COMSAT Laboratories Review

1994

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Since 1967, COMSAT Laboratories has conducted research and development to advance satellite communications technology. Portions of this effort were funded by COMSAT World Systems and paid for with revenues derived from international communications services carried via the International Telecommunications Satellite Organization (INTELSAT) satellite network. Other portions were funded by COMSAT Mobile Communications and paid for with revenues derived from international communications services carried via the Inmarsat satellite network. Work conducted for COMSAT World Systems and COMSAT Mobile Communications that is not paid for with such funds, as well as work conducted on behalf of other elements of the corporation (COMSAT Entertainment Group, COMSAT RSI, and COMSAT International Ventures), is shareholder-funded. Documentation concerning work funded by international communications services revenue is available to the public through the *COMSAT Data Catalog*, which announces the publication of relevant COMSAT Laboratories papers and reports.

In recent years, revenue sources outside the Corporation have accounted for approximately 50 percent of the total operating expenses for COMSAT Laboratories, with the U.S. Army, NASA, INTELSAT, and Inmarsat being our largest regular customers. Some of this work was undertaken as a subcontractor to other organizations with whom the Laboratories is allied. Important elements of this work include services such as subjective evaluation of voice codecs, life testing of satellite batteries, and antenna performance verification and qualification testing. Development and support funding (30 percent of the total) is increasingly being directed to nearer-term applications, which are undertaken by the Laboratories on a contract-like basis with the various lines of business of the Corporation. The balance of funding (20 percent) goes to various research programs to advance technology, with the goal of developing products and improving communications systems cost and performance over the long term.

The Laboratories supplies hardware for highly specialized applications, and emphasizes the transitioning of Laboratories-developed technology to the marketplace. A new activity for the Laboratories in the technology transfer arena culminated in 1994 with an equity investment in a small company—Superconducting Core Technologies—through which our filter design expertise can be brought to market.

The capabilities, products, and services of COMSAT Laboratories are available to both commercial and government enterprises. We invite further inquiry regarding our products, services, or license opportunities. Contact information is provided on the inside back cover of this Review.

J. V. Evans

John V. Evans
President, COMSAT Laboratories

The Laboratories Today

COMSAT Corporation was created in 1963 following passage of the Communications Satellite Act, signed into law by President Kennedy in late 1962. When the International Telecommunications Satellite Consortium (INTELSAT) was established in 1964 to facilitate international communications between fixed points by satellite, COMSAT was named its U.S. Signatory. Initially, INTELSAT had 11 participants. This number has since grown to 136 member countries, with service being provided to 200 nations.

Today, COMSAT Corporation comprises four separate operating divisions:

COMSAT International Communications (CIC) was formed in mid-1995 to direct three existing divisions which have a common focus in the global telecommunications arena. *COMSAT World Systems* (CWS) provides voice, data, video, and audio communications services on the INTELSAT network and serves as U.S. Signatory to INTELSAT. *COMSAT Mobile Communications* (CMC) provides mobile communications to maritime, aeronautical, and land mobile customers using the Inmarsat satellite system, and serves as U.S. Signatory to Inmarsat. It is also investing in a company formed to provide satellite-based handheld communications services by the turn of the century, using a new system of intermediate-orbit satellites. *COMSAT International Ventures* (CIV) develops, acquires, and manages telecommunications companies in high-growth overseas markets.

Melvin R. Laird
Chairman of the Board
COMSAT Corporation

John V. Evans
President
COMSAT Laboratories

Bruce L. Crockett
President & CEO
COMSAT Corporation

COMSAT Entertainment Group (CEG) is a full-service entertainment company that produces major theatrical, film, and television entertainment, as well as live television sports; owns and operates the NBA *Denver Nuggets* and Colorado's new NHL franchise, the *Colorado Avalanche*; manages arena and theme park interests; and provides on-demand information and entertainment to hotels.

COMSAT RSI (CRSI) was created in 1994 by combining Radiation Systems, Inc., of Sterling, Virginia, with COMSAT Technology Services (CTS) to provide turnkey communications systems, systems integration, and consulting services, and to place increased emphasis on transitioning Laboratories technology to profitable business applications.

COMSAT Laboratories is the central R&D organization for COMSAT Corporation. It was formed in 1967 to help the Corporation meet the challenges associated with its role as technical manager of INTELSAT—a role it fulfilled from INTELSAT's inception until 1979. Initially located in Washington, D.C., COMSAT Laboratories moved to its present quarters in Clarksburg, Maryland, in 1969. Today, it occupies approximately one-third of a 360,000-square-foot facility on a 230-acre tract along Interstate 270, about 35 miles north of Washington, D.C.

This Review summarizes COMSAT Laboratories' recent research, development, and applications activities. It is organized by areas of technology, as represented by the Labs' four divisions: Network Technology (NTD), Communications Technology (CTD), System Development (SDD), and Satellite and Systems Technologies (SSTD).

About half of the work performed at COMSAT Laboratories is won through competitive bidding. Major customers include the U.S. Army, the U.S. Air Force, NASA, INTELSAT, and Inmarsat. The balance of the Laboratories' work is performed for internal proprietary programs or for the regulated activity of international communications, either directly or indirectly via INTELSAT and Inmarsat. This work is directed toward solving operational problems; participating in standards creation; and developing future systems, services, and products.

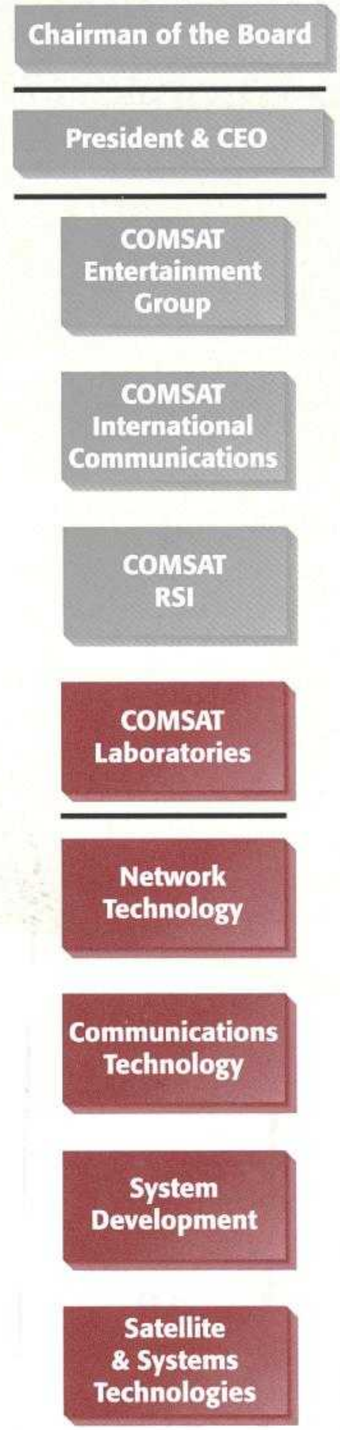
The significance of COMSAT's pioneering contributions to the advancement of satellite technology was recently affirmed when NASA honored the COMSAT Laboratories team responsible for designing and developing the network system management and control software and the TDMA equipment for NASA's Advanced Communications Technology Satellite (ACTS) program.

In this new era of telecommunications deregulation and intense competitive pressure, there is increasing interest in reducing the time lag from the conception of new ideas to their field application. Today, COMSAT Laboratories is focusing its energies on this objective. New approaches, applications, and activities that form the basis for future products are described in this Review. For additional product information, or teaming or licensing opportunities, contact the persons listed on the inside back cover.

Join us . . . and become part of COMSAT's seamless communications window to the world!

William L. Cook, *Vice President*
System Development Division
Benjamin A. Pontano, *Vice President*
Network Technology Division

Christoph E. Mahle, *Vice President (retired)*
Satellite & Systems Technologies Division
Russell J. F. Fang, *Vice President*
Communications Technology Division
Albert E. Williams, *Vice President*
Satellite & Systems Technologies Division



1994 RIM Committee

Overseeing the R&D activities of the Laboratories and other corporate entities, and related business concerns, is the Committee on Research and International Matters (RIM), one of five standing committees of COMSAT's Board of Directors. The RIM Committee also considers and makes recommendations to the Board on matters relating to the Corporation's international activities and responsibilities under the Communications Satellite Act.

STANDING, FROM LEFT: Howard M. Love, Rudy Boschwitz, Lucy Wilson Benson, Peter W. Likins (Chairman), Peter S. Knight, Dolores D. Wharton. SEATED: Barry M. Goldwater, Melvin R. Laird.

Network Technology

The Network Technology Division (NTD) performs research and development related to the analysis, design, implementation, and product development of advanced satellite- and terrestrial-based communications systems. ◆ Areas of application include satellite networks, integrated services digital networks, data communications and protocols, time-division multiple access, onboard baseband switching and processing, intelligent systems, and optical communications and processing. ◆ NTD activities range from conducting studies to implementing hardware- and software-based systems. ◆ NTD's work encompasses fixed and mobile satellite networks, the interworking between satellite and terrestrial networks, and terrestrial wireless networks.

ADVANCED VSAT

Recent developments in satellite and communications technologies, along with increasing demand for advanced user services, have created new opportunities for advanced satellite-based networks. Ongoing R&D in the Network Technology Division (NTD) covers a broad spectrum of satellite networking technologies. These include time-division multiple access (TDMA), high-density programmable digital hardware design, advanced modem and codec design, data networking and satellite-efficient protocols, local area network/wide area network (LAN/WAN) interconnect technologies, integrated services digital networks (ISDNs), frame relay, asynchronous transfer mode (ATM), real-time software development, and advanced network management systems. This R&D has led to the rapid development of several key next-generation satellite networks.

These networks offer the low cost and small size of very small aperture terminals (VSATs); data rates from 64 kbit/s to 16 Mbit/s, previously found only in high-end systems; and the functionality and flexibility of dynamic bandwidth on demand, ISDN, packet switching, and LAN interconnection. With such systems, COMSAT can offer its customers flexible, efficient, on-demand full-mesh networking that supports major telecommunications and data interfaces and protocols.

Bandwidth on Demand I

The Bandwidth on Demand I (BOD-I) system, developed by NTD for COMSAT World Systems (CWS), is a variable-rate, on-demand, single-channel-per-carrier mesh network. BOD-I is ideal for service providers and private businesses that require point-to-point and point-to-multipoint connections among geographically disparate sites. The system can carry voice, data, video, or fax traffic, and offers metered, clear channel connections at data rates from 56 kbit/s to 2.048 Mbit/s, with selectable modulation and forward error correction (FEC). Satellite channels may be requested at a BOD-I site via a dial-up modem, or automatically by a customer using V.25 bis signaling protocol, which is supported by a variety of data communications devices such as routers, video codecs, and intelligent multiplexers. In addition, periodic scheduled (time-of-day) or ad hoc connections can be defined at the network management station (NMS). The SUN-workstation-based NMS uses open systems standards such as UNIX, X Window, and Motif. Remote stations can be fully monitored and controlled from the NMS, even when they are actively engaged in calls.

RIGHT: The Bandwidth on Demand system provides efficient multimedia services such as desktop videoconferencing.

Satellite BOD-II TDMA System

The satellite BOD-II TDMA networking product, also developed for CWS, offers advanced, full-featured multimedia user interfaces for voice telephony, video teleconferencing, and data communications, based on the standard ISDN primary rate interfaces (PRIs) for both 23B+D and 30B+D. Data services are targeted to the rapidly expanding LAN/WAN interconnect market.

An innovative multi-transmission-rate, multicarrier TDMA approach provides network bandwidths sufficient for large user networks that operate with either domestic loopback satellites or the non-loopback spot beam configurations characteristic of INTELSAT satellites. COMSAT is licensing this technology to interested parties who can effectively manufacture, market, and support the product.

ATM VIA SATELLITE

NTD has conducted a series of experiments and demonstrations of ATM via satellite for the Defense Information Systems Agency under the Commercial Satellite Communications Initiatives (CSCI) contract. The ATM communications standard defines the efficient transport of multimedia information and offers bandwidth-on-demand capacity to system users. During the experiment phase, tests were undertaken to quantify the impact of satellite propagation delay and bit error characteristics on the operation of the Physical Layer Convergence Protocol

Network Architectures

Asynchronous Transfer Mode

TDMA

Bandwidth on Demand

Frame Relay

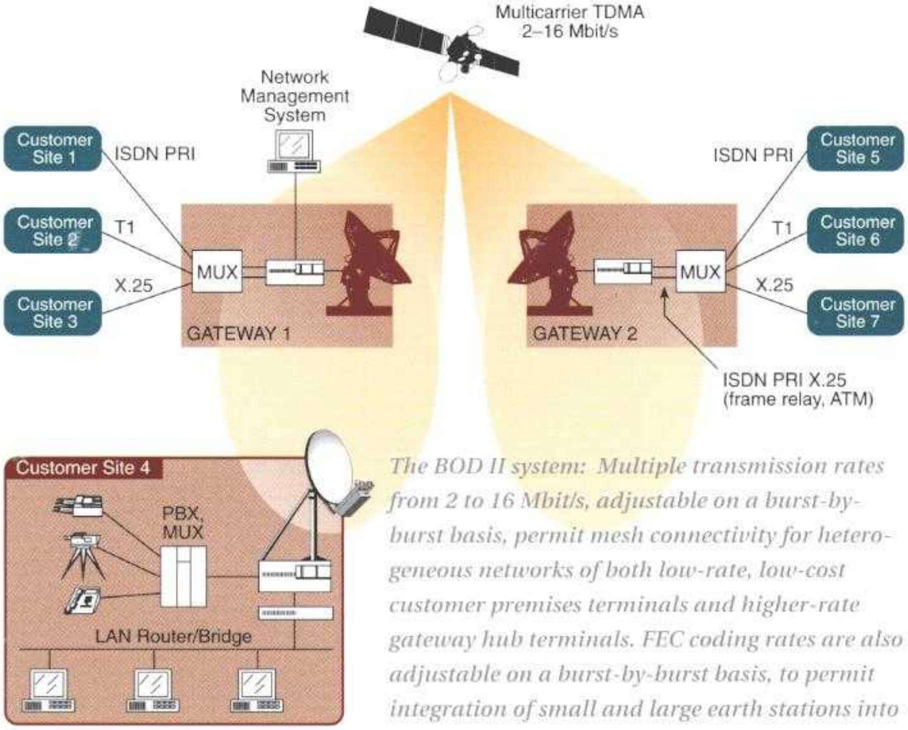
ISDN

Onboard Processing

Fast Packet Switching

Optical Communications

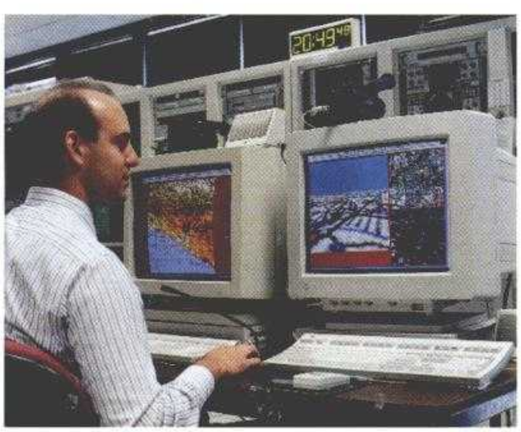
Data Protocols



The BOD II system: Multiple transmission rates from 2 to 16 Mbit/s, adjustable on a burst-by-burst basis, permit mesh connectivity for heterogeneous networks of both low-rate, low-cost customer premises terminals and higher-rate gateway hub terminals. FEC coding rates are also adjustable on a burst-by-burst basis, to permit integration of small and large earth stations into the network.

(PLCP), ATM, the ATM adaptation layer (AAL), the Service-Specific Connection-Oriented Protocol (SSCOP), and the Transmission Control Protocol (TCP) over 45-Mbit/s satellite links.

Some of the major conclusions drawn from the experiments were: ◆ The ATM link enhancer (ALE), developed for CWS, significantly improves the ability to maintain physical layer framing in a burst error environment and reduces ATM cell loss probability by several orders of magnitude. ◆ The SSCOP performs at high efficiency in both error-free and degraded satellite environments. ◆ In a satellite environment, SSCOP clearly provides better throughput performance than TCP, which experiences serious degradation due to satellite delay. ◆ Backward explicit congestion notification via resource management cells (BCN RM) outperforms forward explicit congestion notification by orders of magnitude in terms of cell loss ratio. BCN RM was successfully implemented on the ATM switch, and rate controllers were developed by COMSAT for the ATM workstations.

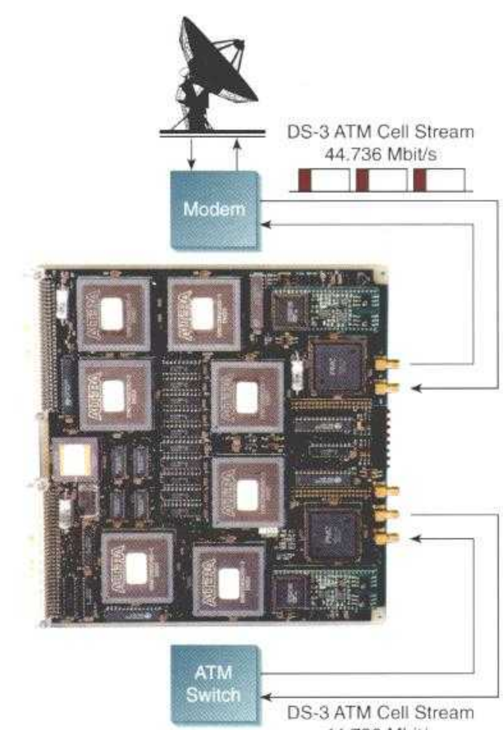


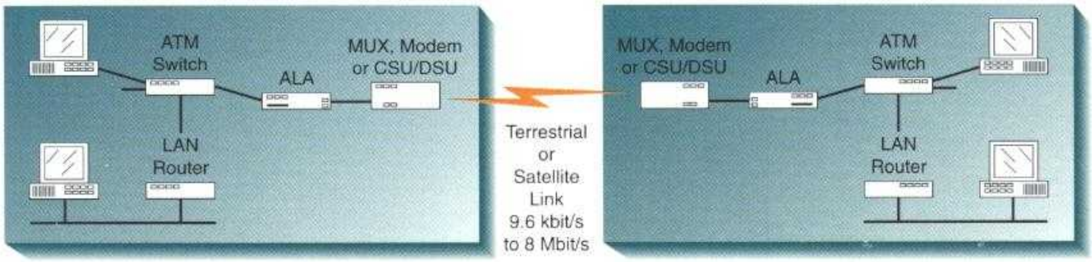
ABOVE: During the demonstration phase, a number of applications were integrated into the ATM Satcom system. Telemedicine, interactive mission planning, meteorological data access, videoconferencing, and high-speed file transfer operated simultaneously as statistically multiplexed ATM traffic over the satellite link. RIGHT: The ATM link enhancer provides fiber-equivalent cell loss ratio over 45-Mbit/s satellite links.

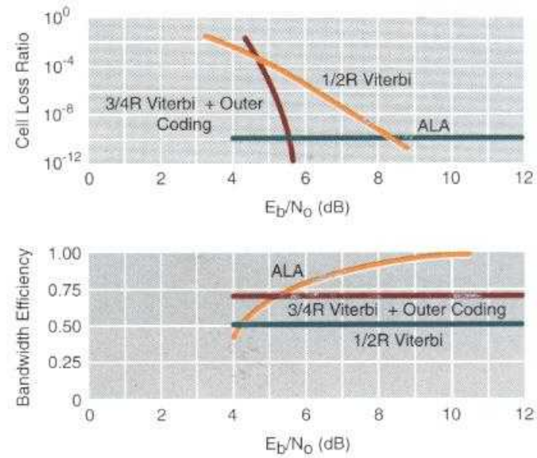
ATM Link Accelerator

The COMSAT ATM link accelerator (ALA) allows customers to significantly improve network performance and reduce the cost of WAN ATM links, especially satellite or terrestrial wireless links. The ALA offers powerful cell-based, Reed-Solomon-based FEC, providing fiber-like link quality over noisy satellite or wireless point-to-point links. With its adaptive coding mechanism, the ALA can dynamically change the Reed-Solomon coding rate, as well as the modem Viterbi coding rate (depending on the quality of the link), for higher throughput on "clear" days. The ALA supports a variety of interfaces to the ATM switch (DS-3, E3, T1, E1, and RS-449) and connects to the WAN equipment using a programmable-rate RS-449 interface. These interfaces allow ATM equipment to be connected over nonstandard-rate WAN links.

The ALA can perform lossless data compression of selected ATM virtual circuits, thereby doubling or tripling the effective link rate for ATM available bit rate (ABR) traffic and reducing the need to upgrade expensive leased or dial-up data lines. The ALA includes the COMSAT Time Sequence Protocol (TSP), which provides data integrity and very high throughput performance







LEFT: The ATM Link Accelerator (ALA) interconnects ATM switches over satellite and wireless links at up to 8 Mbit/s. It offers adaptive coding, data compression, and congestion control to provide fiber-like quality and enhanced throughput for ATM traffic. BELOW: Demonstrated improvement in cell loss ratio performance (TOP) and bandwidth efficiency (BOTTOM) with the ALA.

over terrestrial, single-hop satellite, and double-hop satellite links. TSP uses a sophisticated selective retransmission strategy and continuously adapts its algorithms and parameters based on link quality.

The ALA is easy to install into existing customer networks. It is inserted between the user ATM switch and the WAN transmission device (modem, multiplexer, or channel service unit/digital service unit [CSU/DSU]). No changes are necessary to end user equipment or protocols.

ONBOARD PROCESSING

ATM Onboard Switching Demonstration Payload

Future technical telecommunications networks will be ATM-based and will provide multimedia services.

For NASA's post-ACTS (Advanced Communications Technology Satellite) era, NTD has developed a concept for a low-cost satellite system which includes the experimental payload and ground segment architectures. The experimental payload architecture centers around an onboard fast packet switch capable of supporting ATM traffic from four earth stations. Continuous transmission through four high-gain, steerable spot beams is used to access the payload. The onboard processor, which processes uplink packets containing ATM cells, employs commercially available chips for Reed-Solomon decoding and for the fast packet switch fabric. Application-specific integrated circuits (ASICs) perform the input and output functions associated with the switch.

