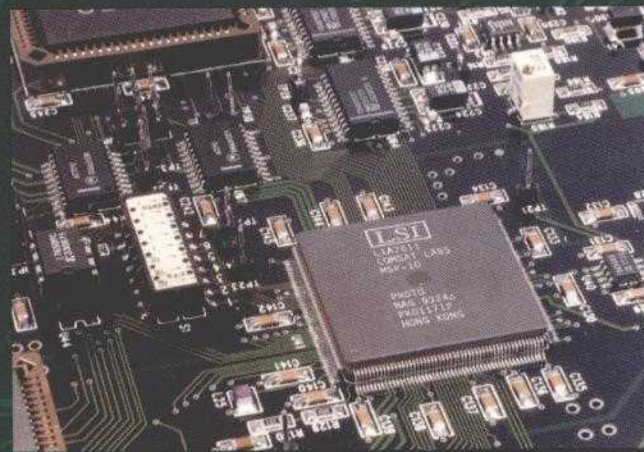

COMSAT Laboratories

Annual Review 1993

Contents

***On the Cover**: The COMSAT MSP-10 modem application-specific integrated circuit (ASIC) was developed by COMSAT Laboratories' Communications Technology Division. The ASIC is housed in a surface-mount 208-pin quad flat-pack package which requires approximately 9 cm² of circuit board space, making it ideal for incorporation into small, low-cost satcom modem products.*

The MSP-10 represents a significant advance in digital modem technology for transmission rates up to 10 Msymbol/s. Incorporated into this device are all of the primary transmit and receive baseband functions of a digital phase-shift keying modem, as well as circuits for receive carrier and clock generation and transmit clock synthesis. Key to the design are COMSAT-patented techniques for phase-locked loop carrier and clock recovery processing, and receive finite impulse response implementation.

Other modem products currently under development at COMSAT Laboratories include a multicarrier demodulator ASIC and a high-speed (150-MHz clock rate) multiplier-accumulator ASIC for use in high-speed modem implementations.

COMSAT Laboratories is now in its 26th year of conducting basic research and development to advance satellite communications technology. This eleventh in a series of annual reviews summarizes our R&D activities during 1993. Portions of this effort were funded by COMSAT World Systems and paid for with revenues derived from international communications services carried via the International Telecommunications Satellite Organization (INTELSAT) satellite network, and by COMSAT Mobile Communications and paid for with revenues derived from international communications services carried via the Inmarsat satellite network. Work conducted for COMSAT World Systems and COMSAT Mobile Communications that is not paid for with such funds, and work conducted on behalf of other elements of the corporation—COMSAT Video Enterprises and COMSAT Technology Services—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 publication of Labs papers and reports.*

In 1993, the operating expenses for COMSAT Laboratories totaled $38 million. Revenue sources outside the Corporation accounted for 46 percent of the total, with the Army, NASA, INTELSAT, and Inmarsat being our largest regular customers. Some of this work was undertaken as a subcontractor to other organizations with whom the Labs is allied. Development and support funding (35 percent of the total) was directed to nearer-term applications, and projects were undertaken by the Laboratories on a contract-like basis with the various lines of business of the Corporation. Technical support addressed immediate operational concerns. The balance of the funding (19 percent) went to various research programs to advance technology, with the goal of improving communications systems cost and performance over the long term.

The structure of COMSAT Laboratories changed in 1993 with the sale of the Microwave Electronics Division to AMP, Inc. This new subsidiary of AMP is called Microwave Signal, Inc. (MiSig), and is collocated with COMSAT Laboratories at our Clarksburg, Maryland, facility. Close cooperation with MiSig is anticipated for current and future programs.

The capabilities and products of COMSAT Laboratories are available to both commercial and government enterprises. The Labs supplies hardware for highly specialized applications and emphasizes the transitioning of Laboratories-developed technology to the marketplace. We invite further inquiry, and have provided contact information on the inside back cover of this Review.

J. V. Evans

John V. Evans
President, COMSAT Laboratories

The Laboratories Today

COMSAT Corporation was created in 1963 following passage of the Communications Satellite Act, signed into law by President Kennedy in late 1962. When the International Telecommunications Satellite Consortium (INTELSAT) was established in 1964 to facilitate international communications between fixed points by satellite, COMSAT was named its U.S. Signatory. Initially, INTELSAT had 11 participants. This number has since grown to 133 member countries, and the organization currently provides service to 200 nations.

COMSAT also served as technical manager of INTELSAT from its inception until 1979. To help meet the challenges associated with this role, COMSAT Laboratories was formed in 1967. Initially located in Washington, D.C., the Laboratories moved to its present quarters in Clarksburg, Maryland, in 1969. The Laboratories occupies approximately one-third of a 360,000 square foot facility on a 230-acre tract along Interstate 270, about 35 miles north of Washington.

The Corporation in 1993 comprised four separate operating divisions. COMSAT World Systems (CWS) serves as U.S. Signatory to INTELSAT, COMSAT Mobile Communications (CMC) serves as U.S. Signatory to Inmarsat, and COMSAT Video Enterprises (CVE) provides entertainment and guest services to hotels, and also owns the Denver Nuggets basketball team. The fourth division, COMSAT Technology Services (CTS), was formed in 1992 to offer private satellite communications systems and services, placing increased emphasis on transitioning Laboratories technology to profitable business applications. In June 1994, COMSAT acquired Radiation Systems, Inc., of Sterling, Virginia, which was merged with CTS to form COMSAT RSI.

COMSAT Laboratories is the central R&D organization for all four operating divisions. Overseeing the R&D activities of the Laboratories and other corporate entities and related business concerns is the Committee on Research and International Matters (RIM), one of five standing committees of COMSAT's Board of Directors. The

Melvin R. Laird
Chairman of the Board
COMSAT Corporation

John V. Evans
President
COMSAT Laboratories

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President & CEO
COMSAT Corporation

RIM Committee considers and makes recommendations to the Board on matters relating to the Corporation's international activities and responsibilities under the Satellite Act, INTELSAT, and Inmarsat, and its relationships with other international bodies, foreign governments, and entities.

In 1993, nearly half of the work performed at COMSAT Laboratories was won through outside competitive bidding. Major customers included the U.S. Army, U.S. Air Force, NASA, INTELSAT, and Inmarsat. The balance of the Laboratories' work is performed for internal proprietary programs or for the regulated activity of international communications, either directly or indirectly via INTELSAT and Inmarsat. This work is directed toward solving operational problems, participating in standards creation, and developing future systems and services.

The significance of COMSAT's pioneering contributions to the global reach of satellite technology was affirmed in 1993 when the National Broadcasting Association presented an Emmy Award to COMSAT and several current and former Laboratories employees for "outstanding achievement in the science of television technology" (see p. 40).

The Laboratories consists of four divisions: Communications Technology (CTD), Network Technology (NTD), Satellite and Systems Technologies (SSTD), and System Development (SDD). This Review summarizes the Laboratories' research, development, and applications activities for 1993. It is organized by areas of technology, as represented by the four divisions.

In this new era of telecommunications deregulation and intense competitive pressure, there is increasing interest in reducing the time lag from the conception of new ideas to their field application. In response, COMSAT Labs is focusing its energies on this objective. New products, applications, and activities that form the basis for future products are described in this Review. For additional product information, or teaming or license opportunities, contact the experts listed on the inside back cover . . . *join us in building global communications for tomorrow!*

Chairman of the Board

President & CEO

COMSAT Mobile Communications

COMSAT Video Enterprises

COMSAT World Systems

COMSAT Technology Services

COMSAT Laboratories

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C. E. Mahle, Executive Director

Communications Technology Division
R. J. F. Fang, Executive Director

Network Technology Division
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System Development Division
W. L. Cook, Executive Director

RIM Committee








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Lucy Wilson Benson

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THE SATELLITE AND SYSTEMS TECHNOLOGIES DIVISION (SSTD) CONDUCTS RESEARCH AND DEVELOPMENT, SYSTEMS ENGINEERING, AND ANALYSIS ON A VARIETY OF SATELLITE COMMUNICATIONS TECHNOLOGIES, AND PRODUCES SPACE-QUALIFIED HARDWARE. ■ DIVISION WORK ENCOMPASSES NEXT-GENERATION SATELLITE SYSTEMS; MULTI-BEAM ANTENNAS AND ON-BOARD RF PROCESSING HARDWARE; REPEATER SUB-SYSTEMS, ANTENNA FEEDS, AND COMPONENTS; POWER, COMMAND/CONTROL, THERMAL, AND MECHANICAL SUB-SYSTEMS; AND PROPAGATION STUDIES. ■ SSTD ALSO DESIGNS AND INSTALLS TURN-KEY SYSTEMS FOR IN-ORBIT TESTING AND SYSTEM PERFORMANCE MONITORING. ■ 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 THROUGH FINAL PRODUCT REALIZATION. ■ SUCH BROAD INVOLVEMENT IN SATELLITE SYSTEMS AND HARDWARE PROVIDES THE FOUNDATION FOR THE MANY SYSTEM STUDIES SSTD CONDUCTS AND THE CONSULTING SERVICES IT OFFERS.

ANTENNAS

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

EARTH STATION ANTENNAS

In 1993, SSTD completed work on the Automated Antenna Verification (AAV) system, which is used for the accurate and efficient testing of a wide variety of earth station antennas. The system is computer-controlled, with a spectrum analyzer, a power meter, and a synthesized signal generator as the primary measurement equipment. Parameters measured include radiation patterns, directive gain, low-noise amplifier (LNA) noise temperature, antenna and system temperature profiles, gain-to-noise temperature ratio (G/T), return loss, and insertion loss. The AAV system also calculates pointing information for satellites and ephemeris data for radio stars and the moon. The ability of the system to measure swept frequency noise temperature is particularly useful in accurately characterizing antennas and LNAs.

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

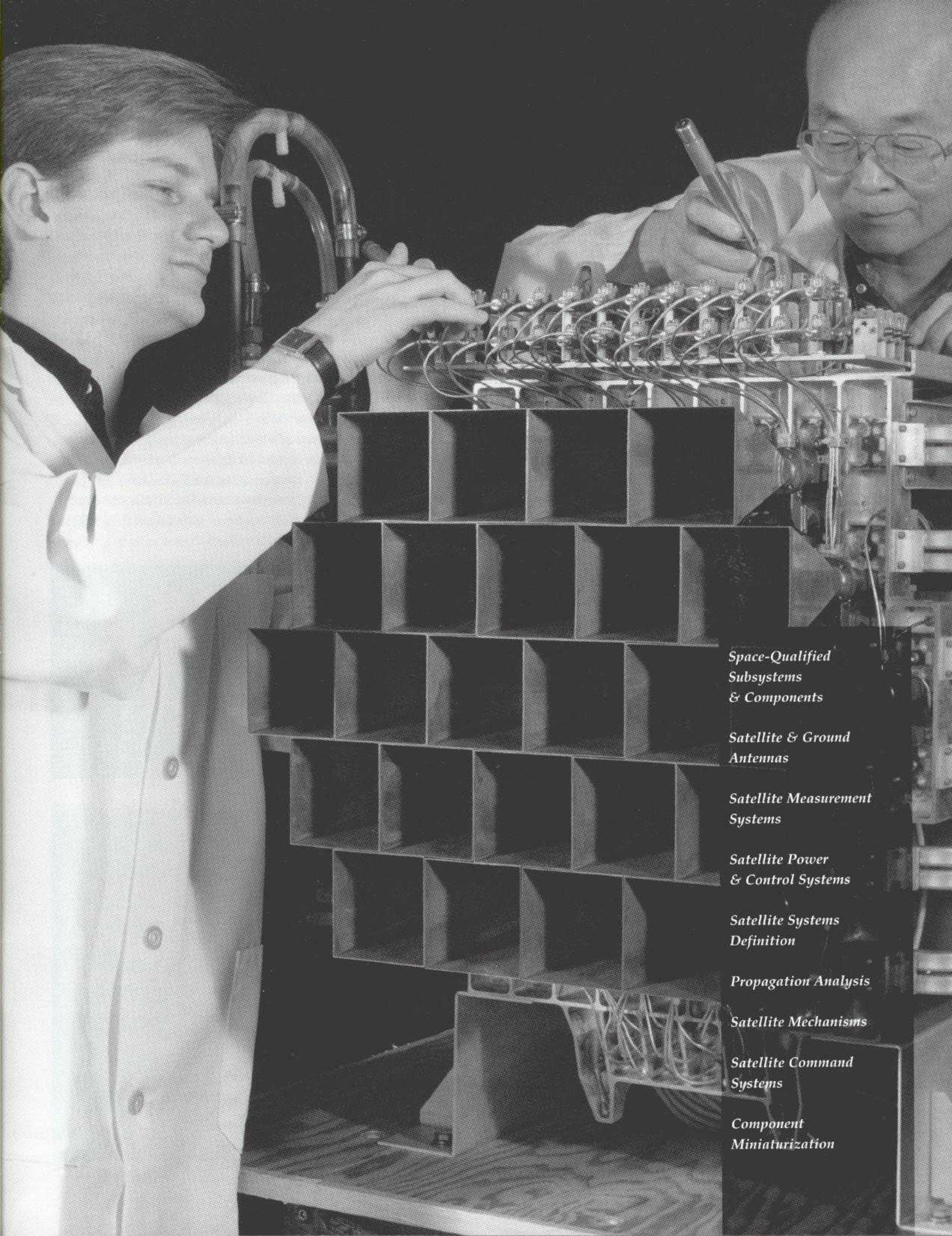
In 1993, AT&T contracted with COMSAT Laboratories to modify the Lenox, West Virginia, 19-m earth station antenna to dual (C- and Ku-) band operation. This was part of a major upgrade of the earth station which will enable it to offer emergency restoration of service. A four-band, corrugated-wall feed horn is being custom-designed for the Lenox antenna. Also, the subreflector will be replaced by a new design to convert the optical system from the present beam waveguide geometry to a standard Cassegrain feed geometry. The feed, which is scheduled to be installed and tested at Lenox in 1994, will make the station compatible with both INTELSAT Standard A and C earth station antenna specifications.

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

SATELLITE ANTENNAS

SSTD has recently completed the integration, calibration, and performance testing of a Ku-band high-power multibeam phased array. The four-beam, 24-element array includes 24 radiating waveguide horns, 24 2-W solid-state power amplifiers (SSPAs), and a 4 x 24 beam-forming matrix (BFM) with 96 monolithic microwave integrated circuit (MMIC) phase shifters. The calibration provides extensive characterization and optimization of the 4 x 24 BFM, the SSPAs, and the cable interface between the BFM and the SSPAs. Comprehensive software tools developed at COMSAT were used in system simulations to develop predictions of third-

Right: In SSTD's Satellite Antenna Department, final adjustments are made to the prototype Ku-band 24-element phased array prior to performance testing.



Space-Qualified Subsystems & Components

Satellite & Ground Antennas

Satellite Measurement Systems

Satellite Power & Control Systems

Satellite Systems Definition

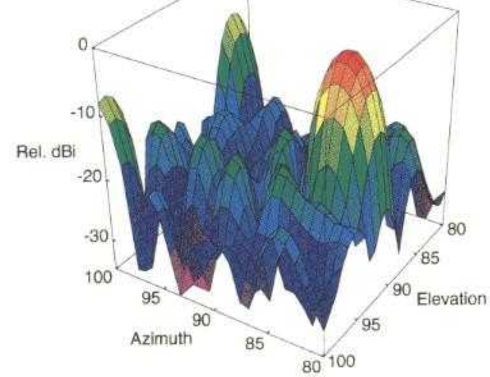
Propagation Analysis

Satellite Mechanisms

Satellite Command Systems

Component Miniaturization

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



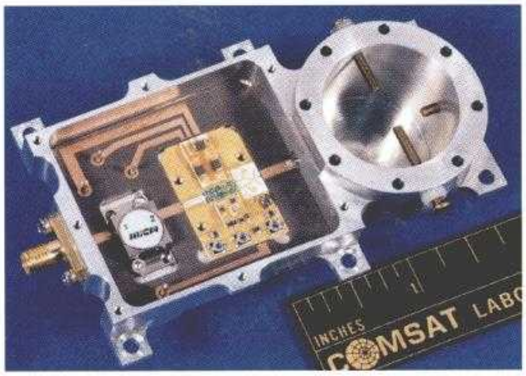
order intermodulation product beam levels and locations in multicarrier situations.

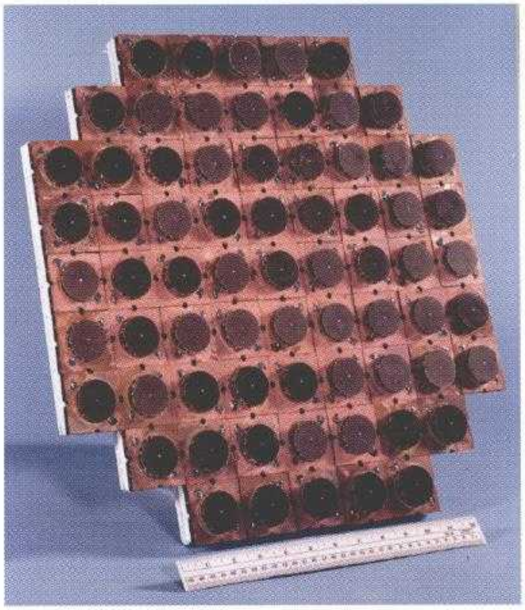
As part of a program supported by the U.S. Government, SSTD is developing an active, multiple-beam antenna that meets the requirements of future Defense Satellite Communication System (DSCS) networks. The goal of this effort is to demonstrate the feasibility of active phased arrays by building and testing a prototype of an X-band phased array. The transmit phased array is part of a satellite that provides multiple coverages which can be reconfigured dynamically to meet changing traffic demands. The antenna simultaneously generates four beams of variable shapes, with sizes ranging from 2° to full earth coverage.

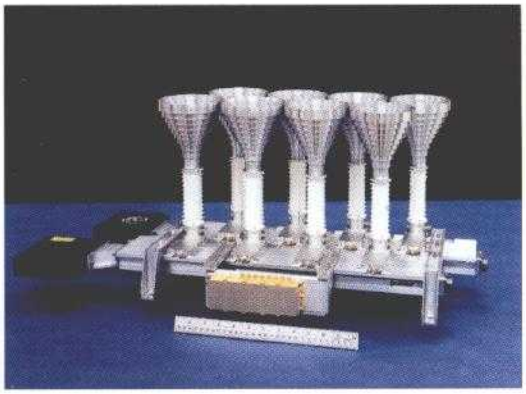
To demonstrate the technology involved, an eight-element subarray was developed and built as a model of the full-scale phased array. The scalar ring horns and pin polarizers provide radiation patterns with excellent polarization purity over the complete coverage area. A 2-W SSPA in an integrated housing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

A two-beam, eight-output BFM was also designed and fabricated for the X-band program. The design was implemented in a highly modular fashion to facilitate both fabrication and modification. The use of 5-bit MMIC phase shifters and attenuators behind each array element permits control of excitation coefficients, providing the flexibility to synthesize a wide variety of radiation patterns for many types of coverage. By incorporating MMIC technology in the BFM, components can be manufactured with a high degree of uniformity. Consequently, beam patterns can be synthesized with a high degree of confidence. The phase shifters are fabricated as switched lines, implemented in printed coplanar waveguide, to give the true time-delay beam steering required in wideband applications.

