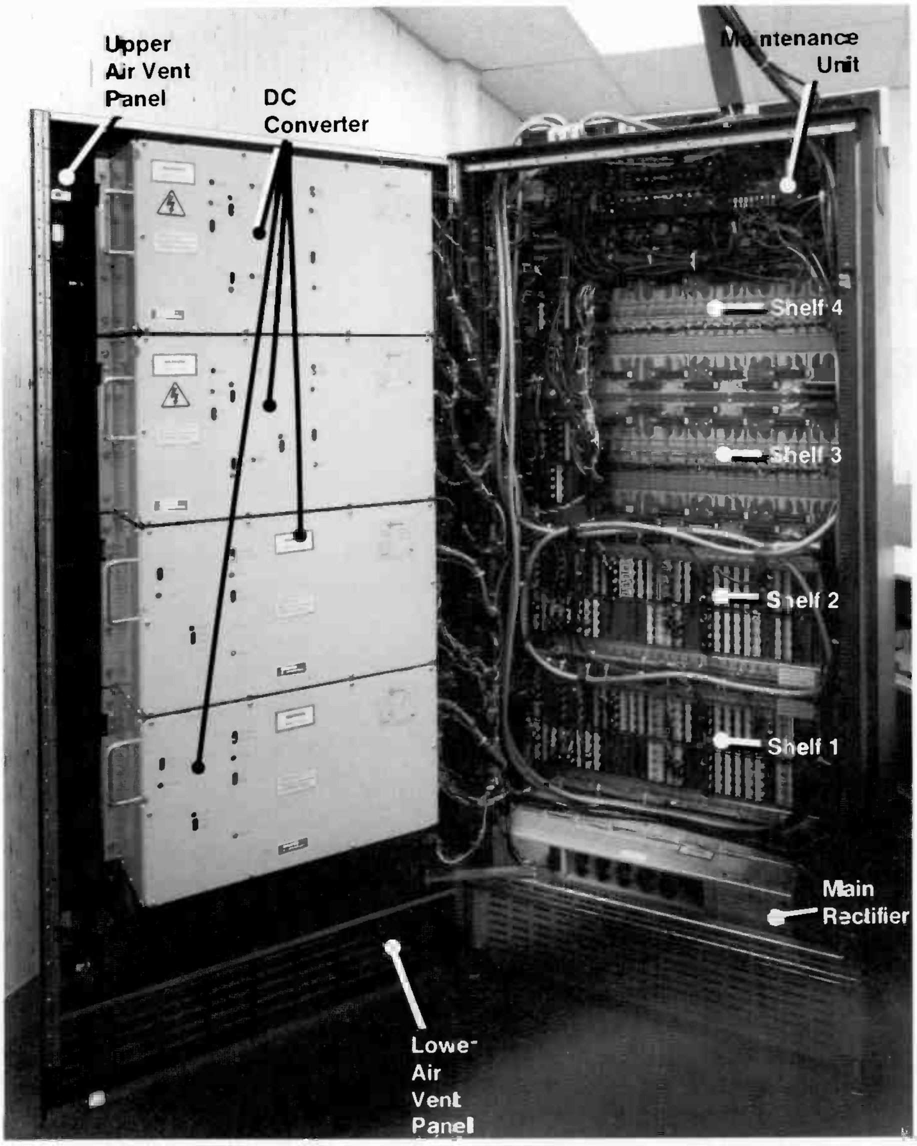

Fig. 5. *Cabinet, rear view, showing the dc converter mounted on the rear cabinet door. The design allows access to the circuitry backplane and cabling. The main rectifier, which is located beneath the four logic shelves, is used when the system is operated by ac power. Also contained in this physical area are thermostatically-controlled fans.*

Murray Kaminsky holds both a BSEE and an MSEE in Electrical Engineering from the University of Pennsylvania. He joined RCA in 1958 and worked in various design and development areas. Mr. Kaminsky left RCA in 1970 to become Chief Engineer of the Spectron Corporation. He then joined Optical Scanning Corporation as Manager of Electronic Engineering.

Mr. Kaminsky returned to RCA in 1975 as Manager of Telecommunications Engineering for RCA Corporate Staff. He was responsible for the implementation of a worldwide data communications network. In 1977, Mr. Kaminsky was assigned to implement and test a Bell Enhanced Private Switched Communication Service telephone network for RCA, and was responsible for the operation of the network through 1981. In 1982, Mr. Kaminsky joined the RCA Service Company as Manager of Engineering Integration. He was responsible for developing plans and programs to match company needs and capabilities to technological advances. He is presently Director, Engineering.

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J.G.N. Henderson

Radio-controlled models rely on simple communications systems

For hobbyists who control models by radio, thinking about the radio link is part of the fun.

Working models of boats, automobiles, and flying machines always followed hard upon the introduction of their full-scale counterparts. For the most part, these models moved freely after release, subject only to the initial conditions of rudder, elevator, or sail trim and some hopeful but ineffective body English. The situation was relatively tractable for model cars and boats, and even contributed to a thorough understanding of the balance between hydrodynamic and aerodynamic forces in moving sailing vessels. However, for airplanes—despite continuing sophistication in model design, handling, and "de-thermalizing" devices—free flight generally features large open flying sites and depends on small motorcycles for recovery of models. Despite the beauty and purity of free-flight, the flying of models from tethers that can also provide control inputs (U-Control) became a necessary and popular way to manage airplanes on small fields.

Abstract: *Engineers and experimentalists began building radio control systems for model airplanes, boats, and automobiles near the end of the vacuum tube radio era. Early designs used primitive transistors for low frequency functions, but depended on vacuum tubes for rf circuits. Consumer popularity came when the whole system could be transistorized and made inexpensive and relatively reliable. Today, spectrum space is reserved by the FCC for model operation. The modulation schemes, however, remain relatively simple, the antenna configurations tenuous, the battery charge levels uncertain, and the mechanical integrity of all circuit components (operated in an environment of high engine vibration levels and "hard" landings) suspect. All these factors combine to stimulate the adrenalin of those of us who think about the radio system but fly anyway.*

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The advent of radio control offers the possibility of controlled flight at great distances, freedom and flexibility in maneuvering, and the hope that the model can be returned to the same (small) field from which it started. For boats and automobiles, it provides the same controlled flexibility and the possibility of very realistic racing. This article will describe some of the evolution of radio control for models (which began with vacuum tube receivers) and the current crop of IC-based, inexpensive, and relatively reliable systems.

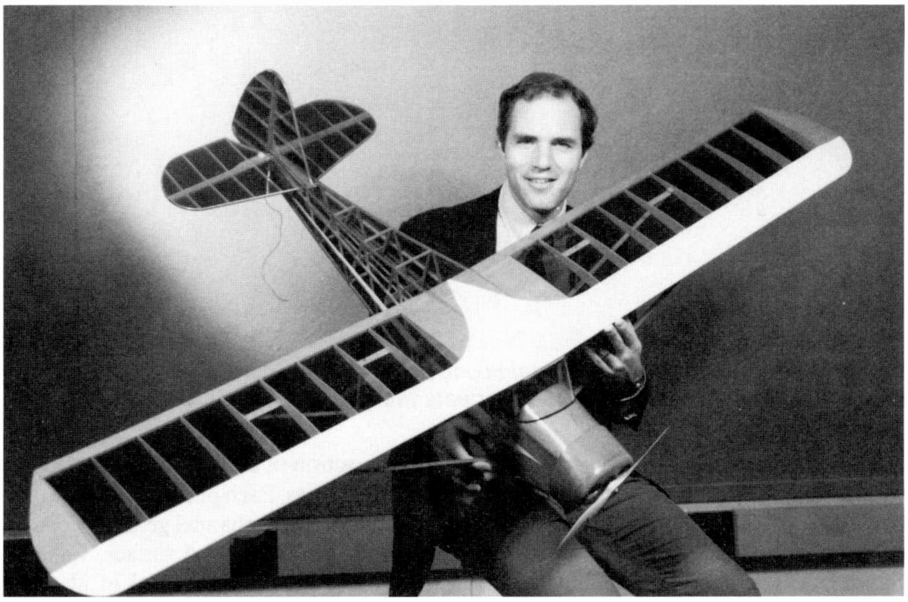
Some history

The first flyers of radio-controlled airplanes were good builders. They had to be. Their receivers required vacuum tubes and were consequently heavy, fragile, and prodigious users of power. All this power came from batteries carried in the plane. Not only were big batteries heavy, but their weight was concentrated, placing tremendous local loads on a balsa, spruce, and thin plywood structure if landings were less than perfect. Structure can be, and was reinforced, but it is a simple matter to make a plane too heavy to fly (and the engines in those days were not the miniature powerhouses that we have today). Moreover, flying speed increases as the square root of weight, making exciting landings even more dramatic and consequential. The engines were and still are typically single-cylinder, glow-ignition affairs, turning the propeller at speeds around 10,000 rpm, sometimes 20,000 rpm. Vibration levels are high, despite relatively (remember the weight) massive engine mountings. High vibration is unfriendly to both vacuum tubes and batteries, and makes for not-uncommon, full-fledged crashes. (As an editorial aside, this history of radio problems in the hobby continues to provide excuses for poor flying—I rarely hear of crashes, other than my own, of course, that are due to "pilot error.") Exercising and perfecting building skills was probably the major part of a hobby that called itself "flying."

In the early days, model airplanes typically had a 5-to 6-foot wingspan, weighed several pounds, and featured high-wing, almost free-flight designs. Their innate stability was fortunate and necessary, even if the radio worked perfectly, because the original methods of moving the control surfaces, while varied, had a common thread of uncertainty. One approach was a ratcheting escapement, powered by a rubber band. Compared with a geared and servoed electric motor for control, this saved weight and battery current. The rudder (often this was the only movable control surface) moved through a sequence like LEFT-RIGHT-CENTER, LEFT-RIGHT-CENTER in response to control pulses from the receiver. Thus, to make a right turn from straight flight, the pilot had to issue two control pulses. The pilot also tried to keep track—by remembering past commands and hoping they had been received—of the current rudder position. The controlled surfaces did not move through a continuum of angles in proportional response to a joystick's position, but rather banged abruptly from center, to full left, to full right. I have never flown such a plane nor seen one fly, but flights (which could include primitive aerobatics) are reliably reported, and the pilots have my admiration.