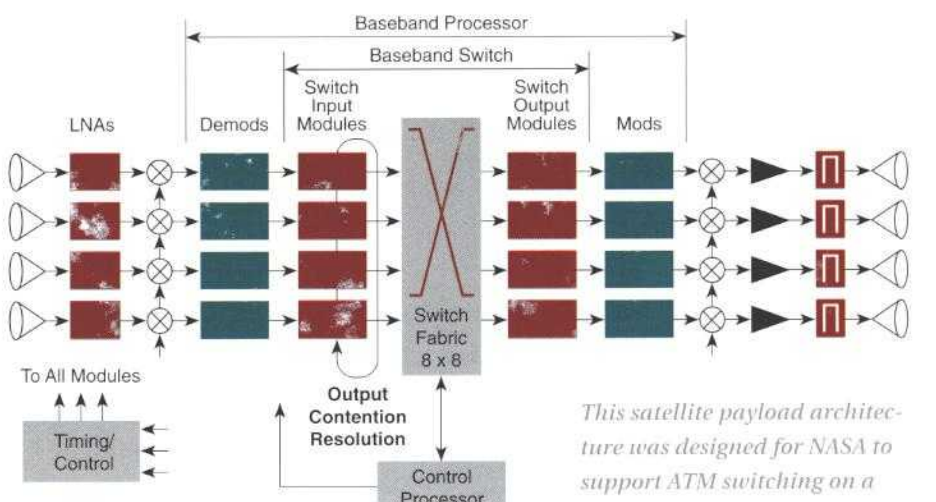
Satellite Onboard ATM Switch

Under NASA sponsorship, NTD has developed an engineering model of an onboard multicast ATM switch and test bed that can be used to evaluate switch contention and congestion algorithms for ATM traffic. The model is implemented as an 8 x 8 switch with input and output ports operating at 164.24 Mbit/s. The switch fabric is implemented as a data-directed space switch capable of supporting data rates of 1.6 Gbit/s.

The test bed was developed to demonstrate and characterize the flexibility of an onboard fast packet switch, and to gain a better understanding of the problems associated with the operation of such a switch for onboard applications.

Baseband Switch

NTD has designed and developed a fiber optic baseband switch for satellite onboard applications. The switch provides for interconnection between four input and four output transponders at rates up to 155 Mbit/s, or up to eight input and eight output transponders at 78 Mbit/s. Interconnection is also provided between different services and modulation formats (e.g., frequency-division multiple access/intermediate data rate [FDMA/IDR] on the uplink and high-speed TDMA on the downlink). The design is suitable for both circuit switching (e.g., 120-Mbit/s TDMA) and packet



This satellite payload architecture was designed for NASA to support ATM switching on a small satellite bus.

Top left: The satellite onboard ATM switch test bed will be used to characterize the performance of onboard fast packet switching. Center left: NTD's baseband switch employs destination-directed (packet) switching over a 1-Gbit/s fiber optic ring.

switching (e.g., 155-Mbit/s ATM), and has multicast and broadcast switching capability. On-line status monitoring and redundancy switching control are also provided.

Optical Technology for Satellite Networking

The objective of COMSAT's photonic R&D is to reduce the mass, power, and size of the onboard processing payload, and consequently, payload and launch costs. NTD's photonics projects include systems architecture and technology tradeoff studies, analyses, and design. The Division has also developed proof-of-concept hardware to demonstrate the feasibility of using onboard photonics in beam-forming and steering, multicarrier demultiplexing, and switching and data routing.

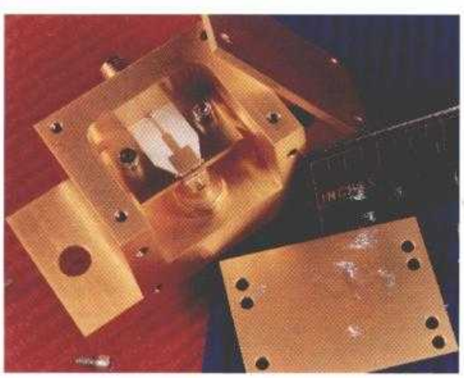
A tradeoff study on the frequency-agile optical beam-forming of phased-array antennas was performed for SPAR, Canada. NASA, under the In-Space Technology Program (IN-STEP), recently awarded COMSAT a project to develop a flight demonstration and experiments on photonic beam-forming. Also, NTD designed a high-reliability fiber optic network for use in rain diversity links for the new handheld I-CO Global Communications system.

The photonics hardware developed by the Division includes a reactively matched broadband optical transceiver that demonstrates more than 32-dB improvement in RF-optical-RF conversion loss (typically 45 dB in commercial optical links), with an in-band ripple of less than or equal to 0.5 dB. In addition, NTD's electro-optic polymer channel waveguide devices exhibit some of the best overall performance characteristics reported to date. Both of these components will serve as building blocks for compact, lightweight onboard satellite systems.

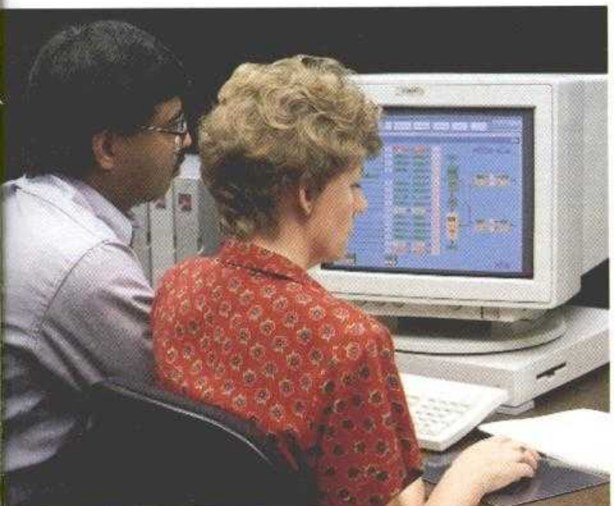
SECOND-GENERATION TDMA

The second-generation INTELSAT 120-Mbit/s TDMA terminal currently under development in NTD reduces the large, 12-rack, first-generation equipment into a single rack. In addition, the terminal's efficiency, operation, monitoring, and self-testing are improved.

NTD has also developed a second-generation operation and maintenance center (OMC) for use with first-generation INTELSAT TDMA equipment. Employing state-of-the-art display and workstation technology, the new OMC has



Three examples of optical technology ideally suited for satellite applications: Left: an impedance-matched high-efficiency microwave-optical transmitter; Center: a true time-delay fiber optic beam-forming matrix for C-band phased-array antennas; Right: an integrated optical waveguide and power splitter using state-of-the-art nonlinear materials. Each optical technology reduces onboard mass and power for lower satellite and launch vehicle costs.



NTD personnel demonstrate the TDMA status screen of the user-friendly terminal in the Operations & Maintenance Center. The screen displays the status of each element of the second-generation TDMA terminal, from the up- and down-converters to the terrestrial interfaces. From the console, a user can easily update terminal configuration and operational parameters.

dramatically reduced operator errors and significantly decreased equipment size.

In conjunction with the second-generation OMC, a new direct digital interface (DDI) has been developed for use with first-generation TDMA equipment. The DDI permits the direct connection of 2.048-Mbit/s primary multiplex carriers, from switching centers or digital circuit multiplication equipment (DCME), to the first-generation INTELSAT TDMA terminal.

The DDI can accommodate as many as 40 on-line, 2.048-Mbit/s primary multiplex carriers and provides 1-to-N redundancy, while significantly decreasing equipment size.

The new OMC and DDI equipment has been installed in AT&T's INTELSAT earth stations. Both developments drew on the expertise of AT&T earth station personnel to craft user-friendly, efficient OMC operator interfaces and to incorporate on-line self-analysis features into the DDI.

SEAMLESS INTEGRATION OF SATELLITE & TERRESTRIAL NETWORKS

Wide Area Communications Server

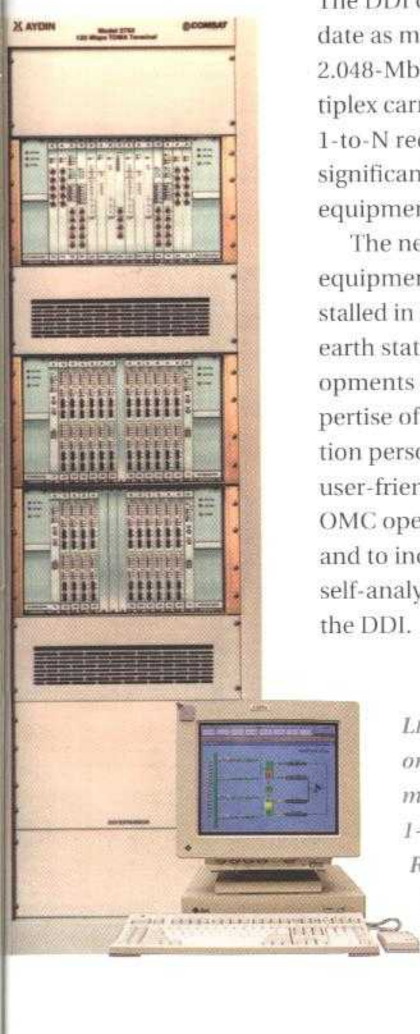
The COMSAT Wide Area Communications Server (WACS) allows customers to significantly improve network performance and reduce the cost of WAN data links. The WACS was developed for NASA's Jet Propulsion Laboratory for use in its Deep Space Information Network. With its data compression feature, the WACS can double or triple the effective link rate, thereby reducing the need for NASA to upgrade expensive leased lines.

Even with satellite links operating at bit error ratios (BERs) of 10^{-4}, with the COMSAT TSP, the WACS provides 70- to 80-percent throughput before compression. By using a sophisticated selective retransmission strategy and continuously adapting its algorithms and parameters based on link quality, COMSAT's TSP significantly outperforms standard retransmission protocols such as TCP, TP-4, LAP-B, and LAP-F.

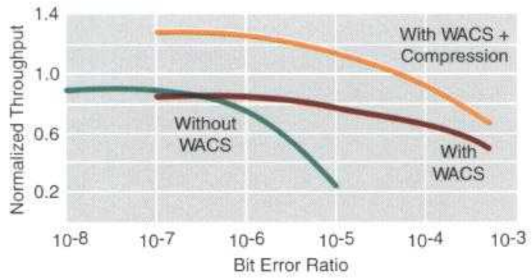
Data Communications

With the increasing use of personal computers, workstations, and LANs, data communication is one of the fastest growing segments of the communications market. In response, NTD is developing technologies to improve the efficiency of data communications over satellite circuits.

The X.75 protocol is used to interconnect national public data networks. Converter units developed for INTELSAT provide for efficient use of the protocol over satellite links. As part of this project, a satellite-efficient



LEFT: The terrestrial interface capability of NTD's second-generation TDMA terminal, now under development, is expandable from 2 to 32 E-1 interfaces, with 1-to-N redundancy to accommodate any size user.
RIGHT: This OMC, along with NTD's new direct digital interface, has been installed at two of AT&T's INTELSAT earth stations.



With the WACS, transmission control protocol/Internet protocol (TCP/IP) transfer performance is significantly improved.

protocol was developed which incorporates multi-selective reject error recovery to provide throughput efficiency greater than 75 percent, even in the presence of degraded link BER conditions (10^{-5}). The protocol converter also incorporates an advanced multiprocessor architecture that can support multiple X.75 links operating at 2.048 Mbit/s.

ACTS Frame Relay

The ACTS frame relay access switch (FRACS) developed at COMSAT Laboratories by NTD provides a BOD frame relay interface to the NASA ACTS TDMA network. The FRACS transports LAN packets over ACTS TDMA circuits, and dynamically allocates ACTS circuits between different pairs of sites, based on an adaptive, rate-based bandwidth management scheme.

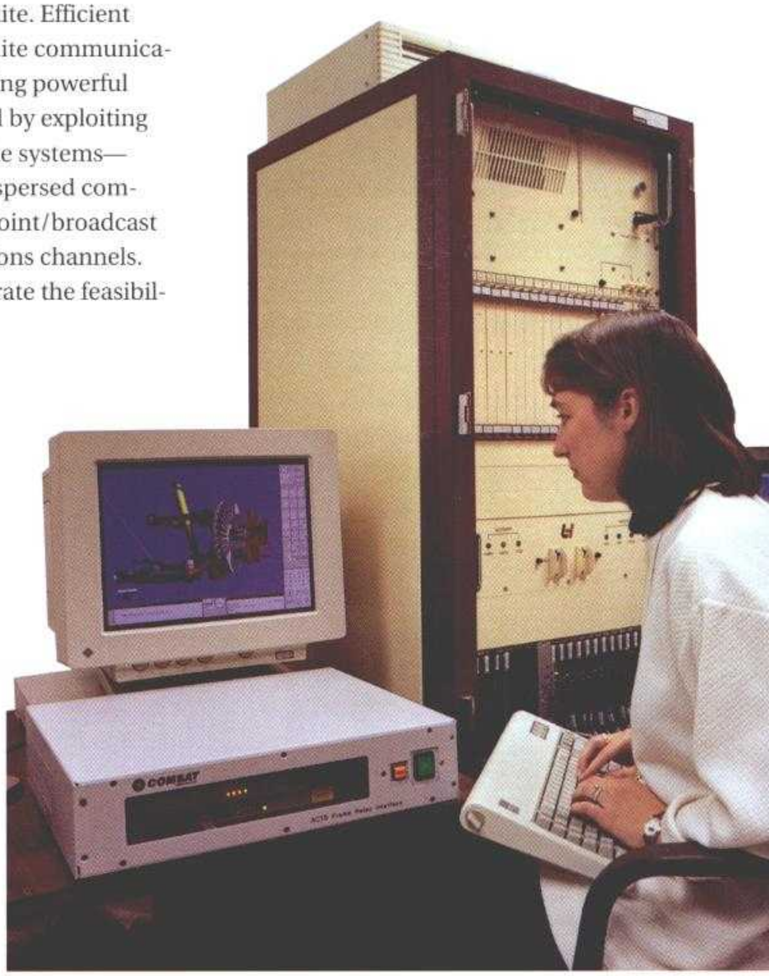
ISDN

ISDN Satellite Switch—Under the sponsorship of CWS, NTD developed the ISDN Satellite Switch (ISS) to provide high-quality, cost-effective ISDN services via satellite. Efficient integration of ISDN with a satellite communications network is achieved by using powerful out-of-band ISDN signaling and by exploiting the strengths inherent in satellite systems—their accessibility to a widely dispersed community of users, and the multipoint/broadcast nature of satellite communications channels. The ISS is intended to demonstrate the feasibility of this integration.

The effectiveness of carrying ISDN traffic over satellites was demonstrated through field trials using the ISS and the AT&T Integrated Access Terminal (IAT). The functionality of the ISS, the ISDN access capability, resource allocation on demand, better transport through the satellite network, and switching directives all complement the IAT, which packetizes, compresses, and cross-connects different types of traffic.

ISDN, SDH & ATM via INTELSAT—INTELSAT contracted with NTD to assist in ensuring that INTELSAT's global satellite communications system can function as a subnetwork of developing international public telecommunications networks such as ISDN, future broadband ISDN (BISDN), and synchronous digital hierarchy (SDH) transport network infrastructures. Under this contract, NTD developed top-level specifications for satellite subnetworks and their functional subsystems, and analyzed the performance of the subnetworks. Details of the functional integration between the satellite subnetworks and the interconnected ISDN terrestrial network elements were also developed.

In a related activity, NTD led the development of international standard Q.768, which governs signaling between a satellite subnetwork and an international ISDN gateway. Prior to Q.768, if an international call request arrived at an outgoing ISDN switching center, the switch permanently assigned an appropriate trunk between the outgoing and incoming international switches. As a result, satellite capacity could lie idle, depending on traffic intensity. Q.768 signaling allows international switching centers to request a satellite circuit on a per-call basis.



RIGHT: The frame relay access switch offers an International Telecommunication Union-Telecommunications Sector standards-compatible interface that can be used to interconnect any number of LANs, workstations, and personal computers over the ACTS system.

Mobile Satellite/Terrestrial Interworking

Mobile communications is another fast-growing area of telecommunications. NTD has focused its research in this area on mobile network architectures and the interoperation of terrestrial and satellite mobile communications systems.

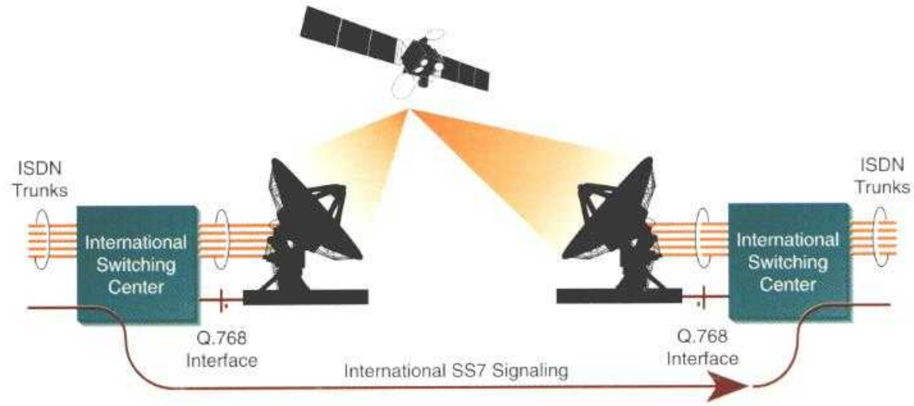
The Division has evaluated the networking capabilities of the European Global System for Mobile (GSM) cellular system and the North American D-AMPS digital cellular system, including the respective GSM and IS-41 mobile application port (MAP) network signaling necessary for roaming and call handoffs. These networking capabilities, together with intelligent network functionality, will provide for the extension of personal communications services to satellite networks.

MOBILE SATELLITE NETWORKS

Inmarsat-B High-Data-Rate Gateway Switch

The Inmarsat-B system supports high-data-rate (HDR), 56/64-kbit/s services to mobile users. NTD designed, developed, delivered, and installed HDR gateway switches (HGSs) for COMSAT Mobile Communications (CMC) that allow CMC to extend the terrestrial ISDNs offered by regional Bell operating companies and interexchange carriers (IXCs) to be available to mobile terminals anywhere in the world via CMC's land earth stations (LESs) in Connecticut, California, and Malaysia. The HGS also allows mobile-to-mobile HDR calls within the same ocean region, and from any ocean region to any other, worldwide. The gateway switch complements the existing CMC service offerings of Inmarsat-B low-speed (9.6-kbit/s) voice, data, and facsimile.

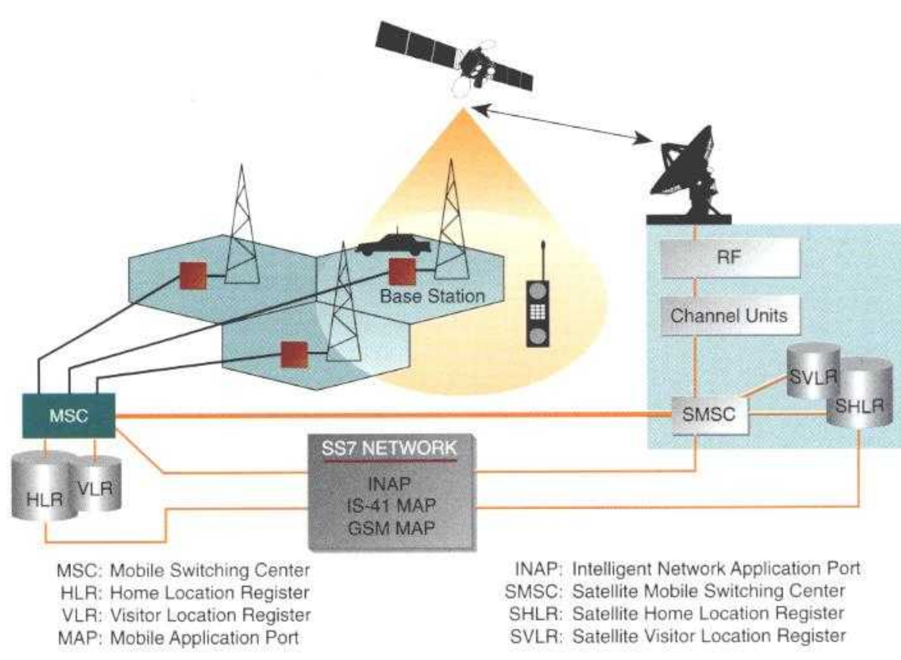
The HGS interfaces to the access and control equipment (ACE) within the CMC LES for the exchange of signaling messages, and with HDR channel units for receiving and transmitting data to the mobile terminal. For connectivity to the fixed user, the HGS interfaces to switched 64-kbit/s IXC networks in accordance with the PRI ISDN specifications defined by the International Telecommunication Union-Telecommunications Sector (ITU-T) and the American National Standards Institute (ANSI). The HGS compensates for all incompatibilities between the D-channel signaling to the terrestrial network, and the signaling to the ACE/Inmarsat-B terminals. Inter-HGS connectivity is also supported to minimize terrestrial connectivity requirements at each HGS site and to support HGS calls between mobile terminals in different ocean regions. To facilitate diagnostics and testing, the HGS provides for 56/64-kbit/s test ports, as well as a user-friendly operator interface for configuration, accounting, and fault management.



ITU-T Recommendation Q.768 enables satellite network managers to control their internal capacity more efficiently and improve the quality of service for calls routed on satellite circuits.

Aeronautical Broadcast

COMSAT's FlightNews™ service, which was successfully demonstrated by NTD, uses idle capacity on the Inmarsat Aeronautical P channel to broadcast up-to-the-minute teletext news and graphics to CMC's commercial and general aviation customers. This unique value-added service can be made available to passengers on commercial long-haul transoceanic flights, as well as those on corporate jets. For the demonstration, live news stories culled from



The ultimate goal of mobile communications is seamless intersystem operation that will allow users with dual-mode terminals to roam transparently between terrestrial cellular and mobile satellite systems for truly global service.

The high-data-rate gateway switch enables CMC to provide switched 56/64-kbit/s services to mobile users throughout the world.

wire services were composed at workstations in Liverpool, England, and deposited at COMSAT's multicast communications server at Clarksburg, Maryland. The COMSAT-developed Aeronautical Multicast Messaging Protocol was then used to broadcast the stories from COMSAT's ground earth station in Santa Paula, California, via an operational P channel, to the Inmarsat Pacific Ocean Region. The news was received by an E-Systems airborne earth station and displayed on video monitors.

Network Architecture for I-CO Global Communications

COMSAT Corporation has made a major commitment to a next-generation mobile satellite system employing handheld terminals. A key aspect of this system is the terrestrial network architecture that will link the central satellite access nodes and provide interworking and access to public switched telephone networks (PSTNs) and data networks. NTD has supported the development and definition of the ground network architecture for the I-CO Global Communications system.

The Division has provided both networking expertise and technical analyses in support of CMC's I-CO Global investment. NTD introduced system design modifications and encouraged a network architecture and service philosophy aimed at securing the optimum level of service provision and control for national service wholesalers. It is also engaged in establishing system and service architectures by which CMC's current network operation can evolve toward the services I-CO Global will deliver in the future.