Another active antenna program involves the design and fabrication of a 69-element C-band phased array for INTELSAT applications, to permit dynamic synthesis of beam coverages. Two sets of redundant 2-W SSPAs







Left: The high polarization purity of the elements in the X-band array makes it suitable for dual-polarization applications. ***Above right:*** *The 2-W SSPA used for the X-band phased array.* ***Right:*** *The C-band phased array employs lightweight printed-circuit technology for its antenna elements.*

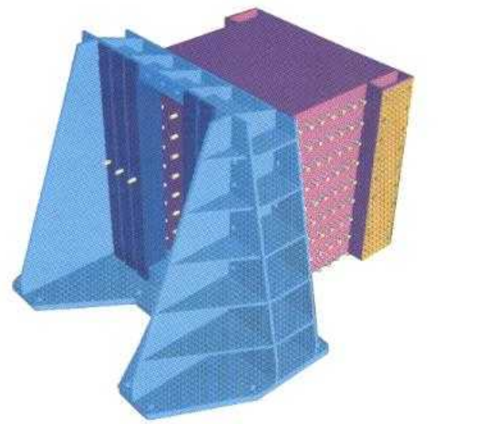
are incorporated behind each element to produce both left- and right-hand circular polarizations with high purity. Each sense of polarization receives signals from a separate BFM, which is designed to produce a total of eight beams with 5-bit phase and amplitude control for each array element. The beams are reconfigurable to provide the various coverages required for INTELSAT satellites.

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

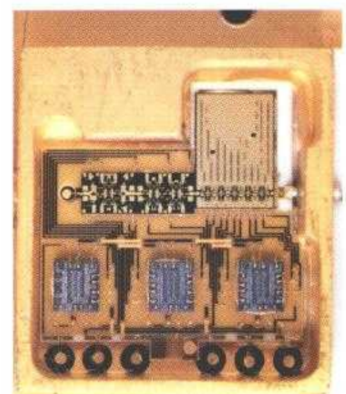
Each SSPA is coupled to a microstrip patch radiating element in the overall module assembly. Other components include isolators, a gain block amplifier, signal monitoring circuitry, and a bias distribution network. As many as nine SSPA modules are assembled on a single chassis to form a linear antenna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

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

A series of measurement programs was performed for INTELSAT using the INTELSAT VII and VIII prototype and flight hardware. The components measured were the INTELSAT VII C-spot feed, the INTELSAT VII transmit and receive hemi/zone arrays, and an engineering prototype of the INTELSAT VIII transmit hemi/zone array. The polarization isolation of the hemi/zone horn element embedded in the array environment was of particular interest. The element was first evaluated by itself, and then within the array environment. Factors contributing to cross-polarization error were identified and quantified.



Left: The modular architecture of the BFM can accommodate various beam configurations at different frequencies with only minor redesign. ***Below:*** *The most basic building block in the BFM is the MMIC package, containing the 5-bit MMIC phase shifter, the 2- and 3-bit MMIC attenuators, and three digital control integrated circuits. The package was designed to minimize size and mass, yet provide a rugged, hermetically sealed environment for the BFM electronics.*



Payload Components & Testing

The payload of a spacecraft contains the components that support its communications-carrying functions (as opposed to its housekeeping functions). Because the spacecraft is not accessible for repair in geosynchronous orbit, payload components must perform reliably for about 15 years. SSTD works to develop highly reliable components with optimum performance characteristics, and to design techniques for testing payload elements in orbit. Each ounce of satellite mass placed in orbit is very expensive; consequently, reducing the size and mass of satellite transponders, subsystems, and components is crucial to decreasing overall subsystem integration and spacecraft launch costs.

Microwave Components

COMSAT has completed a contract with Alcatel Espace to deliver 80 MMIC, Ku-band, 1-W SSPA modules for a communications satellite phased-array antenna program. The performance uniformity required among all modules of the active array necessitated custom, process-insensitive MMIC designs with DC and RF on-wafer test capability. A computer-controlled system was developed for efficient small- and large-signal module-level RF measurement and data acquisition for each amplifier. The gain flatness for each SSPA module is within ±0.5 dB across a

2-GHz band (within a 2-dB window). Other key performance parameters are a peak PAE of 30 percent and C/I linearity greater than 15 dB, which are crucial to successful operation in a multicarrier communications environment.

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

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

SSTD is investigating the failure mechanism in order to recommend a safe operating condition and to develop a cost-effective screening procedure. It has been determined that the failure is caused by reverse breakdown of the field-effect transistor (FET) Schottky barrier gate under large RF overdrive. In addition, SSTD has developed a large-signal model to predict the instantaneous gate-drain voltage and breakdown current as a function of RF overdrive.

The mass and volume of future satellite payload hardware will be significantly reduced by replacing a large number of the electromechanical switches, used for redundancy and signal routing, with electronic switches. Currently under development in SSTD are highly reliable, lightweight switches with low-loss connectivity and electronic redundancy for onboard satellite applications. The goal is to develop broadband, low-loss redundancy switch configurations and static switch matrices for the C- and Ku-bands, employing passive FETs and MMIC technology. The use of technology that is compatible with hardware on board high-capacity multibeam satellites will reduce hardware interface problems. Development of low-loss switches will also provide redundancy for LNA outputs and SSPA inputs.

SSTD's diplexer is a key enabling technology for miniaturizing Standard M terminals and making available a low-cost, portable, mobile satellite service terminal.

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

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

A miniature diplexer is being developed for COMSAT Mobile Communications (CMC). The diplexer uses state-of-the-art miniature ceramic resonators with high Q to provide low insertion loss within a small volume. An innovative filter circuit was successfully implemented in a PCB, which permits large-quantity reproduction at reduced cost. The final diplexer volume is expected to be more than one order of magnitude smaller than the diplexer previously employed. SSTD's diplexer is considered a key enabling technology for miniaturizing Standard M terminals and making available a low-cost, portable, mobile satellite service terminal.

Under a follow-on contract with Alenia Spazio, SSTD has designed, fabricated, and delivered a second in-orbit test transponder (IOTT2), which is to be mounted on the ITALSAT F2 multibeam spacecraft. IOTT1 was part of the ITALSAT F1 spacecraft launched in January 1991. It is still in use and contains what is believed to be the first MMIC circuitry ever launched on a communications satellite.

The onboard IOTT has performed successfully in space. Typical spacecraft tests are conducted by transmitting a 30-GHz signal from an earth station and detecting the received 20-GHz signal. The tests include flux density, effective isotropically radiated power (EIRP), traveling wave tube amplifier (TWTA) transfer characteristics, and transponder linear gain.

The IOTT incorporates MMIC Ku-band amplifiers, lightweight waveguide Ku-band filters, and electronic power control and combined IOTT telemetry/control circuitry, all designed and fabricated by COMSAT Laboratories. It bypasses the onboard regenerator and connects the input sections of the TWTAs, thereby converting the ITALSAT digital payload into transparent analog transponders and allowing full characterization of the transponders.

IOT Measurement Techniques & Systems

Transponders on communications satellites must be tested following successful launch but prior to entering revenue-generating service. For more than 20 years, SSTD has pioneered computer-controlled in-orbit test (IOT) measurement techniques, and has designed, assembled, and installed automated IOT systems for numerous satellite operators, including INTELSAT, GTE, SBS, EUTELSAT, and Hughes.

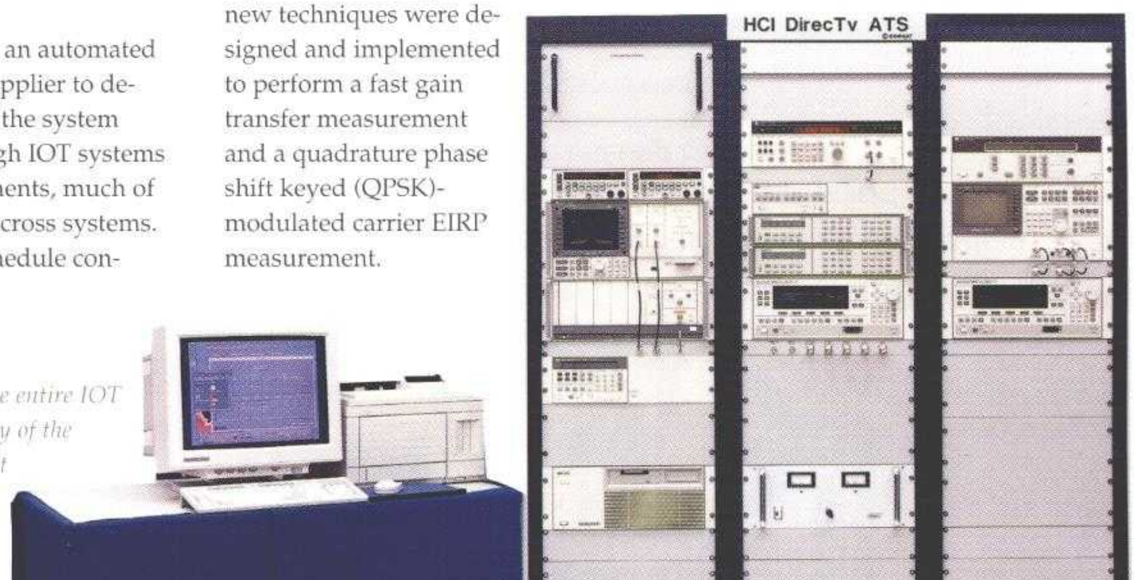
Satellite operators procuring an automated IOT system often require the supplier to design, fabricate, test, and deliver the system against tight schedules. Although IOT systems must satisfy customer requirements, much of their functionality is common across systems. To accommodate operators' schedule constraints and avoid costly and time-consuming custom software development, SSTD has focused on building an engineered platform of integrated software that is highly reusable from one IOT system to another. Reusing and leveraging existing, field-tested, modular software building blocks results in decreased cost and time to deployment and facilitates the development of turnkey systems.

The effectiveness of this approach was demonstrated during 1993 when SSTD designed, assembled, integrated, installed, and tested a state-of-the-art automated IOT facility for Hughes Communications for use in testing its DirecTV™ direct broadcast satellite.

The Automated Test System (ATS) performs a large suite of standard IOT measurements, as well as some new tests. The operator controls measurement parameters through graphic windows on a bit-mapped color display. With their mouse-oriented, point-and-click interactive methodology, the user interface windows are easy to use and operationally flexible. The IOT software executes on a high-performance engineering workstation with a UNIX operating system that supports multiuser/multitasking operation and remote control of the IOT equipment over local and wide area networks.

SSTD is continually enhancing computer-controlled microwave measurement techniques to support the increasing sophistication of satellite operators and required system capabilities. During 1993, new techniques were designed and implemented to perform a fast gain transfer measurement and a quadrature phase shift keyed (QPSK)-modulated carrier EIRP measurement.

Automated in-orbit tests are performed to determine the post-launch service readiness of a communications satellite, to investigate anomalous behavior, and to monitor communications performance during the satellite's lifetime.



Contracted in early spring 1993, the entire IOT system, including in-house assembly of the microwave and computer equipment and integration with the system control and measurement software, was delivered to Hughes before year-end. The engineered platform of reusable software components allowed SSTD to meet its customer's challenging schedule.

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. SSTD maintains expertise in these diverse disciplines to support advances in these technologies and maximize the performance of in-orbit subsystems. This expertise is readily available to INTELSAT and Inmarsat, and is marketed to organizations such as NASA, the Department of Defense (DOD), and spacecraft prime contractors.

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

Optical Properties of Spacecraft Components

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

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

SSTD's new optical measurement technique is expected to . . . benefit future programs by enabling component and spacecraft manufacturers to more accurately evaluate new products during their development and integration into spacecraft designs.

A second problem also involved new coatings and materials that were being tested to reduce solar absorption in solar cell coverslides. While the measurements were made with incident light close to perpendicular, no appropriate reflectance standards were available to provide the required accuracy. In addition, absorption values were very low, approaching the limits of reproducibility. The solution to the oblique-angle measurement problem also provided the answer to the coverslide problem. SSTD's new double-reflection technique permitted the absolute measurement of reflectance without the need for a comparison standard. Furthermore, the two reflections doubled the sensitivity of the measurement and reduced the effect of systematic errors associated with low absorptance values.

These measurements have been important in determining the use of new components in both INTELSAT and Inmarsat programs. SSTD's new optical measurement technique is expected to be universally accepted and thereby benefit future programs by enabling component and spacecraft manufacturers to more accurately evaluate new products during their development and integration into spacecraft designs.

In addition to the optical measurement of OSRs and solar cells, SSTD provides full electrical characterization for solar cells. Absolute solar intensity calibration is ensured by using primary standard cells that have flown on high-altitude balloons and higher altitude rockets, so that measurements can be conducted in sunlight beyond more than 98 percent of the earth's atmosphere. An unusually well-collimated and optically matched solar simulator uses these standard cells to set the output intensity for the level of sunlight in geostationary orbit. Solar cells exposed to this illumination will respond exactly as they would initially in space. However, in space they would be damaged by the radiation and solar ultraviolet light to which they are exposed.

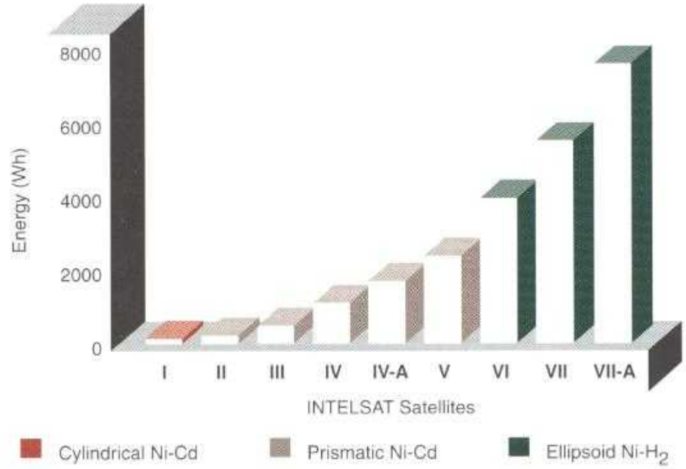
Most testing of environmental damage requires only relative measurements to determine the percent of degradation in material or electrical properties. However, reproducibility and a well-characterized environment are critical, since some of the effects observed are small.

Electrochemical Battery Development

Nickel-cadmium (Ni-Cd) and nickel-hydrogen (Ni-H_2) battery technologies continue to be subjects of intense scrutiny. The size and sophistication of satellite batteries—especially of Ni-H_2 batteries, which COMSAT Labs invented and perfected in 1983—have changed considerably over time. During 1993, SSTD investigated the capacity fading of Ni-H_2 cells with extended storage, the performance decrease in Ni-Cd cells due to the negative-limited condition, positive plate active material utilization, and the use of radiative calorimetry and destructive physical analysis for battery evaluation.

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

The destructive physical analysis of Ni-Cd cells indicated a higher carbonate content in a group of cells manufactured for flight. The cells did not show any evidence of separator decomposition, which is the major source of carbonate, and there was no increase in precharge. The higher carbonate was ultimately attributed to contaminated electrode components.



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

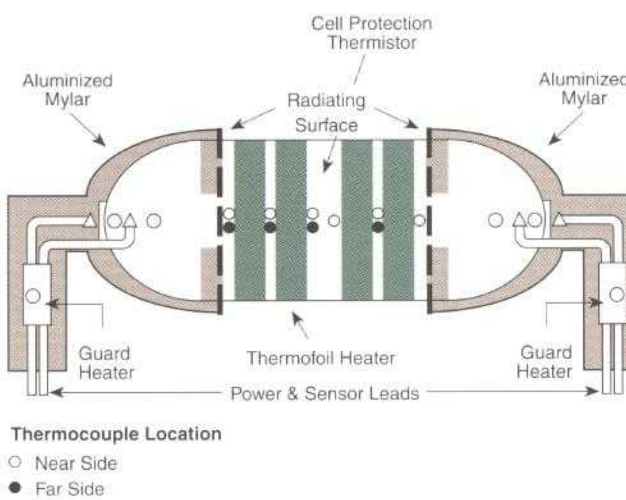
Ni-H_2 CPV Telemetry Methods & Processor Circuit

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

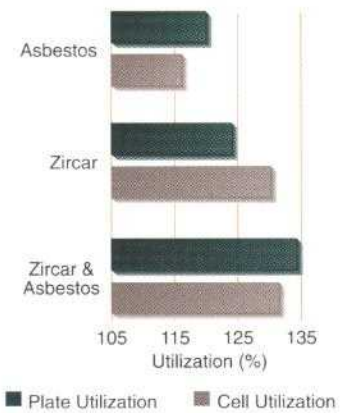
The size and sophistication of satellite batteries—especially of Ni-H_2 batteries, which COMSAT Labs invented and perfected in 1983—have changed considerably over time.

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

A reliable, lightweight, and efficient TPC has also been designed for this application,



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



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

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

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

Command & Control

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

SSTD's investigation of neural networks for satellite command and control is now focused on diagnosing dynamic faults in the attitude control system of a three-axis-stabilized satellite by functional representation, reasoning, and the interpretation of sensor patterns.

State-of-the-art radiation-hardened components and a novel redundancy architecture were combined to implement a small, lightweight, high-performance, space-qualified satellite processor design.

Using both supervised and unsupervised neural paradigms, SSTD is developing a modular system that will work in real time in conjunction with a larger, ground-based conventional expert system. The overall system uses satellite telemetry for system diagnosis, rectification, and control.

Spacecraft Subsystems & Mechanisms

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

Thermal models of both spacecraft were prepared for the various configurations they had experienced in orbit, and the results were compared with flight data to determine the offsets to be applied to the various units. The combination of thermal analysis and flight data with the thermal test and flight experience acquired on more than 10 satellite programs led to minimum predictions for the communications model that were within 2°C of actual. It was also demonstrated that reductions in the number of communications payload transponders posed no danger to the service module.

Propagation Studies

Most of SSTD's propagation studies address such areas as tropospheric effects on earth-space propagation, propagation measurement systems, propagation impairment amelioration techniques, and mobile-satellite propagation issues.