Although rudder-only control is sufficient for successful flight with suitably designed planes, it is better, or more fun, or certainly more confusing, to have additional controlled surfaces. As soon as radio, servo, and battery technology and design permitted, elevator, throttle, and aileron controls were included. Modern airplane models sometimes add landing gear, flaps, and spoilers to the basic four. Helicopter models have complex and interconnected controls. Controls of automobile models are relatively simple unless special functions are added, but the design of efficient variable and reversing speed controls remains a technical challenge for solid state devices and their designers (currents can be several amperes and voltage loss must be absolutely minimized, or more batteries must be carried). Model boats, particularly sailboats, offer a seemingly endless list of functions to be controlled, beginning with rudder and single sail control and progressing to independent control of trim and hoisting of main, jib, spinnaker, boom vang, Cunningham, outhaul, and backstay tension. Some models of square-rigged warships not only feature rudder and multiple sail controls, but also, under radio control, operate batteries of miniature cannon firing CO_2-propelled BBs.

As will become apparent in the following discussions, multiple channels are relatively easily added to a modern radio control system, affecting only the number of encoder and decoder channels, AGC time constants in the receiver, and the servo centering and damping time constants.



Author shown with his model of a Porterfield Collegiate.

The radio link

Models can be legally operated in three frequency bands—72 & 75 MHz, and 27 MHz. Some additional bands are available to amateur radio operators of Technician level or higher—6 meters (53 MHz) is most popular. The 27-MHz band consists of five frequencies interspersed among the citizen's band radio frequencies. Its utility is marginal because the spectrum is contaminated by deliberate or accidental overmodulation by CB operators, and model receivers can be overloaded by illegally high-powered CB radios. In an act of serious self-restraint, I have foregone the indulgence of recounting my experiences learning to fly on an R/C frequency adjacent to CB channel 19 (breaker one-nine), the favorite of truckers.

Today, most models are operated on the 72-and 75-MHz bands. Until recently, only seven frequencies were available, but the Academy of Model Aviation, an umbrella organization that also services the radio spectrum needs of car and boat operators, successfully petitioned the FCC for more spectrum space and additional frequencies. By 1991 there will be 86 legal channels in the 72-, 73-, and 75-MHz bands—50 reserved for "exclusive" aircraft use, the other 36 for surface models. The channels will be 20 kHz apart, but spaced in between commercial operations, which are therefore only 10 kHz away. Their high power will undoubtedly cause problems for some radios in some locations, but modelers are secondary users of the spectrum and so must be the ones to change frequency.

The output power of typical R/C transmitters is specified at about 0.5 W. This provides literally out-of-sight range in the air, and more than adequate ground range for cars and boats, assuming that interference is minimal. That assumption can be dangerous. Some of "our" frequencies are shared with other, higher-power, radio services, such as paging. Usually such problems are known to modelers in the local area (guess how they learned), and those channels are avoided. The most common source of interference is another modeler accidentally operating on the same frequency. Model clubs and contest directors have evolved systems for frequency control that work *almost* all the time. A problem that may become increasingly important as the number of channels increases is cross-modulation between two or three transmitted model frequencies. New receiver designs may help; narrower IF passbands and double-conversion receivers are being designed and advertised. Cross-modulation problems are aggravated when models on the ground pass near the hand-held transmitters of other flyers (model airplanes taxi on the ground) or when planes make low passes bringing them nearer transmitters other than their own. Cars and boats, normally operated in close proximity to many transmitters, have similar problems, although radio interference can produce somewhat less dramatic results.

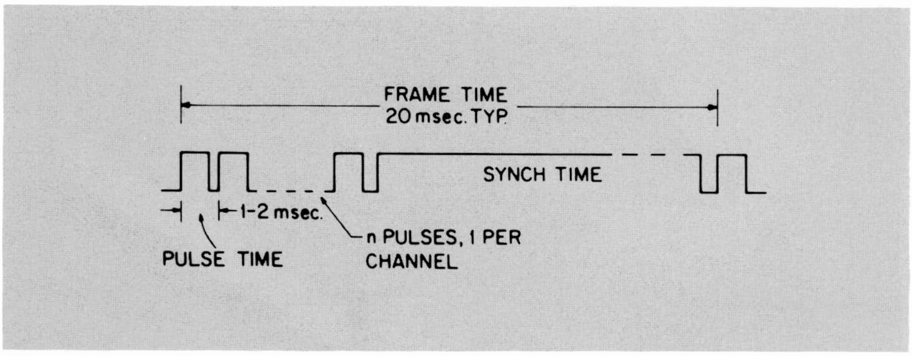


Fig. 1. *The modulating signal contains one pulse for each controlled function, has a long pulse for synchronization, and repeats the information every 20 ms.*

There are also many sources of electrical noise located right near the receiver. The servos that move the control surfaces contain small dc motors whose commutators arc despite attempts at RFI suppression with capacitors. Radio batteries, especially weak ones, can exhibit voltage variations under load. Increasing numbers of models of all sorts use electric motors for propulsion; these are also dc motors, typically at 10-20 volts, drawing up to 20 amperes. They generate significant electrical noise, usually readily detectable on the ground as decreased radio range. Some aficionados use old-time spark-ignition gas motors instead of glow ignition; the sparks make noise.

The antennas, both transmitter and receiver, are particularly weak links. Each is a monopole, with uncertain ground plane. The transmitter is hand-held, and grounded in a complex way through the operator's body. The receiving antenna is a 3-foot piece of wire stretched, traditionally and hideously, between back of wing and tail and then left to twirl in the breeze, although I believe that all models not having most of the antenna hidden in the fuselage should be stepped on, hard. Antenna directionality is not clear in such configurations, but the transmitter does seem to have a null off the end of the antenna, as expected. Unfortunately, most transmitters are designed to be held in such a way that the null points at the model, especially an airborne model. Ground-wave reflections can create interesting cancelling signals that are not normally problematical, but they can add to the excitement of landing if a long, low approach is made.

The modulation scheme

The carrier is 100-percent amplitude-modulated, which permits an inexpensive and compact system. The information (the desired position of each servo) is carried in a string of pulses. Each pulse is referred to as a "channel," and a channel generally corresponds to one controlled surface. Figure 1 shows the modulating signal in idealized form; generally, the rf output is switched (100-percent modulation) ON when this signal is high. As shown, a typically 20-ms-long frame contains *n* channel pulses grouped together at the beginning; a relatively long "synchronization" time separates the group of information-bearing pulses and identifies the start of each frame. The frame time is fixed, but the length of each of the channel pulses can vary between 1 and 2 ms to determine the servo position. Therefore, the sync time is variable, although 7 ms is a typical minimum specification. The length of the gap between the pulses is typically 300 μs. In practice, the leading and trailing edges of the pulses would be sloped or rounded somewhat either in the modulator or the output stage in an attempt to do something considerate with the transmitted bandwidth.

At the risk of appearing repititious, I would like to reinforce some points in the above paragraph for later reference. For a 6-channel transmitter (not unusual), the synch time varies between 8 and 14 ms. Receivers generally are designed to handle transmitters with as few as two channels and as many as six; eight-channel systems are not unknown. The channel pulses vary *continuously* between 1 and 2 ms; servo rotation is correspondingly and proportionately continuous. Mysteriously, these systems are called "*Digital* Proportional" (emphasis mine), even though the pulse widths vary continuously and are usually generated by a one-shot multivibrator, which is certainly a marginal example of a digital circuit. (Maybe the name has something to do with the squarish shape of the pulses.) The servo positions are updated at a 50-Hz rate. The channels are assembled in arbitrary, but known, order by the encoder; the user is reponsible for plugging the correct servo into the correct decoder output (seems simple, doesn't it!). Servos can be specified to rotate in either direction as the pulses widen and narrow, which can have amusing consequences, for instance, when ailerons are carelessly connected.

Although laudable for its simplicity, the modulation scheme described above has some serious deficiencies. The receiver looks for bursts of carrier separated by gaps with no carrier. The threshold is set by the overall receiver gain, controlled by the AGC in response to the detected signal level "averaged" over some reasonable time interval. Problems arise when the gaps get filled in by noise or interference. Manifestations are that the receiver makes incorrect determination of sync, reassigns the channel pulses, or thinks some of the pulses are very long and positions the servos accordingly. An opposite problem occurs if distortion turns one long pulse into two short ones. In both cases, the loss of control can be spectacular, usually resulting in splinters unless the signal is reacquired before the operator becomes disoriented.

Various "fail-safe" systems are often proposed. It is relatively easy to detect when the received signal is out of spec, but then what? If the controls are frozen on recognition of a bad signal, a plane will either fly away or crash, depending on the initial conditions. Returning the controls to some preset value—a slow, downward spiral, for instance—is no guarantee that a plane will land safely or will come down quickly enough to still be in a safe place. Multiple, redundant, transmitters and receivers are expensive and impractical when only a limited number of radio channels is available to multiple users.

On the positive side, the system offers truly simple and low-cost radios, and is probably responsible for the growth of the hobby. Since the modulation is switched ON and OFF, some limiting is possible in the detector, which eases the the design. Recent FCC rulings permit frequency modulation, and manufacturers are beginning to offer such systems. An FM receiver is not so easily fooled by noise and interference.

A typical transmitter

Figure 2 is a block diagram of an R/C transmitter. Basic timing comes from a 50-Hz frame clock, which resets the encoder to begin the sequence. Each channel pulse is formed by a circuit that acts like a one-shot (sometimes it is a literal one-shot), where the length of the pulse is set by a potentiometer attached to one axis of a joystick. The pulses are strung together by the encoder, shaped somewhat, and sent to the modulator. The other input to the modulator comes from a crystal-controlled oscillator. The modulated signal is amplified to a power level of about 0.5 watt and passed through a filter to limit the transmitted bandwidth and allegedly perform some antenna matching. My (admittedly limited) measurements and spec reading account for some jaundice regarding the efficacy of the matching efforts. The antennas are usually monopoles tuned at the base, although center-loaded antennas have been used on 27 MHz. Power comes from a 10-volt (nominal) battery, usually built from eight NiCad 0.5-Ah cells.