NTD continues to study the networking and control aspects of the new handheld I-CO Global system, focusing on the development of ground segment architectures based on elements employed in current terrestrial mobile systems, such as switches and databases. Investigations of call handoff and global roaming in a global mobile satellite system were undertaken, and requirements for interworking with European and U.S. mobile systems have been identified. In addition, NTD developed a simulation model to assess the coverage capabilities of various ground segment scenarios and to model the dynamic traffic loading of the spacecraft onboard processor. This effort included investigation of the efficiencies of alternate demand-assigned multiple access (DAMA) control and signaling architectures for a geostationary satellite system, and simulations to determine optimum architectures for such a system.

NTD has been actively involved in the Inmarsat-P Network Experts team, developing specifications for the terrestrial network and chairing Network Expert working group meetings. The Division was responsible for writing the first version of the terrestrial network specification and conducting data and telephony requirements analyses for the Inmarsat-P network. NTD is currently supporting the Network Experts working group in the areas of network service architectures, terrestrial interconnections, and terrestrial call routing. The Division is also providing technical supervision of development activities for the high-power short-message service.

FlightNews™ text and graphics can be viewed on overhead monitors on commercial aircraft.

Intelligent Networks

Intelligent networking will play a key role in future mobile satellite communications. By providing the infrastructure needed to manage sophisticated mobility services in both wired and wireless networks, intelligent networking will allow mobile satellite service providers to extend into their networks the services currently offered in terrestrial networks. NTD has conducted a study of emerging intelligent network architectures and standards, focusing on their application to Mobile Satellite Service. Services supported by the current Bellcore and ITU capability sets were investigated, and the potential for using intelligent networking to perform mobility management functions in next-generation mobile satellite systems was assessed.

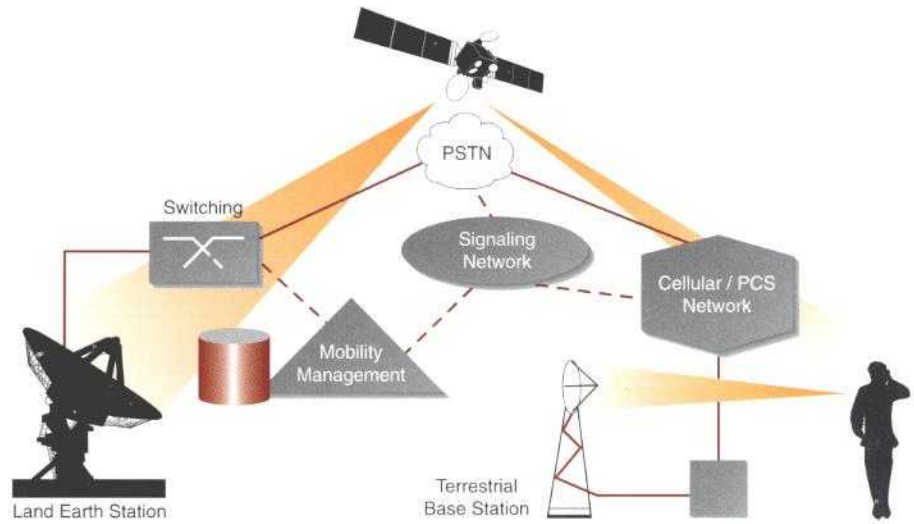
TERRESTRIAL WIRELESS NETWORKS

Wireless Local Loop

Telecommunications service providers the world over are evaluating cost-effective alternatives for deploying telephone services in the local loop. The wireline technology traditionally used for this purpose incurs a significant cost (approximately $2,500 per subscriber), especially in sparsely populated areas. Radio access, which is used extensively for mobile communications, has the potential to reduce this cost to under $1,000 per subscriber. In view of the large market projected for radio access technology, NTD is currently designing and developing a wireless local loop product which draws upon years of experience and incorporates technology previously developed for satellite communications systems. The satellite technologies being incorporated into the product include TDMA, multiplexing, switching, PSTN interfaces, protocols, real-time communications software, and network management systems.

A joint product development and marketing agreement has been established between NTD and Aydin Telecom for development of the Aydin DigiCall™ wireless local loop product line. The product is based on GSMLite™ technology, a streamlined version of the internationally accepted GSM specifications. By simplifying the networking architecture and eliminating requirements associated with mobility management, GSMLite™ enables fixed wireless local loop users to enjoy the benefits of GSM without incurring the cost overhead. The DigiCall™ product also incorporates Aydin's proprietary half-rate vocoder and fax/data technology to improve bandwidth efficiency and quality of service. NTD has primary responsibility for software development, while Aydin is responsible for hardware and firmware development and product manufacturing.

The DigiCall™ product has two primary components: the central office terminal (COT) and the base transceiver station (BTS). The COT consists of the network access subsystem, which interfaces to the local exchange and implements the call control functions, and the base station controller, which manages the radio resources. The BTS includes multiple transcoder and rate adapters that implement the vocoder and fax/data interworking functions, as well as transceivers that implement the channel coding, framing, and modulation/demodulation functions. To deal with the regulatory environments in different countries, the product is designed to be flexible in the RF band. In addition to supporting the standard 900-MHz and 1.8-GHz frequency bands, the product can be configured to support other bands of operation. It also supports both custom-made fixed subscriber units that interface to two-wire telephones, and commercial off-the-shelf GSM handsets.



The support of dual-mode satellite/cellular handsets will be a key aspect of the I-CO Global Communications system.

The high-data-rate gateway switch is installed at the Southbury and Santa Paula land earth stations.

Communications Technology

The Communications Technology Division (CTD) at COMSAT Laboratories focuses on the communications aspects of end-to-end circuit connections in order to maximize bandwidth efficiency and signal quality while reducing operating and equipment costs. ◆ The Division's business and R&D efforts are concentrated in the areas of wireless voice, data, facsimile, broadband video, and multimedia, as well as on new technologies and their incorporation into leading-edge commercial products. ◆ CTD also offers specialized test and evaluation services that profit from the experience and laboratory facilities it has developed in over 25 years in the industry. ◆ CTD's work encompasses transmission, video, and voice frequency-band processing; systems simulation; and systems analysis and synthesis. ◆ CTD conducts studies and produces algorithms, software, and hardware for both experimental and commercial applications. ◆ The hardware ranges from ASIC-level implementations to fully integrated systems—all produced to the highest standards of quality and performance.

RIGHT: Using COMSAT's extensive satellite simulation facilities, a CTD engineer performs detailed measurements to evaluate the performance of advanced transmission technologies.

ADVANCED COMMUNICATIONS TECHNOLOGY R&D

The historical focus of efforts within the Communications Technology Division (CTD) has been on R&D. While CTD is expanding into product and specialized service businesses, its R&D capability will continue to serve COMSAT corporate customers, as well as government and industry. Highlighted below are some of CTD's accomplishments in the areas of source processing and compression, modulation/channel coding/multiple-access, and communications systems analysis and design.

Communications Systems Analysis Engineering & Design

In this area, the operative word is "systems," suggesting multidisciplinary work which focuses on developing tradeoffs in system-level designs in order to maximize the quality and cost-effectiveness of a given communications service. This work requires highly developed skills in communications systems design, communications and information theory, analog and digital circuit design, transmission/modulation/multiple-access technologies, digital signal processing, the state of the art in hardware and software technologies, regulatory constraints, and operational constraints. The end product is generally a study or specification; however, in many cases prototype equipment is built to demonstrate the feasibility of a new enabling technology. CTD makes extensive use of its hardware and software simulation facilities to augment and verify theoretical analyses. Recent work in this area includes:

Digital Video Transmission System Study—This comprehensive system design study provides the Industrial Technology Research Institute (ITRI) with a complete architecture for a digital video satellite broadcast system. Technical and operational issues addressed include analysis of alternative space segment options, link design, video codec technology, and conditional access control.

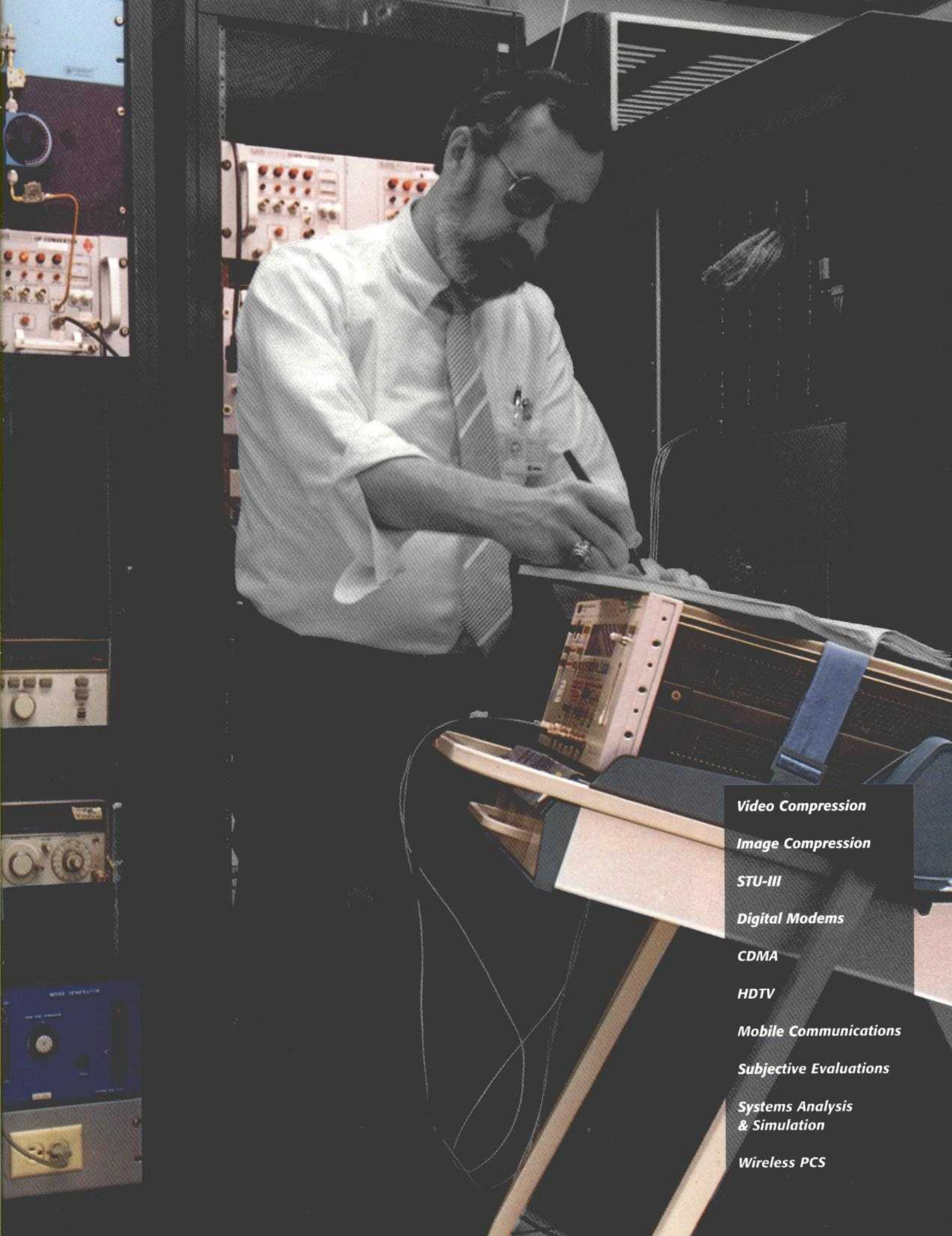
Inmarsat-3 Interference Study—For Inmarsat, techniques were investigated, and software was developed, to estimate the level of interference in the Inmarsat-3 system, and to determine carrier frequency assignment strategies to maximize capacity. Sources of interference considered included intrasatellite, intersatellite (from the same system and from different systems), fixed-service terrestrial systems operating in the L-band service link bands, and C-band feeder links operating in the Fixed Satellite Service.

Inmarsat-3 L-L/C-C Transponder Utilization Study—The most effective ways to use the L-to-L and the C-to-C transponders on the Inmarsat-3 spacecraft were investigated in this study for Inmarsat. These features are new to the Inmarsat system. The L-to-L transponder provides a capability for mobile earth stations to communicate directly with each other. The C-to-C transponder provides improved interstation communications and signaling throughout the Inmarsat system.

Satellite Paging Study—A major component of this study for Inmarsat involved field trials and analysis of prototype paging receiver performance in a variety of operational scenarios. This work resulted in several important recommendations to Inmarsat which would improve the performance of the proposed satellite paging service. In a follow-on study, the architecture of a paging system using the new handheld I-CO Global Communications system was developed. This major effort should open additional business opportunities for the new system.

Mini-M System Study—For Inmarsat, CTD helped to develop the key technologies required to demonstrate the feasibility and cost parameters of the new Mini-M Inmarsat terminal product. Based on this work, COMSAT and Inmarsat elected to pursue the Mini-M program, which will result in low-cost, laptop-size satellite terminals for use with the new Inmarsat-3 spacecraft.

Satellite Newsgathering Study—In a joint effort with SS/Loral, the Laboratories studied satellite newsgathering (SNG) system architectures for INTELSAT, to recommend designs that best meet SNG service objectives. The study



Video Compression

Image Compression

STU-III

Digital Modems

CDMA

HDTV

Mobile Communications

Subjective Evaluations

Systems Analysis & Simulation

Wireless PCS

Computer analysis was used to determine the areas of hypothetical urban landscapes which were blocked from a direct line of sight view of the geosynchronous satellite. Users of handheld terminals in the unshaded areas can always communicate with the satellite, while users in the shaded regions must move to an unshaded region.

included frequency band selection, modulation and multiple-access formats, earth segment considerations, and spacecraft implementation considerations.

Mobile Satellite Link Availability—CTD has analyzed the service availability of geosynchronous satellite constellations designed to provide telephony service to handheld terminals. In a recent study, three candidate constellations of four, five, and six equally spaced geosynchronous satellites were evaluated. The study assessed and compared the ability of these satellite constellations to provide coverage in environments where shadowing and blockage are likely, and defined the variability of coverage for users in different locations around the world.

International Standards Development—The development of national and international standards is a critical activity in the rapidly evolving communications arena. Up-to-date standards permit new communications services to be introduced quickly, with minimal equipment compatibility problems. Standards also stimulate the supply of equipment from multiple vendors, thus giving greater freedom of choice to network, equipment, and service providers while reducing the cost to the consumer.

Over the years, CTD has been a leading contributor to standards relating to transmission performance, echo control, circuit multiplexing, voice processing, video processing, transmission, error correction, and interference assessment. Division personnel chair several standardization and radio communications sector groups within the International Telecommunication Union (ITU). Recently, CTD personnel contributed to, and led, efforts culminating in new standards in the areas of audiovisual and multimedia communications, voice compression, future public land mobile systems (called personal communications systems [PCS] in the U.S.), transmission quality assessment, and spectrum engineering.

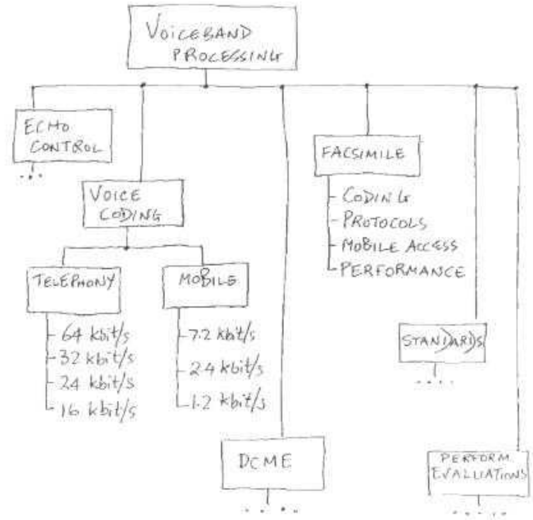
Source Processing & Compression

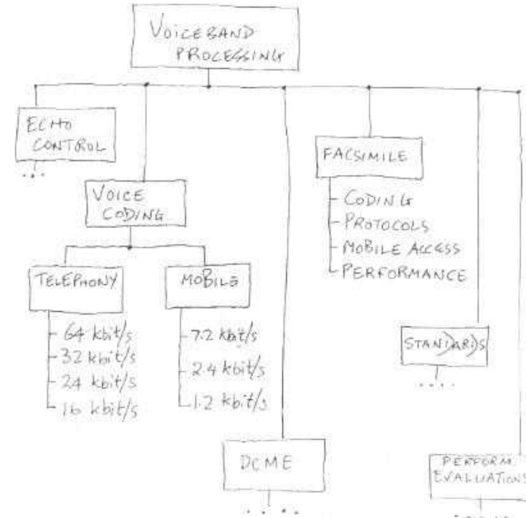
Source coding involves the conversion of analog source signals (speech, facsimile, or video) into digital representations that maximize transmission quality and bandwidth efficiency. CTD-developed algorithms and techniques exploit statistical features of the source signal to yield high compression ratios while maintaining acceptable quality at the receiver. Tradeoffs between encoder/decoder complexity must be analyzed, and the robustness of the coding algorithms to transmission errors must be evaluated. Typically, CTD implements the newly developed algorithms in software and/or hardware and evaluates their performance over a variety of representative input signals and channel impairments. This work requires specialized knowledge of the characteristics of the source signal, the related human perception characteristics, and advanced hardware and software development. Any codec generally requires significant real-time digital processing, and implementations are frequently limited by the existing state of the art in digital technologies. The end product of this work may be an algorithm, and/or a codec implemented in software or hardware, along with performance data. Some related accomplishments include:

MPEG-2 Video Compression—The Motion Picture Experts Group video compression standard, MPEG-2, is supported worldwide and offers such benefits as compatibility, superior picture quality, and the potential for low-cost implementation in application-specific integrated circuit (ASIC) chips. Building on a broad understanding gained through intense study of the technology and its applications, the Laboratories has adopted MPEG-2 as the technology base for its future digital video work.

Multispectral Image Compression—COMSAT Laboratories has expanded its expertise to include image processing. Under a contract with the U.S. Defense Landsat Program Office, CTD has developed novel techniques for lossless and lossy compression of remotely sensed multispectral images. Computer simulations of sev-

COMSAT's Maximum Differences (MD 1 x 2) facsimile compression algorithm offers the end user near transparent image quality while reducing the amount of transmitted information by a factor of 2:1 when compared against standard Group-3 facsimile. This algorithm offers high reconstruction intelligibility with little additional quality degradation (TOP) when compared with a standard resolution source image (BOTTOM).





eral types of multispectral imagery have shown that the CTD-developed compression technique, which is simple enough for onboard implementation, is virtually lossless in terms of visual quality, even at compression ratios as high as 40:1.

Facsimile Compression—CTD has developed techniques for reducing the bit rate required for facsimile transmission over low-rate channels. These techniques are particularly useful in mobile satellite applications, where facsimile transmission may be limited to 2,400 or 4,800 bit/s. Compression rates in excess of 2:1 have been achieved with little or no degradation in fax quality. CTD is also investigating the use of this technology in the terrestrial cellular telephony market, where it could be applied to speed cellular fax transmission, or alternatively to provide room for additional error protection to improve quality.

Simplified Vector Quantization for NTSC & HDTV—As early as 1990, COMSAT recognized that digital video compression held the key to more efficient video transmission. Because there was no digital video standard then, COMSAT developed an innovative vector quantization algorithm for generating highly compressed, motion-compensated video data. A prototype digital codec was developed in 1992 which was capable of transmitting three broadcast-quality National Television System Committee (NTSC) signals in a single satellite transponder. Under a contract with NASA, COMSAT developed a proof-of-concept high-definition television (HDTV) codec that combined the vector quantization scheme with subband processing to provide high-quality HDTV transmission at 45 Mbit/s.

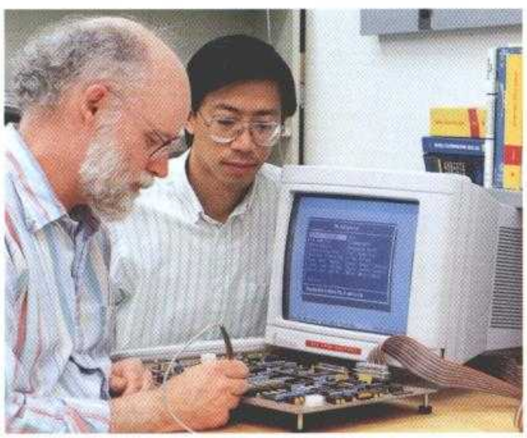
Speech Codecs—COMSAT Laboratories is an established leader in high-quality audio and low-bit-rate voice compression algorithm development. CTD has been involved in developing and evaluating speech codecs for more than 20 years. Most recently, a 1,200-bit/s speech codec was invented which reproduces speech with quality equivalent to the Department of Defense (DOD) LCP-10e 2,400-bit/s codec. This technology is immediately applicable to a variety of mobile personal communications markets, and potentially in some of the emerging mobile communications systems.

Magnified portions of a multispectral image of an airfield which has been compressed at 40:1 using spectral compression in conjunction with discrete cosine transform processing. The three-band composite images of the original (LEFT) and compressed/decompressed (RIGHT) images are virtually indistinguishable.

Audio Compression Codecs—CTD conducts R&D on adaptive predictive coding with transform domain quantization (APC-TQ) technology, which is applicable in direct broadcast audio systems and can be used to provide efficient multilingual simulcast for direct broadcast video systems.

Modulation/Channel Coding/Multiple Access

Using innovative concepts in modulation and coding, CTD has recently developed a variety of equipment for use in fixed and mobile satellite facilities. The basic objective of this work is to maximize the amount of information (bits) that can be transmitted in a given bandwidth and power, while minimizing the bit errors introduced by the noise inherent in any communications channel. CTD has developed new modulation and coding methods at the theoretical level, simulated their performance in software, and implemented prototype equipment to evaluate performance in hardware simulations or in tests over satellite links. The hardware developed employs leading-edge integrated circuit technology to achieve high performance at lower cost. Major accomplishments in this area include:



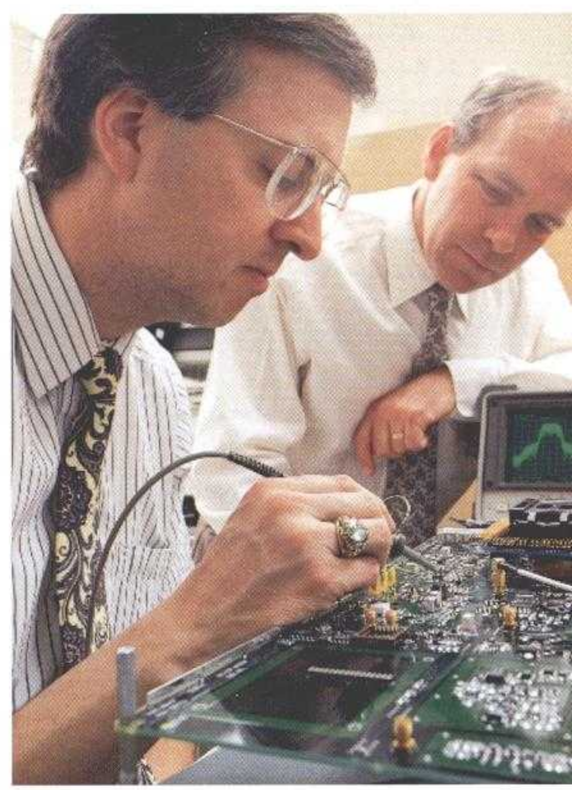
Two CTD engineers test the modulator for the programmable digital modem being developed for NASA. The modulator operates over the full data rate range without any component changes or filter bandwidth switching.