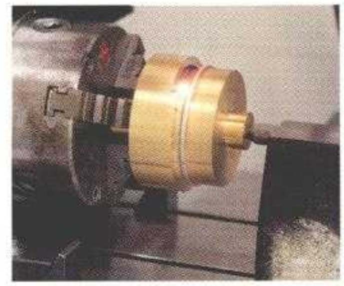
As part of Inmarsat's Project 21 effort to develop satellite-supported omnidirectional handheld communications systems, SSTD investigated the behavior of propagation channels. The signal strength of L-band carrier signals delivered by one of the Inmarsat-2 satellites was measured and the data were analyzed and modeled. The study considered ground reflections, tree shadowing, the effects of satellite motion due to inclined orbit, and interference from the user's body.

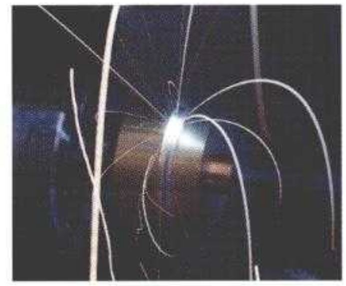
Low-elevation-angle propagation effects become important in regard to operating inclined-orbit satellites and extending their coverage area, both of which can bring economic benefits to satellite operators. In this context, SSTD undertook an INTELSAT-sponsored study to investigate low-elevation-angle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

SSTD has successfully developed a hybrid beacon/radiometer system in which the beacon receiver and radiometer share the same propagation path and RF front end, including the antenna. This arrangement results in significant cost savings. The radiometer is based on the Dicke switching principle. A high degree of temperature regulation of the radiometer system components and careful timing of the Dicke switching rate enable the otherwise incompatible systems to coexist on the same RF paths. Three beacon/radiometer systems were built in 1993. All operate at Ka-band frequencies and are capable of receiving 19- and 27-GHz beacon signals from NASA's Advanced Communications Technology Satellite (ACTS).

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

Rain fading is a limiting factor at Ku-band frequencies, and most Ku-band satellite links in heavy rainfall regions are expected to use uplink power control to increase uplink (only) availability. A power control system capable of controlling up to 12 IF carriers was developed in 1993. The prototype unit built to test and validate the design features a complete user interface and remote control capability.





Design & Fabrication Center

In support of its technical activities, SSTD's modern, well-equipped Design and Fabrication Center manufactures precision-machined parts and assemblies. Part sizes range from a few thousandths of an inch, with a tolerance of 0.0001 in., to large parts up to 15 feet in length and weighing over a thousand pounds.

With the modern, numerically controlled multi-axis machines in general, and specifically the wire electrical discharge machine, microminiature machine parts are becoming commonplace. During 1993, YAG (yttrium aluminum garnet) laser welding was used in manufacturing microwave feeds for outside customers and precision parts for the medical industry. The laser also performed cost-effective drilling of ceramic substrates used in microwave circuits.

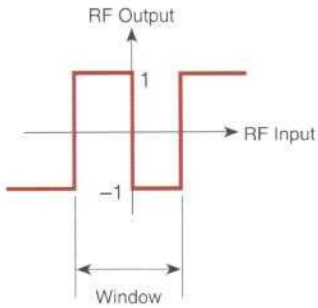
The above photographs show the versatility of the laser hermetically welding an aluminum housing with microcircuits installed. This welding application uses three of the four simultaneously controlled axes of motion.

Satellite Systems Studies

SSTD's experts conduct system engineering tradeoff studies for emerging satellite systems. Top-level conceptual studies provide information on the cost and performance of these advanced systems.

Active Nonlinear Devices for RFI Suppression in Radio & Satellite Systems

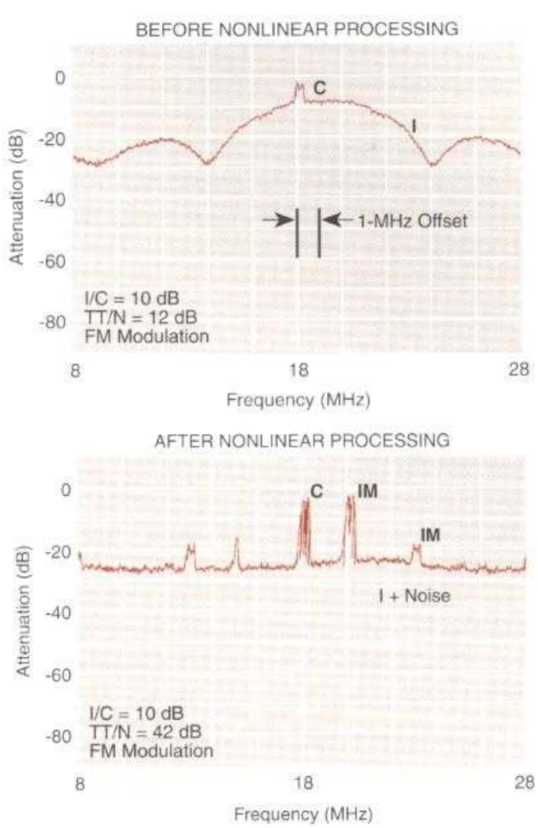
In 1993, SSTD focused on developing and implementing an improved broadband interference-reduction circuit to reduce radio



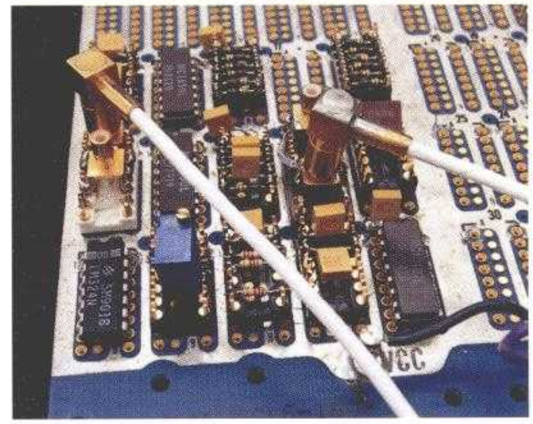
The principle of operation of the biased inverting limiter (BIL) may be explained in terms of "equivalent gain": To an interference signal, the equivalent gain is very low, while a small wanted signal added to the interference experiences a nominally high gain. The point at which the equivalent gain is set in the BIL is determined by the variable "window," which is set proportional to the strength of the unwanted signal.

frequency interference (RFI). The circuit, called a biased inverting limiter (BIL), performs a voltage-variable nonlinear I/O function. It can take a communications channel with interference several orders of magnitude stronger than the desired carrier (an interference-to-wanted-carrier ratio, I/C, of tens of dB) and greatly reduce the interference without distorting the desired carrier. The use of the BIL therefore reduces by tens of dB the amount of modulation immunity (offered by such techniques as bandspreading or coding) normally needed when operating in a high-RFI environment. Increased channel bit rate capacity and reduced transmitter power result from this favorable tradeoff. Unlike notch filtering, the new approach is broadband and does not rely on differentiating signals on the basis of their spectral properties.

Two prototype BIL circuits were designed, built, and tested using successive generations of emitter-coupled logic. The first prototype had an effective operating range from DC to 30 MHz, while the second works to well above 100 MHz. Preliminary testing has been performed on the second, faster prototype. With sinusoidal test signals, as much as 35 dB of effective S/N improvement was achieved. With two devices in hand, cascading becomes possible and should lead to even greater improvements.



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



Laboratory tests on the first prototype circuit showed improvements of up to 35 dB in effective channel signal-to-noise ratio.

Inmarsat Project 21

During 1992, COMSAT Laboratories carried out extensive systems studies on the three unique space segment configurations that have the potential to provide personal handheld voice communications: low earth orbit (LEO), intermediate circular orbit (ICO), and geostationary earth orbit (GEO). Inmarsat was directed by its signatories to continue these studies with the spacecraft industry, with the goal of choosing the most efficient orbit.

In 1993, to support these studies and arrive at an independent view on the subject, and to focus on one particularly attractive solution, the Laboratories was directed by COMSAT Mobile Communications to develop a geostationary L-band satellite design that would support the existing Inmarsat services (Inmarsat-A, -B, -C, Aero, and -M) and the personal handheld communications service (Inmarsat-P) envisaged for Project 21. This combined-service GEO-C satellite has the potential to provide significant system and business advantages for Inmarsat if a cost-effective design can be realized.

The Laboratories' study began by following the Project 21 communications system assumptions and mobile link margin of 7 dB. These translate into a satellite antenna of approximately 7.5-m diameter, generating 150 spot beams to cover the global field of view. For efficient routing of the individual carriers to the appropriate spot beams, and to realize minimum C-band feeder-link bandwidth, digital processors and beam-forming technologies were also assumed. In addition, particular attention was paid to minimizing the cross interference between the existing services and Inmarsat-P service signal levels. Overall payload and satellite mass/power models were developed and compared to existing INTELSAT and Inmarsat spacecraft.

Commercial Satellite Communications Initiatives

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

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

Once the link performance parameters were established, frequency coordination and interference problems that might occur when FSS transponders are used by mobile terminals were investigated. The results of the analyses led to the selection of small earth stations for mobile applications, in combination with spread-spectrum modulation to mitigate potential off-axis emission.

An important objective of this work was to demonstrate that commercial satellites using C-band frequencies and providing global communications (e.g., via INTELSAT satellites) could be employed to deliver broadband signals to mobile terminals in ways which would not interfere with the primary FSS allocation. The study focused on the INTELSAT VII series, but other regional or global commercial satellite systems may work as well or better if the beams are more concentrated. INTELSAT satellites have an advantage in that their coverage beams tend to favor international connectivity, which is very useful for these purposes. A global beam provides coverage of more than one-third of the earth's surface; hemispheric beams cover about one-sixth of the earth; and zone beams cover about one-twelfth.

The Communications Technology Division (CTD) at COMSAT Laboratories 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 maintain its competitive edge in satellite communications, CTD employs advanced communications system architectures and technologies to realize lower equipment costs and improved transmission efficiency and quality. ■ These architectures and technologies are enhanced by the extensive use of digital signal processing techniques.

Video & Image Processing

Video Compression

COMSAT Laboratories has extensive experience in transmitting high-quality video via satellite. Many years ago, the Labs conceptualized time-multiplexed television (TMTV) transmission and developed a compact prototype codec to achieve efficient video transmission. TMTV equipment is capable of transmitting two broadcast-quality video signals in a single 36-MHz transponder. Due to recent advances in video processing technology and high-speed hardware, digital video compression has demonstrated the potential to squeeze even more TV signals into a single satellite transponder, as discussed below.

Digital HDTV & TV Compression

Simplified vector quantization (SVQ)—an efficient compression algorithm invented at COMSAT Labs—currently serves as the core technology for digital high-definition television (HDTV) and TV compression systems. SVQ features a high compression ratio, moderate encoder complexity, and a simple decoder. To transmit digital TV signals in a bandwidth-efficient manner, the Laboratories developed a codec system that uses the SVQ algorithm in conjunction with motion estimation and compensation, and variable-length coding. For applications in fixed-rate channels subject to transmission errors, the codec incorporates packetization, forward error correction (FEC), and buffer control. The encoder and decoder have relatively low complexity and can be sized compactly for production.

Various video sources, from sports to movies, were tested on a prototype SVQ-based codec, and high-quality video suitable for broadcast network distribution was demonstrated at between 12 and 16 Mbit/s. The codec has many of the system attributes required by the emerging Motion Picture Experts Group (MPEG)-2 video standard, such as picture format, motion estimation, and packetized transmission.

Digital video compression can also improve the efficiency of HDTV transmission via satellite. The lower bandwidth requirement of digitally compressed HDTV permits earth station antenna size and satellite power to be reduced. Most HDTV compression algorithms face a stringent high-speed processing requirement; however, COMSAT Laboratories has developed a subband system that circumvents this problem and increases coding efficiency as well.

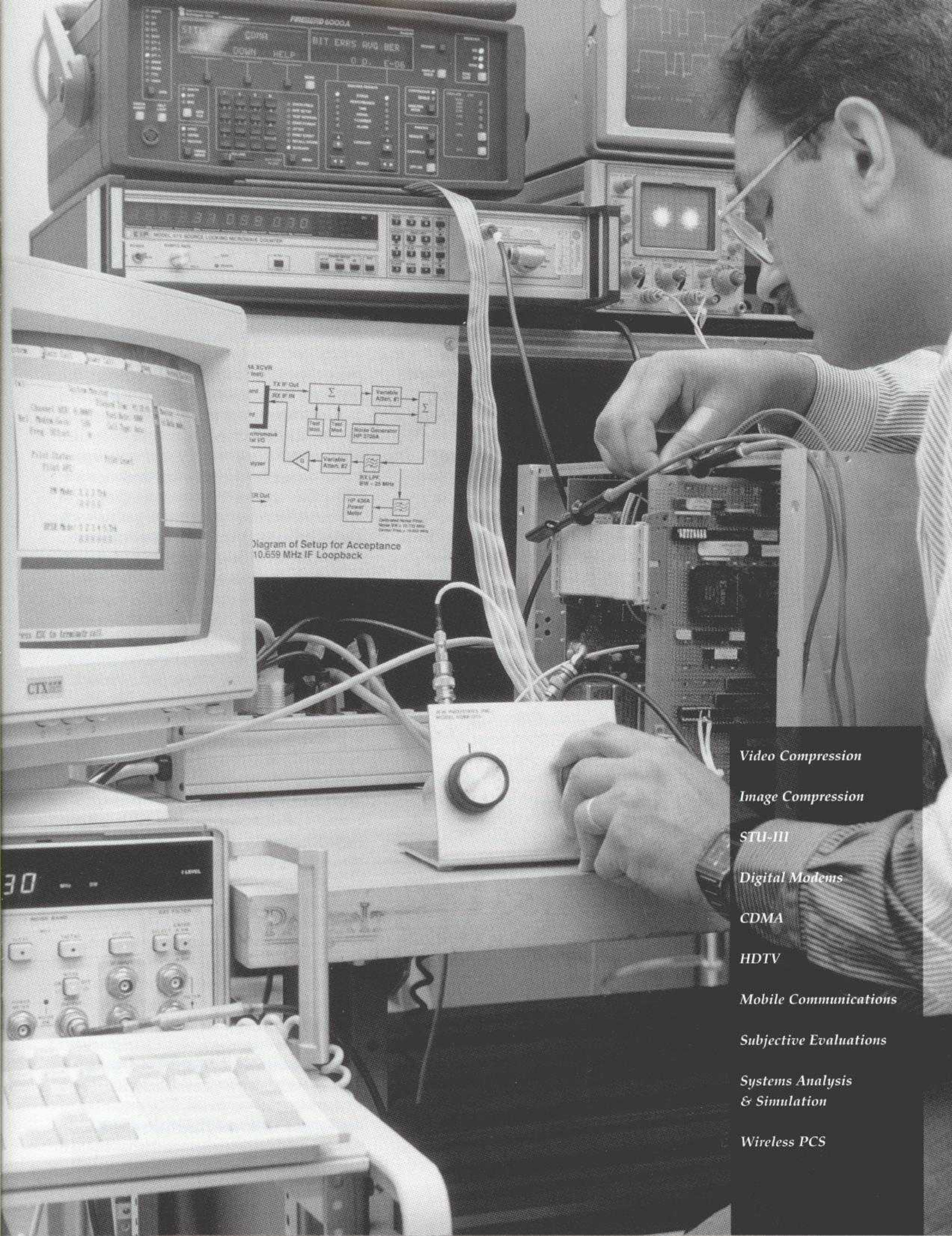
Under contract with NASA, COMSAT developed a proof-of-concept prototype employing both subband processing and SVQ. In this system, four-band subband processing was applied to the luminance signal, and motion-compensated SVQ was subsequently applied to the horizontally low and vertically low (LL) band. Hardware developed to estimate the bit rate for the LL band and display the results confirms the prediction of earlier software simulations that nearly distortion-free HDTV compression can be achieved at bit rates from 27 to 55 Mbit/s. This codec is ideal for HDTV transmission at the DS-3 rate of 45 Mbit/s.

Interactive Graphics & Video Systems

Interactivity will be the key to successful video distribution systems of the future. Growth in interactive capabilities is being spurred by technologies such as video compression, audio compression, networking, and digital switching, as well as by innovations in the development of graphical user interfaces. CTD is actively contributing to this growth through development efforts with both COMSAT Video Enterprises and On Command Video.

Recently, in association with On Command Video, CTD developed a digital Interactive

Right: *CTD has developed a low-cost CDMA transceiver for use in a portable satellite communications terminal. Here, a CTD engineer tests the performance of the transceiver.*



Video Compression

Image Compression

STU-III

Digital Modems

CDMA

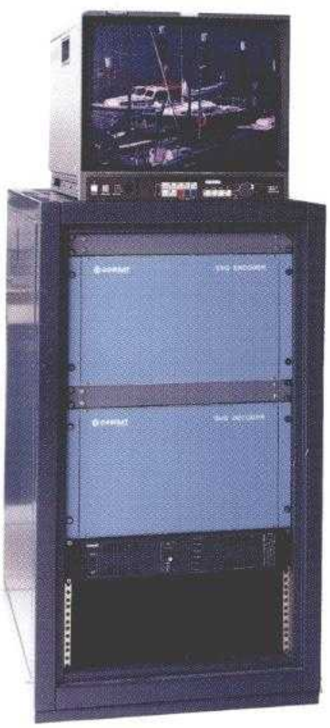
HDTV

Mobile Communications

Subjective Evaluations

Systems Analysis
& Simulation

Wireless PCS



Above: *The compressed digital TV prototype based on low-complexity simplified vector quantization technology has been shown to achieve near broadcast quality at a fraction of the bandwidth of conventional analog transmission.* *Below:* *The digital HDTV proof-of-concept system, implemented with off-the-shelf components, uses subband processing to increase compression efficiency and alleviate high-speed computational requirements. The system has demonstrated near transparent quality at bit rates between 27 and 55 Mbit/s, which is ideal for satellite transmission.*

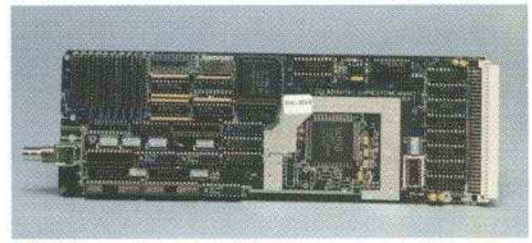
Graphics and Video System (IGVS) for use in hotels. This system is one of the initial steps in transforming the hotel industry into an important component of the National Information Infrastructure. It clears the way for interactivity by creating a distributed parallel processing environment. At the head end, each guest is dynamically assigned a graphics and video processor which allows instant personalized graphics and improved resolution, and serves as an access point for digital video and images. The IGVS also eases navigation through the service and entertainment offerings of the On Command Video system by enabling in-room electronic catalog shopping, requesting concierge services, and improved selection menus. On Command Video is currently integrating the IGVS into its existing system.