The joysticks themselves come in several styles. Usually the four main control channels (aileron, elevator, rudder, throttle) are organized on two, 2-axis sticks. Each stick is operated by one of the pilot's thumbs. The most popular arrangement is aileron-elevator under the right thumb and rudder-throttle under the left. A small minority of us prefer aileron-throttle under the right thumb, and rudder-elevator under the left, which places the primary roll and pitch controls on separate joysticks. Some flyers use a single 3-axis stick with ailerons controlled by left-right motion, elevator by forward-back, and rudder by rotation; throttle is a separate lever controlled by the other hand. All controls except throttle are spring-returned to center; all controls have adjustable trim, especially important for the exciting first test flight. Modelers with cars and boats often use transmitters with a rotating steering wheel. Auxiliary channels are either rotating knobs, levers, or 2-position switches.

The newly-permitted closer frequency spacing described above will affect transmitter design only in the rf section. The general idea is to obtain better control of the transmitted spectrum. Crystal tolerances must be slightly tighter, and the output sections must be narrower-band. Since many more frequencies will be available, manufacturers will offer sets with "swappable" crystals in matched transmitter-receiver pairs. This will permit more operators on-air at the same time—a dubious benefit in most R/C applications, except perhaps sailboat racing. Top-of-the-line systems will offer phase-lock-loop synthesized frequency selection, presumably with fail-safes to avoid sweeping out the sky during frequency selection or in event of synthesizer malfunction.

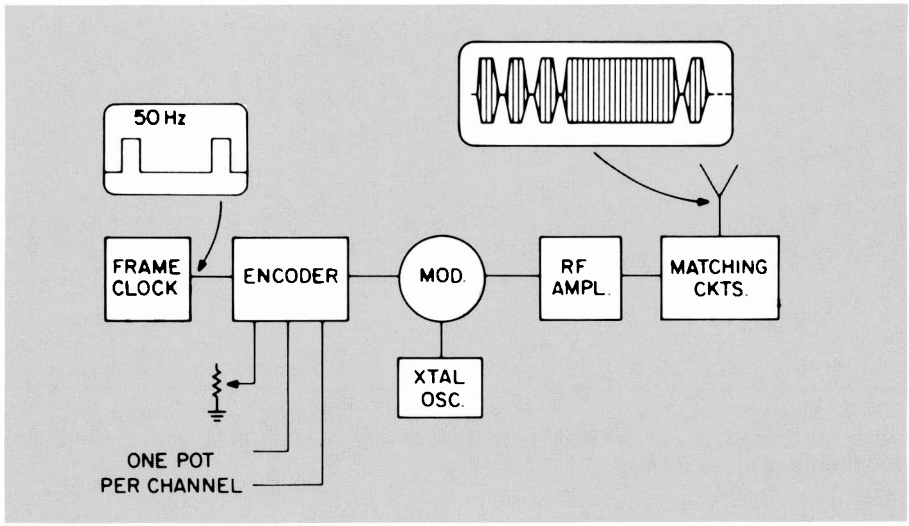


Fig. 2. *The transmitter amplitude-modulates the encoded pulses onto a crystal-controlled carrier and amplifies the signal to about 0.5 watts.*

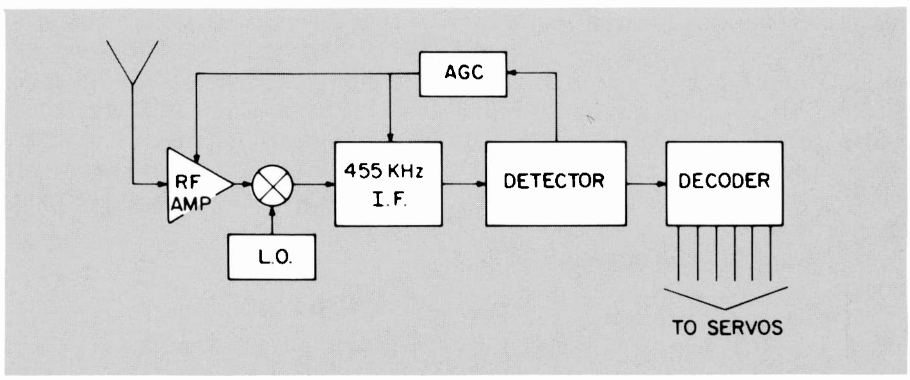


Fig. 3. *The receiver is a simple AM radio, crystal-controlled and optimized for the recovery of pulsed waveforms. The decoder separates the pulses, sending one to each servo.*

A typical receiver

Figure 3 shows a simplified block diagram of a receiver. The rf amplification is often implemented with a separate, tuned, bipolar transistor. Tuning may be as simple as a single L-C, or as elaborate as a triple-tuned circuit. The mixer may be either FET, MOS, or bipolar, and it is sometimes designed with enough gain to eliminate a separate rf amplifier. The IF is almost always 455 kHz, achieving selectivity with three transformers of the type used in portable AM radios. The detector is a simple diode function, usually with enough gain for limiting. AGC is derived from the detected signal level and usually controls both the rf and first IF stages. AGC must act slowly enough so that gain is set by the carrier pulses and noise is below threshold. It must be fast enough to follow fluctuations in signal strength in a rapidly moving plane and to handle quickly-changing reflections for cars raced inside buildings with metal frames. A 0.3-s time constant is typical.

The decoder receives a train of pulses as shown in Fig. 1, must recognize sync, and must gate each channel pulse to the appropriate servo lead. This can be accomplished with J-K flip-flops using a diode and capacitor circuit to reset on sync. Custom ICs have also been designed.

Closer frequency spacings seriously affect receiver design. Overload and intermodulation products are more likely, and adjacent channel sidebands are close. Both front-end and IF circuits must become more narrow band. Some manufacturers are changing to double conversion receivers, with first IF around 10.7 MHz and second IF at 455 kHz. All these solutions inevitably increase cost.

Servo systems

The servo is the electromechanical device that turns the decoded pulses into control

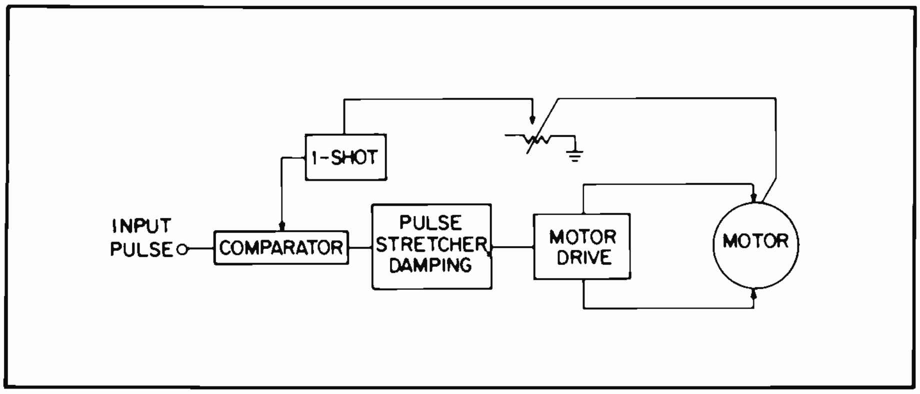


Fig. 4. *Servos contain a geared dc motor driving an output shaft and a feedback potentiometer. Correct position is achieved when the internal pulse width matches the received pulse width.*

surface motion. A typical servo weighs about 1.3 oz, and is approximately 1.5 × 1.5 × .5 inches. It contains a high-speed electric motor geared down so that the output shaft rotates through about 100° total motion in about 0.5 seconds, and supplies about 25 inch-ounces of torque. Position feedback is provided by a potentiomenter connected to the final output gear. The pot is the timing element for a one-shot internal to the servo drive circuit. The shaft rotates the pot until the internal one-shot pulse length matches the incoming pulse from the decoder.

Normal servo design considerations apply. Position control must be accurate, and deadband must be tight. However, enough laxness must be accepted to avoid hunting or jittering by the servo motor, or else battery drain would be intolerable. A position accuracy of ±1 percent is a typical specification. Smooth motion is expected even though pulses only come by every 20 ms, and only last 1-2 ms. The servo drive circuit includes pulse stretching, tailored to the 50-Hz frame rate. Figure 4 is a block diagram of such a system.

Batteries

Receiver batteries are usually four nickel-cadmium cells of 0.5-Ah capacity, nominally supplying about 5 volts. As stated above, transmitters usually require eight cells. The receiver battery is more critical because its power drain is not as predictable (it depends on the amount of servo motion and the loads on the surfaces), because it operates in an environment of high vibration, and because its charge state cannot be constantly monitored by a meter (which transmitters usually contain). A 0.5-Ah battery in good shape and fully charged can be expected to operate a four-channel system safely for about 2 hours, depending on the courage of the operator. Most of the electrical parts, but especially the batteries, are wrapped in foam for vibration isolation, and are also wrapped in a plastic bag in an attempt to control damage in the event of a fuel leak. Fuel is usually a mixture of castor or synthetic oil lubricant (about 20 percent) with methanol, plus a little nitromethane (about 10 percent) thrown in to make certain that the stuff dissolves nearly everything with which it comes into accidental contact.

Electric propulsion

Relatively recently, interest in using electric motors for driving an airplane propeller has emerged. The advantages are several, including no mess, little noise, and easy starting. There is only one disadvantage, but it is important—a low power/weight ratio. Depending on motor and plane size and expected performance, motors may draw 5 to 15 amperes at anywhere from 8 to 20 volts. Power is most commonly supplied by NiCad batteries of 1.2-Ah capacity; they drive the motor for about 5 to 15 minutes, depending on plane design (weight, size, and flying speed), on prop size, and on expected flight performance.

NiCad cells supply nominally 1.2 volts and weigh about 2 oz in the above size. A battery pack to fly a plane weighs between 1 and 3 pounds, and is a large fraction of the total flying weight. An example may illustrate the problem. I have built a 6-foot wingspan, semi-scale model of a 1930s-era high-wing monoplane (a Porterfield Collegiate). It is intended to fly sedately, slowly, and without aerobatic capabilities, as was the case with the original. Experience and some calculations that are not germane to this article indicate a desired total weight of 55-60 oz. This was achieved with a weight breakdown approximately as follows:

Motor battery	16 oz.
Motor, prop, gear reduction	8 oz.
Three-channel receiver, servos, battery	8 oz.
Wheels, landing gear, etc.	6 oz.
Covering, paint, trim	7 oz.
Airframe	12 oz.
Total	57 oz.