NASA Programmable Digital Modem—Under contract with NASA Lewis Research Center, CTD developed an experimental programmable digital modem (PDM) that operates at data rates from 2 to 300 Mbit/s in a variety of modulation formats, including quadrature phase shift keying (QPSK), minimum shift keying, octal PSK (8-PSK), 16-level quadrature amplitude modulation, and 16-PSK. A high-speed, emitter-coupled-logic ASIC used in several locations in the demodulator is responsible for the flexibility of this design. The ASIC is used to implement digital data filtering, acquisition estimations, and tracking loops. The basic technology developed in the PDM was applied in developing the MSP-10 modem ASIC and the 120-Mbit/s INTELSAT time-division multiple access (TDMA) modem.

MSP-10 Modem ASIC—For applications at medium data rates, CTD has developed a single chip that contains the key elements of both the modulator and the demodulator. The MSP-10 modem ASIC operates from 32 ksymbol/s to 10 Msymbol/s for binary PSK (BPSK), QPSK, and 8-PSK modulation formats, resulting in a maximum data rate of 20 Mbit/s for QPSK and 30 Mbit/s for 8-PSK. The ASIC is implemented in a 0.8-μm complementary metal oxide semiconductor (CMOS) process, and packaged in a 208-pin device. This chip is being used in several modem products developed at COMSAT.

155/140-Mbit/s BISDN Modem—An experimental 155/140-Mbit/s broadband integrated services digital network (BISDN) modem capable of delivering fiber optic quality over conventional 72-MHz satellite channels has been developed. This modem employs coded trellis modulation consisting of 8-PSK modulation and multistage variable-rate coding, thus efficiently utilizing both satellite bandwidth and power.

Multicarrier ASIC-Based Demodulator—With support from COMSAT World Systems and INTELSAT, CTD is developing a multicarrier ASIC-based demodulator for onboard processing satellites. The demodulator will be capable of processing up to thirty-two 64-kbit/s carriers, six 2.048-Mbit/s carriers, or various combinations



CTD engineers test the MSP-10 in a board designed for use in intermediate data rate systems. The board contains all the functions for both transmit and receive, with fully synthesized IF channelization. In addition to modem functions, the card contains a Viterbi decoder chip for rate 1/2 and 3/4 operation.

of these, together with 1.544-Mbit/s carriers. Only eight ASICs are needed to process an entire 36-MHz transponder, because on-chip memory is used to store intermediate results in the demodulation process for each carrier. One of the most important features of this chip is its ability to demodulate signals with asynchronous clock signals and different data rates. The ASIC is being developed using a CMOS process, which has a direct implementation path to a radiation-hardened part.

Another application for the multicarrier demultiplexer/demodulator processor is in the area of central processing hub-type earth stations. In this application, a single processor could replace tens or hundreds of intermediate data rate (IDR) demodulators, resulting in significant cost savings for earth station owners and operators. The system would employ off-the-shelf, fast Fourier transform (FFT) ASICs for the demultiplexer, combined with COMSAT's demodulator ASIC.

Self-Interference-Free CDMA—CTD has an ongoing program to develop a means of generating CDMA codes that are free of self-interference. This will allow both satellite and terrestrial CDMA systems to carry more traffic within a given bandwidth and power allocation.

Variable Data-Rate DSP-Based Modem—A low-cost digital signal processor (DSP)-based modem design was optimized for use in mobile (Inmarsat) environments where severe fading channels with Doppler create unique transmission impairments.

140-Mbit/s Trellis-Coded Modulation System—Equipment was developed and field-tested to demonstrate the ability to restore TAT-8 fiber optic facilities over a single 72-MHz satellite transponder. The same technology has been employed in a highly bandwidth-efficient modem operating at 200 Mbit/s in burst mode.

WIRELESS COMMUNICATIONS PRODUCTS

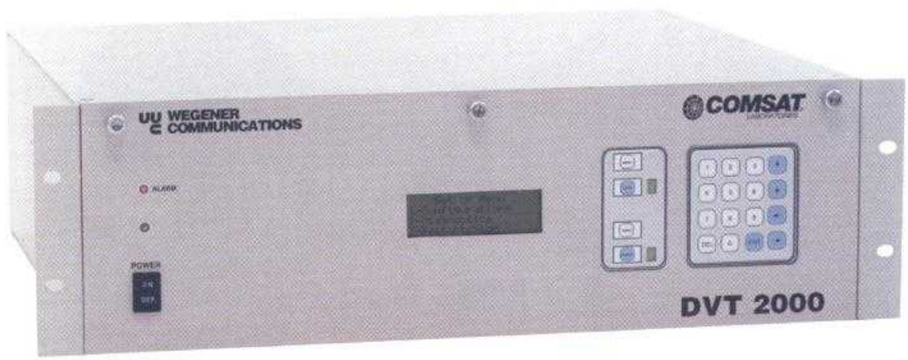
CTD has embarked on an ambitious program of product development, intended to capitalize on its extensive technology base. Some of the division's major product activities are described below.

MPEG-2 Video Codec

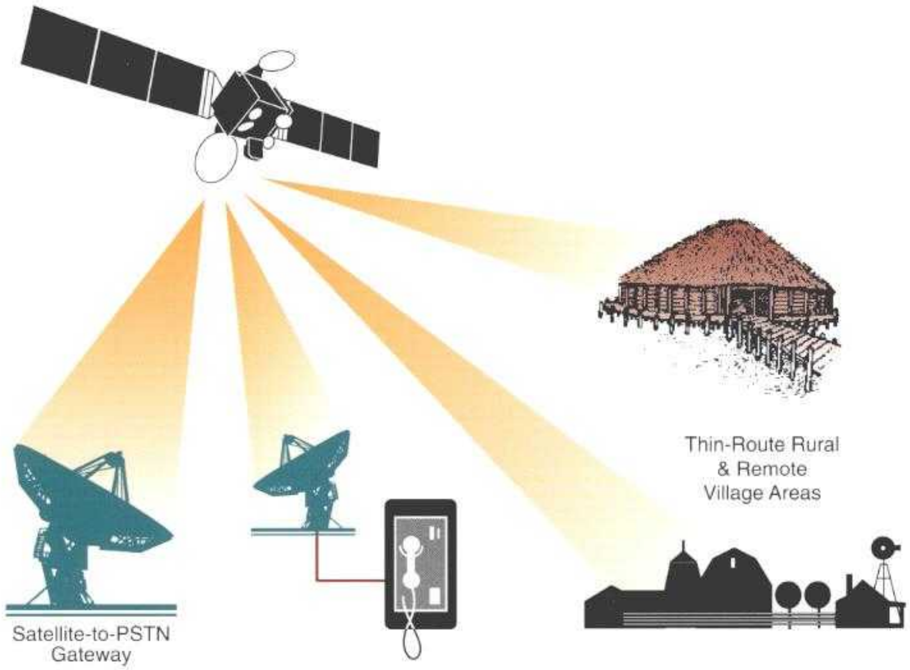
Combining technical expertise in MPEG technology with market knowledge developed through recent SNG systems studies, COMSAT decided to pursue development of a digital SNG codec utilizing newly available MPEG-2 ASIC devices. This codec has evolved into a commercial product called the DV2000™, which includes an integrated satellite modem based on the COMSAT MSP-10 modem ASIC. The SNG transmitter (DVT2000™) and the digital video receiver (DVR2000™) are compact, lightweight, and ruggedized for vehicle and flyaway installations. The highly efficient MPEG-2 compression technology reduces required transponder bandwidth and allows transmission of three to eight TV signals in one 36-MHz transponder.

Key components developed by CTD include a variable-rate video modem card, a programmable MPEG-2 video compression card, a system/multiplexing card, and an integrated demultiplexing and MPEG audio/video decoder card. The video modem is based on CTD's MSP-10 modem chip. The modem card supports variable-rate transmission ranging from 2.5 to 20 Mbit/s and has 70-MHz transmit and L-band receive IF interfaces. The MPEG-2 video output rate is adjustable between 1.5 and 15 Mbit/s, permitting the codec to be used for a wide range of applications. The system uses concatenated convolutional and Reed-Solomon forward error correction (FEC) codes to provide a highly reliable link for satellite transmission. The FEC coding is compliant with the European Digital Video Broadcasting (DVB) standard.

The developed technology has been licensed to Wegener Communications for manufacturing and distribution—an example of the Labs' push to transfer its technical assets into the commercial marketplace. In addition to SNG, other applications include distance learning, cable head-end distribution, and asynchronous transfer mode (ATM) network transmission.



The DV2000™ digital video compression system combines state-of-the-art MPEG-2 technology with the COMSAT-developed MSP-10 modem ASIC to provide broadcast-quality digital video compression in a compact, rugged, cost-effective package. Ideally suited for digital satellite newsgathering, the DV2000™ products also provide the flexibility needed to support a broad range of satellite video transmission and broadcasting applications.



The CDMA terminal provides a cost-effective means of bringing basic telephone service to thousands of remote areas of the world which have never had access to telecommunications services.

CDMA Personal Satellite Communications Terminal

A major area of R&D for CTD involves the application of direct-sequence spread spectrum code-division multiple-access (DS-CDMA) technology to satellite-based mobile and personal communications. CDMA offers many features that are of particular advantage in a fading mobile satellite link, including relative immunity to frequency-selective fading, graceful degradation with capacity overuse, and the ability to be "overlaid" with other narrowband carriers to conserve valuable spectrum. Another key advantage of CDMA is that it permits the use of smaller aperture antennas than would be required for traditional transmission schemes. This is because the lower power spectral density of CDMA transmission reduces the interference into adjacent satellites caused by the broad radiation pattern emanating from small antennas.

COMSAT Laboratories' portable demonstration C/Ku-band satellite terminal provides voice, data, and fax services from remote sites interconnecting them to the public switched telephone network using available and inexpensive C/Ku-band space segment from DOMSATs or INTELSAT.

CTD has exploited this aspect of CDMA transmission to produce a personal satellite communications terminal which drastically reduces the size of the antenna and terminal compared to conventional flyaway C/Ku-band satellite terminals. The entire terminal, including the antenna and power supply, is packaged into a briefcase similar to a standard office briefcase. Antenna sizes range from 0.3 m at Ku-band to 0.8 m at C-band. The transmit power requirements range from 200 mW to about 1 W, depending on the space segment selected. The portable terminal is also offered in a battery-powered version for business travelers, disaster relief agents, law enforcement forces, and so on. Thus, lower-cost C/Ku-band space segment can now be accessed using satellite terminal packages which previously could only access expensive L-band space segment.

Each terminal offers voice, data, and fax ports. High-quality compressed voice at 4,800 bit/s makes efficient use of the system, with quality comparable to the North American 8-kbit/s digital cellular standard. Multirate data services ranging from 300 to 9,600 bit/s, with a default rate of 2,400 bit/s, are available, and quasi-real-time fax transmission with a default rate of 2,400 bit/s is provided. Higher rate data and fax services can be requested on demand during call setup if adequate system capacity is available.

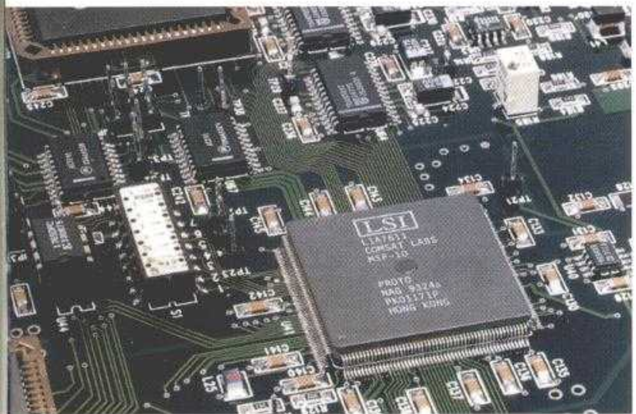
Several packaging options support at least three broad-based applications. These are a portable Ku-band personal satellite terminal for voice and data; a very low-cost, single-line telephone terminal (C- or Ku-band) for remote villages; and a low-cost voice, data, and fax mobile terminal with a motion-stabilized antenna for shipboard and railroad users.

MSP-10 Modem ASIC

The MSP-10 modem ASIC can be used as the basis for video distribution modems and IDR/International Business Service (IBS) modem implementations, and is adaptable for burst-mode systems such as bandwidth-on-demand, low-rate TDMA terminals.

The ASIC uses digital data shaping on the modulator side to give a programmable filter shape that is perfectly matched to the data rate. An on-chip synthesizer for oversampling in the modulator results in a data rate range of 32:1, with only a single pair of replication-removal filters. The addition of a second set of switched filters extends the range to 1,024:1.

On the receive side, the MSP-10 performs data-shaping, carrier recovery, clock recovery, and automatic gain control. Internal numerically controlled oscillators are provided for



CTD's MSP-10 modem ASIC is housed in a surface-mount 208-pin quad flat-pack package which requires approximately 9 cm² of circuit board space, making it ideal for incorporation into small, low-cost satcom modem products.

the carrier and clock frequency sources. A COMSAT-patented technique provides programmable data filtering with square-root Nyquist responses and filter rolloffs down to 40 percent.

CTD has employed the MSP-10 in several modems, including the variable-rate modem used in the DV2000™ digital SNG codec and a low-cost IDR/IBS modem. The MSP-10 is available as either a chip-level product, or integrated on a VME-based modem board complete with a frequency synthesizer supporting a 70-MHz IF interface.

120-Mbit/s INTELSAT TDMA Burst-Mode Modem

CTD's digitally implemented 120-Mbit/s burst-mode TDMA modem designed for the INTELSAT system is significantly less costly than the original analog implementation. The digital implementation also allows greater flexibility and improved performance of the recovery circuits since the configuration can be switched instantaneously from acquisition to tracking mode. Phase-locked loop (PLL) carrier and clock recovery circuits will provide improved stability and reduced maintenance costs. The majority of the digital circuits are implemented using CMOS programmable gate array technology to minimize power consumption. The small size of the modem allows it to be placed in three card slots of the TDMA controller shelf rather than require a separate shelf, as in previous designs. Integrated into the modem are the transponder hopping switches for both the transmit and receive sides. This modem is part of the second-generation INTELSAT 120-Mbit/s TDMA terminal developed in the Labs' Network Technology Division, and will be fully compatible with future adaptive equalizer technology.

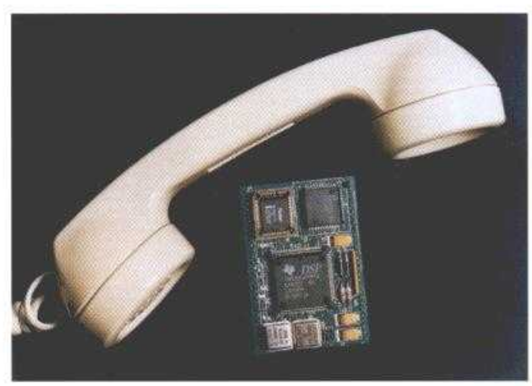
BOD-II TDMA Burst Modem

For lower data rates, a burst modem is being developed for bandwidth-on-demand (BOD) systems where low cost and small-size customer premises equipment is important. This modem is based on a number of recently released digital signal processing ASICs employing CMOS technology. These ASICs provide flexible data filtering for variable-rate operation, numerically controlled oscillators for carrier and clock recovery and complex multiplication for the carrier phase rotator. Most other functions are implemented using CMOS programmable gate array technology. This modem will have the capability of changing both data rate and carrier center frequency on a burst-to-burst basis. Also, a new algorithm has been developed for reliable burst acquisition in the presence of relatively large frequency offsets. Open-loop phase acquisition estimates are combined with PLL tracking circuits to provide optimum performance with short preamble lengths.

1,200-bit/s Voice Compression Codec

COMSAT recently developed the 1,200-bit/s line spectral frequency split vector quantizer (LSF-Split VQ) voice codec algorithm, which has been shown through subjective evaluation to provide speech quality equivalent to the 2,400-bit/s LPC-10e DOD voice codec standard. Because of its excellent performance, the COMSAT LSF-Split VQ voice codec is ideally suited for numerous applications, such as ◆ land mobile radio ◆ miniature transceivers ◆ tactical communications ◆ voice annotation ◆ high-gain multiplexers, rural telephony and thin route ◆ HF/VHF packet radio ◆ and paging services.

The COMSAT 1,200-bit/s LSF-Split VQ voice codec algorithm is optimized to operate on a real-time TMS320C31 DSP platform. Software for this platform is available for licensing from COMSAT Laboratories, along with an evaluation board for use in product development.



The COMSAT 1,200-bit/s LSF-Split VQ voice codec has been optimized to run on a miniature digital signal processing platform, enabling it to be used in a variety of voice telephony, digital radio, and voice messaging applications.

System Development

The System Development Division (SDD) at COMSAT Laboratories develops satellite system management facilities and software products. ◆ These include computer-aided satellite system planning tools; real-time earth station and network monitoring and control systems; tracking, telemetry, and command subsystems; cryptographic key management, user access, and accounting subsystems; and specialized value-added user services such as mobile tracking and data collection. ◆ SDD's customers span the commercial, government, and military sectors. ◆ Current activities are directed toward system planning and analysis, satellite system management, software engineering, and software sales and consulting.

RIGHT: SDD is developing an advanced world mapping capability that will be incorporated into several existing and planned satellite system management facilities.

SYSTEM PLANNING & ANALYSIS

Workbench Products

The System Development Division (SDD) at COMSAT Laboratories has developed, and continues to enhance, workbench products that provide mapping and analysis capabilities incorporating a graphical user interface (GUI) shell with a built-in relational database and tested analysis algorithms. Users can now select multiple entries from a list box, and can use a mapping feature to produce color, presentation-quality maps. In addition, the software has been updated to include the latest capabilities of the AXIS Toolkit. A prototype was developed within the workbenches to view data files such as news clippings accessible through the UNIX server, and diagrams such as satellite system block diagrams that have been optically scanned into the workbench. The system runs under the UNIX operating system on engineering workstations, and uses the X Window System, Open Software Foundation (OSF)/Motif, and COMSAT's AXIS development environment.

CWS STAR™—The COMSAT World Systems (CWS) Satellite Tools and Resources (STAR) product provides a common interactive user interface to a comprehensive database of INTELSAT system parameters, including satellite configurations and deployment, antenna gain patterns, earth station data, traffic data, and operational transmission plans. It also offers a broad range of analysis capabilities for evaluating system performance.

STAR permits a user to view and prepare reports containing INTELSAT earth station, satellite, Signatory, and frequency planning data. Users may interactively select fields from the database for inclusion in a report, constrain the data to be retrieved, and specify the order of retrieval. Once a report is generated, the user can sort, rearrange, or delete columns. Moreover, the reporting facility has been enhanced to allow results to be plotted on a world map. For example, a user can retrieve data on all the U.S. Standard A antennas from the database, then click a button to plot their locations on a world map. The layout and contents of the map are easily changed—any portion can be rotated, scaled, or zoomed in on—or the map may be saved for later modification.

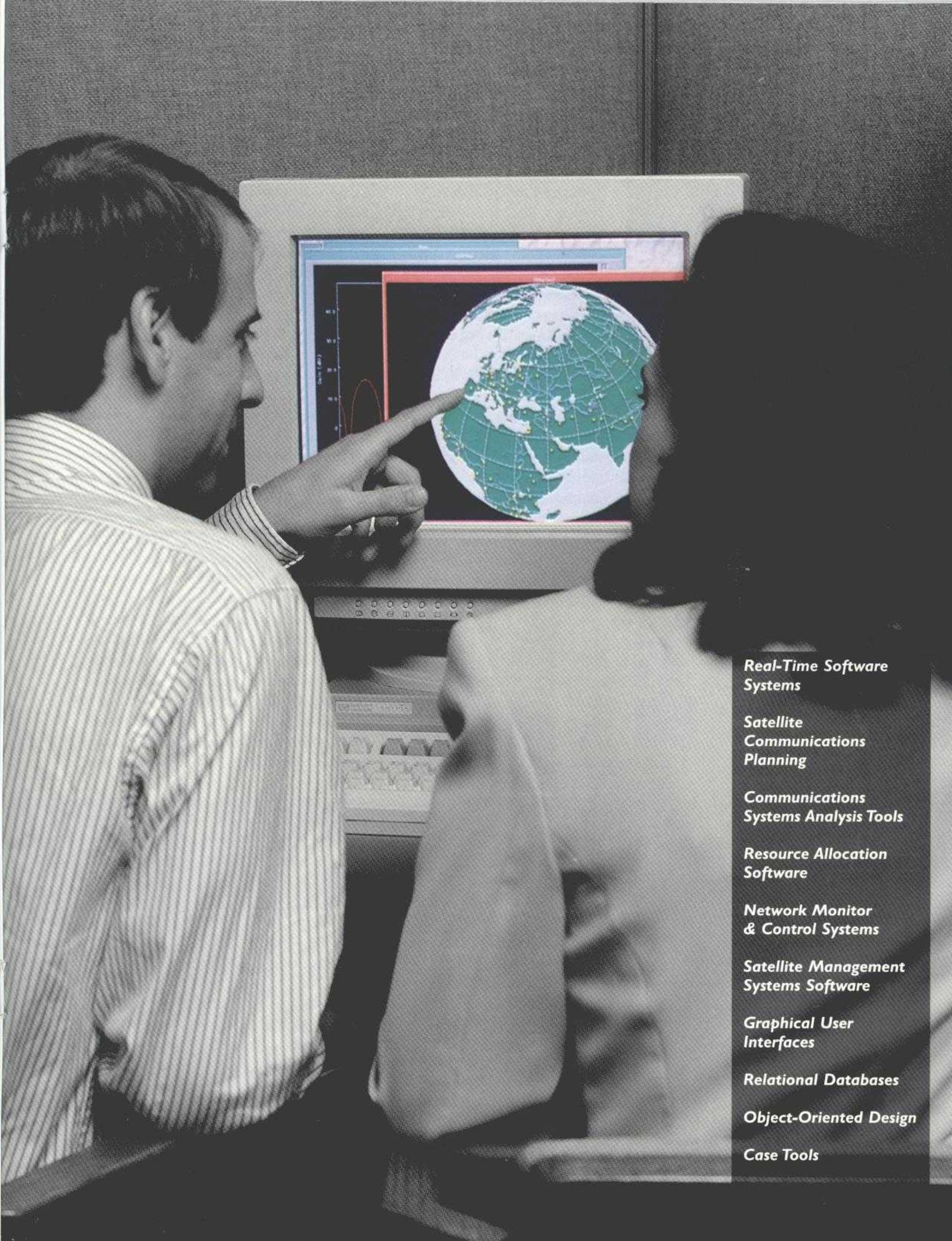
INTELSAT antenna coverage patterns also can be displayed on the world map. After a user specifies an INTELSAT satellite location, the workbench displays a list of the antenna beam patterns available for that satellite. Uplink or downlink contours may be plotted for one or more antenna beams.