Based on the success of the IGVS development, CTD is now directing its efforts toward innovative products and services for the marketplace. The current focus is on the effective transport of digitally compressed video and data, based on internationally accepted standards such as MPEG and MPEG-2. Areas of development include conditional access, video encryption, compressed video format conversion, and HDTV.

Multispectral Image Compression

The Laboratories is expanding its area of expertise to include image processing. Under a contract with the U.S. Defense Landsat Program Office, COMSAT has developed novel techniques for lossless and lossy compression of remotely sensed multispectral images. These images of the earth are collected in different optical bands by sensors on board low-earth-orbit spacecraft. Future high-resolution imaging sensors, such as those aboard the Advanced Land Remote Sensing Satellite (Landsat-8) to be launched early in the 21st century, will generate enormous amounts of data that will require onboard compression for efficient transmission to earth in real time.

The images in different optical bands are highly correlated, and this correlation can be modeled by simple linear regressions linking the intensities of collocated pixels in different bands. This knowledge led CTD engineers to develop a low-complexity spectral compression technique which can be combined with standard spatial compression methods such as vector quantization or the discrete cosine transform to provide high compression ratios with little degradation in image quality. While the simplicity of the technique makes it particularly attractive for onboard implementations, the algorithm can also be used effectively to compress ground-based multispectral data archives.



This interactive graphic and video board allows instant personalized graphics and improved resolution, as well as serving as an access point to digital video and images.

Because the new compression scheme works with blocks of pixels, it is highly adaptable to variations in terrain. First, two anchor bands are chosen and compressed with high fidelity, using spatial compression. The anchor bands are then decompressed and used to predict the intensities of the blocks of the other bands, employing a simple linear prediction model. The resulting prediction error in each band is then spatially compressed. Since the prediction error has much lower energy than the original band, it requires fewer bits for transmission. Computer simulations of several types of multispectral imagery have shown that the CTD-developed compression technique is virtually lossless in terms of visual quality, even at compression ratios as high as 40:1.

In applications such as medical imagery, data integrity is crucial, and minor distortion introduced by lossy compression cannot be tolerated. For these applications, lossless compression can reduce the amount of data that must be stored or transmitted. Based on earlier work on lossy compression, CTD engineers developed a very powerful lossless multispectral compression scheme which uses

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

inter/intraband differential pulse-coded modulation (DPCM) in combination with a two-dimensional, higher-order conditional entropy coding technique. This predictive compression technique is pixel-by-pixel adaptive, and therefore more powerful than the block-adaptive method. The higher-order entropy coding technique exploits the lower- and higher-order correlation between the DPCM residual-image pixels to further compress the data. Simulation results indicate that higher-order DPCM can provide compression ratios almost twice those obtained using conventional methods. Higher-order DPCM is expected to be very useful in archiving and distributing multispectral data.

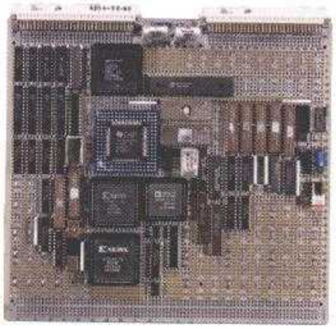
Mobile & Personal Communications

Mobile Satellite Link Availability

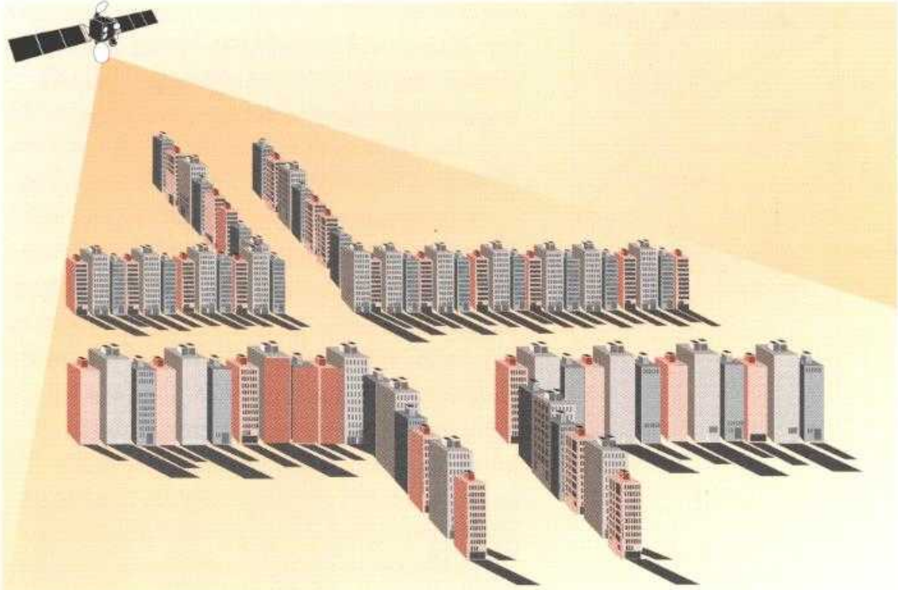
CTD has analyzed the service availability of geosynchronous satellite constellations designed to provide telephony service to hand-held terminals. In a recent study, three candidate constellations of four, five, and six equally spaced geosynchronous satellites were evaluated. The study assessed and compared the ability of these satellite constellations to provide coverage in environments where shadowing and blockage are likely, and defined the variability of coverage for users in different locations around the world. Computer models of specific environments were used to determine the percentage of area over which communications could be maintained with a geosynchronous constellation, assuming that diversity would be used when multiple satellites were visible.

CDMA Processor

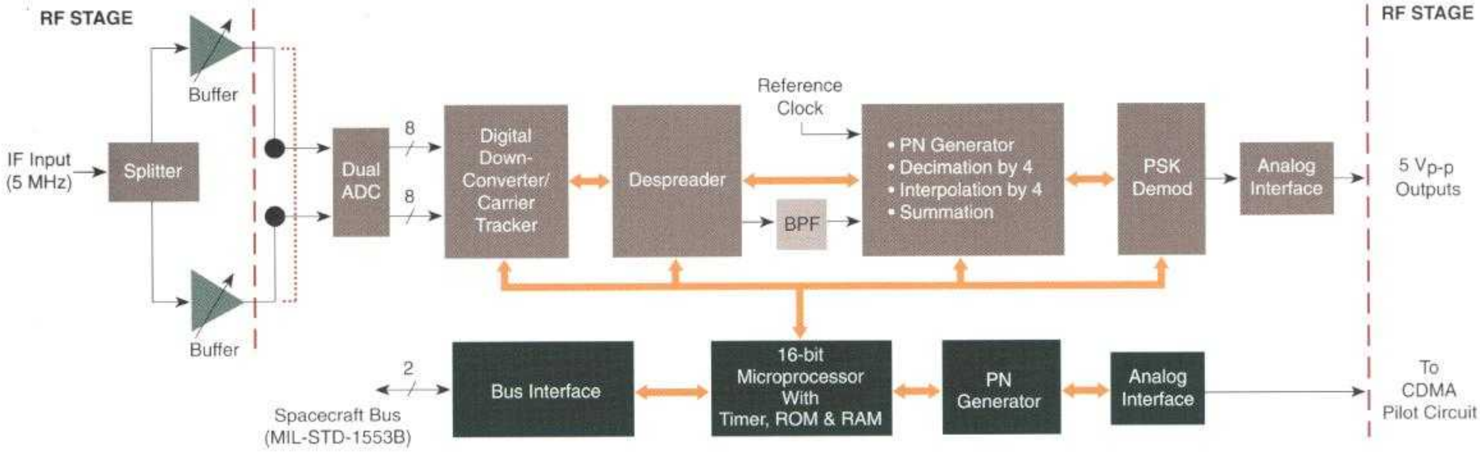
A major area of research for CTD has been the application of direct-sequence spread spectrum code-division multiple-access (DS-CDMA) technology to satellite-based mobile and personal communications. CDMA offers many features that are of particular advantage in a fading mobile satellite link, including relative immunity to frequency-selective fading, graceful degradation with capacity overuse, and the ability to be "overlaid" with other narrowband carriers to conserve valuable spectrum. CTD research efforts have included detailed system designs, link budgets, power and frequency control issues, interference issues, overall system capacities,



The current prototype CDMA processor implementation fits on one 6U VME bus card, shown above.



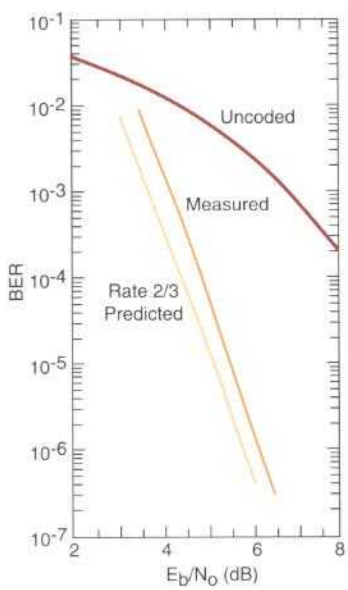
Computer analysis was used to determine the areas of hypothetical urban landscapes which were blocked from a direct line-of-sight view of the geosynchronous satellite. Users of handheld terminals in the unshaded areas can always communicate with the satellite, while users in the shaded regions must move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



Above: CDMA processor designs investigated by CTD include this onboard processor for voice and data communications via a low-earth-orbit satellite. Careful attention was given to the availability of space-qualified or -qualifiable components. To minimize the size and cost of this processor, system tradeoffs were made for the pseudorandom noise code length, error coding mechanism, and implementation complexity.

required transponder bandwidths, call signaling, public switched telephone network interfacing, and implementation tradeoffs.

CTD has successfully translated this research effort into working CDMA processor boards for use as the IF/baseband sections of portable CDMA terminals. User interfaces include 4.8-kbit/s encoded voice, variable data rates up to 4.8 kbit/s, and store-and-forward facsimile. Binary phase shift keying (BPSK) modulation with convolutional rate 2/3 FEC is used, and the baseband signal is spread over a 10-MHz bandwidth. By including a suitable RF front end, two types of terminals are feasible: a complete C-band portable terminal with hub-and-spoke communications, operating with INTELSAT V satellites and INTELSAT A/B hubs; and a Ku-band portable terminal with mesh communications capability. Several key technologies, including low-bit-rate voice coding, flat plate antennas, and advanced signal processing techniques, were incorporated in the system design.

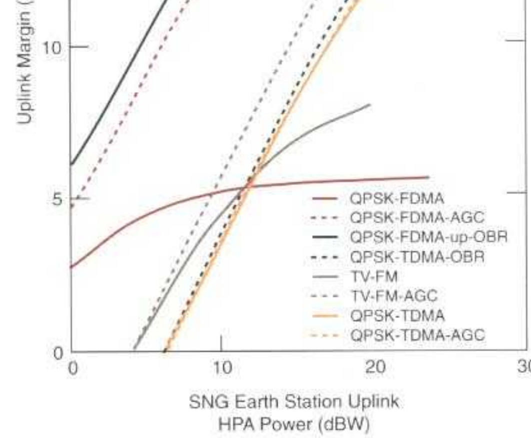


Bit error ratio (BER) performance test results for the CDMA processor at IF loopback indicate less than 1.0-dB implementation loss at BERs from 10^{-2} to 10^{-6}.

Satellite Newsgathering

Satellite newsgathering (SNG) service is expected to become a major market for INTELSAT in the near future. As the demand for SNG increases, INTELSAT should be able to provide this service to customers in a cost-effective and reliable manner. SNG service involves the transmission of real-time programming from small transportable earth stations at news sites, via satellite, to a broadcast center where it is integrated into broadcast programming. The remote earth stations used for SNG must be easily transportable, operating costs must be relatively low, and operation should be able to be initiated on demand, with as few operating restrictions as possible.

In a joint effort with SS/Loral, the Laboratories studied SNG system architectures for INTELSAT in order to recommend the designs that best meet SNG service objectives. The study included frequency band selection, modulation and multiple-access formats, earth segment considerations, and spacecraft implementation considerations. Specifically, the study assessed the suitability of the Ku- and Ka-bands for SNG remote uplinks, optimized transmission schemes, compared transponder architectures for SNG services, and defined requirements for an SNG add-on spacecraft payload package.



The relationship between the uplink margin and the SNG earth station's high-power amplifier (HPA) size is shown for a variety of transmission and multiple-access formats. The uppermost curves offer the most protection against rain fade for a given HPA size.

Speech & Facsimile Processing

Equipment Evaluation

Due to its world-renowned expertise in digital circuit multiplication equipment (CME) technology, CTD's Voiceband Processing Department was approached by two major CME manufacturers to conduct an impartial evaluation of transmission performance over their respective facsimile transmission equipment (FTE). Although the two companies are direct and fierce competitors in the development and installation of advanced CME, both companies chose COMSAT to conduct the performance evaluations.

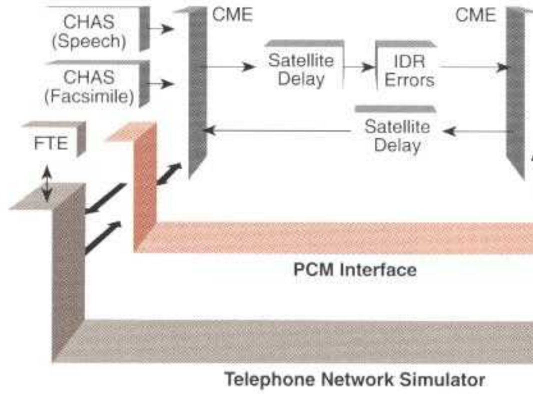
The CME under test was interfaced with an automated facsimile generator and analysis tool which permits more than 1,200 facsimile pages to be transmitted and analyzed in real time, per day. This highly sophisticated test function permits a large number of facsimile pages to be carefully analyzed without risk of human error.

Facsimile transmission performance is typically measured over the CME test bed by evaluating facsimile image quality and call completion rate under a variety of terrestrial channel and satellite channel degradations. These include terrestrial echo return loss, tail circuit impairments, satellite transmission delay, and satellite channel bit and burst errors.

Along the same lines, CTD's Subjective Speech Evaluation facility was elected by the Telecommunications Industry Association (TIA) to act as the host facility and listening laboratory for the evaluation and ultimate selection of the codec to be incorporated into the half-rate traffic channel for the time-division multiple access (TDMA) digital cellular standard. Throughout both the CME and subjective evaluations, COMSAT Laboratories demonstrated its ability to provide a professional environment for the unbiased evaluation of highly sophisticated communications equipment in preparation for its introduction into the commercial marketplace.

STU-III

CTD has been instrumental in the design and development of an Inmarsat-M STU-III certification platform, and in the development and testing of the first commercial STU-III secure communications service to be offered over COMSAT Mobile Communications land earth stations (LESs).

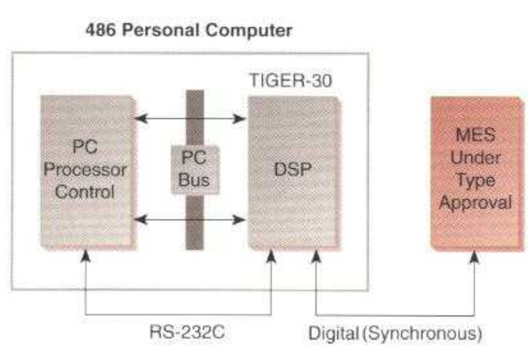


The CME test bed includes simulated speech and facsimile loading (channel activity simulation [CHAS] units), as well as provisions to inject simulated INTELSAT intermediate data rate (IDR) channel bit and burst errors.

The STU-III certification platform permits Inmarsat-M mobile earth stations (MESs) and LES terminal manufacturers who have equipped their terminals with the STU-III secure voice service to be certified by COMSAT in accordance with established U.S. Government procedures. By monitoring the STU-III protocol sequences and analyzing the associated responses from the MES and LES terminals under type-approval, COMSAT is able to verify all elements of the complex communications protocol prior to its commercial release into the Inmarsat-M system. This flexibility makes the certification platform uniquely adaptable to the needs of fixed and mobile terminal manufacturers, and has accelerated the successful deployment of this service.

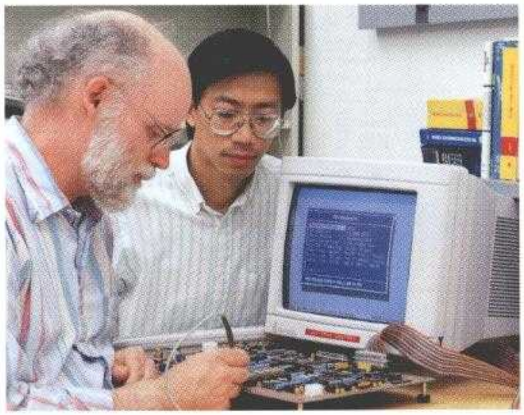
The STU-III certification platform and the LES secure voice service were natural extensions of the STU-III Secure Protocol developed by CTD in 1992. Through both of these advances, COMSAT Laboratories made significant contributions to the rapid and successful deployment of a unique STU-III secure communications service into the commercial Inmarsat-M satellite system market.

The Telecommunications Industry Association is using CTD's Subjective Evaluation Facility to evaluate various half-rate voice codecs for use in the TDMA digital cellular system.



Functional block diagram of the Inmarsat-M STU-III certification platform, which monitors and analyzes the digital STU-III protocol sequences, using a PC-based digital signal processor.

Right: Two CTD engineers test the modulator for the programmable digital modem being developed for NASA. The modulator operates over the full data rate range without any component changes or filter bandwidth switching. ***Below:*** COMSAT engineers test the MSP-10 in a board designed for use in intermediate data rate systems. The board contains all of the functions for both transmit and receive, with fully synthesized IF channelization. In addition to modem functions, the card contains a Viterbi decoder chip for rate 1/2 and 3/4 operation.



Transmission Processing

High-Performance Digital Modem Development

NASA Programmable Digital Modem—Since the early 1980s, COMSAT Laboratories has been developing digital modems to provide flexible solutions for data transmission. Under contract with NASA Lewis Research Center, COMSAT is in the final stages of developing a very flexible digital modem that operates at data rates from 2 to 300 Mbit/s in a variety of modulation formats, including quadrature PSK (QPSK), minimum shift keying, 8-PSK, 16-level quadrature amplitude modulation, and 16 PSK. It also operates in both continuous and burst modes.

