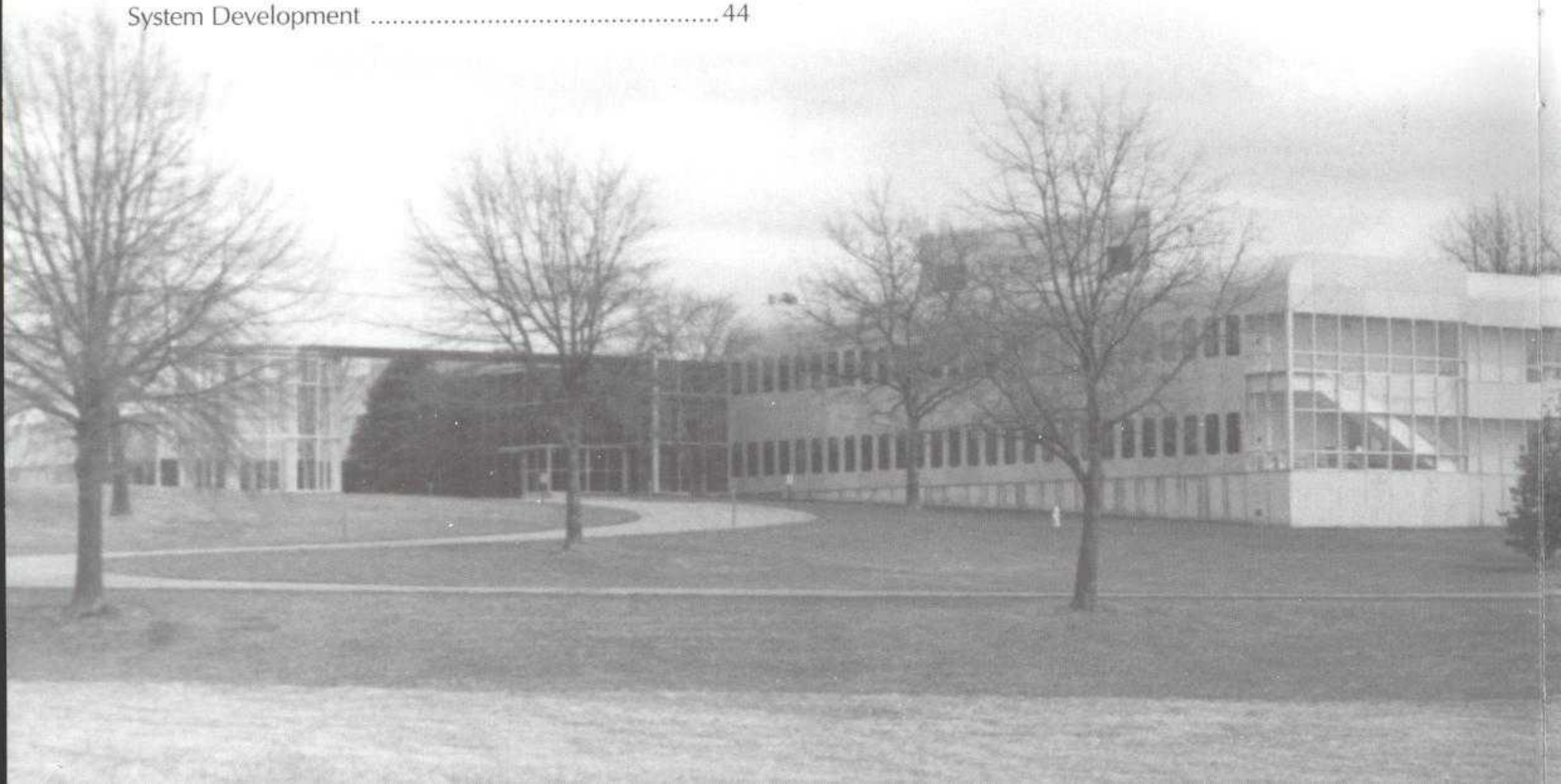
COMSAT Laboratories 1992 Annual Review



A Message From the President of COMSAT Laboratories

This tenth in a series of annual reports summarizes our research and development activities during the calendar year 1992, the 25th anniversary of the founding of COMSAT Laboratories. The Laboratories conducts basic research and development to advance satellite communications technology. Elements of this R&D are funded by COMSAT World Systems and paid for with revenues derived from international communications services carried via the International Telecommunications Satellite Organization (INTELSAT). Work conducted on behalf of other components of the corporation—COMSAT Mobile Communications, COMSAT Video Enterprises, and COMSAT Systems Division—is shareholder-funded. Documentation concerning jurisdictional work (that is, work wholly or partially funded by the end user of the system) is available to the public through the *COMSAT Data Catalog*, which announces the availability of published papers and reports.

In 1992, the operating expenses for the Laboratories totaled $44 million. Nearly half of the Laboratories revenues are derived from sources outside the corporation. The Labs performs work on a regular basis for NASA, INTELSAT, and Inmarsat. Recently, COMSAT Laboratories has pursued alliances with organizations that have similar goals, but that lack some of the Labs' capabilities. The Labs has also begun supplying hardware for highly specialized applications, and in cases where other suppliers do not exist.

Corporate funding for 1992 was divided among three areas: research (27 percent), development (35 percent), and technical support (38 percent). Research funding is used to create new technology, with the goal of improving communications systems over the long term. Development efforts are directed toward nearer term applications and are undertaken by the Laboratories on a contract-like basis with the various elements of the corporation. The balance of corporate funding is for technical support performed to address immediate concerns regarding technical issues such as systems outages.

The capabilities and products of COMSAT Laboratories are available to both commercial and government enterprises. We invite further inquiry, and have listed persons to contact on the inside back cover. As the Laboratories begins a second quarter-century of commitment to international communications, its mission remains unchanged from that set forth at its inception: *Technical Excellence in Systems, Services, and Products for Global Communications.*

J. V. Evans

COMSAT ORGANIZATION 1992

COMSAT CORPORATION

B. Crockett
PRESIDENT & CEO

B. Alewine, President
COMSAT WORLD SYSTEMS

R. Mario, President
COMSAT MOBILE COMMUNICATIONS

C. Lyons, President
COMSAT VIDEO ENTERPRISES

J. Alper, President
COMSAT SYSTEMS DIVISION

J. Evans, President
COMSAT LABORATORIES

MED • *Microwave Electronics*

SSTD • *Satellite & Systems Technologies*

CTD • *Communications Technology*

NTD • *Network Technology*

SDD • *System Development*

B. Pontano, NTD *J. Evans, President* *C. Mahle, SSTD*
K. Pande, MED *R. Fang, CTD* *W. Cook, SDD*

HONORS & AWARDS

Jack Rieser, Manager of the Voiceband Processing Department in COMSAT Laboratories' Communications Technology Division, was the recipient of the 1992 Outstanding Achievement Award presented by the American National Standards Institute (ANSI). Mr. Rieser was recognized for leading the team that developed ANSI Standard T1.309-1990 for digital channel multiplication equipment (DCME).

ANSI standards are used by manufacturers worldwide to produce the equipment that becomes the fabric of the global communications infrastructure. Recognition of Mr. Rieser is also recognition of COMSAT as a leader of technical innovation in the communications industry.

Christine A. King, Manager of the Systems Analysis Software Department in the System Development Division (SDD) at COMSAT Laboratories, was the recipient of COMSAT Corporation's prestigious President's Award, for outstanding leadership of her department. The award is given periodically to a COMSAT employee whose work is judged to be exemplary and indispensible to the corporation.

As manager of her department, Ms. King developed and maintained software systems critical to the planning and evaluation of satellite networks. Her department is also responsible for research and application of state-of-the-art software technology and interactive software systems, and maintenance of an open architecture computer network.

PATENTS

The following is a list of U.S patents issued to employees of COMSAT Laboratories.

Earl, M., "Method for Rejuvenating Ni-H_2 Batteries," U.S. Patent No. 5,100,745, issued March 31, 1992.

Upshur, J., and B. Geller, "Low-Loss 360° X-Band Analog Phase Shifter," U.S. Patent No. 5,119,050, issued June 2, 1992.

Geller, B., and A. Zaghloul, "Low-Noise Block Down-Converter for Direct Broadcast Satellite Receiver Integrated With a Flat Plate Antenna," U.S. Patent No. 5,125,109, issued June 23, 1992.

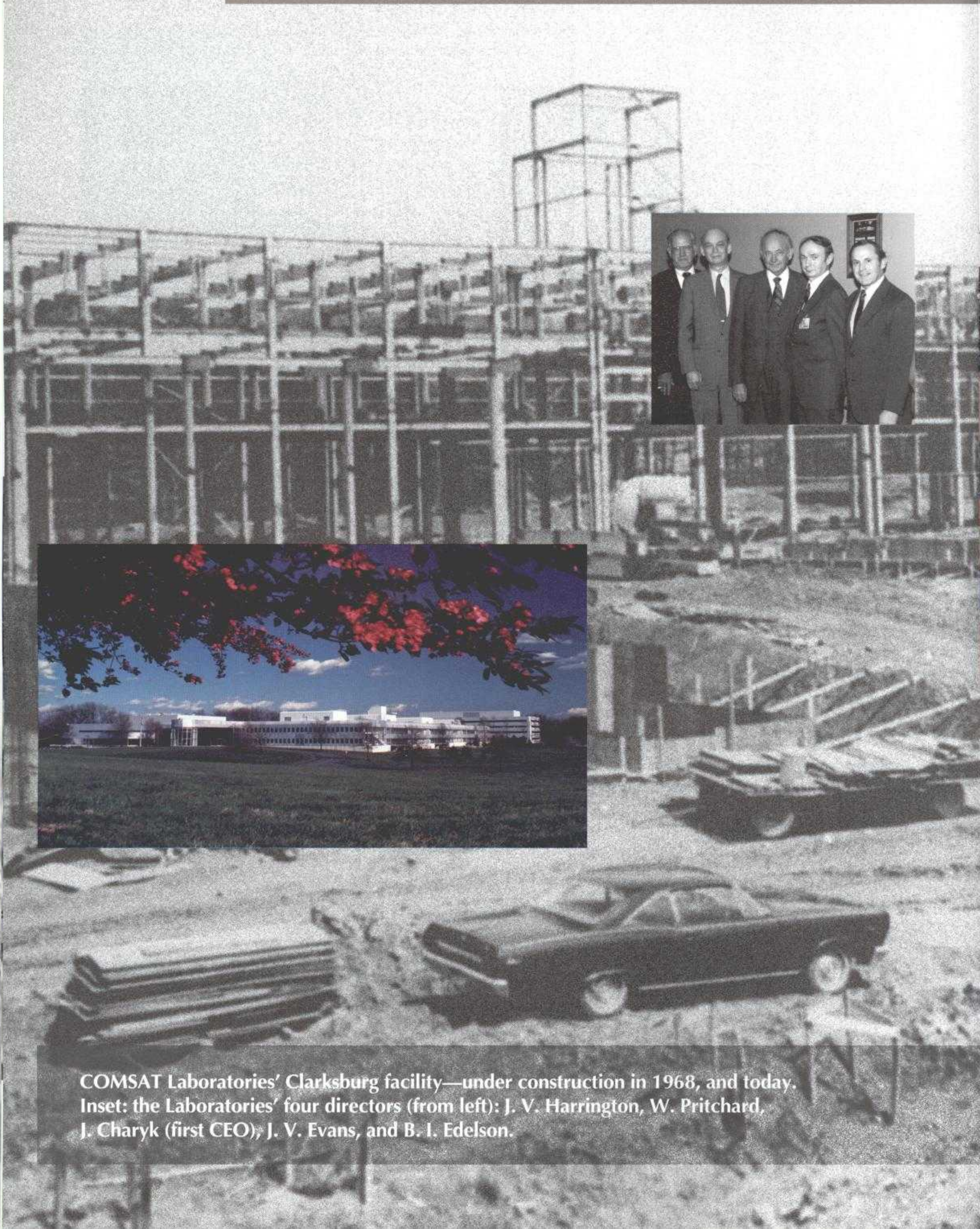
Zaks, C., "Carrier Signal Detection Circuit Featuring a Wide Range of Signal/Noise Performance," U.S. Patent No. 5,140,701, issued August 18, 1992.

Smith, T., H-C. Huang, and C-H. Lee,* "Non-Destructive Semiconductor Wafer Probing System Using Laser Pulses to Generate and Detect Millimeter-Wave Signals," U.S. Patent No. 5,142,224, issued August 25, 1992.

Smith, T., "Planar-Doped Valley Field Effect Transistor (PDVFET)," U.S. Patent No. 5,151,758, issued September 29, 1992.

*Non-COMSAT employee.

THEN & NOW
25 *Years of Excellence*

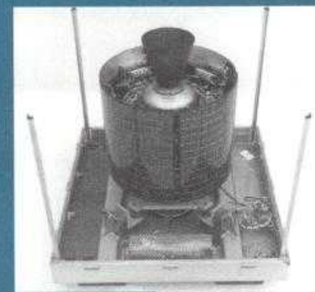


COMSAT Laboratories' Clarksburg facility—under construction in 1968, and today. Inset: the Laboratories' four directors (from left): J. V. Harrington, W. Pritchard, J. Charyk (first CEO), J. V. Evans, and B. I. Edelson.

COMSAT Corporation was created in 1963, following passage of the Communications Satellite Act, which President John F. Kennedy signed into law in late 1962. Subsequently in 1964, the International Telecommunications Satellite Organization (INTELSAT) was formed to facilitate international communications between fixed points by satellite, and COMSAT was named as its U.S. representative. Initially, INTELSAT had 11 participants; this number has since grown to 125 member countries.

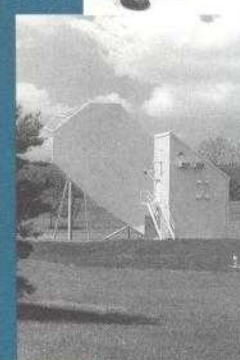
From its inception to 1979, COMSAT served as the technical manager for INTELSAT. To help meet the challenges of this role, COMSAT Laboratories was formed in 1967. Initially located in Washington, D.C., the Labs moved to its present quarters in Clarksburg, Maryland, in 1969. It currently has a staff of approximately 300 and occupies about 250,000 square feet in buildings located on a 230-acre tract along Route I-270. Since its establishment, COMSAT has been awarded 308 U.S. patents and about 75 foreign patents on its inventions.

Over the years, Laboratories engineers have worked to improve the efficiency and quality of satellite communications. Communication via radio links over satellites introduces unique problems that do not exist in most other modes of communication. The remoteness of the satellite relay station demands that the spacecraft be reliable over its entire operating life. It must also be capable of surviving passage through two harsh environments: the tremendous mechanical stresses of launch, and the vacuum of space with its accompanying radiation. In addition, the unusually long distances that transmissions must travel introduce a signal delay of nearly 0.25 second for each trip from earth to the satellite and back, despite the high-velocity propagation of radio waves.

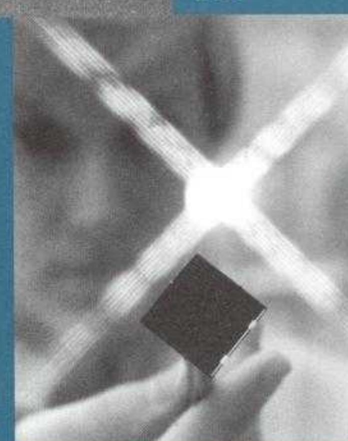


1965

1970

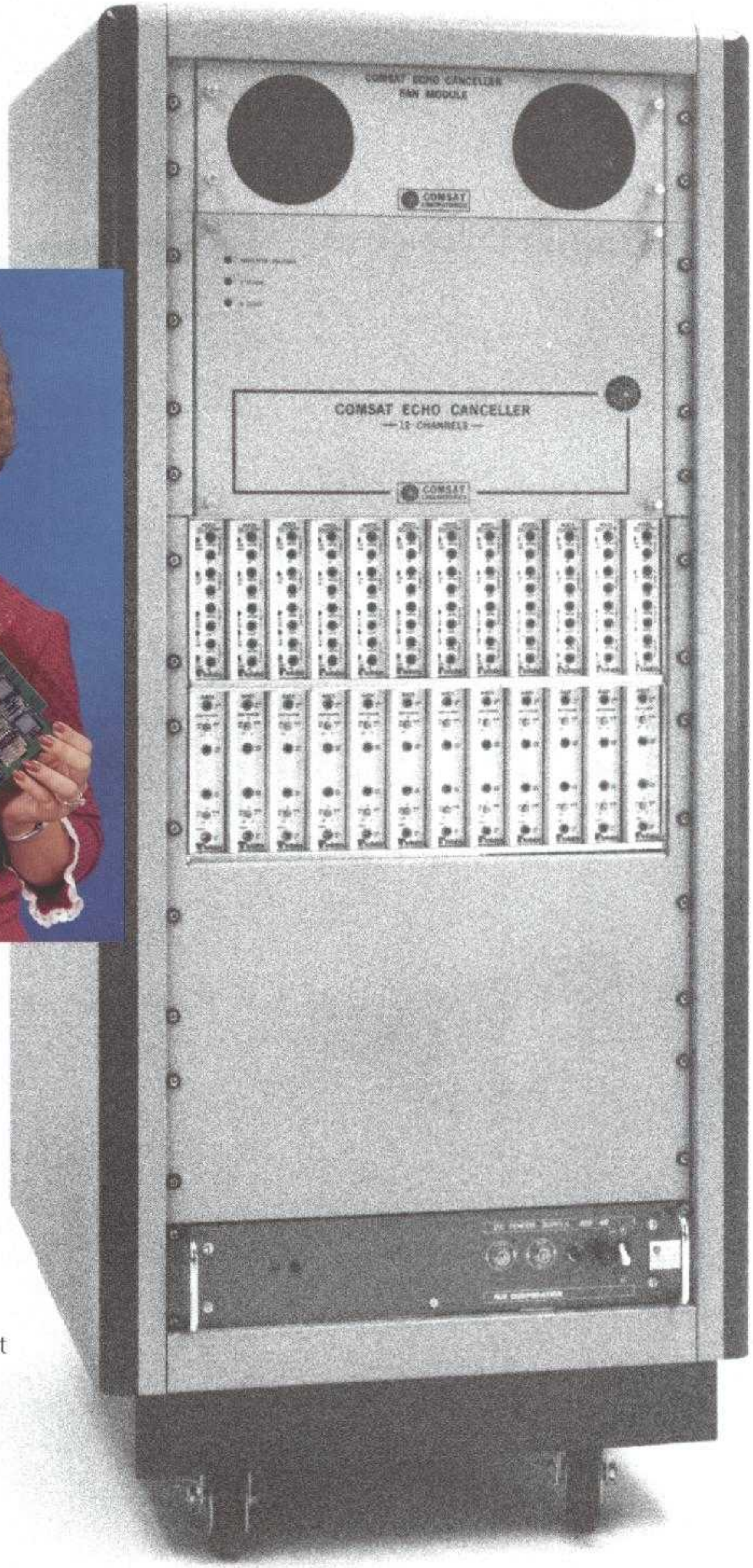


1970



1973

1965 • Early Bird launch, world's first commercial communications satellite
1970 • First version of echo canceller built
1970 • Torus antenna and unattended earth station
1972 • "Violet" silicon solar cell invented



COMSAT Laboratories' prototype echo canceller. Inset: As technology advanced, the size of the echo canceller was reduced—from a nearly 6-foot-high rack, to tabletop size, to hand size. The newest echo cancellers made by Coherent (not shown) will fit into the palm of a hand.

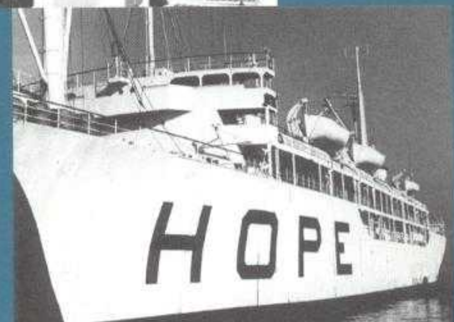
In voice transmission, an echo is formed on the far end of the satellite link and returns to the speaker after a delay of about 0.50 second. This produces an annoying distortion in speech transmission. By applying adaptive digital techniques, Labs engineers in 1970 developed an echo canceller that virtually eliminates this echo. Work continues today to make these echo cancellers compatible with equipment on circuits used for other types of transmission, such as facsimile.

In the early 1970s, Labs engineers were experimenting with the transmission and reception of communications signals over satellites, using very small antennas, different frequencies, and mobile earth stations. These experiments led to field trials that paved the way for providing mobile maritime communications services via satellite. The first field test using the Cunard QE2 demonstrated that voice, teletype, and facsimile could be sent via satellite. The success of this trial quickly let to another trial, with the hospital ship SS Hope. These were the beginnings of what was to become Inmarsat in 1976.

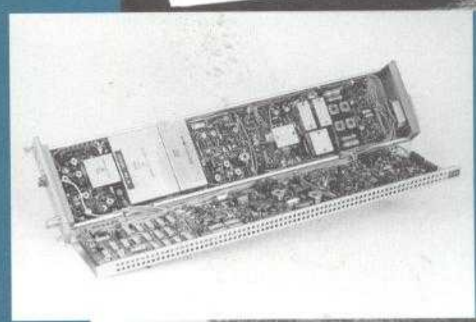
In the mid-1980s, COMSAT was successful in its bid to design and implement the ground segment and control station for the NASA Advanced Communications Satellite Technology (ACTS) Program. The program, with a value of about $75 million, was carried out over several years and involved all divisions within the Laboratories. With the corporation moving into new, nonregulated businesses, this program marked the beginning of a steady climb toward generating more of the Laboratories' revenues outside of the corporation.

To improve the efficiency and reduce the cost of satellite transmission, one objective is to send as many carriers as possible through a transponder without impairing transmission quality. This requires filters with well-defined bandwidths and very sharp

1972



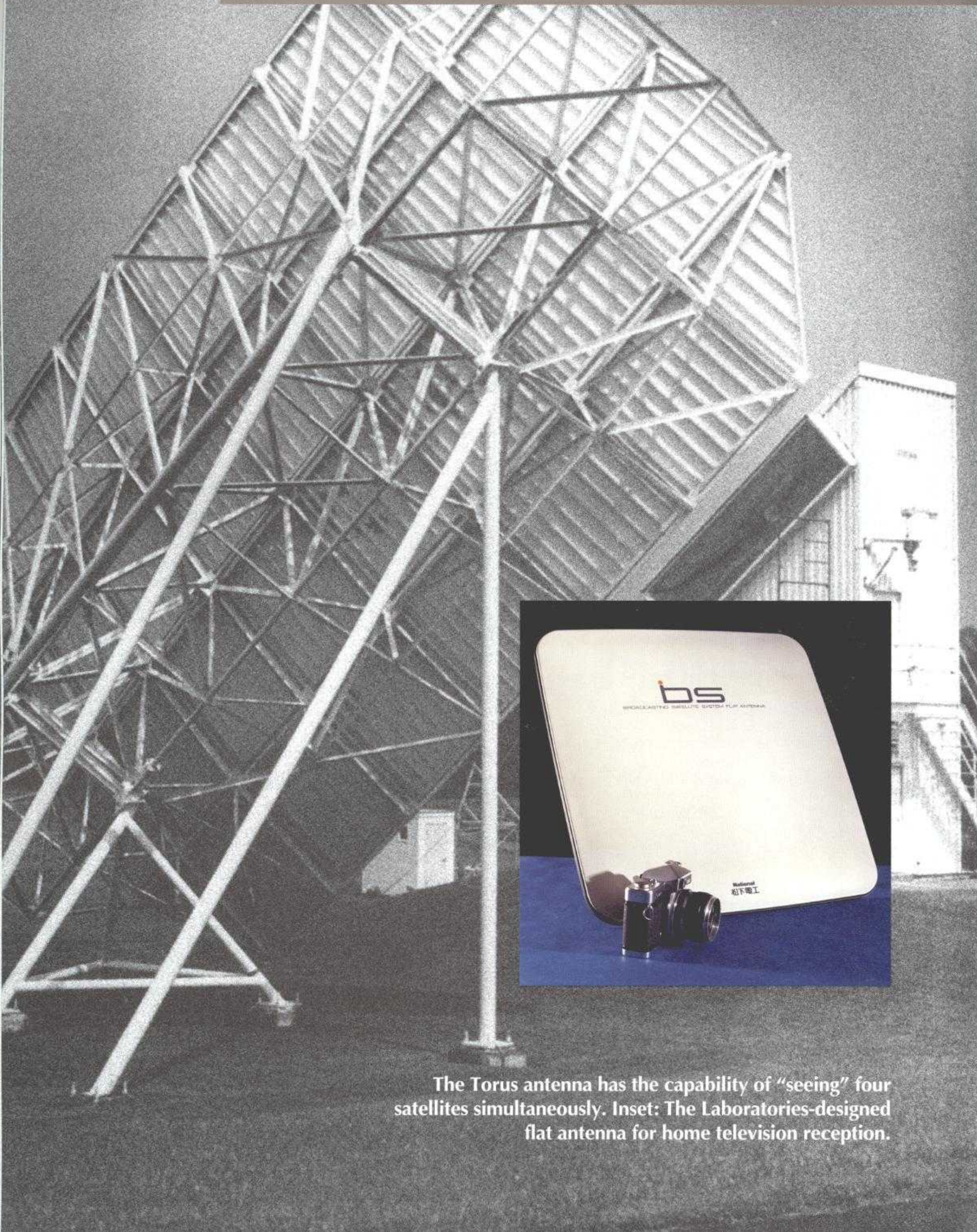
1973



1974

1977

1972 • First field test of mobile maritime service on board the *Cunard QE2*
1973 • Field trials performed on board *SS Hope*
1974 • SPADE, the world's first international digital voice communications service, provided satellite circuits on demand
1977 • Small earth station used for disaster communications during the Johnstown, PA, flood



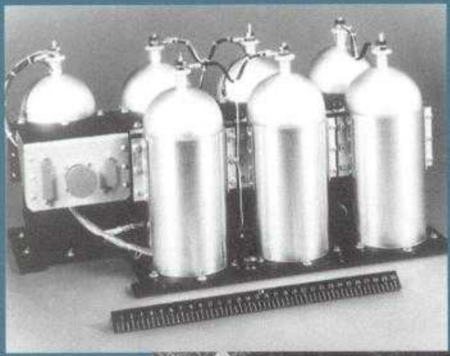
The Torus antenna has the capability of "seeing" four satellites simultaneously. Inset: The Laboratories-designed flat antenna for home television reception.

transitions from bandpass to bandstop. Laboratories' scientists have been developing such filters for several years and have achieved significant reductions in size and mass without sacrificing quality. They are now developing filters that employ the new high-temperature superconductor technology to obtain even greater savings.