Using INTELSAT's algorithm, the STAR beta-factor calculator computes the nominal uplink and downlink pattern advantage at an earth station for a user-specified INTELSAT satellite type, orbital location, and beam. The inclined-orbit calculator analyzes the effect of the inclined orbit on elevation and azimuth angles for a set of earth stations. The rain outage calculator computes the uplink and downlink rain impairments corresponding to rainfall parameters for a user-specified earth station and satellite propagation path. Each calculator accesses the CWS relational database and provides the user with default values, as well as lists of values from which to choose. The inclined-orbit and rain outage calculators can also be used with non-INTELSAT data.

Features recently added to CWS STAR™ include a calculator to determine the INTELSAT satellite and beam that will support a link between two points on the earth, a calculator to compute the effects of sun outages, access to a database of city locations, and access to a new world map database with enhanced mapping capabilities.

CMC Workbench—The COMSAT Mobile Communications (CMC) Workbench has the same mapping, data viewing, data reporting, and calculator features as CWS STAR™. The CMC Workbench retrieves data from the Mobile System Database—a technical database of Inmarsat satellite system, land earth station, and mobile terminal parameters—which was developed concurrently with the workbench.

Link budget and inclined-orbit calculators, as well as a traffic analysis prototype, have been



Real-Time Software Systems

Satellite Communications Planning

Communications Systems Analysis Tools

Resource Allocation Software

Network Monitor & Control Systems

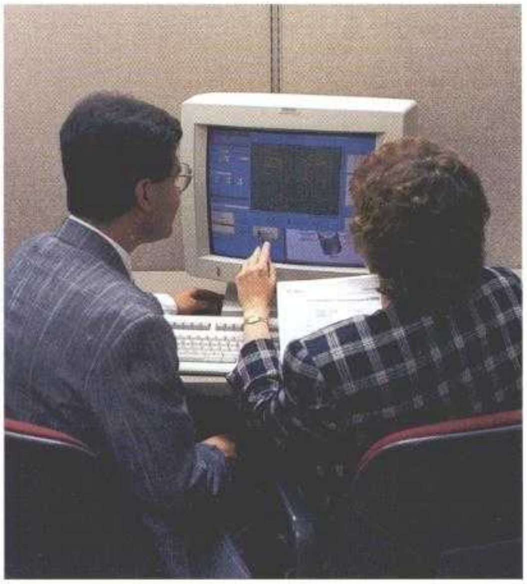
Satellite Management Systems Software

Graphical User Interfaces

Relational Databases

Object-Oriented Design

Case Tools

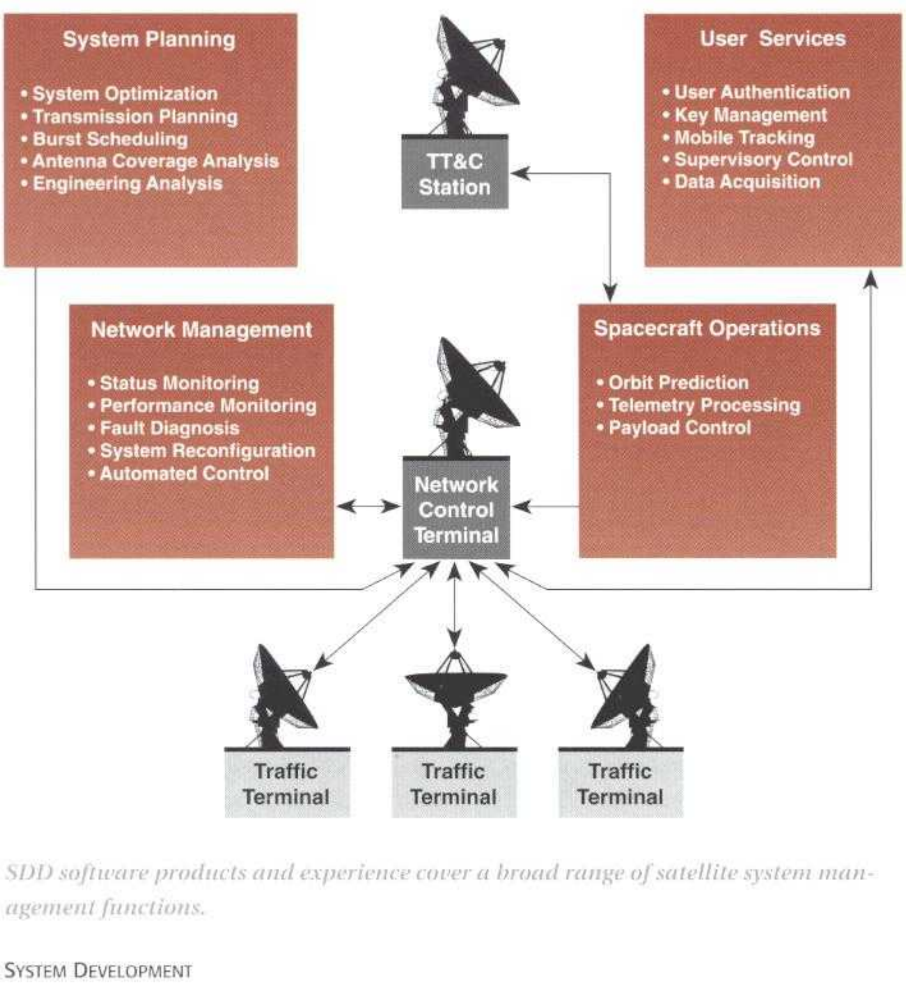


The CWS STAR™ program permits system planners to view the current system configuration and to plan new communications circuits and analyze their performance.

added to the CMC Workbench. The link budget calculator provides a spreadsheet application for analyzing all Inmarsat services. A supporting link budget data module was designed, implemented, and populated for the Mobile System Database. The traffic analysis prototype determines the amount of satellite capacity and effective isotropically radiated power (EIRP) required by a given set of traffic data and user-specified criteria.

Transmission Planning

The INTELSAT satellite communications system provides international and domestic telephone, video, and data communications services using several different series of geostationary satellites located over the Atlantic, Pacific, and Indian ocean regions. These satellites permit multiple reuse of the allocated RF bandwidth through either spatial separation of the beams or polarization isolation. SDD developed the comprehensive transmission planning capabilities employed by INTELSAT operations personnel to optimize use of the INTELSAT satellite network.



SDD software products and experience cover a broad range of satellite system management functions.

STRIP

INTELSAT uses the SDD-developed Satellite Transmission Impairments Program (STRIP) to support transmission planning for its satellites. STRIP employs transmission impairment analysis algorithms, along with substantial supporting specifications and measured data, to evaluate and optimize the performance of all carriers in a satellite transponder bank. The impairments computed by STRIP for each carrier include thermal noise, interference, and intermodulation. A power optimization analysis determines the carrier power levels that will enable the worst carrier in the plan to achieve an acceptable level of performance. This analysis considers both clear-sky and rain-degraded conditions. Originally, STRIP was intended to evaluate and optimize frequency-division multiplexed (FDM)/FM carrier performance on INTELSAT IV satellites. Over the years, it has been enhanced to model characteristics for digital, time-division multiple access (TDMA), and television services on subsequent spacecraft series.

The latest version of STRIP (STRIP7) employs a distributed architecture in which high-performance computers and data servers communicate with an interactive user interface that provides ease of use and immediate, comprehensive diagnostic feedback. The system includes a relational database management system consistent with INTELSAT's shared-data environment.

All STRIP7 executables reside on multiple UNIX processors for efficient workload distribution, with the exception of the user interface and the database administrator interface modules, which reside on IBM-compatible PCs. All PCs and UNIX processors communicate with each other over the INTELSAT local area network (LAN). The new system is easy to maintain and enhance. Compared to previous versions, it provides greatly improved performance, with new analysis and diagnostic capabilities.

Burst Time Plan Generation

COMSAT Laboratories is developing a new Burst Time Plan (BTP) Generation System to support the modernization and expansion of INTELSAT's TDMA networks. This system will produce BTPs for both fixed and satellite-switched TDMA networks. A BTP provides complete timing assignments for a TDMA network, including traffic assignments, control assignments, and satellite switching sequences. The fixed networks can include up to 24 transponders, and the satellite-switched networks can include up to 12 transponders. Each transponder operates at 120 Mbit/s. A network can contain as many as 50 traffic terminals, which can "frequency-hop" across up to four transponders within the 2-ms frame. The satellite-switched networks use 6 x 6 microwave switch matrixes, which are included on each INTELSAT VI satellite, to route bursts arriving on various uplink beams to various downlink beams.

INTELSAT currently uses two separate BTP generation systems—one for fixed and one for satellite-switched operation. Both are command-driven systems that operate on the IBM mainframe. Considerable effort is usually required to prepare, coordinate, distribute, and activate a new BTP using the existing facilities. Activating BTPs requires a global change in which every network element must participate. SDD's new BTP generation system will offer the following advances:

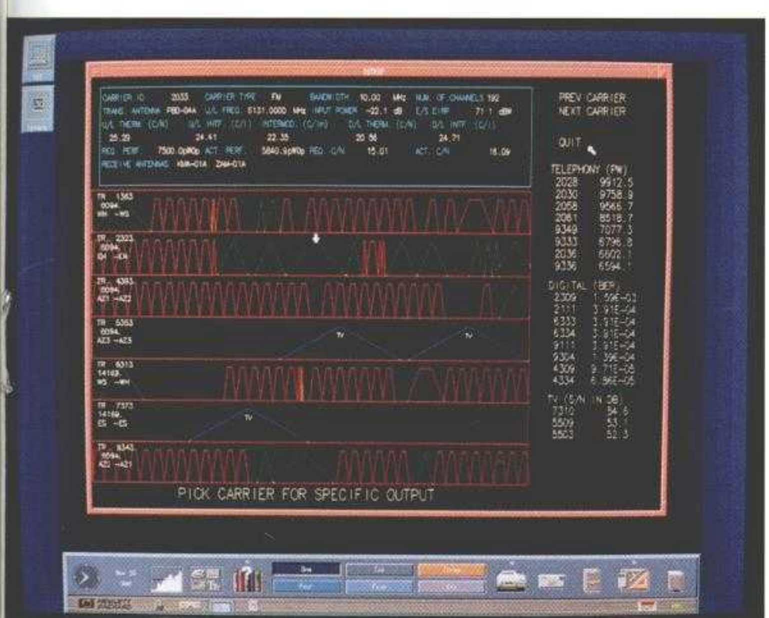
- Combine the capabilities of the two existing systems into a single system.
- Shorten the time required to generate BTPs.
- Display BTPs graphically on the user's screen, and allow the user to interactively manipulate bursts and subbursts.
- Allow incremental BTP changes that involve only a limited number of affected terminals.
- Support occasional-use traffic, which can be activated as needed.
- Use a client-server architecture employing INTELSAT's new distributed computing environment of PCs on users' desks and Hewlett-Packard UNIX workstations as central servers.

SDD and NTD staff members are developing a new TDMA BTP generation system for INTELSAT which will greatly increase the flexibility of the system to respond to changing traffic requirements.

The new BTP generation system will be a companion to a new, low-cost TDMA traffic terminal (LCT) being developed by the Labs' Network Technology Division (NTD) and expected to be available in 1996. The new LCTs will support features such as occasional-use traffic, which existing INTELSAT Earth Station Standard (IESS)-307 terminals cannot support. The LCTs will also support a new direct digital interface (DDI) terrestrial interface module (TIM) that operates at the European standard E-1 rate of 2.048 Mbit/s. The BTP generation system will support full interworking between the IESS-307 terminals and LCTs.

To schedule bursts and produce a BTP, the new software system must accommodate hundreds of rules and constraints related to TDMA architecture and ground equipment capabilities. Several steps in the scheduling algorithm are known to be NP-complete problems. Producing an optimum BTP involves many tradeoffs between space segment and ground segment efficiencies (e.g., frame utilization *vs* number of terminals and interfaces).

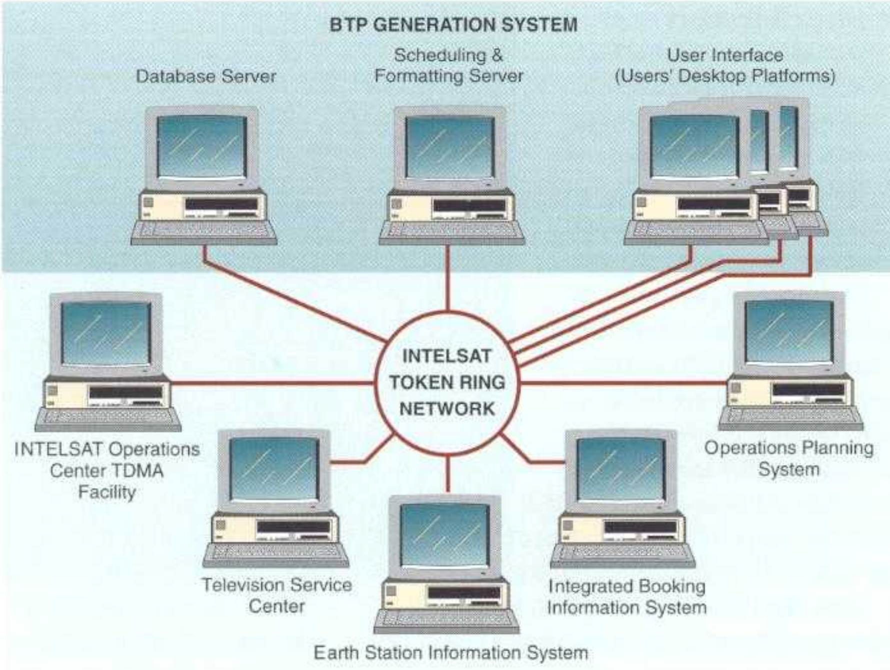
The speed and ease of generating time plans using the new BTP generation system, combined with the features and lower cost of the LCTs, will support a significant expansion of INTELSAT's TDMA networks.



LEFT: Users of STRIP can interactively define and analyze carrier frequency plans or invoke optimization algorithms to determine the transmit carrier power levels needed to achieve their grade-of-service objectives.

Antenna Modeling

The General Antenna Program (GAP) is a general-purpose software tool for analyzing the performance of reflecting antenna systems of arbitrary geometry. GAP uses a ray-tracing and integration technique to predict the patterns produced by a reflecting antenna system. Recent enhancements to the software include the addition of three methods for modeling more complex reflector geometries. In the first method, the



The BTP generation system will allow INTELSAT planners to generate TDMA BTPs based on station-to-station traffic projections, and to format these plans for distribution via the INTELSAT Operations Center TDMA Facility.

program is modified to permit a surface to be defined as a composite of surface segments. The second exploits finite element techniques so that a surface can be specified by a set of triangular elements. In the third method, the user can define a surface as a distorted polynomial.

An optimization algorithm was added to GAP to generate the input amplitude and phase parameters for each feed, which are necessary to meet specified far-field requirements. Gain and isolation requirements are entered for a number of points in the far field, and a least-squares algorithm generates the input parameters that minimize the difference between the actual and desired gain or isolation.

New feed models have also been added to GAP. They include a circular microstrip patch feed model and a measured feed model in which the user enters measured gain values at regular intervals of azimuth and elevation.

SATELLITE SYSTEM MANAGEMENT

In addition to developing analytical tools, SDD is expert in devising software systems that actively monitor and control communications systems. This capability is provided to customers outside of COMSAT, as well as to intra-corporate lines of business. Some state-of-the-art system management products recently developed by SDD are described below.

UMS/ISPC

The Division has developed a planning, monitoring, and control facility, called the Interim System Planning Computer (ISPC), for the U.S. Army's Universal Modem System (UMS). The UMS will provide fixed-ground, transportable-ground, airborne, and ship users with survivable antijam, antiscintillation, low-probability-of-exploitation interoperable digital data communications. It will use nonprocessing transponders on U.S., British, French, and NATO satellites (including DSCS II and III, SKYNET 4, SYRACUSE, and NATO III and IV). The ISPC provides scenario definition, resource allocation, monitoring, database dissemination, control handover, and computer operations, as well as general support for the UMS. SDD's work is in support of Magnavox, the prime contractor for UMS development.

ISPC Functions—The ISPC operates on both the system and network levels. A system may span five satellites and include up to 32 networks and 512 modems, whereas a network is limited to a single satellite and may include up to 128 modems. Specifically, the ISPC

- Plans communications scenarios, including network architecture, requested circuits, resources available to support user requests, and anticipated threat levels.
- Controls external equipment to generate cryptographic keys, and then assigns, distributes, and tracks the keys.
- Allocates satellite, earth terminal, and modem resources, including power, bandwidth, and end user equipment.
- Calculates the satellite ephemeris to enable modems to determine satellite-to-earth-terminal range and range rate (Doppler shift).
- Disseminates databases to inform other ISPCs and universal modems of plans.
- Monitors UMS status and compliance with resource limits.
- Reallocates resources and reconfigures the UMS in response to threats or changes in communications needs.
- Manages both planned and unplanned handover of control functions to other ISPCs, to ensure UMS survival.
- Manages ISPC startup, recovery after brief outages, and shutdown.
- Provides general support functions, including database management, operator interface, alarm and message handling, and logging and retrieval.
- Emulates the operator interface units for collocated universal modems.

The ISPC source code was written in the Ada programming language, and the software development process conformed to the requirements of Department of Defense Standard DOD-STD-2167A.

ISPC Operational Environment—The operator interface for the ISPC is an interactive dialog interface based on the X Window System, OSF/Motif, and COMSAT's AXIS Toolkit. The interface controls two screens, so an operator can (for example) position monitoring dialogs on one screen and planning dialogs on the other.

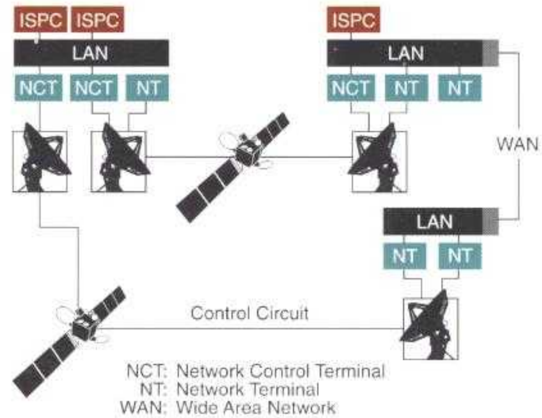
The ISPC relational database stores enough system and network data to define a 32-network UMS. The data are both scenario-independent and scenario-dependent. (A scenario defines how system or network equipment and resources are set up and allocated to respond to an anticipated threat environment.) The ISPC stores up to 10 system scenarios and 10 network scenarios per network. An operator can also create scenarios for "what if" planning.

All system data are automatically disseminated to the other ISPCs in the system, and all network data to those ISPCs that serve as alternate network controllers. An operator can also elect to transfer unofficial data to other ISPCs. Automatic dissemination of these data provides redundancy and helps ensure the survival of the UMS.

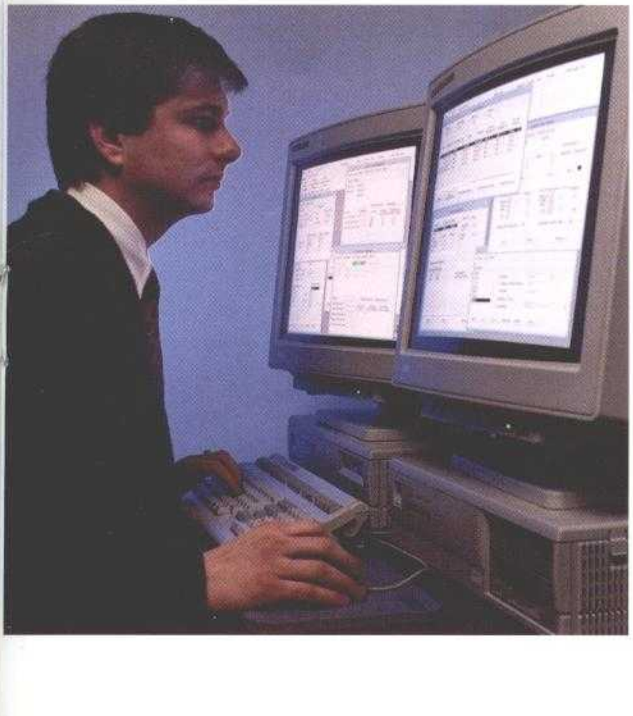
Ephemeris Calculations—Ephemeris calculations are designed to manage and perform all computations within the ISPC that are concerned with predicting satellite position and velocity. Ephemeris calculations are used by the UM to predict earth-terminal-to-satellite range and Doppler effects for up to 36 days into the future. The calculations are necessary because satellite orbits may be inclined up to 12° from the equatorial plane. Based on the precise state of the satellite at a single known point in time, a sophisticated four-body orbit model is used to predict the position and velocity of the satellite at hourly intervals over an operator-defined schedule. A Gaussian "variation of parameters" formulation of the equations of motion expresses the acceleration of the satellite as a function of the forces acting upon it. The relevant forces modeled are the point-mass gravitational forces of the earth, sun, and moon; the nonspherical component of the earth's gravitational potential; and solar radiation pressure. The equations of motion are numerically integrated using the Bulirshe-Stoer method to predict precision state vectors at intervals of (nominally) 1 hour for each day, over the 36-day period.

The output of this process is a table of Keplerian orbital parameter sets for the period—one set for each day. Each set defines an elliptical Keplerian orbit obtained by a least-squares error fit of the precision state vectors generated for that day to the simpler two-body model of the universal modem. One such Keplerian parameter will allow the modem to run the simpler orbital model for a day to predict earth-terminal-to-satellite range and Doppler effects to the desired accuracy, in order to aid the modem in acquiring and tracking signal timing and frequency.