The major component that gives the modem its extreme flexibility is a high-speed, emitter-coupled-logic application-specific integrated circuit (ASIC) used in several locations in the demodulator. The ASIC is used to implement digital data filtering, acquisition estimations, and tracking loops. The all-digital implementation and high-speed operation of the modem will prove very useful in a wide range of applications that require bandwidth efficiency and high speed.

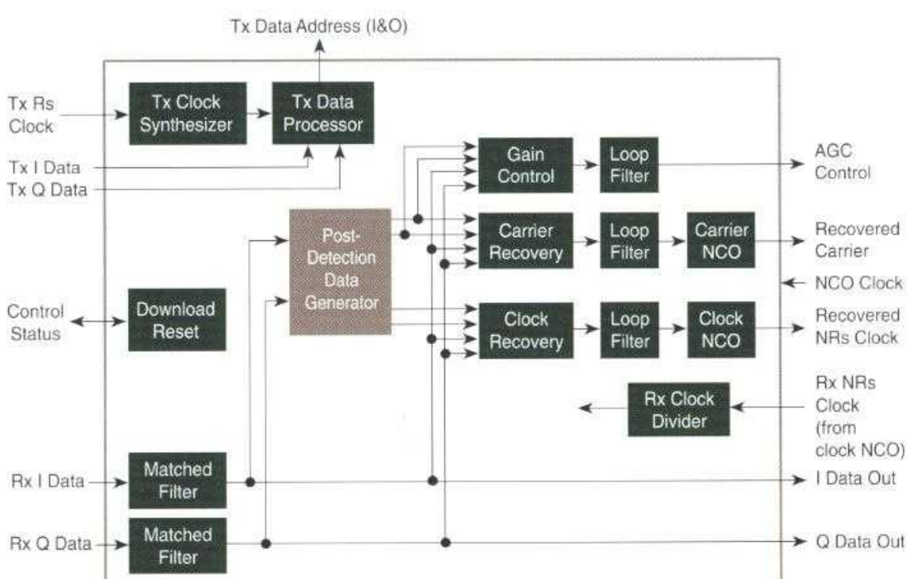
MSP-10 Modem ASIC—For applications at medium data rates, COMSAT Laboratories has developed a single chip that contains the key elements of both the modulator and demodulator. The MSP-10 modem ASIC operates from 32 ksymbol/s to 10 Msymbol/s for BPSK, QPSK, and 8-PSK modulation formats, resulting in a maximum data rate of 20 Mbit/s for QPSK and 30 Mbit/s for 8-PSK. The ASIC can be used as the basis for video distribution modems and intermediate data rate/International Business Service (IDR/IBS) modem implementations, and is easily adapted for burst mode systems such as bandwidth-on-demand low-rate TDMA terminals.

The ASIC uses digital data shaping on the modulator side to give a programmable filter shape that is perfectly matched to the data rate. An on-chip synthesizer for oversampling on the modulator results in a data rate range of 32:1, with only a single pair of replication-removal filters. The addition of a second set of switched filters extends the range to 1024:1.

On the receive side, the MSP-10 performs data shaping, carrier recovery, clock recovery, and automatic gain control. Internal numerically controlled oscillators are provided for the carrier and clock frequency sources. A COMSAT-patented technique provides programmable data filtering with square-root Nyquist responses and filter rolloffs down to 40 percent. The chip is packaged in a 208-pin quad metal flat pack, which allows it to be used in low-cost applications without forced-air cooling.

IDR Outer Codecs

CTD has been largely responsible for introducing outer codecs into the INTELSAT system. The addition of a Reed-Solomon outer codec to a standard IDR modem (which



Left: Although originally developed for continuous-mode applications, the MSP-10 chip has been designed with inputs to accept burst mode acquisition signals. This feature will ensure that the ASIC will have applications in future low-rate TDMA systems currently under development.

employs QPSK modulation and Viterbi decoding) results in improved bit error ratio performance. Since the coding is added without changing the frequency allocation, the bandwidth efficiency of the system is maintained. During 1993, the IDR outer codec was tested between the U.S. and Thailand to obtain additional performance data. Long-term data have been collected comparing links with and without the outer codec.

As higher data rate links are established, outer coding at the DS-3 rate of 45 Mbit/s will be required. CTD has already begun to develop this codec. Its structure is similar to the previously developed outer codec, but its implementation relies on high-speed programmable logic components rather than a single-chip, digital signal processor-based design. CTD's development of a high-data-rate codec continues COMSAT's effort to match the data quality of fiber optic links.

Multicarrier ASIC-Based Demodulator

The future of satellite communications promises flexible data rate service to a large number of geographically distributed users by means of small, inexpensive earth terminals. To support this service, the basic architecture of the satellite must change from a simple repeater to one with onboard demodulation and carrier routing, and perhaps even the routing of circuits within a carrier. To provide the flexibility needed for a satellite's typical 15-year life span, CTD has pursued a DSP approach.

In the past, COMSAT relied largely on medium-scale-integration discrete components in developing an entire demultiplexer/demodulator prototype for onboard processing. The use of ASICs now makes it possible to dramatically reduce the size, power, and mass of the processor.

With support from COMSAT World Systems and INTELSAT, CTD is developing a multicarrier ASIC-based demodulator for onboard processing satellites. The demodulator is capable of demodulating up to 32 64-kbit/s carriers, six 2.048-Mbit/s carriers, or some combination of these together with 1.544-Mbit/s carriers. Only eight ASICs are needed to process an entire 36-MHz transponder, because on-chip memory is used to store intermediate results in the demodulation process for each carrier. One of the most important features of this chip is its ability to demodulate signals with asynchronous clock signals, and in fact different data rates. A unique algorithm for processing asynchronous signals has been developed which does not rely on large and costly interpolating filters. The ASIC is being developed in

CTD's development of a high-data-rate codec continues COMSAT's effort to match the data quality of fiber optic links.

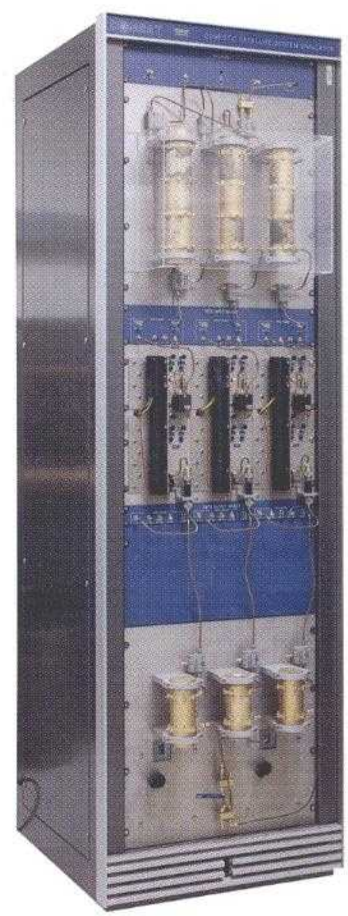
complementary metal-oxide semiconductor technology, which has a direct implementation path to a radiation-hardened part.

Another application for multicarrier demultiplexer/demodulator processors is in the area of central processing hub-type earth stations. A single processor can replace tens or hundreds of demodulators, resulting in significant cost savings for earth station owners and operators. With off-the-shelf fast Fourier transform chips, a demultiplexer is easy to implement and, when combined with COMSAT's demodulator, can provide economical multicarrier demodulation.

Hardware & Software Evaluation, Simulation & Testing

Through simulation, complex communications transmission systems can be parametrically analyzed, and system configurations can be tested and optimized in a timely and cost-effective manner. Software simulation permits rapid, modular analysis of well-understood transmission problems, while hardware simulation lends itself to experimentation with system parameters and the characterization of less mathematically tractable transmission problems.

CTD has designed and constructed a number of satellite transponder simulators, such as a 24-channel simulator with multiple receivers, channel input/output multiplexers, traveling wave tube amplifiers, solid-state power amplifiers, and full-matrix-interconnect switching. The Division's software simulation computer programs and hardware satellite simulators have been used to characterize various transmission channel impairments, including interference and propagation effects.



CTD's C-band satellite transponder simulator is used to evaluate new modulation formats over both existing and planned satellites.

THE NETWORK TECHNOLOGY DIVISION (NTD) PERFORMS RESEARCH AND DEVELOPMENT RELATED TO THE ANALYSIS, DESIGN, IMPLEMENTATION, AND TESTING OF ADVANCED SATELLITE- AND TERRESTRIAL-BASED COMMUNICATIONS SYSTEMS. ■ AREAS OF APPLICATION 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. ■ NTD ACTIVITIES RANGE FROM CONDUCTING STUDIES TO IMPLEMENTING HARDWARE- AND SOFTWARE-BASED SYSTEMS. ■ THE DIVISION'S WORK ENCOMPASSES FIXED SATELLITE AND MOBILE SATELLITE NETWORKS, AND THE INTERWORKING BETWEEN SATELLITE AND TERRESTRIAL NETWORKS.

ADVANCED VSAT

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

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

BANDWIDTH ON DEMAND I

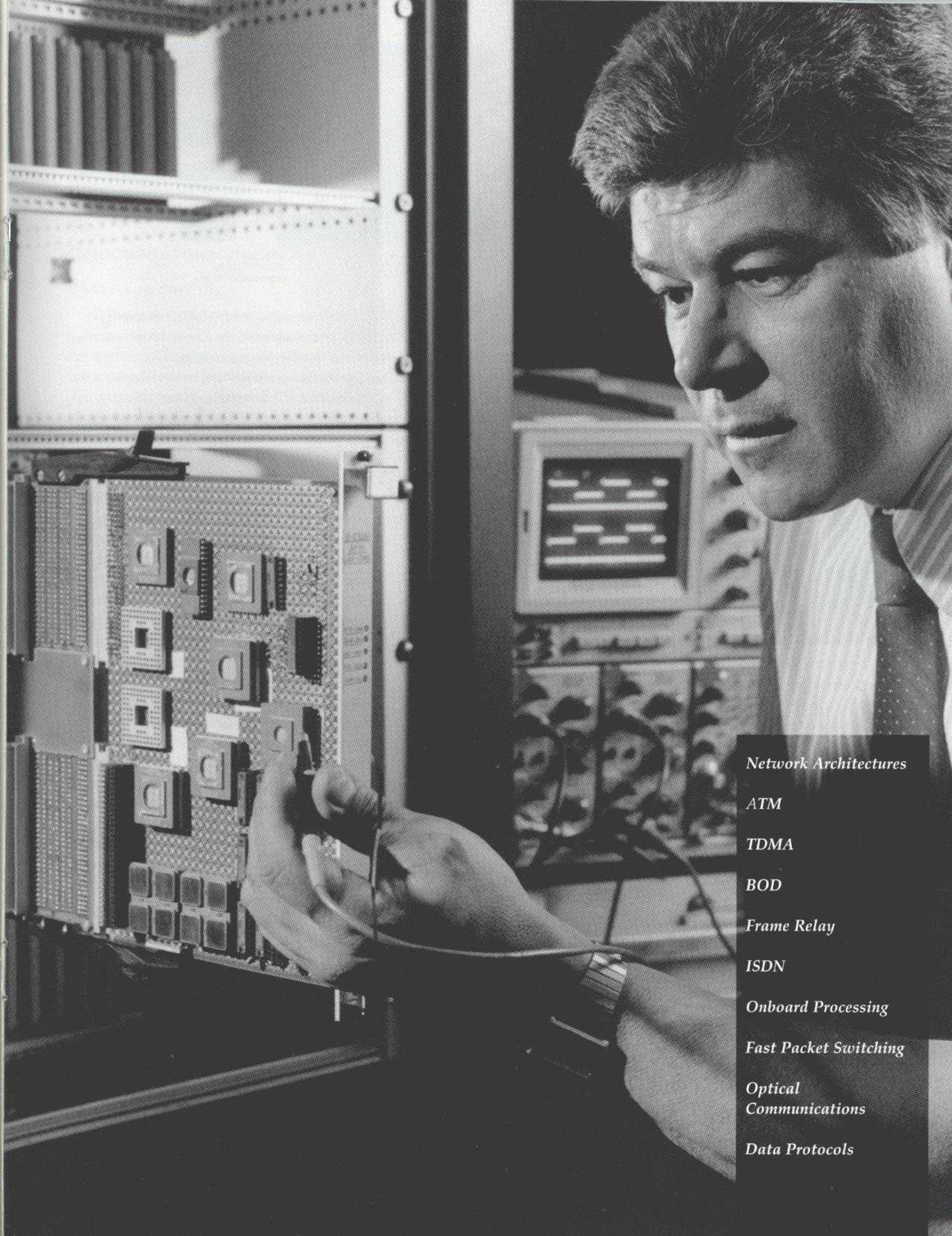
The Bandwidth on Demand-I (BOD-I) system, developed for COMSAT World Systems (CWS), is a variable-rate, on-demand, single-channel-per-carrier (SCPC) mesh network developed at COMSAT Labs by NTD. BOD-I is ideal for service providers and private businesses that require point-to-point and point-to-multipoint connections among geographically dispersed sites. The system can carry voice, data, video, or fax traffic, and offers metered, clear channel connections at variable data rates from 56 kbit/s to 2.048 Mbit/s, with selectable modulation and forward error correction (FEC). Satellite channels may be requested at a BOD-I site via a dial-up modem, or automatically by a customer using V.25 BIS signaling protocol, which is supported by a variety of data communications devices such as routers, video codecs, and intelligent multiplexers. In addition, periodic scheduled (time-of-day) or ad hoc connections can be defined at the network management station (NMS).

The SUN workstation-based NMS uses open systems standards such as UNIX, X Windows, and Motif. Remote stations can be fully monitored and controlled from the NMS, even when they are actively engaged in calls. CWS plans to offer switched International Business Service (IBS) services to Latin America via this system, which is currently undergoing a pre-operational trial involving IBS earth stations in New York, Sao Paulo, and Santiago.

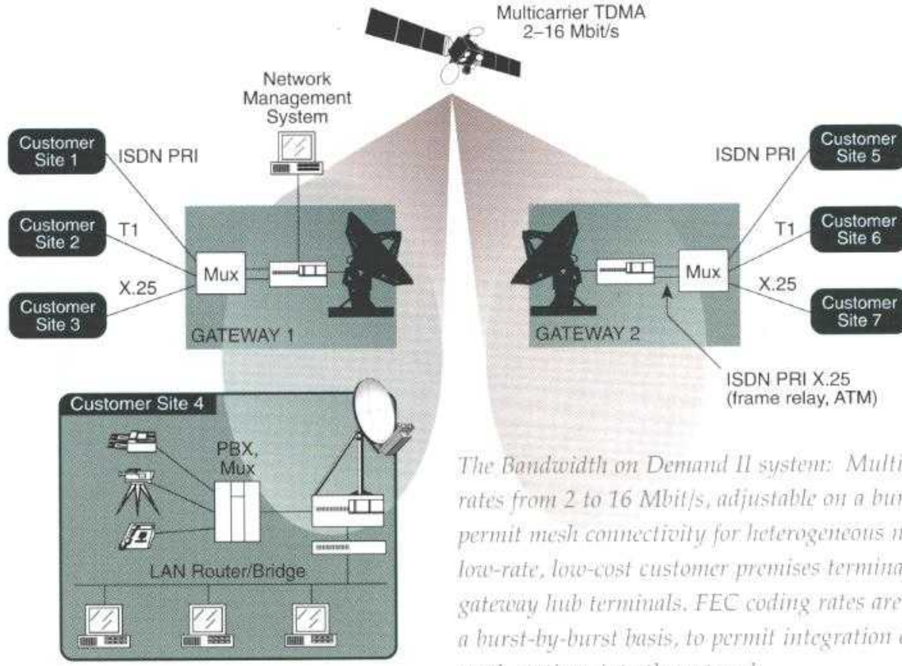
SATELLITE BOD-II TDMA SYSTEM

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

Right: An NTD engineer tests the ATM link enhancer, which will make ATM feasible over satellite links.


Network Architectures
ATM
TDMA
BOD
Frame Relay
ISDN
Onboard Processing
Fast Packet Switching
Optical Communications
Data Protocols

The Bandwidth on Demand system provides efficient multimedia services such as desktop-to-desktop videoconferencing.



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

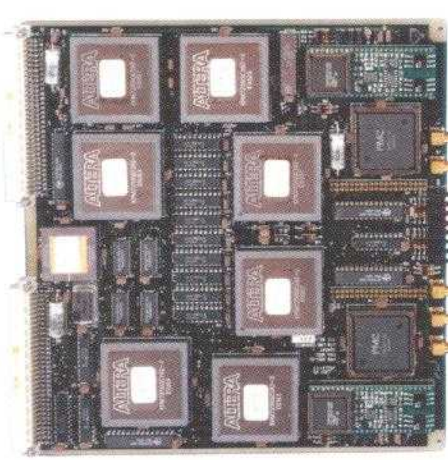
During the demonstration phase, a number of applications were integrated into the ATM Satcom system. Telemedicine, interactive mission planning, meteorological data access, videoconferencing, and high-speed file transfer operated simultaneously as statistically multiplexed ATM traffic over the satellite link.

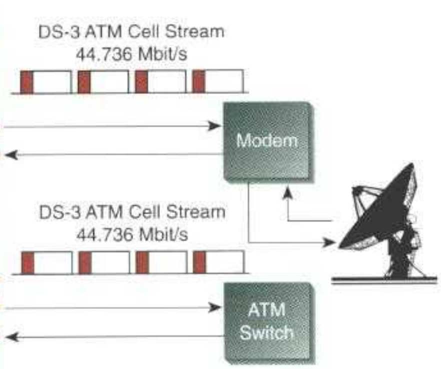
An innovative multi-transmission-rate, multicarrier TDMA approach provides network bandwidths sufficient for large user networks that operate with either domestic loopback satellites or the non-loopback spot beam configurations characteristic of INTELSAT satellites.

ATM via Satellite

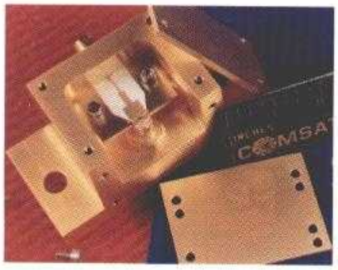
NTD has conducted a series of experiments and demonstrations of ATM via satellite for the Defense Information Systems Agency (DISA) under the Commercial Satellite Communications Initiatives (CSCI) contract. ATM is a communications standard which defines the efficient transport of multimedia information while offering bandwidth-on-demand capacity to system users. During the experiment phase, tests were undertaken to quantify the impact of satellite propagation delay and bit error characteristics on the operation of the Physical Layer Convergence Protocol (PLCP), ATM, the ATM adaptation layer (AAL), the Service-Specific Connection-Oriented Protocol (SSCOP), and the Transmission Control Protocol (TCP).