The provision of flight power required more than 40 percent of the total weight. The only real variable left to the builder is the weight of the airframe, and so thoughtful engineering, careful construction, and selected balsa are what separate electric-powered flight from the more common glow-engine power. Very few kits are adequate for electric flight.

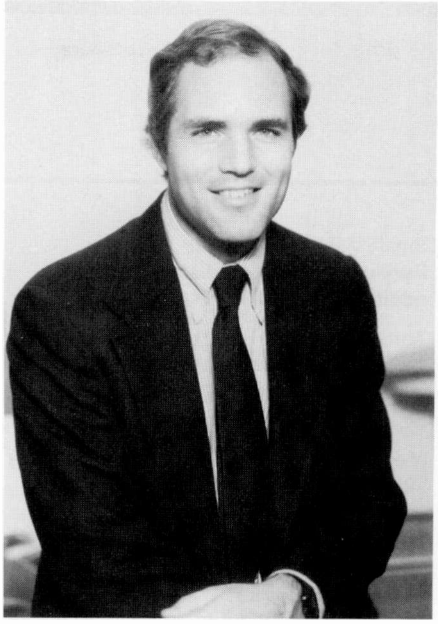
Another engineering problem is the choice of propeller. A large, high-pitched prop will provide good power, but will drain the batteries in astonishingly short time, if it doesn't burn out the motor brushes first. Small, low-pitched propellers simply may not fly the plane. Relatively large propellers (12-to 14-inch diameters) turning at fairly low rpm (5000-7000) seem best for sailplanes and slow scale planes; gear reduction ratios between 2:1 and 3:1 are common to allow the motor to operate at an efficient speed. However, the added weight of the gear reduction and large prop counts against the better efficiency. Finding the appropriate propeller to achieve the required flight performance and still retain a reasonable flight time is an important part of successful electric flight; glow engines are much more tolerant of a poor match.

Future directions

As in all other matters electronic,the microprocessor should be the focal point for new and improved products. A microprocessor, either receiving signals from digitally-encoded joysticks or immediately passing the voltage on their potentiometers through an A/D converter, would be the basis of a truly digital encoder. If desired, it could provide deliberate, well-defined, and user-specified nonlinearities for selected control functions. It would permit easy setting of limits on the throw of some controls, preventing stalling of the servo (with attendant power drain and possible motor or drive transistor burn-out) at the extremes. A microprocessor would also allow flexible control mixing, required, for example, when the same movable wing trailing edges are used for both aileron and flap functions or for V-tailed aircraft when elevator and rudder share the same surfaces.

A phenomenon known for many years but not often exploited in model aircraft is the sensing of the earth's electrostatic potential at the wingtips. It varies with height by an amount detectable over a few feet with a probe of sufficiently high impedance and sensitivity. The effect has been used for automatic roll and pitch control on record-setting duration flights. With suitable sophistication and signal processing "smarts," it could provide some measure of security for fledgling pilots, and perhaps offer the possibility of programmable flight maneuvers. The processing is not simple, as the field gradient is not constant and can even reverse near atmospheric electrical disturbances.

The traditional hobbyist will continue to build models and apply his creativity to their realistic and detailed appearance or to improvement of his own control techniques. Corresponding growth and sophistication will continue in control electronics, created by another sort of hobbyist, acting first as a tinkerer and finally as an IC designer and programmer. Past developments have been bounded by the size and power consumption of the circuitry required. CMOS logic and microprocessors allow intelligent processing in both receiver and transmitter and fit nicely into a model. However, in order to gather the information, development of clever sensors (of such variables as electric field, altitude, rate of change of altitude, airspeed, etc.) must follow suit. At present, the hobby is far from fully exploiting the capabilities of electronics even without improved sensors, but once the dust has settled on designs for the new frequency allocations, intelligent controls will be the next focus for development.



John Henderson received the BSEE degree from the University of Pennsylvania in 1967 and the MSE degree from Princeton University in 1969. He joined RCA Laboratories in 1967. He has worked on various consumer electronics projects, including IF filters using conventional and surface acoustic wave components, and both frequency and voltage synthesis approaches to television tuning systems. In 1981 he was named Head, VideoDisc Signal Systems Research, and in 1984 he became Head, Systems Technology Research in the Television Research Laboratory. He holds 14 issued patents and has received four RCA Laboratories Outstanding Achievement awards. He is a member of Tau Beta Pi, Eta Kappa Nu, and Sigma Xi, and received the Eta Kappa Nu Outstanding Young Electrical Engineer Award for 1977.

Contact him at:
RCA Laboratories
Princeton, N.J.
Tacnet: 226-2531

Erratum:

Nov./Dec. *RCA Engineer*

U.S. color television fundamentals—a review," an article by D. H. Pritchard, contains two errors.

Page 17, second column, second paragraph:

Incorrect:

However, experiments have shown that certain nonspectral colors cannot be reproduced by any one choice of three imaginary, or "nonphysical," primaries was made by CIE in setting up an international standard;

Correct:

However, experiments have shown that certain nonspectral colors cannot be reproduced by any one choice of three real light sources. Thus, a choice of three imaginary, or "nonphysical," primaries was made by the CIE in setting up an international standard;

Page 22, first column, bottom:

Incorrect:

The "sum" products are selected and linearly combined to form a composite chromaticity subcarrier whose instantaneous phase represents the hue of the scene at that moment, and whose amplitude—is a measure of saturation.

Correct:

The "sum" products are selected and linearly combined to form a composite chromaticity subcarrier whose instantaneous phase represents the hue of the scene at that moment, and whose amplitude—relative to the brightness signal amplitude—is a measure of saturation.

Corrected copies of the entire article are available from Dalton Pritchard, RCA Laboratories.

Patents

Astro-Electronics

Profera, C.E./Soule, H.H., Jr.
Phase reconfigurable beam antenna system—4471361

Communications Systems Division

Zorbalas, G.S.
Automatic scan tracking with ringing control—4471392

Consumer Electronics

Erber, D.J./Ross, R.S., Jr.
VideoDisc player—275668

Griffis, P.D.
Frequency translation phase-locked loop television sound detection system utilizing a single IF amplifier—4470070

Griffis, P.D.
Switching arrangement for a stereophonic sound synthesizer—4479235

Hakala, D.F.
Process for treating high density information disc recording substrates—4469563

Huck, R.H./Nyman, F.R./Berry, D.A.
VideoDisc processing—4472337

Kirschner, T.F.
VideoDisc player having carriage locking mechanism—4471478

Muterspaugh, M.W.
Electronic tracking for tuners—4476583

O'Leary, D.B.
VideoDisc player—275566

Prusak, J.J.
Apparatus for manufacturing a disc record package—4470795

Prusak, J.J./Patel, B.P.
Apparatus for injection molding an article—4478566

Prusak, J.J.
Method for the manufacture of record stampers—4479853

Rindal, A.E.
Television sound detection system using a frequency translation phase-locked loop—4470071

Sheean, D.A.
Deviation detector for FM video recording system—4476498

Smith, T.E./Wang, C.C.
Purification of video disc lubricant additives—4479851

Torrington, L.A.
Disc record player having carriage locking apparatus—447296

Turner, R.L./Prusak, J.J.
Method and apparatus for manufacturing video disc caddy—4475966

Welch, P.G./Mitchell, E.E.
Target support adjusting fixture—4478701

Whitehurst. M.L.
Method for the manufacture of capacitive electronic discs—4470940

Government Communications Systems

Anderson, W.G.
Switching circuit including pin diodes for impedance matching—4477817

Clurman, S.P.
Protective cartridge for disc recorder—4477894

Daniel, J.W., Jr.
Phaselock receiver with input signal measuring capability—4479253

Mattei, A./Hahn, W.L., Jr.
Symbol synchronizer for MPSK signals—4475220

Nossen, S.J./McGuire, K.E./Brokl, S.S.
Multiple synchronous counters with ripple read—4477918

Laboratories

Bloom, S./Hockings, E.F.
Method of fabricating a metalized electrode assembly—4470822

Bolger, T.V.
Color channel signal-to-noise improvement in digital television—4472733

Chen, T.Y./Gibson, W.G.
Video disc player with caption generator having character background—4477841

Dischert, R.A./Walter, J.M.
Multiplier for digital video signals using a cascade of signal-selectable memories—4470125

Dischert, R.A.
Television camera mechanical apparatus driven by recorder motor—4471388

Faughnan, B.W./Crandall, R.S.
Electrochromic films having improved etch resistance and method for making same—4475795

Fisher, A.W.
Local oxidation of silicon substrate using LPCVD silicon nitride—4472459

Flory, R.E./Thompson, C.R.
Chrominance channel bandwidth modification system—4472746

Fox, L.P./Dimarco, L.A.
Conductive molding composition and discs therefrom—4472295

Gorog, I.
Multi-bandwidth optical playback apparatus having minimum baseband distortion—4477891

Hernqvist, K.G.
CRT with internal neck coating for suppressing arcing therein—4473774

Heyman, P.M.
Method for intaglio printing and selectively alterable inking plate therefor—4473008

Hoffman, D.M.
Process for radiation free electron beam deposition—4472453

Kumar, M./Upadhyayula, L.C.
Power divider/combiner circuit as for use in a switching matrix—4472691

Lewis, H.G. ,Jr./Bolger, T.V.
Reduced data rate digital comb filter—4470069

Miller, A.
Method of cleaving a crystal to produce a high optical quality corner—4469500

Pankove, J.I./Tarng, M.L.
Method and structure for passivating a PN junction—4473597

Prabhu, A.N./Boardman, S.M.
Thick film resistor inks—4479890

Reitmeier, G.A.
Adaptive error concealment using horizontal information determination from adjacent lines—4470065

Sauer, D.J.
Pipe-lined CCD analog-to-digital converter—4471341

Strolle, C.H.
Phantom raster generating apparatus scanning TV image memory in angular and orthogonal coordinates—4471349

Tosima, S./Nishikawa, M.
Surface acoustic wave device having a pyramid shaped tip for recording video information on a substrate—4477892