Resource Allocation—The resource allocation function determines the terminal and satellite resources (power, bandwidth, and user equipment) required for a specified system scenario. The power required for each UMS circuit, referenced to the input of the satellite transponder, is determined by a basic link budget computation that accounts for the satellite transponder nonlinearity, which introduces intermodulation products and also accounts for small-signal suppression at the transponder output. The model for the nonlinear transponder is derived from the COMSAT Intermodulation Analyzer, which approximates transponder



The ISPC provides comprehensive system planning and network management capabilities for networks of universal modems (operating either as NTs or NCTs) on DSCS, SKYNET, SYRACUSE, and NATO satellites.



An SDD software engineer develops the operator interface for the ISPC. This environment includes dual displays and the X Window System.

nonlinearities by using a Fourier-Bessel expansion with constant coefficients. The effects of jamming, high-altitude nuclear explosions (introducing scintillation), and atmospheric fading are also included in the analysis.

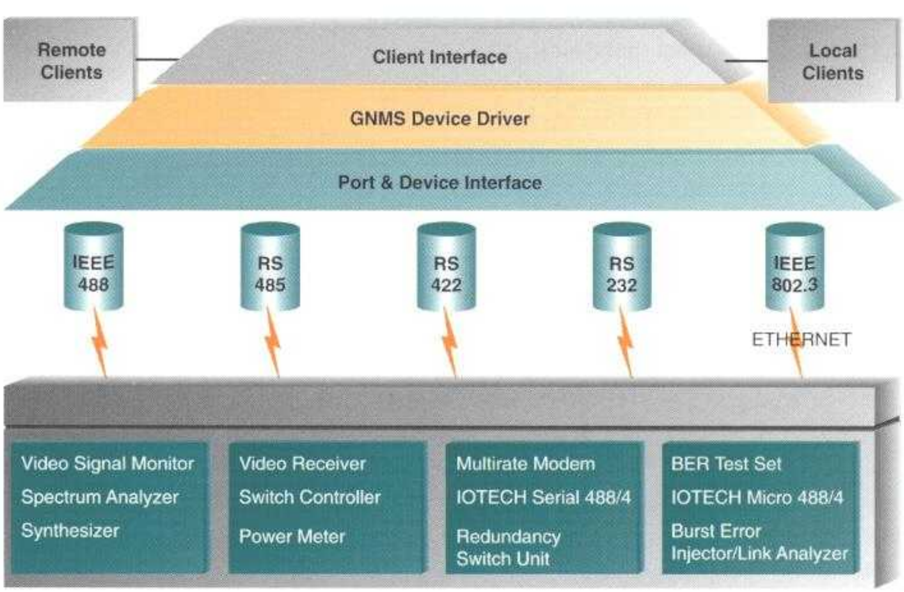
In circuit power allocation, the required signal power must be determined for each circuit, given the link maximum bit error ratio (BER), which determines the minimum energy-per-bit to noise-power density ratio, E_b/N_o, required at the receive terminal. From this, the carrier-to-noise ratio, C/N, needed at the receive terminal for each circuit in the universal modem network can be determined. These C/N's can then be used to establish the satellite transponder input powers required for satisfactory circuit performance.

GNMS Device Driver

Working with CWS engineering and operations personnel, SDD has developed a Generalized Network Management System (GNMS) device driver to support real-time monitoring and control of earth station equipment. The driver was developed using the C++ programming language to operate on an HP Apollo Model 755 reduced instruction set computing (RISC) workstation under the HP-UX UNIX-based operating system. The client applications can execute on an HP Model 755 computer, or on a compatible workstation, a PC, or a terminal attached to the Network Control Center (NCC) LAN or to a serial communications link (X.25).

SDD's GNMS device driver provides a standardized interface for controlling earth station equipment from a centralized Network Control Center.

During normal operation, the driver accepts commands from one or more client applications, sends the commands to the target devices over the appropriate ports, and returns responses to the client applications. It sets up connections, monitors link status, and ensures that the device responses (or proper error returns) are returned to the clients in the correct sequence. The driver is designed so that multiple clients can simultaneously monitor and control devices, with the restriction that a single client application can control only one device at a time.



In addition, the driver is capable of interfacing with new clients or new earth station equipment without changes to the software. This is accomplished through a configuration editor and various tables, which enable a system administrator to establish port-to-interface and port-to-device relationships.

A client application called the Satellite Monitoring and Control System (SCS) was developed which employs the GNMS device driver. The new software augments the present Satellite Monitoring System (SMS), which was developed by CWS to monitor the spectra of satellite carriers in the Atlantic and Pacific ocean regions. The SMS provides for remote monitoring and control of several earth stations through an NCC in Bethesda, Maryland. CWS will enhance SMS capabilities to include intermediate data rate/International Business Service BER testing and video signal testing at the Andover, Maine, and Clarksburg, Maryland, earth stations. The SCS software consists of multiple client applications that access a configuration database of earth station equipment. It also provides a GUI designed and implemented using the AXIS reusable software previously developed by SDD.

COMSAT Television Schedule Service

The COMSAT Television Schedule Service (CTVS) is a dial-in service through which users of the INTELSAT system can request television service over an INTELSAT satellite. Users may view information relating to their booked and pending service requests, and schedule and track the transponder switching activity associated with the INTELSAT-K satellite. The service also provides information on INTELSAT earth stations and television service tariffs. Recently, SDD added a satellite calculator to the CTVS to provide subscribers with look angle, beta-factor, and link budget calculators.

The look angle calculator allows the user to compute the elevation and azimuth angles of an earth station antenna, given either the name of the antenna or its geographic location and the satellite it accesses. The beta-factor calculator

SDD has supported COMSAT Mobile Communications in developing a maritime message referral, tracking, and display system which was used to monitor the BOC Challenge. With COMSAT-supplied software on their PCs, users could display the current position and historical track of the racers superimposed on a world map.

enables a user to compute the geographical advantage of an earth station with respect to a given INTELSAT satellite, and a particular beam on the satellite, by specifying an orbital position, a satellite, a beam, and either the name or geographic location of an earth station antenna. The link budget calculator computes link budgets for TV carriers by using INTELSAT's standard link budget equations. The user must provide a series of inputs, including satellite location and uplink and downlink satellite beam coverage, as well as information about the transmit and receive earth station antennas, the transponder, and the TV carrier.

Tracking the BOC Challenge

The BOC Challenge was a solo, around-the-world sailboat race with approximately 35 racers which started in Charleston, South Carolina, in September 1994 and ended in May 1995. This race and its sister race, the BOC Transatlantic Challenge, were organized by The BOC Group, a British company which was the primary sponsor. CMC, also a sponsor of the races, provided satellite communications and information services to the racers and race management, and tracked the racers to provide the news media with constantly updated information on each boat's location, and other race news.

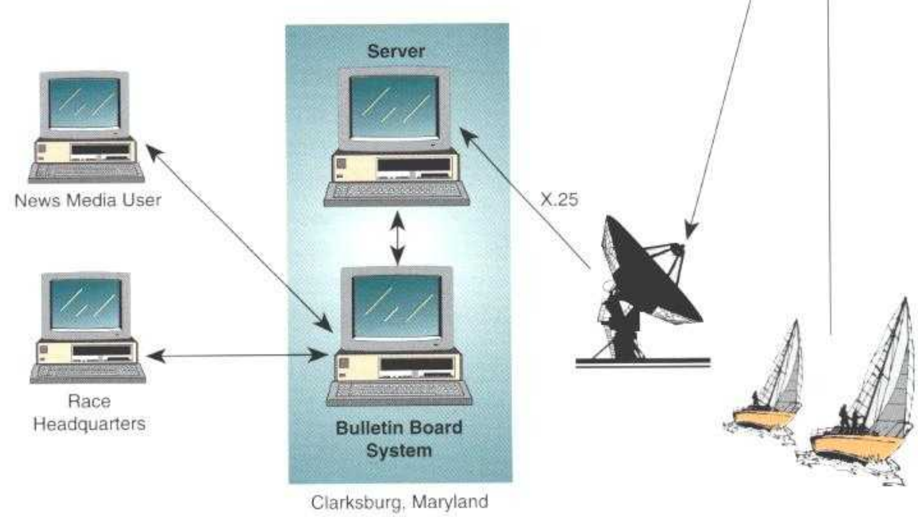
All racers were equipped with Inmarsat-C mobile earth stations having integrated global positioning (GPS) satellite receivers. This automated equipment reports its position periodically, without manual intervention. The race position reports passed through one of the Inmarsat land earth stations and were collected at COMSAT's server in Clarksburg, Maryland. The server, an IBM-compatible PC, published the reports on a computer bulletin board, allowing simultaneous access by users around the world.

VTSS Product Assistance

SDD contributed to the design and development of a Vessel Traffic System Simulator (VTSS) for the Port of Rotterdam. The Division led the design, implementation, and documentation effort for the simulator's GUI, which was implemented using rule-based artificial intelligence tools for the X Window System. Reusable browsers and editors were developed to create and edit a library of multimedia objects (such as full-motion graphics, text, and audio) that can be used in any exercise.

Although the VTSS was developed in an object-oriented environment, much of its data were stored in a relational database. SDD designed the relational model for the different categories of system data, including map, vessel movement, text, and audio data. SDD was also responsible for mapping the relational concepts into the object model (e.g., handling object-oriented inheritance and complex object-oriented data types).

The VTSS is a distributed system encompassing many processes on many different workstations. To support this architecture, SDD



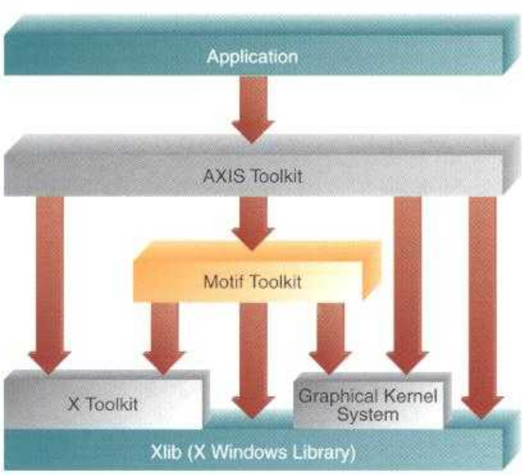
BOC race reports generated by GPS receivers passed through Inmarsat land earth stations and were collected at Clarksburg, where they were published for user access worldwide.

developed reusable libraries based on multiple protocols. In addition, SDD designed and implemented the integrated communications system and the underlying speaker and microphone manager subsystems, which allow audio communications over simulated VHF channels, intercoms, and telephone lines.

U.S. Coast Guard AMVER System

SDD is proud to be part of the COMSAT team supporting the U.S. Coast Guard's (USCG's) Automated Mutual Assistance Vessel Rescue (AMVER) system, which has been saving lives at sea for more than 35 years. With this system, ships around the world voluntarily report their position to the Coast Guard via Inmarsat every 48 hours. When a distress call comes in, the USCG Rescue Coordination Center can immediately display the position and course of all known ships within 250 nmi of the vessel in distress and contact the closest ship to request assistance.

CMC receives messages from ships at its Inmarsat land earth stations in Southbury, Connecticut, and Santa Paula, California. The messages are sent to a server in Clarksburg via an X.25 network. SDD's role in support of CMC has been to develop the server software. The server performs protocol conversion, looks up information about the ship (including its call sign) from a database, adds this information to the message, and forwards it to the USCG's center in Martinsburg, West Virginia. Some messages from ships include meteorological readings. For these, the server creates an additional message which it sends to the National Oceanic and Atmospheric Administration, where the information is used to construct a global weather model.



The AXIS Toolkit design uses the layered approach found in the X Window System and Motif. The design architecture builds on the functionality found in X Window and Motif and provides extended capabilities that offer the software developer the most flexible system possible.

SOFTWARE ENGINEERING

AXIS User Interface Development Environment

The AXIS User Interface Development Environment (UIDE) system contains software libraries, productivity tools, and application templates that software developers use in designing and implementing advanced GUIs to software applications. The system improves user interface consistency, programmer productivity, and software quality by providing and enforcing standard mechanisms, methods, and architectures for the software that drives the interfaces.

AXIS was developed at COMSAT Laboratories under a proprietary research program, and is based on the X Window System and OSF/ Motif standards. Currently in its third release, AXIS is maintained and enhanced by SDD programmers.

The most significant productivity tools included with AXIS are an easy-to-use Motif-based text editor, and Xware, an advanced screen design and code-generation facility. The menu-driven AXIS Text Editor incorporates numerous programmer-friendly features and provides software developers with a productive tool for entering and editing source code. Xware enables a user to interactively and graphically design the screens of an interactive user interface, and then generates the software needed to implement the screens.

The major software component of AXIS is the AXIS Toolkit, a collection of utilities that simplify the design and implementation of interactive applications. The toolkit features simple methods for managing information related to the user interaction objects that make up a user interface. These functions significantly reduce the complexity of writing an interactive application.

The AXIS Toolkit is implemented in the C programming language. For DOD software development projects, SDD developed an Ada binding to the AXIS Toolkit for use on VMS.

GRAXIS

SDD developed the initial release of GRAXIS, a graphics toolkit for developing software applications. The toolkit is written in today's most widely used object-oriented language, C++. Its object-oriented application programming interface is designed to shorten the learning curve for applications programmers and improve the maintainability of the toolkit.

GRAXIS supports a broad range of functions, including two- and three-dimensional modeling and rendering. It also supports event-driven interaction with graphically displayed objects, and allows the use of state transition tables to define an object's behavior. The toolkit is particularly well suited for the rapid development of prototype applications. With GRAXIS, programmers can quickly tailor an interactive graphical interface to meet a customer's needs.

Mapping Software

SDD has developed a library of object-oriented tools for generating and interacting with graphical data displays. The effort initially focused on the interactive display of geographical information to support satellite communications analysis applications. The tools developed consisted of a device-independent graphics package, file management software for storing and retrieving geographical data, and an application programming interface (API) to mapping and graph-generating software.

Currently, the mapping package supports a basic set of features for drawing maps of the world through an API. The mapping capabilities access a geographical database that includes continent and political boundaries, major inland waterways, and major cities. To support applications related to mobile communications, the database will soon be expanded to include airports, major highways, canals, railroads, and other features. The software allows these features to be drawn using a variety of projections (including perspective) for arbitrary map dimensions and map center locations. The system permits a change in projection, as well as zooming and panning. Additional annotative features will include a labeled graticule, title, footnote, text labels, and legend. An interactive interface will also be developed to support these and other features, such as the import/export of user data, text and line drawing annotations, distance and location calculations, and import/export of the map layer.

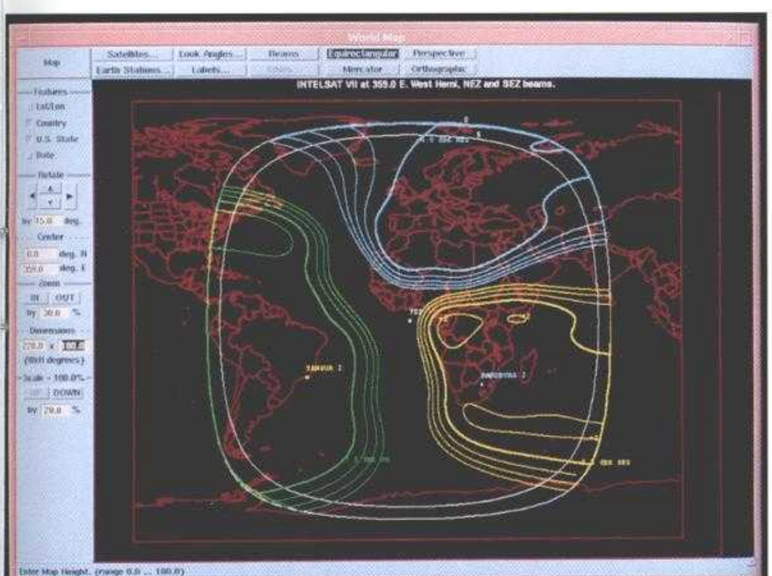
A database has been structured to provide efficient access to map data objects through a variety of indexes, without duplicating primitives such as edges and points. Currently, the software offers a single low-level index to the geographical data—which at this level consist of polylines, points, and text features—with limited information about the data class to which they belong (e.g., a polyline may belong to a country, coastline, and/or inland water class). At the highest level, a map object will be indexed by its unique identifier or class, or through a geopolitical class hierarchy index or spatial index. Users will be able to create their own data features and feature classes, and use any of the indexes to access their data.

SDD has demonstrated expertise in custom software development, employing current methodologies such as object-oriented design, graphical user interfaces, relational databases, and object-oriented databases, using C, C++, Ada, and other languages.

The underlying device-independent 2D graphics software will support 3D wire frame drawings in perspective, and orthographic projections. The retained-mode package also provides double buffering and hierarchical data modeling, and enables the map to be displayed as a static background over which additional user or application data layers can be displayed. The software currently provides a driver for X Window. A Postscript driver has also been implemented.

SOFTWARE PRODUCTS

SDD has developed a library of specialized software analysis tools which are regularly enhanced and updated for use with new applications and platforms. The library contains a number of unique satellite communications-related programs that provide the engineering analyst with automated support for such functions as link budget calculations, communications system planning, intermodulation analysis, antenna system design and evaluation, resource tracking and mapping, channel modeling, antenna coverage plotting, rain and sun outage prediction, and TDMA burst scheduling and planning.



World mapping capabilities support the display of satellite and earth station locations, visibility contours, and satellite antenna gain patterns on the surface of the earth. The user may select the map projection and, optionally, display geographical information such as country and state boundaries, cities, and major rivers and highways.

Satellite & Systems Technologies

The Satellite and Systems Technologies Division (SSTD) conducts research and development, systems engineering, and analysis on a variety of satellite communications technologies, and produces space-qualified hardware. ◆ Division work encompasses next-generation satellite systems; multibeam antennas and on-board RF processing hardware; repeater subsystems, antenna feeds, and components; power, command/control, thermal, and mechanical subsystems; and propagation studies. ◆ SSTD also designs and installs turn-key systems for in-orbit testing and system performance monitoring. ◆ Resources that include state-of-the-art computers and software enable SSTD engineers to engage in technical programs from initial concept development through final product realization. ◆ Such broad involvement in satellite systems and hardware provides the foundation for the many system studies SSTD conducts and the consulting services it offers.

RIGHT: An engineer tests a dissolved positive battery cell plate for chemical composition and impurities in SSTD's electrochemical battery analysis laboratory.

ANTENNAS

The Satellite and Systems Technologies Division (SSTD) is COMSAT's primary, in-house source for the design and engineering of earth station and satellite antennas, which are key contributors to overall communications system capacity.

Earth Station Antennas

An automated antenna verification (AAV) system has been developed by SSTD for accurately and efficiently testing a wide variety of earth station antennas. The system is computer-controlled, with a spectrum analyzer, a power meter, and a synthesized signal generator as the primary measurement equipment. Parameters measured include radiation patterns, directive gain, low-noise amplifier (LNA) noise temperature, antenna and system temperature profiles, gain-to-noise temperature ratio (G/T), return loss, and insertion loss. The AAV system also calculates pointing information for satellites, and ephemeris data for radio stars and the moon. The ability of the system to measure swept frequency noise temperature is particularly useful in accurately characterizing antennas and LNAs.

INTELSAT has purchased SSTD's AAV software for use in the certification testing of its new communications system monitoring stations. The software is also available for purchase by U.S. individuals and companies involved in testing and verifying earth station antennas. The AAV system is fundamental to antenna testing and to the consulting services that COMSAT Laboratories provides to numerous earth station suppliers and operators.

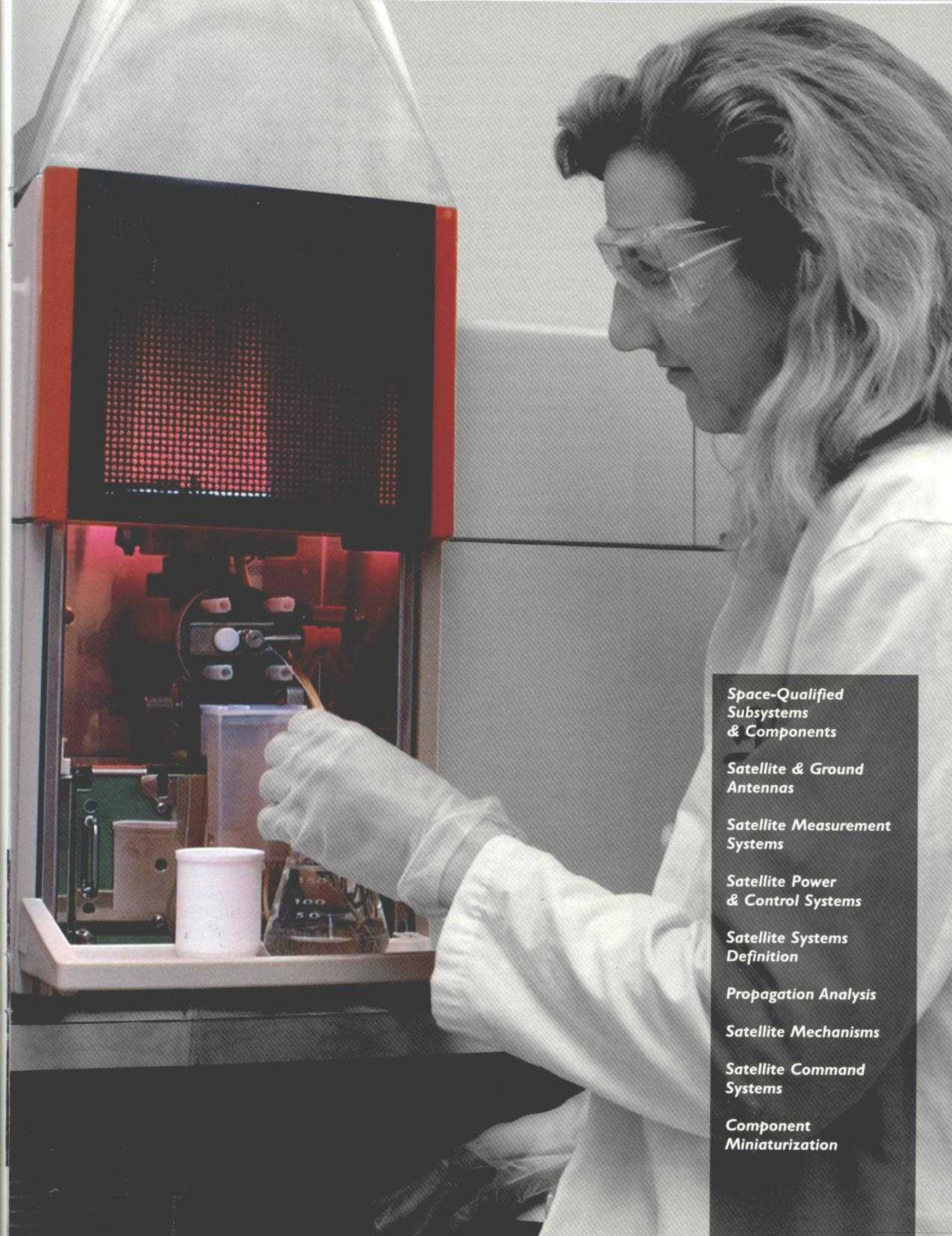
AT&T contracted with COMSAT Laboratories to modify its Lenox, West Virginia, 19-m earth station antenna to dual (C- and Ku-) band operation. This step was part of a major upgrade of the earth station which enables it to offer emergency restoration of service. A four-band, corrugated-wall feed horn was custom-designed for the Lenox antenna. Also, the subreflector was replaced by a new design to convert the optical system from a beam waveguide geometry to a standard Cassegrain feed geometry. With the feed installed and the antenna tested, the station is now compliant with both INTELSAT Standard A and Standard C earth station antenna specifications.