Some of the major conclusions of the experiments were: ▪ The ATM link enhancer (ALE), developed for CWS, performs selective interleaving on the cell header and the payload, significantly improving performance in two areas: maintaining physical layer framing in a burst error environment, and reducing ATM cell loss probability by several orders of magnitude. ▪ The SSCOP can perform at high efficiency in both error-free and degraded satellite environments. ▪ In a satellite environment, SSCOP clearly provides better throughput performance than TCP, which experiences serious degradation due to satellite delay. ▪ Backward explicit congestion notification (BECN) outperforms forward explicit congestion notification by orders of magnitude in terms of cell loss. BECN was successfully implemented on the ATM switch, and rate controllers were developed by COMSAT for the ATM workstations.

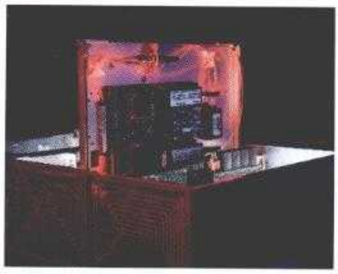




Left: The ATM link enhancer provides fiber-equivalent cell loss over 45-Mbit/s satellite links.



Left: Three examples of optical technology ideally suited for satellite applications: an impedance-matched high-efficiency microwave-optical transmitter; a true time-delay fiber optic beam-forming matrix for C-band phased-array antennas; and an integrated optical waveguide and power splitter using state-of-the-art nonlinear materials. Each optical technology reduces onboard mass and power for lower satellite and launch vehicle costs. ***Below:*** NTD's baseband switch employs destination-directed (packet) switching over a 1-Gbit/s fiber optic ring.



Onboard Processing

Baseband Switch

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

Optical Technology for Satellite Networking

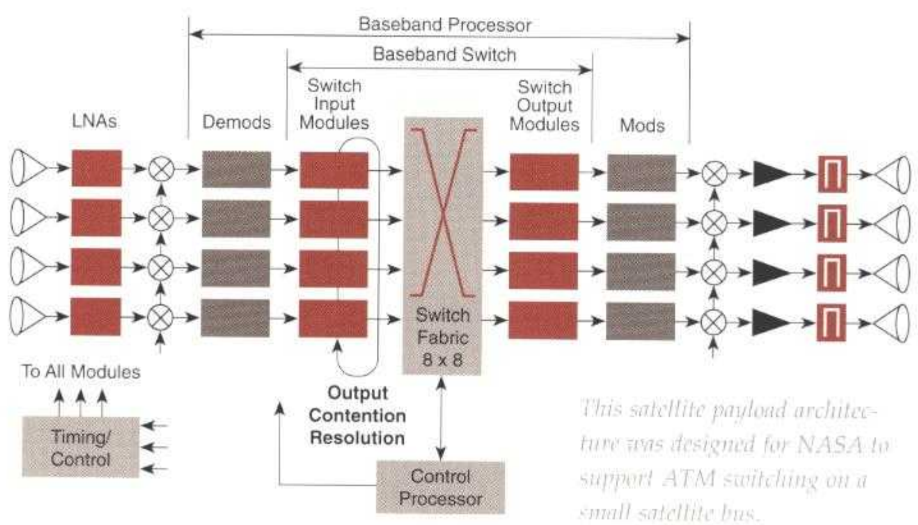
The objective of COMSAT's photonic R&D is to reduce the mass, power, and size of the onboard processing payload, and consequently payload and launch costs. NTD's photonics projects include systems architecture and technology tradeoff studies, analyses, and designs. The Division has also developed proof-of-concept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

A tradeoff study on the frequency-agile optical beam-forming of phased-array antennas was performed for SPAR, Canada. NASA, under the In-Space Technology Program (IN-STEP), recently awarded COMSAT a project to develop and demonstrate flight experiments on photonic beam-forming. Also, NTD designed a high-reliability fiber optic network for use in rain diversity links for Inmarsat's Project 21.

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

ATM Onboard Switching Demonstration Payload

For NASA's post-Advanced Communications Technology Satellite (ACTS) era, NTD has developed a concept for a low-cost satellite system which includes the experimental payload and ground segment architectures. The experimental payload architecture centers around an onboard fast packet switch capable of supporting ATM traffic from four earth stations. Continuous transmission through four high-gain, steerable spot beams is used to access the payload. The onboard processor, which processes and uplinks packets containing ATM cells, based on a simple header,

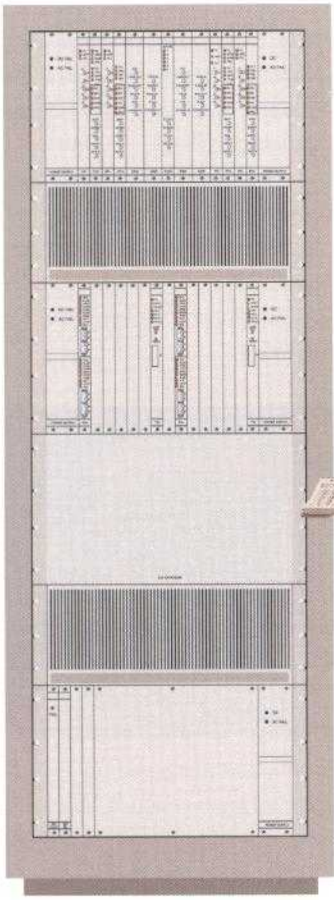


This satellite payload architecture was designed for NASA to support ATM switching on a small satellite bus.

employs commercially available chips for Reed-Solomon decoding and for the switch matrix. Application-specific integrated circuits (ASICs) perform the input and output functions associated with the switch.

Second-Generation TDMA

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



The terrestrial interface capability of NTD's second-generation TDMA terminal, now under development, is expandable from 2 to 32 E-1 interfaces, with 1-to-N redundancy to accommodate any size user.

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

In conjunction with the second-generation OMC, a new direct digital interface (DDI) was developed for use with first-generation TDMA equipment. The DDI permits the direct connection of 2.048-Mbit/s primary multiplex carriers, from switching centers or from digital circuit multiplication equipment (DCME), to the first-generation INTELSAT TDMA terminal. The DDI can accommodate as many as 40 on-line 2.048-Mbit/s primary multiplex carriers and provides 1-to-N redundancy, while significantly decreasing equipment size.

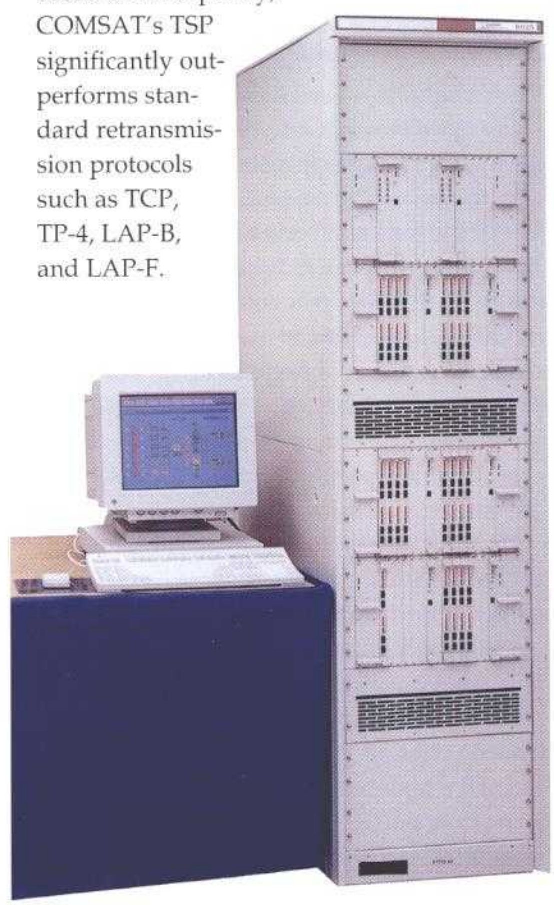
The new OMC and DDI equipment has been installed in AT&T's INTELSAT earth stations. Both developments drew on the expertise of AT&T earth station personnel to craft user-friendly, efficient OMC operator interfaces and to incorporate on-line self-analysis features into the DDI.

Seamless Integration of Satellite & Terrestrial Networks

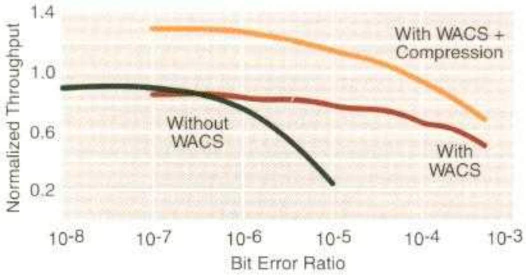
Wide Area Communications Server

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

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



***Left:** NTD personnel demonstrate the TDMA status screen of the user-friendly terminal in the Operations & Maintenance Center. The screen displays the status of each element of the second-generation TDMA terminal, from the up- and down-converters to the terrestrial interfaces. From the console, a user can easily update terminal configuration and operational parameters. **Right:** This OMC, along with NTD's new direct digital interface, has been installed at two of AT&T's INTELSAT earth stations.*



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

Data Communications

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

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

ACTS Frame Relay

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

ISDN

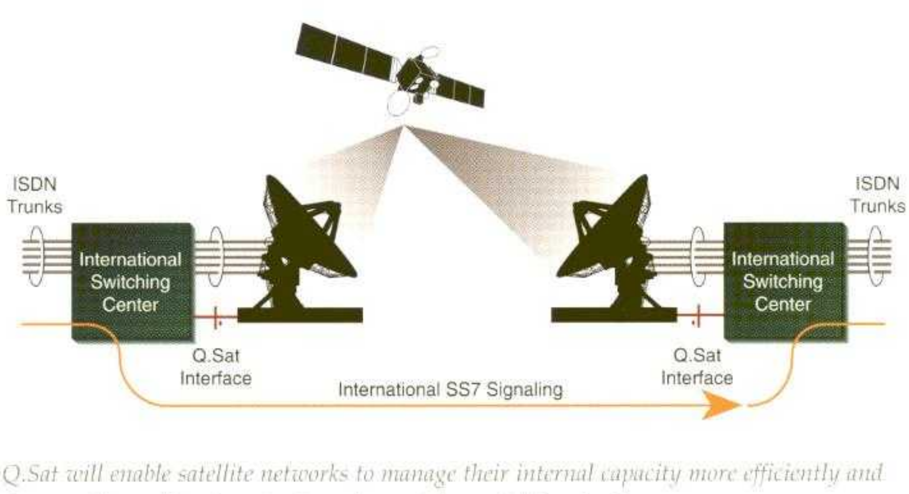
ISDN Satellite Switch—Under sponsorship by CWS, NTD developed the ISDN Satellite Switch (ISS) to provide high-quality, cost-effective ISDN services via satellite. Efficient integration of ISDN with a satellite communications network is achieved by using powerful out-of-band ISDN signaling and by exploiting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

The effectiveness of carrying ISDN traffic over satellites was demonstrated through field trials using the ISS and the AT&T integrated access terminal (IAT). The functionality of the ISS, the ISDN access capability, resource allocation on demand, better transport through the satellite network, and switching directives all complement the IAT, which packetizes, compresses, and cross-connects different types of traffic. An effort is under way to merge the capabilities of COMSAT's ISS and AT&T's IAT to provide integrated, resource-efficient transport of ISDN via satellite.

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

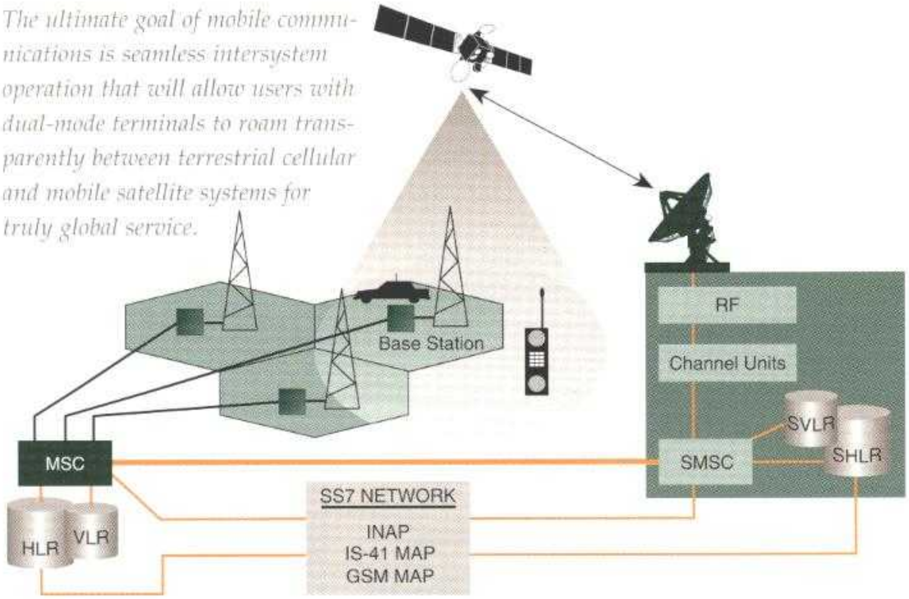
In a related activity, NTD is leading the development of an international standard called "Q.Sat," which will govern signaling between a satellite subnetwork and an international ISDN gateway. Currently, if an international

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

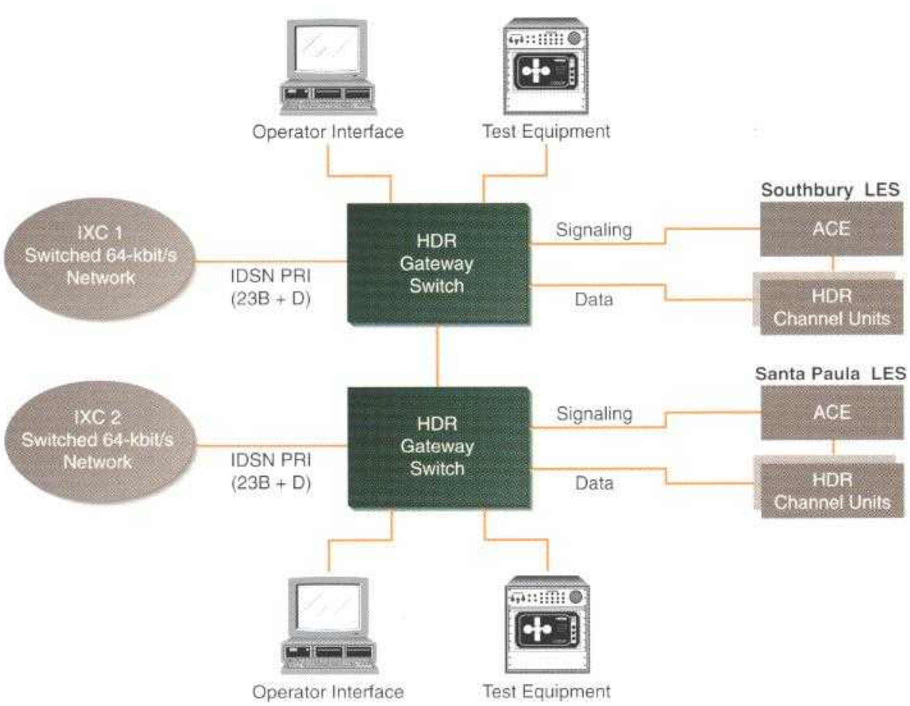


Q.Sat will enable satellite networks to manage their internal capacity more efficiently and improve the quality of service for calls routed on satellite circuits.

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



call request arrives at an outgoing ISDN switching center, the switch permanently assigns an appropriate trunk between the outgoing and incoming international switches. As a result, satellite capacity may lie idle, depending on traffic intensity. Q.Sat signaling will allow international switching centers to request a satellite circuit on a per-call basis.



The high-data-rate gateway switch will enable CMC to provide switched 56/64-kbit/s services to mobile users.

Mobile Satellite/Terrestrial Interworking

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

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

Mobile Satellite Networks

Inmarsat-B High-Data-Rate Gateway Switch

In addition to voice, low-speed data (9.6-kbit/s), and facsimile, the Inmarsat-B system supports high-data-rate (56/64-kbit/s) services to mobile users. Under COMSAT Mobile Communications (CMC) sponsorship, NTD is specifying, designing, and developing a high-data-rate gateway switch (HGS) that will provide these services at CMC land earth stations (LESs) in Santa Paula, California, and Southbury, Connecticut. The gateway switch will make it possible for Inmarsat to offer the full complement of high-data-rate services (i.e., simplex, duplex, 56-kbit/s, 64-kbit/s, and asymmetric) to mobile users.

The HGS interfaces with the access and control equipment (ACE) at the CMC LES to exchange signaling messages, and with high-data-rate channel units to receive and transmit data to the mobile terminal. For connectivity to fixed users, the gateway switch interfaces to switched 64-kbit/s interexchange carrier (IXC) networks in accordance with the primary rate interface (PRI) ISDN specifications defined by International Telecommunication Union-Telecommunications Sector (ITU-T) and the American National Standards Institute (ANSI). The HGS compensates for all incompatibilities between D-channel signaling to the terrestrial network and signaling to ACE/Inmarsat-B terminals. Inter-HGS connectivity is also supported to minimize terrestrial connectivity requirements at each HGS site, and to support HGS calls between mobile terminals in different ocean regions.

Aeronautical Broadcast

COMSAT's FlightNews™ service was successfully demonstrated by NTD in 1993. FlightNews™ uses idle capacity on the Inmarsat Aeronautical P channel to broadcast up-to-the-minute teletext news and graphics to CMC's commercial and general aviation customers. This unique value-added service will be available to passengers on commercial long-haul transoceanic flights as well as those on corporate jets. For the demonstration, live news stories culled from wire services were composed at workstations in Liverpool, England, and deposited at COMSAT's Multicast Communications Server (MCS) at Clarksburg, Maryland. The COMSAT-developed Aeronautical Multicast Messaging Protocol was then used to broadcast the stories from COMSAT's ground earth station in Santa Paula, California, via an operational P channel, to the Inmarsat Pacific Ocean Region. The news was received by an E-Systems airborne earth station and displayed on video monitors.