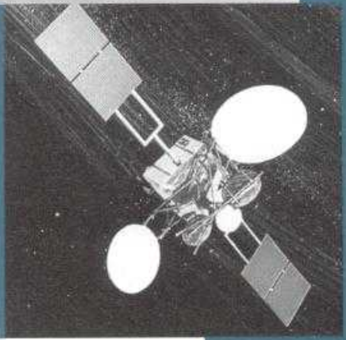
In 1991, COMSAT was organized into five separate operating divisions. COMSAT World Systems (CWS) serves as the U.S. Signatory to INTELSAT; COMSAT Mobile Communications (CMC) is the U.S. Signatory to Inmarsat; COMSAT Video Enterprises (CVE) delivers in-room entertainment programming and hospitality services via satellite to hotels; and COMSAT Systems Division (CSD) offers private satellite communications systems and services. The Laboratories is the central R&D organization for these four divisions. Today the Laboratories comprises five divisions: Microwave Electronics, Satellite and Systems Technologies, Communications Technology, Network Technology, and System Development.

To increase the applications for state-of-the-art technology, the resources of CSD and the Laboratories were merged in late 1992 to create COMSAT Technology Services (CTS). This action coincided with the Laboratories' evolution toward serving an increasing number of customers outside the corporation.

To expand technical knowledge and the understanding of communications satellites internationally, COMSAT Laboratories originated the first journal devoted exclusively to satellite communications technology and systems. In the 22 years since the first issue appeared, COMSAT Technical Review (CTR) *has published nearly 400 papers and notes initiated by members of COMSAT's professional staff and collaborators, and has helped to spread COMSAT's reputation for R&D excellence worldwide. A five-issue series is now in production that focuses on the*

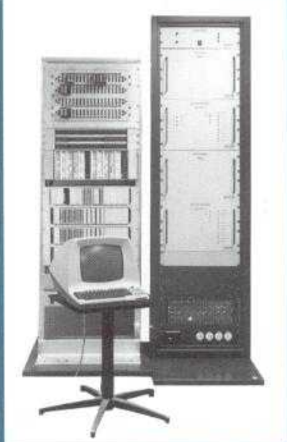


1977



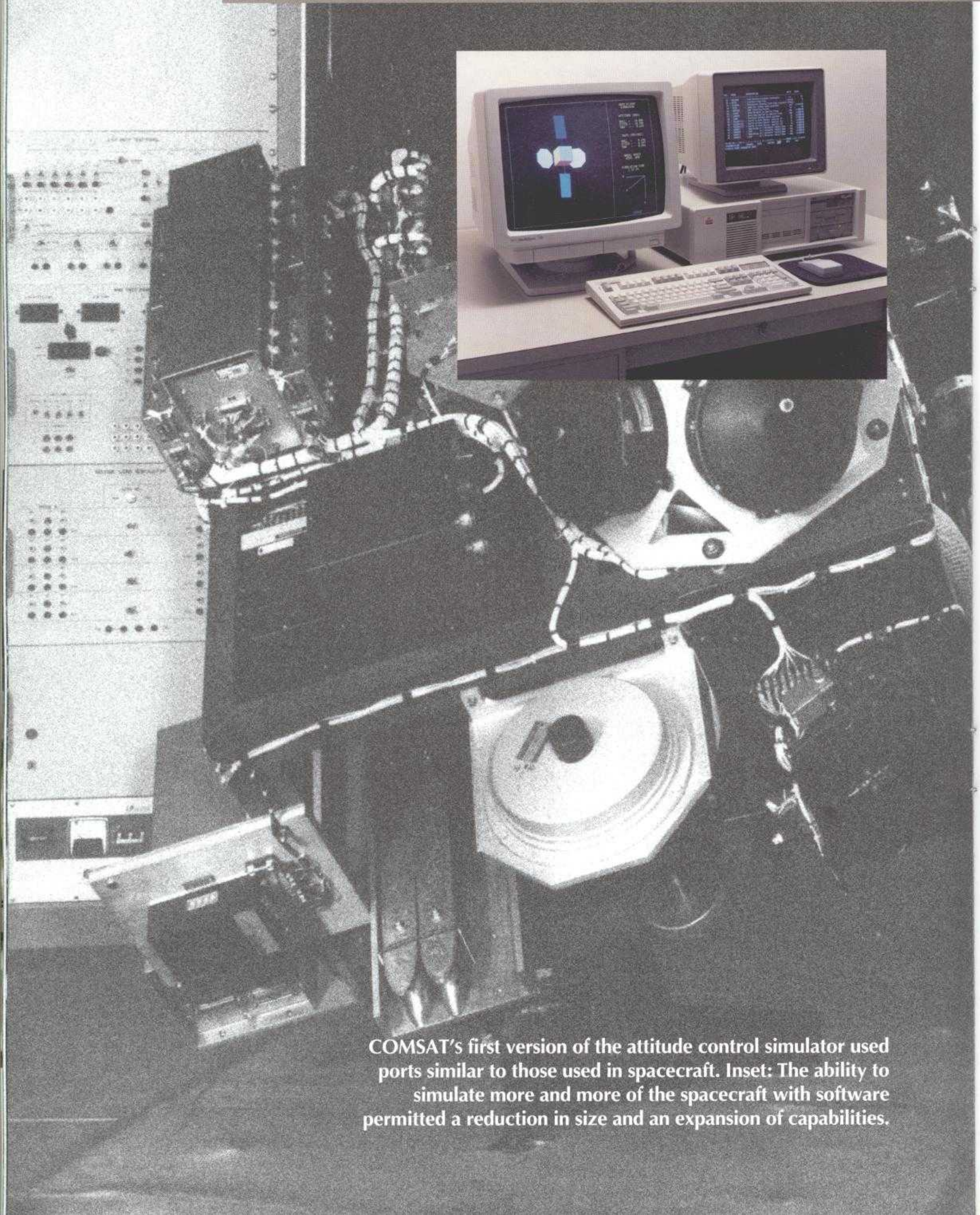
1984

1985



1986

1977 • Prototype $Ni-H_2$ battery launched on Navy satellite NTS-2
1984 • Ground elements of NASA Advanced Communications Technology Satellite contract awarded to COMSAT
1985 • Protoype 140-Mbit/s modem built
1986 • Digital speech interpolation system offers 40% increase in international telephone traffic over satellite links



COMSAT's first version of the attitude control simulator used ports similar to those used in spacecraft. Inset: The ability to simulate more and more of the spacecraft with software permitted a reduction in size and an expansion of capabilities.

1992

INTELSAT VI satellites, from their conception, through design and testing, to highly successful in-orbit operation. Also discussed are system applications and the first commercial implementation of satellite-switched time-division multiple access (SSTDMA). Today, CTR reaches scientists and engineers in more than 70 countries, presenting state-of-the-art advances, trends, and applications of communications technology in support of an expanding market for communications services in the global community.

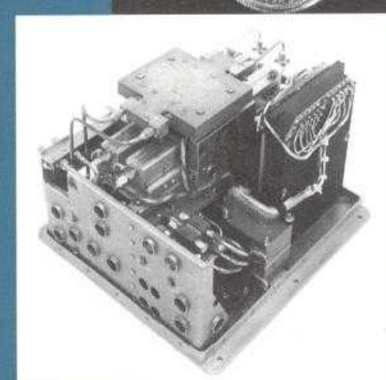
The Laboratories is active in furthering technical advances in community and educational areas as well. It is host to the 4-H Adventures in Science program, which matches volunteer scientists and professionals with children ages 8 to 15 and their parents for extracurricular, hands-on participation in science and technology projects.

Through the Maryland Industrial Partnerships (MIPS) program, the Laboratories staff has carried out joint research programs with the University of Maryland. MIPS fosters the commercialization of technology and economic progress in the state of Maryland by teaming local companies and U of M researchers on development projects. In 1992, COMSAT was recognized for its program to develop non-destructive, optical methods for quickly and accurately characterizing microwave devices and monolithic microwave integrated circuits (MMICs) before they are separated from the wafer. These methods should result in significant cost savings for large-volume MMIC production.

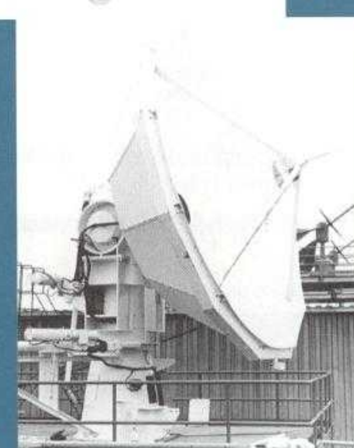
From "Then" to "Now," spanning 25 years and extraordinary achievements, COMSAT has been on the leading edge of satellite communications technology. The following pages offer COMSAT Laboratories' state-of-the-art systems, services, and products for global communications—the present made possible by COMSAT's pioneering past.

1989

1990

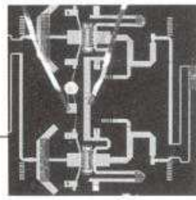


1991



1992

1989 • Image processing simulation facility used to develop broadcast-quality video compression systems
1990 • COMSAT Labs, MIT Lincoln Lab, and AT&T Bell Labs collaborate to achieve revolutionary microwave filter development
1991 • IOTT flown aboard ITALSAT—first known use of MMIC technology in commercial spacecraft
1992 • 5.5-meter ACTS antenna



Microwave Electronics

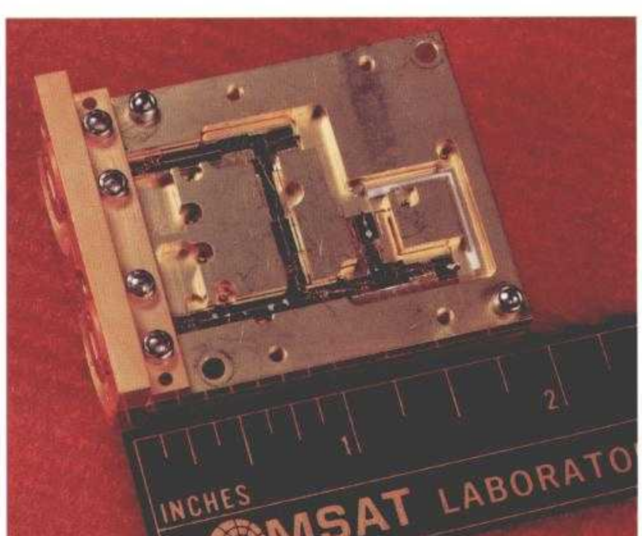
The Microwave Electronics Division (MED) specializes in the development and production of monolithic microwave integrated circuit (MMIC) products for commercial and government system applications such as communications and radar. MMIC components are being inserted into next-generation communications satellites to improve system affordability, reliability, size, weight, and performance. Such components are expected to play an important role in implementing new satellite capabilities, through their use in intersatellite microwave links and electronically configurable/steerable antenna beams. Satellites with multibeam capabilities can be used to reroute traffic and thus increase system capacity. MED's vertically integrated MMIC production services include chip/component design, fabrication, packaging, testing, and space qualification.

Millimeter-Wave MMICs

COMSAT Laboratories has become a recognized leader in the design and production of millimeter-wave MMIC components through MED's involvement in high-profile government MMIC chip/module programs in the role of prime contractor, subcontractor, or team member with aerospace systems houses. As a subcontractor to the Harris Corporation, COMSAT is developing for Rome Air Development Center an extremely high-frequency translator (EFT) that up-converts lower-frequency synthesized signals to V-band frequencies for future intersatellite link applications.

MED's approach to EFT design allows several critical RF signal processing functions to be integrated in a single small housing, thereby reducing mass, size, and complexity. Eleven MMICs are used in the module assembly. The design incorporates several advanced concepts, including all-MMIC implementation of multipliers, mixers, and amplifiers; 0.25-μm gate length pseudomorphic high-electron-mobility transistors (P-HEMTs); and passive mixers for low spurious output and low DC power consumption.

One of the main goals of the EFT project was to develop a millimeter-wave up-converter that accepts microwave-frequency signals from



An extremely high-frequency translator module populated with P-HEMT-based MMICs, for use in future intersatellite links at V-band. The EFT incorporates multipliers, mixers, and amplifiers fabricated by electron-beam lithography to achieve 0.25-μm gate lengths.

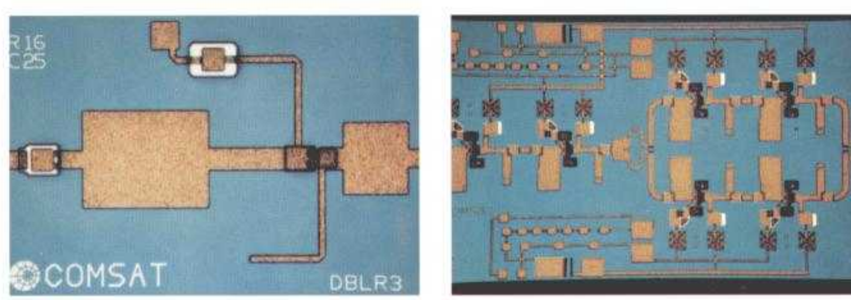
MED technicians produce gallium arsenide wafers, each consisting of 150 to 600 monolithic microwave integrated circuits. Production takes place inside class 100 clean-rooms to ensure high wafer yield.

an existing frequency synthesizer developed by Harris and outputs two V-band signals, one at about 55 GHz and one at about 61 GHz. Using a waffle-line RF interconnect, the baseband/RF portion of the synthesizer was designed to easily accommodate up-converters for other millimeter-wave bands. MED developed two MMIC, Ka-band frequency doublers; two V-band MMIC mixers; and all of the necessary passive components such as filters, transitions, feedthroughs, and interconnects. The measured RF output from the transmit and receive local oscillator ports showed spurious noise signals at the translated frequency that were down 22 dB from the primary signal.

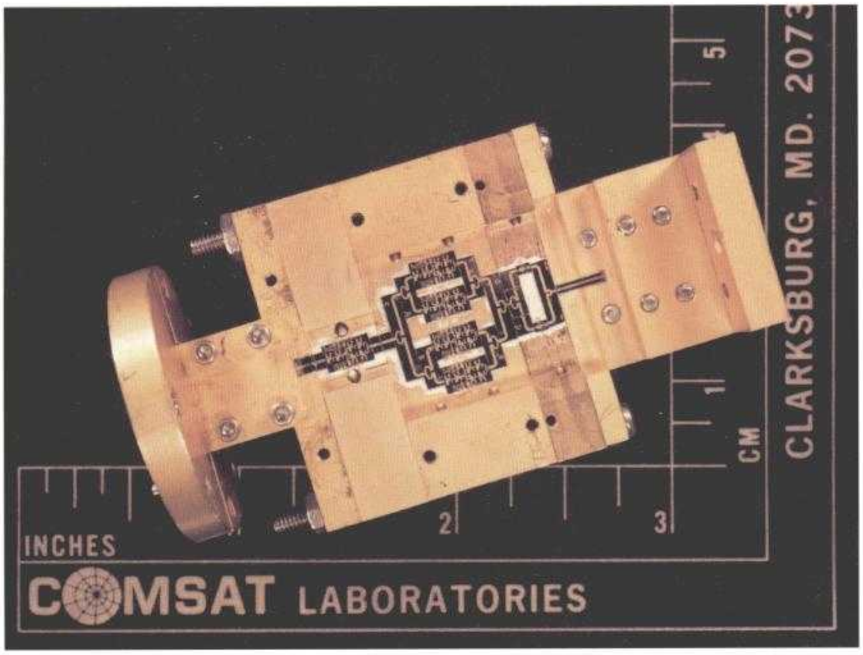
W-Band Integrated Power Module

MED has successfully designed and fabricated a W-band MMIC frequency doubler for missile-seeker applications, using a novel approach based on a disk-type varactor diode with optimized structure, dimension, and doping concentration. In a demonstration, the millimeter-wave doubler achieved a record performance of 65-mW saturated power output. It exhibits a maximum efficiency of 25 percent (6-dB conversion loss), with associated output power of 55 mW.

Again using millimeter-wave technology, MED engineers developed a four-stage, 47-GHz power amplifier MMIC chip. This chip exhibits 165-mW output power with an associated gain of 14.2 dB—the highest gain and complexity achieved for a single MMIC chip at U-band. The four-way combined-power amplifier using these chips demonstrates output power of 460 mW, with associated gain of 16.6 dB. The saturated output power of the 47-GHz amplifier exceeds 0.6 W. These values also



Photomicrographs of millimeter-wave gallium arsenide MMICs that exhibit record-setting performance. The disk-type varactor diode optimized for W-band frequency doubling (left) and the four-stage 47-GHz integrated power amplifier chip (right) are intended for missile-seeker applications.



The completed W-band integrated power module produces 90 mW of output power with an associated gain of 29 dB at 94 GHz.

represent record power and gain at U-band.

To achieve usable power and gain for a 94-GHz seeker system, an integrated power module was developed that employs a 0.5-W, 47-GHz power amplifier to drive two-way combined 94-GHz MMIC doublers. The module achieved output power of 90 mW with an associated gain of 29 dB—unparalleled output power and gain at 94 GHz for metal-semiconductor field-effect transistor (MESFET) technology.

COMSAT's pioneering efforts led to the first use of MMICs in a commercial satellite via in-orbit test transponders that were developed in the Labs' Satellite and Systems Technologies Division and flown on ITALSAT satellites. Currently, MED is producing components such as channel amplifiers and attenuators for use on the N-Star, Superbird, and INTELSAT VII satellites.

C-Band Solid-State Power Amplifier

Reduced mass, lower power consumption, and increased reliability are all achievable in power amplifiers that have full solid-state design. For the satellite market, MED is developing a C-band (3.6- to 4.2-GHz) solid-state power amplifier (SSPA) that exhibits 50-dB gain at 1.8-W high-linearity output power and 35-percent power-added efficiency (PAE).

In order to achieve the required linearity at C-band, the doping profile of a power FET was optimized. (No FETs available on the open market were found that have the necessary performance characteristics.) The optimized FET, with a gate periphery of 5.1 mm, operating in a single-ended amplifier circuit, produces more than 1 W of output power with 60-percent PAE at 4 GHz.

MED engineers used the measured RF characteristics of the newly optimized FETs to develop a hybrid microwave integrated circuit (MIC) power amplifier design for the last two stages of the SSPA. The first of these stages uses two cells to drive

Space-Qualified Components

MMICs and related components will greatly enhance the capabilities of space-based applications *if* they can be made more reliable and have less mass than the items they replace. Drawing from COMSAT's experience with space-related technology, MED has established a proven procedure for qualifying payload hardware, and has qualified its MMIC fabrication line for the production of space-qualified chips.

Two types of MMIC linearizers were designed for the solid-state power amplifier: The bottom chip is the version used in the C-band SSPA, while the top chip is used in an integrated amplifier. Both chips are pictured atop a 29¢ U.S. postage stamp.

the last stage, which consists of two chips containing three cells each.

Simulations of the final two stages showed a small-signal gain of 27 dB, which will compress 3 dB at the rated output power. The rest of the module consists of low-power drivers and a linearizer to improve the distortion characteristics of the SSPA. The low-power gain stages employ several MMIC amplifiers to boost the overall gain of the SSPA to 50 dB, as well as to compensate for the losses in the linearizer.

All SSPAs produce distortion when operated at or near their maximum efficiency point. The linearizer is an MMIC chip whose function is to remove (at least partially) this distortion. The particular type of linearizer used in the SSPA is called a "predistortion" linearizer because it actually introduces its own distortion, which is adjusted to cancel the distortion created by the amplifier. The particular approach used makes use of a gallium arsenide MESFET as the nonlinear element and a pair of lumped-element branchline couplers to present good impedance matches at both the input and output.

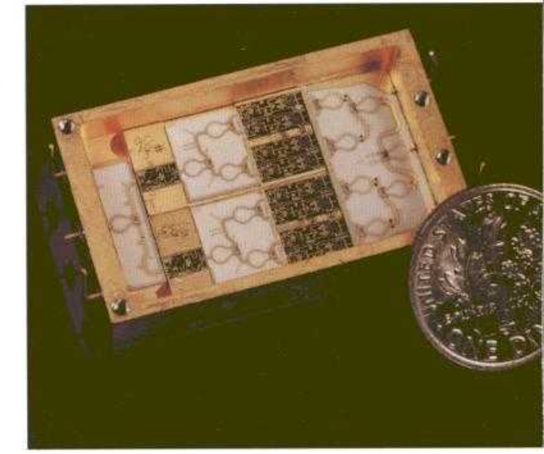
The gate bias circuit is designed so that gate current will not affect the bias point of the FET when it reaches saturation. The package floor is constructed of metal matrix materials to reduce weight while maintaining high thermal conductivity. The SSPA will be hermetically sealed. The complete SSPA will be space-qualified in a package not exceeding 2 x 1 x 0.2 in. To demonstrate performance, 75 amplifiers will be assembled and tested as a phased-array antenna.

Custom High-Performance Modules

Although a primary benefit of MMIC technology is its ability to produce large numbers of identical units, there is also a significant advantage to be realized by fabricating custom components for specialized applications. COMSAT's fully vertically integrated facility for MMIC production results in a greater likelihood of success, particularly for customized units.

X-Band Power Module for High-Power Phased-Array Radar

With COMSAT's recent development of an MMIC-based 10-W power module, an X-band phased-array radar system with output power in kilowatts is now feasible. This high-power module was achieved by combining two 5-W amplifiers, each consisting of a dual-stage driver MMIC and two sets of dual-stage power MMICs, in a single package. Fabrication yields for the 5-W MMICs were consistently high, reflecting their robust design and the well-controlled fabrication process.

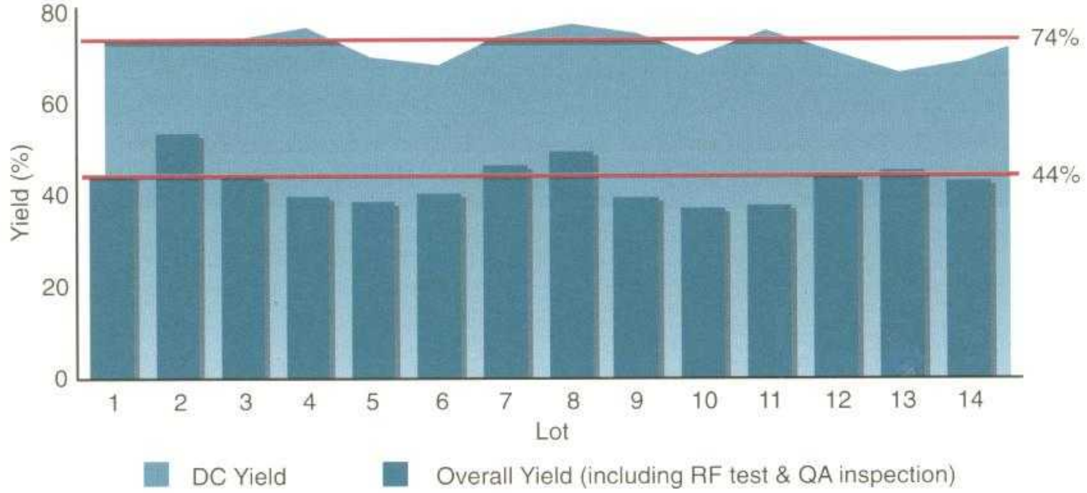


The 10-W X-band power amplifier uses offset Wilkinson combiners and two sets of dual-stage power MMICs to combine the output of two 5-W MMIC amplifiers.