An antenna design development program for next-generation miniaturized Inmarsat-M terminals was completed. The objective was to develop terminal antennas smaller than those currently used in briefcase-size terminals. Three L-band antenna models (a single patch antenna with 8-dBi gain, a four-element patch array with 11-dBi gain, and a collapsible disk-on-rod antenna with 12-dBi gain) were fabricated and tested. The models were manufacturing prototypes and achieved the goal of minimizing size, weight, and manufacturing cost.

Satellite Antennas

SSTD designed, constructed, and completed the performance testing of a Ku-band high-power multibeam phased array. The four-beam, 24-element array includes 24 radiating waveguide horns, twenty-four 2-W solid-state power amplifiers (SSPAs), and a 4 x 24 beam-forming matrix (BFM) with 96 monolithic microwave integrated circuit (MMIC) phase shifters. Comprehensive software tools developed at COMSAT were used in system simulations to predict third-order intermodulation product beam levels and locations in multicarrier situations. The measured patterns of the intermodulation products agreed with predictions. The active phased array was further characterized by bit error ratio (BER) measurements for different channel loadings of the array system.

As part of a program supported by the U.S. Government, SSTD developed an active, multiple-beam antenna that will meet the requirements of future Defense Satellite Communication System networks. The goal of this effort was to demonstrate the feasibility of active phased arrays by building and testing a prototype X-band phased array. The transmit phased array is part of a satellite which provides multiple coverages that can be reconfigured dynamically to meet changing traffic demands. The antenna simultaneously generates four



Space-Qualified Subsystems & Components

Satellite & Ground Antennas

Satellite Measurement Systems

Satellite Power & Control Systems

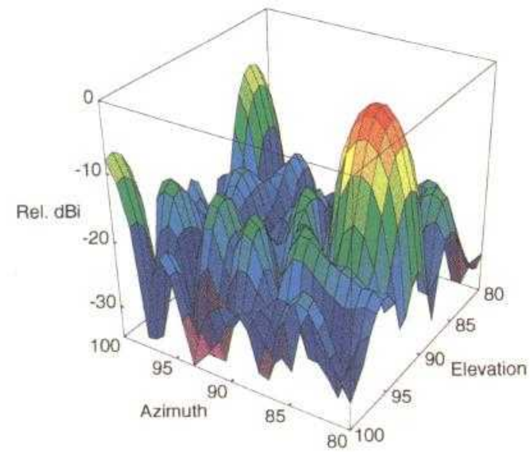
Satellite Systems Definition

Propagation Analysis

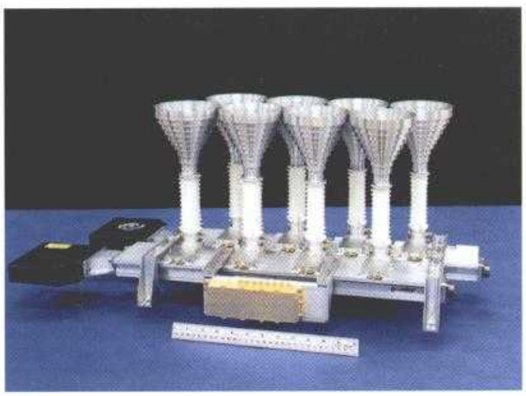
Satellite Mechanisms

Satellite Command Systems

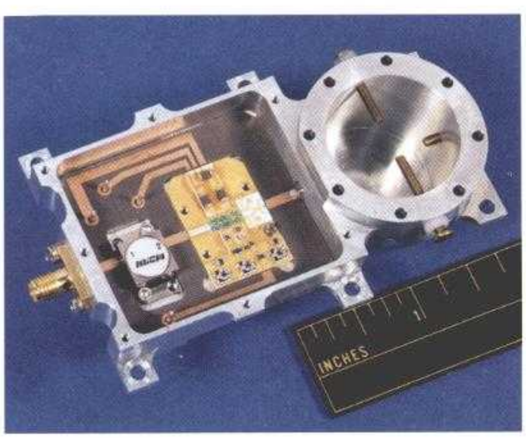
Component Miniaturization



Testing of the Ku-band active phased array included measuring radiation patterns at multiple frequencies and power levels, performing holographic measurements, and evaluating system performance of intermodulation levels and bit error ratios under multicarrier conditions.



The high polarization purity of the elements in the X-band array makes it suitable for dual-polarization applications.



The 2-W SSPA used for the X-band phased array.

beams of variable shapes, with sizes ranging from 2° to full earth coverage.

To demonstrate the technology involved, an eight-element subarray was developed and built as a model of the full-scale phased array. Scalar ring horns and pin polarizers were used to provide radiation patterns having excellent polarization purity over the complete coverage area. A 2-W SSPA in an integrated housing feeds each array element, permitting high-efficiency power generation and allowing flexible power-sharing among the beams for efficient use of satellite resources.

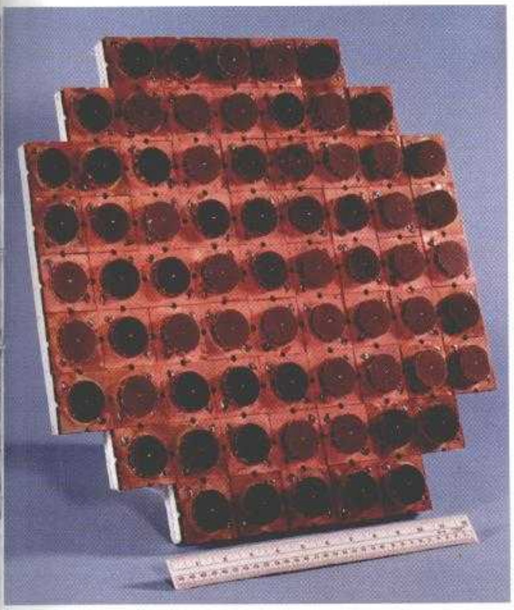
A two-beam, eight-output BFM was also designed and fabricated for the X-band program. The design was implemented in a highly modular fashion to facilitate both fabrication and modification. The use of 5-bit MMIC phase shifters and attenuators behind each array element permits control of excitation coefficients, providing the flexibility to synthesize a wide variety of radiation patterns for many types of coverage. By incorporating MMIC technology in the BFM, components can be manufactured with a high degree of uniformity and, consequently, beam patterns can be synthesized with a high degree of confidence. The phase shifters are fabricated as switched lines, implemented in printed coplanar waveguide, to give the true time-delay beam steering required in wideband applications. The assembled X-band array was tested in an anechoic chamber to demonstrate the formation and scanning of the two independent beams. The radiation patterns of the two beams, and of the intermodulation products that result from multicarrier operation of the active array, were measured. Agreement between the measured patterns and those predicted by COMSAT's software simulation tools was very good.

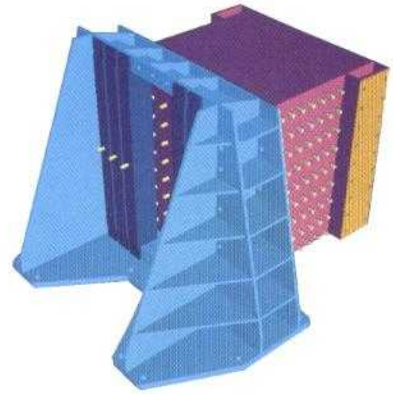
Another active antenna program in SSTD involved the design and fabrication of a 69-element C-band phased array for INTELSAT applications, to permit dynamic synthesis of beam coverages. Two sets of redundant 2-W SSPAs were incorporated behind each element to produce both left- and right-hand circular polarizations with high purity. Each sense of polarization receives signals from a separate BFM, which was designed to produce a total of eight beams with 5-bit phase and amplitude control for each array element. The beams are reconfigurable to provide the various coverages required for INTELSAT satellites.

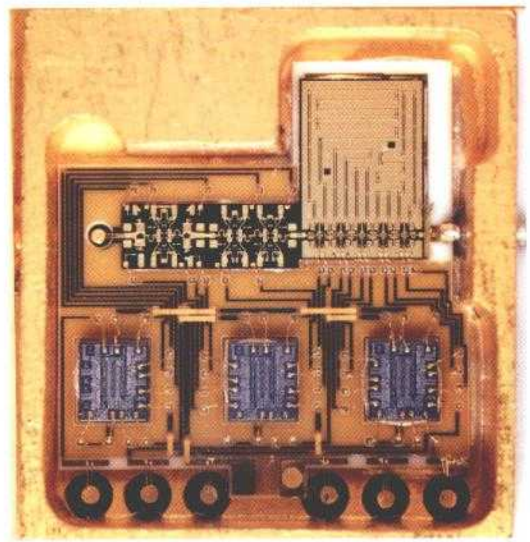
The SSPA and radiating element are integrated in a single module. Each power amplifier incorporates a linearizer to facilitate operation in multibeam and multicarrier environments with good linearity and high power-added efficiency (PAE). Linearization enables the amplifier to operate at a PAE of better than 30 percent, while maintaining carrier-to-intermodulation ratio, C/I, of 20 dB and achieving over 50-dB gain. The SSPAs are produced in custom packages on aluminum/silicon carbide base material for reduced mass and efficient thermal dissipation.

Each SSPA is coupled to a microstrip patch radiating element in the overall module assembly. Other components include isolators, a gain block amplifier, signal monitoring circuitry, and a bias distribution network. As many as nine SSPA modules are assembled on a single chassis to form a linear antenna array. The chassis assemblies are then positioned in parallel to complete the full two-dimensional, 69-element radiating surface of the active antenna. The modularity of the design enables efficient assembly, and may be extended to larger apertures for future satellite communications systems.

SSTD has carried the modular approach forward into the BFM design. The matrix can provide eight independently steerable and reconfigurable beams for the 69-element, C-band active phased-array antenna. Its integration approach ensures low-risk, low-cost assembly, while providing low mass, small size, high reliability, and state-of-the-art performance. Wide bandwidth performance is achieved in all circuits within the BFM, including the gallium arsenide (GaAs) MMIC phase shifter and attenuator.







LEFT: The C-band phased array employs lightweight printed-circuit technology for its antenna elements. TOP RIGHT: The modular architecture of the BFM can accommodate various beam configurations at different frequencies with only minor redesign. CENTER RIGHT: The most basic building block in the BFM is the MMIC package, containing the 5-bit MMIC phase shifter, the 2- and 3-bit MMIC attenuators, and three digital control integrated circuits. The package was designed to minimize size and mass, yet provide a rugged, hermetically sealed environment for the BFM electronics.

PAYLOAD COMPONENTS & TESTING

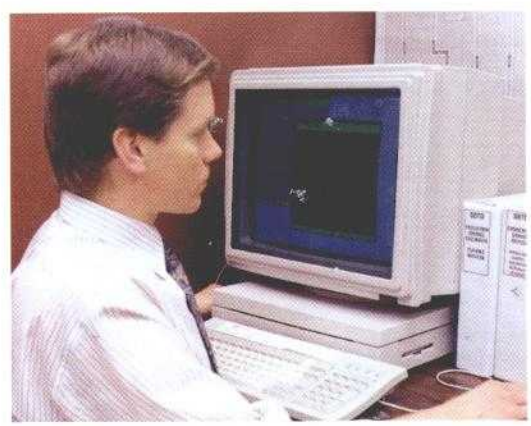
Microwave Components

Ku-Band 1-W SSPAs—COMSAT delivered 100 MMIC, Ku-band, 1-W SSPA modules to Alcatel Espace for a communications satellite phased-array antenna program. The performance uniformity required among all modules of the active array necessitated custom, process-insensitive MMIC designs with DC and RF on-wafer test capability. A computer-controlled system was developed for efficient small- and large-signal module-level RF measurement and data acquisition for each amplifier. The gain flatness for each SSPA module is within ±0.5 dB across a 2-GHz band (within a 2-dB window). Two other key performance parameters are a peak PAE of 30 percent and C/I linearity greater than 15 dB, which are crucial to successful operation in a multicarrier communications environment.

SSPA Power Slump—When an SSPA is RF-overdriven into saturation, its output power degrades after only a few hundred hours of operation—a condition known as "power slump." A number of SSPA manufacturers have experienced the problem in varying degrees. The time to the onset of power slump, and the rate of degradation, depend on the degree of overdrive. There is no well-accepted screening procedure for the failure mechanism, since it cannot be predicted by the conventional high-temperature accelerated life test which uses the Arrhenius equation.

SSTD has investigated power slump in satellite transponder SSPAs, in order to recommend a safe operating condition and develop a cost-effective screening procedure. The cause of the failure was determined to be the reverse breakdown of the field-effect transistor (FET) Schottky barrier gate under large RF overdrive. SSTD then developed a large-signal model to predict the instantaneous gate-drain voltage and breakdown current as a function of RF overdrive.

Low-Loss Switches—The mass and volume of future satellite payload hardware can be significantly reduced by replacing a large number of the electromechanical switches, used for redundancy and signal routing, with electronic switches. Currently under development in SSTD are highly reliable, lightweight electronic switches with low-loss connectivity and electronic redundancy for on-board satellite applications. The goal is to develop broadband, low-loss redundancy switch configurations and static switch matrixes for the C- and Ku-bands, employing passive FETs and MMIC technology. The use of technology that is compatible with hardware on



During the past 2 years, a number of broadband MMIC single-pole, double-throw transmit/receive switches have been designed, fabricated, and tested. An 8-for-6 redundancy switch module was constructed using eight MMIC transfer switch chips.

board high-capacity multibeam satellites will reduce hardware interface problems. Low-loss switches also will provide redundancy for LNA outputs and SSPA inputs.

Lightweight Satellite Receiver—SSTD is developing a small, lightweight 6/4-GHz receiver for satellite applications. The receiver was designed using a mix of microwave integrated circuit (MIC) and MMIC technology to obtain high reliability and performance, and to reduce assembly and testing costs.

A low-cost C-band synthesizer and an L-band phase-locked oscillator (PLO) were developed for C-band very small aperture terminal (VSAT) outdoor unit applications. One of SSTD's major design goals for the implementation—minimizing production costs—was achieved by selecting a design with the minimum component count and minimum required assembly time which will provide the desired electrical performance. The selected configuration was a double-loop phase-locked loop in which both loops are phase-locked to a stable 10-MHz reference. Both the synthesizer and the PLO are fabricated on a single multilayer printed circuit board. The C-band synthesizer has a tuning step of 10 MHz, minimum output power of 10 dBm, and phase noise of -93 dBc at 100-kHz offset from the carrier. The L-band PLO has an output frequency of 1,000 MHz, minimum output power of 10 dBm, and phase noise of -122 dBc at 100-kHz offset from the carrier.

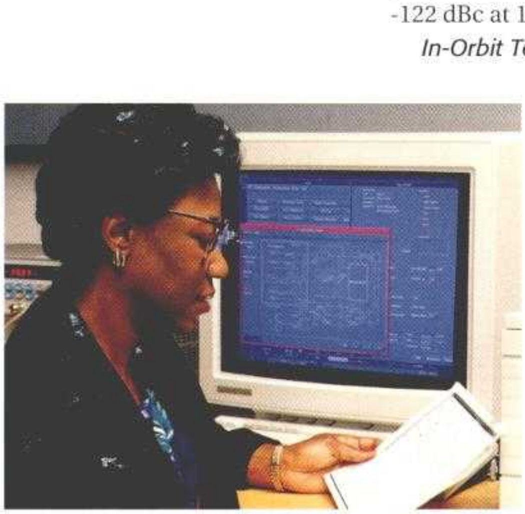
In-Orbit Test Transponder—An in-orbit test transponder (IOTT1) designed, manufactured, and space-qualified by SSTD was part of the ITALSAT F1 spacecraft launched in January 1991. The onboard IOTT has performed successfully in space. Typical spacecraft tests are conducted by transmitting a 30-GHz signal from an earth station and detecting the received 20-GHz signal. The tests include flux density, effective isotropically radiated power (EIRP), traveling wave tube amplifier (TWTA) transfer characteristics, and transponder linear gain.

The IOTT incorporates MMIC Ku-band amplifiers, lightweight waveguide Ku-band filters, electronic power control, and combined IOTT telemetry/control circuitry, all designed and fabricated at COMSAT Laboratories. The transponder bypasses the onboard regenerator and connects the input sections of the TWTAs, thereby converting the ITALSAT digital payload into transparent analog transponders and allowing full characterization of the transponders. The IOTT is still in use and contains what is believed to be the first MMIC circuitry ever launched on a communications satellite. Under a follow-on contract with Alenia Spazio, SSTD designed, fabricated, and delivered a second IOTT (IOTT2) for flight on the ITALSAT F2 multibeam spacecraft.

IOT Measurement Techniques & Systems

Transponders on communications satellites must be tested following successful launch but prior to the satellite entering revenue-generating service. For more than 25 years, SSTD has pioneered computer-controlled in-orbit test (IOT) measurement systems and techniques, and has designed, assembled, installed, and supported automated IOT systems for numerous satellite operators, including INTELSAT, GTE, SBS, EUTELSAT, and Hughes.

To accommodate satellite operators' often tight schedule constraints and to reduce costly and time-consuming custom software development, SSTD has focused in recent years on building an engineered platform of integrated measurement and system control components that is highly reusable from one IOT system to another. This approach results in decreased



ABOVE: Automated in-orbit tests are performed to determine the postlaunch service readiness of a communications satellite, to investigate anomalous behavior, and to monitor communications performance during the satellite's lifetime. RIGHT: The entire IOT system, including in-house assembly of the microwave and computer equipment and integration with the system control and measurement software, was delivered to Hughes within 8 months. An engineered platform of reusable software components allowed SSTD to meet its customer's challenging schedule.

cost and time to deployment, and facilitates the rapid development of turnkey systems.

The effectiveness of this platform approach continues to be demonstrated. For example, the automated IOT facility delivered to Hughes Communications, Inc., was used, with SSTD technical support, for in-orbit testing of the first two *DirecTv*™ direct broadcast satellites prior to their entering revenue-producing service. SSTD has also upgraded an older BASIC-based Hughes IOT system (which we had earlier designed and built) to the current UNIX-based system for testing several different satellites.

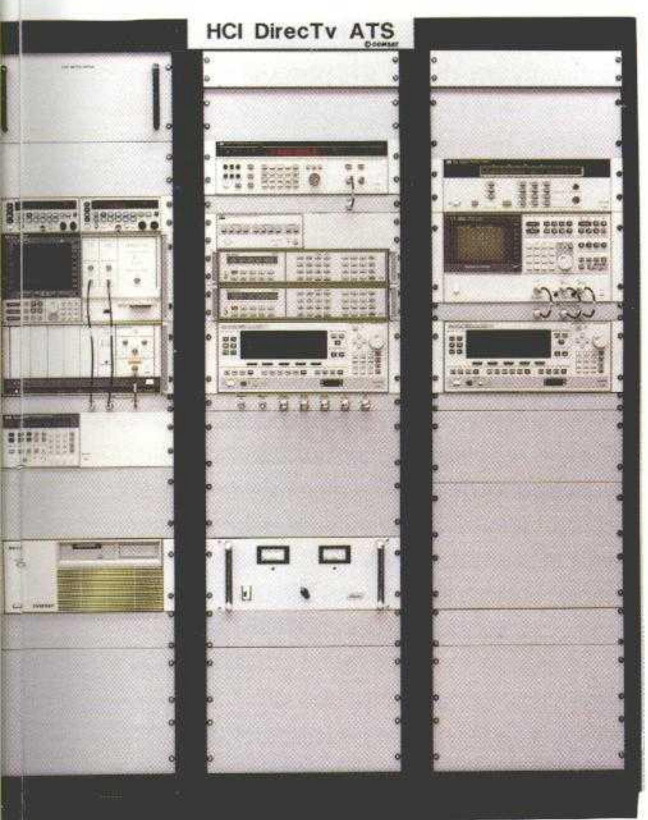
For EUTELSAT, SSTD had previously built and installed an automated IOT facility in France which was used for in-orbit testing of EUTELSAT II satellites F1, F2, F3, and F4. The IOT capability of this facility has since been enhanced significantly to support a dual-station configuration in which one earth station in Belgium transmits and measures the uplink test carrier, while a second earth station hosting the IOT facility performs downlink measurements. The uplink station IOT equipment is remotely controlled by the IOT facility via a network connection between the two stations.

SSTD designed and constructed an automated IOT facility for COMSAT RSI which was used to test the American Mobile Satellite Corporation's (AMSC's) first satellite, launched in early 1995. The facility can also be used to test SBS and, potentially, other satellites. This IOT facility operates with three earth station antennas—two Ku-band and one L-band.

SSTD also designed, assembled, tested, and delivered an L-band transportable earth station for AMSC. The trailer-mounted transportable can be towed to any location. Once set up, it can communicate with and be controlled by COMSAT RSI's IOT facility via the dial-up telephone network. The ability to measure antenna patterns in two locations results in enhanced pattern measurement accuracy.

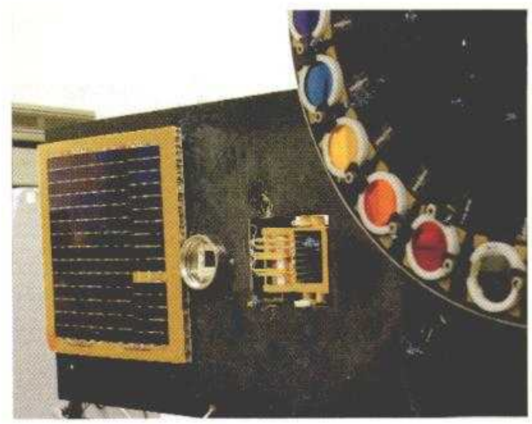
Another automated IOT system designed and built by SSTD is currently being installed in Indonesia for testing Satelindo's PALAPA C spacecraft at both C- and Ku-bands.