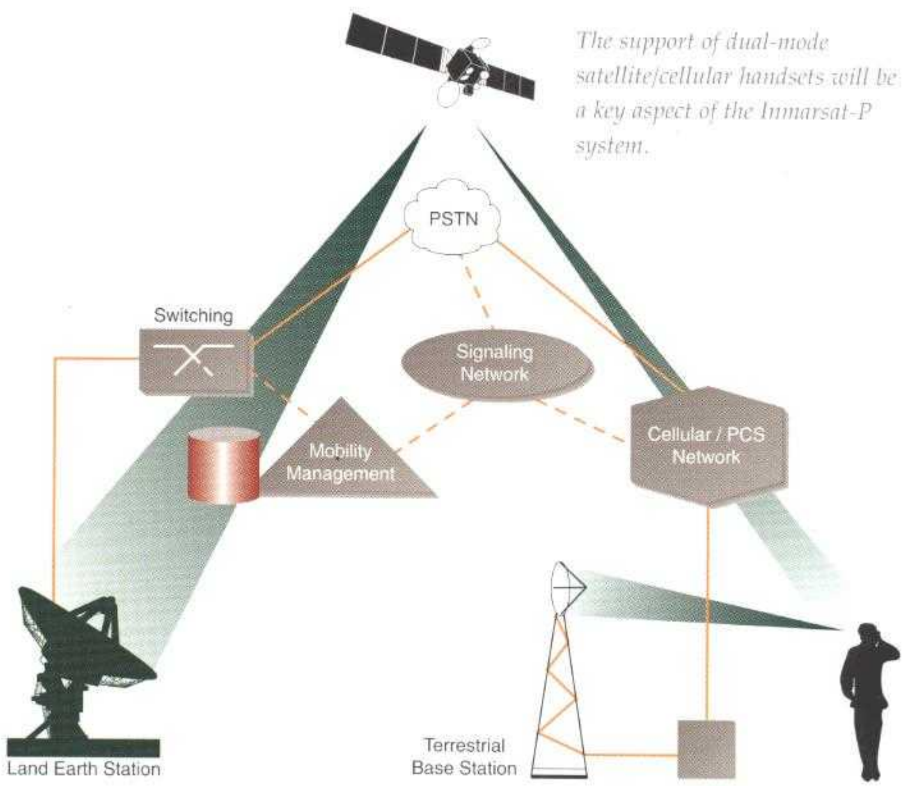
Network Architecture for Project 21

NTD is also actively supporting CMC in the development of the next-generation Inmarsat mobile satellite system employing hand-held terminals. A key aspect of Inmarsat-P is the definition of a ground support network architecture that will provide access to public networks, interworking with terrestrial networks, and effective management of satellite resources. In the past year, NTD has continued its study of the networking and control aspects of Inmarsat-P, focusing on the development of ground segment architectures based on elements employed in current terrestrial mobile systems, such as switches and databases. Investigations of call handoff and global roaming in a global mobile satellite system were undertaken. In addition, NTD developed a simulation model to assess the coverage capabilities of various ground segment scenarios and to model the dynamic traffic loading of the spacecraft onboard processor. The effort also included investigation of the efficiencies of alternative demand-assigned multiple access (DAMA) control and signaling architectures for a geostationary satellite system, and simulations to determine optimum architectures for such a system.

Intelligent Networks

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

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



The support of dual-mode satellite/cellular handsets will be a key aspect of the Inmarsat-P system.

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

System Planning & Analysis

Workbench Products

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

CWS Workbench—This software analysis tool provides a common, interactive user interface to the COMSAT World Systems (CWS) Relational Database Management Facility (a technical database of INTELSAT satellite system and earth station parameters developed using Sybase) and to a number of the analysis programs developed by SDD. The CWS Workbench has been enhanced to include beta-factor, inclined-orbit, and rain outage calculators.

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

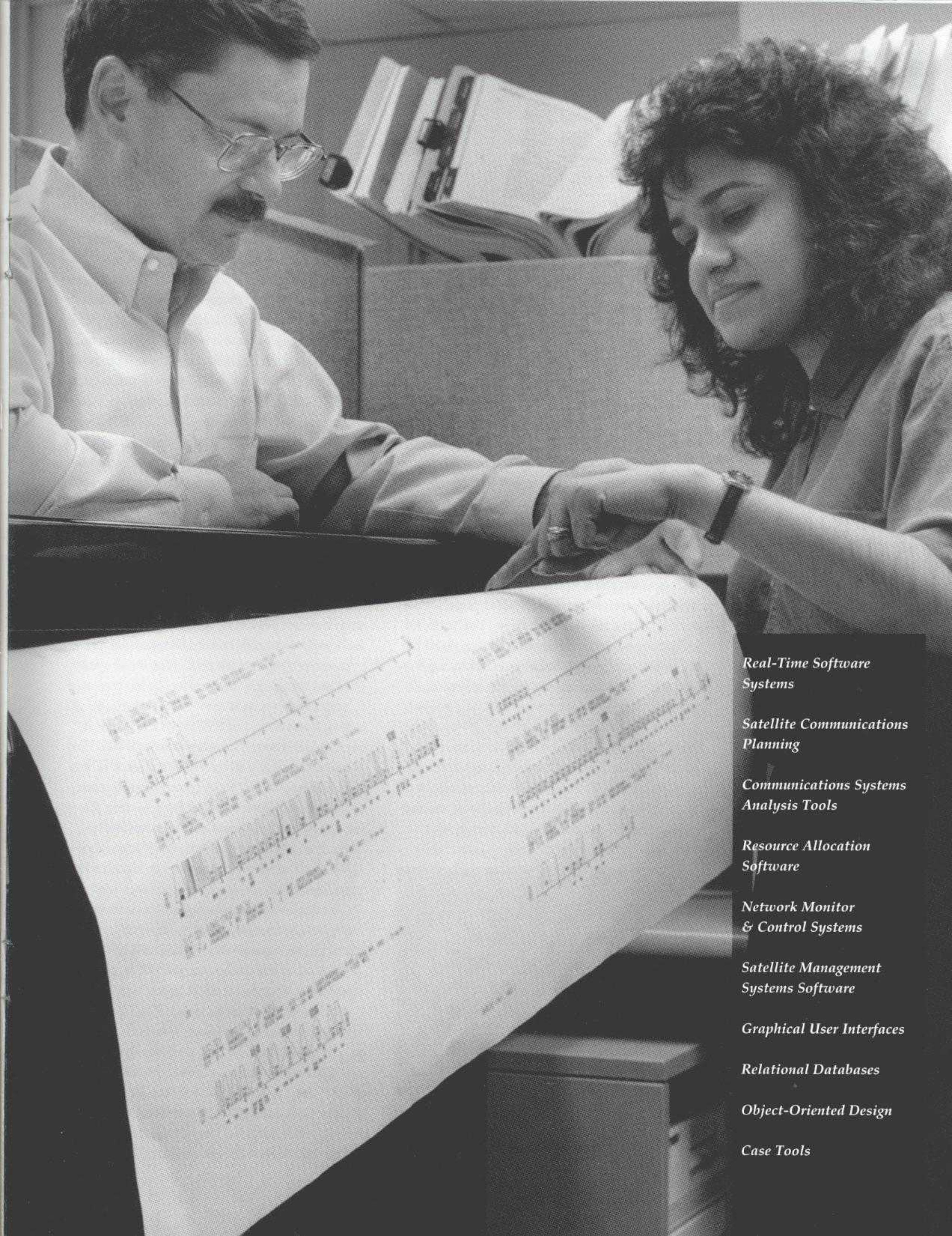
SDD has begun work on a link budget calculator, which uses INTELSAT's standard link budget equations to analyze one or more links. The calculator operates in two modes. In the first, the user specifies the effective isotropically radiated power (EIRP) of a carrier and the calculator computes the receive carrier-to-noise ratio (C/N) and, optionally, the signal-to-noise ratio (S/N). In the second mode, the user specifies the carrier's desired C/N and the calculator computes the carrier's EIRP and, optionally, S/N. If the link budget calculator is analyzing a digital carrier, it will also compute the energy-per-bit to noise-power density ratio (E_b/N_o). In both modes, the user will receive messages stating whether leased resources have been exceeded, whether off-axis emissions are excessive, and whether the power flux density at the earth's surface is excessive. Currently, the link budget calculator analyzes analog and digital carrier types.

In 1994, several new features will be added to the CWS Workbench, including a calculator to determine the INTELSAT satellite and beam that will support a link between two points on the earth; a calculator to compute the effects of sun outages; access to a database of city locations; and access to a new world map database with enhanced mapping capabilities.

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

Link budget and inclined-orbit calculators as well as a traffic analysis prototype have been added to the CMC Workbench. The link

Right: SDD performs transmission planning and interference analysis using software tools developed in-house.



Real-Time Software Systems

Satellite Communications Planning

Communications Systems Analysis Tools

Resource Allocation Software

Network Monitor & Control Systems

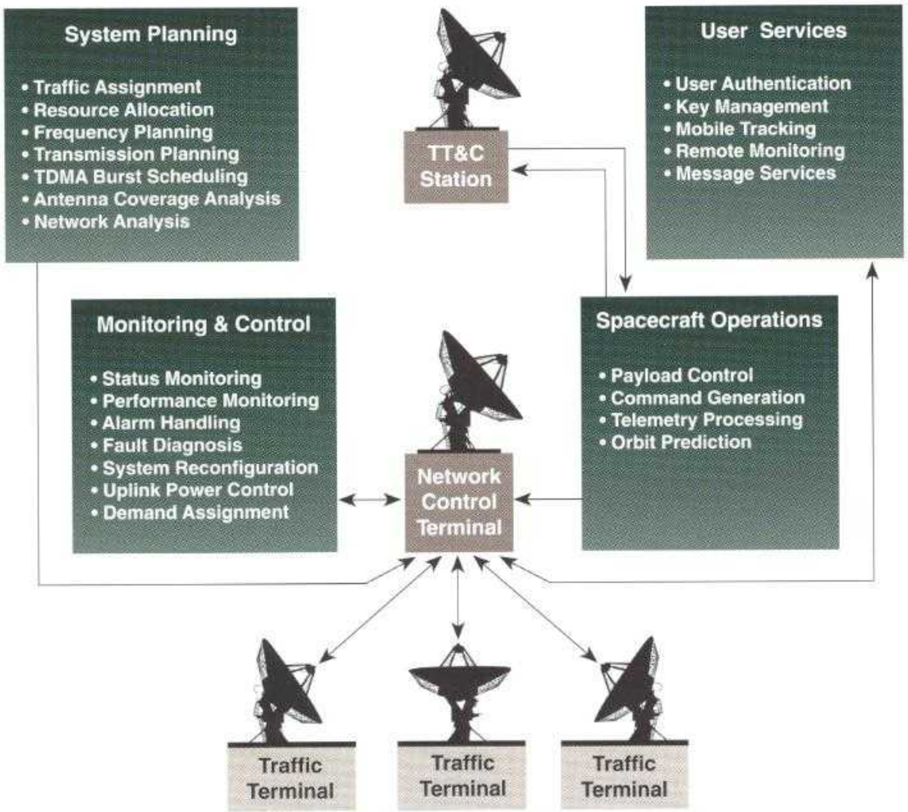
Satellite Management Systems Software

Graphical User Interfaces

Relational Databases

Object-Oriented Design

Case Tools



Above: SDD software products and experience cover the full range—from engineering analysis to planning and allocating resources to monitoring and controlling operational performance.

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

Satellite Transmission Impairments Programs

SDD has continued to develop and enhance STRIP6I, STRIP7, and ISTRIP—three software systems used to ensure that quality-of-service requirements are met for carriers on the INTELSAT system. Frequency planning studies were also conducted in support of CWS, the U.S. Signatory to INTELSAT.

STRIP6I—INTELSAT uses the Satellite Transmission Impairments Program, Version 6 - Integrated (STRIP6I) to support transmission planning on its satellites. STRIP6I evaluates and optimizes the performance of all carriers in a bank of transponders that reuse the RF bandwidth. The transmission impairments computed for each carrier include thermal noise, interference, and intermodulation in both clear-sky and degraded weather conditions. Power optimization analysis determines the carrier power levels necessary for every carrier in a transmission plan to perform at an acceptable level. COMSAT originally developed STRIP6I to evaluate and optimize FDM/FM carrier performance on INTELSAT IV satellites. Over the years, it has been enhanced to model characteristics for digital, time-division multiple access (TDMA) and TV services on several newer spacecraft, and to automatically access a large INTELSAT database of spacecraft, earth station, and carrier technical data.

STRIP7—SDD developed the functional design for STRIP7, a replacement for STRIP6I, and began its implementation, scheduled in stages over a period of several years. STRIP7 includes a relational database management system consistent with INTELSAT's shared-data environment.

INTELSAT'S ISTRIP—SDD maintains an interactive version of INTELSAT's STRIP6I for the operations planning staff at CWS. This version is referred to as ISTRIP. Both CWS and SDD use ISTRIP to provide support services for users of the INTELSAT system. Users can access graphical representations of current and future transmission plans on INTELSAT satellites; analyze current and future satellite capacity; determine the feasibility of equipment changes at earth stations; and plan carrier frequency assignments in transponders leased from INTELSAT.

As part of the continuing STRIP software upgrade, a team from SDD and the Communications Technology Division (CTD) has developed a new, more effective algorithm for power optimization analysis. The algorithm has already been implemented and tested in the STRIP6I and ISTRIP systems. In developing the new algorithm, SDD took a heuristic, rule-based approach that considers all of the constraints inherent in a system of hetero-

Right: The STRIP7 functional design reuses the basic communications system theory, algorithms, and models of STRIP6, in combination with a distributed architecture. High-performance workstations and data servers communicate with a PC-based interactive user interface for ease of use and to provide immediate, comprehensive diagnostic feedback.

geneous carriers and earth stations, and optimizes the carrier power levels while conserving as much power as possible on board the satellite. An additional enhancement to the software allows the user to view a graphical representation of the intermodulation power spectral density levels in a transponder and to watch these levels change as carrier frequency is reassigned or carriers are added.

Transmission Planning Studies

SDD has used ISTRIP to perform several transmission planning analyses in support of CWS operations staff, in planning transmission assignments. Studies were performed to determine the effect on satellite capacity of reconfiguring some of the west hemi/west spot beam connectivities on the INTELSAT 307° satellite, and the feasibility of using an existing antenna in a proposed disaster recovery plan for traffic through the Roaring Creek, Pennsylvania, and Etam, West Virginia, earth stations. Other studies were performed to determine the additional capacity generated by changing the forward error correction (FEC) rate for selected International Business Service (IBS) carriers on the 307° satellite as well as the feasibility of two proposed scenarios for transmission plans for a 36-MHz lease on the 332.5° satellite, and the effect on satellite capacity of providing more stringent carrier rain-degraded performance criteria.

Antenna Modeling

The General Antenna Program (GAP) is a general-purpose tool for analyzing the performance of reflecting antenna systems of arbitrary geometry. GAP uses a ray tracing and integration technique to predict the patterns produced by a reflecting antenna system. Recent enhancements to the software include the addition of three methods for modeling more complex reflector geometries. The first method modifies the program to permit a surface to be defined as a composite of surface segments. The second exploits finite element techniques so that a surface can be specified by a set of triangular elements. In the third method, the user can define a surface as a distorted polynomial.

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

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

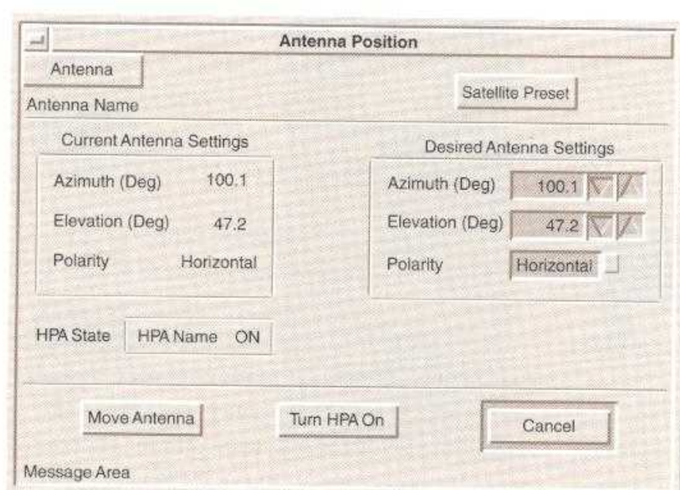
ISTRIP accesses a relational database of INTELSAT transmission plans and supporting satellite, earth station, and service data. The requested plan is presented in the form of a sawtooth diagram that allows the user to interactively add, reassign, or remove carriers, and to analyze impairments and optimize carrier power levels in a bank of frequency reuse transponders.

Satellite System Management

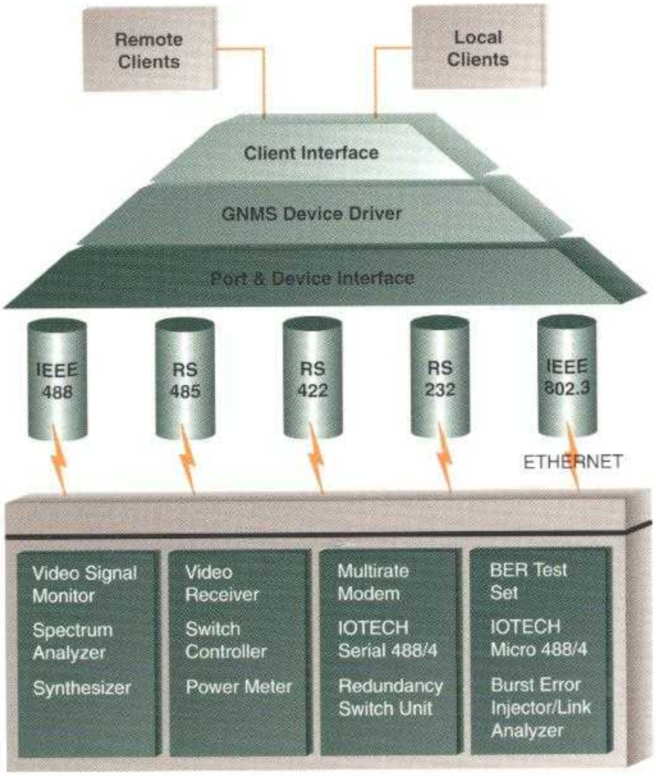
GNMS Device Driver

SDD is working with CWS engineering and operations personnel to define the architecture for a Generalized Network Management System (GNMS) device driver. The driver is being developed using the C++ programming language to operate on an HP Apollo Model 755 reduced instruction set computing (RISC) workstation under the HP-UX Unix-based operating system. The client applications will be able to execute on an HP Model 755 computer, or on a compatible workstation, a PC, or a terminal attached to the NCC LAN or a serial communications link (X.25).

During normal operation, the driver will accept commands from one or more client applications, send the commands to the target devices over the appropriate ports, and return responses to the client applications. It will set up connections, monitor link status, and ensure that the device responses (or proper error returns) are returned to the clients in the correct sequence. The driver will be designed so that multiple clients can simultaneously monitor and control devices, with the single



A GNMS operator can control azimuth and elevation angles and the polarity of an antenna by using buttons and toggles which emulate the device front panel and give a feeling of direct, hands-on control.