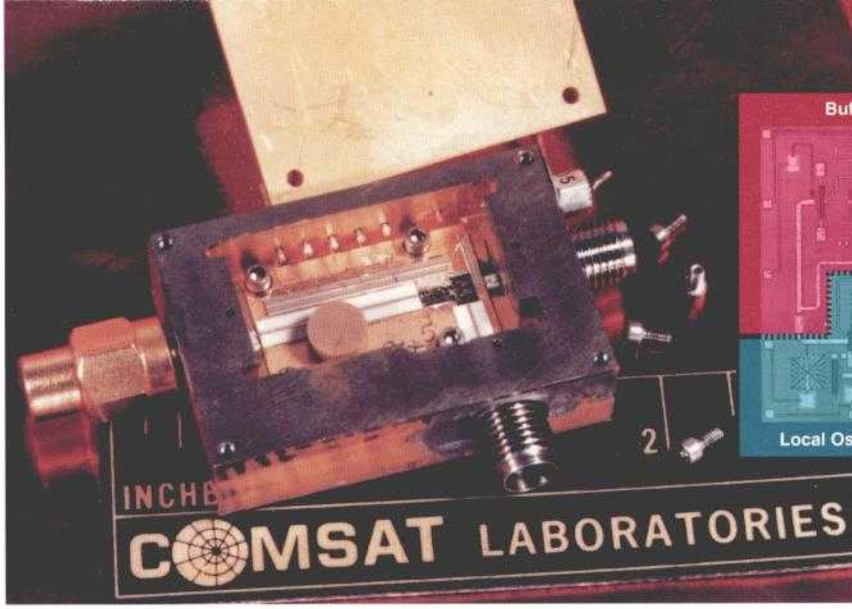
Power-combining of the 5-W amplifiers was achieved with offset Wilkinson combiners. The finished 10-W module consists of the six MMICs and combiner networks in a hermetic package. At 10-W output power, typical PAE is 27 percent, with an associated gain of 29.5 dB.

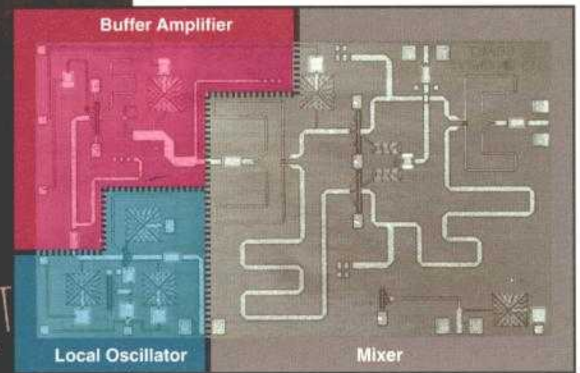
Ku-Band P-HEMT Integrated Receiver

During 1992, MED developed a Ku-band integrated receiver that is optimized for future satellite multibeam/multicarrier and phased-array antenna applications. The use of P-HEMT and space-qualified MMIC



Consistently high DC yields (average 74 percent) and final RF yields (average 44 percent) were obtained from several fabrication runs of the 5-W X-band MMICs. These circuits are suitable for spaceflight qualification.





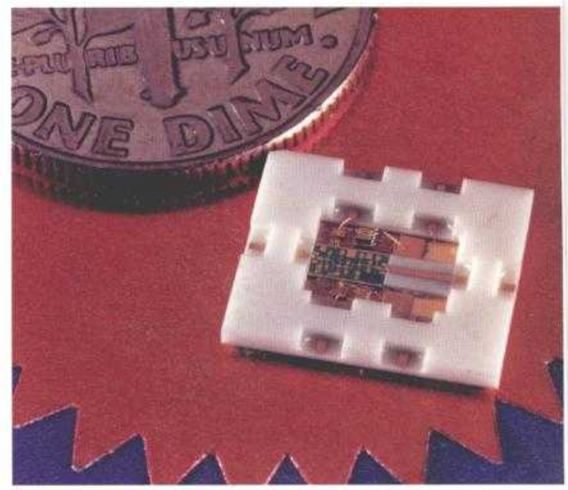
Ku-band integrated receiver. Inset: A local oscillator, a buffer amplifier, and a mixer are combined on one MMIC used in the receiver.

technology for the receiver offers improved performance uniformity, as well as reduced mass and volume, compared to the MIC approach. Communications capacity can thus be increased without additional mass.

P-HEMT-based MMIC components developed for the 14/4-GHz receiver include a low-noise amplifier (LNA), a mixer, and a local oscillator. The LNA provides a noise temperature about 50 K lower than that of its MESFET counterpart; the mixer employs a pair of P-HEMTs operating in passive mode and balanced configuration to achieve low spurious performance and high linearity; and the X-band local oscillator consists of a P-HEMT voltage-controlled oscillator stabilized by a dielectric resonator and phase-locked to a crystal oscillator. A buffer amplifier enables the local oscillator to provide sufficient drive for the mixer, as well as good isolation between the oscillator and the mixer. For improved matching and reduced loss, the oscillator, buffer amplifier, and mixer are combined on one MMIC chip. Typical measured performance for the integrated receiver is greater than 30-dB conversion gain and less than 2.5-dB noise figure over the 14.0- to 14.5-GHz band.

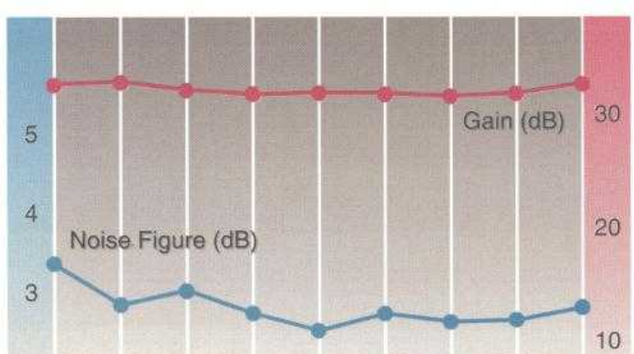
20-GHz Low-Noise Amplifier

LNAs are critical components of receivers because they allow the detection of very low-level signals. The most important performance parameters of LNAs are noise figure and gain. The noise figure is a measure of the degree to which noise generated internally in the device will corrupt even the most noise-free received signal, while the gain is a measure of the signal amplification.



This packaged K-band low-noise amplifier was developed for downlink applications in commercial and military satellites.

MED has been developing LNAs at frequencies up to 60 GHz, and has recently completed the development of a single-chip MMIC LNA for the 20-GHz satellite downlink band, which is used for both commercial and military communications applications. The chip dimensions are 1.5 x 3.9 mm. The circuit utilizes P-HEMTs developed by MED. It performs better and is smaller and lighter weight than the microwave integrated circuit version it replaces.



MED's P-HEMT-based low-noise amplifier produces 30-dB gain from 18 to 22 GHz, with low noise figures between 2.5 and 3.0 dB.

COMSAT's booth at the 1992 IEEE International Microwave Symposium in Albuquerque—MED showcased its highly reliable, space-qualified microwave and millimeter-wave components. Visitors from defense, commercial, and satellite industries had an opportunity to discuss their applications for microwave products with COMSAT representatives.

SATELLITE & SYSTEMS TECHNOLOGIES

The Satellite and Systems Technologies Division (SSTD) conducts R&D, systems engineering, and analysis on all aspects of satellite communications technologies, and produces space-qualified hardware. Division work encompasses definition of next-generation satellite systems; development of multibeam antennas and onboard RF processing hardware; and design and delivery of repeater subsystems, antenna feeds, and components; and propagation studies. SSTD also designs and installs turnkey systems for in-orbit test and system performance monitoring. SSTD's resources include state-of-the-art computers and software, as well as a modern Design and Fabrication Center. These capabilities enable SSTD engineers to engage in technical programs from initial concept development to final product realization. Such broad involvement in satellite systems and hardware provides the foundation for a variety of systems studies and consulting services.

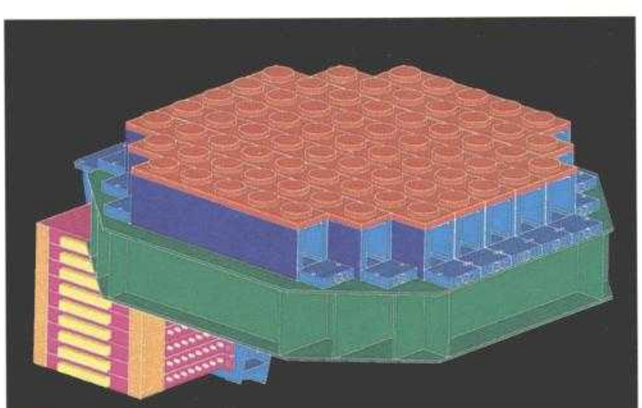
ANTENNAS

SSTD is COMSAT's primary in-house source for design and engineering of satellite and earth station antennas, which are a key contributor to overall communications system capacity.

An active phased array capable of generating a number of high-gain narrow beams at C-band is being developed to meet future INTELSAT requirements for flexible capacity allocation. The array is intended for spacecraft applications and uses lightweight, printed-circuit elements arranged in a highly modular structure, along with efficient distributed solid-state power amplifiers (SSPAs).

The amplitude and phase aperture distribution necessary for the array to produce the eight beams is achieved through a highly integrated beam-forming matrix (BFM) consisting of eight independent parallel beam-forming networks connected in an 8-input, 69-output crossbar configuration. In the C-band BFM currently under development, monolithic microwave integrated circuit (MMIC) phase shifters and attenuators, along with their digital control circuits, are integrated into separate modules located at the matrix crosspoints.

The BFM's modular design allows for relatively low-risk manufacturing and facilitates scaling to different numbers of elements and beams, as well as to other frequency bands, thus reducing the development costs for custom units. Modularity also facilitates testing, which reduces the manufacturing cost and schedule risk for production.

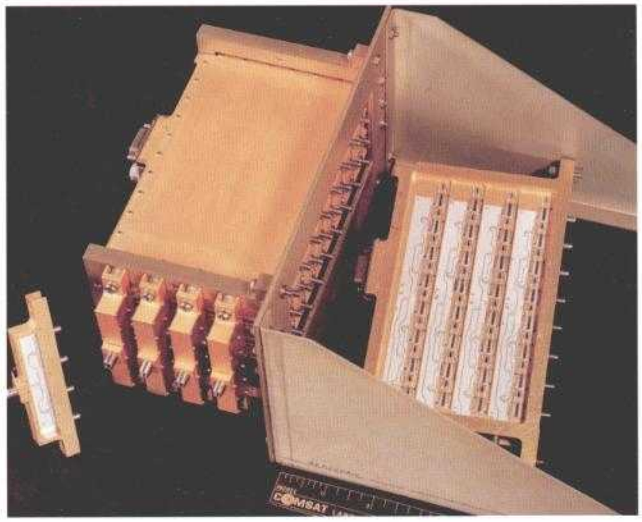


This array, under development for COMSAT World Systems, consists of 69 dual circularly polarized elements and produces eight beams that can be steered independently and/or simultaneously.

An active phased array with 24 horn elements operating at Ku-band was completely assembled in 1992. The four-beam, 24-element array includes the radiating elements, a 4 x 24 BFM, SSPAs, and the associated cooling system. The BFM provides complete power sharing among the four beams.

The BFM and power amplifiers were characterized extensively to ensure the uniformity of various signal paths through the array elements for the different beams. In 1993, the array will be tested under multibeam conditions for radiation patterns and system performance, including bit error rate, signal-to-noise ratio, and intermodulation components.

Comprehensive software tools developed at COMSAT were used to analyze and optimize the performance of the active phased array.



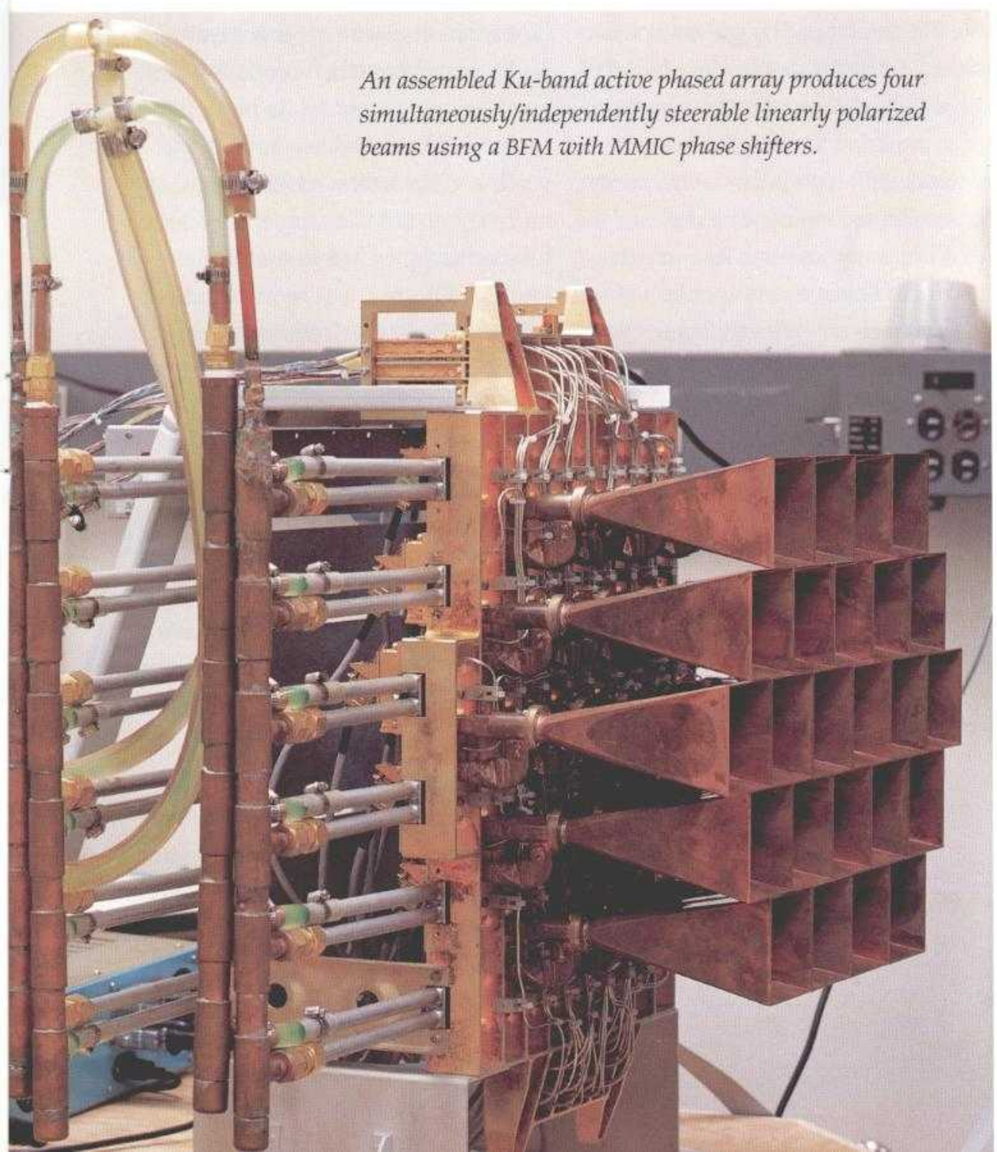
The 24 outputs of this BFM with integrated MMIC phase shifters feed SSPAs, which in turn feed the radiating horns of a Ku-band active phased array.

The validity of these tools had been demonstrated on previously developed arrays. The performance of a direct radiating array can be predicted by using the ARRAY software, while the performance of an array-fed reflector system can be evaluated using the General Antenna Program (GAP).

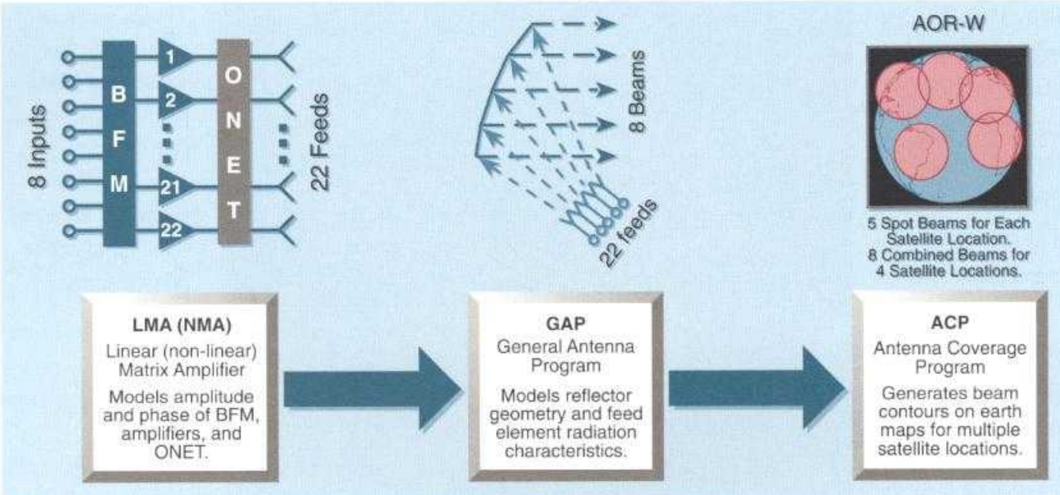
The Inmarsat-3 multibeam communications payload includes a multimatrix, multibeam transmit subsystem. To maintain the high quality of signals transmitted by this system, the hardware components must maintain uniform performance over the design lifetime of the satellite. In order to accurately predict potential performance degradations resulting from hardware imperfections, a software simulation model that can analyze a multimatrix multibeam system was developed.

The simulation software model can be used to validate/verify the Inmarsat-3 L-band transmit subsystem during the operational lifetime of the satellite series. Also, should anomalies occur in the spot-beam antenna patterns, beam-to-beam isolation, or spot beam carrier-to-intermodulation ratio (C/I), this model can help to identify the hardware that may be the source of the observed anomaly. Further, the C/I prediction capability can be used to optimize transponder loading for a specified C/I performance.

Several earth station antenna programs are currently under way in SSTD, including a dual C- and Ku-band feed. This feed has eight rectangular waveguide input/output ports and provides opposite-sense circularly polarized signals in the 4- and 6-GHz bands, as well as



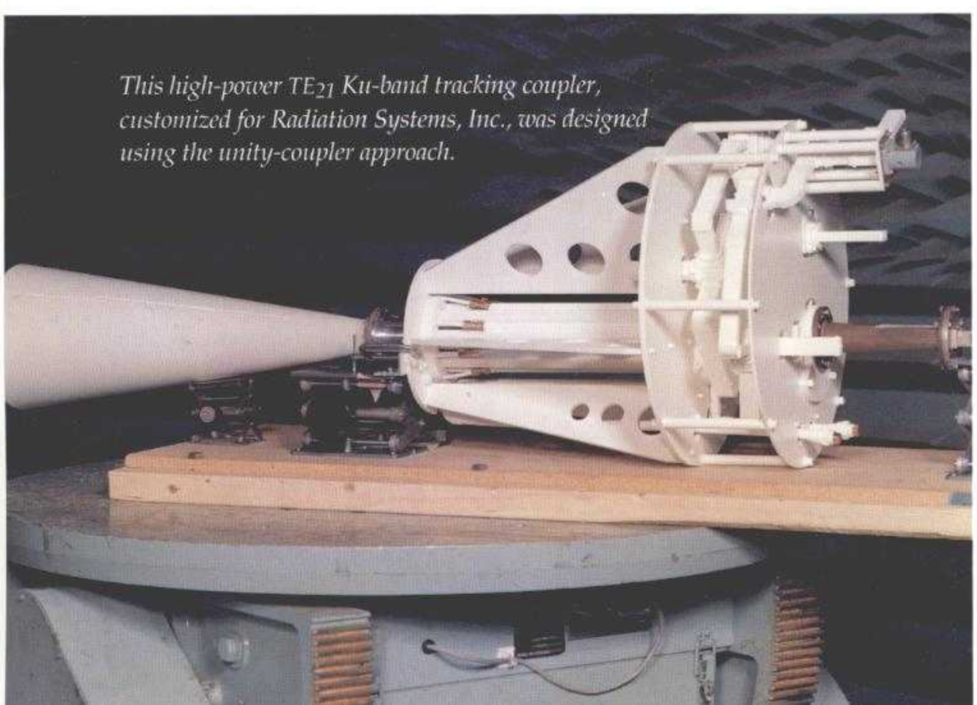
An assembled Ku-band active phased array produces four simultaneously/independently steerable linearly polarized beams using a BFM with MMIC phase shifters.



This software simulation model, together with COMSAT's GAP and ACP software, can predict spot-beam antenna patterns, antenna far-field contours of the intermodulation components, and C/I's in the patterns.

orthogonal linear polarizations in the 11- and 14-GHz bands. A four-band corrugated-wall feed horn was also designed. A unique unity-coupler approach is used to couple the Ku-band signals, and arrays of small coupling holes are used to couple from radially disposed rectangular WR75 waveguides into a 2.125-in.-diameter waveguide. This waveguide couples the 11- and 14-GHz bands into a common circular waveguide carrying the C-band energy. The configuration achieves excellent mode purity of the Ku-band energy and is also amenable to other dual-band and wideband feed applications, as well as higher-order mode TE_{21} tracking couplers. In addition, a special-purpose feed for compact and near-field ranges was developed for the National Institute of Standards and Technology (NIST) and Nearfield Systems, Inc.

In a related effort, a C-band compact diplexer is being developed for smaller-diameter, front-fed reflector earth station antennas and for possible use as a feed for future dual-polarized 4/6-GHz offset reflector satellite antennas. The compactness of the COMSAT Laboratories coaxial waveguide diplexer is a primary factor in realizing a small, lightweight network with high polarization purity for satellite operation. The diplexer is used in numerous earth station antennas, including special-purpose high-performance antennas such as INTELSAT in-orbit test antennas at Paumalu, Hawaii, and Clarksburg, Maryland, and Inmarsat tracking, telemetry, and command (TT&C) antennas at Beijing, China; Fucino, Italy; and Southbury, Connecticut.



This high-power TE_{21} Ku-band tracking coupler, customized for Radiation Systems, Inc., was designed using the unity-coupler approach.

Another SSTD specialty is retrofitting existing earth station antennas for new INTELSAT or Inmarsat applications. Retrofitting antennas for new frequency bands and/or different polarization requirements is generally far less expensive than procuring and erecting new antennas. As part of these retrofits, antennas are fully measured and documented for acceptance by INTELSAT or Inmarsat. The full-performance antenna at Santa Paula, California, was recently retrofitted for dual-polarized operation with the Inmarsat-3 satellite series, and also as a Pacific Ocean Region TT&C antenna.

Precision gain calibration of earth station antennas, using radio star flux sources, is also provided. The Inmarsat TT&C antennas at Southbury, Connecticut, and Santa Paula, California, were precision calibrated in 1992 for measurement of satellite parameters.

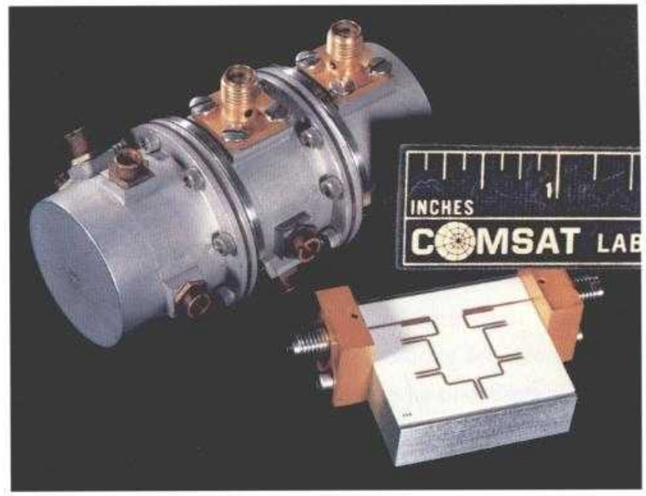
An on-site antenna verification system was developed to test earth station antennas for entrance into the INTELSAT operating system. The verification system includes a PC-controlled spectrum analyzer and other test equipment to conduct a variety of microwave antenna measurements, including noise temperature, radio star gain-to-noise temperature ratio (G/T) data, star ephemeris calculations, radiation patterns, and return loss. The ability to perform psuedo-swept frequency noise temperature measurements has been beneficial in improving the accuracy of G/T measurements, and in the subsequent gain calibration of Inmarsat and INTELSAT earth station antennas. In 1992, antenna test evaluation programs at COMSAT Labs and various remote sites were conducted for Hughes Network Systems, AT&T, Teletronics, GE America Communications, Andrew Corporation, and the Naval Observatory.