SSTD is continually enhancing computer-controlled microwave measurement techniques to support the increasing sophistication of satellite operators and required system capabilities. New techniques have been developed and implemented to support remote measurement control for the EUTELSAT dual-station capability, and to operate with multiple earth station antennas for both the COMSAT RSI and Satelindo IOT systems.



SPACECRAFT BUS

The spacecraft bus is the mechanical structure that houses a satellite's primary and secondary power sources, fuel, and propulsion for stationkeeping and attitude control, as well as its thermal control subsystem. SSTD maintains expertise in these diverse disciplines to support advances in these technologies and to maximize the performance of in-orbit subsystems. This expertise is available to INTELSAT and Inmarsat, and is marketed to organizations such as NASA, the Department of Defense (DOD), and spacecraft prime contractors.



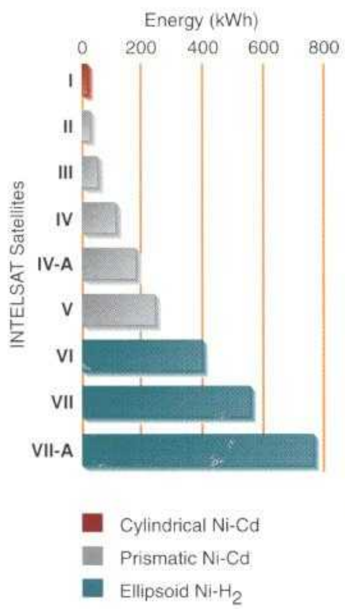
Solar cells mounted in fixtures on this test plane can be electronically characterized during exposure to a light beam that accurately simulates sunlight level in space at the earth's orbit about the sun. The color filters transmit light only in selected regions of the solar spectrum and are used to determine the solar cell electrical output in these regions.

Optical Properties of Spacecraft Components

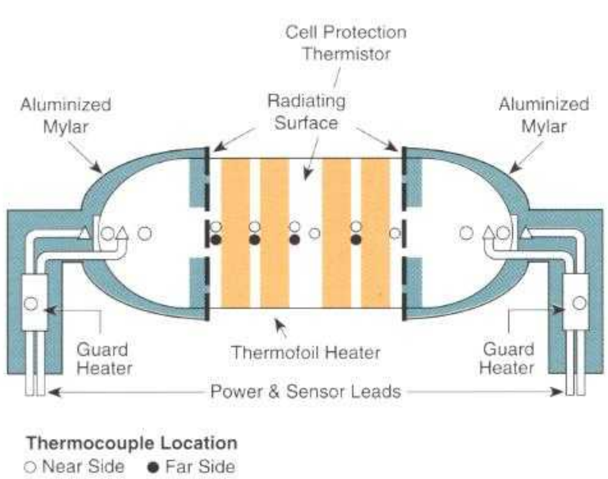
Knowledge of the optical properties of spacecraft components, and the stability of these properties in space, is vital to designing and predicting the performance of communications satellites. For more than 25 years, SSTD has maintained a state-of-the-art capability to make optical measurements and simulate environmental damage to solar cell assemblies, optical solar reflectors (OSRs), and other components exposed to solar ultraviolet or spacecraft contamination environments. While most of the measurements are routine (having been well defined over many years), recent problems requiring nonroutine measurements have provided an opportunity to extend SSTD's capabilities and improve the accuracy of its measurements.

One such challenge was a requirement to measure the reflectance of OSRs at glancing angles. These reflectors are used as radiators, and thus are kept out of sunlight as much as possible; however, during summer and winter solstice, they are exposed to sunlight at oblique angles. New coatings have been developed to increase the reflection of the nonuseful portion of sunlight by solar cells that look at the sun as directly as possible (i.e., with sunlight perpendicular to the cell faces), and therefore reduce their temperature during critical periods of solar exposure. SSTD wanted to determine if the same coatings would benefit OSRs, and what changes would be needed to provide benefits at angles near their maximum exposure angle of 67° from perpendicular. Since the industry-standard equipment for measuring reflectance was not designed to measure at such oblique angles, SSTD devised an innovative approach that required only minor modification of the equipment to allow simultaneous reflection from two samples at the same angle. The results were remarkable, and oblique angle measurements can now be made with confidence.

In addition to the optical measurement of OSRs and solar cells, SSTD provides full electrical characterization for solar cells. An unusually well-collimated and optically matched solar simulator uses primary and secondary standard cells to set the output intensity for the level of sunlight in orbit. Solar cells exposed to this illumination will respond exactly as they would initially in space. However, in space they would be damaged by the radiation and solar ultraviolet light to which they are exposed.



Battery capacity has increased significantly from generation to generation of communications satellites.



Destructive physical analysis is performed for various reasons, including investigation of anomalous performance, verification of specifications, and evaluation of new designs and components.

A recent space-flight qualification of GaAs solar cells with different blue and red reflecting coverslides (for radiation thermal control) included long-term UV exposure in vacuum of both irradiated and unirradiated components. Because of the high reproducibility of the SSTD measurements, several new effects were identified that would otherwise have been attributed to statistical, systematic, or fabrication error.

Such measurements and tests have been important in determining the use of new components in both INTELSAT and Inmarsat programs, and are expected to benefit future programs by enabling component and spacecraft manufacturers to more accurately evaluate new products during their development and integration into spacecraft designs.

Electrochemical Battery Development

Nickel-cadmium (Ni-Cd) and nickel-hydrogen ($Ni\text{-}H_2$) battery technologies continue to be subjects of intense scrutiny. The size and sophistication of satellite batteries—especially of nickel-hydrogen batteries, which COMSAT invented and perfected in 1983—have changed considerably over time. SSTD recently investigated the capacity fading of $Ni\text{-}H_2$ cells with extended storage, the performance decrease in Ni-Cd cells due to the negative-limited condition, voltage decay of earth station lead acid batteries used for standby power, electrochemical and thermal characteristics of rechargeable lithium ion batteries, and the use of radiative calorimetry and destructive physical analysis for battery evaluation.

Storage-related capacity fading in $Ni\text{-}H_2$ cells was investigated by using various analytical techniques, including determination of residual charged active material in a discharged plate and thermogravimetric analysis of positive active material. Results showed that the phenomenon is attributable to dehydration of positive active material and conversion to a new phase which contains less water in the interstices. Potential sweep voltammetry was used to extend the positive plate deactivation study to cycled plates and plates which showed anomalous capacity at low temperatures (e.g., -5°C).

COMSAT has taken the initiative in examining the new lightweight common pressure vessel

(CPV) Ni-H_2 batteries for satellite applications for NASA-Goddard. Two specially designed and fabricated 27.5-V batteries are undergoing extensive evaluation. Test results have confirmed our expectations and are very encouraging.

Ni-H_2 CPV Telemetry Methods & Processor Circuit

Development of the Ni-H_2 CPV battery has emphasized the need to access individual cell voltages and circuitry to obtain telemetry data. By analyzing these data and altering the way in which the battery is managed, the life of a CPV battery can be extended.

SSTD has developed a method for accessing the individual cells in a CPV battery to transmit cell voltage signals to a telemetry processor circuit (TPC). This method of connection can be realized in a design that is lightweight yet rugged, and compatible with the small clearances between the cells.

A reliable, lightweight, and efficient TPC was designed for this application, and a breadboard version has been successfully tested. Since the TPC is located within the CPV and powered by the battery, its power consumption must be very low. The circuit multiplexes cell voltage data, along with battery temperature and pressure signals, into one serial stream, thus simplifying processing by the spacecraft telemetry system.

Several different methods for transmitting telemetry data from inside the CPV have been examined in detail. The most effective approach found is to simply add an extra feedthrough port to the CPV battery, since pressure vessel seals have become very reliable.

Command & Control

The continuing evolution of radiation-hardened microprocessor technology has enabled a satellite processor to handle more functions. A satellite bus architecture now can be simplified by replacing discrete electronics hardware with software running on a microprocessor. In addition, increased onboard processing power will enable satellites to operate more autonomously, thus simplifying ground station operation. SSTD uses a microprocessor test bed to investigate various advanced processor technologies and computer architectures for satellite applications. State-of-the-art, radiation-hardened components and a novel redundancy architecture have been combined to implement a small, lightweight, high-performance, space-qualified satellite processor design.

SSTD's investigation of neural networks for satellite command and control is now focused on diagnosing dynamic faults in the attitude control system of a three-axis-stabilized satellite by functional representation, reasoning, and the interpretation of sensor patterns. Using both supervised and unsupervised neural paradigms, SSTD is developing a modular system that will work in real time in conjunction with a larger, ground-based conventional expert system. The overall system will use satellite telemetry for system diagnosis, rectification, and control.

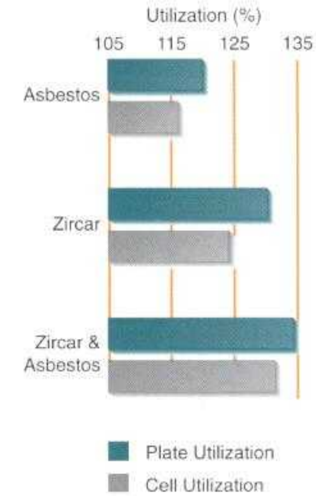
Spacecraft Subsystems & Mechanisms

The inability to return a full charge to the aging Ni-Cd batteries on the two oldest INTELSAT V spacecraft prompted a thermal analysis of the communications and service modules. The design configuration calls for some number of available TWTAs to be operating. Prior to the autumnal eclipse season of 1993, fewer than this number of TWTAs were in use on each of the spacecraft. Even at these low operating levels, the capacities of the lowest battery on each spacecraft would be exceeded by more than 150 percent during maximum eclipse. Therefore, it was imperative that the minimum power configuration be determined during both sunlit operation and eclipse.

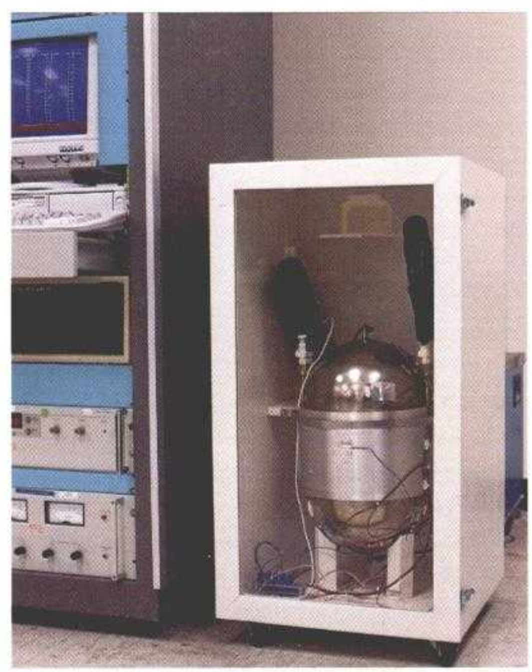
SSTD prepared thermal models of both spacecraft for the various configurations they had experienced in orbit, and the results were compared with flight data to determine the offsets to be applied to the various units. The combination of thermal analysis and flight data with the thermal test and flight experience acquired on more than 10 satellite programs led to minimum predictions for the communications model that were within 2°C of actual in-orbit temperatures.

SATELLITE SYSTEMS STUDIES

SSTD's experts conduct engineering tradeoff studies, top-level conceptual studies, and cost estimates of new satellites for a variety of government and business customers around the world. In the U.S., SSTD engineers have assisted the Defense Information

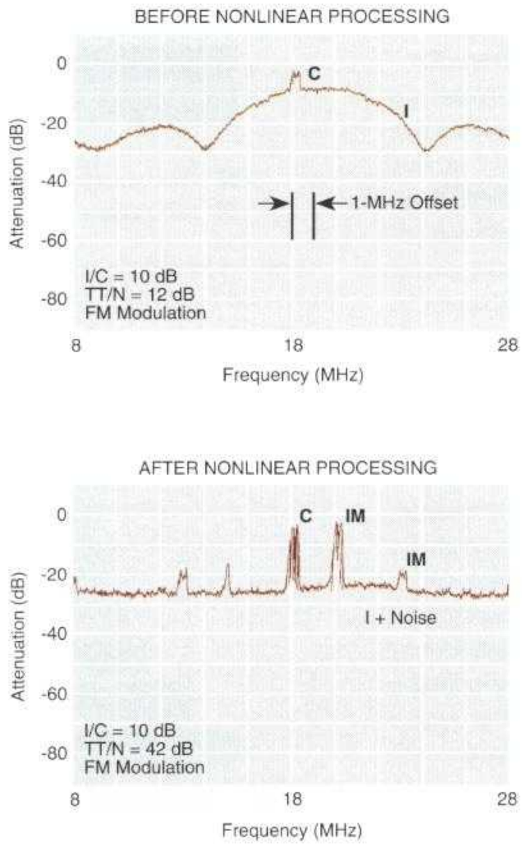


Destructive physical analysis of Ni-H_2 cells indicates that the coefficient of positive plate active material utilization is higher in cells containing two layers of Zircar™, or one layer of Zircar™ and one layer of fuel-cell-grade asbestos, compared to cells with one layer of asbestos.



One of the new lightweight CPV batteries in SSTD's life test chamber.

Systems Agency and NASA's Jet Propulsion Laboratory. Radio frequency interference (RFI) is a growing problem with mobile communications, and SSTD's signal processing studies have led to practical devices that can reduce RFI—for example, in the radar environment of a U.S. Navy ship.



A before-and-after test of an interfering 5-Mbit/s binary phase shift keying signal added to a wanted FM carrier of bandwidth 200 kHz using the BIL circuit. Note that the interference was 10 dB stronger and spectrally overlapped the wanted signal. At the BIL output, the interference is reduced to the same order of magnitude as the background noise leaving the original carrier, along with an intermodulation signal of equal power and a very much improved test-tone-to-noise ratio, TT/N. Note that a conventional notch filter does not work in this situation because the interference and the wanted carrier have overlapping spectra.

Active Nonlinear Devices for RFI Suppression in Radio & Satellite Systems

SSTD recently began developing and implementing a new type of broadband interference-reduction circuit to reduce RFI. Known as a *biased-inverting limiter* (BIL), such a circuit performs a voltage-variable nonlinear input-output transformation that can take a communications channel with interference several orders of magnitude stronger than a desired carrier (e.g., an interference-to-wanted-carrier ratio, I/C, of tens of dB) and greatly reduce the interference without distorting the desired carrier.

The use of the BIL reduces by tens of dB the amount of modulation immunity (offered by such techniques as band spreading or coding) normally needed when operating in a high-RFI environment. Increased channel bit rate capacity and reduced transmitter power result from this favorable tradeoff.

Three prototype BIL circuits have been built using successive generations of emitter-coupled logic. The first prototype had an effective operating range from DC to 30 MHz, while the second two prototypes work to well above 100 MHz. With sinusoidal test interference signals, as much as 35 dB of effective signal-to-noise-ratio (S/N) improvement has been achieved. Cascading devices have been shown to provide much greater RFI rejection capability.

Commercial Satellite Communications Initiatives

The Commercial Satellite Communications Initiatives program is sponsored by the U.S. Government to investigate expanding the use of commercial satellite communications systems to meet current and projected DOD communications requirements. COMSAT Laboratories provided engineering support for the Fixed Satellite Service (FSS) and Mobile Satellite Service system architectures developed for this program.

SSTD provided system engineering and conducted tradeoff studies to determine the feasibility of using existing commercial FSS assets, such as INTELSAT satellites, to satisfy capacity and coverage requirements for DOD satellite communications via mobile platforms, including aeronautical, land mobile, and maritime platforms. Typical coverage patterns and satellite characteristics were examined for the case where mobile terminals with small antennas communicate with a land-based hub station in a star configuration. Link analyses were conducted to determine the overall traffic-handling capability of a transponder in terms of megabits per second of throughput.

Interference problems that might occur when FSS transponders are used by mobile terminals also were investigated. This led to the selection of small earth stations for mobile applications, in combination with spread-spectrum modulation to mitigate potential off-axis emission. An important objective of this work was to demonstrate that commercial satellites using C-band frequencies and providing global communications (e.g., via INTELSAT satellites) could deliver broadband signals to mobile terminals in ways that would not interfere with the primary FSS allocation. The study focused on the INTELSAT VII series, but other regional or global commercial satellite systems may work as well or better if the beams are more concentrated. INTELSAT satellites have an advantage in that their coverage beams tend to favor international connectivity, which is very useful for these purposes. A global beam provides coverage of more than one-third of the earth's surface; hemispheric beams cover about one-sixth of the earth; and zone beams cover about one-twelfth.

I-CO Global Communications

Over the past few years, the Laboratories has carried out extensive system studies related to the three unique space segment configurations that have the potential to provide personal handheld voice communications: low earth orbit (LEO), intermediate circular orbit (ICO), and geostationary earth orbit (GEO). Together with Inmarsat's own studies, this work has led to the selection of a satellite communications system employing an ICO with 10 active satellites. With two planes of five satellites in a 10,355-km, 6-hr orbit, single satellite coverage can be realized for elevation angles greater than 18°, and dual satellite coverage can be achieved on average more than 80 percent of the time.

To finalize the satellite design, COMSAT Laboratories was requested by COMSAT Mobile Communications to study and provide system tradeoffs between communications link budgets on the one hand and satellite power and mass on the other. Our studies began with a basic spot beam design of 85 beams. For a vocoder channel rate of 4 kbit/s, this gives a nominal 7-dB link margin at a 20° elevation angle. The 85 receive and transmit spot beams are generated with separate 2-m phased arrays having 85 feed elements.

Greater link margin can be achieved by directly scaling the antenna aperture or, alternatively, by packing more spot beams into the field and thus reducing beam crossover. A compromise solution involves increasing the aperture dimension to 2.25 m with about 150 antenna elements, and at the same time reducing beam crossover from 2.5 to 1.0 dB. This design realizes a minimum link margin of 10 dB for 241 spot beams.

This enhanced ICO satellite design shows some 25-percent increase in power (principally due to the digital processor) and 10-percent increase in mass (due to the processor and antenna element increase) compared to the baseline.

PROPAGATION STUDIES

Most of SSTD's propagation studies address such areas as tropospheric effects on earth-space propagation, propagation measurement systems, propagation impairment amelioration techniques, and mobile-satellite propagation issues. SSTD has investigated the behavior of propagation channels as part of I-CO Global Communications' effort to develop satellite-supported omnidirectional handheld communications systems. The strength of L-band carrier signals delivered by one of the Inmarsat-2 satellites was measured, and the data were analyzed and modeled. The study considered ground reflections, tree shadowing, the effects of satellite motion due to inclined orbit, and interference from the user's body.

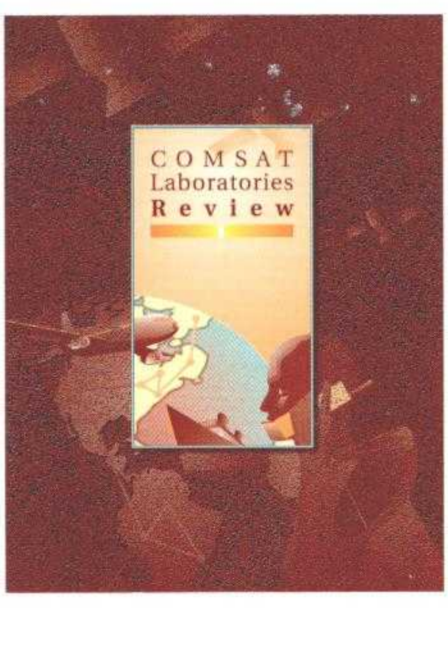
Low-elevation-angle propagation effects become important in regard to operating inclined-orbit satellites and extending their coverage area, both of which can bring economic benefits to satellite operators. In this context, SSTD undertook an INTELSAT-sponsored study to investigate low-elevation-angle effects at frequencies between 10 and 15 GHz. As a result, new propagation models were developed to predict the fading caused by cloud, melting layer, and tropospheric clear-air phenomena. In addition, a measurement system was placed in operation, collecting data by means of a C-band beacon signal at an elevation angle of 2°.

SSTD has successfully developed a hybrid beacon/radiometer system in which the beacon receiver and radiometer share the same propagation path and RF front end, including the antenna. This arrangement results in significant cost savings. The radiometer is based on the Dicke switching principle. A high degree of temperature regulation of the radiometer system components, combined with careful timing of the Dicke switching rate, enable the otherwise incompatible systems to coexist on the same RF paths. Three beacon/radiometer systems have been built, all of which operate at Ka-band frequencies and are capable of receiving 19- and 27-GHz beacon signals from NASA's Advanced Communications Technology Satellite (ACTS).

ACTS provides an excellent opportunity to study propagation issues and develop the system concepts required for commercial exploitation of the 20/30-GHz frequency band. To this end, SSTD is undertaking studies of propagation measurements (including site diversity), uplink power control (ULPC), wide-area diversity, and advanced networking concepts. The first three experiments are sponsored by NASA, and the fourth by INTELSAT. Both the wide-area diversity and the advanced networking studies seek to take advantage of the finite size of rain cells to combat the rain fading that affects VSAT networks operating in metropolitan areas.

Rain fading is a limiting factor at Ku-band frequencies, and most Ku-band satellite links in heavy rainfall regions are expected to use ULPC to increase uplink (only) availability. SSTD has developed a power control system capable of controlling up to 12 IF carriers.

The prototype ULPC system was built to test and validate the design features of a complete user interface and remote control capability.



ABOUT THE COVER:

Today, users are driving technology to create systems that will allow sophisticated communications—mobile, aeronautical, or land-based—anytime and anywhere. COMSAT Laboratories is committed to the development of an infrastructure that will permit such systems to work globally, in developed as well as emerging nations. In the very near future, the seamless integration of communications satellites, cable, and cellular and other wireless systems will open a transparent communications "window to the world."

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COMSAT LABORATORIES
22300 COMSAT Drive
Clarksburg, MD 20871-9471 USA
Telephone (301) 428-4000
Fax (301) 428-4600
Product Development Manager (301) 428-4010
e-mail: eric.timmons@comsat.com
Patents & Intellectual Property Licensing (301) 428-5044

NETWORK TECHNOLOGY DIVISION
Fax (301) 428-7747
Vice President (301) 428-4059
Director of Operations (301) 428-4167

COMMUNICATIONS TECHNOLOGY DIVISION
Fax (301) 428-4534
Vice President (301) 428-4477
Director of Operations (301) 428-4263

SYSTEM DEVELOPMENT DIVISION
Fax (301) 428-3186
Vice President (301) 428-4682
Director of Operations (301) 428-4684

SATELLITE & SYSTEMS TECHNOLOGIES DIVISION
Fax (301) 540-8208
Vice President (301) 428-4067
Director of Operations (301) 428-4141

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