Wendt, F.S.
Self-regulating saturating core television receiver power supply—4471271

White, L.K./Popov, M.
Preparation of organic layers for oxygen etching—4470871

Wu, C.P./Schnable, G.L./Stricker, R.E./Lee, B.W.
Method of making a semiconductor device to improve conductivity of amorphous silicon films—4472210

Missile and Surface Radar

Bowman, D.F.
Three horn E-plane monopulse feed—4476470

Guhn, D.K.
Phase lock loss detector—4473805

RCA Service Company

Kaminsky, M.F.
Charge time start control for interconnect PABX—4472600

Solid State Division

Baar, L.S.
Electrical connector—4478472

Henry, D.V.
Modular welding apparatus—4473734

Hope, G.P./Rhodes, R.D.
Lid latching apparatus—4476994

Isham, R.H.
Bidirectional interface—4471243

Kaplan, L.A.
Output protection circuit for preventing a reverse current—4471237

Landis. W.C./Nyul, P.
Light emitting assembly and a method of making same—4479698

Wilson, R.E.
Control circuit for telephone receiver and transmitter—4472601

Steckler, S.A./Balaban, A.R.
Current supplying circuit as for an oscillator—4471326

Solid State Technical Center

Wacyk, I.T./Stewart, R.G./Dingwall, A.G.
Memory system with error storage—4472805

Video Components and Display Division

Duschl, R.A.
Charge coupled device based system and method for measuring projected figures—4480264

Pen and Podium

Recent RCA technical papers and presentations

To obtain copies of papers. check your library or contact the author or his divisional Technical Publications Administrator (listed on back cover) for a reprint.

Astro-Electronics

J.F. Balcewicz/S.H. Colodny/H.C. Johnson
Active array antenna for the next generation direct broadcast satellite—Globcom '84 Atlanta, Ga. (11/84)

T.B. Curbishley/R.J. Lutz
Computer aided engineering and manufacturing—Prime Medusa Users Special Interest Group Meeting, Philadelphia, Pa. (10/29/84)

R.S. Green
Accelerated and real-time geosynchronous life cycle test performance of nickel-hydrogen batteries—NASA Goddard Battery Workshop, Greenbelt, Md. (11/15/84)

J. Keigler/W. Braun
RCA Sat networks: high tech and low user costs—*IEEE Proceedings*, Special Edition (11/84)

R. Landers
The assurance of reliability in the design process—ASME Chicago Annual Technology Review Meeting, Chicago, Ill. (11/84)

P. Papula/C. Stowell
Surface temperature of a solar array under simulated failure orbital conditions—SPIE Thermosene VII, Cambridge, Ma. (11/84)

S.F. Schiffer
RCA's planned test program for NiCd cells containing two different separators—Pellon 2536 vs Pellon 2505—NASA Goddard Battery Workshop, Greenbelt, Md. (11/84)

Government Communications Systems

D.G. Herzog/S.L. Corsover/D.W. Donze
Critical parameters associated with specia laser image recorder—1983 International Congress on the Applications of Lasers and Electro-Optics, Boston, Mass. fying (11/15/84)

S.P. Masticola
A single-board signal processor network using the Texas Instument TMS-320—GOMAC '84 (Government Microcircuit Applications Conference), Las Vegas, Nev., published in the *Proceedings* (11/6/84)

J. Springer
The architecture and operation of a multiple microcomputer radar signal processing system—4th International Conference on distributed Computer Systems, San Francisco, Cal., published in the *Proceedings* (5/14/84)

Laboratories

Russell R. Barton
Minimization algorithms for functions with random noise—*American Journal of Mathematical and Management Sciences*, Vol. 4, Nos. 1 & 2, 109-138 (1984)

J.K. Butler/D. Botez
Lateral mode discrimination and control in high-power single-mode diode lasers of the large-optical-cavity (LOC) type—*IEEE Journal of Quantum Electronics*, Vol. QE-20, No. 8 (8/84)

P.D. Gardner/S.Y. Narayan/Y. Yun
Characteristics of the low-temperature-deposited $SiO_2Ga_{0.47}In_{0.53}$ as metal/insu-

lator/semiconductor interface—*Thin Solid Films*, 117, 173-190 (1984)

G. Kaganowicz/V.S. Ban/J.W.Robinson
Room temperature discharge deposition of silicon oxides from SiH_4 and N_2O—*J. Vac. Sci. Technol.* A 2 (3), July-Sept. (1984)

H.P. Kleinknecht
Diffraction and interference optics for monitoring fine dimensions in device manufacture—Inst. Phys. Conf. Ser. No. 69, paper presented at ESSDERC/SSSDT 1983, Canterbury (9/83)

R.W. Klopfenstein/C.R. Carlson
Theory of shape-invariant imaging systems—*J. Opt. Soc. Am.* A, Vol. 1, No. 10 (10/84)

S.G. Liu/S.Y. Narayan
Rapid capless annealing of ^{28}Si, ^{64}Zn, and ^{9}Be implants in GaAs—*Journal of Electronic Materials*, Vol. 13, No. 6 (1984)

C.H. Lu/C.N. Dorny
Ambiguity resolution in self-cohering arrays—*IEEE Transactions on Antennas and Propagation*, Vol. AP-32, No. 8 (8/84)

J.I. Pankove/R.O. Wance/J.E. Berkeyheiser
Neutralization of acceptors in silicon by atomic hydrogen—*Appl. Phys. Lett.* 45 (10) (11/15/84)

H. Schade/Z.E. Smith/A. Catalano
Correlation between bulk p-layer properties of a-$Si_{1-x}C_x$:H and performance of a-$Si_{1-x}C_x$:H/a-Si:H heterojunction solar cells—*Solar Energy Materials* 10, 317-328 (1984)

H. Schade/Z.E. Smith/J.H. Thomas III/A. Catalano
Hydrogen plasma interactions with tin oxide surfaces—*Thin Solid Films* 117, 149-155 (1984)

E.F. Steigmeier/H. Auderset
Structural perfection testing of films and wafers by means of optical scanner—*J. Electrochem. Soc.* (7/84)

C. Steinbruchel
A simple formula for low-energy sputtering yields—*Appl. Phys.* A 36, 37-42 (1985)

L.K. White
Approximating spun-on thin film planarization properties on complex topography—*Journal of Electrochemical Society*, 132 (1), 168 (1984)

R. Williams/A. Zangvil/A. Karnieli
A portable evaporimeter for rapid measurement of the evaporation rate of water—*Agricultural and Forest Meteorology*, 32, 217-224 (1984)

R.A. Zang
Applied robotics: A videotaped course—Presented at the International Conference on Robotics and Factories of the Future, Charlotte, N.C., and published in the *Proceedings* (12/4/84)

Missile and Surface Radar

R.M. Blasewitz
Why Ada as a PDL? Defense of the IEEE working group's position on Ada as a PDL—National AdaTec Conference, Hyannis, Mass. (7/84)

R.M. Blasewitz
Managerial concerns and Ada—IEEE Working Group Meeting on Ada as a PDL, Arlington, Va. (10/84)

R.M. Blasewitz
Software engineering standardization efforts—Panelist/speaker, Consac '84, Chicago, Ill. (11/84)

F. J. Buckley
Overview of national standards for software panelists—IEEE Computer Society—Computer Software and Applications Conference, Chicago, Ill. (11/84)

F.J. Buckley
The IEEE software engineering standards process—IEEE Global Telecommunications Conference, Atlanta, Ga. (11/28/84); Eighth Annual Symposium on Computer Applications in Medical Care, Washington, D.C. (11/5/84)

D.J. Coyle
Current and future applications of fiber optics in shipboard environments—IEEE, University of Pennsylvania Faculty Club, Philadelphia, Pa. (11/20/84)

D.J. Coyle
Fiber optics for non-electrical engineers—Washington University, Washington, D.C. (11/6/84)

G.S. Edelson
Sidelobe reduction of the random array by third moment diversity—Valley Forge Research Center, University of Pennsylvania (11/30/84)

A.G. Hopper
The RCA laser range pole—An inverted plumb bob—*The Georgia Land Surveyor* (10/84)

G.W. Kaizar
AEGIS Cruiser CG-47 class maintainability consideration—Presented at the ITEA Symposium, Washington, D.C., and published in the *Proceedings* (11/6/84)

S.A. Steele
Digital signal processing technology—Security Affairs Support Association (SASA) West Coast Symposium '84 (11/14/84)

H. Urkowitz
Some applications of Z-Transforms and state variables to feedback shift registers—*RCA Review*, Vol. 45, No. 3, 421-448 (9/84)

S.M. Yuen
A new super-resolution spectral estimation technique using staggered PRFs—Valley Forge Research Center, University of Pennsylvania (11/30/84)

Engineering News and Highlights

Dukes named Associate Editor of *RCA Review*

Eva Dukes has been named Associate Editor of the *RCA Review*. She continues as Editorial Representative to the *RCA Engineer*, a position to which she was appointed in 1981.

Ms. Dukes, Senior Technical Editor, Technical Publications, joined RCA Laboratories in 1976 as Administrator, Documentation and Reports. She has also held the title of Administrator, Technical Editing. In these capacities she was responsible for the publication of government contract reports and proposals. In 1981 she was editorial coordinator for IR&D from the Laboratories.

She recently won an Award of Excellence from the New York Chapter of the Society for Technical Communication for her paper "How to Get Your Book Published Successfully" (IEEE *Conf. Record*, Atlantic City, October 10-12, 1984).

Staff announcements

Americom

Eugene F. Murphy, Chairman of the Board, RCA American Communications, Inc., announces that the Board of Directors of RCA American Communications, Inc. elected **James J. Tietjen** President and Chief Executive Officer.

Walter H. Braun, Vice President, Systems Engineering and Program Management, announces the appointment of **Michael J. Noon** as Manager, Systems Engineering.

Gerald D. Zeigler, Manager, CTO, Western Operations, announces the appointment of **William L. Tate** as Supervisor, Kansas City CTO.

Patrick F. Egan, Manager, CTO Eastern Operations, announces the appointment of **Keith A. Hildonen** as Supervisor, Boston CTO.

Robert E. Smylie, Vice President, Government and Business Networks Services, announces the appointment of **David J. Trautman** as Manager, Federal Systems.