Spacecraft Payload

The payload of a spacecraft comprises communications-carrying (as opposed to housekeeping) functions. Because the spacecraft is not accessible for repair in geosynchronous orbit, payload components must perform reliably for about 15 years. SSTD personnel continuously work to develop highly reliable components with optimum performance characteristics.

For more than 20 years, COMSAT Laboratories has maintained a leadership position in developing payload components for satellite communications. Original, innovative research has led to significant savings in transponder mass and volume, which are critical parameters in the design of communications satellites. For example, optimum-response filters are efficiently designed and tuned with the aid of COMSAT's high-precision mathematical models and software. Recent R&D has focused on multimode, active, microwave monolithic and superconducting filters. Accomplishments include the design and realization of the first successful high-temperature superconducting microwave filter, the first quadruple-mode multiplexer, and the first hexamode filter, as well as pioneering contributions to MMIC active filter design and fabrication.

When COMSAT's coupled-line, six-pole elliptic microstrip filter is manufactured using superconducting film technology, its performance characteristics will be comparable with those of the larger six-pole dielectrically loaded filter.



During 1992, SSTD developed two new techniques for the analysis and design of miniature filters with transmission zeros, such as the multicoupled microstrip line and the dual-plane filter. These filter circuit configurations are suitable for both miniaturization of moderate-bandwidth conventional filters and realization of superconducting narrowband filters. Comparison of measured results with closed-form design equations derived directly from electromagnetic field solutions has demonstrated a high degree of accuracy. Three prototype units were successfully designed and built to validate this approach: a four-pole, elliptic L-band microstrip filter; a six-pole, quasi-elliptic, coupled-line filter; and a four-pole, elliptic, L-band, dual-plane filter.

SSTD has also focused on developing highly reliable components for satellite and ground applications. During 1992, COMSAT was under contract with Alcatel Espace to deliver 80 MMIC, Ku-band, 1-W SSPA modules for a communications satellite phased-array antenna. This program required the development and implementation of MMIC driver and power chips, and full documentation of assembly and test procedures.

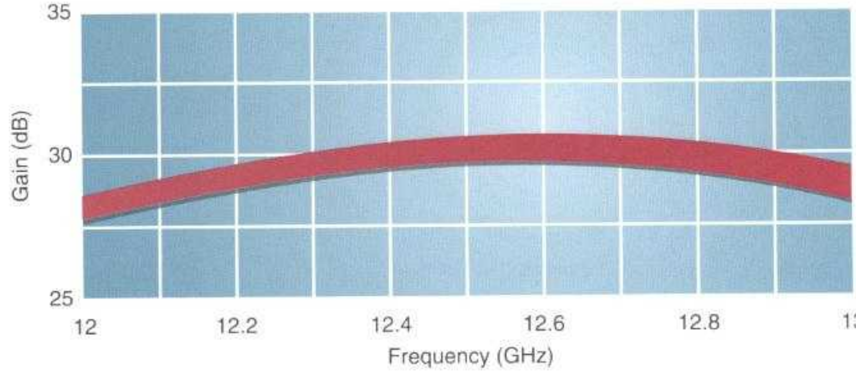
Performance uniformity among all modules is critical to active array applications. Key elements include process-insensitive MMIC designs with DC and RF on-wafer probe capability,

A metal cover protects the MMIC section of the SSPA module, which consists of a single-stage driver amplifier followed by a two-stage power amplifier. The bias supplies are integrated on the carriers, external to the cover.

and a production/assembly procedure with full traceability. Completed modules are tested using a computer-controlled system for small- and large-signal module-level measurements. The test system is also capable of storing and reporting test data.

The gain flatness for each amplifier module is within ±0.5 dB across a 2-GHz band. Other key performance features are a peak power-added efficiency of 30 percent and C/I linearity greater than 15 dB, which are crucial to successful operation in a multicarrier communications environment.

For the past 4 years, SSTD has been developing space-qualified MMIC components for satellite payloads. For Space Systems Loral, SSTD continues to provide space-qualified Ku-band MMIC (30-dB) gain modules and MMIC digital attenuators (24-dB range and 1-dB resolution) for N-Star satellites. Under a second contract, SSTD has delivered MMIC C-band (30-dB) gain modules and MMIC digital attenuators for INTELSAT VII-A series satellites. COMSAT is also under contract to deliver a second flight-unit in-orbit test transponder for ITALSAT.



In addition to enhanced reliability and reduced mass, SSTD's representative Ku-band MMIC modules exhibit very good performance uniformity.

IN-ORBIT TESTING & MONITORING

Even though every effort is made to produce a perfectly operating spacecraft, it must still be thoroughly tested in orbit before it can accept traffic. Because of the significant investment required to build and launch a spacecraft, it is important to achieve operating status quickly.

For the past 20 years, SSTD personnel have pioneered techniques for testing satellite transponders in orbit. Starting with INTELSAT IV-A, computer-controlled microwave measurement equipment and in-orbit test measurements have been continuously perfected and expanded. SSTD has also designed, developed, fabricated, and installed communications systems monitoring equipment, such as the INTELSAT TDMA system monitor, to oversee numerous operational satellite networks.

Transponders must be tested prior to initial operational deployment and throughout the satellite's lifetime. In-orbit testing is performed periodically for acceptance testing, anomaly investigation, and routine monitoring. SSTD designs, fabricates, installs, and tests turnkey computer-controlled, automated measurement systems for communications satellite owners and operators such as INTELSAT, GTE, and, recently, the European Telecommunications Satellite Organization (EUTELSAT). Current systems execute multiuser, multitasking, UNIX-based, software-controlled microwave measurements under operator control through easy-to-use, point-and-click windows.

Although in-orbit test systems are custom-built for specific customers, much of the required functionality is common to all of the systems. Because of the cost, effort, and time required to develop software that performs system control, automated measurement, user interfacing, and data processing for custom-built systems, SSTD has focused its efforts on building an engineered platform of integrated, pre-tested modules with a high level of code reusability from one system to another. This approach facilitates development of in-orbit test measurements and complete systems, resulting in decreased cost and time to deployment, while providing a flexible and functionally rich system capability that includes extensive networking support.

This engineered platform approach was employed successfully on two recent systems: a turnkey system for EUTELSAT and the RF Terminal Supervisor (RFTS) for the NASA Ground Station of the Advanced Communications Technology Satellite Program (ACTS). The EUTELSAT system is currently being used to test second-generation F-1, F-2, F-3, and F-4 communications satellites.

The ACTS RFTS remote control capability will enable operators in New Jersey—equipped with a workstation running software created by SSTD, and a wide-area network connection to NASA's Lewis Research Center (LeRC)—to access the same control and status functions as station operators at LeRC. This remote capability is particularly important when LeRC is unstaffed.

To enhance the functionality and performance of in-orbit test systems, SSTD continues to develop computer-assisted microwave measurement techniques that exploit new instrumentation and the computational power available from low-cost workstations. For example, in 1992 SSTD, working with EUTELSAT, developed a new technique that measures a satellite's antenna contour from a single earth station site by slewing the spacecraft and measuring the received signal. Post-measurement processing in the workstation correlates the received signal as a function of time with the telemetry stream received from the satellite during the measurement. This technique is simpler, easier, and less costly than traditional multisite measurement techniques that use a mobile earth station to conduct measurements.

Spacecraft Bus

The spacecraft bus is the mechanical structure that houses the primary and secondary power sources, fuel, and propulsion for stationkeeping and attitude control, as well as the thermal control subsystem.

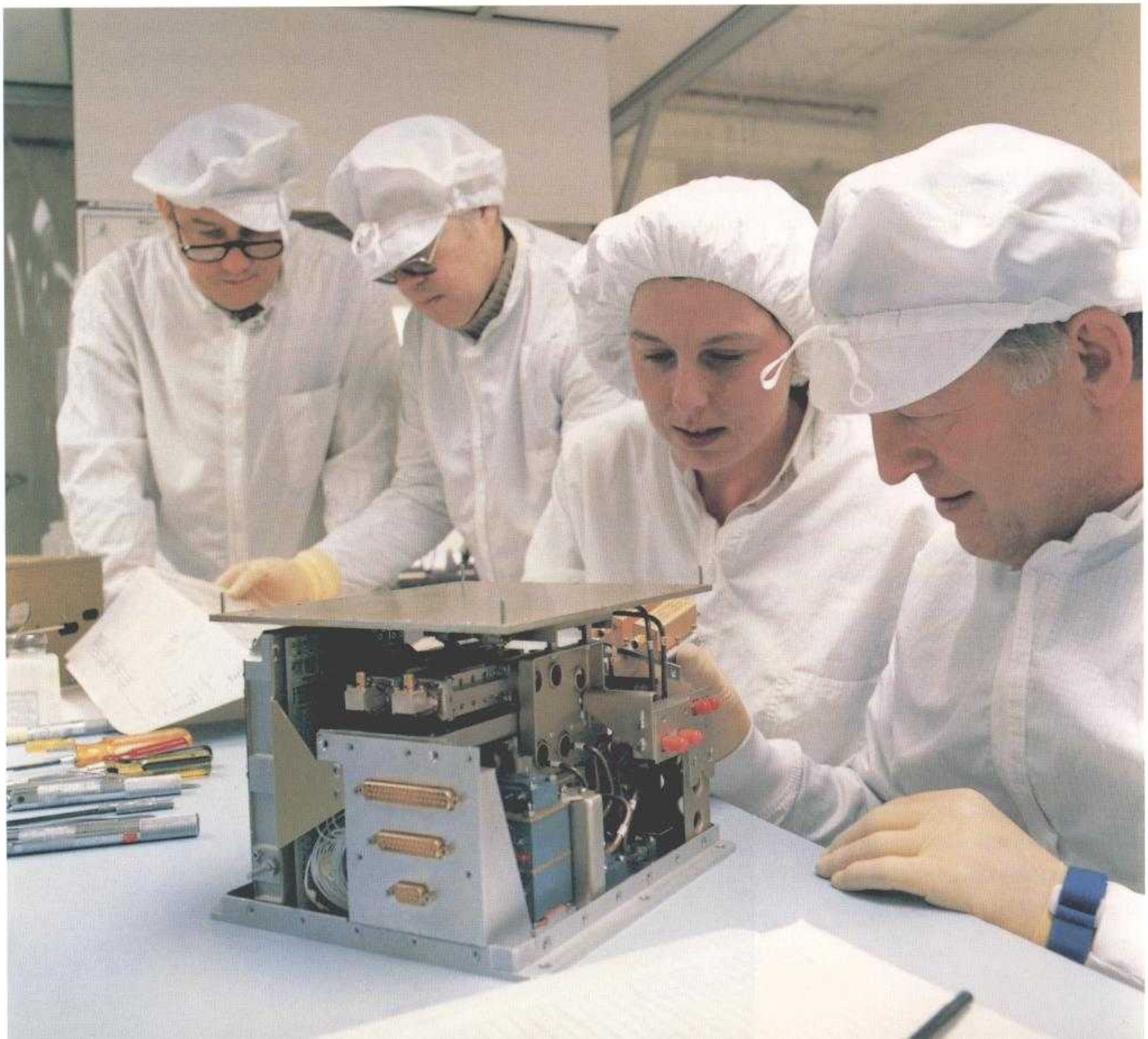
Command & Control Automation

SSTD is actively investigating automation techniques and technologies for more effective spacecraft command and control. The Division has developed a demonstration expert system that can aid in diagnosing anomalies in the attitude determination and control system of a representative spacecraft.

SSTD has found that neural network approaches are promising for determining whether certain onboard equipment is exhibiting anomalous behavior, based on real-time telemetry data. Four diverse neural network paradigms—multilayer backpropagation, adaptive resonance theory, counter-propagation, and learning vector quantization—were used with a programmable coprocessor board that plugs into a personal computer. Actual telemetry data were used to compare the networks' performance in terms of accuracy and training time. Both the adaptive resonance theory and the learning vector quantization networks yielded satisfactory results.

During 1992, SSTD began developing a satellite processor test bed to investigate the complex hardware and software issues related to satellite

A COMSAT team performs clean-room assembly of flight hardware for the ITALSAT in-orbit test transponder (IOTT), which features COMSAT's MMIC Ku-band amplifiers and lightweight waveguide filters.



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

onboard processing. In operating large fleets of satellites, INTELSAT and Inmarsat require greater satellite autonomy to reduce the workload on operations personnel. A centralized satellite processor using today's more advanced microprocessors can handle many functions that previously required larger and heavier hardware units. The use of a centralized microprocessor to implement onboard satellite bus functions has become critical as more autonomous satellites are required to reduce ground support.

Electrochemical Battery Development

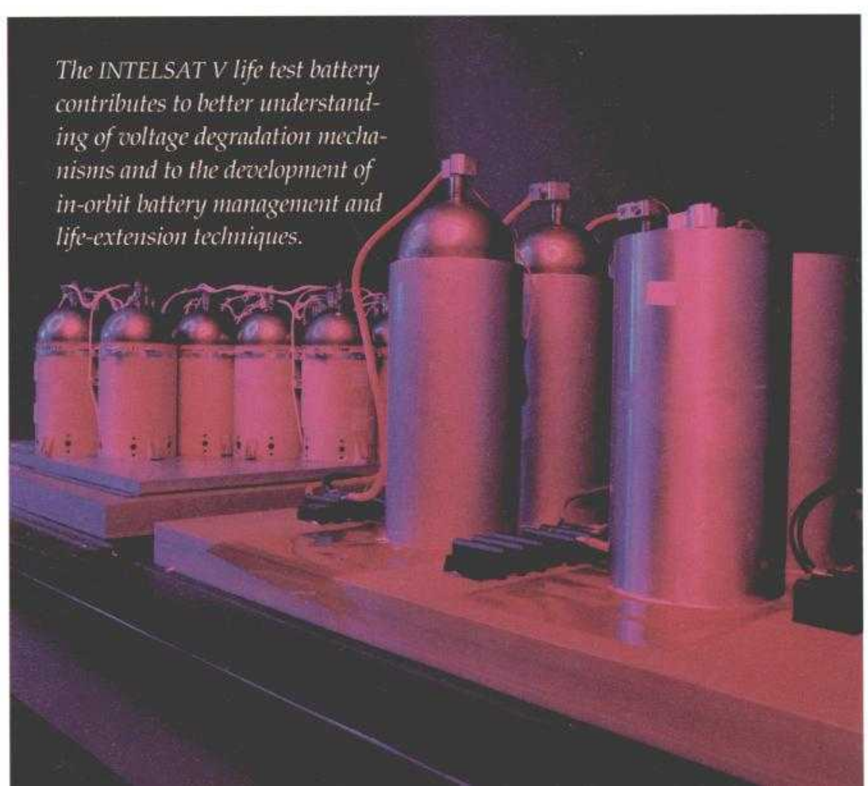
COMSAT Laboratories maintains extensive facilities and personnel capabilities in the power system area. The disciplines covered are solar arrays, power electronics, and energy storage. Batteries continue to be a potentially life-limiting component in spacecraft. As such, the investigation of electrochemical batteries is a predominant concern in energy storage R&D.

The Laboratories pioneered the development of nickel-hydrogen ($Ni\text{-}H_2$) battery cells, the energy storage technology currently used on satellites. During 1992, SSTD continued to advance the development of a lighter and smaller common-pressure-vessel version of this battery with an improved cycle life.

SSTD is also developing new techniques for in-orbit battery management to extend battery lifetimes beyond the satellite design. During ongoing battery life testing, some $Ni\text{-}H_2$ battery cells began to exhibit suppressed end-of-discharge voltages, which were similar to the voltage degradation first observed in certain cells in the INTELSAT V life test battery.

The mechanism responsible for the voltage degradation was identified by fitting valves onto the fill tubes of both normal and anomalous cells and cycle-testing them in the simulated geostationary earth orbit (GEO) regime. A resulting accumulation of water in the anomalous cells indicated that water loss from the electrode stack was responsible for the voltage anomaly.

A technique based on the enhanced vapor diffusion of displaced



The INTELSAT V life test battery contributes to better understanding of voltage degradation mechanisms and to the development of in-orbit battery management and life-extension techniques.

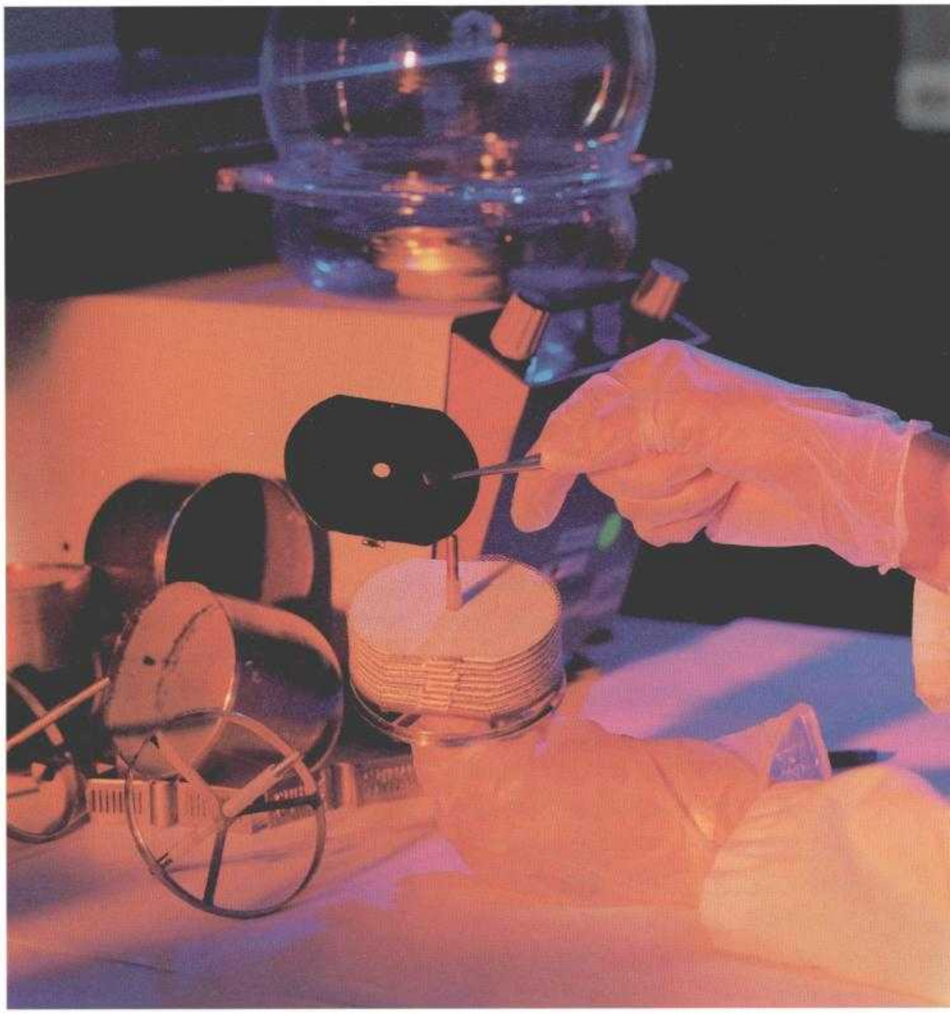
water returning to the stack was developed for in-orbit batteries and implemented through ground command procedures. It is now performed routinely to rejuvenate batteries with cells that exhibit water loss and subsequent voltage degradation.

The charge efficiency for flight-configuration INTELSAT VI Ni-H_2 cells was determined as a function of overcharge with concurrent measurement of heat rate in a radiative calorimeter. The study showed that a recharge ratio of 1.045 was not only adequate to maintain the voltage, but also enabled operation of the battery at high charge efficiency with minimum heat dissipation.

Another focus of 1992 research was the destructive physical analysis (DPA) of flight-model nickel-cadmium (Ni-Cd) and Ni-H_2 cells. Destructive analysis is generally performed to determine whether cell components are made to specification and whether adequate control has been exercised in manufacturing.

DPA of the Ni-Cd cells indicated that some cells were negative-limited on discharge, as evidenced by decreasing capacity with each subsequent cycle, a sharp drop in voltage during resistor drain, and attainment of maximum charge voltage at lower and lower states of charge.

Analysis of cycled Ni-H_2 cells showed that capacity decay can be traced to deactivation of the positive plate active material (as opposed to loss of electrolyte from the electrode stack due to swelling). Some Ni-H_2 cells also showed evidence of the rapid reaction of oxygen with hydrogen (popping) in the form of burn holes in the negative electrode, blown off Teflon wet-proofing membrane, and burn marks in the separator and positive plate. X-ray radiography of the cell showed a correlation between the negative electrode configuration and popping damage.



Physical analysis of Ni-H_2 battery cells is used to investigate anomalous behavior of the cell, and to track the degradation of components with cycling and aging.

SPACECRAFT SUBSYSTEMS & MECHANISMS

SSTD has extensive experience and capabilities in spacecraft subsystems and mechanisms, including the bearing and power transfer assembly (BAPTA), momentum wheels, command and control automation, attitude determination and orbit control, and spacecraft power and electrical systems. SSTD's mechanism and tribological expertise is used to analyze and test momentum wheel bearings, BAPTAs, and solar array drives. Life-testing of bearings and BAPTAs evaluates lubricant film thickness and the effects of bearing cage instabilities.

Environmental and subsystem life testing and evaluation are principal SSTD activities. The Division performs environmental testing for both product qualification and research. Recent activities have included flight vibration qualification of MMIC amplifiers and other units for Loral, thermal vacuum and vibration testing of the ITALSAT in-orbit test transponder, static load and vibration testing of the payload adapter fixture for the COMET spacecraft, and Ni-H_2 battery cell calorimetry.

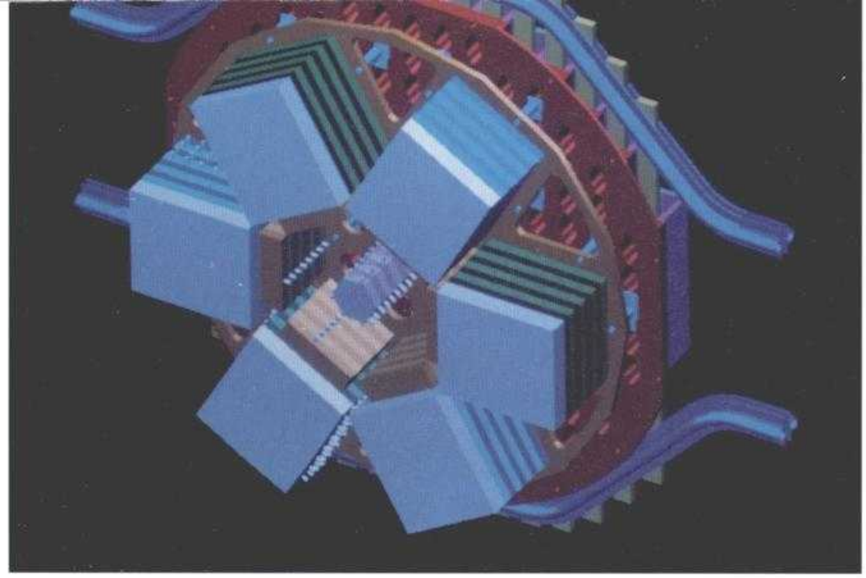
PROPAGATION STUDIES

Since the principles that describe how the propagation medium affects the quality of a microwave radio link are similar to the electromagnetic radiation principles used in antenna technology, SSTD is a logical choice for measuring propagation effects.

The Division's expertise covers all aspects of radio propagation along earth-space paths in the frequency range of 1 to 30 GHz and beyond. SSTD performs propagation impairment modeling, data collection, and analysis; develops impairment mitigation techniques and systems; and develops and fabricates propagation measurement instruments such as beacon receivers and radiometers. Division personnel serve as consultants and participate in International Telecommunications Union/International Radio Consultative Committee (ITU/CCIR) forums. Propagation analysis packages and turnkey systems for propagation measurements, including data collection and analysis capabilities, are used to facilitate propagation studies. Recent work has focused on Ku-band uplink power control development, the effects of scintillation on satellite communications, low-elevation-angle clear-air effects, propagation measurement field support, and participation in CCIR activities and conferences.

During 1992, SSTD performed a wide variety of work for INTELSAT and Teleglobe of Canada, as well as for COMSAT World Systems (CWS) and COMSAT Mobile Communications (CMC). Projects included the design, development, and fabrication of a low-cost Ku-band uplink power control unit for CWS, and L-band propagation measurements for CMC.

As higher frequency bands are brought into service to alleviate congestion in the lower frequency bands, it becomes increasingly important to minimize propagation impairments. The Division actively supports the development of higher frequency bands for communications services through R&D on power control, antenna pointing under adverse propagation conditions, and wide-area diversity.



This solid model of a C-band lightweight antenna shows the beam-forming matrix and heat pipe thermal control system to demonstrate the possibility of integrating a large antenna array onto an existing spacecraft bus.