SDD's Generalized Network Management System (GNMS) device driver will provide a standardized interface for controlling earth station equipment from a centralized network control center (NCC). Typically, the device driver will reside on the NCC computer and serve multiple clients that remotely monitor and control equipment at several earth stations. The driver will be capable of controlling up to 16 ports, each supporting one of the following protocol standards: IEEE 488, RS-485, RS-422, RS-232, or IEEE 802.3. These protocols will enable the driver to communicate with a large variety of devices.

restriction that only one device can be controlled by a single client application at a time.

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

In 1994, SDD plans to develop a client application called the Satellite Monitoring and Control System (SCS) which will use the GNMS device driver. The new software will augment the present Satellite Monitoring System (SMS), which was developed by CWS to monitor the spectra of satellite carriers in the Atlantic Ocean Region and Pacific Ocean Region. SMS provides for remote monitoring and control of several earth stations at a central NCC in Bethesda, Maryland. CWS will enhance SMS capabilities to include IDR/IBS bit error ratio (BER) testing and video signal testing at the Andover, Maine, and Clarksburg, Maryland, earth stations. The SCS software will consist of multiple client applications that will access a configuration database of earth station equipment and provide a graphical user interface. The GUI will be designed and implemented using the AXIS reusable software previously developed by SDD.

COMSAT Television Schedule Service

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

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

VTS Simulator Product Assistance

During 1993, SDD supported COMSAT Technology Services in the design and development of a vessel traffic system (VTS) simulator (VTSS) for the Port of Rotterdam. SDD led the design, implementation, and documentation effort for the simulator's GUI, which was implemented using rule-based artificial intelligence tools for the X Window System. Reusable browsers and editors were developed to create and edit the library of multimedia objects (such as full-motion graphics, text, and audio) that can be used in any exercise.

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

The VTSS is a distributed system encompassing many processes on many different workstations. To support this architecture, SDD developed reusable libraries based on multiple protocols. In addition, SDD designed and implemented the integrated communications system and the underlying speaker and microphone manager subsystems, which allow audio communications over simulated VHF channels, intercoms, and telephone lines.

Tracking the BOC Challenge

The BOC Challenge—a solo, around-the-world sailboat race with approximately 35 racers—will start in Charleston, South Carolina, in September 1994. This race and its sister race, the BOC Transatlantic Challenge, are organized by The BOC Group, a British company which is the primary sponsor. CMC, also a sponsor of the races, will provide satellite communications and information services to the racers and race management, and will track the racers to support the news media with constantly updated information about each boat's location and other race news.

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

U.S. Coast Guard AMVER System

SDD is proud to be part of the COMSAT team supporting the U.S. Coast Guard's (USCG's) Automated Mutual Assistance Vessel Rescue (AMVER) system, which has been saving lives at sea for 35 years. With this system, ships around the world voluntarily report their position to the Coast Guard via Inmarsat every 48 hours. When a distress call comes in, the USCG Rescue Coordination Center can immediately display the position and course of all known ships within 250 nmi of the vessel in distress and contact the closest ship to request assistance. More than 14,000 ships from 130 countries participate in the AMVER system, which is credited with saving at least 58 lives in 1992.

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

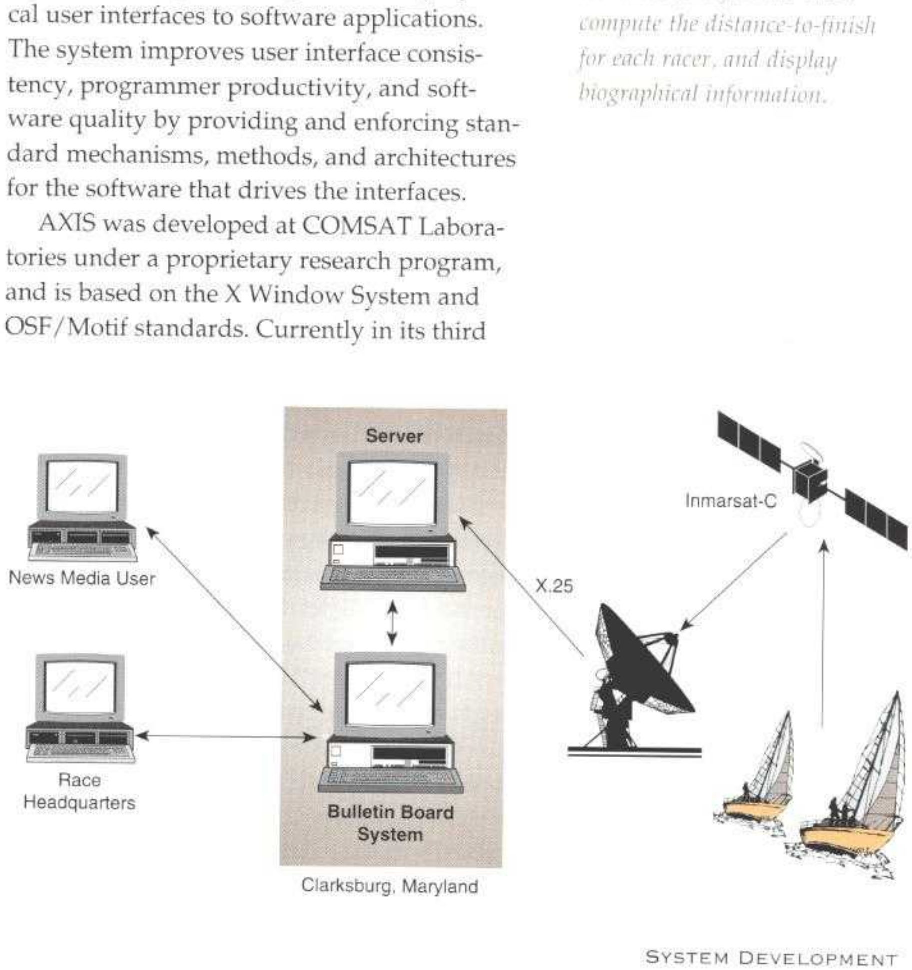
Software Engineering

AXIS User Interface Development Environment

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

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

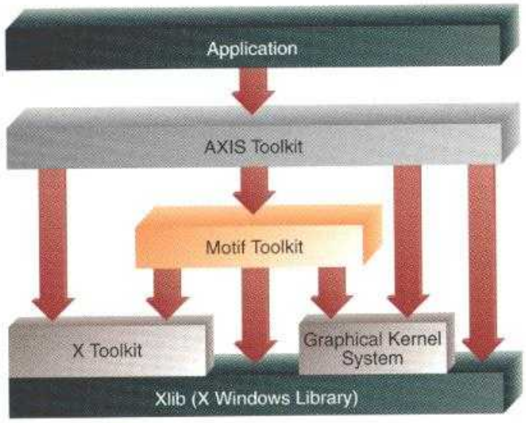
SDD has supported COMSAT Mobile Communications in developing a maritime message referral, tracking, and display system, which is being used to monitor the BOC Challenge sailboat race. With COMSAT-supplied software on their PCs, users can display the current position and historical track of the racers, superimposed on a world map. A variety of display options allow users to zoom in on particular regions, select which racers to display, and add labels to elements in the display. The software can also display pictures of the boat and captain (scanned-in before the race), compute the distance-to-finish for each racer, and display biographical information.



Right: *BOC race reports generated by global positioning satellite receivers pass through Inmarsat land earth stations and are collected in Clarksburg, where they are published for user access worldwide.*

Object-Oriented Technology: Terms & Acronyms

- Class: An abstraction of a real-world entity into a structure, complete with data and methods.
- Class Hierarchy: A collection of classes, with their subclasses and superclasses.
- Object: A specific instance of a class that has been given attribute values which may change over time, independent of other objects.
- OOA: Object-oriented analysis. A systematic approach for analyzing a real-world system to formulate a corresponding object model.
- OODBMS: Object-oriented database management system. A database system that allows the definition and storage of objects, and provides object sharing, transaction control, locking, and concurrency.
- Method: A procedure that implements a specific behavior of an object.
- Message: A signal sent from one object to another requesting that the receiving object execute one of its methods.
- Inheritance: The ability of objects in a class to inherit properties from another class.
- Data Abstraction: The principle of ignoring those aspects of an entity that are not relevant to current purposes in order to concentrate more fully on those that are.



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

release, AXIS is maintained and enhanced by SDD programmers.

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

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

The AXIS Toolkit is implemented in the C programming language. SDD has also developed an Ada binding to the AXIS Toolkit for use on VMS, for Department of Defense software development projects.

Right: A key feature of GRAXIS is its layered design. At the top, the API layer separates the application programmer from the other two layers, which are often platform- or vendor-specific. Thus, GRAXIS supports porting between platforms and underlying vendor packages.

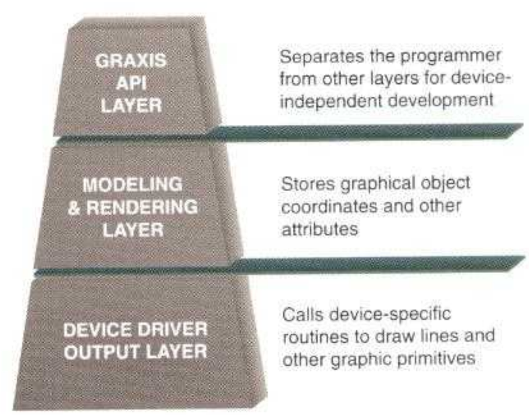
GRAXIS

During 1993, SDD developed the initial release of GRAXIS, a graphics toolkit for developing software applications. The toolkit is written in today's most widely used object-oriented language, C++. Its object-oriented application programming interface (API) is designed to shorten the learning curve for application programmers and improve the maintainability of the toolkit.

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

Object-Oriented Technology

Object-oriented technology promises significant gains in software productivity because of the software reuse and reduced complexity inherent in the object model. Reusing proven software reduces the development time for new products, as well as the maintenance required during the operational life of the product. Object-oriented technology enables a software developer to create a simple model of a complex, real-world entity by focusing on the behavior of the entity. Complexity is further reduced by decomposing the entity into its constituent parts. The resulting model is easier to implement because problem-domain (real-world) entities are directly mapped to system model objects, which encapsulate the data and procedures that determine the behavior of the object. In other words, objects are modular and potentially reusable.



SDD's primary business is to implement system management functions for satellite communications systems, which consist of a hierarchy of physical and logical objects. The two highest-level objects—the ground segment and the space segment—can be decomposed into lower-level objects such as earth stations, network control centers, antennas, and transponders. SDD has analyzed these objects and used their designs in systems such as the Interim System Planning Computer (ISPC) and STRIP7. However, work in the past has focused on algorithms and procedures, rather than on object-oriented techniques. With the availability of new object-oriented methodologies, tools, languages, user interfaces, and databases, SDD has initiated work to define a complete satellite system object model.

In 1994, SDD engineers will work on several projects involving object-oriented technology. These include STRIP7 software for INTELSAT, map display software, GRAXIS, and AXIS.

Mapping Software

In 1993, SDD began developing a library of object-oriented tools for generating and interacting with graphical data displays. The effort initially focused on the interactive display of geographical information to support satellite communications analysis applications. The tools developed consisted of a device-independent graphics package, file management software for storing and retrieving geographical data, and an API to mapping and graph-generating software.

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

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

> *With the availability of new object-oriented methodologies, tools, languages . . . SDD has initiated work to define a complete satellite system object model.*

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

Software Sales & Consulting

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

SDD has demonstrated expertise in custom software development, employing current methodologies such as object-oriented design, graphical user interfaces, relational databases, and object-oriented databases, using C, C++, Ada, and other languages. The Division's software programs are available off-the-shelf or customized, and are used by SDD staff in consulting contracts to meet specific customer requirements.

Live via Satellite

Emmy

YELLOWSTONE NATIONAL PARK, July 4, 1976—Today, three COMSAT engineers and a portable earth terminal gave new meaning to the words "live via satellite."

It was nearly a generation ago, and the country was bursting with bicentennial celebrations. NBC, preparing to televise a segment of its 10-hour commemorative program, "The Glorious Fourth," from Yellowstone National Park, had asked COMSAT to provide a small transportable earth terminal for the transmission.

The 2-meter Ku-band antenna arrived at Yellowstone atop a rented six-wheel RV, with the electronics inside, and was deployed quickly, in about 3-1/2 hours. The COMSAT engineers who had designed and built the terminal from the ground up with commercial off-the-shelf parts—Joachim "Kim" Kaiser, Fred Seidel, and Dave Reiser—had also driven it cross-country from Maryland to the Wyoming broadcast site.

At 8 a.m. Eastern Daylight Time on the Bicentennial Fourth, after two days of dry runs with the NBC crew, the three-man COMSAT team began transmitting the live video. Simultaneously, viewers on both coasts could watch Old Faithful erupting at Yellowstone!

Seventeen years after that milestone in satellite communications, the three engineers were together again, this time in New York City, to receive an Emmy on behalf of COMSAT for their work that summer of '76.

The Emmy—the highest honor bestowed by the National Academy of

"At the time we were conducting these experiments and demonstrating the applications of this technology, we had no idea of the far-reaching impact it would have on society."

—David Reiser
Senior Engineer, COMSAT Technology Services

"The technology pioneered during that period is now in common use. Today we think nothing of 'live via satellite' for news events we see on television. We expect it."

—Joachim Kaiser

Television Arts and Sciences (NATAS) on an individual, company, or scientific/technical organization—is awarded for major advances that "materially have affected the transmission, recording, or reception of television." In presenting the statuette to COMSAT, NATAS praised the corporation for its "outstanding achievement in the sciences of television technology" for "miniature, lightweight, rapid deployment earth terminals for satellite news gathering."

Accepting the Emmy award are, from left, the three engineers who worked on the project: David Reiser, Joachim Kaiser, and Fred Seidel. John Morris, Vice-President of COMSAT Technology Services, is shown holding the statuette.

News gathering via satellite has become an indispensable element in the virtually instantaneous reporting demanded by the global community today. The broadcast trucks and portable terminals now so commonplace are a direct outgrowth of COMSAT's experimentation with miniature terminals in the early 1970s. This technology has played a crucial role in bringing the people of the world face to face with the human side of major events such as rapidly unfolding political crises in the Middle East and Somalia; natural disasters in California, Florida, and Mexico; and fast-breaking news stories worldwide.

"The Emmy is a tribute to the enterprising spirit and pioneering work of COMSAT Laboratories staff. The work of Kim Kaiser, Fred Seidel, and David Reiser has forever changed the way persons around the world receive and react to current events."

—John V. Evans, President, COMSAT Laboratories

Awards

IEEE Honors COMSAT Engineer With Outstanding Achievement Award

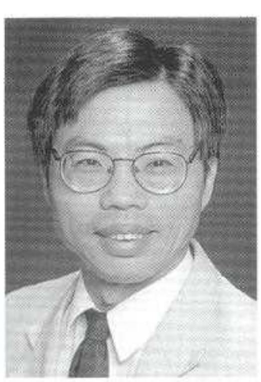
Dr. Spiros Dimolitsas of COMSAT Laboratories was the 1993 recipient of the IEEE Standards Medallion in recognition of his work on the standardization of source coding technology for international communications. The IEEE awards this honor for "outstanding achievement in the development and implementation of electro-technology standards." Highlighted in the citation accompanying the award was Dr. Dimolitsas' leadership in the development of a new 16-kbit/s speech coding standard for international and personal communications systems.

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

Dr. Dimolitsas is a Director of Program Development in the Labs' Communications Technology Division, and chairs programs related to signal processing in the areas of transmission systems and equipment within the International Telecommunications Union Standardization Sector. He is actively involved in developing technology related to value-added mobile communications services, and supports the technology needs of COMSAT's businesses in the areas of voice compression, facsimile transmission, and secure communications.

Dr. Dimolitsas (left) accepts the IEEE Standards Medallion from Mr. Henri Suyderhoud at the IEEE International Conference on Acoustics, Speech and Signal Processing in Minneapolis in July 1993.

IEEE Video Technology Transactions Best Paper Award



Dr. Kou-Hu Tzou

Dr. Kou-Hu Tzou, Manager of the Image Processing Department in COMSAT Laboratories' Communications Technology Division, was a co-recipient of the 1993 IEEE Video Technology Best Paper Award presented by the IEEE Circuits and Systems Society. The paper, entitled "Design and Hardware Architecture of High-Order Conditional Entropy Coding for Images," describes an innovative and practical technique for realizing high-efficiency compression of image and video data. It was published in the June 1992 issue of *IEEE Transactions on Circuits and Systems for Video Technology*, Vol. 2, No. 2, pp. 176–186.

Dr. Tzou is well-recognized in the international video signal processing community for his contributions to advances in TV/HDTV coding. His department at COMSAT is responsible for developing state-of-the-art video coding technology for satellite transmission.

U.S. Patents

The following U.S. patents were issued to employees of COMSAT Laboratories in 1993:

B. R. U. Bhaskar

"Transform Domain Quantization Technique for Adaptive Predictive Coding," U.S. Patent No. 5,206,884, issued April 27, 1993.

S. I. Sayegh

"Method and Apparatus for Carrier Synchronization Acquisition in a Digital Burst Mode Communication System," U.S. Patent No. 5,214,674, issued May 25, 1993.

J. J. Poklemba

"Programmable Noise Bandwidth Reduction by Means of Digital Averaging," U.S. Patent No. 5,216,696, issued June 1, 1993.

F. T. Assal, J. V. Evans, C. E. Mahle, A. I. Zaghloul & R. K. Gupta

"Switch Matrix Including Both B Switching Elements and Crossbar Switch Matrices," U.S. Patent No. 5,220,320, issued June 15, 1993.

V. N. Gupta, M. Onufry, Jr., J. H. Rieser, H. G. Suyderhoud & K. Virupaksha

"Low-Rate Encoding/Digital Speech Interpolation System," U.S. Patent No. 5,226,044, issued July 6, 1993.

R. R. Bonetti & A. E. Williams

"Microwave Filter With a Wide Spurious-Free Band-Stop Response," U.S. Patent No. 5,254,963, issued October 19, 1993.

G. M. Hegazi, K. P. Pande, A. Ezzeddine, R. Sorbello & B. Geller

"Monolithic Gallium Arsenide Phased Array Using Integrated Gold Post Interconnects," U.S. Patent No. 5,262,794, issued November 16, 1993.

H. Chalmers, F. B. Verahrami & A. Shenoy

"Digitally Implemented Fast Frequency Estimator/Demodulator for Low Bit Rate Maritime and Mobile Data Communications Without the Use of an Acquisition Preamble," U.S. Patent No. 5,272,446, issued December 21, 1993.

TECHNICAL EXCELLENCE IN SYSTEMS, SERVICES AND PRODUCTS FOR GLOBAL COMMUNICATIONS

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