Patrick F. Egan, Manager, CTO Eastern Operations, announces the appointment of **Charles E. Lapierre** as Supervisor, Washington, D.C. CTO.

Astro-Electronics

Charles A. Schmidt, Division Vice President and General Manager, announces the appointment of **John E. Keigler** as Principal Scientist.

Jack A. Frohbieter, Division Vice President, Communications Satellites, announces the appointment of **Robert S. Lawton** as Manager, Advanced Communications Technology Satellite Program (ACTS).

Automated Systems

Andrew T. Hospodor, Division Vice President and General Manager, Automated Systems Division, announces his organization as follows: **Duane M. Belden**, Plant Manager, Burlington Plant; **Thomas E. Fitzpatrick**, Director, Vehicle Test Systems; **Andrew T. Hospodor**, Acting Director, C³I Systems; **Andrew T. Hospodor**, Acting Director, Marketing and Advanced Planning; **James A. Kupec**, Manager, Employee Relations; **Kenneth I. Pressman**, Director, Finance; **David M. Priestly**, Director, Automatic Test Systems; **Murray D. Radlo**, Manager, Materials; **F. Ralph Shirak**, Director, Special Programs; and **Eugene M. Stockton**, Chief Engineer, Engineering.

Andrew T. Hospodor, Acting Director, C³I Systems, announces his organization as follows: **Eugene B. Galton**, Manager, Program Operations; **Glenn L. Anderson**, Manager, Project Engineering; **Joseph D. Aronson, Jr.**, Manager, Project Management; and **Joseph A. Jascewsky, Jr.**, Manager, Project Engineering.

David M. Priestly, Director, Automatic Test Systems, announces his organization as follows: **Donald R. Bartlett**, Manager, Program Operations; **Oliver T. Carver**, Manager, Program Operations; **John H. Groff**, Manager, Program Operations; **John Hallal**, Manager, Program Operations; **James A. Murnane**, Manager, Business deveopment; and **Walter R. Wadden**, Staff Scientist, Technical Assurance.

Eugene F. Stockton, Chief Engineer, Engineering, announces his organization as follows: **Anthony Amato**, Manager, Products Engineering; **Richard T. Cowley**, Manager, Vehicle Test Systems Engineering; **Henry L. Fischer**, Manager, Vehicle Electronics Systems Engineering; **Raymond K. Gorman**, Manager, Command and Control Engineering; **Fernand F. Martin**, Manager, Avionics Test Systems Engineering; **Richard P. Percoski**, Manager, Automatic Test Systems Engineering; **Gerald T. Ross**, Manager, Program Operations, C³I; **Albert J. Skavicus**, Manager, Engineering Services; **Lawrence B. Smith**, Administrator, Engineering; **Chris A. Wargo**, Manager, Software Engineering; and **David Wellinger**, Manager, Technology Planning.

Richard T. Cowley, Manager, Vehicle Test Systems Engineering, announces his organization as follows: **Robert E. Cullen**, Manager, Design Engineering; **Bradford A. Smith**, Unit Manager, Engineering; **Ronald E. Tetrev**, Unit Manager, Engineering; **Auguste H. Fortin, Jr.**, Manager, Design Engineering; **Robert E. Hartwell**, Manager, Design Engineering; **David Nowak**, Unit Manager, Engineering; **Jeffrey D. Sherman**, Unit Manager, Engineering; **Lee A. Stratton**, Unit Manager, Engineering; and **Marc F. LeVarn**, Manager, Design Engineering.

Henry L. Fischer, Manager, Vehicle Electronic Systems Engineering, announces his organization as follows: **Stephen C. Hadden**, Manager, Design Engineering; **Paul Berrett**, Unit Manager, Engineering; **Michael D. Lospinuso**, Unit Manager, Engineering; **John S.J. Harrison**, Manager, Design Engineering; **Vincent E. Furno**, Unit Manager, Engineering; and **Herbert L. Resnick**, Unit Manager, Engineering.

Gerald T. Ross, Manager, Program Operations, C^{3}I, announces his organization as follows: **Richard A. Barnhill**, Manager, Project Management; **James A. Colligan**, Manager, Program Operations, **Sidney J. Cronsberg**, Manager, Project Development; **William T. Meyer**, Manager, Systems Requirements; and **John L. Velie**, Manager, Project Management.

Eugene M. Stockton, Chief Engineer, Engineering, announces the Advanced Missions Group organization as follows: **Eugene M. Stockton**, Chairman, Advanced Missions Group; **John M. Anderson**, Manager, Advanced Program Operations; **Edwin H. Miller**, Manager, Advanced Program Operations; **John J. Morris**, Manager, Advanced Program Operations; and **Allan R. Stern**, Manager, Advanced Program Operations.

Broadcast Systems Division

Carl O. Foerster, Manager, Engineering Technical Support, announces that the Broadcast Technical Training organization will report to the Engineering Technical Support organization. **Robert N. Hurst**, Manager, Broadcast Technical Training, will report to the Manager, Engineering Technical Support.

C. Robert Thompson, Manager, Video Systems Engineering, announces that **Stanley C. Starr**, Unit Manager, Engineering Staff, will report to the Manager, Video Systems Engineering.

Consumer Electronics

Richard A. Sunshine, Director, Mechanical design engineering, announces his organization as follows: **Robert N. Boyd**, Manager, Product Protection Engineering; **Melvin W. Garlotte**, Manager, Mechanical Engineering, Large Screen Television; **A. Dale Goshen**, Supervisor, Engineering Drafting; **Dana L. Holbert**, Manager, CAD/CAM Systems; **Robert L. Kinkead**, Administrator, Computer-Aided Graphics; **John M. Wilde**, Administrator, Computer-Aided Graphics; **Roger D. Sandefer**, Manager, Information Systems Planning; **Marjorie K. Ullery**, Administrator, Engineering Information; **Fred R. Stave**, Manager, Mechanical Engineering, Portable Television and Remotes; **Leo J. Rhoda**, Supervisor, Engineering Drafting; **E. A. Walker**, Manager, Printed Circuit Board Design; **Jerry L. Fuson**, Supervisor, Engineering Drafting; and **Robert E. Hunter**, Supervisor, Engineering Drafting.

Perry C. Olsen, Director, Project Engineering, announces his organization as follows: **Eldon L. Batz**, Manager, Resident Engineering; **Elmer L. Cosgrove**, Manager, Engineering Services; **Paul E. Crookshanks**, Manager, Project Engineering; **Roger W. Fitch**, Manager, Component Engineering; **Dal F. Griepentrog**, Manager, Competitive Analysis; **Harry W. Kidwell**, Administrator, Data Management; **Donald J. Snyder**, Manager, Engineering—Juarez; **Paul C. Wilmarth**, Manager, Project Engineering; and **Perry C. Olsen**, Acting Manager, Product Improvement Design Group.

Randall R. Mitchell, Manager, Plant Quality Control, announces his organization as follows: **Dennis W. Campbell**, Manager, Production Quality Control; **Thomas W. Copeland**, Manager, Material Quality Control; and **Robert A. Straub**, Manager, Production Quality Control.

Corporate Technology

Howard Rosenthal, Staff Vice President, engineering, announces his organization as follows: **John D. Bowker**, Director, Frequency Management and Product Safety; **Fred L. Dixon**, Manager, Product Safety; **Joseph P. McConville**, Administrator, Spectrum Allocations; **Edward E. Thomas**, Manager, RCA Frequency Bureau, Washington Office; **John F. Clark**, Director, Space Allocations and Technology; **George A. Kiessling**, Director, Special Projects; **William J. Underwood**, Director, Technical Excellence Center; **Anthony J. Bianculli**, Manager, Engineering Information; and **Frank E. Burris**, Manager, Engineering Education.

Government Communications Systems

Donald D. Miller, Chief Engineer, announces his organization as follows: **John N. Breen**, Administrator, Technical Projects; **Robert H. Chan**, Manager, Design Engineering, Engineering Skill Center; **Daniel Hampel**, Manager, Technology Department, Engineering Skill Center; **Ben P. Lee**, Manager, Engineering Operations; **G. Thomas Rogers**, Staff Engineering; **Manuel Robbins**, Manager, Communications Systems, Engineering Skill Center; **James L. Sullivan**, Manager, Information Systems, Engineering Skill Center; **Edward G. Tyndall**, Manager, Software, Engineering Skill Center; **John E. Vetack**, Manager, Microwave Engineering; **Donald B. Wolfe**, Manager, Engineering Systems, Design Integrity; and **Gerald W. Wroblewski**, Manager, Radio Engineering.

Globcom

Eugene M. Gaetano, Vice President, Pacific Operations, announces that the responsibility for the Point Reyes and Bolinas Radio Stations is transfered to the Pacific Operations organization. **Charles Derapelian** will continue as Manager, Point Reyes and Bolinas and will report to the Vice President, Pacific Operations.

James R. McDonald, Director, New York Operations, announces that the responsibility for the Chatham Radio Station is transfered to the New York Operations organization. **William A. Farris** is appointed Manager, Chatham Radio Station and will report to the Director, New York Operations.

Government Systems Division

David Shore, Division Vice President, Strategic Defense Initiative, announces the appointment of **Robert Wentz** as Technical Director, Strategic Defense Initiative. In addition, Mr. Went will serve as Deputy Program Manager for the Strategic Defense Initiative.

Thomas A. Martin, Director, Technical Planning and Advanced Programs, announces the appointment of **Richard F. Kenville** as Manager, Technical Planning.

William W. Thomas II, Manager, Engineering Documentation and Standards, announces his organization as follows: **Charles D. Fisher**, Manager, Engineering Documentation; and **William W. Thomas II**, Acting Manager, Standards.

NBC

Steve Bonica, Vice President, Engineering, announces the appointment of **Warren Allgyer** as Managing Director, Systems Engineering, NBC Operations and Technical Services, New York.

RCA Communications

Albert W. Weinrich, Vice President, Technology and Planning, announces the appointment of **Peter H. Plush** as Director, Facilities Planning.