Satellite System Studies

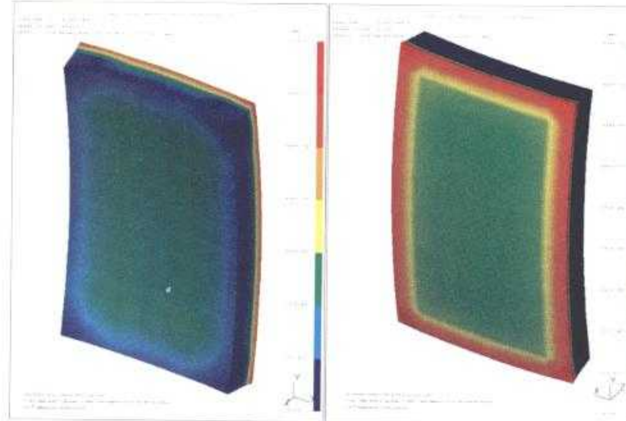
Another area of SSTD expertise involves system engineering trade studies for satellite systems. The Division specializes in top-level conceptual studies leading to cost and performance analysis of emerging satellite systems such as Inmarsat's Project 21, or future military applications of commercial satellite systems. Specific skills include communications performance analysis, estimation of traffic handling and transponders and earth station capacity, traffic loading, interference reduction, satellite sizing, and international standards.

For U.S. Department of Defense satellite systems, SSTD has experience with secure, antijam and spread spectrum communications, and with military satellite systems such as DSCS and MILSTAR. The Division's capabilities and experience can be applied to problems confronting U.S. government agencies such as the Advanced Research Projects Agency, DOD, and others concerned with future UHF, super high frequency, or extremely high frequency satellites.

During 1992, SSTD investigated a high-capacity satellite concept that could lead to significantly lower cost per circuit for the year 2010 INTELSAT system. In addition, a study was performed for the DISA Engineering Center to determine the feasibility of using nonlinear adaptive signal processing for a satellite-based antijam capability based on a new device, Smart AGC™, invented at COMSAT.

Also in 1992, SSTD led other Labs' divisions in a major study to provide global telephony service via handheld transceivers operating directly via satellite. This concept is being actively investigated by Inmarsat under the name "Project 21." COMSAT Mobile Communications, as a major shareholder and Signatory to Inmarsat, commissioned COMSAT Laboratories to undertake a comprehensive, detailed analysis of a number of different satellite systems, each with the potential to provide direct satellite service (Inmarsat-P) via a transceiver handheld terminal.

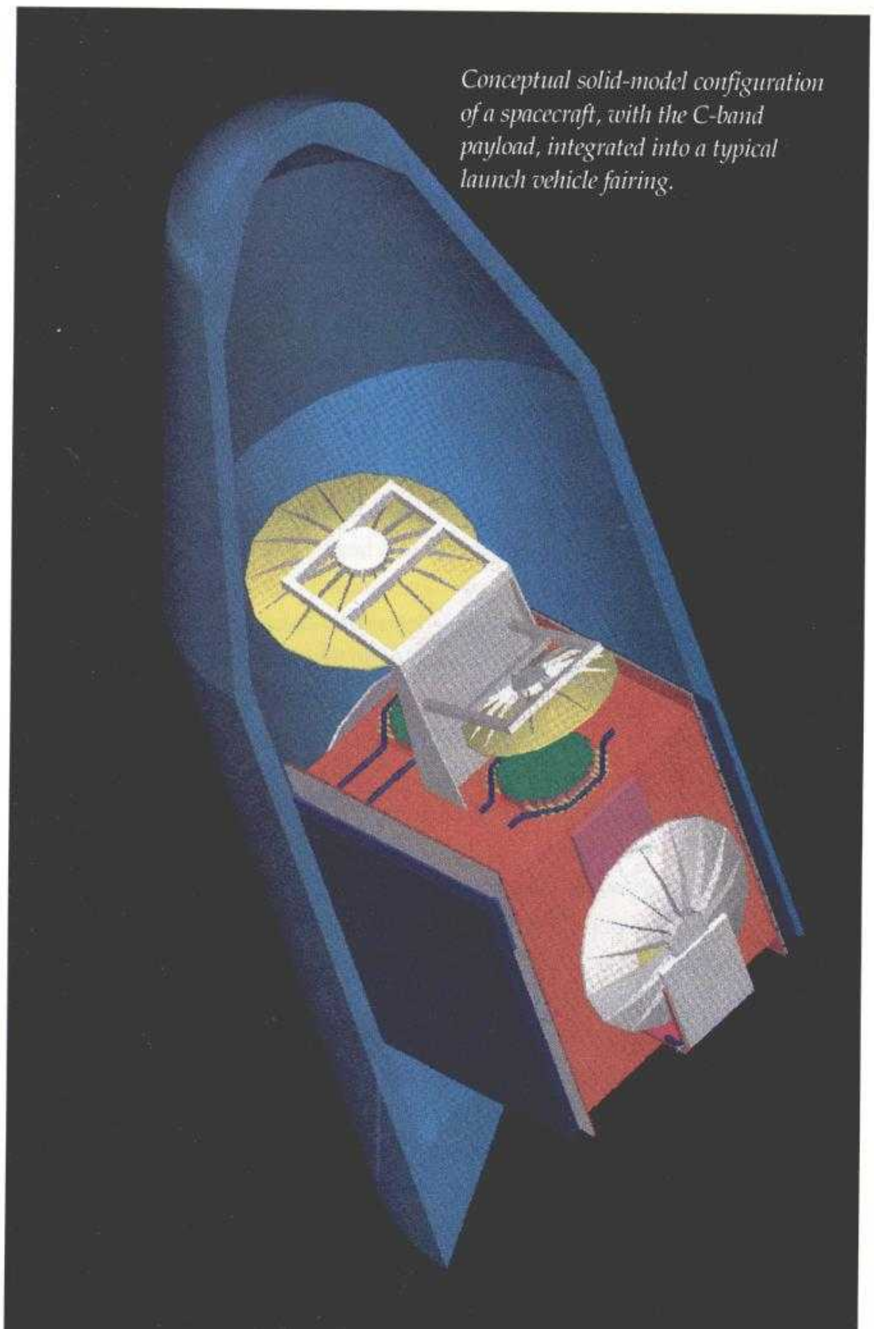
The technical and financial performance of three unique and separate space segment configurations—geostationary, low earth orbit, and intermediate circular orbit—was evaluated. Parametric models of the three satellite networks were developed to support the analysis by designing mission strategies and performing mission analyses of numerous launch vehicles in terms of capabilities, number of spacecraft per launch, launch payload mass, and launch cost; communications payload and satellite antennas; spacecraft mass and power budgets; and financial performance for various amounts of system capacity and numbers of subscribers. The study helped CMC to better understand the technical and financial drivers of such a system.



Analytical tools enable SSTD engineers to depict the structural deformation of an MMIC chip resulting from temperature-induced stress.

SSTD engineers performed conceptual configuration studies of advanced C-band phased-array spacecraft. Solid-model mechanical and thermal design drawings of the C-band phased-array payload were developed in preparation for the fabrication phase of the program.

The Division maintains an extensive library of computer software to support disciplines such as control systems, structural and dynamic analyses, mechanical design, thermal analyses, and power systems. Other typical tools include analysis and color depiction of thermal material stress in an MMIC chip under temperature loading, and the dynamic characteristics of a momentum wheel bearing.



Conceptual solid-model configuration of a spacecraft, with the C-band payload, integrated into a typical launch vehicle fairing.

To facilitate efficient development of the satellite planning process, a new computer-aided design tool called SC Designer™ is being devised which combines the existing computer programs used by a variety of SSTD personnel with newly developed tools. The design and breadboard implementation of this new tool was completed in 1992, and work is continuing toward its full implementation.

When completed, the tool will assist the satellite system planner in developing conceptual designs for communications satellites. A planner will be able to display communications components such as amplifiers, filters, mixers, multiplexers, and switches on a computer screen by selecting with a mouse from a menu of stored components and connecting them as desired. The planner can use this tool to quickly review the power, mass budget, overall cost, and other parameters of the proposed design and reconfigure the topology to explore alternative designs.

COMMUNICATIONS TECHNOLOGY

The Communications Technology Division (CTD) focuses on the communications aspects of the end-to-end circuit connection. Division research and development encompasses transmission, video, and voice frequency band processing; systems simulation; and systems analysis and synthesis. To help maintain the competitive edge of satellite communications, CTD employs advanced communications system architectures and technologies to realize lower equipment costs and improved transmission efficiency and quality. Such architectures and technologies are enhanced by the widespread use of digital signal processing techniques.

MOBILE & PERSONAL COMMUNICATIONS

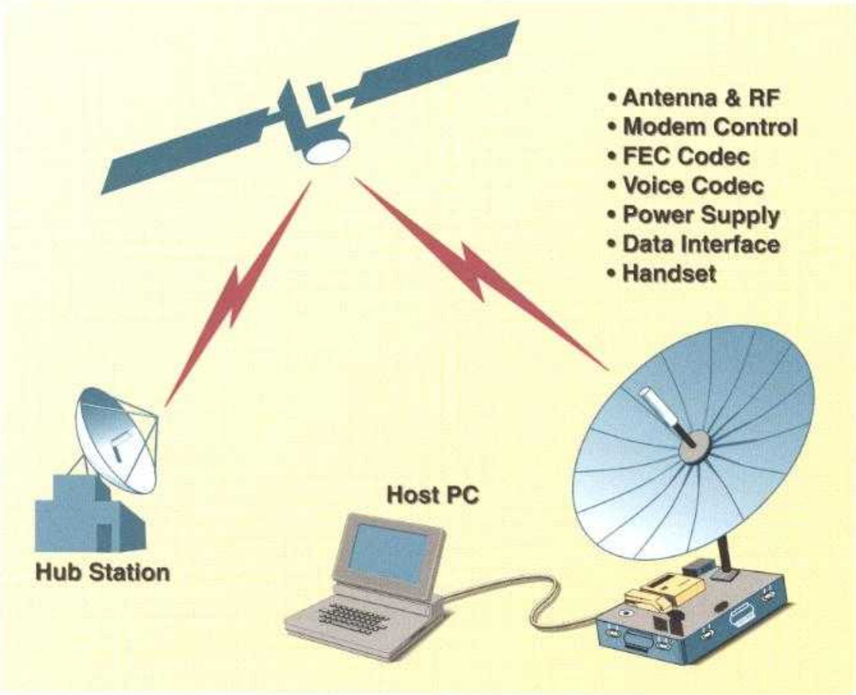
Mobile and personal communications systems for land, maritime, and aeronautical applications have become an important part of today's worldwide wireless communications networks. Delivery of these services via satellite affords the advantage of high-quality global coverage with minimal restrictions on receiver mobility anywhere within the satellite beam (unlike limited-range local wireless or radio-based personal networks).

Ongoing research and development in satellite-based mobile communications at COMSAT Laboratories brings together diverse groups from CTD in the areas of simulation, channel modeling, digital techniques, and speech processing. Division capabilities in this area range from system concept, tradeoff analysis, and simulation, through the design, development, and implementation of digital and analog hardware and software.

Recently, CTD investigated the application of direct-sequence spread spectrum code-division multiple access (DS-CDMA) technology for satellite-based mobile and personal communications. Point-to-point and point-to-multipoint variable-bit-rate voice and data communications were evaluated for a DS-CDMA C-band portable microterminal with hub-and-spoke communications, operating with INTELSAT V satellites and INTELSAT E2/E3 hubs.

The use of direct-sequence spread spectrum modulation for both the C- and Ku-band systems minimizes interference to adjacent satellites and terrestrial networks, and simplifies network control and operation. The major system parameters (network operation, call setup, and call takedown), frequency and power control methods, public switched telephone network (PSTN) interfaces, and signal formats have been established by extensive detailed analysis and computer simulations.

For personal portable communications, terminal size, weight, and cost will be of paramount importance, particularly for the handheld satellite communications terminals of the future. CTD has already developed working hardware and software that implement the complete baseband-to-IF sections of a small, briefcase-size Ku-band spread-spectrum-based satellite terminal, complete with a multirate data port, a voice port, and store-and-forward facsimile. Simple network control software for direct terminal-to-terminal communication without a hub was implemented in the laptop personal computer that is an integral part of the terminal. The design incorporates user-friendly pull-down menus; visual and audi-



The microterminal includes several key technologies—low-bit-rate voice coding, portable antennas, and advanced signal-processing techniques.

tory call-progress feedback; innovative concepts in call setup, billing, and recordkeeping; rain-fade compensation; and frequency and power control.

In keeping with the general trend toward smaller and smaller terminals, the Division conducted a major study on miniaturizing the current L-band Inmarsat-M mobile terminals, with the goal of reducing the terminals from their current briefcase size to that of a laptop personal computer or a lunch box, and eventually, a handheld personal terminal. Novel concepts in digital down-conversion and demodulation, developed as a result of the study, led to the elimination of a large number of analog IF components. Proposals for further size reduction include using an RF gate array for the RF/IF down-conversion from L-band, and developing a semi-custom, application-specific integrated circuit (ASIC) for the digital down-conversion.

Also investigated in the study were baseband processing and the terminal controller, the user voice/data/fax interfaces, the up-converter and modulator, the power supply, and the packaging. The Satellite and Systems Technologies Division at COMSAT Laboratories developed solutions for miniaturizing the antenna, the high-power amplifier, the low-noise amplifier, and the diplexer. Antenna testing confirmed that a lunch-box-size terminal is feasible with off-the-shelf technology.

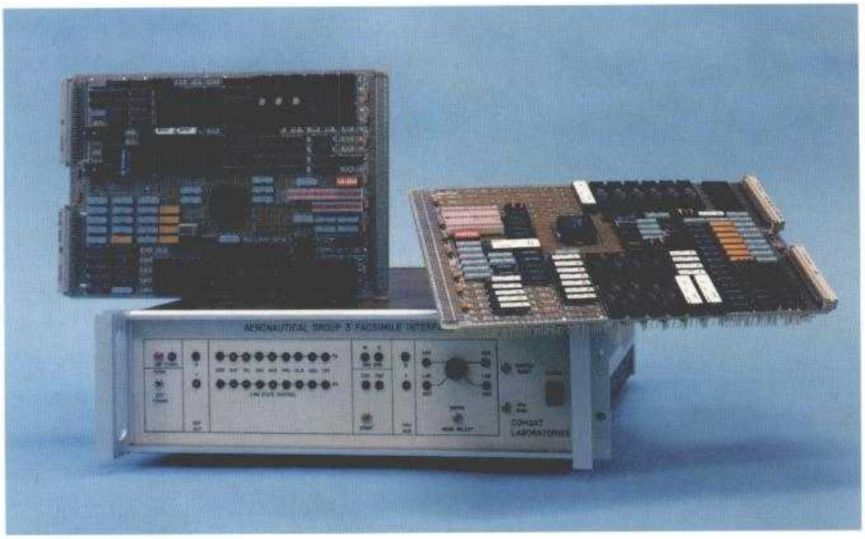
Speech, Facsimile & Multimedia Processing

COMSAT Laboratories' 25-year record of accomplishments in voiceband transmission research underscores its commitment to high-quality signal transmission over fixed telephony and mobile communications networks. Research on various signal processing technologies is complemented by a comprehensive objective and subjective evaluation facility, and by active participation in national and international standards organizations.

CTD's current mobile-terminal voice coding research focuses on the development of 1,200-bit/s source coding techniques to provide communications-quality performance. In 1992, the first development phase of a line spectral pair (LSP) split vector-quantization (VQ) speech codec was completed. This 1,200-bit/s codec, based on the transformation of linear predictive coding coefficients to LSPs, exploits interframe and intraframe redundancies to permit speech to be encoded with high intelligibility and speaker feature retention at low transmission rates. Mapping to LSPs permits the implementation of a split form of VQ that is computationally efficient, and also leads to a natural way of exploiting the characteristics of human hearing to achieve more natural-sounding speech at 1,200 bit/s.

As the growth of mobile communications has spurred interest in low-rate speech coding, parallel growth in multimedia communications has highlighted the need for the efficient transmission of facsimile over mobile networks. However, transmitting Group 3 facsimile over narrowband digital mobile channels presents a challenge because facsimile signals are transmitted as high-speed voiceband data over the PSTN and cannot be reliably encoded and transmitted as voiceband signals by standard waveform coding techniques operating below 40 kbit/s. Since the user data channel capacity in mobile systems rarely exceeds 16 kbit/s, real-time interworking with terminals connected to the PSTN requires specialized, cost-effective solutions. Such solutions must reduce bandwidth utilization as well as convert facsimile protocols to a format suitable for transmission over digital mobile satellite networks.

In 1992, COMSAT Laboratories completed the implementation of real-time facsimile interface units (FIUs) for the Inmarsat-B, -M, and



The facsimile interface unit was designed to compensate for the longer access and transport link delays encountered in mobile satellite systems.

Aeronautical systems. The FIUs perform three basic functions. First, they convert incoming signal waveforms from the voiceband to the baseband domain for transmission over satellite channels. Second, they remodulate baseband digital signals received over the satellite channel and transmit them to the end customer's facsimile terminal. Finally, the FIUs perform protocol conversions to make Group 3 facsimile protocols compatible with the transport channel constraints of the Inmarsat system.

Today, facsimile transmission is considered essential for mobile communications. However, another type of communication—videotelephony—is expected to become popular over fixed integrated services digital networks (ISDNs) in the future.

In 1992, CTD conducted a study to subjectively assess the impact of transmission delay on ISDN videotelephony. The study used two 64-kbit/s video telephones connected over links that incorporate simulated one-way circuit propagation delays of 0, 250, and 500 ms—representing a local connection, a single satellite hop, and a double satellite hop, respectively. Test participants were asked to converse over a succession of circuit conditions randomly incorporating each of the three delays. After exposure to each condition, the participants expressed their perception of link performance. In general, no significant performance degradation was observed between terrestrial and single-hop satellite connections.

Video Processing

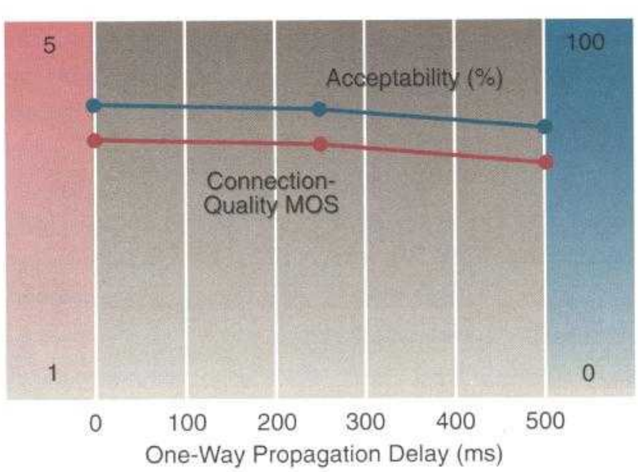
Video transmission via satellite is an effective means of point-to-multipoint video delivery. Of primary concern in satellite video transmission are picture quality and cost-effectiveness. To achieve these goals, CTD has focused its video processing activities on high picture quality and bandwidth-efficient transmission techniques. COMSAT Laboratories conceptualized the time-multiplexed television video transmission (TMTV) technique many years ago, and recently developed a compact prototype codec. Today, TMTV is the only equipment that can achieve sufficiently high quality for broadcast applications, with two television signals in one 36-MHz transponder.

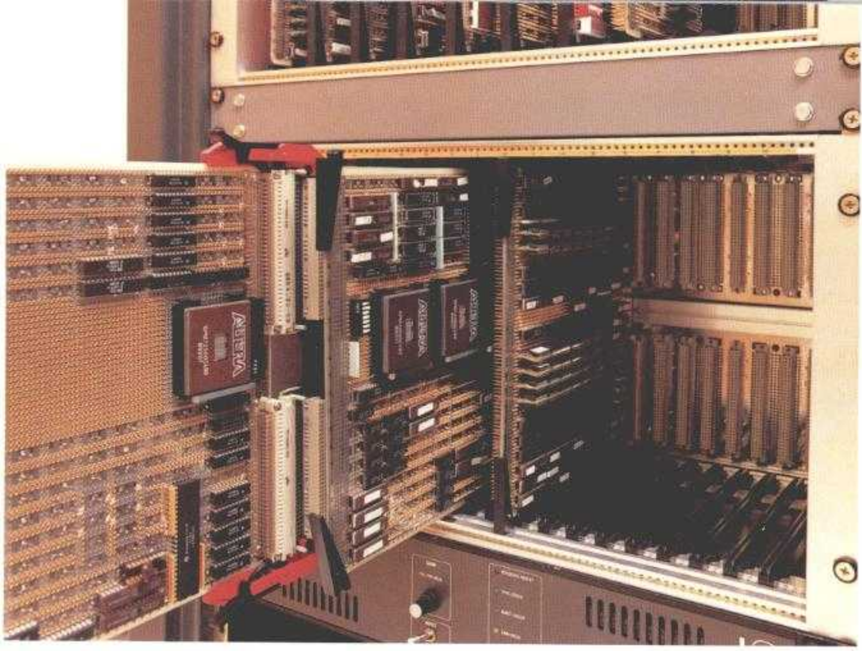
During the last few years, digital video compression techniques and very large-scale integration (VLSI) technology have advanced rapidly, and more video transmission is becoming digital. Compressed digital video has the potential to deliver higher picture quality using less bandwidth. CTD's research in this area resulted in the invention of simplified vector quantization (SVQ) in 1989. This core technology has been applied to both National Television System Committee (NTSC) and high-definition television (HDTV) compression.

SVQ Codec

With recent advances in video compression techniques and VLSI technology, the compression of video signals has become cost-effective. Currently, digital video at bit rates ranging from 56 kbit/s to 45 Mbit/s is widely used for various applications. For satellite transmission of television

In ISDN videotelephony, propagation delay does not adversely affect the ability to communicate as transmission delay is gradually increased.





The SVQ-based video codec offers a low-cost, high-quality solution for transmitting multiple video channels in a single transponder.

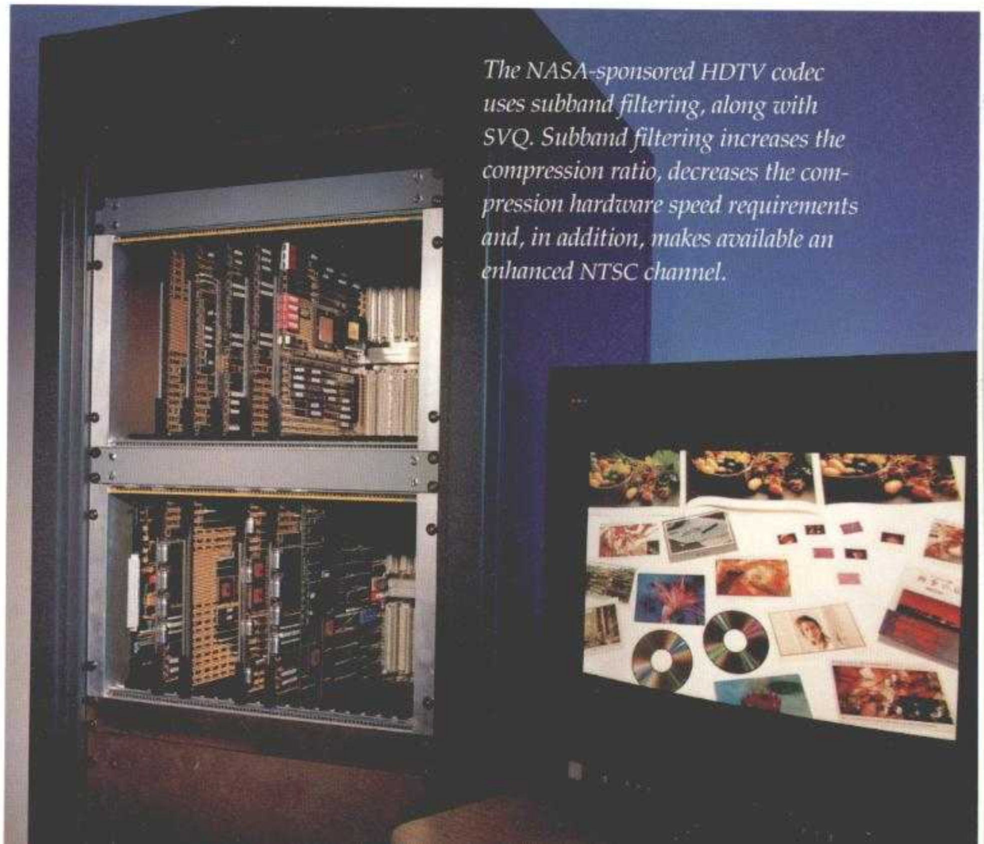
signals, network operators consider the 45-Mbit/s codec to be the only digital codec capable of achieving broadcast quality. However, at this bit rate only one television signal can be transmitted in a 36-MHz satellite transponder. For economical point-to-multipoint transmission of compressed video signals in the satellite environment, the decoder must be simple. For other applications, such as satellite newsgathering, the encoder also should be as simple as possible. CTD has developed a video coding technique that features a high compression ratio, moderate encoder complexity, and a simple decoder. This technique employs the proprietary SVQ algorithm in conjunction with motion estimation/compensation.

In 1991, CTD designed a video codec breadboard based on SVQ technology to evaluate picture quality at different bit rates. With this system, high picture quality was expected to be achievable at around 10 Mbit/s. In 1992, the breadboard system was extended to a complete prototype codec by incorporating other essential processing, including entropy coding, packetization, forward error correction (FEC), and buffer control. The encoder and decoder hardware has relatively low complexity and can be sized compactly for production. Various video sources, from sports to movies, were tested on the prototype, and high-quality video was demonstrated at 12 to 16 Mbit/s. At these rates, each 36-MHz transponder can potentially carry three broadcast-quality NTSC signals. For applications that require lower bit rates, the SVQ core technology can be applied by relaxing the quality constraint and modifying some system modules.

High-Definition Television

The excellent picture quality and high resolution of HDTV present many new opportunities for services that demand high-quality video, such as telemedicine, remote sensing, and entertainment applications. However, satellite transmission of HDTV requires wide bandwidth and high power. To reduce earth station size and satellite power, these requirements should be minimized by compressing the HDTV signal. A basic HDTV compression research effort initiated by CTD in 1990 led to a contract award from NASA.

As a result of the NASA HDTV Phase I study, a subband-based signal decomposition and reconstruction method was proposed to reduce the high-speed processing requirement for HDTV. During 1992, CTD developed a system that splits the luminance signal into four spatial subbands. A digital compression subsystem performs motion estimation/compensation and



The NASA-sponsored HDTV codec uses subband filtering, along with SVQ. Subband filtering increases the compression ratio, decreases the compression hardware speed requirements and, in addition, makes available an enhanced NTSC channel.

SVQ encoding and decoding on one of those subbands. Analog interface units for both the transmit and receive sides were developed to demonstrate the breadboards by using real HDTV source materials and displaying the results on HDTV monitors. Although the breadboard system is not yet a complete codec, it demonstrates the picture quality resulting from single-band compression. The low vertical and the low horizontal (LL) frequency bands carry most of the information, and the picture reconstructed from them is almost indistinguishable from the original. Hardware developed to estimate the bit rate for the LL band and display the results on LEDs also confirms a prediction from earlier software simulations that nearly distortion-free HDTV compression can be achieved at bit rates from 27 to 55 Mbit/s.

Video Compression Based on Motion Compensation

Motion compensation is a type of video predictive coding that achieves a high video compression rate by reducing redundancy in interframe data. A motion compensation coder first predicts the gray level of each pixel in the current frame, based on the video data in the previous frame and an estimate of interframe motion. The coder then transmits the prediction error (not the gray level) of each pixel.

A widely used motion estimation algorithm is the block matching algorithm (BMA). The video frame is divided into blocks, each containing an identical number of pixels, and the BMA generates a constant estimate of interframe motion, called a motion vector, for all the pixels in each fixed-size block. One difficulty with the BMA is selecting the optimal block size. A fast-moving video sequence favors a small block division for accurate motion estimates. Conversely, for a slow-moving video sequence, a large block division can reduce the number of overhead bits necessary to represent the motion vectors, while still providing good motion estimates for each pixel. To mitigate this drawback of conventional BMAs, variable-size BMAs (VSBMAs) were recently proposed based on the concept of dynamically adjusting the block size in accordance with the content of the video sequence to simultaneously achieve accurate motion estimation and low overhead transmission.

A class of quad-tree-based VSBMAs (QBMAs) was developed by CTD to achieve a higher video compression rate than conventional fixed-size BMAs. The QBMAs are classified into split-only QBMAs (SQBMAs) and merge/split QBMAs (MQBMAs). An *m*-level SQBMA—a simpler version of the QBMA—divides the video frame hierarchically into blocks of *m* different sizes, according to a specified distortion criterion. To achieve optimal division of the blocks, an *m*-level MQBMA merges four adjacent small blocks into a large block after the hierarchical splitting is completed. Computer simulation has projected that a three-level QBMA can attain about a 0.3-bit/pixel saving at a 40-dB quantization signal-to-noise ratio (S/N) and a 1-bit/pixel video coding rate.

The hardware architecture of the QBMA is based on a systolic array structure, which is designed using a computation regularization procedure to reduce the large computation redundancy remaining in the QBMA. While the complexity of the QBMA grows exponentially with an increasing number of different block sizes, the designed systolic array maintains a moderate increase in hardware complexity. Compared to a typical systolic array for a fixed-size BMA, the designed array for a two- or three-level QBMA requires less than a 30-percent increase in hardware complexity, and can process video data at the same speed.

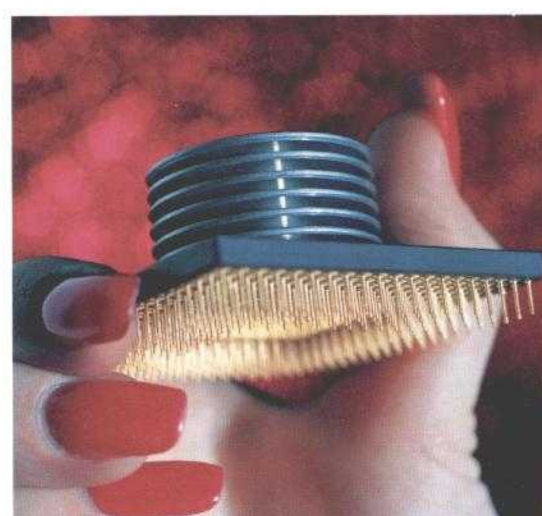
Transmission Processing

The steady increase in satellite system usage has motivated an ongoing effort to improve both the bandwidth efficiency of the satellite system and the quality of service to users. In digital data transmission, this means higher data rates through a fixed bandwidth, and better bit error ratio (BER) performance. Coding and modulation systems based on available link margins have been developed to optimize bandwidth efficiency and performance. A variety of modems and codecs—from digital signal processor (DSP)-based, low-speed designs to 200-Mbit/s, bandwidth-efficient coded modulation systems—were implemented for a wide range of applications.

Digital Modem Development

A major cost element in any earth station terminal is the modem equipment. Today's changing requirements, coupled with the steadily increasing demand for capacity, have led to frequent upgrades in the bit rate of modems, or to a larger num-

The ASIC is utilized in nine distinct locations throughout the demodulator—proving its flexibility in the current design.



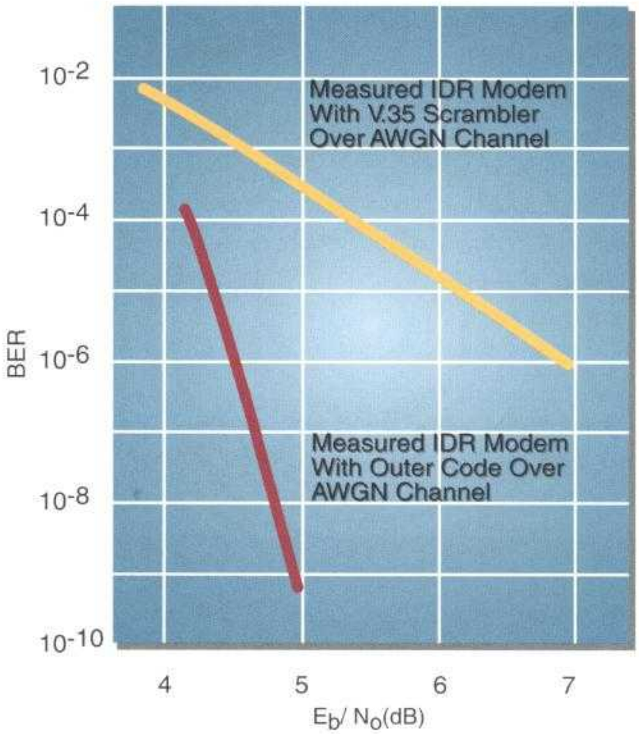
ber of modems. A variable-bit-rate modem, whose data rate can be increased to meet the demand for increased traffic capacity, offers an attractive means of cost containment.

COMSAT is currently developing a variable-rate, flexible-format, programmable digital modem (PDM) under contract to NASA's Lewis Research Center. The modem operates from 2 to 300 Mbit/s with a variety of modulation formats, including quadrature PSK, minimum shift keying, 8 PSK, 16 quadrature amplitude modulation, and 16 PSK. For maximum flexibility, it also operates in both burst and continuous modes.

All critical modem functions (i.e., data filtering, acquisition, and tracking loops) are implemented using a custom-designed, emitter-coupled-logic ASIC chip. The chip was designed as a building block for the high-speed digital signal processing functions typically used in modem and other applications.

A further application of the PDM is for processing on board satellites. The long lifetime of satellites requires onboard communications equipment that is flexible enough to handle system upgrades over a number of years. The flexibility offered by the PDM ensures that the capability will exist to demodulate most possible uplinked signals.

Another ASIC-based digital modem is under development to satisfy continuous medium-data-rate modem users. It operates from 64 kbit/s to 20 Mbit/s, with most of its circuitry contained in a single complementary metal oxide semiconductor ASIC chip. Carrier and clock-recovery oscillators are implemented using numerically controlled oscillators to obtain wide bit rate performance. The low parts-count for the overall modem, and the minimal alignment time due to digital implementation, result in an inexpensive, flexible modem.



The measured bit error rate performance of COMSAT's IDR outer codec at 1.544 Mbit/s illustrates the dramatic improvement obtained with concatenated coding.

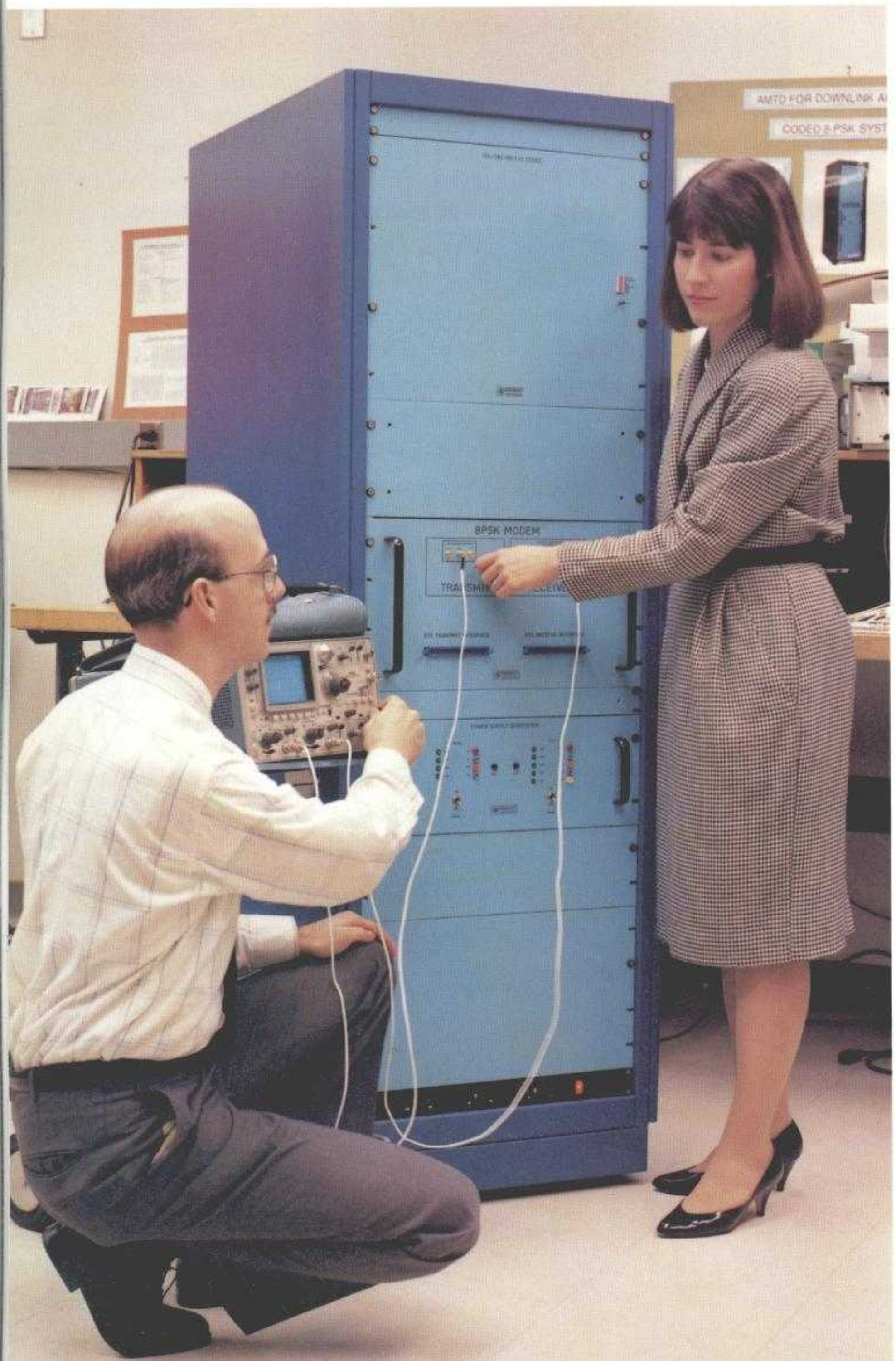
IDR OUTER CODEC

The intermediate data rate (IDR) outer codec was developed to provide INTELSAT's IDR digital frequency-division multiple access (FDMA) service with the transmission quality necessary in modern telecommunication networks. This was accomplished by concatenating a high-rate Reed-Solomon (RS) block code with the system's existing rate 3/4 convolutional code. A new coding method has been shown to supply the needed improvement for the existing IDR system by improving the current 1×10^{-3} threshold BER to 1×10^{-6} without a loss of transponder capacity.

The hardware designer of the IDR outer codec (the small black box on top of the rack) conducts bit error rate performance tests with an off-the-shelf IDR modem.

The IDR outer codec was designed to interface with existing in-service IDR satellite modems. The hardware implementation uses a low-cost, commercially available DSP and an off-the-shelf RS codec integrated circuit to accommodate the INTELSAT Earth Station Standards (IESS)-308 T1 and E1 data rates. Laboratory and field tests of the unit have shown measured performance very close to the theoretical results. Performance degradation of no more than 0.2 to 0.3 dB was experienced under typical adjacent channel and co-channel interference. A field test demonstrated virtually error-free operation for an IDR circuit with outer coding operating under typical conditions. The test also proved the interoperability of the outer codec with existing IDR modems and associated transmission equipment over an actual satellite channel.

COMSAT engineers prepare to demonstrate the superior performance of the 155-Mbit/s modem with concatenated coding. The system brings fiber optic quality to the satellite transmission of broadband ISDN and improves BER performance by four orders of magnitude.



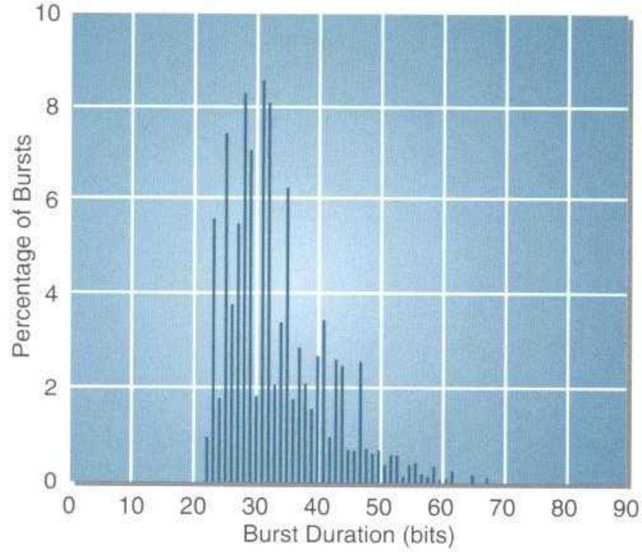
As a testament to the success of the IDR outer codec development project, a new Appendix was added to the IESS specification for IDR service (IESS-308). The Appendix includes an option for outer coding on open-network INTELSAT IDR services and International Business Service (IBS). The outer codec development was also singled out as an outstanding example of responding to customer needs by one of the largest users of the INTELSAT system.

155-MBIT/S MODEM WITH CONCATENATED CODING

To facilitate 155-Mbit/s broadband ISDN transmission over satellites, and to enable 140-Mbit/s fiber optic cable restoration, COMSAT recently developed a versatile, high-speed system combining octal phase shift keying (8 PSK) modulation with a concatenated variable-rate code. The system transmits information at rates of 155.52 or 139.264 Mbit/s through a single 72-MHz transponder. This represents a capacity increase of up to 29 percent relative to the existing 120-Mbit/s carriers and, more importantly, allows this bandwidth-efficient transmission to take place over existing satellite channels.

The concatenated code employed by the system includes a high-rate RS outer code and a multistage rate 8/9 inner code. The power-efficient performance of the combined coded modulation system is indistinguishable from fiber optic cable quality.

The initial testing, performed with the system operating at the 155.52-Mbit/s information rate through a linear channel, resulted in data consistent with both theoretical analysis



A time domain computer simulation of a realistic satellite transmission channel provided burst error data for an INTELSAT IDR carrier using a rate 3/4 convolutional FEC code.

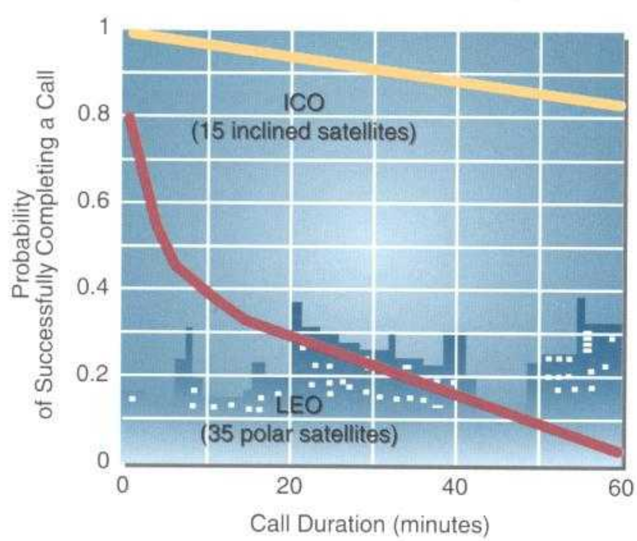
and computer simulation. Additional tests performed with co-channel and adjacent channel interferers also yielded excellent results.

Systems Simulation, Testing & Modeling

COMSAT Laboratories maintains an extensive capability to model and analyze problems related to satellite transmission, in both fixed and mobile satellite services. As the need arises for new satellite services, transmission modeling is used in developing new systems solutions and transmission techniques.

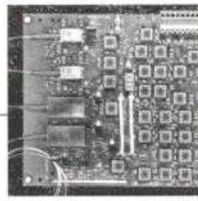
CTD conducted a study to parametrically quantify the burst error patterns that can occur in digital signals if insufficient carrier power is available, or if interference is too high. These patterns depend on the FEC coding scheme employed. In addition to generating burst error statistics, CTD analyzed the effect that these errors have on transmission systems. Particularly with respect to digital circuit multiplication equipment, errors occurring in bits that convey information on how time-multiplexed voice spurts are to be demultiplexed have a more serious effect on signal quality than errors in the encoded voice data.

In a related effort, CTD studied the link availability for various low earth orbit (LEO) and intermediate circular orbit (ICO) satellite constellations designed to provide telephony service to handheld terminals. Two candidate orbits were compared—a LEO constellation where the minimum elevation angle of the best satellite is 10°, and an ICO constellation, where the minimum elevation angle is 30°.The object of this study was to assess and compare the ability of various constellations to provide reliable and continuous service in environments where shadowing and blockage are likely. In such environments, the higher the elevation angle of the highest satellite, the better the service capability.



Computer analysis gives the probability that a user, at a particular location within a hypothetical cityscape consisting of buildings and streets of specific dimensions, will complete a call lasting n *minutes.*

NTD



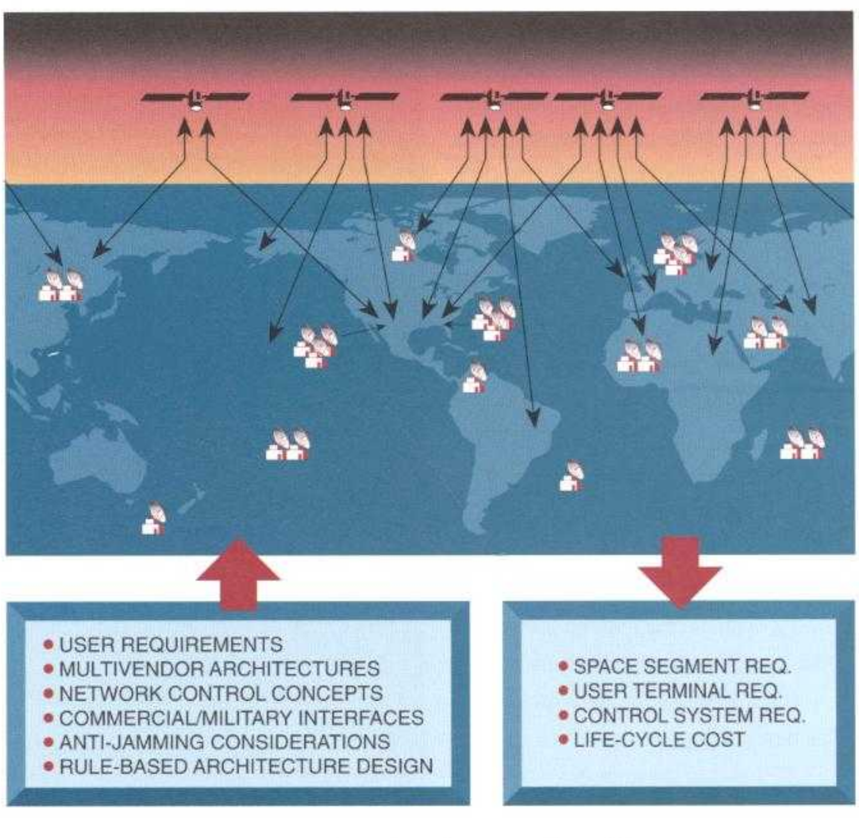
NETWORK TECHNOLOGY

The Network Technology Division (NTD) performs R&D related to analysis, design, implementation, and testing of advanced satellite and terrestrially based communications systems. Applications areas include fixed and mobile 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. Activities within the Division range from conducting studies to implementing hardware- and software-based systems. The work carried out in NTD can be grouped into three categories: fixed satellite networks, mobile satellite networks, and interworking between satellite and terrestrial networks.

FIXED SATELLITE NETWORKS

DOD'S COMMERCIAL SATELLITE COMMUNICATIONS INITIATIVES

The Commercial Satellite Communications Initiatives (CSCI) program is sponsored by the Defense Information Systems Agency to investigate the capability of commercial satellite communications systems to meet current and projected Department of Defense communications requirements. COMSAT, the prime contractor, and its team members GTE and TRW, received the CSCI contract for both fixed satellite service (FSS) and mobile satellite service (MSS) systems. COMSAT Laboratories has provided extensive systems engineering support for the development of FSS and MSS network architectures and network operations/control concepts.



The network architecture shows the ability of commercial satellites to meet DOD's user requirements with associated study methodology.

COMSAT Labs was the first to develop the INTELSAT 120-Mbit/s TDMA terminal in 1982. Here, NTD personnel complete the final checkout of the terminal.

Second-Generation TDMA

The second-generation INTELSAT 120-Mbit/s time-division multiple access (TDMA) terminal currently under development in NTD reduces the large, 12-rack, first-generation TDMA equipment into a single rack. The terrestrial interface capability of this second-generation terminal is expandable from 2 to 32 E1 interfaces, with 1-to-*N* redundancy to accommodate any size user. In addition to the reduction in size, features have been added to the INTELSAT 120-Mbit/s TDMA terminal to improve its efficiency, operation, monitoring, and self-testing.