RCA Records

Devendra Mishra, Director, Manufacturing and Distribution Operations, announces his organization as follows: **Fred Alvarez**, Manager, Operations-Systems, Planning and Developing; **Victor E. Beretta**, Manager, Weaverville Plant; **Howard F. Birnbaum**, Manager, Product Assurance and Operations Engineering; **Ananthanrayan Devarajan**, Manager, Plant Operations; **Devendra Mishra**, Acting Manager, Employee Relations—Indianapolis; **Steven Margeotes**, Manager, National Distribution; **John A. Rucker**, Manager, National Orders and Special services; **James L. Stiegelmeyer**, Manager, National traffic; and **Richard E. Valetta**, Manager, National Inventory Management.

Solid State Division

Carl. R. Turner, Division Vice President and General Manager, Solid State Division, announces the staff and responsibilities of **John A. Shroyer**, Division Vice President, LSI and Technology Development as follow: **Charles J. Nuese**, Director, LSI Products; **James W. Hively**, Director, Semicustom Device Operations; **H. Gene Patterson**, Director, Memory and Microprocessor Operations; **Thomas M. Stavish**, Manager, Palm Beach Gardens Operations; and **John R. Steiner**, Director, Environmental and Plant Engineering—SSD. In addition to the above responsibilities, Mr. Shroyer will continue his role as Chairperson of RCA SSD Working Committee on the RCA/Sharp Joint Venture in CMOS VLSI Integrated Circuits.

Carl R. Turner, Division Vice President and General Manager, Solid State Division, announces the appointment of **Heshmat Khajezadeh** as Division Vice President, Standard and High Reliability IC Products, and his staff is announced as follows: **Stephen C. Ahrens**, Director, Engineering-Standard IC Products; **Richard E. Davey**, Director, Manufacturing—Standard IC Products; **John R. Kowolak**, Administrator, Standard and High Reliability IC Products Administration; **James L. Magos**, Director, Marketing—Standard IC Products; and **John P. McCarthy**, Director, Government and High Reliability Operations.

Carl R. Turner, Division Vice President and General Manager, Solid State Division, announces the appointment of **Robert F. Jones** as Division Vice President, Power Products and International Manufacturing, and his staff is announced as follows: **Donald E. Burke**, Manager, Power Engineering; **Joseph V. Colarusso**, Manager, Materials Planning and Operations Support; **Ronald J. Costlow**, Director, Solid State International Manufacturing; **William B. Hall**, Manager, Wafer Fabrication—Power; **Eugene M. Reiss**, Director, Assembly Technologies and Manufacturing Support; **Allen L. Sands**, Manager, Quality and Reliability Assurance and High Reliability Products—Power; **Joseph R. Spoon**, Manager, Employee Relations—Mountaintop; and **Parker T. Valentine**, Manager, Product Marketing-Power.

Professional activities

Toscano AUTOTESTCON Man of the Year

Patrick Toscano, RCA Automated Systems Program Manager of the US Army Apache AH64A ATE contracts, was honored on November 6, 1984 by the IEEE/AUTOTESTCON 84 Executive Committee with their Man of the Year award. Pat's many years of professional achievements as an ATE engineer were recognized with this citation: "You were selected based upon your long and meritorious service to ATE and the ATE community and your ability to lead and encourage personnel under your tutelege and guidance to strike out in many diverse directions and areas to further the development, application and implementation of ATE in the government-industrial complex."

Pat has been with RCA since 1950. His broad-based RCA Service Company maintenance experience, coupled with hardware design and management experience, have made him an all-round contributor to ATE. From 1960, he headed various groups of engineers involved in Automatic Test Equipment design, specializing in computer control systems and custom peripheral equipment. The systems for which he was responsible included Multipurpose Test Equipment (MTE), Depot Installed Maintenance Automatic Test Equipment (DIMATE), Land Combat Support System (LCSS), and Equate.

In 1974, he was chairman and organizer of a six-session IEEE-sponsored Colloquium entitled "Software for the Engineer." Mr. Toscano is a Senior Member of the IEEE and has actively participated in Professional Groups in Engineering Management, Information Theory, and Electronic Computers. He has published technical papers in several engineering specialties, but most recently in ATE-related subjects. He is a registered professional engineer in Massachusettes and belongs to the AIAA.

Robbi elected VP of IEEE society

Dr. Anthony D. Robbi, RCA Laboratories, Princeton, N.J. has been elected Vice President of the IEEE Society on Social Implications of Technology, for 1985.

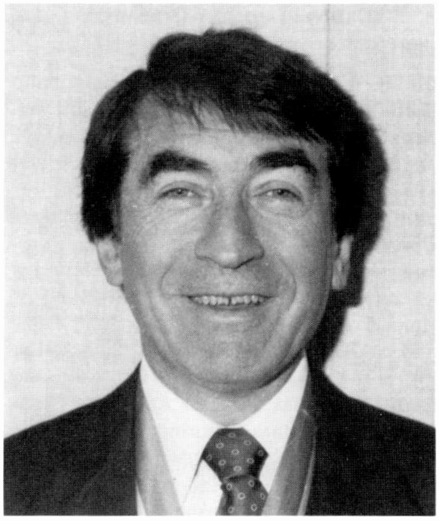
Morris to head legal group

Birgit E. Morris, Director, Electronic Materials and Devices, Patent Operations, RCA Laboratories, has been elected President of the New Jersey Patent Law Association for 1985. This is an organization of about 400 attorneys who practice in the intellectual property law field.

Miller in Who's Who

Harvey P. Miller, Government Communications Systems, will be included in the 1984/1985 edition of *Who's Who in Frontier Science and Technology*. Inclusion in this publication is "limited to those individuals who have demonstrated outstanding achievement in their own fields of endeavor and who have, thereby, contributed significantly to the betterment of contemporary society."

Gaston receives AIAA award



The American Institute of Aeronautics and Astronautics has awarded the 1984 Aerospace Power Systems Award to **Stephen J. Gaston**, Principal Member of the Technical Staff, Astro-Electronics. The citation reads: "For providing technical leadership in the diverse disciplines associated with electrochemical storage design and development. His contributions have been realized in the longlife batteries on the RCA Satcom satellites. His efforts continue to advance the applications of electrochemical energy storage."

Mr. Gaston is the battery engineer on the RCA Satcom communication satellite series. The batteries on two of these satellites, Satcom F1 and Satcom F2, have been operating without breakdown or significant degradation for over eight years.

Four elected IEEE Fellows

Four RCA engineers, one of them retired, have been elected Fellows of the Institute of Electrical and Electronics Engineers, effective January 1, 1985. Fellow is the highest membership grade attainable in the IEEE, and is conferred upon "persons of outstanding and extraordinary qualifications in their particular fields." They are:

Dr. James E. Carnes, Division Vice President, Engineering, Consumer Electronics, "for contributions to the development and practical application of charge-coupled devices, and for technical leadership in consumer electronics."

Dr. Edgar J. Denlinger, Head, Signal Conversion Systems Research, RCA Laboratories, "for the studies of microstrip transmission line characteristics, and the development of microwave solid state devices and circuits."

Dr. Michael Ettenberg, Head, Optoelectronic Devices Research Group, RCA Laboratories, "for contributions to the understanding, development, and fabrication of optoelectronic devices."

John W. Wentworth (retired), "for contributions to color television development, standardization, and education."

Dr. Chu elected to ASME post

David F. Chu has been elected Secretary of the Shock and Vibration Committee, American Society of Mechanical Engineering, for one year effective July 1, 1984. He will be Chairman of the committee for one year beginning July 1, 1985.

Herschitz to teach at Rutgers

Dr. Roman Herschitz, Senior Member of the Technical Staff, Astro-Electronics has received an appointment as adjunct faculty member in the Department of Mechanics and Materials Science at Rutgers University. He will be teaching graduate level courses in materials science.

Technical excellence

Two Mountaintop awards presented

Al Purta received a November Technical Excellence Award for defining the cause of product degradation in Malaysia, and for improving the parameter control and product capability throughout his product line.

Joe Meluzzo's award was for design improvements to the Eaton Automotive Test Set that allow its use for high voltage, low current I_sB categorization. Joe's contribution toward the design of a wafer sensing circuit led to a significant reduction of wafer breakage in the Photo Resist area.

TEC award to Keller of Americom

The November Americom Technical Excellence Award went to **Bradley Keller**, Member of the Engineering Staff, Systems Engineering. Brad developed procedural software to link the Wang Word Processing System to the Cherry Hill IBM 370 computer, thereby allowing the transfer and edit of technical files. This has dramatically improved efficiency, flexibility, and speed in the preparation of technical proposals. Brad undertook this project on his own initiative, and had a successfully operating system in less than two months.

Findlay Technical Excellence Awards

Shinabarger **Povenmire**

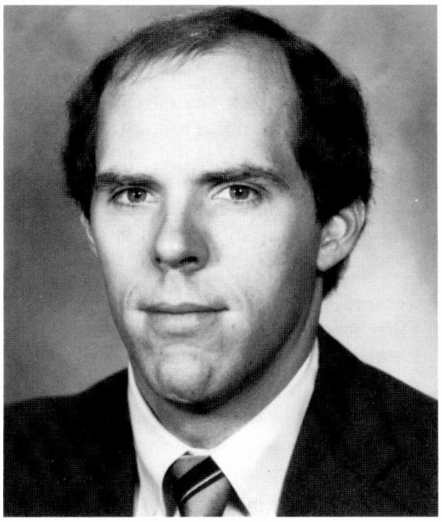
On November 14, the Findlay Technical Excellence Committee presented awards to **Ginger Povenmire** and **Cindy Shinabarger**. Ginger's award was for reducing the COSMOS monthly photo recycle rate from 9 percent to 5.5 percent, setting up a soft-contact QMOS photo process with a higher circuit probe yield and lower D_i than other RCA QMOS photo areas, and setting up a Canon projection aligner and establishing all critical dimension biases for QMOS masks.

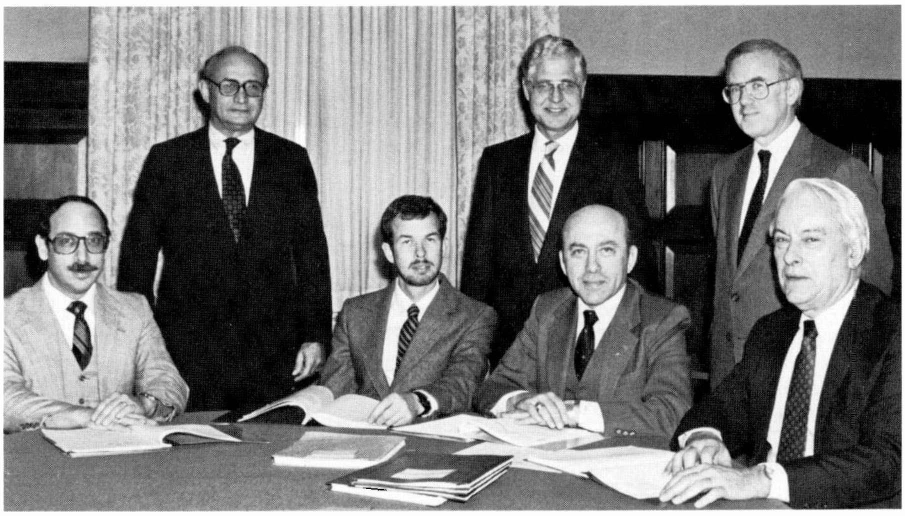
Cindy's award was for her work in reducing P^+ pitting and extending the life of boron sources, with a resultant cost savings of over $100,000. She was also instrumental in reducing the number of COSMOS control wafers used at a time when control wafer costs have nearly doubled.

Sergi and Viola win GCS team award

Joe Sergi and **Jeff Viola** of Digital Communications Equipment Engineering have won the Technical Excellence Team Award for their outstanding work in the development and demonstration of a high-reliability fiber optic local data distribution network. This system operates in the 200-500 Mbs data range, and is capable of serving hundreds of subscribers.

Parker recognized by Eta Kappa Nu





1984 Eta Kappa Nu Jury of Award. Seated (L to R): Dr. Bruce A. Eisenstein, Chairman of the Electrical and Computer Engineering Department, Drexel University; Mr. William Buffington, Manager of Research and Development, Avondale Division of Hewlett-Packard Corp.; Dr. Irving Engelson, Director of Technical Activities, IEEE; Mr. Joseph B. Siedlarz, Jr., Assistant Vice President for Network, Bell of Pa. / Diamond State Telephone Co. Standing (L to R): Dr. John Blair, Director of Research, Raytheon Corp.; Mr. William A. Black, President, Indiana and Michigan Electric Co.; and Mr. James A. D'Arcy, RCA Corp., Chairman of the Eta Kappa Nu Award Organization Committee.

The 1984 Eta Kappa Nu (Honorary Electrical Engineering Society) Jury of Award has selected **Robert P. Parker**, Director, Signal Systems, RCA Consumer Electronics for Honorable Mention in the award program recognizing outstanding young electrical engineers. Mr. Parker is being recognized for "his contributions to the fields of color television receiver technology and engineering management, and for his involvement in community activities." Dr. William E. Moerner, a Research Staff Member at IBM Corporation, San Jose, California, has been named the winner. Two other young electrical engineers have been selected to receive Honorable Mention: Cecelia Jankowski, a Digital Design Engineer at Grumman Aerospace Corporation, Bethpage, New York; and Dr. Stanley M. Belyeu, a Systems Architect at IBM Corporation, Boca Raton, Florida. Three others are being recognized as finalists.

Since 1936, Eta Kappa Nu has recognized outstanding young electrical engineers on an annual basis. The purpose of this recognition is to "emphasize among electrical engineers that their service to mankind is manifested not only by achievements in purely technical affairs, but in a variety of other ways. It holds that an education based upon the acquisition of technical knowledge and the development of logical methods of thinking should fit the engineer to achieve substantial success in many lines of endeavor."

Dr. Moerner, Mr. Parker, and the others receiving Honorable Mention, including those being recognized as finalists, will be honored at the next Eta Kappa Nu Award Banquet on Monday evening, April 22, 1985, at the Omni Park Central Hotel in New York City. Each winner will receive an appropriately inscribed certificate, presented by the President of Eta Kappa Nu; Dr. Moerner's name will be engraved on a bowl that is kept at IEEE Headquarters.

Since 1936 there have been 49 young engineers—under 35 years old—who have received the award, and 105 others who have received Honorable Mention. The most recent RCA employee to be named the winner is **John G. N. Henderson**, RCA Laboratories, who was selected in 1977.

If you would like more information concerning this award program, refer to the July/August issue (29-4) of the *RCA Engineer*, or contact **Jim D'Arcy**, RCA Astro-Electronics, **Tacnet: 229-2359**. If you have ever been a member of Eta Kappa Nu, the RCA Technical Excellence Center in Princeton would like to know. Call **Gerry Moss** at **Tacnet: 226-2410**.

Materials symposium held at DSRC

A symposium entitled "Materials Characterization: Problems, Methods, Solutions" was held at the David Sarnoff Research Center on December 13, 1984. The purpose of the symposium was to illustrate the capabilities of the Materials Characterization Group at RCA Laboratories, and the all-day session featured oral presentations, a poster session, and lab tours.

Materials characterization is one of today's most rapidly changing areas of research, and its impact is felt in nearly every one of RCA's businesses. Interest is clearly widespread—the 288 people who attended represented 12 RCA business units:

RCA Laboratories, Astro-Electronics, Government Communication Systems, New Products Division, Consumer Electronics, Video Component and Display Division, Distributor & Special Products, Solid State Division, Broadcast System Division, Missile & Surface Radar, RCA Records, Solid State Technology Center.

David Richman, Director, Materials and Processing Research Laboratory, RCA Laboratories was the keynote speaker. In his opening remarks he said that "materials characterization is one of the more dynamic areas in research these days. It is also one of the most expensive to support. Capital equipment costs are usually in units of several hundred thousands of dollars, and they are going up rapidly. We have been very fortunate in that the management here [RCA Laboratories] has recognized the need to maintain a first-class materials characterization area and has supported us in maintaining a state-of-the-art capability."

Bill Harrington, Head, Materials Characterization Research, chaired the symposium, asked his audience if the Materials and Processing Laboratory is meeting the challenge.

"We are constantly pushed by your questions about more demanding materials, smaller dimensions, and more control processes. The real purpose of this symposium is to ask you if we are meeting those challenges."

There were eight presentations, with a concurrent poster session and self-directed tour of the Materials Characterization labs.

Papers presented:

Materials Characterization at RCA Labs: Are we meeting the challenges?

William L. Harrington

The Materials Characterization Group at the David Sarnoff Research Center is a centralized company resource, providing specialized skills and instruments (Methods) to aid in solving (Solutions) materials and process problems encountered in both research and manufacturing.

Scanning Electron Microscopy: The Cornerstone of Analysis

Edward R. Levin

There is already wide familiarity with the imaging capabilities of SEM, but relatively little general awareness of the range of information obtainable with the supplementary modes, such as energy-dispersive X-ray analysis, back-scattered electron detection, cathodoluminesence and electron bombardment-induced currents.

The Modern Transmission Electron Microscope as an Analytical Electron Optical Bench.

Joseph T. McGinn

The modern transmission electron microscope (TEM) has evolved into a highly versatile instrument. The intrinsic high magnification of the TEM has been combined with the ability to collect a variety of signals arising from the elctron beam-sample interactions.

Electron-Probe Microanalysis

Eugene P. Bertin

Electron-probe microanalysis is a non-destructive instrumental method of qualitative and quantitative analysis for chemical elements in microscopic regions by use of characterisitic x-ray spectra excited by a small-diameter electron beam ("probe").

Organic Mass Spectrometry: Fingerprinting Materials for the Electronics Industry.

P. Jane Gale

Analysis of organic materials used extensively in fabricating and processing semiconductor devices has received increased attention in recent years. At RCA Laboratories, mass spectral characterization of organic solids, liquids, or gases is accomplished with quadrupole mass spectrometers.

Infrared Spectroscopy: Applications to Materials Characterization

Peter J. Zanzucchi

Infrared spectroscopy is used to identify materials because every material has its own unique infrared spectrum. By this technique organic (e.g., plastics), inorganic (e.g., phosphors) and semiconductor (e.g., Czochralski grown silicon) materials can be identified and many of their properties determined (e.g., purity).

Electron Spectroscopy for Surface and Thin Film Analysis

John H. Thomas, III

Electron spectroscopy is a surface technique sensitive to the first few atomic layers of a material. Used with ion beam sputtering, this technique can measure the elemental composition of thin films with high in-depth resolution.

Secondary Ion Mass Spectrometry: A Thin Film Analytical Technique With Trace Element Sensitivity

Charles W. Magee

Secondary Ion Mass Spectrometry (SIMS) is a thin film analysis technique with very high sensitvity. In SIMS, an energetic (5 keV) ion beam impinges upon the sample causing the atoms of the outermost monolayer to be sputtered off.

Obituary

Waldemar J. Poch,
40 years with RCA

Waldemar J. Poch, a Life Member of the SMPTE, died October 13, 1984. Born in London, England, Mr. Poch was graduated from the University of Michigan with the BSEE degree in 1928, and from the University of Pennsylvania with the MSEE degree in 1954.

He began a distinguished 40-year career with RCA in 1930 at Camden, N.J., where, as member of the Research Group on Television Receivers and Studio Equipment, he was involved in pioneering developments in monochrome television cameras. One of his assignments with the Research Group, starting in 1937, was a 10-month tour of duty in the USSR, where he supervised the installation of television studio and transmitting equipment in Moscow.

His experience in Russia sparked an interest in that country, its people, and its language that continued throughout his life. Study of the language began even before his first expedition. In recent years, especially during retirement, he was a freelance translator of Russian technical literature into English.

Beginning in 1950, he became an Engineering Section Manager in charge of development and design of early color studio equipment. In 1959 he returned to the Moscow Television Center as a participant in the American Exhibition. In 1962 he joined RCA's Astro-Electronics Division, where he worked with a team of scientists and engineers on the analysis and prediction of radiation damage in satellite solar cells and on the devlopment of electron-beam film recording cameras. He retired from Astro-Electronics in 1970.

A registered professional engineer in New Jersey, Mr. Poch published numerous technical papers and held 31 patents. He was a Fellow of the Institute of Electrical and Electronic Engineers. Since the mid-fifties, he was member of the AIEE-IRE Committee on Video Techniques (which became the IEEE Audio-Video Techniques Committee), later serving as secretary until early in 1984.

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