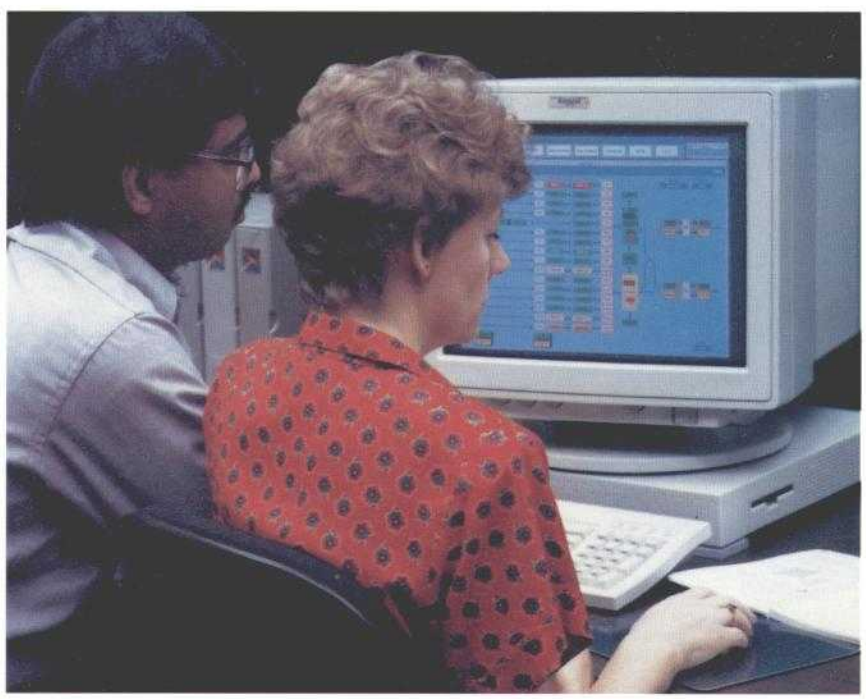
Satellite Bandwidth on Demand

Advanced full-featured user interfaces are offered for voice telephony, video teleconferencing, and data communications, based on the standard integrated services digital network (ISDN) primary rate interfaces for both 23B+D and 30B+D. Data services are targeted to the rapidly expanding local/wide area network interconnect market.

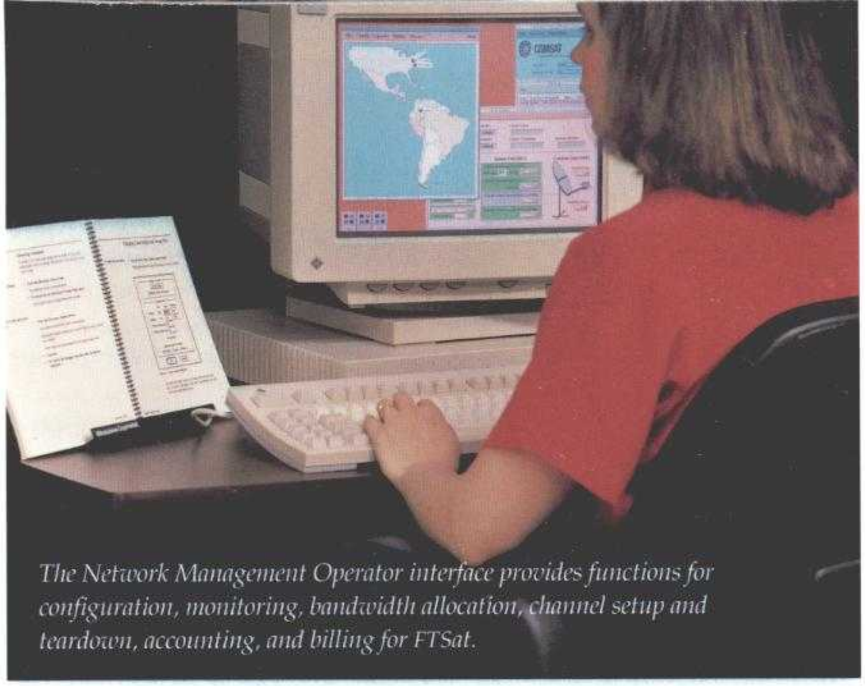
An innovative multitransmission-rate, multicarrier frequency TDMA approach provides network bandwidths sufficient for large user networks that are capable of operating with either domestic loopback satellites or the non-loopback spot beam configurations characteristic of INTELSAT satellites. Multiple 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, also adjustable on a burst-by-burst basis, permit sufficient integration of small and large earth stations in the network.

Fractional T1 Satellite System

The Fractional T1 Satellite System (FTSat) is a variable-rate, bandwidth-on-demand, single channel per carrier mesh network developed by COMSAT Laboratories. FTSat is ideal for service providers and private businesses that require point-to-point and point-to-multipoint connections among geographically dispersed sites. The system offers metered, clear-channel simplex, multipoint, and full-duplex connections at variable data rates from 19.2 kbit/s to 2.048 Mbit/s, along with selectable modulation and forward error correction (FEC). It can carry voice, data, video, or facsimile traffic.



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

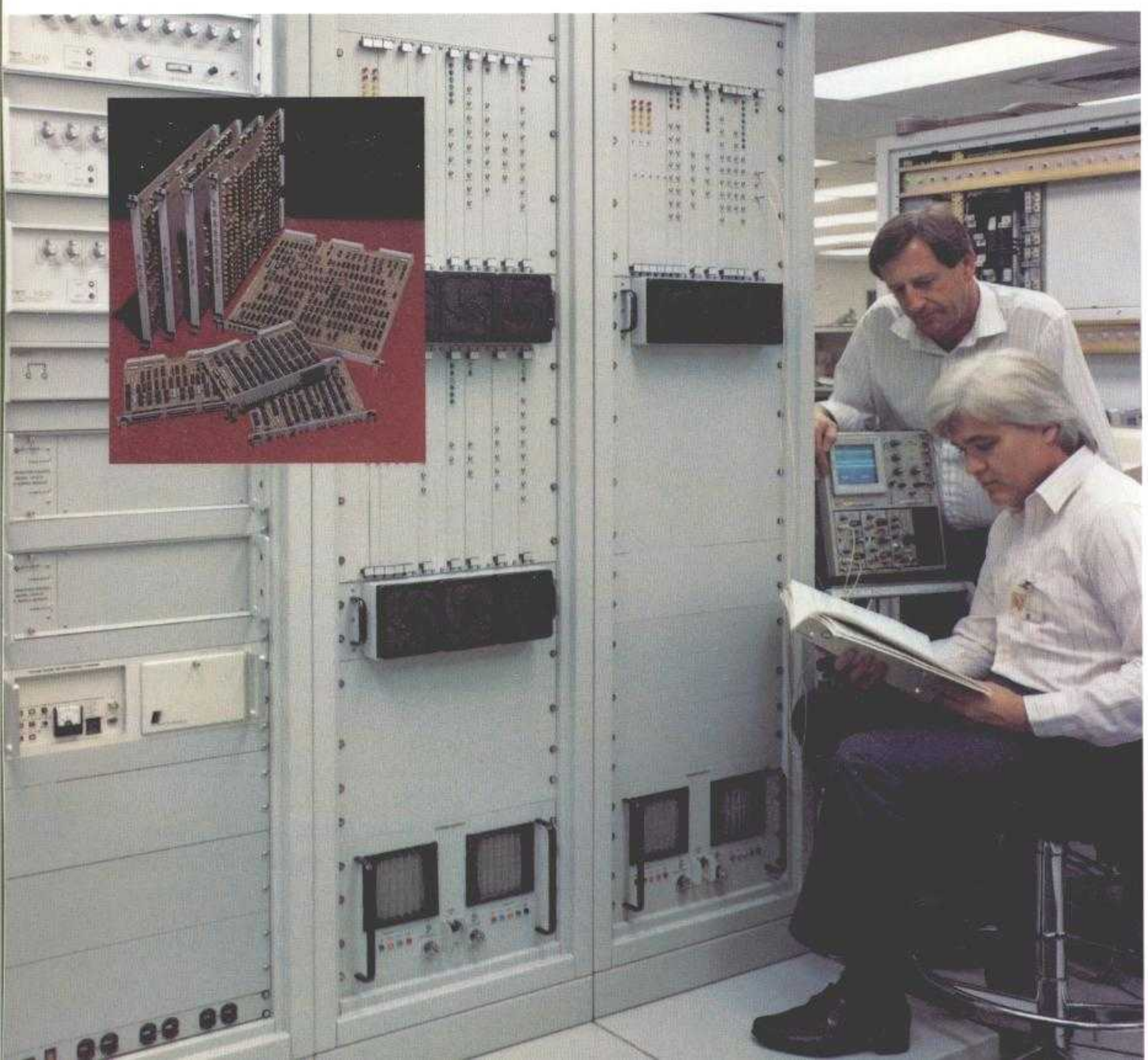


The Network Management Operator interface provides functions for configuration, monitoring, bandwidth allocation, channel setup and teardown, accounting, and billing for FTSat.

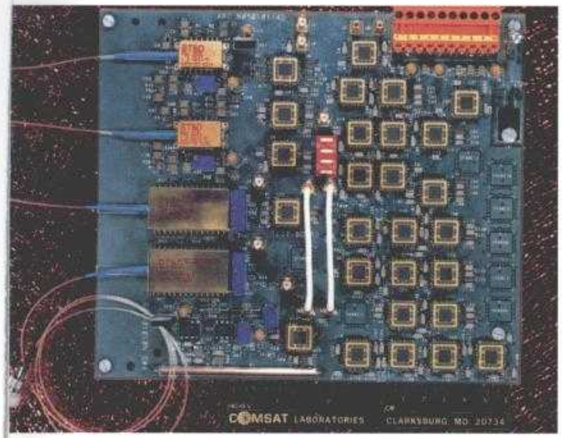
Each traffic station contains a control unit; one or more automated, variable-rate data modems; a 1.8- to 2.4-meter antenna; and optional trackers for operation with inclined-orbit satellites. Satellite channels may be requested at a traffic site by a local operator using a keypad, or automatically by customer equipment using the International Telephone and Telegraph Consultative Committee (CCITT) V.25bis signaling protocol. This protocol is supported by a large number of data communications devices such as routers, video codecs, and intelligent multiplexers. Periodic scheduled (time-of-day) and ad hoc connections can also be defined at the network management station.

ACTS TDMA

NTD developed several TDMA terminals for NASA's Advanced Communications Technology Satellite (ACTS) Program, including the network reference station, the 110-Mbit/s traffic terminal, and the 27.5-Mbit/s traffic terminal. More than 286 boards were produced from 36 custom designs, and over 60,000 lines of code were developed. The equipment has been operating flawlessly since it left the NTD laboratory. Subsequent to delivery of the TDMA equipment in 1990, NTD has also designed, developed, integrated, and tested a primary-rate ISDN interface for the ACTS TDMA.



The 110-Mbit/s TDMA terminal provides both reference station and traffic terminal functions, along with special test equipment to simulate the onboard baseband switch and master control station functions for terminal self-test. Here, final system checkout is performed before shipment to NASA. Inset: Thirty-six custom board designs were developed for the ACTS TDMA Program.



The onboard baseband switch evaluation board, fabricated with surface-mount technology, allowed testing of critical elements of a 1-GHz fiber optic baseband switch. The optical fiber ring provides a lightweight, RFI-free signal routing network.

Onboard Baseband Processor & High-Speed Optical Interconnect Ring

When used in conjunction with other onboard processing functions and multiple spot beams, onboard baseband switching offers enhanced service and functionality, leading to reduced earth station complexity and cost. Coupled with multiple spot beams, baseband switching can provide interbeam carrier and channel routing that makes efficient use of spacecraft mass and power.

NTD is currently developing a modular baseband switch and associated processing support functions. The switch will accept traffic from a number of digital satellite services, such as INTELSAT intermediate data rate (IDR), TDMA, and International Business Service (IBS); demultiplex it to extract baseband information; and forward it to various output modules/downbeams for transmission to the ground.

The input and output modules are interconnected via a fiber optic ring operating in a time-division multiplex mode. Data transferred over the ring are routed by means of data-directed packets. The switch will support six input and output modules handling a total throughput of 500 Mbit/s. To minimize potential risks, certain critical functions, such as the optic drive and receiver logic to the fiber optic ring and clock recovery circuitry, were fabricated for testing.

Fast Packet Switching

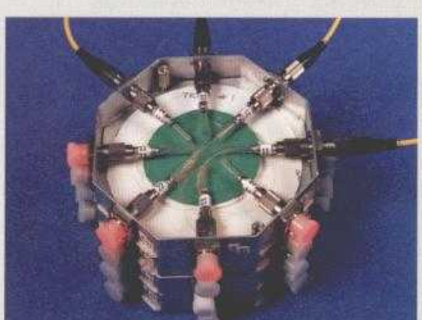
Under NASA sponsorship, NTD investigated a fast packet switching concept (also known as destination-directed packet switching) as an alternative means of switching/routing user traffic on board the satellite. NTD is also examining onboard broadband ISDN fast packet switching architectures for NASA. Under contract, NTD will develop a proof-of-concept fast packet switch, which will be fabricated, tested, and delivered to NASA in 1994. Unique features of the concept design are a switching speed of 155 Mbit/s, accommodation of circuit- and packet-switched traffic, a congestion control mechanism, fault tolerance, monitoring, and measurement of traffic activity.

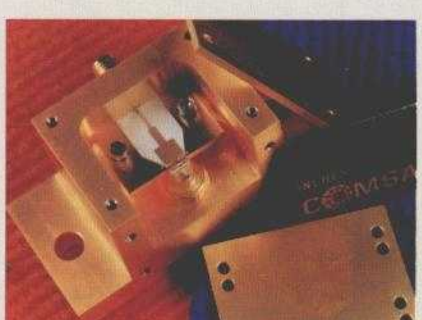
COMSAT Laboratories has also provided technical support in onboard fast packet switching to SS/Loral and SPAR, Canada, for the Canadian Advanced Satcom system, and a review of onboard clock control procedures for the N-STAR system.

Optical Technology for Satellite Networking

Since 1979, optical technology R&D at COMSAT Laboratories has focused on system tradeoff studies and proof-of-concept hardware development. Of specific interest for optical technology are onboard baseband switching, carrier demultiplexing, antenna beam-forming, and intersatellite links. The object of this work is to reduce the mass, power, and size of the onboard processing payload, and subsequently to reduce payload and launch vehicle costs. Application to high-speed switching and multiplexing

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





for ground segment subsystems is also envisioned.

In addition to the baseband switch using the high-speed optical interconnect ring, NTD is working on optical beam-forming for a C-band phased-array antenna, optical processing of frequency-division multiplexed signals in a bulk demultiplexer, and nonlinear optical polymer channel waveguides.

With the support of the Laboratories' Microwave Electronics Division, NTD has developed state-of-the-art nonlinear optical polymer channel waveguide devices (a power splitter, a combiner, and phase shifters) using Hercules, Inc., polymer material for signal distribution and control on board a satellite. Integrated polymer channel waveguides have a low optical loss and high modulation bandwidth. They require very small voltage for electro-optical activity and, most importantly, allow compatible low-temperature processing of optical integrated circuits for monolithic integration with other active devices on semiconductor wafers.

Mobile Satellite Networks

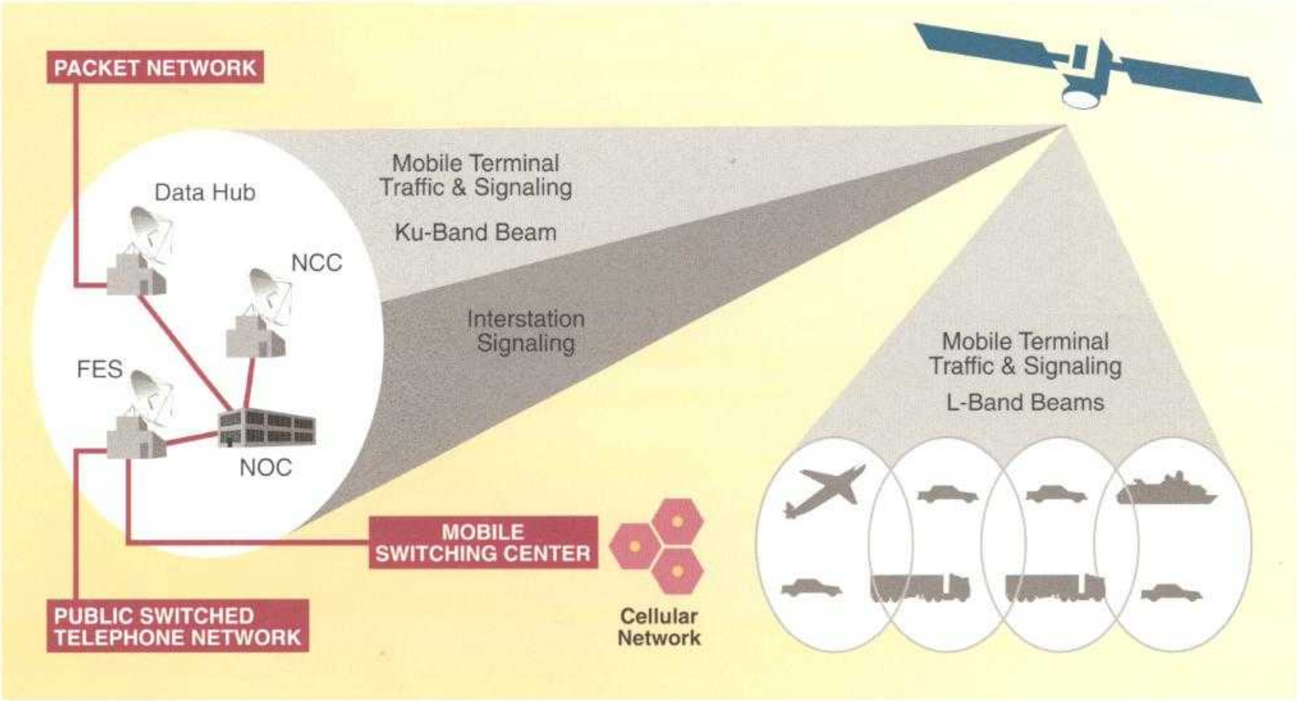
Mobile Satellite Systems

The American Mobile Satellite Corporation (AMSC) and Telesat Mobile, Inc. (TMI), are implementing the North American Mobile Satellite Services (MSS) system, initially using two dedicated satellites, one owned by AMSC and the other by TMI. COMSAT Laboratories designed the ground segment for the new system, including communications channel design, transmission performance, signaling, protocol simulation, maintenance and restoral, echo control, Group 3 facsimile, and ISDN compatibility. A top-level system specification and eight detailed lower level specifications for individual system elements were written, and a system design and cost model were provided. In addition to the MSS system design, NTD developed the design and specification for the mobile data service, which will provide packet data services to mobile terminals. In late 1992, the Labs was selected by the Mexican Institute of Communications, Inc., to conduct ground segment definition studies and write a top-level system specification for a Mexican MSS system.

FlightNews™

In 1992, NTD designed and developed a broadcast communications server (BCS) to support COMSAT Mobile Communications' (CMC's) FlightNews™ service. FlightNews™ will provide constantly updated news text and graphics to long-haul commercial flights via the Inmarsat Aeronautical system.

As the key element in this service, the BCS functions as the interface between news composition workstations and CMC aeronautical ground earth stations (GES's). It is responsible for managing priorities, transmitting



Using the AMSC/TMI MSS system, mobile terminals and feeder-link earth stations (FES's) can access one or more geostationary satellites to provide communications services to land, maritime, and aeronautical users. COMSAT Labs' design includes the Network Control Center (NCC), the Network Operations Center (NOC), the FES's, the data hub, and the mobile terminals.

When incorporated into the transmission path, this satellite-compatible broadband ISDN hardware will allow satellite service providers to meet CCITT performance requirements and will make ATM practicable over satellite links. Here, an NTD engineer tests the ATM link enhancer circuit board.

schedules, and aging news items composed by workstation operators. It also implements the highly optimal, NTD-designed Aeronautical Multicast Messaging Protocol over Inmarsat GES-specific data broadcast signal units, sent via X.25 switched virtual circuits to GES's. The signal units broadcast by the GES's are received by aircraft satellite news units, which regenerate news items in a format suitable for video projection.

Control & Networking for Satellite-Based Handheld Communications Systems

In 1992 the Laboratories performed a study for CMC on geostationary earth orbit (GEO), intermediate circular orbit (ICO), and low earth orbit (LEO) satellite systems for handheld personal communications services. As part of the overall effort, NTD conducted a detailed investigation of associated communications, signaling, and network control concepts for successfully implementing the three scenarios.

Signaling protocols for demand-assigned multiple access (DAMA) were developed, and onboard baseband switching architectures were studied. Control techniques to avoid interference in regions where LEO satellite constellation coverage overlaps were also investigated. The frequency of handoffs for LEO systems was determined, and techniques for making handoff decisions were examined.

Interworking of Satellite & Terrestrial Networks

Broadband ISDN

Widespread deployment of broadband ISDN (BISDN) is expected in the near future. In contrast to circuit-switched paradigms used in the past, BISDN uses a fast packet-switching technique called asynchronous transfer mode (ATM) to provide connection-oriented bearer services for diverse applications such as voice, video, and data. NTD is involved in the design and development of protocols, algorithms, hardware, and software that will enable BISDN to be deployed effectively over satellite links.

Currently, the performance of ATM (*i.e.*, the cell discard probability) is unacceptable over satellite links, given the error characteristics associated with the high link rates used in BISDN. NTD has developed a technique that provides for orders of magnitude of improvement in the performance of satellite-based ATM, and is now developing hardware that implements these ATM link enhancement techniques.

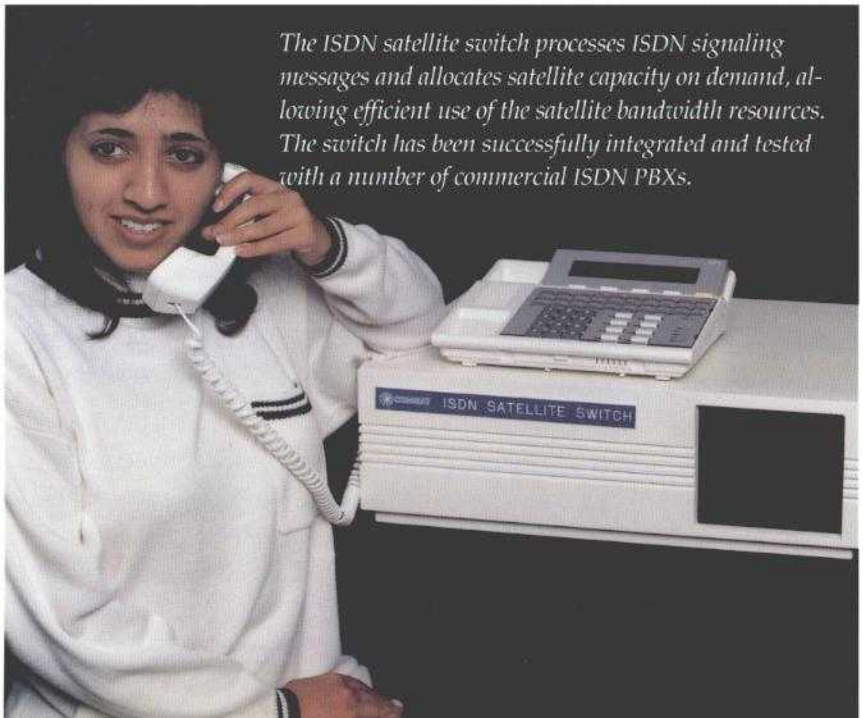
NTD has developed a satellite-efficient Service-Specific Connection-Oriented Protocol (SSCOP), which is currently undergoing standardization in the International Telephone and Telegraph Communications Committee and the American National Standards Institute. This protocol, a sublayer within the ATM adaptation layers (classes 3, 4, and 5), will enable data applications to achieve throughput performance over satellite BISDN which is comparable to that of fiber-based networks.

NTD is also investigating congestion control and call admission control, two issues that are very important for technologies such as ATM which employ statistical multiplexing. The propagation delay associated with satellite links has a significant impact on BISDN congestion control. NTD has developed algorithms that can reduce this impact and effectively control congestion.

Call admission control, which deals with the efficient management of network resources, is also a complex issue for BISDN. Call admission control must take into account the call parameters (average rate, peak rate, and maximum burst size) to meet the various service requirements, while ensuring that the quality of existing calls is not affected. NTD is studying the use of neural network technology for resource management in satellite networks.

ISDN Satellite Switch

The goal of NTD's ISDN satellite switch development program is 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 inherent strengths of the satellite system, namely, its accessibility to a widely dispersed community of users and the multipoint/broadcast nature of satellite communications channels. NTD developed the ISDN satellite switch to demonstrate the feasibility of this integration.



The ISDN satellite switch processes ISDN signaling messages and allocates satellite capacity on demand, allowing efficient use of the satellite bandwidth resources. The switch has been successfully integrated and tested with a number of commercial ISDN PBXs.

The effectiveness of carrying ISDN traffic over satellites was demonstrated through field trials. One such trial, conducted jointly with AT&T, enabled scientists at Corning, N.Y., to conduct project reviews with scientists at St. Petersburg, Russia. The ISDN satellite switch played a key role in allowing AT&T's PBX Definity to work with its Integrated Access Terminal, to provide switched ISDN connections to end users and to optimize satellite resources. A second test was conducted at the Multi-Media Services Showcase (part of the National Institute of Standards and Technology-sponsored TRIP'92), where videoconferencing, personal videoconferencing (workstation to workstation), data, Group IV facsimile, and voice were demonstrated via satellite.

Mobile Satellite/Terrestrial Cellular Interworking

Land-mobile satellite communications is experiencing explosive growth, with second-generation land-mobile satellite systems such as Inmarsat-M being deployed worldwide. These systems can stand alone, or complement terrestrial cellular systems, which typically provide lower cost services in metropolitan areas. Terrestrial cellular systems are not cost-effective in rural areas because the low population density makes the initial cost of setting up such systems uneconomical. Given its larger coverage capability, a land-mobile satellite system can easily serve such areas without additional ground segment equipment. It can also share the traffic when the cellular system is congested. With access to two systems, users of dual-mode terminals can also benefit from increased service availability.

Recognizing the importance of dual-mode operation for land-mobile satellite systems, NTD is investigating various issues related to cellular system interworking. The feasibility of providing call handoff and automatic routing has been investigated. The intersystem operations defined by the U. S. Interim Standard (IS)-41 protocols were analyzed, and potential shortcomings in the standard dealing with call handoff between satellite and land-mobile systems were identified. In the case where the earth station operates in a stand-alone manner within the satellite network, the intersystem operations subsystem includes the home location register and visitor location register databases.

The NTD-developed wide area communications server provides NASA's Jet Propulsion Laboratory with efficient data communications over satellite links. The wide area server enables JPL to collect deep space data over satellites with data throughput comparable to those of fiber optic cables.

Data Communications

With the increasing use of personal computers, workstations, and local area networks, data communications has become one of the fastest growing communications segments. NTD is developing technologies to improve the efficiency of data communications over satellite circuits.

The X.75 protocol converter units developed for INTELSAT provide for the efficient deployment of this protocol (used to interconnect national public data networks) over satellite links. A satellite-efficient protocol which incorporates multiselective repeat error recovery was developed as part of this project. This protocol provides for throughput efficiency greater than 75 percent, even in the presence of degraded link bit error rate (BER) conditions (10^{-5}). The protocol converters also incorporate an advanced multiprocessor architecture that can support multiple X.75 link rates operating at 2.048 Mbit/s.

NTD developed the Wide Area Communications Server (WACS) for NASA's Jet Propulsion Laboratory (JPL) for use in its Deep Space Information Network. The network moves data gathered by tracking stations in California, Australia, and Spain from several NASA probes to JPL in Pasadena, California. The WACS units can use terrestrial or satellite links to connect local area networks that are based on standard networking protocols and implements the COMSAT time sequence protocol to dramatically improve data transfer throughput performance over satellite links. In laboratory tests using transmission control/internet application protocols over a 10^{-6} BER, 1.544-Mbit/s satellite link, the units consistently achieved 85-percent link efficiency, compared with 65-percent efficiency obtained without the WACS.

Q.SAT Protocol

The satellite subnetworks used to link terrestrial networks are not integrated into the Signaling System No. 7 network; instead, they provide semipermanent circuits between international switching centers. For efficient delivery of ISDN services, and increased network efficiency from the sharing of satellite resources, interworking is required between terrestrial ISDNs and satellite subnetworks. A new signaling interface between an international switching center and the satellite subnetwork will fulfill this requirement.

The new interface will make it easier to provide $N \times 64$-kbit/s ISDN connections in a resource-efficient manner (bandwidth on demand within the satellite subnetwork), which is not possible under current configurations. More importantly, it will pave the way for the satellite subnetwork to provide the fiber-equivalent quality of service required for many data applications and Group 4 facsimile carried over ISDN connections.

SDD

SYSTEM DEVELOPMENT

The System Development Division (SDD) provides solutions to engineering problems primarily through the development of software systems and tools. SDD designs systems to allocate communications resources and to monitor and control communications networks. It also develops operations and engineering tools that model and evaluate the architectures and performance of complex communications systems and components, both planned and operational.

SDD's capabilities in software engineering and computer technologies are maintained at a state-of-the-art level by an in-house research program. The staff maintains expertise in essential supporting technologies such as databases, user interfaces, and distributed processing. Division personnel are experienced in using military and industry software life-cycle development methodologies and adhering to standards such as DOD-STD-2167A and IEEE software engineering standards.

SATELLITE TRANSMISSION IMPAIRMENTS PROGRAMS

An area of concern in a large communications system is quality of service. As a system grows more complicated and operates closer to its limits, it is more likely that the quality of the communications links will be compromised. For complex systems, such as the INTELSAT system, transmission planning software is used to ensure that the required quality of service will be met. The INTELSAT 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. The RF bandwidth of each satellite is divided into segments based on the frequency band and beam connection employed to meet traffic requirements. Banks of satellite transponders reuse these frequency segments.

Version 6 of the Satellite Transmission Impairments Program (STRIP6) software is used by INTELSAT to support transmission planning on its satellites. STRIP6 employs transmission impairments 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 STRIP6 for each carrier include thermal noise, interference, and intermodulation. A power optimization analysis determines the carrier power levels necessary to enable the worst carrier in the plan to achieve an acceptable level of performance. This analysis considers both clear-sky and rain-degraded conditions.

Developed by COMSAT 20 years ago, the original version of STRIP was intended to evaluate and optimize frequency-division multiplexing (FDM)/FM carrier performance on INTELSAT IV satellites, but has been enhanced over the years to model characteristics for digital, time-division multiple access (TDMA), and television services on subsequent spacecraft series. Because STRIP6 is nearing the end of its design life, modifications for modeling new spacecraft and services are becoming increasingly difficult and costly. The program requires a long run-time and is difficult to use. During 1992, SDD developed the functional design for a replacement software system, STRIP7.

The STRIP7 effort began with a requirements analysis. A study was made of the capabilities and limitations of STRIP6 and the enhancements required in the new system, as well as INTELSAT's long-term objectives for corporate data management and a distributed computing environment. The basic algorithms and models used in STRIP6 were left largely intact for STRIP7, since they have proven to be reliable and consistent. Additional algorithms were defined for the new program functions.

STRIP7 will use a distributed architecture, in which high-performance computers and data servers communicate with an interactive user interface, which will provide ease of use and immediate, comprehensive diagnostics feedback. The system will include a relational database management system consistent with INTELSAT's shared-data environment.

The entire system will consist of seven independent modules. Five modules will interact to perform STRIP7 analysis, while the sixth and seventh will be executed to maintain the STRIP7 relational database management system. All STRIP7 executables will reside on multiple UNIX processors for efficient workload distribution, with the exception of the user interface and the database administrator interface modules, which will reside on IBM-compatible personal computers (PCs).

All personal computers and UNIX processors will communicate with each other over the INTELSAT local area network (LAN). Interprocess communications will be implemented using sockets and/or remote procedure calls or Structured Query Language queries. Specifications were developed for external interfaces to the system, including interactive users, batch users, and users from other environments at INTELSAT.

SDD expects that the new system will be easy to maintain and enhance, while providing greatly improved performance over STRIP6, with new analysis and diagnostic capabilities. The proposed STRIP7 system is scheduled for implementation in mid-1993.

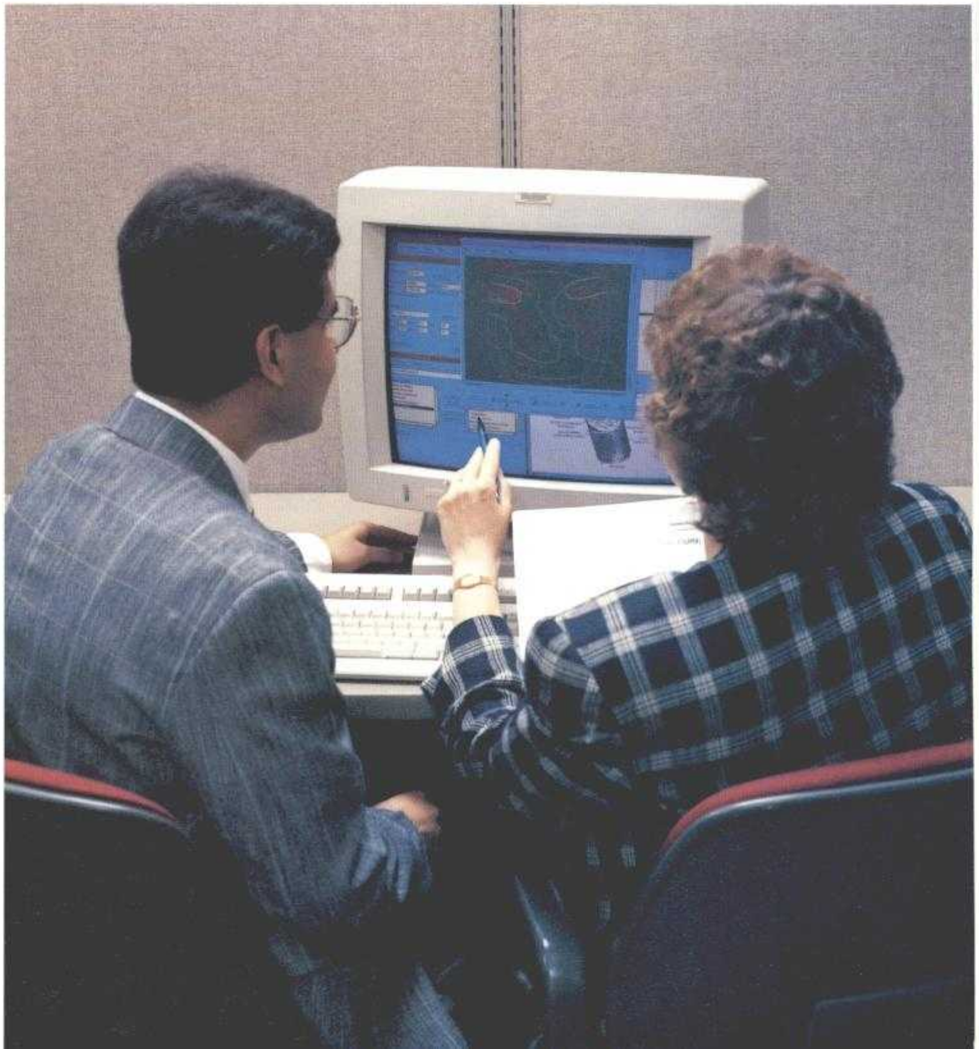
Engineering Workbenches

Large international communications networks such as those of INTELSAT and Inmarsat are very complicated systems. In order to use the systems effectively and serve as signatory to the organizations, COMSAT must have ready access to the operating characteristics of each system. This availability is provided by analysis tools called engineering workbenches.

The COMSAT World Systems (CWS) Workbench developed by SDD provides a common, interactive user interface to the CWS Relational Database Management Facility (a technical database of INTELSAT satellite system and earth station parameters) and to several analysis programs and functions developed for CWS by the Division's Systems Analysis Software Department. The software runs under the Ultrix operating system on engineering workstations, and uses the X Window System, the Open Software Foundation (OSF)/Motif, and COMSAT's AXIS development environment.

The workbench includes the ability to view and prepare reports of 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, a user can sort, rearrange, or delete columns from it. Moreover, the reporting facility has been enhanced to allow report results to be plotted on a world

Systems analysis software engineers review the new features of the CWS Workbench. The screen display includes the earth station report generator, the mapping facility, and a scanned block diagram.



map. For example, a user can retrieve all the U.S. Standard A antennas from the database, then click a button to plot them on a world map. The layout and contents of the map are also 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 were recently added to the mapping feature. After a user specifies an INTELSAT satellite location, the workbench displays a list of antenna beam patterns available for that satellite. Uplink or downlink contours may be plotted for one or more antenna beams.

The CWS Workbench expansion also includes three separate "calculators." The first computes look angles for a given satellite location and a given point on the earth. A user can select INTELSAT satellite and earth station data from the database, or enter non-INTELSAT values. The second calculator converts a point of latitude and longitude stored in degrees, minutes, and seconds to decimal values, and vice versa, and the third converts a point in earth coordinates to satellite-centered coordinates, and vice versa.

The COMSAT Mobile Communications (CMC) Workbench is similar to the CWS Workbench—they share the same mapping, calculator, and data viewing and reporting features. However, the CMC Workbench retrieves data from the Mobile System Database—a technical database of Inmarsat satellite system, land earth station, and mobile terminal parameters.

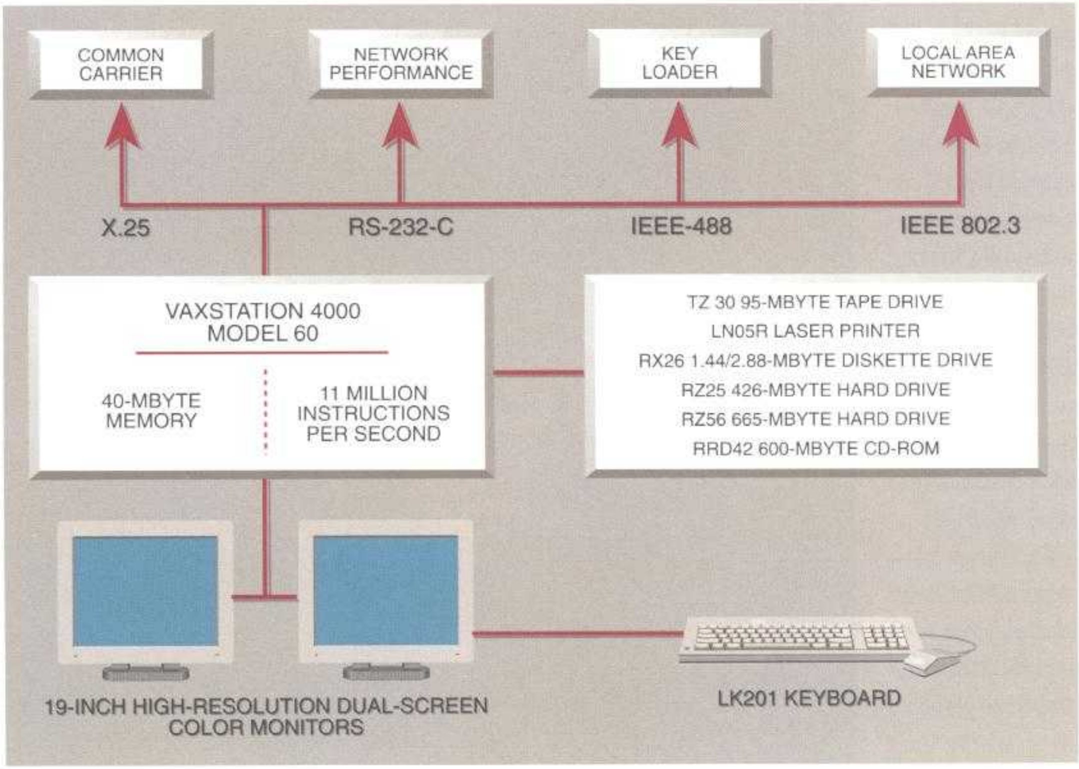
Recent expansion of the CMC Workbench allows the viewing and reporting of Inmarsat signatory and Inmarsat-A and -C terminal distribution data. With the addition of a feature for viewing block diagrams of Inmarsat system components, a user can display and print an image that has been scanned into the workbench.

Both workbenches are continually being improved with new features and updated system data. Items such as mobile terminal data for the Inmarsat system will be added, and link budget calculations will soon be available in each workbench.

Universal Modem System

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 intracorporate lines of business.

The Division is currently designing a planning, monitoring, and control facility—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 will provide scenario definition, resource allocation, monitoring, data-



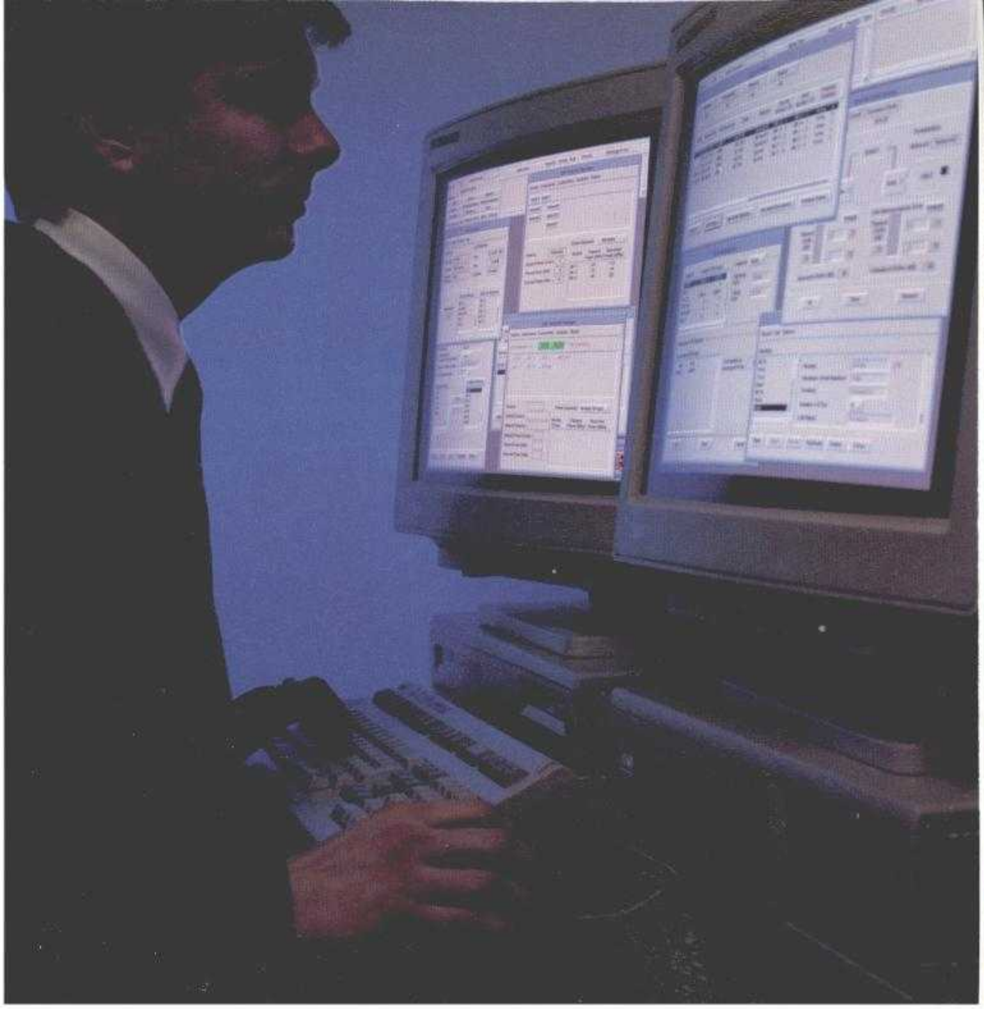
Block diagram of the Interim System Planning Computer for the U.S. Army's Universal Modem System.

base 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 the UMS development.

ISPC FUNCTIONS

The ISPC will operate 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 UMs 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.



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

- Emulates the operator interface units for collocated UMs.

The ISPC hardware includes dual screens controlled from a single keyboard and mouse, and uses the VMS operating system. The ISPC source code is being written in the Ada programming language, and the software development process conforms to the requirements of Department of Defense Standard DOD-STD-2167A.

ISPC OPERATOR INTERFACE

The operator interface under development 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.

A prototype ISPC operator interface developed using the advanced features of the AXIS user interface development environment was used to demonstrate ISPC system capabilities to Magnavox. It was also evaluated by human factors engineers and end users. Their combined feedback will form the basis for system revisions. SDD's capability for rapid prototyping will result in the design and implementation of a higher quality product for Magnavox and the U.S. Army.

ISPC RELATIONAL DATABASE

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; plus, an operator can 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 primarily by the UM to predict earth-terminal-to-satellite range and Doppler effects for up to 36 days into the future. These 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.

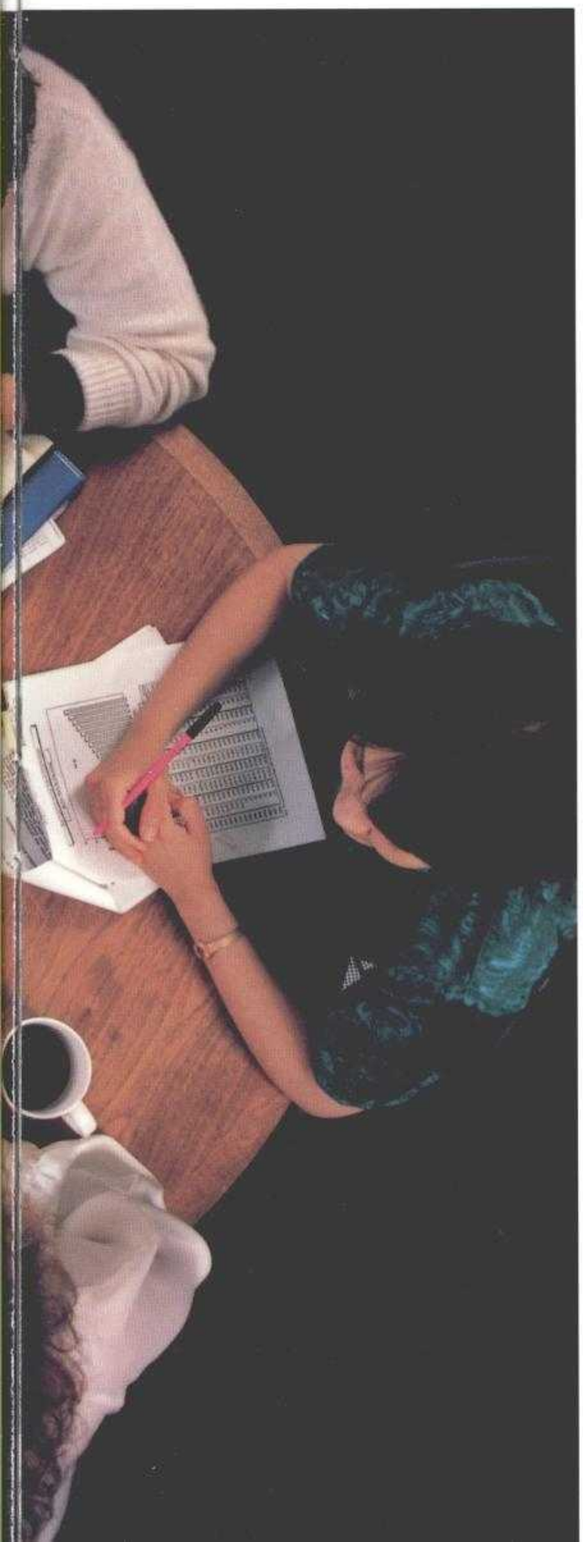
The output of this process is a table of Keplerian orbital parameter sets for the period—one set for each day. Each set defines an elliptical Keplerian orbit obtained by a least-squares error fit of the precision state vectors generated for that day to the simpler two-body model of the UM. One such Keplerian parameter will allow the UM 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 UM 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

SDD's Database Team for the Universal Modem System project reviews relational database triggers to ensure referential data integrity.

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 (CIA), which approximates transponder 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 rate (BER), which determines the minimum energy-per-bit to noise-power density ratio (E_b/N_0) required at the receive terminal. From this, the carrier-to-noise ratio (C/N) needed at the receive terminal for each circuit in the UM network can be determined. These C/N's can then be used to establish the satellite transponder input powers required for satisfactory circuit performance.

AXIS User Interface Development Environment

In addition to developing software tools for solving engineering problems, SDD pursues an active research program that investigates new software engineering principles and computer technology.

AXIS, COMSAT's user interface development environment (UIDE), was enhanced during 1992 with an Ada binding for use on VMS. Binding the C language toolkit with Ada required a revised AXIS architecture, and the result was a nearly identical interface across both languages. SDD also refined the AXIS Toolkit and rapid prototyping tools.

Object-Oriented Software

As part of its overall strategy of establishing reusable libraries, SDD is developing a reusable object class library for use in all C++ software development. This library combines enhanced public domain classes with in-house-developed software to create an American National Standards Institute (ANSI) standard class library that will enhance the productivity of object-oriented software development projects.

Graphics & Visualization

During the past year, SDD began developing GRAXIS, a graphics package that supports general two- and three-dimensional (2D and 3D) graphics, visualization, and user interaction tools. GRAXIS will complement AXIS with complex graphic tools; flexible, high-performance and highly portable graphics capabilities; and an object-oriented graphics library.

The keystone of GRAXIS is the specification of an object-oriented application programmer interface (API) for generating 2D and 3D interactive graphics. A graphics library based on this API will be implemented using C++ and the reusable object class library.

A commercial off-the-shelf graphics library serves as the rendering layer under the object-oriented API, providing the basis for the development of more functions. A separate driver to the rendering layer will be written, so that different libraries can be used if necessary.

With the development of an inhouse, object-oriented API, SDD's graphics tools will be portable to any platform—a PC or high-end workstation. The API layer will be independent of both the underlying graphics drivers and the underlying rendering library routines. This three-tiered system, used in the leading commercial packages, allows for true portability.

Next year, SDD plans to develop interaction and visualization tools using AXIS and GRAXIS. These tools will include an interactive mapping facility, as well as interactive charting and plotting applications.

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The cover design is based on a photograph taken during an experiment to grow thin layers of unsupported silicon dioxide of a known area. A silicon wafer was oxidized to the required thickness, and the wafer was etched selectively and anisotropically from the side opposite the oxide layer. Immediately before the last of the supporting silicon was etched, it was thin enough to transmit the red portion of white light.